Acoustics
Vibration
Structural Dynamics

5 BLUE STREET NORTH SYDNEY

Railway Noise and Vibration Assessment

19 March 2026

5 Blue Street c/o Lighthouse Project Group

TQ108-01F01 Noise and Vibration Report (r1)

Sydney Melbourne Brisbane Gold Coast Canberra Kuwait Singapore
Renzo Tonin & Associates ABN 29 117 462 861
Level 1/418A Elizabeth St SURRY HILLS NSW 2010 | PO Box 877 STRAWBERRY HILLS NSW 2012
P (02) 8218 0500 F (02) 8218 0501 sydney@renzotonin.com.au www.renzotonin.com.au

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Address:	Suite 201, 157 Walker Street North Sydney, NSW, 2060
Attention:	James Hallows

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1 Introduction

This report relates to the proposed mixed-use development at 5 Blue Street, North Sydney. The existing building at this location is a commercial building and is positioned directly above the western end of North Sydney Train Station.

The foundations of the existing building are located between the railway tracks as columns and integrated with the station platforms. Vibration from train operations can be transmitted into the building foundation columns and propagate up through the columns and into the building. This vibration has the potential to be perceived by building occupants as tactile vibration or heard as low-frequency ground-borne noise.

Zurich is considering an adaptive reuse of the existing commercial building. The proposed works include reuse of the existing building columns and footings, strip off and replacement of the existing building facade and an internal fitout of the building for predominantly residential use. The ground floor is proposed to include a residential lobby and retail area. Co-living spaces are proposed on Levels 1, 2, and 3. Residential apartments are proposed on Levels 4 to 15.

Renzo Tonin & Associates was engaged by Zurich to identify the potential extent of noise and vibration impacts within the proposed development and the indicative mitigation treatments that may be required for the proposed retail and residential areas.

The assessment undertaken herein represents a preliminarily assessment of the potential noise and vibration impacts and in-principal mitigation measures that are suitable to support a Development Application for the building, which demonstrates that the appropriate noise and vibration objectives can be achieved. A more detailed assessment will be required during the detailed design stage.

This report provides a summary of the relevant noise and vibration criteria, site measurement results, the potential noise and vibration impacts and recommendations relating to future design stages.

Appendix A contains a glossary of acoustic terms used in this report.

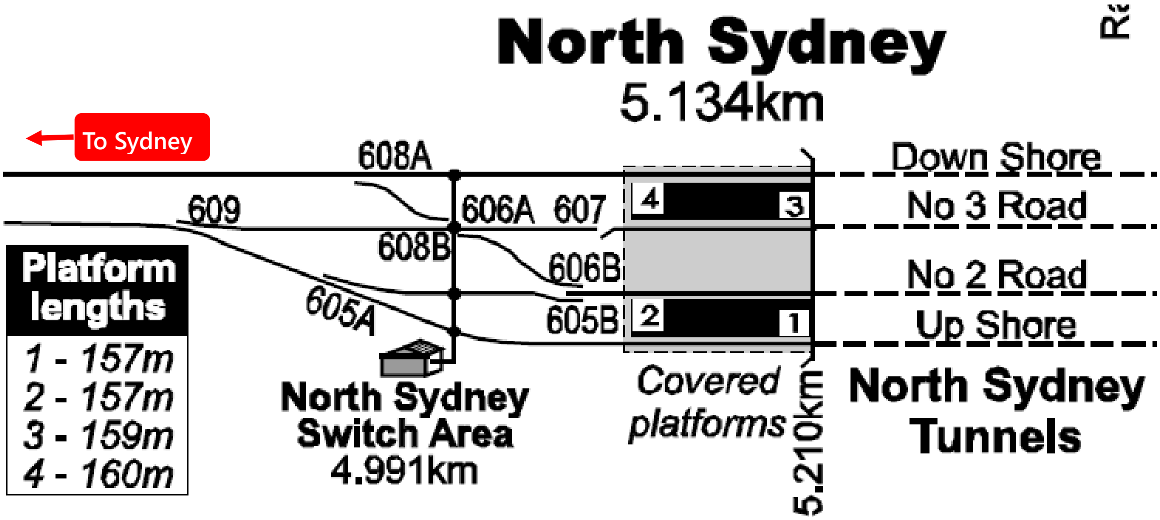
2 Background information

North Sydney Station is a busy suburban railway line, with frequent passenger services. T1 (North Shore Line), T9 (Northern Line) and CCN (Central Cost and Newcastle Line) services operate through North Sydney Station. It is understood that all revenue services stop at North Sydney Station.

Train operations are timetabled to operate between approximately 4:30 am (first service) and 2:00 am (last service). Non-revenue services may operate between 2:00 am and 4:30 am.

There are four platforms at North Sydney Station. These are shown in the track diagram in Figure 2-1.

Figure 2-1:North Sydney Station Track Diagram



The track form on the Up Shore (Platform 1) and Down Shore (Platform 4) lines consists of ballasted track with concrete sleepers (refer left photo in Figure 2-2). The majority of train movements through North Sydney Station operate on the Up and Down Shore Lines. The track form on the No 2 Road (Platform 2) and No 3 Road (Platform 3) lines consist of slab track with Delkor Type Alt 1 rail fasteners[1] (refer left photo in Figure 2-2.

The current Drivers Route Knowledge Diagrams (December 2025)[2] identify that a maximum train speed of 30 km/h is applicable in the vicinity of 5 Blue Street.

[1] The type of rail fasteners is not known with 100% certainty, but the baseplates are stamped with a Delkor marking. The Delkor Type Alt 1 rail fasteners are commonly used on the Sydney Trains network and look the same as the rail fasteners in this photo.

[2] https://railsafe.org.au/__data/assets/pdf_file/0005/55535/North-Shore-Line-Central-to-Hornsby.PDF

Figure 2-2: Slab track (left) and ballast track (right) – Western end of North Sydney Station

The existing commercial building at 5 Blue Street is located directly above the western end of North Sydney Station. A plan view showing the location of 5 Blue Street in relation to the railway corridor is provided in Figure 2-3. The columns and footings are located central to the North Sydney Station platforms (see also left photo in Figure 2-2).

The building loads of the existing building are transferred into the foundations located between the platforms. These will remain unchanged for the proposed building fitout.

