Sydney Opera House

Building Renewal Project

Noise Impact Assessment – Works Package 2

Rev C | 21 November 2016

This report takes into account the particular instructions and requirements of our client.

It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

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Acoustic Glossary

1 Introduction

This report presents the results of an assessment of noise from some of the proposed works for the Sydney Opera House (SOH) Building Renewal project.

A glossary of acoustic terminology has been included in Appendix B.

1.1 Scope of Assessment

This assessment reviews operation and construction noise issues for the following proposed components of the SOH Building Renewal Works Package 2 projects included as part of Development Application 2b:

- Under the Steps
- Creative Learning Centre
- Southern Foyers

2 Summary

The assessment of noise levels has shown that operational noise as a result of the modifications is not likely to have any adverse impact on noise sensitive receivers around the site.

The Sydney Opera House (SOH) has recognised noise issues affecting nearby neighbours during external construction works in the past. Therefore the Sydney Opera House intends that contractors who are undertaking noisy external works identify mitigation measures for this work in their Construction Noise Management Plan (CNMP) which they will be required to prepare before work starts on site. This CNMP will be reviewed by the SOH and their noise consultants prior to approval and implementation on site.

The Contract with the Managing Contractor will include a clause allowing SOH to disallow any equipment that it considers to be excessively noisy. Similarly the Managing Contractor may include incentives, as it sees fit, for sub-contractors who can provide noise mitigation measures as part of their contract works.

As well as the work practices noted earlier in this report, a noise logger will be installed and maintained which can be interrogated remotely by SOH staff as well as the Managing Contractor. The logger will also be required to automatically send a text message to a Managing Contractor's representative on site once the 'warning' threshold is breached. The SOH representative on site during the works will also be copied in with the warning texts.

The following noise limits will be applied:

Receiver	Time Period[1]	Warning level, $L_{Aeq(15min)}$	Maximum Level, $L_{Aeq(15min)}$
Bennelong Apartments	Day (standard hours)	65 dB	68 dB
	Day (outside hours)	60 dB	63 dB
	Evening	59 dB	62 dB
	Night	50 dB	53 dB
Kirribilli	Day (standard hours)	61 dB	64 dB
	Day (outside hours)	56 dB	59 dB
	Evening	54 dB	57 dB
	Night	48 dB	51 dB
Potts Point	Day (standard hours)	58 dB	61 dB
	Day (outside hours)	53 dB	56 dB
	Evening	53 dB	56 dB
	Night	47 dB	50 dB

Should complaints be received, attended acoustic monitoring will be undertaken to ascertain the 'noisier' work activities and address specific work practices and locations to better alleviate noise complaints from that particular activity.

Following identification that all noise levels have returned to being consistently below the above maximum levels the monitoring will revert to remote monitoring.

Nearby residents will be provided with a notice that informs them of the nature of the works, the duration and the extent of works being undertaken. 24hr contact details will be provided to allow complaints to be logged and addressed as soon as possible by the Opera House.

[1] *day* refers to 0700 to 1800h, *evening* refers to 1800 to 2200h and *night* refers to 2200h to 0700h. *Standard hours* refers to standard working periods (Monday to Friday 0700 to 1800h and Saturday 0800 to 1300h).

3 Proposed Works

3.1 Construction

The exact construction techniques and equipment will be finalised by the eventual contractor for the project. Based on the best information available, the following are likely to be involved.

- External demolition (removal of façade and road pavement/curbing)
- Internal demolition
- Concreting
- External fitout works
- Internal fitout works
- Waste handling/removal
- Deliveries/removal

More detail is given in Section 7.1 of this report. Some works will need to be done outside of normal working hours because of the sensitivity of the internal spaces within the Opera House.

3.2 Proposed Uses

The following uses are anticipated by SOH for the different spaces.

Under the Steps

- Space to function as a new SOH front door, i.e. pedestrian arrivals (peak arrivals to coincide with departures)
- Patron congregation around the space – sheltering from sun and rain, resting at the new curved seats
- Limited vehicular drop-offs (disabled, less abled and VIP drop off) with valet service
- Other specific functions/future uses would be addressed in the future by a separate Development Application when required

Creative Learning Centre

- New creative learning programs – the space is anticipated to primarily be used for creative play and teaching and learning activities with school children
- Use of the space may include amplified music, etc. but this is not expected to be a significant factor as no external/outdoor interface is proposed with the space (other than entry / exit)
- Patron arrival for program sessions with entrance by patrons from the Western Broadwalk and the Western Foyer as pedestrians only (no vehicles).

Proposed capacities:

- Primary learning space: 147 people standing and 32-49 for creative play
- Secondary/Digital learning space: 46 people standing and 10-16 for creative play

Southern Foyers

- Foyer bar function to the Joan Sutherland Theatre and Concert Hall (i.e. no change to current use), both have interfaces with external podium however there is a glazed façade and the use of the spaces is typically for limited periods at a time (e.g. pre and post show)
- No anticipation at this time to change the use
- Lift 36 services Box Office to Joan Sutherland Theatre Southern Foyer

4 Existing Environment

The NSW Industrial Noise Policy (INP)[2] sets out a methodology to characterise the background noise environment at a proposed development and to derive appropriate criteria for noise from plant affecting the environment.

This is based on the levels of existing noise at sensitive receivers located around the site which in turn are derived from an extensive survey of existing ambient noise levels. Methods outlined within the NSW INP were used to measure and derive the Rating Background Level (RBL). Subsequent noise criteria for different applications were then derived based on the RBL data as presented in Section 5.

Further details of the noise surveys carried out are provided in Appendix A.

4.1 Description of Site

The site is located on the Bennelong Point peninsula in Sydney Harbour and is near to a major passenger ferry terminal. The area around the Opera House is effectively pedestrianised although there are some occasional deliveries and drop-offs that visit the southern end of the site. Most of the traffic visiting the site accesses the car parking via an underground route.

The site is characterised by general pedestrian activity and noise from the harbour activity, with occasional aircraft movements. The background noise environment also contains traffic noise from the Cahill Expressway (located to the south and west on the Harbour Bridge) and rail noise from the Harbour Bridge (located to the west).

[2] NSW Industrial Noise Policy. Environment Protection Authority. January 2000

4.2 Noise Sensitive Receivers

The nearest residential noise sensitive receivers with potential to be affected are located as shown in Figure 1.

