SYDNEY OPERA HOUSE

VEHICLE ACCESS & PEDESTRIAN SAFETY

Operational and Construction Noise Assessment

Issued

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Executive Summary

This noise assessment report applies to the Sydney Opera House (SOH) proposed modifications for improvements in vehicle access and pedestrian safety (VAPS).

The VAPS project has been categorised as a Major Project to be determined under Part 75F of the Environmental Planning & Assessment Act 1979 and, as such Director General's Environmental Assessment Requirements have been issued for the preparation of an Environmental Assessment for the proposed development.

The proposal involves the construction of a new underground loading dock and associated above ground entry in order to remove delivery vehicles circulation from the surface road currently surrounding the SOH buildings. The proposal will provide improved access to the Opera House premise to the service vehicles and increase pedestrian amenity.

Noise generated by the development is addressed in this report. In particular an increase in the exiting traffic noise impacts at nearby residential receivers associated with delivery trucks using the new underground loading dock, and noise and vibration generated during the operational stage of the project.

Increase in noise impacts associated with the new underground loading dock has been found to be negligible and therefore it is expected that the acoustic targets for the operational stage of the project presented in this report will be met.

A construction noise and vibration assessment has also been conducted to establish the potential impacts of noise and vibration from the proposed construction and appropriate criteria for both noise and vibration have been discussed and set according to established guidelines and standards.

To ensure adverse effects are avoided at all receivers, monitoring of noise and vibration levels could be carried out. If the noise and vibration criteria are exceeded, the offending activities could be stopped, providing it is safe to do so, and action taken to ensure compliance. Noise control measures and construction best practices are presented to minimise noise impacts on the neighbourhood.

1 Introduction

Sydney Opera House (SOH) proposes to redevelop its loading dock facilities and access in order to ameliorate vehicle access to its premises and improve pedestrian safety.

The proposal involves the construction of a new underground loading dock and associated above ground entry in order to remove heavy vehicles currently circulating on the surface road surrounding the SOH buildings.

The VAPS project has been categorised as a Major Project to be determined under Part 75F of the Environmental Planning & Assessment Act 1979 and, as such Director-General's Requirements have been issued for the preparation of an Environmental Assessment for the proposed development. This acoustic assessment report has been prepared in support of the Environmental Assessment for the proposed VAPS project.

Noise generated by the development is addressed in this report accordingly to relevant Australian Standards and State and Local Authority documents and guidelines.

The acoustic report assesses noise impacts at nearby residential receivers due to operation of the VAPS project once it is completed.

Furthermore, a construction noise and vibration assessment has been conducted for the proposed construction stage of the VAPS project.

This report presents the findings of both traffic and construction noise assessment. It includes measured environmental noise survey data and environmental noise limits, based on the measured noise levels in the area. Compliance with these limits will ensure that any noise from the overall development will not impact negatively on the nearest existing residences. The report also provides recommendations for appropriate vibration level criteria during construction.

2 Description of Proposal

2.1 Project Background

The SOH is a State, National and World Heritage listed national icon and a premier tourist destination attracting around 7.4 million visitors each year. It has seven (7) primary venues: Concert Hall, Opera Theatre, Drama Theatre, Playhouse, The Studio, Forecourt and the Utzon Room.

Nearing 40 years of age, there is currently a need for the venue to conduct formal upgrades that pair the SOH capacities with similar performing art centres around the world while retaining its status of world-class centre of excellence.

One of the critical issues is the conflict between pedestrian and heavy vehicles servicing the SOH premises which are now sharing the site's main entry from Circular Quay and Macquarie Street. The VAPS project intends to solve that issue and consists of three components:

Diversion of the Bennelong Drain – a stormwater drain servicing parts of the Sydney CBD which now runs under the SOH Forecourt (this part is being dealt as a different Application and therefore is not considered in this acoustic assessment);

Design and construction of a new underground road and loading dock to service all business deliveries to SOH; and

Refurbishment of the existing aboveground roadway.

2.2 Site Location

The project is located below the Boardwalk level (i.e. underground) with a vehicle ramp accessible from Macquarie Street that descends from the south-western end of the Forecourt and opens to a new loading dock under the SOH buildings, below the sea level.

The nearest residential properties are located to the south-west of the proposed project, at a high-rise building sited at the end of Macquarie Street.

Figure 1 below shows the location of the project and the surrounding area.

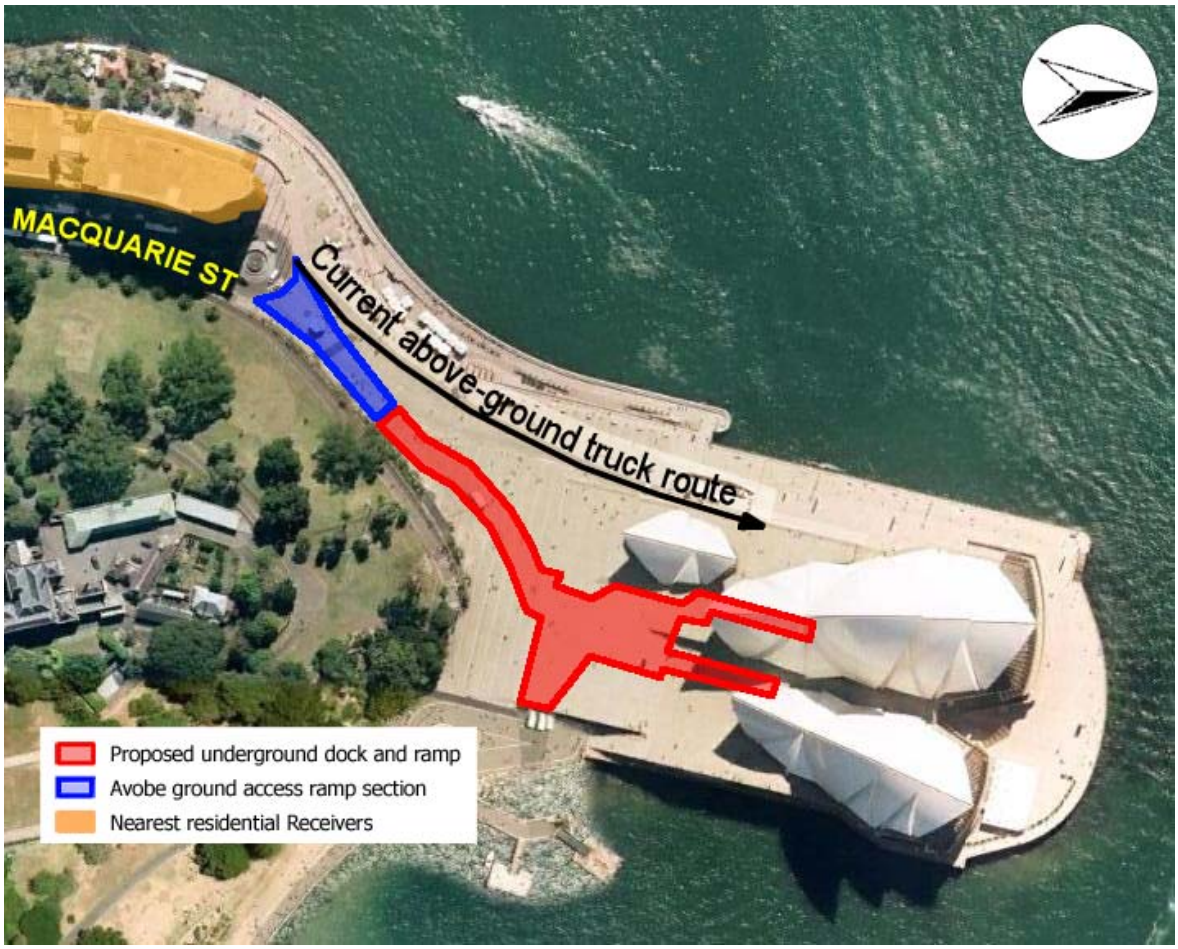

Figure 1: Project site and surrounds

Corridors are to connect the new loading dock with lifts located east and west of the SOH Central Passage to carry scenery and other deliveries up to the Central Passage, from which goods are to be transferred to theatres, food and beverage outlets and administration areas.

2.3 Hours of Operation

Once the VAPS project is completed, the loading dock is to be operative 24 hours a day, 7 days a week.

3 Acoustics Issues

As per Director General's Requirements, the following acoustic issues are to be addressed as part of the Environmental Assessment for the VAPS project:

The impact of operational noise generated by heavy vehicle movements associated with the project on existing traffic noise levels.

The traffic levels generated by delivery trucks accessing the new loading dock is to be compared to the existing traffic levels generated by the current SOH loading dock operations.

The operational noise impact assessment has been presented in Section 5.

The impact of noise and vibration generated during the construction stage of the project on surrounding residential, retail and commercial premises.

The development will contribute noise and vibration to the surrounding environment during the construction stage of the VAPS project. Typically, this will result from intermittent noise from construction equipment and plant commonly used in construction sites.

Design noise and vibration limits have been set for the project and construction noise impacts have been anticipated from standard construction procedures. These limits and expected impacts are reported in Section 6 of this report.

4 Existing Noise Environment

4.1 General Survey Information

A survey of the existing noise environment around the VAPS site was conducted with an unattended noise monitor used to continuously record the noise levels around the site. Long term noise monitoring was carried out from Monday 10th May to Monday 17th May 2010 to establish the range of ambient noise levels around the SOH site and surrounding residential properties.

Long term noise monitoring was carried out with an RTA Technology Environmental Noise Logger Type 02. The calibration of the logger was checked before and after use and no variation was noted.

Operator attended short term monitoring was carried out between 1.30am and 2.30am on Tuesday 4th May 2010 in order to confirm the validity of the long term data across the site.

Short term measurements were made with a Brüel & Kjær Hand-held Analyser Type 2250 (Serial Number 2446899). The calibration of the analyser was checked before and after the survey and no variation in level occurred.

A windshield was used to protect the microphone of both the logger and the analyser.

Weather conditions were calm and dry during the attended noise survey.

Matthew Shriffer and Laura Lapena of Acoustic Studio Pty Ltd carried out the surveys.

4.2 Monitoring Locations

Long and short noise monitoring locations are shown in Figure 2.

