global environmental solutions

Cross River Rail

Environmental Impact Statement

Operational Noise and Vibration

PART A

Report Number 20-2524-R3

6 June 2011

SKM-Aurecon Joint Venture
PO Box 3848
South Brisbane QLD 4101

Version: Revision 0

Cross River Rail

Environmental Impact Statement

Operational Noise and Vibration

PREPARED BY:

SLR Consulting Australia Pty Ltd
Ground Floor, Suite 7, 240 Waterworks Road Ashgrove QLD 4060 Australia
Telephone 61 7 3858 4800 Facsimile 61 7 3858 4801
Email brisbane@slrconsulting.com Web www.slrconsulting.com

DOCUMENT CONTROL

Reference	Status	Date	Prepared	Checked	Authorised
20-2524-R3	Revision 0	6 June 2011	Jennifer Uhr Henrik Malker John Sleeman	Shane Elkin Conrad Weber Richard Heggie	Shane Elkin

EXECUTIVE SUMMARY

1 INTRODUCTION

SLR Consulting Australia Pty Ltd (SLR Consulting) has been commissioned by the SKM-Aurecon CRR Joint Venture (CRR JV) to prepare an assessment of the operational noise and vibration aspects of the Cross River Rail (CRR) for inclusion in the Environmental Impact Statement (EIS).

CRR is a major project for the City of Brisbane, South East Queensland and the State of Queensland. It will provide a new north-south rail line in Brisbane's inner city that includes a new river crossing and inner city train stations. From the existing southern rail network, it will pass under the central business district (CBD) of Brisbane and connect with the existing northern rail network via the Exhibition loop. The project will include a tunnel under the Brisbane River and four new underground stations as well as upgrades to existing train stations.

Please note that all table and figure numbers in this Executive Summary have been kept the same as the corresponding tables and figures in the main body of the text for ease of reference.

1.1 Terms of Reference

The specific requirements of the Terms of Reference in relation to operational noise and vibration impacts associated with the project are reproduced below.

- Description of Environmental Values
  - Describe the existing noise and vibration environment.
  - Conduct additional baseline noise and vibration monitoring at representative sites in accordance with DERM's Noise Measurement Manual.
  - Identify sensitive noise and vibration receptors adjacent to more significant project components (eg proposed tunnel alignment, station and tunnel portal locations).
  - Nominate appropriate performance indicators and standards with reference to the Environmental Protection (Noise) Policy 2008 (EPP(Noise)) and DERM's EcoAccess Guideline Planning for Noise Control, where appropriate.
- Potential Impacts and Mitigation Measures – Operational
  - Assess the levels of noise and vibration generated, including noise and vibration generated by underground and surface rail operations (including tunnel ventilations shafts at surface locations).
  - Assess the impact of noise, including low frequency noise (noise with components below 200Hz) and vibration at all potentially sensitive receivers and transport related infrastructure within and around the study corridor compared with the nominated performance indicators and standards.
  - Develop proposals to minimise or eliminate any effects, including details of any screening, lining, enclosing or bunding (earth mounds) of facilities.
  - Analyse noise levels from proposed rail surface traffic against the planning levels stated in the Queensland Rail Code of Practice for Rail Noise Management.
  - Develop likely operational noise and vibration management measures.

EXECUTIVE SUMMARY

1.2 Objectives

The objectives of this report in relation to the project description are to:

- Address the acoustical requirements detailed in the project's Terms of Reference in relation to the operational phase of the project.
- Evaluate the operational noise and vibration impacts at sensitive locations in terms of planning levels identified in the EPP(Noise), Queensland Rail Code of Practice and other standards and guidelines.
- Define noise and vibration goals by which operational noise and vibration impacts at sensitive locations may be evaluated and assessed.
- Evaluate and assess the extent of resulting impacts and the scope for the reduction of these impacts through reasonable and feasible mitigation strategies.
- Recommend appropriate impact mitigation measures.

2 IMPACT ASSESSMENT GOALS

2.1 Community Values Relating to Noise and Vibration

The EPP(Noise) defines the values to be protected as the qualities of the acoustic environment that are conducive to:

a. Protecting the health and biodiversity of ecosystems.

b. Enhancing human health and wellbeing, including by ensuring a suitable acoustic environment for individuals to do any of the following-

  - Sleep
  - Study or learn
  - Be involved in recreation, including relaxation and conversation

c. Protecting the amenity of the community.

2.2 Surface Rail Operation

The applicable noise goals for the railway surface track airborne noise emissions are in accordance with Queensland Rail's Code of Practice – Railway Noise Management (Queensland Rail's Code of Practice).

Queensland Rail's Code of Practice outlines the operational "planning levels" applicable to this project.

The Planning Levels are:

- 65 dBA, evaluated as the 24 hour average equivalent continuous A-weighted sound pressure level, $L_{Aeq(24hour)}$.
- 87 dBA, evaluated as a Single Event Maximum sound pressure level.

The planning levels refer to an assessment location one metre in front of the facade of an affected noise sensitive building.

EXECUTIVE SUMMARY

2.3 Ground-borne Vibration

There are several sources from which relevant vibration criteria may be drawn. These include:

- Australian Standard AS 2670.2 1990 “Evaluation of Human Exposure to Whole Body Vibration - Part 2: Continuous and Shock Induced Vibration in Buildings (1 Hz to 80 Hz)”.
- The United States Federal Transit Administration (FTA) Guideline “Transit Noise and Vibration Impact Assessment”.
- British Standard BS 6472-1:2008 “Guide to evaluation of human exposure to vibration in buildings Part 1: Vibration sources other than blasting”.
- The NSW Department of Environment, Climate Change and Water (DECCW) document “Assessing Vibration: A Technical Guideline”.

The vibration goals have been expressed both in terms of vibration velocity mm/s and decibels (dB_V re 10^{-9} m/s). A level of 100 dB corresponds to 0.1 mm/s (rms) and a level of 120 dB corresponds to 1 mm/s (rms).

Based on the above references, the proposed vibration goals are listed in **Table 3**. For assessment purposes, these goals may be regarded as applicable to the maximum 1 second rms vibration level, not to be exceeded by more than 5% of train passbys.

Table 3 Ground-borne Vibration Goals

Receiver Type	Period	Vibration Goal[1,2] (Vibration Velocity)
Residential	Day/Night	106 dB_V (0.2 mm/s)
Commercial (including schools and places of worship)	When in use	112 dB_V (0.4 mm/s)
Industrial	When in use	118 dB_V (0.8 mm/s)
Sensitive equipment within medical or research facilities	When in use	82 dB_V (0.013 mm/s) [3]

Note 1: The vibration goals are based on the maximum 1 second rms vibration level, not to be exceeded by more than 5% of train passbys.
2: dB_V re 10^{-9} m/s
3: Unless actual equipment manufacturer data are available.

In the case of railway tunnels, the ground-borne noise goals, presented below, almost always dictate lower vibration emission levels than the vibration goals indicated in **Table 3**. Hence other than at specific facilities with equipment with particularly high sensitivity to vibration, compliance with the ground-borne noise goals ensures that the vibration goals will also be achieved.

2.4 Ground-borne Noise

There are no Australian Standards specifically addressing the issue of ground-borne noise from railway operations. Guidance can be obtained, however, from the following International and Australian references:

- International Standard ISO 14837-1:2005(E) Mechanical vibration - Ground-borne noise and vibration arising from rail systems - Part 1: General Guidance, First Edition 2005
- American Public Transit Association (APTA), Guidelines for Design of Rapid Transit Facilities, 1991

EXECUTIVE SUMMARY

- Federal Transit Administration (FTA), US Department of Transport, Transit Noise and Vibration Impact Assessment, May 2006.
- The Association of Noise Consultants Measurements & Assessment of Groundborne Noise & Vibration, 2001.
- Harris Miller Miller and Hanson Inc. Transit Noise and Vibration Impact Assessment, 1995 (a guideline prepared for the United States Department of Transportation).
- NSW DECCW's Interim Guideline for the Assessment of Noise from Rail Infrastructure Projects (IGANRIP).

All the above standards and guidelines acknowledge and are specifically designed to take into account the intermittent and low frequency character of ground-borne noise and subjective characteristics of underground rail operations as part of the assessment criteria. Therefore, these guidelines have been deemed more relevant than the more general (ie not specific to ground-borne noise from underground rail operations) Ecoaccess Draft Guideline *Assessment of Low Frequency Noise*.

ISO 14837 provides guidance in relation to the prediction of ground-borne noise levels and factors that need to be considered in the prediction process. Acceptability criteria are not included in Part 1 of the ISO Standard, but are anticipated to be included as Part 4 (when available).

Based on the criteria within the above Australian and International standards and guidelines, **Table 5** provides a summary of the proposed ground-borne noise goals for the CRR project.

Table 5 Ground-borne Noise Goals

Receiver	Time of Day	Noise Trigger Level (dBA)[1]
Residential	Day (7.00 am to 10.00 pm)	40 dBA
	Night (10.00 pm to 7.00 am)	35 dBA
Schools, educational institutions, places of worship[2]	When in use	40 dBA to 45 dBA
Retail Areas	When in use	50 dBA to 55 dBA
General Office Areas	When in use	45 dBA
Private Offices and Conference Rooms	When in use	40 dBA
Theatres	When in use	35 dBA

Note 1: Evaluated as the L_{Amax} "Slow" response noise level (interpreted as applicable to the 95th percentile train passby event ie typically the highest 1 in 20 event).

Note 2: The lower value of the range is primarily applicable where low internal noise levels are expected, such as in areas assigned to studying, listening, quiet contemplation and praying.

2.5 Mechanical Plant and Ventilation

Relevant assessment criteria for operational mechanical plant noise can be found in the following:

- EPP(Noise)
  - Minimising Background Creep – Existing L_{A90} + 0 dBA
  - Acoustic Quality Objectives – Refer to Schedule 1 in EPP(Noise)
- DERM Ecoaccess Guideline Planning for Noise Control (Ecoaccess PNC)
  - Minimising Background Creep – Refer to Table 1 and Table 2 of Ecoaccess PNC

EXECUTIVE SUMMARY

- Planning Noise Levels (PNL) – Refer to Table 3 and Table 4 of Ecoaccess PNC
- Specific (Intrusive) Noise Levels (SNL) – Existing Rating Background Level (RBL) + 3 dBA (assessed as L_{Aeq})

- DERM Ecoaccess Draft Guideline *Assessment of Low Frequency Noise* (Ecoaccess ALFN) – Refer to Table 3 of the draft Ecoaccess ALFN.
- Brisbane City Council (BCC) Noise Impact Assessment Planning Scheme Policy (NIAPSP)
    - Minimising Background Creep – Existing L_{A90} + 0 dBA (for noise categories R3 to R6 as per Appendix A of AS 1055.2)
    - Comparison of Like Parameters – Existing LA90 + 0 dBA
    - AS/NZS 2107: 2000 Acoustics – Recommended design sound levels and reverberation times for building interiors (AS 2107) internal noise levels – Refer to Table 1 in AS 2107

The applicable statutory requirement for noise emissions associated with fixed mechanical plant is the EPP(Noise). The EPP(Noise) nominates long term acoustic quality objectives and background creep criteria applicable to stationary mechanical plant.

The background creep criteria according to the EPP(Noise) are identical to the background creep criteria according to the BCC NIAPSP. The Ecoaccess PNC includes more complex background noise criteria. In determining the appropriate background creep goals, the statutory and Brisbane City Council criteria have been adopted.

Mechanical ventilation noise is generally steady state (ie the noise emission varies very little with time in the short term) and therefore the difference between the L_{A90} the L_{Aeq} will be small. As a result, based on the criteria/limits discussed above, the L_{A90} based background creep criteria will be stricter than the L_{Aeq} based intrusive noise criterion. In determining the appropriate goals, a conservative approach has been adopted and thus only a background creep goal has been recommended.

The Ecoaccess ALFN guideline gives advice regarding assessment of infrasound and low frequency noise. The mechanical ventilation and/or emergency ventilation noise associated with the CRR project is not anticipated to generate any infrasound or distinctly low frequency noise and therefore will not require a specific assessment.

On the basis of the above references and discussion, the proposed noise goals for mechanical plant are presented in **Table 6**.

EXECUTIVE SUMMARY

Table 6 Operational Mechanical Plant Noise Goals

Receiver	Time of Day	Background Noise Creep[1] dBA LA90(1hour)	Acoustic Quality Objectives[2] dBA LAeq(1hour)
Residential (for outdoors)	7am to 10pm	b/g + 0 [3]	50 [3]
	10pm to 7am	b/g + 0	-
Residential (for indoors)	7am to 10pm	-	35
	10pm to 7am	-	30
Library and educational institution (including a school, college and university) (for indoors)	when open for business or when classes are being offered	-	35
Commercial and retail activity (for indoors)	when the activity is open for business	-	45

Note 1: Background creep criteria in accordance with the EPP(Noise) and BCC NIAPSP for continuous noise sources, adopting the Rating Background Level in accordance with the DERM Ecoaccess PNC. Applicable for noise contribution from the source only.
2: Long term acoustic quality objectives according to EPP(Noise).
3: The lower of the background creep LA90(1hour) and Acoustic Quality Objectives LAeq(1hour) is applicable.

2.6 Road Traffic Noise

The effects of CRR will require realignment of a few nearby sections of roadway . Road traffic noise emissions from realigned road sections within the study area are assessed against the planning noise levels outlined in the Department of Transport and Main Roads (DTMR) Code of Practice – Road Traffic Noise Assessment. The Code of Practice provides planning noise levels for proposed roads, road upgrades and existing roads for residential land use developments as well as criteria for other noise sensitive land uses. The relevant planning noise levels for the realigned road sections is that of Category 2 “Upgrading Existing Roads “of the DTMR Code of Practice as shown in **Table 7**.

Table 7 DTMR Code of Practice – Road Noise Goal for Existing Residences

Description	Noise Descriptor	Goal
Category 2 Upgrading Existing Roads	LA10(18hour)[1] – external	68 dBA

Note 1: Arithmetic average of the 18 hourly LA10 levels over the consecutive hours from 6.00am to midnight.

In **Table 7**, the external assessment location (for existing residences) is 1 m from the most exposed facade of the “noise sensitive” building and 0.5 m below the surveyed eaves height of the “noise sensitive” building.

It should be noted that the noise assessment planning noise levels presented within DTMR’s Code of Practice are guidelines for consideration of the impact of road traffic noise on noise sensitive development. Consideration needs to be given to technical feasibility, cost effectiveness, aesthetics, equity, community consultation and practicality in recommending noise attenuation measures. This acknowledges that in some instances, certain noise attenuation measures may not be feasible and therefore not recommended.

3 IDENTIFICATION OF NOISE SENSITIVE BUILDINGS

Apart from the residential dwellings that are in the vicinity of the CRR alignment, other noise/vibration sensitive receivers have been identified. These have been considered in this report when assessing the potential for impacts arising from airborne or ground-borne noise and vibration.

EXECUTIVE SUMMARY

These include the following types of facilities:

- Medical Facilities
- Child Care and Educational
- Places of Worship
- Heritage
- Commercial
- Hotel

4 EXISTING NOISE AND VIBRATION ENVIRONMENT

4.1 Noise

Ambient noise monitoring was conducted at twenty (20) residential and special use (ie educational or medical) locations spaced at representative intervals along the study corridor. Both operator-attended and unattended ambient noise measurements have been conducted in order to document the existing noise environment with an appropriate level of confidence. The measured ambient noise levels have been used (in part) to determine applicable project noise goals.

The unattended ambient noise measurements were used to determine the Rating Background Levels (RBL) for the daytime (7.00 am to 6.00 pm), evening (6.00 pm to 10.00 pm) and night-time (10.00 pm to 7.00 am) periods at each location. The RBL is the median of the 90th percentile background (L_{A90}) noise levels in each assessment period (day, evening and night) over the duration of the monitoring (as defined in the DERM's *Ecoaccess PNC*). **Table 9** presents the determined RBL for each measurement location.

EXECUTIVE SUMMARY

Table 8 Measured Rating Background Levels

Monitoring Location	Rating Background Levels (RBL), LA90 (dBA)		
	Day	Evening	Night
1 1/19 Chalk St	54	45	38
2 28 Bridge St	49	45	38
3 St Josephs College	50	48	40
4 Brisbane Girls Grammar	61	60	46
5 St Andrew War Memorial Hospital	55	53	51
6 Parkland Cres	54	50	47
7 191 George St	58	57	54
8 QUT Gardens Point	49	48	46
9 58 Leopard St	53	50	46
10 143 Park Rd	43	39[1]	34
11 Dutton Park State School	44	40	35
12 19 Dutton St	43	42	37
13 4 Fenton St	39	38	34
14 17 Lagonda St	42	41	39
15 Yeronga State High School	43[2]	41[2]	36[2]
16 3 Cardross St	42	37	33
17 1223 Ipswich Mwy	53	48	46
18 2/59 Brook St	50	43	42
19 Nyanda State High School	54	50	46
20 14 Bellevue Ave	45	45	44

Note 1: Adjusted to remove the influence of atypical insect noise.
Note 2: Background noise level representative of only one day of noise data, due to vandalism of the noise logger.

On review of the measured ambient noise levels, the statistical noise plots (**Appendix B**), the 1/3 octave band attended measurements and operator notes during attended measurements, only one location (143 Park Rd) showed the presence of atypical insect noise. The short periods (around 6.00 pm) dominated by insect noise at 143 Park Rd were excluded when determining the RBL in **Table 9** to generate a conservatively low (ie no insects present) background noise level.

It is expected that there would be periods during the year when ambient and background noise levels along the project could be higher than those shown in **Table 9** due to the presence of insect and bird noise.

It should be noted that the Brisbane Girls Grammar school has high ambient noise levels and is representative of a location close to a Motorway (Inner City Bypass) with no existing noise barriers.

High noise levels have also been monitored at St Andrew Hospital and 191 George Street. These are representative of typical inner city locations with high density road traffic, pedestrian activity and nearby mechanical noise.

Monitoring locations 10 through to 16 show lower ambient noise levels, representative of the locations with more suburban characteristics - ie larger distances from receivers to dominant noise sources. For most locations, including these suburban locations (somewhat) distant to major roads, road traffic noise still dominates background noise levels.

EXECUTIVE SUMMARY

Furthermore, monitoring locations 1, 6, 9, 17 and 19 are near major connector roads and accordingly show higher ambient noise levels.

4.2 Vibration

Unlike noise, existing ambient vibration levels at residences and other sensitive buildings are not particularly relevant in the assessment of potential vibration issues. This is primarily because vibration impacts are assessed based on absolute criteria rather than criteria that are expressed relative to an existing ambient level. Never-the-less, existing vibration levels along the study corridor were measured to compare (if required) with future vibration levels with the CRR project in operation.

Ambient vibration monitoring was conducted at eleven (11) residential and special use (ie educational/research or medical facilities) locations along the study corridor.

The unattended ambient vibration measurements were used to determine the Average Minimum Background Level (V_{90}), Average Maximum Level (V_{10}) and Maximum Level (V_1) for the daytime (7.00 am to 6.00 pm), evening (6.00 pm to 10.00 pm) and night-time (10.00 pm to 7.00 am) periods at each location. **Table 11** contains the determined vibration levels for each measurement location. Graphs showing the peak particle velocity (mm/s) measured at each monitoring location during the monitoring period are presented in **Appendix D**.

EXECUTIVE SUMMARY

Table 10 Measured Existing Ambient Vibration

Monitoring Location[1]	Average Minimum Background Vibration V_{90} (mm/s) [2]			Average Maximum Vibration V_{10} (mm/s) [3]			Maximum Vibration V_1 (mm/s) [4]		
	Day	Evening	Night	Day	Evening	Night	Day	Evening	Night
1	0.07	0.04	0.02	0.66	0.20	0.14	2.31	0.82	0.49
2	0.04	0.04	0.04	0.05	0.05	0.05	0.08	0.05	0.05
3	0.03	0.03	0.02	0.08	0.05	0.04	0.17	0.08	0.06
4	0.04	0.04	0.03	0.06	0.05	0.04	0.07	0.07	0.06
5	0.02	-	-	0.02	-	-	0.03	-	-
6	0.01	0.01	0.01	0.04	0.14	0.02	0.16	0.57	0.16
7	0.04	0.04	0.04	0.06	0.10	0.05	0.19	0.49	0.10
8	0.03	0.03	0.03	0.04	0.04	0.03	0.31	0.04	0.04
9	0.04	0.06	0.04	0.70	0.84	0.23	2.69	1.61	0.71
10	0.04	0.04	0.04	0.05	0.05	0.04	0.11	0.08	0.13
11	0.10	0.04	0.03	0.30	0.22	0.21	1.50	0.50	0.35

Note 1: All locations are residential excluding locations 2 to 5.

Note 2: The V_{90} is the vibration velocity exceeded 90% of a given measurement period and is representative of the average minimum background vibration.

Note 3: The V_{10} is the vibration velocity exceeded 10% of a given measurement period and is utilised normally to characterise average maximum vibration.

Note 4: The V_1 is the vibration velocity exceeded for 1% of a given measurement period. This parameter is sometimes used to represent the maximum vibration in a given period. The absolute maximum peak particle velocity is higher than this V1 as can be seen in **Appendix D**.

The background vibration level (V_{90}) for all sites varies between 0.01 mm/s to 0.1 mm/s during daytime and evening. During the night-time, the background vibration level (V_{90}) varies between 0.01 mm/s to 0.04 mm/s. Maximum vibration levels (V_1) for the residential monitoring locations were in the range of 0.11 mm/s to 2.69 mm/s during daytime and evening. During night-time, vibration levels (V_1) of 0.04 mm/s to 0.71 were measured. The average maximum levels (V_{10}) for the residential monitoring locations ranged 0.04 mm/s to 0.84 mm/s during daytime and evening.

It can be noted that high vibration levels have been monitored at locations 1, 9 and 11 which are on timber floors in residential dwellings. This shows that normal activities (ie closing doors, drawers and cupboards, walking, moving and sitting on furniture etc) in these residential dwellings with light-weight (timber) floors generate vibration levels significantly above the vibration goals presented in **Section 2.3**.

For receivers with vibration sensitive equipment locations 3 (St Andrews Hospital) and location 5 (QUT), background vibration levels (V_{90}) of 0.02 mm/s to 0.03 mm/s and maximum vibration levels (V_1) of 0.03 mm/s to 0.17 mm/s, were measured.

5 GROUND-BORNE VIBRATION ASSESSMENT

During train operations within the tunnels, vibration generated at the wheel/rail interface will be transferred via the rail mounts into the track support system and surrounding ground. It then travels through the ground or structures and in some circumstances may sometimes be felt as tactile vibration by the occupants of buildings.

EXECUTIVE SUMMARY

For the ground-borne noise and vibration modelling, there are currently no commercially available modelling software packages. The modelling for the CRR project was therefore carried out using a SLR Consulting-developed modelling process for the core calculations. The algorithms incorporated into the in-house model are well documented in authoritative references and are widely used within the acoustical consulting profession, both in Australia and internationally.

This model was validated using measurement data collected from the Epping to Chatswood Railway Line (ECRL) in Sydney which was opened to the public in February 2009. The ECRL and proposed CRR projects share similar design characteristics in relation to the circular tunnel cross section and the slab track design. Where differences exist between the ECRL and CRR (eg ground conditions, rolling stock and track/rolling stock maintenance practices), these have been accounted for in the ground-borne noise and vibration predictions. To ensure ground conditions along the CRR alignment were taken into account, borehole vibration testing at three locations was undertaken to determine the ground vibration attenuation versus distance characteristics.

The modelling approach was based on the guidelines contained in International Standard ISO 14837-1 2005 “Mechanical vibration - Ground-borne noise and vibration arising from rail systems - Part 1: General Guidance”, taking into account the source vibration levels, the propagation in the ground between the source and receiver and the vibration propagation within the building.

For most new railway lines, the standard track design usually incorporates resilient rail fasteners to reduce the dynamic forces that occur at the wheel-rail interface. This resilience also serves to provide some isolation of ground-borne vibration, which in turn reduces the ground-borne noise levels in buildings near the railway tunnel.

For the proposed CRR, three trackforms have been proposed as part of the Reference Project to achieve the ground-borne vibration and noise objectives. These comprise a “Direct Fixation” trackform incorporating standard “stiff” rail fasteners (ie not specifically designed for vibration isolation – merely track durability), “Resilient” trackform incorporating moderately resilient rail fasteners and “Highly Resilient” trackform incorporating highly resilient rail fasteners. The latter two types are specifically designed to reduce vibration and ground-borne noise propagation.

Whilst the Reference Project is based on the Pandrol Sleeper systems – Pandrol HDPE (Direct), VIPA (Resilient) and Vanguard (Highly Resilient) – equivalent performance track design options are available from several other suppliers (ie Delkor, Sonneville etc). These may be adopted for the final design (on the proviso that the acoustic performance is equivalent to or better than the Pandrol Sleeper systems).

For the Reference Project, the design team has proposed a trackform configuration along the alignment as described in **Table 15**. The proposed trackform was based on preliminary predictions performed by the design team.

EXECUTIVE SUMMARY

Table 15 Extent of Reference Project Trackforms

Track Chainage (km)	Proposed Reference Project Trackforms
0 – 0.36	Direct Fixation with rail pads on ballast track
0.36 – 0.95	Highly Resilient rail fasteners
0.95 – 2.95	Resilient rail fasteners
2.95 – 3.15	Highly Resilient rail fasteners
3.15 – 5.95	Resilient rail fasteners
5.95 – 6.55	Direct Fixation with rail pads
6.55 – 9.05	Resilient rail fasteners
9.05 – 10	Direct Fixation with rail pads

Note: The direct fixation, resilient and highly resilient trackforms are modelled as the Pandrol HDPE, Pandrol VIPA and Pandrol Vanguard respectively.

On the basis of the proposed Reference Project alignment, operating speeds and design/maintenance assumptions, the predicted ground-borne vibration levels with the proposed Reference Project trackform are more than a factor of 3 below the residential vibration goal at the nearest sensitive receiver locations as shown in **Table 19**. On this basis, vibration levels from train passbys are not likely to be perceptible within nearby buildings.

The predicted ground-borne vibration levels comply with the instrument-specific vibration criteria given for the electron microscope at the Eco-science precinct. As a risk management precaution, it is recommended that more detailed measurements and predictions be performed at this site due to the short slant distance between the underground rail operations and vibration sensitive equipment (in the Eco-science precinct) to confirm that operation will be undisturbed.

EXECUTIVE SUMMARY

Table 19 Summary of Predicted Operational Ground-borne Vibration Levels (Reference Project Trackform)

Chainage (km)	Type of Building	Min. Slant Distance to Track Level	Predicted Ground-borne Vibration Level (mm/s)[1]	Residential Night-time Vibration Goal (mm/s)[1,2]	Reference Design Mitigation Measure[3]
0.36 – 0.95 Southern Portal to Christensen St, Yeronga	Residential Commercial Educational/Heritage Worship	18 m – 108 m 57 m – 81 m 77 m 24 m – 26 m	0.001 to 0.027 mm/s 0.003 to 0.006 mm/s 0.002 mm/s 0.006 mm/s	0.2 mm/s	Highly Resilient Rail Fasteners
0.95 – 2.0 Christensen St, Yeronga to Southern Ventilation Building (Bledisloe St)	Residential Commercial Worship Medical	25 m – 117 m 34 m – 80 m 88 m 35 m	0.002 to 0.039 mm/s 0.003 to 0.015 mm/s 0.002 mm/s 0.008 mm/s	0.2 mm/s	Resilient Rail Fasteners
2.0 – 2.95 Southern Ventilation Building (Bledisloe St) to Stimpson St, Fairfield	Residential Commercial Worship Medical	21 m – 115 m 26 m – 85 m 26 m – 61 m 41 m	0.003 to 0.047 mm/s 0.002 to 0.011 mm/s 0.014 to 0.034 mm/s 0.007 mm/s	0.2 mm/s	Resilient Rail Fasteners
2.95 – 3.15 Stimpson St, Fairfield to Fenton St, Fairfield	Residential Commercial	18 m – 82 m 18 m – 21 m	0.003 to 0.038 mm/s 0.012 to 0.014 mm/s	0.2 mm/s	Highly Resilient Rail Fasteners
3.15 – 3.95 Fenton St, Fairfield to Boggo Road Station	Residential Commercial Heritage Medical	23 m – 108 m 20 m – 110 m 28 m – 63 m 28 m – 29 m	0.002 to 0.035 mm/s 0.002 to 0.025 mm/s 0.005 to 0.017 mm/s 0.023 to 0.024 mm/s	0.2 mm/s	Resilient Rail Fasteners
3.95 – 5.1 Boggo Road Station to Woolloongabba Station	Residential Commercial Educational Worship Hotel	15 m – 94 m 22 m – 89 m 76 m – 111 m 60 m – 97 m 43 m	0.002 to 0.038 mm/s 0.003 to 0.031 mm/s 0.003 to 0.005 mm/s 0.005 to 0.010 mm/s 0.014 mm/s	0.2 mm/s	Resilient Rail Fasteners

EXECUTIVE SUMMARY

Chainage (km)	Type of Building	Min. Slant Distance to Track Level	Predicted Ground-borne Vibration Level (mm/s)[1]	Residential Night-time Vibration Goal (mm/s)[1,2]	Reference Design Mitigation Measure[3]
5.1 – 6.85 Woolloongabba Station to Albert Street Station	Residential Commercial Educational Worship Medical Hotel	38.5 m – 202 m 26 m – 168 m 37 m – 234 m 42 m – 192 m 201 m 19 m – 146 m	0.001 to 0.025 mm/s 0.002 to 0.023 mm/s 0.002 to 0.015 mm/s 0.001 to 0.008 mm/s 0.002 mm/s 0.001 to 0.023 mm/s	0.2 mm/s	Resilient Rail Fasteners (Chainage 5.95 – 6.55 km rail section under the Brisbane River with Direct Fixation Rail Fasteners)
6.85 – 7.9 Albert Street Station to Roma Street Station	Commercial Educational Worship Heritage Medical Hotel	17 m – 91 m 52 m – 58 m 52 m – 82 m 33 m – 67 m 32 m – 98 m 22.5 m – 82 m	0.004 to 0.059 mm/s 0.009 to 0.025 mm/s 0.015 to 0.029 mm/s 0.023 to 0.056 mm/s 0.012 to 0.058 mm/s 0.006 to 0.044 mm/s	0.2 mm/s	Resilient Rail Fasteners
7.9 – 9.55 Roma Street Station to Northern Portal	Residential Commercial Educational Medical Hotel	38 m – 121 m 50 m – 113 m 43 m – 122 m 138 m 51 m – 108 m	0.002 to 0.023 mm/s 0.003 to 0.018 mm/s 0.003 to 0.021 mm/s 0.003 mm/s 0.005 to 0.017 mm/s	0.2 mm/s	Resilient Rail Fasteners (Chainage 9.05– 9.55 km rail section with Direct Fixation Rail Fasteners)

Note 1: The predicted vibration levels and vibration goal are based on the maximum 1 second rms vibration level, not to be exceeded by more than 5% of train passbys.
Note 2: The residential night-time vibration goal is the most stringent operational vibration goal.
Note 3: The proposed Reference Project trackform is detailed in **Table 15**.

EXECUTIVE SUMMARY

6 GROUND-BORNE NOISE ASSESSMENT

Train noise in buildings adjacent to rail tunnels is predominantly caused by the transmission of ground-borne vibration rather than the direct transmission of noise through the air. The vibration is initially generated by wheel/rail interaction (as described above) and is transmitted from the trackbed, through the tunnel structure, via the ground and into the adjacent building structures. After entering a building, this vibration causes the walls and floors to vibrate faintly and hence to radiate noise (commonly termed “ground-borne noise”).

If it is of sufficient magnitude to be audible, this noise has a low frequency rumbling character, which increases and decreases in level as a train approaches and departs the site. This type of noise can be commonly experienced in buildings adjacent to urban underground rail systems.

The ground-borne noise goals for residential receiver locations are based on the ground-borne noise trigger levels in the NSW DECCW’s IGANRIP. This guideline recommends a ground-borne noise “trigger level” of $L_{Amax\ (slow)}$ 35 dBA during the night-time period. At other sensitive receiver locations, ground-borne noise goals have been based on IGANRIP (for educational facilities and places of worship) as well as on SLR Consulting experience on other underground railway lines in Australia and internationally.

A summary of the predicted ground-borne noise levels at all sensitive receivers above or near the tunnel alignment with the Reference Project trackform configuration is shown in **Table 21**.

Exceedances of nominated project goals have been shown in bold red.

EXECUTIVE SUMMARY

Table 21 Summary of Predicted Ground-borne Noise Levels (Reference Project Trackform)

Chainage (km)	Type of Building	Min. Slant Distance to Track Level	Predicted Ground-borne Noise Level (dBA)	Ground-borne Noise Goal (dBA)	Reference Design Mitigation Measure
0.36 – 0.95 Southern Portal to Christensen St, Yeronga	Residential Commercial Educational/Heritage Worship	18 m – 108 m 57 m – 81 m 77 m 24 m – 26 m	<10 dBA to 27 dBA <10 dBA <10 dBA 20 dBA to 21 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA	Highly Resilient Rail Fasteners
0.95 – 2.0 Christensen St, Yeronga to Southern Ventilation Building (Bledisloe St)	Residential Commercial Worship Medical	25 m – 117 m 34 m – 80 m 88 m 35 m	<10 dBA to 33 dBA 12 dBA to 28 dBA <10 dBA 28 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA	Resilient Rail Fasteners
2.0 – 2.95 Southern Ventilation Building (Bledisloe St) to Stimpson St, Fairfield	Residential Commercial Worship Medical	21 m – 115 m 26 m – 85 m 26 m – 61 m 41 m	<10 dBA to **36 dBA** 10 dBA to 32 dBA 17 dBA to 31 dBA 25 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA	Resilient Rail Fasteners
2.95 – 3.15 Stimpson St, Fairfield to Fenton St, Fairfield	Residential Commercial	18 m – 82 m 18 m – 21 m	<10 dBA to 31 dBA 33 dBA to 36 dBA	35 dBA (night-time) 40 dBA	Highly Resilient Rail Fasteners
3.15 – 3.95 Fenton St, Fairfield to Boggo Road Station	Residential Commercial Heritage Medical	23 m – 108 m 20 m – 110 m 28 m – 63 m 28 m – 29 m	<10 dBA to 32 dBA <10 dBA to 28 dBA <10 dBA to 35 dBA 27 dBA to 28 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA	Resilient Rail Fasteners
3.95 – 5.1 Boggo Road Station to Woolloongabba Station	Residential Commercial Educational Worship Hotel	15 m – 94 m 22 m – 89 m 76 m – 111 m 60 m – 97 m 43 m	<10 dBA to **36 dBA** <10 dBA to 29 dBA <10 dBA <10 dBA to 15 dBA 20 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA 35 dBA (night-time)	Resilient Rail Fasteners

EXECUTIVE SUMMARY

Chainage (km)	Type of Building	Min. Slant Distance to Track Level	Predicted Ground-borne Noise Level (dBA)	Ground-borne Noise Goal (dBA)	Reference Design Mitigation Measure
5.1 – 6.85 Woolloongabba Station to Albert Street Station	Residential Commercial Educational Worship Medical Hotel	38.5 m – 202 m 26 m – 168 m 37 m – 234 m 42 m – 192 m 201 m 19 m – 146 m	<10 dBA to 26 dBA <10 dBA to 25 dBA <10 dBA to 23 dBA <10 dBA <10 dBA <10 dBA to 27 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA 40 dBA 35 dBA (night-time)	Resilient Rail Fasteners (Chainage 5.95 – 6.55 km rail section under the Brisbane River with Direct Fixation Rail Fasteners)
6.85 – 7.9 Albert Street Station to Roma Street Station	Commercial Educational Worship Heritage Medical Hotel	17 m – 91 m 52 m – 58 m 52 m – 82 m 33 m – 67 m 32 m – 98 m 22.5 m – 82 m	<10 dBA to 36 dBA 13 dBA to 23 dBA 16 dBA to 30 dBA 21 dBA to 34 dBA 13 dBA to 35 dBA <10 dBA to 33 dBA	40 dBA 40 dBA 40 dBA 40 dBA 40 dBA 35 dBA (night-time)	Resilient Rail Fasteners
7.9 – 9.55 Roma Street Station to Northern Portal	Residential Commercial Educational Medical Hotel	38 m – 121 m 50 m – 113 m 43 m – 122 m 138 m 51 m – 108 m	<10 dBA to 25 dBA <10 dBA to 21 dBA <10 dBA to 24 dBA <10 dBA <10 dBA to 20 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA 35 dBA (night-time)	Resilient Rail Fasteners (Chainage 9.05– 9.55 km rail section with Direct Fixation Rail Fasteners)

Note: Extent of Reference Project trackform is detailed in **Table 15**. Also the LAmax,Slow noise level refers to the 95th percentile train passby event. The ground-borne noise level of the “average” or median train event would typically be approximately 3 dB lower than the 95th percentile event.

