Acoustic compliance with F5.6 of the Building Codes of Australia for waste water pipes

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ABSTRACT
The National Construction Code (NCC) 2016 for Class 2, 3 and 9c buildings requires services to be acoustically separated from habitable and non-habitable rooms by a specified performance criterion outlined in Part F5.6. Pipe systems consisting of lagged or acoustic pipes provide an acoustic benefit over traditional PVC pipes. Since neither lagged or acoustic pipes contribute to the separating construction between the services and room, rating their acoustic performance in accordance with the NCC Deemed-to-Satisfy Provisions in Part F5.6 is impossible. This paper presents and describes an established method to test and a unique calculation method to rate these acoustic pipe systems to demonstrate that the construction of these systems provides an acoustic benefit that may be compared against the NCC requirement. Results of tested lagged and acoustic pipes that are in the public domain are summarised. Various issues with the testing method, calculation procedure and NCC criteria are discussed. This paper promotes discussion directed towards the establishment of an Industry Code of Practice for Australian acousticians to enable standardised acoustic rating of innovative pipe systems in accordance with the NCC.

1 INTRODUCTION

The National Construction Code (NCC) 2016 for Class 2, 3 and 9c buildings require soil and waste pipes to be separated from habitable and non-habitable rooms by a construction that meets certain acoustic performance criteria as specified in Part F5.6 of Volume 1 of the NCC, also referred to as the Building Codes of Australia (BCA).

The deemed-to-satisfy provisions given in Part F5.6 of the BCA state the following:

> *a duct, soil, waste or water supply pipe be separated from the rooms of any sole-occupancy unit by construction with an Rw + Ctr (airborne) not less than –*
>
> - *40 if the adjacent room is a habitable room (other than a kitchen); or*
> - *25 if the adjacent room is a kitchen or non-habitable room.*

While Part F5.6 relates to the acoustic separation of ducts, soil, waste and water supply pipes, this paper is only concerned with the acoustic separation of soil and waste pipes.

A strict interpretation of the above deemed-to-satisfy requirements implies that a partition construction separating the pipe from the adjacent room must be of a sufficient weighted sound reduction index with the spectrum adaption term (R_w + C_{tr}) regardless of the pipes emitted noise level. Under this interpretation, a low noise pipe system such as a lagged pipe or a heavy-walled acoustic pipe has no benefit, despite the noise level in the receiving room being drastically reduced. Therefore, acousticians use a relaxed interpretation and include pipe lagging and acoustic pipes as part of the “separation from the rooms of any sole occupancy unit” allowing for partition constructions to be lighter and cheaper. Consequently, this interpretation makes in situ testing of the weighted sound reduction index challenging as a reasonable source location does not exist. Therefore, to satisfy Part F5.6 requirements, a deemed-to-satisfy construction system which includes the pipe, pipe lagging and the partition construction that has been tested in a laboratory and rated using a comparison method is employed.

1.1 History

To the authors best knowledge, the first mention in Australia of the requirement for soil and waste pipe separation from habitable and non-habitable spaces is in Ordinance 70 (1975) under the *Local Government Act – 1919* (NSW). The requirements in Ordinance 70 use the Sound Transmission Class (STC) descriptor and require a STC of not less than 50 for habitable rooms and 30 for all other non-habitable rooms. Ordinance 70 also introduced requirements for access panels and doors that are included in construction that separate pipes and habitable spaces. The BCA 2000 replaced the STC descriptor with the R_w weighted sound reduction index. The BCA 2004 introduced the low frequency weighting term C_{tr} forming the current requirement of $R_w + C_{tr}$ 40 for habitable rooms and $R_w + C_{tr}$ 25 for non-habitable rooms.

Complying with the current BCA 2016 requirements in Part F5.6 for soil and waste water pipes using the deemed-to-satisfy provisions method requires accurate test data of the pipe, lagging and partition components. Laboratory testing of waste water or soil pipes is challenging as no Standard exists to evaluate the acoustic performance of soil and waste pipes lagged with acoustic lagging or to evaluate the acoustic performance of heavy walled acoustic pipes. Both these constructions provide a benefit to the residential occupant that may potentially be affected by the noise from the pipe system. This posits a dilemma of existing acoustic criteria without standardised tests to ensure compliance with these criteria.

