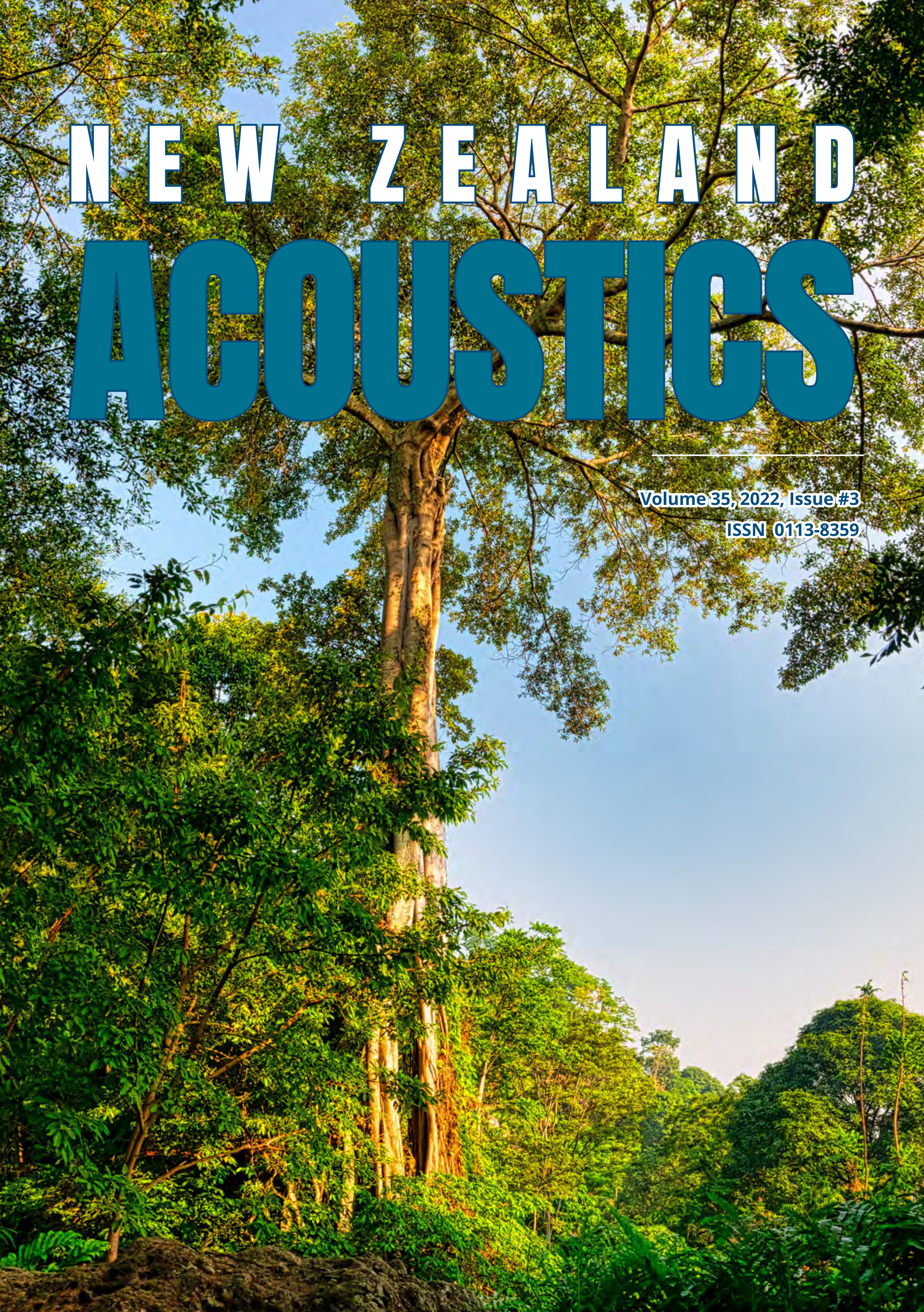

NEW ZEALAND ACOUSTICS

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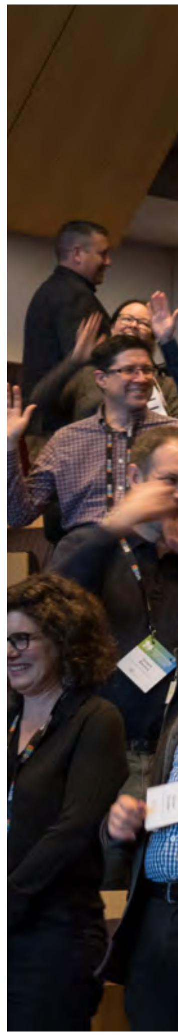
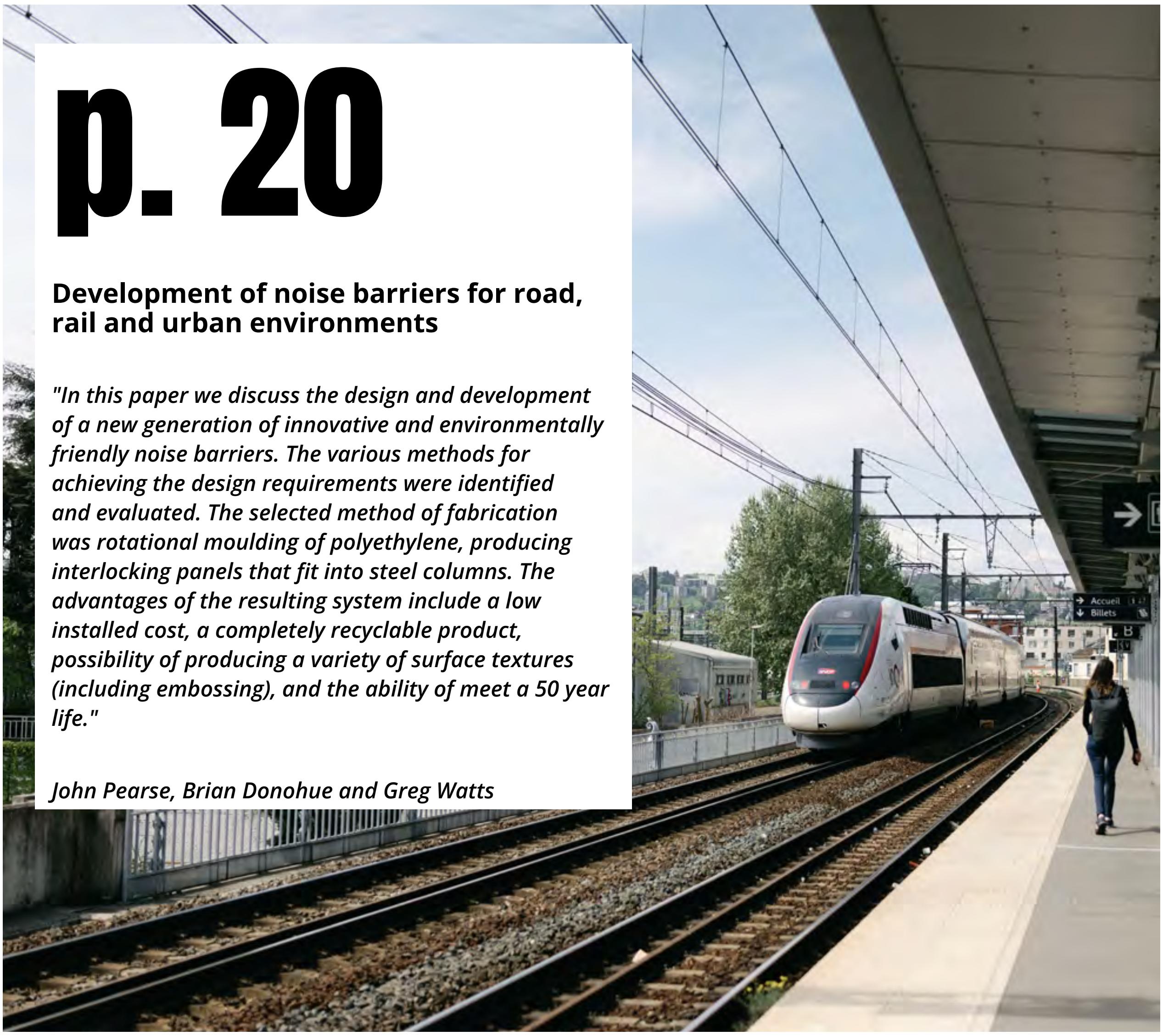


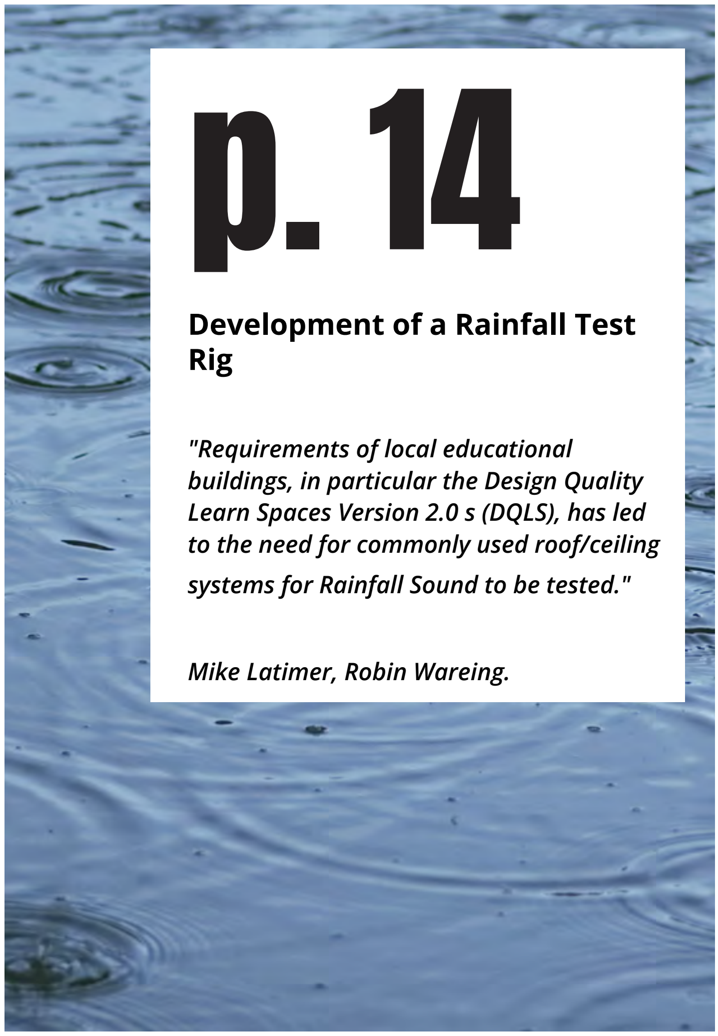


p. 20

Development of noise barriers for road, rail and urban environments

"In this paper we discuss the design and development of a new generation of innovative and environmentally friendly noise barriers. The various methods for achieving the design requirements were identified and evaluated. The selected method of fabrication was rotational moulding of polyethylene, producing interlocking panels that fit into steel columns. The advantages of the resulting system include a low installed cost, a completely recyclable product, possibility of producing a variety of surface textures (including embossing), and the ability of meet a 50 year life."

John Pearse, Brian Donohue and Greg Watts



"Requirements of local educational buildings, in particular the Design Quality Learn Spaces Version 2.0 s (DQLS), has led to the need for commonly used roof/ceiling systems for Rainfall Sound to be tested."

Mike Latimer, Robin Wareing.

"The Christchurch District Plan contains a rule requiring new residential dwellings which are to be constructed in close proximity to some roads to be designed to provide an enhanced level of external sound insulation. As part of a programme to improve the Christchurch District Plan, a review was undertaken of approximately 50 residential building projects which had interacted with the rule."

Jeremy Trevathan and Clare Dykes

FLOC PANEL

PREMIER WOOL ACOUSTIC PANEL.

100% NEW ZEALAND STRONG-WOOL.

Floc harnesses the sustainable nature of wool, adding multiple health, wellness and acoustic benefits to commercial interior environments. At end of life it can be returned to the earth as the product is fully compostable.

Made from 100% strong-wool, Floc is born, grown and processed in Aotearoa.

The 8-10mm thick needle-punched wool panels achieve a Group 1-S fire rating and an NRC of 0.4, to perform as an acoustic solution for interiors. Floc Panels are available in a range of dyed colours, printed patterns and custom colours.

Pending NZ Patent App. No. 788814

T&R

FLOC

Tēnā koutou katoa,

Hopefully the rush to get all possible jobs done before Christmas is not too frantic for everyone. I'm looking forward to doing plenty of camping and sailing over the break and forgetting all about work. Bring on summer!

The recent ASNZ's Acoustics 2022 conference at Te Papa was, by all accounts, a huge success. We had record-breaking attendance, including a large number of Australian and even more exotic overseas delegates in attendance. Despite my best efforts to derail the event by contracting Covid-19 a couple of days before it started, the conference ran like a smoothly oiled machine. Thanks to James Whitlock and Jon Styles for impersonating me and completing my presidential duties with aplomb and style. And, of course, a huge thank you to the organising committee – Tracy Hilliker, Mike Kingan, Wyatt Page, Mathew Legg, Jon Styles, Hedda Landreth, Christian Vossart, Lindsay Hannah, Oliver Hutchison, James Whitlock, Siiri Wilkening and Tracy Young from OnCue – for putting on the event.

I am grateful to have been reappointed as President of your society at the AGM and will try my best over the next two years to further advance the presence of the ASNZ and promote acoustics as a scientific field of the highest importance.