EXECUTIVE SUMMARY

The predicted ground-borne noise levels (see **Table 21**) indicate that the Reference Project trackform configuration (see **Table 15**) will not achieve compliance with the ground-borne noise goals at all sensitive receiver locations. The section of "Highly Resilient" trackform at chainages 2.95 km to 3.15 km has to be extended to chainages 2.75 km to 3.15 km and a new section with "Highly Resilient" trackform at chainages 4.15 km to 4.35 km will be required to comply with the ground-borne noise goals at all sensitive receivers as shown in **Table 22**.

Table 22 Proposed Trackforms to Comply with the Ground-borne Noise Goals

Track Chainage (km)	Proposed Reference Project Trackforms
0 – 0.36	Direct fixation with rail pads on ballast track
0.36 – 0.95	Highly resilient rail fasteners
0.95 – 2.75	Resilient rail fasteners
2.75 – 3.15	Highly resilient rail fasteners
3.15 – 4.15	Resilient rail fasteners
4.15 – 4.35	Highly resilient rail fasteners
4.35 – 5.95	Resilient rail fasteners
5.95 – 6.55	Direct fixation with rail pads on slab track[2]
6.55 – 9.05	Resilient rail fasteners
9.05 – 10	Direct fixation with rail pads

Note 1: The direct fixation, resilient and highly resilient trackforms are specified in **Figure 11**.

Note 2: The direct fixation with standard "stiff" rail pads on slab track is normally not recommended. For slab track design, it is common to include a product like the resilient (ie Pandrol VIPA or Delkor Alt 1) to minimise the potential for damage to the concrete slab.

With the proposed trackform configuration (see **Table 22**) all sensitive receivers above or near the CRR tunnel alignment are predicted to comply with the ground-borne noise goals.

7 AIRBORNE NOISE ASSESSMENT – TRAIN OPERATIONS

7.1 Modelling Methodology

A SoundPLAN (Version 6.5) computer noise model has been used for the prediction of noise levels at sensitive receivers. The noise model comprises topography, buildings, number of trains and calibrated noise emission levels (against measurements), rail movements and relevant noise sources for the rail stabling yard and the location of noise sensitive receivers.

Two different computation algorithms were utilised within the SoundPLAN model. The Nordic Rail Traffic Noise Prediction Method (Kilde 130) has been used for all surface rail noise assessments and the CONCAWE industrial prediction model has been used to account for the additional noise emission through the portal openings and for the noise from stationary trains in the stabling yard (ie auxiliary equipment and air conditioning units).

7.2 Train Operations – Upgraded Rail Alignments including CRR

The SoundPLAN model was created from topography, rail alignments, existing buildings, resumption plans and traffic volumes supplied by the CRR project team. The topography, reference design rail alignments and existing buildings were supplied in 3-D; the existing rail alignments and resumption plans were supplied in 2-D. A digital ground model was created, based on the supplied topography, and applied to the existing rail alignment strings to generate the 3-D model for the model verification. Details of existing noise barriers within the model area were supplied by Queensland Rail.

EXECUTIVE SUMMARY

With no speed profiles available, it was assumed that freight traffic travelled at a speed of 60 km/h and suburban trains travelled at a maximum speed of 80 km/h within the modelling area. Suburban trains were modelled as a mixture of 6-car SMU/IMU and 9-car SMU, based on the service plans provided by the CRR project team. As no data were available, freight trains were assumed to comprise a double-header current generation locomotive with 620 m of consist for the existing scenario (model verification) and 1,500 m of consist for both future scenarios.

Noise source levels from all trains except the new 9-car passenger trains are based on Queensland Rail's standard table of noise emissions. The 9-car passenger train noise levels were extrapolated from the 6-car SMU noise levels.

Corrections for curves, bridges and turnouts have been modelled based on features identified in the Reference Design, existing track alignments and aerial photography.

Portal noise emissions have been modelled as a vertical area noise source across the tunnel portal openings. A sound power level has been assigned to these portal noise sources based on in tunnel noise measurements in rail tunnels in Sydney. The source level has for the Reference Project assumed no absorption in the tunnel, resulting in a higher reverberant build up noise level in the tunnels. The average LAeq(24hour) sound power level for the portals have been calculated following the methodology outlined in a paper "*Prediction of sound radiated from tunnel openings*" by Wolfgang Probst, 2010.

Directivity for the portal opening area noise sources in accordance with recommendations in (Wolfgang Probst, 2010) has been adopted.

The predicted noise levels include contributions from the through traffic, stabling yards and tunnel portals and include shielding from any existing noise barriers. All predicted levels include a +2.5 dBA facade correction.

In the northern section, all sensitive locations are predicted to comply with Queensland Rail's operational planning levels in both Year 2021 and Year 2031. Therefore, no mitigation measures are required in this section.

In the southern section, 28 sensitive locations are predicted to exceed Queensland Rail's operational planning levels in Year 2021 and 37 sensitive locations are predicted to exceed the planning levels in Year 2031 (both assessments include the existing noise barriers supplied by Queensland Rail). Noise barriers have been designed (as far as practicable) for these locations to target compliance with Queensland Rail's operational planning levels. Due to Queensland Rail's policy not to build noise barriers adjacent to existing train Stations for safety reasons, there are 10 sensitive receivers adjacent to the Salisbury Station and 1 adjacent to the Rocklea Station that exceed the Queensland Rail's operational planning levels taking into account the proposed CRR noise barriers.

7.3 Train Operations – Existing Rail Alignments (no upgrade) between Portals

The rail tracks between the portals in Yeerongpilly and Victoria Park will not be changed as part of the CRR project. However, the CRR project will free up capacity on these surface tracks by redirecting a significant portion of the passenger rail operation through the rail tunnels. This increased capacity will enable the number of freight trains on the surface tracks between the portals to be increased.

The passenger train numbers for modelling Year 2021 and Year 2031 have been sourced from the CRR Rail Operations report. The existing passenger train numbers have been sourced from Queensland Rail's published timetables.

EXECUTIVE SUMMARY

The freight train numbers for existing and modelling Year 2021 and Year 2031 have been sourced from the CRR Freight Report. Based on information received from Queensland Rail, the existing freight trains between Salisbury to Park Road are currently 620 m long and are proposed to be increased to 1,500 m by 2031; this has been incorporated in the modelling as a “worst case”. All freight trains on the other freight lines have been assumed to be 1,500 m long for both existing and future modelling years.

The incremental changes to the daily averaged $L_{Aeq(24hour)}$ noise emission levels from the existing surface rail tracks between the portals due to change in freight and passenger train numbers as a result of the CRR project have been assessed.

The predicted noise levels indicate that the $L_{Aeq(24hour)}$ noise emission levels increase by up to 2 dBA due to the change in passenger and freight train traffic for the modelling Year 2031.

It is generally recognised in acoustics that changes in noise levels of 2 dBA or less are undetectable to the human ear and therefore negligible.

The maximum noise level during train passbys will not change due to the change in passenger and freight train numbers. There would only be a change to the number of train passby events. In fact over time it is likely that the maximum noise levels from train passbys would be reduced as new generation rollingstock are progressively introduced into Queensland Rail’s operation.

7.4 Train Stabling Operations

Moving rollingstock within the stabling yard has been modelled in accordance with Queensland Rail’s noise emissions data (with trains modelled at 30 km/h) and points have been modelled with a 5 dBA increased noise emission in accordance with Queensland Rail’s Network Noise Management Plan (NNMP) Development Standard Gauge Line. The noise emission levels used for the stationary trains auxiliary systems and air conditioning units are based on previous measurement results for Queensland Rail rollingstock contained in SLR Consulting’s noise source database.

A typical “worst case” scenario has been modelled for the stationary trains in the stabling yard consisting of trains on the closest tracks to the sensitive receivers with the auxiliary systems and air conditioning units operating. Trains on stabling tracks behind the trains on the closest track to the receivers will be significantly shielded and the modelled case is considered a typical worst case. This typical “worst case” noise emission from the stationary trains in the stabling yard has been modelled as operating over a total period of approximately 2 hours during parking and 2 hours during pick-up.

The noise contribution from the stabling yard operations to the overall rail noise emissions is negligible. The through traffic dominates the single event maximum and $L_{Aeq(24hour)}$ noise levels and there are no predicted exceedances of Queensland Rail’s operational planning levels adjacent to either stabling yard.

There is, however, a risk that the stationary trains at the stabling yards may have a sleep disturbance impact due to the more steady-state character of the noise sources compared to normal rail operations and the length of time (2 hours) that the air conditioning can operate. The predicted typical “worst case” noise emission levels from the stabling yards during parking and pick-up exceed The World Health Organisation’s internal sleep disturbance criterion of 30 dBA L_{Aeq} (external criterion of 40 dBA L_{Aeq}, assuming a 10 dBA facade noise reduction) for stationary noise sources. Therefore, even though the Queensland Rail operational planning levels are achieved, there is a risk that the noise emissions from the air conditioning units after parking and before pick-up may cause sleep disturbance.

EXECUTIVE SUMMARY

The possible sleep disturbance caused by the noise emission from the air conditioning units after parking and before pick-up may be mitigated by prudent operational management of the stabling yards. It is proposed that train stabling would be prioritised to the outer tracks in the yards (closest to the homes) during daytime hours and then successively fill the inner tracks and conversely for pick-up (ie the outer tracks would be picked up last). This would result in the trains on the outer tracks acting as noise barriers for the trains stabled on the inner tracks and also ensure maximum distance between noise source and receivers during the night-time. This operational management plan would most likely result in night-time external noise levels less than 40 dBA L_{Aeq}.

8 AIRBORNE NOISE ASSESSMENT – ANCILLARY FACILITIES

Ancillary noise sources would typically include mechanical plant facilities, ventilation shafts for underground areas and feeder stations for power distribution of the CRR rail operations. For fire and life safety requirements, a ventilation and emergency shaft located mid-way between Yeerongpilly and Boggo Road stations has also been proposed.

8.1 CRR Feeder Stations

Three 25 kV feeder stations are proposed. The locations of the feeder stations are at Mayne Yard (to replace an existing feeder station), near the northern portal at the Exhibition grounds and near the southern portal at Yeerongpilly. The Reference Project proposes that each feeder station for the CRR project will require a capacity of approximately 18 MVA. The Australian Standard AS 2374.6-1994 *Power Transformers – Part 6; Determination of transformer and reactor sound levels*, gives generic sound power levels as a function of the power requirement. For a power transformer of 18 MVA capacity, the sound power levels provided in Appendix AA of AS 2374.6-1994 are presented in **Table 29**.

Table 29 Sound Power Level for Transformers According to AS 2374.6-1994

Power Transformer	LWA(standard maximum) (dBA)	LWA(reduced maximum) (dBA)
18 MVA	92	84

Note: If there are components with tonal character, an adjustment to the measured noise level of +5 dBA is required in accordance with AS 1055.1-1997.

The harmonic filters are likely to have noise emissions with tonal character and a 5 dB adjustment to the sound power levels in **Table 29** have been applied.

The CRR feeder stations will typically consists of the following components:

- 110 kV switchgear building – 21 m x 14 m x 12 m (length x width x height)
- 3 x 110/25 kV transformer enclosures – 8 m x 7 m x 7 m each
- 25 kV control building – 16 m x 5 m x 6 m
- 3 x 25 kV harmonic filter enclosures 15 m x 10 m x 6 m each

Based on the design for the recently completed Roma Street feeder station, all components will be enclosed in buildings with the transformer building partially open (towards the direction of the tracks).

The nearest sensitive receiver is more than 200 m from the proposed feeder station at Mayne Yard, approximately 160 m from the proposed feeder station at Exhibition and 200 m from the proposed feeder station at Yeerongpilly. A noise reduction through the feeder station building facades (in the direction of propagation towards receivers) of approximately 20 dBA has been assumed.

EXECUTIVE SUMMARY

The feeder stations have been assessed against the background creep criterion in accordance with the EPP(Noise) (refer to **Section 2.5**). Using the sound power level in **Table 29**, adjusted for tonality (ie +5 dB), the predicted noise levels at the sensitive receiver nearest to each of the feeder station locations are below the existing background RBL noise level for all sensitive receivers at the respective feeder station locations.

Noise predictions with detailed equipment sound power levels and final designs of feeder station buildings will be required during the detailed design phase to confirm these predictions.

8.2 Southern Intermediate Ventilation Shaft

The noise emission for emergency ventilation is not assessed as part of this EIS (due to it happening on very seldom occasions during exceptional circumstances ie fire events) and it is assumed that the southern intermediate ventilation shaft will have forced ventilation only during emergency events.

Although the proposed railway line will operate underground at this location, noise generated during train passbys does have the potential to escape from the tunnels via the tunnel ventilation shaft.

An in-tunnel maximum reverberant noise level of 102 dBA L_{Amax} was used to predict train passby noise levels from tunnel shaft break-out noise. Based on the in-tunnel maximum noise level and a conservatively assumed 20 dBA noise reduction for the emergency ventilation exhaust and supply fans' noise attenuators, the maximum noise level at the nearest sensitive receiver (approximately 35 m away from the proposed shaft) from a train passby is predicted to be 50 dBA L_{Amax}. This is in compliance with the operational planning levels in the Queensland Rail's Code of Practice (refer to **Section 2.2**).

Train noise break-out through the Southern Intermediate Ventilation shaft from trains operating within the tunnel is not expected to exceed the noise goals and is expected to be less than existing car passby noise levels from Fairfield Road.

8.3 Underground Stations Mechanical Plant and Ventilation

8.3.1 Modelling Methodology

The modelling of the mechanical services airborne noise presented in this assessment is based on the preliminary plant locations which are still potentially subject to change. Specific equipment is also not known at this stage and the expected noise levels can therefore not be predicted. As such, the maximum total allowable emitted sound power level at each location has been calculated, specifying the acoustic emission limit for all equipment (combined operation) at each location. The noise sources have been assumed to operate without a noticeable tonal, impulsive or intermittent nature. Based on previous experience, these emission limits are achievable with appropriate equipment selection and silencing treatments, if required.

8.3.2 Noise Predictions for Station Mechanical Plant and Ventilation Shafts

The maximum allowable sound power levels emitted by industrial-type noise sources have been predicted for each location in order to meet the noise goal (refer to **Table 6**) at nearby sensitive receivers. The results are presented in **Table 31**.

EXECUTIVE SUMMARY

Table 31 Station Ancillary Facilities - Maximum Acceptable Noise Emissions

Site Location	Ancillary Location	Distance to Nearest Sensitive Receiver (m)	Noise Goal (dBA LA90)[1]	Maximum Acceptable Sound Power Level emitted from the Ancillary Facility (dBA)
Boggo Rd Station	Southern Entry, south of Boggo Rd Jail	~90	37	84
	Northern Entry supply and exhaust outlets towards Boggo Road Busway	~90	34	82
Woolloongabba Station	Central station box is open to natural light and ventilation. Ventilation supply and exhaust outlets east and west of the station building.	~100	46	94
Albert St Station	Alice St Entry	~45	46	87
	Mary St Entry	~25	54	90
Roma St Station	Southern Entry	~80	47	93
	Parkland Cres plant and ventilation shaft	~130	47	97

Note 1: Background creep noise goal in accordance with EPP(Noise) refer to **Table 6**. The background creep is the RBL + 0 assessed as the LA90 parameter. Existing background noise levels RBLs as presented in **Table 9**.

The locations and designs of the mechanical plant items and air exhausts and intakes for the CRR project will be assessed when more detail is available during the detailed design phase.

9 AIRBORNE NOISE ASSESSMENT – ROAD TRAFFIC

Associated with CRR is the realignment of several roadways adjacent to the southern railway corridor (Section 1000). There are three areas where the realignment of the adjacent roads is significant being Dollis Street near Salisbury Railway Station, Fairfield Road entry ramp to Ipswich Road and Wilkie Street east of Yeerongpilly Railway Station. The potential traffic noise impact associated with the realignment of these roads has been assessed at nearby residences. The relevant noise goal is the DTMR Code of Practice road traffic noise goal of 68 dBA $L_{A10(18hour)}$ for a realigned road.

Noise modelling of the relevant areas of the project was carried out using the UK Department of Transport, “Calculation of Road Traffic Noise” (CORTN 1988) algorithms incorporated in the SoundPLAN 6.5 noise software. The modelling allows for traffic volume and mix, type of road surface, vehicle speed, road gradient, reflections off building surfaces, ground absorption and shielding from ground topography and physical noise barriers.

Predicted road traffic noise levels for the realigned road sections are presented in **Table 33**. The range corresponds to predicted noise levels at the nearest row or group of residences to the realigned roads.

EXECUTIVE SUMMARY

Table 33 CRR Realigned Roads Predicted Traffic Noise Levels (dBA)

Realigned Road	Residential Receivers	Predicted $L_{A10(18hr)}$ Noise Level
Dollis Street	Olivia Avenue	48 dBA to 51 dBA
Fairfield Road entry ramp	Brooke St	54 dBA to 60 dBA
Wilkie Street	Crighton St, Stamford St, Green St, Livingston St	58 dBA to 64 dBA

Note 1: The predicted noise levels include a +2.5 dBA façade reflection.

As presented in **Table 33** for each of the three roads being realigned, the highest noise levels are 51 dBA at Olivia Avenue, 60 dBA at Brooke Street and 64 dBA at Green Street. All residences adjacent to the realigned road sections comply with the *DTMR Code of Practice* road traffic noise goal of 68 dBA $L_{A10(18hr)}$ for the design Year 2031.

TABLE OF CONTENTS

1 INTRODUCTION 1

1.1 Terms of Reference 2

1.2 Objectives 3

2 IMPACT ASSESSMENT GOALS 4

2.1 Community Values Relating to Noise and Vibration 4
2.1.1 Acoustic Quality Objectives 5
2.1.2 Evaluating Impacts 5

2.2 Surface Rail Operation 5
2.2.1 Operational Noise Metrics 5
2.2.2 Operational Planning Levels 5

2.3 Ground-borne Vibration 6
2.3.1 Human Comfort 6
2.3.2 Human Subjective Response to Vibration 6
2.3.3 Effects of Vibration on Building Contents 7
2.3.4 Safe Vibration Levels for Common Services 7
2.3.5 Effects of Vibration on Structures 7
2.3.6 Ground-borne Vibration Goals 8

2.4 Ground-borne Noise 9

2.5 Mechanical Plant and Ventilation 11

2.6 Road Traffic Noise 13

3 NOISE AND VIBRATION TERMINOLOGY 14

3.1 Noise 14

3.2 Vibration 16

3.3 Ground-borne Noise 17

4 EXISTING NOISE AND VIBRATION ENVIRONMENT 18

4.1 Noise 18
4.1.1 Noise Monitoring Methodology 18
4.1.2 Instrumentation 19
4.1.3 Noise Monitoring Locations 19
4.1.4 Noise Monitoring Results 20

4.2 Vibration 27
4.2.1 Vibration Monitoring Methodology 27
4.2.2 Instrumentation 27

TABLE OF CONTENTS

4.2.3 Vibration Monitoring Locations 27
4.2.4 Vibration Monitoring Results 28

5 IDENTIFICATION OF NOISE AND VIBRATION SENSITIVE BUILDINGS 29

6 GROUND-BORNE VIBRATION ASSESSMENT - TRAIN OPERATIONS 30

6.1 Introduction 30

6.2 Ground-borne Vibration Modelling Methodology 31
6.2.1 Modelling Approach 32
6.2.2 Source Vibration Levels 33
6.2.3 Propagation Path 42
6.2.4 Receivers 45

6.3 Ground-borne Vibration Predictions 46

6.4 Ground-borne Vibration Assessment 49
6.4.1 Special Receivers Which May Contain Highly Vibration Sensitive Equipment 49
6.4.2 Heritage Structures 50

7 GROUND-BORNE NOISE ASSESSMENT - TRAIN OPERATIONS 50

7.1 Introduction 50

7.2 Ground-borne Noise Modelling Methodology 51

7.3 Ground-borne Noise Mitigation Options 52

7.4 Ground-borne Noise Predictions 54

7.5 Other Sensitive Receivers 61

8 AIRBORNE NOISE ASSESSMENT - TRAIN OPERATIONS 61

8.1 SoundPLAN Modelling Methodology 63

8.2 Train Operations – Upgraded Rail Alignments including CRR 64
8.2.1 Model Inputs and Assumptions – Through Traffic 64
8.2.2 Modelling Assumptions – Portal noise emissions 65
8.2.3 Modelling Assumptions – Stabling Yards 66
8.2.4 Predicted Noise Levels 67
8.2.5 Mitigation Measures 68

8.3 Train Operations – Existing Rail Alignments (no upgrade) between Portals 69
8.3.1 Model Inputs and Assumptions 69
8.3.2 Predicted Future Change in Rail Noise Emission between Portals 70

9 AIRBORNE NOISE ASSESSMENT – ANCILLARY FACILITIES 71

9.1 CRR Feeder Stations 71

TABLE OF CONTENTS

9.1.1 Mayne Yard Feeder Station 71
9.1.2 Exhibition Feeder Station 72
9.1.3 Yeerongpilly Feeder Station 73

9.2 Southern Intermediate Ventilation Shaft 74

9.3 Underground Stations Mechanical Plant and Ventilation 76
9.3.1 Modelling Methodology 76
9.3.2 Noise Predictions 76
9.3.3 Mitigation Measures 77

10 AIRBORNE NOISE ASSESSMENT – ROAD TRAFFIC 77

10.1 Road Traffic Noise Modelling Methodology 77

10.2 Noise Assessment – Realigned Road Sections 78

10.3 Summary 79

11 CONCLUSIONS 79

11.1 Ground-borne Noise and Vibration – Train Operations 79

11.2 Airborne Noise Assessment – Train Operations 80

11.3 Airborne Noise Assessment – Ancillary Facilities 81

11.4 Airborne Noise Assessment – Traffic Noise 81

12 REFERENCES 82

13 CLOSURE 83

TABLES

Table 1 Vibration Levels and Human Perception of Motion 6
Table 2 Floor Vibration Tolerance for JEM-1400 7
Table 3 Ground-borne Vibration Goals 9
Table 4 IGANRIP Ground-borne Noise Trigger Levels for Sensitive Receivers 10
Table 5 Ground-borne Noise Goals 11
Table 6 Operational Mechanical Plant Noise Goals 13
Table 7 DTMR Code of Practice – Road Noise Goal for Existing Residences 13
Table 8 Typical Noise Levels 15
Table 9 Measured Rating Background Levels 21
Table 10 Attended Ambient Measurement Results – Day, Evening and Night-Time Periods 22
Table 11 Measured Existing Ambient Vibration 29
Table 12 Reference Source Vibration Levels for CRR Trains (Tunnel Wall Vibration Levels at reference speed of 80 km/h) – Lmax,Slow 34
Table 13 Location of Curve Radii approximately 600 m or Less 35
Table 14 Properties of Pandrol, Delkor and Sonneville Rail Fasteners 37
Table 15 Extent of Reference Project Trackforms 39
Table 16 Coupling Loss Values (dB) 45
Table 17 Floor-to-Floor Loss Values 45

TABLE OF CONTENTS

Table 18 Amplification within Buildings 46
Table 19 Summary of Predicted Ground-borne Vibration Levels (Reference Project Trackform).47
Table 20 Special Receivers Which May Contain Highly Vibration Sensitive Equipment 50
Table 21 Summary of Predicted Ground-borne Noise Levels (Reference Project Trackform)......55
Table 22 Proposed Trackforms to Comply with the Ground-borne Noise Goals 57
Table 23 Summary of Predicted Ground-borne Noise Levels (Proposed Trackform) 59
Table 24 Daily (24hour) Train Movements – Surface Tracks....65
Table 25 Average LAeq(24hour) Sound Power Level per Portal 66
Table 26 Number of Stabled Trains for each Stabling Yards....66
Table 27 Existing and Future Train Numbers on Surface Tracks between Portals 70
Table 28 Predicted Incremental Changes in Rail Noise Emission for Tracks between Portals.....70
Table 29 Sound Power Level for Transformers According to AS 2374.6-1994 71
Table 30 In-tunnel Reverberant Noise Levels 75
Table 31 Station Ancillary Facilities - Maximum Acceptable Noise Emissions 77
Table 32 Traffic Volume Details for the CRR Realigned Roads 78
Table 33 CRR Realigned Road Predicted Traffic Noise Levels (dBA) 78
Table 34 Designed Operational Noise Barriers....80

FIGURES

Figure 1 Project Overview Map 2
Figure 2 Graphical Display of Typical Noise Indices 15
Figure 3 Typical Vibration Levels 17
Figure 4 Vibration and Ground-borne Noise Transmission Paths....18
Figure 5 Overview of Noise Monitoring Locations....20
Figure 6 Overview of Vibration Monitoring Locations....28
Figure 7 Ground-borne Vibration/Noise Modelling Approaches (from ISO 14837-1:2005(E)).....31
Figure 8 Example of Source, Propagation and Receiver System (ISO 14837) 33
Figure 9 Reference Source Vibration Levels for CRR Trains (Tunnel Wall Vibration Levels at Reference Speed of 80 km/h) – Lmax,Slow....34
Figure 10 CRR Reference Project Tunnel Depth vs Chainage....35
Figure 11 Reference Project Proposed Trackforms....38
Figure 12 Reference Project Tunnel Alignment and Trackform 40
Figure 13 Speed Profile for CRR Reference Project....41
Figure 14 Excess Attenuation Due to Material Damping....44
Figure 15 Graphical Representation Indicating Possible Propagation Paths from a Train in a Tunnel....44
Figure 16 Ground-borne Noise Level (Resilient Rail Fasteners) Versus Slant Distance Illustrative Only - Not to be used for Assessment 52
Figure 17 Generic Trackforms to Mitigate Ground-borne Noise and Vibration on Slab Track.......53
Figure 18 Extent of Proposed Trackforms....58
Figure 19 Overview of Northern Section (CRR Section 3000) Surface Rail Operations 62
Figure 20 Overview of Southern Section (CRR Section 1000) Surface Rail Operations....63
Figure 21 Proposed location of Mayne Yard Feeder Station 72
Figure 22 Proposed location of Exhibition Feeder Station 73
Figure 23 Proposed location of Yeerongpilly Feeder Station....74
Figure 24 Proposed location of the Fairfield Gardens Ventilation Shaft 75
Figure 25 Southern Ventilation Shaft – Architectural Sketch 76

APPENDICES

Appendix A Noise Monitoring Locations
Appendix B Graphical Presentation of Statistical Ambient Noise Levels
Appendix C Vibration Monitoring Locations

TABLE OF CONTENTS

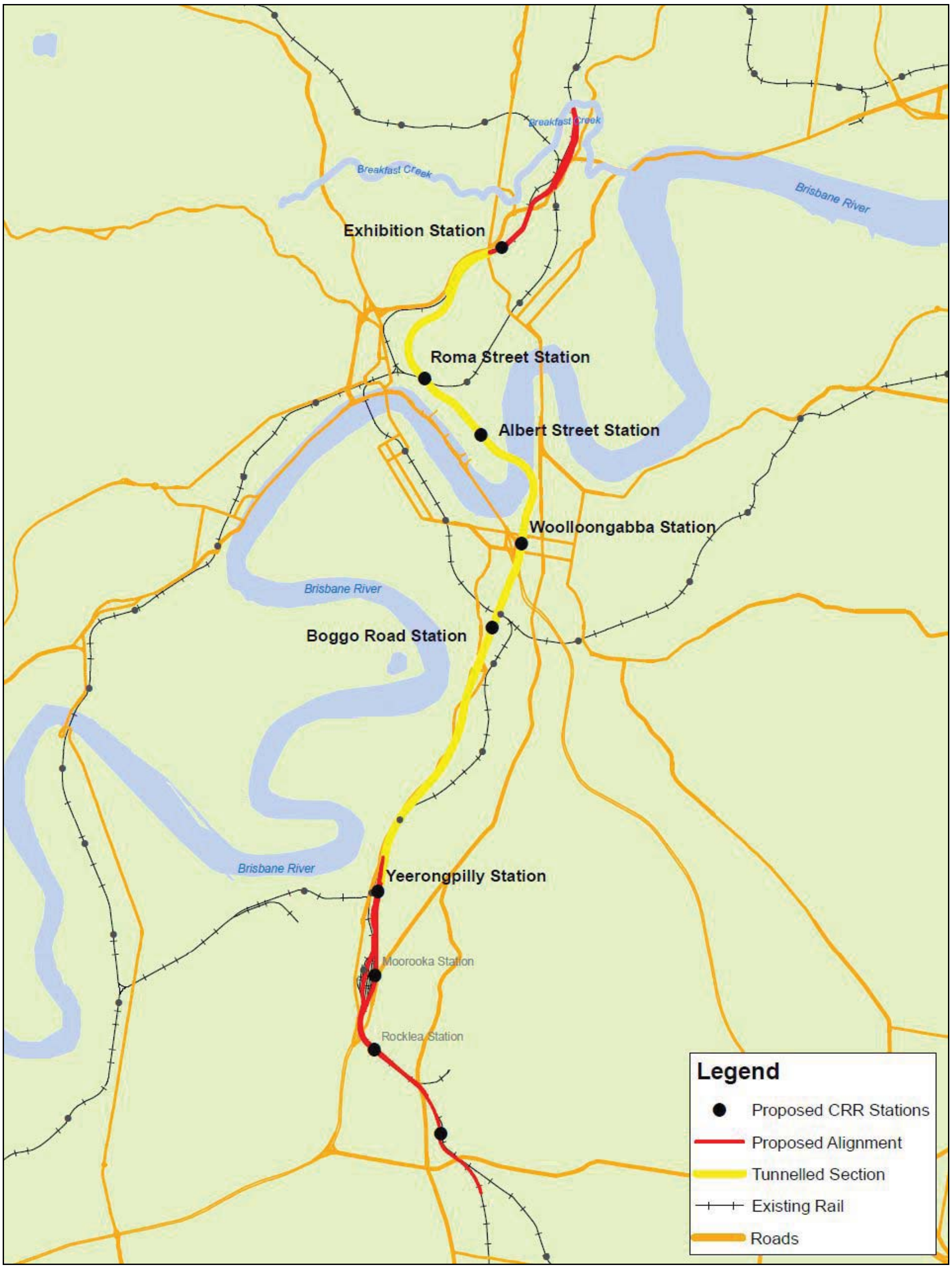
Appendix D Graphical Presentation of Ambient Vibration Levels
Appendix E Special Noise and Vibration Sensitive Receivers
Appendix F Predicted Operational Noise Levels
Appendix G Year 2021 Operational Noise Contours
Appendix H Year 2031 Operational Noise Contours
Appendix I Year 2031 Operational Noise Contours With Designed Mitigation
Appendix J Year 2031 Realigned Road Sections – Noise Contours

1 INTRODUCTION

SLR Consulting has been commissioned by the SKM-Aurecon CRR Joint Venture (CRR JV) to prepare an assessment of the operational noise and vibration aspects of the Cross River Rail (CRR) for inclusion in the Environmental Impact Statement (EIS).

CRR is a major project for the City of Brisbane, South East Queensland and the State of Queensland. It will provide a new north-south rail line in Brisbane's inner city that includes a new river crossing and inner city train stations. From the existing southern rail network, it will pass under the central business district (CBD) of Brisbane and connect with the existing northern rail network via the Exhibition loop. The project will include a tunnel under the Brisbane River and four new underground stations as well as upgrades to existing train stations. A project overview with the defined Reference Project alignment is shown in **Figure 1**. Approximately 6 km of the alignment is above ground and approximately 9.5 km is underground.

Figure 1 Project Overview Map



1.1 Terms of Reference

The specific requirements of the Terms of Reference[1] in relation to operational noise and vibration impacts associated with the project are reproduced below.

3.8.1 Description of environmental values

[1] Queensland Government's Department of State Development and Innovation, Cross River Rail Project – Terms of Reference for an Environmental Impact Statement.

This section should describe the existing noise and vibration environment that may be affected by the project in the context of environmental values as defined by the Environmental Protection (Noise) Policy 2008 (EPP (Noise). DERM's Noise Measurement Manual should be considered and references should be made to the DERM's EcoAccess Guidelines Noise and Vibration from Blasting and Planning for Noise Control, as appropriate.

Likely sensitive noise receptors adjacent to more significant project components (e.g. proposed station and major worksite locations) should be identified and typical background noise and vibration levels estimated based on surveys at representative sites. The potential sensitivity of such receptors should be discussed and performance indicators and standards nominated.

3.8.3 Potential impacts and mitigation measures — operation

The EIS should describe the impacts of noise and vibration generated during the operational phase of the project. Noise and vibration impact analysis should include:

- *the levels of noise and vibration generated, including noise and vibration generated by underground and surface rail operations (including tunnel ventilations shafts at surface locations), with noise contours, assessed against current typical background levels, using modelling where appropriate*
- *the impact of noise, including low frequency noise (noise with components below 200Hz) and vibration at all potentially sensitive receivers and transport related infrastructure within and around the study corridor compared with the performance indicators and standards nominated above*
- *proposals to minimise or eliminate these effects, including details of any screening, lining, enclosing or bunding of facilities, or timing schedules for construction and operations that would minimise environmental harm and environmental nuisance from noise and vibration*
- *develop likely operational noise and vibration management measures for sensitive places and options if unable to achieve a satisfactory internal noise level.*
- *an analysis of acoustic noise levels from proposed rail traffic against the criteria stated in the Queensland Rail Code of Practice for Rail Noise Management.*

1.2 Objectives

The objectives of this report in relation to the project description are to:

- Address the acoustical requirements detailed in the project's Terms of Reference in relation to the operational phase of the project.
- Evaluate the operational noise and vibration impacts at sensitive locations in terms of planning levels identified in the EPP[Noise] and other Guidelines.
- Define noise and vibration goals by which operational noise and vibration impacts at sensitive locations may be evaluated.
- Evaluate the extent of resulting impacts and the scope for the reduction of these impacts through reasonable and feasible mitigation strategies.
- Recommend appropriate mitigation measures.

2 IMPACT ASSESSMENT GOALS

The noise and vibration associated with the operational phase of the CRR project can be divided into the following main categories:

- Noise and vibration generated by surface rail operations.
- Ground-borne vibration generated by underground rail operations.
- Ground-borne noise generated by underground rail operations.
- Noise emission from mechanical ventilation plant at stations.

The relevant noise and vibration goals for these categories are outlined in the following section. In addition to the noise and vibration goals discussed for the above main categories **Section 2.1** gives a general discussion of the community values with regard to noise and vibration.

2.1 Community Values Relating to Noise and Vibration

The Queensland Environmental Protection (Noise) Policy 2008 (EPP[Noise]) defines the values to be protected as the qualities of the acoustic environment that are conducive to:

- The qualities of the acoustic environment that are conducive to protecting the health and biodiversity of ecosystems.
- The qualities of the acoustic environment that are conducive to human health and wellbeing, including by ensuring a suitable acoustic environment for individuals to do any of the following-
  a. Sleep
  b. Study or learn
  c. Be involved in recreation, including relaxation and conversation
- The qualities of the acoustic environment that are conducive to protecting the amenity of the community.

Sleep

A person's ability to sleep is perhaps the most important value that can be impacted by noise and/or vibration. Noise and vibration effects on sleep are generally referred to as sleep disturbance.

Education and Work

The needs for education and work in relation to the acoustic environment relate to the need to be able to communicate effectively either face-to-face or by telephone, and the ability to think or focus on auditory information without undue intrusion from other sources of noise.

Recreation

Recreation is an important aspect of a healthy lifestyle. Recreation may include time spent both indoors and outdoors. In terms of acoustic function, recreation may involve communication with others in verbal conversation or simple enjoyment of an outdoor or indoor soundscape.

2.1.1 Acoustic Quality Objectives

The EPP(Noise) includes long term acoustic quality objectives. It is intended that the acoustic quality objectives be progressively achieved as part of achieving the purpose of the EPP(Noise) policy over the long term. The EPP(Noise) states that it is not applicable for assessing noise mentioned in the reprint No 8 (2009) of the Environmental Protection Act 1994 (the Act), Schedule 1, Part 1 which refers to safety and transportation noise. Therefore, the acoustic quality objectives are not considered applicable for assessing the operational noise associated with rail operations for this project. The acoustic quality objectives will be considered for assessing the ventilation and mechanical plant noise associated with the new stations as these will be permanent long-term noise sources.

