Fundamentals of Wheel-Rail Noise and Vibration

1. Concepts
2. Wheel-rail noise and vibration generation mechanisms
3. Common issues
4. At-source mitigation strategies

Transit:

"People keep buying / building next to the tracks… they should expect some noise"

Freight:

"We don't care we can make as much noise as we want"

Alternative:

"Noise is harmful to health… we want to be good neighbors"

"Excessive noise or vibration indicates our system is not working optimally. Reducing noise aligns with other goals"

Fundamentals

Noise and vibration are both particle oscillations

- Noise is small pressure fluctuations in air we detect with our ears
- Vibration is oscillation of particles in solids
- Vibration may be felt, or vibrating structures can re-radiate noise
- Vibration can also affect sensitive equipment

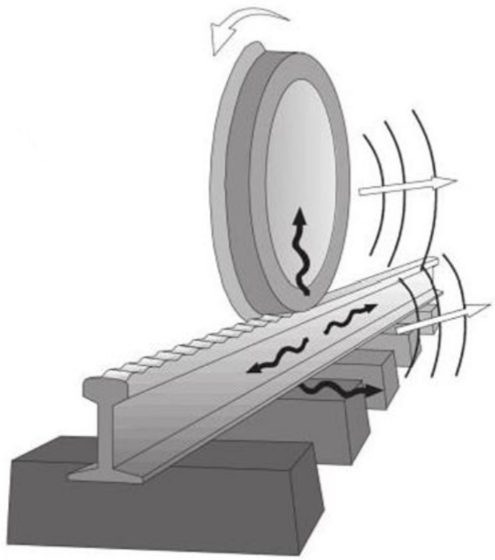


Figure reproduced from *Railway Noise and Vibration Mechanisms, Modelling and Means of Control* David Thompson, 2009

The wheel/rail interface is the source of many railway noise and vibration issues

Frequency content

Frequency (Hertz) is the number of oscillations per second

- determines the pitch of sound

Environmental noise and vibration issues in railways manifest over a wide frequency range

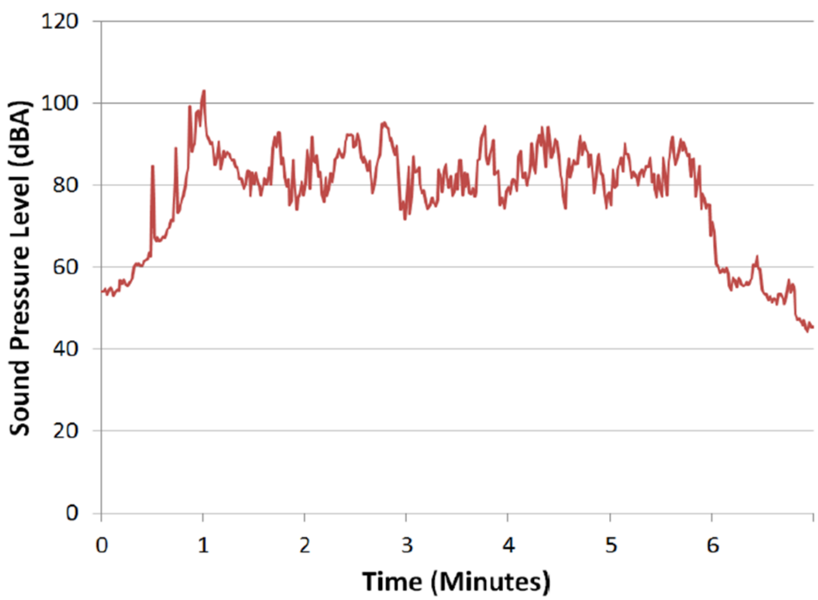
Very Low Frequency < 100 Hz	Low Frequency Up to ~300 Hz	Mid Frequency ~300 – ~2000 Hz	High Frequency > ~2000 Hz
Perceptible vibration Effects on sensitive equipment	Ground-borne noise / structure radiated noise	Rolling noise, corrugation, impact noise	Squeal noise, flanging noise

Decibel noise levels

dBA	Example	
130	Threshold of pain	Intolerable Extremely Noisy
120	Heavy rock concert	
110	Grinding on steel	Very noisy
100	Loud car horn at 3 am	
90	Construction pneumatic hammering	Loud
80	Curbside of busy street	
70	Loud radio or television	Moderate to quiet
60	Department store	
50	General Office	Quiet to very quiet
40	Inside private office	
30	Inside bedroom	Almost silent
20	Recording studio	

