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Source Noise Control to Mitigate Airborne Noise at High Rise Developments - Epping to Chatswood Rail Link

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ABSTRACT

The Epping to Chatswood Rail Link (ECRL) commenced operating in 2009. At the Chatswood end of the project, the railway corridor contains two existing tracks (with conventional ballast and sleeper design) and two new concrete slab tracks, the design of which incorporates sections of low stiffness rail fasteners and floating slab track. During commissioning, noise measurements were undertaken at the upper floors of two high rise buildings which overlook the railway corridor. Noise from the new ECRL tracks was found to include prominent tones which added to the subjective loudness of train passbys and were approximately 5 dBA higher than the existing tracks. The noise controls incorporated into the final mitigation package included additional rail grinding and the installation of rail dampers and acoustic panels. Computer noise modelling and a simplified cost-benefit analysis approach were adopted to optimise the mitigation measures. This paper discusses the noise benefits associated with each mitigation measure and provides a comparison between the predicted and measured noise level reductions.

INTRODUCTION

This paper addresses airborne noise from electric passenger trains in the section of track between Railway St and William St in Chatswood North. A photograph of the study area as viewed from an upper floor of one of the nearby buildings (looking north) is provided in Figure 1.

Prior to construction of the Epping to Chatswood Rail Link (ECRL), the existing railway corridor contained two tracks with a conventional track form design comprising ballast and timber sleepers. As part of the ECRL project, two additional tracks were constructed in the centre of the railway corridor. The new tracks are initially located at the same vertical height as the existing tracks (in the foreground of the picture), and gradually become lower in height compared to the existing tracks, as trains travel down a dive structure before entering the main ECRL tunnels (towards the top of the photo).

Unlike the existing ballasted tracks, the ECRL track design comprises concrete slab track, consistent with the track form constructed within the main ECRL tunnels. The as-built design includes sections of continuous concrete slab track with low stiffness Delkor Egg rail fasteners, and sections of floating slab track (FST) with moderate stiffness Delkor Alt 1 rail fasteners.

During the environmental assessment and preliminary design stage of the project (1999 to 2002), the nearest residential receivers were located in buildings up to three levels high. These existing receivers can be seen in the top two-thirds of the photo. At this stage of the project, it was proposed to construct the new surface tracks with a conventional ballast and concrete sleeper design (ie similar to the existing tracks).

Figure 1. Study area in Chatswood North as viewed from balcony of high rise residential building

During the ECRL construction period (2003 to 2008), several high-rise residential buildings were constructed in the vicinity of the project area including the two residential buildings discussed in this paper. The above photo was taken from an upper floor of one of the new buildings that was not originally considered at the outset of the ECRL project.

When train operations commenced on the new ECRL tracks in 2009, a small number of complaints were received from residents in relation increased railway noise within the study area. These complaints related to a perceived increase in noise levels from trains operating on the new ECRL tracks compared with the existing tracks. Nearby receivers also reported that the character of the noise emissions from trains operating on the new tracks was different and of an intrusive nature.

An initial noise investigation was undertaken by the railway operator (RailCorp) to assist in understanding the nature of the complaints. Detailed measurements were subsequently undertaken by Heggies Pty Ltd (on behalf of Transport Infrastructure Development Corporation - the proponent), to investigate the source of the noise emissions more fully and determine the extent of potential mitigation measures (if required).

HIGH RISE RECEIVERS

As discussed in the introduction and illustrated in Figure 1, there are a number of residential buildings adjacent to the railway corridor within the study area. For the existing low-level receivers on the eastern side of the railway corridor, the ECRL design included the construction of noise barriers in order to comply with the airborne noise objectives.

For the high rise developments that are the subject of this paper, noise barriers are not effective in attenuating noise from the railway corridor. The most cost-effective means of reducing noise levels at elevated receivers is to reduce the source noise levels at the wheel/rail interface.

