WHEEL SQUEAL MEASUREMENT, MANAGEMENT AND MITIGATION ON THE NEW SOUTH WALES RAIL NETWORK

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Abstract

This paper provides an update of RailCorp's recent progress with the measurement, management and mitigation of wheel squeal on the New South Wales rail network. Recent mitigation measures have focussed on the application of a friction modifier to the head of the rail. This has been very successful at some sites, but it is now clear that it is only partially effective at others. The paper discusses the results of wheel squeal noise monitoring during a number of recent tests and mitigation trials and explains the emerging focus on freight rolling stock for management of the issue in the future.

Introduction

Wheel squeal is a high frequency tonal noise sometimes generated by trains on curved sections of track with a radius of curvature less than approximately 600m. It can generate high noise levels (often over 100 dB(A) at surrounding properties) and the tonal characteristics contribute significantly to subjective annoyance.

Wheel squeal has been extensively researched over recent decades and is known to be caused by "stick-slip" interaction between the wheel tread and the running surface of the rail [1]. Stick-slip motion is caused by lateral creep of a wheel tread on the rail surface in conjunction with a friction characteristic that includes a negative slope (referred to as a "negative friction characteristic").

Wheel squeal effects show remarkable variation: some rail systems are affected more than others; some sites on a given rail system are affected more than other similar sites; and, at a given site, the effects may vary significantly over time. These variations have often undermined efforts to carry out field trials and validation of research findings [2].

For example, in many cases a particular train has been observed to generate substantially different wheel squeal levels during multiple passes of the same curve. Much of the variation at a particular site is thought to be due to the variation in friction characteristic at the wheel/rail interface due to changes in meteorological conditions, environmental pollutants and rail by-products such as grease, sand and brake dust.

Variations between sites may be at least partially caused by changes in friction characteristic, but may also involve many more parameters such as track geometry, operating conditions and rolling stock.

The characteristics and underlying causes of wheel squeal are quite distinct from other curving noise phenomena, the most prevalent of which is flanging noise. Flanging noise occurs when there is contact between the wheel flange and the gauge face of the rail (normally the high rail in curves). Some researchers have suggested that flanging noise may also arise as a result of an interaction between the wheel tread and the running surface of the rail (without the need for flange contact) [3]. This paper does not deal with flanging noise.

History of Wheel Squeal in NSW

Evidence suggests that wheel squeal is not a new phenomenon on the NSW rail network, but that the severity of the issue and / or the related community response has grown significantly since problems were first studied in detail at Beecroft (Sydney) in the late 1980's. There are now over a dozen complaint sites in the Sydney region and a similar number of complaint sites elsewhere in the state.

An in-depth study was carried out at Wollstonecraft (Sydney) in 1996 and provided a clear understanding of the underlying mechanism of the problem [4]. Top-of-rail friction modification was shown to effectively eliminate wheel squeal at Wollstonecraft. Other possible solutions, such as noise barriers or changes to rolling stock, were found to be either impractical and/or substantially less cost-effective.

Since 1997 effort in NSW has therefore been focussed on the design and implementation of a track-side device suitable for automatic application of friction modifier to the running surface of the rail. Friction modification had previously been used by some overseas rail systems (notably tram systems, with tight curves and captive fleets) via on-train systems. This was not practical in NSW because of the extensive network and large quantity of rolling stock. The routine application of the product to the rail surface was a possibly world first [5]. Figure 1 (overleaf) shows the rail mounted applicator.

More recent tests in NSW have shown that friction modification provides other benefits aside from noise, particularly under freight traffic, namely a reduction in lateral forces on curves and a reduction in component deterioration on turnouts [6].

Unfortunately the top-of-rail applicator in operation to date has proved to be maintenance intensive and very unreliable, despite a number of modifications and improvements. Where applicators have been installed, ongoing community complaints about wheel squeal have often occurred but have been attributed to poor applicator reliability. However, there has been a growing body of evidence that a proportion of freight rolling stock is not responding to friction modification and that additional or alternative steps will be necessary to resolve wheel squeal from freight traffic.

