EFFECT OF RAIL GRINDING ON RAIL VIBRATION & GROUNDBORNE NOISE: RESULTS FROM CONTROLLED MEASUREMENTS

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Abstract

The Sydney Conservatorium of Music is located close to the City Circle underground rail line, and significant work has been done to reduce groundborne rail noise within the performance and rehearsal areas. This paper reports the results of measurements of groundborne noise within a number of spaces, conducted before and after a regular rail grinding treatment. Rail track vibration levels were also measured within the tunnel by Richard Heggie Associates and RailCorp, and these results are also reported. Rail grinding is found to have a significant impact on vibration and noise levels, for both curved and tangent track. The implications for the control of groundborne noise are discussed. In particular, to reduce the maximum expected noise level it will often be more cost-effective to improve the control of rail roughness rather than to incorporate direct mitigation measures in the form of track or building modifications.

Introduction

Major expansion and renovation works were undertaken at the Sydney Conservatorium of Music, commencing in 1998. The goal of the project was to produce a world class music education facility.

During the initial design stages, it was quickly realized that groundborne noise from the nearby City Circle underground rail line would have a major impact on acoustic quality. It was at this point that Wilkinson Murray was commissioned to advise suitable noise control measures to limit groundborne noise.

Construction was completed in July 2001 with noise from train passbys within acceptable levels. In 2002, comments were made by staff at the facility that noise levels from train passbys appeared to have increased since the facility opened in 2001. A study was conducted during September 2002, which confirmed that noise levels from train movements had indeed risen since opening. An increase in rail roughness resulting from corrugation was considered a possible cause of increased groundborne noise levels. As a result, rail grinding was conducted during October 2003. This paper presents results of detailed measurements conducted during this process, highlighting the effect of rail condition on groundborne noise levels.

Site Details

Figure 1 shows the design of the upgraded Conservatorium building and its relationship to the rail tracks. In response to vibration and noise problems within the old Conservatorium building complex, the inner (western) rail track had been isolated on Delkor 'Cologne Egg' track fasteners. The outer (eastern) track had not been similarly treated, and is fixed to the tunnel invert using Delkor 'Alternative 1' fasteners. The design team's recommendations on vibration and noise control, presented during the design of the redevelopment, were that the outer track should be similarly isolated. This recommendation has not yet been implemented.

As a result, groundborne noise levels from outer track movements were significantly higher than those from the inner track, even though the outer track was further away from the measurement positions. The rail grinding in October 2003 was conducted on the outer track.

Criteria for the critical performance spaces within the redevelopment, as shown in Figure 1, were set in terms of Preferred Noise Criteria (PNC) to account for the low frequency noise produced by rail movements.

Both the inner and outer tracks are curved below the Conservatorium, having curve radii of 207m and 213m respectively.

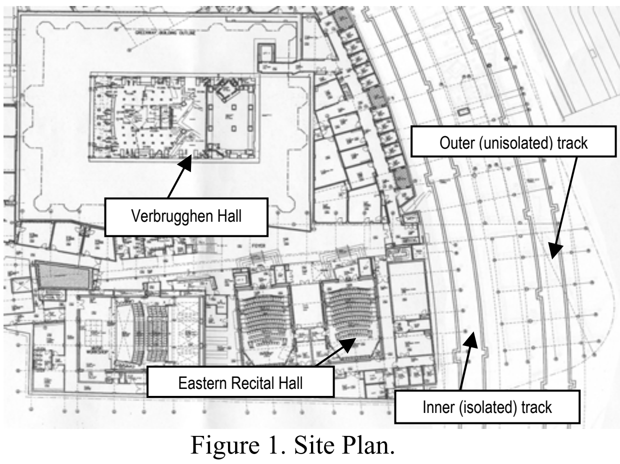

Figure 1. Site Plan.

Background

Rail corrugation is the longitudinal wear pattern formed during operation. As rail corrugations worsen, noise and vibration levels increase. This is a common problem, more likely to be found on curved track, although corrugation has been observed on tangent track. Nelson [1] discusses noise and vibration levels from rail and wheel corrugations indicating that noise and vibration levels can rise 10-15dB for severely corrugated rail or wheels. It is generally accepted that rail corrugation or worn track can increase vibration and groundborne noise levels by 10dB [2].

There appears to be no definitive agreement on the mechanisms resulting in rail and wheel corrugation. The 'stick-slip' behaviour of wheel sets due to differing path lengths as they negotiate curves is often implicated.

Currently, routine maintenance in the form of rail grinding appears to be the only method to control rail corrugation.