A test procedure first developed by the National Acoustic Laboratories (NAL) in 1995 and modified by Day Design Pty Ltd has become common practice. This procedure has allowed the acoustic emission of the waste or water pipes to be evaluated as a single value acoustic rating in accordance with the $R_w + C_{tr}$ requirement of the BCA.

The NAL procedure is in the public domain and is identified in several reports including ATF Report 158A (National Acoustic Laboratories 1995) and ATF Report 750B (National Acoustic Laboratories 1999). Subsequent testing by NAL, in collaboration with Day Design, have used similar testing procedures with minor variations to the geometry, number of pipes, volumetric flow rate etc. The CSIRO in Clayton, VIC have adopted the same procedure in the last years.

The European standard BS EN 14366:2004 (British Standards Institution 2004) and German standard DIN 4109 (Deutsches Institut für Normung, 2018) outline a procedure for testing noise emission from a pipe. The pipe traverses from the top of the source chamber, to the bottom of the source chamber vertically downwards. The noise emission is measured in an adjacent chamber. These Standards have not been adopted in Australia because the results from the NAL procedure would be incompatible with the European Standards results.

1.2 Aims

The purpose of this paper is to outline the test procedure (Section 2) and calculation procedure (Section 3) that are currently adopted by CSIRO and Day Design for measuring and rating soil and waste pipe systems. The testing and calculation procedure are presented for review and critique by the acoustic industry. It is hoped that the procedure might be refined, improved and lead to an Industry Code of Practice.

2 TEST PROCEDURE

The general test procedure currently employed by Day Design in conjunction with CSIRO is outlined in this Section. The complete test procedure is described in laboratory reports which can be provided on request to selected manufacturers. Testing in this field of research has occurred in a number of laboratories with different parameters and differing methods.

2.1 General

Water is pumped from outside the measuring chamber to inside the measuring chamber through a pipe system at a rate of 4.0 litres per second through a defined contour as shown in Figure 1. The interaction of the flowing water within the pipework in the measuring chamber generates and radiates noise that is analysed by a real-time analyser monitoring a microphone mounted to a continuously rotating boom. The contour of the pipe work as shown in Figure 1 was chosen because it radiates a high noise level and includes a variety of fluid motions such as vertical straights, horizontal straights and four bends which generate turbulence and sharp changes in kinetic energy.