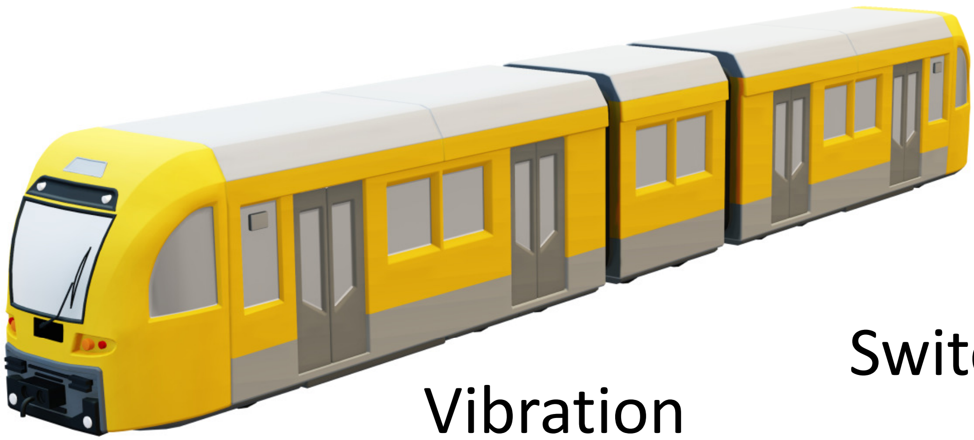
- The decibel (dB) describes loudness of sounds
- A-weighted decibels (dBA) describe loudness of sounds adjusted for human hearing sensitivity.

Time-varying descriptors



- Railway noise and vibration varies over time
- The max noise level (LAmax) during a train passby is louder than the average railway noise level during the event, or in a 16 hour day or 8 hour night (LAeq)
- There are other statistical descriptors of noise level over time
- …. lots and lots of descriptors
- …. not all decibels are directly comparable

