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Rail Dampers – The First Australian Field Trial

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ABSTRACT

Rail damping is an emerging technology for mitigating airborne railway noise at the source. Rail dampers may be described as pre-formed or adjustable elements that are attached to the sides of the rails. These pre-formed elements improve the rail's ability to decay noise-inducing vibrations resulting from the rolling contact between the wheel and rail. The implementation of source controls such as rail dampers can potentially avoid or reduce the need to consider further mitigation options such as noise barriers and building treatments. A field trial was undertaken in cooperation with a European rail damper manufacturer in order to quantify the noise reduction on a section of standard ballast track on the NSW metropolitan rail network. The results of the field trial have highlighted the complexities of selecting and tuning a rail damper for a particular track-form and minimising airborne noise emissions at the wayside. This paper presents a description of the rail dampers (as tested), the methodologies used to evaluate the rail damper performance, outcomes of the field trial and the challenges associated with undertaking such a trial within an operational rail corridor.

INTRODUCTION

The Kingsgrove to Revesby Quadruplication (K2RQ) project forms part of the NSW Government's Rail Clearways Program which aims to develop independent rail clearways across the CityRail network [1]. The K2RQ project involves the construction of two additional tracks between Kingsgrove and Revesby, a distance of approximately 8 km.

During the Environmental Assessment (EA) stage of the project, Heggies Pty Ltd (Heggies) was commissioned by Transport Infrastructure Development Corporation (TIDC) to undertake an assessment of the potential noise and vibration impacts during construction and operations.

As part of the detailed design, TIDC (via the K2RQ Alliance) undertook a study to quantify the likely noise reduction associated with installing dampers attached to the rails between sleepers (rail dampers).

SOURCES OF RAILWAY NOISE

During a train passby, noise is emitted from several sources including the wheels, rails, sleepers and other sources on the train [2]. The overall noise level at the wayside results from the combined effect of all of theses sources.

At the typical train speeds within the K2RQ project area (50 km/h to 100 km/h), wayside noise levels are predominantly influenced by general rolling noise.

The reduction in overall noise levels at a receiver location as a result of rail dampers would therefore depend on the relative contributions of the wheels, rails and other rail vehicle related noise emissions.

RAIL DAMPERS

What are Rail Dampers?

Rail dampers may be described as pre-formed or adjustable elements that are attached to the sides of the rails. These pre-formed elements improve the rail's ability to decay noise-inducing vibrations resulting from the rolling contact between the wheel and rail.

The function of the rail dampers is to reduce the noise radiated by the rails, which can be a significant component of the overall A-weighted passby noise levels.

The rail dampers tested in this trial were designed, manufactured and supplied by Schrey & Veit GmbH (S&V). S&V are based in Germany and supplied sufficient quantity for a 90 m test section within the K2RQ project area.

The S&V rail dampers (Figure 1) are of a modular design that comprises three primary components: a rail foot damper and two web dampers (one on either side of the rail cross-section). The assembly of these components, by way of a bolted fastening system, clamps the dampers to the rail.

The rail dampers are clamped to both rails (mid sleeper) and behave as multi degree of freedom spring-mass systems. The modular design of the S&V rail dampers (i.e. a series of layered steel and elastomeric plates) allows for a particular frequency or frequencies to be targeted or tuned, depending on the design and operation of the track and rollingstock (i.e. rail pad stiffness, rail fastening / track support mechanism, type of rollingstock etc).

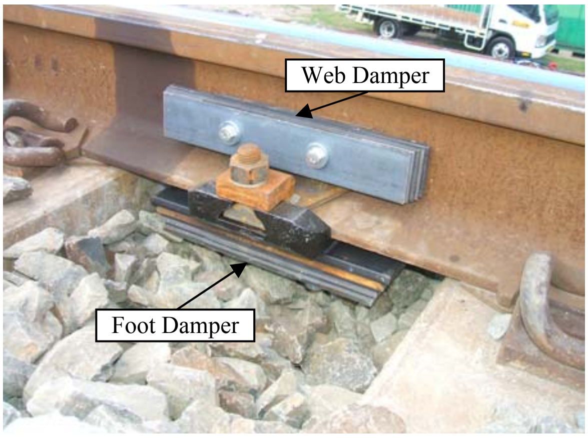

Figure 1. S&V Rail Damper

Why Trial Rail Dampers on the K2RQ Project?