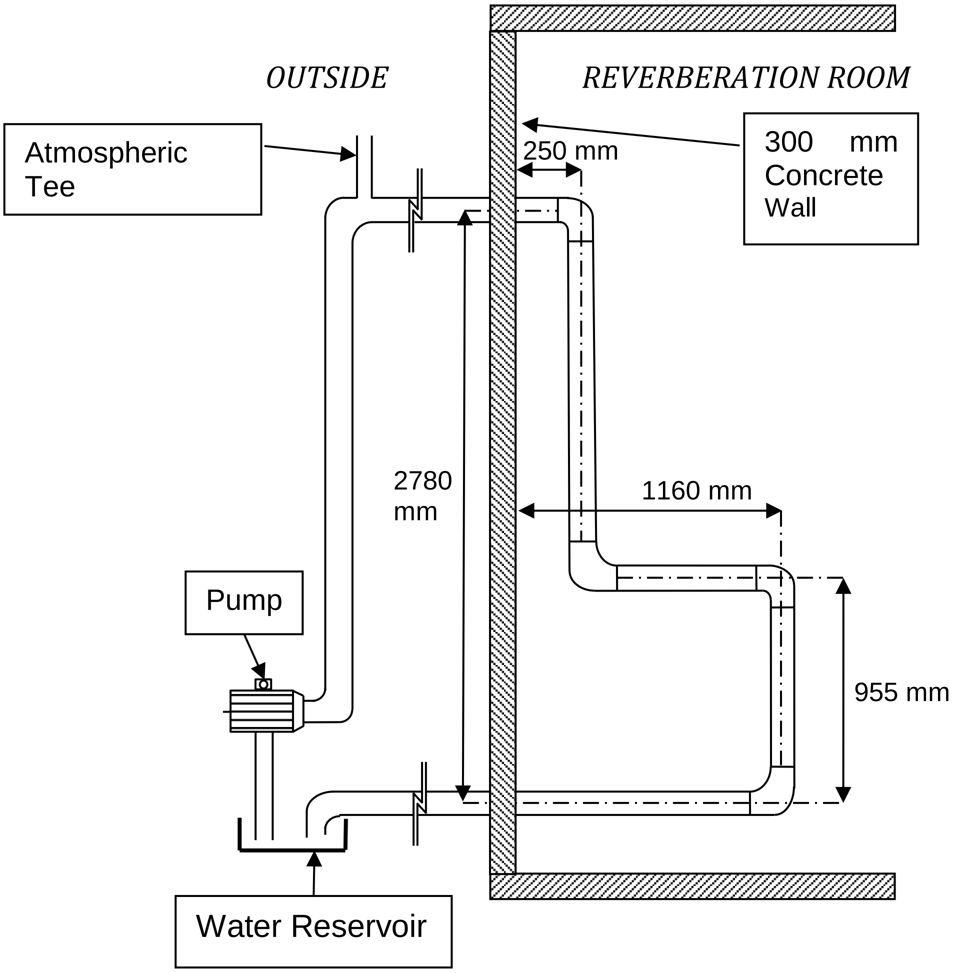

Figure 1 Schematic of pipe configuration in the NAL testing method

2.2 Laboratory Description

A reverberation room is used to test the piping systems. In previous testing, the water circulation system was in a separate reverberation chamber containing the water reservoir and water pump. In recent testing, the water circulation system was located outside. The measurement chamber contains the pipe system.

The measurement chamber requires a reasonable sound diffusivity. Previous laboratories have had non-parallel walls and sloped ceilings. In recent testing, diffusion was enhanced with randomly oriented reflector plates.

2.3 Test Rig Description

A water reservoir and pump are installed outside the measurement chamber a few metres away from the wall. Water flow from the pump is controlled using a ball valve outside the water handling chamber, and monitored using an Electronic Flow Meter.

After exiting the pump, the valve and the meter, the water was fed though a flexible hose and coupled to each pipe system in turn. An atmospheric tee with a 1 metre vertical riser is inserted between the water-feed and the upper opening of the pipe system under test, to provide an atmospheric vent, thus minimising the risk of the pipe system under test filling up with water, and ensuring the free fall of water within the pipe system. The discharge water is directed back into the reservoir below the surface of the water to minimise generation of airborne noise.

The temperature, barometric pressure and relative humidity inside the reverberation room are monitored throughout the testing program.

2.4 Equipment

Microphones with a Type 1 accuracy as defined in AS IEC 61672.1-2004 (Standards Australia 2004) are mounted on a rotating boom with a radius of 1.65 metres. The microphone boom continuously rotates with a 33 second period during measurements. Calibration of the microphone is conducted before and after the measurements to ensure calibration drift is less than 0.1 dB.

2.5 Test Procedure

2.5.1 Sound Level Measurements

Water is pumped through each pipe system at 4.0 litres per second. The sound pressure levels in the measuring chamber are averaged over space (by a microphone mounted to a continuously rotating boom in the chamber) and time (by integrating the sound level over two whole traverses of the microphone – 66 seconds).

2.6 Background Noise Correction

The noise associated with the water circulation system is measured using a dummy pipe set up bypassing the pipework inside the measurement chamber. “Live” background noise levels are measured with water being pumped into the dummy pipe at 4.0 L/s and discharged into the receiving trough; the background noise levels are used to apply corrections to the signal levels measured in the receiving room. The “Dead” background noise levels (noise due to factors other than the flow of water within the pipe under test), are also measured. Possible background noise sources include electrical noise, airborne noise, structure borne noise and noise associated with the water circulation system. The “Live” background noise measurements are employed in the background correction as described.

The following formula is used to determine the corrected signal sound pressure level:

$$L_p = 10\mathrm{Log}_{10}\left[10^{L_{pr}/10} - 10^{L_{br}/10}\right]\ \mathrm{dB} \quad (1)$$

Where L_p = corrected signal sound pressure level;
L_{pr} = measured signal sound pressure level;
L_{br} = measured “Live” background sound pressure level.

Applying relevant standards for laboratory acoustic measurements of building elements (AS 1191-2002(R2016) (Standards Australia 2002(R2016)), and ISO 140.6 (Standards Australia 2006)) background corrections are limited to 1.3 dB if the measured signal sound pressure level is within 6 dB of the background sound pressure level.

2.7 Normalised Sound Pressure Levels

The average reverberation time in the measurement chamber is determined for each 1/3rd octave band centre frequency. The corrected signal sound pressure levels are normalised to 10 m^2 equivalent area.