Measurement Locations

To evaluate the noise levels before and after rail grinding had taken place, two critical performance spaces were chosen:

the Verbrugghen Hall; and

Eastern Recital Hall

Increased groundborne noise levels had been reported in both of these spaces.

As part of the noise control measures recommended, the Eastern Recital Hall is supported by high performance spring isolators. For the analysis, a microphone was located in the centre of the Eastern Recital Hall and another in a fire stair directly below. An accelerometer was also placed in the fire stair, measuring the vertical direction.

In the Verbrugghen Hall, microphones were located near the front row of seating and in the rear aisle. An accelerometer was mounted on the southern wall as the floor was isolated on rubber pads.

Measurements of train passbys were conducted in these locations before rail grinding and approximately three weeks after grinding. The results presented are L_{eq} measured over the audible part of the train passby event (typically 8-12 seconds).

Measurement Results

Eastern Recital Hall

After rail grinding, a substantial reduction in groundborne noise levels was observed for rail movements on the outer line. Figures 2 and 3 show the 1/3rd octave levels for each measured passby before and after rail grinding for outer and inner line movements respectively.

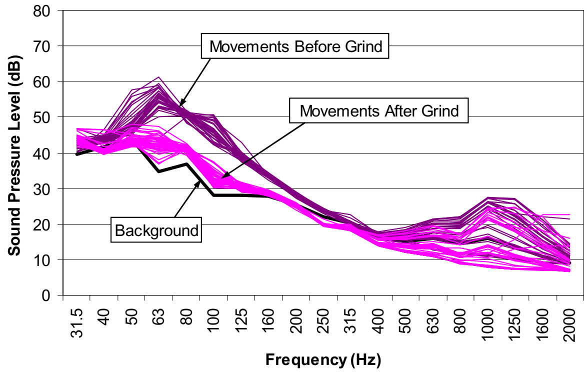

Figure 2. Eastern Recital Hall Audience Microphone (outer line movements).

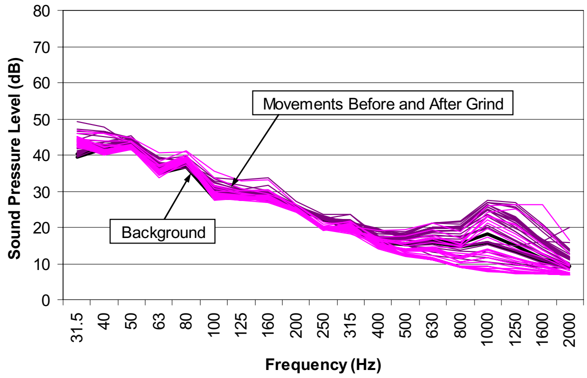

Figure 3. Eastern Recital Hall Audience Microphone (inner line movements).

As seen in Figure 2, a 10 to 15dB reduction in noise levels was observed in the 50 to 100Hz 1/3rd octave bands for outer line movements. For inner line movements Figure 3 shows little difference between noise levels before and after the rail grinding, which is expected given that no modifications were performed to this line.

Similar results are reflected in Figures 4 to 7 for the microphone and accelerometer located in the fire stair.

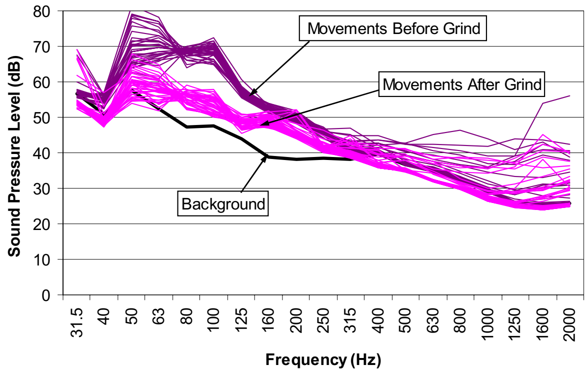

Figure 4. Eastern Recital Hall Fire Stair Microphone (outer line movements).

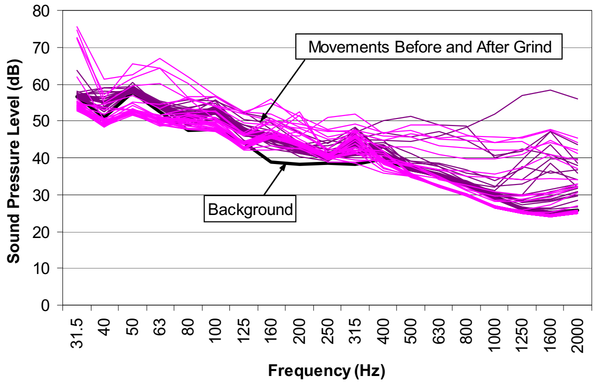

Figure 5. Eastern Recital Hall Fire Stair Microphone (inner line movements).