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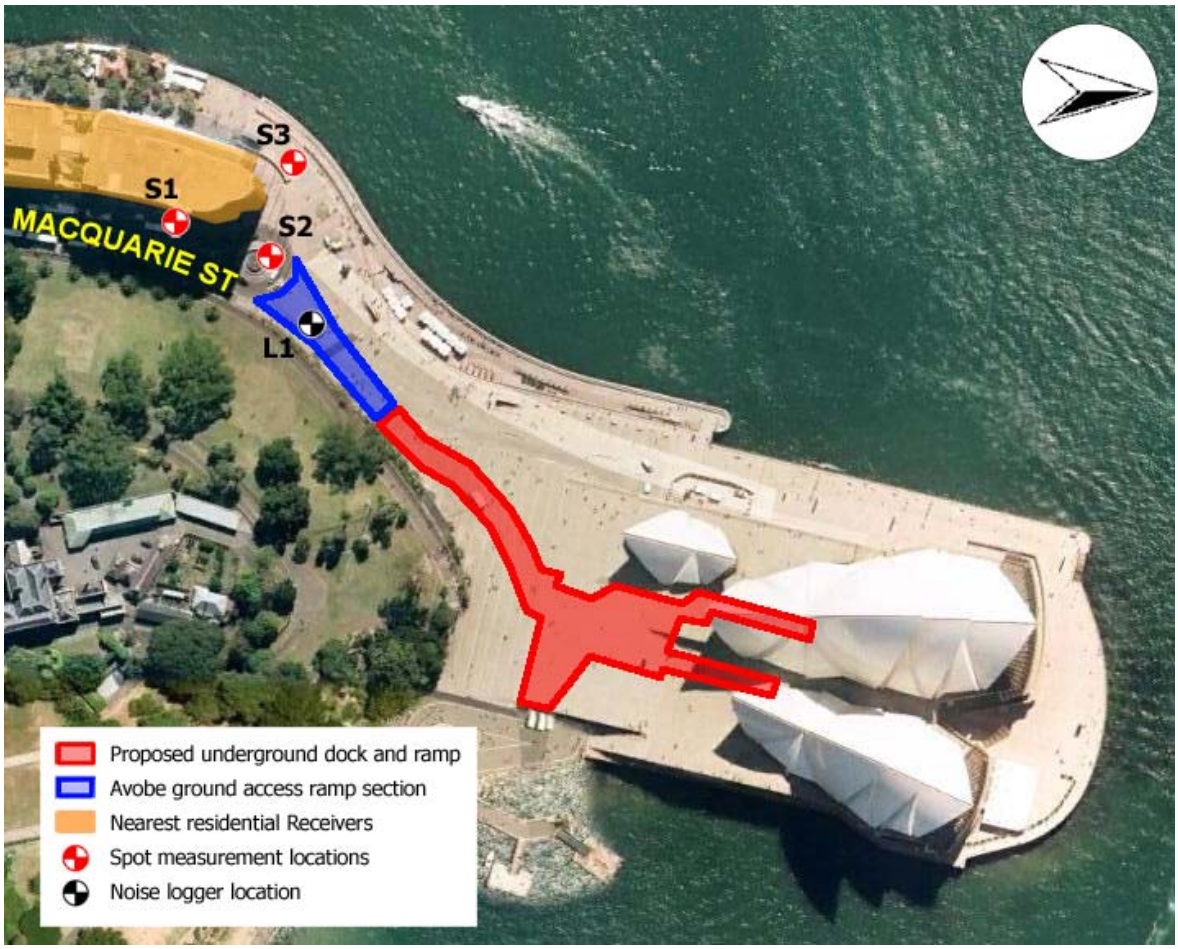

Figure 2: Noise Monitoring Locations

4.3 Long-term Noise Monitoring

Unattended long term noise monitoring was carried out from Monday 10th May to Monday 17th May 2010 to establish ambient and background noise levels around SOH site and surrounds.

The long term noise monitoring position was a secure location on the rooftop of the security gate building currently sited at the south-western corner of the SOH forecourt. The noise monitor was set up in the free-field (i.e. away from reflective surfaces). The selected logger location was found representative of the ambient and background noise environment around the proposed VAPS project site.

The results of the long term noise monitoring at Location L1 are shown in Appendix A and the measurement location is shown in Figure 2.

Table 1 below shows background and ambient noise levels measured for three time periods (day, evening and night).

Location	L_{90} Background Noise Levels, dB(A)			L_{eq} Ambient Noise Levels, dB(A)		
	Day 7am-6pm	Evening 6pm-10pm	Night 10pm-7am	Day 7am-6pm	Evening 6pm-10pm	Night 10pm-7am
L1 – Security Gate rooftop	55	53	45	64	60	57

Table 1: Long-term background and ambient noise levels measured around VAPS site

4.4 Short-term Noise Monitoring

Three (3) short term noise monitoring locations were chosen as representative of the most sensitive residences located nearby the proposed VAPS site as follows:

Location S1 was at Macquarie Street footpath, on the eastern boundary of the residential property sited at 1 Macquarie Street and approximately 1.5 metres from the road kerb. Measurements were undertaken in the free-field (i.e. away from reflective surfaces).

Location S1 is representative of background and ambient noise levels at the residences facing the eastern side of 1 Macquarie Street high-rise residential building.

Background and ambient noise levels at the time of the measurements were dominated by continuous noise from mechanical plant associated with commercial / residential developments located at Macquarie Street and intermittent traffic on the same road.

Location S2 was at the centre of the roundabout located at the end of Macquarie Street. Measurements were undertaken in the free-field (i.e. away from reflective surfaces).

Location S2 is representative of background and ambient noise levels at the residences facing the northern side of 1 Macquarie Street high-rise residential building.

Background and ambient noise levels at the time of the measurements were dominated by a general urban hum at and intermittent traffic on Macquarie Street.

Location S3 was at the SOH Boardwalk access, facing the Circular Quay Ferry Wharf and approximately 10 metres from the water boundary of Sydney Cove. Measurements were undertaken in the free-field (i.e. away from reflective surfaces).

Location S3 is representative of background and ambient noise levels at the residences facing the western side of 1 Macquarie Street high-rise residential building.

Background and ambient noise levels at the time of the measurements were dominated by continuous noise from plant associated with the Circular Quay Ferry Wharf.

The results of the short term background and ambient noise monitoring are shown in Table 2 below.

Location	Day & Time of Measurements	$L_{eq,15min}$ Ambient Noise, dB(A)	$L_{90,15min}$ Background Noise, dB(A)
S1 – 1 Macquarie St (east)	04/05/10 1:30am	45	43
S2 – 1 Macquarie St (north)	04/05/10 1:45am	47	45
S3 – 1 Macquarie St (west)	04/05/10 2:00am	50	48

Table 2: Short-term background and ambient noise levels measured around VAPS site

5 Operational Noise Impact Assessment

As required by Director General's Requirements for the VAPS project, control of noise levels generated during the project construction stages of new SOH underground loading dock and associated ramp will be necessary.

5.1 Assessment Methodology

It is anticipated that any environmental noise impacts onto surrounding receivers from the operations of the new SOH underground loading dock, as proposed within the VAPS project, will mainly be due to traffic noise impact from service vehicles, especially from heavy vehicles, accessing the SOH premises and using the new facilities.

There are a number of relevant documents currently dealing with impact of traffic noise in Australia. In NSW, the ECRTN[1] provides traffic noise criteria and is generally accepted to develop strategies for the control of traffic noise from new and developed roads and also for land use developments to create additional traffic on local roads.

However, the proposed VAPS project is not intended to either modify the exiting NSW road network or increase the number of vehicles in local roads associated with the SOH premises. As discussed before, the main aim of the project is to ameliorate both service vehicle access to the premises and to improve pedestrian safety in the SOH surrounds. Therefore, the ECRTN is not directly applicable to the proposed development.

Currently, service vehicles are accessing the loading dock through Macquarie Street and then driving through the Circular Quay Boardwalk and SOH Forecourt. After the VAPS project is undertaken, all service vehicles associated with SOH will still approach the site from Macquarie Street but will enter in the new underground loading dock using a ramp to be built along the Royal Botanic Gardens Boundary.

From data collected during our site visits and noise surveys, it is very likely that current traffic noise levels already exceed ECRTN noise limits recommendations for residences along Macquarie Street. It is also noted that not all those impacts are caused by service vehicles associated with the SOH, as private vehicles and taxis travel and stop frequently along that north section of Macquarie Street.

Therefore, this operational noise assessment is to be conducted on the basis of a comparison between current and future traffic noise impacts at nearest residential receivers.

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[1] *Environmental Criteria for Road Traffic Noise*, May 1999 – Department of Environment, Climate Change and Water (DECCW) formerly the Environment Protection Authority (EPA).

5.2 Noise Sources

It is anticipated that any environmental noise impacts onto residential receivers from the operations of the proposed underground loading dock will be due to service vehicles associated with SOH, especially from heavy vehicles, travelling through Macquarie Street and then the above-ground access ramp.

Currently, a number of service vehicles regularly use the SOH loading dock facilities. Those operations are not expected to change in the future, once the VAPS project is completed, and are therefore relevant for the purpose of this operational noise assessment.

Vehicle movements for normal SOH operations are as follows:

In-house caterers	:	Approximately 350 vehicles per week
(Food and beverages)		Delivery times 6am to 6pm
In-house contractors and departments	:	Approximately 100 vehicles per week
(Electrical, facilities, marketing...)		Delivery times 6am to 6pm
Theatre sets and performing equipment:		Depending on performance requirements
(Opera Australia, Sydney Symphony...)		Delivery anytime over 24 to 48 hr periods
Waste Handling	:	Approximately 7 vehicles per week
		Pick up time approximately 3am to 4am

It is noted that a diverse range of light and heavy vehicles are expected to use the loading dock facilities depending on delivery requirements, from UTE's and medium size vans to semi trailers and heavy rigid vehicles.

Table 3 below shows a range of noise levels for a diverse range of heavy vehicles. In the absence of specific truck noise level data for the SOH site, the data has been compiled from Acoustic Studio database and confirmed with the maximum noise levels recorded during the unattended long-term noise monitoring.

Type of vehicle	Distance vehicle – receiver (m)	L_1 of pass-by event, in dB(A)
UTE's and small vans	7	70
Garbage truck	7	75
Medium-size heavy vehicles	7	85
Trailers and rigid heavy vehicles	7	90

Table 3: Light and heavy vehicle noise levels estimated for VAPS project

5.3 Noise Criteria

As explained in section 5.1, in the absence of specific noise criteria for the VAPS project it is stated that if there is no increase in traffic noise impacts due to the VAPS project in relation with current traffic noise impacts observed in the area, the project will not to be an issue for nearest residential receivers.

