Rail Transit Noise and Vibration

PRINCIPLES COURSE

August 26-28, 2025

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Rail Transit Noise and Vibration

1. Concepts and fundamentals
2. Sources of railway noise and vibration
   - Wheel rail interface root causes
   - Targeted mitigation measures derived from root causes
3. Monitoring and management
   - Monitoring methods, options and examples
   - Considerations in planning new systems
   - Strategies to minimise noise and vibration during operations

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

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

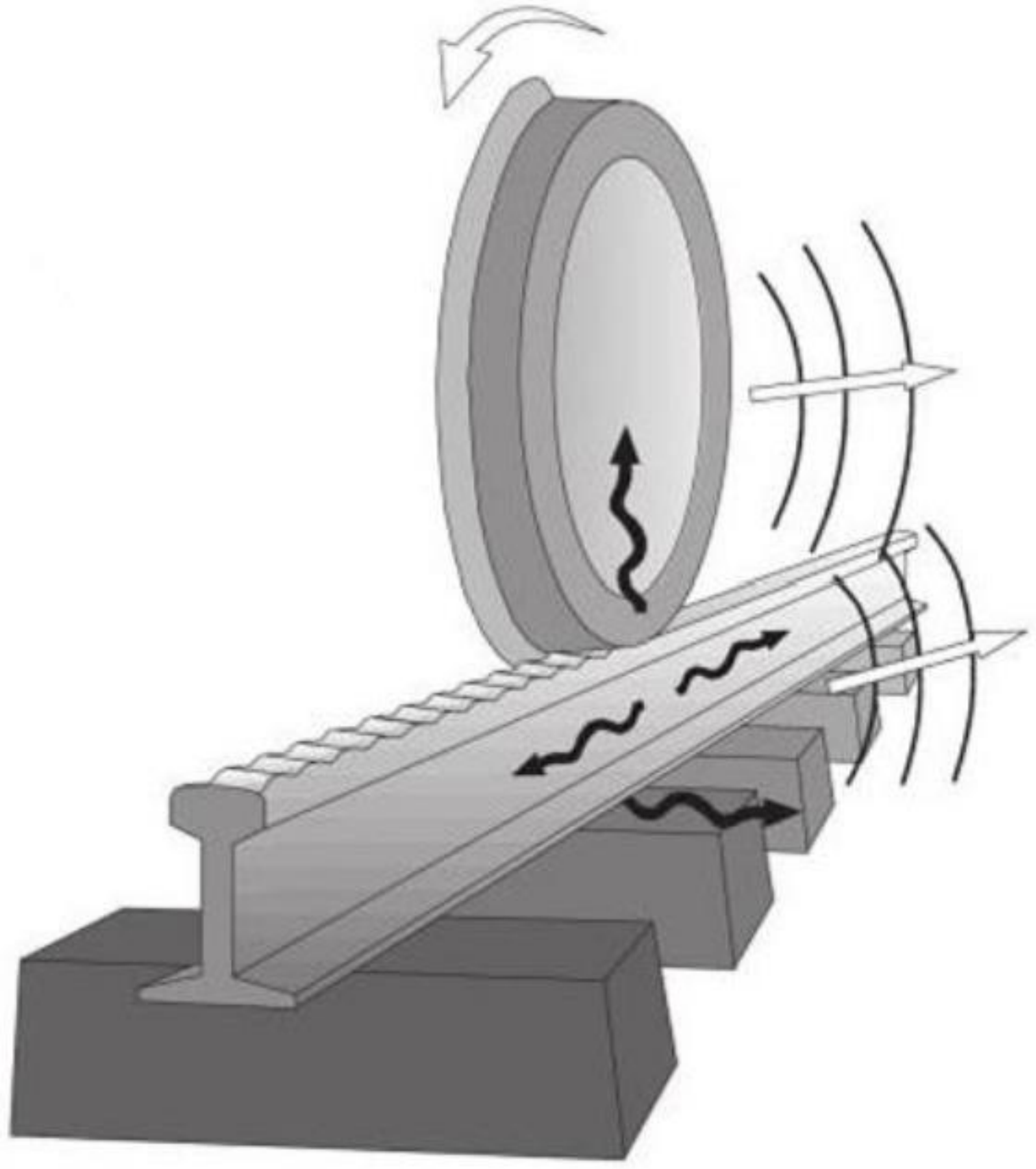


Figure reproduced from *Railway Noise and Vibration Mechanisms, Modelling and Means of Control* David Thompson, 2024 [1]

Fundamentals – Frequency Content

Frequency (Hertz) is the number of oscillations per second

- determines the pitch of sound

Noise and vibration from rail transit occurs 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 Diesel engine noise	Ground-borne noise, structure radiated noise, rumbling of floating slab track	Rolling noise, corrugation, impact noise, traction noise	Curve squeal noise, flanging, brake squeal

Fundamentals – decibel noise levels

The decibel (dB) describes the loudness of sounds

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

dB ≠ dBA

There are other weightings

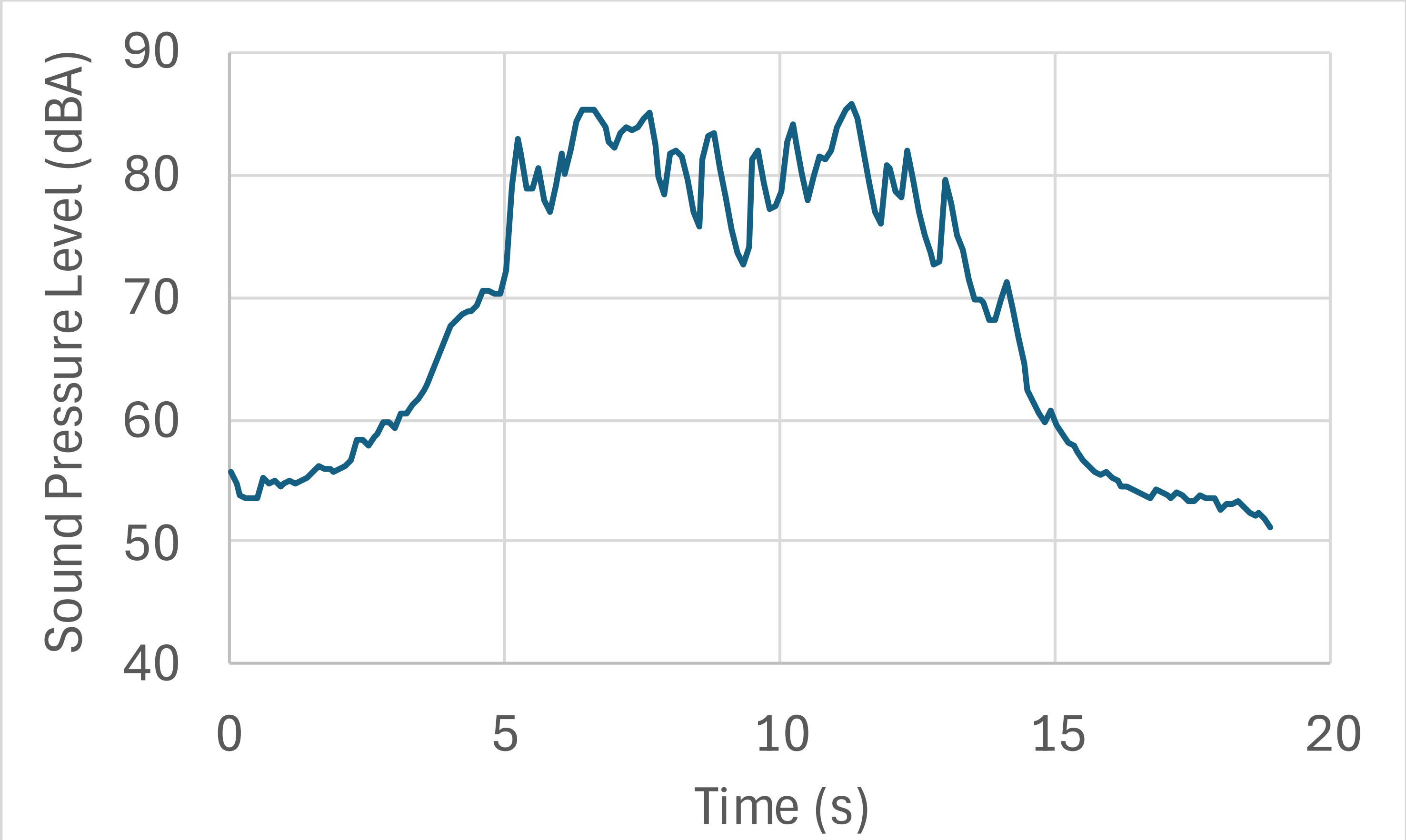
dB, dBA, dBLin, dBZ, dBC …

dBA	Example	
130	Threshold of pain	Intolerable Extremely Noisy
120	Heavy rock concert	
110	Grinding on steel	Very noisy
100	Loud car horn at 3m	
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	