When conditions change in the measurement room, such as when the acoustic lagging is applied or removed, the reverberation time is measured again and used to normalise the corrected signal sound pressure levels measured for the base system.

The following formula according to ISO 140.6-2006 (Standards Australia 2006) is used to determine the normalised sound pressure levels:

$$L_n = L_p + 10\log_{10}\left(\frac{A}{A_0}\right) \text{dB} \qquad (2)$$

Where L_n = Normalised sound pressure level in one third octave bands;
L_p = Measured sound pressure level in one third octave bands;
A = Measured equivalent absorption area;
A_0 = Reference absorption area 10 m^2.

The measured equivalent absorption area is calculated using the following formula in AS ISO 354 (Standards Australia 2006)

$$A = \frac{55.3\,V}{c\,T} \qquad (3)$$

Where: V = Volume of the room, in m^3;
T = Reverberation time, in seconds;
c = Speed of sound in air, in metres per second.

2.7.1 Reverberation Time Measurements

Reverberation times in the measuring room are determined using the interrupted noise method in accordance with Australian Standard AS ISO 354-2006 (R2016). Broadband noise (pink noise) is played through omni-direction speakers in the room at a number of source and measurement locations, then the sound is cut and the sound decay pattern analysed; 60 decays are overlayed and used to calculate the reverberation time in each 1/3rd octave frequency band of interest. Reverberation times are measured for each test and the data used to normalise the noise levels.

3 CALCULATION PROCEDURE

The R_w+C_{tr} of a waste or soil pipe and partition system cannot be directly measured and therefore it must be deduced through comparison testing such as the method described in this Section.

To determine the weighted sound reduction index with low frequency spectrum adaption, R_w+C_{tr}, of a new test system, the calculation method is as follows:

1. The sound reduction index ($R_{reference}$) in each 1/3rd octave band centre frequency of a partition with a known R_w+C_{tr} (normally either 40 or 25) is established in accordance with AS 1191-2002 (R2016). This test is generally done separately to the waste water pipe testing. An example of a construction that achieves R_w+C_{tr} 40 and its corresponding $R_{reference}$ spectrum is provided in Table 1.
2. The normalised, background corrected sound pressure level (L_{n1}) of a PVC-U pipe containing flowing fluid behind a partition construction established in Step 1 above is measured. This forms the reference sound level to which other test systems are compared against. Testing procedure for this step is defined in Section 2 of this paper.
3. The normalised, background corrected sound pressure level (L_{n2}) of a test system containing flowing fluid is measured. This forms the test sound level which is compared against L_{n1}. Typical test system variations include changing the pipe construction, lagging the pipe and changing the partition construction. Testing procedure for this step is defined in Section 2 of this paper.
4. The level difference (D) between L_{n1} and L_{n2} is calculated.

$$D = L_{n2} - L_{n1} \tag{4}$$

5. Add the level difference (*D*) to the $R_{reference}$ established in Step 1 in each 1/3 octave band centre frequency to determine the sound reduction index (R_{test}) of the new test system:

$$R_{test} = R_{reference} + \mathrm{D} \tag{5}$$

6. Finally, use the spectrum for R_{test} to calculate the effective R_w+C_{tr} of the test system in accordance with AS/NZS 1276.1.

Two constructions known to have achieved a R_w+C_{tr} 40 result is as follows:

- Reference 1 - Two layers of 10 mm plasterboard / 90 mm timber studs with insulation / 13 mm plasterboard (National Acoustic Laboratories 2011)
- Reference 2 - Two layers of 13 mm CSR Fyrechek plasterboard / 64 mm steel studs with insulation / Two layers of 13 mm CSR Fyrechek plasterboard (CSIRO North Ryde 1992)

The R spectrum of these constructions are shown in Table 1.

Table 1: R_w+C_{tr} 40 partition spectra

	Third Octave Centre Band Frequency (Hz)																	
	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000
Ref 1 - NAL	25	26	34	39	37	37	41	42	44	47	49	52	54	54	53	50	51	55
Ref 2 - CSIRO	21	29	36	38	40	43	47	51	52	54	56	58	58	52	48	51	55	56

4 RESULTS

Tests have shown that both acoustically lagged PVC pipes and heavy walled acoustic pipes provide a lower noise emission and therefore an acoustic benefit over standard PVC-U pipes. Figure 2 shows the calculated average noise level of acoustically lagged PVC-U pipe or acoustic pipe behind a 10 mm set plasterboard partition.