5.4 Operational Noise Assessment Results

For the purpose of this operational noise assessment, the following scenarios have been considered for the current situation and future situation, once VAPS project is completed:

Pass-by event of a garbage truck during the night (daily event approximately 3-4am)

Pass-by event of a heavy truck during the day (anytime depending on performances)

Figure 4 and Figure 5 show current and future calculated sound pressure levels at most affected residential receivers located at the residential building sited at 1 Macquarie Street for the two scenarios considered. Current and future truck access paths are shown in Figure 3 below.

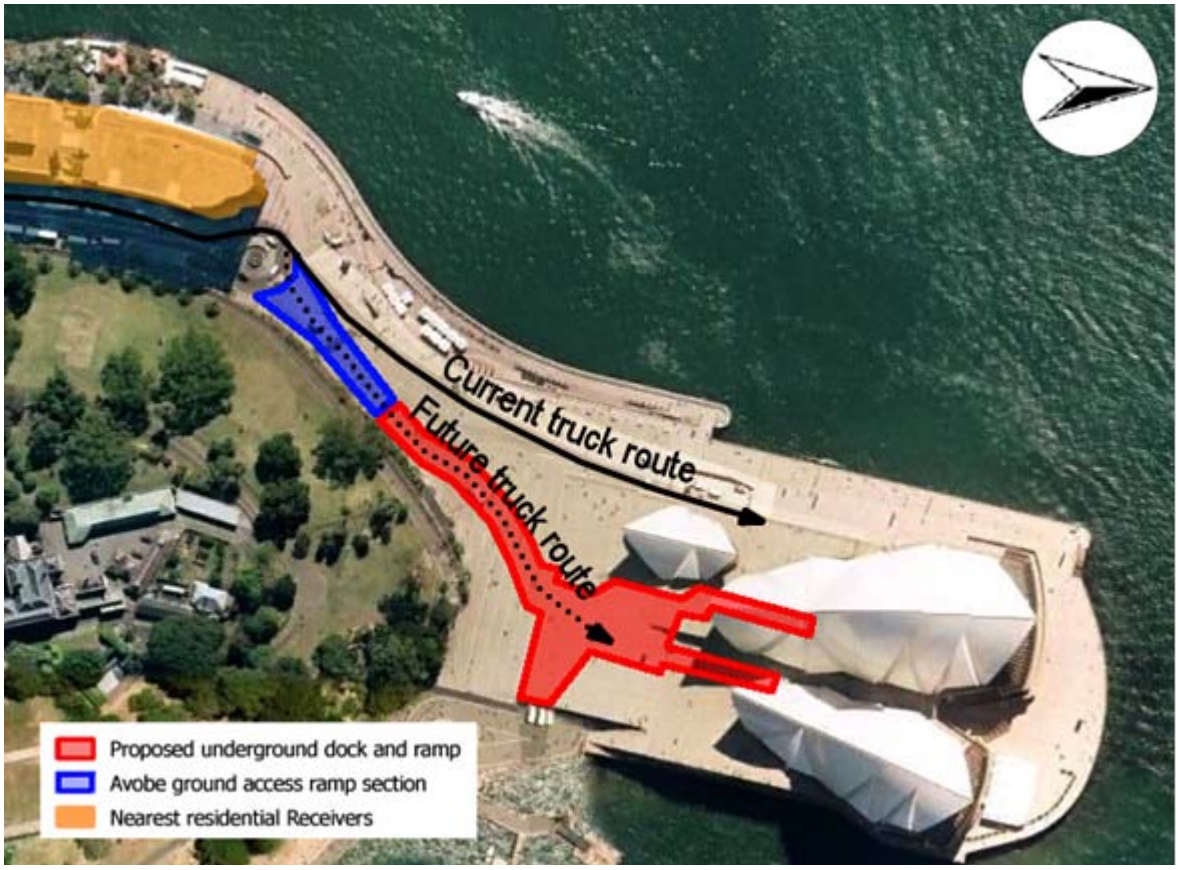


Figure 3: Aerial photo showing approximate current truck route and proposed truck route after VAPS project is completed

Sound pressure levels for both scenarios have been calculated considering the truck noise data presented in Table 3 and distance attenuation between the source of noise (i.e. specific truck type) and the receiver. Both graphs show a pass-by event of a truck approaching SOH from Macquarie Street and driving pass the nearest residences in the direction of the loading areas. It is noted that the current truck route is completely above-ground, while the future truck route reaches the fully-enclosed underground ramp approximately at 100m from closest residence.

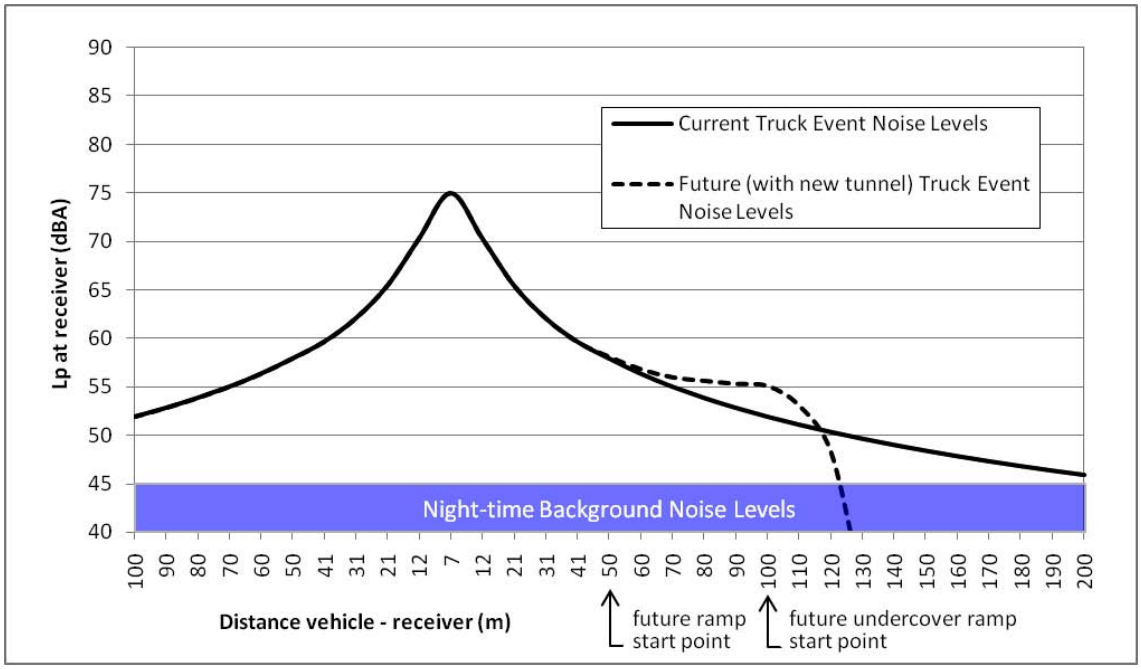


Figure 4: Calculated sound pressure level at nearest residential receiver during a garbage truck pass-by event (night-time)

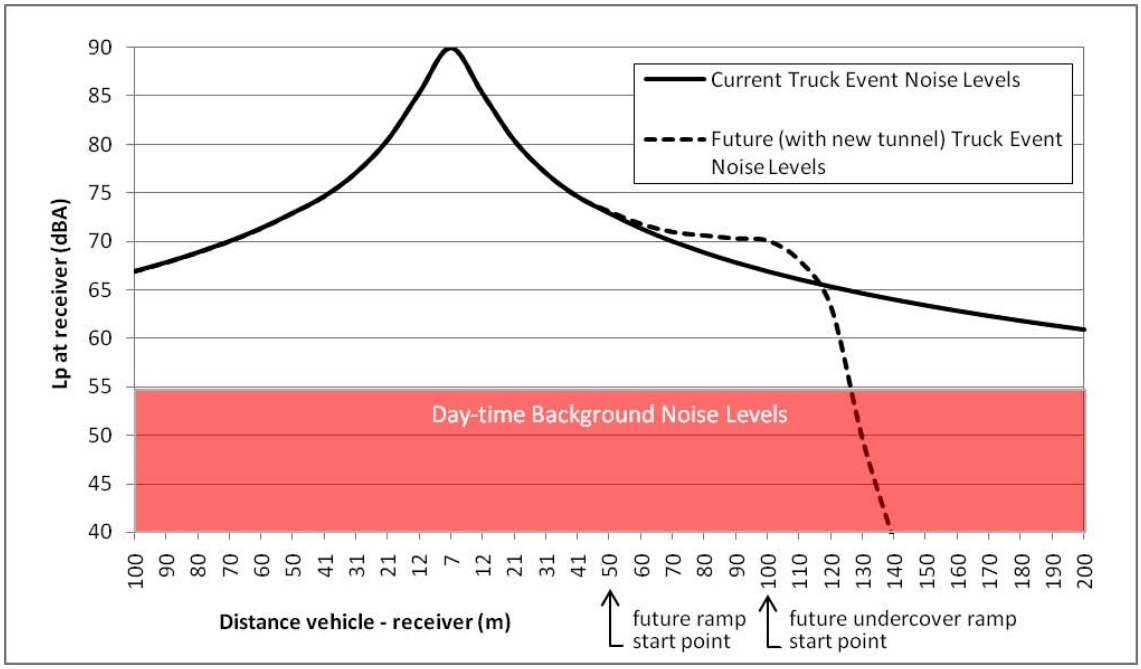


Figure 5: Calculated sound pressure level at nearest residential receiver during a heavy truck pass-by event (day-time)

From the graphs above, the following observations can be made:

Sound pressure levels generated by truck pass-by event reach a maximum peak when the trucks are still in Macquarie Street in from of the most affected residential receiver. That is, approximately at 7m from receiver. From that point, noise levels are expected to decrease depending on distance between source and receiver.

Maximum sound pressure levels of truck pass-by event are expected to exceed background noise levels in both current and future situations, depending on type of truck and time of the day.

Truck pass-by event is to remain unchanged till the point where the future truck route reached the ramp to the underground loading dock. At the point where the ramp became fully enclosed, sound pressure levels are expected to experience and increase of up to 2-3 dB at nearest residences, considering no absorptive materials are to be installed in the walls of the future underground ramp.

In the future scenario, truck noise suddenly decreases below background noise levels once the truck completely enters the underground ramp, due to shielding of intervening structures. That is not the case in the current situation as the noise from trucks perceived at residences depends only from the distance travelled by the truck.