Specific railway issues



Squeal noise

Corrugation

Grinding induced corrugation

Switch impact noise

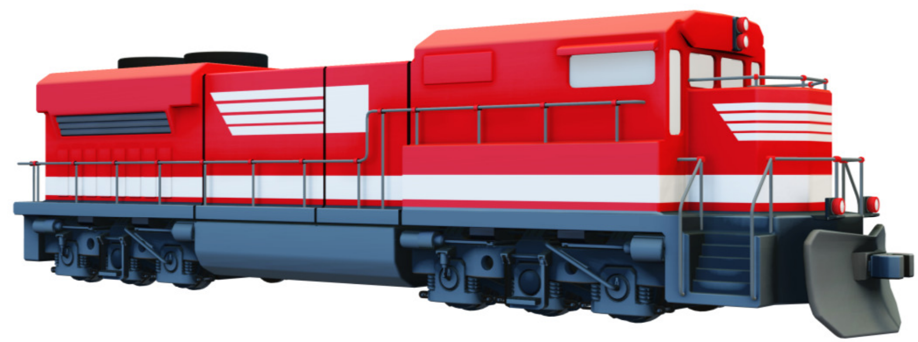
Wheel flats

Vibration

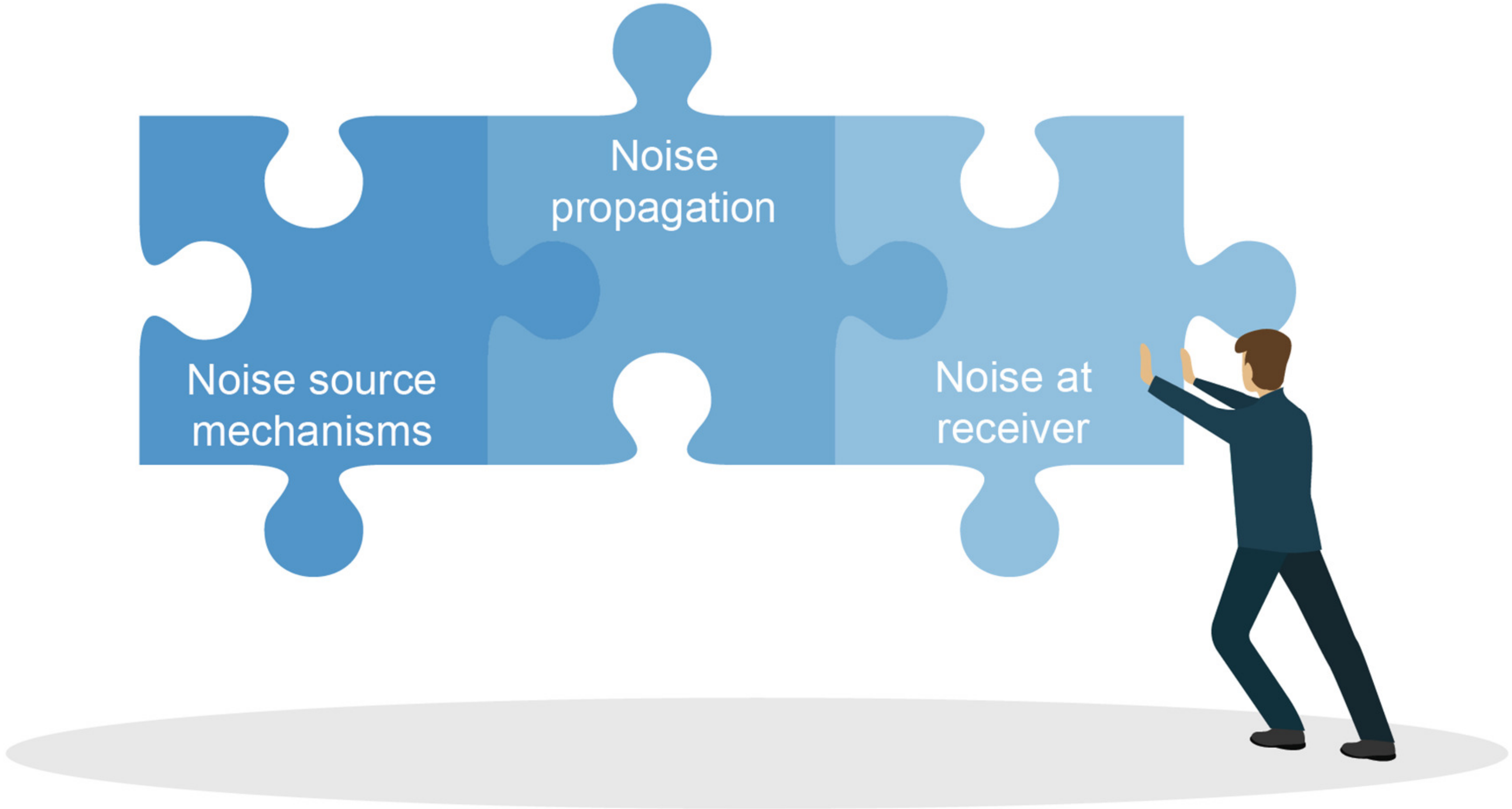
Rolling noise

Flanging

Ground-borne noise

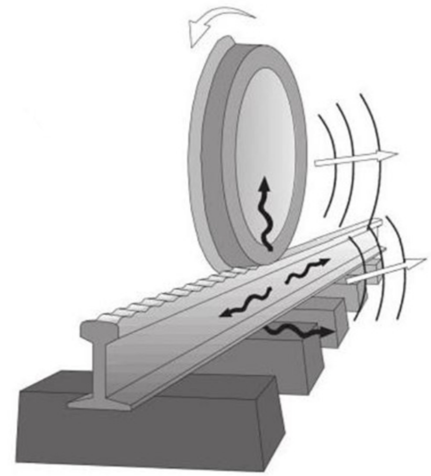


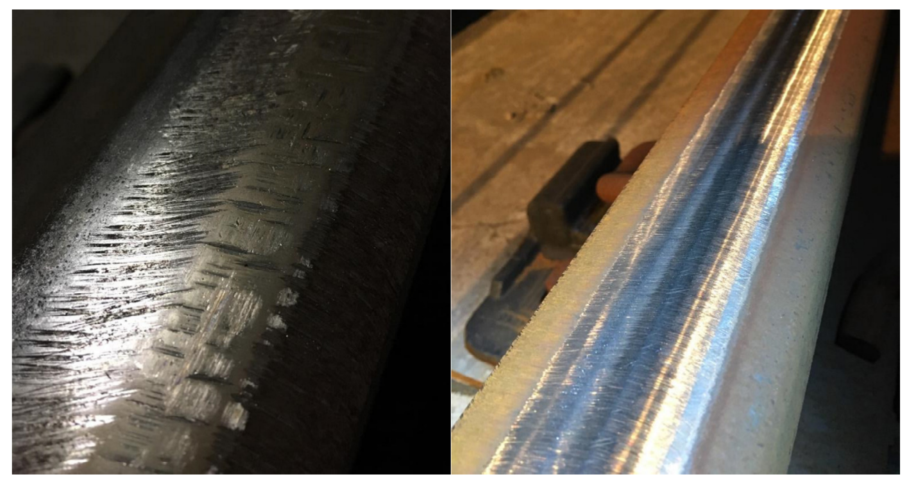
Target for control



Rolling noise

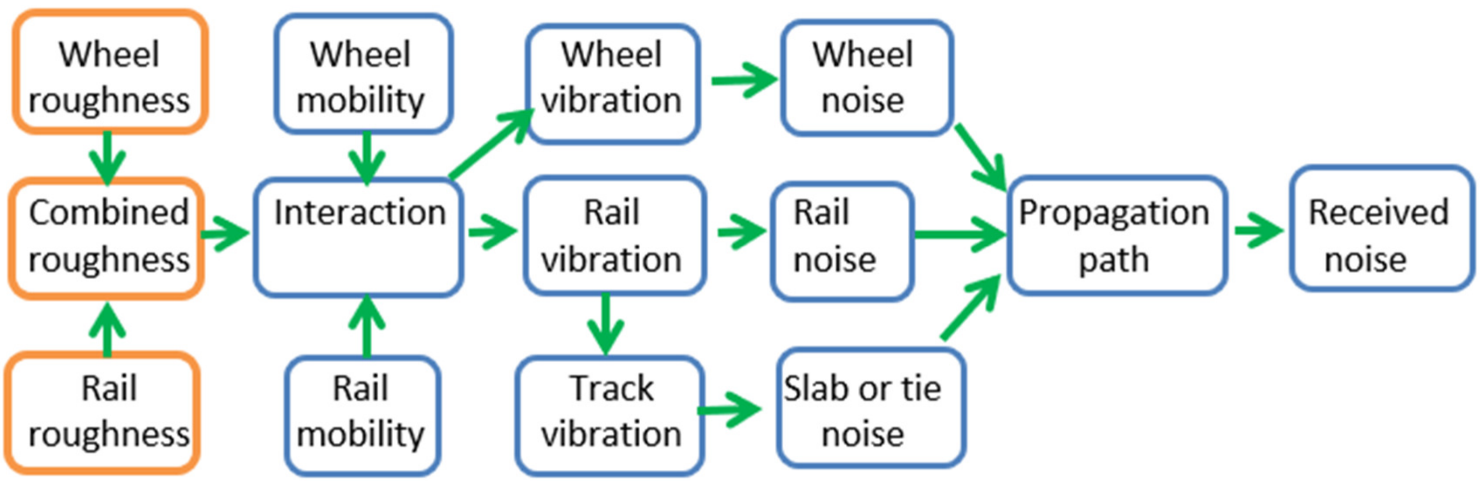
- Present on every system (except maglev)
- Noise level depends on:
  - Rail roughness
  - Wheel roughness
  - Wheel design (size, shape)
  - Track design (components, support stiffness)