The new ASNZ Council has been elected, and it is with great pleasure that I introduce:

James Whitlock – Secretary
Hedda Landreth – Treasurer
Tracy Hilliker – Vice President, Te Waipounamu (South Island)
Mike Kingan – Vice President, Te Ika-a-Māui (North Island)
Christian Vossart
Jon Styles
Mike Latimer
Victoria Rastelli
Wyatt Page

A special thanks goes to Siiri Wilkening who is stepping down after 20 years of continuous service on the ASNZ Council as either Treasurer or Secretary of the Society. Thank you for your enormous contributions over this period.

Lunch Bunches are continuing in the new year, so keep an eye (or ear) out for further information on these scheduled educational events. If you're in Auckland, I encourage you to come along in person. If you're in another part of the country, or need to join remotely, a live stream video link will be available.

The Council and I will keep you updated with further ASNZ activity as the new year unfolds. Until then, have a great break and we'll see you in the new year.

All the best,
Tim Beresford
President of the Acoustical Society of New Zealand

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Follow ASNZ on LinkedIn


Lindsay Hannah


Wyatt Page

Kia ora, Talofa and welcome to the third and final issue of **New Zealand Acoustics** for 2022. The past few months have been full of news and events. In mid-September the Government loosened the rules around mask wearing; this certainly was a signal that things were improving around the Covid Health Pandemic. It certainly felt very weird moving around with no mask. In September we also had the passing of her Majesty Queen Elizabeth II and ascension to the throne of King Charles III.

We of course had the Acoustical Society of NZ "The Nature of Acoustics" Conference at Te Papa Wellington. Thank you to all that attended and took part by either simply turning up or presenting. A very special thanks must also go out to **Tracey Hilliker** the Conference Chair for organising the event. The time and resources Tracey personally spent leading the conference committee of which Wyatt and I were both part of was incredible.

In this issue, we have a selection of papers across a range of topics, there is a varied range of news items, along with the quiz and other general items for you to enjoy over your break.

We are planning a special edition (SE) in 2023 on construction noise and vibration which will include a review around NZS *6803: 1999 Acoustics Construction Noise*, a stable NZ Standard used by many of our members. Thank you to all that have given feedback when preparing the SE. Keep an eye out for this SE this in 2023!

As this is the final issue, I would like to take the opportunity to thank the journal team for all the work this year and especially thank our newest team member **Holly Wright** who is doing a fantastic job with the design and production of each new issue. I also thank our advertisers as without your kind support there would be no journal. Finally thank you to the NZ Acoustic Society Committee for the on-going support of the journal this year.

Enjoy the summer break and holidays. Season greetings to you all. See you all again in 2023.

Lindsay Hannah & Wyatt Page
Principal Editors

NEWS

Sizzling sound of deep-frying reveals complex physics

Researchers carefully studied bubbles that form when water droplets come into contact with heated cooking oil and found that the type and number of bubbles formed depends on the amount of water absorbed by the chopsticks as well as the chopstick material. The water droplet explodes when it hit the hot oil, in three types of bubble events: an explosion cavity, an elongated cavity, and an oscillating cavity.

https://www.sciencedaily.com/releases/2022/06/220607120858.htm

The Theatre at Epidaurus and Epidaurus' Acoustics

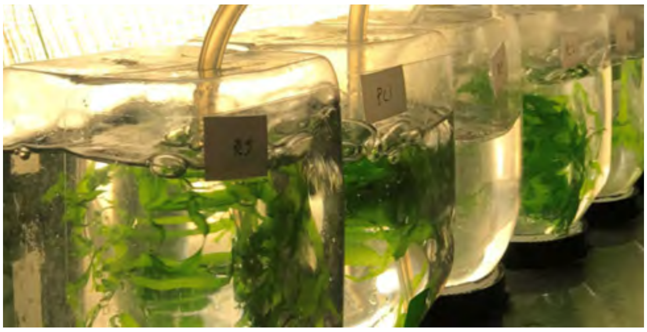
Researchers at the Georgia Institute of Technology have pinpointed the elusive factor that makes the ancient amphitheatre an acoustic marvel. It's not the slope, or the wind.

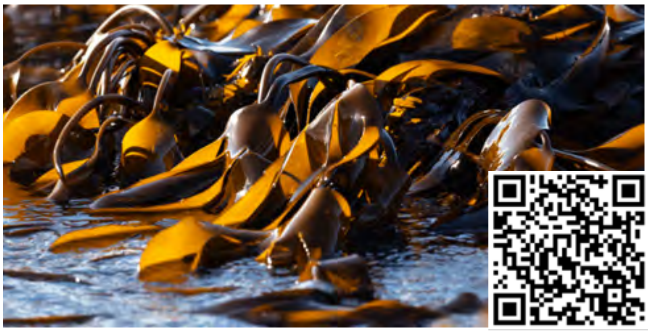
https://www.sciencedaily.com/releases/2007/04/070404162237.htm

The Rule of Two helps make spaces sound better

Acoustics researchers of Aalto University have improved the most common method for measuring the acoustics of a room, the sine sweep technique. The new approach will make it easier and faster to design a room so that the right sounds reach the right spots.

https://www.sciencedaily.com/releases/2022/03/220330103202.htm





Eco-friendly sound absorbers from seaweed

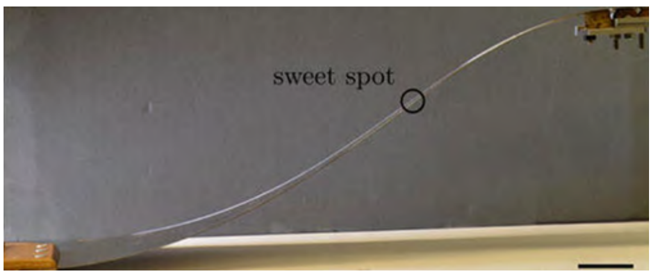
From airplanes to apartments, most spaces are now designed with sound-absorbing materials that help dampen the droning, echoing and murmuring sounds of everyday life. But most of the acoustic materials that can cancel out human voices, traffic and music are made from plastic foams that aren't easily recycled or degraded. Now, researchers have created a biodegradable seaweed-derived film that effectively absorbs sounds in this range.

https://www.sciencedaily.com/releases/2022/07/220714145044.htm

The physics of a singing saw

Researchers have used the singing saw to demonstrate how the geometry of a curved sheet, like curved metal, could be tuned to create high-quality, long-lasting oscillations for applications in sensing, nanoelectronics, photonics and more.

https://www.sciencedaily.com/releases/2022/04/220422114732.htm



New Zealand Ports Tackle Noisy Vessels

New Zealand ports are collaborating to tackle noise generated from vessels.   Hugh Morrison, Port Nelson's Chief Executive, recognises the importance of shipping lines continuing to provide regular services to the Te Tauihu community, whilst ensuring reduced noise from operations. "Port Nelson has been working with shipping lines to resolve key issues of delays to import and export shipments.

https://www.portnelson.co.nz/news-room/latest-news/2022/august/new-zealand-ports-tackle-noisy-vessels/

Aucklanders lose sleep over mystery humming noise

Stuff has reported people living in Mt Wellington, Penrose and Ellerslie said they were fed up by the sound disrupting their sleep. A mysterious humming noise has been disturbing the residents of three Auckland suburbs. The noise, which was heard for several months, was described as anywhere between a low humming noise and a throbbing electronic pulse.

https://www.stuff.co.nz/national/300690100/aucklanders-lose-sleep-over-mystery-humming-noise-like-wind-in-a-bottle

NASA data, acoustic soundscapes assess health of Amazon rainforest

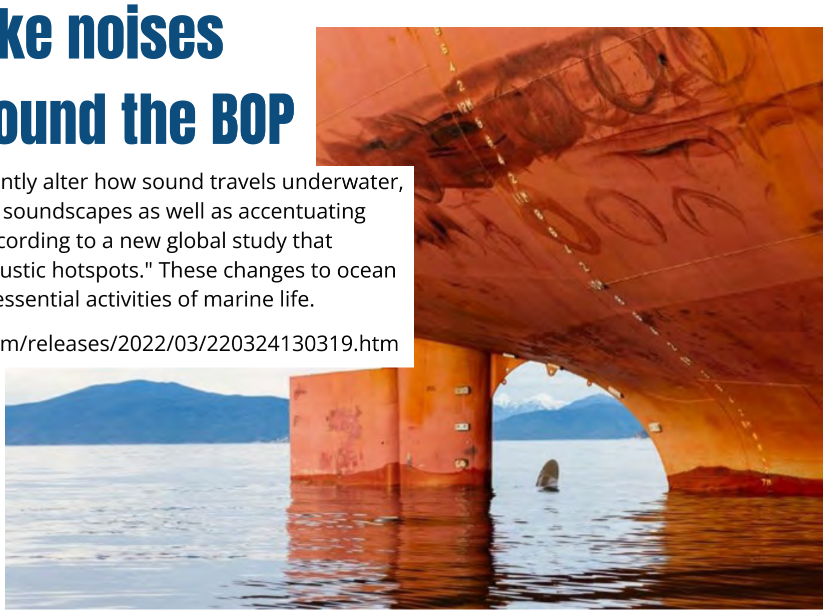
Scientists from NASA's Goddard Space Flight Center in Greenbelt, Maryland, and the University of Maryland, College Park, investigated how the acoustics of a forest can be a cost-effective indicator of its health.

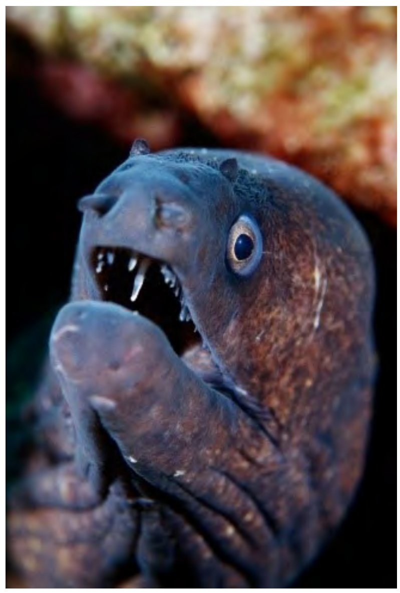
https://phys.org/news/2022-08-nasa-acoustic-soundscapes-health-amazon.html

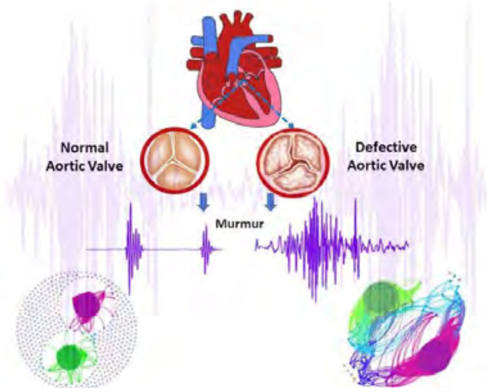
Explosion-like noises reported around the BOP

Climate change will significantly alter how sound travels underwater, potentially affecting natural soundscapes as well as accentuating human-generated noise, according to a new global study that identified future ocean "acoustic hotspots." These changes to ocean soundscapes could impact essential activities of marine life.

https://www.sciencedaily.com/releases/2022/03/220324130319.htm







Low-cost disease diagnosis by mapping heart sounds

Researchers develop a method to identify aortic valve dysfunction using complex network analysis that is accurate, simple to use, and low-cost. They used heart sound data to create a complex network of connected points, which was split into sections, and each part was represented with a node.

https://www.sciencedaily.com/releases/2022/08/220830131046.htm

Noise affects life on the seafloor

A study presents evidence that these sounds affect some invertebrates that live in and on the seafloor in ways that important functions they provide for their ecosystems may be impacted.

https://www.sciencedaily.com/releases/2022/08/220818102745.htm

Acoustic Panels, made from 100% NZ strong-wool

As an alternative to polyester, a new acoustic panel has been launched that is made entirely from sheep wool, and meets Group 1-S Fire Rating!

https://www.tris.co.nz/products/info/138/Floc-Panel

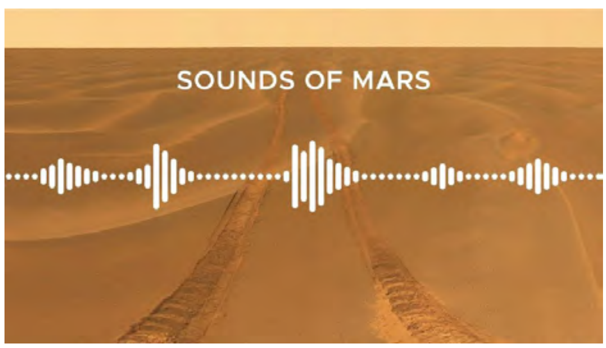
Saturn V - Rocket Melts Concrete!

The Saturn V carried man to the moon and remains the most powerful rocket to successfully launch to orbit. It captures the imagination -- but sometimes, it might capture a bit too much imagination. Abundant internet claims about the acoustic power of the rocket suggest that it melted concrete and lit grass on fire over a mile away.

https://www.sciencedaily.com/releases/2022/08/220823115615.htm

NASA Captures Mars Recordings

https://mars.nasa.gov/mars2020/multimedia/audio/



Saturn V - Rocket Melts Concrete!

