30TH ANNUAL Association of American Railroads RESEARCH REVIEW

ASSOCIATION OF AMERICAN RAILROADS

MxV RAIL

April 29-May 1, 2025 | Pueblo, Colorado

Click titles to jump to presentation

Plenary Sessions

Plenary Session (AM) | Fortino Ballroom A/B

Safety Briefing/Greeting	Scott Cummings
Welcome	Miles Lucero, Pueblo Cty. Commissioner
Keynote Address	Erik Gotlund, TTX
FAST® Digital Transformation	Silvia Galván-Núñez
Track Stability Research	Stephen Wilk and Yi Wang

Plenary Session (PM) | Fortino Ballroom A/B

Vertical Impact Force Measurement	Nate Stoehr
Evolution of Head-of-Train/ End-of-Train System	Matt Holcomb & Bivesh Paudyal
University Grand Challenges	Anish Poudel
2025 Annual Review Closure	Scott Cummings

Technical Sessions - Infrastructure

Technical Sessions - Mechanical

FAST® Digital Transformation

Silvia Galván-Núñez, Ph.D.
Sr. Data Analyst IV

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Overview

- **Motivation**
  - FAST® Overview
  - Tests at FAST
- **FAST Internal Records for Statistics and Testing (FIRST)**
- **Digital Twins for FAST**
  - Digital Twins Definition
  - FAST Digital Twins Vision
- **Conclusions**

Motivation

FAST® is a registered trademark of MxV Rail ©2025 MxV Rail

FAST® Overview

- **Facility for Accelerated Service Testing**
  - Small loop of track for continuous tonnage accumulation; one train pass every four minutes
  - Heavy train—both heavy axle load and total train weight
- **Part of the AAR Strategic Research Initiatives (SRI) program**
- **Rapid tonnage accumulation**
  - More annually than most revenue service mainline tracks
- **Variety of test components**
- **Controlled environment**
  - Continuous monitoring
  - Frequent inspections

Tests at FAST

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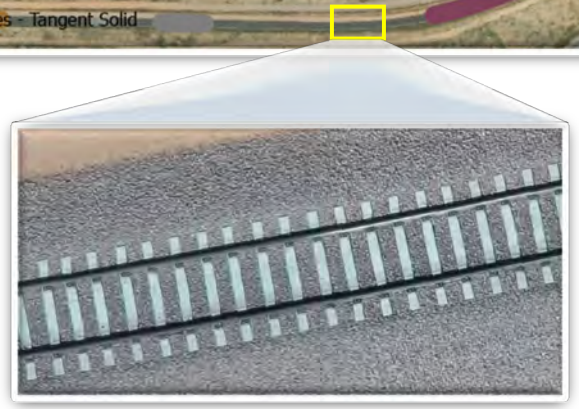
Automatic Secondary Securement Device	HPW3
Tie Uplift Test	WRI Rail Measurements
STPT - FAST General	Wheel measurement
WRI EMFI Measurements	Alternative Broken Rail Detection - MRX
Instrumented Wheel Set Run	



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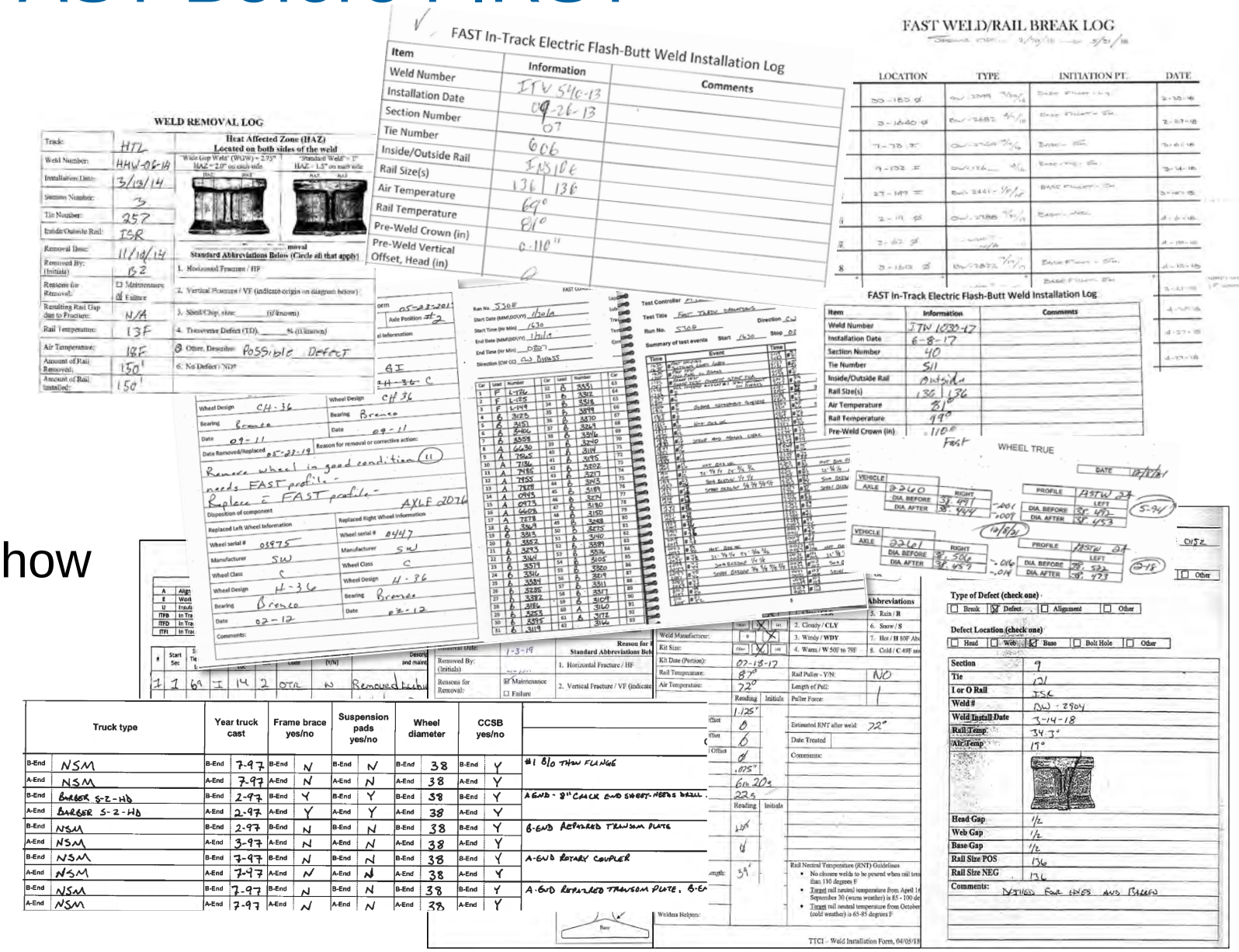
Data Collection at FAST Before FIRST

- **Time Lag**
  - Paperwork often not sent in immediately
- **Inaccuracy**
  - Paper form outdated and fields not current
- **Data Storage Issues**
  - Where do I put form and how does someone find it?
  - Who has access?
  - Long-term storage and access costs



FAST Internal Records for Statistics and Testing (FIRST)

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FAST Internal Records for Statistics and Testing (FIRST)

- **In-house infrastructure, mechanical, and operations data management system**
- **Infrastructure and test inventory to tie level accuracy**
- **Wayside detector data collection**
- **Tracking of test data**
- **Tracking of train operations data**
- **Test and measurements scheduling**
- **Reports and analytics**

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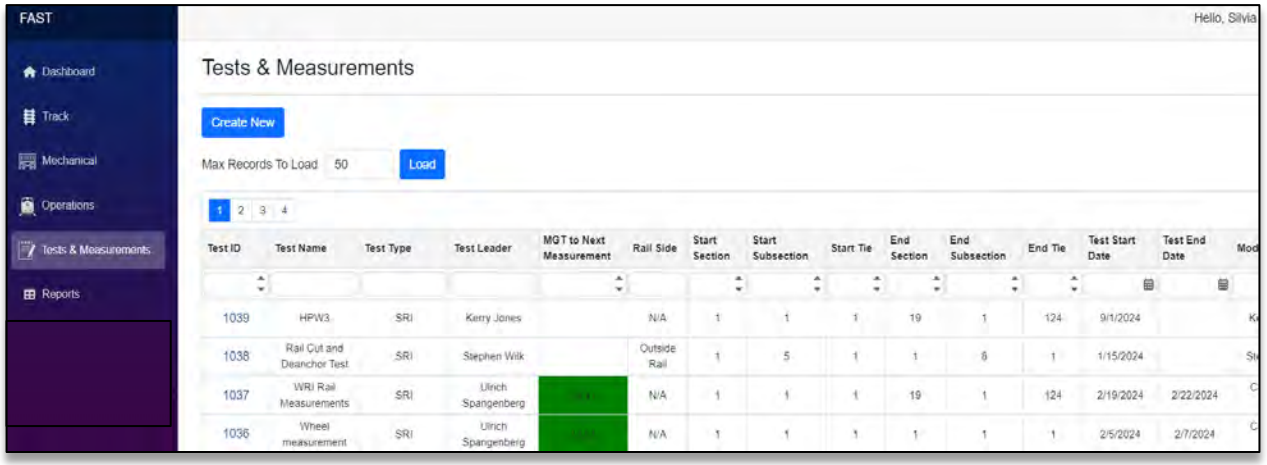
FIRST – Test Management



- **Test tracking throughout its lifecycle**
- **Over 40 tests locations for SRI and commercial projects**
  - Infrastructure tests
  - Mechanical tests
- **Measurements scheduling**
- **MGT and mileage tracking**

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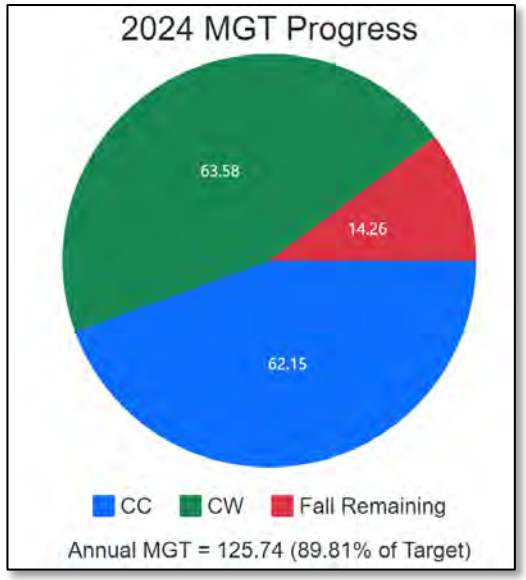
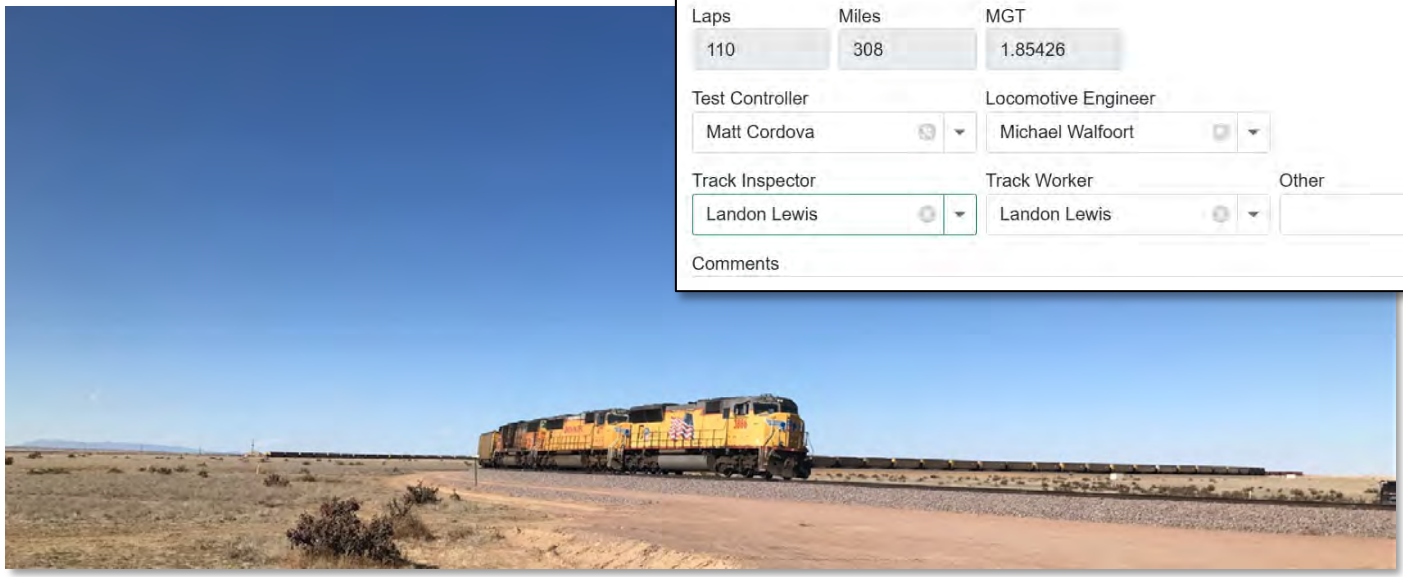
FIRST – Operations

- **This process is critical for MGT and mileage calculation**
- **Consist creation**
- **Event recording every lap**
- **Wayside detector monitoring**
- **Reports**





Run Info | Lap Info | Consist Vehicles | Consist Checklist | Run Event Recording

Run Number: 1063	Start Date: 05/01/2024 21:43:25	Stop Date: 05/02/2024 06:15:13
Direction: CC	Track Loop: M	
Total Vehicles: 108	Total Locos: 3	Total Cars: 105
Unknown Cars: 0		
Lube: Yes		
Laps: 110	Miles: 308	MGT: 1.85426
Test Controller: Matt Cordova	Locomotive Engineer: Michael Walfoort	
Track Inspector: Landon Lewis	Track Worker: Landon Lewis	Other:
Comments:		

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FIRST – Infrastructure

- **Maintenance**
- **Non-destructive evaluation and visual inspection**
- **MGT for track components and tests**
- **Automatic E-mail notifications for defects**
- **Maps**
- **Reports**

Task ID	Task Date ↓	Work Type	Cause	Rail Side	Start Section	Start Subsection	Start Tie
2008	1/30/2025	Weld Removal	Failure	Inside Rail	2	1	18
2007	1/30/2025	Rail Removal	Failure	Inside Rail	1	1	10
2006	1/29/2025	Tie & Fastener Changeout		N/A	15	1	27
1291	1/8/2025	Weld Removal	Maintenance - No Defect	Outside Rail	5	11	9

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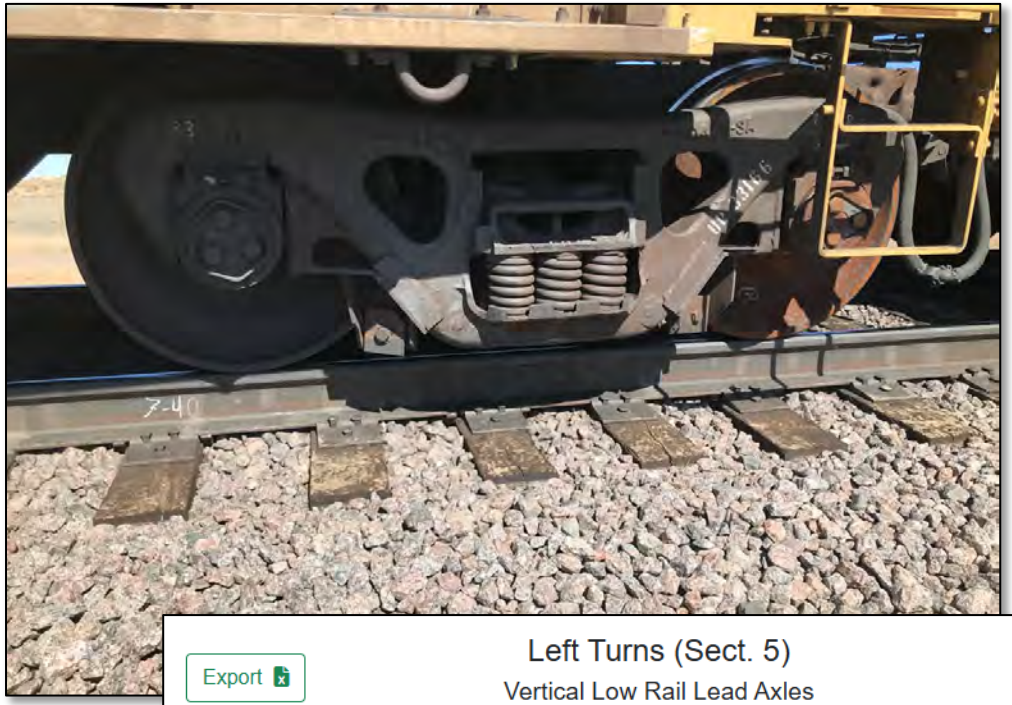
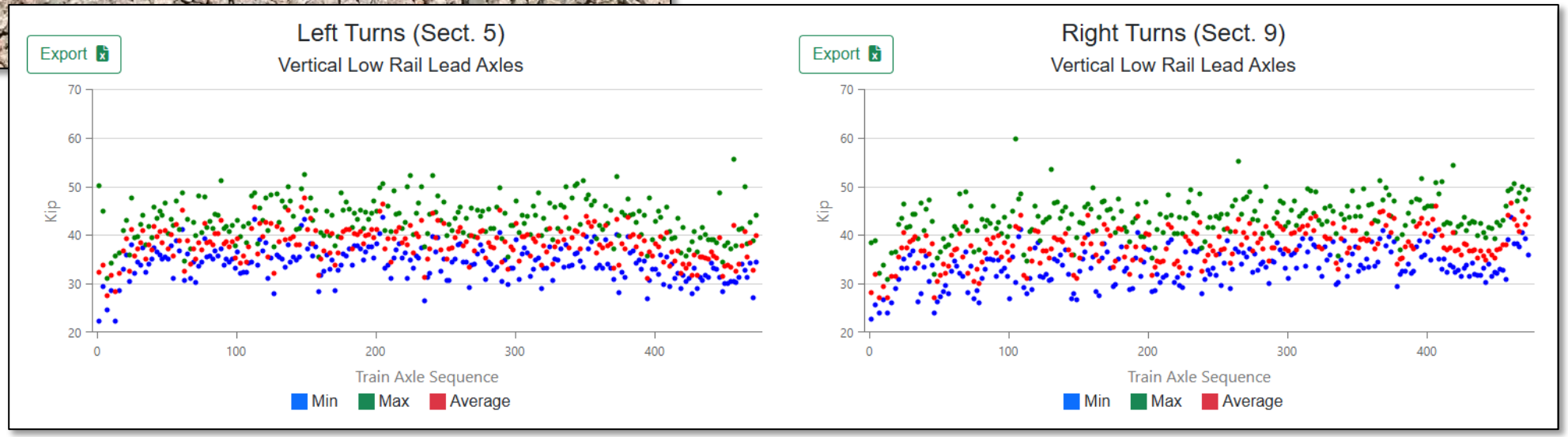
FIRST – Mechanical



- Maintenance
- Non-destructive evaluation
- Wayside detector data
- Mileage tracking
- Reports



Digital Twins for FAST

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What is a Digital Twin?