Figure 2-3: Plan view of 5 Blue Street

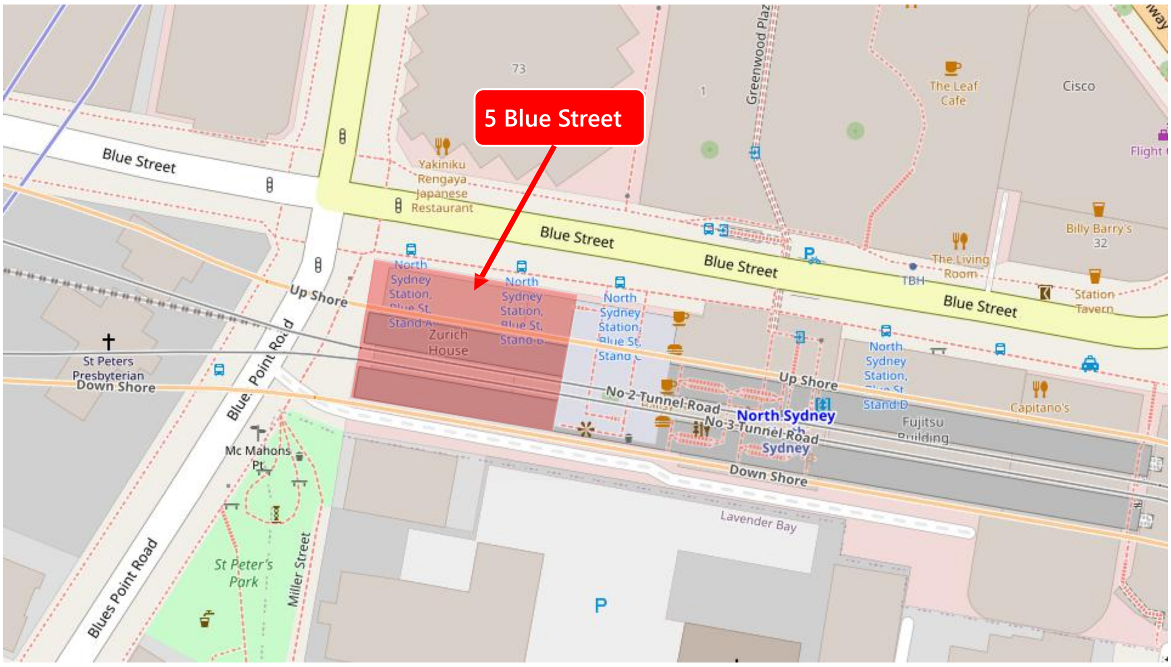


Photo courtesy of OpenRailwayMap (https://www.openrailwaymap.org/)

3 Overview of potential noise and vibration impacts

When a train operates on surface track or in a tunnel environment, vibration occurs at the wheel-rail interface as a result of the combined wheel and rail roughness, and other dynamic forces associated with the track and vehicle interaction.

In the case of buildings located above railway lines, this vibration can be transmitted via the track to the surrounding ground mass, and into the foundations of the building. This vibration can propagate through the building structure and has the potential to be perceptible to building occupants as tactile vibration or heard as low-frequency ground-borne noise (also referred to as regenerated, structure-borne or re-radiated noise). In rare cases, ground vibration levels associated with train operations may impact the satisfactory operation of sensitive measurement equipment located within high technology facilities.

The extent of ground-borne noise and vibration impacts is influenced by several physical aspects such as:

- mass of the train (axle load and unsprung mass)
- train speed and length
- condition of the rail surface (e.g. alignment, the presence of turnouts or crossovers, roughness and defects such as corrugations, etc.)
- condition of the wheels (e.g. roughness, flats or other wheel defects, etc.)
- type of track structure and form (e.g. stiffness or softness of rail track bed and fasteners, etc.)
- ground type beneath the track and between the track and receiver building (e.g. sandstone, soft soil, etc)
- distance between the track and receiver and tunnel depth
- construction of receiver building
- the sensitivity of the receivers within the building (e.g. retail, commercial or residential)
- the time of day (e.g. daytime or night-time)
- the location of receivers within the building (i.e. floor level)

4 Railway noise and vibration criteria

Noise and vibration criteria for airspace and external developments above and adjacent to railway corridors are provided in the Transport for NSW (TfNSW) Standard T HR CI 12090 ST (Airspace and External Developments, version 1.0 dated 1/06/2021).

Section 6.2 of the standard notes that the effects of noise and vibration from railway operations shall be taken into account in the design of developments. Prior to the issue of an occupation certificate, the standard notes that *"a report shall be prepared certifying that the completed development meets the requirements of the ISEPP and Development Near Rail Corridors and Busy Roads - Interim Guidelines"*.

4.1 State Environmental Planning Policy (Transport and Infrastructure) 2021

The State Environmental Planning Policy (Transport and Infrastructure) 2021 (T&I SEPP) officially replaced the former State Environmental Planning Policy (Infrastructure) 2007 (ISEPP) on 1 March 2022.

The following clause in the T&I SEPP is applicable to this project:

2.100 Impact of rail noise or vibration on non-rail development

(1) This section applies to development for any of the following purposes that is on land in or adjacent to a rail corridor and that the consent authority considers is likely to be adversely affected by rail noise or vibration—

(a) residential accommodation,

(b) a place of public worship,

(c) a hospital,

(d) an educational establishment or centre-based child care facility.

(2) Before determining a development application for development to which this section applies, the consent authority must take into consideration any guidelines that are issued by the Planning Secretary for the purposes of this section and published in the Gazette.

(3) If the development is for the purposes of residential accommodation, the consent authority must not grant consent to the development unless it is satisfied that appropriate measures will be taken to ensure that the following LAeq levels are not exceeded—

(a) in any bedroom in the residential accommodation—35 dB(A) at any time between 10.00 pm and 7.00 am,

(b) anywhere else in the residential accommodation (other than a garage, kitchen, bathroom or hallway)—40 dB(A) at any time.

4.2 Development Near Rail Corridors and Busy Roads - Interim Guideline

This guideline provides a summary of the applicable noise and vibration criteria for residential developments near rail corridors, and notes the following:

- **Tactile vibration** - Vibration levels such as the intermittent vibration emitted by trains should comply with the criteria in *Assessing Vibration: a technical guideline (DECC 2006)*. Additional details are provided in Section 4.3.

- **Ground-borne noise** - Residential buildings should be designed so that the 95th percentile of train passbys complies with a ground-borne L_{Amax} noise limit of 40 dB(A) (daytime) or 35 dB(A) (night-time) measured using the "slow" response time setting on a sound level meter. Additional details are provided in Section 4.4.

4.3 Tactile vibration

The applicable criteria relating to the tactile vibration experienced by building occupants are based on guidance in the EPA's '*Assessing Vibration: a technical guideline*' (DEC, 2006). The guideline provides criteria which are based on the British Standard BS 6472-1992 '*Evaluation of human exposure to vibration in buildings (1-80Hz)*'. Sources of vibration are defined as either 'Continuous', 'Impulsive' or 'Intermittent'. Table 4-1 provides definitions and examples of each type of vibration.

Table 4-1: Types of vibration

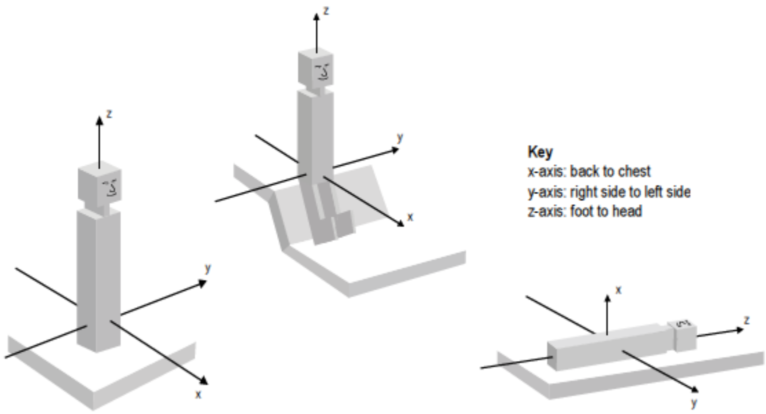
Type of vibration	Definition	Examples
Continuous vibration	Continues uninterrupted for a defined period (usually throughout the day-time and/or night-time)	Machinery, steady road traffic, continuous construction activity (such as tunnel boring machinery).
Impulsive vibration	A rapid build-up to a peak followed by a damped decay that may or may not involve several cycles of vibration (depending on frequency and damping). It can also consist of a sudden application of several cycles at approximately the same amplitude, providing that the duration is short, typically less than 2 seconds	Infrequent: Activities that create up to 3 distinct vibration events in an assessment period, e.g. occasional dropping of heavy equipment, occasional loading and unloading.
Intermittent vibration	Can be defined as interrupted periods of continuous or repeated periods of impulsive vibration that varies significantly in magnitude	Trains, nearby intermittent construction activity, passing heavy vehicles, forging machines, impact pile driving, jack hammers. Where the number of vibration events in an assessment period is three or fewer, this would be assessed against impulsive vibration criteria.