A picture of the high rise receivers discussed in this report is provided in Figure 2. Location A (15th floor) and Location B (27th floor) are approximately 50 metres and 65 metres (horizontally) from the railway corridor respectively.

Figure 2. High rise receiver measurement locations

INITIAL INVESTIGATIONS & RAIL GRINDING

Initial investigations undertaken by RailCorp identified that longitudinal undulations in the rail surface (as a result of previous rail grinding) were one of the likely sources of tonal noise identified by nearby residents. Rail roughness inspections and measurements were subsequently carried out by RailCorp within the project area in order to understand the existing rail condition and how it affects operational noise.

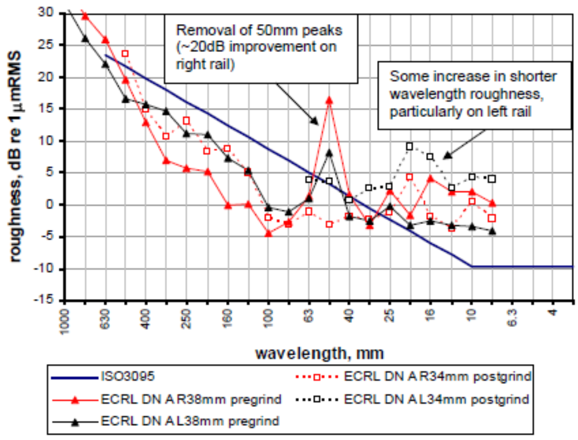
The measurements were undertaken using a Corrugation Analysis Trolley (CAT) device which comprises a trolley mounted measurement probe suitable for pushing along the rail at walking pace. The measurement data was recorded and analysed in accordance with the procedures in International Standard ISO3095:2005(E) [1].

Figure 3 provides an example of the CAT measurements undertaken at a representative location on one of the ECRL tracks. In this example, the initial measurements exhibited an increase in rail roughness levels at a wavelength of 50 mm. At the typical operational speed on this line (60 km/h to 80 km/h), this signature would be expected to cause tonal noise in the region of 330 Hz to 440 Hz.

The CAT results at other measurement locations showed evidence of various grinding signatures within the project area, and several areas with a relatively smooth rail surface (with no evidence of grinding signatures).

Initial Rail Grinding - Mini Grinder

On the basis of the initial CAT measurements and confirmation (via attended measurements) of tonal noise in the relevant frequency range, additional rail grinding was undertaken in selected locations using a so-called mini grinder. The mini grinder successfully removed the 40 to 50 mm grinding signature that was initially observed (see Figure 3).



Source: (measurement data provided by RailCorp)

Figure 3. Rail roughness levels on ECRL Down track prior to and after re-grinding with mini grinder

Attended measurements undertaken before and after the rail grinding works discussed above resulted in an overall noise reduction of approximately 2 dBA to 3 dBA at some locations. Additionally, the rail grinding successfully removed a large proportion of the tonal noise associated with the previous rail grinding signatures.

Rail Polishing

During the initial grinding works with the mini grinder, it was not possible to grind the rail at all locations within the study area. In order to reduce the rail roughness levels as far as practical, and to provide a baseline for further assessment, additional rail grinding was undertaken on the ECRL tracks using a conventional 64 stone rotating spindle grinder. This involved a rail polishing technique which included several passes at a higher than normal train speed, but removing less material from the rail during each pass.

BASELINE NOISE LEVELS AND OBSERVATIONS

Following the rail polishing works, baseline noise measurements were undertaken on the balconies of the two residential apartments identified in Figure 2. These and earlier measurements identified that noise from train operations on the new ECRL tracks were noticeably higher than the existing tracks.

Noise from trains on the ECRL tracks could also be heard for a longer time period than for trains operating on the existing tracks. The main reasons for this were the lack of sound absorption on the concrete slab tracks compared with the existing ballasted tracks, and the presence of tonal noise on the ECRL tracks.