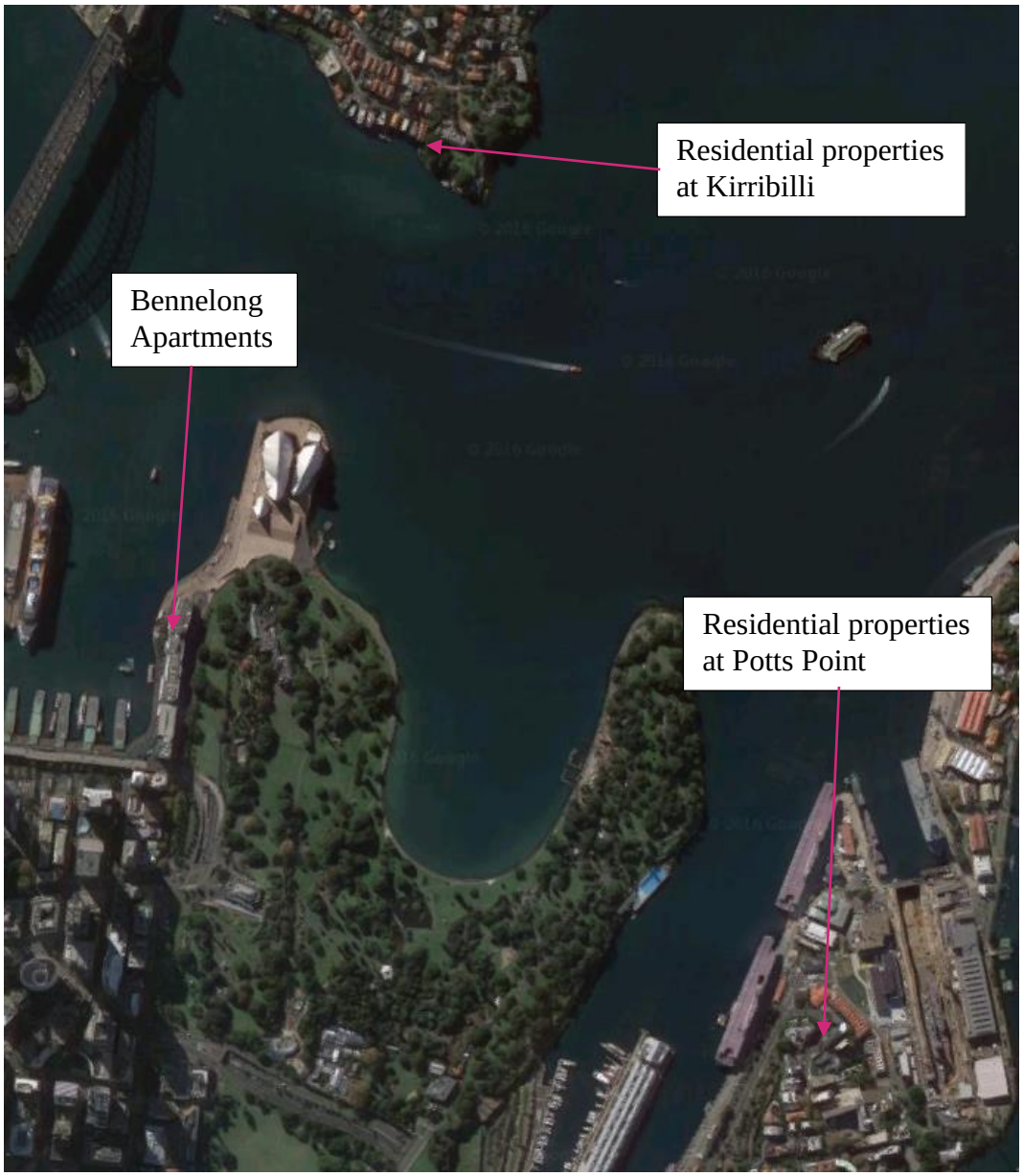


Figure 1: Noise sensitive receivers (image courtesy of Google Maps)

4.3 Measurement of existing noise levels

Surveys of the existing noise levels at the nearest noise sensitive receivers have been conducted.

Measurements at Kirilbilli Point (near harbour in front of the southern façade of 29 Waruda Street, adjacent to Beulah Street Wharf) were undertaken by Arup

using unattended noise logging over the course of one week, supplemented with attended measurements.

Unattended noise logging measurements by Auditoria were undertaken to determine the noise levels at the Bennelong Apartments, East Circular Quay on Levels 4 and 9.

For potential receivers at Potts Point, the significant source-receiver distance (>1 km) means that significant impacts are unlikely and hence background noise measurements were not taken for these receivers. Indicative background noise levels from a previous project in Woolloomooloo have been used to represent the likely existing noise environment at Potts Point. The measurements in Wooloomooloo were previously undertaken by Arup at 31 Nicholson Street using unattended noise logging over the course of one week, along with attended measurements.

Further details of the noise surveys carried out are provided in Appendix A.

5 Noise Criteria

5.1 Background Noise Levels

Single-number background noise measurements ($L_{A90,15min}$ determined using the "tenth percentile" method and time periods as per the NSW Industrial Noise Policy) are summarised in Table 1. Refer to Appendix A for further details.

A customised Rating Background Level (RBL) has also been derived using only 10pm – 12am measurement data at the Kirribilli and Bennelong Apartments receivers to represent a 'worst case' (i.e. lowest background noise) condition that may occur during the typical operating time limits assumed for activities Under the Steps or within the Creative Learning Centre.

Table 1: Background noise levels at noise sensitive receivers, dB re 20µPa

Receiver	Time Period	Rating Background Level ($dBL_{A90,15min}$)
Bennelong Apartments	Day	58
	Evening	57
	Night	48
	10pm – Midnight	56
Kirribilli	Day	54
	Evening	52
	Night	46
	10pm - Midnight	51
Potts Point	Day	51
	Evening	51
	Night	45

5.2 Operational Plant Noise Criteria

No new plant equipment affecting the external environment is planned to be included as part of the proposed development components that are assessed within the scope of this noise impact assessment.

As such, the typical NSW INP criteria has not been derived for the assessment of operational noise from plant equipment and this topic is not discussed further within this report.

5.3 Operational Event Noise Criteria

There are successful existing precedents regarding noise limits from the SOH Northern Broadwalk as defined in the approved Conditions of Consent from a

previous Development Application[3] (DA). The DA sets out various noise criteria which are shown below. These limits are used as a reference for assessment against within this report.

The DA defines two types of external events, these being:

- low impact events (with up to 250 people)
- medium impact events (with up to 1000 people)

Low impact events are allowed for up to 12 days per month and medium impact events for up to 40 times per year. Events have to finish by 2400h.

Noise levels are limited to the following which apply between the hours of 10am to 11pm on Sunday to Thursday and between the hours of 10am to 12 midnight on Friday, Saturday and the eve of a public holiday (refer to Condition of Consent 38).

- 55 dBL_{Amax} and 70 dBL_{Cmax}; or
- dBL_{Amax} not to exceed the background noise level (dBL_{A90}) by more than 5dB(A) and the L_{Cmax} must not exceed the L_{Amax} by more than 15dB

Note: The ambient noise measurements taken as part of this study (refer to Table 1 *and Appendix A) show that before midnight the existing background noise level is above 50 dBL_{A90} so the above criteria a) of 55 dBL_{Amax} and 70 dBL_{Cmax} would apply as the limiting criteria.*

The limits apply at noise sensitive receivers (e.g. residences) and the main locations are identified in the DA conditions as Beulah Street Wharf (off Waruda Street) in Kirribilli and at a point within one metre of the residential boundary nearest to SOH at Bennelong Apartments, East Circular Quay.

5.4 Construction Noise Criteria

This report only considers impacts on receivers external to the Sydney Opera House from construction works at the SOH. Impacts to internal sensitive spaces within the Sydney Opera House will be managed via administrative controls by scheduling of noise-generating activities outside of the operational hours of the SOH venues.

For external receivers, the NSW *Interim Construction Noise Guideline* (ICNG) provides recommended noise levels for airborne construction noise at sensitive land uses for State-controlled projects in NSW. The guideline provides construction management noise levels above which all feasible and reasonable work practices should be applied to minimise the construction noise impact. The ICNG works on the principle of a "screening" criterion – if predicted or measured construction noise exceeds the ICNG levels then the construction activity must implement all "feasible and reasonable" work practices to reduce noise levels. As

[3] DA 444-10-2003 from June 2004 for use of the Northern Broadwalk for temporary functions. Department of Infrastructure Planning and Natural Resources.

such, the noise targets set by the ICNG are "management levels" for noise rather than strict "noise limits".

The ICNG sets out management levels for noise at noise sensitive receivers, and how they are to be applied. These management noise levels for residential receivers are reproduced below, in Table 2. Noise levels apply at the worst affected property boundary of the residence, at a height of 1.5 m above ground level. If the property boundary is more than 30 m from the residences, the noise levels apply at the most noise-affected point within 30 m of the residence.

Table 2: ICNG management levels for airborne construction noise at residences

Time of day	**Management Level, $L_{Aeq(15min)}$**	**How to apply**
Recommended standard hours: Monday to Friday 7 am to 6 pm Saturday 8 am to 1 pm No work on Sundays or Public Holidays	Noise affected RBL + 10 dB	The noise affected level represents the point above which there may be some community reaction to noise. Where the predicted or measured $L_{Aeq\ (15\ min)}$ is greater than the noise affected level, the proponent should apply all feasible and reasonable work practices to meet the noise affected level. The proponent should also inform all potentially impacted residents of the nature of works to be carried out, the expected noise levels and duration, as well as contact details.
	Highly noise affected 75 dB(A)	The highly noise affected level represents the point above which there may be strong community reaction to noise. Where noise is above this level, the relevant authority (consent, determining or regulatory) may require respite periods by restricting the hours that the very noise activities can occur, taking into account: • Times identified by the community when they are less sensitive to noise (such as before and after school for works near schools, or mid-morning or mid-afternoon for works near residences). • If the community is prepared to accept a longer period of construction in exchange for restrictions on construction times.
Outside recommended standard hours	Noise affected RBL + 5 dB	A strong justification would typically be required for works outside the recommended standard hours. The proponent should apply all feasible and reasonable work practices to meet the noise affected level. Where all feasible and reasonable practices have been applied and noise is more than 5 dB(A) above the noise affected level, the proponent should negotiate with the community.

For work within standard construction hours, if after implementing all "feasible and reasonable" noise levels the site still exceeds the Noise Affected Level, the

ICNG does not require any further action – since there is no further engineering scope for noise mitigation.