The K2RQ project considered a variety of noise mitigation measures during the EA including noise barriers, building treatments etc. Rail dampers were also considered as they have the potential to be more cost-effective than noise barriers and building treatments based on measurement data documented in the literature from Europe [3, 4].

As a result, the K2RQ Alliance decided to undertake a field trial to quantify the potential noise reduction that may be achieved by the incorporation of rail dampers into the noise mitigation strategy for the K2RQ project with a view to using rail dampers as an at-source mitigation measure in lieu of or for reducing the potential extent of path and receiver controls (e.g. noise barriers and treatment of dwellings).

What are the Assessment Parameters?

In order to quantify the noise reduction provided by rail dampers on the K2RQ project, it was important to evaluate the noise benefit in terms of the project-specific noise goals.

For the K2RQ project, the operational noise assessment was undertaken in accordance with the guidance provided in the *"Interim Guideline for the Assessment of Noise from Rail Infrastructure Projects"* (IGANRIP) [5].

The noise assessment parameters relating to airborne noise are described below.

- $L_{Amax,95\%}$ The $L_{Amax\ (fast\ response)}$ noise level not exceeded by more than 5% of train passbys.
- $L_{Aeq,T}$ The L_{Aeq} noise level evaluated over the 15-hour daytime period (7.00 am to 10.00 pm), 9-hour night-time period (10.00 pm to 7.00 am) and 1-hour period.

For the purpose of evaluating the overall noise reductions from the rail dampers, the L_{AE} Sound Exposure Level (representative of the L_{Aeq}), and the Average L_{Amax} were used. As discussed later in the paper, the $L_{Amax,95\%}$ was also used, but proved to be an unreliable descriptor of the rail damper performance.

THE K2RQ RAIL DAMPER TRIAL

The Trial Site

The rail damper trial site was situated on a 90 m section of track within the K2RQ project area near Narwee. A reference (control) section was also included in the trial to allow noise levels from the same train to be compared with and without rail dampers (assuming that the train speed was maintained throughout the test area and that the rail roughness of each section of track was consistent). The site plan (Figure 2) shows the 90 m test section, the reference section and sound level meter (SLM) measurement locations.

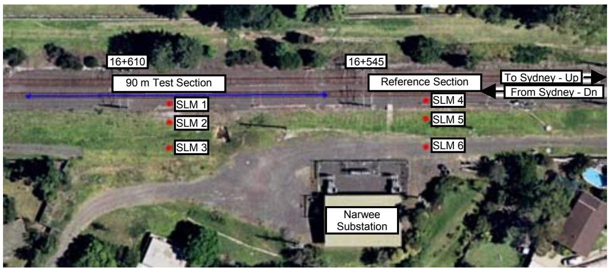

Figure 2. Site Plan

The Challenges

The measurement campaign introduced a number of challenges (not atypical for work in the rail environment):

- Undertaking the trial within a busy operational metropolitan rail corridor. (The trial had to be undertaken at a site within the K2RQ project area).
- A very tight program meant that a significant portion of work (particularly with regard to the modification and installation of the rail dampers was required to be undertaken at night).
- The track alignment at this location was not ideal from an acoustic measurement perspective in that the track was situated on an embankment up to 5 m above local ground level. This meant that the microphones had to be elevated utilising extension poles and anchored with guy wires in order to provide the necessary stability.
- A rail grinder passed through the test site midway through the measurement program which provided an additional challenge in ensuring that any changes in rail condition did not significantly affect the outcomes of the trial.

The Program

The measurement program allowed for two iterations in order to optimise the noise benefit of the rail dampers (by varying the configuration of the steel masses and elastomeric components). The general approach was to undertake a set of "before" measurements within the test section and reference location (without rail dampers) followed by two sets of "after" measurements (with rail dampers). An additional set of "before" measurements was required as a result of the rail grinding operation that occurred toward the beginning of the trial.