Fundamentals – time varying descriptors

Railway noise and vibration varies over time:

- The maximum noise level L_{Amax} during this train passby is 86 dBA
- The equivalent average L_{Aeq} railway noise level during the passby is 81 dBA
- The equivalent average L_{Aeq} railway noise level for one train passby in an 9 hour night is 46 dBA
- The day –night noise level L_{DN} noise level for 8 train passbys during the night plus 24 during the daytime is 61 dBA
- There are other statistical descriptors of noise level over time – many describe noise averaged over time
- Not all decibels or dBA levels are directly comparable



Sources of noise and vibration

Curves

Corrugation

Rolling contact

Switch impacts

Wheel flats

Flanging

Grinding induced roughness

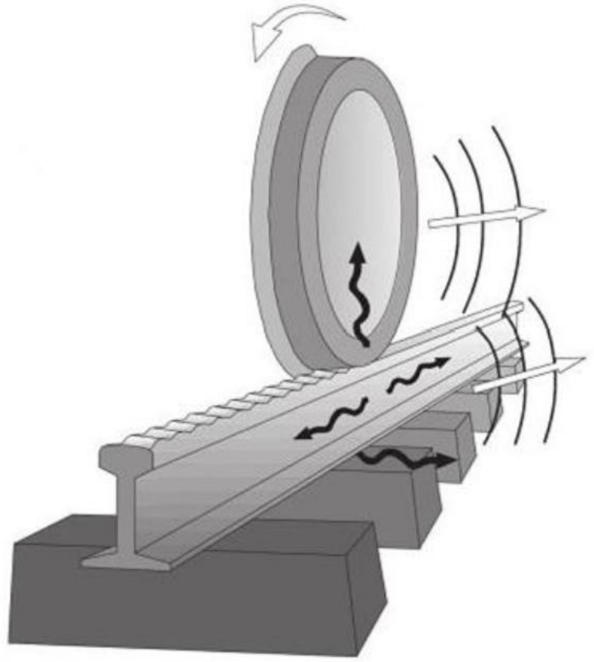
Traction systems

Rolling Noise

Broadband (not tonal) mid frequency noise 300 - 2000 Hz, always present with wheel/rail contact

Rolling noise level depends on:

- Rail roughness
- Wheel roughness
- Wheel design (size, shape)
- Track design (components, support stiffness)
- Train speed



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Corrugation

Rolling noise dominated by a particular frequency (tonal)

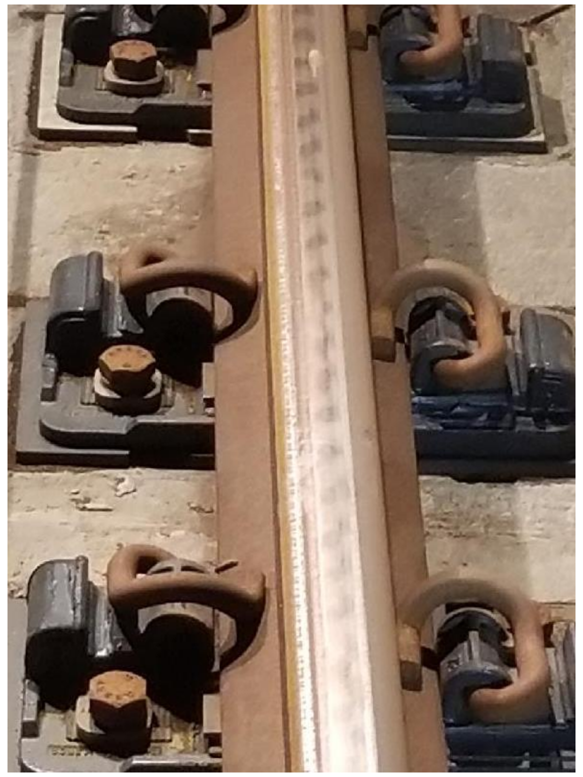
$$frequency = \frac{train\ speed}{corrugation\ wavelength}$$

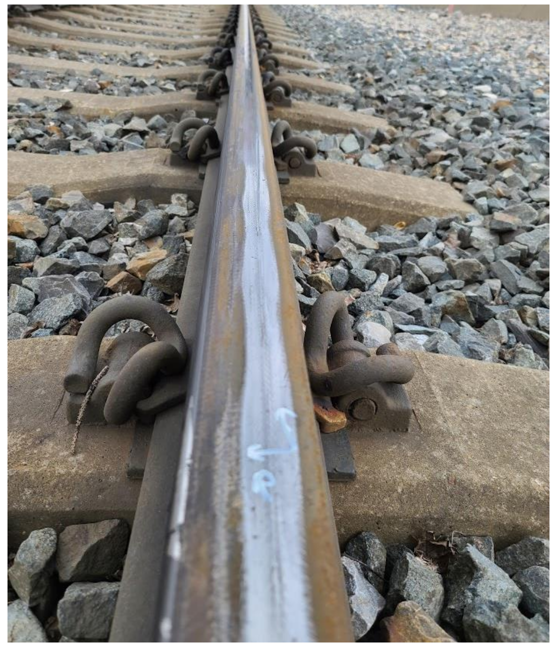
Appears on all types of systems, straight track and curves, can have wide range of wavelengths

Particularly common issue for metros on low rail of curves - linked to torsional resonance of driven axles

Multiple mechanisms

Conflicting anecdotes about causes

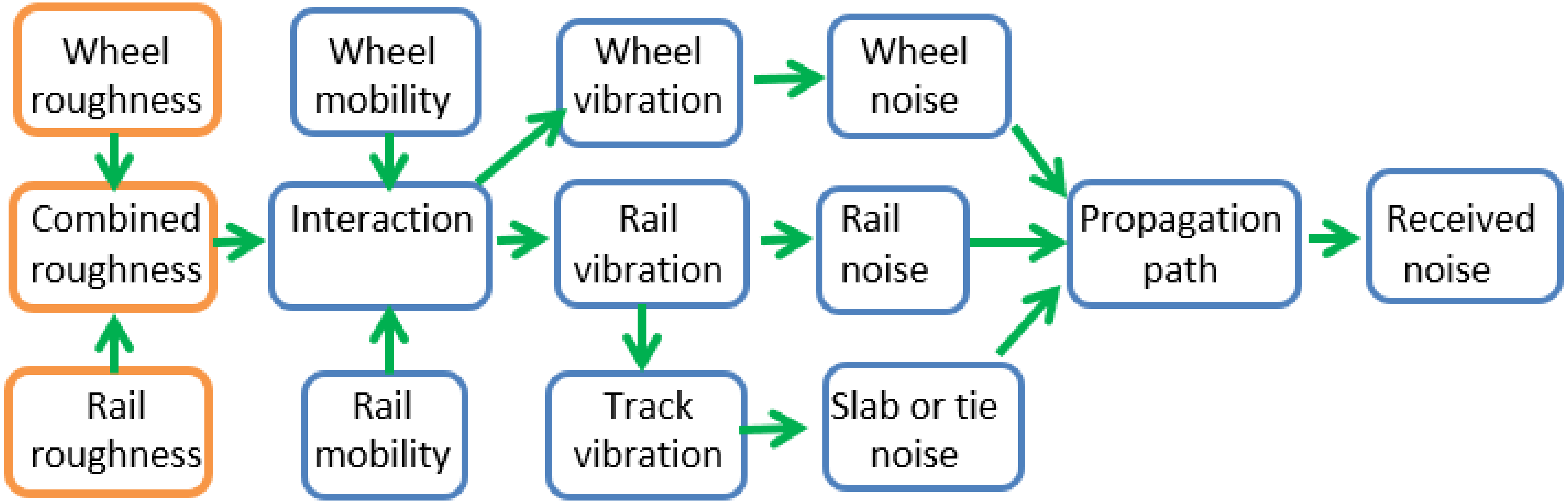




Corrugation example

Mitigation principles – rolling noise

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 examples

Smoother rails

Rail dampers + track absorption
(applicable only in specific situations)

