Studs, Squats, and similar damage mechanisms

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Outline

- History of Squats
- The new Squat => Squat-type defect (stud)
- European and Australian research since 1990
- North American case studies

History of Squats

- In Japan observed since 1950s on Shinkansen high speed tracks – dark spots
- In France and UK since the late 1970's
- Massed renaissance in Europe/Australia since the late 1990s

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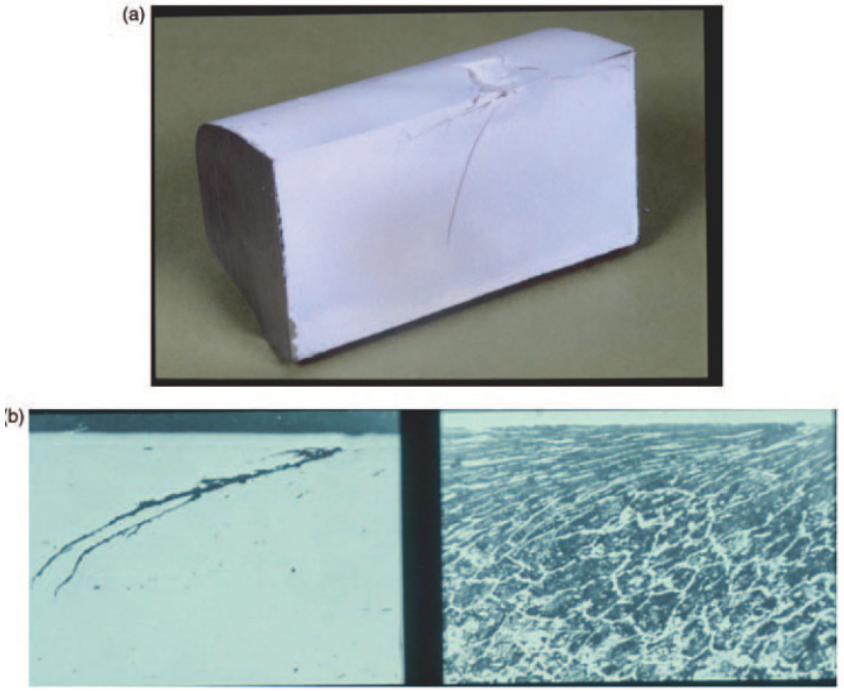
Squat-Defect

- Kidney shaped widening of the contact band (dark spot)
- V-Crack (gauge side)
- Full grown defect:
  - Crack re-surfacing on field side

Photo: voestalpine

Characteristics of a Squat (Pre 1990)

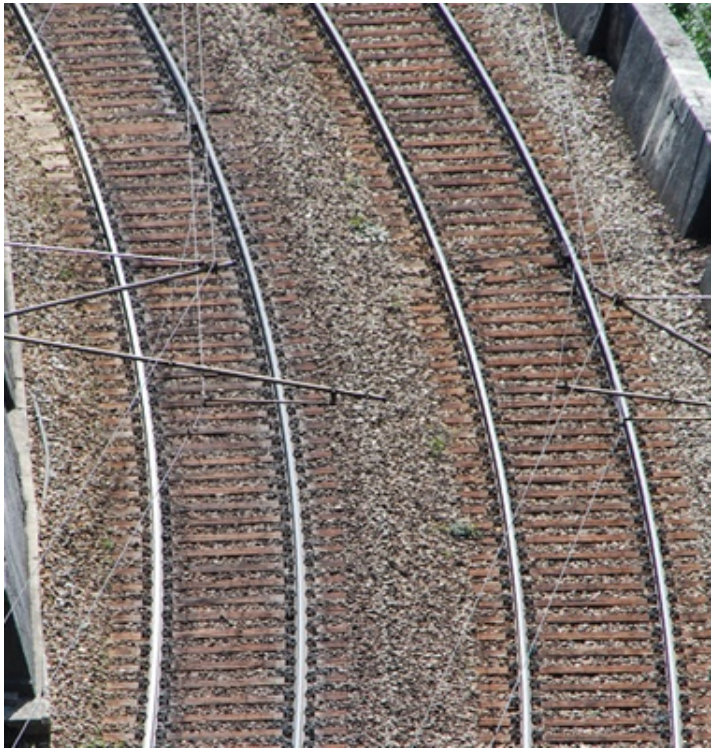
- Heavily sheared rail surface
- Crack initiation and growth by ratcheting (RCF)
- Initiation after a few 10s of MGT
- Slow growth (within 100+ MGT) to full size
- Straight track and shallow curves
- Can result in rail break