Work on-site occurred during daytime and night-time periods in order to complete the various acoustic measurement components (including airborne noise, track vibration, track decay rates and rail roughness), and rail damper installations and modifications. Due to the challenging timeframes, all measurements were operator attended in order to ensure that relevant parameters influencing the wayside noise levels (such as train speed, type and wheel/track defects) were recorded.

NOISE MEASUREMENTS

Noise measurements associated with Configuration 1 of the rail dampers are referred to as Stage 1 measurements. Measurements associated with Configuration 2 of the rail dampers are referred to as Stage 2 measurements.

The airborne noise measurements were undertaken at three different offset distances from the track centreline (1 m, 7.5 m and 15 m):

- Noise measurements undertaken at a distance of 1 m from the track are sufficiently close to evaluate the noise contribution from each bogie (2 axles per bogie) and identify wheels with or without audible defects. These measurements assisted in determining whether the noise reduction provided by the rail dampers was the same or different for wheels in good or poor condition. An additional advantage in undertaking noise measurements at this location was that a technical study by Verheijen and Paviaotti [6] provides a tool for separating the noise contribution from the train and the noise radiated by the track.
- Noise measurements undertaken at a distance of 7.5 m from the track centreline and 1.2 m above rail level were consistent with the requirements of International Standard ISO 3095:2005 *"Railway applications - Acoustics - Measurement of noise emitted by railbound vehicles"* [7]. This is advantageous because it allows the measurement results from the K2RQ rail damper trial to be benchmarked against comparative measurements across Europe where rail dampers have been trialled at a number of locations. It also allows for the noise contribution from the train and rail to be evaluated [6].
- Noise measurements undertaken at a distance of 15 m from the track centreline and 1.5 m above rail level were consistent with the requirements of Australian Standard AS 2377:2002 *"Acoustics—Methods for the measurement of railbound vehicle noise"* [8]. Measurements at this distance were also useful as they provide a good indication of the potential noise benefit at the nearest residential receivers within the K2RQ project area.

The setup of the microphones at the test and reference sections is provided in Figure 3 and Figure 4.

Figure 3. Test Section SLM Setup

Figure 4. Reference Section SLM Setup

NOISE MEASUREMENT RESULTS

It was concluded that the measurement results at the 15 m locations provided the most reliable information in relation to the reduction in overall A-weighted noise levels in the context of the K2RQ project and project-specific noise parameters applicable at nearby sensitive receivers (i.e. a typical worst case source to receiver offset distance is in the order of 15 m).

Figure 5 and Figure 6 provide a summary of the average 1/3 octave band L_{Amax} noise levels at the 15 m measurement locations for the Stage 1 and Stage measurements respectively. These figures illustrate that without dampers, the overall A-weighted noise level is influenced significantly by noise energy in the 400 Hz 1/3 octave frequency band. At least 20 train passby events were captured for each measurement set.

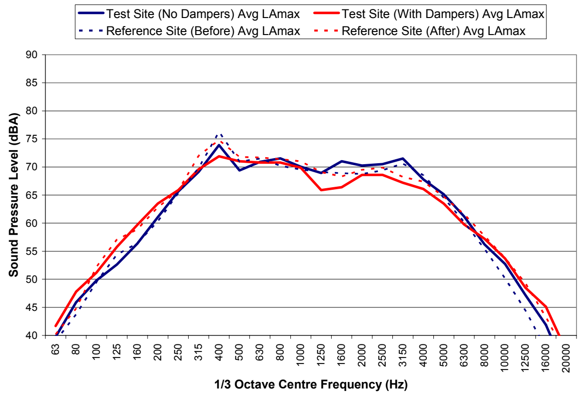

Figure 5. Average L_{Amax} Noise Levels at 15 m Measurement Locations (Stage 1)