Further to the observations above, Table 4 below shows the $L_{Aeq,event}$ and $L_{Amax,event}$ values anticipated for the two truck pass-by event scenarios considered. It is noted that truck pass-by events will be changing in duration, depending basically on truck speed. However, considering an average speed of 35-40 km/h for trucks approaching SOH the truck pass/by events will not probably exceed 1 minute of audible duration.

Type of truck event	Scenario	Time Period	Background Noise L_{90}, in dB(A)	Event Noise $L_{eq,event}$, in dB(A)	Event Noise $L_{max,event}$, in dB(A)
Garbage truck approaching SOH	Current	Night time	45	59	75
	Future			59	75
Heavy truck approaching SOH	Current	Daytime	55	74	90
	Future			74	90

Table 4: Short-term background and ambient noise levels measured around VAPS site

As table above shows, it is anticipated that the future situation, after VAPS project is completed, will not imply an increase in traffic noise impacts for the most affected residential receivers for any of the scenarios considered.

Furthermore, as show in figures above the VAPS project is to introduce a slight amelioration in traffic noise impacts, as the duration of truck pass-by events exceeding the background levels will be reduced as part of the truck route will happen underground.

6 Construction Noise and Vibration Assessment

As required by Director General's Requirements for the VAPS project, control of noise and vibration levels generated during the project construction stages of new SOH underground loading dock and associated ramp will be necessary.

Currently the project is at a preliminary design stage and the detailed construction program is not yet fully defined. This report provides general recommendations only and provides applicable criteria together with best noise and vibration control practices to be observed during the construction of the proposed development.

6.1 Relevant Codes and Standards

In preparing this construction noise and vibration assessment, the following legislation, codes and standards have been found to be relevant for the VAPS project:

The City of Sydney "*Construction Hours / Noise within the Central Business District – Code of Practice"*, 1992

The Department of Environment, Climate Change and Water (DECCW) *"Interim Construction Noise Guideline"*, 2009

The Department of Environment, Climate Change and Water (DECCW) *"Assessing Vibration: A Technical Guideline"*, 2006

Environment Protection Authority (EPA, currently DECCW) *"Environmental Noise Control Manual"*, 1994

Standards Association of Australia *"AS 2436-198: Guide to Noise Control on Construction, Maintenance & Demolition Sites"*, 1981

Standards Association of Australia *"AS 2670.2-1990: Evaluation of human exposure to whole-body vibration – Part 2: Continuous and shock-induced vibration in buildings (1 to 80 Hz)"*, 1990

British Standards Institution *"BS 6472:1992 – Evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)"*, 1992

Protection of the Environment Operations Act 1997

6.2 Definitions

Contractor

Refers to the Contractor employed to undertake the construction works in accordance with the contract requirements.

Acoustic Consultant

Refers to a suitably qualified acoustic consultant appointed by the Contractor to measure and assess noise impacts in accordance with the statutory requirements.

Background Noise Level

Refers to the L_{A90} sound pressure level (equivalent to the average minimum, $L_{A\ av\ min,\ T}$). When used in assessing the nuisance level, the background noise level is the 8-hour background L_{Aeq} noise level.

$L_{A\ av.\ max,\ T}$

Refers to the average maximum sound pressure level, measured in dB(A) on fast response during the stated measurement period, generated by a machine when operating in a normal operational duty cycle.

For the purpose of this assessment, the duration interval (T) shall be 1 minute when considering noise at a distance of 7 m from an appliance.

$L_{A10,\ T}$

Refers to the sound pressure level, measured in dB(A), exceeded for 10 percent of the stated measurement period, T.

For the purpose of assessment of compliance with this procedure the duration interval (T) shall be 1 minute when considering noise at a distance of 7 m from an appliance. L_{A10} is deemed to be equivalent to $L_{A\ av.\ max}$.

6.3 Construction Noise Assessment

6.3.1 Control Elements

As a general rule, prevention should be applied as universal work practice at any time of day, but especially if any construction works are to be undertaken at critical times outside normal daytime/weekday periods. It is noted that the reduction of the noise at the source and the control of transmission paths between the construction site and the receivers are the preferred options for noise minimisation. Providing treatments at the affected residences or other sensitive land uses should only be as a last resort.

Construction noise should be managed by implementing the strategies listed below:

- Plant and equipment
  - Use quieter methods.
  - Use quieter equipment.
  - Operate plant in a quiet and effective manner.
  - Where appropriate, limit the operating noise of equipment
  - Maintain equipment regularly.
  - Where appropriate, obtain acoustic test certificates for equipment
- On site noise management
  - Strategically locate equipment and plant.
  - Avoid the use of reversing alarms or provide for alternative systems.
  - Maximise shielding in the form of existing structures or temporary barriers.
  - Schedule the construction of barriers and structures so they can be used as early as possible.
- Consultation, notification and complaints handling
  - Provide information to neighbours before and during construction.
  - Maintain good communication between the community and project staff.
  - Have a documented complaints process and keep register of any complaints.
  - Give complaints a fair hearing and provide for a quick response.
  - Implement all feasible and reasonable measures to address the source of complaint.
- Work scheduling
  - Schedule activities to minimise noise impacts.
  - Ensure periods of respite are provided in the case of unavoidable maximum noise levels events.
  - Keep truck drivers informed of designated routes, parking locations and delivery hours.

6.3.2 Working Hours and Site Operational Noise Level Limits

The proposed construction hours for all external works are in accordance with typical daytime construction hours, namely:

Monday to Friday	:	7am to 6pm
Saturday	:	8am to 1pm

However, due to the large volumes of pedestrians accessing the SOH Forecourt, and in order to minimise the adverse visual, heritage, amenity and safety impacts caused by the disruption to the Forecourt during the construction process, it is essential that the duration of the construction phase be kept as short as possible.

As such, it is proposed that once the loading dock is at a stage where it is enclosed, construction work to all internal areas of the proposal will be carried out throughout the day and night.

It is also proposed to carry out some limited external construction works outside of the standard hours, including:

- The portion of the entry tunnel works which is over the car park pedestrian link. For safety reasons it is preferred to undertake these works outside of the car park operating hours.
- Works in the vehicle concourse. These works are more then 180 metres from the nearest residences and are naturally screened by the Monumental Stairs.

The carrying out of *internal* works outside usual construction hours is consistent with previous approvals granted for works on the site. For those limited *external* works, acoustic screening will be put in place to mitigate the noise impacts at the closest affected residential receivers.

Monitoring of noise levels will also be put in place to ensure that the noise levels comply with the requirements of The City of Sydney's "Construction Hours / Noise within the Central Business District – Code of Practice", 1992.

Furthermore, deliveries of building materials and spoil removal, etc will be managed so as to not unreasonably impact on the amenity of the patrons of the Sydney Opera House and the surrounding residential receivers outside of the standard daytime construction hours.

The ability to carry out internal works plus some limited external works outside of the standard (daytime) construction hours is expected to considerably reduce the total construction timeframe. This is considered to be of significant benefit in terms of heritage, safety and visual impacts on the site, with no unacceptable amenity impacts to surrounding premises.

Given the above proposals for construction hours, all categories of working hours and associated noise criteria presented in the City of Sydney Construction Works Code of Practice (CWCP) for the CBD area will be applicable to the VAPS project at this stage. These are shown below.

DAY	TIME ZONE	CATEGORY	NOISE CRITERIA (which must not be exceeded)
Monday to Friday	00.00 - 07.00	4	Background + 0 dBA
	07.00 - 08.00	1	Background + 5 dBA
	08.00 - 19.00	1	Background + 5 dBA + 5 dBA to be determined on a site basis
	19.00 - 23.00	2	Background + 3 dBA
	23.00 - 24.00	4	Background + 0 dBA
Saturday	00.00 - 07.00	4	Background + 0 dBA
	07.00 - 08.00	1	Background + 5 dBA
	08.00 - 17.00	1	Background + 5 dBA + 5 dBA to be determined on a site basis
	17.00 - 23.00	2	Background + 3 dBA
	23.00 - 24.00	4	Background + 0 dBA
Sundays and Public Holidays	00.00 - 07.00	4	Background + 0 dBA
	07.00 - 17.00	3	Background + 3 dBA
	17.00 - 24.00	4	Background + 0 dBA

Table 5: Categories of construction works hours and noise criteria for VAPS project

All noise levels presented in the table above are to be measured at the nearest residential receivers. The permissible noise level is to be complied during each 15-minute period of the relevant Category of Hours.

Special requirements, such as noise monitoring, will apply for work intended during Category 2, 3 and 4 hours.

6.3.3 Managing Plant and Equipment Noise Levels

Specific equipment / plant to be used during the construction stages of VAPS project are not yet defined.

Therefore, the allowance noise levels for construction appliances as per City of Sydney CWCP for the CBD areas are shown in Table 6 below.

It is noted that all noise levels shown in the table below are to be $L_{A\ av.\ max,\ T}$ measured at 7 metres from the point nearest to and appliance. Furthermore, a Certificate of Acoustic Performance (see Form D from City of Sydney CWCP on Appendix C) shall be provided for each appliance on Group A.

GROUP A (see Note 2)	GROUP B 90dBA	GROUP C 85dBA	GROUP D 80dBA	GROUP E 75dBA	GROUP F 70Dba
Pile drivers Hydraulic hammers Machine mounted rock breakers Sand blasters Steam cleaners Mole borers	Earthmoving equipment of engine capacity above 200kW NEP Warning sirens* Reversing alarms+ Trucks	Impulsive tools - air, electric or hydraulic Earthmoving equipment of engine capacity between 100kW and 200kW NEP Explosive power tools Impact wrenches Refuse chutes* Scabblers Chain saws Rock drills	Concrete agitators Concrete pumps Concrete saws Cranes (fixed) Cranes (mobile) Earthmoving equipment up to and including engine capacities of 100kW NEP Concrete vibrators Portable hand tools Vibratory compacters	Air compressors above 170 L/s capacity Construction dumpers over $1m^3$ capacity Public address system* Internal combustion or electrically driven equipment (unless grouped elsewhere) over 14kW NEP	Air compressors up to 170 L/s capacity Fluid pumps Internal combustion or electrically driven equipment (unless grouped elsewhere) up to 14kW NEP

* To be measured at the site boundary closest to the affected area.
\+ Reversing alarms must be controlled so that noise levels produced do not exceed the background sound level by more than 10dBA.