For out-of-hours work, the ICNG uses a level 5 dB above the noise-affected level as a threshold where the proponent should negotiate with the community.

Although the ICNG does not use this terminology, in this report, the term "Highly-Noise Affected Level" has been used to refer to this level (i.e. 5 dB(A) above the Noise Affected Level for out-of-hours work) for reasons of brevity.

Table 3: ICNG screening criteria for SOH Construction Works, dB re 20µPa

Receiver	**Time Period**	**Noise Affected Level, $L_{Aeq(15min)}$**	**Highly Noise Affected Level, $L_{Aeq(15min)}$**
Bennelong Apartments	Day (standard hours)	68 dB	75 dB
	Day (outside hours)	63 dB	68 dB
	Evening	62 dB	67 dB
	Night	53 dB	58 dB
Kirribilli	Day (standard hours)	64 dB	75 dB
	Day (outside hours)	59 dB	64 dB
	Evening	57 dB	62 dB
	Night	51 dB	56 dB
Potts Point	Day (standard hours)	61 dB	75 dB
	Day (outside hours)	56 dB	61 dB
	Evening	56 dB	61 dB
	Night	50 dB	55 dB

6 Operational Event Noise

6.1 Under the Steps

6.1.1 Usage and Assessment

The intended uses of the Under the Steps (UtS) space is limited to small scale activities with minimal sound reinforcement (i.e. assumed limited to typical amplified speech or announcements). No formal events are planned so noise levels will be controlled by general speech occupational noise.

Activity within the UtS is proposed to end by Midnight.

6.1.2 Noise levels

To estimate the noise generated within the UtS space, reference has been made to a research paper[4] which proposes an empirical method for estimating noise levels from crowds. Based on an occupancy of 500, a sound power level of 105 dBL_{Aeq} is predicted. This results in an estimated noise level at Bennelong Apartments of 46 dBL_{Aeq} after accounting for the relevant propagation losses.

This is 10 dB below the existing 'worst case' rating background noise level taken from 10pm - Midnight (RBL of 56 dBL_{A90}) and also below the reference event noise limit of 55 dBL_{Amax} presented in Section 5.3.

As such, no issues with operational noise from the proposed activity in the UtS space is anticipated.

6.2 Creative Learning Centre and Main Foyers

All activity in these space is expected to take place internally and not expected to generate high levels of noise. The Creative Learning Centre (CLC) is a fully enclosed space with full air conditioning and it is not envisaged that there be any loud activities that would take place with doors open. The space is anticipated to primarily be used for creative play and for teaching and learning activities with school children.

It is worth noting that the Primary Learning Space within the CLC is buffered from the western façade by other spaces – a smaller Secondary/Digital Learning Space and a toilet block.

Prediction calculations have been done to check on potential noise breakout through the area of the northern glazed façade that faces Kirribilli. A 'loud'

[4] Prediction of Noise from Small to Medium Sized Crowds
M.J. Hayne (1), J.C. Taylor (1), R.H. Rumble (1) and D.J. Mee (2)
(1) Ron Rumble Renzo Tonin, 96 Petrie Terrace, Petrie Terrace QLD Australia 4000
(2) School of Mechanical and Mining Engineering, The University of Queensland, Brisbane, Australia 4072

internal music noise level has been assumed as shown in Table 4 as representative of a worst case usage scenario.

Table 4: Assumed L_{10} sound pressure level incident directly on façade within the CLC

Event Type	Sound Pressure Level, L_{10} (dB re 20 µPa)									
	Single Figure		Octave Band Centre Frequency (Hz)							
	dB(A)	dB(C)	63	125	250	500	1k	2k	4k	8k
Loud Music (amplified)	90	97	93	92	88	88	84	83	77	70

Using *measured* data for the in-situ sound insulation of the existing façade type including doors (D_w 25, C_{tr} -2) and taking pessimistic assumptions about propagation losses using CONCAWE[5] Category 6 conditions (i.e. downwind), the noise level at Kirribilli and Bennelong apartments is calculated as less than 24 dBL_{A10}.

Predictions to each receiver location which allow for open doors are less than 41 dBL_{A10}, which is still more than 10 dB below the 'worst case' custom night time L_{A90} background noise levels at each location during assumed typical operating time limits (refer to the RBLs taken between 10pm – Midnight in Table 1).

No significant impact on the surroundings is therefore expected from the proposed activities in the CLC.

6.3 Southern Foyer

The southern foyer will continue to be used as it is currently. Noise levels in the space will need to be controlled in order to protect the highly-sensitive venues within the SOH and so no noisy activities will take place.

Arup is not aware of any reported external noise complaints from the existing foyer noise and it is therefore reasonable to assume that there would be no noise issues caused by the proposed changes to the foyer which are largely cosmetic.

[5] The propagation of noise from petroleum and petrochemical complexes to neighbouring communities. CONCAWE report no 4/81.

7 Construction Noise

7.1 Source Levels and Assumptions

Indicative construction activity noise source levels have been assumed for the SOH Building Renewal Works Package 2 construction works, based on previous construction noise assessments for building projects conducted by Arup and on the likely construction methodology for the project.

The following major construction activities have been modelled:

- External demolition (removal of façade and road pavement/curbing)
- Internal demolition
- Concreting
- External fitout works
- Internal fitout works
- Waste Handling/ removal
- Deliveries/removal

For each activity, typical construction equipment used for that activity has been combined into an overall source sound power level for the activity, accounting for the likely usage patterns of items of equipment over a typical 15-minute period (which is the assessment time frame for construction noise levels under the ICNG).

Sound levels for items of construction plant have been obtained from the databases in BS5228.1[6] and AS2436[7].

Items of plant that have particularly-annoying characteristics (e.g. impulsive or tonal noise characteristics, such as cutting, piling or drilling equipment) has had a +5 dB adjustment penalty applied to account for these characteristics, as required by the ICNG.

For on-site deliveries, equivalent line-source sound power levels have been calculated based on the published maximum pass-by levels for haul trucks from BS 5228.1.

It is worth noting that some deliveries are expected to make use of the underground route and so will not disturb the nearest residential receivers from the noise of loading and unloading activities.

For internal demolition works, minimal allowance has been made for the sound insulation of the building envelope. This represents the ‘worst case’ where openings in the building envelope are left open during activities.

6 British Standard BS5228-1: 2009 + A1 :2014 *Code of practice for noise and vibration control on construction and open sites – Part 1: Noise*

7 Australian Standard AS2436 (2010) *Guide to noise and vibration control on construction, demolition and maintenance sites*

Table 5 summarises the construction source levels and the major items of construction equipment modelled for each major construction activity:

Table 5 Construction Activities, SOH Building Renewal Works Package 2

Activity	Construction Equipment	Activity Sound Power Level, dB re 1pW
External demolition	Mobile cranes Demolition saw Core drill Concrete breakers (mechanised) Small excavators/bobcats Work platforms	$L_{eq,adj,15min}$ 128 dB(A)
Internal demolition	Demolition saw Core drill Concrete breakers (handheld) Small excavators/bobcats Work platforms	$L_{eq,adj,15min}$ 116 dB(A)
Concreting	Concrete trucks Concrete pumps Vibrators	$L_{eq,adj,15min}$ 109 dB(A)
External fitout works	Core drill Mobile cranes Small excavators/bobcats/forklifts	$L_{eq,adj,15min}$ 117 dB(A)
Internal fitout works	Hand tools Small excavators/bobcats Work platforms	$L_{eq,adj,15min}$ 104 dB(A)
Waste handling/ removal	Excavators loading trucks	$L_{eq,adj,15min}$ 104 dB(A)
Deliveries/removal	Haul truck/trailer	$L'_{eq,adj,15min}$ 71 dB(A)/m[8]

7.2 Predicted Noise Levels

Construction noise levels have been predicted for the sources given in Table 5 using a spreadsheet based noise model developed for the SOH Building Renewal Works Package 2 projects. The predictions generally implemented the CONCAWE environmental noise model, which allows prediction under adverse meteorological conditions to be made, with the exception of the ground effect component. CONCAWE was developed for propagation over sound-absorbing terrain (acoustically-"soft" ground) whereas the propagation geometry for the most-affected receivers from the SOH is mainly over acoustically-reflective ("hard") ground – i.e. pavement or water. To account for this, the ground effect component from the ISO 9613.2 noise model has been used.

8 Note this is a sound power per metre for a line source of noise corresponding to the haulage routes on site.

Noise levels have been predicted under neutral ("still") meteorological conditions to show the average expected noise levels and to allow ready comparison of the relative impacts between individual activities; as well as under adverse ("downwind") conditions to indicate the potential increase in noise level under adverse conditions.