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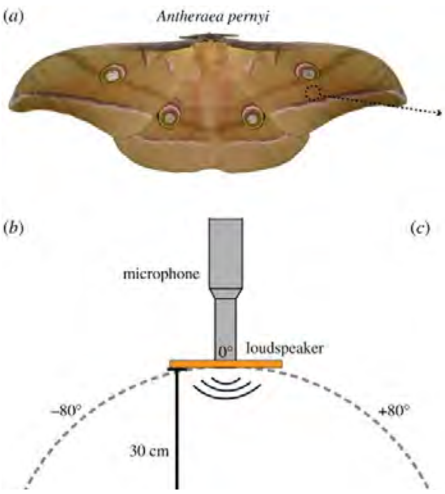


Moth wing-inspired sound absorbing wallpaper in sight after breakthrough

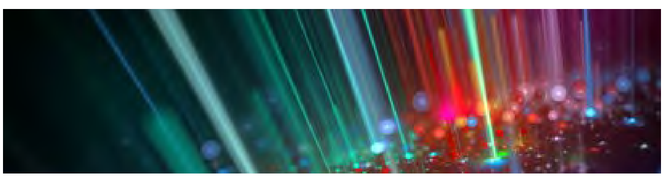
Experts at the University of Bristol have discovered that the scales on moth wings act as excellent sound absorbers even when placed on an artificial surface.

https://www.sciencedaily.com/releases/2022/06/220615102920.htm

Hearing better with skin than ears

A research team develops a sound-sensing skin-attachable acoustic sensor. The new sensor decreased in size and increased in flexibility and is applicable as auditory electronic skin.

https://www.sciencedaily.com/releases/2022/07/220701102740.htm



Scientists invent 'quantum flute' that can make particles of light move together

Physicists have invented a 'quantum flute' that, like the Pied Piper, can coerce particles of light to move together in a way that's never been seen before.

https://www.sciencedaily.com/releases/2022/07/220706165409.htm

NZ researchers claim tinnitus breakthrough

Auckland University researchers say they have had a breakthrough in the management of tinnitus that they hope will be rolled out worldwide.

https://www.biospectrumasia.com/news/53/20867/breakthrough-in-search-for-tinnitus-cure-by-new-zealand.html

Which F1 Engine Sounds the Best?

https://www.youtube.com/watch?v=JImF7gw9lgU

Researchers develop a paper-thin loudspeaker

Researchers created an ultrathin loudspeaker that can turn any rigid surface into a high-quality, active audio source. The fabrication process can enable the thin-film devices to be produced at scale. The flexible, thin-film device has the potential to make any surface into a low-power, high-quality audio source.

https://www.sciencedaily.com/releases/2022/04/220426153637.htm

NASA Captured The 'Sound' From A Black Hole, And It's Super Eerie

https://www.youtube.com/watch?v=NWBkZ3bMSV0

2022 ACOUSTIC CONFERENCE

The now ubiquitous COVID-19 persisted in taking its toll with self-isolation requirements preventing our President Tim Beresford and another titan of our times Mike Kingan from attending the Acoustical Society of New Zealand's 25th ~~Conference Acoustics 2022~~ at Aotearoa's national museum Te Papa Tongarewa located in Wellington. Their contributions in the lead up to the conference were manifold and their absence felt by the wider Local Organising Committee and the ASNZ generally.

The three-day conference was originally intended to be a joint event between the ASNZ and the Australian Acoustical Society. However, uncertainty surrounding COVID-19 during the early stages of preparation made this impossible. Nonetheless, with the eventual loosening of restrictions in the months leading up to the opening day of the conference on Monday the 31st October many of our Australian cousins made the leap across the ditch, helping to swell the number of delegates to make Acoustics 2022 by far the largest conference in ASNZ's history with two technical sessions running in tandem throughout the conference to cater for record breaking numbers of papers, delegates and sponsors.

Whilst travelling to Wellington on the Sunday the wind howled and the rain fell and I was somewhat relieved that a last minute scramble to arrange accommodation had been successful and I would not have to enact my backup plan of taking a tent and pitching at the nearby Waitangi Square (next to the French Crepe stand obviously!).

The conference theme The Nature of Acoustics allowed us to contemplate the science of sound in numerous ways. Nature is intrinsically linked with sustainability and so after the conference was officially opened by Tracey Hilliker (Conference Chair) in the Soundings Theatre, the first (of four) keynote speakers addressed delegates. Andrew Eagles, CEO of the New Zealand Green Building Council, spoke energetically and informatively about the progress being made and the future requirements revolutionising how we construct and maintain our buildings to reduce the use of carbon and the implications for acoustics going forwards in achieving well-being and sustainability within our built environment.

Nature, by its very definition, is our external world and surrounding environment. On the second day Professor of Mathematics & Data Science at Victoria University of Wellington Stephen Marsland and leader of the AviaNZ research project, and Executive Producer of the Pulse of the Planet (running since 1988), award winning broadcaster and creator of the Metzner archive Jim Metzner, both provided fascinating keynote addresses.

Stephen gave an overview of the AviaNZ research project he leads which combines mathematics, ecology, signal processing and machine learning to provide bioacoustics recordings used to estimate the populations and diversity of avian species. Jim shared his audio journey through life and invited us to explore how we listen and respond to our environment with personally recorded soundscapes. This was spellbinding story telling and both Stephen and Jim have spent an enviable amount of time in the field in the name of research, education and entertainment.

With a dozen different Technical Sessions over the three days a great diversity of session topics included timber buildings, signal processing/sound reproduction, room acoustics, road noise and vibration, building acoustics, vibration and wave propagation, wave propagation/active noise control, construction works, environmental acoustics, underwater noise, music and education and noise exposure/noise perception. With four papers per session delegates were spoilt to a plethora of interesting, entertaining, confidently delivered and informative presentations.

All papers are provided on a conference supplied USB thanks to Lindsay Hannah. Technical Session and Keynote Address Chairs are also to be commended – often taking on additional duties and/or stepping up to cover unavoidable absence on short notice. Thanks go to (amongst others) Wyatt Page and Stephen Chiles.

Sponsors are fundamental to the survival of the ASNZ. Without them, there would not be any conferences. Our corporate sponsors helped facilitate the 'welcome packs'. Whilst our bronze, silver, gold and platinum sponsors showcased their products and services at the trade show held in the Amokura room that served as the hub for the conference where after registration delegates enquired at trade stands and chatted whilst enjoying morning/afternoon tea and lunch. As our sponsors support the ASNZ, our membership must support our sponsors for this symbiotic relationship to continue flourishing.

The Annual General Meeting of the ASNZ was held after the Technical Sessions closed on late Monday afternoon. Jon Styles (aka Tim1) stepped in to announce that Tim Beresford would continue as President of the ASNZ for a second term whilst James Whitlock (Tim2) would continue as Secretary. Siiri Wilkening however, after approximately 25 years of service to the ASNZ as a Council Member (with 20 plus of those years being continuous as Treasurer), would step down and be superseded by Hedda Landreth. Our heart felt respect and gratitude go out to Siiri for her outstanding service. Thank you.

We also thank other departing members Matthew Bronka, Ashkane Ghane, Lindsay Hannah and Matthew Legg for their service whilst we welcome new members Mike Latimer and Wyatt Page and returnees to the ASNZ Council Tracy Hilliker, Michael Kingan, Victoria Rastelli, Jon Styles and Christian Vossart.

The warm welcome provided by the ASNZ was noted by many Australians, and the camaraderie shared by all attendees was never more apparent than at the Welcome Function held on the Monday evening at Te Marae at Te Papa, and the Gala Dinner on the Tuesday evening, with the latter being supported by our Platinum Sponsor Batten and Cradle.

Dinner speeches were made by Tim1 and Tim2 and comedic insight and acerbic wit were provided in abundance by our MC for the night, national treasure Ginette McDonald, entertaining us with anecdotes over dinner and rightly ridiculing everyone including both of the Societies for the lack of gender diversity on display.

Ginette set the scene for a night of much laughter, yarns and tall stories all ably accompanied by the Duke Wellington jazz ensemble. Along with good food at The Harbourside Functions Venue, the bar was well frequented and helped encourage many smiling faces on the night (and a few sore heads the following morning). A friendly, fun and collaborative atmosphere was felt by all.

Gina Sweetman kicked off the last day of the conference with the fourth and final keynote address. Gina has considerable experience being an accredited and experienced Resource Management Act Hearings Commissioner (Chair endorsement) and has been involved in many policy and consenting matters where acoustic effects have been key considerations. Gina drew from her extensive experience of working with acoustic experts and considering their evidence for complex resource consents and notices of requirement, RMA policy statements and plans. Of particular note in the address, was the emphasis placed on health as well as amenity, and a focus on the consideration of outcomes rather than just compliance with numbers and rules.

As the conference came to a close Mathew Legg presented the prize for the best student paper to Chiaki Fenemore of the University of Auckland as adjudicated by the panel of Grant Emms and Mark Poletti.

Te Papa Tongarewa in Te Reo Māori translates literally to 'container of treasured things and people that spring from mother Earth here in Aotearoa'. Te Papa is more colloquially known as 'our place', and a massive thank you to everyone that visited 'our place' and took part in what resulted in a thoroughly successful and enjoyable conference.

I wonder if I can get to the joint AAS/Acoustical Society of America conference in Sydney next year (I might have to take a tent). Failing that there is always the next ASNZ conference to look forward to in Christchurch in late 2024. See you there!

Christian Vossart

(ASNZ Council Member and member of the Conference Local Organising Committee)

FEATURES

Development of a Rainfall Test Rig

Mike Latimer [1], Robin Wareing [2]

[1] Canterbury Acoustic Testing Services, Christchurch, New Zealand
[2] rob@altissimo.nz, Christchurch, New Zealand

Abstract

Requirements of local educational buildings, in particular the Design Quality Learn Spaces Version 2.0 s (DQLS), has led to the need for commonly used roof/ceiling systems for Rainfall Sound to be tested.

Christchurch Acoustic Testing Services (CATS) has developed a rainfall test facility based on the following In-ternational Standards, ISO 10140-1: 2016 [3] and ISO 10140-5:2010/Amd 1:2014 [4].

Previously there have been problems faced in complying with both standards, with other facilities in New Zea-land. This has been due to, constraints on facility layout affecting rig design.

The CATS facility is housed in a large warehouse, allowing for easy access and the correct rainfall height, re-quired in the standard. Nozzles were used to form the rain drops; this development was used to give a higher degree of repeatability in drop formation [1].

ISO 10140-1: 2016 [3] Annex K, subsection K.4 prescribes two measurement techniques, K.4.2 Determination of the sound intensity level (indirect method) and K.4.3 Direct measurement of sound intensity.

CATS used the direct sound intensity measurement. Measurements were made in accordance with ISO 15186-1:2000 [5], to measure the total sound power radiated from the sample excited by Heavy artificial rainfall [3].

1. Introduction

The rainfall sound rig design, construction, commissioning and testing to ISO 10140-5:2010/Amd 1:2014 is de-scribed in this paper.

There are few test facilities available worldwide for the measurement of rainfall sound and these are predominantly based in Europe. Although some testing has been carried out in New Zealand, issues with rig construc-tion and facility layout proved to be problematic and the service is no longer offered.

CATS acoustic test lab was approached by a client to test the performance of several roof structures, in particular those used in New Zealand educational buildings.

The performance of these systems needed to be tested against the Ministry of Education (MOE) document Designing Quality Learning Spaces Acoustics (DQLS) version 2.0 2016. At the time of writing this paper the DQLS has been revised, the latest publication is version 3.0, December 2020.

When the acoustic test lab was constructed in 2018, a test aperture was installed in the control room roof for the measurement of rainfall sound. Design, construction, commissioning, and sample testing was carried out in accordance with ISO 10140-1: 2016 and ISO 10140-5:2010/Amd 1:2014.

1. Design, construction

The rain noise design required consideration of the following elements:

1. Water-supply system
2. Tank with perforated base
3. Fall height
4. Test specimen mount
5. Water drainage
6. Test room
7. Measurement system

A schematic of the final design of the test facility is shown in Figure 1. The following sections describe the development of this design and the key considerations.

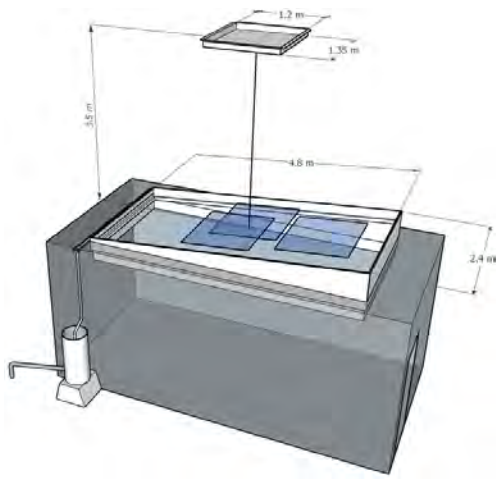


Figure 1: General layout of rainfall test facility

1.1. Rain type

ISO 10140-1: 2016, Annex K sub section K.4.1 General, states.

The standard rainfall type used for comparison between products shall be the heavy type as specified in ISO 10140-5:2010/Amd 1:2014, Table H.1., as shown in Table 1

Rain type	Rainfall rate mm/hr	Volume median drop diameter mm	Fall velocity at fall height m/s
Intense	15	2	4
Heavy	40	5	7

Table 1: Table H.1 Characteristic parameters for generation of artificial raindrops

Based on the requirements of sub section K.4.1 for comparison between products, and previous published measurements carried out in Europe [1], a rainfall type of Heavy was chosen. This rainfall rate then determined the design of the rainfall rig. Table H.2 Specifications, of ISO 10140-1: 2016, Annex K, outlines the essential requirements of the rig design based on the selected rainfall type, as show in Table 2.

Parameters of tank with perforated base		Intense	Heavy
1	Diameter of holes	0.3 mm to 0.5 mm	1 mm
2	Number of holes per unit area	Approx. 25 m^{-2}	Approx. 60 m^{-2}
3	Fall height	Approx. 1 m	Approx. 3.5 m
4	Volume median drop diameter	2 mm	5 mm
5	Distribution of drop size	Max. uniformity	Max. uniformity
6	Fall velocity at fall height	4 m/s	7 m/s
7	Rainfall rate	15 mm/h	40 mm/h
8	Water supply	To allow a constant height of water in the tank (50 mm to overflow limit)	

Table 2: Table H.2 - Specifications

1.2. Tank design

The tank was constructed to the **geometric** requirements of the standard, including dertermination of the following,

The tank was constructed from 5 mm sheet aluminium, not 10 mm polycarbonate as mentioned in the standard. The standard is not specific as to whether polycarbonate must be used, but states.