There are multiple definitions with diverse interpretations!

- **Origins at NASA**
- **A Digital Twin is a virtual representation that serves as the real-time digital counterpart of a physical object or process** (NASA, 2022)
- **Digital Twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level**
  (Grieves and Vickers, 2017)

Apollo 13: The First Digital Twin
Source: B. Danette Allen. “Digital Twins and Living Models at NASA”. ASME Digital Twin Summit. 2021

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Digital Twin Levels

Duplicate a physical object into a digital twin

1 Mirroring

Monitoring and controlling the physical object based on the analysis of the digital twin

2 Monitoring

Optimizing the physical object through the simulation results of the digital twin

3 Modeling & Simulation

Configuring federated digital twins, optimizing complex physical objects, and inter-operating federated digital twins and complex physical objects

4 Federation

Autonomously recognizing and solving problems in federated digital twins and optimizing physical objects according to the federated digital twin solution

5 Autonomous

Adapted from: Jeong, et. al, “Digital Twin: Technology Evolution Stages and Implementation Layers with Technology Elements”, IEEE Access, 2022

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Back to FAST… Why a Digital Twin?

- **2.8 miles of mainline track**
- **Improve train operations and safety**
- **Enhance research capabilities**
- **Support track and mechanical components lifecycle management**
- **Enhance data-driven decision making**

Digital Twin Implementation Layers for FAST

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Physical Layer

- Track and mechanical components
- Wayside and onboard detectors

Data Acquisition Layer

- Inspection and maintenance data
- Wayside detector data
- Onboard detector data
- Test data

Data Processing and Integration Layer

- Data preprocessing algorithms
- Data fusion
- Data storage

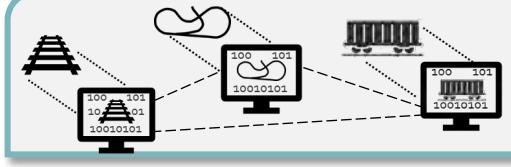
Visualization and User Interface Layer

- (Near)Real-time visualization platforms
- Customized interaction features for end users

Modeling & Simulation Layer

- 3D modeling of track and mechanical components
- Machine learning modeling

Federated Digital Twin Layer



- Federation governance technology
- Interconnected representation of track, train and operations digital twins

Security and Privacy Layer

- Cybersecurity protocols
- Privacy and compliance processes

1 Mirroring

2 Monitoring

3 Modeling & Simulation

4 Federation

Conclusions

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Conclusions

- **FIRST has demonstrated added value to FAST operations and tests.**
- **Current work includes continuing enhancing FIRST capabilities and the creation of the initial digital twin.**
- **The vision and implementation of a digital twin for FAST create opportunities to continue enhancing the safety, reliability, efficiency, and innovation in railroad freight applications.**

Acknowledgements

MxV Rail Team:

- Software: Doug Stoltz, Sergej Dajic, Andrew Koransky, Cayle Cemento
- Data Science: Bea Rael, Tony Sultana, Kenny Morrison, Ryan Alishio
- Operations
- Engineering
- Instrumentation
- Research & Innovation

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Track Stability Research

Stephen Wilk, Ph.D., Principal Investigator II
Yi Wang, Ph.D., Principal Investigator II

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Track Buckle Prevention

- **Thermal misalignments/track buckles can be highly disruptive during summer months**
- **Combined effort between track and vehicle perspectives**
- **Long-term Goals:**
  - Improve rail neutral temperature (RNT) management
  - Improve track buckle strength and identify high-risk scenarios
  - Optimize speed restrictions policies

Track Buckle from 2022 MxV Rail/BNSF Test

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Track Stability – Three Components

- **Track stability involves balancing three main components**

1 Longitudinal Rail Forces

- **RNT re-establishment**
- **Changes in RNT**

2 Track Strength

- **Track type**
- **Effect of maintenance**
- **Modeling**

3 Vehicle Forces

- **Longitudinal forces**
- **Lateral forces**
- **Vertical liftoff**

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Overview

1. Influence of De-anchoring on RNT
2. RNT Change with Maintenance
3. Vehicle Force Updates

Topic 1: Influence of De-anchor Lengths on RNT after Cold-Weather Rail Breaks (TD24-017)

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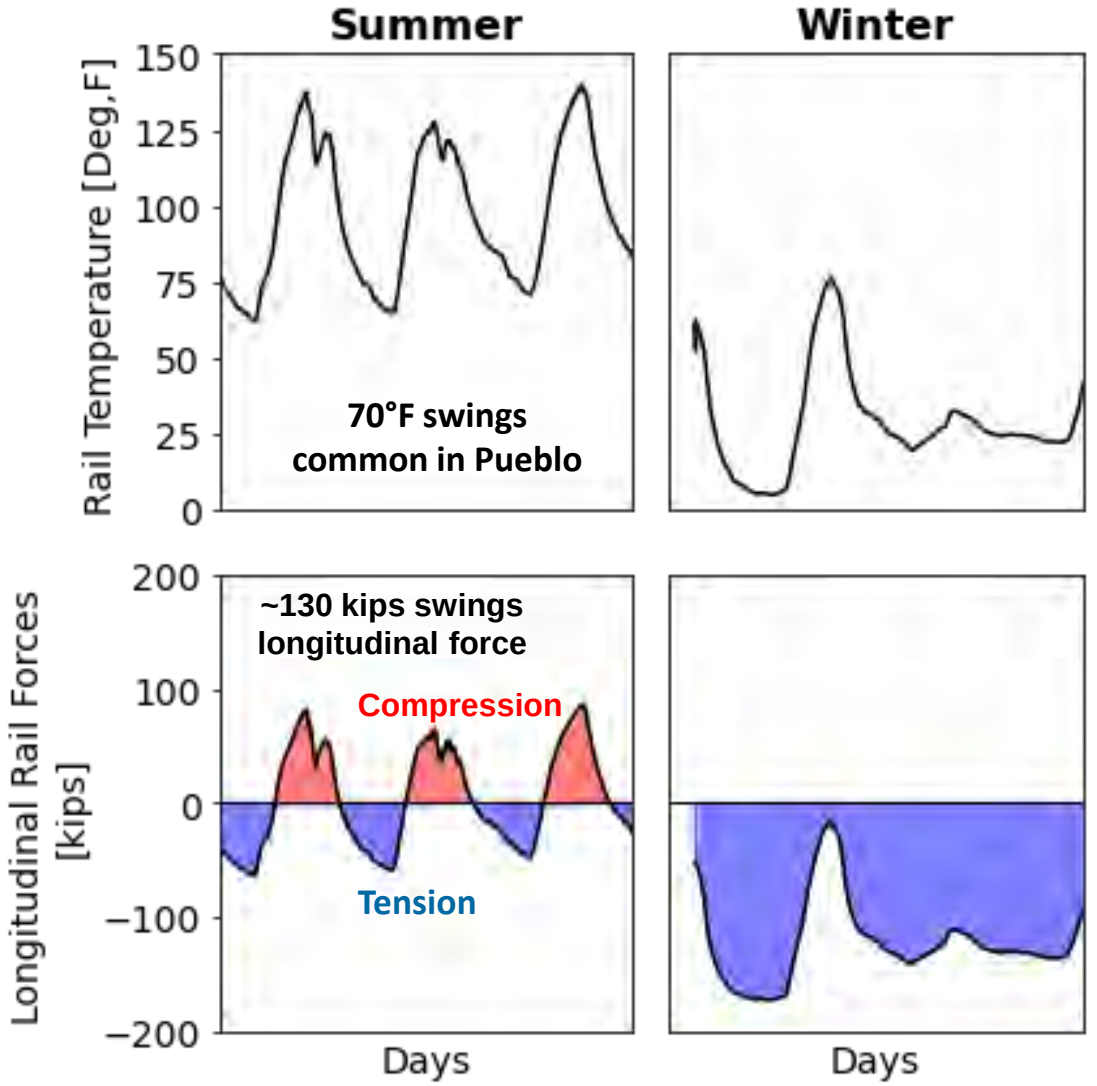
Longitudinal Rail Forces and RNT

- **Temperature swings cause longitudinal compressive and tensile forces**
  - Too high compressive → Track Buckles
  - Too high tensile → Rail breaks and large gaps
- **Longitudinal forces managed by setting RNT**
  - Can change from multiple factors (curves, maintenance, vehicle forces, and others)
  - Difficult to measure (not practical at scale)



Historical Guidance during Rail Breaks

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Historical Guidance

- **Calculate pre-break RNT from rail gap and rail temperature**
- **Calculate amount of rail to add/remove**
- **Calculate de-anchor lengths (hundreds of feet or more)**
- **Pull rail and weld**

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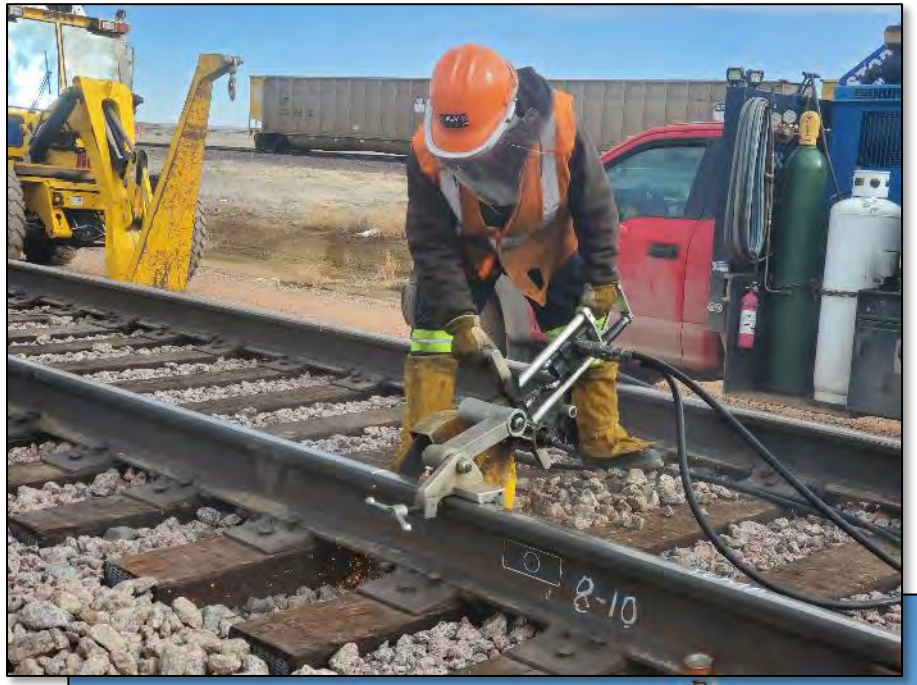
Test Layout

- **Explore tradeoffs of reduced de-anchoring**
  - **Benefits**: Speeds up cut/welding process
  - **Downsides**: Localized high/low RNT regions
  - Does train operations smooth out any localized high/low RNT regions?
- **Simulate cold-winter rail breaks by cutting rail and weld back to same RNT with different de-anchor lengths**
  - 10 ft., 190 ft., 520 ft.
- **Electric Flashbutt Welds (EFB) with Holland**



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Rail Cutting and Rewelding

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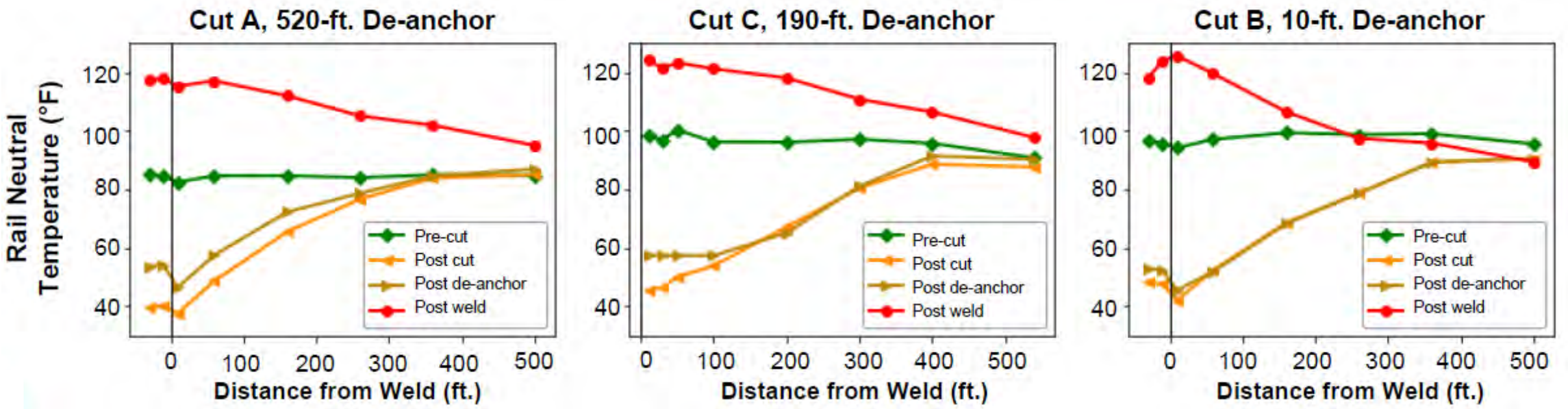
Test Results (1) – RNT Profiles

- **Re-established to similar RNTs**
- **Shorter de-anchor lengths caused higher localized RNT**



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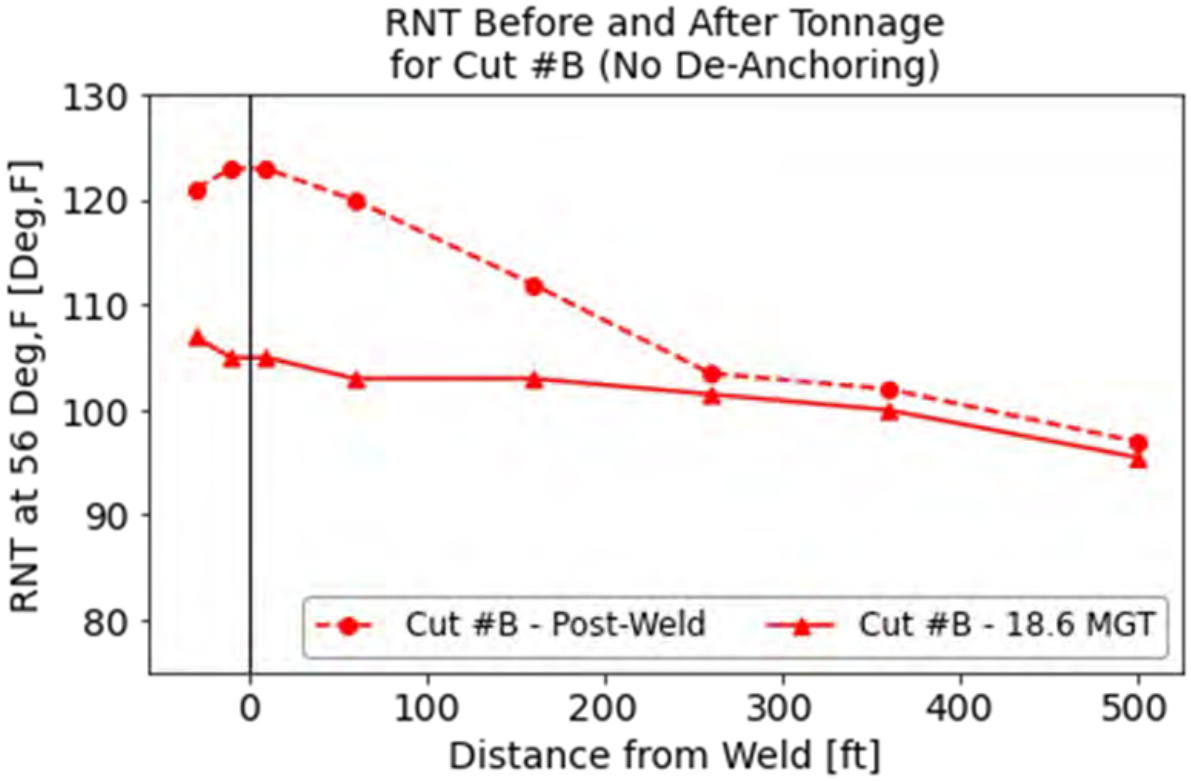
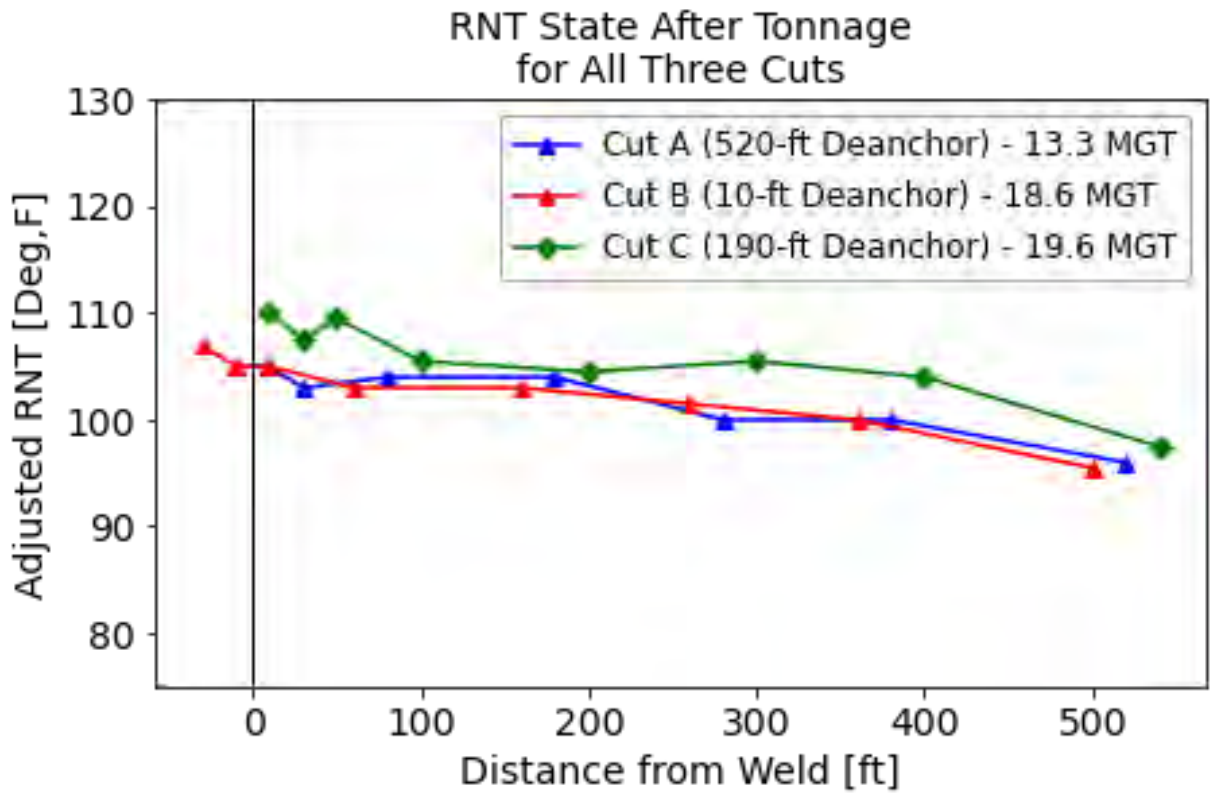
Test Results (2) – Effect of Tonnage