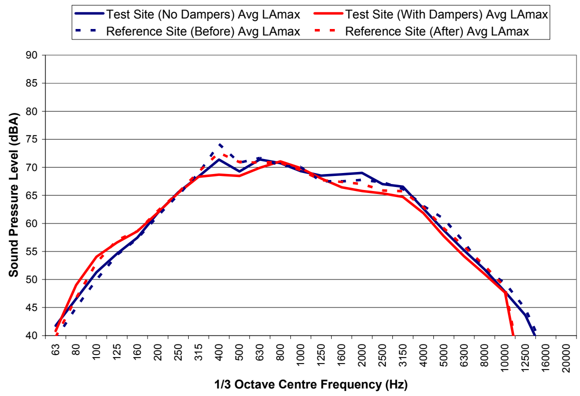

Figure 6. Average L_{Amax} Noise Levels at 15 m Measurement Locations (Stage 2)

A comparison between Figure 5 and Figure 6 shows that the measurement results are similar for the Stage 1 and Stage 2 rail damper trial in terms of spectral content however it was noted that the noise levels at both the test and reference site were slightly lower for the Stage 2 measurements.

The results indicate that the revised rail dampers forming part of the Stage 2 measurements (Figure 6 – solid red line) are providing a marginally higher level of noise reduction in the 315 Hz to 800 Hz 1/3 octave frequency bands compared with the Stage 1 rail damper configuration (Figure 5 – solid red line, noting that the noise reduction in Stage 1 occurred mostly in the 400 Hz frequency band). The noise reduction over a broader frequency range for the Stage 2 rail damper configuration was an expected improvement that resulted from the modifications to the foot and web dampers.

With reference to Figure 5 and Figure 6 it can be seen that the noise levels in the 400 Hz to 630 Hz 1/3 octave frequency bands were reduced by up to 3 dBA. This reduction translated into a reduction in overall A-weighted passby noise levels of approximately 1.1 dBA in L_{AE} and Average L_{Amax} on the basis of the as-measured noise levels (with and without rail dampers on the test section) relative to the reference (control) section of track.

DISCUSSION

The measured reduction in overall noise levels was less than expected by S&V on the basis of previous European trials where reductions in overall passby noise levels of between 2 dBA and 4 dBA have been measured [3, 4].

In order to quantify the measured noise reductions and determine the reasons for the lower than expected noise level reductions additional analyses were undertaken. These analyses included a review of:

- Rail roughness for the test and reference sections,
- The effect of wheel condition on the results,
- The effect of test track length on the results,
- The contribution of wheel noise versus rail noise,
- A review of track decay rates.

Each of these aspects is discussed in the following sections.

Rail Roughness (Effect of Track Condition)

The rail roughness was surveyed at the test and reference sections at several stages during the measurement program in order to verify that any variations in roughness did not adversely influence the outcome of the noise measurements.

The measurements were undertaken by RailCorp using a Corrugation Analysis Trolley (CAT). A CAT is a handheld device that is pushed along the rail. This device measures the rail roughness of a single rail by means of a contacting transducer.

1. An initial rail roughness survey was undertaken in order to determine a baseline rail roughness level that was benchmarked against the ISO3095 reference curve for both the test and reference sections.

2. A second rail roughness survey was undertaken in order to capture the potential changes in rail roughness through the test and reference sections after rail grinding.

3. A third rail roughness survey was undertaken in order to determine whether there had been any notable changes in rail roughness since the Stage 1 noise measurements.

The survey results indicated that the rail roughness levels in the wavelengths of interest (for a train travelling at approximately 80 km/h) remained relatively unchanged between the initial and after rail grinding surveys (surveys 1 and 2 above) for both the test and reference sections and therefore no corrections were made to the measured noise levels.

The final survey (survey 3) indicated that the rail roughness of the left rail was slightly higher in the test section than for the reference section, however no adjustments were made to the measured levels because the noise level reduction could be determined from the difference between the noise levels on the test section directly (with and without rail dampers).

The repeatability of rail roughness measurements has been shown to have an accuracy of ± 2 dB (i.e. undertaking consecutive measurements along the same line of rail roughness would be expected to produce results within ± 2 dB) [2].