Although the rail grinding and polishing works provided a noticeable reduction in tonal noise, a dominant spectral artefact unrelated to the rail surface condition was still present in the 315 Hz and 400 Hz 1/3 octave frequency bands. This was later determined to be a result of the ECRL track design which incorporated low stiffness rail fasteners on slab track.

In addition to elevated noise levels on the ECRL tracks and the presence of prominent tones, the overall L_{Aeq} noise levels from train operations within the railway corridor were predicted to be above the project noise objectives at the commencement of integrated timetable operations in October 2009. At Location A, the calculated $L_{Aeq(24hour)}$ noise level was 63 dBA compared with the project noise objective of 55 dBA.

On the basis of the above findings, it was considered necessary to investigate whether any additional feasible and reasonable mitigation measures could be implemented to address the following three issues:

1. Reduce tonal noise from trains operating on the ECRL tracks
2. Reduce noise levels from the ECRL tracks so that the overall noise levels from the new and existing tracks are comparable
3. Minimise the overall noise levels from the railway corridor as far as practical

POTENTIAL MITIGATION MEASURES AND ESTIMATED NOISE REDUCTIONS

Feasible and Reasonable

Whilst it is desirable to minimise noise levels as far as possible, a feasibility and reasonableness assessment is generally required to ensure that the proposed noise mitigation measures are cost effective.

In NSW Australia, guidance on implementing feasible and reasonable mitigation measures on railway projects is provided in the *Interim Guideline for the Assessment of Noise from Rail Infrastructure Projects* [2]. The selection of noise mitigation measures for this project was guided by the following principles:

- Community considerations should be taken into account as part of the feasible and reasonable assessment.
- Noise mitigation options must also be cost effective, taking into account factors such as the number of people protected, the total cost and cost variation with level of benefit provided, and the potential noise impacts.

An assessment was made of three potential mitigation measures: Rail Dampers, Additional Sound Absorption and mitigation at the Bodan Level Crossing.

Rail Dampers

When trains operate on concrete slab track (or ballasted track), vibration occurs at the wheel/rail interface as a result of the combined wheel/rail roughness and dynamic forces associated with the track/vehicle interaction. For passenger trains travelling at line speed, airborne noise is primarily radiated from the wheel and rail.

Because the ECRL track design incorporates resilient rail fasteners, the rail is less constrained (i.e. more free to vibrate) compared with stiffer rail “pad-type” fasteners commonly used on ballast track. The low stiffness rail fasteners result in lower rail vibration decay rates. This means that during a train passby, a greater length of rail is vibrating compared with stiffer rail fasteners. The longer length (and surface area) of vibrating rail – and possibly higher vibration levels - results in higher rail-related noise emission levels.

A study undertaken by Thompson [3], determined (via numerical prediction) the dependence of rolling noise on vertical rail pad stiffness. The results show that as the vertical pad stiffness of the rail fastener is decreased, the total track noise is controlled by the noise emitted by the rail. As the vertical pad stiffness increases, the total track noise is controlled by the sleeper and wheel.

In order to increase the rail vibration decay rate and therefore reduce the overall noise contribution from the rail, the installation of rail dampers on the ECRL tracks was considered. Rail dampers comprise composite steel/rubber blocks that are bolted or clipped to the sides of the rails to increase the track decay rate and to reduce the airborne noise radiated from the rail.

A 90 m section of Schrey & Veit rail dampers was tested within the main ECRL tunnels to determine the likely reduction in airborne noise levels. The testing involved a sound level meter being placed within the tunnel (outside the train) and operating a test train at a constant speed of 80 km/h past the measurement location. Measurements of the $L_{Aeq(5second)}$ noise levels were undertaken with and without the rail dampers installed on the track for the same test train and operating conditions. The testing was undertaken at a location with direct-fix rail fasteners (Delkor Egg fasteners with dynamic stiffness of 17 MN/m at 700 mm centres). This is the same track form that exists on the continuous concrete slab sections within the Chatswood Dive.

