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Acoustic rail grinding – measures of long term effectiveness: Epping to Chatswood Rail Link case study

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ABSTRACT

The Epping to Chatswood Rail Link (ECRL) commenced operation in February 2009 with approximately 11.1 million gross tonnes of electric multiple unit rolling stock using each of the two tunnels annually. However, during acceptance testing of the ECRL an in-car noise issue was identified which required a reduction of approximately 12 dB. An acoustic rail grinding strategy was then developed and implemented. Grinding on the Sydney rail network has typically been conducted at passby speeds of 10 km/h that leave a longitudinal signature on the rail head with a wavelength of approximately 40 mm, and this in turn leads to tonal noise at approximately 450 Hz. In comparison, the ECRL grinding strategy saw higher speed grinding passbys of 25-30 km/h, with finer stones. This shifted the wavelength of the grinding signature to approximately 100-150 mm and reduced the tonal peaks in the roughness spectrum. This strategy contributed 3 to 4 dB of the overall noise reduction in a cost and time effective manner allowing the ECRL to commence revenue operations. This paper assesses the sustainability and maintainability of this acoustic grinding strategy, and compares the roughness of the freshly ground track to the roughness after approximately five and a half years of operation (shortly before the next scheduled rail grind).

Keywords: Railway, Wheel-Rail Interface, Grinding, Acoustic Roughness
I-INCE Classification of Subjects Number(s): 11.7.2, 13.4.2, 52.4

1. INTRODUCTION

The Epping to Chatswood Rail Link (ECRL) is a 13 km commuter rail line in Sydney's north, connecting the Northern line at Epping to the North Shore line at Chatswood as shown in Figure 1. The ECRL is completely underground in two tunnels, one for each direction of travel, and has three stations between Epping and Chatswood. Rollingstock is limited to the Sydney metropolitan double deck electric multiple units, with an average of 11.1 million gross tonnes (MGT) traversing the ECRL in each direction per calendar year.

During the acceptance testing in 2008, excessive in-car noise was identified. A reduction of 12 dB for in-car noise was required prior to commissioning due to concerns about the impact of noise exposure levels of crew and passengers, as was also reported by the Sydney Morning Herald and the Australian Broadcasting Corporation (1, 2).

Investigations were carried out by a taskforce comprising a number of key stakeholders, who identified a suite of noise mitigation measures to reduce in-car noise levels. The mitigation program applied a systems approach to determine causes and establish a control and implementation plan as discussed by Anderson & Coker, 2010 (3). The identified mitigation measures consisted of rail damping, rigid absorptive blocks glued into the four foot, additional noise insulation around the tunnel walls and a program of acoustic rail grinding as outlined by references (3, 4).

The ECRL began limited operation in February 2009 with a shuttle service and fully integrated service in October the same year. The shuttle service was used to allow the tunnel to become

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operational whilst the in-car noise issue was addressed and the mitigation measures were implemented.

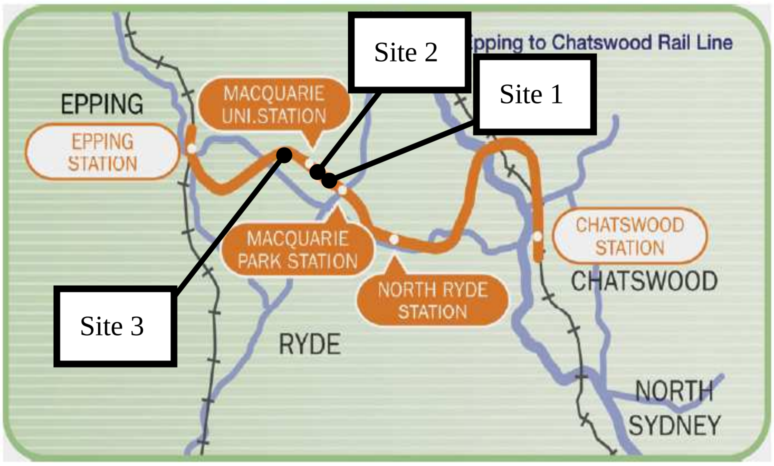

Figure 1: ECRL Map (3)