If the tank with perforated base does not correspond to the geometrical characteristics given above, the drop size, impact velocity and rainfall rate shall be measured as mentioned in ISO 10140-1:2010, Annex K

Section H.2.2 Artificial raindrop generation system of ISO 10140-1: 2016, Annex K, states *"The perforations on the tank base should be distributed over a minimum of 1.6 m²"* and *"a random distribution is preferred rather than a uniform".*

The tank constructed for the CATS rainfall rig was 1.350 x 1.200 m, 1.62 m², therefore complying with the geo-metric requirements of ISO 10140-1:2010, Annex K, and shown in Figure H.1 "Schematic of tank with perforated base", in the standard. The tank had 97 threaded holes in a random distribution, as shown in Figure 2.

1.2.1 Tank perforations

ISO 10140-1: 2016, Annex K, requires 1 mm holes for the "Heavy" rainfall type. From a practical point of view, drilling a 1 mm hole through the aluminium tray is challenging. This is due to the hole size, depth of hole and material recommended in the standard. Alternatively, the holes may be nozzles, but the rainfall from these must be measured against the standard rainfall parameters.

Testing carried out by the CSTB [1] with a tank constructed as per ISO 10140-5:2010/Amd 1:2014, observed that drop formation was not consistent due to, quality of the 1 mm holes and inconsistencies in the flatness of the tank bottom. Furthermore, they noted a greater improvement in reproducibility in measurement results.

For these reasons, nozzles were used in this implementation. The nozzles were CNC machined to give a high level of precision and are pictured in Figure 3.

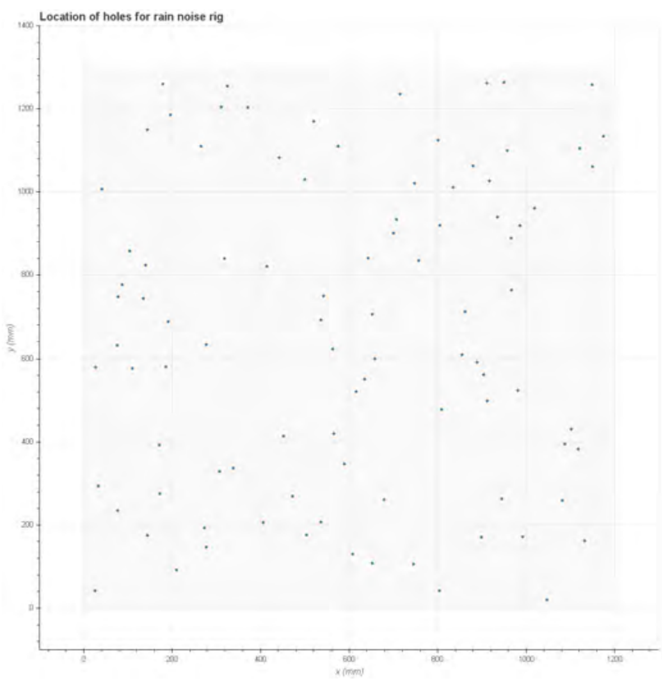


Figure 2: Random hole distribution in tank base

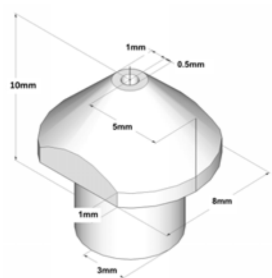


Figure 3: Nozzle design

1.2.2 Tank mounting

The tank sits on a frame that can be levelled precisely with 4 corner jack screws. The frame has wheels and sits on top of a gantry crane, which allows the tray to be moved to several locations for measurements as required by ISO 10140-1: 2016, Annex K subsection K.4.1.

1.3 Water supply system

The water supply needs to supply clean and of consistent flow. The supply side was hooked up to filtered mains water, then fed through a flow regulator to the tank. Two adjustable overflows were installed, the height of the overflow was set to give the correct rainfall rate. The overflow water was fed to waste. This system gives a continuous head to the nozzles, with no fluctuation.

1.3.1 Rainfall water collection

Rainfall impacting on the installed sample runs into a guttering. This runoff is routed through a barrel, which is used as a collection point to check rainfall rate, as shown in Figure 1.

1.4 Test specimen mount

The test specimen mount adapter was constructed from 24 mm plywood, faced with 2 mm steel, with a fall of 5°, as shown in Figure 4.

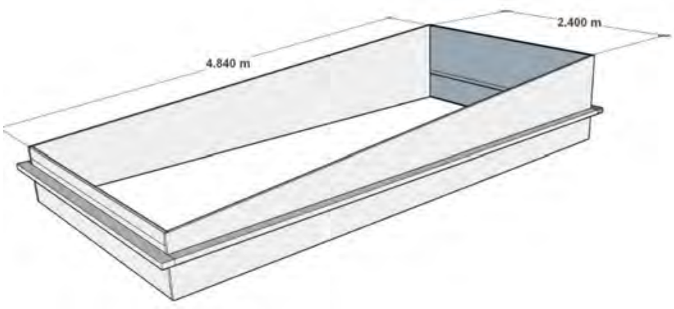


Figure 4: Nozzle design

1.5 Test room

The main control room attached to the reverberation room was use as the receiving room, as pictured in Figure 1. The acoustic parameters of the room were not critical, as the direct sound intensity measurement was used, however certain room parameters need to still be met as per, ISO 15186-1 Acoustics-Measurement of sound insulation in buildings and of building elements using sound intensity Laboratory measurements.

2. Commissioning

ISO 10140-5:2010/Amd 1:2014, subsection H.2.3 Calibration of the raindrop generation system, states:

If a water tank system is used and therefore follows the geometrical characteristics given above, only the rainfall rate shall be checked by collecting the water over a given area over a precisely measured time period.

The tank was constructed to the requirements of the standard with the addition of nozzles. A full commissioning of the rainfall rig was performed, which included measurement of the following.

1. Rainfall rate
2. Drop size
3. Drop velocity

2.1 Prototype rig

Initially a prototype tank was constructed with 10 nozzles, this was mounted on a scaffold 3.5 m above a collection tank sitting on scales, pictured in Figure 5. A high-speed video recorder was used to measure the fall velocity and drop size.

The tank was filled continuously, with dyed red water, while the overflow was set to give a constant head height.

Figure 5: Trial rainfall rig

2.1.1 Velocity and rainfall rate measurement

The rainfall rate was measured by logging the weight of the water over a fixed time, the overflows were adjusted to meet the required Heavy rain type of 40 mm/h.

To measure the raindrop velocity a 10 mm x 10 mm grid was set up behind the raindrops whilst videoing, as shown in Figure 6, the video was processed. By running the video in a slow frame rate, the number of frames were counted against the time it took fall the drop to fall 10 mm, the velocity was then calculated, and velocity measured.

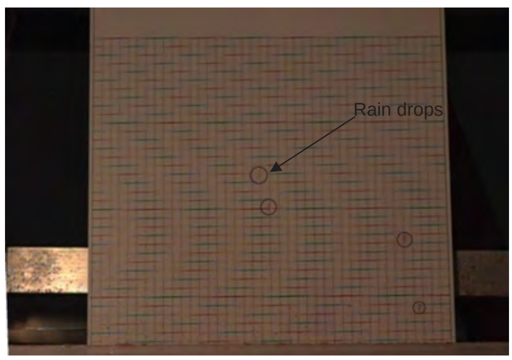


Figure 6: Celocity measurement grid

2.1.2 Drop size

Drop size was measured using high speed photography, screen shots were taken from the video and imported into image processing software. These images were scaled, and the drop size was measured, shown in Figure 7

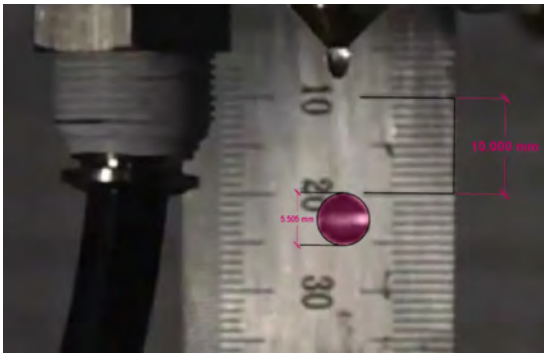


Figure 7: Drop size measurement

3. Acoustic Testing

The direct intensity measurement technique was used for all measurements, in accordance with ISO 15186-1. This measurement can be performed using a manual continuous scan or a series point measurements of the sound intensity under the test sample.

An x-y plotter was implemented to perform a series of intensity measurements at discrete points on a 200 x 200 mm grid patten, the tank was moved into three different positions, as shown in Figure 1, this equated to 783 ten second point measurements over the samples surface. The average sound intensity was calculated from these measurements and the total sound power radiated from the sample was calculated.

3.1 Reference test specimen

ISO 10140-5:2010/Amd 1:2014 Annex I, requires a reference test specimen for quality control and to check the reproducibility of laboratory rain sound measurements in different laboratories.

The reference sample consists of a 1.250 x 1.500m, 6 mm thick pane of (float) glass, as shown in Figure 8, mounting of the glass was in accordance with ISO 10140-1:2010, Annex D.

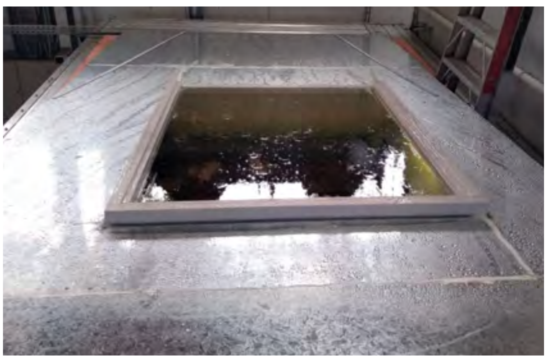


Figure 8: Glass reference sample mounted

The structural decay time T_s of this glass was measured. The sound intensity level was measured, and a correction was applied for differences between the measured loss factor η and the reference loss factor η_{ref} using Table 1.1 in the standard.

The measured sound intensity was compared with the ISO 10140-5:2010/Amd 1:2014 reference spectrum and data published by the CSTB [1]. The results of this comparison are presented in Figure 9.

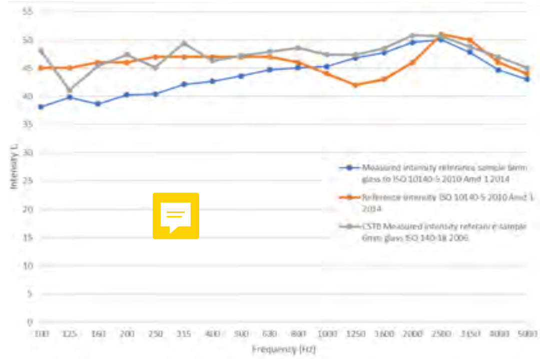


Figure 9: Reference sample comparison

Figure 9 shows some variation in the measured intensity for the reference glass panels, we believe this can be contributed to the following.

1. Glass type:

ISO 10140-5:2010/Amd 1:2014, only specifies glass thickness (6 +- 0.1) mm and area (1.250 x 1.500 +- 50) mm, with a warning to use thermally toughened glass for safety reasons. The standard does not specify what the physical properties should be.

2. Mounting method:

ISO 10140-1:2016 Annex D subsection D.3 Boundary and mounting conditions, requires the glass be sealed “with a type of putty”. Depending on the putty/sealant used, the mounting conditions of the reference sample will differ, effecting how well the sample is isolated and the boundary mounting conditions.

3. Rainfall drop size distribution

Depending on the rain drop size distribution the reference sample frequency spectrum will differ. Previous testing has shown consistent drop size to be an issue [1]. Larger raindrops will excite the reference sample at lower frequencies.

Further investigations will be undertaken in the lab to investigate the causes of this variation from the reference glass panel.

The difference between the measured sound intensity and the reference sample is used to normalise all measured results to the reference lab. This is intended to account for variations in lab design, mounting conditions, and receiving room performance.

3.2 Test sample

The test samples were installed by the client and in accordance with ISO 10140-1: 2016 requirements, all samples were tested at the minimum angle of 5°.

Three different rain fall positions were measured for each test sample as required by ISO 10140-1: 2016. Figure 10 shows a roof sample installed with the measurement plotter underneath.

Figure 10: Roof sample installed

Figure 11 shows a typical build-up of the tested roof system, mounted in the adapter.

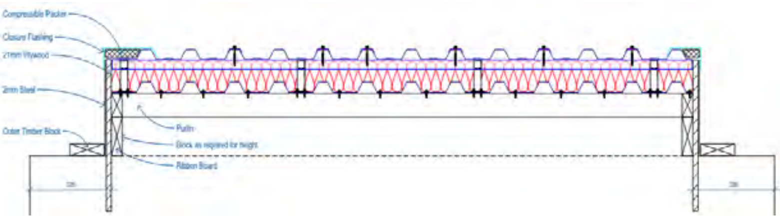


Figure 11: Image supplied by RoofLogic

Typical rool buildup mounted in adapter

4. Conclusions

The rainfall sound rig was constructed in accordance with ISO 10140-5:2010/Amd 1:2014. Measurements were performed in accordance with ISO 10140-1: 2016.

We found the nozzles worked well and we are looking to replace them with smaller diameter ones to measure Intense rainfall.

We found the design of the tank and supporting structure, worked as expected with no commissioning or in-service issues.