Key Findings

- **Tonnage smoothed out localized high spots**
- **RNT profile after 15 MGT similar for all three tests**

Topic 2: Longitudinal Rail Force Changes from Maintenance (TD24-011 & TD25-002)

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Background

- **Track buckles are common near fixed objects**
- **One possible reason is “bunching” of rail during runoffs**
- **Investigate change in RNT during runoff**

Maintenance Activity

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Test #1 (2023) – Track Lifter

Test #2 (2024) – High Speed Surfacing

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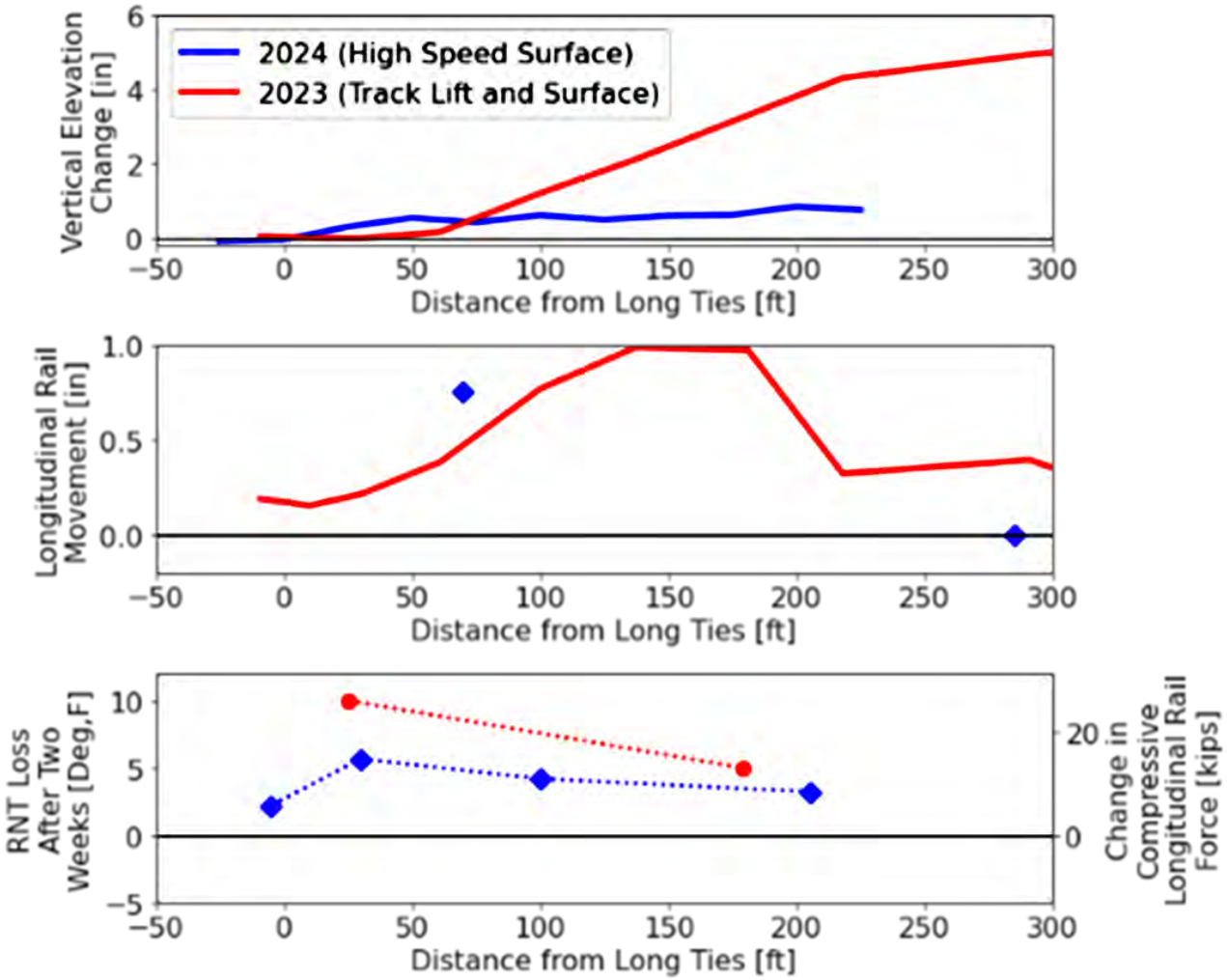
Test #1 (2023) vs. Test #2 (2024)



Key Findings

- **Both tests show RNT reductions that associate with longitudinal rail movement in the runoff (0.75 inch and 1.0 inches)**
  - One potential reason buckles are noticed near fixed objects and around maintenance limits
- **Important factors (lift, runoff length) determining amount of RNT reduction is still unclear**

Topic 3: Vehicle Influences Update

Speed Restriction Work

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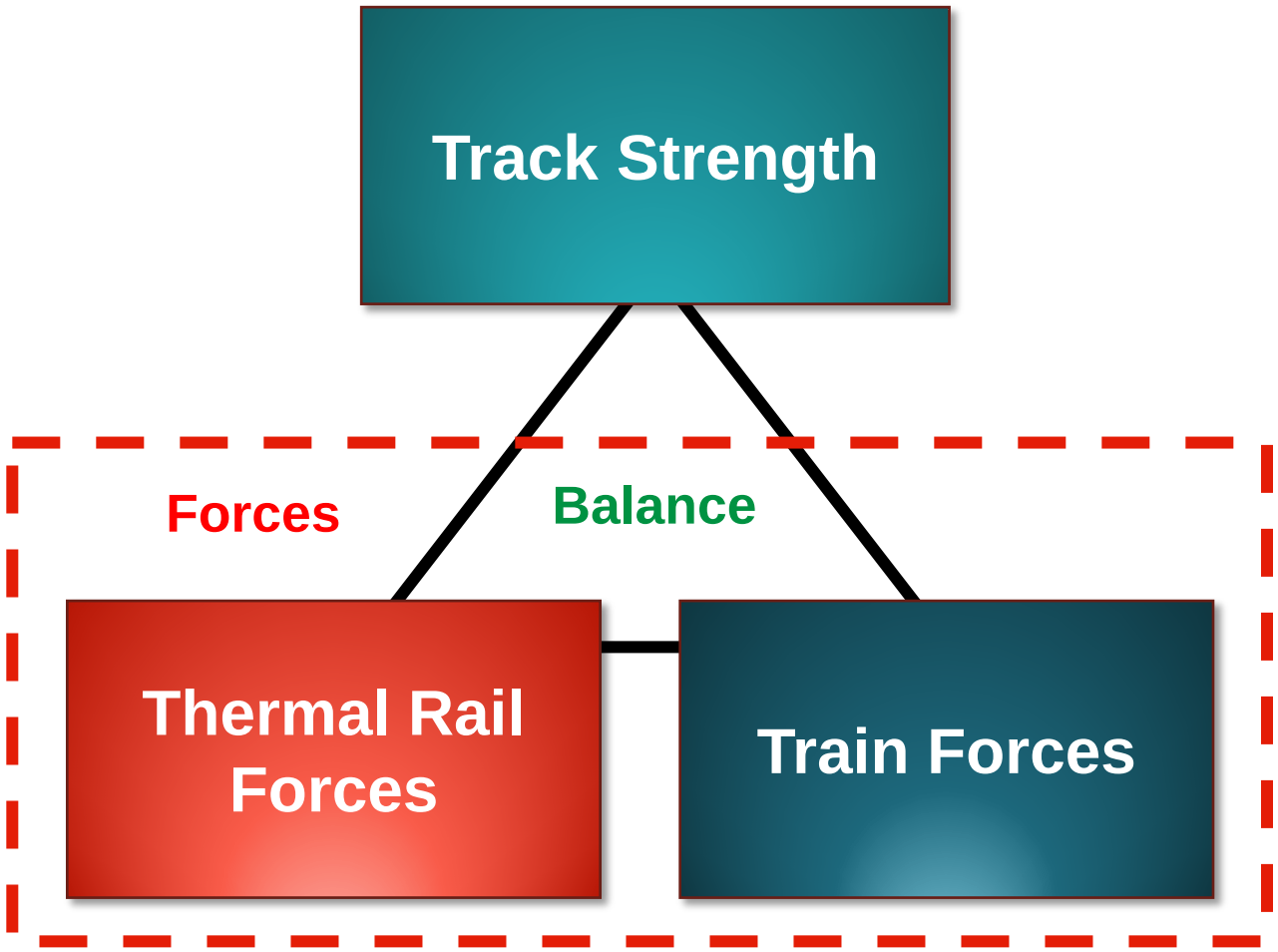

- **Cross-disciplinary effort**
- **Important questions:**
  - What vehicle forces can produce track buckle during heat events?
  - How can we improve safety against buckle while minimizing impact on service?

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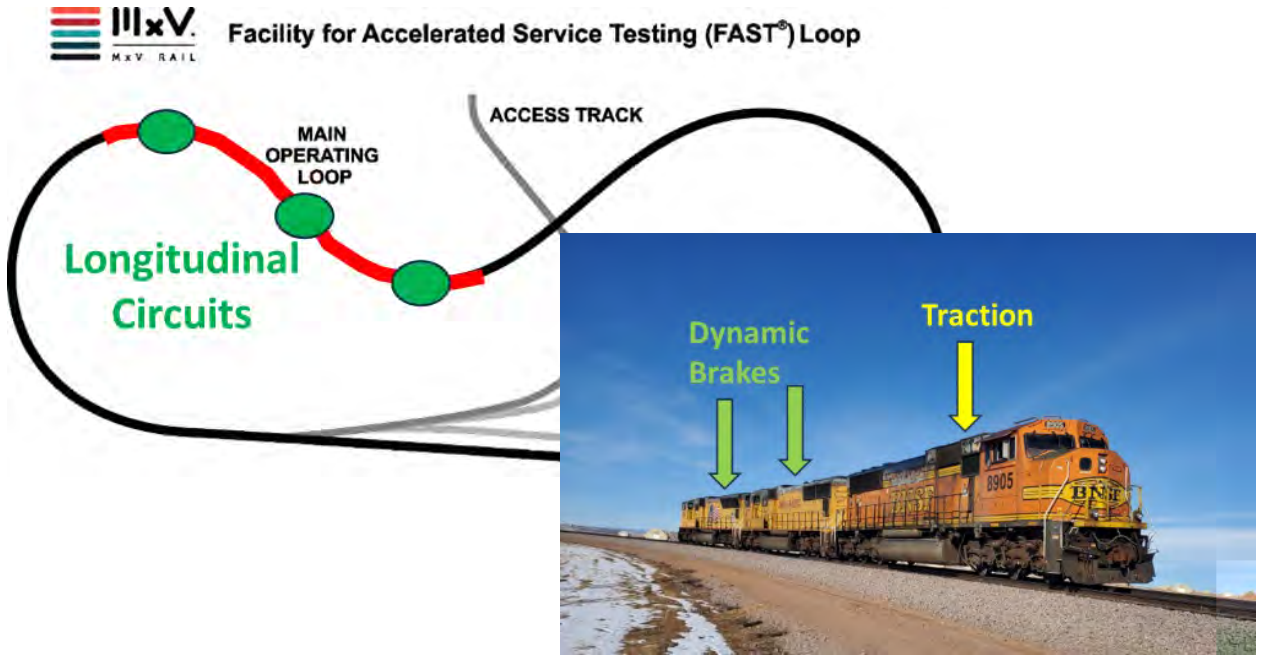
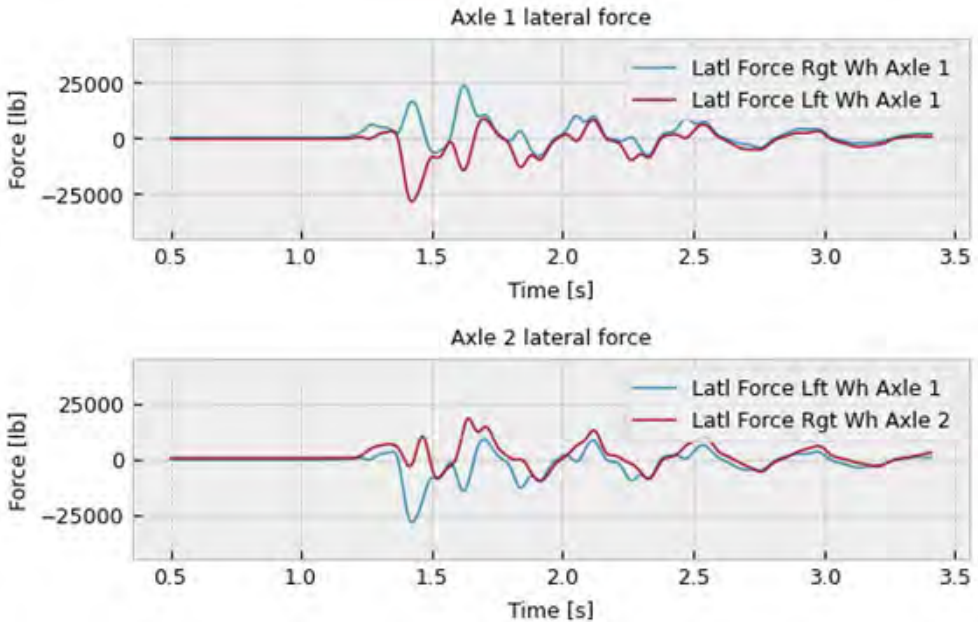
Various Vehicle Influences

- **Focus on vehicle influences on track stability**
  - Higher degree of control, e.g., train handling and speed restrictions
- **Working towards a framework for risk estimation and mitigation in hot weather**