  - Train speed





Rolling noise mitigation

Roughness input	Wheel/rail interaction	Vibration of components	Noise radiation	Noise propagation	Noise at receiver



Reduce roughness	Change component design	Add damping	Barriers, absorption	Façade treatment

Rolling noise mitigation

Corrugation

Rolling noise, but with dominant roughness in particular wavelength

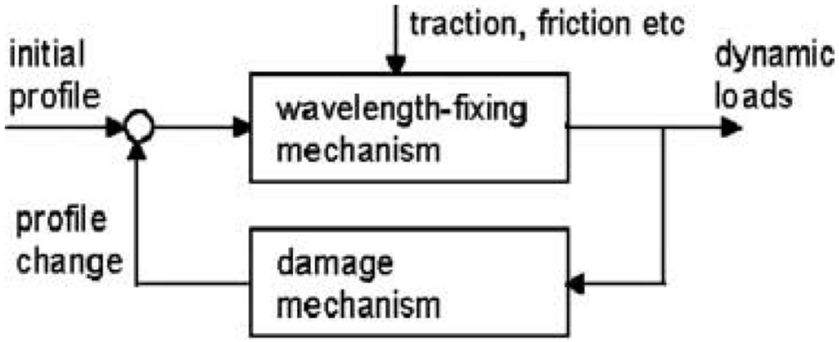
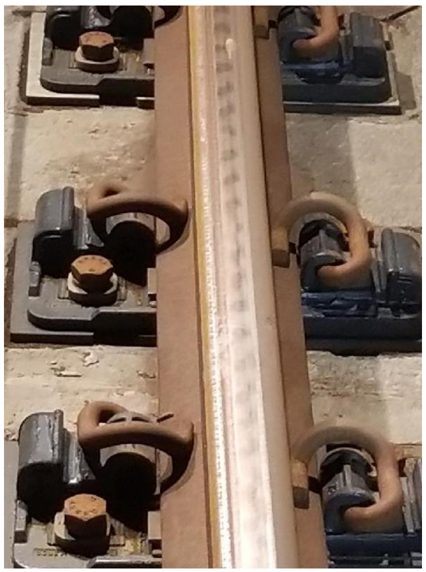


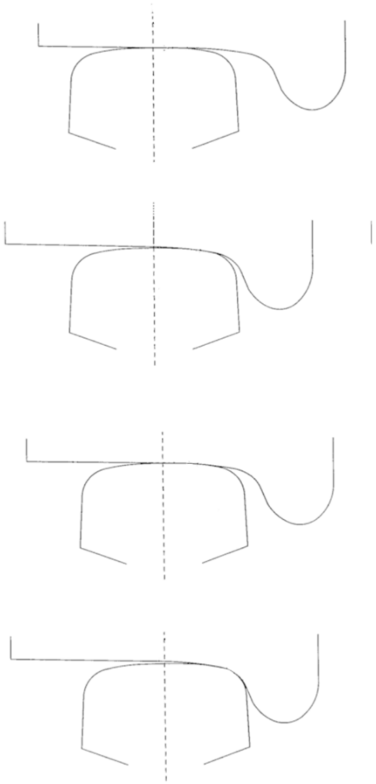
Image from Stuart Grassie: *Rail corrugation: characteristics, causes, and treatments* (JRRT, 2009)