Indicative noise source locations were assumed as follows:

- Northern sources — At the northern façade intermediate between the JST and Concert Hall (Creative Learning Centre works)
- Southern sources — At the southern façade edge of the JST (Southern Foyer, Under the Steps works)

Due to the actual distance between the SOH construction works and noise sensitive receivers being of the order of >250 m, the actual source location chosen has minimal influence on the results, and hence activities in similar areas (e.g. the Southern Foyer and Under the Steps works) can be modelled as a single source location with minimal error.

For truck deliveries, line sources of noise have been used to model truck movements along the western boardwalk for occasional truck movements where it is not practicable to access the site via the underground VAPS route (e.g. delivery of large components). A maximum of one truck movement over a 15-minute assessment period has been assumed.

A site plan showing the indicative construction source locations is presented in Figure 2.

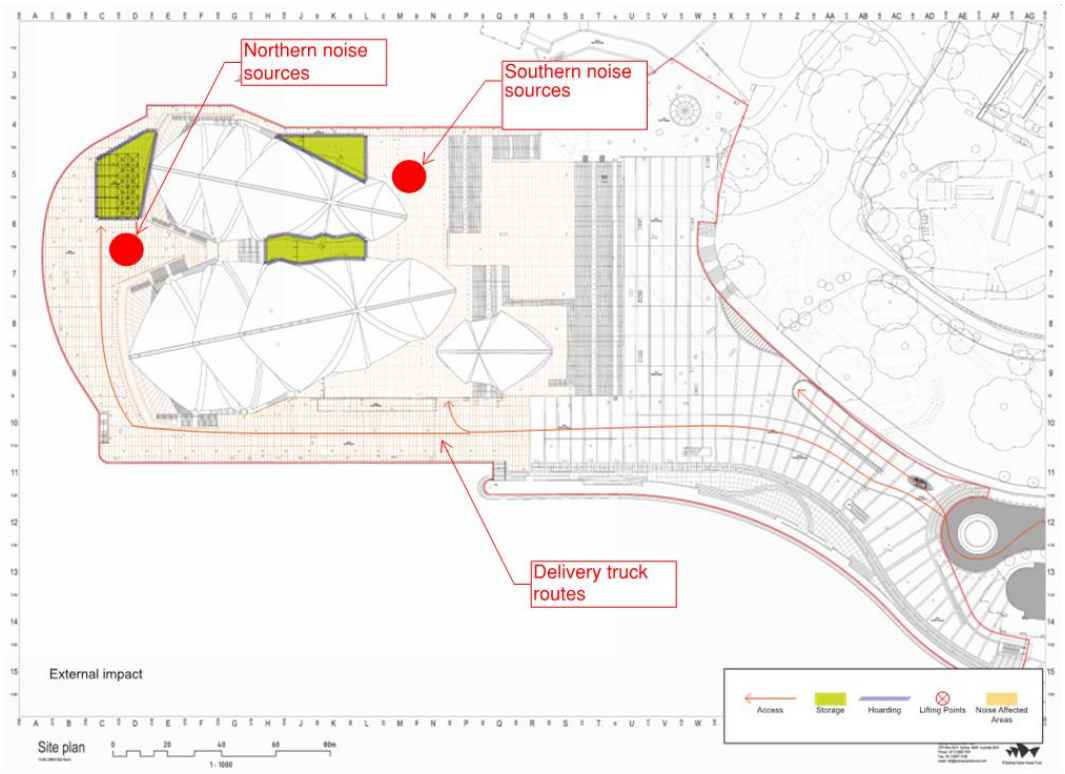


Figure 2 Indicative construction source locations, Sydney Opera House construction works (Building Renewal Works Package 2)

For each of these source locations, the following tables (Table 6, Table 7 and Table 8) present a summary showing the highest predicted noise level at each noise-sensitive receiver catchment (Bennelong Apartments, Kirribilli and Potts Point), and presents the ICNG construction screening criteria for comparison.

Table 6 Construction Noise Screening Calculations, Sydney Opera House, Northern Sources (Creative Learning Centre), dB re 20 µPa

Source Location	**Activity**	**Receiver**	**Predicted Construction Noise Level, dB $L_{Aeq,adj,15min}$**	**Noise Affected Level, dB(A)**		
				Day	**Evening**	**Night**
Creative Learning Centre	Internal Demolition	Bennelong	36-40	68	62	53
		Kirribilli	49-54	64	57	51
		Potts Point	29-35	61	56	50
	Concreting	Bennelong	31-35	68	62	53
		Kirribilli	45-50	64	57	51
		Potts Point	24-30	61	56	50
	Internal Fitout Works	Bennelong	25-29	68	62	53
		Kirribilli	39-44	64	57	51
		Potts Point	17-24	61	56	50
	External Fitout Works	Bennelong	33-38	68	62	53
		Kirribilli	47-53	64	57	51
		Potts Point	25-32	61	56	50
	Waste Handling	Bennelong	26-30	68	62	53
		Kirribilli	40-45	64	57	51
		Potts Point	20-26	61	56	50

*Marginal exceedance of 1-2 dB(A) is not noticeable and not significant.

Table 7 Construction Noise Screening Calculations, Sydney Opera House, Southern Sources (Southern Foyers and Under the Steps), dB re 20 µPa

Source Location	Activity	Receiver	Predicted Construction Noise Level, dB $L_{Aeq,adj,15min}$	Noise Affected Level, dB(A)		
				Day	Evening	Night
Southern Foyers Under the Steps	Internal Demolition	Bennelong	57-60	68	62	53
		Kirribilli	26-31	64	57	51
		Potts Point	32-38	61	56	50
	Concreting	Bennelong	53-55	68	62	53
		Kirribilli	20-26	64	57	51
		Potts Point	28-34	61	56	50
	Internal Fitout Works	Bennelong	47-50	68	62	53
		Kirribilli	14-19	64	57	51
		Potts Point	21-27	61	56	50
	External Fitout Works	Bennelong	57-60	68	62	53
		Kirribilli	22-28	64	57	51
		Potts Point	29-36	61	56	50
	Waste Handling	Bennelong	47-50	68	62	53
		Kirribilli	16-21	64	57	51
		Potts Point	23-30	61	56	50

Table 8 Construction Noise Screening Calculations, Sydney Opera House, Western Sources (Deliveries), dB re 20 µPa

Source Location	Activity	Receiver	Predicted Construction Noise Level, dB $L_{Aeq,adj,15min}$	Noise Affected Level, dB(A)		
				Day	Evening	Night
Western Broadwalk	Deliveries	Bennelong	50-51	68	62	53
		Kirribilli	26-31	64	57	51
		Potts Point	6-13	61	56	50

The initial construction noise predictions indicate that construction noise impacts are expected for the following activities:

- External demolition activities (during standard hours for southern source locations; at evening/night for all source locations)
- Internal demolition (at night for southern source locations)
- External fitout works (at night for southern source locations)

As required by the ICNG, all "feasible and reasonable" noise mitigation measures should be implemented to reduce noise levels from these activities. A discussion of mitigation measures is given in Section 7.3.

7.3 Noise Mitigation

Initial construction noise mitigation measures have been developed for each major activity of construction in order to reduce construction noise emission.

These mitigation measures represent an initial estimate of all "feasible and reasonable" work practices suitable for consideration in the construction process. During detailed design of the construction process, a subsequent review of these mitigation measures with the selected contractor should be conducted to determine whether these measures are still relevant to the developed construction process.

A further factor that may need to be considered is the effect of meteorological conditions on the noise propagation – e.g. avoiding noisy works if the wind is blowing from source to receiver.

These mitigation measures consist of a combination of universal work practices that should be followed for all activities, as well as specific mitigation measures for individual construction activities.

7.3.1 Universal Work Practices

The following noise mitigation work practices are recommended to be adopted at all times on site:

- Regularly train workers and contractors (such as at toolbox talks) to use equipment in ways to minimise noise
- Ensure site managers periodically check the site and nearby residences for noise problems so that solutions can be quickly applied
- Avoid the use of radios or stereos outdoors during night time works
- Avoid the overuse of public address systems
- Avoid shouting, and minimise talking loudly and slamming vehicle doors, especially during night time works
- Use non-"beeper" reversing/movement alarms such as broadband (non-tonal) alarms or ambient noise-sensing alarms
- Turn off all vehicles, plant and equipment when not in use
- Use residential-grade mufflers on plant
- Ensure all doors/hatches are shut
- Conduct work behind temporary hoardings/screens wherever possible. Site hoardings should be located as close to the noise source as possible, and should be as high as feasible considering the structural support of the hoarding. Site hoardings may not be effective at screening noise to upper floors of sensitive receivers, but can be an effective noise mitigation measure for receivers located on lower floors.