A lagged pipe has a good sound reduction in the high frequencies, moderate sound reduction in the mid-range frequencies and performs poorly at low frequencies. In some tests, acoustically lagged PVC pipes were shown to increase the radiated noise level in the low frequency range between 80 Hz to 160 Hz usually in just one 1/3rd octave band. It is hypothesised this occurs due to the increase in surface area and creation of an air gap provided by the foam component of the lagging which creates a coupling resonant frequency.

A heavy walled pipe typically performs acoustically well in the lower frequency range and moderately well in the mid frequency range. Heavy wall pipes do provide a small sound reduction in the high frequency range, yet significantly less than acoustically lagged pipes.

Only recently has the practice of calculating the R_w+C_{tr} as described in Section 2 of this paper been employed. Previously, only the insertion loss was calculated and compared with the base R_w+C_{tr} 40 partition plus bare pipe system.

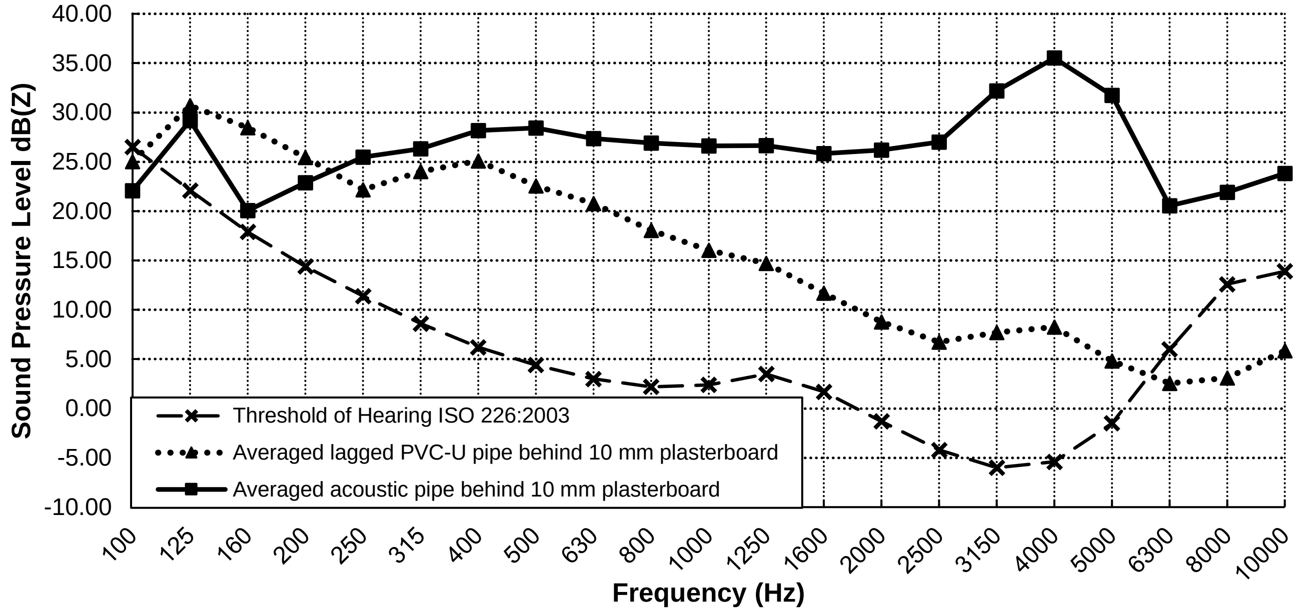

Figure 2 Calculated sound pressure levels of lagged and acoustic pipes behind a 10 mm plasterboard partition

Typical constructions for acoustic pipes, lagged pipes and bare pipes are shown in Table 2:

Table 2: Typical construction details for acoustic, acoustically lagged and bare pipes

Pipe Product	Partition Type	Insulation Type	Acoustic Rating
High Performing Acoustic Pipe	10 mm set plasterboard	75 mm R1.5 glasswool insulation	R_w+C_{tr} >40
Lagged Pipe	13 mm set plasterboard	75 mm R1.5 glasswool insulation	R_w+C_{tr} >40
Bare Pipe	13 mm set plasterboard	75 mm R1.5 glasswool insulation	R_w+C_{tr} >25

5 DISCUSSION

This Section discusses the concerns in the acoustic industry relating to the BCA Part F5.6 requirements and approach, the testing procedure and the calculation method.