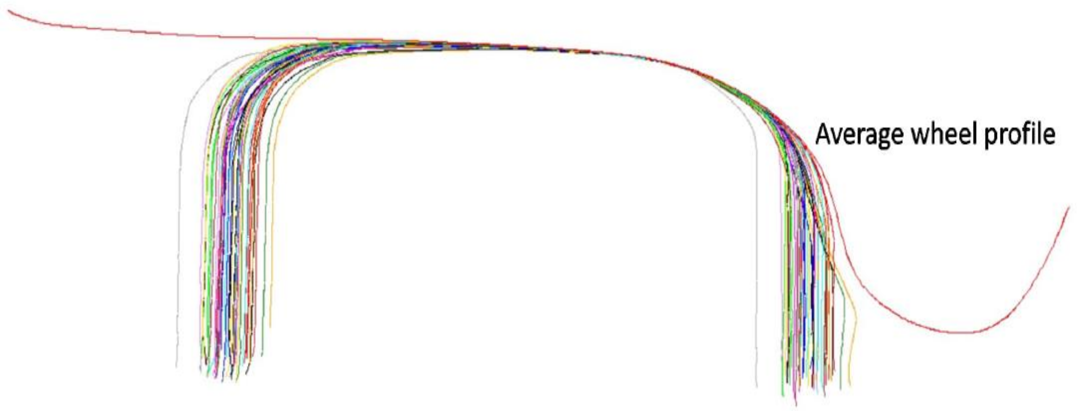
Corrugation – specific mitigation

Immediate / direct / mechanical means:

- Grinding / milling
- Maintenance grinding / rail reprofiling can increase roughness and noise if rails are not corrugated

Long term:

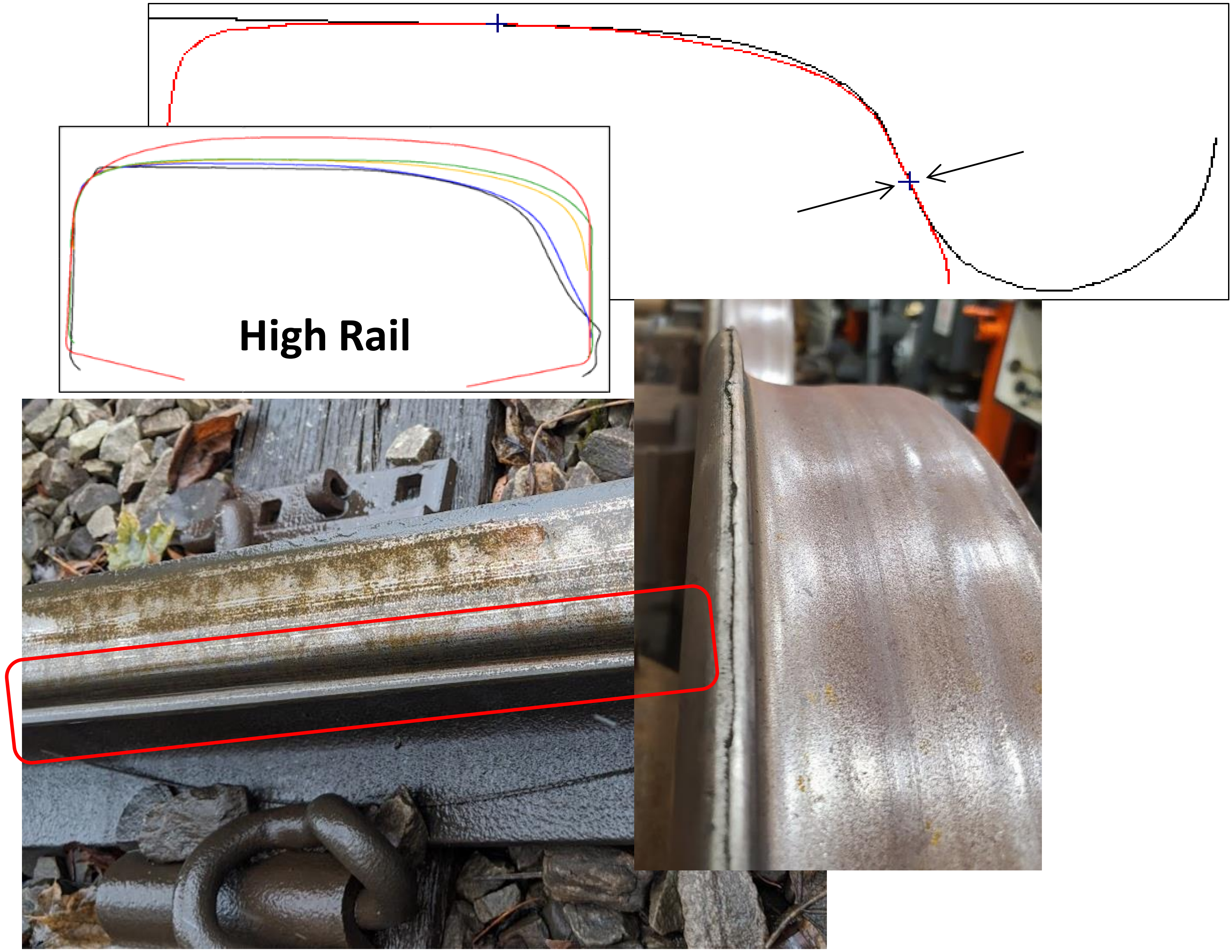
- Optimize wheel and rail profiles
- Friction modifiers – reducing top of rail friction reduces wear, so corrugation takes longer to grow
- Rail hardness – hard rails reduce wear, so corrugation takes longer to grow
- Harder rails require different grinding strategies (need better acoustic surface finish with harder rails)
- Avoiding / shifting resonances (but hard to guarantee outcome)



Flanging noise

- High frequency > 2000 Hz
- Sound is a mix of tones and can excite several wheel modes

- Typically associated with curves (sharp curves)
- Can indicate wheel/rail interface or steering issues (angle of attack)