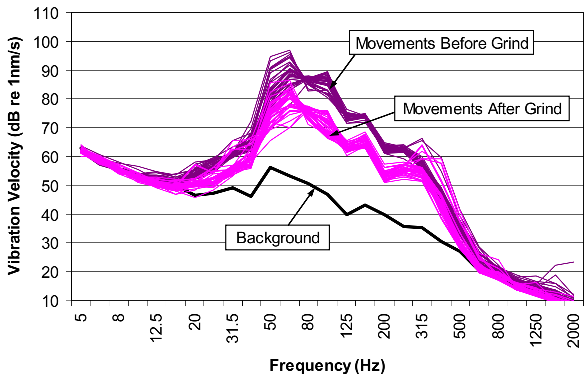

Figure 6. Eastern Recital Hall Fire Stair Accelerometer (outer line movements).

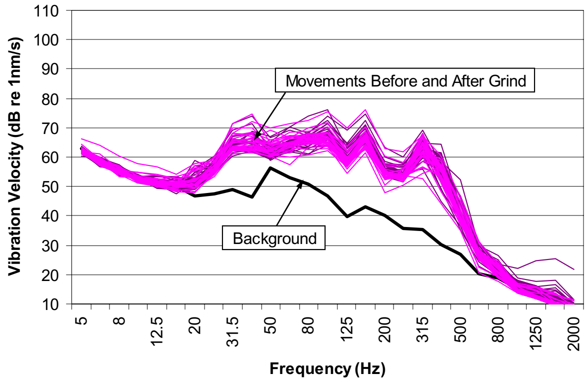

Figure 7. Eastern Recital Hall Fire Stair Accelerometer (inner line movements).

Verbrugghen Hall

Similar results were obtained in the Verbrugghen Hall. Noise levels measured at the two microphone locations were very similar and reflected similar reductions to those measured in the Eastern Recital Hall. Figures 8 to 13 show the passby results obtained in Verbrugghen Hall.

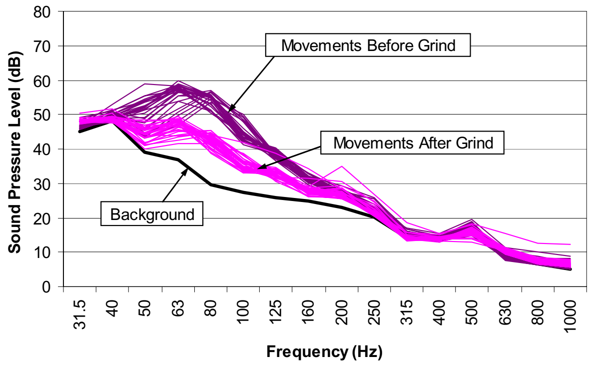

Figure 8. Verbrugghen Hall Front Row Microphone (outer line movements).

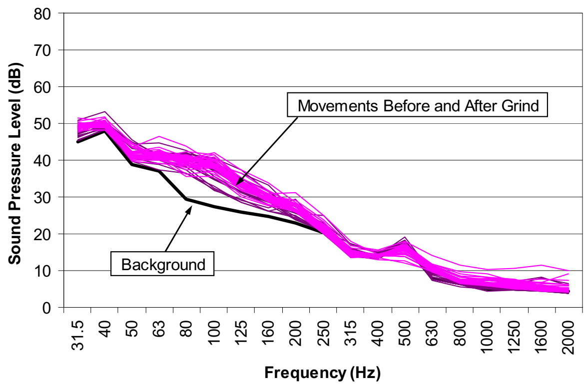

Figure 9. Verbrugghen Hall Front Row Microphone (inner line movements).

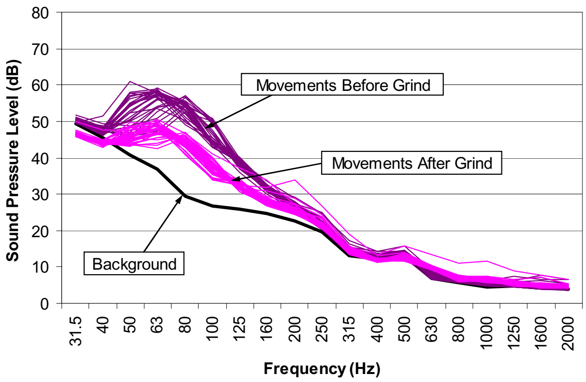

Figure 10. Verbrugghen Hall Rear Aisle Microphone (outer line movements).