In addition, specific recommended working practices for individual activities are as follows:

7.3.2 Demolition

- Provide resilient damping material on bin trucks or receptacles to minimise impact noise from materials loaded on truck
- Avoid metal-to-metal contact on equipment wherever possible
- Fit mufflers/silencers to pneumatic tools (e.g. breakers)
- Use dampened bits on impulsive tools such as jackhammers to avoid "ringing" noise
- Avoid dropping materials from height
- Use of concrete pulverisers or "munchers" as a lower-noise alternative to concrete breakers

7.4 Assumed Noise Mitigation

Indicative noise mitigation for different noise mitigation measures have been obtained from the guidance of AS2436 and BS5228.1, as summarised below in Table 9.

Table 9: Indicative Noise Reduction Provided by Noise Mitigation Measures

Construction Equipment	Noise Mitigation Measure	Indicative Noise Reduction	Source
Concrete breaker	Substitution of concrete pulveriser	15 dB(A)	BS5228.1
Hand-held tools Drilling rigs Demolition saws	Screening	5 dB(A)	Table C3 AS2436:2010
Excavators/loaders Trucks Mobile cranes	Residential-grade silencer	10 dB(A)	Table C2 AS2436:2010

Mitigated noise levels using these noise reduction values are presented in the following sections.

7.5 Mitigated Noise Levels

Table 10 Mitigated Construction Noise Screening Calculations, Sydney Opera House, Northern Sources (Creative Learning Centre), dB re 20 µPa

Source Location	Activity	Receiver	Predicted Construction Noise Level, dB $L_{Aeq,adj,15min}$	Noise Affected Level, dB(A)		
				Day	Evening	Night
Creative Learning Centre	Internal Demolition	Bennelong	31-35	68	62	53
		Kirribilli	45-50	64	57	51
		Potts Point	24-30	61	56	50
	Concreting	Bennelong	23-27	68	62	53
		Kirribilli	37-42	64	57	51
		Potts Point	16-22	61	56	50
	Internal Fitout Works	Bennelong	24-28	68	62	53
		Kirribilli	38-43	64	57	51
		Potts Point	17-24	61	56	50
	External Fitout Works	Bennelong	28-32	68	62	53
		Kirribilli	42-48	64	57	51
		Potts Point	20-27	61	56	50
	Waste Handling	Bennelong	26-30	68	62	53
		Kirribilli	40-45	64	57	51
		Potts Point	20-26	61	56	50

Table 11 Mitigated Construction Noise Screening Calculations, Sydney Opera House, Southern Sources (Southern Foyers and Under the Steps), dB re 20 µPa

Source Location	Activity	Receiver	Predicted Construction Noise Level dB $L_{Aeq,adj,15min}$	Noise Affected Level, dB(A)		
				Day	Evening	Night
Southern Foyers Under the Steps	Internal Demolition	Bennelong	52-55	68	62	53
		Kirribilli	21-26	64	57	51
		Potts Point	27-34	61	56	50
	Concreting	Bennelong	44-47	68	62	53
		Kirribilli	13-18	64	57	51
		Potts Point	20-26	61	56	50
	Internal Fitout Works	Bennelong	46-49	68	62	53
		Kirribilli	14-19	64	57	51
		Potts Point	21-27	61	56	50
	External Fitout Works	Bennelong	51-55	68	62	53
		Kirribilli	17-22	64	57	51
		Potts Point	24-30	61	56	50
	Waste Handling	Bennelong	47-50	68	62	53
		Kirribilli	16-21	64	57	51
		Potts Point	23-30	61	56	50

Table 12 Mitigated Construction Noise Screening Calculations, Sydney Opera House, Western Sources (Deliveries), dB re 20 µPa

Source Location	Activity	Receiver	Predicted Construction Noise Level dB $L_{Aeq,adj,15min}$	Noise Affected Level, dB(A)		
				Day	Evening	Night
Western Broadwalk	Deliveries	Bennelong	40-41	68	62	53
		Kirribilli	16-21	64	57	51
		Potts Point	0-3	61	56	50

The predictions indicate that even with all "feasible and reasonable" mitigation measures in place, some residual exceedances of the noise management levels are predicted to occur at the Bennelong Apartments as shown in Table 11 at the following locations:

- External demolition works during night time for southern source locations (Southern Foyers and Under the Steps)

For these locations, noise levels at the Bennelong Apartments are predicted to be more than 5 dB above the Noise Affected Level. Where this occurs, the ICNG states that "the proponent should negotiate with the [affected] community".

Where residual impacts occur, the ICNG requires additional noise management measures to be determined in consultation with affected receivers. These measures could include:

- Scheduling of respite periods where no construction activity occurs (e.g. scheduling demolition works during the day time, subject to the requirement to avoid impacts on internal SOH receivers)
- Providing designated times where no works occur (e.g. agreeing with residents a schedule of nights when construction will and will not occur).

Although northern sources (and other activities at southern source locations) are predicted to meet the ICNG noise management levels under neutral conditions, impacts may still occur under adverse meteorological conditions. This may require monitoring of weather conditions (particularly wind speed and direction) and adjustments to the construction schedule should "adverse" conditions occur. This should be confirmed by noise monitoring at potentially-affected properties to determine the actual noise levels under adverse conditions, since the CONCAWE model (developed for propagation over soft ground) may not adequately predict the increase in noise level for propagation across water.

8 Recommendations

On the basis of the above analysis, it is concluded that the proposed development of the Creative Learning Centre, Under the Steps and Southern Foyers with modifications to the SOH described in this document would not have a detrimental impact on the nearest noise sensitive receivers. However, to minimise potential for noise nuisance, the following recommendations are made.

8.1 Construction Noise

The Sydney Opera House (SOH) has recognised noise issues affecting nearby neighbours during external construction works in the past. Therefore the Sydney Opera House intends that contractors who are undertaking noisy external works identify mitigation measures for this work in their Construction Noise Management Plan (CNMP) which they will be required to prepare before work starts on site. This CNMP will be reviewed by the SOH and their noise consultants prior to approval and implementation on site.

The Contract with the Managing Contractor will include a clause allowing SOH to disallow any equipment that it considers to be excessively noisy. Similarly the Managing Contractor may include incentives, as it sees fit, for sub-contractors who can provide noise mitigation measures as part of their contract works.

As well as the work practices noted earlier in this report, a noise logger will be installed and maintained which can be interrogated remotely by SOH staff as well as the Managing Contractor. The logger will also be required to automatically send a text message to a Managing Contractor's representative on site once the 'warning' threshold is breached. The SOH representative on site during the works will also be copied in with the warning texts.

Should complaints be received, attended acoustic monitoring will be undertaken to ascertain the 'noisier' work activities and address specific work practices and locations to better alleviate noise complaints from that particular activity.

Following identification that all noise levels have returned to being consistently below the above maximum levels the monitoring will revert to remote monitoring.

To summarise:

- The recommendations regarding noise mitigation given in Section 7.3 above be implemented.
- Minimise the scheduling of external demolition works to take place during the Night time period whenever it can be considered "feasible and reasonable".
- The eventual Contractor be required to prepare a Construction Noise Management Plan.
- A noise logger be installed at Bennelong Apartments throughout construction to check on noise levels during construction.

8.2 Operational Noise

8.2.1 Under the Steps

- Activities in the Under the Steps space be limited to activities that do not require significant sound reinforcement beyond that installed for typical amplified speech or announcements.
- Activities in the Under the Steps space to finish by Midnight to reduce risk of noise disturbance from large groups of people leaving an event.

8.2.2 Creative Learning Centre

The activities within the Creative Learning Centre will take place internally in a fully air conditioned space and are not expected to impact on the external environment.

No specific restrictions are considered necessary as it is not expected that any loud activities would take place with the doors open or that events would be sufficiently loud to cause any disturbance to the noise sensitive receivers.

8.2.3 Southern Foyers

The activities within the southern foyer will be the same as those currently undertaken. No noise impacts are considered likely and no specific restrictions are proposed.

Appendix A

Environmental Noise Surveys

A1.1 Environmental Noise Survey

The noise environment is typical of a busy harbour and inner city. The major noise sources consist of nearby road vehicle traffic and railway noise (i.e. Harbour Bridge) as well as helicopter and ferry noise in Sydney Harbour.