Photos taken from: S.L. Grassie: Squats and squat-type defects in rails: the understanding to date. In Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 2012, Volume 226, Issue 3, 235 – 242
Original: British Rail Research, CO Frederick

Solution of the Problem

- Introduction of cyclic-preventive maintenance
  - Frequent removal of damaged layer
- Introduction of higher strength rail grades
  - From R200/R220 to R260
  - Less plastic deformation and damage



The NEW Squat

- Mid 1990s reports of increased Squat appearance
- Superficial similarity to Squats
- Massed appearance

The Squat-Type Defect (stud)

- Characteristics:
  - Almost no plastic deformation
  - Formation within 10MGT or less
  - Old and new rails, tangent and curves
  - Presence of WELs
  - Not found in tunnels
- Preventive rail maintenance strategies of limited mitigation success

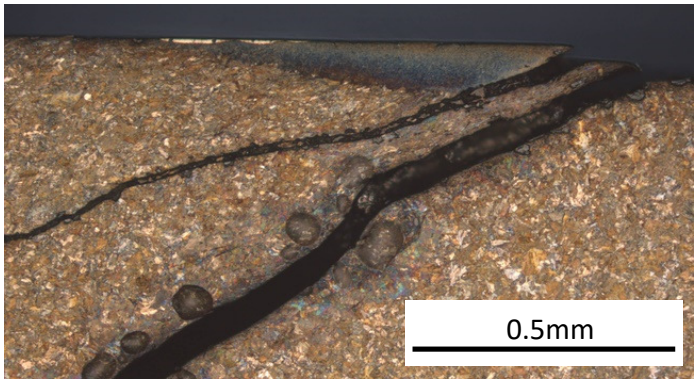


Photo by voestalpine

RESEARCH CONDUCTED IN EUROPE AND AUSTRALIA SINCE THE 1990S

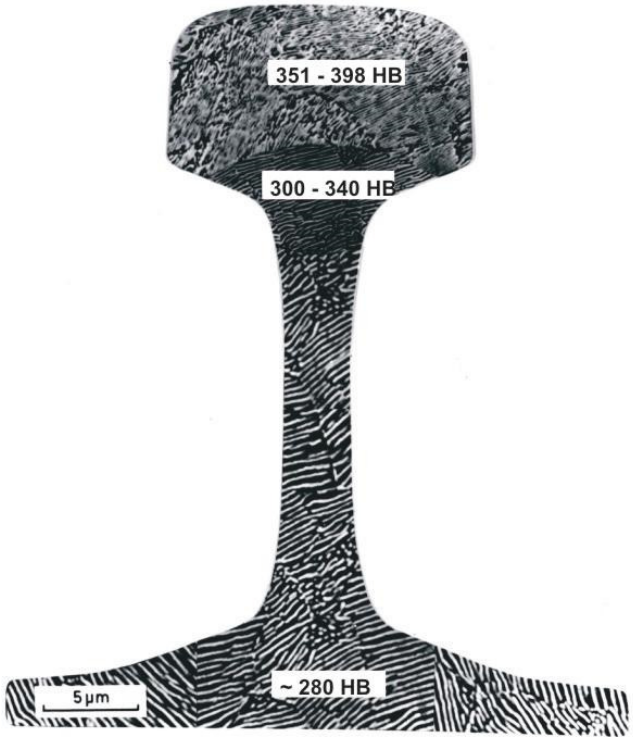
Finding a Cause

- In the late 1990s, early 2000s a lot of research activity focused (again) on Squats
- First Question asked:
  - What has changed?
- Quick answer found:
  - Heat Treated Rails (introduced around the same time)