The measurement results in Figure 4 show that the rail dampers provided an overall airborne noise reduction of 4 dBA and that the attenuation was highest over the frequency range 315 Hz to 800 Hz.

On the basis of these results, and additional track decay rate measurements, it was determined that the installation of rail dampers on the ECRL tracks would provide a 4 dBA reduction in overall noise levels and eliminate the tonal noise characteristics.

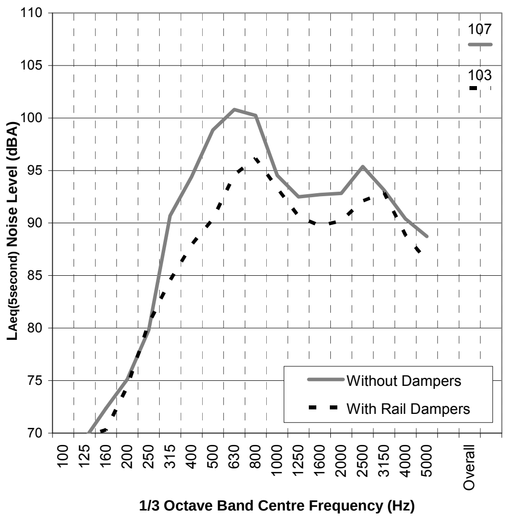


Figure 4. Airborne noise levels with and without Schrey & Veit rail dampers in ECRL tunnel for train speed of 80 km/h. Measurements on slab track with Delkor Egg rail fasteners.

Additional Sound Absorption

The ECRL dive structure contains minimal sound absorption due to the use of slab track and the acoustically reflective retaining walls. The lack of sound absorption within the ECRL dive would result in higher noise levels compared with trains operating on the conventional ballasted tracks. The United States FTA *Transit Noise and Vibration Impact Assessment* guideline [4] recommends an adjustment of +3 dBA for embedded track on grade (i.e. concrete slab track), compared with conventional ballasted track.

At various locations within the main ECRL tunnels, acoustic panels manufactured by Quietstone were placed within the four foot (between the rails) in order to reduce airborne noise levels within the tunnel. On the basis of the measured noise reductions and guidance in the FTA manual [4], it was determined that the installation of Quietstone acoustic panels within the ECRL dive could reduce overall noise levels by 3 dBA.

Bodan Level Crossing

In the area of the railway corridor closest to the high rise buildings, a vehicle access ramp is provided off Wilson Street. A Bodan level crossing is situated at the bottom of the access ramp to allow hi-rail maintenance vehicles to access the railway corridor. The design of the crossing includes acoustically reflective concrete panels which results in an approximate 3 dBA increase in source noise levels compared with conventional ballast track.

As the Bodan level crossing is located close to the high rise buildings, this section of track has a significant influence on the overall noise levels experienced at nearby receivers.

Several options were considered for replacing and/or upgrading the level crossing to reduce the source noise levels from this section of track. All of these options were deemed not to be feasible and reasonable on the basis of reliability, cost effectiveness or operational constraints.

ASSESSMENT OF MITIGATION OPTIONS

Development of Noise Mitigation Options

In order to assist in determining the extent and cost effectiveness of the mitigation options discussed in the previous section (i.e. rail dampers and additional sound absorption), 10 mitigation scenarios (A to J) were developed in consultation with RailCorp and Transport Infrastructure Development Corporation (refer Table 1).

For rail dampers, two scenarios were considered. The first scenario included the installation of rail dampers on the section of track closest to the high rise developments for a distance of approximately 100 m. The second scenario included the installation of rail dampers over the full extent of concrete slab track up to the tunnel portals (approximately 300 m). The second scenario provided the additional benefit of ensuring that tonal noise would not be audible at sensitive receivers.

For the additional sound absorption, two placement scenarios were evaluated. The four foot is the area between the two rails (on each track). The six foot is the area between the two ECRL tracks.