Figure 1: Top-of-rail applicator

Most of the wheel squeal noise investigations carried out in NSW over the last decade or so have involved monitoring and observations over a day or two before and after an intervention or mitigation measure. In many of these cases the results have been inconclusive. This is due, in large measure, to variability of wheel squeal effects (as described in the introduction to this paper). As a result, a number of important questions remained unanswered for some years, including:

- Whether there was any substance to the anecdotal evidence that track with concrete sleepers generates more wheel squeal than track with timber sleepers.
- Whether temporary speed restrictions could provide an interim reduction in wheel squeal.
- Whether the use of top-of-rail friction modification could effectively eradicate the problem at all affected sites.
- Whether there was any substance to the observation that certain freight trains caused more wheel squeal than others.

In the meantime, considerable effort had been directed to wheel squeal problems at a number of other sites in Australia and overseas.

Work by Queensland Rail [7] implicated concrete sleepers, identified the need for improved centre-bowl lubrication on coal wagons to promote better tracking, and found that friction modification with TramSilence and Kelsan products was beneficial. New passenger rolling stock has been fitted with wheel damping and squeal problems at some freight yards have been successfully mitigated using water sprays.

Australian Rail Track Corporation (ARTC) has carried out a number of investigations of wheel squeal generated by freight traffic in the Adelaide Hills, in conjunction with the EPA of South Australia. Friction modification was not successful and squeal was found to be highly correlated with excessive angle-of-attack. Trials were carried out in 2003 using the Vipac “RailSqad” system to identify squealing axles requiring corrective maintenance [8]. Initial results showed that the majority of the problem was caused by a very small proportion of axles (around 2%).

The Transit Cooperative Research report 97 [3] overviews recent wheel squeal work in the USA. Wheel and rail damping have received considerable attention on transit systems, but have been only partially effective in some cases. Friction modification has also given mixed results. Finally, rail hardfacing (normally used to reduce wear rates) has shown some promising results in squeal reduction (at least on a temporary basis) due to the adoption of dissimilar compounds for wheel and rail.

Recent Trials and Measurements

Top-of-rail friction modifier

During earlier trails at Wollstonecraft, application of “TramSilence” friction modifier (manufactured by Fuchs) to the running surface of the rail had been found to eradicate wheel squeal. A number of subsequent attempts had been made to verify the effectiveness of top-of-rail friction modification at other sites by carrying out noise monitoring before and after installation of applicators. However, these attempts had failed to achieve conclusive results due to changes in meteorological effects and (in several cases) failure of the applicator under test. A more extensive monitoring regime was therefore carried out at Teralba before and after installation of applicators on each track in September 2003.

The curve in question is located approximately 147 km north of Sydney, comprises two tracks (one for each direction of travel) of 315 m radius and carries both passenger and freight services. Track construction is 60 kg/m head hardened rail on concrete sleepers. Monitoring was carried out at 25 m from the track using an outdoor microphone unit and recording the audio signal via a PC sound card. Initial analysis was carried out by replaying the recordings via headphones and applying a simple subjective rating of squeal (“none”, “mild”, “moderate” and “severe”). A consultant was subsequently engaged to carry out a thorough quantitative analysis of the recordings, the results of which were remarkably consistent with the subjective analysis.

The monitoring had been planned to continue for at least 2 weeks after the installation of applicators (one on each track). In the event, frequent failures of the applicators meant that monitoring had to be continued for approximately 3 months until sufficient data had been collected for the “applicators operational” scenario. As a result, this was by far the most comprehensive wheel squeal noise monitoring exercise carried out in NSW.

The results showed that, without applicators:

- Only freight trains generated wheel squeal
- Wheel squeal noise levels frequently exceeded 110 dB(A) at 25m from the track.
- Dominant squeal frequencies were typically in the 1600 to 2500 Hz one-third octave frequency bands (although significant peaks were also encountered at 4000 Hz and above).
- Nearly 50% of freight trains generated “moderate” or “severe” categories of squeal, with levels over 95 dB(A) or 105 dB(A) respectively.

With applicators operational the proportion of freight trains generating “bad” squeal reduced to around 35%. This is a significant reduction, but by no means a solution to the community noise issue. Figure 2 illustrates these results. Limited trials with the application of friction modifier to the low rail only suggested that this may be as effective as application to both rails.