Source: Assessing Vibration; a technical guideline, Department of Environment & Climate Change, 2006

The EPA guideline notes that for train vibration, the intermittent vibration criteria are applicable, which permit higher vibration levels than for continuous vibration. However, for the purpose of this project, and based on our experience from past projects, and given the prestige nature of the proposed residential apartments at 5 Blue Street, the continuous vibration criteria are best applied. The continuous vibration criteria for residential receivers (night-time) more closely align with the threshold of perception level of approximately 0.14 mm/s (refer page 20 of EPA guideline). If vibration levels are below the threshold of perception, then the risk of complaints from tactile vibration is unlikely.

When applying the criteria, it is important to note that the three directional axes are referenced to the human body, i.e. x-axis (back to chest), y-axis (right side to left side) or z-axis (foot to head). Vibration may enter the body along different orthogonal axes and affect it in different ways. Therefore, application of the criteria requires consideration of the position of the people being assessed, as illustrated in Figure 4-1. For example, vibration measured in the horizontal plane is compared with x- and y-axis criteria if the concern is for people in an upright position, or with the y- and z- axis criteria if the concern is for people in the lateral position.

Figure 4-1: Orthogonal axes for human exposure to vibration



The preferred and maximum values for continuous vibration are defined in Table 2.2 of the guideline and are reproduced in Table 4-2, expressed in terms of vibration velocity levels.

Table 4-2: Preferred and maximum levels for human comfort (vibration velocity, mm/s)

Location	Assessment period[1]	Preferred values		Maximum values	
Continuous vibration (velocity, mm/s, 1-80Hz)					
Critical areas[2]	Day- or night-time	0.10	0.29	0.20	0.57
Residences	Daytime	0.20	0.57	0.40	1.14
	Night-time	0.14	0.40	0.28	0.80
Offices, schools, educational institutions, and places of worship	Day- or night-time	0.40	1.14	0.80	2.28
Workshops	Day- or night-time	0.80	2.28	1.60	4.56

Notes: Daytime is 7:00am to 10:00pm and night-time is 10:00pm to 7:00am

Examples include hospital operating theatres and precision laboratories where sensitive operations are occurring. There may be cases where sensitive equipment or delicate tasks require more stringent criteria than the human comfort criteria specify above. Stipulation of such criteria is outside the scope of their policy and other guidance documents (e.g. relevant standards) should be referred to. Source: BS 6472-1992

4.4 Ground-borne noise

The applicable criteria relating to the ground-borne noise experienced by occupants within buildings are based on the Department of Planning's *"Development near Rail Corridors & Busy Roads – Interim Guideline"* (2008) and are consistent with the criteria in the *"State Environmental Planning Policy (Transport and Infrastructure) 2021"*. Table 4-3 summarises the noise limits for sleeping and living spaces within residential occupancies.

Table 4-3: Recommended internal noise criteria for ground-borne rail noise – residential receivers

Occupancy	Time Period	L_{ASmax} Noise Limit [1]
Living areas (includes open-plan kitchens, dining, family room, media and study rooms)	7am – 10pm	40 dB(A)
Sleeping areas	10pm – 7am	35 dB(A)

Notes: 1. L_{ASmax} – is the A-weighted maximum sound pressure level measured using "Slow" response time. 95% of rail pass-by events must be below the L_{ASmax} noise limits.

5 Summary of proposed development

Various configurations are possible for the proposed residential conversion. The preferred option includes co-living spaces on Levels 1 and 2 and apartments from Level 3 to Level 14. From a ground-borne noise and vibration perspective, the various configurations are considered equivalent, with negligible change in the expected ground-borne noise and vibration impacts. For all configurations, the existing structure above the railway platforms will be adaptively reused, with building loads continuing to be transferred to the existing foundations below Platforms 1 to 4 in a manner consistent with the current structure.

The proposed development involves an adaptive reuse of the existing building, retaining the existing columns and footings, stripping the existing facade and replacing it with a new facade, and fitting out the interior for residential use. This approach is less intrusive within the rail corridor compared to a demolish-and-rebuild strategy, as no new piers or significant foundation works within the platform areas are anticipated.

Given that the existing columns and footings are to be reused rather than replaced or substantially modified, the incremental change in foundation loads relative to the existing structure is expected to be limited. As a result, ground-borne noise and vibration levels transmitted into the building are not expected to be materially different from those associated with the existing structure, and no significant reduction or increase in vibration levels is anticipated from changes in foundation loading.

The first level of sleeping areas is proposed to be located on Level 1. The building incorporates 2 basement levels (including a loading dock), a residential lobby and retail usage at ground floor level, and residential occupancies on Level 1 to Level 14.

6 Noise and vibration measurements

Noise and vibration measurements were undertaken within the existing building on 4 March 2026 for the purpose of quantifying the existing level of noise and vibration from train passbys.

6.1 Vibration measurements

Vibration measurements were undertaken on the carpark level (RL 56.3 m) and on Level 2 (RL 68.99 m) of the existing building. The platforms are located at RL 46.74 m.

The vibration measurements on the carpark level were undertaken on a structural column located near Platforms 1 and 2, at the western end of the station. The floor vibration measurements on Level 2 were undertaken within a common area on the eastern side of the lift core. At both measurement locations, vibration measurements were made in the three orthogonal directions (vertical, lateral and longitudinal).

The vibration measurements were undertaken on 4 March 2026 between 4:30 pm and 5:45 pm. During this period all train arrivals and departures occurred on Platform 1 (Up Shore) and Platform 4 (Down Shore). Vibration measurements were made for 10 trains on each track. A time lapse camera was positioned adjacent to Platform 4 to confirm the arrival and departure times of the trains on each track.

On the carpark level, a picture showing the measurement setup is shown in Figure 6-1. A picture showing the measurement setup on Level 2 is shown in Figure 6-2.

Figure 6-1: Vibration measurement location in carpark – above Platforms 1 and 2

Figure 6-2: Noise and vibration measurements on Level 2

At both measurement locations, continuous recordings of the vibration levels (velocity) were made. The vibration levels are expressed in terms of decibel units (dB_V). In this report, a reference vibration velocity level of 1 nm/s (one nanometre per second) is used. Using this reference, a vibration level of 1 mm/s is equal to 120 dB_V. A vibration level of 0.1 mm/s is equal to 100 dB_V. A vibration level of 0.14 mm/s represents the approximate threshold of tactile vibration perception and is equal to 103 dB_V.

Detailed results for each measurement location showing the measurement range, median and 95th percentile vibration levels and background (ambient) vibration levels are provided in graphical format in APPENDIX B. A description of the measurement equipment and methodology is also provided.