Force Measurements



NUCARS® Simulation



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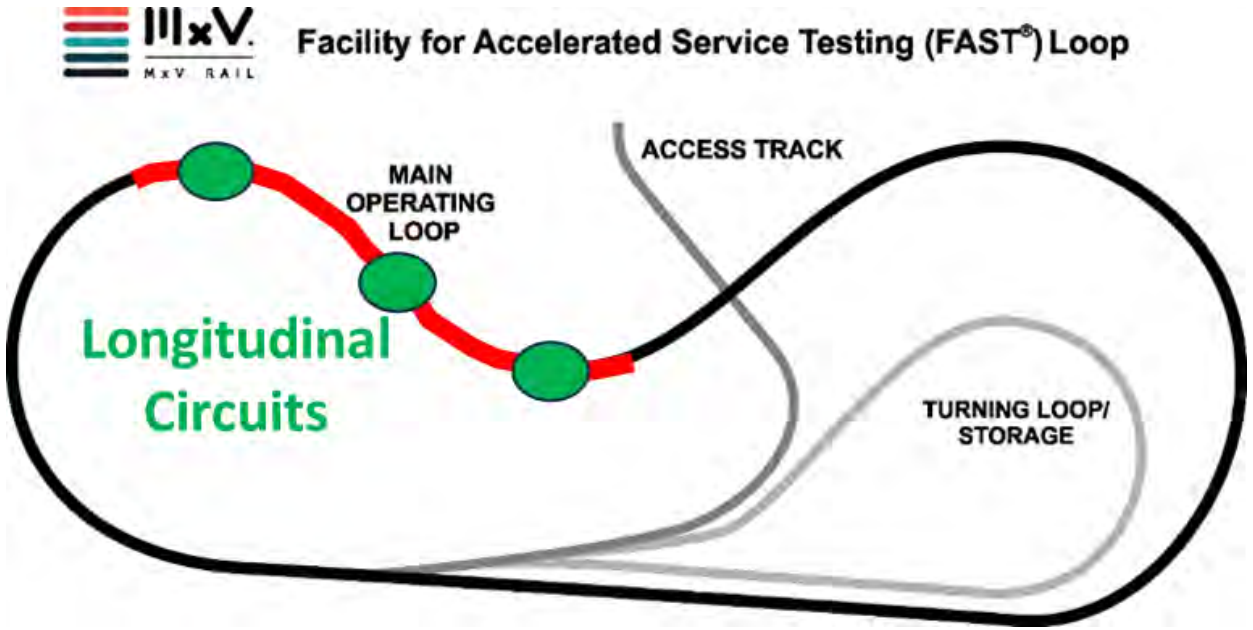
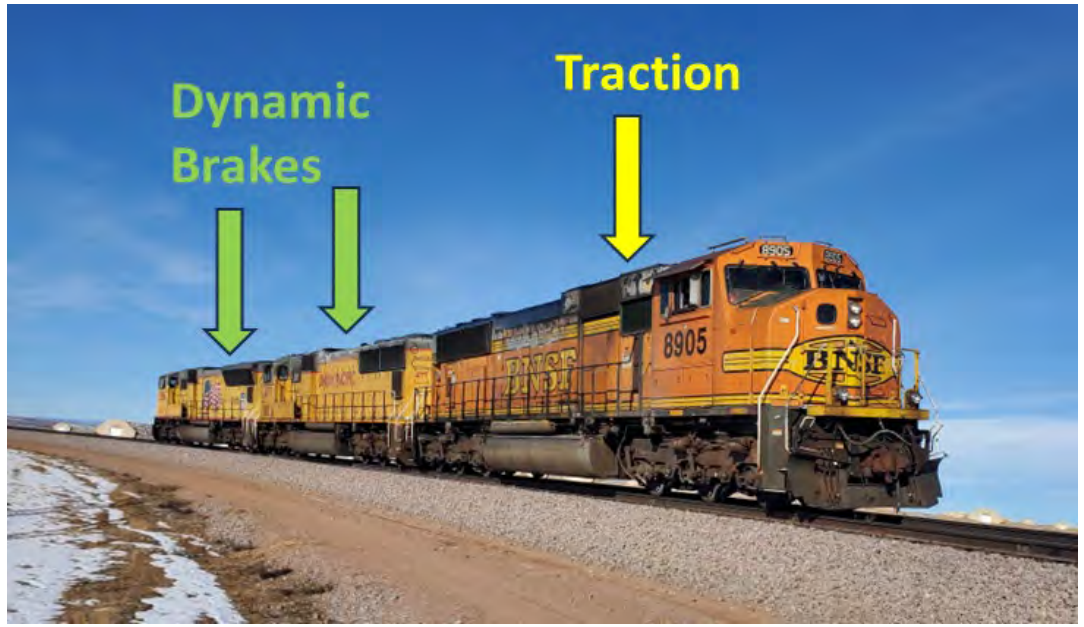
Longitudinal Forces (Traction/Braking)

- **Compression (braking) or tension (traction) ahead of the lead locomotive**
- **Test to verify 10% of tractive/dynamic braking effort is distributed to each rail (80% into track structure)**

Force Measurements





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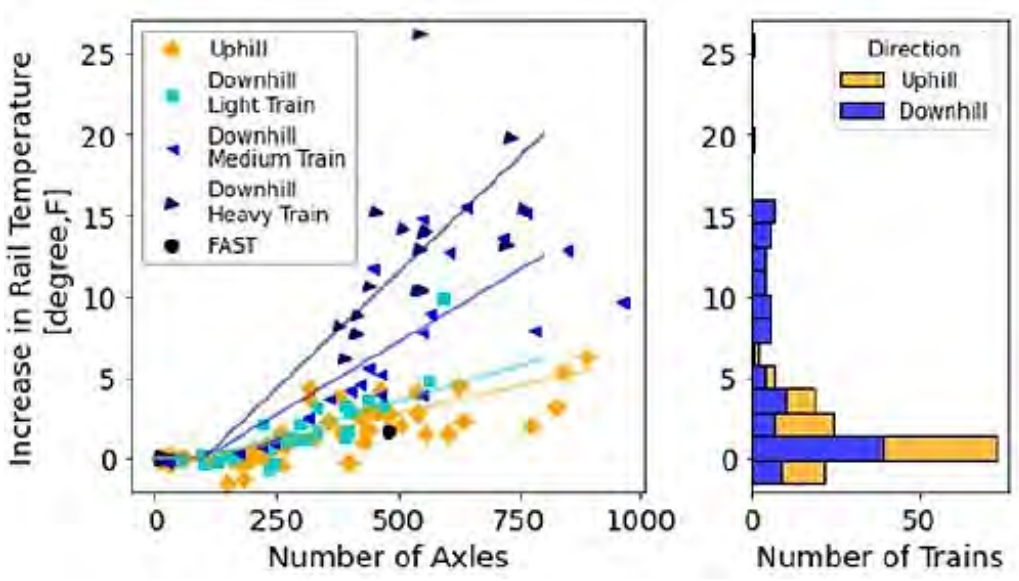
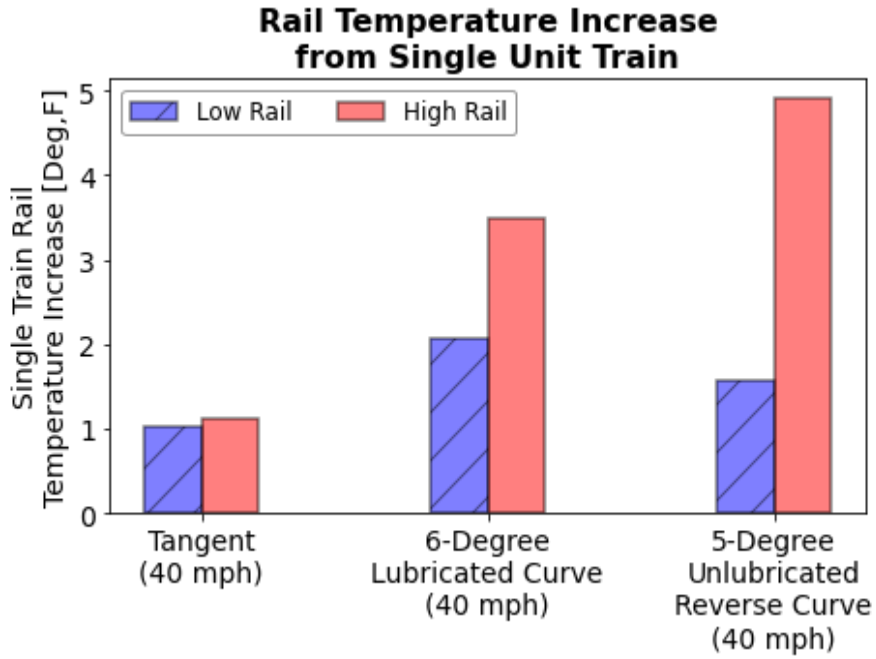
Rail Temperature Increase from Wheel Heat

- **Heat from tread (air) braking**
  - Depending on train weight, grade, brake cylinder pressure, time, frequency
- **Heat from train passage (wheel/rail friction)**
  - Depending on train weight, vehicle steering, curvature, friction/lubrication, frequency

Revenue Service Measurements



Measurements from FAST®



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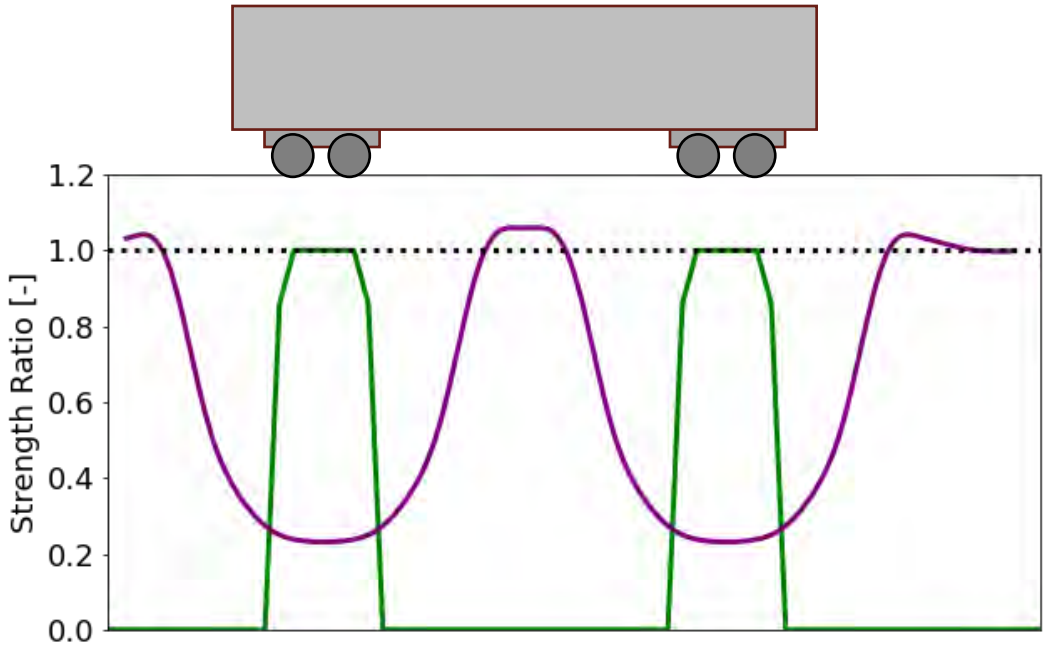
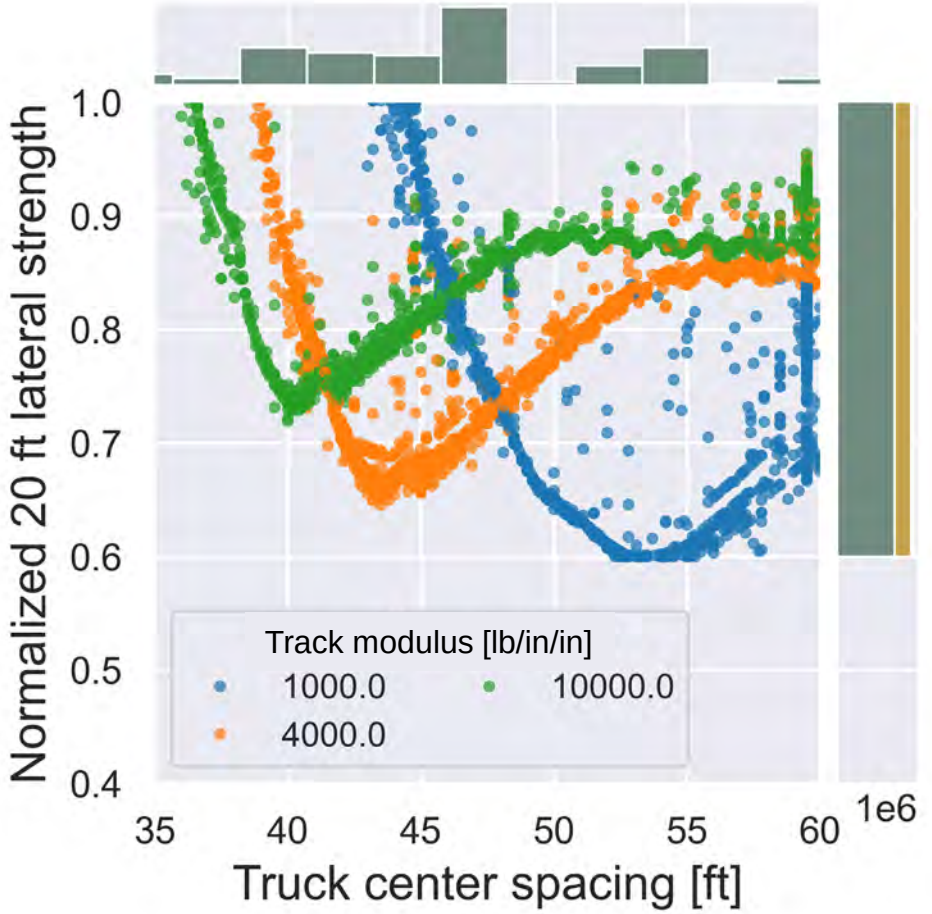
Dynamic Uplift

- **Distribution of uplift based on Umler® data**
- **Uplift is plugged into buckle model to get equivalent rail temperature increase**



Vehicle-Induced Lateral Force

Track Buckle Risk (higher more risk)



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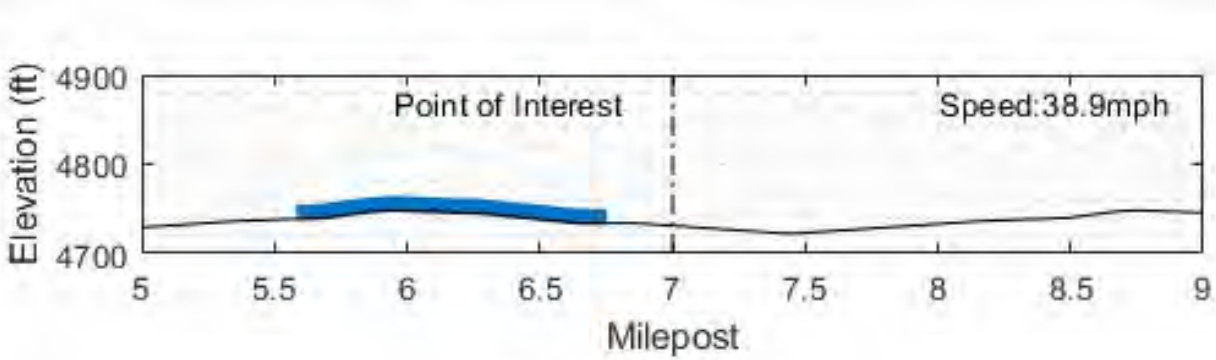
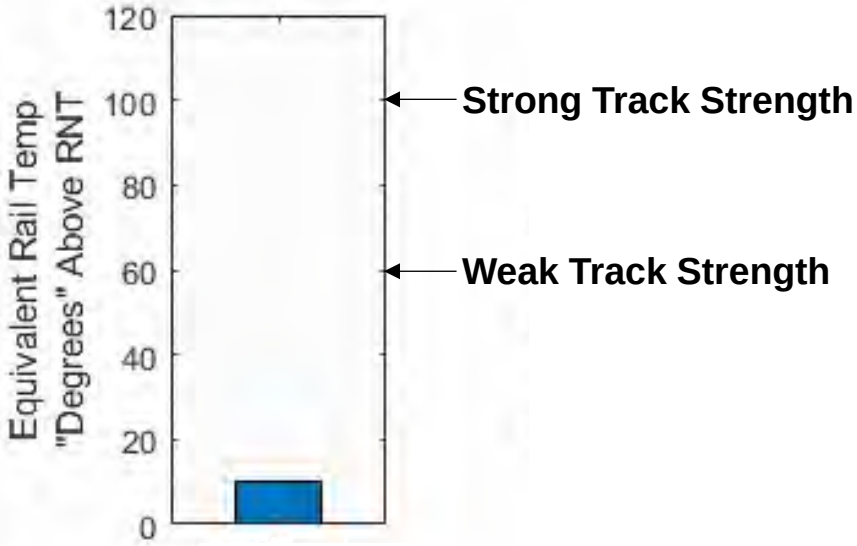
Force Accumulation

- **Accumulation of forces based on operating scenario and train configuration**
  - Not a simple sum
  - Accumulation is time and space dependent





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Summary

- **Rail Cut Test**
  - Different de-anchor lengths (10, 190, 520 feet) produced similar long-term RNT profile
  - Train operations smoothed high-RNT locations with majority occurring in initial 5 MGT
- **RNT Change from Maintenance**
  - Measured RNT reductions in runoff from two separate tests
  - RNT reductions associated with longitudinal rail movement
  - More work to determine if certain maintenance practices can reduce RNT reduction
- **Vehicle Influences on Track**
  - Focused on estimating various vehicle influences relative to track strength and equivalent rail temperature increase

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Acknowledgements

- BNSF
- Holland
- Track Buckling Prevention and Heat Speed Restriction Technical Advisory Groups
- MxV Rail Engineering Teams (Track Infrastructure, Vehicle, and Data Science)
- MxV Rail Instrumentation, Track, and Operations Teams

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Wheel/Rail Vertical Impact Force Measurement Comparisons

Nate Stoehr
Principal Systems Engineer
Communications and Train Control

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Overview

- **Wheel/Rail (W/R) Vertical Impact Force Measurement Comparisons**
  - Background and Objectives
  - Testing Based on Innovative Methods
  - Test Results and Sample
  - Conclusions
  - Future Work

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Background and Objectives

- **Wheel Impact Load Detector (WILD) is important for the railroad industry**
- **AAR *Manual of Standards and Recommended Practices* (MSRP) Section F, Standard S-6101:**
  - Specifies the static calibration and validation requirements for traditional strain gage-based WILD systems
    - Alternative WILD technologies/systems are being introduced around the world (i.e., accelerometers, fiber optics, load cells, etc.)
    - Alternative WILD technologies require a more generalized method of ensuring accuracy than the method originally defined in S-6101

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Background and Objectives

- **At the request of the AAR Equipment Health Monitoring Committee (EHMC)**
  - MxV Rail developed a process for validating WILD systems regardless of the type of technology deployed
    - Multi-year project, which included a range of innovative studies and three phases of on-track testing
    - Evaluated the accuracy of various existing and newly developed techniques to generate and measure impact loads
- **Objective**
  - Develop a benchmark measurement of the W/R vertical impact force that can be used for validating any WILD system