Photo by voestalpine

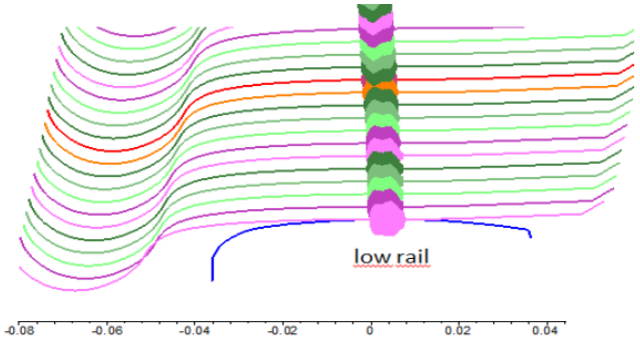
Heat Treated (HT) Rails

- Premium (HT) rails:
  - increased hardness and strength, similar toughness
  - Increased wear and RCF resistance
- Squats found on premium (increased likelihood) and on standard grade rails
- Conclusion: Studs in areas with low rail wear

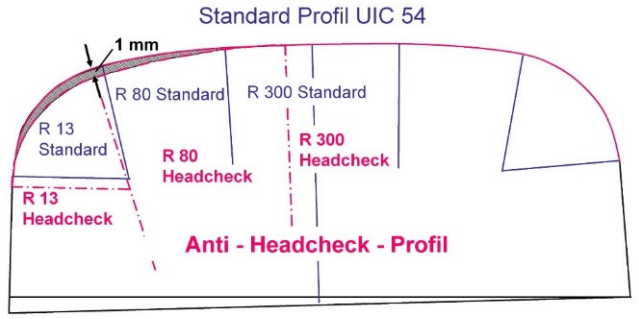


Profiles

- Anti-Head Check profiles introduced in 1990s
  - Gauge corner undercutting
  - Concentrating contact on TOR
- Conclusion: concentrated contact conditions favor formation of studs
- Especially of concern when <u>combined</u> with low wear situations



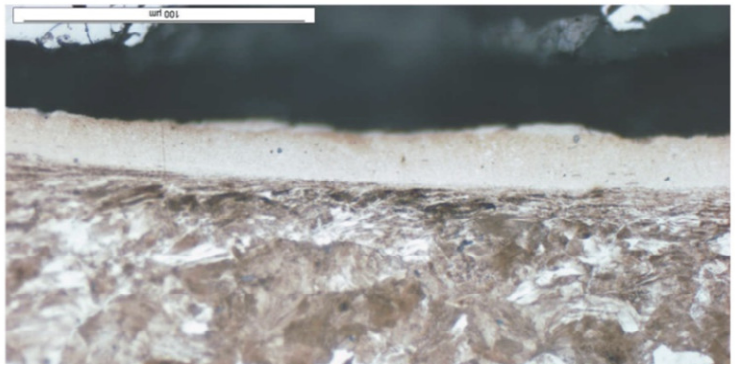
A. Jörg, R. Stock, S. Scheriau, H.P. Brantner, B. Knoll, M. Mach, W. Daves. The Squat Condition of Rail Materials - a Novel Approach to Squat Prevention. Proceedings of CM2015 conference.

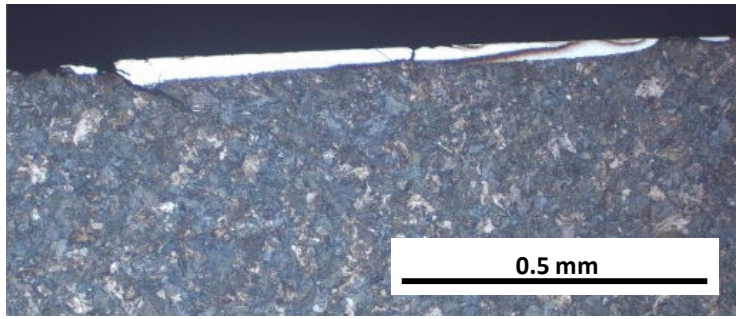


R. Stock, W. Schöch: Keeping Rolling Contact Fatigue under Control - Steel Grade Selection & Appropriate Rail Maintenance. WRI 2011 Conference, Chicago