As required by NSW Industrial Noise Policy, an ambient noise survey was conducted in the area from Wednesday, 13 July 2016 to Thursday, 21 July 2016 to determine the existing ambient noise levels at the nearest residential receivers. Additional data was obtained from previous surveys conducted by Arup and Auditoria.

Unattended (noise logging) and attended measurements were conducted to determine representative ambient noise levels in the vicinity of the site during the relevant hours of operation.

A1.2 Methodology

Long term noise monitoring equipment was set up at four locations to log 15 minute measurement intervals of L_{Aeq}, L_{A10} and L_{A90} with a fast (0.125s) time weighting.

Meteorological conditions were monitored during the survey period. The relevant measurement intervals affected by adverse weather and extraneous noise events were removed.

Short term 15 minute attended measurements were undertaken at logger location 3 on Wednesday, 13 July 2016 and Thursday, 21 July 2016 to obtain detailed noise information for weekday daytime activities. Attended Measurements were taken at location 4 on Thursday, 7 March 2013.

A1.3 Measurement Locations

Figure 1 shows the four noise logger locations on a map of the area. Logger locations were chosen taking into account security and access restrictions and are considered representative of the surrounding areas and nearest potentially affected receivers.

Unattended noise monitoring data was provided by Auditoria for locations 1 and 2. Loggers were positioned on level 4 and level 9 at the northern façade of Bennelong Apartments as shown in figure 2 (left).

Noise logger 3 was positioned in front of the southern façade of an apartment building at 29 Waruda Street Kirribilli with line of sight view of the Sydney Opera House as shown in figure 2 (right).

Logger 4 is from a previous noise assessment conducted by Arup from 7 March 2013 to 15 March 2013 at the Juanita Nielsen Centre (JNC) located in Woolloomooloo, Sydney. It is considered representative of the ambient noise in

the nearby suburb of Potts Point. A noise logger was installed on the first floor approximately 1m off the 31 Nicholson Street façade.

Figure 1: Map of logger locations.

Figure 2: Noise monitoring location at Bennelong Apartments (left) and Kirribilli (right).

Figure 3: Noise logger setup, Juanita Nielsen Centre Woolloomooloo.

A1.4 Equipment

The equipment used to measure the baseline noise levels is detailed in Table 1. Equipment used at location 3 and 4 was checked for calibration before and after measurements with no significant drift in calibration being recorded. All equipment used at location 3 and 4 held a current NATA calibration certificate at the time of the survey.

Table 1: Equipment used to conduct noise survey

Type	Model	Serial No.	Location
Noise Logger	ARL Ngara Type 1 Microphone	8780b4	Bennelong level 4
Noise Logger	ARL Ngara Type 1 Microphone	8780f0	Bennelong level 9
Noise Logger	ARL Ngara Type 1 Microphone	8780e8	29 Waruda St Kirribilli
Noise Logger	RTA Technology 04	T229736	JNC Woolloomooloo
Sound Level Meter	Brüel & Kjaer Type 2250	2449851	
Calibrator	Brüel & Kjaer Type 4231	3000079	

A1.5 Short Term Attended Noise Measurement Results

Short term measurements (15 minutes) of environmental noise were carried out at location 3 at the time of commissioning and decommissioning the noise loggers. At location 4, attended measurements were conducted at both the logger (JNC level 1) and at 1.5m above ground at the corner of Nicholson Street and Dowling Street. The attended measurement results a summarized in Table 2.

Table 2: Attended noise survey results

Location	Date	Time	$L_{Aeq, 15min}$	$L_{A90, 15min}$	$L_{A10, 15min}$	$L_{A1, 15min}$
29 Waruda Street Kirribilli	13-Jul-16	15:00	62 dB	59 dB	57 dB	76 dB
	13-Jul-16	09:30	57 dB	55 dB	54 dB	73 dB
1st Floor of JNC	7-March-13	09:40	60 dB	53 dB	63 dB	65 dB

Location	Date	Time	$L_{Aeq, 15min}$	$L_{A90, 15min}$	$L_{A10, 15min}$	$L_{A1, 15min}$
Nicholson Street/ Dowling Street Corner	7-March-13	10:10	56 dB	48 dB	59 dB	65 dB

A1.6 Long Term Unattended Noise Logging Results

Measured noise levels from the unattended noise survey at all four locations is summarised in Table 3. Summary results have been split into standard Day, Evening and Night time periods as defined in the NSW Industrial Noise Policy.

Averaged daily summary graphs of the noise logging are provided in Section A1.7 and individual daily graphs are available upon request.

Table 3: Summary of measure noise indices

Location	Time Period	Rating Background Level (RBL) – dB(A)	$L_{Aeq (period)}$, dB
Location 1 - Level 4, 1e Macquarie Street	Day (7:00 – 18:00)	59	64
	Evening (18:00 – 22:00)	59	62
	Night (22:00 – 7:00)	48	57
Location 2 - Level 9, 1e Macquarie Street	Day (7:00 – 18:00)	58	62
	Evening (18:00 – 22:00)	57	61
	Night (22:00 – 7:00)	49	56
Combined Bennelong data for report*	Day (7:00 – 18:00)	58	62
	Evening (18:00 – 22:00)	57	61
	Night (22:00 – 7:00)	48	56
Location 3 - 29 Waruda Street Kirribilli	Day (7:00 – 18:00)	54	61
	Evening (18:00 – 22:00)	52	57
	Night (22:00 – 7:00)	46	54
Location 4 – JNC, Nicholson Street Woolloomooloo	Day (7:00 – 18:00)	51	63
	Evening (18:00 – 22:00)	51	61
	Night (22:00 – 7:00)	45	56

*Note: The background noise levels from two monitoring locations at Bennelong Apartments were combined for simplicity in the report (Section 4.1 - Table 1). The lowest values were taken for the most stringent criteria.

A1.7 Observations

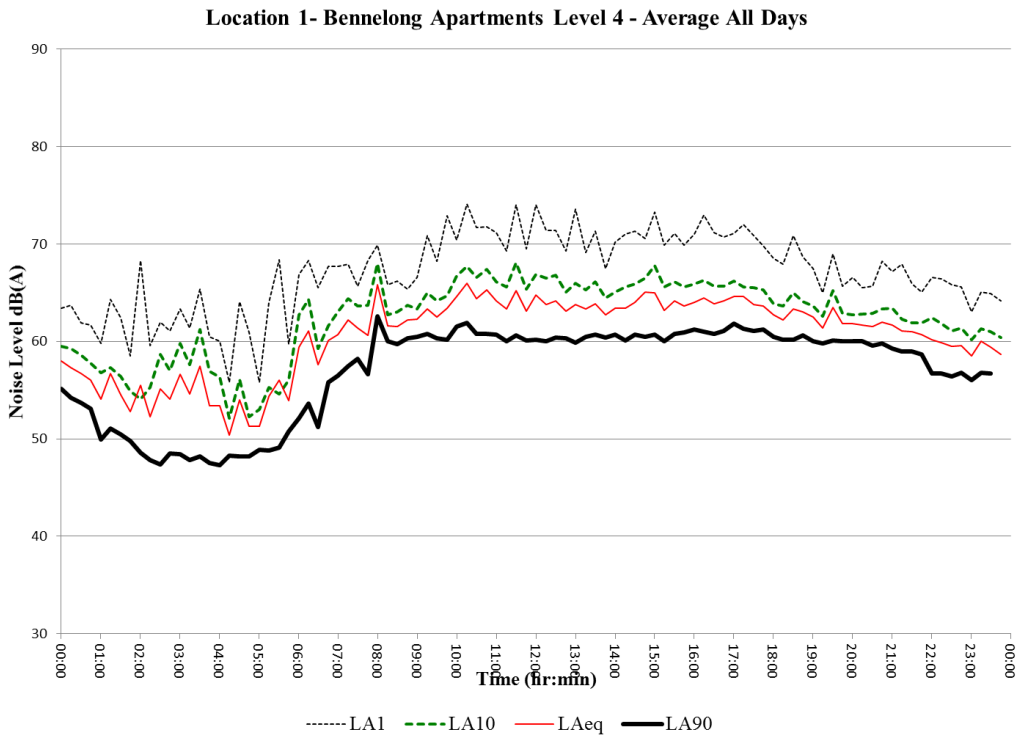
Ambient noise levels are generally constant between the hours of 8:00 am and 9:00 pm for the receivers located at the Bennelong apartments.