A summary of the overall vibration levels in relation to the vibration perception threshold of 103 dB_V is provided in Table 6-1. At the basement measurement location, the 95th percentile $L_{max, slow}$ vertical vibration level in the worst-case direction was 83 dB_V. At the Level 2 measurement location, the 95th percentile $L_{max, slow}$ vibration level in the most sensitive (vertical) direction was 88 dB_V. Both are well below the 103 dB_V threshold of perception for tactile vibration.

When vibration propagates through a building structure, it is common for levels measured on upper floors to exceed those recorded at the foundation. The foundation column in the basement is a heavily loaded, stiff structural element. As the vibration energy travels upward through the building frame, the vibration energy usually dissipates. The floor slabs on upper levels have their own natural frequencies and the resulting vibration levels mid-span are commonly higher than at the columns. This is the likely reason why the measured vibration levels on the Level 2 floor are higher than the measured vibration levels at the foundation in the basement.

For ground-borne noise, the relevant frequency range is 10 Hz to 250 Hz. The 1/3 octave vibration spectra results in APPENDIX B indicate that the vibration energy from trains are above the ambient (background) vibration levels in the frequency range above 50 Hz at the basement level and are above the ambient levels over a very narrow frequency range between 80 Hz and 100 Hz on Level 2.

Table 6-1: Summary of overall vibration levels

Measurement location	Direction (1)	$L_{max,\ slow}$ vibration level, dB_V re 1 nm/s			
		Perception Threshold	Measured vibration level (background)	Measured vibration level (median)	Measured vibration level 95th percentile
Foundation column Basement Level	Vertical	103	68	80	82
	Lateral	103	63	81	83
	Longitudinal	103	62	81	83
Level 2	Vertical	103	84	84	88
	Lateral	103	78	78	83
	Longitudinal	103	85	84	88

Note 1: Lateral direction is perpendicular to the train direction and longitudinal is parallel with the train direction

6.2 Noise measurements

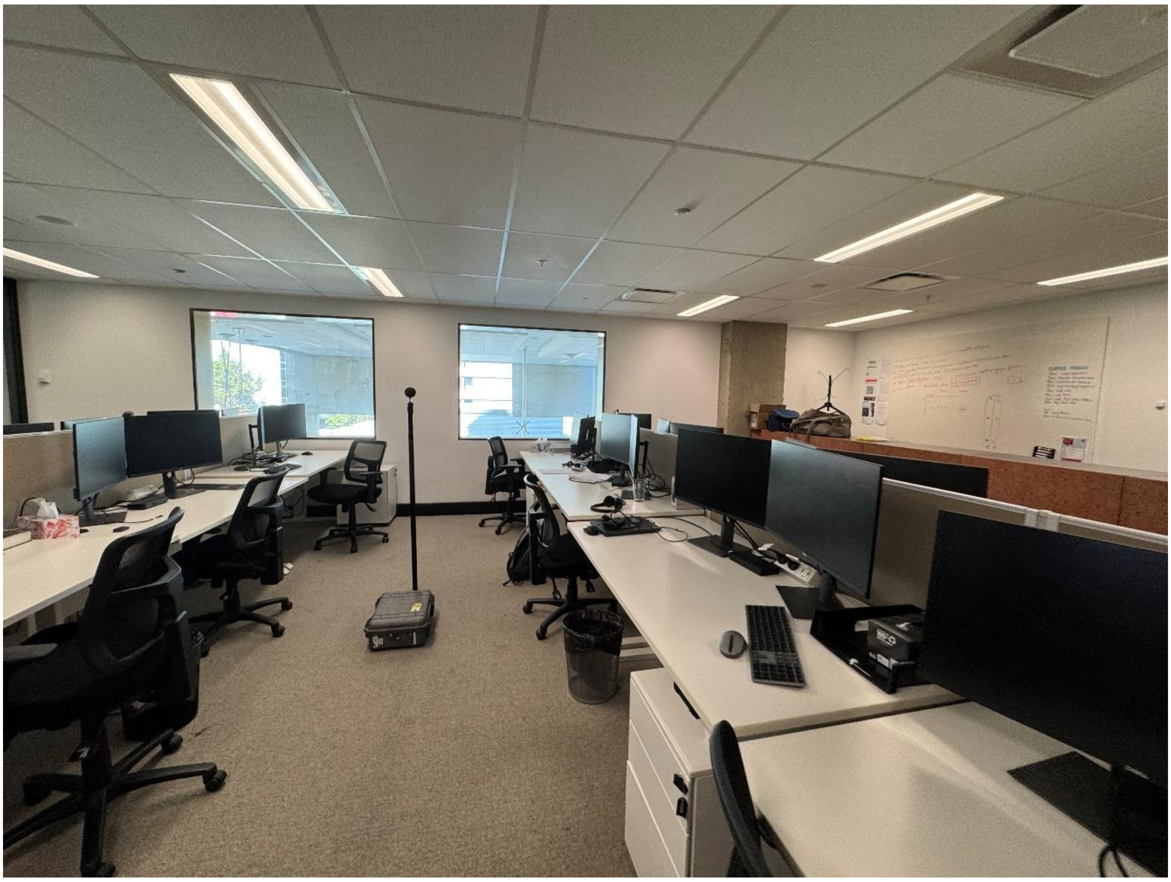
Noise measurements were undertaken on Levels 1 and 2.

On Level 1, an unattended noise logger was setup within the open plan office area of the North Projects tenancy. The open plan office is located on the eastern side of the building. The unattended noise logger was set up at 3:35 pm on 4 March 2026 and collected the following day at 11:25 am. Analysis of the measured noise levels for 20 consecutive train passbys was undertaken between 9:00 pm and 11:00 pm during a period when the office was unoccupied and the air conditioning system was switched off. A picture of the measurement location is provided in Figure 6-3.

On Level 2, attended noise measurements were undertaken on 4 March 2026 between 4:30 pm and 5:45 pm, within a common area on the eastern side of the lift core. A picture showing the measurement setup on Level 2 is shown in Figure 6-2.

At each measurement location, the microphone of the sound level meter was set up 1.5 m above the floor level and near the centre of the office space / common area.

Figure 6-3: Noise measurement position within North Projects tenancy (Level 1)



A summary of the measured noise levels is provided in Table 6-2. Detailed results showing the measurement range, median and 95th percentile noise levels and background (ambient) noise levels are provided in graphical format in APPENDIX C. A description of the measurement equipment and methodology is also provided.

Table 6-2: Summary of the measured noise levels

Measurement position	Residential $L_{ASmax,95\%}$ noise limit, dB(A) Daytime / Night-time	Measured noise levels		
		Background L_{A90} noise level, dB(A)	Train noise level, median L_{ASmax} dB(A)	Train noise level, typical maximum $L_{ASmax,95\%}$ dB(A)
Level 1	40 / 35	26	31	34
Level 2	40 / 35	32-34	35 (33) [1]	40 (36) [1]
Note 1: The numbers without brackets represent the measured noise levels, including background noise. The numbers in brackets represent the estimated train noise levels only, excluding background noise.				

On Level 1, the measured $L_{ASmax,95\%}$ train noise level was 34 dB(A). This is 6 dB(A) below the ground-borne L_{Amax} noise limit of 40 dB(A) (daytime) and 1 dB(A) below the ground-borne L_{Amax} noise limit of 35 dB(A) (night-time).