Corrugation



- Appears on light rail, metro transit and heavy haul, straight track and curves, wide range of wavelengths
- Common issue for metros on low rail of curves
  - Linked to torsional resonance of driven axles
- Multiple mechanisms
- Conflicting anecdotes about causes

Corrugation mitigation

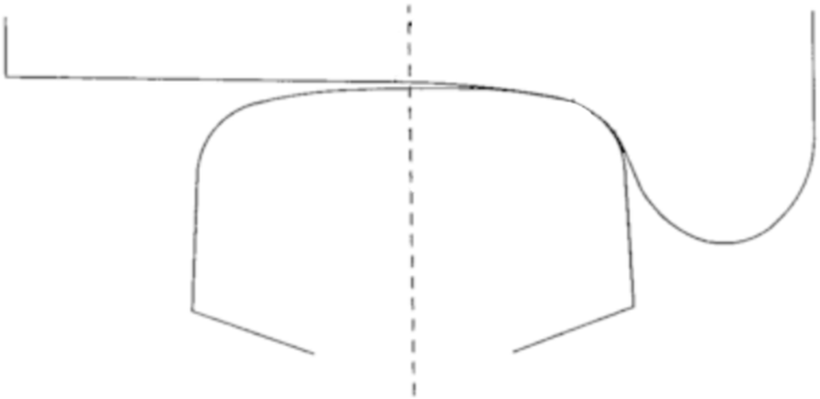


- Optimize wheel/rail profile design
- Harder rails (wear resistance)
- Top of rail friction modifier
- Rail grinding
- Rail milling

Grinding Induced Corrugation

- Corrugation / residual roughness after grinding
- Higher frequency, tonal, whiny
- Depending on starting condition, grinding can increase noise
- With soft rails, typically resolves in days/weeks
- With hard rails, can last months
- Mitigation: finer stones / polishing, manage expectations

Flanging

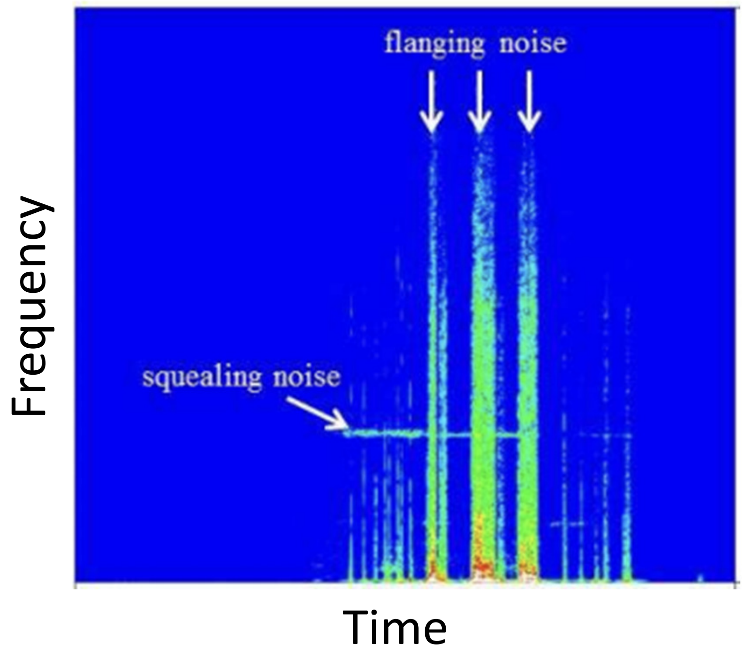


- Typically on curves
- Worse on tighter curves
- Can occur elsewhere
- Can indicate wheel rail interface or steering issue (angle of attack)
- Sound is a mix of multiple tones
- Several wheel modes excited

Flanging mitigation

- Optimise wheel/rail profile design
- Gauge face lubrication (wayside)
- Vehicle based wheel flange lubrication
- Vehicle steering
- TORFM (improving steering through curves)