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Wheel/curve Squeal

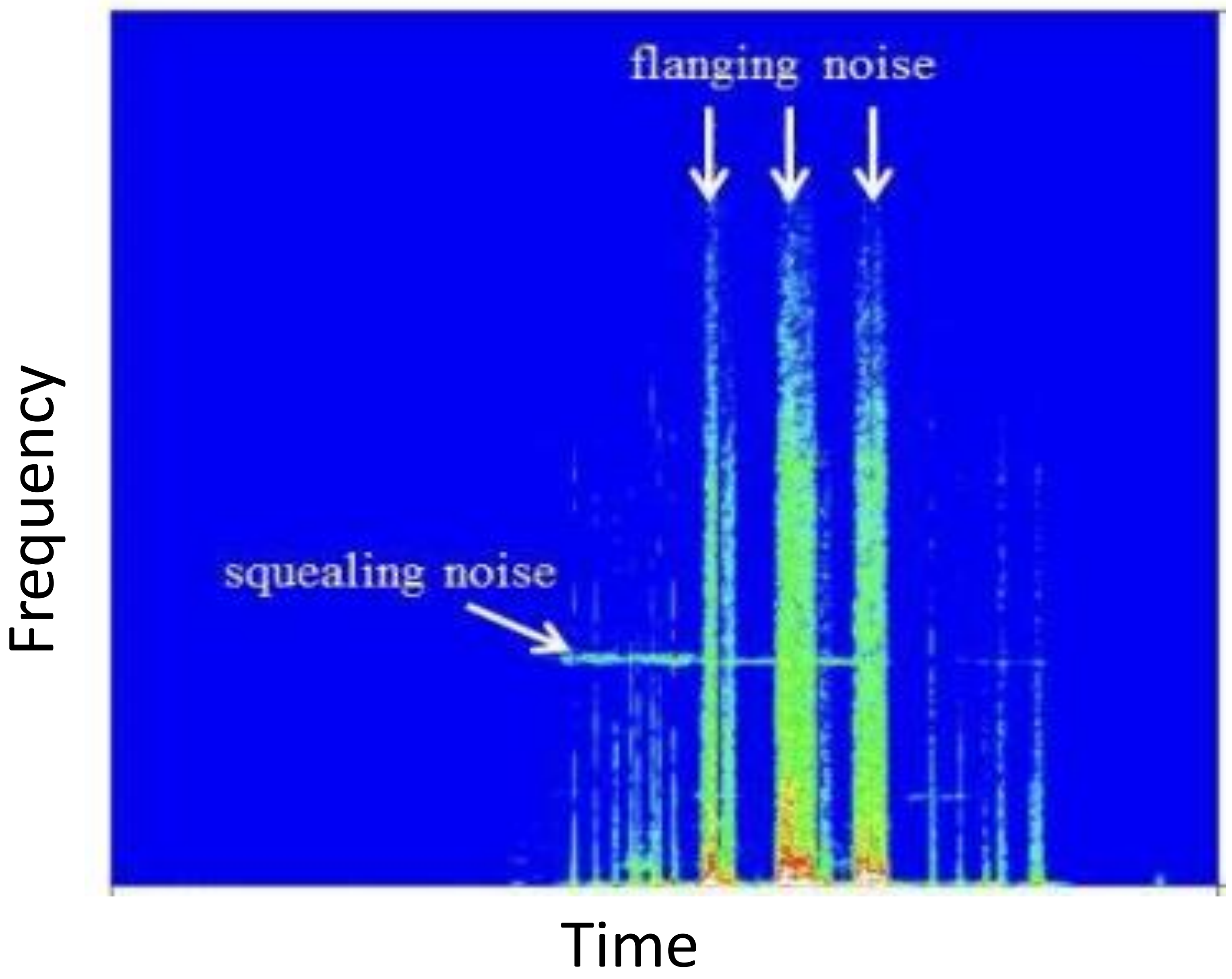
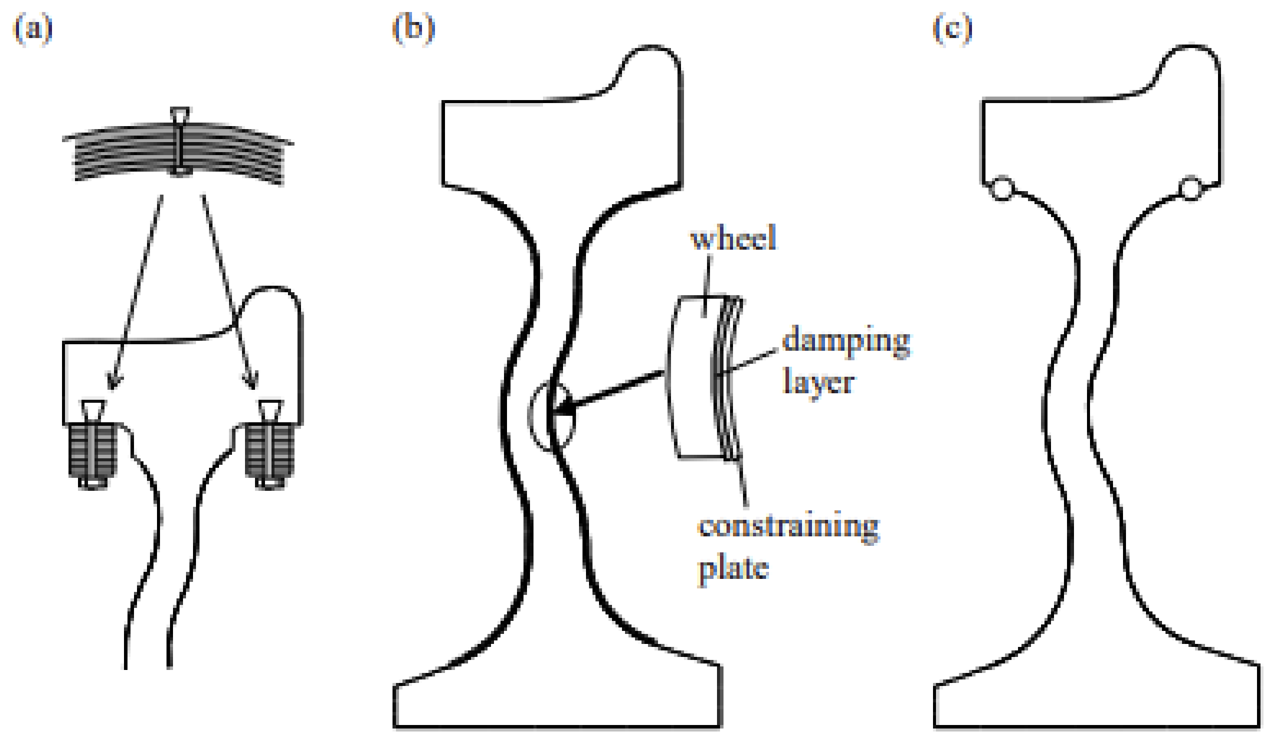


Image from Helmut Venghaus: *The impact of weather conditions on the noise radiation level of curve squeal* (IWRN13, Ghent, 2019)

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

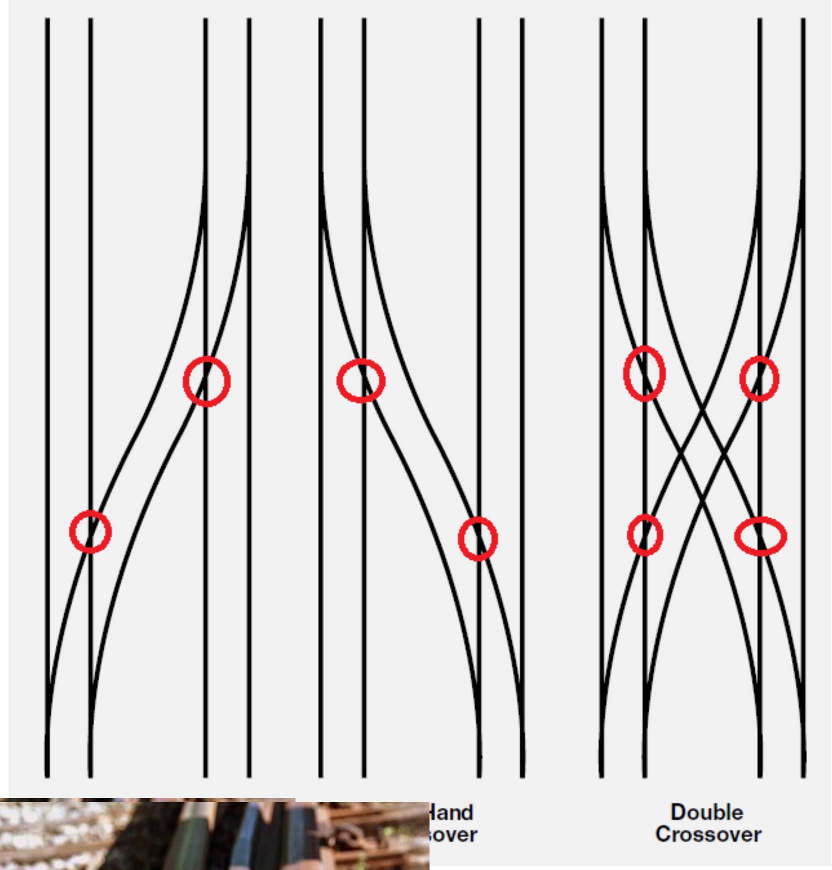
Mitigation – flanging and squeal

- Maximise curve radius in design
- Vehicle steering, truck design, angle of attack
- Resilient wheels
- Wheel dampers
- Vehicle based wheel flange lubrication
- TORFM (improving steering through curves)
- Optimise wheel/rail profile design
- Wayside gauge face or check rail lubrication
- Gauge widening / dynamic gauge widening
- Gauge narrowing (systems with check rail)



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)