This paper reviews the long term effectiveness of the ECRL acoustic grinding program in maintaining low acoustic rail roughness levels, when compared to other locations around the Sydney metropolitan rail network where standard grinding techniques (5) have been used on various track structures with mixed traffic. The ISO 3095:2005 (6) rail roughness curve for noise measurements was relevant at the time of the original measurements in 2008 and has been used as the primary roughness reference data set throughout this work. The recently updated ISO 3095:2013 (7) rail roughness curve is also provided as a reference roughness data set.

2. RAIL GRINDING

2.1 Methodology

The normal network maintenance grinding program uses a 64 stone 'Rail Rectifier' grinding train for mainline grinding which operates at approximately 10-12 km/h. This process gives rise to a residual Grinding Induced Corrugation (GIC) with a wavelength of approximately 40 mm, resulting in a tonal noise at a frequency of around 450 Hz (4) at 80 km/h rolling stock speeds. This GIC was identified as a contributing factor to the in-car noise issue for the ECRL. Therefore one of the key objectives was to reduce the GIC, which would reduce overall noise as well as tonal noise at the corresponding frequency.

An acoustic grinding method was developed to address the GIC following a period of research and development. Field trials of different grinding techniques were undertaken at a number of locations around the network and inside the tunnels, which then led to the creation of a High Speed Grinding Strategy for ECRL. The grinding requirements outlined in maintenance manual TMC 103 section C6-5 (8), were as follows:

- Minimum of four polish passes at 25-30 km/h;
- Sections between stations and / or crossovers to be ground continuously;
- Resultant amplitude of rail roughness in wavelengths under 100 mm should be no more than 5 dB re 1 micron (μm), and preferably less than 0 dB re 1 μm;
- An assessment of the roughness of at least one 20 m section of each rail after polishing passes to gauge compliance; and
- Measurement of rail roughness after several days of normal operation should be undertaken to assess final compliance.

The aim of the strategy was to shift tonal peaks in the noise spectrum from the sensitive hearing range of 400-4000 Hz into a less disruptive, lower frequency range. Typical rail acoustic roughness has greater amplitudes at longer wavelengths than at shorter wavelengths, so by shifting the wavelength of the GIC to longer wavelengths the grinding-induced noise becomes masked by the “background” roughness. The higher polishing speeds correspond to an approximate GIC wavelength of 150 mm which corresponds to noise emissions at 150 Hz for 80 km/h rolling stock speeds, which is considered to be in the lower frequency range.

2.2 Timing

An initial standard grind for ECRL was carried out in the first half of 2008, followed by an acoustic grind in November 2008.

Recent grinding undertaken during May 2014 was triggered by the gross annual tonnage passing over the line in compliance the requirements of ESC 100 - Civil Technical Maintenance Plan (9) that mandates grinding intervention periods. The requirement to grind was not initiated as a consequence of defect population or characteristics.

3. STUDY METHODOLOGY

3.1 Rail roughness measurements and analysis

Rail roughness data was collected using RailMeasurement’s Corrugation Analysis Trolley (CAT). The first set of CAT measurements was carried out in June 2008 after standard grinding of the ECRL as outlined by Anderson, D. 2008 (10). The same procedure was used for subsequent CAT measurements in November 2008 and May 2014. The recent measurements were undertaken at similar locations to the original measurements, and a section of Floating Slab Track not previously measured was also added. At each location, measurements were taken over 100 m lengths on both the rails of the Down track. The measurement methods were consistent with CEN/TR 15874:2009 (11).

Measurements in November 2008 were carried out immediately after grinding of relatively new rail so there was no identified running band / contact patch observed on the head of the rail. The lateral probe position of the CAT was set based on an estimate of where the running band would be expected to sit. However for the 2014 measurements, the running band was identifiable and easily distinguished from the head of the rail, therefore the lateral positions of the CAT measurement probe are slightly different between the 2008 and 2014 measurements. For clarity, most figures presented in Section 4 provide results only for one probe position on each rail. Measurements in 2008 and 2014 were taken at multiple lines (probe positions) as described in Table 1. The roughness measured along different lines for each rail was generally consistent, with minor variations between lines across the rail head in the expected range of variation for roughness measurements.