White Etching Layer (WEL)

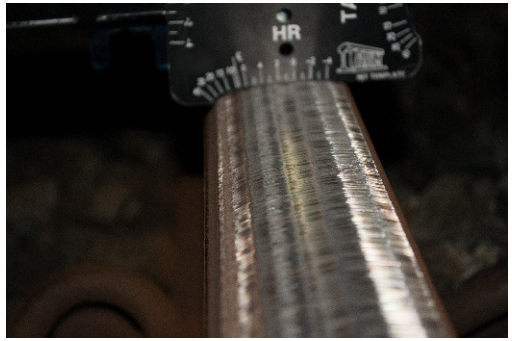
- Thin, hard layer on rail surface
  - Cause: thermal transformation
- WELs always present at Studs – contributing factor
- WELs found everywhere in track (not only at Stud areas)
  - Usually, these layers wear away





WEL and Rail Maintenance

- WELs can be caused by rail grinding
  - Dependent on grinding parameters
- Rail grinding creates facets and grinding marks
  - Both can act as stress risers
- Milling does not result in WEL
  - However: polishing process can result in WEL
- Newest research results indicated that WEL after rail maintenance has minor impact on Stud formation



Traction Systems

- Significant changes in traction technology since 1990s
  - DC to AC traction systems (increased tractive forces and higher slip)
  - Trains with multiple driven axles
  - Individual wheelset control instead of traction groups
- Significant increase of traction forces during the last 30 years

Traction Systems and WEL

- Traction and braking can cause WELs
- Traction and braking systems are proprietary technologies of OEMs – black box
- Friction conditions will change along the track and with time of day and season
- Interaction of these systems with (rapidly) changing friction conditions unclear

System Stiffness

- Empirical evidence: Stiff vehicle suspension or stiff track structures favor formation of Studs
- High system stiffness will increase dynamic reaction of vehicles

Studs

- Complex, multifactor problem
- Each factor individually not a problem
- Combination of factors will result in Stud formation

Seattle, Vancouver, Others

CASE STUDIES ON THE APPEARANCE OF THESE DEFECTS IN NORTH AMERICA

Seattle Sound Transit

- Specific 5-mile segment of elevated track
  - Includes high speed segment (55 mph)
- Occurs in tangent, curves, and grades
  - First high occurrence area was level, tangent track with corrugation
- Started in small batches and were weld head repaired, eventually ground, milled and/or replaced

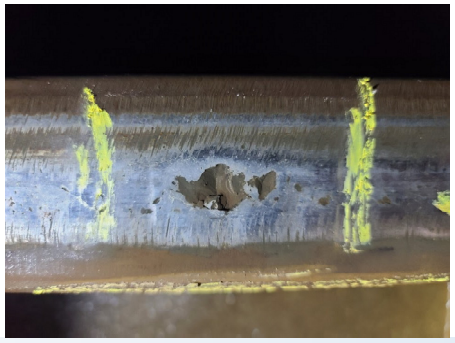
Seattle Sound Transit

- Suspected originally that defects could be associated with “bad” rail
- Defects found in almost all ages of rail but since 2018 limited reccurrence

Seattle Sound Transit

- Major concern was potential for a rail break and safety concerns
  - Secondary: ride quality and noise
- No evidence that rail breaks had or will occur from these defects
  - Operational impact still exists due to slow orders