The direct intensity measurement technique worked well using the x-y plotter, a total of 783 point measurements were taken, then processed to give the total sound power radiated from the sample.

Acknowledgements

Special thanks to Rob Wareing for advice and technical backup, Kelvin Walker from Angus Ceiling for advice and help with rig construction, Rooflogic Ltd, for construction of the sample mounting adapter and using the facilities for product testing.

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Chéné Jean-Baptiste, CSTB. 2010. *Rainfall noise measurements: Assessment and perspective four years after the publication of EN ISO 140-18*

ISO *10140-1:2016 Acoustic – Laboratory measurements of sound insulation of building elements – Part 1: Annex K Roofs, roof/ceilings systems, roof windows and skylights Rainfall sound*

ISO 10140-5:2010/Amd 1:*2014 Acoustic – Laboratory measurements of sound insulation of building elements – Part 5: Requirements for test facilities and equipment – Amendment 1: Rainfall sound*

ISO 15186-1:2000 *Acoustics — Measurement of sound insulation in buildings and of building elements using sound intensity — Part 1: Laboratory measurements.*

Photo credit: T Williams and G Moon

Development of noise barriers for road, rail and urban environments

John Pearse [1], Brian Donohue [2] and Greg Watts [2]

[1] Acoustics Research Group, Dept of Mechanical Engineering, University of Canterbury, Christchurch, New Zealand
[2] Acoustics Research Group, Dept of Mechanical Engineering, University of Canterbury, Christchurch, New Zealand
[3] Bradford Centre for Sustainable Environments, University of Bradford, Bradford, United Kingdom

Abstract

In this paper we discuss the design and development of a new generation of innovative and environmentally friendly noise barriers. The various methods for achieving the design requirements were identified and evaluated. The selected method of fabrication was rotational moulding of polyethylene, producing interlocking panels that fit into steel columns. The advantages of the resulting system include a low installed cost, a completely recyclable product, possibility of producing a variety of surface textures (including embossing), and the ability of meet a 50 year life. Installation costs are significantly reduced by the relatively long panels and ease of installation. The panel surface is very hard and not amenable to etching. The product development process is described with particular attention to obtaining the required acoustic performance and wind-load ratings. Future developments in terms of enhanced acoustic performance are identified and discussed.

1. Introduction

In this paper we discuss the design, manufacture, testing and commissioning of a new generation of noise bar-riers. The design process is described, including the development of the panels and the methodology followed to obtain the required acoustic and mechanical performance.

2. Design considerations

The noise barrier requirements were to obtain a minimum sound tranmission loss rating of Rw 25 with a system with a minimum of components, that could be easily and quickly installed. Other requirements included a 50 year design life and a surface that is easy to clean and graffiti resistant. An interlocking panel concept was selected that enabled the design requirements to be met in an effective way.

2.1 Sound absorption

Whilst recognising that sound absorption would be a necessary characteristic to include, it was not part of the original design brief. Several options were considered at the design stage however, with a mind to make inclu-sion an easy option at a later stage.

2.2 Sound transmission loss

The sound transmission loss was set at a minimum desired rating of D3 according to EN 1793-6 (2012) and would be determined in accordance with the in-situ methodologies described in this standard.

2.3 The panels

A panel concept was selected that facilitates a modular construction with installation advantages and enables individual components to be readily replaced in case of damage. The panels are light weight so a crane is not required for installation with consequent cost savings. Although each panel is only 50 kg using two people makes installation easier as the panel length can be up to four metres. The ends of the panels are shaped so that they slide over the flange of a standard I-beam or column providing an acoustic seal. The top and bottom of each panel are also shaped so that they interlock when stacked. Having carried out in-situ evaluations of several different types of road traffic-noise barrier we recognised that leakage at the joints with the supporting posts degraded the performance of the system.

2.4 The posts

Steel columns with a standard I-section were selected for reasons of cost and availability. This also enabled the system wind loading requirements to be met. The columns are set in concrete in the ground and galvanised to resist weathering effects.

2.4 Materials

Polyethylene was selected as the material of choice as it has many advantges over the more traditional materi-als used such as timber, concrete and acrylic. This choice was founded on our experience in developing her-metically sealed panel absorbers for use as hygenic ceiling tiles.

2.5 Fire rating

The base polyethylene resin meets the flammability requirement of UL 94HB. In laymen's terms, it cannot be ignited by a cigarette lighter. A higher flammability rating can be obtained by employing additional flame retardants.

3. Manufacturing considerations

The lowest cost method for processing polyethylene is rotational moulding. This process is traditionally used for products of symmetrical form such as cyclinders and is widely used for manufacture of water storage tanks. By controlling the way heat flows around the mould various shapes can be moulded. Popular non cy-lindrical shapes include kayaks, surfboards, pump housings, road traffic safety and crash barriers. Tooling is a lot less costly than injection moulding and incorporation of surface features in the product are easily catered for.

4. Barrier evaluation

4.1 Simulation

The sound absorption and transmission loss were predicted together with the wind loading.

4.2 Test facility

A dedicated test facility with a length of four panels and a height of four metres was constructed.

The method used for evaluating the transmission loss of the barriers was an in-situ method described in BS EN1793-6 (2012). The measurement equipment consisted of:

- An array of nine Bruel & Kjaer type 4189 ½" microphones, mounting frame and tripod
- A loudspeaker (12 inch, 600W) and tripod
- An amplifier and power supply for the loudspeaker
- A Bruel & Kjaer PULSE C-frame for data acquisition and signal processing
- Test signal (MLS or swept sine)
- A laptop computer

A diagram of the measurement set-up is shown in Figure 1 and a photograph of the microphone array in-situ is shown in Figure 2. A similar test without the barrier present was also carried out in order to calculate the transmission loss.

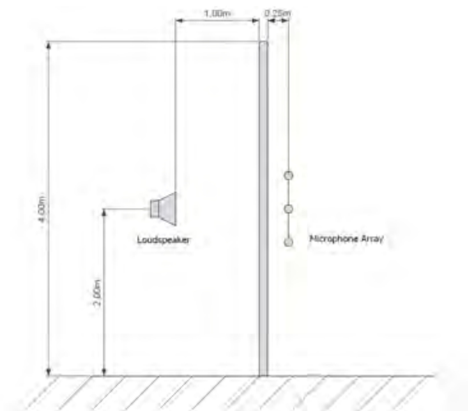

Figure 1: Schematic of in-situ test arrangment

Figure 2: Microphone array in position for in-situ testing

4.3 Wind loading

In Australasia, designs for noise barriers must include for wind loading as a structure using the joint standard AS/NZS1170.2 Structural design actions, Part 2: Wind actions. The design procedure begins by defining a wind action W, which has two components: Wu and Ws, the regional wind actions for annual probability of exceed-ance (P) for ultimate and serviceability states. In this procedure, the regional wind speeds (VR) have to be selected based on where the barrier is to be installed. The site wind speed (Vsit,β) is then determined from the regional wind speed modified to account for terrain factors. The design wind speed (Vdes, θ) is taken as the maximum cardinal site wind speed interpolated within a ±45° range to the orthogonal direction being considered. The design wind pressures and distributed forces are then found from the design wind speed and then the wind actions are calculated. Thus each installation is site specific and referring to Table.1 it can be seen that the regional wind speeds vary between 30 to 69 m/s for non-cyclonic regions, corresponding to 108 km/h to 240 km/h.

Regional wind speed (m/s)	Region				
	Non-cyclonic			Cyclonic	
	A (1-7)	W	B	C	D
V_1	30	34	26	23 x *Fc*	23 x *Fc*
V_5	32	39	28	33 x *Fc*	35 x *Fc*
V_{10}	34	41	33	39 x *Fc*	43 x *Fc*
V_{20}	37	43	38	45 x *Fc*	51 x *Fc*
V_{25}	39	43	39	47 x *Fc*	53 x *Fc*
V_{50}	41	45	44	52 x *Fc*	60 x *Fc*
V_{100}	43	47	48	56 x *Fc*	66 x *Fc*
V_{200}	43	49	52	61 x *Fc*	72 x *Fc*
V_{250}	43	49	53	62 x *Fc*	74 x *Fc*
V_{500}	45	51	57	66 x *Fc*	80 x *Fc*
V_{1000}	46	53	60	70 x *Fc*	85 x *Fc*
V_{2000}	48	54	63	73 x *Fc*	90 x *Fc*
V_{2500}	48	55	64	74 x *Fc*	91 x *Fc*
V_{5000}	50	56	67	78 x *Fc*	95 x *Fc*
V_{10000}	51	58	69	81 x *Fc*	99 x *Fc*

Table 1: Regional Wind Speeds

The design wind speed is modified by factors related to the structure and its dynamic response to fluctuations in the wind. The design wind pressure is then calculated and applied normal to the barrier surface for calculation of stresses and deformations. Barriers to be installed in regions where cyclonic conditions can be expected are also subject to an assessment for fatigue loading.

5. Validation

5.1 Acoustic performance

The transmission loss of the barrier is shown in Figure 3 below.

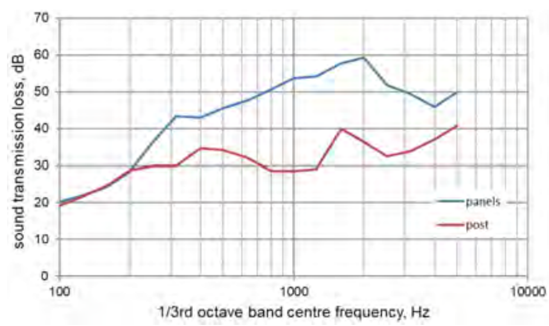

Figure 3: In-situ sound transmission loss

The results indicate that the barrier system complies with category D3 according to Appendix A of BS EN1793-6 (2012). Whle the transmission loss provided by the panels falls in the D3 category and a small increase in their thickness would increase their transmission loss and tip them into the D4 category.

Following BS EN 1793-1 (2017) method the sound absorption obtained from reverberation room measurments for an early version of the moulded panels is shown in Figure 4 below.

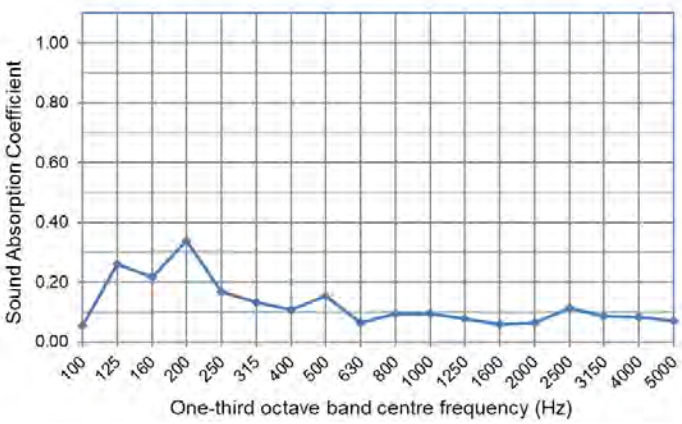

Figure 4: Sound absorption coefficients of sample road traffic barrier

5.2 Wind loading

An analysis of stress and deflection of the noise barrier was conducted for application in regions where the wind speed does not exceed 150 km/h, corresponding to V_{100}, which applies to all areas of New Zealand except Wellington. The elements of the barrier were modelled using Solid Works and assembled into a model for analysis using ANSYS.

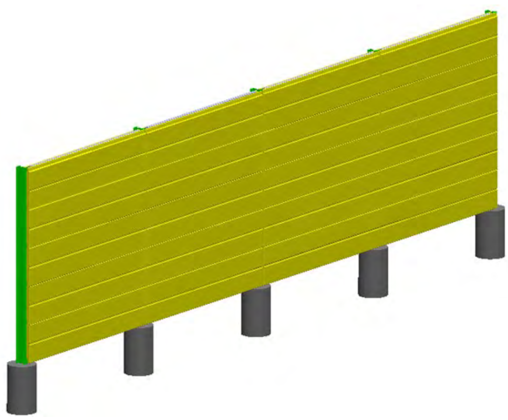

Figure 5: Solid Works model of a 4-bay noise barrier, 4m high

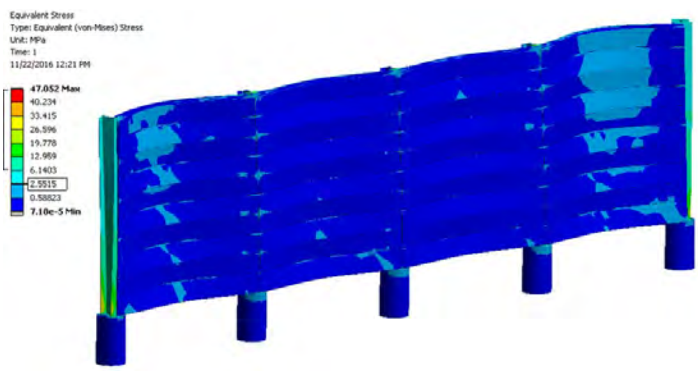

Figure 6: Stress distribution for model expossed to 150km/h steady wind load

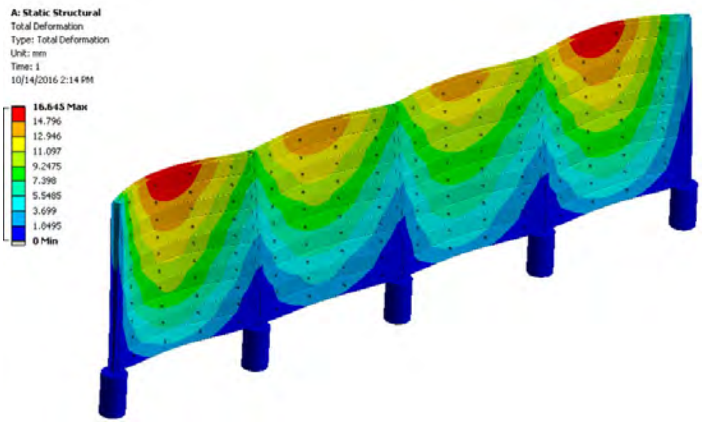

Figure 7: Deflections in model exposed to 150km/h steady wind load

Studies were also carried out for different size columns (for lower wind loading regions) and for cases including stiffeners layed horizontally between each 'plank'.