Analysis of all collected data was completed using the same version of the RailMeasurement's CAT analysis software, exported to Microsoft Excel for comparison to other locations and probe positions and the ISO 3095:2005 and 2013 roughness levels.

The data was also compared to roughness measurements from other locations around the Sydney network that included an example of severe corrugation in the Sydney underground, the ECRL after standard rail grinding, and standard ballasted track on the Main North Line at Rhodes.

3.2 Locations and track structures

The rail roughness measurements were carried out at three sites that represented three different types of track present within the ECRL tunnels. Table 1 outlines the locations and detail of the areas of track, and the lines of roughness measured at each site. Figure 2 shows the two types of track structure present.

Table 1 – ECRL tunnel Down track details and roughness measurement lines

Chainage (km)	Track structure	Curvature Radius	Gradient	Distance from Gauge Face 2008 (mm)	Distance from Gauge Face 2014 (mm)
Site 1 20.000-20.100	Direct Fixation Fastener Delkor Sydney Egg baseplates with rail dampers	-	1:699 Falling	L: 28, 34, 40 R: 28, 34, 40	L: 32, 37 R: 32, 37
Site 2 20.640-20.740	Floating Slab Track Delkor Alt. 1 baseplates no rail dampers	-	Level	N/A	L: 32, 37 R: 32, 37
Site 3 21.900-22.000	Direct Fixation Fastener Delkor Sydney Egg baseplates with rail dampers	860 m	1:227 Rising	L: 34, 40 R: 34, 40	L: 28, 38 R: 28, 38

Note: L – Left (Down) rail, R – Right (Up) rail

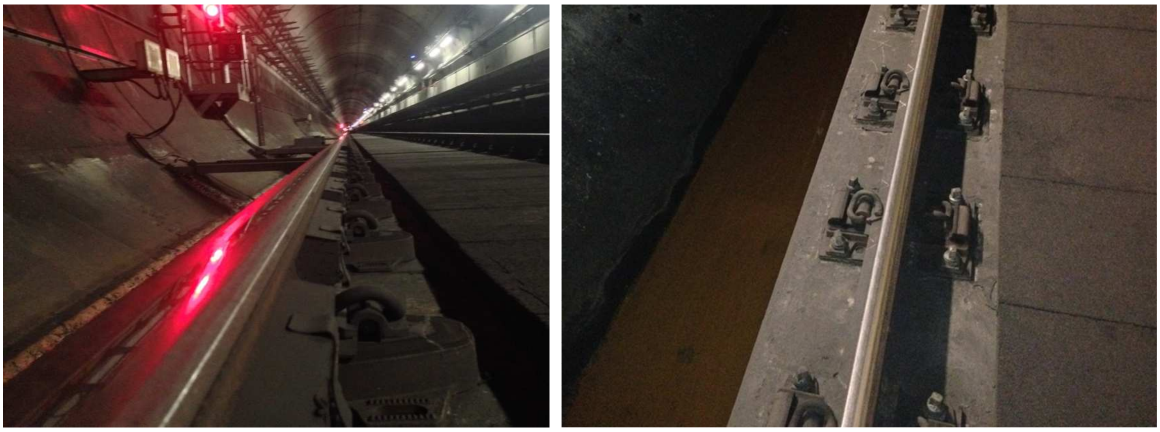

Figure 2 – Left - Direct Fixation Fastener via Delkor Sydney Egg baseplates with rail dampers; Right - Floating Slab Track via Delkor Alt. 1 baseplates without rail dampers

4. MEASUREMENT RESULTS

This section presents the measured rail roughness immediately after the implementation of acoustic grinding in November 2008 and after more than five years of rail traffic in 2014. Rail roughness measurements from other areas around the Sydney network are also presented in Figure 3 for comparison of the variation in acoustic roughness around the network, and to demonstrate the difference between the ECRL acoustic grinding and standard grinding. All of the measurements are referenced against the ISO 3095:2005 and 2013 rail roughness levels.