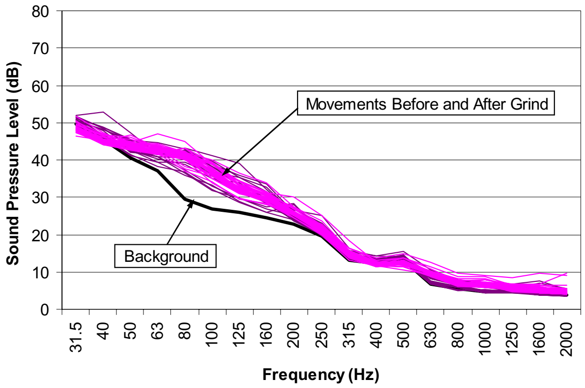

Figure 11. Verbrugghen Hall Rear Aisle Microphone (inner movements).

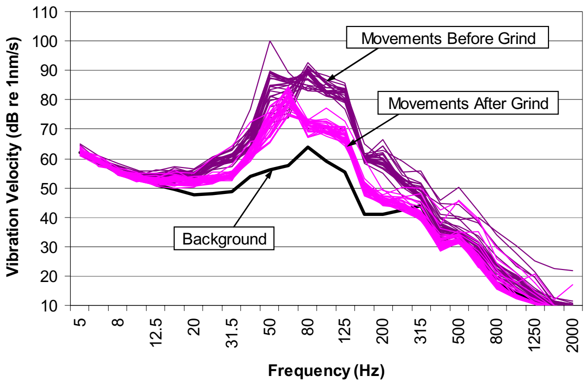

Figure 12. Verbrugghen Hall South Wall Accelerometer (outer movements).

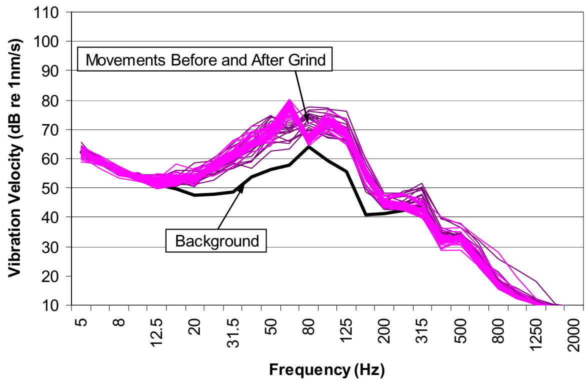

Figure 13. Verbrugghen Hall South Wall Accelerometer (inner movements).

Assessment of Noise Levels

As mentioned previously, groundborne noise from train passbys were assessed using PNC curves. The results obtained are presented in Tables 1 and 2.

Table 1. Summary of PNC levels – Eastern Recital Hall (Audience Microphone)

Before/After Grind	Track	Mean (PNC)	Range (PNC)
Before Grind	Outer	39	36-45
Before Grind	Inner	20	18-22
After Grind	Outer	23	20-29
After Grind	Inner	18	17-23

Table 2. Summary of PNC levels – Verbrugghen Hall (Front Row Microphone)

Before/After Grind	Track	Mean (PNC)	Range (PNC)
Before	Outer	41	35-44
Before	Inner	21	17-25
After	Outer	27	22-31
After	Inner	22	18-27

In the Eastern Recital Hall, noise levels produced by outer line movements were reduced from PNC 39 to PNC 23 (16dB). Movements on the inner line saw a marginal reduction (2dB). This was attributed to minor differences in the sample sets such as wheel condition, train speed, etc.

In the Verbrugghen Hall, the mean PNC for outer rail movements dropped from PNC 41 before the rail grinding to PNC 27 after the rail grinding (14dB). A minor increase from PNC 21 to PNC 22 was realized for inner movements. Once again, this was attributed to minor differences in the sample set.

Noise Level Increase with Time

Rail passby noise has been measured on three different occasions since opening in July 2001. These were compliance measurements conducted in 2001, dedicated rail noise measurements conducted September 2002 (in response to staff concerns), and the latest study of rail grinding effectiveness conducted October 2003. Unfortunately, previous measurements were not conducted with the same level of detail; however, Table 3 presents a comparison of the ranges measured during each survey. Movements on both inner and outer tracks have been included in the ranges shown.

Table 3. PNC Ranges Measured during Three Different Surveys

Location	Range (PNC)			
	2001	2002	2003 (Before Grind)	2003 (After Grind)
Eastern Recital Hall	21-28	33[1]-38	18-45	17-29
Verbrugghen Hall	16-18[2]	20-37	17-45	18-33

Notes: 1 - Lower limit may not be correct due to high background noise
2 - Upper limit may not be accurate due to small measurement sample

The noise levels measured during the three different surveys show a significant increase in maximum noise level with time.