Table 6: Listed appliances and allowable noise levels for VAPS project

6.3.4 Monitoring and Reporting

As a condition of approving construction works during Category 2, 3 and 4 hours, the Department of Planning may require that the applicant undertake noise monitoring at nominated affected occupancies and report to Council at specified times that monitoring is being conducted in accordance with Form B of CWCP as shown in the table below.

FORM B

Noise Monitoring Procedures

1. Noise Monitoring shall be carried out when Operations are being performed on the Construction Site and also during one weekday, one Saturday and one Sunday/public holiday (as appropriate) when no Construction Work is being performed.

2. Monitoring locations. Monitoring shall be carried out at locations specified by the Council at a point 1.2 metres above the ground or the floor (inside and outside) as appropriate. Details of the monitoring locations and of the occupancy at which monitoring is carried out are to be recorded.

3. Monitoring equipment. Equipment used for monitoring shall be a sound level meter complying with AS1259, or any other instrument approved by the Council.

4. Noise measures to be recorded. Statistical noise measurements shall be carried out during each 15 minute period over the specified hours and the L_{A1}, L_{A10}, ($L_{A\ av\ max}$), L_{A50} and L_{A90} descriptors shall be determined. These descriptors shall be graphed for each 24 hour period and shall be retained in accordance with para 47 of the Code.

Table 7: Noise monitoring procedures for VAPS project

6.3.5 Communication and Complaints

The Contractor should establish a communications register for recording incoming complaints. The registration of a particular item will remain open until the complaint has been appropriately dealt with.

In addition, the following procedures are an example of the procedures that should be specifically adopted for complaints relating to noise. Upon receipt of a complaint the Contractor should:

- Try to ascertain from the complaint which appliance is causing the problem i.e. inside or outside the site and in what position.
- Establish from the monitoring equipment if the allowable noise levels have been complied with.
- Establish if the appliance positioning has previously been highlighted as a problem area. If not and the noise levels are above the allowable limit, then the equipment and its position shall be noted.
- Move machinery if the allowable levels have been exceeded or take other acoustic remedial action.

If the activity is occurring during Category 2, 3 or 4 working hours, the activity should be immediately stopped. Where stopping the activity would create a safety issue the activity may be permitted to continue only as long as is necessary to make the area safe. The activity should then cease.

Any activity which is directed to cease due to excessive noise should not recommence until the Project Manager is satisfied that the requirements of the CWCP can be met and has given permission to recommence the activity. The Site Supervisor should ensure that a report of any incident is provided to the Project Manager.

The Contractor should provide a 24 hour telephone contact number and this number should be prominently displayed on the site.

6.3.6 Safety

Personnel involved in operations should be issued with ear plugs or ear muffs which must be used whenever noise levels interfere with normal speech when individuals are standing at a distance of 1m from each other, or when the eight hour equivalent continuous A-weighted sound pressure level, $L_{Aeq,8hr}$ measured with a properly calibrated sound level meter exceeds 85 dB.

Signs should be erected and made visible at the entry to all areas where noise levels will exceed 85 dB(A).

6.3.7 Non-compliances

Non-compliance reports should be used as appropriate to deal with failures to meet the construction noise management plan requirements.

6.3.8 Site-specific Construction Noise Assessment Results

6.3.8.1 Noise Sources and Anticipated Airborne Noise Levels

As detail of construction noise equipment / plant to be used during the construction stages of the project was not know at the time of this assessment, a generic approach has been adopted and noise sources normally found in construction sites similar to the VAPS site have been taken into consideration.

The anticipated airborne noise levels for the likely construction noise sources for the VAPS project are listed in Table 8.

Item	Typical Plant or Equipment	Max Noise Level $L_{A\ AV.\ MAX}$ at 7 m
Jack hammers	With silencing bags	85
Air track drill	800 CFM compressor	96
Compactor	Vibrating plate	92
Vibratory roller	10 – 12 tonne	89

Item	Typical Plant or Equipment	Max Noise Level $L_{A\ AV.\ MAX}$ at 7 m
Water cart		88
Dump trucks	35 tonne	96
Excavator	Kato 750	86
Rock breaker	Hydraulic on Kato 750	97
Truck		80
Crane	Truck mounted	85
Compressor	600 CFM	75
Backhoe		88
Tip truck		83
Generator	Diesel	79
Mechanical broom		83
Concrete truck		83
Concrete pump		84
Concrete vibrators		80
Drill	Air	85
Welders		85
Concrete saw		93
Cherry picker	On truck	80

Table 8: Anticipated airborne noise levels for construction noise sources/plant

6.3.8.2 Noise Sensitive Receivers

Nearest sensitive receivers to the VAPS site which are potentially affected by noise from the construction works are located at the 1 Macquarie Street high-rise building as shown in Figure 1.

These nearest residential receivers are located at a distance of approximately 50 metres from the construction site boundary and 100 metres from the fully-covered ramp starting point to the underground loading dock.

6.3.8.3 Construction Noise Criteria

As presented in Clause 6.3.2, noise limits at locations affected construction noise will depend on the day of the week and time period, associated to 4 different Categories, as defined in City of Sydney Code of Practice for Construction Site Works.

Table 9 below shows the stated noise criteria for each Category, being the time frames of those categories as defined in Clause 6.3.2 and the long-term and short-term background noise levels as presented in Section 4.

It is noted that construction works for the VAPS project might not occur at all time frames presented.

Day	Time Zone	Category	Noise Criteria	Noise Limit
Monday to Friday	7am – 8am	1	Background + 5dB	56 + 5 = 61
	8am – 7pm	1	Background + 5dB + 5dB[1]	56 + 10 = 66
	7pm – 11pm	2	Background + 3dB	53 + 3 = 56
	11pm – 7am	4	Background + 0dB	45 + 0 = 45
Saturday	7am – 8am	1	Background + 5dB	53 + 5 = 58
	8am – 5pm	1	Background + 5dB + 5dB[1]	56 + 10 = 66
	5pm – 11pm	2	Background + 3dB	57 + 3 = 60
	11pm – 7am	4	Background + 0dB	48 + 0 = 48
Sunday and Public Holidays	7am – 5pm	3	Background + 3dB	53 + 3 = 56
	5pm – 7am	4	Background + 0dB	42 + 0 = 42

Note: 1. It might be reduced to Background + 5dB (to be determined on a site basis)

Table 9: Construction noise criteria for sensitive receivers around VAPS site

Further to the criteria presented in the table above, the Contractor must also comply with individual equipment / plant levels as explained in Clause 6.3.3.

6.3.8.4 Predicted Construction Noise Levels

At this stage of the project there is no detailed information on the types of plant and equipment that will be used during construction, or on the construction scheduling or program. Therefore, this assessment provides potential noise impact of various generic items of plant and equipment at most affected receivers.

Table 10 below presents the predicted construction noise levels at the nearest affected location for each item of equipment considered in the assessment.

Noise levels are predicted for each item of equipment located at 50 m and 100 m from the sensitive receiver location and assuming continuous operation over the assessment period. Allowances have been made for distance attenuation, shielding, ground reflections and reflections from existing structures.

Item	Noise Criteria (Weekday less restrictive / Sunday most restrictive)	Predicted equipment noise level, (plant at 50m/100m from receiver)
Jack hammers	66 / 42	68 / 62
Air track drill	66 / 42	79 / 73
Compactor	66 / 42	75 / 69
Vibratory roller	66 / 42	72 / 66
Water cart	66 / 42	71 / 65
Dump trucks	66 / 42	79 / 73
Excavator	66 / 42	69 / 63
Rock breaker	66 / 42	80 / 74
Truck	66 / 42	63 / 57
Crane	66 / 42	68 / 62
Compressor	66 / 42	58 / 52
Backhoe	66 / 42	71 / 65
Tip truck	66 / 42	66 / 60
Generator	66 / 42	62 / 56
Mechanical broom	66 / 42	66 / 60
Concrete truck	66 / 42	66 / 60
Concrete pump	66 / 42	67 / 61
Concrete vibrators	66 / 42	63 / 57
Drill	66 / 42	68 / 62
Welders	66 / 42	68 / 62
Concrete saw	66 / 42	76 / 70
Cherry picker	66 / 42	63 / 57

Table 10: Predicted equipment/plant noise levels at nearest sensitive receiver location

Table 10 indicates whether or not a particular item of plant complies with the less restrictive noise criteria (weekday day-time criteria) as well as the most restrictive criteria

(Sunday night-time criteria). The predicted equipment noise levels shown in red indicate non-compliance with the weekday daytime less restrictive (weekday day-time) noise criteria. It should be noted that the noise levels from all items of plant and equipment are non-compliant with the most restrictive criteria (Sunday night-time).

6.3.8.5 Noise Control Measures to Manage Noise

Where an item of equipment exceeds ether the noise criteria as per Table 9 at any location or the equipment noise level limits given in Table 6, the following noise control measures, together with construction best practices presented in Clause 6.3.1, should be considered to minimise the noise impacts on the neighbourhood.

- Schedule noisy activities to occur outside of the most sensitive times of the day for each nominated receiver. For example, the residential receivers are likely to be more sensitive to noise before 9 am than the retail and commercial receivers are.
- Consider implementing equipment-specific screening or other noise control measures recommended in Appendix E of AS2436.
- Arrange for vehicle access to the site to be as far from noise-sensitive receivers as possible.
- Limit the number of trucks on site at the commencement of site activities to the minimum required by the loading facilities on site.
- Provide exit ramps to the street and all internal haul roads at the lowest grade practicable.
- During the demolition of the concrete elements, consider using concrete crushing jaws to minimise the use of rockbreakers.
- Remove rock by a “ripper” attached to a large dozer wherever practical.
- When loading trucks, adopt best practice noise management strategies to avoid materials being thrown into dump trucks.
- Avoid unnecessary idling of trucks and equipment.
- Provide enclosed spoil and wast chutes for demolition work being carried out on upper floors.
- Locate concrete mixers as far from noise-sensitive receivers as possible.
- Ensure that any miscellaneous equipment (extraction fans, etc) not specifically identified in this plan incorporates silencing equipment as required to meet the noise criteria.
- No blasting to occur on site.

6.4 Construction Vibration Management

This section of the report includes general procedures to be followed, vibration surveys and monitoring to be carried out and vibration criteria to ensure human comfort and prevent building damage to the neighbouring buildings and their occupants.

On-site measurements should be considered at the commencement of each key construction process to determine the level of vibration generated by the particular equipment used.

This document discusses general guidelines for the management strategy of vibration arising from the construction works in relation to this project. Criteria to ensure human comfort and prevent building damage and disruption to equipment and processes are discussed in Appendix D.