In comparing measurement results, it is noted that rail roughness measurements have been found to exhibit approximately a ± 2 dB variation when different measurements are taken of the same line (12). Differences in measured roughness are not necessarily significant unless the difference is greater than the measurement uncertainty of ± 2 dB.

4.1 Rail roughness around the Sydney network

Figure 3 shows four examples of rail roughness measured on the Sydney network.

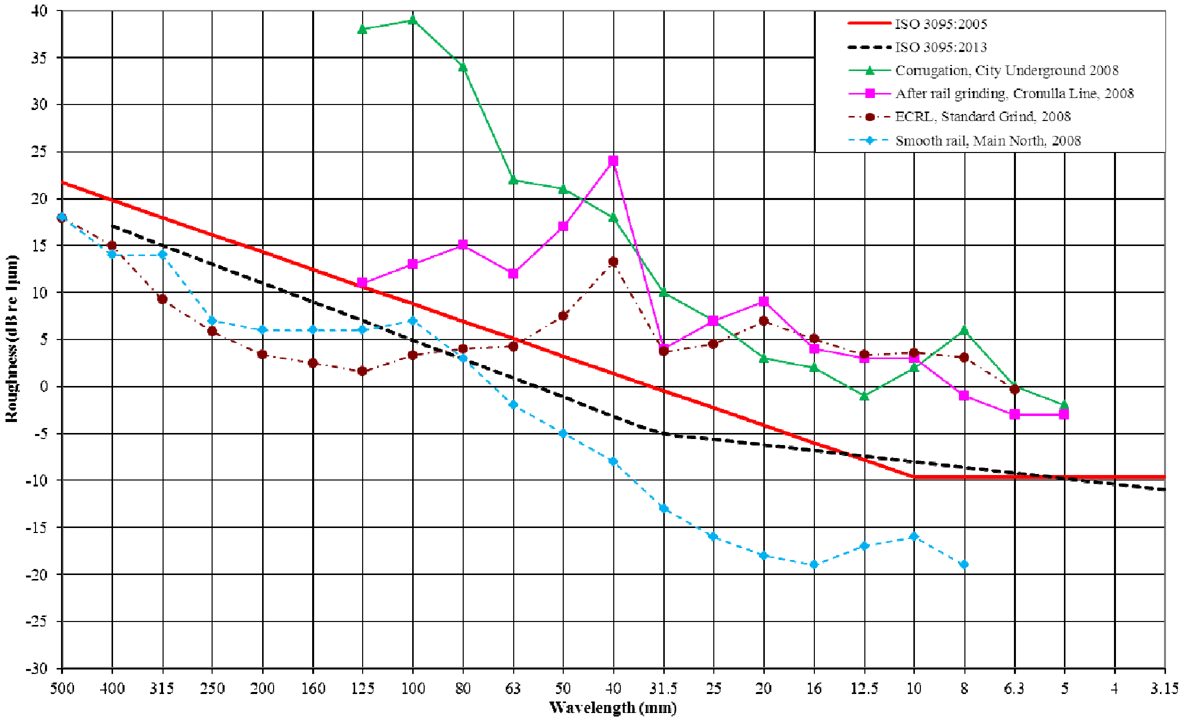

Figure 3 – Rail roughness measurements from around the Sydney network

High levels of corrugation can quickly develop in some areas of the city underground tunnels due to tight track curvatures and the dynamic characteristics of the track form in some locations. As can be seen in Figure 3, the corrugation levels observed can be significantly above the ISO 3095 recommend level of roughness.

The Cronulla and ECRL data lines in Figure 3 show the typical rail roughness following standard rail grinding, including GIC at a wavelength of approximately 40 mm. This wavelength is a direct result of the rail grinder's 10 km/h passby speed.