Wheel Squeal / Curve Squeal

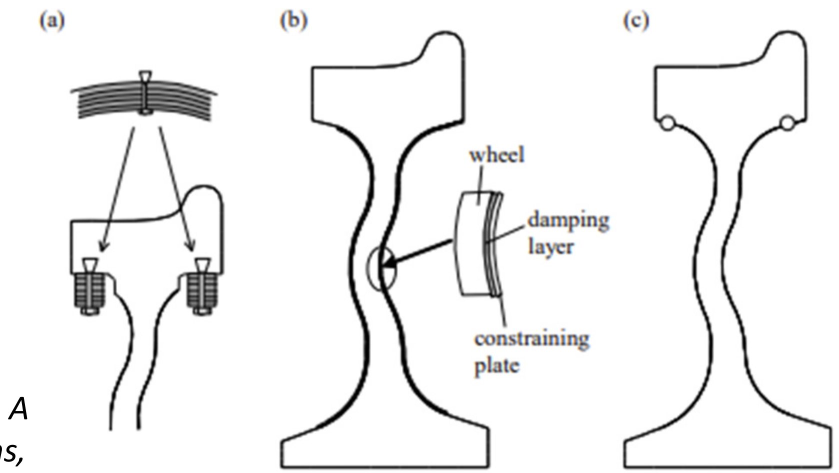


- Like flanging, more common on curves and worse on tighter curves
- Can indicate wheel rail interface or steering issue (angle of attack)
- Pure tones (very annoying) linked to specific modes of wheel
- Hard to predict / model

Image from Helmut Venghaus: *The impact of weather conditions on the noise radiation level of curve squeal* (IWRN13, Ghent, 2019)

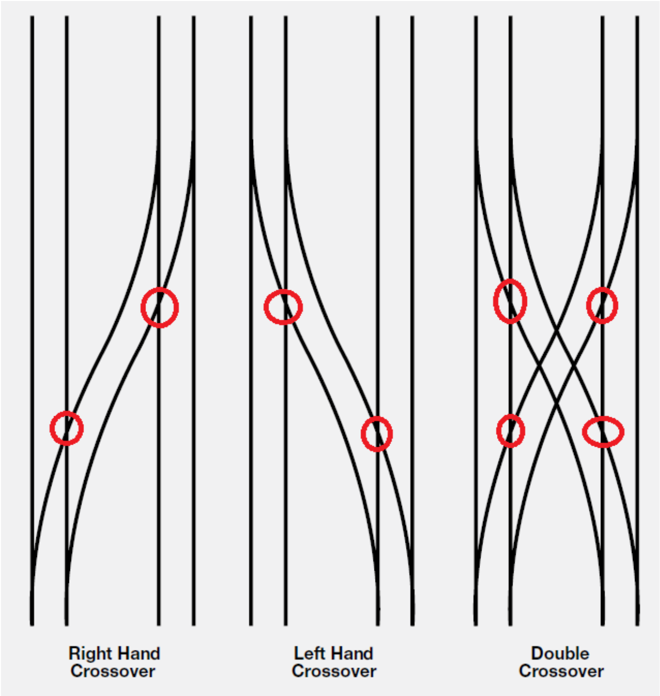
Squeal mitigation

- Optimise wheel/rail profile design
- Angle of attack (bogie maintenance + design factors)
- Gauge face or check rail lubrication (if that is source of excitation)
- Resilient wheels
- TORFM
- Wheel dampers



Wheel damper image from D.J. Thompson, G.Squicciarini and B. Ding: *A state-of-the-art review of curve squeal noise: phenomena, mechanisms, modelling and mitigation* (IWRN12, Terrigal, 2014)

Switch Impact



- Predictions / modelling typically add 10 dB correction at each discontinuity
- Noise proportional to size of discontinuity
- Similar to noise over a rail defect

Switch Impact mitigation

- Eliminate gap:
  - Swing nose crossing
  - Conformal frogs

- Locate away from sensitive receivers

Wheel flats

- Noise + vibration proportional to size of discontinuity
- Freight wagons with wheel flats 7-12 dBA louder than wagons without
- Some new generation passenger trains produce 5 dB less vibration on average than older trains (wheel slide protection system improvements)