2.1.2 Evaluating Impacts

The impact of a project on community values relating to noise and vibration is normally evaluated using statutory regulations and policies which describe acceptable levels of noise and vibration from various sources.

For types of noise for which specific levels are not listed in statutory regulations or policies, it is common to refer to relevant Australian or internationally recognised standards that define acceptable levels of noise and vibration in various human and structural contexts. Such standards can serve an advisory function to regulatory organisations and may be adopted by statutory authorities for the purpose of defining regulatory levels.

2.2 Surface Rail Operation

The applicable noise criteria for the railway surface track airborne noise emissions are in accordance with Queensland Rail's *Code of Practice – Railway Noise Management* (Queensland Rail Code of Practice). The Queensland Rail Code of Practice refers to the following operational noise metrics and operational planning noise levels.

2.2.1 Operational Noise Metrics

The two primary noise metrics used to describe railway noise emissions in accordance with the Queensland Rail Code of Practice are:

- **Single Event Maximum Level** Queensland DERM and Queensland Rail have reached agreement on the definition of single event maximum level as being the *"arithmetic average of the 15 highest maximum noise levels in the 24 hour period"*.
- **$L_{Aeq(24hour)}$** "Equivalent Continuous Noise Level", sometimes referred to as the "energy-averaged noise level". The $L_{Aeq(24hour)}$ may be likened to a "noise dose", representing the cumulative effect of all train noise events occurring in one day and is calculated from the sound exposure level (SEL)[2] of each individual train passby.

2.2.2 Operational Planning Levels

Queensland Rail's Code of Practice outlines the operational "planning levels" applicable to this project.

The Planning Levels are:

- 65 dBA, assessed as the 24 hour average equivalent continuous A-weighted sound pressure level, $L_{Aeq(24hour)}$.
- 87 dBA, assessed as a Single Event Maximum sound pressure level.

The planning levels refer to an assessment location one metre in front of the facade of an affected noise sensitive building.

2 SEL – Is the total sound energy for the train passby referenced to 1 second.

2.3 Ground-borne Vibration

The effects of vibration in buildings can be divided into four main categories:

- Human comfort.
- Effects of vibration on building contents.
- Safe vibration levels for common services.
- Structural damage.

A fifth effect is the noise generated within buildings as a result of the vibration. This is termed "ground-borne noise" and is discussed further in **Section 2.4**.

2.3.1 Human Comfort

Humans are far more sensitive to vibration than is commonly realised. They can detect and possibly even be annoyed at vibration levels which are well below those causing any risk of damage to a building or its contents.

2.3.2 Human Subjective Response to Vibration

The actual perception of motion or vibration may not, in itself, be disturbing or annoying. An individual's response to that perception, and whether the vibration is "normal" or "abnormal", depends very strongly on previous experience and expectations, and on other connotations associated with the perceived source of the vibration. For example, the vibration that a person responds to as "normal" in a car, bus or train is considerably higher than what is perceived as "normal" in a shop, office or dwelling.

Human tactile perception of random motion, as distinct from human comfort considerations, was investigated by Diekmann and subsequently updated in German Standard *DIN 4150 Part 2 1975*. On this basis, the resulting degrees of perception for humans are suggested by the continuous vibration level categories given in **Table 1**.

Table 1 Vibration Levels and Human Perception of Motion

Approximate Vibration Level	Degree of Perception
0.10 mm/s	Not felt
0.15 mm/s	Threshold of perception
0.35 mm/s	Barely noticeable
1 mm/s	Noticeable
2.2 mm/s	Easily noticeable
6 mm/s	Strongly noticeable
14 mm/s	Very strongly noticeable

Note: These approximate vibration levels (in floors of building) are for vibration having frequency content in the range of 8 Hz to 80 Hz.

Table 1 suggests that people will just be able to feel continuous floor vibration at levels of about 0.15 mm/s and that the motion becomes "noticeable" at a level of approximately 1 mm/s.

Although people are able to perceive relatively low vibration levels, it is not appropriate to set vibration emission limits requiring "no vibration", since there will always be some measurable vibration in any environment. Realistic design goals should therefore be set to minimise disturbance and adverse impacts on amenity. The recommended approach is discussed in the ground-borne vibration goals section below.

2.3.3 Effects of Vibration on Building Contents

People can perceive floor vibration at levels well below those likely to cause damage to building contents or affect the operation of typical equipment. As such, the controlling vibration design goals during operations will be the human comfort goals, and it is therefore not necessary to set separate design goals for the CRR project in relation to the effect of railway vibration on common building contents.

Some scientific equipment (eg electron microscopes and microelectronics manufacturing equipment) can however require more stringent design goals than those applicable to human comfort. In such cases, vibration design goals should be obtained from the specific equipment manufacturers. If specific vibration design goals are not available, recommended vibration levels are provided in the Association of Noise Consultants "Measurement and Assessment of Ground-Borne Noise & Vibration" (ANC Guidelines 2001) and Ungar et Al "Vibration Control Design of High Technology Facilities", Journal of S & V, (Ungar 1990). The vibration criterion curve BBN - C provided in the ANC Guidelines 2001 should be used as a trigger level for further investigation for identified receivers likely to have highly vibration sensitive equipment. The BBN – C curve (also referred to as the VC-C curve in other literature) specifies a limit of 0.013 mm/s (or expressed in decibels 82 dB_V re 10^{-9} m/s) per 1/3 Octave band for frequencies between 8 Hz and 80 Hz and is appropriate for most lithography and inspection equipment down to 1 micron detail size.

The most sensitive equipment adjacent to the CRR alignment is a Transmission Electron Microscope (TEM) located in the basement of the Eco-Science Precinct. A technical paper received from the tenant for this specific TEM (JEOL type JEM-1400) gives a vibration deflection tolerance as presented in **Table 2**. Also included in **Table 2** are the estimated equivalent vibration velocity criteria, based on evenly distributed vibration energy within each of the specified frequency ranges.

Table 2 Floor Vibration Tolerance for JEM-1400

Frequency Range	Vibration Displacement (μm)		Vibration Velocity (mm/s)	
	Vertical	Horizontal	Vertical	Horizontal
3 Hz or less	2	0.6	0.019 mm/s	0.006
3 Hz to 10 Hz	0.5	0.5	0.02	0.02
10 Hz or higher	1	0.2	0.3	0.06

Note: It should be noted that normally the horizontal vibration is significantly lower in buildings than the vertical vibration, especially at basement and lower floor levels. The very strict horizontal vibration criteria indicate that the JEOL vibration criteria could be based on actually measured floor vibrations at a successful installation site rather than based on forced vibrations until disturbances are noticed in the equipment.

2.3.4 Safe Vibration Levels for Common Services

The levels of vibration required to cause damage or disruption to common services are at an order of magnitude (10 times) higher than those at which people may consider the vibration to be intrusive. Therefore, it is not necessary to set separate assessment goals for this project in relation to vibration induced effects on common services for the operational phase.

2.3.5 Effects of Vibration on Structures

As for common services above, the levels of vibration required to cause damage to buildings (including sensitive heritage buildings) tend to be at least an order of magnitude (10 times) higher than those at which people may consider the vibration to be intrusive. Therefore, it is not necessary to set separate assessment goals for the operational phase of this project in relation to building damage from railway vibration.

2.3.6 Ground-borne Vibration Goals

On the basis of the above discussion, the vibration goals adopted for this project are based on human comfort considerations, rather than the less stringent building damage risk criteria or potential effects on building contents, except at the Eco-science precinct TEM facility.

There are several sources from which relevant vibration criteria may be drawn. These include:

- Australian Standard AS 2670.2 1990 "Evaluation of Human Exposure to Whole Body Vibration - Part 2: Continuous and Shock Induced Vibration in Buildings (1 Hz to 80 Hz)".
- The United States Federal Transit Administration (FTA) guideline "Transit Noise and Vibration Impact Assessment".
- British Standard BS 6472-1:2008 "Guide to evaluation of human exposure to vibration in buildings Part 1: Vibration sources other than blasting".
- The NSW Department of Environment, Climate Change and Water document "Assessing Vibration: A Technical Guideline".

The following discussion expresses vibration levels in terms of both vibration velocity in mm/s and decibels (dB_V re 10^{-9} m/s). A level of 100 dB corresponds to 0.1 mm/s (rms) and a level of 120 dB corresponds to 1 mm/s (rms). They are both included below since many of the International references in relation to vibration from railways give the vibration limits in decibels, however, in Queensland it is most common to express vibration limits in mm/s. All values are in root mean square (rms) averaged values.

AS 2670.2 provides recommended vibration levels corresponding to 106 dB_V (0.2 mm/s) to 112 dB_V (0.4 mm/s) for residential buildings during the daytime, reducing to 103 dB_V (0.14 mm/s) during the night-time. These levels apply to both continuous and intermittent vibration. For office and industrial buildings, the recommended vibration levels are 112 dB_V (0.4 mm/s) and 118 dB_V (0.8 mm/s) respectively, independent of the time of day. Much higher vibration levels are permitted for transient events with only a few occurrences per day.

For residential buildings, the US FTA guideline recommends a vibration level of 100 dB_V (0.1 mm/s) for frequent events (ie more than 70 per day), 103 dB_V (0.14 mm/s) for occasional events (ie between 30 and 70 per day) and 108 dB_V (0.25 mm/s) for infrequent events (ie less than 30 per day). For schools, churches, quiet offices, etc, the recommended vibration levels are 3 dB higher than residential receivers.

BS 6472 includes a vibration dose relationship for intermittent events such as trains, which for a "low probability of adverse comment" would permit vibration levels of up to approximately 110 dB_V (0.32 mm/s) on the basis of the frequent nature of the rail operations in the proposed CRR tunnel.

The Department of Environment, Climate Change and Water's (DECCW's) "*Assessing Vibration: A Technical Guideline*" is based on the guidelines contained in BS 6472. The acceptable values for intermittent vibration are the same as detailed above (namely 110 dB_V).

The proposed vibration goal for residential receivers is based on the lower daytime value in AS 2670, namely 106 dB_V (0.2 mm/s). This level is recommended for both the daytime and night-time periods, recognising that the intermittent nature of train vibration events and that the frequency of train passby events will be lower during the night-time period.

The recommended level of 106 dB_V for residential receivers is 3 dB_V higher than the 103 dB_V night-time level (for continuous vibration) in AS 2670, but 4 dB_V lower than the BS 6472 and DECCW guidelines.

For other sensitive receiver categories, the proposed vibration goals are listed in **Table 3**. For assessment purposes, these goals may be regarded as applicable to the maximum 1 second rms vibration level, not to be exceeded by more than 5% of train passbys.

Table 3 Ground-borne Vibration Goals

Receiver Type	Period	Vibration Goal[1,2] (Vibration Velocity)
Residential	Day/Night	0.2 mm/s (106 dB_V)
Commercial (including schools and places of worship)	When in use	0.4 mm/s (112 dB_V)
Industrial	When in use	0.8 mm/s (118 dB_V)
Sensitive equipment within medical or research facilities	When in use	0.013 mm/s (82 dB_V) [3]

Note 1: The vibration goals are based on the maximum 1 second rms vibration level, not to be exceeded by more than 5% of train passbys.

2: dB_V re 10^{-9} m/s

3: Unless actual equipment manufacturer data are available.

In the case of railway tunnels, the ground-borne noise goals, presented in **Section 2.4**, almost always dictate lower vibration levels than the vibration goals indicated in **Table 3**. Hence other than at specific facilities with equipment with particularly high sensitivity to vibration, compliance with the ground-borne noise goals should ensure that the vibration goals will also be achieved.

2.4 Ground-borne Noise

The fact that ground-borne train noise may be audible does not necessarily indicate that it is offensive or disturbing. In many cases, the train noise may pass unnoticed due to the “masking” effect of other ambient noise sources, activities or distractions.

Some especially sensitive spaces and activities, such as theatres, cinemas, studios and sleeping areas are more prone to disturbance from ground–borne noise than others, such as shopping areas, office spaces or industrial premises.

There are no Australian Standards specifically addressing the issue of ground-borne noise from railway operations. Guidance can be obtained, however, from the following International and Australian references.

- International Standard ISO 14837-1:2005(E) Mechanical vibration - Ground-borne noise and vibration arising from rail systems - Part 1: General Guidance, First Edition 2005
- American Public Transit Association (APTA), Guidelines for Design of Rapid Transit Facilities, 1991
- Federal Transit Administration (FTA), US Department of Transport, Transit Noise and Vibration Impact Assessment, May 2006.
- The Association of Noise Consultants Measurements & Assessment of Groundborne Noise & Vibration, 2001.
- Harris Miller Miller and Hanson Inc. Transit Noise and Vibration Impact Assessment, 1995 (a guideline prepared for the United States Department of Transportation).
- NSW DECCW’s Interim Guideline for the Assessment of Noise from Rail Infrastructure Projects (IGANRIP).

All the above standards and guidelines acknowledge and are specifically designed to take into account the intermittent and low frequency character of ground-borne noise and subjective characteristics of underground rail operations as part of the assessment criteria. Therefore, these guidelines have been deemed more relevant than the more general (ie not specific to ground-borne noise from underground rail operations) Ecoaccess Draft Guideline *Assessment of Low Frequency Noise*.

ISO 14837 provides guidance in relation to the prediction of ground-borne noise levels and factors that need to be considered in the prediction process. Acceptability criteria are not included in Part 1 of the ISO standard, but are anticipated to be included as Part 4 (when available).

The APTA Guidelines recommend a ground-borne noise goal of 40 dBA for multi-family dwellings in average to high-density residential areas and a design goal of 35 dBA for single family dwellings in these areas. For hospital buildings, schools, libraries and university buildings, the Guidelines recommend a ground-borne noise design goal of 35-40 dBA. For auditoriums and music rooms a design goal of 30 dBA is recommended, while for churches and theatres the design goal is 30-35 dBA.

The FTA Guideline presents ground-borne noise impact criteria for residential (sleeping area) between 35 dBA and 43 dBA (maximum passby levels) for infrequent (less than 30) events and frequent (more than 70) events. The FTA Guideline also presents ground-borne noise and vibration criteria for special buildings (concert halls, TV studios, recording studios, auditoriums and theatres) ranging from 25 dBA to 35 dBA for frequent events.

The noise criteria contained within the IGANRIP guideline are expressed as non-mandatory "trigger levels", which if exceeded will trigger the need to consider feasible and reasonable mitigation measures. A summary of the ground-borne noise trigger levels provided in IGANRIP guideline is presented in **Table 4**.

Table 4 IGANRIP Ground-borne Noise Trigger Levels for Sensitive Receivers

Receiver	Time of day	Noise trigger levels dB(A)
		Development increases existing rail noise levels by 3 dB(A) or more ***and*** resulting rail noise levels exceed:
Residential	Day (7 am–10 pm)	40 L_{Amax} (slow)
	Night (10 pm–7 am)	35 L_{Amax} (slow)
Schools, educational institutions, places of worship	When in use	40–45 L_{Amax} (slow)

The ground-borne noise levels in **Table 4** refer to noise contributed from the proposed rail operations only and do not include ambient noise from other sources such as major roads and industry. The train noise levels are evaluated inside buildings at the centre of the most affected habitable room.

"Residential" typically means any residential premises located in a zone as defined in a planning instrument that permits new residential land use as a primary use. The LAmax noise level refers to the 95th percentile train passby event (ie 5% of train passbys are permitted to exceed the trigger levels). The absolute maximum event is not used for design, as it cannot be precisely defined and would be a highly infrequent event. The ground-borne noise level of the "average" or median train event would typically be approximately 3 dB lower than the 95th percentile event.

For new rail projects, the noise trigger levels apply immediately after operations commence and for projected traffic volumes over an indicative period into the future that represents the expected typical level of rail traffic usage (eg 10 years or a similar period into the future).

For schools, educational institutions and places of worship, the lower value of the range is most applicable where low internal noise levels are expected, such as in areas assigned to studying, listening and praying.

The IGANRIP guideline also states:

> *"It appears reasonable to conclude that ground-borne noise at or below 30 dB LAmax will not result in adverse reactions, even where the source of noise is new and occurs in areas with low ambient noise levels. Levels of 35–40 LAmax are more typically applied and likely to be sufficient for most urban residential situations, even where there are large numbers of noisy events.*
>
> *The noise trigger levels … are aimed at providing a reasonable basis for triggering the assessment of impacts from ground-borne noise. They 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 suitable for urban areas where background noise levels are relatively high."*

For commercial receivers, shopping centres and industrial buildings, IGANRIP does not provide guidance on acceptable levels. On other projects, SLR Consulting has applied ground-borne noise goals of 45 dBA for general office areas and 50 dBA to 55 dBA for retail areas depending on the particular sensitivity of the receiver. A ground-borne noise design goal of 40 dBA is desirable for commercial receivers with private offices or conference rooms.

Based on the above, **Table 5** provides a summary of the proposed ground-borne noise goals for the CRR project.

Table 5 Ground-borne Noise Goals

Receiver	Time of Day	Noise Trigger Level (dBA)[1]
Residential	Day (7.00 am to 10.00 pm)	40 dBA
	Night (10.00 pm to 7.00 am)	35 dBA
Schools, educational institutions, places of worship[2]	When in use	40 dBA to 45 dBA
Retail Areas	When in use	50 dBA to 55 dBA
General Office Areas	When in use	45 dBA
Private Offices and Conference Rooms	When in use	40 dBA
Theatres	When in use	35 dBA

Note 1: Evaluated as the LAmax "Slow" response noise level (interpreted as applicable to the 95th percentile train passby event ie typically the highest 1 in 20 event).

Note 2: The lower value of the range is primarily applicable where low internal noise levels are expected, such as in areas assigned to studying, listening, quiet contemplation and praying.

2.5 Mechanical Plant and Ventilation

Relevant assessment criteria for operational mechanical plant noise can be found in the following:

EPP(Noise)

- Minimising Background Creep – Existing L_{A90} + 0 dBA
- Acoustic Quality Objectives – Refer to Schedule 1 in EPP(Noise)

DERM Ecoaccess Guideline Planning for Noise Control (Ecoaccess PNC)

- Minimising Background Creep – Refer to Table 1 and Table 2 of Ecoaccess PNC
- Planning Noise Levels (PNL) – Refer to Table 3 and Table 4 of Ecoaccess PNC

- Specific (Intrusive) Noise Levels (SNL) – Existing Rating Background Level (RBL[3]) + 3 dBA (assessed as L_{Aeq})

DERM Draft Ecoaccess Guideline Assessment of Low Frequency Noise (Ecoaccess ALFN) – Refer to Table 3 of the draft Ecoaccess ALFN.

Brisbane City Council (BCC) Noise Impact Assessment Planning Scheme Policy (NIAPSP)

- Minimising Background Creep – Existing L_{A90} + 0 dBA (for noise categories R3 to R6 as per Appendix A of AS 1055.2)
- Comparison of Like Parameters – Existing LA90 + 0 dBA
- AS/NZS 2107: 2000 Acoustics – Recommended design sound levels and reverberation times for building interiors (AS 2107) internal noise levels – Refer to Table 1 in AS 2107

The applicable statutory requirement for noise emissions associated with fixed mechanical plant is the EPP(Noise). The EPP(Noise) nominates long term acoustic quality objectives and a background creep criteria applicable to stationary mechanical plant.

The background creep criteria according to the EPP(Noise) is identical with the background creep criteria according to the BCC NIAPSP. The Ecoaccess PNC includes more complex background noise criteria. In determining the appropriate background creep goals, the statutory and Brisbane City Council criteria have been adopted.

Mechanical ventilation noise is generally steady state (ie the noise emission varies very little with time in the short term) and therefore the difference between the L_{A90} the L_{Aeq} will be small. As a result, based on the criteria/limits discussed above, the L_{A90} based background creep criteria will be stricter than the L_{Aeq} based intrusive noise criterion. In determining the appropriate goal, a conservative approach has been adopted and thus only a background creep goal has been recommended.

The Ecoaccess ALFN guideline gives advice regarding assessment of infrasound and low frequency noise. However, the mechanical ventilation and/or emergency ventilation noise associated with the CRR project is not anticipated to generate any infrasound or distinctly low frequency noise and therefore will not require a specific assessment.

On the basis of the above references and discussion, the proposed noise goals for mechanical plant are presented in **Table 6**.

[3] The RBL is the median of the 90th percentile background (L_{A90}) noise levels in each assessment period (day, evening and night) over the duration of the monitoring (as defined in the Queensland Department of Environmental Resources Management (DERM) *Ecoaccess Guideline Planning for Noise Control*)

Table 6 Operational Mechanical Plant Noise Goals

Receiver	Time of Day	Background Noise Creep[1], dBA LA90(1hour)	Acoustic Quality Objectives[2], dBA LAeq(1hour)
Residential (for outdoors)	7am to 10pm	b/g + 0 [3]	50 [3]
	10pm to 7am	b/g + 0	-
Residential (for indoors)	7am to 10pm	-	35
	10pm to 7am	-	30
Library and educational institution (including a school, college and university) (for indoors)	when open for business or when classes are being offered	-	35
Commercial and retail activity (for indoors)	when the activity is open for business	-	45

Note 1: Background creep criteria in accordance with the EPP(Noise) and BCC NIAPSP for continuous noise sources, adopting the Rating Background Level in accordance with the DERM Ecoaccess PNC. Applicable for noise contribution from the source only.

2: Long term acoustic quality objectives according to EPP(Noise).

3: The lower of the background creep $L_{A90(1hour)}$ and Acoustic Quality Objectives $L_{Aeq(1hour)}$ is applicable.

2.6 Road Traffic Noise

The effects of CRR will require realignment of a few nearby sections of roadway . Road traffic noise emissions from realigned road sections within the study area are assessed against the planning noise levels outlined in the Department of Transport and Main Roads (DTMR) Code of Practice – Road Traffic Noise Assessment. The Code of Practice provides planning noise levels for proposed roads, road upgrades and existing roads for residential land use developments as well as criteria for other noise sensitive land uses. The relevant planning noise levels for the realigned road sections is that of Category 2 "Upgrading Existing Roads "of the DTMR Code of Practice as shown in **Table 7**.

Table 7 DTMR Code of Practice – Road Noise Goal for Existing Residences

Description	Noise Descriptor	Goal
Category 2 Upgrading Existing Roads	$L_{A10(18hour)}$[1] – external	68 dBA

Note 1: Arithmetic average of the 18 hourly LA10 levels over the consecutive hours from 6.00am to midnight.

In **Table 7**, the external assessment location (for existing residences) is 1 m from the most exposed facade of the "noise sensitive" building and 0.5 m below the surveyed eaves height of the "noise sensitive" building.

It should be noted that the noise assessment planning noise levels presented within DTMR's Code of Practice are guidelines for consideration of the impact of road traffic noise on noise sensitive development. Consideration needs to be given to technical feasibility, cost effectiveness, aesthetics, equity, community consultation and practicality in recommending noise attenuation measures. This acknowledges that in some instances, certain noise attenuation measures may not be feasible and therefore not recommended.

3 NOISE AND VIBRATION TERMINOLOGY

3.1 Noise

The terms "sound" and "noise" are almost interchangeable, except that in common usage "noise" is often used to refer to unwanted sound. Sound (or noise) consists of minute fluctuations in atmospheric pressure capable of evoking the sense of hearing. The human ear responds to changes in sound pressure over a very wide range. The loudest sound pressure to which the human ear responds is ten million times greater than the softest. The decibel (abbreviated as dB) scale reduces this ratio to a more manageable size by the use of logarithms.

The symbols SPL, L or L_P are commonly used to represent Sound Pressure Level. The symbol L_A represents A-weighted Sound Pressure Level. The noise level descriptors that have been utilised within this report are illustrated in **Figure 2** and described below.

L_{Amax} The maximum A-weighted noise level associated with a sampling period.

L_{A1} The A-weighted noise level exceeded for 1% of a given measurement period. This parameter is often used to represent the typical maximum noise level in a given period.

L_{A10} The A-weighted noise level exceeded 10% of a given measurement period and is utilised normally to characterise average maximum noise levels.

L_{Aeq} The A-weighted average noise level. It is defined as the steady noise level that contains the same amount of acoustical energy as a given time-varying noise over the same measurement period.

L_{A90} The A-weighted noise level exceeded 90% of a given measurement period and is representative of the average minimum background noise level (in the absence of the source under consideration), or simply the "background" level.

Figure 2 Graphical Display of Typical Noise Indices

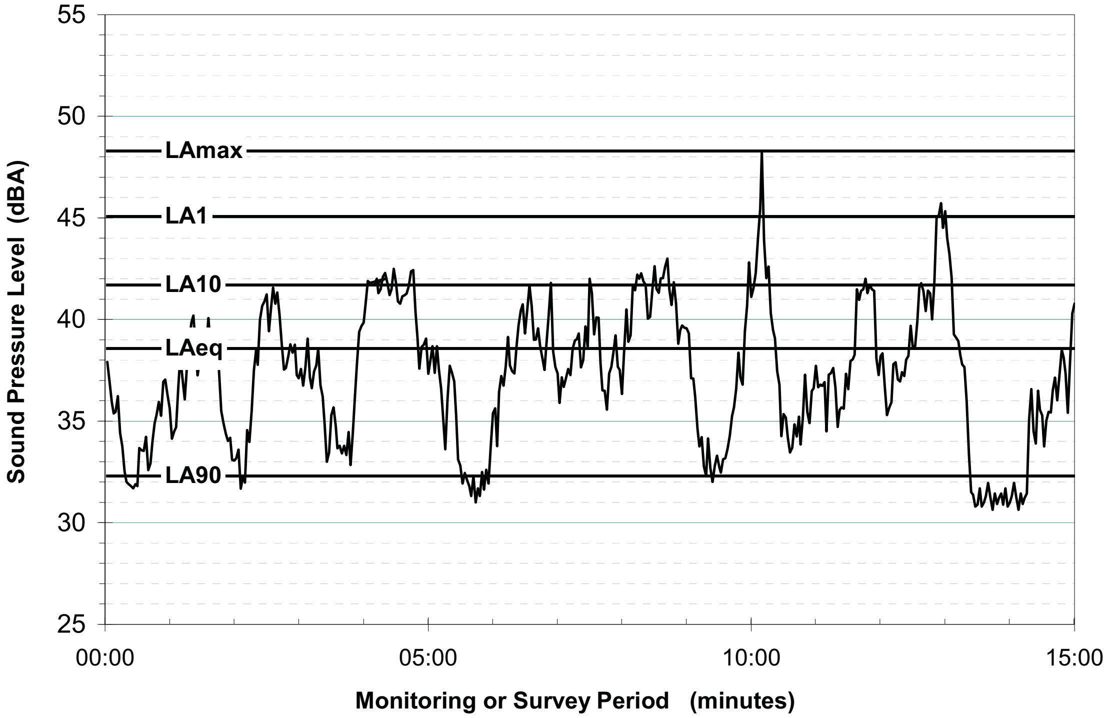


Table 8 presents examples of typical noise levels.

Table 8 Typical Noise Levels

Sound Pressure Level (dBA)	Typical Source	Subjective Evaluation
130 120 110	Threshold of pain Heavy rock concert Grinding on steel	Intolerable Extremely noisy
100 90	Loud car horn at 3 m Construction site with pneumatic hammering	Very noisy
80 70	Kerb side of busy street Loud radio or television	Loud
60 50	Department store General Office	Moderate to Quiet
40 30	Inside private office Inside bedroom	Quiet to Very quiet
20	Unoccupied recording studio	Almost silent

When dealing with numerous days of statistical noise data, it is sometimes necessary to define the typical noise levels at a given location for a particular time of day. A standardised method is available for determining these representative levels. This method produces a level representing the "average minimum" background (L_{A90}) noise level over the relevant daytime, evening and night-time periods, and is referred to as the Rating Background Level (RBL).

A change of up to 3 dBA in the level of a sound is difficult for most people to detect, whilst a 3 dBA to 5 dBA change corresponds to a small but noticeable change in loudness. A 10 dBA change corresponds to an approximate doubling or halving in loudness.

3.2 Vibration

Vibration is the term used to describe the oscillating or transient motions in physical bodies. This motion can be described in terms of vibration displacement, vibration velocity or vibration acceleration. Most assessments of human response to vibration or the risk of damage to buildings use measurements of vibration velocity. These may be expressed in terms of “peak” velocity or “rms” velocity. The former is the maximum instantaneous velocity, without any averaging, and is sometimes referred to as “peak particle velocity”, or PPV. The latter incorporates “root mean squared” averaging over some defined time period.

Vibration measurements may be carried out in a single axis or alternatively as triaxial measurements. Where triaxial measurements are used, the axes are commonly designated vertical, longitudinal (aligned toward the source) and transverse. The common units for velocity are millimetres per second (mm/s).

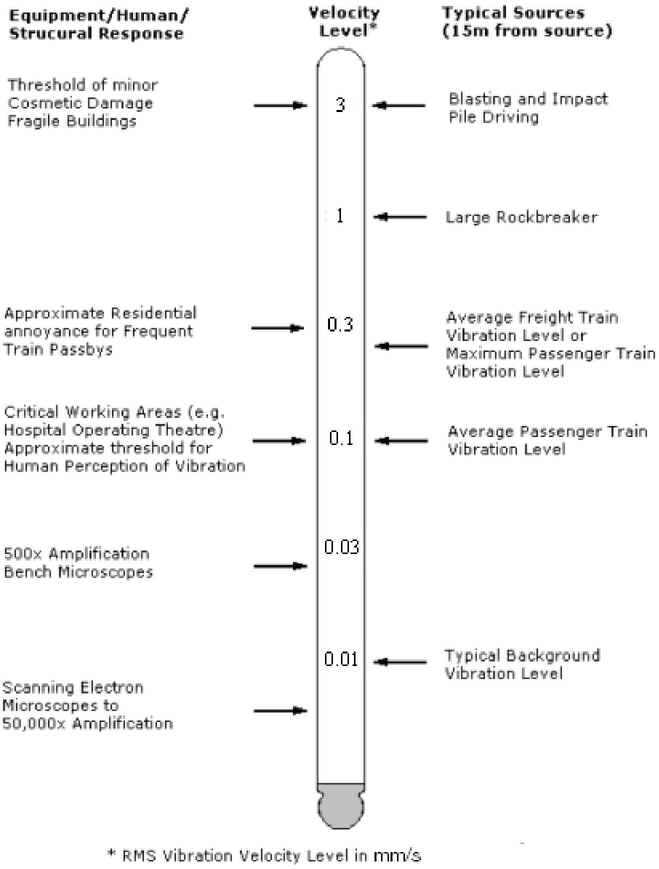
As with noise, decibel units can also be used, in which case the reference level should always be stated. Usually, the vibration velocity level is expressed in dB_V (ref 10^{-9} m/s). The character of vibration emissions can be continuous, intermittent or impulsive.

As for noise, the vibration can be described with the same level descriptors as presented and explained in **Section 3.1**. The corresponding vibration descriptors are V_{max}, V_1, V_{10}, V_{eq}, V_{90}.

Figure 3 gives examples of typical vibration levels associated with surface and underground railway projects together with the approximate sensitivities of buildings, people and precision equipment. The vibration levels are expressed in terms of the vibration velocity (in mm/s).

Vibration and sound are intimately related. Vibrating objects can generate (radiate) sound and, conversely, sound waves (particularly lower frequencies) can also cause objects to vibrate.

Figure 3 Typical Vibration Levels



3.3 Ground-borne Noise

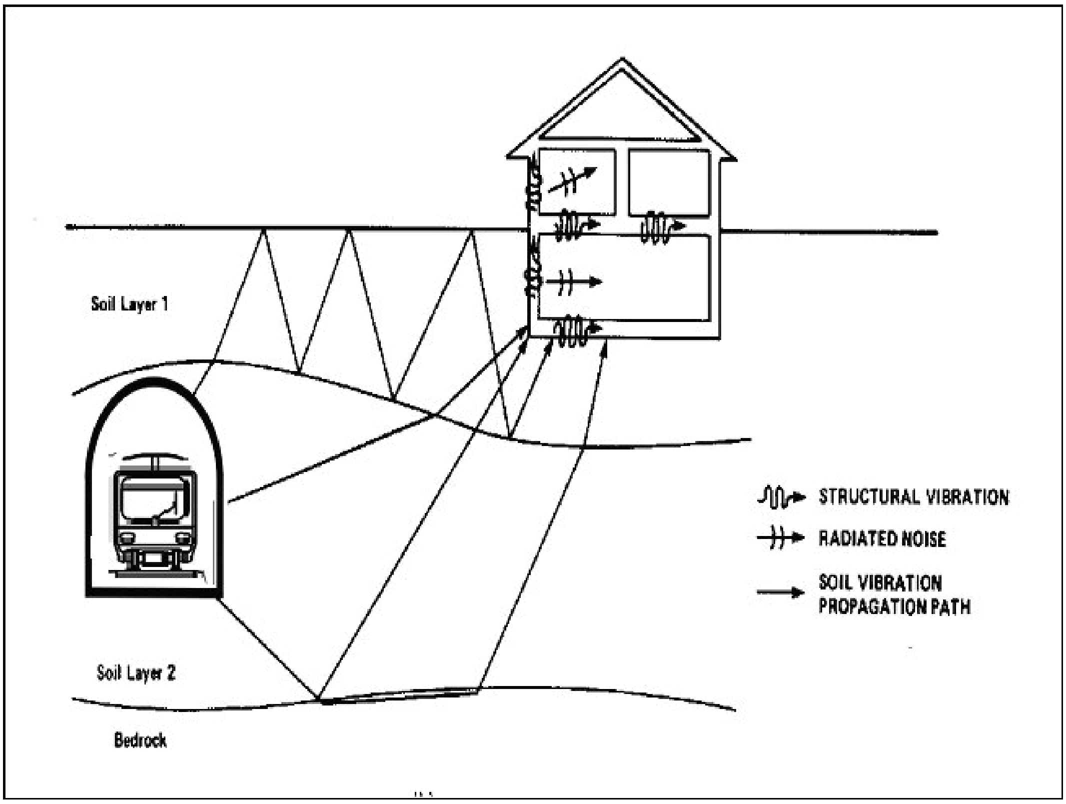
Noise that propagates through a structure as vibration and is radiated by vibrating wall, ceiling and floor surfaces is termed “ground-borne noise”, “regenerated noise”, or sometimes “structure-borne noise”. Ground-borne noise originates as vibration and propagates between the source and receiver through the ground and/or building structural elements, rather than through the air.

Typical sources of ground-borne noise include underground railway operation, tunnelling construction works, excavation plant (eg rockbreakers) and building services plant (eg fans, compressors and generators).

For surface rail operations, the airborne noise will be significantly higher than the ground-borne noise for most situations. It is only if the airborne noise is highly attenuated by very effective noise barriers that the ground-borne noise component may become dominant. This rare situation has not been identified next to the existing surface rail tracks throughout the study corridor.

Figure 4 presents the various paths by which vibration and ground-borne noise may be transmitted to a receiver for underground railway operation occurring within a tunnel.

Figure 4 Vibration and Ground-borne Noise Transmission Paths



4 EXISTING NOISE AND VIBRATION ENVIRONMENT

4.1 Noise

This section presents the results of the ambient monitoring surveys carried out for the project. Ambient noise monitoring was conducted at twenty (20) residential and special use (ie educational or medical) locations evenly spaced along the study corridor. Both attended and unattended ambient noise measurements have been conducted in order to accurately document the existing noise environment. The measured ambient noise levels have been used in part to determine applicable project noise goals.

4.1.1 Noise Monitoring Methodology

In order to determine the existing ambient noise environment along the study corridor, information about the existing ambient noise environment has been obtained from the following sources:

- Unattended continuous noise measurement of sound pressure levels at the selected monitoring locations over a seven (7) day period.
- Attended 15 minute noise measurement of sound pressure levels at the selected monitoring locations during the daytime (7 am to 6 pm), evening (6 pm to 10 pm) and night-time (10 pm to 7 am) periods.

The noise monitoring was performed between 7 May and 28 May 2010 for at least seven (7) days at each monitoring location (except at Yeronga State High School where the noise logger was vandalised after 1 day monitoring).

4.1.2 Instrumentation

The ambient noise monitoring was undertaken using Acoustic Research Laboratories Type EL-316 and SVAN Type 957 Environmental Noise Loggers programmed to record various statistical noise levels over consecutive 15 minute intervals.

Each logger was checked for calibration before and after the survey with a Rion NC-73 Sound Level Calibrator and no significant drift (greater than 0.5 dBA) in calibration was detected.