Measurements Conducted at Rail Level

During the course of our measurements in the Conservatorium, a similar study was conducted by Richard Heggie Associates and RailCorp at rail level.

Measurements were analysed using a different method averaging the 1/3rd octave band, fast weighted L_{max} spectra. While not the same method, a comparison of the mean vibration results in the Verbrugghen Hall before and after rail grinding is presented in Figure 14.

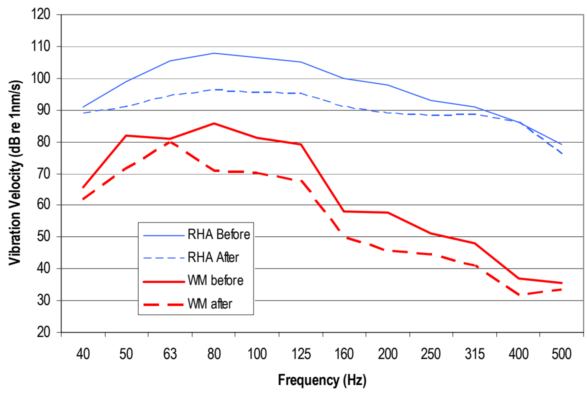

Figure 14. Comparison with Measurements by Richard Heggie Associates Before and After Rail Grinding.

Given the distance and consequent ground attenuation between the two locations, these results appear comparable. Figure 15 presents the difference in vibration level measured before and after rail grinding in the Verbrugghen Hall and the rail tunnel.

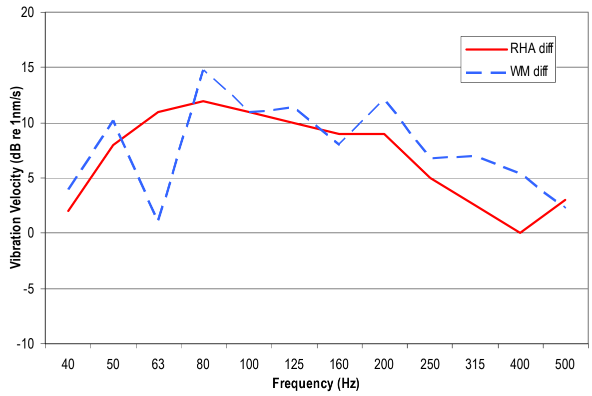

Figure 15. Reduction in Vibration Level due to Rail Grinding.

The measured difference between before and after rail grinding measurements at the two locations is similar given the differences in analysis methods, the effect of ambient vibration and local effects at the Conservatorium.

A site inspection was also conducted after rail grinding had taken place. It was noted that corrugations were still visible on the rail head, although at a reduced depth. Given this, further reduction in groundborne noise may be possible by grinding further into the rail at this location. However, overall noise levels are a factor of both wheel and rail condition. As rail roughness is significantly reduced, wheel roughness becomes the dominant factor. Therefore, the incremental improvement in overall noise level may not be as significant with further improvement in rail roughness.

Conclusion

Measurements were conducted at the Sydney Conservatorium of Music to determine the effectiveness of rail grinding of the outer City Circle line. On inspection by RailCorp and Richard Heggie Associates prior to rail grinding, rail corrugations were clearly visible.

Noise and vibration measurements taken in two of the critical performance spaces within the development indicated a 10 to 15dB reduction across the 50 to 100Hz range in both the noise and vibration spectra. Rail grinding resulted in a reduction from PNC 39 to PNC 23 in the Eastern Recital Hall, with a similar reduction observed in the Verbrugghen Hall.

When reviewing measurements conducted prior to rail grinding, noise levels from train passbys have risen significantly since opening in July 2001.

Vibration measurements conducted by RailCorp and Richard Heggie Associates at rail level confirmed these findings.

The results indicate that rail roughness is a considerable factor in groundborne noise levels from rail movements. Where groundborne noise is the limiting criterion for the overall design, rail condition should be accounted for during the design phase.

Acknowledgements

The author wishes to thank RailCorp, in particular Mr David Anderson, for their information and support during the course of this study.

References

[1] Nelson PM, “Transportation Noise Reference Book”, Butterworths, London, 17/15 1987.

[2] Harris Miller Miller & Hanson Inc, “Transit noise and vibration: Impact Assessment”. Report DOT-T-95-16 prepared fro Office of Planning, Federal Transit Authority, U.S. Department of Transportation, 1995.