An example of smooth rail (roughness below the ISO 3095:2005 levels) from the Main North line at Rhodes is also shown in Figure 3. This line consists of ballasted track carrying a mixture of freight and passenger rolling stock with average traffic of 16 MGT annually. At this location, standard rail grinding was conducted around two years before the displayed roughness measurement.

4.2 Site 1 – Tangent track on resilient baseplates (20.00-20.10 km)

Rail roughness measured after acoustic grinding in 2008 was relatively broadband except for a minor peak in the 100 mm wavelength region as shown in Figure 4. This peak is attributed to GIC at the higher passby polishing speed. The rail roughness was typically up to 15 dB above the ISO 3095:2005 levels for wavelengths shorter than 100 mm.

After the passage of approximately 50 MGT of rolling stock, the roughness amplitude at the 100 mm wavelength was reduced by approximately 10 dB. A minor peak in the 2014 roughness spectra is evident in the 50-63 mm wavelength region. The rail roughness in 2014 was typically below the ISO 3095:2005 levels and was consistent between the left and right rails on this section of tangent track.

Roughness wavelengths up to 100 mm in length were observed to decrease over time between 2008 and 2014. When measurement uncertainty is considered, no clear trend in roughness development over time can be identified at wavelengths longer than 100 mm.

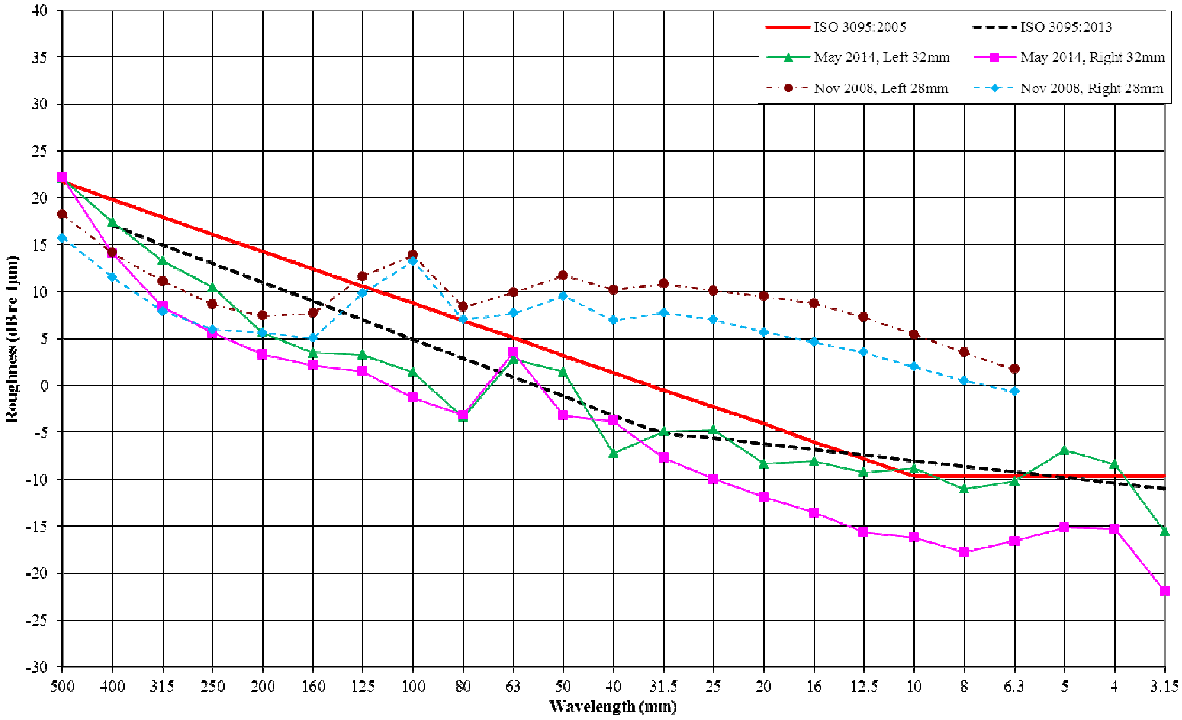

Figure 4 – Rail roughness on tangent track, resilient baseplates with rail dampers at Site 1