On Level 2, it was not possible to obtain a direct measurement of the ground-borne noise levels from train passbys in the presence of ambient noise from the air conditioning system, lift noise and office staff moving about the building. However, during quiet periods, ground-borne noise levels from train passbys in the Down direction (towards Waverton) were faintly audible. These faint levels and the associated vibration levels were used to estimate the ground-borne noise levels from train passbys. The estimated $L_{ASmax,95\%}$ train noise level was 36 dB(A). This is 4 dB(A) below the ground-borne L_{Amax} noise limit of 40 dB(A) (daytime) and 1 dB(A) above the ground-borne L_{Amax} noise limit of 35 dB(A) (night-time).

International Standard ISO 14837-1:2005 notes that "noise levels near walls or at the corners of rooms are higher than those near the centre". For a typical co-living space with a room floor area of 17 m^2, the ground-borne noise levels are expected to be 1 dB(A) lower than the measurement results on Level 2 (which were undertaken within a narrow corridor – refer Figure 6-2).

For ground-borne noise, the relevant frequency range is 10 Hz to 250 Hz. The 1/3 octave noise spectra results presented in APPENDIX C indicate that the median noise levels from trains are above the ambient (background) levels on Level 1 in the frequency range between 63 Hz and 250 Hz. On Level 2, the median noise levels from trains are less reliable as they are similar in level to the measured background noise levels.

7 Track inspection

7.1 Track types and features

A visual track inspection was undertaken at North Sydney Station on 14 January 2026. The purpose of the inspection was to confirm the track construction types in the vicinity of the 5 Blue Street development and to visually inspect the rail surface condition.

On the western end of North Sydney Station (below 5 Blue Street), ballasted tracks are present on the Up and Down Shore lines through Platforms 1 and 4. On the Number 2 and 3 roads through Platforms 2 and 3, a concrete slab track with Delkor Alt 1 rail fasteners is present. The concrete slab track commences at the Milsons Point end of Platforms 2 and 3 and continues through the station platform area beyond the 5 Blue Street development.

No turnouts are present in proximity to the 5 Blue Street development.

7.2 Visual inspection

The condition of the rail running surface in proximity to the columns and footings of the 5 Blue Street development can have a significant influence on the noise and vibration levels within occupied areas of the existing and future building. When viewed from the platforms, no visual track defects could be seen with the naked eye.

8 Discussion, recommendations and conclusions

8.1 Summary of noise and vibration measurements

Noise and vibration measurements were undertaken on 4 March 2026 for the purpose of quantifying the level of existing noise and vibration from train passbys.

The noise measurements were performed on Level 1 and Level 2, at locations equivalent to the co-living areas of the refurbished building. The noise results indicated that the maximum noise levels from train passbys was likely to be within ± 1 dB(A) of the most stringent ground-borne noise criterion of 35 dB(A), applicable to sleeping areas.

Vibration measurements were undertaken within the basement carpark area, on one of the structural columns above Platforms 1 and 2. The floor vibration levels were measured to be well below the 103 dB_V threshold of perception for tactile vibration.

The preliminary results indicated that there is a risk that ground-borne noise levels within residential areas of the future building could be higher than the noise criterion.

8.2 Potential mitigation measures to minimise noise and vibration risks

Based on the vibration measurements, there is a negligible risk that vibration levels within the refurbished building will be above the preferred continuous vibration levels in Table 4-2.

Co-living spaces are proposed on Level 1 and Level 2 of the refurbished building. Based on the measured noise levels on these floors, train noise levels were measured to be within ± 1 dB(A) of the most stringent ground-borne noise criterion of 35 dB(A). Noise levels on higher floors are typically 2 dB lower per floor (for levels 1-5) and 1 dB lower per floor (for levels 5-10)[3].

The NSW Rail Infrastructure Noise Guideline (EPA 2013) notes that the ground-borne noise criteria of 40 dB(A) day and 35 dB(A) night for residential receivers are *"necessarily set to the lower end of the range of possible trigger values so that potential impacts on quieter suburban locations are addressed. In practice, higher levels of ground-borne noise than the trigger level for assessing impacts may be appropriate for urban areas where background noise levels are relatively high"*. In this context, a marginal exceedance of 1 dB(A) of the most stringent ground-borne noise criterion of 35 dB(A) is not likely to be significant, given the urban nature of North Sydney.

If further noise reductions are desirable because of the prestige nature of the proposed residential occupancies, the potential risk of noise exceedances can be further minimised by implementing one or more of the design measures outlined in the below sections.

[3] US Federal Transit Administration (FTA) Transit Noise and Vibration Impact Assessment Manual, FTA Report No. 0123, 2018

8.2.1 Track isolation and maintenance

Reducing vibration levels at the source (railway track) is often the most cost-effective approach to minimising potential impacts.

At North Sydney Station, replacement of the existing ballast track on Platforms 1 and 4 with a concrete slab track design and highly resilient Egg type rail fasteners could be utilised to reduce vibration levels entering the future building. Egg type rail fasteners are utilised at several locations on the existing Sydney Trains network and could be suitable for this project.

8.2.2 Building design measures

The structural design of the refurbished building should maximise the vibration attenuation (structural damping) within the building and avoid floor vibration modes that align with the dominant train vibration frequencies. Local stiffening of floor slabs could be undertaken to adjust the resonant frequencies.

On the lowest residential occupancy levels, ground-borne noise levels can be minimised in sleeping areas by minimising the reverberation time of the internal spaces, by providing carpet, soft furnishings and other absorptive finishes, rather than timber floorboards or tiles. Floating floors could be installed to minimise the re-radiated structural noise from the floor slabs.

Australian Standard AS/NZS 2107:2016 includes recommended internal design sound levels for residential buildings. For residential apartment buildings in inner city areas, entertainment districts or near major roads, the recommended L_{Aeq} design sound level range for sleeping areas is 30 dB(A) to 40 dB(A), and 5 dB(A) lower for apartments in suburban areas or near minor roads. If the proposed building includes air-conditioning systems, the steady noise levels may assist in masking the audibility of train-related noise.

8.3 Conclusion

The result of the detailed noise and vibration measurements indicate that there is a negligible risk that vibration levels within the refurbished building will be above the preferred continuous vibration levels that correspond to the approximate threshold of human perception.

There is a minor risk that noise levels from train passbys will be above the most stringent night-time ground-borne noise design objective of 35 dB(A) on the lowest residential levels. The measured noise levels on Levels 1 and 2 were within ± 1 dB(A) of the 35 dB(A) design objective, with predicted noise on higher floors reducing by 1-2 dB per floor.

On the lowest residential occupancy levels, ground-borne noise levels can be minimised in sleeping areas by minimising the reverberation time of the internal spaces, by providing carpet, soft furnishings and other absorptive finishes, rather than timber floorboards or tiles. Floating floors could be installed to minimise the re-radiated structural noise from the floor slabs.

The visual track inspection did not identify any obvious track defects that could be seen with the naked eye, in are area near 5 Blue Street. If track defects were to occur in the area adjacent to the existing foundation columns of the 5 Blue Street, this would likely generate higher noise and vibration levels within occupied areas of the building. Where rail corrugation or other defects are present, rail grinding would be required to restore the rail surface condition to acceptable levels.

APPENDIX A Glossary of terminology

The following is a brief description of the technical terms used to describe noise to assist in understanding the technical issues presented.