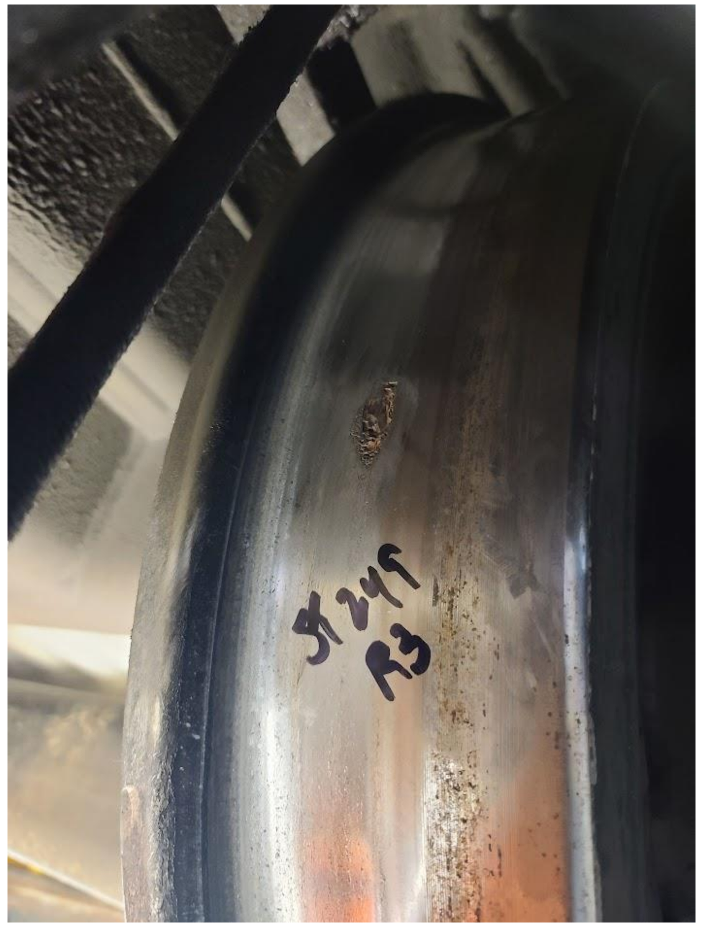
Switch impact noise

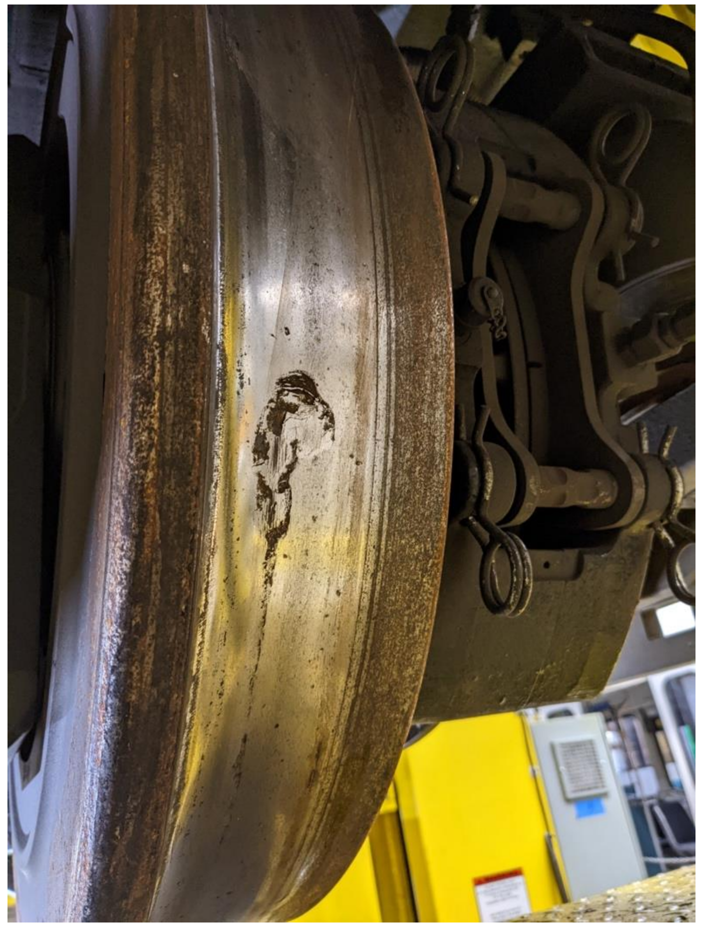


- Predictions / modelling typically add 10 dB correction at each discontinuity
- Noise proportional to size of discontinuity
- Similar to noise over a rail defect

Wheel flats

- Noise and vibration proportional to size of discontinuity
- Wheel flats on rolling stock can increase rolling noise by up to 12 dBA [2]
- Some new generation passenger trains produce 5 dB less vibration on average than older trains (wheel slide protection system improvements) [3]
- “New” does not guarantee less wheel flats – in several cases newer trains result in increased wheel flats





Mitigation – wheel flats

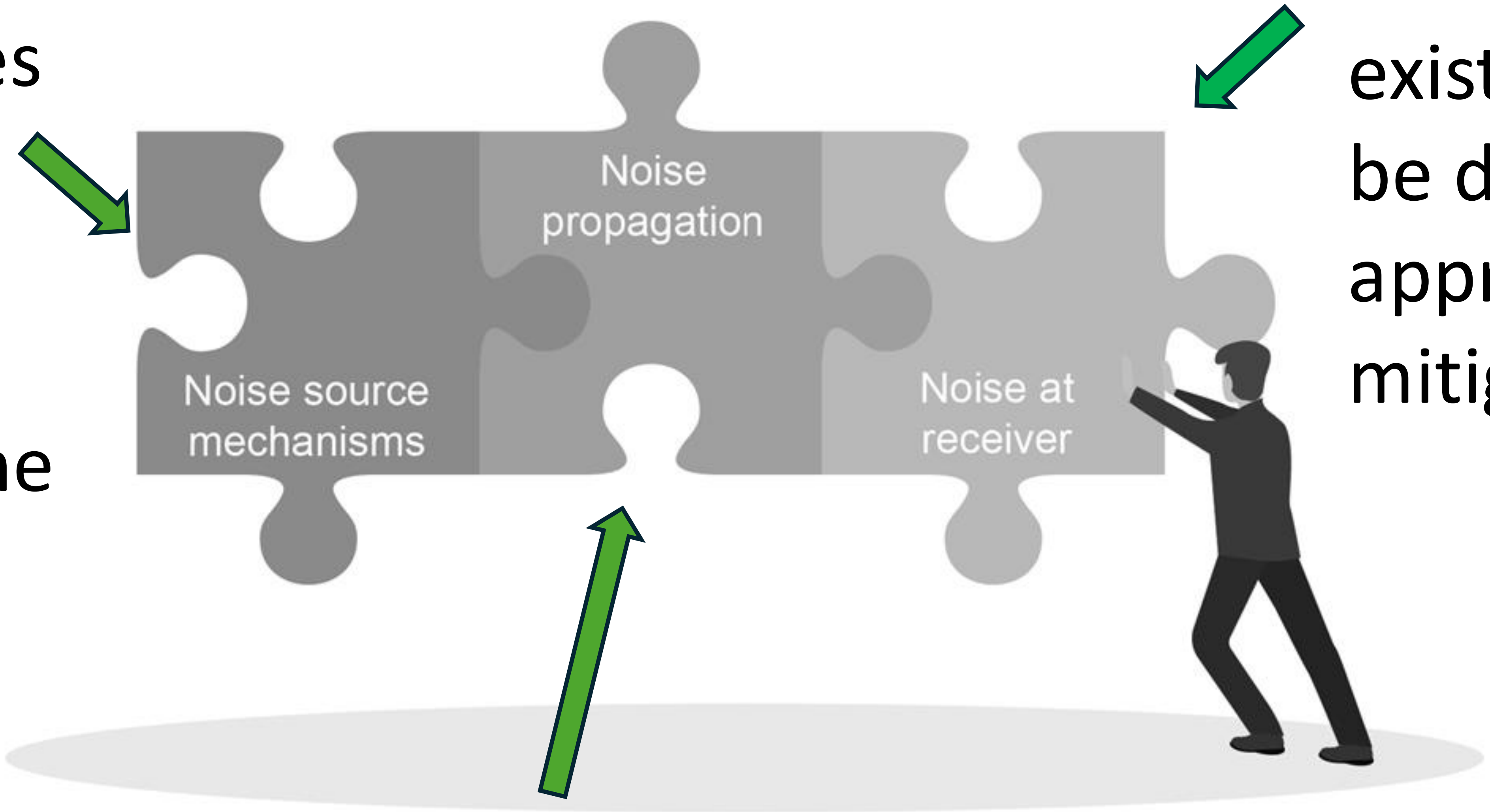
- Wheel impact load detectors
- Reprofiling
- Optimizing friction management

- Wheel slide protection systems
- Driverless trains
- Driver training/review of operating practices

- Braking software / programming (may need recertification of vehicles)

Summary of mitigation considerations

Most of the measures identified and discussed today are "source control". Typically these are the most cost effective.