Effect of Wheel Condition

A review of time coincident $L_{Amax,fast}$ noise levels versus time graphs (including an aural assessment on-site and by listening to a recording of the relevant train passbys), showed that the $L_{Amax,passby}$ noise levels for trains with wheel defects on damped rail were controlled by the wheel noise component. This was determined by calculating the difference between the $L_{Amax,fast}$ noise levels from the defective wheel on damped and un-damped rail.

The result was that the reduction in $L_{Amax,fast}$ noise levels for a defective wheel was less than for wheels with no defects (ie no wheel flats). Typically, these trains controlled the $L_{Amax,95\%}$ noise levels and it is for this reason that this parameter was not providing a reliable measure of the damper performance (albeit, this would be one of the compliance assessment parameters if the rail dampers were implemented on the project).

Figure 7 provides an example of a train passby where the L_{Amax} noise level for the passby was governed by wheel defect related noise. Figure 7 indicates that the noise reduction is higher for wheels without defects (approximately 4 dBA to 5 dBA) compared with the wheel with a defect (approximately 1 dBA) at the 1 m sound level meter location. This result indicates that rail dampers are more effective at reducing overall A-weighted noise levels for trains with good wheel condition (i.e. free from defects such as wheel flats).

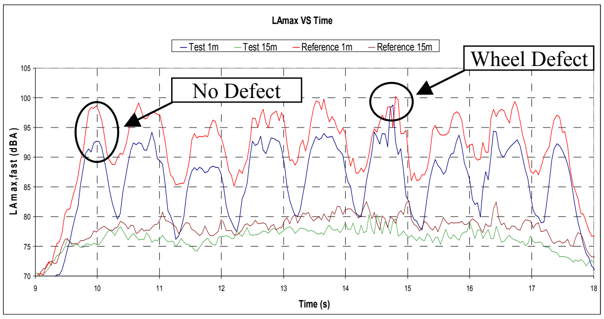

Figure 7. $L_{Amax,fast}$ Noise Level vs. Time Indicating the Effect of Poor Wheel Condition on Noise Reduction Potential

Effect of the Test Track Length

A typical length of an eight car train operating on the Sydney metropolitan rail network is approximately 160 m compared with a test section length of 90 m.

A sensitivity analysis was undertaken by S&V and Heggies in order to determine the potential for the untreated rail outside of the test section to result in higher L_{Aeq} noise levels than would otherwise not occur if the length of treated track was equal to or greater than the length of the trains operating on the line.

The sensitivity analysis showed that the L_{Amax} noise noise levels (95th percentile and average LAmax) would not be significantly affected by the length of treated track (in this case 90 m).

The results indicated that the L_{Aeq} noise levels may be affected as follows:

- 7.5 m measurement location (microphone 1.2 m above top of rail) - range of 0.1 to 0.2 dBA higher for a 90m test section (assuming a range of reductions in overall noise emissions from the treated track of 1.5 dBA to 3 dBA)
- 15 m measurement location (microphone 1.5 m above top of rail) - range of 0.2 to 0.4 dBA higher for a 90 m test section (assuming a range of reductions in overall noise emissions from the treated track of 1.5 dBA to 3 dBA)

These values were calculated assuming that the noise emissions from the wheels and rails contribute equally to the overall noise level.

It is on this basis that the actual "noise reduction adjustments" would depend on the wheel condition of the trains in question, the stiffness of the track (ie whether a particular passby was wheel controlled or track controlled) and therefore the actual achievable reduction in overall noise levels.

The sensitivity analysis showed that the noise reduction due to the rail dampers is likely to be slightly higher than measured (a reduction of up to 1.5 dBA compared to a measured reduction of 1.1 dBA).

Rail Noise or Wheel Noise?

The measured reductions in overall noise levels were lower than anticipated by S&V possibly due to the fact that standard ballasted track on the Sydney Metropolitan Network utilise relatively stiff rail pads.

The consequence of this is that the rail is already well constrained relative to “softer” rail pads which are common on European railway lines and hence European rail damper trials.