ARL EL-316 and SVAN 957 Noise Loggers are NATA certified Type 1 meters. It is common practice to use Type 1 (or 2) noise loggers for measuring ambient noise levels in accordance with the Australian Standard AS 1055.1 *Acoustics – Description and measurement of environmental noise*. The noise floor of EL-316 loggers is approximately 20 - 22 dBA and the SVAN 957 loggers is approximately 10 - 15 dBA.

Attended measurements were undertaken using Precision Sound Level Meters (SLM); a Rion NA-27, a SVAN Type 948 and a Brüel & Kjær Type 2250. All the SLMs were Type 1 Sound Level Meters. The noise floors of the SLMs are approximately 10 dBA. The SLM's were checked for calibration before and after each set of noise measurements using a Rion NC-73 Sound Level Calibrator and no significant drift (greater than 0.5 dBA) in calibration signal level was observed.

All items of acoustic instrumentation employed during the noise monitoring were set to 'Fast' response in accordance with the relevant Australian Standards and the Queensland Department of Environment and Resource Management (DERM) *Noise Measurement Manual*. All items of acoustic instrumentation employed during the noise measurement surveys were designed to comply with AS IEC 61672.2-2004 *Electroacoustics-Sound level meters–Specifications* and carry current calibration certificates.

4.1.3 Noise Monitoring Locations

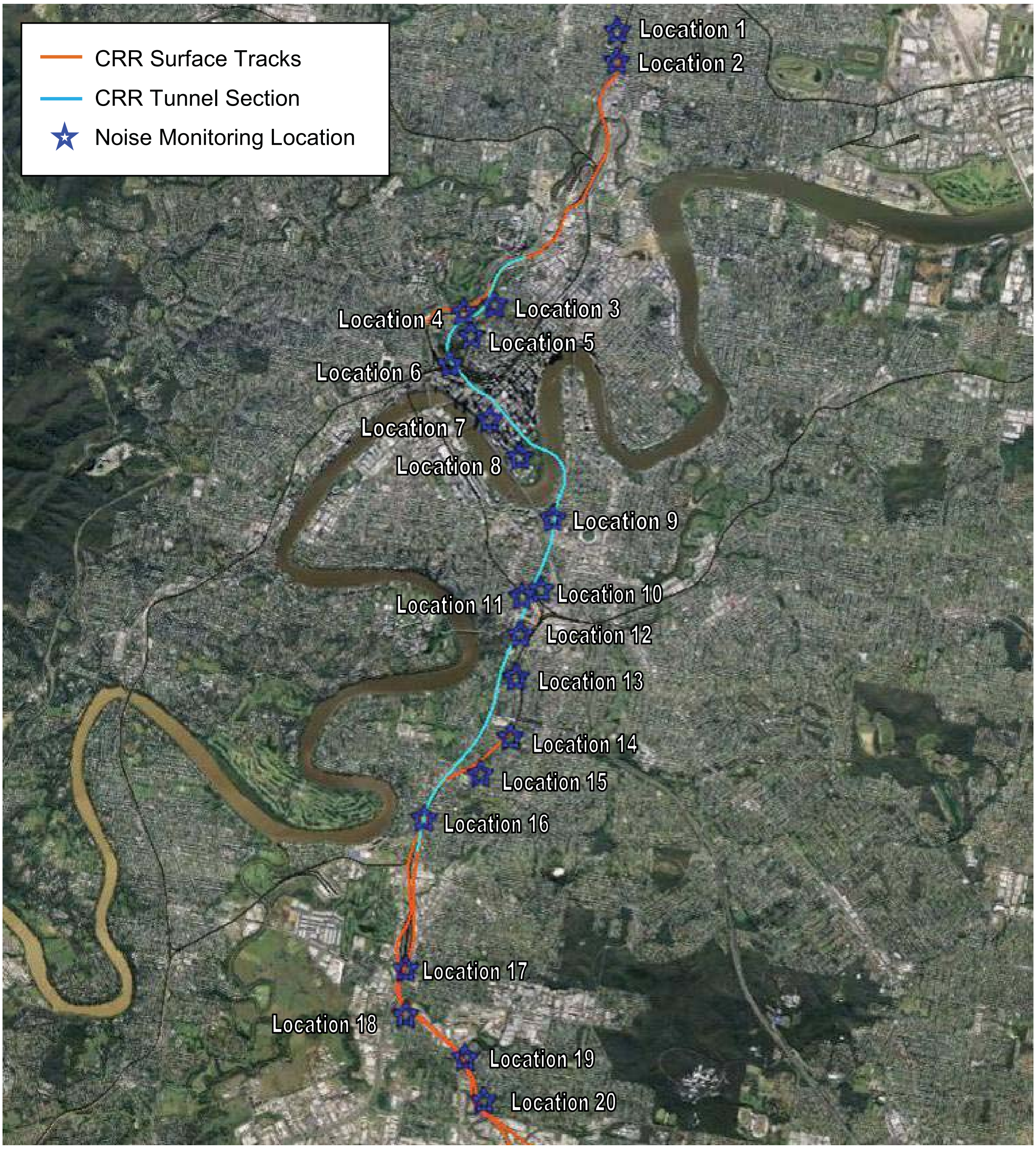
Noise monitoring locations have been selected to be representative of residential areas as well as special receivers (ie Educational and Health Care Facilities) along the corridor that may be potentially affected by the CRR project. Noise monitoring locations have been selected to provide spatial coverage of the areas with sensitive receivers along the length of the study corridor.

The final location of tunnel portals and construction sites was not known at the time of noise monitoring. Monitoring locations were selected to cover a range of potential locations for the tunnel portals and construction sites.

An overview of the selected monitoring locations is shown in **Figure 5**.

The details of the selected noise monitoring locations are summarised in **Appendix A**.

Figure 5 Overview of Noise Monitoring Locations



4.1.4 Noise Monitoring Results

Unattended Logging

The unattended ambient noise measurements were used to determine the Rating Background Levels (RBL) for the daytime (7.00 am to 6.00 pm), evening (6.00 pm to 10.00 pm) and night-time (10.00 pm to 7.00 am) periods at each location. The RBL is the median of the 90th percentile background (L_{A90}) noise levels in each assessment period (day, evening and night) over the duration of the monitoring (as defined in the *Ecoaccess PNC*). **Table 9** contains the determined RBL for each measurement location.

Table 9 Measured Rating Background Levels

Monitoring Location	Rating Background Levels (RBL), LA90 (dBA)		
	Day	Evening	Night
1 1/19 Chalk St	54	45	38
2 28 Bridge St	49	45	38
3 St Josephs College	50	48	40
4 Brisbane Girls Grammar	61	60	46
5 St Andrew War Memorial Hospital	55	53	51
6 Parkland Cres	54	50	47
7 191 George St	58	57	54
8 QUT Gardens Point	49	48	46
9 58 Leopard St	53	50	46
10 143 Park Rd	43	39[1]	34
11 Dutton Park State School	44	40	35
12 19 Dutton St	43	42	37
13 4 Fenton St	39	38	34
14 17 Lagonda St	42	41	39
15 Yeronga State High School	43[2]	41[2]	36[2]
16 3 Cardross St	42	37	33
17 1223 Ipswich Mwy	53	48	46
18 2/59 Brook St	50	43	42
19 Nyanda State High School	54	50	46
20 14 Bellevue Ave	45	45	44

Note 1: Adjusted to remove the influence of insect noise.
Note 2: Background noise level representative of only one day of noise data, due to vandalism of the noise logger.

On review of the measured ambient noise levels, the statistical noise plots (**Appendix B**), the 1/3 octave attended measurements and operator notes in **Table 10**, only one location (143 Park Rd) showed the presence of atypical insect noise. The short periods (around 6.00 pm) dominated by insect noise at 143 Park Rd were excluded when determining the RBL in **Table 9** to generate a conservatively low (ie no insects present) background noise level.

It is expected that there would be periods during the year when ambient and background noise levels along the project could be higher than those shown in **Table 9** due to the presence of insect noise.

Graphs showing the statistical noise levels measured at the monitoring locations over the whole monitoring period are presented in **Appendix B** for each 24-hour period. The graphs show various statistical noise levels, including the background (L_{A90}) noise level at each site.

15 minute weather data during noise monitoring periods was sourced from the Bureau of Meteorology (Brisbane Airport, Brisbane and Archerfield Met Stations). The weather conditions during the monitoring periods were generally fine. Some rainfall was recorded during the monitoring period and these periods have been excluded from the measurement results. The weather conditions during the remainder of the monitoring period are considered to be suitable for obtaining ambient noise measurements.

It should be noted that the Brisbane Girls Grammar school has high ambient noise levels and is representative of a location close to a Motorway (Inner City Bypass) with no existing noise barriers.

High noise levels have also been monitored at St Andrew Hospital and 191 George Street. These are representative of typical inner city locations with high density of road traffic, pedestrian activity and nearby mechanical noise.

Monitoring locations 10 through to 16 show lower ambient noise levels, representative of the locations with more suburban characteristics - ie larger distances from receivers to dominant noise sources. For most locations, including these suburban locations (somewhat) distant to major roads, road traffic noise still dominates background noise levels.

Furthermore, monitoring locations 1, 6, 9, 17 and 19 are near major connector roads and show higher ambient noise levels accordingly.

Attended Ambient Noise Measurements

Attended ambient noise measurements were also conducted at each site to confirm background noise levels and to observe typical noise sources associated with the ambient noise environment during the daytime, evening and night-time periods. The attended ambient noise measurements were conducted for one (1) 15 minute period during each of the daytime (7.00 am to 6.00 pm), evening (6.00 pm to 10.00 pm) and night-time (10.00 pm to 7.00 am) periods at each location (ie three (3) 15 minute attended measurements were taken at each location). The results of these measurements are summarised in **Table 10.**

Table 10 Attended Ambient Measurement Results – Day, Evening and Night-Time Periods

Monitoring Location	Date	Time (start of 15 min period)	Measured Noise Level (dBA)				Dominant Noise Sources/Comments
			LA90	LAeq	LA10	LA1	
1.	24/05/10	16:34	57	67	70	77	Road traffic noise frequent to constant ~ 70 dBA. Train passby noise. Domestic noises occasionally. Some birds just audible.
	24/05/10	19:52	48	62	66	70	Road traffic noise dominant (intermittent to frequent) ~ 58-65 dBA. Train passby noise ~ 60+ dBA. Some low level insect noise. Plane pass-over.
	25/05/10	06:16	55	67	71	76	Road traffic noise dominant (intermittent to frequent) ~ 60+ dBA. Train passby noise. Plane pass-over. Nearby reverse beep few minutes.
2.	20/05/10	15:45	53	63	66	75	Road traffic noise dominant. Birds chirping intermittently. Train passby noise. A few concrete truck passby.
	24/05/10	20:15	46	64	62	75	Road traffic noise dominant first few minutes ~ 60-70 dBA. Traffic and electrical (power-lines on train tracks) hum just audible in background. Train passby noise ~ 63-66 dBA. Some insects. Dog barking loudly most of measurement ~60-90 dBA.
	21/05/10	01:52	39	47	48	58	Some insect noise. Intermittent road traffic noise.
3.	19/05/10	15:20	54	63	66	71	Road traffic noise dominant. Children talking nearby.
	20/05/10	18:30	51	62	66	69	Road traffic noise dominant. Distant railway noise.
	21/05/10	01:20	38	49	50	63	Intermittent road traffic noise dominant.

Monitoring Location	Date	Time (start of 15 min period)	Measured Noise Level (dBA)				Dominant Noise Sources/Comments
			LA90	LAeq	LA10	LA1	
4.	17/05/10	17:35	65	67	68	73	Road traffic noise dominant. Train passby noise.
	20/05/10	18:55	63	68	68	81	Road traffic noise dominant. Train passby noise. Occasional siren from inside the gymnasium just audible.
	21/05/10	00:55	47	58	61	67	Road traffic noise dominant, though intermittent. Distant low level ventilation/construction noise. Some low level insect noise.
5.	10/05/10	17:20	57	60	63	67	Road traffic noise dominant. Various city noises.
	12/05/10	18:40	54	57	59	79	Road traffic noise dominant. Low level noise from ventilation at car park some distance away.
	13/05/10	00:35	51	53	54	60	Road traffic noise dominant. Ventilation noise. Road cleaner passed by.
6.	18/05/10	15:30	55	63	66	74	Road traffic noise. Some low level noise from ventilation. Train passby noise including warning horn and wheel squeal. Ambulance siren.
	20/05/10	21:20	51	62	65	73	Train passby noise including warning horn and wheel squeal. Some road traffic noise and ventilation noise.
	21/05/10	00:30	48	51	54	58	Low noise levels from distant road cleaner, ventilation and insects. One distant low level train passby including some wheel squeal. Some bird noise and road traffic noise.
7.	25/05/10	11:49	68	69	70	71	Ventilation noise constant. Some clangs and bangs from alley-way. Road traffic noise just audible in background.
	20/05/10	20:50	58	60	62	65	Ventilation noise dominant. Live music started playing at the Irish Murphy's at 9.00 pm. Plane pass-over. Patron noises. Intermittent road traffic noise.
	26/05/10	01:30	54	55	56	58	Ventilation noise constant and dominant noise source. Road traffic noise intermittent. Pedestrians talking occasionally.
8.	07/05/10	15:55	51	56	57	64	Distant road traffic noise. People talking loudly most of the time.
	13/05/10	18:45	50	56	58	66	Pedestrian noise dominant most of the time. Some low level insect noise. Distant road traffic noise. Occasionally bird noise. Ambulance siren.
	13/05/10	01:15	47	48	48	50	Distant ventilation noise. Some low level insect noise and road traffic noise.
9.	25/05/10	08:13	54	57	59	75	Noises from children playing dominant ~57-64 dBA. Hum from road traffic noise constant ~ 54 dBA. Various vehicle and domestic noises

Monitoring Location	Date	Time (start of 15 min period)	Measured Noise Level (dBA)				Dominant Noise Sources/Comments
			LA90	LAeq	LA10	LA1	
							intermittent.
	18/05/10	18:10	52	56	58	70	Road traffic noise dominant. Domestic noises intermittent. Ambulance siren.
	26/05/10	00:55	46	49	51	55	Road traffic noise dominant. Low level ventilation noise.
10.	25/05/10	08:49	44	57	61	67	Road traffic noise dominant. Plane pass-over intermittent. Train passby noise ~ 48-55 dBA. Some bird noise.
	25/05/10	18:55	42	52	56	60	Road traffic noise dominant most of the time. Significant contribution from insect noise. Train passby noise.
	26/05/10	00:20	37`	44	48	55	Distant road traffic noise dominant. Sporadic local road traffic. Freight train passby.
11.	18/05/10	14:10	45	57	61	70	Distant road traffic noise. Train passby noise including warning horn and wheel squeal. Plane pass-over. Occasional bird noise. Some noises from children playing/talking.
	20/05/10	20:15	42	51	52	63	Distant road traffic noise. Plane pass-over. Train passby noise. Pedestrians occasionally passing by.
	20/05/10	22:20	37	49	43	66	Stationary train with auxiliary units operating at station for a few minutes and train passby noise dominant. Plane pass-over.
12.	25/05/10	09:17	44	54	56	66	Plane pass-over. Birds intermittent ~ 54-58 dBA. Constant low level road traffic noise. Some domestic noises. Train passby noise ~ 48-54 dBA
	20/05/10	21:29	39	47	45	61	Road traffic noise intermittent. Insect noise (low noise level) constant in background. Occasional domestic noises. Train passby noise including warning horn and pass-bys ~46-49 dBA. Plane pass-over.
	20:/05/10	23:50	39	42	43	51	Distant road traffic noise. Train passby noise. Distant low-level ventilation/industrial and construction noise.
13.	07/05/10	16:53	45	55	58	64	Road traffic noise dominant. Train passby noise ~ 55-65 dBA. Some bird noise. Plane pass-over. Some domestic noises.
	17/05/10	20:55	39	50	52	62	Train passby noise ~ 48-64 dBA. Insects just audible. Road traffic noise intermittent. Plane pass-over. Occasional domestic noises/wildlife in trees.
	18/05/10	00:001	34	49	51	62	Road traffic noise intermittent. Insects just audible in background. Train passby noise ~ 40-66 dBA. Wildlife in trees occasionally. Helicopter pass-over.

Monitoring Location	Date	Time (start of 15 min period)	Measured Noise Level (dBA)				Dominant Noise Sources/Comments
			LA90	LAeq	LA10	LA1	
14.	07/05/10	15:26	46	53	51	66	Train passby noise. Road traffic noise. Birds chirping occasionally.
	17/05/10	20:31	39	53	51	67	Intermittent noise from bats and possums in trees ~ 50dBA. 'Hum' noise from pool pump constant ~ 39 dBA. Train passby noise ~ 48-75 dBA. Local traffic just audible in background.
	17/05/10	23:30	38	55	57	68	Intermittent noise from bats and possums in trees. 'Hum' noise from pool pump constant ~ 39 dBA. Train passby noise ~ 60-73 dBA.
15.	18/05/10	13:10	45	57	57	69	Noises from children playing dominant. Freight and passenger train passby noise. Distant road traffic noise. Plane pass-over. Bird noise intermittent.
	20/05/10	19:40	43	50	54	60	Intermittent road traffic noise. Insect noise dominant. Aircraft pass-over. Some rail traffic. Some domestic noises.
	20/05/10	22:50	34	44	48	56	Insect noise in background. Road traffic noise intermittent. Train passby noise. Helicopter pass-over.
16.	11/05/10	08:23	44	51	53	60	Road traffic noise dominant ~ 45-50 dBA. Low level intermittent bird noise. Train passby noise ~ 50-62 dBA. Talking nearby.
	17/05/10	20:03	37	46	47	59	Local traffic noise occasional. Some road traffic noise from main road. Domestic noises. Train passby noise ~ 48-60 dBA
	18/05/10	0:30	31	47	49	60	Train passby noise ~ 56-60 dBA. Intermittent domestic noises nearby. Road traffic noise quiet and intermittent. Bats and possums in trees occasionally.
17.	17/05/10	15:20	56	61	63	70	Road traffic noise dominant. Some domestic noises. Train passby noise. Helicopter pass-over.
	24/05/10	18:08	53	60	63	70	Road traffic noise dominant (frequent to constant0. Train passby noise ~62-73 dBA. Insect noise audible most of the time. Some domestic noises. Plane pass-over.
	20/05/10	23:15	43	53	56	66	Road traffic noise dominant, though intermittent. Some insect noise. Train passby noise.
18.	10/05/10	16:11	54	58	61	67	Road traffic noise intermittent ~ 60-67 dBA. Train passby noise ~ 60-67 dBA. Domestic noises intermittent. Some birds. Generator noise constant in background.
	17/05/10	19:36	45	54	55	66	Road traffic noise constantly intermittent in background. Vehicle pass-bys ~ 60+ dBA. Train passby noise. Occasional domestic noises.

Monitoring Location	Date	Time (start of 15 min period)	Measured Noise Level (dBA)				Dominant Noise Sources/Comments
			LA90	LAeq	LA10	LA1	
							Insects in background.
	18/05/10	01:51	40	45	48	54	Road traffic noise intermittent ~ 38-40 dBA. Talking at train station fairly loud. Low level insects noise in background. Domestic noises.
19.	11/05/10	09:04	56	61	63	71	Noise from announcements in hall intermittent first few minutes ~ 70 dBA. Road traffic noise, frequent ~ 58-65 dBA. Intermittent bird noise. Plane pass-over.
	17/05/10	19:11	51	58	59	70	Road traffic noise dominant ~ 54 dBA. Insect noise just audible. Train passby noise. Some talking in distance occasionally.
	18/05/10	01:03	45	49	51	55	Intermittent road traffic noise. Low level insects noise in background. Bats and possums in trees occasionally. Distant industrial noises.
20.	19/05/10	15:28	50	55	58	65	Road traffic noise constant. Domestic noises intermittent. Plane pass-over just audible. Train passby noise ~60+ dBA
	17/05/10	18:46	48	52	54	60	Road traffic noise dominant, constantly ~ 48 dBA. Occasional domestic noises. Train passby noise.
	18/05/10	01:23	44	48	50	53	Road traffic noise 'hum' constant ~ 45-50 dBA. Bats and possums in trees occasionally.

Note: Daytime (7.00 am to 6.00 pm), evening (6.00 pm to 10.00 pm) and night-time (10.00 pm to 7.00 am)

The attended measurements and observations summarised in **Table 10,** show that railway noise and/or road traffic noise is dominant at the majority of monitoring locations during daytime and evenings. The night-time period was dominated by road traffic noise at most locations, though it was mostly a distant traffic noise.

Only two monitoring locations (143 Park Rd and Yeronga State High School) had the ambient background environment dominated by insect noise during the evening period. Insect noise has been adjusted for where necessary at 143 Park Rd. The noise logger at Yeronga State High School was vandalised, and as such noise logger data is only available for one (1) 24 hour period. The available noise data did not show adverse interference by insect noise.

At monitoring location 1 and 2 there were increased levels of road traffic during the daytime for the monitoring period due to concrete trucks associated with the Airport Link Project. The increased number of truck pass-bys during daytime will not significantly affect the measured RBL during daytime.

Monitoring location 7 was located in an alley next to Irish Murphy's and was more representative of a commercial location than a residential location. The noise environment was dominated by ventilation noise, patron noise and music. As such, noise levels obtained at this location are assumed to be slightly higher than expected for the city residential area (where ventilation noise, music and patron noise is less prevalent), but never-the-less is representative of CBD living.

4.2 Vibration

Unlike noise, existing ambient vibration levels at residences and other sensitive buildings are not significant in the assessment of potential vibration issues. This is primarily because vibration impacts are assessed based on absolute criteria rather than criteria that are expressed relative to an existing ambient level. Existing vibration levels along the study corridor were measured to (if required) compare with future vibration levels with the CRR project in operation.

This section presents the results of the ambient vibration monitoring surveys carried out for the project. Ambient vibration monitoring was conducted at eleven (11) residential and special use (ie educational/research or health care facilities) locations along the study corridor.

4.2.1 Vibration Monitoring Methodology

In order to determine the existing ambient vibration environment along the study corridor, 24 hour unattended vibration measurements were conducted at each selected site.

The vibration monitoring was performed between 7 May and 25 May 2010, for a period of at least 24 hours at each monitoring location.

4.2.2 Instrumentation

The vibration measurements were conducted using Instantel Minimate Plus vibration loggers with one triaxial (transverse, vertical and longitudinal) geophone installed inside the building at the monitoring locations. The vibration loggers were programmed to record Peak Particle Velocity (PPV) in mm/s every 60 seconds over the monitoring period.

The vibration instrumentation employed during the vibration measurement surveys carry current calibration certificates by an ISO 17025 accredited laboratory.

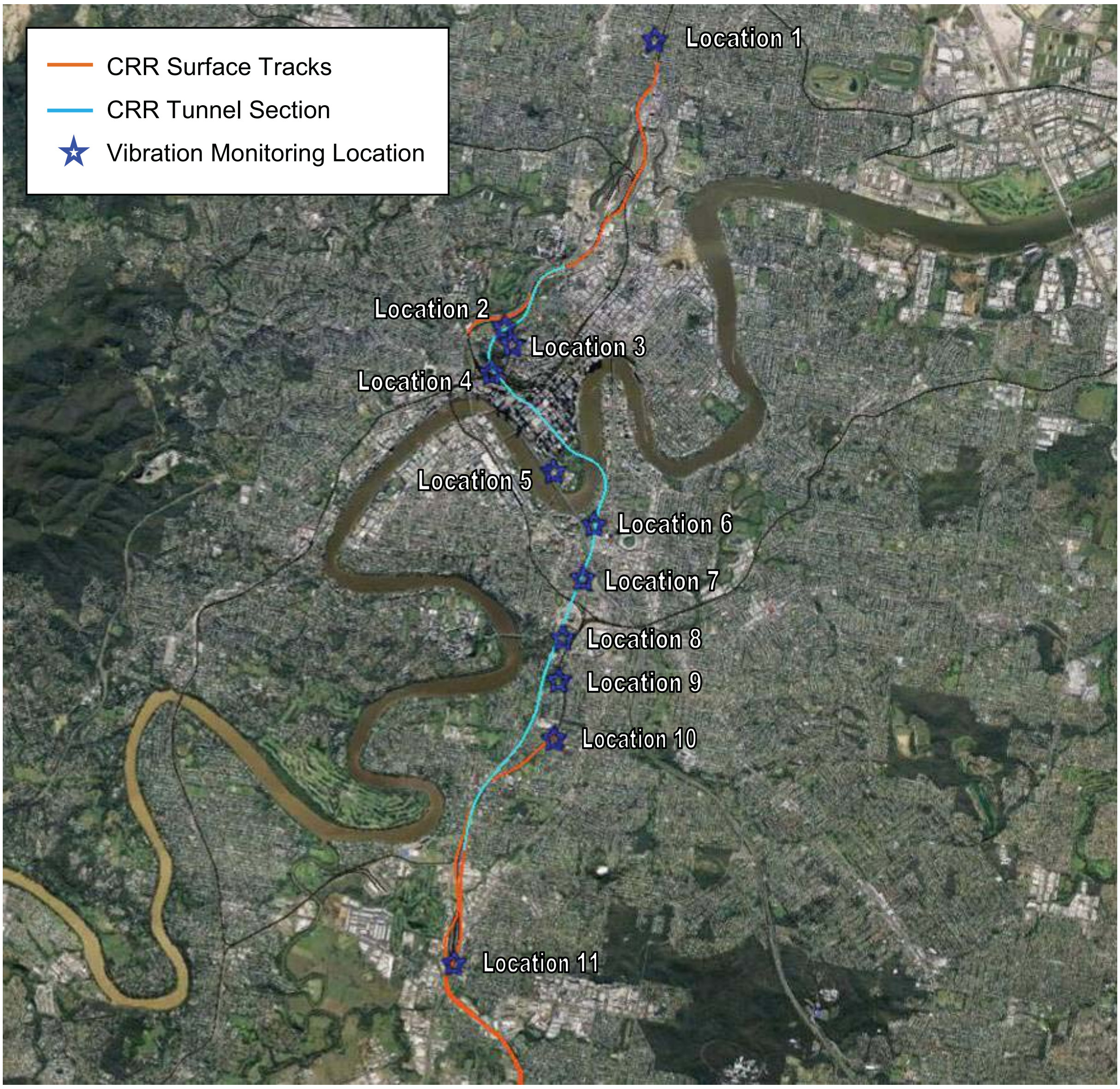
4.2.3 Vibration Monitoring Locations

Vibration monitoring locations have been selected to be representative of residential areas as well as special receivers (ie educational/research or health care facilities) along the corridor that may be potentially affected by the CRR project. Vibration monitoring locations have been selected to provide spatial coverage of the areas having sensitive receivers within the whole study corridor.

An overview of the selected vibration monitoring locations is shown in **Figure 6**.

The details of the selected vibration monitoring locations are summarised in **Appendix C**.

Figure 6 Overview of Vibration Monitoring Locations



4.2.4 Vibration Monitoring Results

The unattended ambient vibration measurements were used to determine the Average Minimum Background Level (V_{90}), Average Maximum Level (V_{10}) and Maximum Level (V_1) for the daytime (7.00 am to 6.00 pm), evening (6.00 pm to 10.00 pm) and night-time (10.00 pm to 7.00 am) periods at each location. **Table 11** contains the determined vibration levels for each measurement location. Graphs showing the peak particle velocity (mm/s) measured at each monitoring location during the monitoring period are presented in **Appendix D**.

Table 11 Measured Existing Ambient Vibration

Monitoring Location[1]	Average Minimum Background Vibration V_{90} (mm/s) [2]			Average Maximum Vibration V_{10} (mm/s) [3]			Maximum Vibration V_1 (mm/s) [4]		
	Day	Evening	Night	Day	Evening	Night	Day	Evening	Night
1	0.07	0.04	0.02	0.66	0.20	0.14	2.31	0.82	0.49
2	0.04	0.04	0.04	0.05	0.05	0.05	0.08	0.05	0.05
3	0.03	0.03	0.02	0.08	0.05	0.04	0.17	0.08	0.06
4	0.04	0.04	0.03	0.06	0.05	0.04	0.07	0.07	0.06
5	0.02	-	-	0.02	-	-	0.03	-	-
6	0.01	0.01	0.01	0.04	0.14	0.02	0.16	0.57	0.16
7	0.04	0.04	0.04	0.06	0.10	0.05	0.19	0.49	0.10
8	0.03	0.03	0.03	0.04	0.04	0.03	0.31	0.04	0.04
9	0.04	0.06	0.04	0.70	0.84	0.23	2.69	1.61	0.71
10	0.04	0.04	0.04	0.05	0.05	0.04	0.11	0.08	0.13
11	0.10	0.04	0.03	0.30	0.22	0.21	1.50	0.50	0.35

Note 1: All monitoring locations are residential excluding locations 2 to 5.
Note 2: The V90 is the vibration velocity exceeded 90% of a given measurement period and is representative of the average minimum background vibration.
Note 3: The V10 is the vibration velocity exceeded 10% of a given measurement period and is utilised normally to characterise average maximum vibration.
Note 4: The V1 is the vibration velocity exceeded for 1% of a given measurement period. This parameter is sometimes used to represent the maximum vibration in a given period. The absolute maximum peak particle velocity is higher than this V1 as can be seen in **Appendix D**.

The background vibration level (V_{90}) for all sites varies between 0.01 mm/s to 0.1 mm/s during daytime and evening. During the night-time, the background vibration level (V_{90}) varies between 0.01 mm/s to 0.04 mm/s. Maximum vibration levels (V_1) for the residential monitoring locations were in the range of 0.11 mm/s to 2.69 mm/s during daytime and evening. During night-time, vibration levels (V_1) of 0.04 mm/s to 0.71 were measured. The average maximum levels (V_{10}) for the residential monitoring locations ranged 0.04 mm/s to 0.84 mm/s during daytime and evening.

It can be noted that high vibration levels have been monitored at locations 1, 9 and 11 which are on timber floors in residential dwellings. This shows that normal activities (ie closing doors, drawers and cupboards, walking, moving and sitting on furniture etc) in these residential dwellings with light-weight (timber) floors generate vibration levels significantly above the vibration goals presented in **Section 2.3**.

For receivers with vibration sensitive equipment locations 3 (St Andrews Hospital) and location 5 (QUT), background vibration levels (V_{90}) of 0.02 mm/s to 0.03 mm/s and maximum vibration levels (V_1) of 0.03 mm/s to 0.17 mm/s, were measured.

5 IDENTIFICATION OF NOISE AND VIBRATION SENSITIVE BUILDINGS

The sensitivity of occupants to noise and vibration varies according to the nature of the occupancy and the activities performed within the affected premises. For example, recording studios are more sensitive to vibration and ground-borne noise than residential premises, which in turn are more sensitive than typical commercial premises.

The sensitivity may also depend on the existing noise and vibration environment. For example, the AS/NZS 2107:2000 *"Recommended Design Sound Levels and Reverberation Times for Building Interiors"* recommend higher acceptable noise levels in urban areas compared with suburban areas. Guidelines produced by the American Public Transit Association (APTA) also nominate higher ground-borne noise goals for multi-family dwellings than for single-family dwellings.

Following receipt of the Reference Design, SLR Consulting has classified all buildings within a corridor extending approximately 100 m either side of the nearest CRR track alignment. Each building was classified into the following receiver categories:

- Residential
- Commercial
- Educational
- Medical
- Place of Worship
- Heritage Item
- Industrial

In the noise and vibration modelling presented in this report, all residential receivers are considered to be of a sensitive nature. Commercial receivers are generally less sensitive to noise and vibration compared to residential receivers.

For receivers that fit more than one category above (eg heritage building used as a child care centre or residential occupancy) the most sensitive receiver type has been used.

Appendix E presents details of non-residential noise and vibration sensitive receivers that are situated along the length of the alignment.

6 GROUND-BORNE VIBRATION ASSESSMENT - TRAIN OPERATIONS

6.1 Introduction

Railway vibration is generated by dynamic forces at the wheel-rail interface and occurs, to some degree, even with continuously welded rail and smooth wheel and rail surfaces (due to the moving loads, finite roughness and elastic deformation of the surfaces). Higher vibration levels occur in the presence of rail and wheel surface irregularities.

This vibration propagates via the rail mounts into the ground or track support structures. It then travels through the ground or structures and in some circumstances may sometimes be felt as tactile vibration by the occupants of buildings. If the levels of vibration are sufficiently high (ie in buildings very close to rail tracks), then rattling or visible movement of loose objects (crockery, plants, etc) may also sometimes occur.

The effects of vibration in buildings can be divided into four main categories:

- Those in which the occupants or users of the building are inconvenienced or possibly disturbed (human perception or human comfort vibration).
- Those where the building contents may be affected.
- Those where common services may be affected.
- Those in which the integrity of the building or the structure itself may be prejudiced.

A fifth effect is the noise generated within buildings as a result of the vibration. This is termed “ground-borne noise” and is discussed further in **Section 7**.

For this project, the potential ground-borne vibration impacts would be limited to receivers located within an approximate 50 m wide corridor above the centreline of the proposed tunnels. The applicable ground-borne vibration goals are discussed in **Section 2.3**.

6.2 Ground-borne Vibration Modelling Methodology

International Standard ISO 14837-1 2005 "*Mechanical vibration - Ground-borne noise and vibration arising from rail systems - Part 1: General Guidance*" provides useful guidance in relation to the extent of assessment that is normally required for new rail systems including:

- **Scoping Model** at the very earliest stages
- **Environmental Assessment Model** during planning process and preliminary design
- **Detailed Design Model** to finalise extent and form of mitigation for construction

At this stage of the detailed feasibility phase of CRR, a combined Environmental Assessment/Detailed Design Model has been adopted to assess the potential impact of ground-borne noise and vibration levels and identify, in-principle, the extent of likely mitigation measures. A brief description of the modelling options is provided in **Figure 7**.

Figure 7 Ground-borne Vibration/Noise Modelling Approaches (from ISO 14837-1:2005(E))

A single model may be used for all stages with appropriate selection of input parameters (e.g. worst case for scoping assessment). Otherwise, three types of ground-borne vibration and/or ground-borne noise prediction model should be considered, as follows.

a) **Scoping model**: to be used at the very earliest stages of development of a rail system to identify whether ground-borne vibration and/or ground-borne noise is an issue and, if so, where the "hot spots" along the length of the system's alignment are located. This type of model should be used to generate input to either environmental comparative frameworks (as part of the selection of a mode of transport) or the scoping stage of an environmental assessment.

b) **Environmental assessment model**: to be used to quantify more accurately the location and severity of ground-borne vibration and/or ground-borne noise effects for a rail system and the generic form and extent of mitigation required to reduce or to remove the effects. This type of model should form part of the planning process for a scheme, developing the environmental statement where required and supporting preliminary design.

c) **Detailed design model**: to be used to support the detailed design and specification of the generic mitigation identified as being required by the environmental assessment model. This type of model should form part of the design and construction stages of a scheme, with particular focus on the rolling stock and permanent-way design.

In accordance with the ISO standard, the ground-borne noise and vibration modelling considers all of the parameters that are critical in determining the absolute levels of ground-borne noise and vibration, and the benefits (or otherwise) of different design and mitigation options. The key parameters are listed under the following headings:

- **Source** - route alignment, rolling stock design, rail type, trackform design, tunnel design, construction tolerances, operations and maintenance
- **Propagation Path** - ground type and vibration propagation wave types
- **Receiver** - Building construction

The following sections provide a brief summary of the modelling algorithms that have been adopted for the CRR assessment.

6.2.1 Modelling Approach

The prediction of ground-borne vibration from rail systems is a complex and developing technical field. Whilst much research has been undertaken into various aspects associated with ground-borne noise and vibration from underground rail systems, there are currently no widely accepted modelling software packages available, and several different modelling approaches are currently in use (including empirical methods, finite element methods, boundary element methods and combinations of these). Whilst a number of possible calculation methods are available, each method needs to take into account the key parameters identified in the ISO standard.

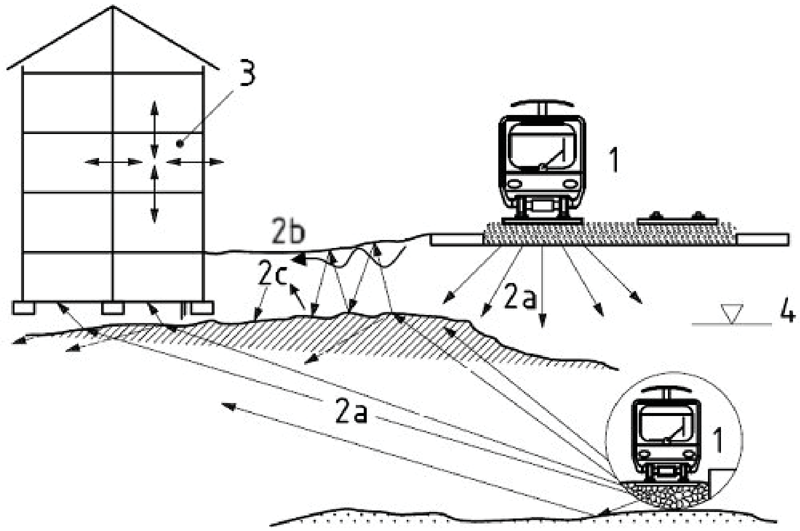
The modelling for the CRR project was therefore carried out using a SLR Consulting-developed modelling process for the core calculations. The algorithms incorporated into the in-house model are well documented in authoritative references and are widely used within the acoustical consulting profession, both in Australia and internationally.