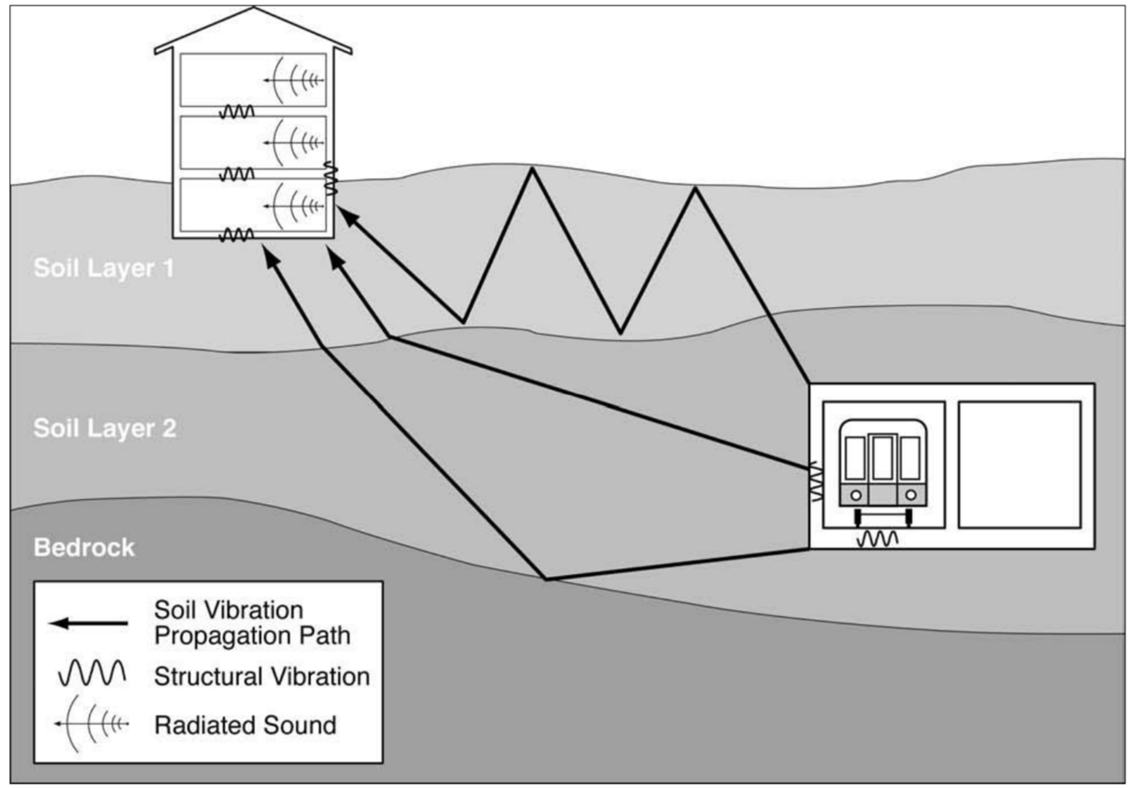
Wheel flat mitigation

- Wheel impact load detectors
- Reprofiling
- Friction management

- Wheel slide protection systems

Vibration + Groundborne Noise

- Lower frequency effects
- Source influences include:
  - longer wavelength roughness
  - track components / design
  - impacts / discontinuities
  - special trackwork
  - unsprung mass
  - vehicle suspension
  - wheel out of roundness



Vibration + Groundborne Noise

"We believe that it is unreasonable to expect better than 10dB prediction accuracy from any predictive model." Dr Hugh Hunt

15 % change in soil parameters -> 6 dB change in vibration prediction

Sources of uncertainty:

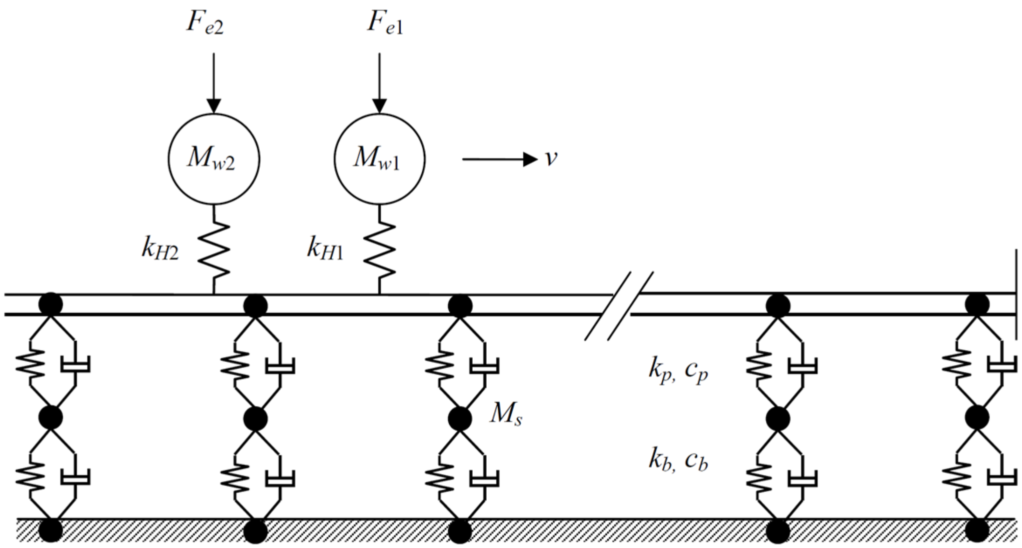
Ground layers, voids, foundation coupling, ground water, excitation, model assumptions and simplifications, amplification at structure resonances

Vibration + Groundborne Noise

- Rule of thumb predictions eg US FTA manual give a reasonable estimate of vibration and ground-borne noise
- Predictions are no substitute for measurement in sensitive areas
- Consider difficulty of retrofitting mitigation – might seem a big effort to do measurements in preliminary stages, but better to understand issues early

Vibration / GBN Mitigation

- Vehicle: minimize unsprung mass + wheel defects / out of roundness
- Track: design with vibration isolation
  - Add mass and/or resilience
  - For best effect, reduce stiffness and maximise mass above resilient element

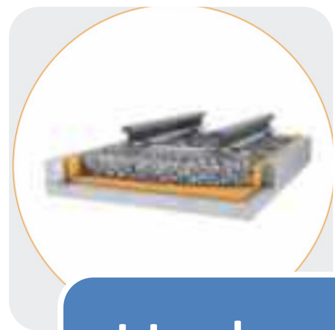


Vibration / GBN Mitigation (ballast)