Adverse weather	Weather effects that enhance noise (that is, wind and temperature inversions) that occur at a site for a significant period of time (that is, wind occurring more than 30% of the time in any assessment period in any season and/or temperature inversions occurring more than 30% of the nights in winter).
Ambient noise	The all-encompassing noise associated within a given environment at a given time, usually composed of sound from all sources near and far.
Assessment period	The period in a day over which assessments are made.
Assessment Point	A point at which noise measurements are taken or estimated.
Background noise	Background noise is the term used to describe the underlying level of noise present in the ambient noise, measured in the absence of the noise under investigation, when extraneous noise is removed. It is described as the average of the minimum noise levels measured on a sound level meter and is measured statistically as the A-weighted noise level exceeded for ninety percent of a sample period. This is represented as the L90 noise level (see below).
Decibel [dB]	The units that sound is measured in. The following are examples of the decibel readings of common sounds in our daytime environment:

threshold of hearing	0 dB	The faintest sound we can hear
	10 dB	Human breathing
almost silent	20 dB	
	30 dB	Quiet bedroom or in a quiet national park location
generally quiet	40 dB	Library
	50 dB	Typical office space or ambience in the city at night
moderately loud	60 dB	CBD mall at lunch time
	70 dB	The sound of a car passing on the street
loud	80 dB	Loud music played at home
	90 dB	The sound of a truck passing on the street
very loud	100 dB	Indoor rock band concert
	110 dB	Operating a chainsaw or jackhammer
extremely loud	120 dB	Jet plane take-off at 100m away
threshold of pain	130 dB	
	140 dB	Military jet take-off at 25m away

dB(A)	A-weighted decibels. The A- weighting noise filter simulates the response of the human ear at relatively low levels, where the ear is not as effective in hearing low frequency sounds as it is in hearing high frequency sounds. That is, low frequency sounds of the same dB level are not heard as loud as high frequency sounds. The sound level meter replicates the human response of the ear by using an electronic filter which is called the "A" filter. A sound level measured with this filter switched on is denoted as dB(A). Practically all noise is measured using the A filter.
dB(C)	C-weighted decibels. The C-weighting noise filter simulates the response of the human ear at relatively high levels, where the human ear is nearly equally effective at hearing from mid-low frequency (63Hz) to mid-high frequency (4kHz), but is less effective outside these frequencies.

Frequency	Frequency is synonymous to pitch. Sounds have a pitch which is peculiar to the nature of the sound generator. For example, the sound of a tiny bell has a high pitch and the sound of a bass drum has a low pitch. Frequency or pitch can be measured on a scale in units of Hertz or Hz.
Impulsive noise	Having a high peak of short duration or a sequence of such peaks. A sequence of impulses in rapid succession is termed repetitive impulsive noise.
Intermittent noise	The level suddenly drops to that of the background noise several times during the period of observation. The time during which the noise remains at levels different from that of the ambient is one second or more.
L_{Max}	The maximum sound pressure level measured over a given period.
L_{Min}	The minimum sound pressure level measured over a given period.
L_1	The sound pressure level that is exceeded for 1% of the time for which the given sound is measured.
L_{10}	The sound pressure level that is exceeded for 10% of the time for which the given sound is measured.
L_{90}	The level of noise exceeded for 90% of the time. The bottom 10% of the sample is the L90 noise level expressed in units of dB(A).
L_{eq}	The "equivalent noise level" is the summation of noise events and integrated over a selected period of time.
Reflection	Sound wave changed in direction of propagation due to a solid object obscuring its path.
SEL	Sound Exposure Level (SEL) is the constant sound level which, if maintained for a period of 1 second would have the same acoustic energy as the measured noise event. SEL noise measurements are useful as they can be converted to obtain Leq sound levels over any period of time and can be used for predicting noise at various locations.
Sound	A fluctuation of air pressure which is propagated as a wave through air.
Sound absorption	The ability of a material to absorb sound energy through its conversion into thermal energy.
Sound level meter	An instrument consisting of a microphone, amplifier and indicating device, having a declared performance and designed to measure sound pressure levels.
Sound pressure level	The level of noise, usually expressed in decibels, as measured by a standard sound level meter with a microphone.
Sound power level	Ten times the logarithm to the base 10 of the ratio of the sound power of the source to the reference sound power.
Tonal noise	Containing a prominent frequency and characterised by a definite pitch.

The following is a brief description of the technical terms used to describe vibration to assist in understanding the technical issues presented.

Acceleration	The rate of change of velocity, often measured in m/s^2 or g's. 1 g = 9.81 m/s^2. Commonly used to assess human response to vibration and for machine condition monitoring.
Accelerometer	A vibration transducer sensor that is used to measure acceleration.
ANC	The Association of Noise Consultants, UK.
Ambient vibration	The all-encompassing vibration occurring at a given location, at a given time, composed of all vibration sources near and far.
Amplification	Vibration amplification refers to an increase in vibration. Amplification may occur due to resonance, when an object or structure is excited at its natural frequency.
Attenuation	Attenuation refers to a reduction in vibration. This may occur due to damping of a vibration system, the inclusion of attenuating devices or, in the case of ground vibration, during propagation through the ground. Ground attenuation is determined by the dynamic properties of the site's soil and rock.
AVTG	Assessing Vibration: A Technical Guideline. NSW Department of Environment and Conservation's (DEC) 2006 guideline for assessing human responses to vibration. Based on BS 6472–1992.
Axis	A fixed reference line for the measurement for the measurement of vibration in a particular direction. Vibration is commonly measured in transverse (T), longitudinal (L) and vertical (V) axes (or X, Y and Z).
Background vibration	The underlying level of vibration present in the ambient environment, measured in the absence of the vibration sources of interest.
Blasting	Excavation or demolition using explosives.
Borehole transducer	A geophone transducer rigidly mounted at the bottom of a borehole (either permanently or temporarily) to measure underground vibration.
Broadband vibration	The overall vibration level which encompasses a wide range of frequencies. As opposed to vibration levels for specific frequency bands (see Octave) or narrowband vibration levels as produced by FFT.
BS	British Standard.
Continuous vibration	Vibration that continues uninterrupted over a defined period.
Cosmetic damage	Damage to a structure due to vibration that only affects the appearance of the structure and can be easily repaired, e.g. hairline cracks in mortar joints of brick or concrete constructions, or cracks in plasterwork.
Coupling loss	The change in vibration level when vibration is transmitted from the ground to a building's foundations.
Crest factor	The ratio of the peak value of a vibration event to the RMS value of a vibration event.
Damping	Reduction of vibrational energy due to friction or other forces.
DEC	NSW Department of Environment and Conservation, now the Department of Planning, Industry and Environment.
Decibel [dB]	The logarithmic unit used to represent sound and vibration levels. A vibration level in dB equals 20 times the logarithm to the base 10 of the ratio of the vibration level relative to the reference level. For vibration velocity, the reference level is commonly 1 nm/s. For vibration acceleration, the reference level is commonly 1 $\mu m/s^2$. Other reference values are commonly used. The reference value should always be stated.
DIN	German Standard.
Displacement	Change in position of a body from a reference point. Usually measured in m or mm.
EPA	Environment Protection Authority.
eVDV	Estimated Vibration Dose Value. See also VDV.