Table 1. Noise Mitigation Options A to J

Option	Dampers (100m)	Dampers (300m)	6’ Absorption (100m)	6’ absorption (300m)	4’ Absorption (100m)	4’ Absorption (300m)
A	√					
B	√	√				
C	√		√			
D	√	√	√			
E	√		√		√	
F	√	√	√		√	
G	√		√	√		
H	√	√	√	√		
I	√		√	√	√	√
J	√	√	√	√	√	√

Computer Noise Modelling

The Nordic Rail Traffic Noise Prediction Method (Kilde Rep. 130) as implemented by SoundPLAN Version 6.5 [5] was used to calculate the airborne noise from train operations and calculate the noise benefit provided by each mitigation option.

Each track within the project area was broken down into segments with a source noise level defined for each on the basis of the track design. For the Bodan level crossing section, a correction of +3 dBA was applied to the source noise levels. For sections of track with Delkor Egg rail fasteners, a correction of +3 dBA was applied for concrete slab track, plus an additional correction of +4 dBA due to the increased rail radiation. For floating slab track sections, a correction of +3 dBA was applied for concrete slab track, plus an additional correction of +1.5 dBA due to the increased rail radiation (stiffer rail fasteners on floating slab track results in lower rail radiated noise emissions).

A validation of the computer noise model was undertaken by comparing the measured noise levels at the two high rise receiver locations with the computer noise modelling results. At Location A, the measured noise levels were 1 dBA higher than the modelling results. At Location B, the measured noise levels were 2 dBA higher than the modelling results.

A sample output from the computer noise modelling is provided in Figure 5.

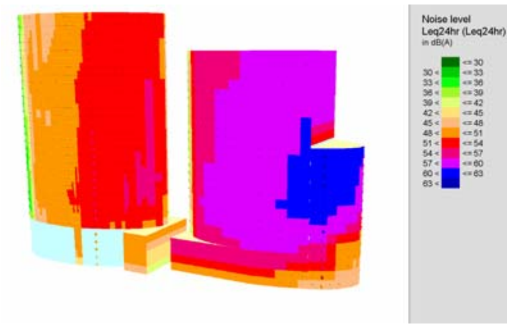


Figure 5. Sample computer noise modelling results at high rise residential buildings.

Simplified Cost-Benefit Analysis

A simplified cost-benefit analysis was undertaken to evaluate the relative cost-benefit performance of the various mitigation options presented in Table 1. The methodology described below is similar to that applied by Heggies as part of the RAC Noise Pollution Reduction Program [6] and Rail Clearways Program [7].

1. Determine noise levels at all existing receivers in the vicinity of the project area where the L_{Amax} and/or $L_{Aeq(24hour)}$ noise levels are above 80 dBA and 55 dBA respectively. These calculations are undertaken without mitigation and form the base case for comparative options. In the case of the high rise buildings, each apartment is assigned its own separate calculation point so as to accurately evaluate the number of receivers receiving a noise benefit from the proposed mitigation measure.
2. For each noise mitigation scenario, the computer noise model is run and the noise levels at each receiver location calculated.
3. For each mitigation scenario, the overall noise reduction (compared with the base case) is determined to provide the overall noise benefit. This is evaluated for the L_{Amax} and $L_{Aeq(24hour)}$ noise parameters. A noise benefit is only calculated when the overall L_{Amax} and/or $L_{Aeq(24hour)}$ noise levels are above 80 dBA and 55 dBA respectively.
4. For each mitigation scenario, the total cost of the mitigation measures is calculated. This calculation enables the total noise reduction to be plotted against the Cost/dBA and/or the Total Cost in order to compare options. The mitigation option which provides the lowest cost per dBA noise reduction is the most cost effective. The overall cost of the mitigation measures is also important.
5. It is also necessary for each mitigation option to quantify the overall noise reduction at representative receiver locations. Mitigation measures should aim to provide a minimum noise reduction of 3 dBA, representing a noticeable change.