6.4.9 Control Elements

The Contractor should carry out a preliminary assessment to determine whether the existence of significant vibration levels justifies a more detailed investigation.

A more detailed investigation would involve methods of constraining activities generating high vibration levels. A method of monitoring vibration levels could then be put in place. Vibration mitigation measures and a review of vibration criteria may then be necessary.

All practical means should be used to minimise impact on the affected buildings and occupants from activities generating significant levels of vibration on site.

The following considerations should be taken into account:

- The layout of the site, including the location of static sources of vibration.
- Techniques used in construction to minimise generated vibration levels.
- Hours of work with regard to the nature of operations in the affected buildings and the duration of the works.

6.4.10 Vibration Surveys

Since the actual vibration levels experienced will be dependent upon the site characteristics and the specific equipment being used, early vibration level checks should be carried out on site at the outset of each key vibration generating activity (if vibration is considered to be an issue).

Shortly before the commencement of each activity the background vibration level could be measured and again once the activity has begun. If the survey indicates levels of vibration

exceeding those expected, the vibration management strategy for that process could be re-assessed.

6.4.11 Vibration Monitoring

A vibration monitoring system could be implemented. This system would monitor vibration levels when there is potential for them to change. This could happen in various situations, such as, changes in equipment and activities or changes to work procedures that might affect existing vibration control measures. The monitoring procedure would be carried out with appropriate equipment so that results obtained are readily comparable with results obtained earlier. If results indicate vibration levels exceeding allowable limits appropriate action, as described in Clause 6.4.12 would be taken.

6.4.12 Control of Vibration

If measured vibration levels exceed the appropriate criteria, one or more of the following measures could be taken:

- Modifications to construction equipment used.
- Modifications to methods of construction.
- Rescheduling of activities to less sensitive times.

If the measures given above cannot be implemented or have no effect on vibration levels or impact generated, a review of the vibration criteria should be undertaken and the vibration management strategy amended.

6.4.13 Non-compliances

Non-compliance reports can be used as appropriate to deal with failures to meet the construction vibration management and control requirements.

6.4.14 Site-specific Vibration Management Considerations

6.4.14.1 Vibration Sources

Potential sources of perceptible vibration include:

- Demolition and excavation plant including rock-breakers, jack hammers.
- Truck movements on site.
- Installation of structural steel work.
- Grinding, cutting and drilling of existing building structures.

The Contractor should carry out a review of vibration generated by construction activities. The levels of vibration generated will be site specific and will depend upon the type of activity, the particular equipment used, and the proximity of the construction activity to the nearest occupied spaces within the affected properties.

The Contractor should carry out a preliminary vibration survey will determine whether a means of vibration mitigation will be necessary on the site.

6.4.14.2 Vibration Sensitive Receivers

Neither the City of Sydney Council nor the DECCW relevant documentation to construction issues does not include any discussion of vibration criteria and, therefore, cannot be referred to for any appropriate criteria.

Relevant Australian and international vibration criteria to ensure human comfort, prevent building damage and prevent disruption to equipment and processes are discussed in Appendix D.

Vibration limits for building damage are less stringent than limits for human comfort, and both are relevant to this plan, as follows.

Human comfort

Occupants of the residences along Macquarie Street, 24 hours a day, 7 days a week.

Staff and patrons of retail/commercial premises adjacent to VAPS site, when in use.

Building damage

- Residences along Macquarie Street, 24 hours a day, 7 days a week.
- Nearby retail and commercial structures adjacent to VAPS site 24 hours a day, 7 days a week.

6.4.14.3 Vibration Criteria for Human Comfort

Vibration levels arising from demolition, excavation and construction activities should not exceed the following limits:

Location	Continuous Vibration (r.m.s.), mm/s	Intermittent Vibration (r.m.s.), mm/s
In any residence adjacent to VAPS site along Macquarie Street	Curve 2 in Figure 5b, AS2670.2:1990	Curve 60 in Figure 5b, AS2670.2:1990
Within any retail / commercial premises adjacent to VAPS site along Macquarie Street	Curve 4 in Figure 5b, AS2670.2:1990	Curve 128 in Figure 5b, AS2670.2:1990

Table 11: Vibration criteria for human comfort

6.4.14.4 Vibration Criteria for Building Damage

The criteria given in Table 11 (Human Comfort) shall generally form the limiting vibration criteria for the project.

For unoccupied buildings, or during periods when the buildings are unoccupied, the criteria for building damage suggested by Australian Standard AS2187-1993 of 5 mm/s should be adopted.

7 Conclusions

As indicated in Director General's Requirements for the Sydney Opera House VAPS project, an environmental noise assessment associated with the operation and construction of new underground loading dock and access ramp has been undertaken.

Long and short term noise monitoring has been carried out to establish the existing background and ambient noise levels around the proposed site.

An operation noise assessment has been carried out in order to evaluate noise impacts associated with the new premises. Noise form service vehicle movements associated with the SOH has been considered as the main source of potential noise impact.

In the absence of specific noise criteria for the project, the assessment methodology used is based on the comparison of current and future traffic noise impacts.

The outcome of the operational noise assessment is that the stated criteria will be met. Therefore, it is anticipated that the proposed development will have no adverse noise impact at the nearest residential receivers.

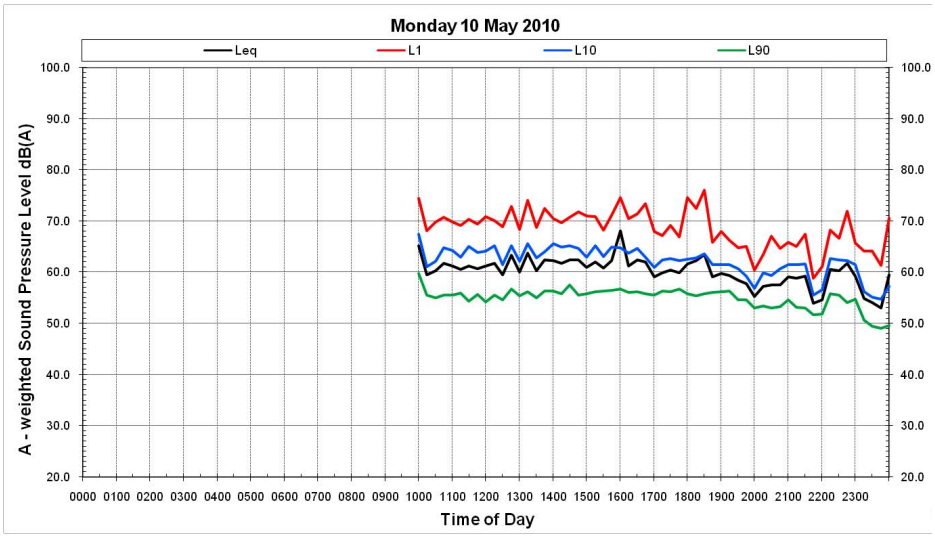
A construction noise and vibration assessment has also been conducted to establish the potential impacts of noise and vibration of the proposed construction associated with the VAPS project in nearest sensitive receivers.

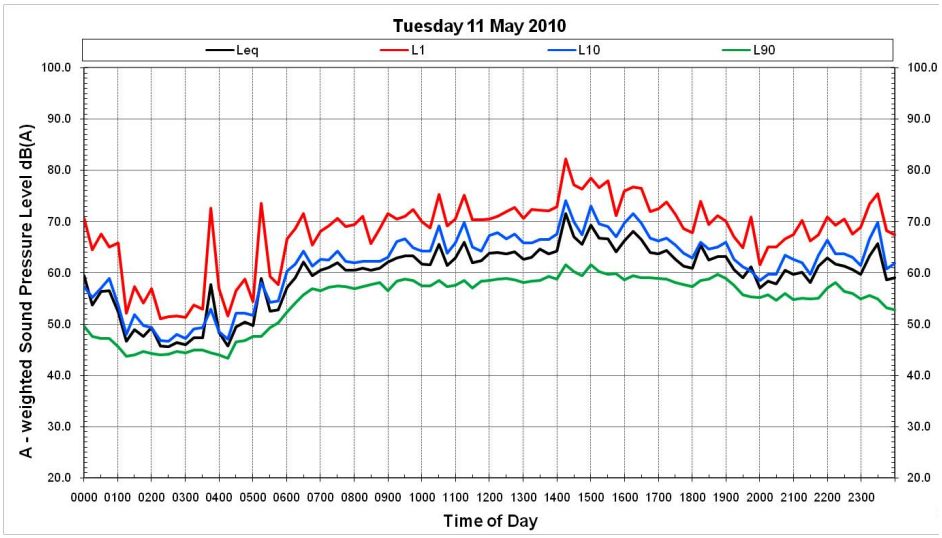
Appropriate criteria for both noise and vibration have been discussed and set according to established guidelines and standards.

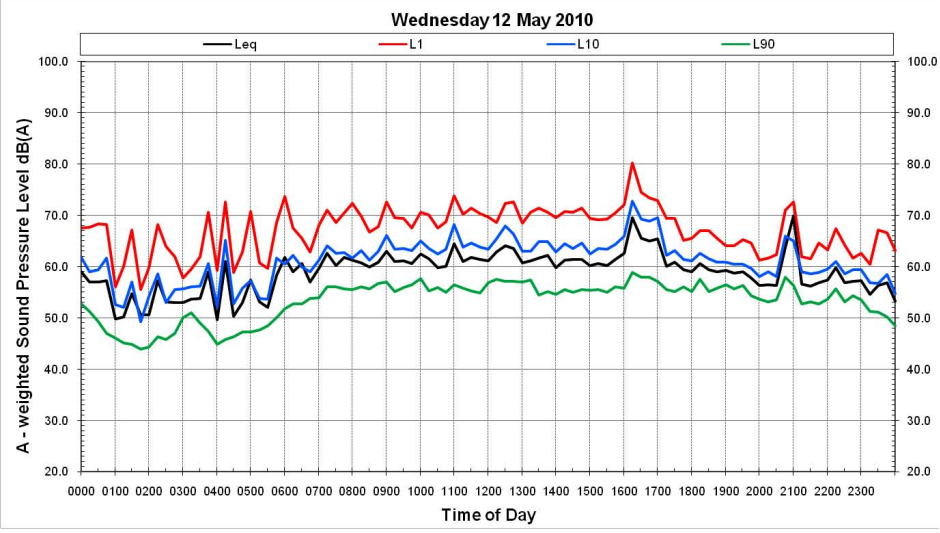
To ensure adverse effects are avoided at all receivers, monitoring of noise and vibration levels could be carried out. If the noise and vibration criteria are exceeded, the offending activities could be stopped, providing it is safe to do so, and action taken to ensure compliance. Noise control measures and construction best practices are presented to minimise noise impacts on the neighbourhood.