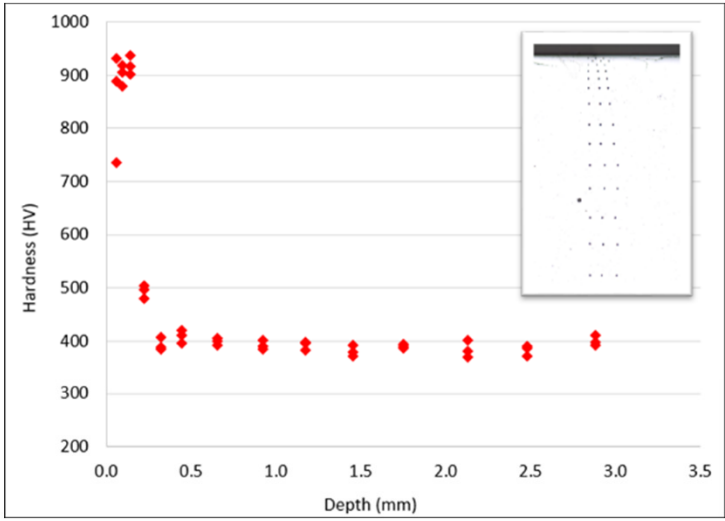


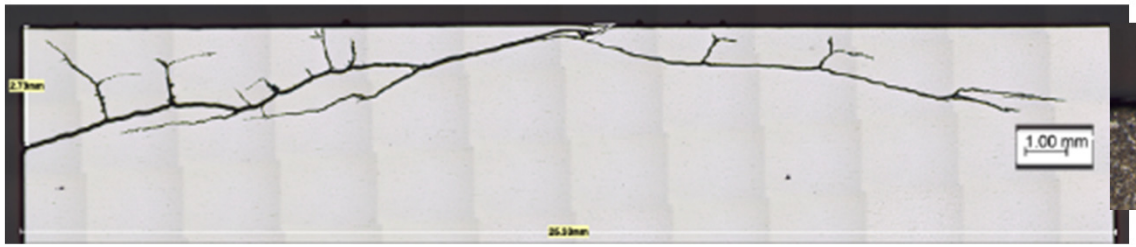

Seattle Sound Transit

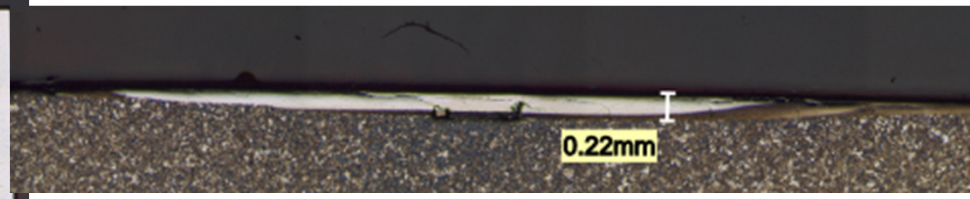
- Significant effort put into monitoring
  - Routine visual inspections
  - Eddy Current
  - Noise and Vibration
  - Ultrasonic
  - Grinding, Milling, and Rail Replacement
- Still need to understand root cause and potential for safety impacts

Seattle Sound Transit

- Metallurgical analysis identified
  - No quality issues with original rail
  - WEL present at all defects
    - Hardness levels as high as 900 Vickers
  - No vertical cracks