Filter	An electrical circuit that allows signals of certain frequency ranges to pass through, and blocks all other frequencies. Types of filters include low pass filters, high pass filters, and band pass filters.
FFT	Fast Fourier Transform. An algorithm that converts a signal from the time domain to the frequency domain.
Frequency	In the case of vibration, frequency is the number of oscillations that occurs per second. Frequency is measured in units of Hertz (Hz).
Geophone	A vibration transducer sensor that is used to measure velocity.
Ground-borne noise	Vibration propagated through the ground and then radiated as noise by vibrating building elements such as wall and floor surfaces. This noise is more noticeable in rooms that are well insulated from other airborne noise. An example would be vibration transmitted from an underground rail line radiating as sound in a bedroom of a building located above.
Ground spike	A metal stake with a flat top that is driven into the ground and used to mount a vibration transducer to measure vibration levels.
Habitable Area	Includes a bedroom, living room, lounge room, music room, television room, kitchen, dining room, sewing room, study, playroom, family room, home theatre and sunroom. Excludes a bathroom, laundry, water closet, pantry, walk-in wardrobe, corridor, hallway, lobby, photographic darkroom, clothes drying room, and other spaces of a specialised nature occupied neither frequently nor for extended periods.
Intermittent vibration	Either interrupted periods of continuous vibration or repeated periods of impulsive vibration.
Impulsive vibration	Vibration that rapidly builds up to a peak followed by a damped decay. May consist of multiple impulsive events, typically less than 2 seconds in duration.
Isolation	The process of reducing the vibrational energy transmitted to an object, such as a piece of equipment or building, from the source of vibrations.
Minor damage	Damage to a structure due to vibration that affects the serviceability of residential style buildings or other sensitive structures but does not affect the structural elements. E.g. cracks in plastered or rendered surfaces, existing cracks enlarged or partitions detached.
Mode	A mode of vibration is a characteristic pattern or shape in which a mechanical system will vibrate. The actual vibration of a structure is a combination of all the vibration modes, but to varying degrees, depending on the vibration source.
Natural frequency	The frequency at which a system tends to oscillate in the absence of any driving or damping force.
Noise floor	The residual level of unwanted signal measured by an instrumentation system. The signal of interest must be above the noise floor to be measured accurately. See also Signal to noise ratio.
Octave	An octave represents a doubling or halving in frequency. Noise or vibration levels across a frequency spectrum are commonly given in octave or one-third octave frequency bands.
Peak-to-peak	The difference between the highest positive peak level and the lowest negative peak of a vibration event.
Peak vibration velocity	The absolute maximum value of the vibration velocity signal measured in the X, Y or Z axis during a given time interval. Also referred to as the peak component particle velocity.
PPV	Peak Particle Velocity. The absolute maximum value of the vibration velocity signal measured in any axis during a given time interval.
PVS	Peak Vector Sum. The vector sum of the peak vibration velocities measured in the three orthogonal axes.
Resonance	The phenomenon of increased amplitude that occurs when the frequency of an applied force is equal or close to the natural frequency of the system.
RMS	Root Mean Square value representing the average value of a signal.
Sampling rate	The number of samples per second taken from a continuous signal to make a discrete or digital signal. Measured in Hertz. To accurately record the signal and determine the spectrum, the sampling rate must two or more times the maximum frequency of interest.

Settlement	The movement of soil due to vibration or other forces, often in relation to a building's foundations. The indirect effect of settlement and ground movement may cause building damage, separately from the direct of effect of building vibration.
Signal to noise ratio	A ratio of the level of a desired signal to the level of the background, often expressed in decibels.
Source vibration	A source that generates vibration. Can be quantified by the amplitude, frequency content and duration of the vibration. Common sources of vibration include rail and road traffic, construction and demolition activities and blasting.
Spectrum	The result of transforming a signal from the time domain to the frequency domain.
Structural damage	Damage to a structure due to vibration that may affect its serviceability due to damage to structural elements. May result in the reduced stability of the building and/or reduction in load-bearing capacities.
Structural fatigue	The weakening of a material caused by cyclic loading that results in progressive and localised structural damage and the growth of cracks.
Structure-borne Noise	Audible noise generated by vibration induced in the ground and/or a structure. Vibration can be generated by impact or by solid contact with a vibrating machine. Structure-borne noise cannot be attenuated by barriers or walls but requires the isolation of the vibration source itself. This can be achieved using a resilient element placed between the vibration source and its support such as rubber, neoprene or springs or by physical separation (using an air gap for example). Examples of structure-borne noise include the noise of trains in underground tunnels heard to a listener above the ground, the sound of footsteps on the floor above a listener and the sound of a lift car passing in a shaft.
Tactile vibration	Vibration of a level that can be felt by humans, dependant on the amplitude and frequency of the source. Note that vibration may also be perceived through indirect effects such as ground-borne noise or the shaking of building elements.
Transducer	A device that converts energy from one form to another. Vibration transducers convert either acceleration, velocity or displacement to an electrical signal that is processed by the monitoring system.
Triaxial	Three axes. Measurement systems often consist of three vibration transducers arranged triaxially – oriented at 90° from each other.
VDV	Vibration Dose Value. A measure of tactile vibration levels used to assess intermittent vibration.
Velocity	The rate of change of vibration displacement, usually measured in mm/s.
Vibration	A mechanical phenomenon whereby oscillations occur about an equilibrium point; a periodic back-and-forth motion of an elastic body or medium, commonly resulting when almost any physical system is displaced from its equilibrium condition.
Vrms	Root mean square (RMS) vibration level for the train passby, typically expressed in mm/s
Waveform	A graphical representation of a vibration event in the time domain, showing the measured vibration levels for each sample.

APPENDIX B Detailed vibration measurement results

B.1 Methodology

Vibration measurements were undertaken on the carpark level and Level 2, to continuously monitor vibration from rail operations.

The equipment used for the vibration measurements comprised a triaxial accelerometer on the basement level and three single axis accelerometers on Level 2.

At both locations, the accelerometers were connected to an 8-channel Soundbook spectrum analyser. The Soundbook software (Samurai Version 3.0.0) performed continuous recordings of the time history vibration levels and 1/3 octave spectra. The time histories were post-processed to obtain measurement results for each train passby event.

A summary of measurement equipment is provided in Table 8-1.