A study undertaken by DJ Thompson, determined via numerical prediction, the dependence of rolling noise on rail pad stiffness [2]. A summary of the results from this study is provided in Figure 8.

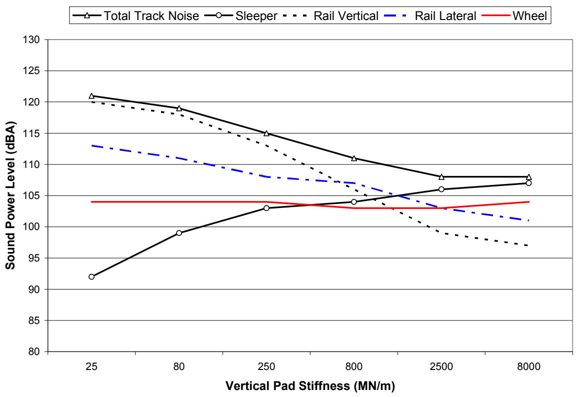

Figure 8. Dependence of Rolling Noise on Rail Pad Stiffness (Source. DJ Thompson)

For a vertical pad stiffness of 800 MN/m (noting that the actual pad stiffness for the existing K2RQ rail corridor is currently unknown) the contribution of the rail (incorporating the rail – lateral and rail – vertical components) is only slightly higher than for the wheel. These results are in line with the findings of the Stage 1 and Stage 2 K2RQ measurements in that the rail dampers provided a relatively small reduction in overall noise levels (approximately 1 dBA to 1.5 dBA) as the wheel (and other vehicle noise components) became the controlling noise sources.

It is noted that for a “softer” vertical pad stiffness of 250 MN/m the rail components would control the overall A-weighted noise levels by dBA bigger margin. It is on this basis that the overall noise levels could be reduced to a larger degree by adding tuned damping to rail supported by more resilient rail pads.

VTN Analysis

In order to determine whether the rail dampers were functioning optimally and to determine how the performance of the rail dampers could be improved, Vibro-acoustic Track Noise (VTN) analysis was undertaken for a selection of trains passing over the section of track fitted with rail dampers.

The VTN analysis methodology was developed and validated by Verheijen and Paviaotti [6] within the European project STAIRRS (Strategies and tools to Assess and Implement noise Reducing measures for Railway Systems). The VTN methodology provides a tool for separating the total passby noise emissions into their constituent parts, the rail track and rail vehicle. The rail vehicle incorporates the wheels, bogies and all other noise producing components. The VTN does not differentiate between the various vehicle components but does separate the track into the sleeper and rail components.

In order to undertake a VTN analysis it is necessary to measure a number of acoustic parameters on the same recording device. The measured parameters should be time coincident.

As a minimum, VTN recommends that the following parameters are measured:

- Vertical Rail Acceleration (m/s^2) – Rail Foot
- Lateral Rail Acceleration (m/s^2) – Rail Head
- Vertical Sleeper Acceleration – Sleeper Close to the rail fastener
- Sound Pressure Level (dBA) – 1 m from near rail (0 m above top of rail and / or 7.5 m from the track centre line (1.2 m above top of rail).

The measured acoustical parameters were processed in accordance with the VTN algorithm to determine the sound power for the rails and sleepers. The vehicle noise component is determined by subtracting the track components from the total measured noise levels at a distance from the track (in this case 1 m).

A typical result of the VTN analysis is provided in Figure 9. The VTN analysis for the undamped case indicates that the contribution from the track to the overall noise level is less than or equal to the vehicle components. The implication of this is that if the noise contribution from the track is reduced, it does not necessarily mean that the overall noise levels would reduce by the same amount.

The reason for this is that the vehicle noise components are controlling the overall noise levels in this instance, ie once the 315 Hz to 800 Hz track component (Figure 5, Figure 6) is reduced the vehicle noise components would control the overall passby noise levels.