Furthermore, as part of the Epping to Chatswood Railway Line (ECRL) project in Sydney, ground-borne noise and vibration measurements have been undertaken by SLR Consulting whilst a test train was operated in the tunnel under controlled conditions. As part of this testing, SLR Consulting undertook ground-borne noise and vibration measurements on the surface and within the tunnel at a number of locations. The results from this testing have been used to validate and refine the ground-borne noise and vibration modelling algorithms for the CRR assessment.

The ECRL and proposed CRR projects share similar design characteristics in relation to a circular tunnel cross-section and similar slab track design. Where differences exist between the ECRL and the CRR project (eg ground conditions, rolling stock and track/rolling stock maintenance practices), these have been accounted for in the ground-borne noise and vibration predictions.

The modelling approach is illustrated in **Figure 8** and takes into account the source vibration levels, the vibration propagation between the tunnel and nearby building foundations, and the propagation of vibration within the building elements. A summary of the key modelling assumptions are provided in the following sections.

Figure 8 Example of Source, Propagation and Receiver System (ISO 14837)



Key

1 source

2 propagation:
- 2 a body waves (compression, shear)
- 2 b surface waves (e.g. Rayleigh, Love)
- 2 c interface waves (e.g. Stoneley)

3 receiver (vibration, re-radiated noise)

4 water table

NOTE The components of the system comprising source, propagation and receiver are interdependent.

6.2.2 Source Vibration Levels

Source vibration levels within tunnels are dependent on a number of factors including the track design, train type, train speed, wheel condition, ground conditions and tunnel design.

Only single-deck passenger trains are proposed to operate in the CRR project. Ultimately there will be a captive fleet of 9 car (approximately 220 m) single-deck passenger trains operating the CRR project.

A desktop assessment of similar rail projects was performed to determine the typical source vibration levels to be used as a starting point for the modelling. Vibration measurements in relation to the ECRL project in Sydney were used to further validate and refine the source vibration level.

Standards are also proposed to be adopted to ensure that the condition of the train wheels and rails are maintained within specified roughness limits in Annex C of ISO 3095:2005(E) "*Railway Applications - Acoustics - Measurement of noise emitted by railbound vehicles*" (ISO 3095).

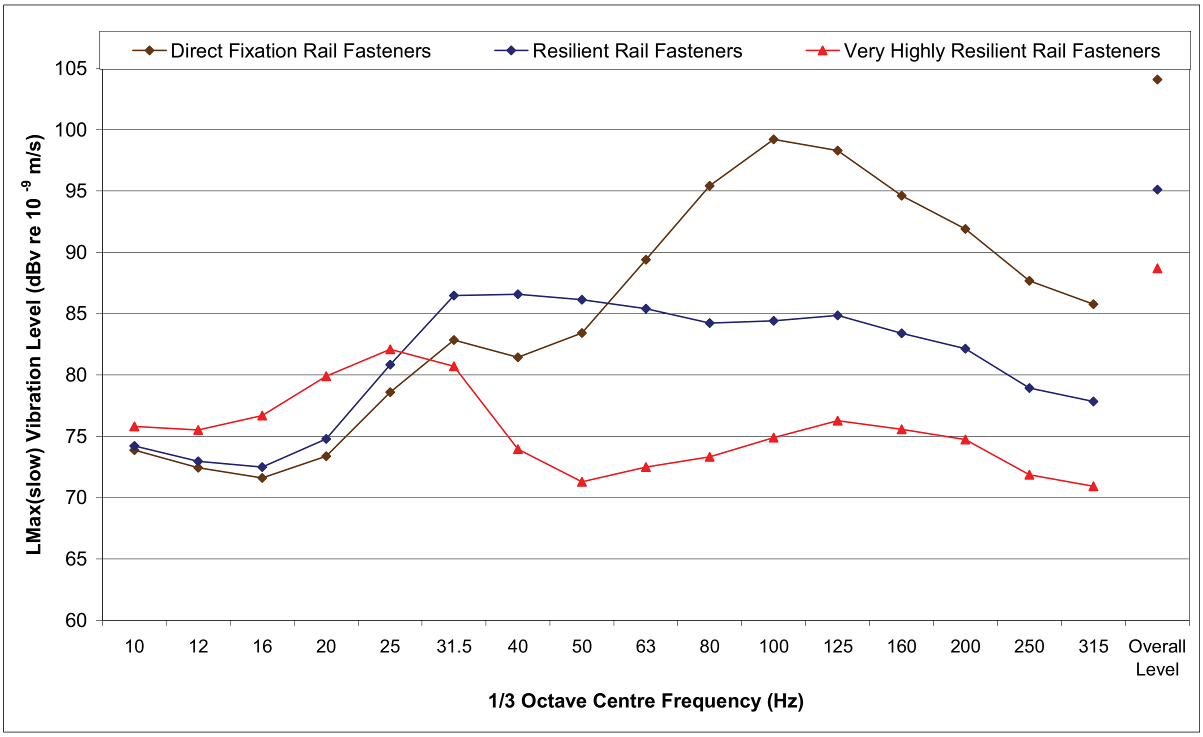
A summary of the reference vibration levels for three forms of track systems are provided in **Table 12** and **Figure 9**. These trackform source vibration levels take into account the relevant design factors of the CRR project and are described further below under the "trackform design" heading.

Table 12 Reference Source Vibration Levels for CRR Trains (Tunnel Wall Vibration Levels at reference speed of 80 km/h) – $L_{max,Slow}$

Track Type	1/3 Octave Vibration Levels (dB$_V$ re 10^{-9} m/s)																Overall Level
	10 Hz	12 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	
Direct Fixation Rail Fasteners	74	72	72	73	79	83	81	83	89	95	99	98	95	92	88	86	104
Resilient Rail Fasteners	74	73	72	75	81	86	87	86	85	84	84	85	83	82	79	78	95
Highly Resilient Rail Fasteners	76	76	77	80	82	81	74	71	72	73	75	76	76	75	72	71	89

Note: The LAmax,Slow noise level are for the 95th percentile train passby event. The absolute maximum event is not used for predictions, as it cannot be precisely defined and would be a highly infrequent event. The source vibration levels assume wheel and rail roughness within the limit spectrum in Annex C of ISO 3095.

Figure 9 Reference Source Vibration Levels for CRR Trains (Tunnel Wall Vibration Levels at Reference Speed of 80 km/h) – $L_{max,Slow}$



Note: The LAmax noise level are for the 95th percentile train passby event. The absolute maximum event is not used for predictions, as it cannot be precisely defined and would be a highly infrequent event. The source vibration levels assume wheel and rail roughness within the limit spectrum in Annex C of ISO 3095.

Route Alignment

For as much as possible, the CRR Reference Project alignment has been located below major roads or existing railway lines including the Inner City Bypass, Gregory Terrace, Albert Street, Fairfield Road and below the railway north of Yeerongpilly Station. From a ground-borne noise and vibration perspective, this is advantageous because in many areas next to major roads or railways, the nearest receptors are of a commercial or industrial nature and are therefore not highly susceptible to ground-borne noise and vibration. In other sections, the proposed alignment runs beneath suburban residential areas away from major roads where the ambient noise environment is quieter and the potential sensitivity to train passbys is increased.

On curved track, wear patterns on the rail and vehicle steering characteristics can affect the source vibration emissions at the wheel rail interface. The risk of poor rail condition (such as corrugation) is also greater on curves than on straights, as is the risk of other effects, such as wheel flanging.

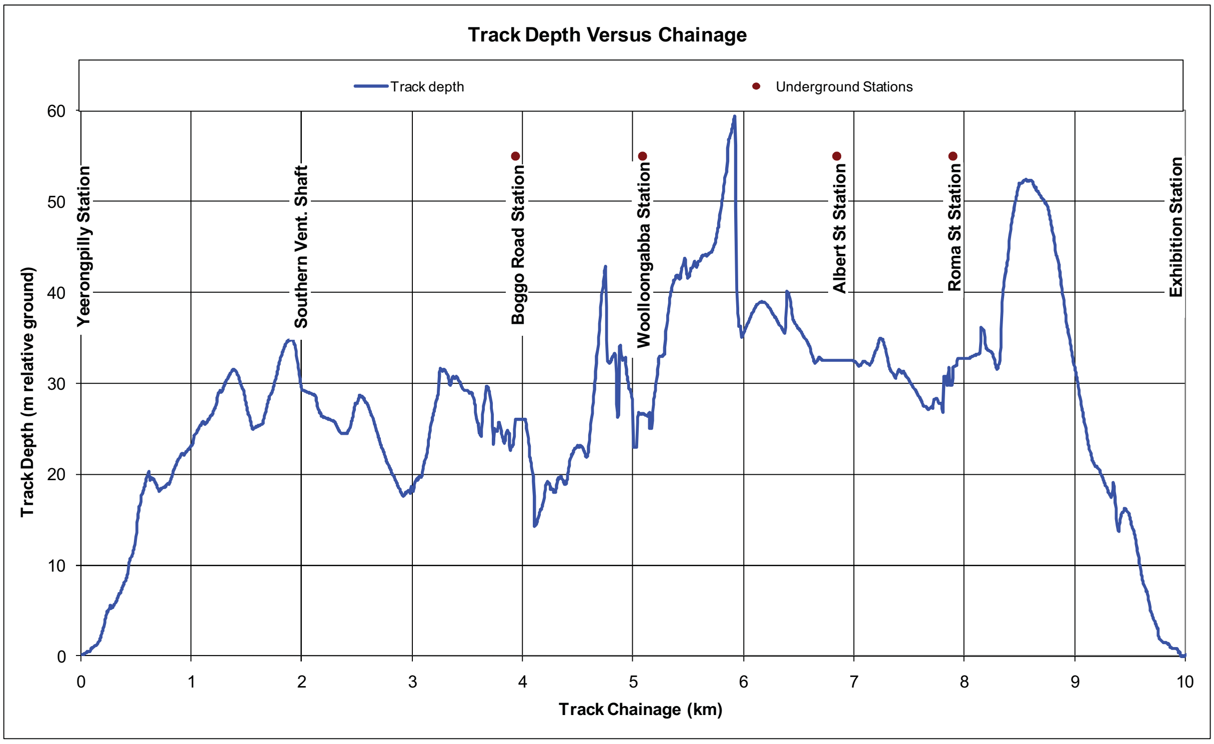
For track radii less than approximately 600 m, measurements undertaken by SLR Consulting on the Singapore Circle Line indicated that there is a general increase in source vibration levels of approximately 5 dB. On this basis, 5 dB has been added to the source vibration levels at the locations identified in **Table 13**.

Table 13 Location of Curve Radii approximately 600 m or Less

Down Track			Up Track		
Start of Curve (km)	**End of Curve (km)**	**Curve Radius (m)**	**Start of Curve (km)**	**End of Curve (km)**	**Curve Radius (m)**
4.74	4.945	614	4.75	4.95	600
5.385	5.515	400	5.39	5.525	414
5.65	6.335	414	5.66	6.325	400
6.445	6.685	400	6.43	6.675	414
7.315	7.525	414	7.305	7.51	400
7.56	6.685	400	7.545	7.76	414
8.055	8.855	400	8.065	8.835	406-425
8.88	9.27	406	8.89	9.27	400
9.535	9.695	400	9.535	9.95	406

The tunnel depth along the Reference Project alignment is shown in **Figure 10**. It can be seen that most of the tunnel under the CBD (chainage 6.5 km to 8 km) is more than 30 m underground.

Figure 10 CRR Reference Project Tunnel Depth vs Chainage



Rolling Stock Design

The ultimately proposed trains are approximately 220 m long in a 9-car configuration. They comprise single deck Electric Multiple Units (EMU) with an assumed maximum axle load of approximately 15 tonnes.

The ground-borne noise modelling assumes an unsprung axle load of 1941 kg/axle. The model has been adjusted to incorporate the length of the proposed 9 car CRR trains.

At this stage of the assessment more detailed information on other rolling stock variables such as wheel diameter, wheel tread profile, axle spacing, bogie spacing, suspension stiffness and the modal properties of the train body have not been included in the modelling. This may have to be considered in more detail at a later stage when information on the proposed rolling stock is available. At this stage in the assessment process, these variables are not considered to be significant.

Rail Type

The proposed rail type for CRR is a 60 kg/m rail.

Trackform Design

The trackform design and its interaction with the rolling stock under consideration is one of the primary ways in which ground-borne noise and vibration can be minimised on new underground railway lines.

The broad principles of vibration isolation of railways consist of the reduction of the dynamic stiffness of the track support, and further, the introduction of (or increase in the mass of) elements of the track support, plus adjustments to damping. In general, the lower the natural frequency of the track support system, the better the vibration isolation. Low natural frequency is achieved by increased mass and reduced dynamic stiffness.[4]

A ballastless (concrete slab) trackform is proposed for the CRR tunnels. For the Reference Project, three different rail fastening systems (Direct Fixation, Resilient and Highly Resilient rail fasteners) have been proposed to achieve the ground-borne noise and vibration goals. Generic performance data has been obtained for the Delkor, Pandrol and Sonneville rail fastening systems. A summary of the dynamic stiffness properties of the Delkor, Pandrol and Sonneville rail fastening systems is provided in **Table 14**.

For the current assessment, it is assumed that the vibration attenuation provided by the different systems are in direct proportion to their dynamic stiffness values. In practice, the vibration attenuation performance will also be affected by other parameters including the loss factor (damping), mass and dynamic interaction with the tunnel and rolling stock. Furthermore, various testing methods are employed in order to calculate the static and dynamic stiffness values of different systems which makes a direct like for like comparison difficult. These other factors will need to be investigated as part of the detailed design.

Care also needs to be exercised during the detailed design stage to ensure that a low stiffness track design does not give rise to excessive passenger discomfort vibration levels or unacceptable reliability, availability, maintainability and safety (RAMS) implications.

For the ground-borne vibration modelling undertaken for CRR, the source vibration levels with ECRL Delkor Egg fasteners have been adopted as a reference, on the basis of attended measurements undertaken by SLR Consulting on the ECRL (refer to **Section 6.2.1**).

4 Association of Noise Consultants (ANC Guidelines), 2001, "*Measurement and Assessment of Groundborne Noise & Vibration"*, Page132

For the Pandrol HDPE, Pandrol VIPA and Pandrol Vanguard fastening system, the relative performance (compared with the ECRL installed Delkor Egg) has been evaluated using a Single Degree of Freedom (SDoF) analysis including the unsprung axle mass of the proposed rolling stock and rail fastening stiffness per track metre. For the Reference Project, a rail fastener spacing of 700 mm has been assumed for all trackform options.

In the ground-borne vibration assessment, the following three trackform options have been evaluated:

- **Direct Fixation Rail Fasteners** - Ground-borne noise performance equivalent to Pandrol HDPE stiff rail foot pads - or equivalent from other suppliers/systems. Assumed dynamic stiffness of 120 kN/mm.
- **Resilient Rail Fasteners** - Ground-borne noise performance equivalent to Pandrol VIPA, Delkor Alt 1 Systems - or equivalent from other suppliers/systems. Assumed dynamic stiffness of 28 kN/mm.
- **Highly Resilient Rail Fasteners** - Ground-borne noise performance equivalent to the Pandrol Vanguard System - or equivalent from other suppliers/systems. Assumed dynamic stiffness of 6 kN/mm.

The source vibration levels for the above trackforms are provided in **Table 12** and photos/sketches of the rail fastening systems are provided in **Figure 11**.

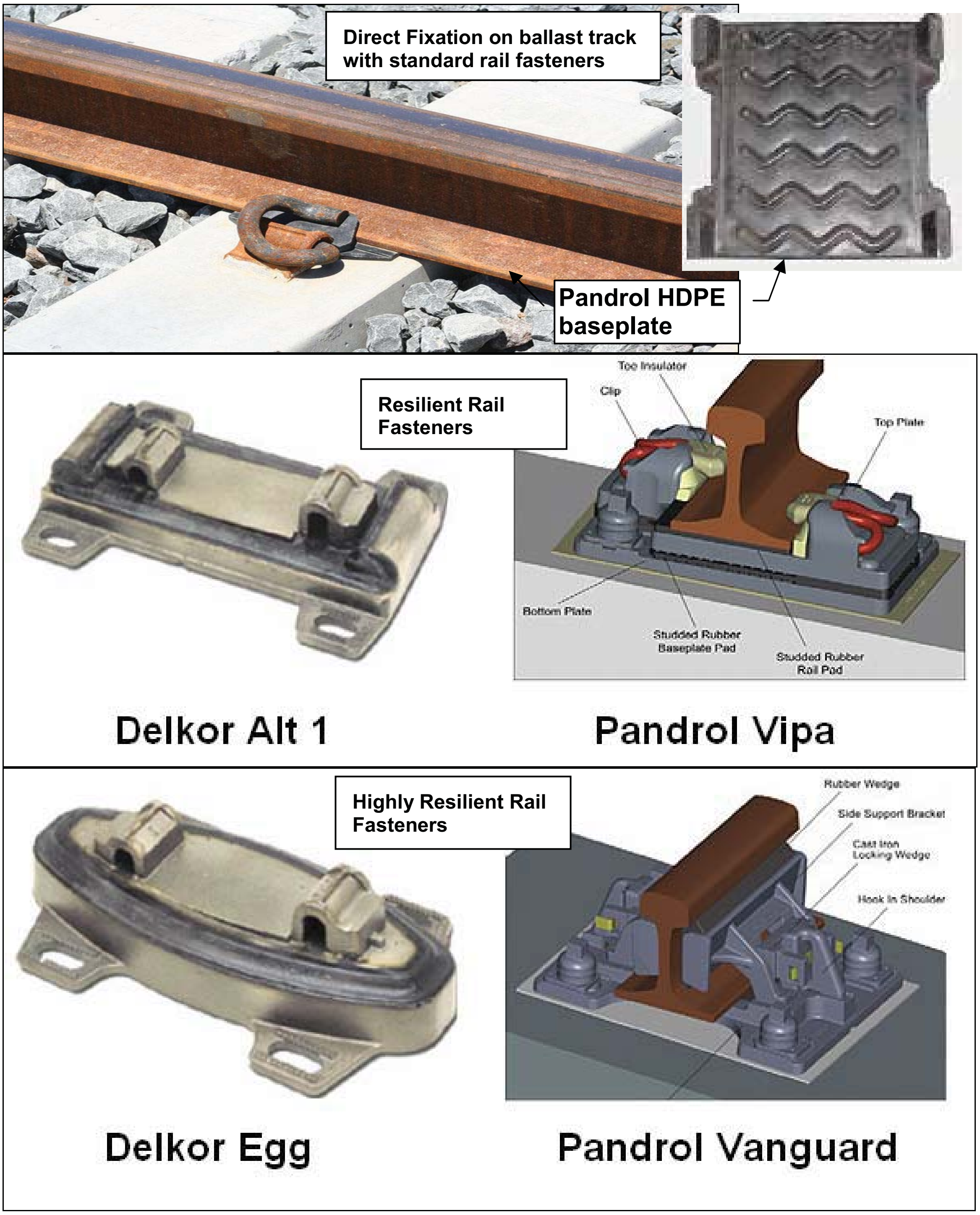
Table 14 Properties of Pandrol, Delkor and Sonneville Rail Fasteners

Fastener Type	Static Stiffness[1,2]	Dynamic Stiffness[1,2]	Dyn/Stat Ratio	Comments
Direct Fixation with Standard Rail Fasteners				
Pandrol HDPE	> 100 kN/mm	> 100 kN/mm	-	Normal “stiff” rail pads usually only used on surface tracks
Resilient Rail Fasteners				
Pandrol Vipa	17 - 20 kN/mm	17-21 kN/mm	1.05	-
ECRL Delkor Alt 1	20 kN/mm	28 kN/mm	1.4	As installed on ECRL
Delkor Alt 1	12 - 30 kN/mm	17-42 kN/mm	1.4	Stiffness options can be varied to suit
Sonneville Standard	18 kN/mm	27 kN/mm	1.5	Mass of Block 100 kg
Highly Resilient Rail Fasteners				
Pandrol Vanguard	3 - 5 kN/mm	5 - 7.5 kN/mm	1.5	Assume Dynamic Stiffness of 6 kN/mm for Modelling
Low Profile Delkor Egg	6 kN/mm	7.2 kN/mm	1.2	Stiffness options can be varied to suit

Note 1: The Static and Dynamic stiffness values have been obtained from product brochures (for Delkor and Pandrol products), from the ECRL 100% Design Report (for the ECRL Alt 1 product) and via e-mail correspondence with the manufacturer (for the Sonneville products).

Note 2: Various testing methods are employed in order to calculate the static and dynamic stiffness values of different systems. This makes a direct like for like comparison of the different systems difficult.

Figure 11 Reference Project Proposed Trackforms



For the Reference Project, the design team proposed a trackform configuration along the alignment as presented in **Table 15** and shown in **Figure 12**. The proposed trackform was based on preliminary predictions performed by the design team, having 100 m spacing between track string calculation points and assuming sensitive receivers located directly above the tunnel along the whole alignment.

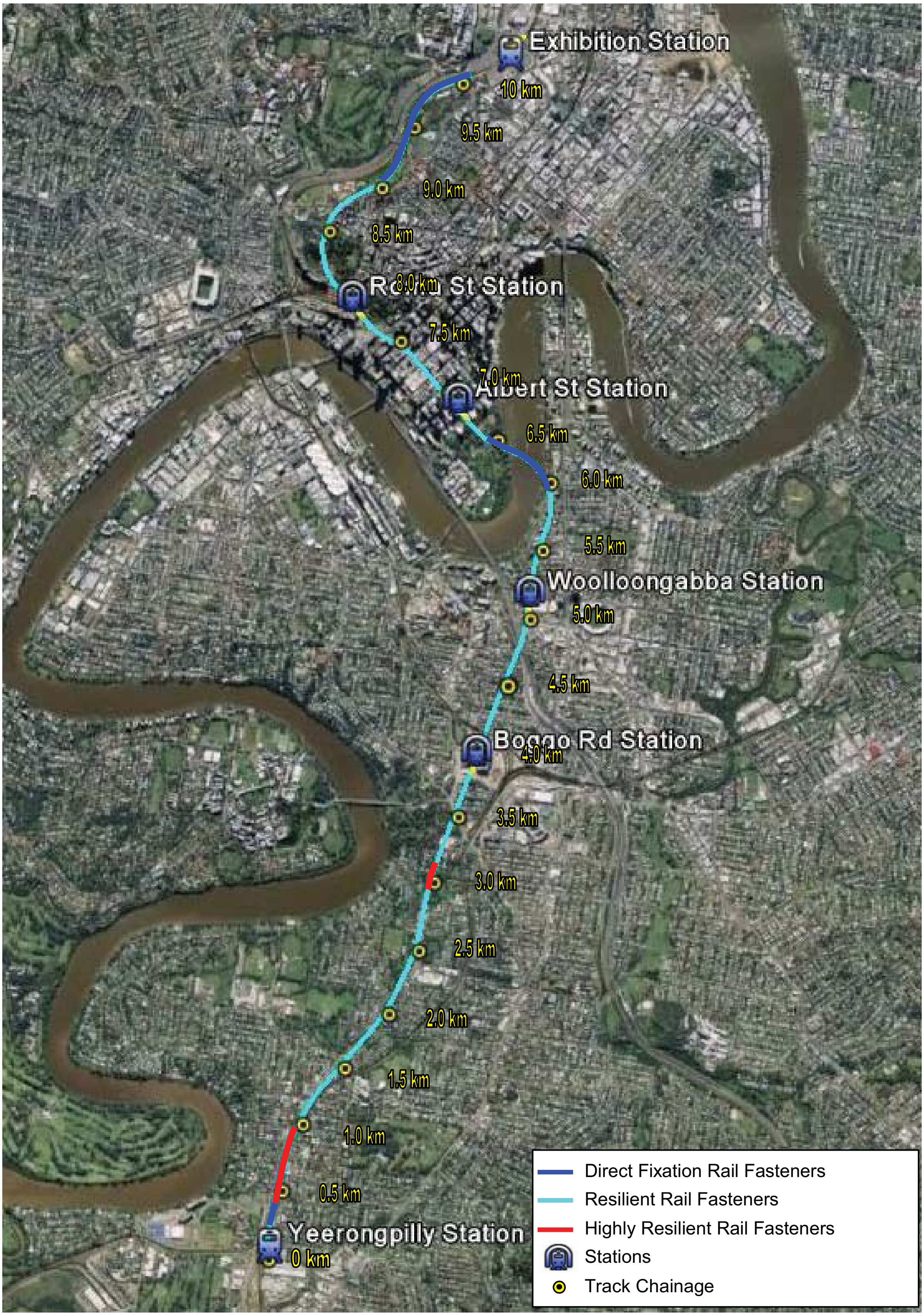
Table 15 Extent of Reference Project Trackforms

Track Chainage (km)	Proposed Reference Project Trackforms[1]
0 – 0.36	Direct fixation with rail pads on ballast track
0.36 – 0.95	Highly resilient rail fasteners
0.95 – 2.95	Resilient rail fasteners
2.95 – 3.15	Highly resilient rail fasteners
3.15 – 5.95	Resilient rail fasteners
5.95 – 6.55	Direct fixation with rail pads on slab track[2]
6.55 – 9.05	Resilient rail fasteners
9.05 – 10	Direct fixation with rail pads on ballast track

Note 1: The direct fixation, resilient and highly resilient trackforms are specified in **Figure 11**.

Note 2: The direct fixation with standard "stiff" rail pads on slab track is normally not recommended. For slab track design, it is common to include a product like the resilient (ie Pandrol VIPA or Delkor Alt 1) to minimise the potential for damage to the concrete slab.

Figure 12 Reference Project Tunnel Alignment and Trackform



Turnouts

References such as the US FTA "*Transit Noise and Vibration Impact Assessment*" indicate that vibration levels are typically 10 dB higher adjacent to turnouts, which is in accordance with SLR Consulting experience on similar projects. There are, however, no proposed turnouts throughout the CRR tunnels.

Tunnel Design

The design properties of the tunnel including the diameter, wall thickness and material properties influence the vibration energy transmitted into the surrounding ground. An inside diameter of 6 m and tunnel lining of 300 mm has been evaluated for the CRR design.

Construction Tolerances

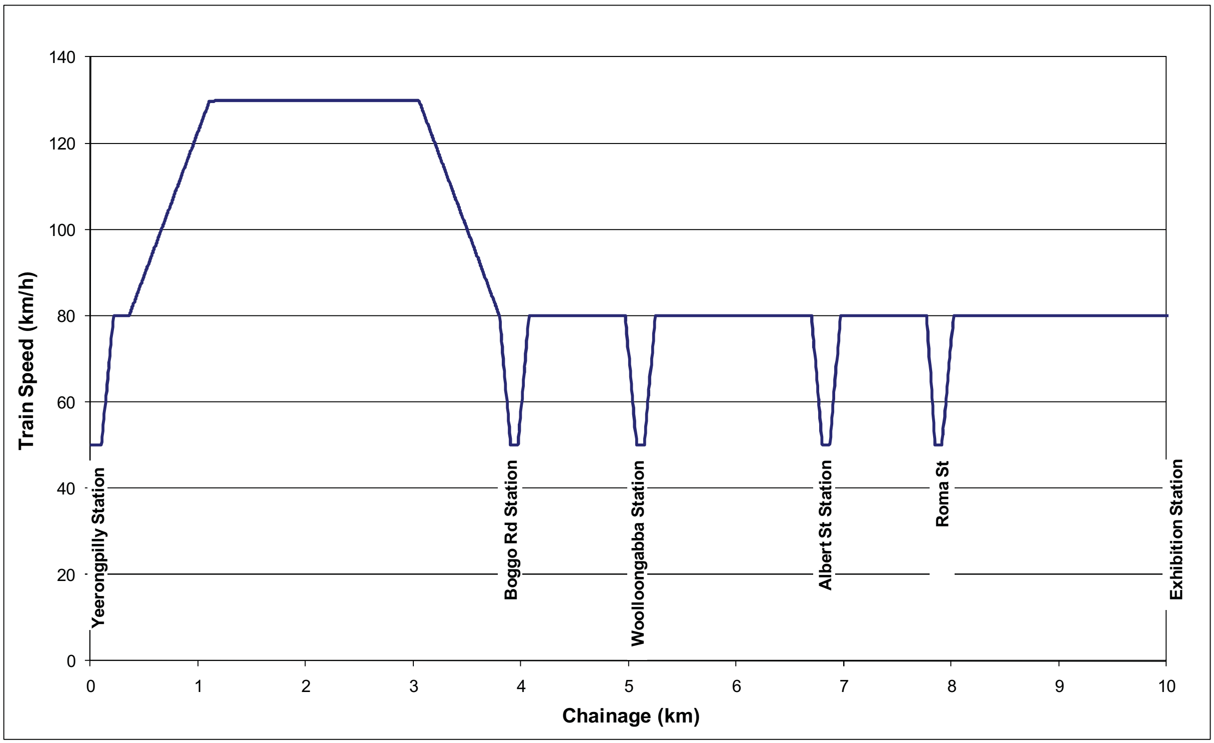
Construction tolerances refer to factors such as the variation in stiffness values between rail fasteners, the quality of the track construction and any change in stiffness values with time.

The potential effect of construction tolerances has not been evaluated as part of CRR assessment and should be addressed in detailed design. These effects are not anticipated to be significant.

Operations

The main factors associated with operational patterns are the train speeds and timetabling. The speed profile used for the modelling are provided in **Figure 13**. For the purpose of the ground-borne noise and vibration modelling, the minimum speed was capped at 50 km/h at the stations.

Figure 13 Speed Profile for CRR Reference Project



For train operations in tunnels, the vibration levels typically increase by 6 dB for each doubling of train speed. This relationship has been observed by SLR Consulting on other projects (including ECRL) and has therefore been adopted for the CRR modelling.

The reference vibration levels adopted in the modelling process are for a train speed of 80 km/h (refer **Table 12**). **Figure 13** shows that for the CRR project, train speeds are expected to be up to 130 km/h between Yeerongpilly and Boggo Rd Stations. North of Boggo Road Station the top speed will be 80 km/h. Speed adjustment of the 80 km/h reference vibration level has therefore been made using the following formula on a 1/3 octave frequency basis:

$$V(speed\_adjusted) = V(reference) + 20\log_{10}\left(\frac{speed}{80}\right)$$

It is possible that trains could be timetabled to cross in separate directions below the same receiver location on a regular basis. The maximum increase in ground-borne noise and vibration levels would be up to 3 dB in the worst case situation. In most cases, the increase in ground-borne noise levels would only be 1 dB or 2 dB.

The potential impact of passing trains at particular receiver locations on a regular basis has not been evaluated as part of the CRR assessment. Should such events occur during operations and the resulting ground-borne noise or vibration levels exceed the goals, consideration will need to be given to scheduling trains to cross at less sensitive locations.

As the proposed CRR will ultimately incorporate a captive fleet of 9 car single deck EMUs, the variation in source vibration levels from train to train is anticipated to be much smaller than an equivalent system with a variety of different rolling stock. As such, the ground-borne vibration modelling assumes that the source vibration levels of the rolling stock will vary in accordance with a normal distribution having a standard deviation of 2 dB. This results in a 95th percentile vibration level approximately 3 dB higher than the mean or 50th percentile level. This factor is included in the source vibration levels in **Table 12**.

Maintenance

The maintenance of the track and rolling stock can have a significant influence on the ground-borne noise and vibration levels. For modelling purposes, a correction of 3 dB has been applied to account for progressive deterioration in wheel and track condition between maintenance activities. This is included in the source vibration levels in **Table 12**.

In the case of poor track condition, it is assumed that rail grinding would be undertaken if the surface roughness values of the track are outside the permitted tolerances. Furthermore, it is also assumed that the condition of the track would be monitored on a regular basis using on-car or hand-held monitoring equipment.

In the case of poor wheel condition, it is assumed that the potential for wheel flats would be minimised through design. If wheel flats or other wheel defects do occur however, it is assumed that these would be identified by a permanent monitoring station and rectified using a wheel lathe or other measures to return the wheel condition to an acceptable degree of smoothness.

6.2.3 Propagation Path

The propagation of vibration through the ground is a complex phenomenon. Even for a simple source, the received vibration at any point includes the combined effects of several different wave types, plus reflections and other effects caused by changes in ground conditions along the propagation path.

Attenuation with distance occurs due to the geometric spreading of the wave front and due to other losses within the ground material, known as “damping”. The attenuation due to geometric spreading occurs equally for all frequencies, whereas the damping component is frequency dependent, with greater loss per metre occurring at high frequencies than at low frequencies.

In the modelling process, the various vibration wave contributions are not sufficiently defined to allow them to be calculated separately. Analytical techniques such as finite element analysis and boundary element analysis would require the ground and buildings to be modelled in great detail to represent the propagation path over the required frequency range. Otherwise, the modelling process could introduce large inaccuracies that may be difficult to trace.

Given the extensive land area along the proposed alignment, such an approach at this stage of the assessment is not feasible (and would only be undertaken at critical locations during detailed design). As such, the CRR modelling was carried out using a combination of theoretical and empirical relationships to determine the attenuation and/or amplification of the ground-borne vibration levels.

Vibration Attenuation due to Geometric Spreading

For geometric spreading, the 220 m long train was modelled as a cylindrical line source based on the estimated tunnel wall vibration levels at a distance of 2 m from the track centreline. For this project, the trains were represented by point sources spaced at 5 m intervals, with the distance attenuation from each point calculated according to the following formula:

$$V(spreading) = 10\log_{10}\left(\frac{2}{\text{Distance}}\right)$$

where;

> *V(spreading)* is the change in vibration level (in dB), distance is the slant distance between the point source and the receiver location and 2 m is the reference distance of the source vibration spectrum.

Vibration Attenuation due to Material Damping

Initial geological surveys indicate that the ground geology along the proposed alignment for the CRR project is Tingalpa Formation between the southern portal and just north of Boggo Rd Station (chainage 0 km to 4.2 km), Neranleigh-Fernvale Beds between Boggo Rd Station and Wooloongabba Station (chainage 4.2 km to 4.8 km), Brisbane Tuff between Wooloongabba Station and the Brisbane River (chainage 4.8 km to 5.8 km), Neranleigh-Fernvale Beds between the Brisbane River and just before the northern portal (chainage 5.8 km to 9.1 km) and Brisbane Tuff around the northern portal (chainage 9.1 km to 9.6 km).