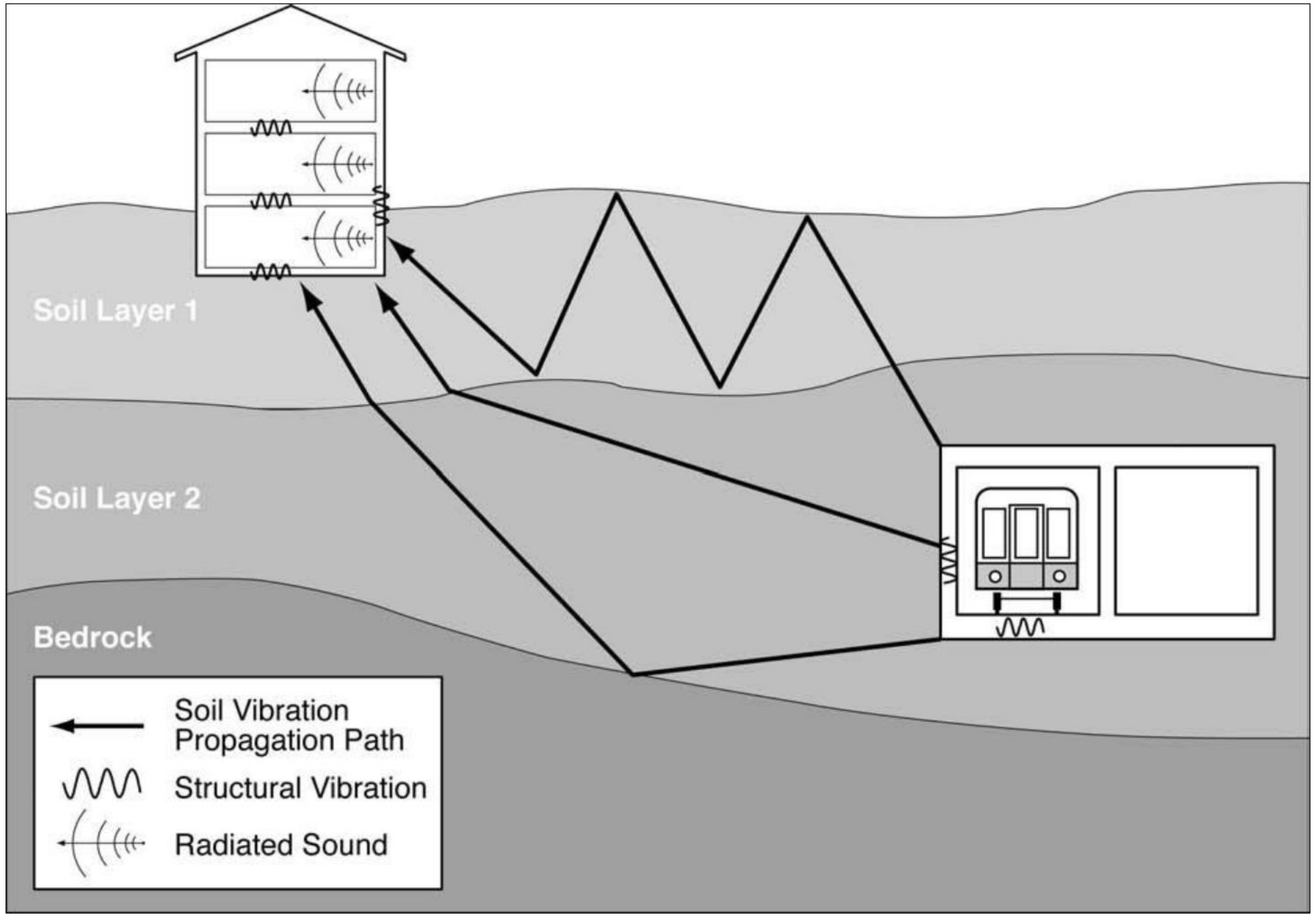


New buildings near existing transit must be designed appropriately to mitigate the noise

Barriers and track absorption can be effective in some situations

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

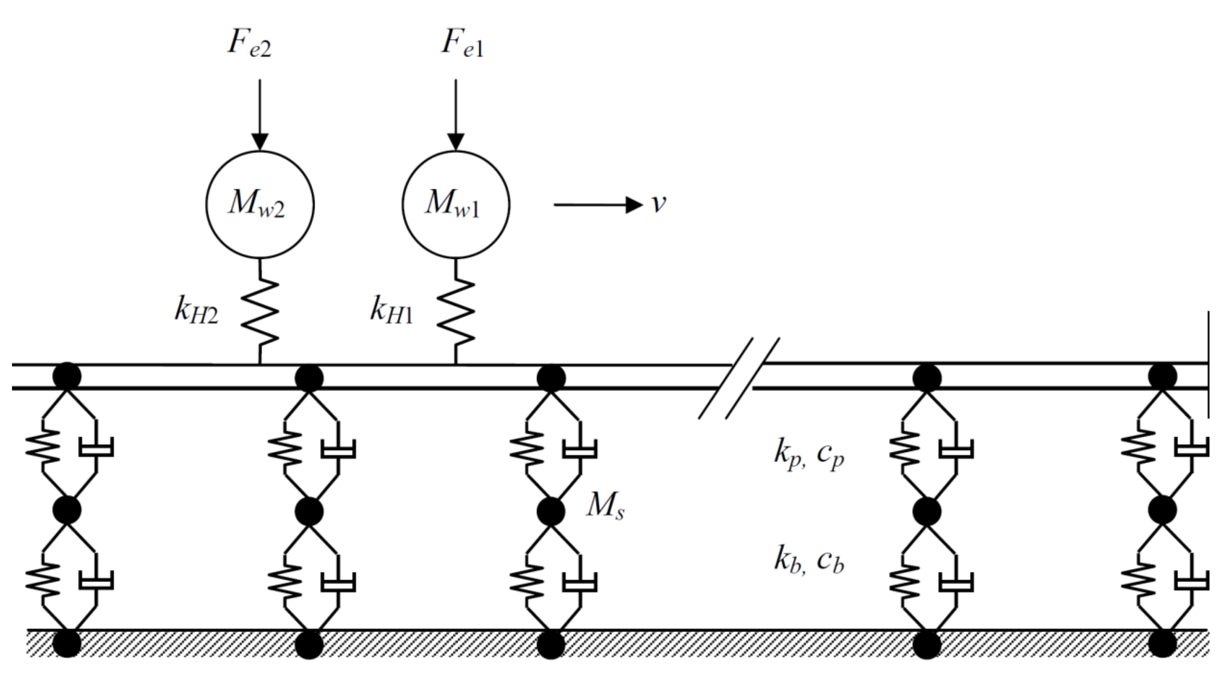
15 % change in soil parameters -> 6 dB change in vibration prediction

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

Vibration + Groundborne Noise

- Empirical predictions eg US FTA manual give a reasonable estimate of vibration and ground-borne noise
- General 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
- Minimize wheel defects / out of roundness
- Resilient wheels

Track:

- Design with vibration isolation
- Add mass and/or resilience in appropriate places
- For best effect, reduce stiffness and maximise mass above resilient element

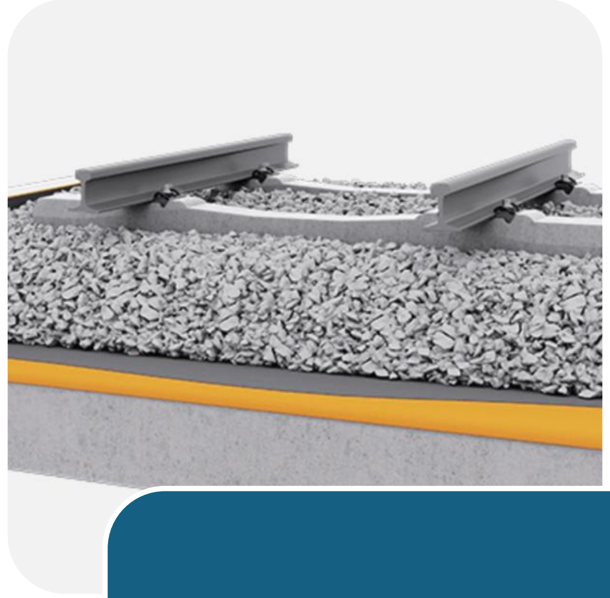
Vibration / GBN Mitigation (ballast)

Increasing benefit with increasing mass above resilient element

Images from Getzner

Softer rail pads

Under-tie pads



Under-ballast mat, tire-derived aggregate

Vibration / GBN Mitigation (slab)

Increasing benefit with increasing mass above resilient element

Images from Getzner

Softer rail pads

Softer baseplate pads

Booted sleepers

Floating slab

Measurement/monitoring overview

Duration – discrete events, days, weeks, ongoing?
Measurement parameter – logging time history, LAmax, Passby LAeq, 9hr night LAeq, 15hr day LAeq?