Figure 6 provides a summary of the Total Noise Reduction (dBA) versus the Total Cost for each mitigation option.

In Figure 6, the most cost effective options in terms of $/dBA Noise Reduction and Total Cost are Options A, C, E, G and I (these options are circled in Figure 6). All of these options are based on the mitigation scenarios which incorporate rail dampers for the nearest 100 m section of concrete slab track closest to the high rise buildings.

For all of these options however, the attended measurement results indicated that tonal noise was likely to remain audible at the elevated receiver locations in the high rise buildings, and would therefore not fully address the *community considerations* aspect discussed in the feasible and reasonable section.

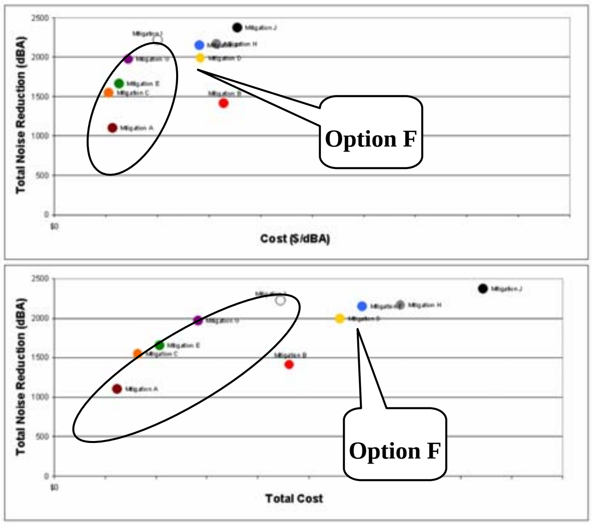


Figure 6. Total Noise Reduction versus Cost for each noise mitigation option.

For the remaining options, Option F is preferred in terms of the $/dBA Noise Reduction and Total Cost. Option F includes the installation of rail dampers on all sections of concrete slab track through to the ECRL tunnel portals and acoustic panels placed within the four foot and six foot for the first 100 m of concrete slab track. This option was subsequently adopted and the proposed mitigation measures installed (refer Figure 7).

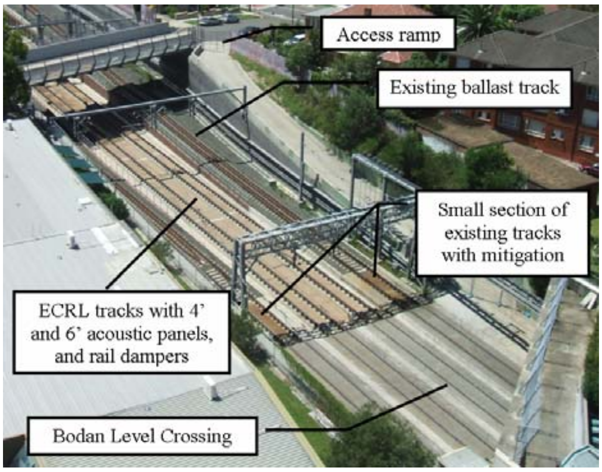


Figure 7. Railway corridor with Option F noise mitigation measures installed. Picture taken from balcony of Location A.

COMPLIANCE MEASUREMENTS

Compliance measurements were undertaken at Locations A and B in February 2010. A summary of the measured L_{Amax} and calculated $L_{Aeq(24hour)}$ noise levels before and after the installation of the proposed mitigation measures is provided in Table 2. The calculated $L_{Aeq(24hour)}$ noise levels are based on the measured Sound Exposure Levels (L_{AE}) and the number of trains in 24 hours for current train timetable operations (2010).