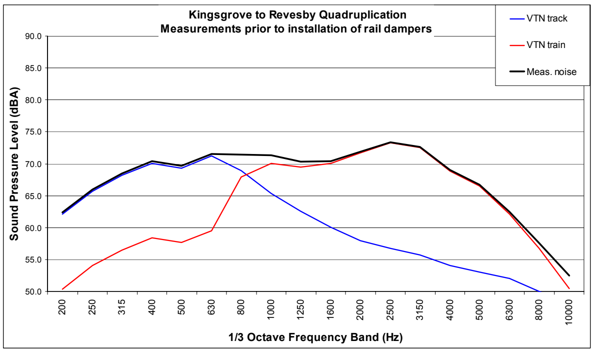

Figure 9. Typical VTN Analysis (based on 1 m noise results)

Track Decay Rate Measurements

The Track Decay Rate (TDR) is defined as the vibration amplitude decay rate of the vertical or transverse bending waves of the rail as a function of the distance along the rail. It is represented by a one-third octave band spectrum of the values of the decay rate, expressed in decibels per metre (dB/m).

TDR measurements were undertaken in accordance with draft European Standard prEN 15461 *"Rail applications - Noise emission - Characterisation of the dynamic properties of track sections for passby noise measurements - English Version"* [9].

Figure 10 indicates that the TDRs in the frequency range of interest (315 Hz to 800 Hz) range between approximately 8 dB/m and 10 dB/m (which is approximately an order of magnitude higher than TDRs measured on resiliently mounted track for the same frequency range and is considered a high TDR) [2].

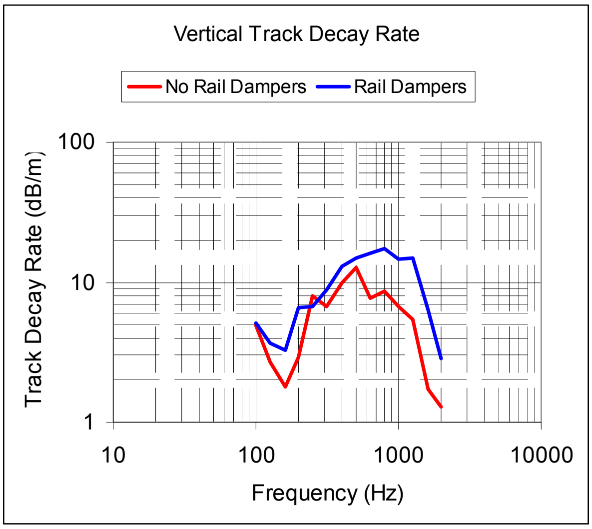

Figure 10 TDR Results for 90 m Test Section (Vertical Direction)

The application of rail dampers onto a highly damped section of rail would therefore not be expected to produce large increases in TDRs, this is evident from the measured TDR spectra.

The higher "baseline" track support stiffness would therefore limit the potential reduction in airborne noise levels (reductions that have been observed from other installations with track supports of a lower stiffness).

CONCLUSIONS

The first rail damper trial in Australia was undertaken as part of the K2RQ project between July and October 2008. The trial was undertaken in order to determine whether rail dampers would be a cost-effective mitigation measure for reducing airborne noise levels at nearby receivers adjacent to the project area.

The potential benefits of the successful implementation of rail dampers on a project such as the K2RQ project would potentially see a reduction in the requirement for path and receiver controls such as noise barriers and building treatments.

The K2RQ rail damper trial has highlighted the importance of selecting an appropriate trial site (where possible within the constraints of a project) and to avoid (where possible), the possibility of rail grinding or any other rail head modifications during a measurement program.

The measured noise reduction in L_{AE} and Average L_{Amax} noise levels was approximately 1.5 dBA. This reduction was lower than anticipated. Further analysis of the results (Track Decay Rate and VTN analysis) indicated that the trackform was already relatively stiff when compared to installations on European track with comparatively lower track stiffness (primarily as a result of the rail pads in use).

The noise measurement results showed that higher noise reductions are achievable for trains with wheels in good condition (free from defects such as wheel flats).

The trial has shown that rail dampers do work and are a cost effective noise mitigation measure on track with lower stiffness rail pads. The results of the trial show that rail dampers can be used as a strategic at-source noise mitigation measure and should be considered at the project inception stage as part of the overall track design.

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