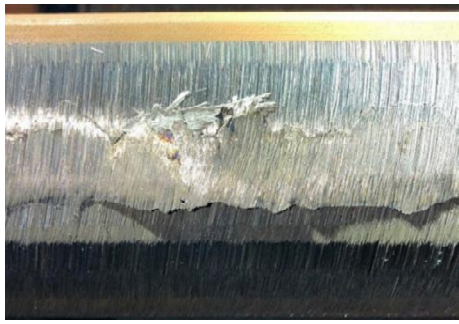


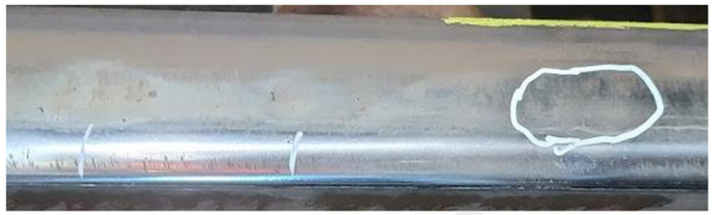


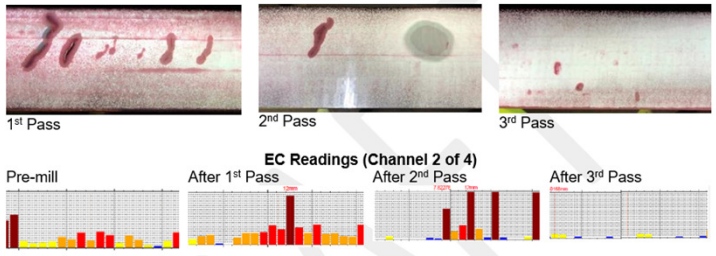


Seattle Sound Transit

- Rail grinding not efficient even at incipient level
  - ‘exposed’ subsurface cracks
- Rail milling required 3+ passes (4mm and more)
  - Severity would get worse before they got better





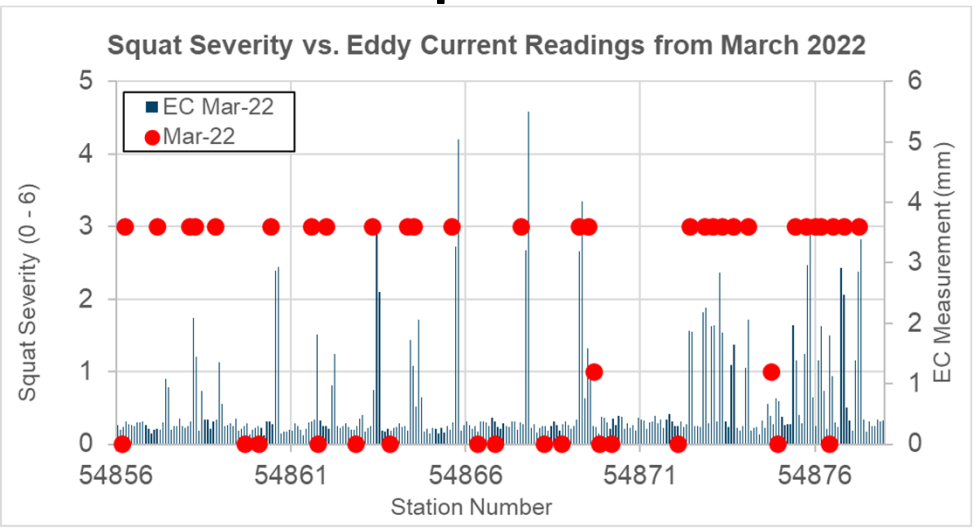


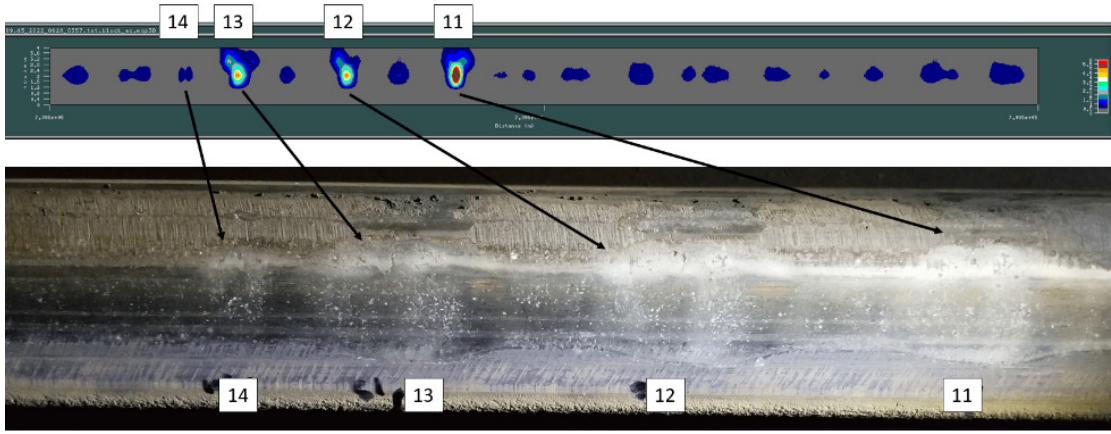
Seattle Sound Transit

- Milled rail after more than 2 years (~15 MGT) has no signs of defects returning
- Replaced rail (c. 2018 and newer) does not have the level of studs of older rail
- Milled and replaced rail segments have been ground regularly starting in 2018
  - Area with studs scheduled for annual grinding