4.3 Site 2 – Tangent track with floating slab (20.64-20.74 km)

Measurements were not taken at this location after the initial acoustic rail grind in November 2008. However since the same grinding method was used throughout the ECRL, it is likely and assumed that the starting roughness at this site was similar to the initial roughness at the other two sites. In particular, the test section at Site 2 is in the same section of track and was part of the continuous grind section between Macquarie University Station and the cross over at the country end of Macquarie Park Station.

Measurements carried out in 2014 after the passing of 50 MGT of rolling stock showed smooth rail with roughness generally below the ISO 3095:2005 levels except for a minor peak in rail roughness on both rails at the 125 mm wavelength as shown in Figure 5 below.

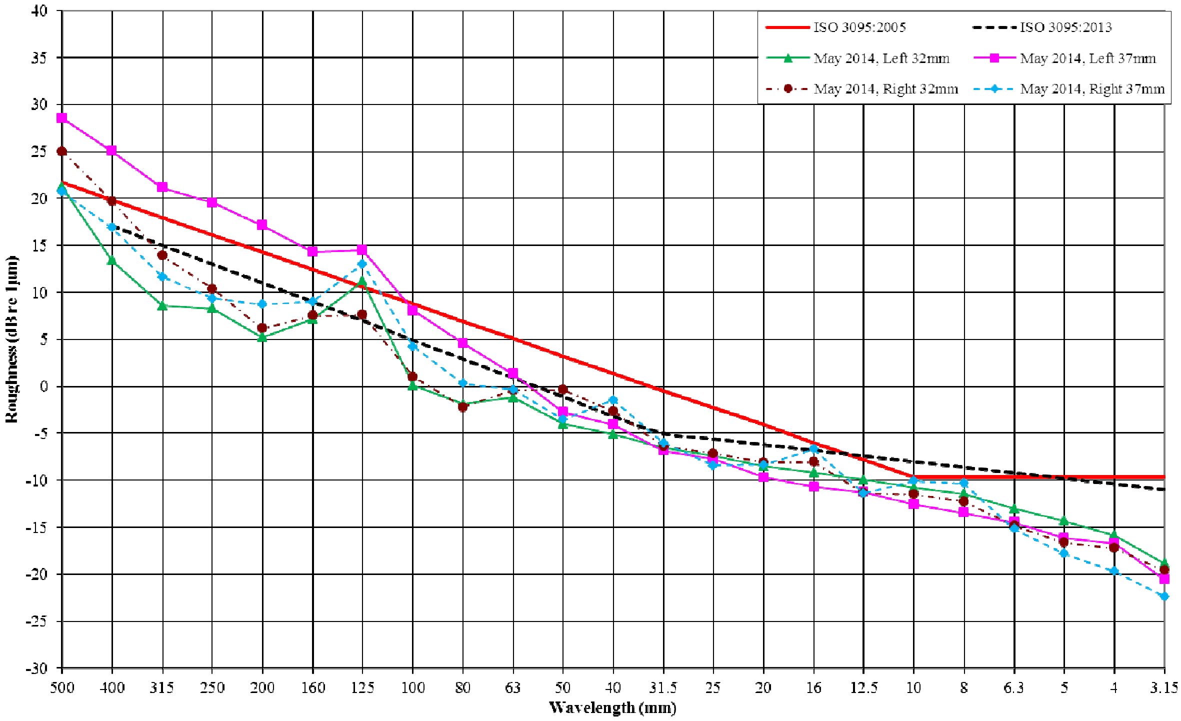

Figure 5 – Rail roughness on tangent, floating slab track with no rail dampers at Site 2

4.4 Site 3 – Curve track on resilient baseplates (21.90-22.00 km)

Figure 6 shows that after the acoustic grinding in 2008 the rail roughness was relatively broadband at this site. A minor peak in the 125 mm wavelength region is due to the GIC at the higher passby polishing speed. The rail roughness was typically up to 12 dB above the ISO 3095:2005 levels for wavelengths shorter than 80 mm.