Mechanical tests incuded static loading (Figure 8), impact testing (Figure 9), and for knife and graffiti damage.

Figure 8: Load testing of a panel

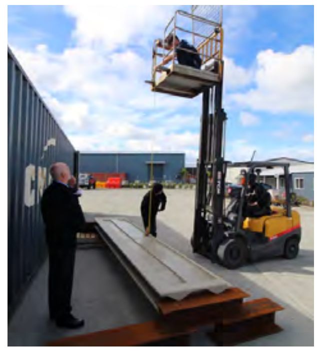

Figure 9: Impact testing of a panel from 3m

6. Conclusions

The barrier system that has been developed has a number of attractive features that include ease of manufacture and installation. The panels are easily tailored in terms of surface features and have an attractive life cycle cost.

A capping to increase the transmission loss for a given barrier height, increasing the sound absorption provided by the barrier and enabling vegetation to grow within the barrier (living wall) to improve the visual aspects of the barrier are being developed..

Acknowledgements

The support of Advanced Rotational Moulding Ltd is gratefully acknowledged.

References

BS EN 1793-6 (2012): Road traffic road traffic noise reducing devices – Test method for determining the acoustic performance – Part 6: Intrinsic characteristics – in situ values of airborne sound insulation under direct sound field conditions

BS EN 1793-1 (2017): Road traffic road traffic noise reducing devices – Test method for determining the acoustic performance – Part 1: Intrinsic characteristics of sound absorption under diffuse sound field conditions

AS/NZS 1170.2 (2011): Structural design actions Part 2: Wind actions


MARSHALL DAY
Acoustics
N.M Spa

Improving the sound insulation of dwellings via a District Plan rule

Jeremy Trevathan [1] and Clare Dykes [2]

[1] Acoustic Engineering Services Ltd, Christchurch, New Zealand
[2] Acoustic Engineering Services Ltd, Christchurch, New Zealand

Abstract

The Christchurch District Plan contains a rule requiring new residential dwellings which are to be constructed in close proximity to some roads to be designed to provide an enhanced level of external sound insulation. As part of a programme to improve the Christchurch District Plan, a review was undertaken of approximately 50 residential building projects which had interacted with the rule. The rule is complex, and so the sample included projects where a 'façade reduction' approach had been taken, an 'internal noise level' approach had been taken, and projects where upgrades were based on a set of 'acceptable solutions'. A number of projects had also progressed via Resource Consent to authorise various non-compliances with the rule. The study enabled the examination and comparison of the effectiveness of these various approaches in providing occupants with a reasonable level of protection from traffic noise. In a number of situations additional cost had been incurred upgrading dwellings where this was not justified. In some other situations, occupants were not provided with an appropriate level of protection. These findings allowed the tension between providing a control which is simple to apply, and actually provides a robust outcome from a technical acoustics perspective, to be explored.

1. Introduction

The Christchurch District Plan Rule 6.1.7.2.1 requires that new buildings, or alterations or additions to existing buildings, intended for a sensitive activity within certain distances of major roads either:

- Be designed and constructed to achieve a minimum external to internal noise reduction of 30 dB $D_{tr,2m,nT,w} + C_{tr}$ to any habitable space; or
- Be designed and constructed to meet an indoor design sound level of 40 dB $L_{Aeq(24h)}$

An exclusion applies where the external traffic noise level is low. An allowance for future traffic volumes must be made. In some circumstances the requirements must be achieved at the same time as the ventilation re-quirements of the New Zealand Building Code. Compliance can be achieved via provision of a design report from a suitable professional, or by using building elements which are contained in a list of acceptable solutions in the Plan.

The Christchurch City Council has received a disproportionate level of feedback regarding the unsuitability of the rule, from both internal and external parties. As part of this work a review was undertaken of how the Rule is currently being applied based on a sample of 48 building projects.

2. The sample

The majority of the buildings in the sample were in suburban locations, and for the projects which involved noise from roads:

- The roads included State Highways (10 %), Main Distributor, Local Distributor or Arterial Roads (55 %) and Collector Roads (35 %).
- In the vast majority of instances, the speed limit of the relevant road was 50 km/hr. The examples where a higher speed limit was involved were typically the State Highways, with speed limits of 60 to 100 km/hr.
- The Annual Average Daily Traffic (AADT) data for the roads indicates traffic volumes ranging between 640 and 32,000. From a noise perspective, all other things remaining equal, the noise generation be-tween these two AADT scenarios would vary by 17 dB.
- The setback distance between the nearside carriageway of the road and the noise sensitive building ranged between 5 and 80 metres. From a noise perspective, all other things remaining equal, the noise received between these two setback scenarios would vary by 12 dB.

The distribution of calculated worst-case noise levels incident on the closest façade of the proposed building in each case are shown in figure 1.

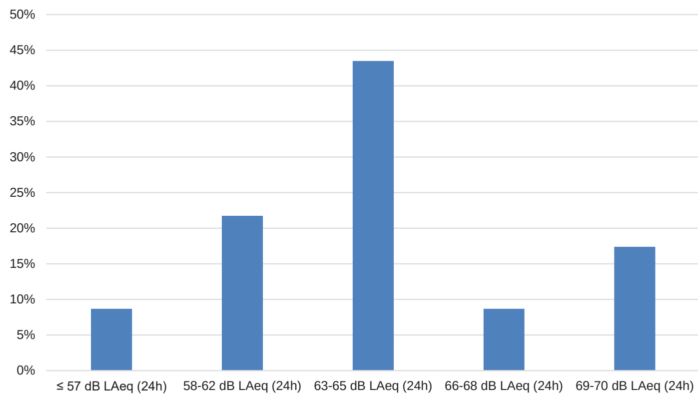

Figure 1: External noise level experienced at the closest façade of noise sensitive buildings in the sample

The Rule requires consideration of noise incident on all facades of a noise sensitive building – not just the most exposed façade. To allow the noise environment for each building in the sample to be fully understood, computa-tional modelling was undertaken which allowed the difference between the noise level received at the closest façade to the road, and other facades, to be examined. The findings of this analysis were:

- For facades perpendicular to the road, the expected noise level is at least 3 dB lower than the most exposed façade. Sometimes the difference was much greater.
- For the rear façade (on the side of building away from the road), the expected noise level is at least 15 dB lower than the most exposed façade.

When combined with the information in figure 1, this analysis provided a good understanding of the external traffic noise circumstances which each project in the sample was likely to have experienced.

3. Projects where detailed analysis had been undertaken

For approximately half of the projects in the sample an acoustic engineer was engaged to undertake analysis to determine whether the proposed building complied with either the 'façade reduction' requirement, or the 'internal noise level' requirement, and to recommend modifications to the building structure where compliance was not expected.

3.1 Typical building upgrades

The sample included buildings which were to be subjected to a range of external noise levels. As expected, the detailed analysis confirmed a variety of upgrades were required. Table 1 summarises the modifications which were required to buildings in the sample, sorted by future external traffic noise level on the most exposed façade.

External traffic noise level	Detailed analysis approach, and typical outcomes
≤ 57 dB $L_{Aeq\ (24h)}$	Internal noise levels were calculated. No upgrades required.
58 – 62 dB $L_{Aeq\ (24h)}$	Internal noise levels were calculated. No upgrades required to the building structure but in some cases bedrooms required a mechanical ventilation system.
63 – 65 dB $L_{Aeq\ (24h)}$	Internal noise levels were calculated for the majority of the examples. Mechanical ventilation systems were often required within bedrooms facing the road. Some habitable spaces also required upgrades to the glazing with a traffic noise reduction in the order of 27 – 29 dB.
66 – 68 dB $L_{Aeq\ (24h)}$	Internal noise levels were calculated for the majority of the examples. Mechanical ventilation systems were required within bedrooms facing the road. Habitable spaces required upgrades to glazing with a traffic noise reduction in the order of 29 – 32 dB. Double plasterboard internal linings were required to facades exposed to the highest external noise levels.
69 – 70 dB $L_{Aeq\ (24h)}$	The majority of examples calculated internal noise levels. Ceiling and/or wall upgrades, glazing upgrades and mechanical ventilation to bedrooms were required. One example used the 'façade reduction' method. This resulted in upgraded glazing to a system with a traffic noise reduction in the order of 26 dB and no mechanical ventilation (due to an issue with the wording of the Rule, discussed below).

Table 1: Building upgrades required to comply with the Rule

From this review, we were able to consider how successful the Rule had been in ensuring a reasonable level of protection from traffic noise, and consistent and cost-effective outcomes.

3.2 Had this aspect of the Rule been successful?

Overall, when applied by a suitably qualified person we found that the Rule typically leads to relatively consistent and reasonable outcomes – as is evident in table 1. The Rule therefore generally fulfils its intended role of pro-tecting people from undesirably high levels of traffic noise within dwellings. However, a number of areas of interest were identified, where the function of the Rule could be improved – and which should be carefully considered when drafting similar rules in other Plans. These issues are discussed in the following sections.

3.2.1 External noise level calculation

Some variation was evident between the calculated external noise levels. This appeared to be potentially due to the traffic count data that had been used and if or how any out-of-date data had been adjusted to the current year. The most common deviation from the predicted external traffic noise level using our standardised method was an underestimate of 1 – 3 dB – although there was one example where an external noise level of 63 dB LAeq (24h) had been used, and we calculated an external noise level of 70 dB LAeq (24h) using the standardised method.

When then applying the 'internal noise level' approach, these variations (and in particular, the underestimates) of the external traffic noise level would have resulted in reduced construction upgrades and higher (and on rare occasions, potentially inappropriate) internal noise levels.

3.2.2 Break-in noise calculation

Once the external noise level had been established, it appeared that the calculations used to establish the expected internal noise level throughout the sample were very similar. As this is a relatively simple calculation pro-cess this is to be expected.

One source of minor variation appeared to be the sound insulation performance that had been assumed for the various façade elements. This is likely to be an unavoidable source of variation as data supplied by manufacturers for nominally identical systems can vary significantly, as can predictions provided by modelling software.

While the sound insulation performance data was rarely recorded in the report provided to Council, no significantly inappropriate assumptions regarding Sound Transmission Loss were evident in the sample (based on the con-sistency of the final outcomes as summarised in table 1). The largest one-off discrepancy identified was a situation where a double-glazed system comprising of 5 mm float glass / 14 mm air space / 4 mm float glass was used in a context which suggested the engineer considered its Sound Transmission Loss performance was similar to 10 mm float glass / 12 mm air space / 4 mm float glass – which is not the case. That incorrect assumption would have led to higher internal noise levels than predicted.

3.2.3 Use of the 'façade reduction' aspect of the Rule

While in most cases analysis appeared to have been undertaken to determine what would be required to comply using both the 'internal noise level' and 'façade reduction' method, only 12 % of the projects ultimately relied on building upgrades determined using the 'façade reduction' aspect of the Rule. This is presumably due to the fact that unless noise levels are 70 dB $L_{Aeq(24h)}$ or higher over all facades of a building, an internal noise level require-ment of 40 dB $L_{Aeq(24h)}$ can be achieved with significantly less upgrades than is required to provide a performance of 30 dB $D_{tr,2m,nT,w} + C_{tr}$ for all facades of the building. As shown in table 1, the highest external noise level in the sample was 70 dB $L_{Aeq(24h)}$, and that was only experienced at the most exposed façade.

In one instance where the 'façade reduction' approach had been adopted, the external traffic noise levels were relatively low, and so the building upgrades recommended were disproportionately extensive, compared to other examples exposed to similar external levels where the 'internal noise level' approach had been used.

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At the other end of the spectrum, there were a number of projects where the external noise level was 70 dB $L_{Aeq\ (24h)}$ – and some examples where each of the approaches had been taken. The outcomes varied considerably both in terms of likely cost to the developer (for example, the projects which relied on the 'internal noise level' method required non-standard glazing, additional linings and a mechanical ventilation system), and the environment provided for building occupants (elevated traffic noise levels would have been experienced within habitable spaces of the projects which relied on the 'façade reduction' method, and no alternative ventilation was provided).

3.2.4 Requirement for mechanical ventilation

Due to ambiguous drafting of the Rule a Practice Note was developed by the Council to explain how the Rule was to be applied in situations where windows needed to be open for ventilation. The Practice Note confirms the 'correct' interpretation of the Rule is that if the 'internal noise level' requirement can only be met with windows closed within bedrooms, then mechanical ventilation needs to be provided in these rooms. However, this does not apply to other habitable spaces, or if the 'façade reduction' method is used.

From the sample it was clear that there was not widespread industry familiarity with the Practice Note, and varying interpretations were evident with regard to this aspect of the Rule. In some situations, it appeared that recommen-dations regarding mechanical ventilation had been provided which were consistent with good practice, and not necessarily in strict accordance with the actual Rule wording or the Practice Note.

While not entirely consistent, the requirement for mechanical ventilation began to feature for those examples with an external noise level of 58 dB $L_{Aeq\ (24h)}$ or above (and where the 'internal noise level' method had been used). As open windows typically provide a sound reduction in the order of 10 – 20 dB, this is a logical outcome where the objective is to limit internal noise levels to 40 dB $L_{Aeq\ (24h)}$.