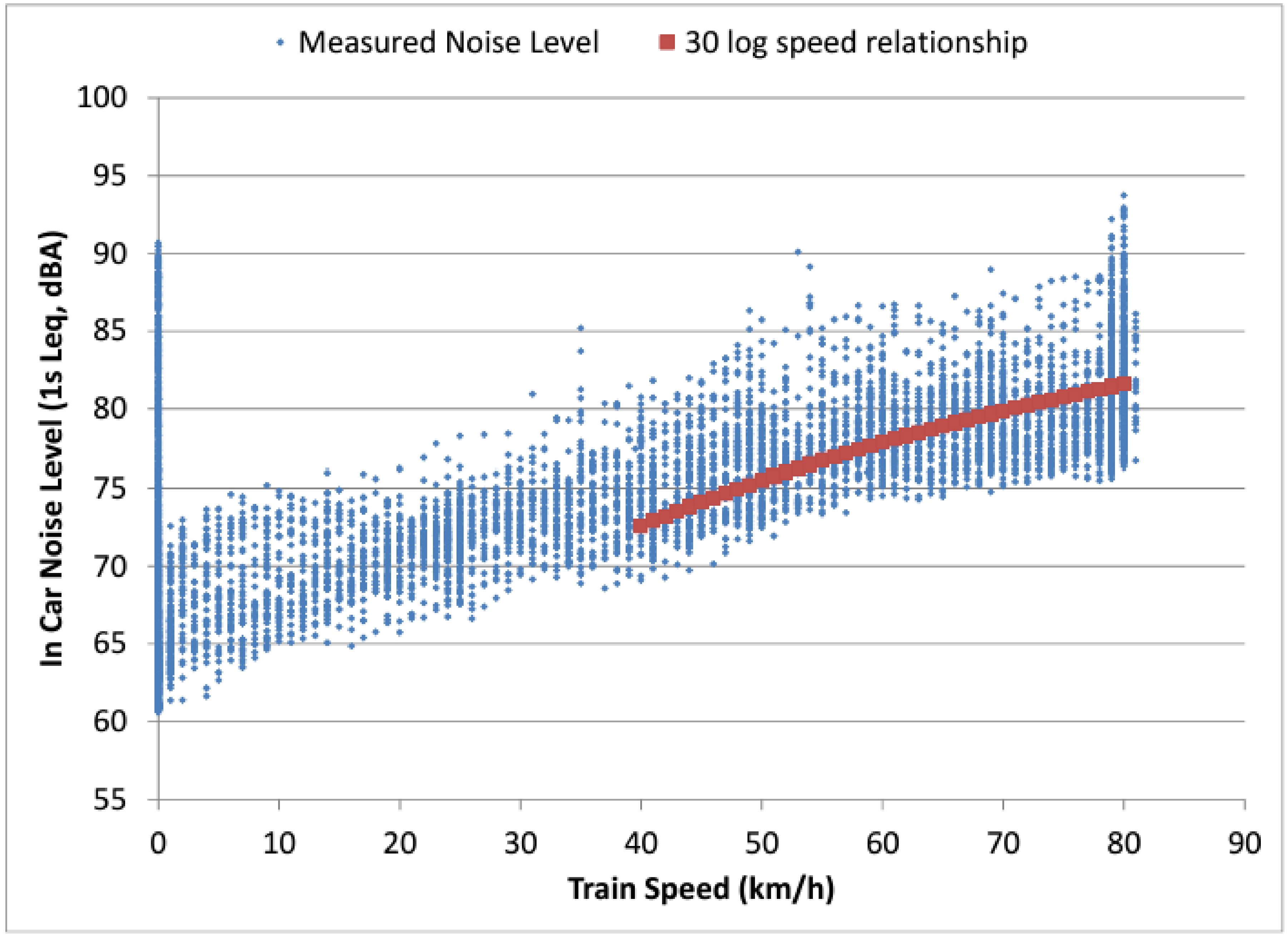
Problem	Monitoring options	Possibilities	
Noise or vibration	Onboard	Microphone in car	Assess noise variation network wide (if large variations exist). Operator attended to locate hotspots, diagnose/identify source.
		Accelerometers (axle box, truck, in car)	Ride quality / track condition systemwide, axle vibration as proxy for whole network rolling noise
	Wayside	Microphone trackside (near-field or far-field)	Quantify noise at specific location, compare to guideline levels or criteria (compliance check)
		Accelerometers (rail, tie, slab, ground, receiver)	Quantify vibration at specific location, characterise track dynamic behaviour, compare to guideline levels or criteria
		Others (no trains)	Track inspection, geometry, tolerances, rail profiles, rail roughness, track decay rate, frequency response functions

Compliance vs knowledge

- Monitoring for compliance - must measure and report noise at the receiver to assess to the criterion

- Understanding the issue may require additional information:
  - Observations noting noise character and frequency content
  - Track components and condition
  - Any defects?
  - Status of lubrication systems
  - Grinding / maintenance history

Onboard monitoring - noise



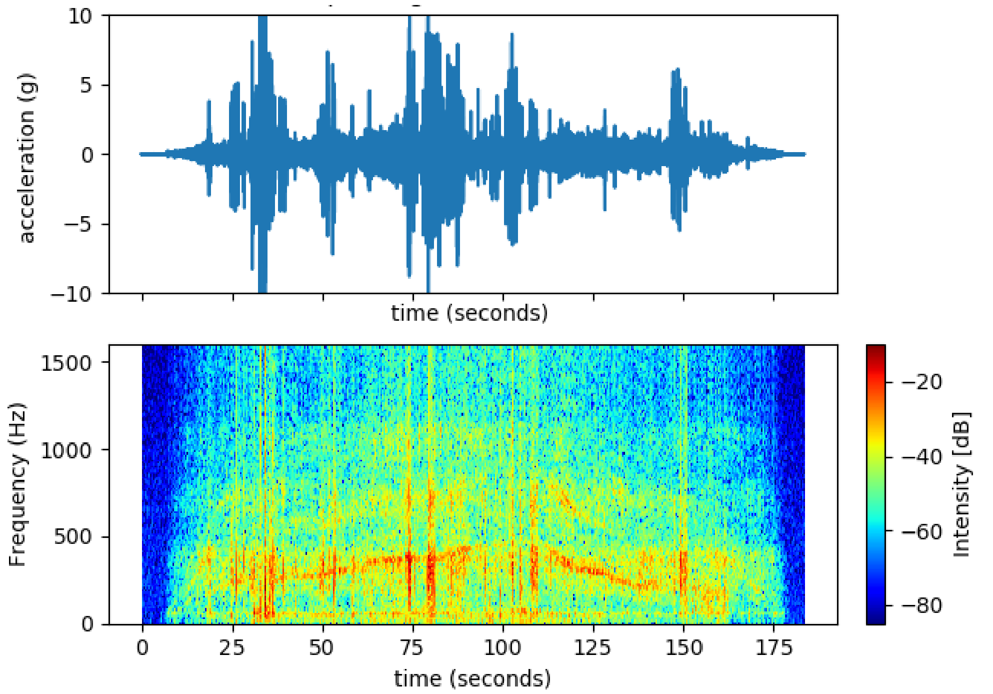
- Sound level meter (microphone) in passenger cabin
- Shows variation in internal noise around network
- 15-20 dBA range at top speed

- Attended measurements onboard useful for diagnosis – squeal vs corrugation, locating hotspots
- Can trend over time vs location*
- Need large variation to be useful

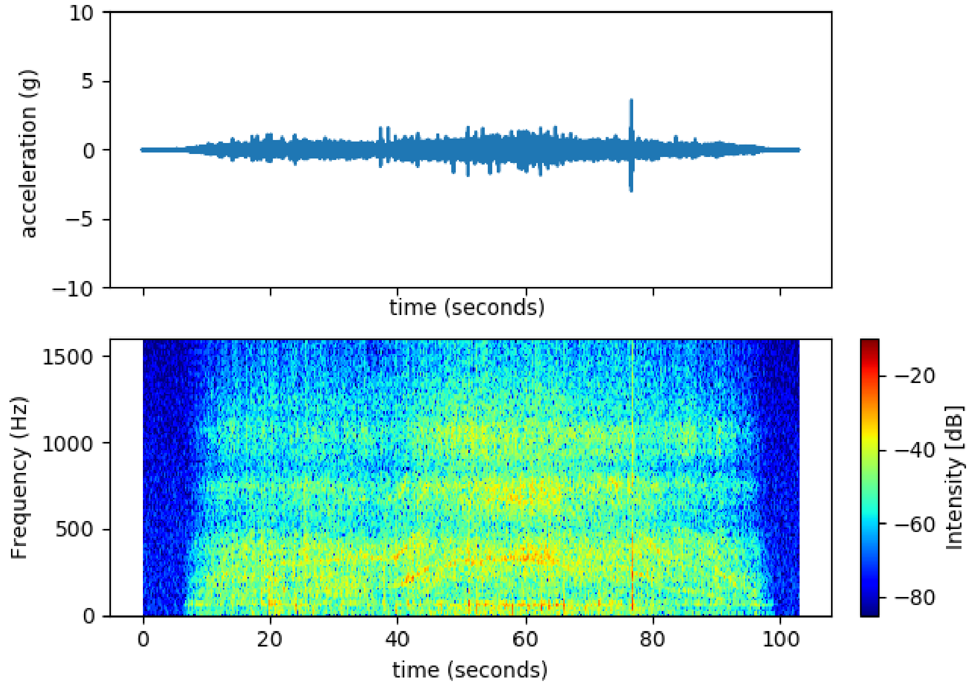
Onboard monitoring – axle vibration

- Wired or wireless
- Can catch corrugation, ride quality, and discrete impacts
- Vehicle-to-vehicle comparisons
- Pre/post analysis of maintenance activities
- System-wide assessment and prioritization (mainline and switches)