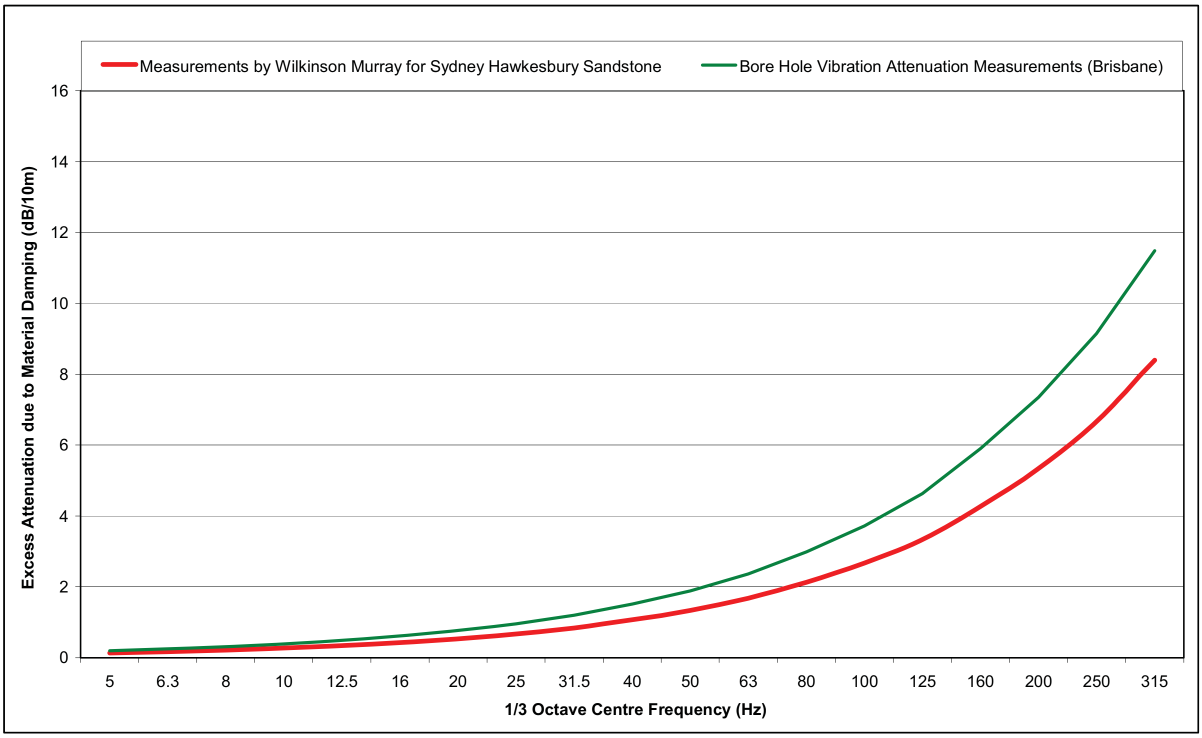
The excess attenuation due to material damping used for recent underground rail tunnel projects in Sydney was based on force transmissibility measurements undertaken by Wilkinson Murray Pty Ltd for the ECRL. The excess attenuation levels (refer to red curve in **Figure 14**) are representative of a conservative estimate for Hawkesbury Sandstone.

Vibration testing has been performed by SLR Consulting on three bore holes between Albert Street Station and Boggo Road Station using a special vibration sensor lowered to different depths in the bore holes and measuring the vibration attenuation. The tested bore holes have ground types consisting of Neranleigh-Fernvale Beds, Brisbane Tuff and at Boggo Road Station a combination of Brisbane Tuff with Mudstone and Tingalpa Formation under.

The measured excess attenuation due to material damping was found to vary between the tested sites (having different ground types and local effects from cracks and layers in the stone). The lowest measured excess attenuation for the Brisbane tested sites has therefore been implemented as a conservative estimate of the excess attenuation (see green curve in **Figure 14**).

This conservative estimate for the excess attenuation due to material damping may result in a slight over-prediction of the ground-borne noise and vibration levels at some locations. However, since it is not possible to know exactly what ground conditions exist at all locations, this conservative approach is required at this stage in the assessment process to provide confidence that the ground-borne noise and vibration goals are achievable at all locations.

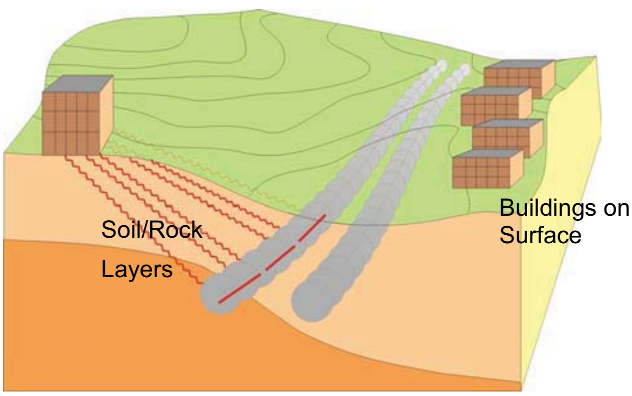
Figure 14 Excess Attenuation Due to Material Damping



Three-Dimensional Modelling

The importance of undertaking three-dimensional modelling is illustrated using the graphical representation in **Figure 15**. For a 220 m long vibration source, changes in trackform or train speed, curves and other local characteristics can result in variations in vibration emissions within the zone of influence of a given building. Hence, it is desirable for modelling to represent the train over its full length. In other words, it is necessary to model the tunnel in three dimensions, rather than as a simple cross section as illustrated in **Figure 8**.

Figure 15 Graphical Representation Indicating Possible Propagation Paths from a Train in a Tunnel



6.2.4 Receivers

Propagation of Vibration into Buildings

With many types of building, a coupling loss occurs at the ground/footing interface, resulting in lower levels of vibration in the building's footings than in the surrounding ground. The model permits assessment with a variety of coupling loss categories, or, alternatively, zero coupling loss can be specified. Typical coupling loss data for common building structures are presented in **Table 16**.

Within the Brisbane CBD, it is likely that most building footings will be founded directly on the underlying bedrock. On this basis, a conservative zero coupling loss has been assumed in the ground-borne noise and vibration modelling for all buildings within the CBD. This conservative zero coupling loss has also been assumed for the new Eco-science Precinct building at Boggo Road. For all smaller commercial and residential buildings outside the CBD, the "Single Residential" building type according to **Table 16** has been adopted.

Table 16 Coupling Loss Values (dB)

Building Type	Coupling Loss (dB) in 1/3 Octave Bands																		
	5 Hz	6.3 Hz	8 Hz	10 Hz	12 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz
Large Masonry on Piles	*6*	*6*	*6*	*6*	*7*	*7*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*13*	*14*	*14*	*15*	*15*	*15*
Large Masonry on Spread Footings	*11*	*11*	*11*	*11*	*12*	*13*	*14*	*14*	*15*	*15*	*15*	*15*	*14*	*14*	*14*	*14*	*13*	*12*	*11*
2-4 Storey Masonry on Spread Footings	*5*	*6*	*6*	*7*	*9*	*11*	*11*	*12*	*13*	*13*	*13*	*13*	*13*	*12*	*12*	*11*	*10*	*9*	*8*
1-2 Storey Commercial	*4*	*5*	*5*	*6*	*7*	*8*	*8*	*9*	*9*	*9*	*9*	*9*	*9*	*8*	*8*	*8*	*7*	*6*	*5*
Single Residential	*3*	*3*	*4*	*4*	*5*	*5*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*5*	*5*	*5*	*4*	*4*	*4*

Note: Coupling loss values have been obtained from Nelson[5] and have been extrapolated to include frequency bands below 16 Hz.

Propagation of Vibration within Buildings

Losses also occur with the transfer of vibration from floor-to-floor within buildings. The model incorporates the losses listed in **Table 17**, which are based on data presented by Nelson (1987), extrapolated to include frequency bands below 16 Hz. The ground-borne noise and vibration levels attenuate by approximately 2 dB per floor for the first 4 floors and by approximately 1 dB per floor thereafter.

Table 17 Floor-to-Floor Loss Values

Floor Level Above Grade	Floor to Floor Loss (dB) in 1/3 Octave Bands																		
	5 Hz	6.3 Hz	8 Hz	10 Hz	12 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz
1	*1*	*1*	*1*	*1*	*1.5*	*1.5*	*1.5*	*2*	*2*	*2*	*3*	*3*	*3*	*2*	*2*	*2*	*3*	*3*	*3*
2	*1*	*1*	*1*	*1*	*1.5*	*1.5*	*1.5*	*2*	*2*	*2*	*2*	*2*	*2*	*3*	*3*	*3*	*3*	*3*	*3*

Note: The floor to floor losses in this table are additive (ie for assessment on the second level above ground, the loss at 50 Hz would be 5 dB).

5 Nelson, J. - Transportation Noise Reference Book (1987)

Low frequency vibration can be amplified within buildings by resonances in floors and walls. On the basis of data presented by Nelson (1987), the amplification spectrum presented in **Table 18** has been adopted. Nelson indicates that amplification values found in practice are typically within ±3 dB of these values. Slightly lower values are assumed for the ground-borne noise calculations as the ANC Guidelines indicate that using the full floor amplification values can result in over-estimation of the resultant noise.

The values in **Table 18** have been adopted in the CRR model for all receivers.

Table 18 Amplification within Buildings

Calculation Type	Amplification (dB) in 1/3 Octave Bands																		
	5 Hz	6.3 Hz	8 Hz	10 Hz	12 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz
Floor Vibration	10	10	10	10	10	10	10	11	11	11	10	9	9	-	-	-	-	-	-
Ground-borne Noise	-	-	-	-	-	-	6	7	7	7	6	6	5	5	4	3	2	1	1

Note: The frequency range used for vibration assessment is 5 Hz to 80 Hz and the frequency range for ground-borne noise assessment is 20 Hz to 315 Hz.

6.3 Ground-borne Vibration Predictions

On the basis of the ground-borne vibration modelling assumptions discussed above, **Table 19** presents a summary of the predicted ground-borne vibration levels for buildings located above or near the proposed rail tunnel alignment.

At this stage in the assessment process, it has been necessary to undertake a best estimate of several parameters that form part of the ground-borne noise and vibration modelling. These parameters include the source vibration levels of the proposed rolling stock, vehicle/track interaction, speed profile and ground conditions. For these reasons, it is considered prudent to incorporate a 5 dBA safety factor on the predicted ground-borne noise and vibration levels.

The predicted ground-borne vibration levels represent the maximum mid-floor vibration levels within multi-storey buildings. For a building with a slab on ground construction, the highest vibration levels would be expected to occur on Level 2, due the amplification resulting from the suspended slab. Calculations are based on the proposed Reference Project trackform configuration (refer to **Figure 12**).

Table 19 Summary of Predicted Ground-borne Vibration Levels (Reference Project Trackform)

Chainage (km)	Type of Building	Min. Slant Distance to Track Level	Predicted Ground-borne Vibration Level (mm/s)[1]	Residential Night-time Vibration Goal (mm/s)[1,2]	Reference Design Mitigation Measure[3]
0.36 – 0.95 Southern Portal to Christensen St, Yeronga	Residential Commercial Educational/Heritage Worship	18 m – 108 m 57 m – 81 m 77 m 24 m – 26 m	0.001 to 0.027 mm/s 0.003 to 0.006 mm/s 0.002 mm/s 0.006 mm/s	0.2 mm/s	Highly Resilient Rail Fasteners
0.95 – 2.0 Christensen St, Yeronga to Southern Ventilation Building (Bledisloe St)	Residential Commercial Worship Medical	25 m – 117 m 34 m – 80 m 88 m 35 m	0.002 to 0.039 mm/s 0.003 to 0.015 mm/s 0.002 mm/s 0.008 mm/s	0.2 mm/s	Resilient Rail Fasteners
2.0 – 2.95 Southern Ventilation Building (Bledisloe St) to Stimpson St, Fairfield	Residential Commercial Worship Medical	21 m – 115 m 26 m – 85 m 26 m – 61 m 41 m	0.003 to 0.047 mm/s 0.002 to 0.011 mm/s 0.014 to 0.034 mm/s 0.007 mm/s	0.2 mm/s	Resilient Rail Fasteners
2.95 – 3.15 Stimpson St, Fairfield to Fenton St, Fairfield	Residential Commercial	18 m – 82 m 18 m – 21 m	0.003 to 0.038 mm/s 0.012 to 0.014 mm/s	0.2 mm/s	Highly Resilient Rail Fasteners
3.15 – 3.95 Fenton St, Fairfield to Boggo Road Station	Residential Commercial Heritage Medical	23 m – 108 m 20 m – 110 m 28 m – 63 m 28 m – 29 m	0.002 to 0.035 mm/s 0.002 to 0.025 mm/s 0.005 to 0.017 mm/s 0.023 to 0.024 mm/s	0.2 mm/s	Resilient Rail Fasteners
3.95 – 5.1 Boggo Road Station to Woolloongabba Station	Residential Commercial Educational Worship Hotel	15 m – 94 m 22 m – 89 m 76 m – 111 m 60 m – 97 m 43 m	0.002 to 0.038 mm/s 0.003 to 0.031 mm/s 0.003 to 0.005 mm/s 0.005 to 0.010 mm/s 0.014 mm/s	0.2 mm/s	Resilient Rail Fasteners
5.1 – 6.85 Woolloongabba Station to Albert Street Station	Residential Commercial Educational Worship Medical Hotel	38.5 m – 202 m 26 m – 168 m 37 m – 234 m 42 m – 192 m 201 m 19 m – 146 m	0.001 to 0.025 mm/s 0.002 to 0.023 mm/s 0.002 to 0.015 mm/s 0.001 to 0.008 mm/s 0.002 mm/s 0.001 to 0.023 mm/s	0.2 mm/s	Resilient Rail Fasteners (Chainage 5.95 – 6.55 km rail section under the Brisbane River with Direct Fixation Rail Fasteners)

Chainage (km)	Type of Building	Min. Slant Distance to Track Level	Predicted Ground-borne Vibration Level (mm/s)[1]	Residential Night-time Vibration Goal (mm/s)[1,2]	Reference Design Mitigation Measure[3]
6.85 – 7.9 Albert Street Station to Roma Street Station	Commercial Educational Worship Heritage Medical Hotel	17 m – 91 m 52 m – 58 m 52 m – 82 m 33 m – 67 m 32 m – 98 m 22.5 m – 82 m	0.004 to 0.059 mm/s 0.009 to 0.025 mm/s 0.015 to 0.029 mm/s 0.023 to 0.056 mm/s 0.012 to 0.058 mm/s 0.006 to 0.044 mm/s	0.2 mm/s	Resilient Rail Fasteners
7.9 – 9.55 Roma Street Station to Northern Portal	Residential Commercial Educational Medical Hotel	38 m – 121 m 50 m – 113 m 43 m – 122 m 138 m 51 m – 108 m	0.002 to 0.023 mm/s 0.003 to 0.018 mm/s 0.003 to 0.021 mm/s 0.003 mm/s 0.005 to 0.017 mm/s	0.2 mm/s	Resilient Rail Fasteners (Chainage 9.05– 9.55 km rail section with Direct Fixation Rail Fasteners)

Note 1: The predicted vibration levels and vibration goal are based on the maximum 1 second rms vibration level, not to be exceeded by more than 5% of train passbys.

Note 2: The residential night-time vibration goal is the most stringent operational vibration goal.

Note 3: The proposed Reference Project trackform is detailed in **Table 15**.

6.4 Ground-borne Vibration Assessment

As discussed in **Section 2.3**, the human comfort (perception) limits for ground-borne vibration tend to be more stringent than other possible design limits relating to building damage risk or the potential effects on building contents. The most stringent ground-borne vibration goal is 0.2 mm/s (103 dB_V) for residential buildings during the night-time period (refer **Table 3**).

On the basis of the speed profile for the CRR project (refer **Figure 13**) and on the proposed vertical alignment and modelling assumptions described in the previous sections, compliance with the ground-borne vibration limits is predicted for all sensitive receiver locations above or near the proposed alignments.

6.4.1 Special Receivers Which May Contain Highly Vibration Sensitive Equipment

The Eco-science precinct, QUT at 2 George Street and St Andrews Hospital has been identified as having special vibration sensitive equipment (ie an electron microscope or Magnetic Resonance Imaging (MRI) systems).

At this stage in the assessment, no other commercial facilities have been identified which contain any highly sensitive measurement equipment. For this detailed feasibility assessment purposes, it is assumed that all nearby research and medical facilities may contain highly sensitive equipment such as lithography and inspection equipment with high resolution. **Table 20** presents predicted ground-borne vibration levels and vibration goals for these facilities that are located in close proximity of the proposed Reference Project alignment.

For the electron microscope at the basement of the Eco-science precinct, an equipment specific vibration criterion has been supplied and included in **Table 20**. It can be seen that the predicted vibration levels are achieving the supplied vibration criteria. However, this is very sensitive equipment and to ensure undisturbed operation of the equipment further studies are recommended to be performed at the detailed design stage, including more detailed measurements of vibration transmissibility from the ground into the building and the location where the electron microscope is installed. Note also that normal at track mitigation (ie more resilient trackform) will lower the resonance frequency (where vibration transmission is amplified) and may increase vibration levels at the receiver below 10 Hz, where the equipment is most sensitive.

The CBD 7 Day Medical Centre has predicted vibration levels exceeding the generic vibration goal for highly vibration sensitive equipment. At the detailed design stage an investigation of what, if any, highly vibration sensitive equipment there are at the CBD 7 Day Medical Centre and if it will be necessary to include a section with Highly Resilient Trackform past this site.

All other special receivers have predicted ground-borne vibration velocity below the limit of 0.013 mm/s (82 dB_V) per octave band.

Table 20 Special Receivers Which May Contain Highly Vibration Sensitive Equipment

Receiver	Location	Chainage (km)	Maximum 1/3 Octave Band Vibration Velocity (mm/s)[1]	
			Predicted	Vibration Goal
Eco-Science Precinct	Boggo Rd, Dutton Park	3.89	0.007 <10Hz [2] 0.022 >10 Hz [3]	0.02 <10Hz [2] 0.3 >10 Hz [3]
Abardeen Medical Clinic	470 Main Street, Kangaroo Point	6.005	0.001	0.013
Queensland University of Technology	2 George Street, Brisbane	6.575	0.001	0.013
CBD 7 Day Medical Centre	245 Albert Street, Brisbane	7.33	0.031	0.013
Brisbane Dental Hospital and College	168 Turbot Street, Brisbane	7.59	0.006	0.013
St Andrews Hospital	457 Wickham Tce, Spring Hill	8.75	0.002	0.013

Note 1: The predicted vibration levels are based on the Reference Project trackform (refer to **Figure 12**).

Note 2: Vibration velocity within frequency range 3 Hz to 10 Hz as specified for the TEM equipment at the Eco-science precinct (ie not maximum 1/3 Octave band as the generic vibration criterion is specified).

Note 3: Vibration velocity for frequencies above 10 Hz as specified for the TEM equipment at the Eco-science precinct (ie not maximum 1/3 Octave band as the generic vibration criterion is specified).

6.4.2 Heritage Structures

As discussed in **Section 2.3**, the levels of vibration required to cause damage to sensitive heritage buildings (2 mm/s according to Department of Transport and Main Roads Technical Standard MRTS51) are an order of magnitude (10 times) higher than those at which people may consider the vibration to be intrusive (0.2 mm/s refer to **Table 3**).

The predicted vibration levels associated with train operations in the tunnels are less than 0.06 mm/s at any buildings near the tunnels and therefore the risk to any heritage buildings is negligible. Similarly, the potential for damage to other key utilities/ infrastructure is also negligible on the basis that the tunnel wall vibration levels are anticipated to be approximately 0.1 mm/s (100 dB_V).

7 GROUND-BORNE NOISE ASSESSMENT - TRAIN OPERATIONS

7.1 Introduction

Train noise in buildings adjacent to rail tunnels is predominantly caused by the transmission of ground-borne vibration rather than the direct transmission of noise through the air. The vibration is initially generated by wheel/rail interaction (by the mechanisms described in Section **6.2**) and is transmitted from the trackbed, through the tunnel structure, via the ground and into the adjacent building structures (as illustrated in **Figure 8**). After entering a building, this vibration causes the walls and floors to vibrate faintly and hence to radiate noise (commonly termed “ground-borne noise”).

If it is of sufficient magnitude to be audible, this noise has a low frequency rumbling character, which increases and decreases in level as a train approaches and departs the site. This type of noise can be experienced in buildings adjacent to many urban underground rail systems.

In some CBD buildings, the rumbling noise can sometimes be heard several storeys above ground level where no precautions have been taken in the tunnel or building design to limit ground-borne noise and vibration effects. For most new underground railway lines, the standard track design usually incorporates resilient rail fasteners to reduce the transmission of dynamic forces that occur at the wheel-rail interface. This resilience serves to provide isolation of ground-borne vibration, which in turn reduces the ground-borne noise levels in buildings near the railway tunnel.

The fact that ground-borne train noise may be audible does not necessarily indicate that it is offensive or disturbing. In many cases, the train noise may pass unnoticed due to the "masking" effect of other ambient noise sources, activities or distractions.

Some especially sensitive spaces and activities, such as theatres, cinemas and sleeping areas are more prone to disturbance from ground–borne noise than others, such as shopping areas, office spaces or industrial premises.

The applicable ground-borne noise goals are discussed in **Section 2.4**.

7.2 Ground-borne Noise Modelling Methodology

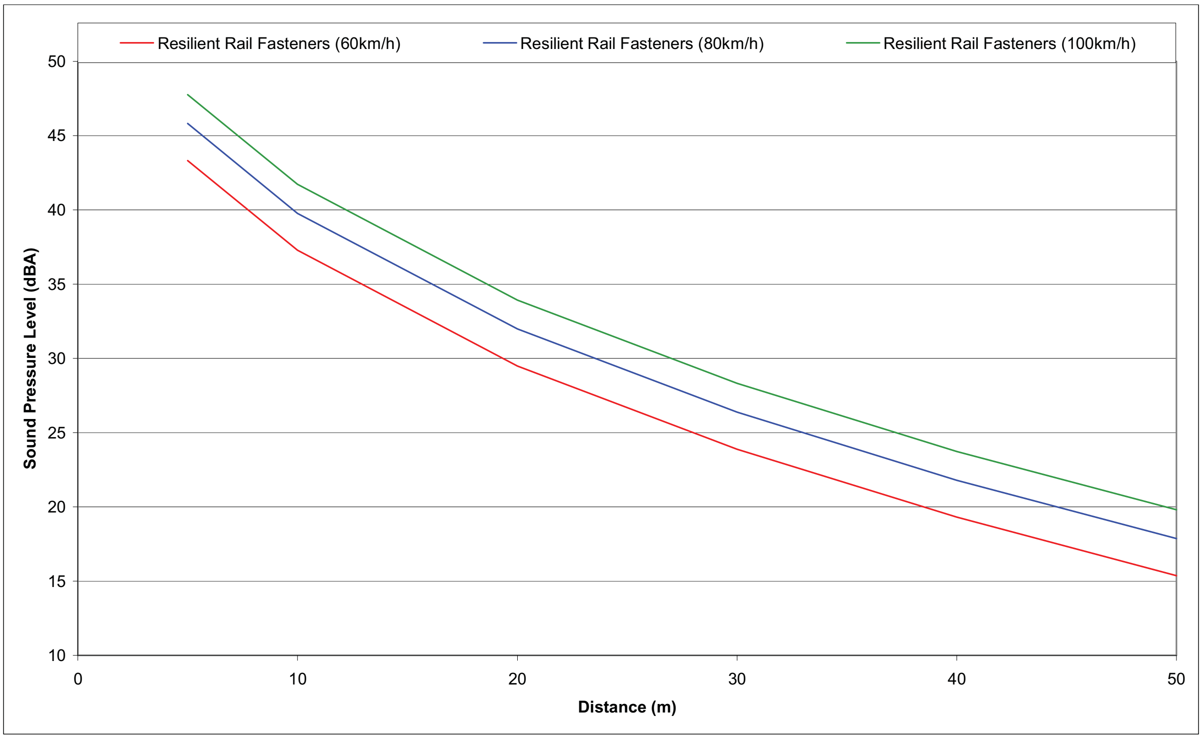
The ground-borne noise modelling methodology followed the same calculation procedure discussed in **Section 6.2** for the ground-borne vibration modelling, with the addition of two final steps to account for the conversion of vibration in a building into noise.

In accordance with Nelson (1987) and the ANC Guidelines (2001), an adjustment of -27 dB was used in the model to convert each 1/3 octave band vibration level (dB_V re 1 nm/s) to a sound pressure level (dB re 20 µPa). The 1/3 octave band sound pressure levels were then A-weighted and logarithmically summed to provide the overall $L_{Amax,Slow}$ noise level predictions.

On the basis of the ground-borne noise and vibration modelling assumptions discussed above and in **Section 6.2**, **Figure 16** presents a summary of the predicted ground-borne noise levels at various distances from the proposed railway tunnel for train speeds of 60 km/h, 80 km/h and 100 km/h, assuming a "Resilient" trackform and "Single Residential" building as specified in **Section 6.2.2**.

Figure 16 is illustrative only and its purpose is to show how ground-borne noise levels are dependent on speed and reduce as the distance between the tunnel (rail level) and receiver increases. The distances are slant distances, and are therefore dependent on the depth of the tunnel (rail level) as well as the horizontal offset distance. For the modelling results presented in the following section, the ground-borne noise level predictions are based on the 3-dimensional track layout, actual train speeds, track features, receiver building type etc, which are not included in **Figure 16**.

Figure 16 Ground-borne Noise Level (Resilient Rail Fasteners) Versus Slant Distance Illustrative Only - Not to be used for Assessment



Note: The distance refers to the slant distance between the receiver location (on the surface) and the track (within the tunnel). For example, if the track is located 20 m below ground and the receiver is located 30 m to the side of the tunnel, the receiver would be located at a slant distance of 36 m from the track. For buildings with piles or otherwise directly connected to the bedrock, a 5 dBA increase of the ground-borne noise levels are expected.

7.3 Ground-borne Noise Mitigation Options

The potential ground-borne noise mitigation options for a new railway line include the following:

- Operational measures such as reduced train speeds or allowing system access only to trains with wheels in “good” condition.
- Track design measures including the provision of resilient rail fasteners, booted sleepers or floating slab track to reduce the vibration energy transferred to the tunnel footing, foundation, surrounding ground and nearby buildings.
- Track maintenance/rolling stock measures such as maintenance to keep rail and wheel roughness within required tolerances, maintaining existing rolling stock to ensure “good” wheel condition and / or implementing long-term measures to improve wheel condition over time.
- Receiver controls at existing or proposed developments such as full or partial vibration isolation of the building using springs or rubber bearings.
- Planning measures such as locating sensitive developments at an acceptable distance from the tunnel alignment.
- Avoiding tight curves (less than approximately 600 m radius) and maximising the vertical alignment (tunnel depth) where possible.

The Reference Project alignment has been designed to avoid major buildings insofar as possible by running the route in-line with existing roads and surface rail tracks. The vertical alignment (tunnel depth) has also been maximised where possible to reduce potential noise and vibration impacts.

Further approaches to mitigation therefore focuses on operational measures, track design, maintenance regimes and source control measures. These options are likely to be far more cost effective than receiver controls such as full or partial vibration isolation of buildings above the railway tunnel (which are also usually impracticable for most existing buildings).

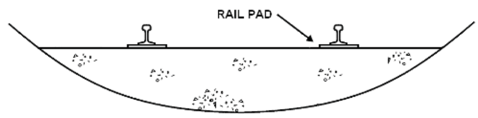
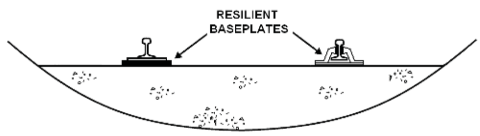
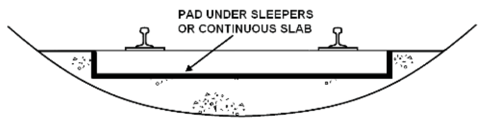
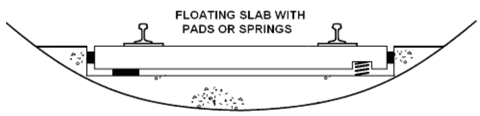
Operational measures such as improved wheel and rail condition would provide ground-borne noise and vibration benefits across the whole project area, whilst track design measures and a reduction in train speeds could provide benefits in specific areas.

For the CRR project, the ground-borne noise and vibration modelling assumed that the condition of the wheels and rails would be maintained at “good” condition (ie within specified roughness limits in Annex C of ISO 3095 or better) and a monitoring program is proposed to be implemented by the operators to identify and repair track and wheels in poor condition.

In order to reduce the potential for ground-borne noise impacts at sensitive receivers without impacting operations via speed reductions, mitigation measures would need to focus on improving the vibration isolation characteristics of the track.

In order to reduce ground-borne noise and vibration levels within buildings located close to railway lines, a range of alternative track designs are available. These generally include the insertion of a resilient layer between the rail and tunnel foundation, either in the form of a resilient rail fastener, booted sleeper, floating track slab or a combination of approaches. The resilience is usually in the form of elastic/resilient pads or mats (or moulded rubber elements in the resilient baseplates/fasteners). **Figure 17** presents the principal features of generic designs for slab tracks and the location of the resilient components in each case.

Figure 17 Generic Trackforms to Mitigate Ground-borne Noise and Vibration on Slab Track

Generic Trackform Layouts	*Acoustic Performance*	*Description*
		*Direct fixation with standard rail foot pads (eg HDPE)*
	*Increasing Ground-borne Noise and Vibration Reduction*	*Resilient rail fasteners (eg, Delkor Alt 1, Pandrol Vipa, Pandrol Double Fastclip)*
		Highly resilient rail fasteners (eg, Delkor Egg or Pandrol Vanguard)
		*Resiliently supported sleepers/blocks or continuously supported slabs (eg slab on ballast mat)*
		*Floating Slab Track (FST) systems using short, long or continuous slabs with rubber or spring elements*

The trackforms included in the assessment for the CRR Reference Project are described in **Section 6.2.2** and include direct fixation with standard “stiff” rail foot pads, resilient and highly resilient rail fasteners.

Resilient rail fasteners can significantly reduce the level of ground-borne noise and vibration; however the following important factors should be noted:

- Careful attention is needed during detailed design to ensure that the loaded natural frequency of the resilient rail fastener does not coincide with other frequencies associated with the fastener spacing, wheel diameter, bogie passing frequency, etc. If this occurs, the performance of the system will be impaired.
- An increase in the fastener spacing and decrease in the static stiffness of the resilient rail fasteners will increase the maximum rail deflection (and rail stress).

7.4 Ground-borne Noise Predictions

On the basis of the speed profile for the CRR project (shown in **Figure 13**), the proposed vertical alignment and the modelling assumptions described in the previous sections, predicted ground-borne noise levels for buildings located above or close to the proposed rail alignments have been performed. These calculations have been performed for the Reference Project trackform configuration as outlined in **Section 6.2.2**.

At this stage in the assessment process, it has been necessary to undertake a best estimate of several parameters that form part of the ground-borne noise and vibration modelling. These parameters include the source vibration levels of the proposed rolling stock, vehicle/track interaction, speed profile and ground conditions. For these reasons, it is considered prudent to incorporate a 5 dBA safety factor on the predicted ground-borne noise and vibration levels.

The ground-borne noise predictions for the sensitive receivers along the tunnel alignment (with the Reference Project trackform configuration) is provided in **Table 21**. Exceedances are shown in bold red.

Table 21 Summary of Predicted Ground-borne Noise Levels (Reference Project Trackform)

Chainage (km)	Type of Building	Min. Slant Distance to Track Level	Predicted Ground-borne Noise Level (dBA)	Ground-borne Noise Goal (dBA)	Reference Design Mitigation Measure
0.36 – 0.95 Southern Portal to Christensen St, Yeronga	Residential Commercial Educational/Heritage Worship	18 m – 108 m 57 m – 81 m 77 m 24 m – 26 m	<10 dBA to 27 dBA <10 dBA <10 dBA 20 dBA to 21 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA	Highly Resilient Rail Fasteners
0.95 – 2.0 Christensen St, Yeronga to Southern Ventilation Building (Bledisloe St)	Residential Commercial Worship Medical	25 m – 117 m 34 m – 80 m 88 m 35 m	<10 dBA to 33 dBA 12 dBA to 28 dBA <10 dBA 28 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA	Resilient Rail Fasteners
2.0 – 2.95 Southern Ventilation Building (Bledisloe St) to Stimpson St, Fairfield	Residential Commercial Worship Medical	21 m – 115 m 26 m – 85 m 26 m – 61 m 41 m	<10 dBA to **36 dBA** 10 dBA to 32 dBA 17 dBA to 31 dBA 25 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA	Resilient Rail Fasteners
2.95 – 3.15 Stimpson St, Fairfield to Fenton St, Fairfield	Residential Commercial	18 m – 82 m 18 m – 21 m	<10 dBA to 31 dBA 33 dBA to 36 dBA	35 dBA (night-time) 40 dBA	Highly Resilient Rail Fasteners
3.15 – 3.95 Fenton St, Fairfield to Boggo Road Station	Residential Commercial Heritage Medical	23 m – 108 m 20 m – 110 m 28 m – 63 m 28 m – 29 m	<10 dBA to 32 dBA <10 dBA to 28 dBA <10 dBA to 35 dBA 27 dBA to 28 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA	Resilient Rail Fasteners
3.95 – 5.1 Boggo Road Station to Woolloongabba Station	Residential Commercial Educational Worship Hotel	15 m – 94 m 22 m – 89 m 76 m – 111 m 60 m – 97 m 43 m	<10 dBA to **36 dBA** <10 dBA to 29 dBA <10 dBA <10 dBA to 15 dBA 20 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA 35 dBA (night-time)	Resilient Rail Fasteners
5.1 – 6.85 Woolloongabba Station to Albert Street Station	Residential Commercial Educational Worship Medical Hotel	38.5 m – 202 m 26 m – 168 m 37 m – 234 m 42 m – 192 m 201 m 19 m – 146 m	<10 dBA to 26 dBA <10 dBA to 25 dBA <10 dBA to 23 dBA <10 dBA <10 dBA <10 dBA to 27 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA 40 dBA 35 dBA (night-time)	Resilient Rail Fasteners (Chainage 5.95 – 6.55 km rail section under the Brisbane River with Direct Fixation Rail Fasteners)

Chainage (km)	Type of Building	Min. Slant Distance to Track Level	Predicted Ground-borne Noise Level (dBA)	Ground-borne Noise Goal (dBA)	Reference Design Mitigation Measure
6.85 – 7.9	Commercial	17 m – 91 m	<10 dBA to 36 dBA	40 dBA	Resilient Rail Fasteners
Albert Street Station to Roma Street Station	Educational	52 m – 58 m	13 dBA to 23 dBA	40 dBA	
	Worship	52 m – 82 m	16 dBA to 30 dBA	40 dBA	
	Heritage	33 m – 67 m	21 dBA to 34 dBA	40 dBA	
	Medical	32 m – 98 m	13 dBA to 35 dBA	40 dBA	
	Hotel	22.5 m – 82 m	<10 dBA to 33 dBA	35 dBA (night-time)	
7.9 – 9.55	Residential	38 m – 121 m	<10 dBA to 25 dBA	35 dBA (night-time)	Resilient Rail Fasteners
Roma Street Station to Northern Portal	Commercial	50 m – 113 m	<10 dBA to 21 dBA	40 dBA	(Chainage 9.05– 9.55 km rail section with Direct Fixation Rail Fasteners)
	Educational	43 m – 122 m	<10 dBA to 24 dBA	40 dBA	
	Medical	138 m	<10 dBA	40 dBA	
	Hotel	51 m – 108 m	<10 dBA to 20 dBA	35 dBA (night-time)	

Note: Extent of Reference Project trackform is detailed in **Table 15**. Also the LAmax,Slow noise level refers to the 95th percentile train passby event. The ground-borne noise level of the "average" or median train event would typically be approximately 3 dB lower than the 95th percentile event.

It can be seen in **Table 21** that there are two track sections (chainage approximately 2.8 km and 4.2 km) where there are residential receivers exceeding the night-time ground-borne noise goal of 35 dBA for the Reference Project trackform.

A summary of the extent of the various trackforms that would be required to achieve compliance with the ground-borne noise goals at all sensitive receiver locations is given in **Table 22** and graphically shown in **Figure 18**. In total 6.9 km of resilient rail fasteners and 1.19 km of highly resilient rail fasteners are required.

A summary of the predicted ground-borne noise levels with the proposed trackform configuration including the additional “Highly Resilient” trackform discussed above is shown in **Table 23**, which show compliance with the ground-borne noise goals at all sensitive receivers.

For this assessment, it is assumed that the extent of the proposed trackforms will be identical for each tunnel. However, in the detailed design stage it may be found that the separation between the two train tunnels of 13.7 m may result in only one of the tunnels requiring the higher order trackform at some locations.

It should also be noted that the modelling results include a 5 dB safety factor which could possibly be refined downwards during the detailed design phase. Alternatively, it may be possible during detailed design for alternative track designs to be used with different dynamic stiffness properties - this may alter the number of receivers above the noise goals.

Table 22 Proposed Trackforms to Comply with the Ground-borne Noise Goals

Track Chainage (km)	Proposed Reference Project Trackforms
0 – 0.36	Direct fixation with rail pads on ballast track
0.36 – 0.95	Highly resilient rail fasteners
0.95 – 2.75	Resilient rail fasteners
2.75 – 3.15	Highly resilient rail fasteners
3.15 – 4.15	Resilient rail fasteners
4.15 – 4.35	Highly resilient rail fasteners
4.35 – 5.95	Resilient rail fasteners
5.95 – 6.55	Direct fixation with rail pads on slab track[2]
6.55 – 9.05	Resilient rail fasteners
9.05 – 10	Direct fixation with rail pads

Note 1: The direct fixation, resilient and highly resilient trackforms are specified in **Figure 11**.

Note 2: The direct fixation with standard “stiff” rail pads on slab track is normally not recommended. For slab track design, it is common to include a product like the resilient (ie Pandrol VIPA or Delkor Alt 1) to minimise the potential for damage to the concrete slab.