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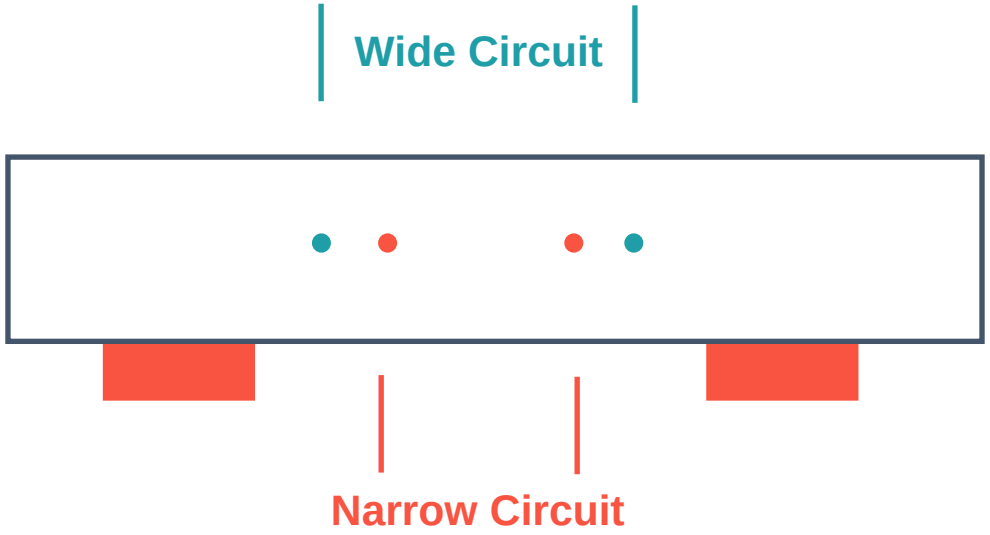
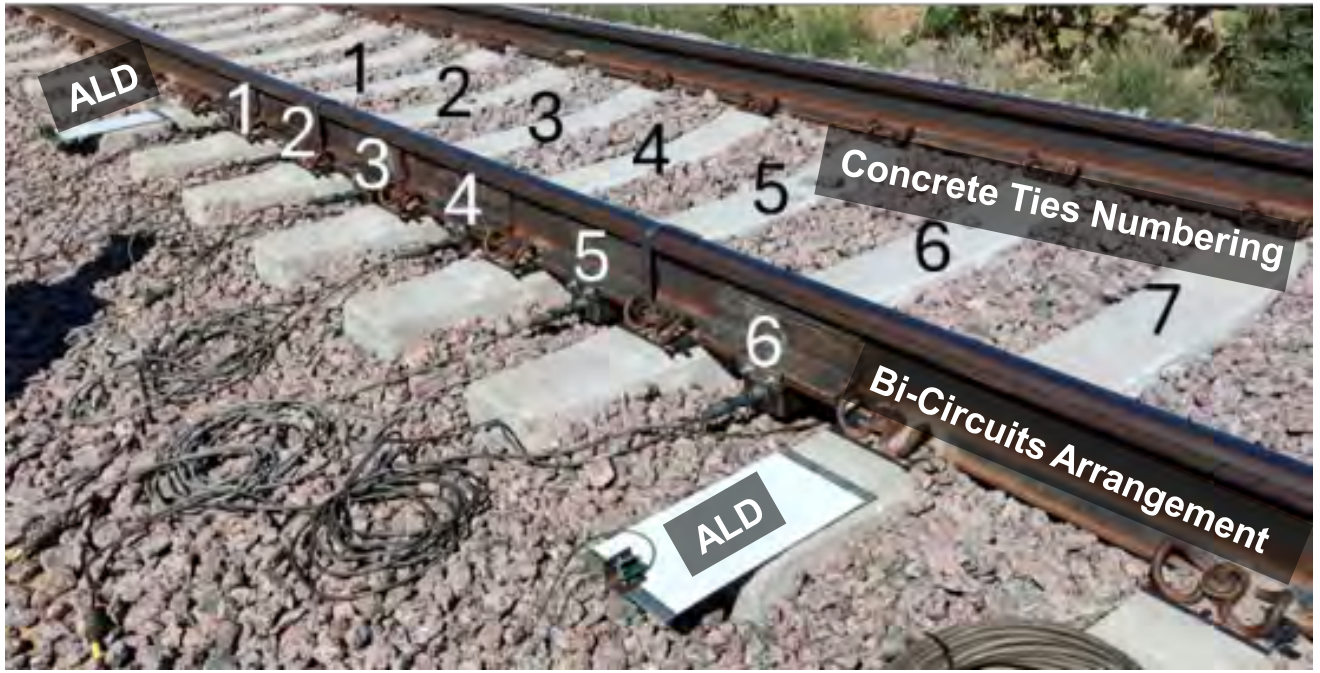
Testing Based on Innovative Methods

- **In-track Hi-Accuracy Bi-Circuit (HAC)**
  - Two Wheatstone full bridge strain gauge circuits per crib
    - Allows for accurate measurements of vertical load over substantial portion of crib





Testing

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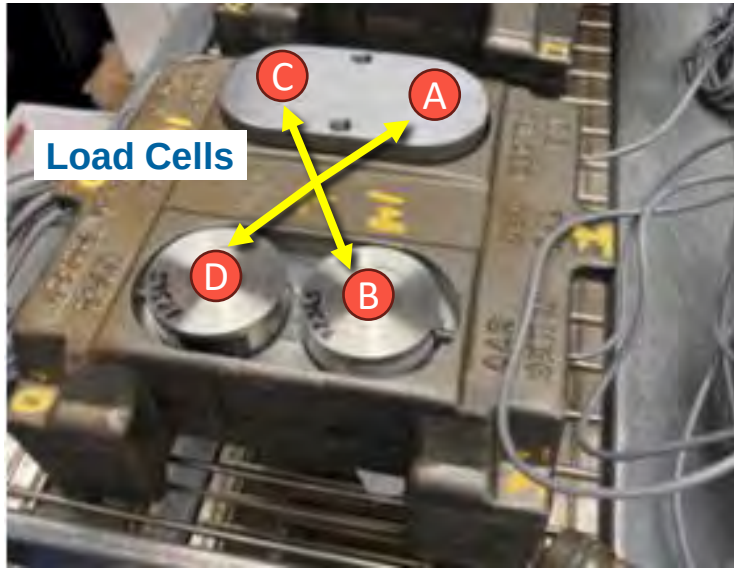

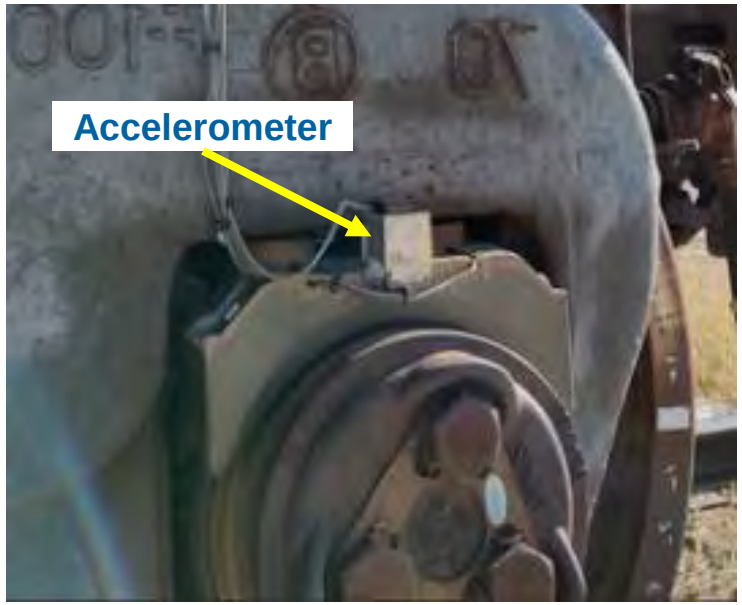

- **Onboard New Bearing Adapter (NBA)**
  - Each NBA configured with four load cells and one accelerometer
    - Eight load cells and two accelerometers per wheelset
    - MxV Rail developed the NBA during previous efforts
      - Addition of the accelerometer(s) provides the “dynamic” component of the forces generated and otherwise damped by the mass of the wheelset and spring nest

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Testing

- **Onboard Instrumented Wheelset (IWS)**
  - Two high accuracy IWS, #67 and #68, used for testing
    - Strain gage-based measurement system
    - Outputs vertical, lateral, and longitudinal forces
    - Mounted on a loaded 110-ton hopper car (axle locations 1 & 4)
    - NBAs mounted at IWS locations for comparative analysis

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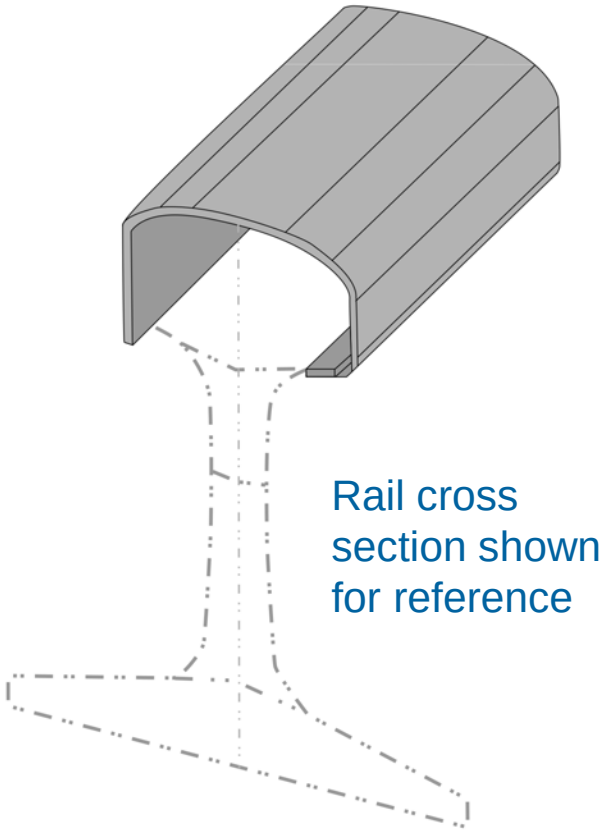
Testing

- **Portable Rail Bump (PRB)**
  - Designed by MxV Rail during previous WILD validation efforts
  - American Iron and Steel Institute (AISI) 4340 steel alloy
    - Material with similar durability and impact resistance may be substituted
  - Used to generate vertical impacts as the test wheel(s) (IWS) move past
  - Mounted to center of cribs 1 and 6 of HAC



PRB Label	Nominal Thickness (inch)
A	0.048 – 0.052
B	0.073 – 0.077
C	0.096 – 0.100
D	0.116 – 0.120

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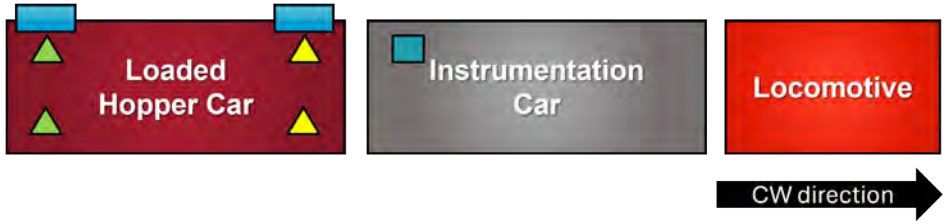
Testing

- **Test Matrix**
  - Test train consisted of a six-axle locomotive, instrumentation passenger car, and a loaded 110-ton hopper car
  - Total of 50 runs
    - Speed ranged from 5 mph to 30 mph
    - One run at 40 mph clockwise (forward)
      - At higher speeds, and when encountering multiple wheels before the IWS, PRBs tended to “release” or be “knocked off” the rail.
      - As a result, all remaining runs were made in the counter-clockwise (reverse) direction to ensure impacts at the IWS

Test Consist



Run Number	Bump Type	Direction	Speed (mph)
1-4	none	CW & CCW	5
5-12	C & D	CW & CCW	20
13-19	A & B	CW & CCW	30
20	A & B	CW	40
21-27	A	CCW	30
28-34	B	CCW	30
35-38	C & D	CCW	15
39-42	C & D	CCW	20
43-48	C & D	CCW	25
49-50	none	CW & CCW	5

PRB Label	Nominal Thickness (inch)
A	0.048 – 0.052
B	0.073 – 0.077
C	0.096 – 0.100
D	0.116 – 0.120

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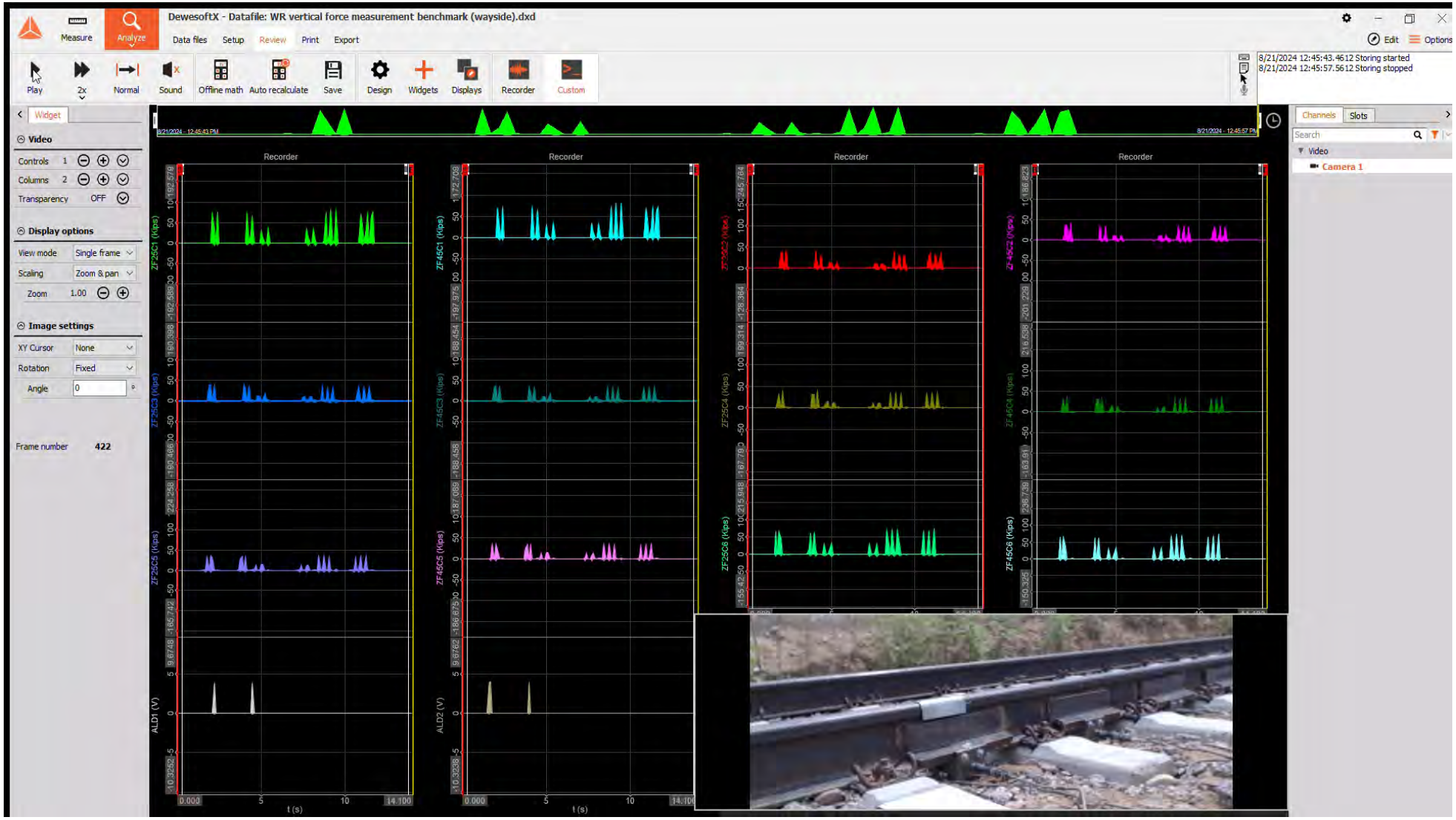
Wayside video



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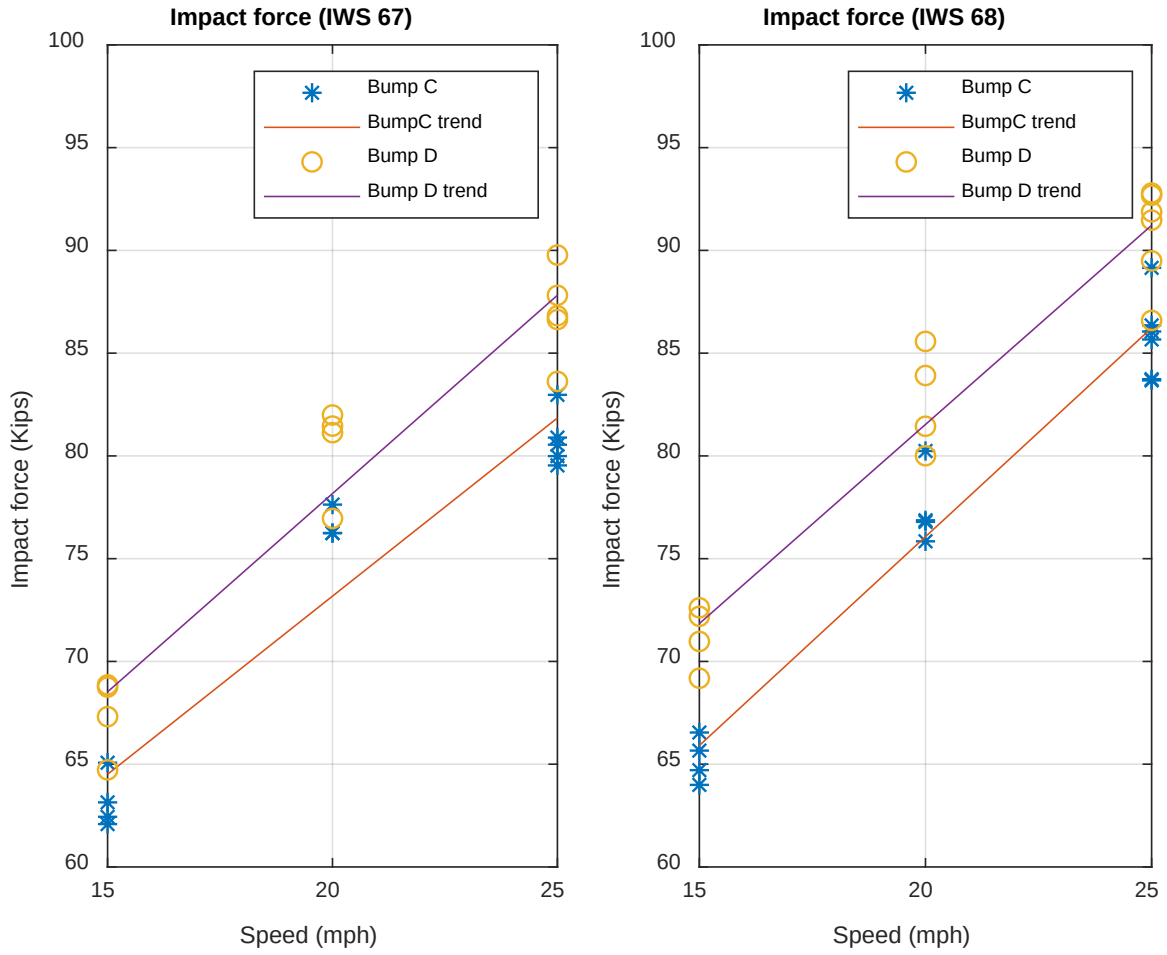
Test Results