The L_{Amax} and $L_{Aeq(24hour)}$ noise levels on the existing North Shore Line (NSL) tracks have been reduced by approximately 1 dBA as a result of the proposed noise mitigation measures. For the ECRL tracks, the L_{Amax} noise levels have been reduced by an average of 3 dBA and the $L_{Aeq(24hour)}$ noise levels have been reduced by an average of 4 dBA.

Table 2. Measured L_{Amax} noise levels and calculated $L_{Aeq(24hour)}$ noise levels with and without proposed mitigation measures.

Receiver	Tracks	Average L_{Amax} Noise Level (dBA)		$L_{Aeq(24hour)}$ Noise Level (dBA)	
		Before	After	Before	After
A	NSL	73	72	57	56
	ECRL	75	73	61	57
	Total	74	73	63	59
B	NSL	65	64	50	49
	ECRL	70	66	53	49
	Total	68	65	55	52

The measured L_{Amax} noise level reductions were marginally lower than predicted by the computer noise modelling, and the measured $L_{Aeq(24hour)}$ noise level reductions were marginally higher than predicted.

Prior to the installation of the proposed mitigation measures, the average maximum noise levels from train operations on the ECRL tracks were approximately 5 dBA higher than the existing tracks. Afterwards, the measurement results show that the average maximum noise levels from the ECRL tracks are 1 dBA to 2 dBA higher than the existing tracks. This finding agrees with the subjective site observations which indicated that trains on the ECRL tracks sounded similar in level to the existing tracks.

Unlike the initial measurements, the time period that train passbys are audible at receiver locations within the high rise buildings are now similar for the existing and new ECRL tracks.

A summary of the measured L_{AE} noise spectra at Location B for one of the ECRL tracks is provided in Figure 8. The results illustrate the presence of the tonal noise in the 315 Hz and 400 Hz 1/3 octave frequency bands in August 2009. After installation of the proposed mitigation measures, the tonal noise is no longer present. This is consistent with the subjective site observations which indicated that the character of noise from ECRL trains is no longer tonal.

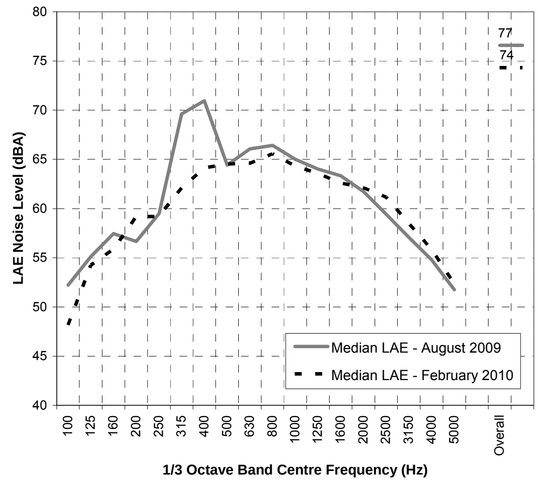


Figure 8. L_{AE} noise spectra at Location B for Up ECRL track before and after installation of mitigation measures

CONCLUSIONS

For elevated receivers in high rise developments overlooking the railway corridor at Chatswood, it was necessary to undertake a detailed investigation to reduce the source noise levels from train operations on the existing and new ECRL tracks.

In order to reduce rail roughness levels as far as practical, and to provide a baseline for further assessment, rail grinding was initially undertaken using two different methods. These works resulted in a noticeable reduction in tonal noise at some locations resulting from previous rail grinding signatures.

With the assistance of computer noise modelling and a simplified cost-benefit analysis technique, a noise mitigation package incorporating a combination of rail dampers and acoustic panels were installed to address the following three issues:

1. Reduce tonal noise from trains operating on the ECRL tracks
2. Reduce noise levels from the ECRL tracks so that the overall noise levels from the new and existing tracks are comparable
3. Minimise the overall noise levels from the railway corridor as far as practical

Compliance measurements undertaken in February 2010 confirmed that the above objectives were achieved with the proposed mitigation measures.

ACKNOWLEDGEMENTS

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