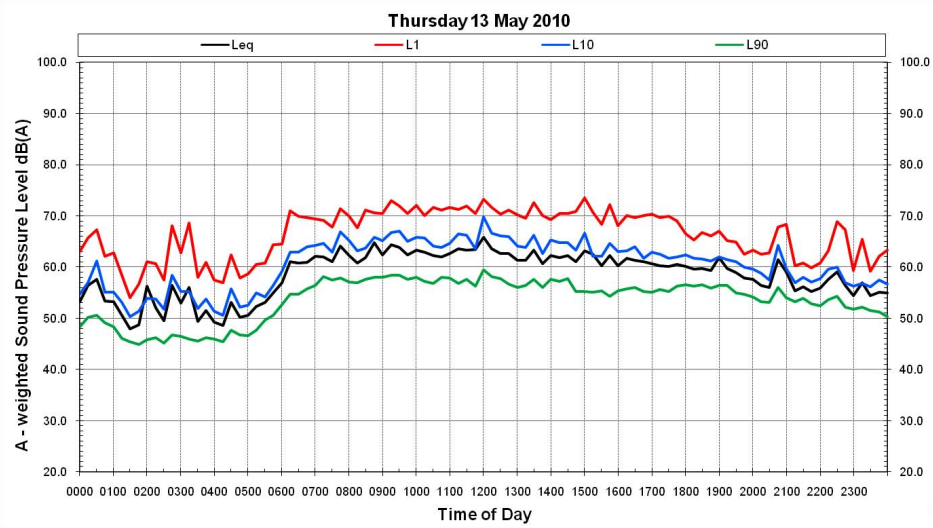
Appendices

Appendix A: Long-term Monitoring Results





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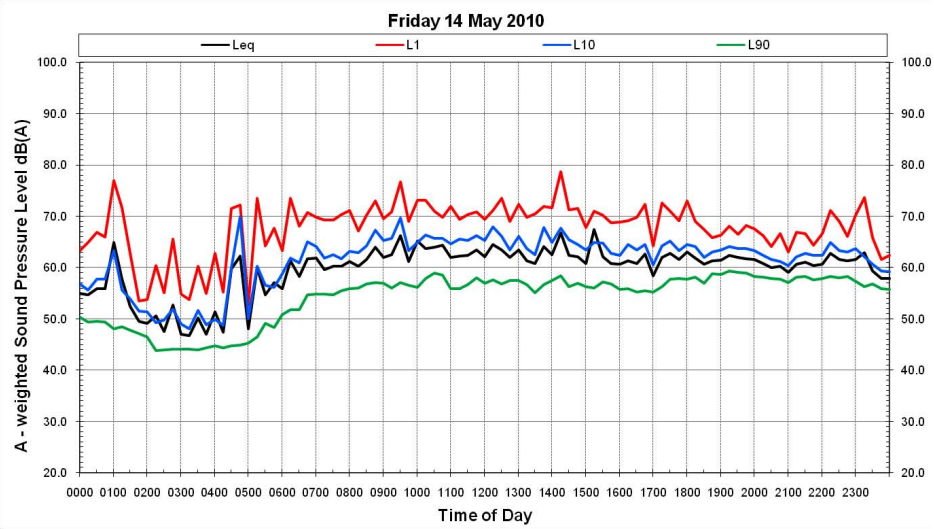
Time of Day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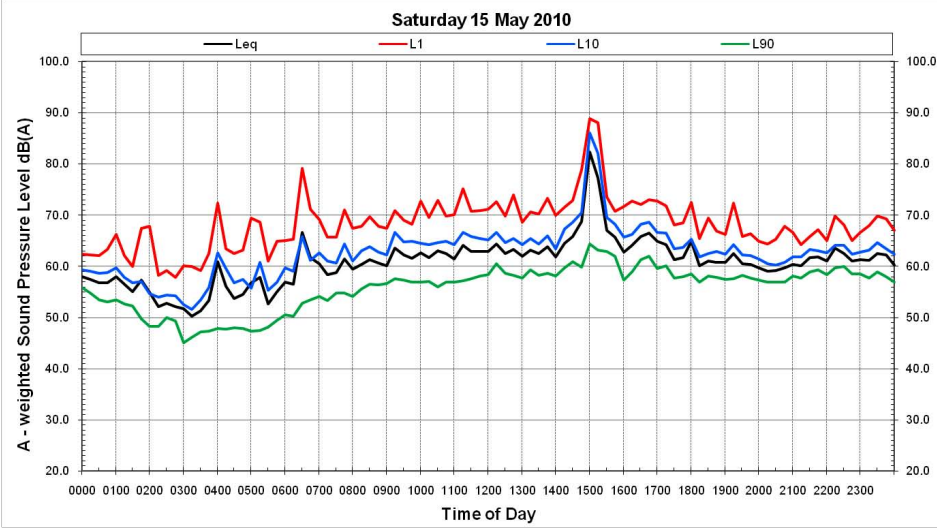
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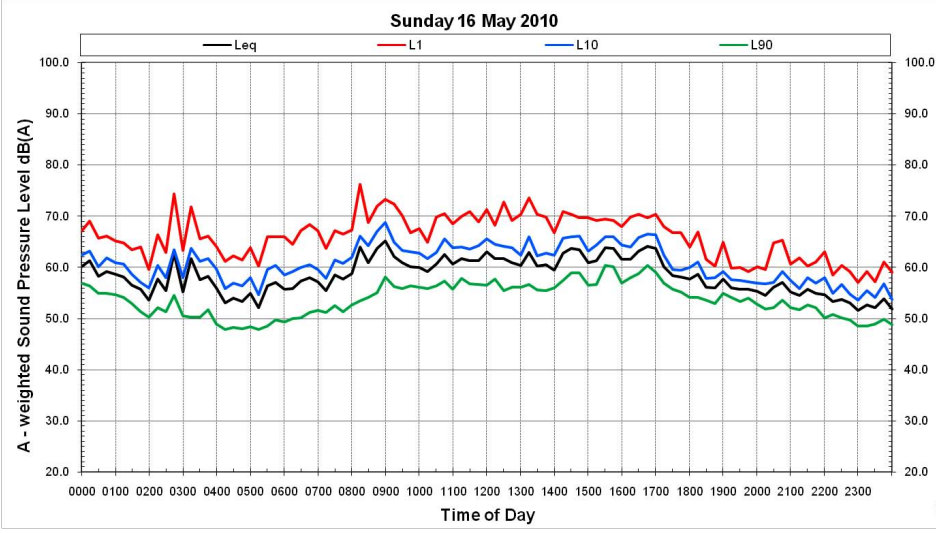
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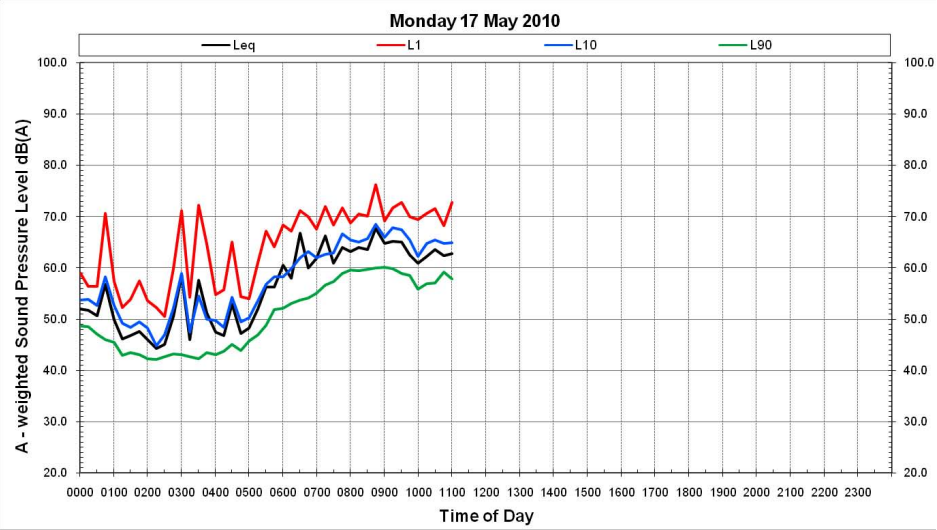
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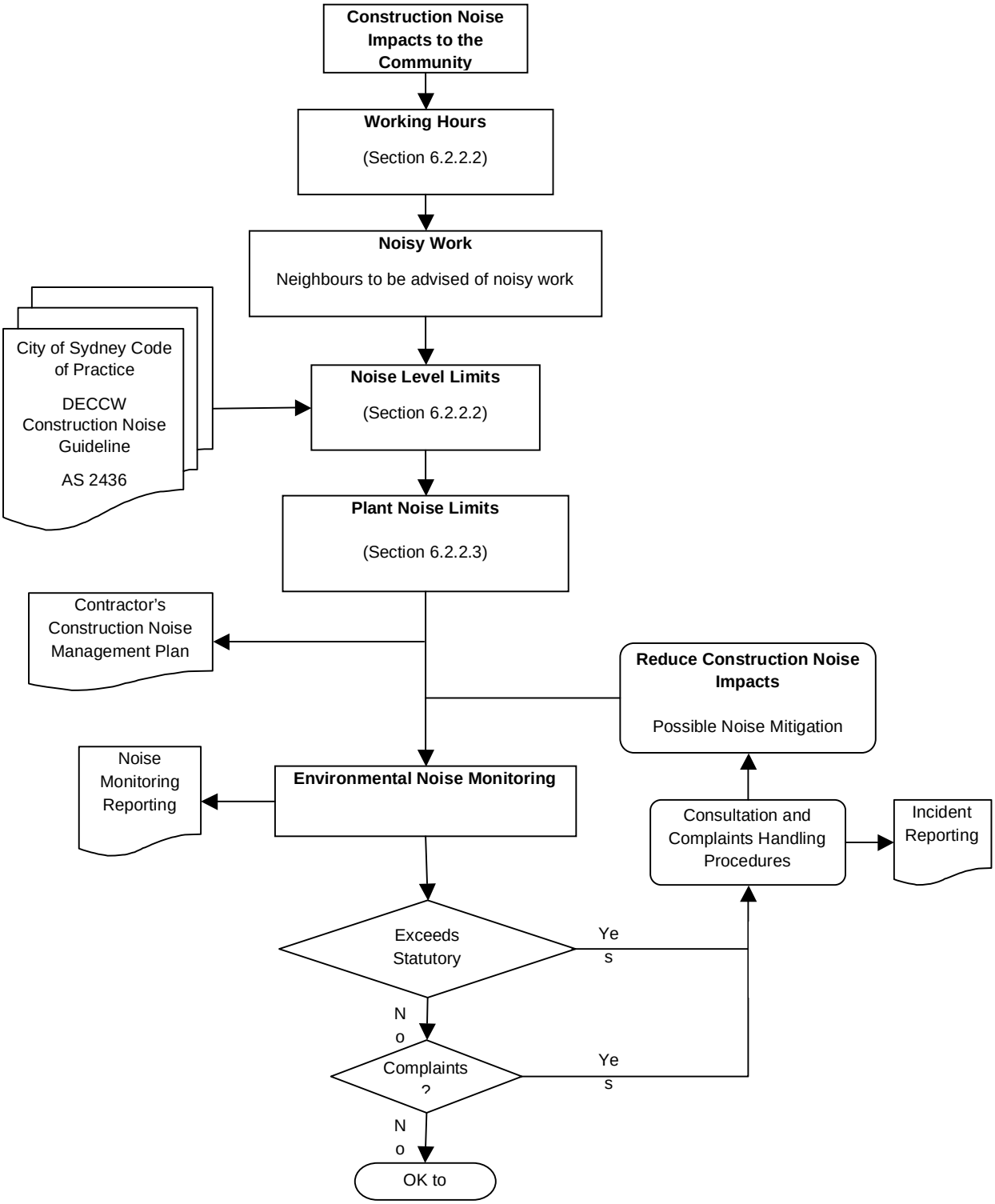
Time of Day