- **Vertical Impact Forces**
  - Total of 162 impact samples collected
  - Generated impacts ranging from 46.5 kips to 97.8 kips
  - Impact magnitude can be controlled by a combination of speed and PRB thickness

PRB Label	Nominal Thickness (inch)
C	0.096 – 0.100
D	0.116 – 0.120



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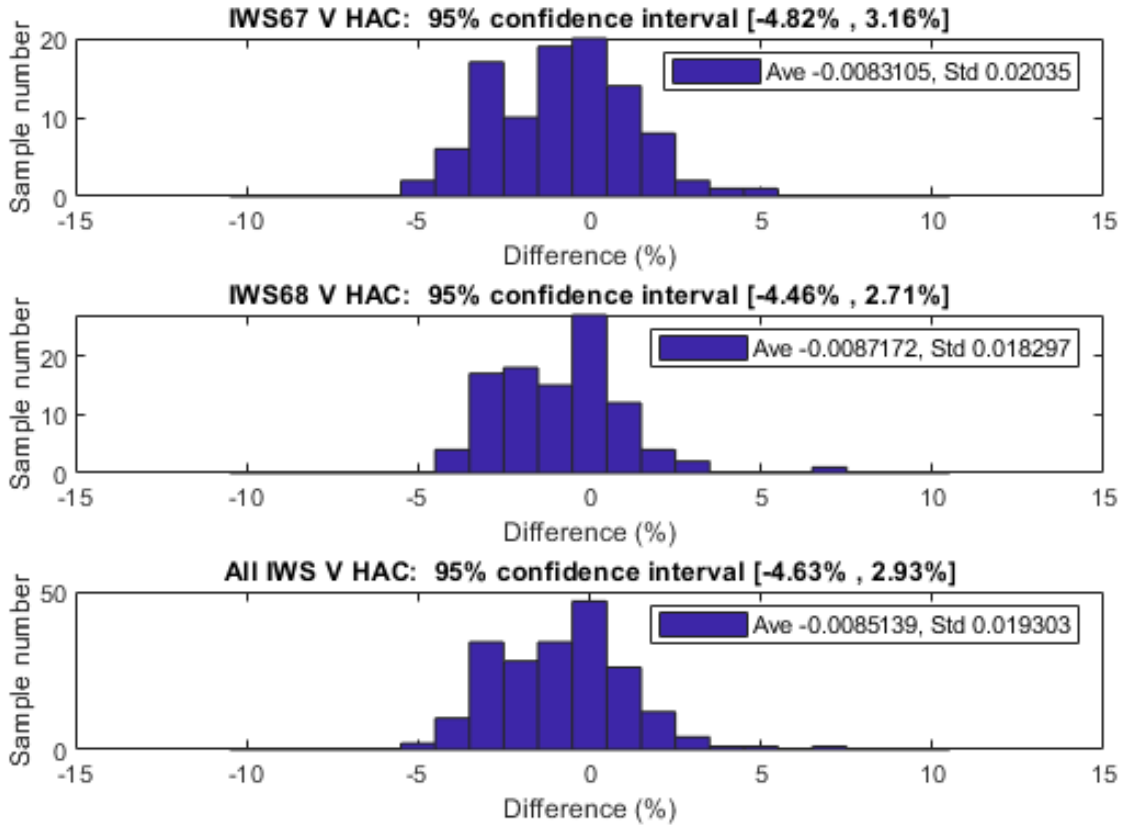
Test Results

- **Data Analysis**
  - Distribution of differences between HAC and IWS show that all but one (1) set of readings are within ±5%
    - (IWS 68, 7.20%)
  - 95% confidence intervals of IWS 67 and IWS 68 were both within ±5%



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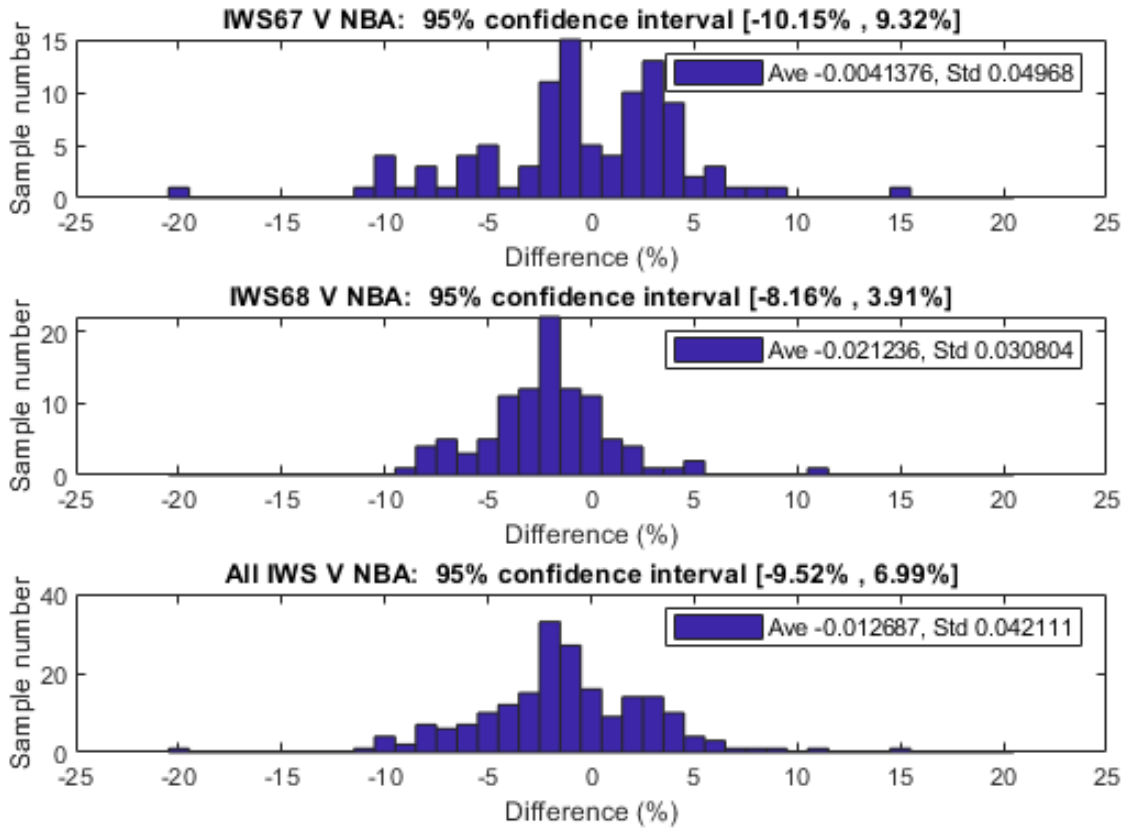
Test Results

- **Data Analysis (cont.)**
  - Distribution of differences between HAC and NBA show that all measurements are within ±10%
  - Max impact value measured and overall distribution of NBA/IWS 67 vs. NBA/IWS 68 is different
    - NBA coupled with IWS 68 shows greater stability
    - Suggests improvements to NBA are required for validation purposes



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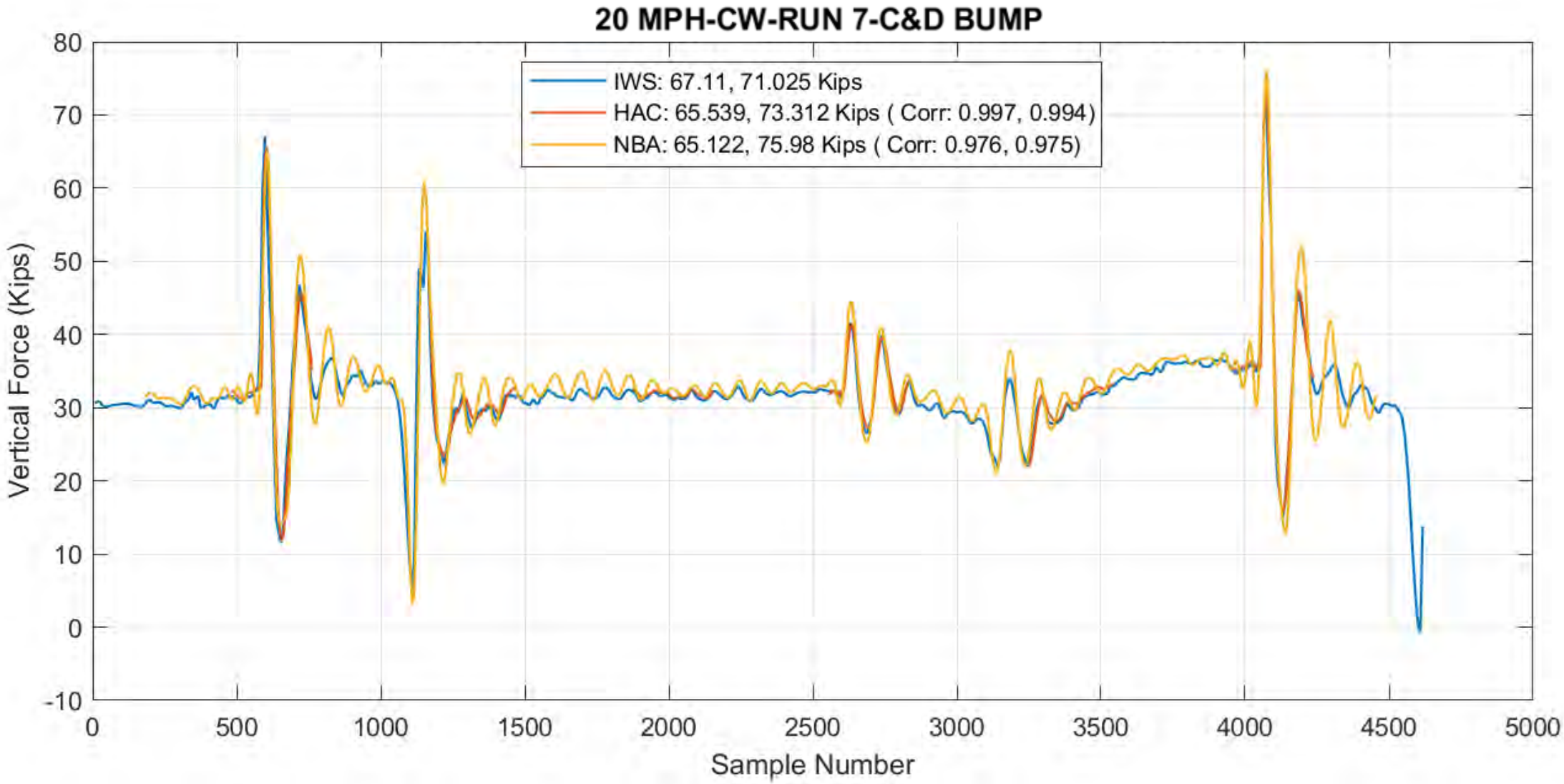
Test sample



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Conclusions

- **Impact forces measured by IWS and HAC within 5 percent**
  - Onboard (IWS) and in-track (HAC) measurements of W/R vertical forces can produce consistent results
  - IWS can be used as a benchmark for validation of WILD systems
- **Impact forces measured by IWS and NBA within 10 percent**
  - While a potential lower-cost solution to using an IWS, the NBA requires further improvements to meet the needs for validation of WILD systems
- **PRBs can generate impacts at levels that approach or exceed the AAR “actionable” limit of 90 kips**
  - Vertical impact force controlled by varying the thickness of PRB and the speed of the test runs
- **IWS + PRB is a viable validation solution**

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Future Work

- **Updates to MSRP-F, S-6101: Detector Calibration and Validation Requirements**
  - Based on the findings of this and previous testing, EHMC and MxV Rail are currently working to formulate a validation standard to be used for all WILD systems, regardless of the technology deployed
  - While not currently being investigated, future work may include improvements to the NBA design and performance
    - Improvements to the NBA could provide for a lower-cost, less operationally obtrusive means of WILD validation

Acknowledgements

- AAR Equipment Health Monitoring Committee (EHMC)
- WILD Validation Taskforce
- MxV Rail Team

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Evolution of North American Head-of-Train/End-of-Train (HOT/EOT) System

Matthew Holcomb, Senior Engineer III
Bivesh Paudyal, Senior Engineer III

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Overview

- HOT/EOT System Overview
- Background and Evolution
- Opportunities for Improvements
- Gen4 HOT/EOT Related Work Status
- Gen4 HOT/EOT OTA Candidate Protocols Testing
- Test Overview
- Key Test Results
- Conclusions and Recommendations

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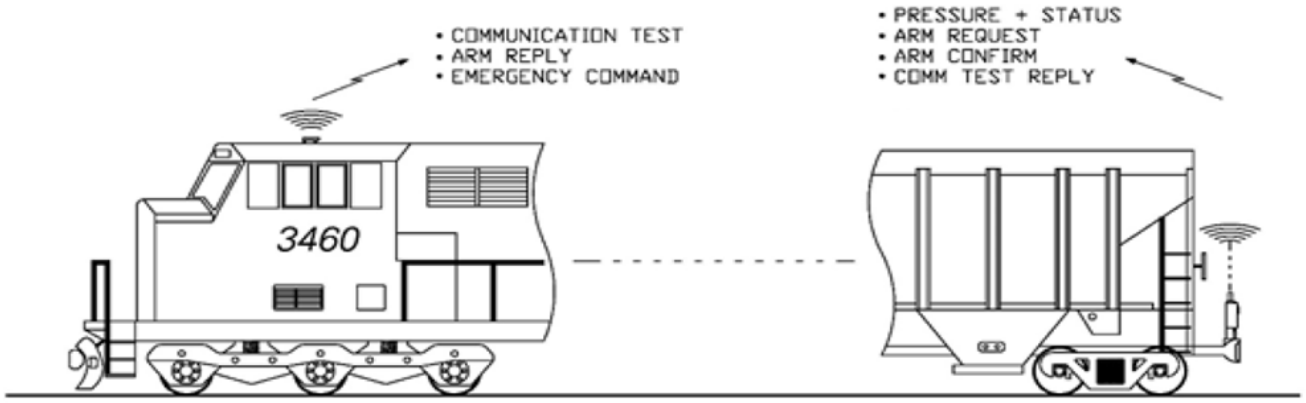
HOT/EOT System Overview

- **Wireless communication front-of-train to rear-of train**
- **HOT function:**
  - Allows locomotive engineer to:
    - Monitor the train integrity
    - Monitor brake pipe pressure
    - Apply rear-of-train emergency brake application, if needed
- **EOT function:**
  - Flashing rear-end device (FRED)
  - Monitors rear-of-train brake line pressure
  - Sends wireless status reports to the lead locomotive
  - Applies the train brakes from rear-of-train on radio command from the engine crew

HOT/EOT System Overview



HOT Unit in the Locomotive

EOT Unit at the rear of the train

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HOT/EOT Evolution

Caboose at the rear of the train with air valve that required onboard crew to operate

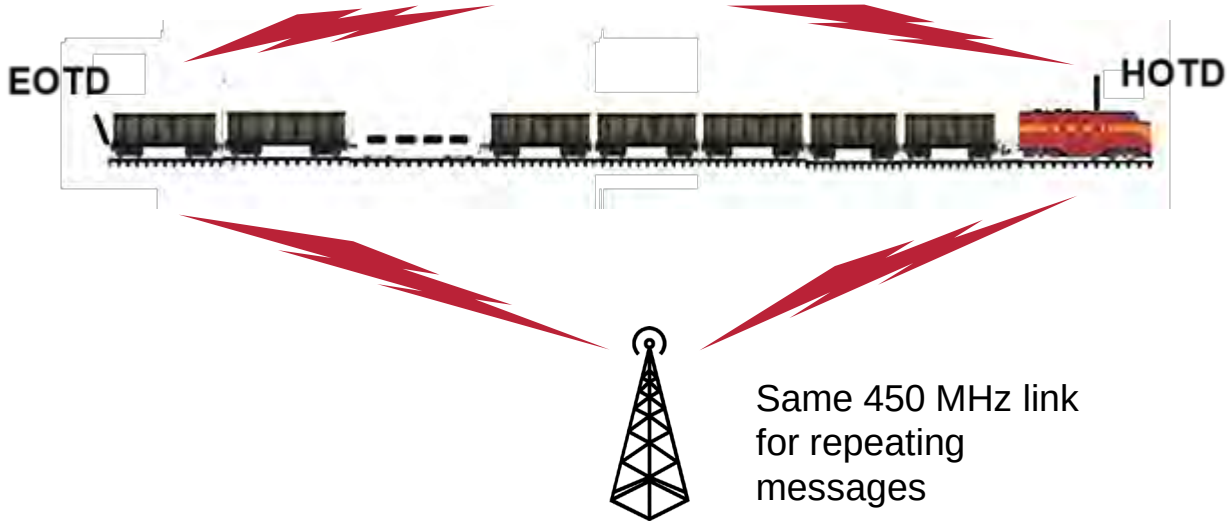
EOTD replacement of caboose:

- Marker light
- One way Telemetry HOTD-EOTD (monitoring)
- Two-way telemetry to monitor and apply brakes
- Wayside repeater to allow for more robust communications, Increased distance between HOT/ EOT, challenging terrain

- **Pressure & status**
- **Comm. test reply**
- **Arm confirm**

- **Communication test**
- **Emergency command**

450 MHz Direct Link



Same 450 MHz link for repeating messages

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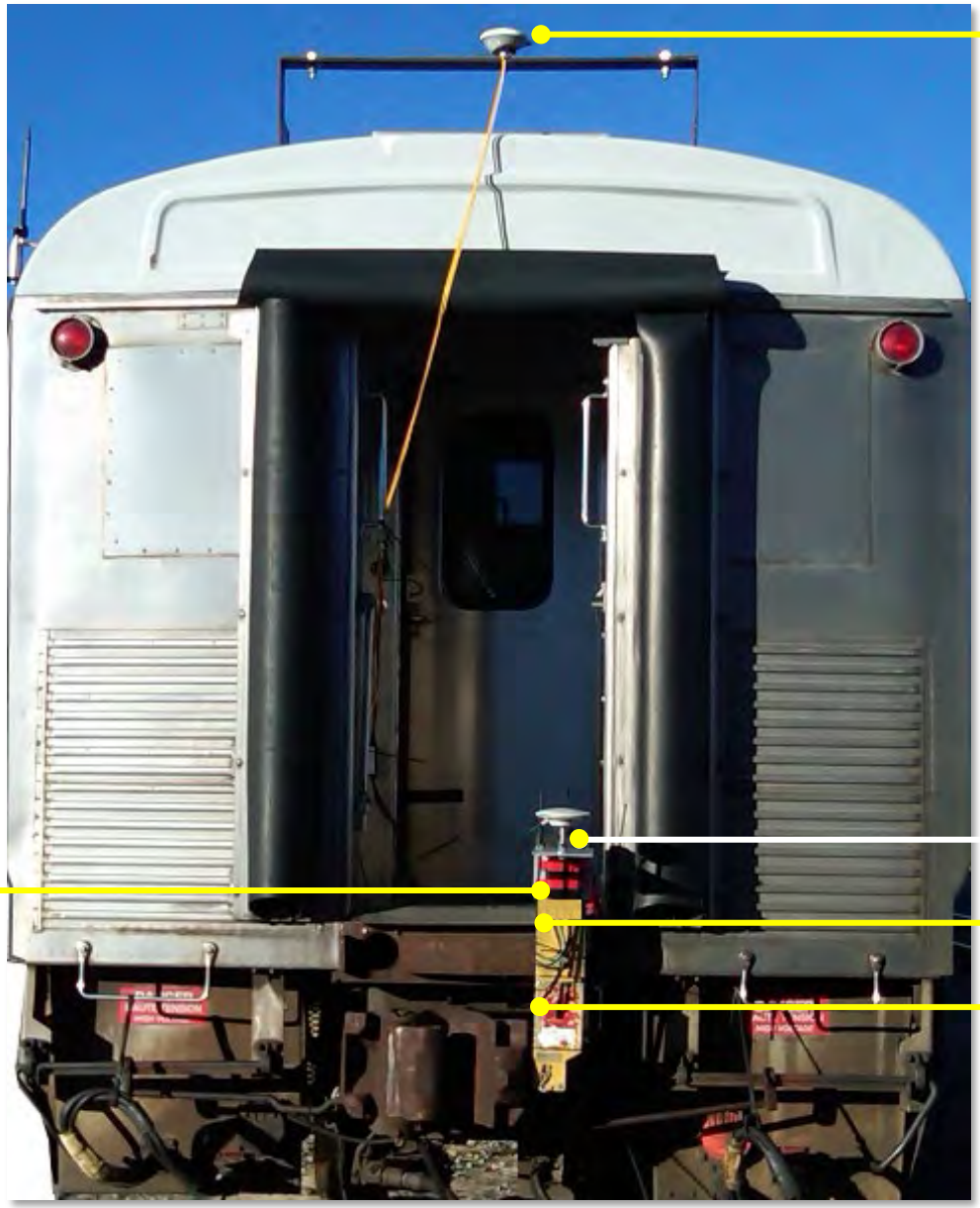
Opportunities for Improvement

- **Improve communications**
  - Reliability
  - Message rates
  - Data robustness and throughput
- **Addition of location reports from EOT**
  - Position and Navigation Module (PNM) receiver
  - Track imaging sensor to refine positioning based on Track Point of Interest (TPOI) with surveyed positions
- **Backup communication paths**



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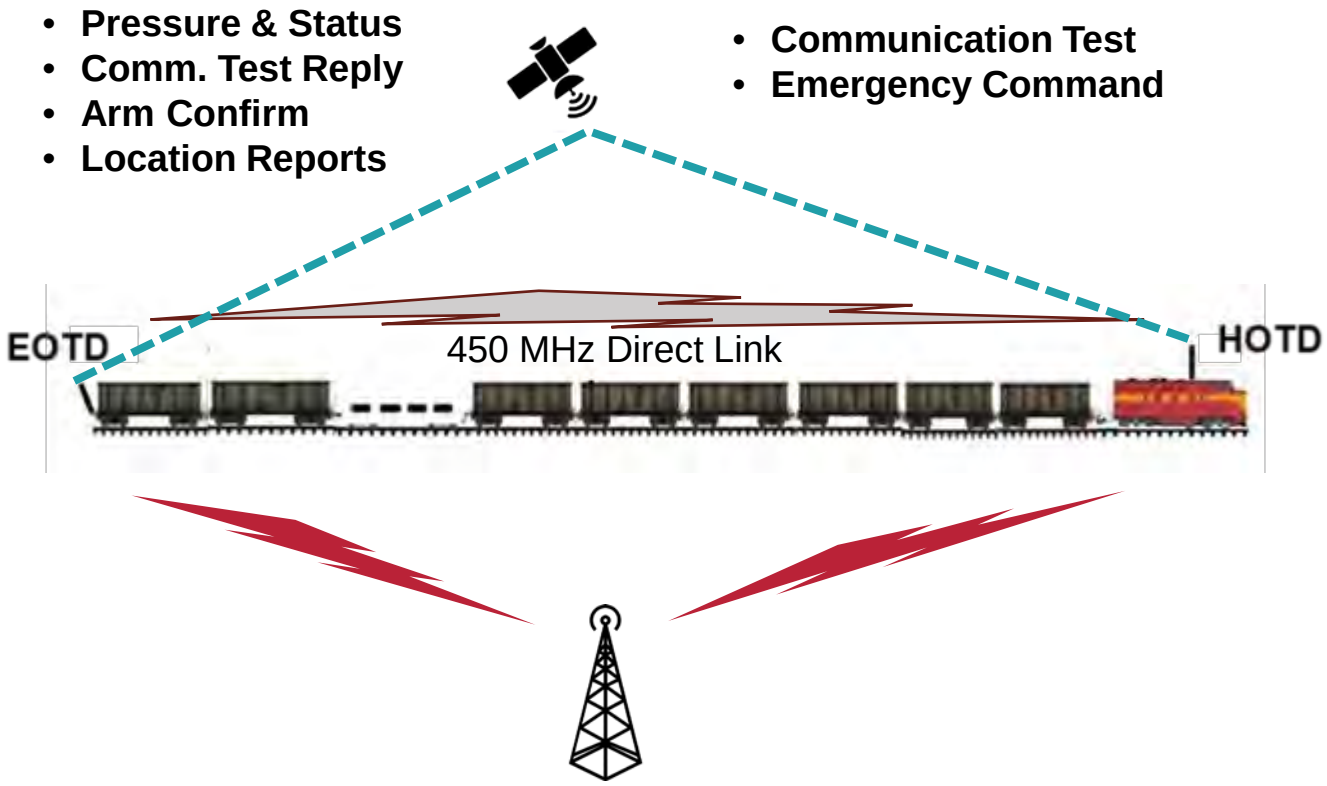
Gen 4 HOT/EOT

Gen4 will provide:

- Spectral efficient over-the-air (OTA) protocol for improved comm. message rates, reliability, and robustness
- Location reports from EOT-HOT to support new use cases for railroad operations
- Backward compatibility with the legacy system



450 MHz & Backup link for repeated message

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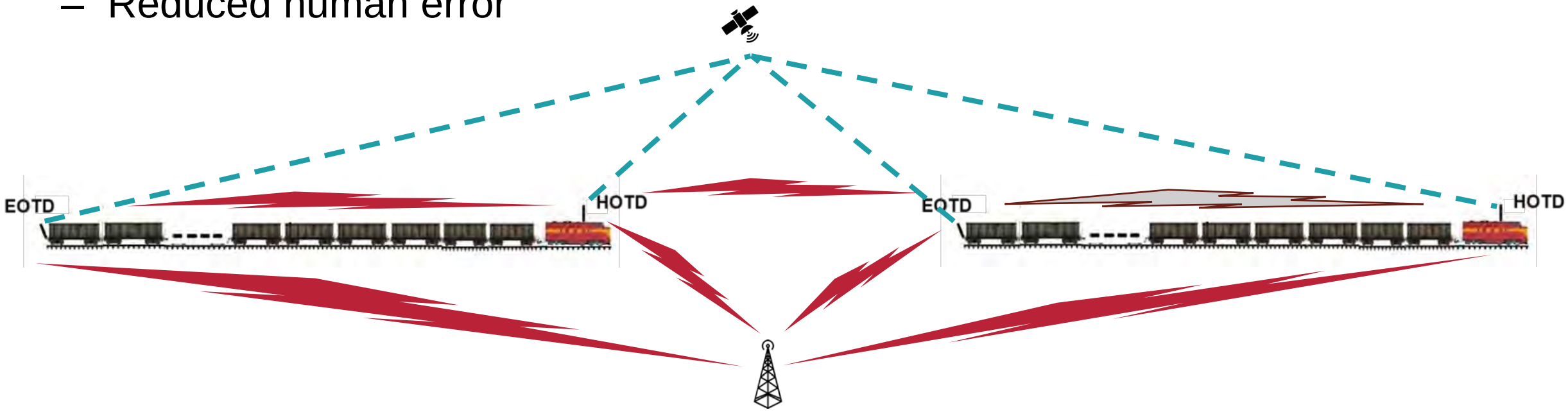
Gen 4 HOT/EOT Benefits

- **Future methods of train control will benefit from enhanced communications and precise rear-of-train positioning**
  - Improved safety
  - More traffic on rail network allowing trains to run smaller headways than on conventional train control systems
  - Reduced human error



450 MHz & Backup link for repeated message

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Gen4 HOT/EOT Related Work

- **Definition of scope for Gen4 HOT/EOT system**
- **Development of suite of systems engineering document including Concept of Operations**
- **Improved positive train location HOT/EOT efforts**
- **Evaluation of over-the-air (OTA) communication protocols**

2024 Gen4 HOT/EOT OTA Protocols Testing at MxV Rail

Bivesh Paudyal
Senior Engineer III

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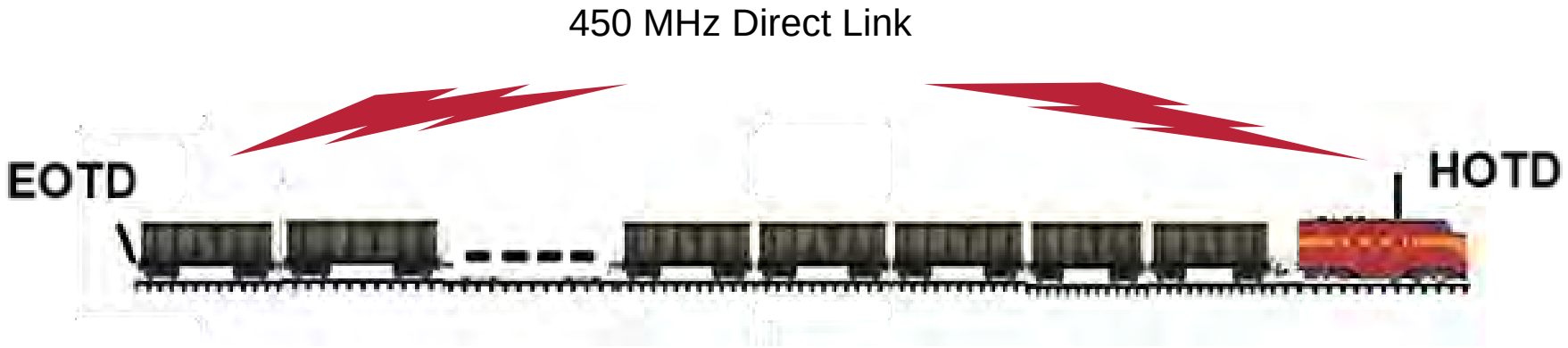
11/24

2024 Gen4 HOT/EOT OTA Protocols Testing

- **Testing Objective**
  - To evaluate performance of various candidate over-the-air (OTA) protocols for direct link between HOT and EOT at 450 MHz.



- **Testing Phases**
  - Phase 1: Facility for Accelerated Service Testing (FAST®) Loop
  - Phase 2: High-Speed Loop (HSL)

FAST® is a registered trademark of MxV Rail

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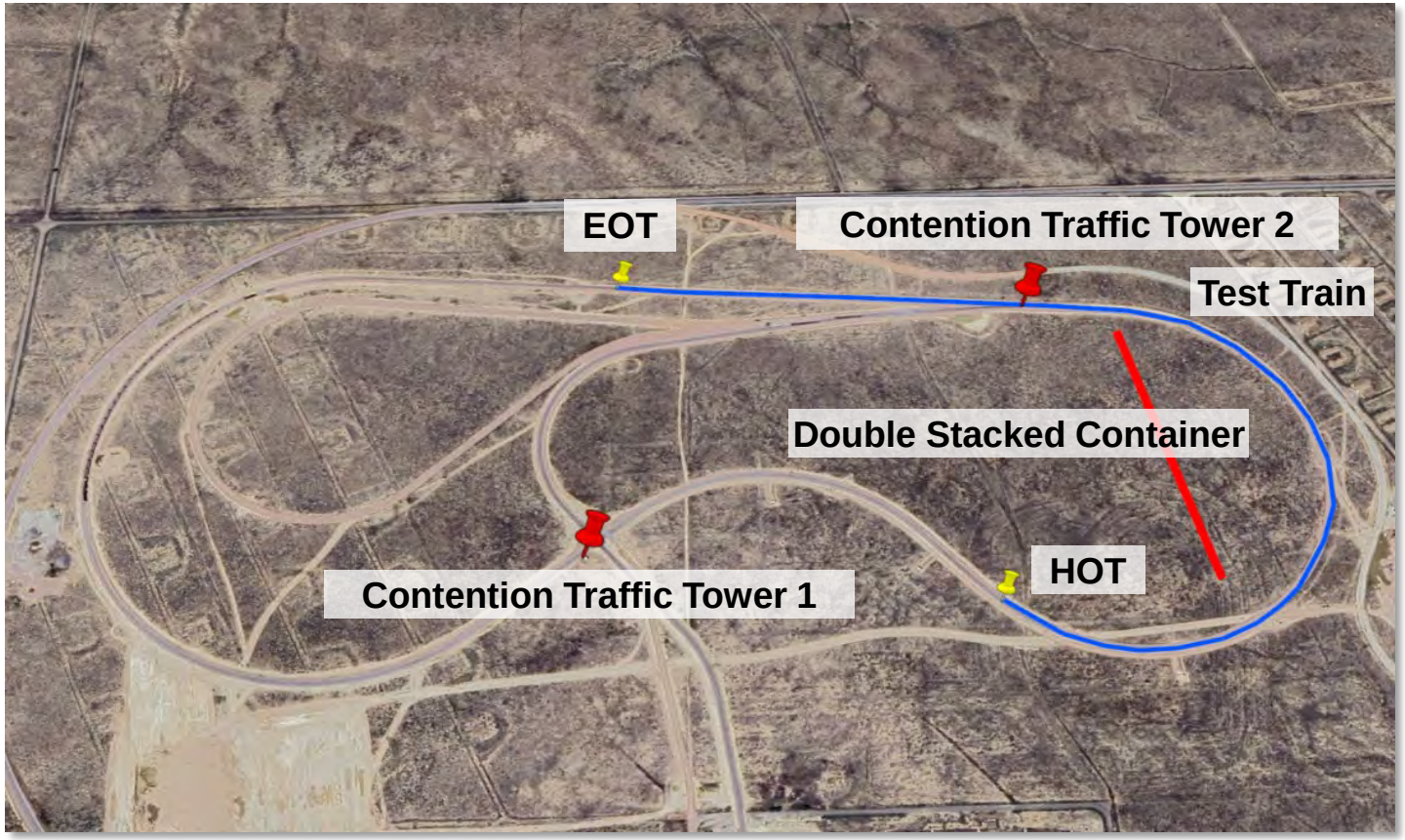
Phase 1: FAST Testing

- **HOT/EOT testing during normal FAST operations**
  - Initial evaluation and check out of test setup.
  - Limited useful test scenarios.