After the passage of approximately 50 MGT of rolling stock, the rail roughness at wavelengths shorter than 80 mm was reduced by around 5-15 dB. The resultant roughness was typically below ISO 3095:2005 levels. The minor peak in roughness at 125 mm remains evident albeit at a reduced level. The roughness on the low rail (Left) and high rail (Right) are broadly similar with no clear trend of higher roughness levels present on the low rail. The curve radius at this location is relatively broad, and the tendency of the low rail to develop roughness or corrugation on a small radius curves is not evident at this location.

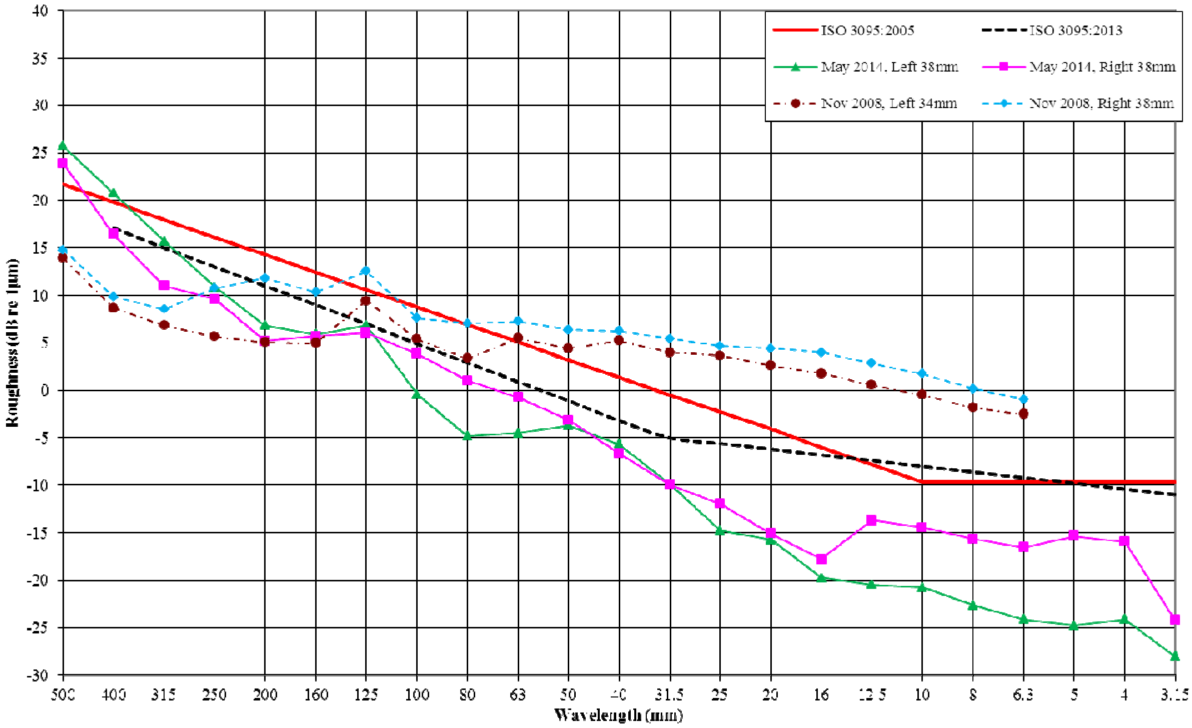

Figure 6 – Rail roughness on curve track on resilient baseplates with rail dampers at Site 3

5. DISCUSSION

The rail roughness within the ECRL after more than five years of revenue service is considered acoustically smooth, with only minor exceedances of the ISO 3095:2005 levels, and the majority of roughness data lies below the ISO 3095:2013 levels. Therefore it is considered that the acoustic rail grinding was successful in shifting GIC from around 40 mm to a longer wavelength (around 125 mm) thus reducing tonal noise at around 450 Hz.