Increasing benefit with increasing mass above resilient element

Softter rail pads

Under-tie pads



Under-ballast mat

Vibration / GBN Mitigation (slab)

Increasing benefit with increasing mass above resilient element

Softer rail pads

Softer baseplate pads

Booted sleepers

Floating slab

System design principles

- Consider how system design can eliminate noise/vibration issues
  - Route options assessment
  - Curve radius, switch locations
  - Vehicle selection (steering, bogie design, wheel design)
  - Rail hardness
  - Wheel/rail profile design
  - Friction management
- Consider cyclic nature of rail maintenance and difficulty of retrofitting solutions

Operation and maintenance

- Common objectives – minimise wear, maximise wheel and rail life, maximise vehicle life
- Design to maintain
  - Track access for grinding / milling equipment
  - Wayside vs vehicle mounted lubrication and friction modifier

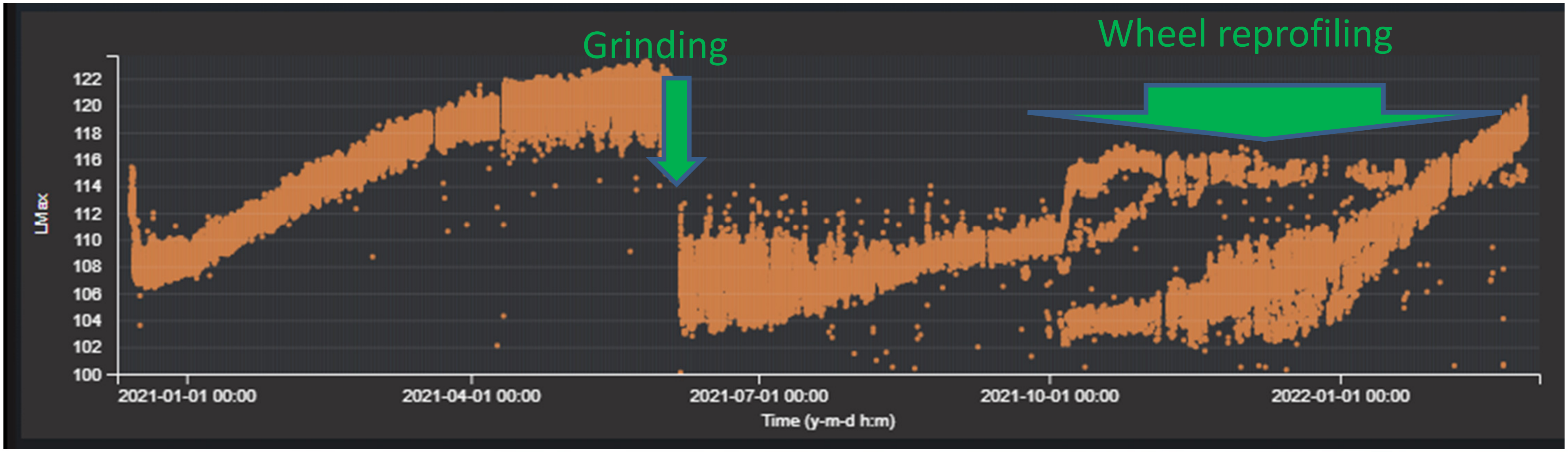
Ongoing monitoring

- More data is not always better, if no-one looks at it
- Monitoring noise and vibration can provide information on wider wheel/rail interface issues
- Network wide data collection is possible
  - Train-mounted accelerometers
  - In car noise

- Opportunities to do more via machine learning, advanced data analysis

Ongoing monitoring example

- Microphone in tunnel at corrugation prone curve
- Shows trends in rail and vehicle maintenance (with train IDs)



Regulatory environment

- Existing freight in North America has minimal regulation of noise or vibration
- New transit systems do have noise and vibration goals
- Assessments for new systems commonly assume everything is always in good condition (not as easy as it sounds to achieve)
- Social license and community relations are increasingly important
- Regulations may not require noise control, but people are starting to expect it
- Noise does affect health. Elsewhere in the world railway noise regulations are rapidly becoming more stringent, expect to see the same in North America

Common objectives

Noise and vibration minimization requires:

- Optimised contact conditions, wheel and rail profiles
- Optimised track components
- Understanding the influence of vehicle design and dynamics
- Lubrication and friction management
- Minimized wear
- Minimized wheel and rail roughness
- Minimized wheel-rail damage / defects
- Ongoing monitoring

Wheel/rail interface

Principles Course agenda

Bonus mystery noise

- Graunching?
- Low speed train on tight curves
- Any ideas what this is?

Discussion + Questions

briony.croft@acousticstudio.com.au

+61 483 134 831