5.1 BCA Drawbacks

5.1.1 Compliance and Alternative Methods

Field compliance of soil and waste pipe noise is often conducted either because it is mandated for occupation certification or a complaint has arisen due to the noise levels of a toilet flush in a neighbouring apartment. Field compliance with Part F5.6 of Volume 1 of the NCC is conducted in one of the following three ways:

1. Show that under typical operation, the waste and soil pipe is inaudible within the habitable or inhabitable room.
2. Show that under typical operation, the maximum sound pressure level in the habitable or non-habitable room (L_{AFmax} or L_{ASmax}) or the equivalent sound pressure level over the time period of the flush (for example $L_{Aeq,\ 20\ second}$) is less than or equal to the relevant indoor design sound level in Australian Standard AS2107:2016 (Standards Australia 2016).
3. Using the deemed-to-satisfy construction method, analyse the soil and waste pipe, lagging and partition construction system and provide an opinion to certify the system meets the BCA requirements.

Method 1 is advantageous as it admits an ideal acoustic environment for occupants in multi-residential buildings. However, it has the disadvantage of being difficult to design for as the level of background noise cannot be determined accurately until construction is complete.

Method 2 is advantageous as it aligns with an established Standard for expected acoustic amenity which is commonly used in the acoustic community. Method 2 allows for easy confirmation of compliance. It allows for simpler designing of the pipe, lagging and partition system that can be included into the overall design of the room (room intrusion and internal acoustic assessments). Method 2 has the disadvantage that it does not consider the background noise level, and the noise emission from the pipe system could be considered offensive even when it complies with AS2107.

Method 3 is the most direct certification method as it quasi-directly shows compliance with the BCA where the other methods are indirect. However, there are a number of inherent issues with method 3 relating to the difference between laboratory testing and field compliance. These issues include differences such as water speed, differences in geometry and differences between laboratory and field construction methods. All these issues generate a probable difference between the acousticians estimate of the R_w+C_{tr} and the actual R_w+C_{tr}.

5.1.2 Difference Between Laboratory and Field Methods

Using the deemed-to-satisfy construction method in certification of a waste water or soil pipe system, it is expected to find a variation between the predicted performance and the performance measured in the field.

There are a number of issues which could cause such a difference. One common issue relate to penetrations in partitions such as downlights or vents. Whilst test data of the acoustic loss of certain penetrations should be included in the predicted performance, it is preferable to acoustically treat penetrations with acoustic plenum boxes for vents and acoustic covers for downlights and then assume the acoustically treated penetration have a negligible effect on the overall sound reduction of the partition.

Another possible difference between the predicted performance of a system and the measured performance can come from variation in construction methods, pipe fittings and pipe materials. This problem is inherent to the deemed-to-satisfy construction certification method yet is accepted by the BCA and therefore assuming acceptable construction methods, this method is valid.

5.1.3 Low Frequency Audibility

Lower frequencies have a greater contribution to the change in R_w+C_{tr} than the mid or high frequencies. Therefore, a well performing pipe system in the lowest 1/3rd octave bands will have a high R_w+C_{tr}.

However, pipes emit low levels of noise at these low frequencies with most of the noise distributed at higher frequencies. To illustrate this, Figure 2 shows a lagged pipe and an acoustic pipe behind a 10 mm plasterboard partition. The transmission loss of the 10 mm plasterboard partition was taken from a test involving a lagged pipe with, and without a 10 mm plasterboard bulkhead. The transmission loss of the 10 mm plasterboard partition was then added to the average of a number of lagged or acoustic pipes, in more than one laboratory.

From Figure 2, we find the sound pressure level of an acoustic pipe and a lagged pipe behind a 10 mm plasterboard partition is less than the threshold of hearing at 100 Hz. If we were to test the performance of two acoustic pipes, we would see one perform better than the other at 100 Hz, yet both would be less than the threshold of hearing. The 100 Hz frequency band can have a significant impact on the C_{tr} and change the overall R_w+C_{tr}. Thus, we are calculating the R_w+C_{tr}, based on a frequency that has negligible real-life effect. If we also consider background noise, the audibility of the low frequency content of the pipe noise behind a partition becomes further reduced.