Figure 18 Extent of Proposed Trackforms

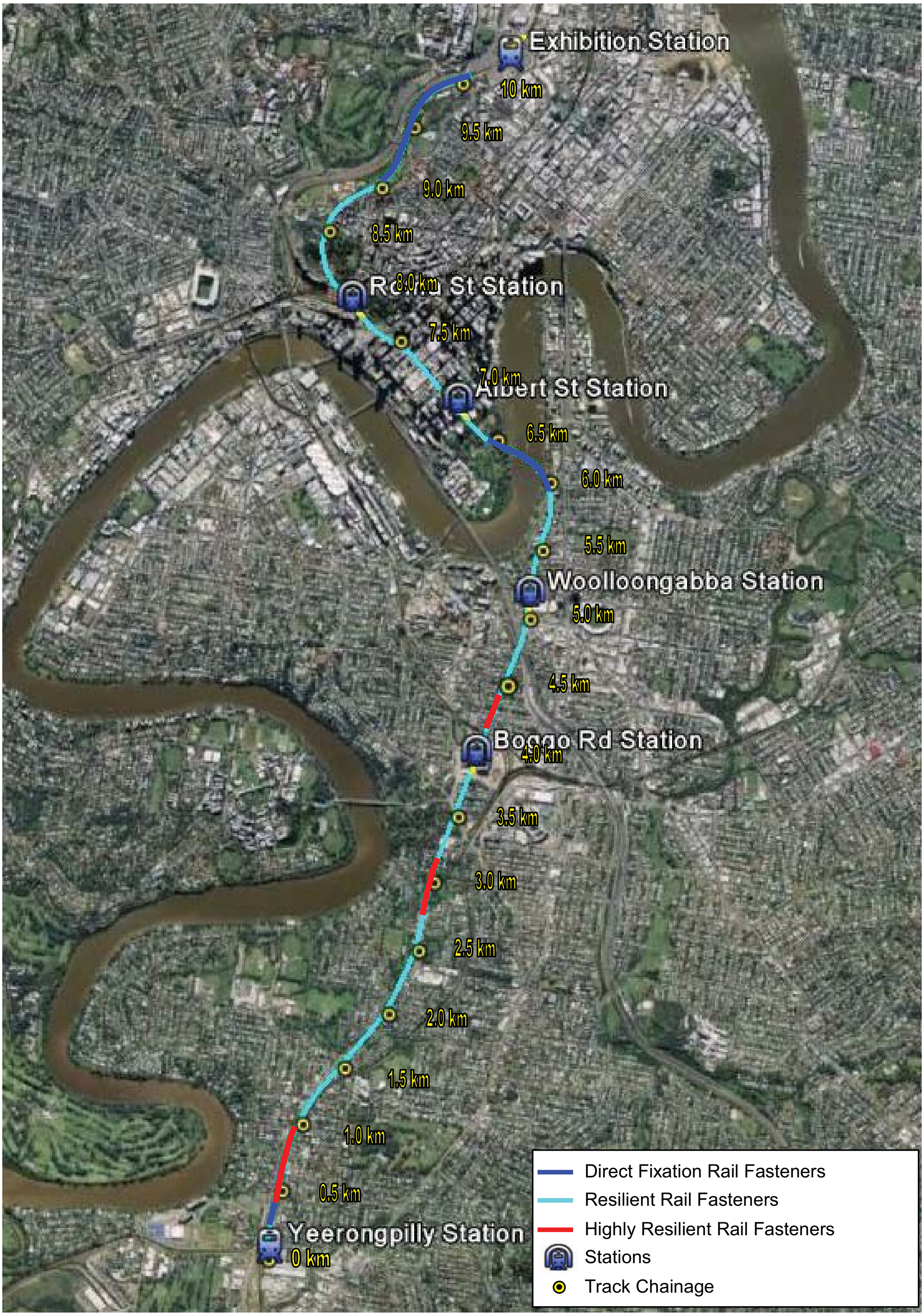


Table 23 Summary of Predicted Ground-borne Noise Levels (Proposed Trackform)

Chainage (km)	Type of Building	Min. Slant Distance to Track Level	Predicted Ground-borne Noise Level (dBA)	Ground-borne Noise Goal (dBA)	Proposed Mitigation Measure
0.36 – 0.95 Southern Portal to Christensen St, Yeronga	Residential Commercial Educational/Heritage Worship	18 m – 108 m 57 m – 81 m 77 m 24 m – 26 m	<10 dBA to 27 dBA <10 dBA <10 dBA 20 dBA to 21 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA	Highly Resilient Rail Fasteners
0.95 – 2.0 Christensen St, Yeronga to Southern Ventilation Building (Bledisloe St)	Residential Commercial Worship Medical	25 m – 117 m 34 m – 80 m 88 m 35 m	<10 dBA to 33 dBA 12 dBA to 28 dBA <10 dBA 28 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA	Resilient Rail Fasteners
2.0 – 2.75 Southern Ventilation Building (Bledisloe St) to Glena St, Fairfield	Residential Commercial Worship Medical	24 m – 115 m 26 m – 85 m 26 m – 61 m 41 m	<10 dBA to 33 dBA 10 dBA to 32 dBA 17 dBA to 31 dBA 25 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA	Resilient Rail Fasteners
2.75 – 3.15 Glena St, Fairfield to Fenton St, Fairfield	Residential Commercial	18 m – 106 m 18 m – 21 m	<10 dBA to 29 dBA 27 dBA to 29 dBA	35 dBA (night-time) 40 dBA	Highly Resilient Rail Fasteners
3.15 – 3.95 Fenton St, Fairfield to Boggo Road Station	Residential Commercial Heritage Medical	23 m – 108 m 20 m – 110 m 28 m – 63 m 28 m – 29 m	<10 dBA to 32 dBA <10 dBA to 28 dBA <10 dBA to 35 dBA 27 dBA to 28 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA	Resilient Rail Fasteners
3.95 – 4.15 Boggo Road Station to Existing Park Road Train Station	Commercial Educational	22 m 76 m – 111 m	25 dBA <10 dBA	40 dBA 40 dBA	Resilient Rail Fasteners
4.15 – 4.35 Existing Park Road Train Station to Abingdon St, Woolloongabba	Residential	15 m – 79 m	<10 dBA to 28 dBA	35 dBA (night-time)	Highly Resilient Rail Fasteners

Chainage (km)	Type of Building	Min. Slant Distance to Track Level	Predicted Ground-borne Noise Level (dBA)	Ground-borne Noise Goal (dBA)	Proposed Mitigation Measure
4.35 – 5.1 Abingdon St, Woolloongabba to Woolloongabba Station	Residential Commercial Worship Hotel	18 m – 94 m 26 m – 89 m 60 m – 97 m 43 m	<10 dBA to 34 dBA <10 dBA to 29 dBA <10 dBA to 15 dBA 20 dBA	35 dBA (night-time) 40 dBA 40 dBA 35 dBA (night-time)	Resilient Rail Fasteners
5.1 – 6.85 Woolloongabba Station to Albert Street Station	Residential Commercial Educational Worship Medical Hotel	38.5 m – 202 m 26 m – 168 m 37 m – 234 m 42 m – 192 m 201 m 19 m – 146 m	<10 dBA to 26 dBA <10 dBA to 25 dBA <10 dBA to 23 dBA <10 dBA <10 dBA <10 dBA to 27 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA 40 dBA 35 dBA (night-time)	Resilient Rail Fasteners (Chainage 5.95 – 6.55 km rail section under the Brisbane River with Direct Fixation Rail Fasteners)
6.85 – 7.9 Albert Street Station to Roma Street Station	Commercial Educational Worship Heritage Medical Hotel	17 m – 91 m 52 m – 58 m 52 m – 82 m 33 m – 67 m 32 m – 98 m 22.5 m – 82 m	<10 dBA to 36 dBA 13 dBA to 23 dBA 16 dBA to 30 dBA 21 dBA to 34 dBA 13 dBA to 35 dBA <10 dBA to 33 dBA	40 dBA 40 dBA 40 dBA 40 dBA 40 dBA 35 dBA (night-time)	Resilient Rail Fasteners
7.9 – 9.55 Roma Street Station to Northern Portal	Residential Commercial Educational Medical Hotel	38 m – 121 m 50 m – 113 m 43 m – 122 m 138 m 51 m – 108 m	<10 dBA to 25 dBA <10 dBA to 21 dBA <10 dBA to 24 dBA <10 dBA <10 dBA to 20 dBA	35 dBA (night-time) 40 dBA 40 dBA 40 dBA 35 dBA (night-time)	Resilient Rail Fasteners (Chainage 9.05 – 9.55 km rail section with Direct Fixation Rail Fasteners)

Note: Extent of Reference Project trackform is detailed in **Table 22**. Also the LAmax,Slow noise level refers to the 95th percentile train passby event. The ground-borne noise level of the "average" or median train event would typically be approximately 3 dB lower than the 95th percentile event.

7.5 Other Sensitive Receivers

A summary of the sensitive receivers (excluding residences) above or close to the proposed alignment is provided in **Appendix E**.

On the basis of the speed profile for the CRR project (shown in **Figure 13**), the proposed vertical alignment, the modelling assumptions described in the previous sections and the proposed trackform in **Table 22**, ground-borne noise levels are predicted to comply with the ground-borne noise goals at all locations.

8 AIRBORNE NOISE ASSESSMENT - TRAIN OPERATIONS

The CRR Rail Operations team has prepared a rail operations summary paper to help the CRR design team to define the scope of infrastructure works required to meet the operational requirements of CRR. Overviews for the existing and proposed new CRR surface tracks for the northern section and southern section (ie north and south of the tunnel portals) are presented in **Figure 19** and **Figure 20** respectively.

In addition to the proposed new or upgraded surface tracks to assist in meeting the operational requirements of CRR, the project also proposes significant upgrades to the Mayne and Clapham stabling yards to facilitate the CRR rollingstock.

The noise assessment for the surface train operations have been performed based on predicted future Year 2021 and Year 2031 train operations. The following sections present modelling methodology, modelling input data and assumptions, predicted noise levels and possible mitigation measures to meet project noise goals where applicable.

Figure 19 Overview of Northern Section (CRR Section 3000) Surface Rail Operations

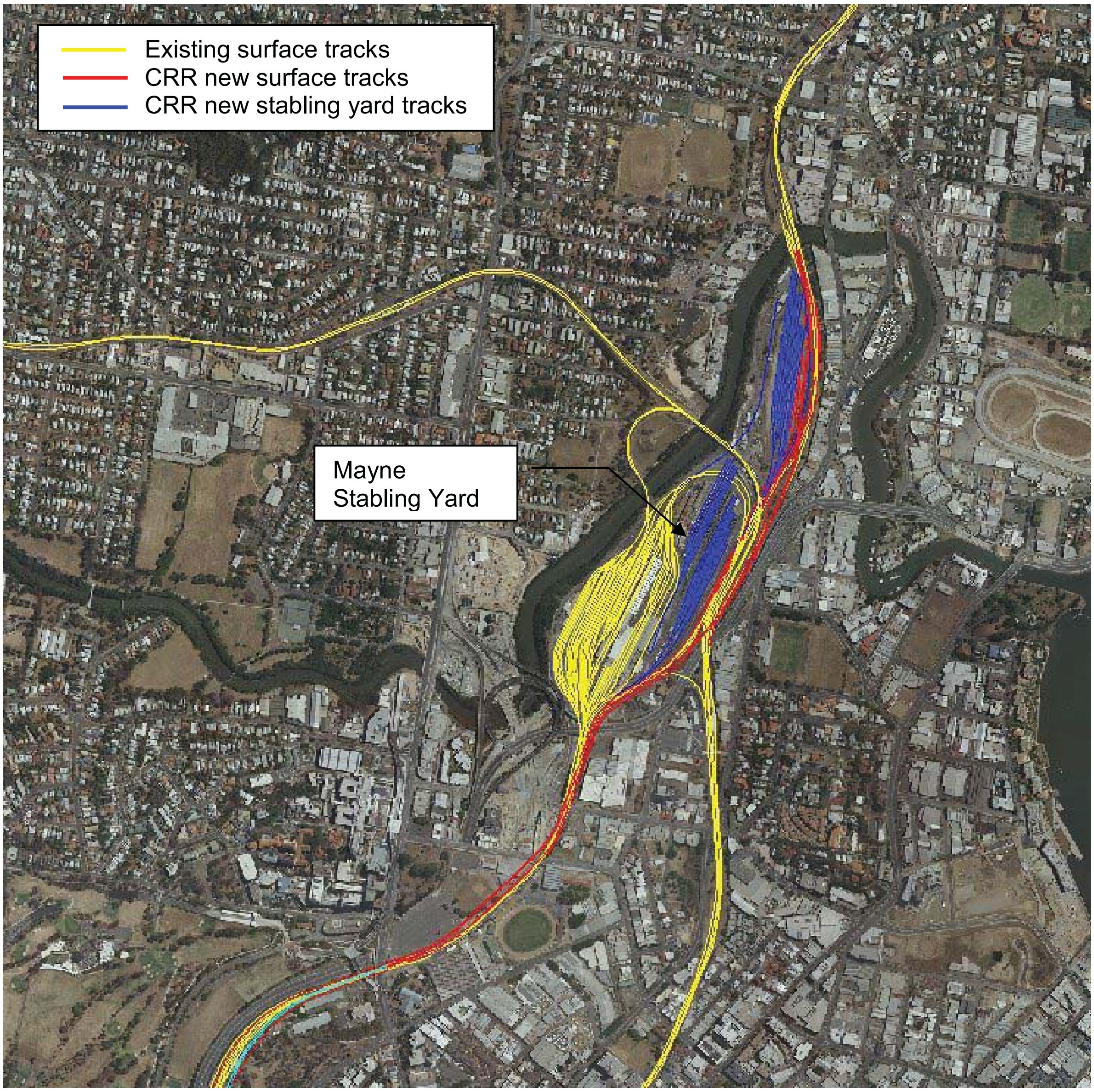
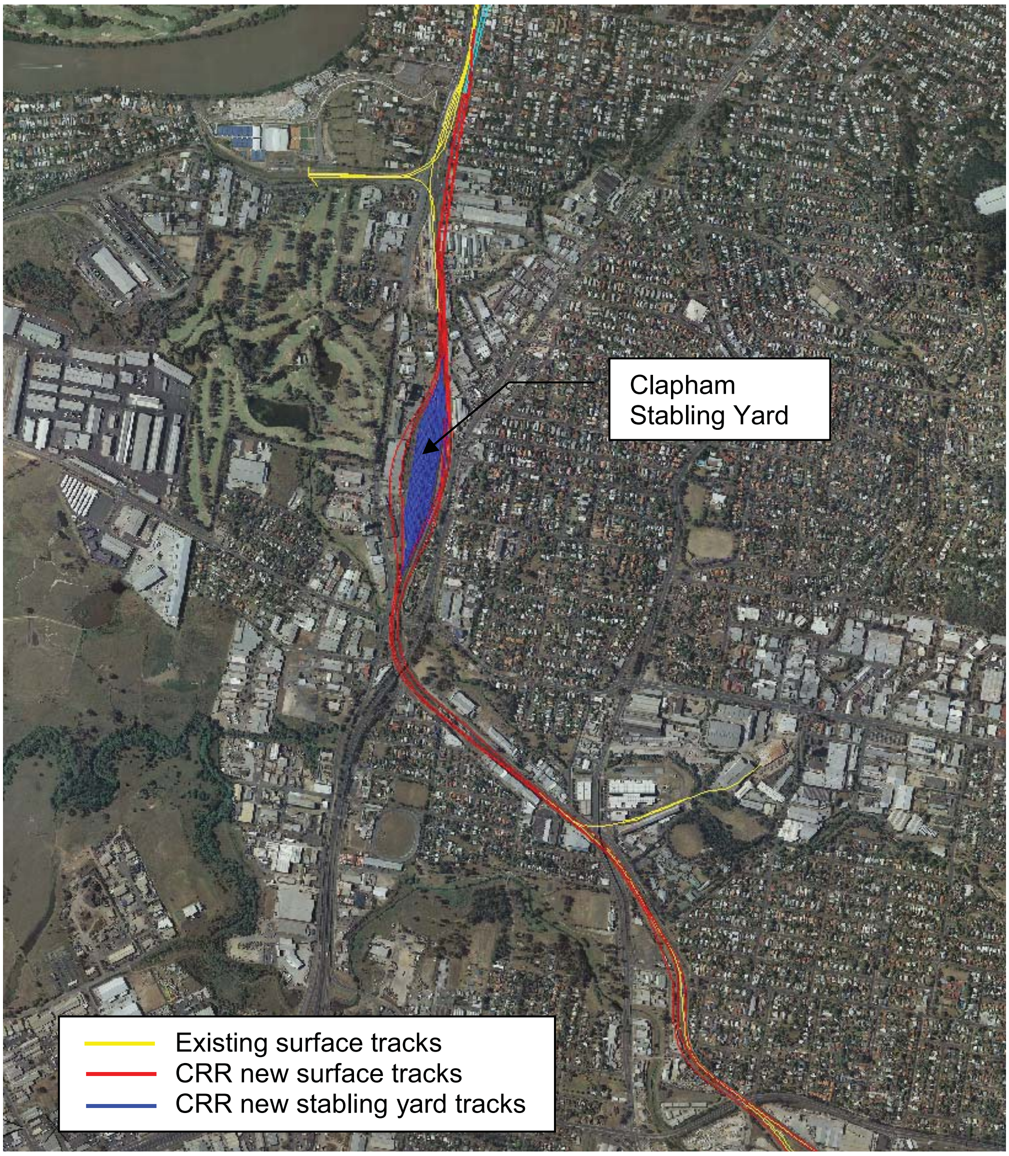


Figure 20 Overview of Southern Section (CRR Section 1000) Surface Rail Operations



8.1 SoundPLAN Modelling Methodology

A SoundPLAN (Version 6.5) computer noise model has been used for the prediction of noise levels at sensitive receivers. The noise model comprises topography, buildings, number of trains and calibrated noise emission levels (against measurements), relevant noise sources for the rail stabling yards and portal noise emissions as well as the location of noise sensitive receivers. The computer model calculates the noise levels at sensitive locations, taking into account:

- All noise source sound power levels and frequency spectra.
- Noise propagation variables such as distance attenuation, ground absorption, air absorption and shielding attenuation from topography, buildings or barriers.

The calculation procedure involves a 360^{o} scan from each receiver point (using fixed angular steps), with the contributions from each angular increment summed to determine the total received noise level. The calculation procedure takes into account the direct noise, the noise diffracting over obstacles or barriers and the noise reflected off buildings.

A separate model run was also carried out using a fixed calculation grid with a spacing of 10 m to produce noise contours. The resultant contours were interpolated between the grid points.

Two different computation algorithms were utilised within the SoundPLAN model. The Nordic Rail Traffic Noise Prediction Method (Kilde 130) has been used for all surface rail noise assessments and the CONCAWE industrial prediction model has been used to account for the additional noise emission through the portal openings and for the noise from stationary trains in the stabling yard (ie auxiliary equipment and air conditioning units). These prediction models and the utilised model inputs are described below.

Nordic Rail Traffic Noise Prediction Method

The Nordic Rail Traffic Noise Prediction Method (Kilde 130) dates from 1984 and is commonly utilised for Queensland Rail noise assessments. It calculates emission noise level based on the number of trains, speed, and length and predicts $L_{Aeq(24hour)}$ and maximum noise levels as required by the Queensland Rail Code of Practice.

The CONCAWE Standard for Industrial Noise Modelling

Noise emissions from the portals and stationary trains in the rail stabling yard have been predicted using the CONCAWE prediction model.

CONCAWE is commonly implemented in industry and resource sector projects for environmental noise prediction. It allows for investigation of effects of wind and atmospheric stability on noise propagation. The CONCAWE standard is based on a research paper published in 1981 under the title "The propagation of noise from petroleum and petrochemical complexes to neighbouring communities".

The statistical accuracy of environmental noise predictions using CONCAWE was investigated by Marsh (Applied Acoustics 15 - 1982), with the conclusion that CONCAWE was accurate to ±2 dBA in any one octave band between 63 Hz and 4 kHz and ± 1 dBA overall.

8.2 Train Operations – Upgraded Rail Alignments including CRR

8.2.1 Model Inputs and Assumptions – Through Traffic

The SoundPLAN model was created from topography, rail alignments, existing buildings and resumption plans supplied by the CRR project team. The topography, reference design rail alignments and existing buildings were supplied in 3-D; the existing rail alignments and resumption plans were supplied in 2-D. A digital ground model was created, based on the supplied topography, and applied to the existing rail alignment strings to generate the 3-D model for the model verification.

The suburban train movements for a typical day were supplied by the CRR Rail Operations Team and are shown in **Table 24**. Freight train movements were provided by System Wide and are also included in **Table 24**.

The CRR Rail Operations Team has advised that the 2031 train movements assume construction of the North West Corridor project and, as such, many of the trains entering the southern portal of the tunnel exit at a portal associated with that project rather than the northern CRR portal (and vice versa). This is the reason for the large difference in train volumes at the southern and northern portals.

Table 24 Daily (24hour) Train Movements – Surface Tracks

Section	Train Lines	2021	2031
Passenger Trains			
South of Yeerongpilly - Surface (not CRR Services)	Kuraby / Loganlea	160	171
South of Yeerongpilly - CRR services only	Beenleigh, Varsity	292	552
North of Ekka - CRR services only	Redcliffe, Nambour, Caboolture	342	--
North of Ekka - CRR services only	NWTC = Nambour, Caboolture, Caloundra	--	384
North of Ekka - CRR services only	Redcliffe	--	168
North of Ekka (not CRR services)	Strathpine	--	219
Immediately North of Bowen Hills (not CRR services)	Ferny Grove	184	181
North of Eagle Junction - Surface (not CRR services)	Shorncliffe, Airport, Doomben	306	343
Freight Trains			
Salisbury to Tennyson		25	30
Tennyson to Port		39	47
North Coast		38	46

Note: Train numbers are the total including both directions

Train noise source data for the existing fleet have been taken from Queensland Rail's standard table of noise emissions. Based on advice from the CRR project team that the proposed new 9-car passenger trains have similar specifications to the existing SMU fleet, the noise emission levels used for the 9-car passenger trains were extrapolated from those for a 6-car SMU citytrain.

Based on the service plans provided by the CRR Rail Operations Team, all suburban trains were modelled as either 9-car SMU (2031 CRR tunnel traffic only) or 6-car SMU/IMU (all other traffic).

As no speed profile was available for the surface tracks of the CRR project, all suburban trains have been modelled with a top speed of 80 km/h. Acceleration and deceleration rates (for approach to and departure from stations) have been based on the speed profile provided for the in-tunnel train movements (refer to **Figure 13**).

In the absence of any data, all freight traffic was modelled as double-header locomotives (current generation) with 1,500 m of consist. Based on advice from Queensland Rail, a consist length of 620 m has been used for the existing case (model verification). All freight movements were assumed to travel at a constant speed of 60 km/h and the locomotives were assumed to be at a notch setting of 6.

Corrections for curves, bridges and turnouts have been modelled based on features identified in the Reference Design, existing track alignments and aerial photography.

Plans and coordinates of existing noise barriers between Southbank and Salisbury were supplied by Queensland Rail. These have been included in the noise modelling as fully reflective noise barriers.

8.2.2 Modelling Assumptions – Portal noise emissions

Noise emissions from the tunnel portals have been modelled as a vertical area noise source across the tunnel portal openings. A sound power level has been assigned to these portal noise sources based on in tunnel noise measurements in rail tunnels in Sydney. The source level has for the Reference Project assumed no absorption in the tunnel, resulting in a higher reverberant build up noise level in the tunnels. The maximum sound power level for the portal noise emission is 121 dBA, based on a reverberant in-tunnel sound pressure level of 105 dBA. The average $LA_{eq(24hour)}$ sound power level for the portals have been calculated following the methodology outlined in a paper "Prediction of sound radiated from tunnel openings" by Wolfgang Probst, 2010. The $LA_{eq(24hour)}$ sound power level for the portals are presented in **Table 25**.

Table 25 Average LAeq(24hour) Sound Power Level per Portal

Portal	2021		2031	
	Train Numbers	SWL (dBA)	Train Numbers	SWL (dBA)
Southern Portals	146[1]	94	276[2]	99
Northern Portals	171[1]	95	84[2]	94

Note 1: Assumes 6 car trains in 2021
Note 2: Assumes 9 car trains in 2031

Directivity for the portal opening area noise sources in accordance with recommendations in (Wolfgang Probst, 2010) has been adopted. The directivity formula for the portal noise emission is:

$$D = -0.115 * \Psi + 3.08 \text{ dB}$$

Where Ψ is the angle between centreline of the tunnel and the line from the centre of the tunnel to the receiver position ($0 \leq \Psi \geq 90^o$).

8.2.3 Modelling Assumptions – Stabling Yards

Moving rollingstock within the stabling yard has been modelled in accordance with Queensland Rail's noise emissions data (with trains modelled at 30 km/h).

Points have been modelled having a 5 dBA increased noise emission in accordance with Queensland Rail's Network Noise Management Plan (NNMP) Development Standard Gauge Line.

The noise emission levels used for the stationary trains auxiliary systems and air conditioning units are based on previous measurement results for Queensland Rail rollingstock contained in SLR Consulting' noise source database. Each existing 6-car suburban train is equipped with 12 air conditioning units, which are the dominant noise sources for the stationary trains after parking and before pick-up. The future 9-car suburban train have been assumed to have 12 air conditioning units (2 per car). Each air-conditioning unit has a sound power level of 87 dBA.

A typical "worst case" scenario has been modelled for the stationary trains in the stabling yard consisting of two trains on the closest tracks to the sensitive receivers (located to the south, there are no sensitive receiver directly to the north) with the auxiliary systems and air conditioning units operating. Trains on stabling tracks behind the trains on the closest track to the receivers will be significantly shielded and the modelled case is considered a typical worst case. This typical "worst case" noise emission from the stationary trains in the stabling yard has been modelled as operating over a total period of approximately 2 hours during parking and 2 hours during pick-up.

The number of stabled trains assumed for the Mayne and Clapham stabling yards are presented in **Table 26**.

Table 26 Number of Stabled Trains for each Stabling Yards

Location	2021	2031
Mayne Yard	90 x 3-car sets	Up to 124 x 3-car sets
Clapham Yard	44 x 3-car sets	Up to 60 x 3-car sets

Note: Train movements in and out of stabling yards have been modelled as specified by the train volumes contained in the CRR Rail Operations Report.

8.2.4 Predicted Noise Levels

Rail traffic noise levels have been predicted for the existing (model verification), Year 2021 (opening) and Year 2031 (10 year horizon) scenarios.

Model Verification

The model has been verified for the existing through traffic against noise measurements undertaken at two locations within the southern section. The prediction difference (predicted level minus measured level) at one location (1241 Ipswich Rd, Moorooka) is +1 dBA (both $L_{Aeq(24hour)}$ and L_{Amax}) and +3 dBA (both $L_{Aeq(24hour)}$ and L_{Amax}) at the second location (15 Lily St, Salisbury). Normal practice for model verification is that ±2 dBA is acceptable. In this instance, these results are considered acceptable as the model is slightly conservative at one of the monitoring locations and the assumed operating conditions for the existing rail traffic may differ from those which occurred during the measurement period.

Future Operational Noise Levels

For the northern section, Year 2021 and Year 2031 rail noise levels of up to 61 dBA $L_{Aeq(24hour)}$ and 82 dBA L_{Amax} are predicted. Based on these predictions, all sensitive locations within the northern section are predicted to comply with Queensland Rail's operational planning levels.

For the southern section, Year 2021 rail noise levels of up to 72 dBA $L_{Aeq(24hour)}$ and 92 dBA L_{Amax} are predicted and Year 2031 rail noise levels of up to 75 dBA $L_{Aeq(24hour)}$ and 92 dBA L_{Amax} are predicted. Based on the predicted noise levels, 28 sensitive locations within the southern section are predicted to exceed Queensland Rail's operational planning levels in Year 2021 and 37 sensitive locations are predicted to exceed the operational planning levels in Year 2031.

The predicted noise levels for Year 2021 and Year 2031 for each section are tabulated in **Appendix F**. The predicted noise levels in **Appendix F** include contributions from the through traffic, stabling yards and tunnel portals and include shielding from any existing noise barriers. All predicted levels include a +2.5 dBA facade correction.

Noise contours for Year 2021 and Year 2031 are presented in **Appendix G** and **Appendix H**, respectively. The noise contours include contributions from the through traffic, stabling yards, tunnel portals and a +2.5 dBA facade correction. The existing noise barriers included in the modelled noise levels are shown on the noise contour plans.

The noise contributions from the stabling yards operations at Mayne and Clapham stabling yards to the overall rail noise emissions is negligible. The through traffic dominates the single event maximum and $L_{Aeq(24hour)}$ noise levels assessed according to Queensland Rail's Code of Practice and there are no predicted exceedances of Queensland Rail's operational planning levels adjacent to either stabling yard.

There is, however, a risk that the stationary trains at the stabling yards can have a sleep disturbance impact due to the more steady-state character of the noise sources compared to normal rail operations and the length of time (2 hours) that the air conditioning equipment may be operated. The typical "worst case" (refer to **Section 8.2.3**) predicted noise emission levels from the stabling yards during parking and pick-up is up to 47 dBA for Mayne Yard and 50 dBA for Clapham Yard. The World Health Organisation gives an internal sleep disturbance criterion of 30 dBA L_{Aeq} for stationary noise sources. Assuming a 10 dBA facade noise reduction, this would correspond to an external noise goal of 40 dBA L_{Aeq}. Based on this, even though the Queensland Rail operational planning levels are achieved, there is a risk that the noise emissions from the air conditioning units after parking and before pick-up may cause a sleep disturbance impact.

8.2.5 Mitigation Measures

As all sensitive locations within the northern section are predicted to comply with Queensland Rail's operational planning levels, no mitigation measures are required in this area.

The Year 2031 operational noise levels are predicted to exceed Queensland Rail's planning levels in four areas of the southern section. Noise barriers have been designed to reduce operational noise levels to achieve compliance with Queensland Rail's planning levels, where possible.

Queensland Rail's Code of Practice states the following with regard to noise barriers adjacent to stations:

> *For safety reasons, noise barriers will not be built at or near stations.*

Noise barriers adjacent to existing train stations have therefore not been included in the below proposed noise barrier design.

Noise Barrier 1 (Salisbury)

A 375 m long existing noise barrier of 1.5 to 4.5 m in height south of the Salisbury Station needs to be upgraded to 6 to 7 m height. North of Salisbury Station, a 214 m long and 5 high noise barrier is required. The total barrier area is approximately 3,415 m^2.

Noise Barrier 2 (Rocklea)

South of Rocklea Station, an 88 m long and 4.5 m high noise barrier is required. North of Rocklea Station a 43 m long and 5 m high noise barrier is proposed. The total barrier area is approximately 612 m^2.

Noise Barrier 3 (Yeronga)

A noise barrier of approximately 165 m in length and is 4.5 m in height is required. The total barrier area is approximately 735 m^2.

Noise Barrier 4 (Yeerongpilly)

A noise barrier of approximately 155 m in length and 4 m in height is required just north of the new Yeerongpilly Station. The total barrier area is approximately 625 m^2.

Due to Queensland Rail's policy not to build noise barrier adjacent to existing train stations for safety reasons, there are 10 sensitive receivers adjacent to the Salisbury Station and 1 adjacent to Rocklea Station exceeding the Queensland Rail's operational planning levels taking into account the proposed CRR noise barriers. There are some significant exceedances adjacent to the Salisbury Station of up to 7 dBA for the $L_{Aeq(24hour)}$ planning level. Adjacent to the Rocklea Station, there is only one marginal 1 dBA exceedance of the $L_{Amax)}$ planning level.

During the detailed design phase, all noise barriers will need to be designed in cooperation with Queensland Rail to take into account all aspects of noise, visual amenity and safety.

The predicted noise levels for Year 2031 with the designed noise barriers are tabulated in **Appendix F**. The predicted noise levels in **Appendix F** include contributions from the through traffic, stabling yards and tunnel portals and include shielding from the designed noise barriers and any retained existing noise barriers. All predicted levels include a +2.5 dBA facade correction.

Noise contours for Year 2031 with the designed noise barriers for the southern section are presented in **Appendix I**. The noise contours include contributions from the through traffic, stabling yards, tunnel portals and a +2.5 dBA facade correction. The designed and (retained) existing noise barriers included in the modelled noise levels are shown on the noise contour plans.

The possible sleep disturbance caused by the noise emission from the air conditioning units after parking and before pick-up may be mitigated by prudent operational management of the stabling yards. It is proposed that train stabling would be prioritised to the outer tracks in the yards (closest to the homes) during daytime hours and then successively fill the inner tracks and conversely for pick-up (ie the outer tracks would be picked up last). This would result in the trains on the outer tracks acting as noise barriers for the trains stabled on the inner tracks and also ensure maximum distance between noise source and receivers during the night-time. This operational management plan would most likely result in night-time external noise levels less than 40 dBA L_{Aeq}.

8.3 Train Operations – Existing Rail Alignments (no upgrade) between Portals

The rail tracks between the portals in Yeerongpilly and Victoria Park will not be changed as part of the CRR project. However, the CRR project will free up capacity on these surface tracks by redirecting a significant portion of the passenger rail operation through the rail tunnels. This increased capacity will enable the number of freight trains on the surface tracks between the portals to be increased.

The incremental change to the daily averaged $L_{Aeq(24hour)}$ noise emission levels from the existing surface rail tracks between the portals due to change in freight and passenger train numbers as a result of the CRR project have been assessed.

The maximum noise level during train passbys will not change due to the change in passenger and freight train numbers. There would only be a change to the number of train passby events. In fact over time it is likely that the maximum noise levels from train passbys would be reduced as new generation rollingstock are progressively introduced into Queensland Rail's operation.

8.3.1 Model Inputs and Assumptions

The passenger train numbers for modelling Year 2021 and Year 2031 have been sourced from the CRR Rail Operations report. The existing passenger train numbers have been sourced from Queensland Rail's published timetables.

The freight train numbers for existing and modelling Year 2021 and Year 2031 have been provided by System Wide on 28 March 2011. Based on information received from Queensland Rail, the existing freight trains between Salisbury and Park Road are currently 620 m long and are proposed to be increased to 1,500 m by 2031; this has been incorporated in the modelling as a "worst case" scenario. All freight trains on the other freight lines have been assumed to be 1,500 m long for both existing and future modelling years.

The existing and future train numbers on the surface tracks between the portals are shown in **Table 27**.

Table 27 Existing and Future Train Numbers on Surface Tracks between Portals

Section	Number of Trains				
	Freight		Passenger		Train Lines/Termini
Existing					
Yeerongpilly - Park Road	28[1]		202		All southern lines (Beenleigh, Varsity, Gold Coast)
Park Road - Roma Street	5		313		All southern lines plus Cleveland (Beenleigh, Varsity, Cleveland)
Roma Street - Bowen Hills	---		616		All lines
Roma Street - Bowen Hills (via Normanby)	29		---		---
Year 2021					
Yeerongpilly - Park Road	39[1]	(+11)	160	(-42)	Kuraby
Park Road - Roma Street	7	(+2)	352	(+39)	Kuraby, Cleveland
Roma Street - Bowen Hills	---		724	(+108)	All lines (except CRR)
Roma Street - Bowen Hills (via Normanby)	38	(+9)	---		---
Year 2031					
Yeerongpilly - Park Road	47[2]	(+19)	171	(-31)	Loganlea
Park Road - Roma Street	7	(+2)	352	(+39)	Loganlea, Cleveland
Roma Street - Bowen Hills	---		742	(+126)	All lines (except CRR)
Roma Street - Bowen Hills (via Normanby)	46	(+17)	---		---

Note 1: Freight trains between Salisbury and Park Road have been assumed to be 620 m long for the existing and future modelling year 2021. All other freight lines through Brisbane assume 1,500 m long freight trains for both the existing and future modelling years.

2: Freight trains between Salisbury and Park Road have been assumed to be 1,500 m long for the future year 2031 as a "worst case" scenario.

8.3.2 Predicted Future Change in Rail Noise Emission between Portals

The rail traffic volumes and assumed freight train lengths in **Table 27** have been used to predict the incremental change in future $L_{Aeq(24hour)}$ rail noise emissions for the surface tracks between the portals, presented in **Table 28**.