Two examples where the external noise level was 70 dB $L_{Aeq\ (24h)}$ used the 'façade reduction' method and therefore no mechanical ventilation was required. Based on an outside to inside reduction of 17 dB with windows cracked for ventilation, for these two dwellings the internal noise levels within the bedrooms at times would be as high as 53 dB $L_{Aeq\ (24h)}$ – significantly above a level which is appropriate for residential living. Another two projects used the 'internal noise level' approach, but did not recommend mechanical ventilation. The calculated external noise levels in those two cases were 61 and 64 dB $L_{Aeq\ (24h)}$ – so again inappropriately elevated internal noise levels would also be expected within these spaces when the windows are open for ventilation. For these four buildings the occupants would therefore have to make a choice between having adequate ventilation to their bedrooms, or having elevated internal noise levels.

4. Projects where the acceptable solutions had been used

For approximately 10 % of projects in the sample the 'acceptable solutions' provided in the District Plan were used. These dwellings experienced external noise levels ranging from less than 55 dB $L_{Aeq\ (24h)}$ up to 69 dB $L_{Aeq\ (24h)}$.

4.1 Typical building upgrades

The acceptable solutions include certain high mass claddings or a high mass RAB layer, glazing area of less than 35 % of the floor area with a glazing system which provides a traffic noise reduction of 32 dB, and 0.55 mm steel roofing. This typically required upgrades to the glazing, roof / ceiling, and external walls over standard residential constructions. As with the 'façade reduction' method, these upgrades are applied to all external facades of habit-able spaces, regardless of external noise level.

4.2 Had this aspect of the Rule been successful?

The maximum external noise level for a project in this group was 69 dB $L_{Aeq\ (24h)}$. With this external noise level, the noise reduction provided by the acceptable solutions would be expected to be of approximately the right order. Appropriate noise levels would therefore have been achieved within the habitable spaces when windows were closed, with no significant façade overdesign. However, as mechanical ventilation is not required under the Rule, the upgrades would be of minimal benefit and internal noise levels would be inappropriately high when windows were open for ventilation.

Overall, external noise levels only approached 70 dB $L_{Aeq\ (24h)}$ in the minority of situations in the sample, and therefore use of the 'acceptable solutions' typically led to upgrades to buildings which were more significant than necessary to provide appropriate internal noise levels. As an example, one project within the sample had an expected external noise level of less than 55 dB $L_{Aeq\ (24h)}$. No upgrades would have been required to provide appropriate internal noise levels. However, the dwelling construction was modified to match the acceptable solutions – resulting in upgrades to the glazing, external walls, and roof / ceiling (including a reduction in the originally proposed external glazing area), all of which was not required from an acoustics perspective.

5. Projects which progressed via resource consent

The remaining 40 % of the sample solutions were accepted by the Council but did not comply with the Rule, via a Resource Consent process. These situations were typically considered by an Environmental Health Officer (EHO) at the Council to determine the associated noise effects. The noise effects arising from deviations from the Rule were concluded to be less than minor for a variety of reasons, as follows.

5.1 Alterations / Extensions

Several of the examples that went to the EHO were for alterations or extensions to existing houses. These were typically small in scale, ranging from changing one element, changing the use of spaces, or proposed new portions of a dwelling.

Factors which the EHO appeared to take into account with these examples when determining the effects included the sound insulation properties of the alteration compared to the rest of the house, whether it was reasonable to upgrade existing elements which otherwise would not have been altered, the external levels likely to be incident on the relevant façade and practical limitations on upgrades that can be applied to an existing building (particularly if there were heritage considerations).

Generally, it appeared that a pragmatic approach was taken where the benefits of the upgrades was balanced against the practicalities of upgrading existing houses.

5.2 Distance

In a small number of examples, non-compliances were allowed due to the relative distance between the habitable spaces and the nearest road. In one of these only a fraction of the building was within the setback which triggers the Rule, and it was determined that the effect of the building having a corner of the room within the setback compared to it being 1 metre further away was minimal, and as such consent was granted.

In another example, while the building was within the setback so the rule was triggered, all habitable spaces within the building were outside the setback. In this case there appeared to be some confusion as to whether the rule applied or not; however, overall, any associated effects were considered to be less than minor.

5.3 Site specific / shielding

There were a small number of examples where the EHO concluded that the overall effects would be less than minor due to the site-specific parameters. One example was a dwelling which was located behind a garage, and at a lower elevation than the road. The EHO concluded that the internal noise levels would be acceptable, and therefore no upgrades would be required. Another example was a replacement dwelling. The EHO determined that the new dwelling would provide a greater level of sound insulation than the previous dwelling, and that the portion of the road which is adjacent was not busy (less than 2000 AADT).

If the external noise levels had been calculated for these situations it would be likely that they would be less than 57 dB $L_{Aeq\,(24\,h)}$ and would therefore comply with the Rule with no additional upgrades required.

6. DISCUSSION

We have considered what can be learnt from the above analysis about how sound insulation requirements should be drafted, and how people are likely to interact with them.

6.1 General approach

Key decisions are required as to the general technical approach to be adopted in any sound insulation rule. As discussed above, the sound insulation rule which we reviewed allowed for multiple means of assessment – the 'internal noise level' method, the 'façade reduction' method, a combination of both of these methods, or the 'ac-ceptable solutions'. One dwelling could be therefore assessed in four different ways, and result in four different sets of upgrade recommendations. For example, a dwelling in the sample with an external noise level of 65 dB $L_{Aeq\,(24h)}$ which was assessed using the 'internal noise level' method required upgraded glazing in one room. When assessed with the 'façade reduction' method the dwelling required glazing, wall, and ceiling upgrades to all hab-itable spaces.

For the specific example of the Christchurch Rule, the multiple approaches only provide a similar outcome if the external noise levels are in the order of 70 dB $L_{Aeq\,(24h)}$. Based on the sample, as shown in figure 1 above, less than 20 % of the dwellings experienced noise levels in the order of 70 dB $L_{Aeq\,(24h)}$.

While there may be other non-acoustic reasons for allowing multiple calculation approaches within one rule – such as consistency with other rules within the District Plan, or other recognised guidance, it seems appropriate to adopt the simplest practical approach, and to attempt to ensure that any rule which allows for multiple means of assessment results in relatively consistent outcomes. We have discussed possible elements of a sound insulation rule in the following sections.

6.1.1 An 'internal noise level' requirement

Our analysis of the Christchurch Rule suggests that an 'internal noise level' approach is most likely to provide an appropriate outcome from an acoustic perspective. This is due to the fact that adverse effects associated with noise ultimately depend on the noise level experienced within a dwelling, and that is something that the internal noise level method seeks to control directly. Within our sample, the examples where detailed analysis had been undertaken and the 'internal noise level' method of the Rule has been used consistently, provided an outcome that was most likely to be the 'correct' one in terms of protection of residents from noise.

We expect that this finding is likely to hold true more globally for any traffic sound insulation rule.

6.1.2 A 'façade reduction' requirement

By comparison, the 'façade reduction' aspect of the Christchurch Rule resulted in compromises. Whether a façade reduction of 30 dB $D_{tr,2m,nTw}+C_{tr}$ is adequate to achieve an appropriate internal noise level depends on the external noise levels. As outlined above, the external noise levels for typical buildings captured by the Rule can vary significantly – both in terms of the type and proximity of the road traffic noise source, and then between the most exposed façade, and other facades of a building. In some cases, the façade reduction may ensure appropriate internal levels, in others internal noise levels may be too high, or money may be invested upgrading structures where noise levels were already satisfactory. To add to the complication, for the Christchurch Rule where the 'façade reduction' method is used no mechanical ventilation is required. This means that (i) people will have to choose between appropriate internal noise levels and fresh air ventilation and so are likely to be exposed to higher than ideal noise levels more often, and (ii) the 'façade reduction' method may therefore be seen as a more cost-effective option by some developers who are not concerned about the acoustic outcome, but rather the cheapest way to navigate through the rule.

However, this finding may be relatively specific to the set of circumstances surrounding the Christchurch Rule. In other situations where external noise levels are consistent over the facades of buildings, and from building to building (or external levels are unknown and the most pragmatic approach is to assume that they are consistent over the facades of buildings, and from building to building) a 'façade reduction' approach then simplifies the analysis while not necessarily compromising the outcomes. This logic may have been more relevant when a similar rule was first introduced in the Christchurch City Plan – as it was restricted to specific zones where the type and arrangement of likely development and noise sources were not as varied as those which a typical traffic noise insulation rule encounters.

Another possible supporting argument for a 'façade reduction' approach is that it provides an alternative where it is suspected that external noise levels are so high that an analysis of the internal noise levels would lead to excessive or impractical constructions, and essentially prohibit development on some sites. The 'façade reduction' method would effectively 'cap' the level of upgrades required and would still enable development on these sites. However, assuming it is accepted that a certain internal noise level is appropriate within dwellings, such an ar-rangement would knowingly enable developments to be completed where people would be exposed to potentially harmful noise levels.

6.1.3 The role of 'acceptable solutions'

The 'acceptable solutions' in the Christchurch Rule have generally been formulated to ensure the composite outside to inside noise reduction of habitable spaces will be at least 30 dB $D_{tr,2m,nTw}+C_{tr}$, even in a worst-case scenario with regard to the sizes of the weakest façade elements. The requirements are therefore conservative, particularly given the low proportion of situations which are exposed to noise levels in the order of 70 dB $L_{Aeq\,(24h)}$. There is therefore a high risk of over-design. As an example, as discussed above one dwelling in the sample was upgraded to comply with the 'acceptable solutions', when the external traffic noise level was 55 dB $L_{Aeq\ (24h)}$. Based on a further research study which was subsequently commissioned by Waka Kotahi NZ Transport Agency building on this work, these upgrades are likely to have attracted unnecessary construction costs of $10,000 to $20,000.

The only argument we are aware of for the provision of an option of acceptable solutions is that this provides an avenue for people who are inclined to avoid spending money on analysis and reports by engineers, and knew would rather spend money on something physical which is arguably a 'benefit' to end users. However, that logic presumably only holds if the additional cost of the acceptable solutions is comparable to the cost of engaging an acoustic engineer (who may have been able to advise you that no upgrades were necessary).

If it was deemed desirable to include acceptable solutions in a traffic sound insulation rule of this kind, thought should be given in its development as to what resultant level of quality is acceptable based on the range of expected external noise levels that the dwelling would be exposed to. Options include:

- Setting the constructions to consider a worst-case situation (such as in the case of the Christchurch Rule), which would be appropriate for external noise levels of 70 dB $L_{Aeq\ (24h)}$. This would result in the majority of dwellings being over-designed for the external noise levels; however, would ensure that the majority of the situations would not result in excessive internal noise levels.
- Setting the constructions to be at an average level. This would result in the internal noise levels being in a reasonable order for the majority of the situations; however, there would still be some dwellings which would be over-designed, and some that would be under-designed.
- Providing a refined version of acceptable solutions which more accurately responds to the individual circumstances of a project – such as different acceptable solutions for different ranges of external noise levels, on the different facades. This would result in the majority of the dwellings having internal noise levels in the appropriate order; however, it would require input from an acoustic engineer to establish the expected external noise level on the most exposed façade.

6.1.4 The requirement for mechanical ventilation

From an acoustic point of view the mechanical ventilation requirement should apply in all situations where the stated requirement (be it an internal noise level, or a façade reduction) cannot be achieved with windows open for ventilation.

6.2 Ensuring consistency of application

This review has confirmed that the specific wording of a sound insulation rule is important to minimise ambiguity as far as possible. As outlined above, there will always be some variation when the rule is then applied (for example, resulting from the traffic and Sound Transmission Loss data used). However, in our sample these variations did not appear to have major implications on the application of the rule as a whole. We considered how these sources of variation could be further reduced – however it is not obvious how this could be achieved in a way which did not add excessive complication (for example, adding a table of the Sound Transmission Loss performance to be assumed in calculations for various double-glazing systems).

The only source of significant variation in the case of the Christchurch Rule was the ambiguity around mechanical ventilation, as discussed above. That could easily be avoided, through improvements to the rule wording.

6.3 Reducing the likelihood of Resource Consents

It is very likely that there will always be numerous instances where a Resource Consent is sought for minor non-compliances with a District Plan sound insulation rule of this kind. This is an inevitable outcome of the fact that the decibel scale is logarithmic and so a 1 – 2 dB change in noise level is not perceptible, but the upgrades required in a wall or glazing system to achieve a 1 – 2 dB improvement may be significant. This is similarly the case with any of the specific parameters typically contained in a sound insulation rule – the setback distances, or the thickness or mass of materials in the acceptable solutions. It is also not possible to foresee every eventuality when drafting a rule, and therefore situations will emerge where complying with the rule would be of no benefit in reality – for example, where a minor alteration is being made to a habitable space, the facades of which otherwise provide a very low level of sound insulation.

In the case of the Christchurch Rule, a change to the wording was proposed which sought to clarify the situation around alterations or extensions, as that was one of the most common queries received by the Council leading to a Resource Consent process.

7. CONCLUSIONS

A review has been undertaken of approximately 50 residential building projects which had interacted with a traffic sound insulation rule in the Christchurch District Plan. The findings, which are likely to be relevant to sound insu-lation rules more generally, include:

- Any sound insulation rule should adopt the simplest practical technical approach, and ensure that any rule which allows for multiple means of assessment results in relatively consistent outcomes.
- An 'internal noise level' approach is the most likely to provide an appropriate outcome from an acoustic perspective.
- In some cases, a 'façade reduction' or 'acceptable solutions' approach may ensure appropriate internal levels, however in the Christchurch situation it often leads to over-designed buildings.
- A mechanical ventilation requirement should apply in all situations where the stated requirement (be it an internal noise level, or a façade reduction) cannot be achieved with windows open for ventilation.
- The specific wording of a sound insulation rule is important to minimise ambiguity as far as possible. However, there will always be some variation when the rule is then applied.
- It is likely that there will always be numerous instances where a Resource Consent is sought for minor non-compliances with a District Plan sound insulation rule, as a small change in noise levels is not perceptible, but modifying a building structure to achieve a small further improvement in sound insulation may be expensive.