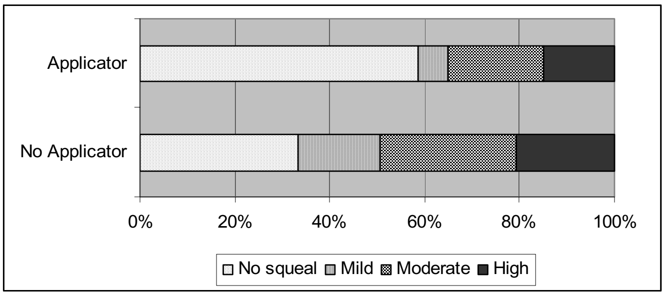

Figure 2: Proportion of all freight trains by squeal category, with and without applicators

Consistent with observations at many other sites, wheel squeal was also found to reduce significantly during wet weather (to around 25% of freight trains).

Where sufficient data was available, the results were reviewed according to train operator and type (steel product trains, coal trains, container trains etc). This confirmed that some types of freight train generated wheel squeal more frequently than others, but also indicated that some responded better to top-of-rail friction modification than others, as shown in Figure 3 below (actual train categories can not be disclosed).

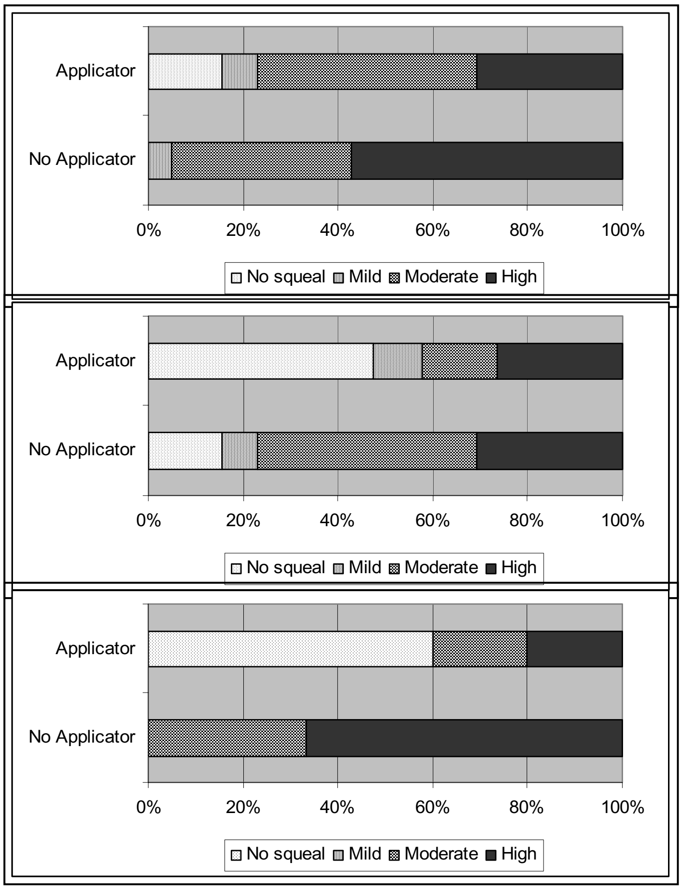

Figure 3: Results for 3 categories of freight train

Track Upgrade to Concrete Sleepers

Despite previous investigations and a wealth of anecdotal evidence, the question of whether wheel squeal became a problem when track was upgraded to concrete sleepers remained hotly debated. Measurements were therefore carried out before and after routine track upgrade works on a curved section of track at Morisset. The curve is located approximately 125 km north of Sydney, comprises two tracks (one for each direction of travel) of 320 m radius and carries both passenger and freight services. Both tracks comprised 54 kg/m rail on timber sleepers during measurements carried out in February 2004. When measurements were repeated in late March 2004, the UP[1] track had been upgraded to 60 kg/m head-hardened rail on concrete sleepers, the profile

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[1] The “UP” track carries traffic towards Sydney, the DOWN track (abbreviated “DN”) away from Sydney

had been ground and sufficient traffic had passed to allow it to "bed in".

The monitoring equipment was the same as that used at Teralba, but the microphone was placed at approximately 15 m from the UP track.

The results show that there was a substantial increase in the amplitude and frequency of occurrence of squeal following installation of concrete sleepers on the UP track (see Figure 4 below). The results on the DN track, which was not subject to re-sleepering, were reasonably consistent before and after the re-sleepering on the UP track, indicating that the changes observed on the UP track were not the result of other factors (such as changes in rolling stock or weather conditions).