Appendix B: General approach to managing construction noise impacts on the community



Appendix C: Certificate of Acoustic Performance for Construction Works Appliances

FORM D

Certificate Of Acoustic Performance

1. General information

   a. Construction Site (address)
   b. Applicant
   c. Acoustic Adviser
   d. Date and time of test
   e. Weather conditions during test
   f. Instruments used for Noise Measurements
   g. Details of Nominated Affected Occupancy (example windows open/closed, air-conditioned)

2. Appliance noise levels. The following $L_{A\ av\ max}$ noise levels were measured at a distance of 7 metres from the nearest point of each Appliance:

   Appliance ..... $L_{A\ av\ max}$ Noise level (dBA) .....

3. Noise levels at boundaries. The following $L_{A\ av\ max}$ noise levels were measured at the boundaries nominated during the Construction Work/...(specified) .. Operation:

   Boundary ..... $L_{A\ av\ max}$ Noise level (dBA) .....

   Boundary ..... $L_{A\ av\ max}$ Noise level (dBA) .....

4. Noise Levels at Nominated Affected Occupancy. The following $L_{A\ av\ max}$ noise levels were measured at the Nominated Affected Occupancy during Construction Work/.... (specified)....Operation:

   Address/ ..... $L_{A\ av\ max}$ Noise level (dBA) .....
   Location

5. Background Noise Levels. The following ambient L_{A90} noise levels were measured during the 15 minute periods shown at the Nominated Affected Occupancy:

   Address ..... Time Period L_{A90} Noise Level (dBA) .....

I ..... (full name) ....., qualified Acoustic Adviser of .....(name of company/employer) ..... certify that this form has been prepared in accordance with the City of Sydney Code of Practice for Construction Hours/Noise Code 1992.

(signature)

Appendix D: Vibration Criteria

Human Comfort

The Environmental Noise Control Manual, Chapter 174, issued by the Environmental Protection Authority (EPA), contains guidelines to limit vibration levels generated by activities on construction sites.

Guidelines are given in terms of satisfactory vibration levels related to the minimum adverse comment level by building occupants. Table A1 gives the vibration limits for both continuous and intermittent vibration to prevent adverse comment in various working areas. Daytime is between 7am and 10pm and night-time is between 10pm and 7am. These limits apply at the site boundary.

Space	Time	Continuous Vibration (mm/s)	Intermittent Vibration (mm/s)
Residential	Day	0.2	6.0
	Night	0.14	2.0
Office	Day	0.4	12.7
	Night	0.4	12.7
Workshops	Day	0.8	12.7
	Night	0.8	12.7
Precision Laboratories	Day	0.1	0.1
	Night	0.1	0.1

Table A1: Vibration Criteria to Ensure Human Comfort

Building Damage

There is little reliable data on the threshold of vibration-induced damage in buildings. Although vibrations induced in buildings by ground-borne excitation are often noticeable, there is little evidence that they produce even cosmetic damage[2]. This lack of data is one of the reasons that there is variation between international standards, why the British Standards Institution (BSI) did not provide guidance before 1992 and why there are still no International Organisation for Standardisation (ISO) guidance limits.

There are however several standards that can be referred to.

[2] Building Research Establishment (1995), 'Damage to Structures from Ground-borne Vibration', *BRE Digest*

German Standard

The relevant German standard is DIN 4150: Part 3: 19862. This standard gives guidelines for short-term and steady state structural vibration. For short-term vibration in buildings the following limits are given:

Structural type	Vibration Velocity, v_i, in mm/s			
	Foundation			Plane of floor of uppermost full storey
	less than 10 Hz	10 to 50 Hz	50 to 100 Hz	Frequency mixture
Commercial, Industrial or Similar	20	20 to 40	40 to 50	40
Dwellings or Similar	5	5 to 15	15 to 20	15
Particularly Sensitive	3	3 to 8	8 to 10	8

Table A2: Guideline Values of Vibration Velocity, v_i, for Evaluating the Effects of Short-term Vibration

The guidelines state that:

Experience to date has shown that, provided the values given in Table A2 are observed, damage due to vibration, in terms of a reduction in utility value, is unlikely to occur. If the values of table A2 are exceeded, it does not necessarily follow that damage will occur. Should these values be significantly exceeded, further investigation is necessary.

Swiss Standard

The relevant Swiss standard is SN 640 312:1978. For steady state vibration, form machines, traffic and construction in buildings the following limits are given:

Structural type	Vibration Velocity, v_i, in mm/s	
	Foundation	
	10 to 30 Hz	30 to 60 Hz
Commercial, Industrial including retaining walls	12	12 to 18
Foundation walls and floors in concrete or masonry. Retaining walls and ashlar construction	8	8 to 12
Foundations and basement floors concrete, with wooden beams on upper floors. Brick walls.	5	5 to 8
Particularly sensitive	3	3 to 5

Table A3: Guideline Values of Vibration Velocity, v_i, for Evaluating the Effects of Steady State Vibration

British Standard

The relevant standard is BS7385: Part 2: 1993[3]. This standard was developed from an extensive review of UK data, relevant national and international documents and other published data, which yielded very few cases of vibration-induced damage. This standard contains the most up-to-date research on vibration damage in structures. Part 2 of the standard gives specific guidance on the levels of vibration below which building structures are considered to be at minimal risk.

The Standard proposes the following limits on the foundations of the building:

Structural type	Peak component particle velocity in frequency range of predominant pulse	
	4 Hz to 15 Hz	15Hz and above
Unreinforced or light framed structures Residential or light commercial type buildings	15mm/s @ 4Hz increasing to 20mm/s @ 15Hz	20mm/s @ 15Hz increasing to 50mm/s @ 40Hz and above

Table A4: Transient Vibration Guide Values for Cosmetic Damage

The standard states in Annex A, that … *the age and existing condition of a building are factors to consider in assessing the tolerance to vibration. If a building is in a very unstable state, then it will tend to be more vulnerable to the possibility of damage arising from vibration or any other ground-borne disturbance.* It is recommended that buildings of importance be considered on a case-by-case basis with detailed engineering analysis being carried out if necessary.

Annex B of the Standard gives a breakdown of data that should be recorded. Included in this are details of the building structure, such as general condition of the structure, list of defects, photographs, details of all major extensions, repairs and renovations. A crack exposure report should be prepared both pre and post exposure, both internally and externally.

Australian Standard

There is no specific Australian Standard referring to structural vibration in buildings. There is however AS 2187.2 - 1993[4], which, in Appendix J, recommends maximum peak particle velocities, measured at the ground surface due to blasting. The lower

[3] BS 7385: Part 2: 1993 Evaluation and Measurement for vibration in Buildings, Guide to damage levels from groundborne vibration

[4] AS 2187.2 - 1993 Explosives - Storage, transport and use. Part 2: Use of explosives

recommended peak particle velocity is 10 mm/s. The standard states however, that structures that may be particularly susceptible to ground-borne vibration should be examined on an individual basis. It is suggested that in the absence of a particular site-specific study then a maximum peak particle velocity of 5 mm/s is used.

Summary

Table A5 gives a summary of recommended vibration limits for buildings to prevent damage. The most stringent limit recommended in the German and Swiss standards is 3 mm/s. However, this criterion is applicable to particularly sensitive constructions such as heritage buildings. Therefore, the next most stringent level of 5 mm/s has been conservatively chosen as an appropriate limit whilst the construction work is carried out. This limit should be met across the full frequency range of relevance i.e. typically 4 Hz – 250 Hz encountered in building construction.

Standard	Type of building	Recommended vibration limit	Comments
DIN 4150	Structures of particular sensitivity or worthy of protection	3 mm/s to 20 mm/s @ < 10 Hz 3-40 mm/s @ 10-50 Hz 8-50 mm/s @ 50 Hz+ Also measurement at the top floor with limit of 8 mm/s to 40 mm/s across frequency range	Limit is for peak particle velocity in x,y, and z directions. Measurement on the top floor in x and y directions only
BS 7385	Un-reinforced or light framed	15 mm/s @ 4 Hz rising to 20 mm/s @ 15 Hz then rising to 50 mm/s @ 40 Hz and above[1]	Limit is for peak particle velocity in x, y, and z directions
AS 2187	Houses and low-rise residential, commercial buildings not of reinforced or steel construction	5 mm/s[1]	For buildings particularly susceptible to vibration. Limit is for peak *resultant* particle velocity, measured on the ground adjacent to the structure
SN 640 312	Structures of particular sensitivity	3 mm/s to 12 mm/s @ 10-30 Hz 3 mm/s to 18 mm/s @ 30-60 Hz	Limit is for peak particle velocity in x, y, and z directions

Table A5: Summary of International Standards