These findings have been used to develop proposed refinements to the Christchurch Rule, and could be used to guide those drafting similar rules in the future.

ACKNOWLEDGEMENTS

The authors would like to thank Christchurch City Council for the opportunity to conduct and present this work.

Semitones: The building blocks of western music

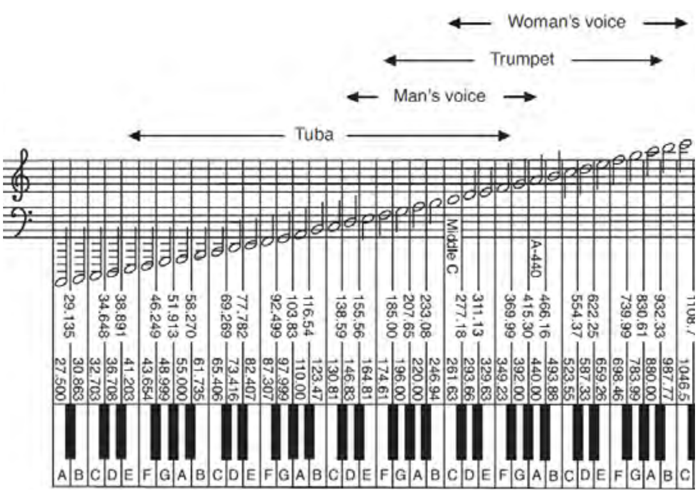
Hedda Landreth [1]

[1] Technical Director, T&R Interior Systems

Most western music new and old, is based on a sequence of 7 notes selected from a total of 12 semitone options. The ascending or descending sequence of 7 notes make up Heptatonic scales. Scales are generally considered to be the building blocks of most music, and the relationships within the scales determine the musical key. The starting note (root) is selected as the beginning of the sequence and the interval pattern of the notes in relation to the root produces either a major or minor key.

Scales span a single octave, with higher or lower octaves simply repeating the pattern. The note steps of the scale are either single, double and even triple semitone steps (for melodic minor scales).

The logic of semitones and scales is visually represented by a piano keyboard. Each individual key is a semitone step. C Major and A Minor use only the repeating 7 white key patterns. All other keys are sequences of the same relationship shifted and therefore other major and minor keys use a mixture of white and black keys (of which there are 5).



Whatever the Hz frequency of the root is, the 8th note (octave above the root) will be double the frequency, while the note an octave below will be half the frequency. Logically, you might expect that all semitones are evenly distributed, and this is true to a certain extent. But in reality it's not that simple. The relationship between semitones is strange and interesting and has been the subject of much debate over the centuries.

An interval denotes distance between notes. Pythagoras discovered that intervals are also mathematical ratios. If you take an open string A (440Hz) and cut it in half, you get an A the octave above (880Hz). Because this is a doubling of frequency the octave ratio is 2:1, two vibrations to one. The ratio 3:2, (three vibrations to two) produces a fifth interval above the note, (an E relative to A); 4:3 is a fourth interval (a D), 5:4 a third (a C) and so on. Western music's twelve-semitone tuning was derived from interval ratios between the first sixteen harmonics.

Pure intonation is when musical intervals are derived as whole number ratios (such as 3:2 or 4:3 and 5:4). They are said to be "pure" because when the two notes are sounded together, the frequency nodes line up perfectly every few wavelengths and no inference beats are heard. An Octave is the most obvious example, but the fifth, fourth and third are also very pleasing to the ear; We can hear that they're "in tune".

However, if you tune a stack of perfect fifths (3:2) above a starting note, you'd expect that after twelve you would arrive back at original root (a number of octaves higher), but this isn't the case! Instead, a stack of perfect fifths end up quite a bit sharper than a stack of octaves does. It is impossible to tune the twelve-note chromatic scale so that all intervals are pure. A series of perfect intervals doesn't end up at a perfect interval from where you started; nature's maths doesn't add up! This anomaly is why tuning is so fraught.

Earlier European tuning systems, such as meantone temperament and just intonation, used cyclic tuning systems in which given intervals were calculated by adding together other "pure" intervals. These were tuned to keys. In other words, if we return to our 440Hz A, the fifth and fourth intervals would be tuned to match with our 440Hz root. Sadly, specific pitch relationships are not the same between the same notes in other keys because they relate differently to the root. The resulting tuning sounds lovely when you stay in the same key but is unpleasantly out of tune in different keys.

Equal-tempered tuning, calculated by subdividing the octave, is called a "divisional" system. Equal Temperament means that all the semitones are equally distant so that everything is slightly out of tune. These small intonational defects are equally distributed among the 12 tones of the chromatic scale. These add up so that each notes' octaves remain as the only acoustically pure interval. Each semitone can be expressed as increasing by a factor of the twelfth root of 2 or in terms of ratio - this equates to 1:1.05946.

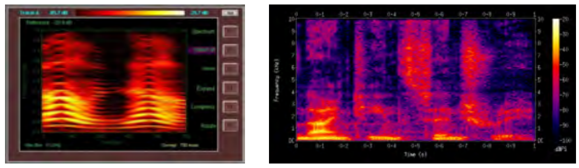
An E above A (a fifth) using 2:3 ratio has a frequency of 660Hz. With Equal-tempered tuning the pitch called "E, a fifth above A" has a frequency of 659Hz. This 1Hz difference of the note itself is imperceptible but means that the wavelengths do not line up like they do with a pure interval. The interval becomes consonant. Because the frequency nodes now do not line up, a beating can be heard (the cycles interact and produce an audible beating sound). Equal Temperament essentially means that every interval apart from the octave is slightly out of tune. The positive of this is that it removes key specific tuning and the interval relationships between notes stay the same regardless of what key you're in.

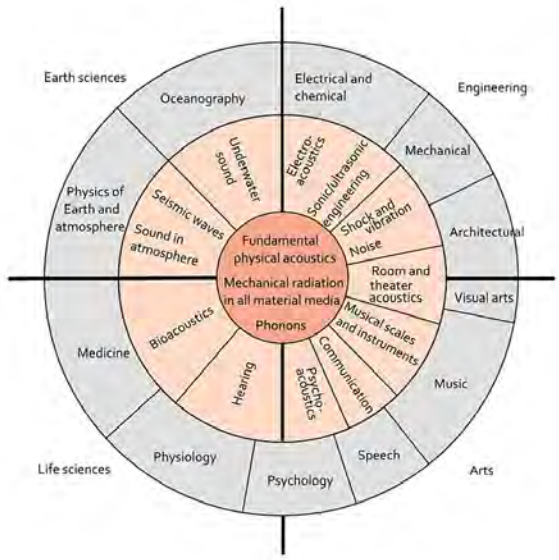
Instruments are hardly ever tuned using only pure intervals – the physics of music makes this impracticable. Instruments of fixed pitch, such as pianos and fretted guitars, are usually tuned using equal temperament.

QUIZ

How sound is your acoustic knowledge?

1 What is the name of the visual representation shown in the following photo set?



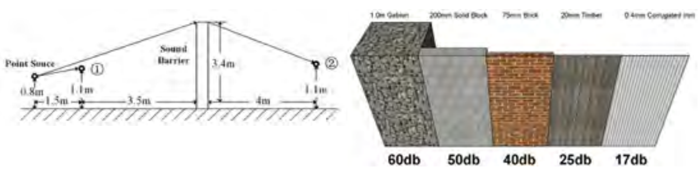


2 The name of the diagram (right) is?

A) Lindsay's Wheel of Acoustics
B) The Fundamental Physical Acoustics Wheel
C) The Wheel of Life Science
D) The Wheel of Fortune

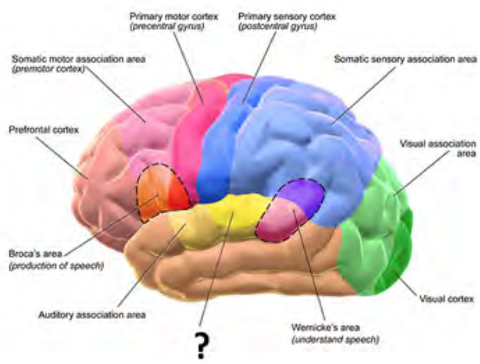
3 'JASA' is the journal of the Acoustical Society of ..?

4 **True of False?**
'ISO Standard 9613-2 Acoustics Attenuation of Sound during Propagation Outdoors' states that the barrier attenuation D_2 in any octave band should not be taken to be greater than 25 dB in the case of a single diffraction (thin barrier)?



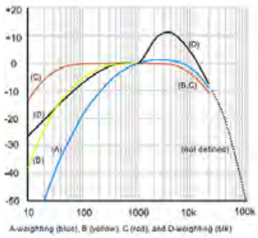
5 **True or False?**
'archaeoacoustics' is also known as the archaeology being sound that is studied by testing the acoustic properties of prehistoric sites, including caves for example?

6 Name the part of the human brain highlighted yellow in the (right) diagram (denoted "?") and briefly describe the relationship this part of the brain has to acoustics.



7 Name the person shown (to right) and briefly describe their contribution to the field of physics and acoustics.

8 Briefly describe the concept of A-weighting?



9 Briefly describe what a 'windshield' or 'windscreen' is used for in acoustics?

10 Briefly define the term 'flutter echo'?

QUICK FIRE BONUS

11 What is a periodic signal?

12 What does 'PNdB' stand for?

13 In 6 words or less define a point source.

14 Henry (H) is a unit of what?

15 True or False? A vector is a quantity which has both a direction as well as a magnitude?

UPCOMING EVENTS

All event dates are current as at time of print.

183rd Meeting of the Acoustical Society of America

5 – 9 December 2022 | Nashville, Tennessee, USA

Acoustics 2023

The Acoustic Society of America (ASA) and Australian Acoustical Society (ASS)

May 14 - May 18, 2023 | The International Convention Centre Sydney (ICC Sydney), Sydney, Australia

https://acoustics23sydney.org/

International Conference on Underwater Acoustics and Ocean Environment ICUAOE

January 21-22, 2023 | London, United Kingdom

https://waset.org/underwater-acoustics-and-ocean-environment-conference-in-january-2023-in-london

NOISECON 2023

May 14 - May 18, 2023 | Grands Rapids Michigan, United States

ICGBAAE 2023: 17. International Conference on Green Building Acoustics and Acoustic Engineering

February 06-07, 2023 | Melbourne, Australia

https://waset.org/green-building-acoustics-and-acoustic-engineering-conference-in-february-2023-in-melbourne

ICANV 2022: 16. International Conference on Acoustics, Noise and Vibration

December 29-30, 2022 | Vienna, Austria

https://waset.org/acoustics-noise-and-vibration-conference-in-december-2022-in-vienna

International Conference on Acoustics, Sound and Vibration ICASV

February 01-02, 2023 | Melbourne, Australia

https://waset.org/green-building-acoustics-conference-in-february-2023-in-melbourne

Inter Noise 2023

20 -23 August 2023 | Chiba Greater Tokyo

https://internoise2023.org/

International Conference on Acoustics of Buildings (ICAB).

January 11 2023 | Singapore

https://waset.org/acoustics-of-buildings-conference-in-january-2023-in-singapore

International Conference on Architectural and Building Acoustics ICABA

January 14-15, 2023 | Bali, Indonesia

https://waset.org/architectural-and-building-acoustics-conference-in-january-2023-in-bali

International Conference on Wind Turbine Acoustics ICWTA

January 28-29, 2023 | Istanbul, Turkey

https://waset.org/wind-turbine-acoustics-conference-in-january-2023-in-istanbul

QUIZ ANSWERS

1. A spectrogram, which is a visual representation of the spectrum and frequencies of a signal as it varies with time.

2. A) Lindsay's Wheel of Acoustics (Acoustic Society of America).

3. JASA is the journal of the Acoustical Society of America

4. False? ISO Standard 9613-2 states that the barrier attenuation for a thin barrier should not be taken to be greater than 20 dB or greater than 25 dB in the case of a double diffraction barrier (thick barrier).

5. True – archaeoacoustics is one of the only ways to experience the past with senses other than our eyes

6. The yellow area is known as the auditory cortex, which is the part of the temporal lobe that processes auditory information in humans and many other vertebrates. This part of the auditory system, preforms basic and higher functions in hearing.

7. Ernst Florens Friedrich Chladni. Ernst was a German physicist and musician. His most important work, for which he is sometimes labelled as the 'father of acoustics', included research on vibrating plates and the calculation of the speed of sound for different gases.

8. A-weighting is the most commonly used frequency-weighting curve and is defined in the International standard IEC 61672 for sound level meters. A-weighting is applied to the sound pressure level measurement in an effort to account for the relative loudness perceived by the human ear.

9. A windshield or windscreen is fitted over a microphone and used to reduce wind (normally externally) from producing spurious wind induced noise at the microphone of the sound level meter.

10. A flutter echo is a series of distinct repeating echoes that occur in rapid succession. The echoes are normally caused by parallel reflecting surfaces.

11. A signal that repeats itself exactly over some interval.

12. PNdB is the unit of perceived noise level, developed in 1959 to attempt to measure the perceived noisiness of jet aircraft by observers on the ground. It is in 'dB, but it is not a measure of sound pressure level.

13. A point source can be defined as a "source with a spherical radiation pattern" or an "acoustic source which radiates spherical waves".

14. A henry (H) is a unit of electrical inductance.

15. True. A vector has a direction as well as a magnitude such as force, displacement, velocity or acceleration.