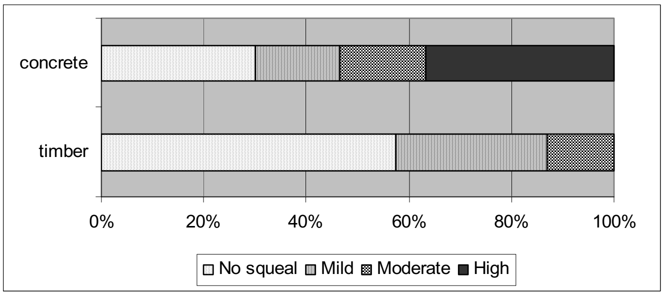

Figure 4: Before and after concrete sleepers

It is clear that some squeal noise did occur on timber sleepers, consistent with anecdotal evidence that squeal noise is not a new phenomenon in NSW. However, the results give very clear evidence that "severe" squeal did not occur on timber, but was generated by nearly 40% of freight trains on concrete. In summary, the results show that wheel squeal may not be new on these curves, but that squeal noise on concrete sleepers can be far higher in level and much more prevalent than previously occurring on timber.

Of the freight train categories analysed in detail, all showed an increase in wheel squeal on concrete sleepers. The overall proportion of freight trains generating "moderate" or "severe" wheel squeal on concrete sleepers at Morisset (approximately 60%) was of the same order as that observed at Teralba (approximately 50%).

Temporary Speed Reduction

It had been noted during investigations in the early 1990's at Wollstonecraft in Sydney that wheel squeal continued to occur even when trains were traveling slowly. Overseas research has even identified cases where wheel squeal reduces as train speed *increases*. Nevertheless, communities affected by wheel squeal often perceive that the issue is caused by "speeding" trains.

A temporary speed restriction of 40 km/h was imposed at Teralba in April 2004 (the normal track speed is 75 km/h) and monitoring was repeated (using the same location and equipment as previously).

The results (see Figure 5 below) show that some measurable and audible differences in wheel squeal occurred as a result of the temporary speed reduction. However, the reductions are not considered worthwhile from a community perspective given that 2 or 3 significant wheel squeal events can be expected to continue each night (compared with 3 to 4 at normal speed). When squeal occurred at reduced speed it was also noted that the duration increased, effectively "prolonging the agony".

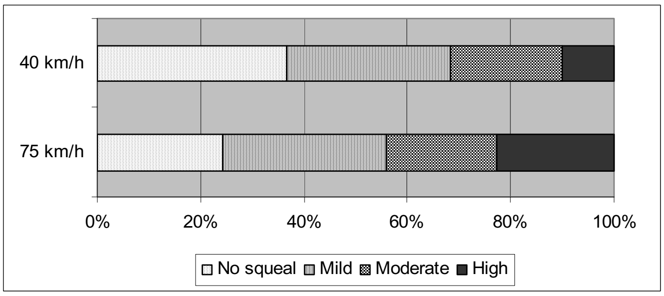

Figure 5: Results for normal and reduced speed

Analysis of specific train categories shows some variation in the effects. Most freight trains showed some measurable reduction in squeal as a result of the speed reduction but one example showed an increase in the proportion that squealed. Differences were also noted between UP and DN tracks, which suggests that other variables such as superelevation may also affect the incidence of wheel squeal.

The overall conclusion from this trial is that a speed reduction at Teralba (and, presumably, other sites with similar characteristics) is not an effective interim means of wheel squeal mitigation.

A new top-of-rail applicator

In conjunction with a private supplier, RIC developed a new prototype top-of-rail applicator for dispensing TramSilence friction modifier. The device uses a track-mounted pump (activated by train wheels) and reservoir identical to that used on RIC track lubricators. (Track lubricators are used extensively throughout the network to apply grease to the gauge face of the high rail on curves, where wheel flange contact without lubrication can cause wheel and rail wear (as well as flanging noise)). A sensor located in a trackside control unit "wakes up" the system when pressure in the line reaches a pre-determined level and dispenses product to a track mounted applicator that is designed to "ooze" product onto the running surface of the rail from the field side. The control unit then activates a delay, during which time any continued pressure build-up (due a passing train) causes product to be re-circulated into the reservoir. After the delay has elapsed, another dose is directed to the track.