At location 3 the ambient noise levels are generally constant between the hours 5:45 am and 9:30 pm. The rise in short term noise levels from 4:00 pm to 5:00 pm is due to increased helicopter and ferry activity during this period of the day. Attended measurements indicate the main continuous noise source was traffic on the Sydney Harbour Bridge approximately 520m to the west and water slapping the sea wall 8m from the logger. A large ferry caused peak levels of 65 dB(A) and a helicopter approximately 200m away caused a peak level of 76 dB(A). An additional measurement taken whilst decommissioning the logger confirmed the main noise sources as traffic on the Harbour Bridge and Ferries. It was noted that bird life contributed to the peak noise levels from 69-73 dB(A).

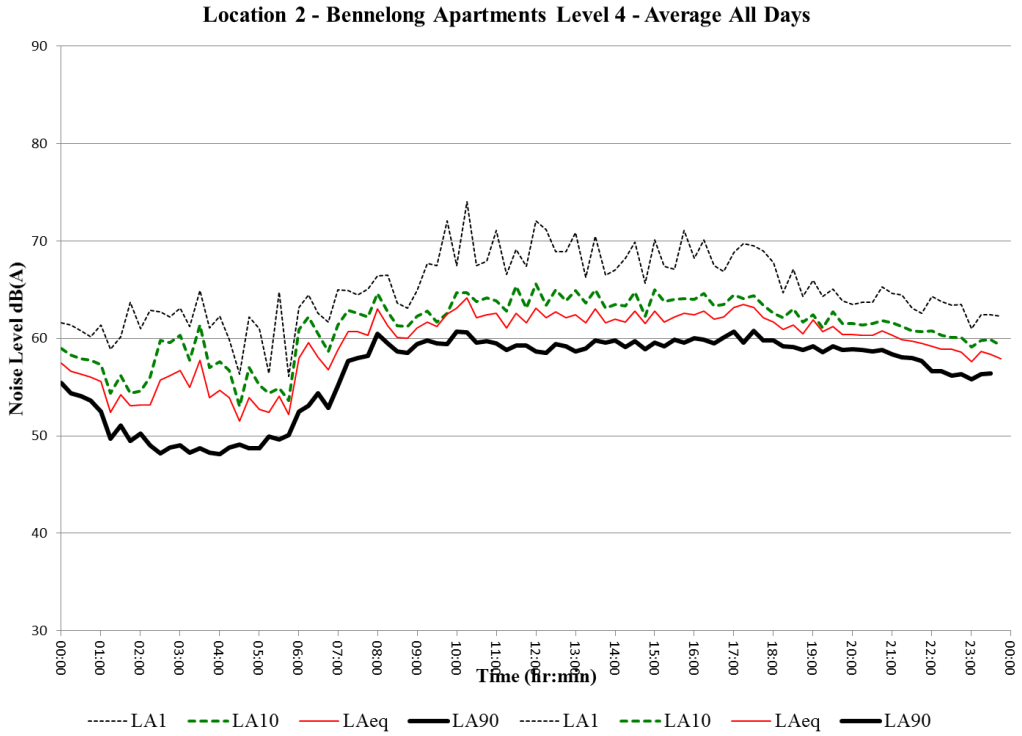
At location 4 the L_{Aeq} noise levels are generally constant from 6:00 am to 8:00 pm however the background noise levels generally increased as the day progressed, reaching the highest value in the evening. This is likely due to the increase in pedestrian activity in the vicinity from the Woolloomooloo entertainment precinct.

A1.8 Survey Data

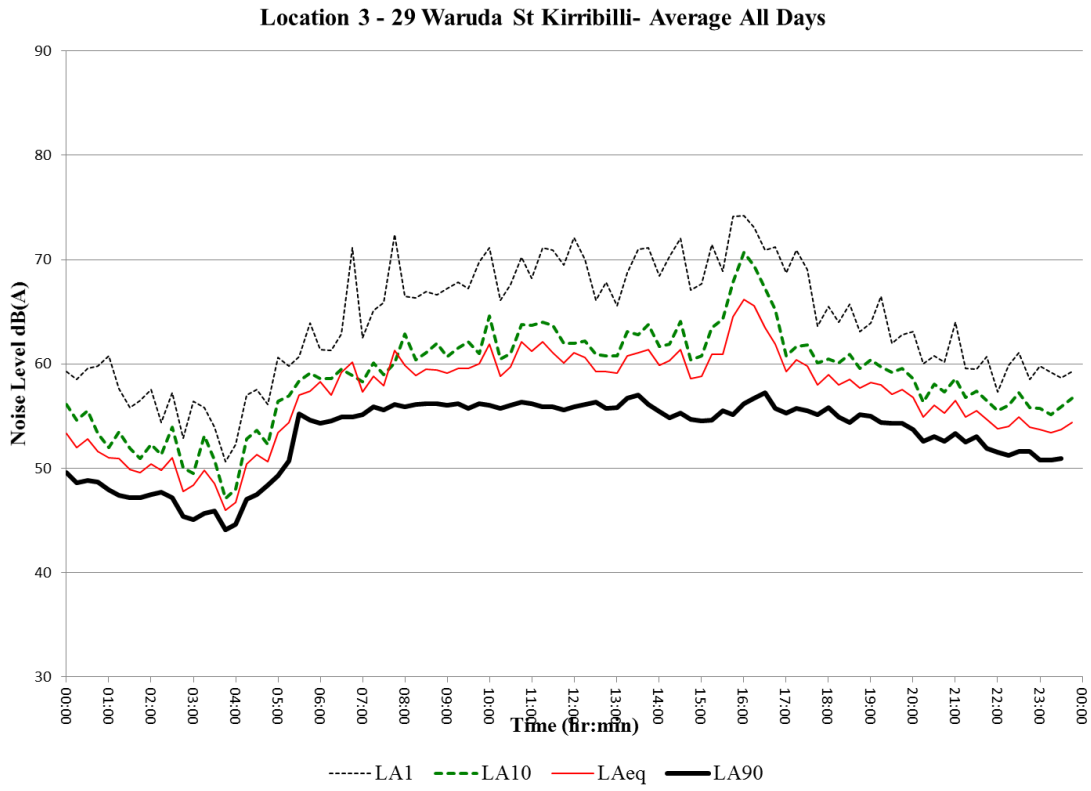
A1.8.1 Location 1 – Bennelong Apartments level 4



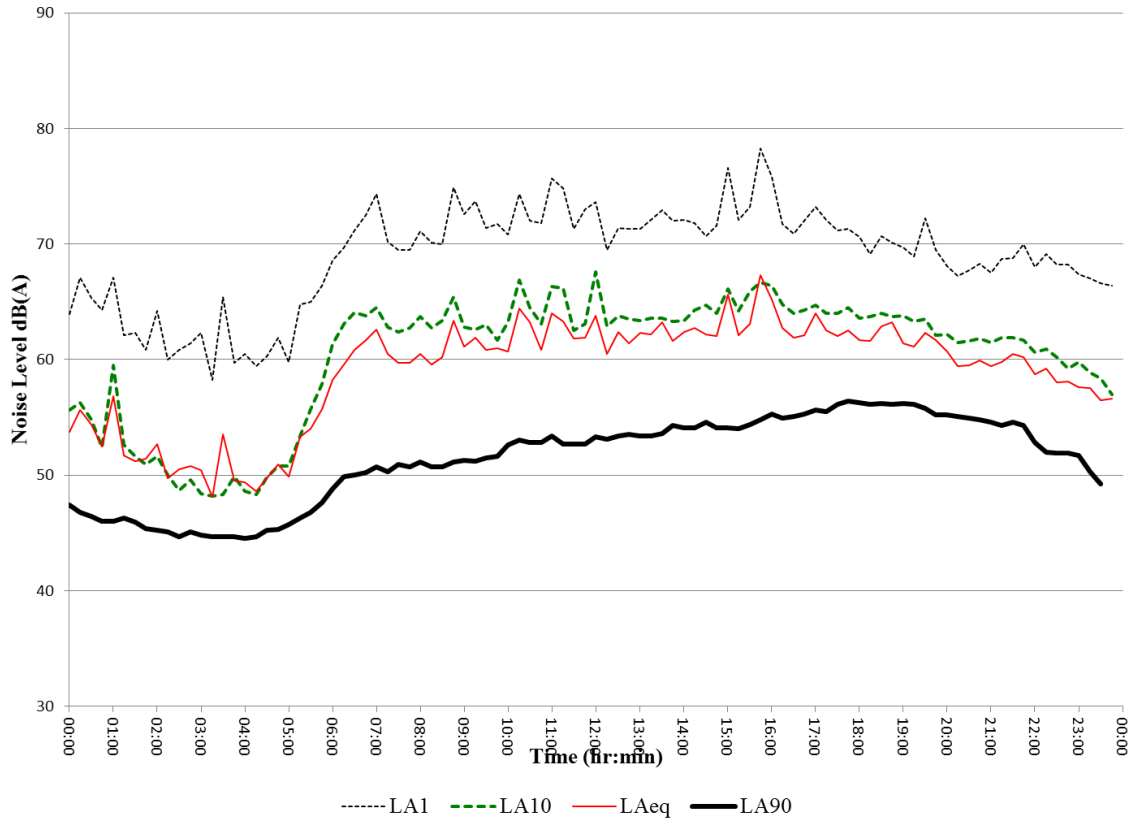
A1.8.2 Location 2 - Bennelong Apartments Level 9