Seattle Sound Transit

- Use of eddy current and ultrasonic inspections show promise for identifying existing studs





Seattle Sound Transit

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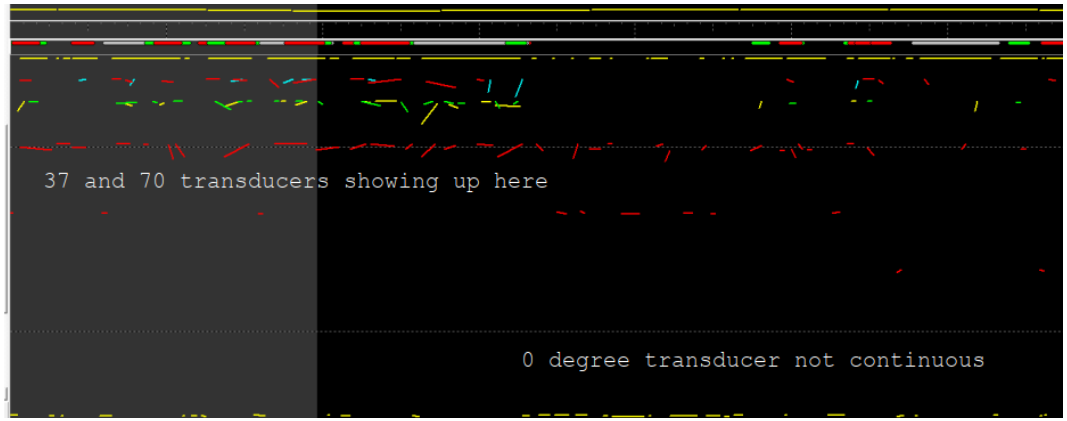
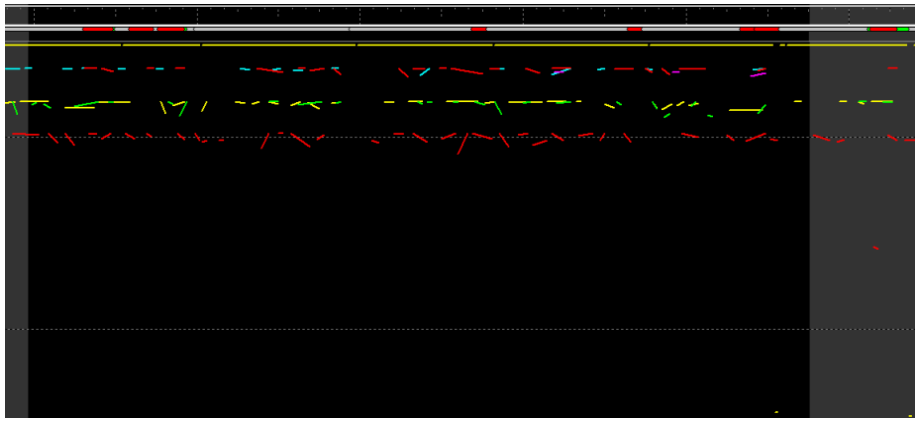
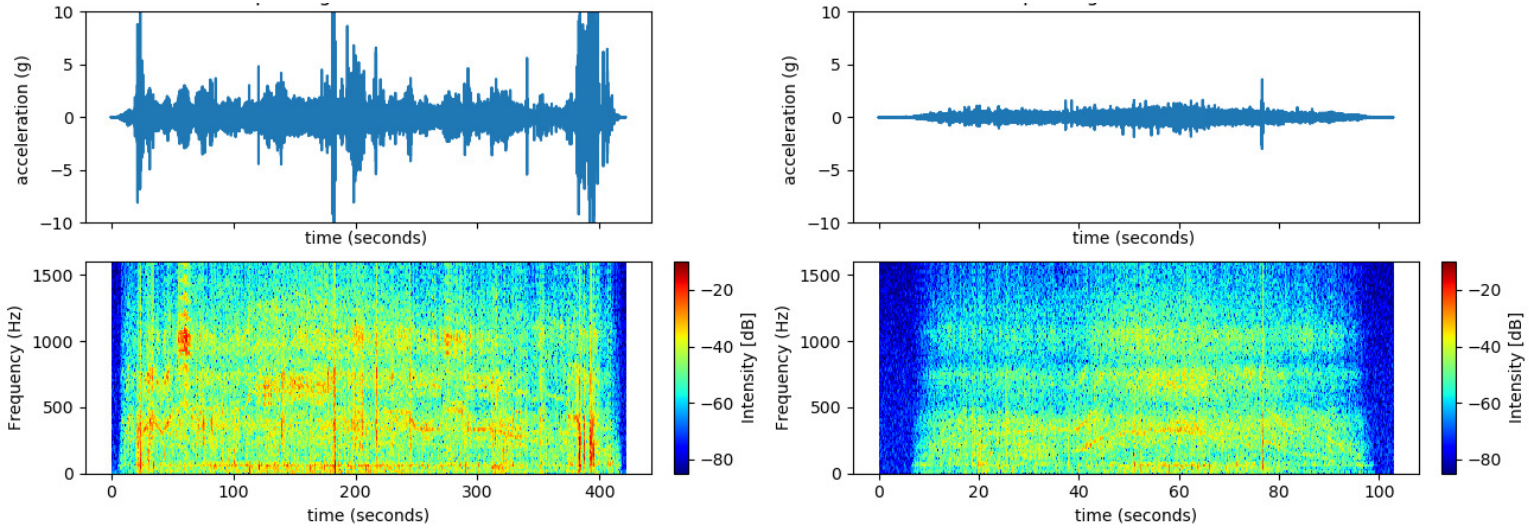