A prototype of the device was installed on the UP track at Teralba in May 2004 and noise monitoring was carried out until mid June. Again, the measurement location and methodology were the same as those used for the previous trials. The applicator was set to dispense 5 grams of TramSilence to each rail per dose, with a delay between successive doses of 13 seconds. These settings were judged by the team to represent:

- The maximum practical dose of TramSilence per "shot" (any more would cause wastage of product either side of the contact patch), and
- The minimum practical time delay between successive doses, resulting in no more than 1 dose per passenger train but multiple doses per freight train.

Based on the average pass-by time and train length observed at Teralba during these trials, the dosage of TramSilence is estimated at approximately 0.1 to 0.15 grams per rail per axle.

With the exception of 1 (relatively infrequent) type of freight train, the monitoring results showed that the new prototype gave better squeal noise mitigation than the previous applicator had achieved in 2003. However, consistent with the previous trial, a proportion of freight trains continued to generate high levels of wheel squeal at the monitoring location, indicating that the application of TramSilence did not completely solve the problem at this site. At the time of writing it is considered possible that this is due to failure of the friction modifier to travel around the full length of the curve; further trials are therefore planned with an additional applicator temporarily located roughly half way around the curve.

The reliability of the new prototype was found to be far superior to the previous device. Some problems were experienced with the battery power supply and, on some occasions, a lack of TramSilence product in the reservoir, but at no time during the trial did any of the system components fail. The on-track components (ie the pump and applicator itself) were in place for approximately 4 months during the trial and did not sustain any damage nor require any more than minor adjustment. This is a marked contrast to the performance of the previous units, which required frequent service and replacement of system components.

Rolling Stock Observations

It must be emphasized that the noise monitoring system used for these studies was far from sophisticated. Unlike the Vipac RailSqad system, it is not possible to determine which axle, or even which wagon, is responsible for particular squeal events. Despite this, some analysis of rolling stock performance trends was possible by observation alone, as follows:

- A high proportion of container and steel product trains squealed, whereas coal and grain trains rarely squealed.
- Loaded and unloaded wagons seemed to behave the same.
- A train may comprise 30 or 40 wagons of the same type, but only a small proportion of them would squeal.
- Squealing wagons were observed at the front, middle and rear of trains.
- Container trains often incorporated "multi-pack" wagons (a series of wagons – typically five – permanently coupled and resting on shared bogies). These seemed to squeal more frequently than other container wagons.

A new weighbridge system was commissioned on the DN track at Sulphide in February 2004, approximately 5 km north of Teralba. The system includes a tag reader to identify each passing locomotive and wagon. Additional analysis of the noise monitoring data is now underway for the period in which weighbridge data is available. The initial results confirm those from the visual observations, and suggest that:

- Trains carrying bulk goods (coal, grain, cement) rarely squealed, whether loaded or unloaded.
- Around 2% of the axles seem to be responsible for the majority of the problem

Proposed Way Forward

RailCorp proposes to continue management of wheel squeal by concentrating on three activities, as follows:

1. To optimise the new top-of-rail applicator for ongoing use at sharper curves.
2. To implement rolling stock detection and monitoring and collaborate with freight operators to investigate and rectify axles that squeal on broader curves.
3. To carry out field trials and maintain contact with researchers on such questions as whether rail hardfacing may provide beneficial squeal noise reduction.

Conclusions

Investigation and mitigation of wheel squeal is a long and slow process as a result of the complexity and ephemeral nature of the problem. The challenge of achieving reliable top-of-rail friction modification also necessitates extended trials. As a result, management of the issue in NSW has required considerable resources, but many of the affected communities are still bothered by squeal noise.

The extensive trials carried out in 2003 and 2004 have provided some answers, namely:

- That track upgrade from timber to concrete sleepers results in an increase in squeal noise;

- That limiting operating speed does not provide a substantial reduction in wheel squeal;
- That wheel squeal at some sites is caused only by freight traffic, and that certain freight services cause squeal far more frequently than others;
- That top-of-rail friction modification may only be partially effective in these situations, and that rectification of "rogue" freight wagons is likely to be required for a full solution;
- That an alternative top-of-rail applicator provides greatly improved reliability.

Despite the above answers, a number of other questions remain unanswered at this time, including:

- The extent to which wheel squeal results in wheel / rail wear.
- The optimum dose of TramSilence per axle (including whether both rails require treatment).
- The distance that friction modifier travels along the track (under various track and traffic scenarios).
- The precise reason(s) that concrete track leads to more squeal than timber (and whether a practical modification can be made to counter this).
- The precise reason that certain axles squeal when others of the same type do not.

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