A1.8.3 Location 3 – 29 Waruda Street Kirribilli



A1.8.4 Location 4 – JNC Nicholson Street Woolloomooloo



Appendix B

Acoustic Glossary

Ambient Noise Level

The ambient noise level is the overall noise level measured at a location from multiple noise sources. When assessing noise from a particular development, the ambient noise level is defined as the remaining noise level in the absence of the specific noise source being investigated. For example, if a fan located on a city building is being investigated, the ambient noise level is the noise level from all other sources without the fan running. This would include sources such as traffic, birds, people talking and other nearby fans on other buildings.

Background Noise Level

The background noise level is the noise level that is generally present at a location at all or most times. Although the background noise may change over the course of a day, over shorter time periods (e.g. 15 minutes) the background noise is almost-constant. Examples of background noise sources include steady traffic (e.g. motorways or arterial roads), constant mechanical or electrical plant and some natural noise sources such as wind, foliage, water and insects.

Assessment Background Level (ABL)

A single-number figure used to characterise the background noise levels from a single day of a noise survey. ABL is derived from the measured noise levels for the day, evening or night time period of a single day of background measurements. The ABL is calculated to be the tenth percentile of the background L_{A90} noise levels – i.e. the measured background noise is above the ABL 90% of the time.

Rating Background Level (RBL)

A single-number figure used to characterise the background noise levels from a complete noise survey. The RBL for a day, evening or night time period for the overall survey is calculated from the individual Assessment Background Levels (ABL) for each day of the measurement period, and is numerically equal to the median (middle value) of the ABL values for the days in the noise survey.

Decibel

The decibel scale is a logarithmic scale which is used to measure sound and vibration levels. Human hearing is not linear and involves hearing over a large range of sound pressure levels, which would be unwieldy if presented on a linear scale. Therefore a logarithmic scale, the decibel (dB) scale, is used to describe sound levels (dB SPL ref 20µPa).

An increase of approximately 10 dB corresponds to a subjective doubling of the loudness of a noise. The minimum increase or decrease in noise level that can be noticed is typically 2 to 3 dB.

dB(A)

dB(A) denotes a single-number sound pressure level that includes a frequency weighting ("A-weighting") to reflect the subjective loudness of the sound level.

The frequency of a sound affects its perceived loudness. Human hearing is less sensitive at low and very high frequencies, and so the A-weighting is used to account for this effect. An A-weighted decibel level is written as dB(A).

Some typical dB(A) levels are shown below.

Noise Level dB(A)	Example
130	Human threshold of pain
120	Jet aircraft take-off at 100 m
110	Chain saw at 1 m
100	Inside nightclub
90	Heavy trucks at 5 m
80	Kerbside of busy street
70	Loud stereo in living room
60	Office or restaurant with people present
50	Domestic fan heater at 1m
40	Living room (without TV, stereo, etc)
30	Background noise in a theatre
20	Remote rural area on still night
10	Acoustic laboratory test chamber
0	Threshold of hearing

L_{10}

The L_{10} statistical level is often used as the "average maximum" level of a sound level that varies with time.

Mathematically, the L_{10} level is the sound level exceeded for 10% of the measurement duration. L_{10} is often used for road traffic noise assessment. As an example, 63 dB $L_{A10,18hr}$ is a sound level of 63 dB(A) or higher for 10% of the 18 hour measurement period.

L_{90}

The L_{90} statistical level is often used as the "average minimum" or "background" level of a sound level that varies with time.

Mathematically, L_{90} is the sound level exceeded for 90% of the measurement duration. As an example, 45 dB $L_{A90,15min}$ is a sound level of 45 dB(A) or higher for 90% of the 15 minute measurement period.

L_{eq}

The 'equivalent continuous sound level', L_{eq}, is used to describe the level of a time-varying sound or vibration measurement.

L_{eq} is often used as the "average" level for a measurement where the level is fluctuating over time. Mathematically, it is the energy-average level over a period of time (i.e. the constant sound level that contains the same sound energy as the measured level). When the dB(A) weighting is applied, the level is denoted dB L_{Aeq}. Often the measurement duration is quoted, thus $L_{Aeq,15\ min}$ represents the dB(A) weighted energy-average level of a 15 minute measurement.

L_{max}

The L_{max} statistical level can be used to describe the "absolute maximum" level of a sound or vibration level that varies with time.

Mathematically, L_{max} is the highest value recorded during the measurement period. As an example, 94 dB L_{Amax} is a highest value of 94 dB(A) during the measurement period.

Since L_{max} is often caused by an instantaneous event, L_{max} levels often vary significantly between measurements.

Frequency

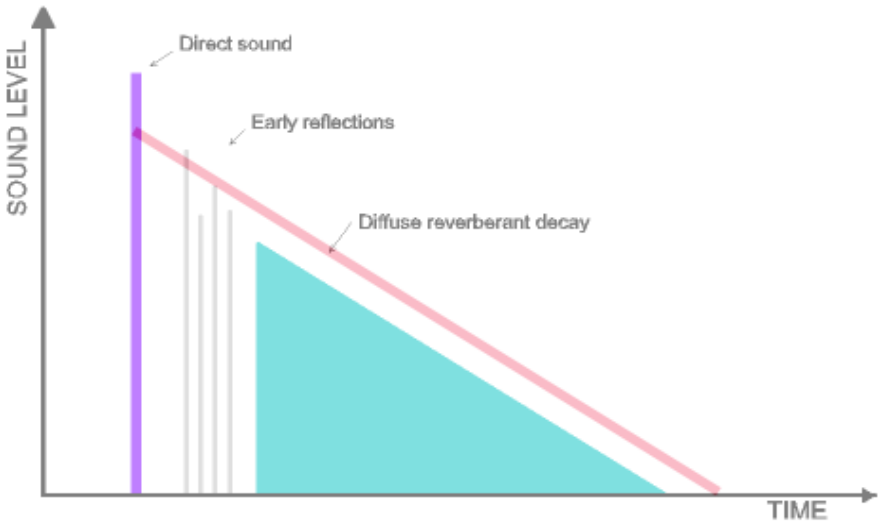
Frequency is the number of cycles per second of a sound or vibration wave. In musical terms, frequency is described as "pitch". Sounds towards the lower end of the human hearing frequency range are perceived as "bass" or "low-pitched" and sounds with a higher frequency are perceived as "treble" or "high pitched".

Reverberation Time (T60)

The time, in seconds, taken for a sound within a space to decay by 60 dB after the sound source has stopped is denoted at the reverberation time. The RT is an important indicator of the subjective acoustic within an auditorium. A large RT subjectively corresponds to an acoustically 'live' or 'boomy' space, while a small RT subjectively corresponds to an acoustically 'dead' or 'flat' space.

Examples of typical design reverberation times are provided below:

Mid-frequency Reverberation Time, s	Example
< 0.1	Anechoic
0.1 – 0.4	Call centres
0.4 – 0.6	Library
0.6 – 0.8	Offices / board rooms
0.8 – 1.0	Small auditorium for speech
1.0 – 1.2	Music studios
1.2 – 1.5	Chamber music venues
1.5 – 2.0	Orchestral music venues
2.0 – 3.0	Church
3.0 – 8.0	Cathedral



Sound Power and Sound Pressure

The sound power level (Lw) of a source is a measure of the total acoustic power radiated by a source. The sound pressure level (Lp) varies as a function of distance from a source. However, the sound power level is an intrinsic characteristic of a source (analogous to its mass), which is not affected by the environment within which the source is located.