5.2 Testing Procedure and Calculation Method

5.2.1 Laboratory Alteration

Testing in different laboratories has the potential to determine different R_w+C_{tr} values. Sources of differences between laboratories have included different manufacturers of PVC pipes, lagging quality, water pumping systems, and method of sealing the pipe to the filler wall. The variation in the measured sound pressure levels will increase or decrease equally throughout all tests at each laboratory and therefore it has been assumed to not affect the final calculated R_w+C_{tr}. Therefore, a correction factor for each laboratory has not been applied.

5.2.2 Toilet Flush Compared to Continuous Flow

The original NAL tests used toilet flushes, whilst recent tests have used a continuous pumped flow to provide a constant value of water flow through the pipes. There are positives and negatives for each method described below.

Using a toilet flush is beneficial as it is more similar to real life applications. This therefore means that there is less difference between the laboratory and the field. Using a toilet flush has the downside that it is difficult to measure as the flush lasts for a short, fixed period of time. This requires the sound recording equipment to be accurately synced with the flush system as the sound recording equipment should begin to measure just before the start of the flush, and finish just after the end of the flush.

Using a continuous flow is beneficial as it provides a steady noise source which is easy to measure. It also reduces the uncertainty in the measurement. The difference between 4 L/s and 2 L/s is also a point of contention. Some proponents believe that 2 L/s should be used as it is more representative of a toilet flush flow rate. The 4 L/s has become standard practice due to its higher noise level and therefore higher signal to noise ratio.

Overall, the standard practice recently has been to use a continuous flow at 4 L/s as it is believed that the difference that the toilet flush provides to the spectrum and level of the radiated noise is outweighed by the improvement in repeatability of measurements.

5.2.3 Difference in Geometry in Field

Vertical fall sections, horizontal sections, bends and pipe fittings will all be different in the field from the laboratory geometry described in this paper. Each section of pipe-work will produce a different spectrum and level of noise. It is expected a laboratory and field system (with different pipe thickness, pipe material, acoustic lagging and partition construction) will have a different R_w+C_{tr}. It is important to use pipe fittings and construction methods in the laboratory that best represent field construction.

5.2.4 Lagging Quality

Quality in acoustic lagging varies significantly between laggers and also between laboratory and field lagging. The quality of the lagging installation often includes gaps in the lagging (usually at bends) or the tightness of the lagging on the pipe varies.

This variation in lagging quality is a known issue in the acoustic industry and tests have been conducted at the National Acoustic Laboratories to determine the effect that gaps have on the acoustic performance of the lagging product. It was found that gaps do reduce the acoustic performance of lagging 1-5 dB depending on the size and quantity of the gaps.

The difference between a high quality lagged product in laboratory testing and a lower quality lagged pipe on site in the field, means the R_w+C_{tr} is reduced. Since this compliance method is of a deemed-to-satisfy construction method, it is impossible to test the poor lagging has on site other than by a thorough usual inspection. This could potentially lead to post-occupation legal issues. For example, if an occupant complains about the noise from a soil or waste pipe and it is observed that the lagging quality is sub-optimal, there is no way to quantitively prove how much the lagging quality is affecting the R_w+C_{tr}.

6 DEVELOPMENT OF INDUSTRY CODE OF PRACTICE

An industry code of practice in this area would assist clients, manufacturers and testing organisations by standardising and simplifying the process of complying with Part F5.6 of Volume 1 of the NCC.

For an industry code of practice to be formulated, the following issues should be investigated as future work:

- Identify concerns with the laboratory and calculation procedure so that it can be improved.
- Develop a robust method of dealing with the uncertainties surrounding predictions relating to the potential differences between laboratory and field installations.

7 SUMMARY

A testing procedure to determine the acoustic performance of systems separating soil and waste pipes from habitable and non-habitable rooms that has been under development since 1995 is described. This paper also outlines a calculation procedure to determine the weighted sound reduction index (R_w+C_{tr}) of a soil or waste pipe behind a partition from the measured sound pressure levels to demonstrate compliance with the Part F5.6 of Volume 1 of the NCC 'Sound insulation rating of internal services'.

A number of issues related to complications in complying with the current BCA Part F5.6 criteria have been raised. These issues highlight the Australian acoustic industry's struggle to comply with the BCA Part F5.6 criteria.

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