Over time, the shifted GIC from acoustic grinding (at around 125 mm wavelengths) was observed to reduce at two of the three measurement locations, where the track form consisted of resilient baseplates with rail dampers installed.

At Site 1 (tangent track – floating slab (20.64-20.74km)), a minor peak in roughness in the 125 mm wavelength band in 2014 was observed but the reason for this is not clear. This peak could be residual GIC from the acoustic rail grinding that has not reduced over time, or a peak that has developed gradually over time, or perhaps the initial roughness starting point included a higher level of GIC than observed elsewhere.

At the other sites on track with resilient baseplates and rail dampers, the GIC around this wavelength was observed to degrade with rail wear over time. Understanding differences in roughness development at different locations and whether they may be linked to differences in track components (and track dynamics) will require further investigation and measurements over the period of the next grinding cycle, including measurement of the initial roughness at this location after grinding.

The measurements indicate that broadband roughness at wavelengths shorter than 100 mm reduced over time between 2008 and 2014, by approximately 10-15 dB. At speeds of 80 km/h, these roughness wavelengths correspond to noise in the frequency range from around 200 Hz up to 3500 Hz. Since these frequencies correspond to the dominant railway rolling noise frequencies, it is possible that overall passby noise emissions in this frequency range have also reduced over time. Any benefit would be dependent on the relative roughness of the wheels, since noise is proportional to the combined roughness of the wheel and rail in the contact patch.

Based on an analysis of the data, it can be demonstrated that the benefits of the 2008 acoustic grinding in the ECRL have been maintained over time. Moving forward, there are likely to be limited opportunities to reduce grinding as there are other maintenance requirements (e.g. to address railhead defects such as squats), however this study has demonstrated that the key objective of reducing GIC and ensuing on-train noise can be achieved by acoustic grinding in place of standard grinding.

Acoustic rail grinding was only one of the mitigation measures implemented within the ECRL to reduce on-train noise levels. Other measures included the installation of rail dampers, track bed and additional wall absorption panels as well as the progressive implementation of new fully air conditioned rolling stock since the opening of the tunnels. All of these measures in conjunction with acoustic rail grinding have reduced on-train noise levels to within appropriate sound pressures that are safe and comfortable for the travelling public.

The development of the acoustic grinding strategy in 2008, including research and implementation period, took approximately two weeks which is considered to be a relatively short time period and was created with a budget of just under 300,000 AUD. It is considered that acoustic grinding has been a cost effective measure to reduce noise for the ECRL, with the added potential to implement acoustic grinding more widely along other parts of the rail network.

Further study on this matter is recommended once the ECRL is incorporated into the North West Rail Link line (expected to commence operation by the end of 2019 13), with single deck passenger rolling stock to operate exclusively in the tunnel. Assessment of the rail roughness growth under new operating conditions would identify whether major changes in rolling stock and operations affect the rate of change of roughness, and the development of peaks at specific wavelengths.

6. CONCLUSION

This paper has reviewed the long term effectiveness of the acoustic grinding strategy to maintain low acoustic rail roughness levels in the ECRL. By using the acoustic grinding method, grinding induced corrugations were successfully shifted to a longer wavelength (from approximately 40 mm to around 125 mm), when compared to the standard grinding technique used on other parts of the Sydney metropolitan network. In addition, rail roughness at wavelengths less than 100 mm, which is important for noise generation, was also further reduced with wear from passenger service trains.

The 2008 acoustic grinding program was able to achieve an immediate reduction of 2-3 dB in overall noise and a reduction of 8-10 dB in tonal peaks at approximately 450 Hz for the 80 km/h operational rolling stock speeds within the ECRL. This benefit was realised quickly and efficiently, and the positive impacts have been observed to be long-lasting. There is also potential for benefits to be realised more widely from acoustic grinding elsewhere on the network, and it is recommended that this should be investigated further.

In conjunction with the other noise mitigation measures acoustic grinding reduced the on-train noise in the ECRL to within appropriate levels that are safe and comfortable for the crew and customers.

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