Table 28 Predicted Incremental Changes in Rail Noise Emission for Tracks between Portals

Section	Change in Noise Level (dBA $L_{Aeq(24hour)}$)					
	2021			2031		
	Freight	Passenger	Total [1]	Freight	Passenger	Total [1]
Yeerongpilly - Park Road	1.4	-1.0	0.5	3.1	-0.7	1.8
Park Road - Roma Street	1.5	0.5	0.7	1.5	0.5	0.7
Roma Street - Bowen Hills	---	0.7	0.7	---	0.8	0.8
Roma Street - Bowen Hills (via Normanby)	1.2	---	1.2	2.0	---	2.0

Note 1: The total change in noise level is the change in the logarithmic sum of the freight and passenger noise levels, not the linear sum of the individual changes for freight and passenger noise levels.

It can be seen in **Table 28** that the $L_{Aeq(24hour)}$ noise emission levels increase up to 2 dBA due to the change in passenger and freight train traffic for the modelling Year 2031.

It is generally recognised in acoustics that changes in noise levels of 2 dBA or less are undetectable to the human ear and therefore negligible.

It should be noted that the maximum noise level during train passbys will not change due to the change in passenger and freight train numbers. There would only be a change to the number of train passby events. The maximum noise levels from train passbys is expected to be reduced as new generation rollingstock are progressively introduced into Queensland Rail's operation.

9 AIRBORNE NOISE ASSESSMENT – ANCILLARY FACILITIES

Ancillary noise sources would typically include mechanical plant facilities and ventilation shafts for underground areas and feeder stations for power distribution of the CRR rail operations. For fire and life safety requirements, a ventilation and emergency shaft located mid-way between Yeerongpilly and Boggo Road Stations has also been proposed.

The following sections present the assessment of these ancillary facilities associated with the CRR project.

9.1 CRR Feeder Stations

Three 25 kV feeder stations are proposed. The locations of the feeder stations are at Mayne Yard (to replace an existing feeder station), near the northern portal at the Exhibition grounds and near the southern portal at Yeerongpilly. The reference project proposes that each feeder station for the CRR project will require a capacity of approximately 18 MVA. The Australian Standard AS 2374.6-1994 *Power Transformers – Part 6; Determination of transformer and reactor sound levels*, gives generic sound power levels as a function of the power requirement. For a power transformer of 18 MVA capacity, the sound power levels provided in Appendix AA of AS 2374.6-1994 are presented in **Table 29**.

Table 29 Sound Power Level for Transformers According to AS 2374.6-1994

Power Transformer	LWA(standard maximum) (dBA)	LWA(reduced maximum) (dBA)
18 MVA	92	84

Note: If there are components with tonal character, an adjustment to the measured noise level of +5 dBA is required in accordance with AS 1055.1-1997.

The harmonic filters are likely to have noise emissions with tonal character and a 5 dB adjustment to the sound power levels in **Table 29** have been applied.

9.1.1 Mayne Yard Feeder Station

The feeder station at Mayne Yard consists of the following components:

- 110 kV switchgear building – 18 m x 14 m x 12 m (length x width x height)
- 2 x 110/25 kV transformer enclosures – 8 m x 7 m x 7 m each
- 25 kV control building – 16 m x 5 m x 6 m
- 2 x 25 kV harmonic filter enclosures 15 m x 10 m x 6 m each

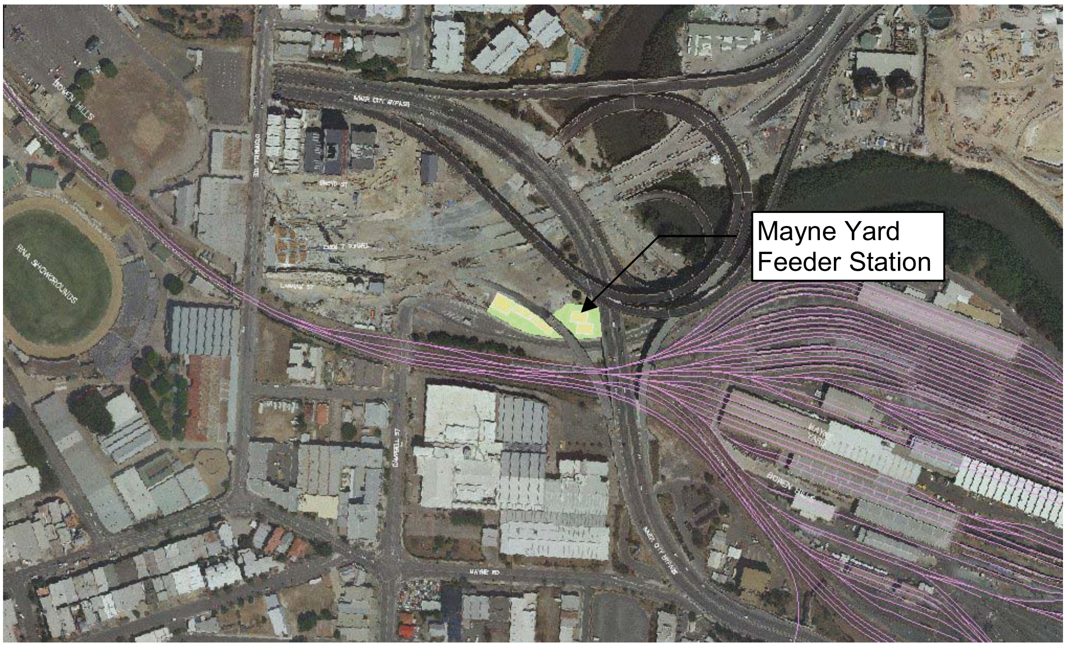
All components will be enclosed in buildings, based on the recently constructed feeder station at Roma Street, the larger building was constructed in brick and the smaller buildings in metal cladding with the transformer building open in the direction of the tracks.

The location of the feeder station at Mayne Yards is shown in **Figure 21**. The nearest sensitive receiver is approximately 230 m from the proposed feeder station location, which is located in an industrial dominated area. The feeder station buildings are assumed to be oriented with no openings away from the railway, which is the direction of the nearest sensitive receivers. A noise reduction through the feeder station building facades of approximately 20 dBA can be expected.

The existing background noise for this area has conservatively been assumed to be 40 dBA RBL (refer to monitoring location 3 in **Table 9,** due to the close proximity to the Mayne Yards and ICB higher background noise levels are expected than at monitoring location 3). The noise goal for continuous mechanical plant noise is RBL + 0 = 40 dBA L_{A90} (refer to **Table 6**).

Using the sound power level in **Table 29**, adjusted for tonality for the harmonic filters (ie +5 dB), the predicted noise levels at the nearest sensitive receiver is less than 30 dBA. The predicted noise emission from the Mayne Yard feeder station is predicted to comply with the noise goal.

Figure 21 Proposed location of Mayne Yard Feeder Station



9.1.2 Exhibition Feeder Station

The feeder station at Exhibition consists of the following components:

- 110 kV switchgear building – 21 m x 14 m x 12 m (length x width x height)
- 3 x 110/25 kV transformer enclosures – 8 m x 7 m x 7 m each
- 25 kV control building – 16 m x 5 m x 6 m
- 3 x 25 kV harmonic filter enclosures 15 m x 10 m x 6 m each

As for the Mayne Yard feeder station, all components will be enclosed in buildings with the transformer building open in the direction of the tracks.

The location of the feeder station at Exhibition is showed in **Figure 22**. The nearest sensitive receiver is approximately 160 m from the proposed feeder station location. The feeder station buildings are assumed to be oriented with no openings away from the railway, which is the direction of the nearest sensitive receivers. A noise reduction through the feeder station building facades of approximately 20 dBA can be expected.

The existing background noise for the area is approximately 40 dBA RBL (refer to monitoring location 3 in **Table 9**). The noise goal for continuous mechanical plant noise is RBL + 0 = 40 dBA L_{A90} (refer to **Table 6**).

Using the sound power level in **Table 29**, adjusted for tonality for the harmonic filters (ie +5 dB), the predicted noise levels at the nearest sensitive receiver is less than 30 dBA. The predicted noise emission from the Exhibition feeder station complies with the noise goal.

Figure 22 Proposed location of Exhibition Feeder Station

9.1.3 Yeerongpilly Feeder Station

The feeder station at Yeerongpilly consists of the following components:

- 110 kV switchgear building – 21 m x 14 m x 12 m (length x width x height)
- 2 x 110/25 kV transformer enclosures – 8 m x 7 m x 7 m each (with provision for 1 more future transformer building)
- 25 kV control building – 16 m x 5 m x 6 m
- 2 x 25 kV harmonic filter enclosures 15 m x 10 m x 6 m each (with provision for 1 more future harmonic filter)

As for the Mayne Yard and Exhibition feeder station, all components will be enclosed in buildings with the transformer building open in the direction of the tracks.

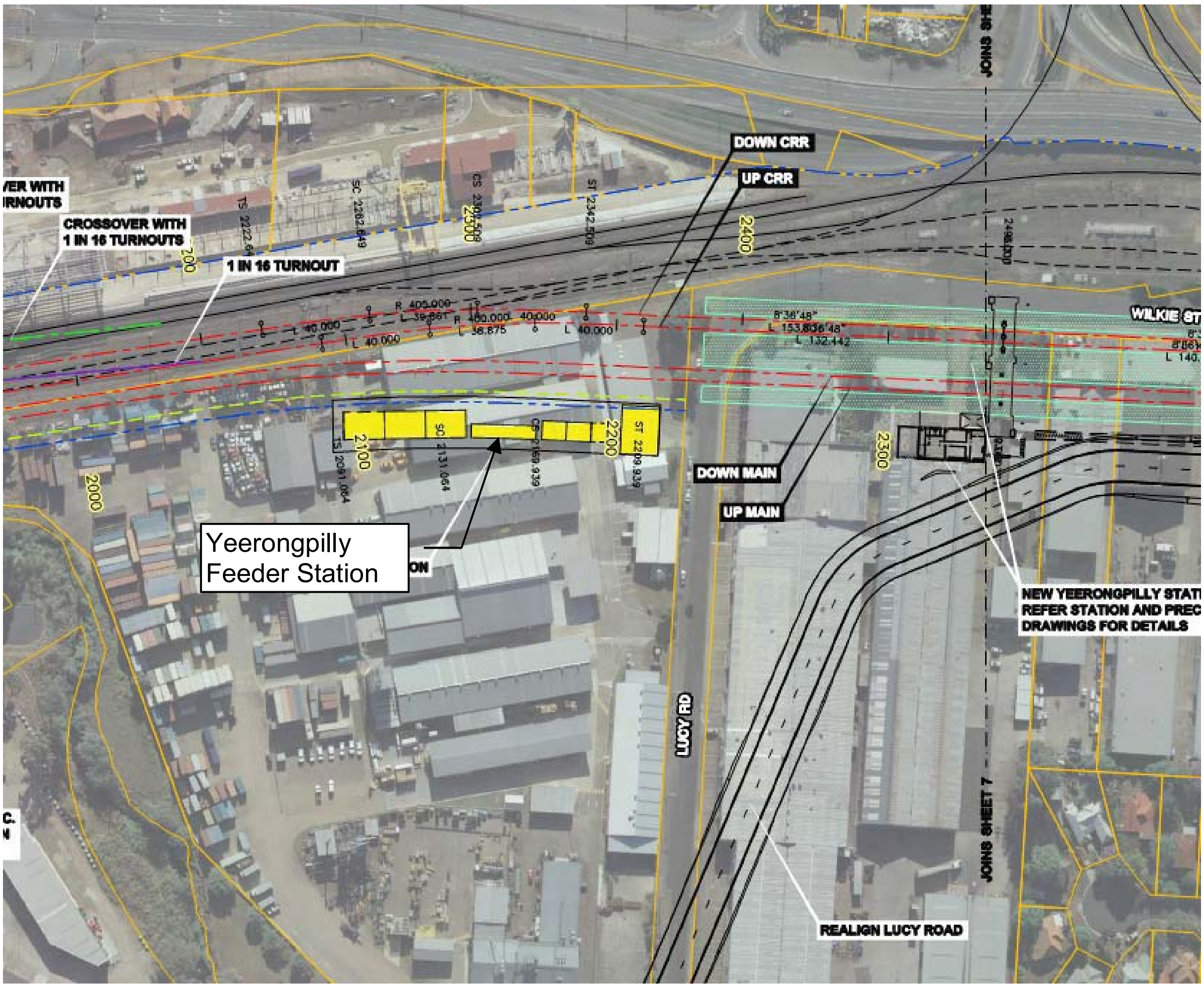
The location of the feeder station at Yeerongpilly is showed in **Figure 23**. The nearest sensitive receiver is approximately 200 m from the proposed feeder station location.

The existing background noise for the area is approximately 33 dBA RBL (refer to monitoring location 16 in **Table 9**). The noise goal for continuous mechanical plant noise is RBL + 0 = 33 dBA L_{A90} (refer to **Table 6**).

The nearest sensitive receivers are in the direction where the feeder station buildings have no openings. A noise reduction through the feeder station building facades of approximately 20 dBA can be expected.

Using the sound power level in **Table 29**, adjusted for tonality for the harmonic filters (ie +5 dB), the predicted noise levels at the nearest sensitive receiver is less than 30 dBA. The predicted noise emission from the Yeerongpilly feeder station complies with the noise goal.

Figure 23 Proposed location of Yeerongpilly Feeder Station



9.2 Southern Intermediate Ventilation Shaft

The southern intermediate ventilation shaft building is proposed to be 8.5 m high and provided with point extraction and Saccardo nozzles to provide longitudinal thrust capability in both tunnels and in both directions away from the ventilation shaft. The noise emission for emergency ventilation is not assessed as part of this EIS (due to it only happening very seldom during exceptional circumstances ie fire events) and it is assumed that the southern intermediate ventilation shaft will only have forced ventilation during emergency events.

Although the proposed railway line will operate underground at this location, noise generated during train passbys has the potential to escape from the tunnels via the tunnel ventilation shaft.

The location and architectural sketch of the southern intermediate ventilation shaft is shown in **Figure 24** and **Figure 25**.

The in-tunnel maximum reverberant noise levels used for predictions of the train noise break-out is presented in **Table 30**.

Table 30 In-tunnel Reverberant Noise Levels

Maximum Noise Levels, Lmax (fast) (dB)										
Octave Band Centre Frequency (Hz)	**31.5**	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**dBA**
In-tunnel Noise Levels	94	88	86	93	101	97	92	90	83	**102**

Note: Noise levels sourced from SLR Consulting noise source database.

The Reference Design proposes the emergency exhaust and supply fans to be fitted with noise attenuators. A conservative 20 dBA noise reduction have been assumed as the train passby noise passes through these on the way to the surface.

Based on the above conservative assumptions, the maximum noise level at the nearest sensitive receiver (approximately 35 m away from the proposed shaft) from a train passby is predicted to approximately 50 dBA LAmax. This is in compliance with the operational planning levels in accordance with the Queensland Rail's Code of Practice (refer to **Section 2.2**).

The predicted breakout noise from train passbys in the tunnels is less than what is expected from existing car passby noise in the area.

Figure 24 Proposed location of the Fairfield Gardens Ventilation Shaft

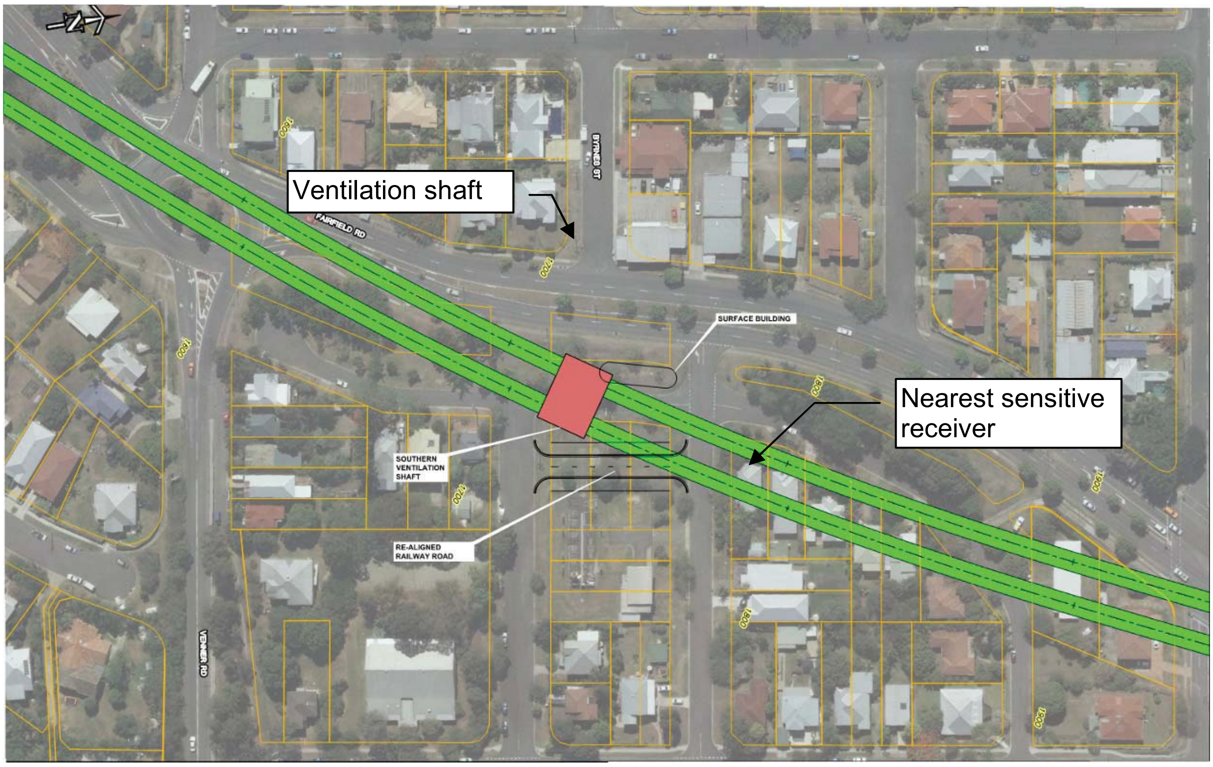
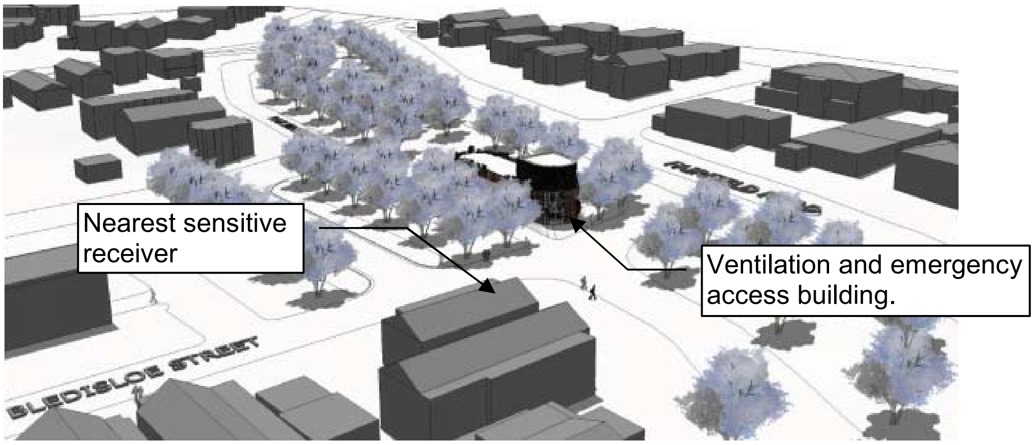


Figure 25 Southern Ventilation Shaft – Architectural Sketch



9.3 Underground Stations Mechanical Plant and Ventilation

9.3.1 Modelling Methodology

The modelling of the mechanical services airborne noise presented in this assessment are based on the preliminary plant locations which are still potentially subject to change. Specific equipment is also not known at this stage and the expected noise levels can therefore not be predicted. As such, the maximum total allowable emitted sound power at each location has been calculated, specifying the acoustic emission limit for all equipment (combined operation) at each location. The noise sources have been assumed to operate without a noticeable tonal, impulsive or intermittent nature. . Based on previous experience, these emission limits are achievable with appropriate equipment selection and silencing treatments, if required.

9.3.2 Noise Predictions

The maximum allowable sound power levels emitted by industrial-type noise sources have been predicted for each location in order to meet the noise goal (refer to **Table 6**) at nearby sensitive receivers. The results are presented in **Table 31**.

Table 31 Station Ancillary Facilities - Maximum Acceptable Noise Emissions

Site Location	Ancillary Location	Distance to Nearest Sensitive Receiver (m)	Noise Goal (dBA LA90)[1]	Maximum Acceptable Sound Power Level emitted from the Ancillary Facility (dBA)
Boggo Rd Station	Southern Entry, south of Boggo Rd Jail	~90	37	84
	Northern Entry supply and exhaust outlets towards Boggo Road Busway	~90	34	82
Woolloongabba Station	Central station box is open to natural light and ventilation. Ventilation supply and exhaust outlets east and west of the station building.	~100	46	94
Albert St Station	Alice St Entry	~45	46	87
	Mary St Entry	~25	54	90
Roma St Station	Southern Entry	~80	47	93
	Parkland Cres plant and ventilation shaft	~130	47	97

Note 1: Background creep noise goal in accordance with EPP(Noise) refer to **Table 6**. The background creep is the RBL + 0 assessed as the LA90 parameter. Existing background noise levels RBLs as presented in **Table 9**.

The locations and designs of the mechanical plants and air exhausts and intakes for the CRR project will need to be assessed in more detail during the detailed design phase.

9.3.3 Mitigation Measures

The maximum allowable mechanical services and ventilation shaft sound power levels emitted at each location have for detailed design purposes been calculated and range from 82 dBA to 97 dBA.

Mitigation measures are likely to be required for some station mechanical plant and ventilation shafts in order to comply with the project noise goals. Mitigation measures that may need to be considered at some locations include appropriate equipment selection, in-duct attenuators, noise barriers, acoustic enclosures and the strategic positioning of critical plant away from sensitive receivers.

10 AIRBORNE NOISE ASSESSMENT – ROAD TRAFFIC

Associated with CRR is the realignment of a number of roads adjacent to the railway corridor. The potential road traffic noise impact associated with the realignment of these roads has been assessed at nearby residential properties.

Section 2.6 of this report presents the *DTMR Code of Practice* road traffic noise goals. For the realigned road sections, the noise goal for "upgrading Existing Roads" of 68 dBA $L_{A10(18hour)}$ is applicable.

10.1 Road Traffic Noise Modelling Methodology

Noise modelling of the relevant areas of the project was carried out using the UK Department of Transport, *"Calculation of Road Traffic Noise*" (CORTN 1988) algorithms incorporated in the SoundPLAN 6.5 noise software. The modelling allows for traffic volume and mix, type of road surface, vehicle speed, road gradient, reflections off building surfaces, ground absorption and shielding from ground topography and physical noise barriers.

The algorithm output of CORTN calculates the $L_{A10(18hour)}$ descriptor directly for comparison with the road traffic noise goal.

10.2 Noise Assessment – Realigned Road Sections

There are 4 areas where roads have been realigned as part of the CRR project as follows:

- Dollis Street near Salisbury Railway Station.
  The Dollis Street realignment moves the road traffic marginally closer to residences on Olivia Avenue as a result of road straightening.
- Heaton Street and Fairlie Terrace at the Beaudesert Road overpass
  The realignment of Heaton Street and Fairlie Terrace at this location is minor and the distance from the road carriageways to the nearest residences will be unchanged. The acoustic impacts will be negligible and therefore this area is not assessed further.
- The Fairfield Road entry ramp to Ipswich Road has been realigned from an underpass to an overpass. The nearest residences are located to the south-east in Brooke Street.
- Wilkie Street is located East of Yeerongpilly Railway Station and has been realigned to the east to allow for the new CRR southern portal and station location. The nearest residences are located in the Wilkie Street cross streets, adjacent to the new Wilkie Street alignment.

For the three roads requiring further assessment, SLR Consulting was provided with Average Annual Daily Traffic Flows (AADT) for the design year 2031 (10 years after opening) and the percentage of heavy vehicles along with the posted speed for the realigned roads. The AADT's were converted to 18 hour traffic flows using a correction of 0.95. The parameters utilised in the noise modelling are summarised in **Table 32.**

Table 32 Traffic Volume Details for the CRR Realigned Roads

Road Section	AADT Traffic Volume (Total)	Percentage Heavy Vehicles	Traffic Speed (km/h)
Future Design Year 2031 (10 Years after Project Opening)			
Dollis Street	2,573	15%	50
Fairfield Road on Ramp to Ipswich Road	17,900	13%	60
Wilkie Street	2,208	15%	50

Predicted road traffic noise levels at the nearest sensitive receivers from the realigned road sections are presented in **Table 33**. The range corresponds to predicted noise levels at the nearest row or group of residences to the realigned roads. Noise contours are also presented in **Appendix J**.

Table 33 CRR Realigned Road Predicted Traffic Noise Levels (dBA)

Realigned Road	Residential Receivers	Predicted $L_{A10(18hr)}$ Noise Level
Dollis Street	Olivia Avenue	48 dBA to 51 dBA
Fairfield Road entry ramp	Brooke St	54 dBA to 60 dBA
Wilkie Street	Crighton St, Stamford St, Green St, Livingston St	58 dBA to 64 dBA

Notes1: The predicted noise levels include a +2.5 dBA facade noise reflection.

10.3 Summary

As presented in **Table 33** for each of the three realigned road sections, the highest noise levels are 51 dBA at Olivia Avenue, 60 dBA at Brooke Street and 64 dBA at Green Street. All residences adjacent to the realigned road sections comply with the *DTMR Code of Practice* road traffic noise goal of 68 dBA $L_{A10(18hr)}$ for the design Year 2031.

11 CONCLUSIONS

For new underground railway projects, consideration of the potential noise and vibration impacts during the design stage is critical in order to achieve a cost-effective and acceptable environmental outcome for the surrounding community. The application of add-on mitigation measures after construction is completed is frequently expensive, and in many cases is not feasible or practical after train operations commence.

11.1 Ground-borne Noise and Vibration – Train Operations

Ground-borne noise and vibration modelling was undertaken for the CRR Reference Project track alignment.

On the basis of the proposed alignment, operating speeds and design/maintenance assumptions, the predicted ground-borne vibration levels with the proposed Reference Project trackform configuration (refer to **Table 15**) are more than a factor of 3 below the vibration goal at the nearest sensitive receiver locations. A potential exceedance of the 0.013 mm/s (82 dB_V) vibration goal for buildings with highly vibration sensitive equipment has been identified at the CBD 7 Day Medical Centre in the Brisbane CBD. Further investigation will be required at this location when further detail is available during detailed design to ensure that operation of any highly sensitive equipment within this facility is not adversely affected by train operations.

The predicted ground-borne vibration levels for the electron microscope at the Eco-science precinct complies with the instrument specific vibration criteria supplied by the tenant. It is, however, recommended that further measurements (ie transmission loss between ground vibration and internal vibration levels on the floor where the electron microscope is installed) and more detailed predictions be performed during the detailed design stage to confirm the electron microscope is not adversely affected by train operations.

For the proposed CRR, three trackforms have been proposed as part of the Reference Project to achieve the ground-borne noise goals. These comprise a “direct fixation” trackform, with standard “stiff” rail fasteners, a “resilient” trackform with moderately resilient rail fasteners and a “highly resilient” trackform incorporating highly resilient rail fasteners.

The ground-borne noise modelling indicates that at critical locations, a “resilient” or “highly resilient” trackform will be required to achieve the ground-borne noise goals. Two additional track sections incorporating the “highly resilient” trackform have been proposed compared to the combination of trackforms proposed by the design team for the CRR Reference Project.

With the proposed combination of trackforms, compliance with the ground-borne noise goals are predicted at all sensitive receiver locations. In total 6.9 km of resilient rail fasteners and 1.19 km of highly resilient rail fasteners are required for the CRR tunnels.

11.2 Airborne Noise Assessment – Train Operations

A SoundPLAN (Version 6.5) computer noise model has been used for the prediction of noise levels at sensitive receivers. Two computation algorithms were utilised within the SoundPLAN model. The Nordic Rail Traffic Noise Prediction Method (Kilde 130) has been used for all surface rail noise assessments and the CONCAWE industrial prediction model has been used to account for the additional noise emission through the portal openings and for the noise from stationary trains in the stabling yard (ie auxiliary equipment and air conditioning units).

The predicted noise levels include contributions from the through traffic, stabling yards and tunnel portals and include shielding from any existing noise barriers. All predicted levels include a +2.5 dBA facade correction.

In the northern section, all sensitive locations are predicted to comply with Queensland Rail's operational planning levels in both Year 2021 and Year 2031. Therefore, no mitigation measures are required in this section.

In the southern section, 28 sensitive locations are predicted to exceed Queensland Rail's operational planning levels in Year 2021 and 37 sensitive locations are predicted to exceed the planning levels in Year 2031. Four sections with noise barriers have been designed for these locations to achieve (as far as practicable) compliance with Queensland Rail's operational planning levels, as described in **Table 34**.

Table 34 Designed Operational Noise Barriers

Noise Barrier	Location	Length (m)	Height (m)	Area (m^2)
1 [1]	South of Salisbury Station	375	6 to 7	2,345
	North of Salisbury Station	214	5	1,070
2	South of Rocklea Station	88	4.5	395
	North of Rocklea Station	43	5	217
3	Yeronga	165	4.5	735
4	Yeerongpilly Station	155	4	625

Note 1: The section of Noise Barrier 1 south of the Salisbury Station (approximately 375 m) replaces an existing noise barrier of 1.5 to 4.5 m in height.

Due to Queensland Rail's policy not to build noise barrier adjacent to existing train stations for safety reasons, there are 10 sensitive receivers adjacent to the Salisbury Station and 1 adjacent to Rocklea Station exceeding the Queensland Rail's operational planning levels taking into account the proposed CRR noise barriers. There are some significant exceedances adjacent to the Salisbury Station of up to 7 dBA for the $L_{Aeq(24hour)}$ planning level. Adjacent to the Rocklea Station, there is only one marginal 1 dBA exceedance of the $L_{Amax)}$ planning level.

The noise contribution from the stabling yard operations to the overall rail noise emissions is negligible. The through traffic dominates the single event maximum and $L_{Aeq(24hour)}$ noise levels and there are no predicted exceedances of Queensland Rail's operational planning levels adjacent to either stabling yard.

There is, however, a risk that the stationary trains at the stabling yards may have a sleep disturbance impact due to the more steady-state character of the noise sources compared to normal rail operations. The predicted typical "worst case" noise emission levels from the stabling yards during parking and pick-up exceed The World Health Organisation's internal sleep disturbance criterion of 30 dBA L_{Aeq} (external criterion of 40 dBA L_{Aeq}, assuming a 10 dBA facade noise reduction) for stationary noise sources. Therefore, even though the Queensland Rail planning levels are achieved, there is a risk that the noise emissions from the air conditioning units after parking and before pick-up may cause sleep disturbance.

The possible sleep disturbance caused by the noise emission from the air conditioning units after parking and before pick-up may be mitigated by intelligent management of the stabling yards. It is proposed that train stabling would be prioritised to the outer tracks in the yards during daytime hours and then successively fill the inner tracks and conversely for pick-up (ie the outer tracks would be picked up last). This would result in the trains on the outer tracks acting as noise barriers for the trains stabled on the inner tracks and also ensure maximum distance between noise source and receivers during the night-time. This operational management plan would most likely result in night-time external noise levels less than 40 dBA L_{Aeq}.

The rail tracks between the portals in Yeerongpilly and Victoria Park will not be changed as part of the CRR project. However, the CRR project will free up capacity on these surface tracks by redirecting a significant portion of the passenger rail operation through the rail tunnels. This increased capacity will enable the number of freight trains on the surface tracks between the portals to be increased.

The incremental changes to the daily averaged LAeq(24hour) noise emission levels from the existing surface rail tracks between the portals due to change in freight and passenger train numbers as a result of the CRR project have been assessed. However, the maximum noise level during train passbys will not change due to the change in passenger and freight train numbers. There would only be a change to the number of train passby events. In fact, over time it is likely that the maximum noise levels from train passbys would be reduced as new generation rollingstock are progressively introduced into Queensland Rail's operation.

The predicted noise levels indicate that the $L_{Aeq(24hour)}$ noise emission levels between the portals will increase by up to 2 dBA due to the change in passenger and freight train traffic for the Year 2031.

It is generally recognised in acoustics that changes in noise levels of 2 dBA or less are undetectable to the human ear and therefore negligible.

11.3 Airborne Noise Assessment – Ancillary Facilities

Three feeder stations are proposed for the power supply to the CRR tunnel section. The feeder stations are proposed to have buildings enclosures of all components, based on the recently completed Roma Street feeder station. Assuming a 20 dBA facade reduction for the enclosures, all three feeder station are predicted to comply with the project noise goals.

Train noise break-out through the Southern Ventilation Shaft from trains operating within the tunnel is not expected to exceed the noise goals and is expected to be less than existing car passby noise levels from Fairfield Road.

At the proposed CRR underground train stations, appropriate noise mitigation measures are likely to be required for some station mechanical plant and ventilation shafts in order to comply with the project noise goals. Mitigation measures that may need to be considered at some locations include appropriate equipment selection, in-duct attenuators, noise barriers, acoustic enclosures and the strategic positioning of critical plant away from sensitive receivers.

11.4 Airborne Noise Assessment – Traffic Noise

Associated with CRR is the realignment of four road sections adjacent to the southern railway corridor (rail section 1000). The realignment occurs at Dollis Street near Salisbury Railway Station, at Heaton Street and Fairlie Terrace at the Beaudesert Road overpass, at the Fairfield Road entry ramp to Ipswich Road and at Wilkie Street East of Yeerongpilly Railway Station.

Predicted road traffic noise levels for the 10 years after opening (Year 2031) as a result of the realignment of the roads comply with design goals set in accordance with the DTMR's Code of Practice.

12 REFERENCES

AS 1055.1, 1997, Acoustics – Description and measurement of environmental noise.

AS/NZS 2107, 2000, Recommended Design Sound Levels and Reverberation Times for Building Interiors.

AS 2374.6, 1994, Power Transformers – Part 6; Determination of transformer and reactor sound levels.

AS 2436, 1981, Guide to Noise Control on Construction, Maintenance and Demolition Sites.

AS 2670.2, 1990, Evaluation of Human Exposure to Whole Body Vibration - Part 2: Continuous and Shock Induced Vibration in Buildings (1 Hz to 80 Hz).

American Public Transit Association, 1981, Guidelines for Design of Rapid Transit Systems

Association of Noise Consultants (ANC Guidelines), 2001, Measurement and Assessment of Ground-Borne Noise & Vibration, Fresco.

BS 6472, 1992, Evaluation of Human Exposure Vibration in Buildings (1 Hz to 80 Hz).

BS 7385 Part 2, 1993, Evaluation and Measurement for Vibration in Buildings Part 2.

Department of Environmental Resources Management, EcoAccess Guideline, Planning for Noise Control.

Department of Transport and Main Roads, 2009, Technical Standard MRTS51

Federal Transit Administration, 2006, Transit Noise and Vibration Impact Assessment.

German Standard DIN 4150 Part 2, 1975,

ISO 14837-1, 2005 Mechanical Vibration - Ground-borne Noise and Vibration Arising from Rail Systems - Part 1: General Guidance.

ISO 3095, 2005, Railway Applications - Acoustics - Measurement of noise emitted by railbound vehicles.

JEOL, Technical Information JEM-1400 Installation Room Environmental Requirements (TI-06058EM016)

NSW Department of Environment, Climate Change and Water, 2007, Interim Guideline for the Assessment of Noise from Rail Infrastructure Projects.

NSW Department of Environment, Climate Change and Water, 2006, Assessing Vibration: A Technical Guideline.

Nelson, J, 1987, Transportation Noise Reference Book, Butterworth.

Wolfgang Probst, March-April 2010, Noise Control Eng. J.58 (2), Prediction of sound radiated from tunnel openings.

Transport Infrastructure Development Corporation, 2007, Construction Noise Strategy (Rail Projects).

Ungar, Sturtz & Amick, 1990, Vibration Control Design of High Technology Facilities, Journal of S & V.

13 CLOSURE

This report has been prepared by SLR Consulting with all reasonable skill, care and diligence, and taking account of the manpower and resources devoted to it by agreement with the client. Information reported herein is based on the interpretation of data collected and has been accepted in good faith as being accurate and valid.

This report is for the exclusive use of SKM-Aurecon CRR Joint Venture; no warranties or guarantees are expressed or should be inferred by any third parties. This report may not be relied upon by other parties without written consent from SLR Consulting.

SLR Consulting disclaims any responsibility to the client and others in respect of any matters outside the agreed scope of the work.