“Rough”



“Smooth”



Wayside noise monitoring – short term

- Sound level meter (microphone)
- Attended measurement can diagnose issue at a particular location, get frequency content, check compliance
- Unattended (eg 1 week logging) can give statistically representative number of passby events

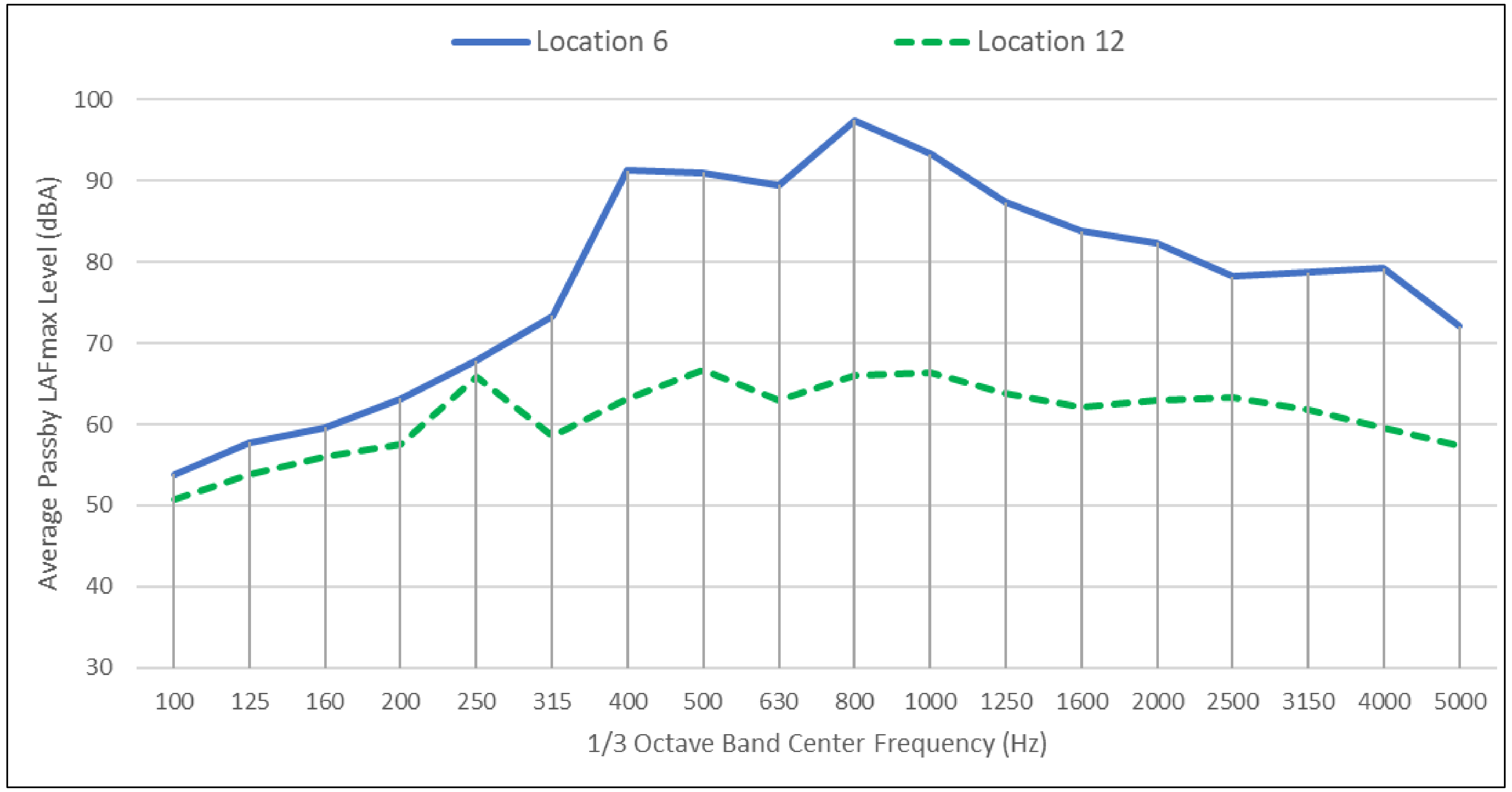
- Single point in time
- Need understanding of track condition / maintenance state

Short term wayside monitoring example

Location Ref.	L_{AFmax} (dBA) corrected to 15m and 80 km/h	
	IB	OB
1	85	82
2	84	82
3	83	89
4	84	78
5	88	77
6*	101	82
7	83	89
8*	92	88
9	81	83
10	83	81
11*	85	80
12	75	81
13	80	83
14	80	83

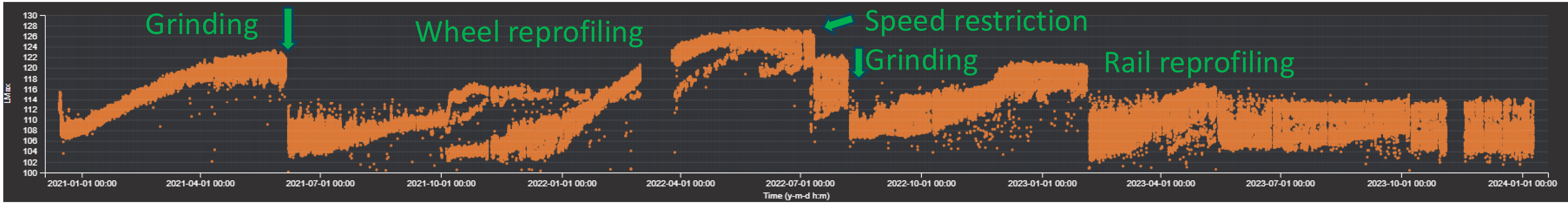
*** Microphone somewhat below guideway height, possibly reducing measured levels especially on far track**

Differences can be attributed to rail condition
Same rolling stock and track components, speed and distance corrected



Data reproduced from Croft et al: *Maintenance effects on rolling noise – metro and light rail* (Acoustics 2021, Wollongong)

Wayside noise monitoring – long term



Jan 2021 **Jan 2022** **Jan 2023** **Jan 2024**

- Microphone in a tunnel at a corrugation prone curve over 3 years
- At times, showed 20 dBA noise increase over about 6 months
- Shows trends in rail and vehicle maintenance (each point has train ID)
- System transitioning to compatible wheel/rail profiles – noise has become much more stable
- Still a large (10 dBA) spread in results for different trains

Planning and design

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

Design to maintain – consider track access for maintenance equipment, benefits of vehicle vs wayside friction management etc

Operation and maintenance

Common objectives: minimizing noise and vibration also minimizes wear, maximises asset life

Cost-effectiveness

- Minimizing corrugation grinding interventions is worth $$$$
- At-source mitigation measures for noise can reduce ongoing maintenance costs
- Reducing rail roughness is often the most effective noise control [4]

Aim for preventative rather than corrective maintenance

- Optimize use of track access time and minimize metal removal
- Reduce risk of more severe surface defects and rail replacement
- Spend more time in best-case condition

Achieving noise and vibration objectives overlaps with best practices in maintaining and achieving state-of-good-repair

Wheel-Rail Noise & Vibration References

1. David Thompson, 2024. *Railway Noise and Vibration Mechanisms, Modelling and Means of Control*.
2. TfNSW (2015) *T MU EN 00002 TI ASA Rail Noise Database*.
3. Croft et al (2022) Investigation of differences in wayside ground vibration associated with train type. Proceedings of International Workshop on Railway Noise (IWRN 14), Shanghai.
4. Croft et al (2024) Rail acoustic roughness outcomes following maintenance interventions. Proceedings of Meetings on Acoustics POMA-D-24-00041

Questions + discussion

b.croft@sahaya.ca