Seattle Sound Transit

- Use of axle box accelerometers can identify bad acting sections of track



Seattle Sound Transit

- Key challenges with studs remains
  - Identifying the primary root cause
    - If martensite: what can we do about it
    - Is corrugation a contributing factor?
  - Measuring early indicators
  - Determining a remediation plan, ideally preventive

Other Metros

- Some evidence of similar type defects
  - Not pervasive
  - No detailed study
- Annual preventive grinding
- Defects have not worsened in 5+ years
- Slowly being replaced as part of scheduled capital renewal

Other Metros

- Studs or squat-type defects have been observed elsewhere
  - Often in combination with increased tractive effort and premium steel
- Agencies are switching out older, softer steels for head hardened rail
  - Solves the wear issue but may be introducing a new set of issues if preventive grinding not employed

Other Metros

EXISTING KNOWLEDGE GAPS

Knowledge gaps

- Martensite: A buildup of martensite layers or single events, most vehicles or rogue incidents. Thickness/depth is key?
- Crack growth – tonnage accumulation before detectable crack develops?
- Role of contact patch size, contact stress?

Knowledge gaps (cont'd)

- Preventive grinding adequate for control?
- Is corrugation a contributor to or result of studs?
- What role do harder steels play?

Conclusions

- Studs, to date, do not show similar behavior as traditional squats
- Still pose risks and concerns
  - Noise and vibration
  - Damage to wheels, car components and rail
  - Potential to hide internal defects from detection as well as act as stress risers
- Root cause is still not known but evidence suggests they are associated with
  - Higher tractive effort and White Etching Layer (Martensite)
  - Outdoor track (probably because low friction under wet conditions)
  - Harder steels (?)

Conclusions

- Studs are difficult to measure at the incipient stage and once measurable tend to be 2mm or deeper
- Preventive grinding has shown some success in preventing their appearance

THANK YOU

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