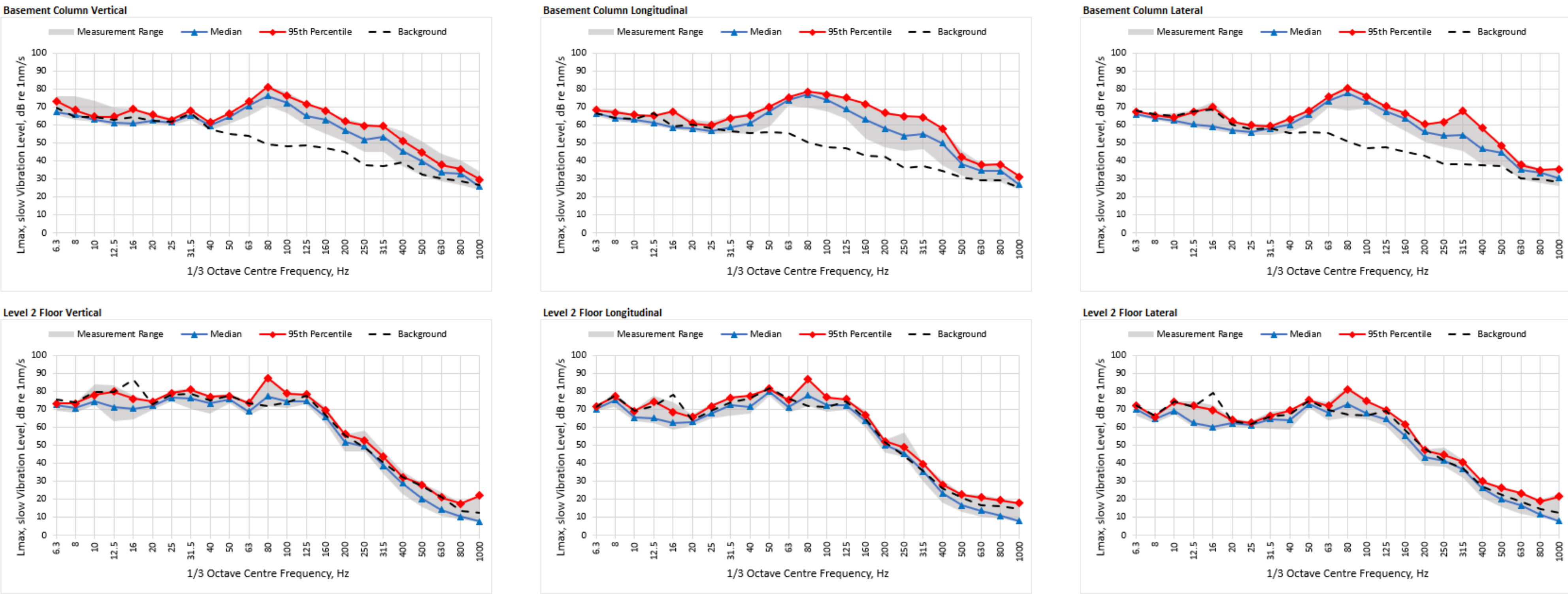
Table 8-1: Summary of vibration measurement equipment

Description	Make	Model	Serial no	Monitoring location
8 channel spectrum analyser	SINUS	Soundbook 2	9194	Level 2 Floor
8 channel spectrum analyser	SINUS	Soundbook 2	7039	Basement Column
Single Axis Accelerometer	PCB	393B12	32172	Level 2 Floor – Longitudinal
Single Axis Accelerometer	PCB	393B12	32173	Level 2 Floor – Lateral
Single Axis Accelerometer	PCB	393B12	32174	Level 2 Floor – Vertical
Triaxial Accelerometer	PCB	356B18	LW380440	Basement Column

B.2 Measurement results

A summary of the vibration measurement results is provided in Figure 8-1.

Figure 8-1: Summary of vibration results



APPENDIX C Detailed noise measurement results

C.1 Methodology

Measurements were undertaken Level 1 and Level 2, to continuously monitor noise the noise levels during rail operations. The equipment used for the noise measurements comprised two sound level meters (SLMs).

The SLMs continuously stored the overall and 1/3 octave spectra in 0.1 second intervals throughout the noise survey period. The time histories were post-processed to obtain measurement results for each train passby event. For ground-borne noise, the relevant frequency range is 10 Hz to 250 Hz.

A summary of measurement equipment is provided in Table 8-2. All equipment was calibrated before and after and no significant deviation in calibration was noted. The noise monitoring equipment used in the surveys comply with AS IEC 61672.1 2004 *"Electroacoustics - Sound Level Meters"* and are designated as Type 1 instruments, suitable for field use.

Table 8-2: Summary of noise measurement equipment

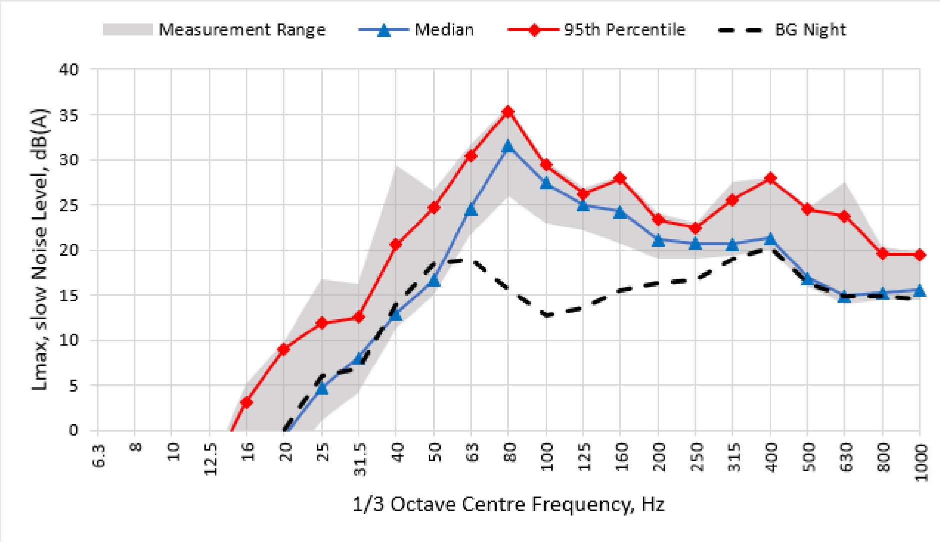
Description	Make	Model	Serial no	Monitoring location
Sound Level Meter	NTI	XL2	A2A-18950-E0	Level 1 office
Sound Level Meter	NTI	XL2	A2A-15733-E0	Level 2 common area
SLM Field Calibrator	BK	4231	3009707	Both locations

C.2 Measurement results

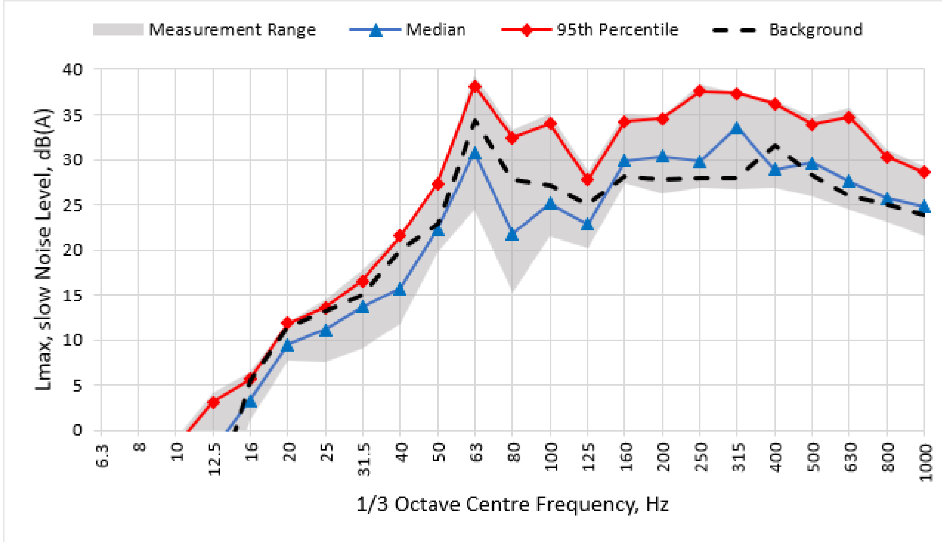
A summary of the vibration measurement results is provided in Figure 8-2.

Figure 8-2: Summary of noise results

Level 1 Noise Results



Level 2 Noise Results



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