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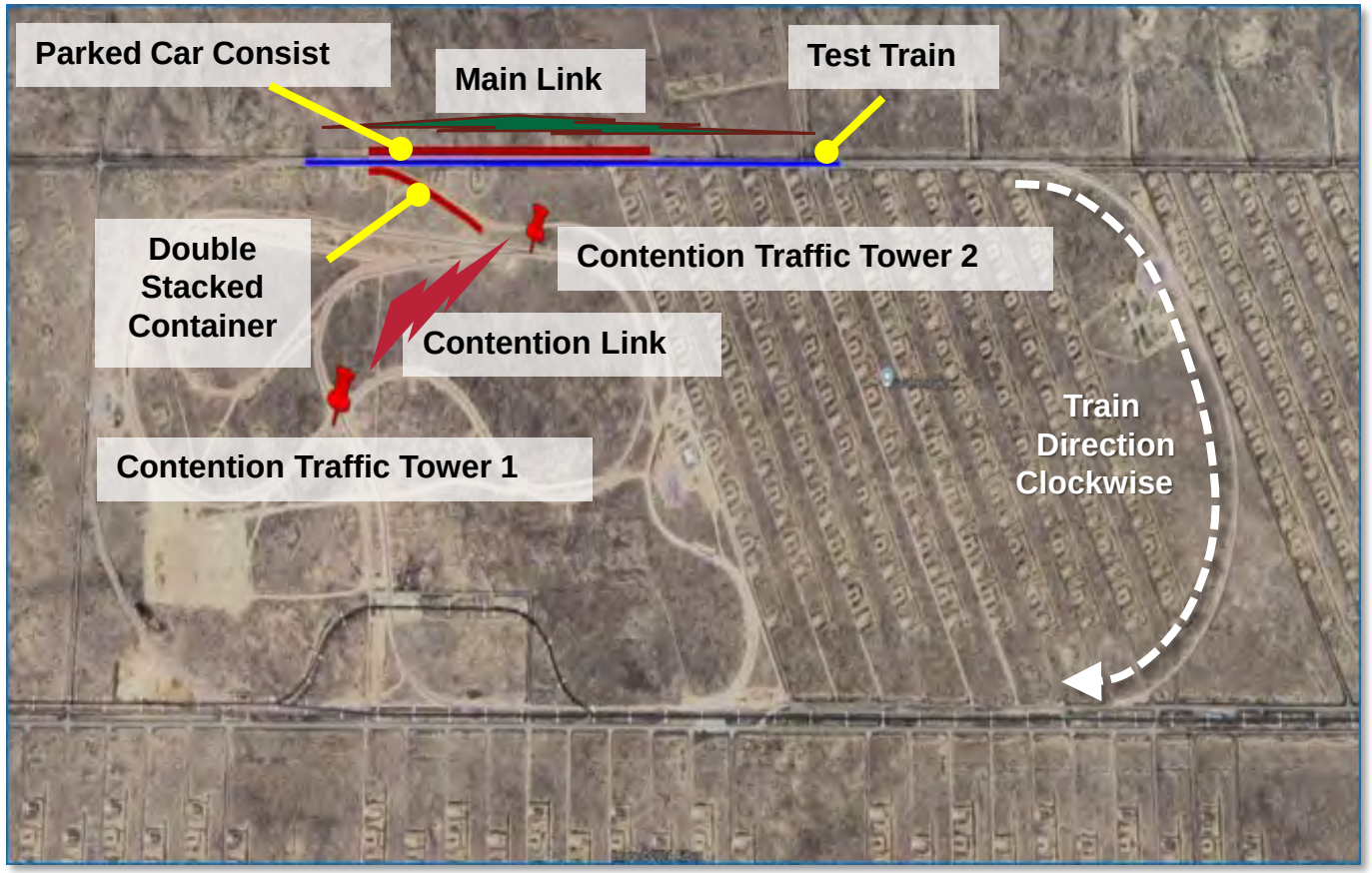
Phase 2: HSL Testing

- **Train length ~ 1.16 mi.**
  - 3 locos, 114 railcars.
- **Double-stacked containers Length: ~0.27 mi (1,450 ft.)**
- **Parked car consist length: ~0.62 mi.**
- **HSL track length: ~ 5.8 mi.**
- **Train speed ~ 26-44 mph**



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Test Train - EOT and HOT Platform Setup

- **Cellular modem was used for remote configuration**
- **GPS was used to log location and time information**
- **Rear-of-train GPS and cellular antenna were attached to metal plate atop railcar**

EOT antenna installed on the last car

HOT devices Installed in second locomotive cab

Parked car consist

Double-stacked containers

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Communication Protocols Tested

1. **Legacy (Current Generation)**
2. **802.16t (Gen4 Candidate)**
3. **NXDN (Gen4 Candidate)**

- **Communication protocol is a set of rules and standards that define how devices transmit and receive data in a network**
  - Each protocol tested uses different Modulation and Coding Scheme (MCS)
  - MCS is a technique of converting data into signals for transmission
- **For devices sharing the same communication channel, different channel access techniques can be used:**
  - The legacy system uses the ALOHA method.
  - The candidate Gen4 systems use Carrier Sense Multiple Access (CSMA)

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Key Metrics for Testing and Evaluation

- **Message error rate:**
  Percentage of messages failed to be received compared to the number of messages sent. The lower the message error rate, the better the communication link.
- **Transmitted power:**
  Power transmitted from Device Under Test (DUT). A protocol that achieves the same performance with lower power transmission is desired.
- **Received Signal Strength Indicator (RSSI) threshold:**
  The lowest signal power level at which messages were successfully received. The lower the RSSI threshold, the better the communication protocol.

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Radio Devices Test Configuration

- **Three configurations for DUT in test cases**
  - DUT-A: Baseline legacy EOT/HOT testing
    - Duplex operation
    - No contention link traffic
  - DUT-B : Gen4 EOT/HOT Testing, no contention link
    - Duplex configuration
    - No contention link traffic
  - DUT-C : Gen4 EOT/HOT Testing, some test cases with contention link and some without contention.
    - Additional Gen4 traffic active during some DUT-C tests on the contention link from two towers
    - Some test cases used Duplex operation while other used Simplex operations

Testing Results

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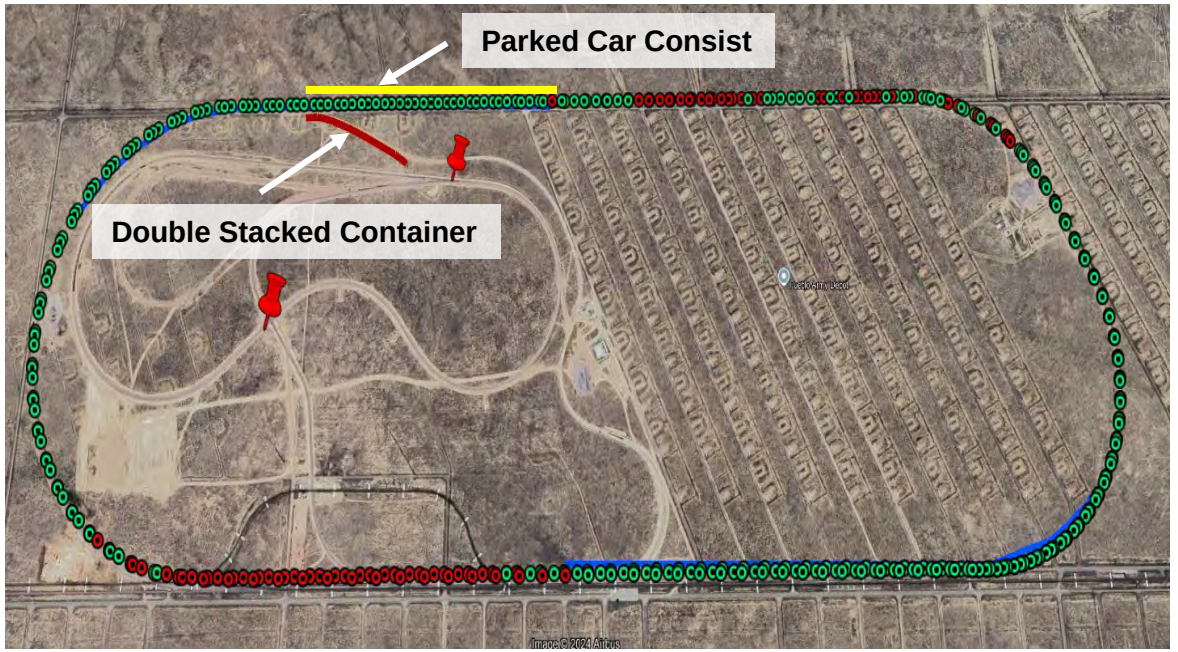
HSL9 HOT to EOT Message Loss vs. Success

HSL 9 Scenario: Simplex, No Contention, No EOT Location Reports



Message Loss vs. Success on HSL

- **Each dot represents location of Head-of-Train Device (HOTD) during testing, train moving in a clockwise direction**
  - Red dots indicate instances when command messages sent by the HOT were lost
  - Green dots indicate instances when command messages were successfully received by EOTD
- **Communication performance degraded when train was entirely on the tangent track**

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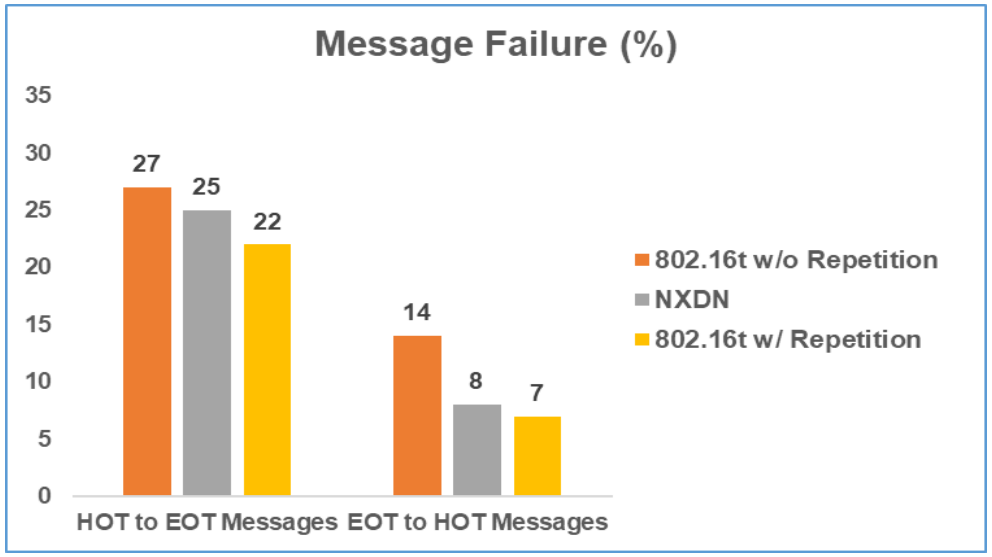
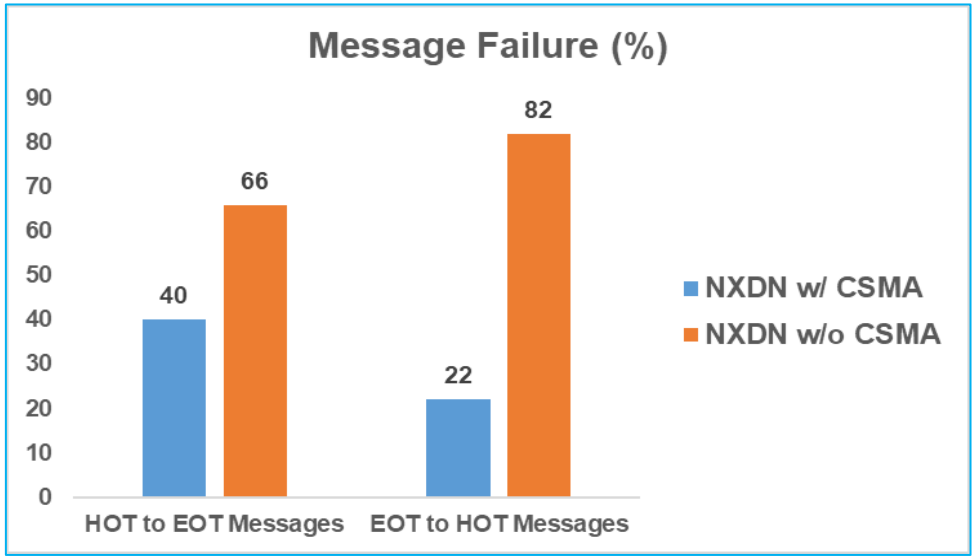
Message Failures – Gen4 Test Results



HSL23 Scenario: Duplex, No Contention, w/ EOT location reports
802.16t TX power: +32.4 dBm
NXDN TX power: +39 dBm



NXDN Performance with ALOHA vs. CSMA, in high contention environment (24 trains in a same area)

Observations from the testing:

- **802.16t required less than 25% TX power as NXDN for approximately same performance**
- **802.16t with codeword repetition achieved even better performance**
- **EOT to HOT link had better performance compared to HOT to EOT link**
- **CSMA significantly reduces the impact of contention (multiple trains in the same area)**

dBm (decibels milliwatt): logarithmic unit of representing power level relative to 1 milliwatt

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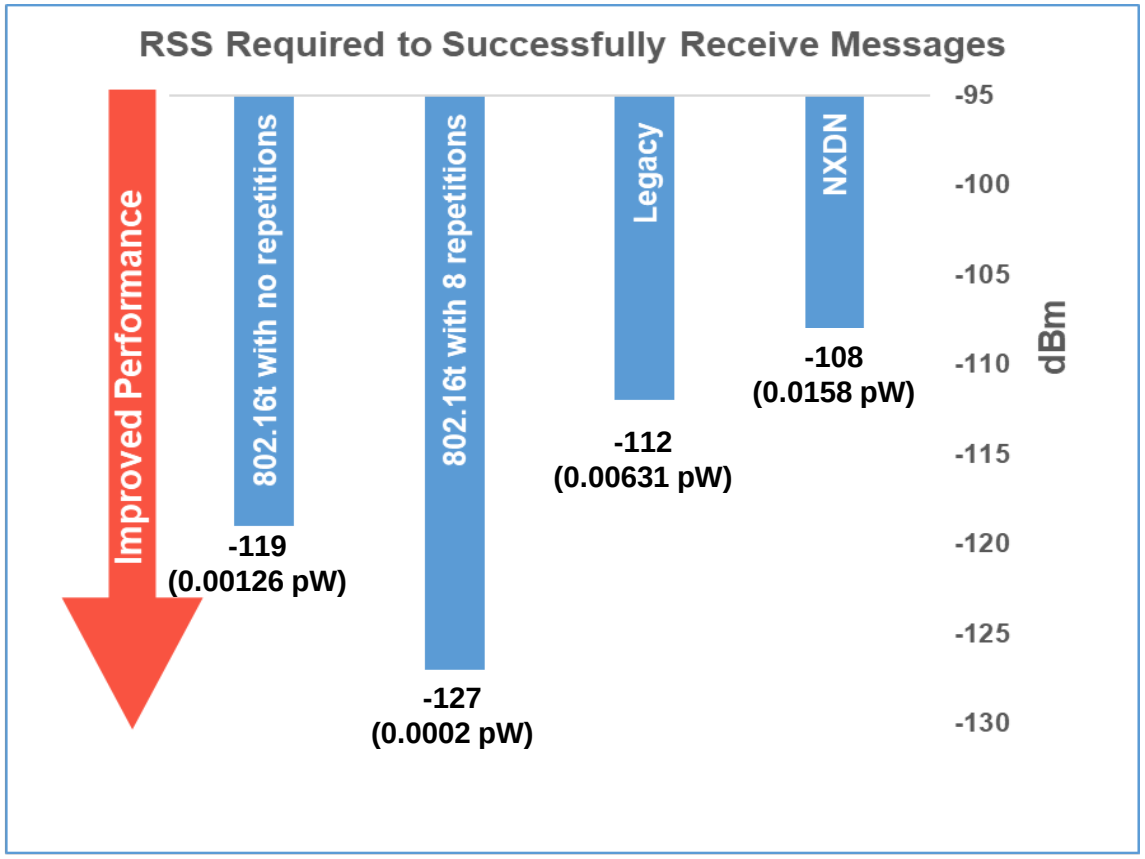
Observed Receiver Sensitivity for Tested Protocols



dBm (Decibels milliwatt): logarithmic unit of representing power level relative to 1 milliwatt.

1 picowatt (pW): 10^{-12} watts (W)

- **Receiver Sensitivity:**
  Lowest Received Signal Strength (RSS) with error-free message reception
  - 802.16t protocol performed better than other protocols tested
  - 802.16t with codeword repetition increases performance
    - Note: Repetition affects channel capacity, so should be reserved for critical messages

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Conclusions and Recommendations

- **Gen4 HOT/EOT system will provide enhanced communications reliability, channel efficiency, and additional EOT location information for other applications**
- **Gen 4 HOT/EOT message reliability – 802.16t vs. NXDN**
  - 802.16t required less than 1/4 as much TX power as NXDN for approx. same performance when neither system used message repetition
  - 802.16t improves message reliability (most critical objective for Gen4) over NXDN for a given transmission power level
- **Additional benefits**
  - With 8-ary codeword repetition and combining, 802.16t allows a further reduction in transmit power by a factor of 8
  - Codeword repetition and combining should be used only when needed to avoid impacting message throughput
  - CSMA reduces contention compared to ALOHA
- **On March 19, 2025, the AAR Wireless Communications Committee (WCC) agreed upon selection of 802.16t as the primary 450 MHz protocol for the Gen4 EOT-HOT system.**

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Next Steps

- **Identify and resolve other communications-related issues**
- **Work with the railroads to complete Gen4 HOT/EOT AAR standards**

Acknowledgements

- TAG: AAR Wireless Communications Committee (WCC)
- MxV Rail C&TC and Operations groups
- Testing partners (suppliers)
  - DPS
  - Ondas/Siemens
  - Wabtec/Aeronix

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University Grand Challenges

Anish Poudel, Scientist
Corey Pasta, Scientist

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Overview

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- **University Programs**
  - Background & Objectives
  - Program Benefits
  - SRI Technology Assessment & Implementation Path
- **Grand Challenge in Railway Engineering**
  - Grand Challenge Project Topics
  - Proposal Selection & Approval Process
- **Funded Grand Challenge Projects**
- **University Days**
- **Acknowledgements**

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AAR/MxV Rail University Programs

- **Program Objectives:**
  - Railroad Advancement
    - Promote knowledge, technology, and innovation for long-term success
  - Research Support
    - Inspire students/researchers in discovery and problem-solving
  - Strategic Collaboration
    - Strengthen ties between universities, railroads, and government agencies

Program Benefits

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- Increased awareness of and exposure to new technologies
- Opportunity to contribute toward the conception of new strategies
- Access to intellectual property, patents, and publications
- Professional networking opportunities
- Highly trained pool of potential personnel for rail industry

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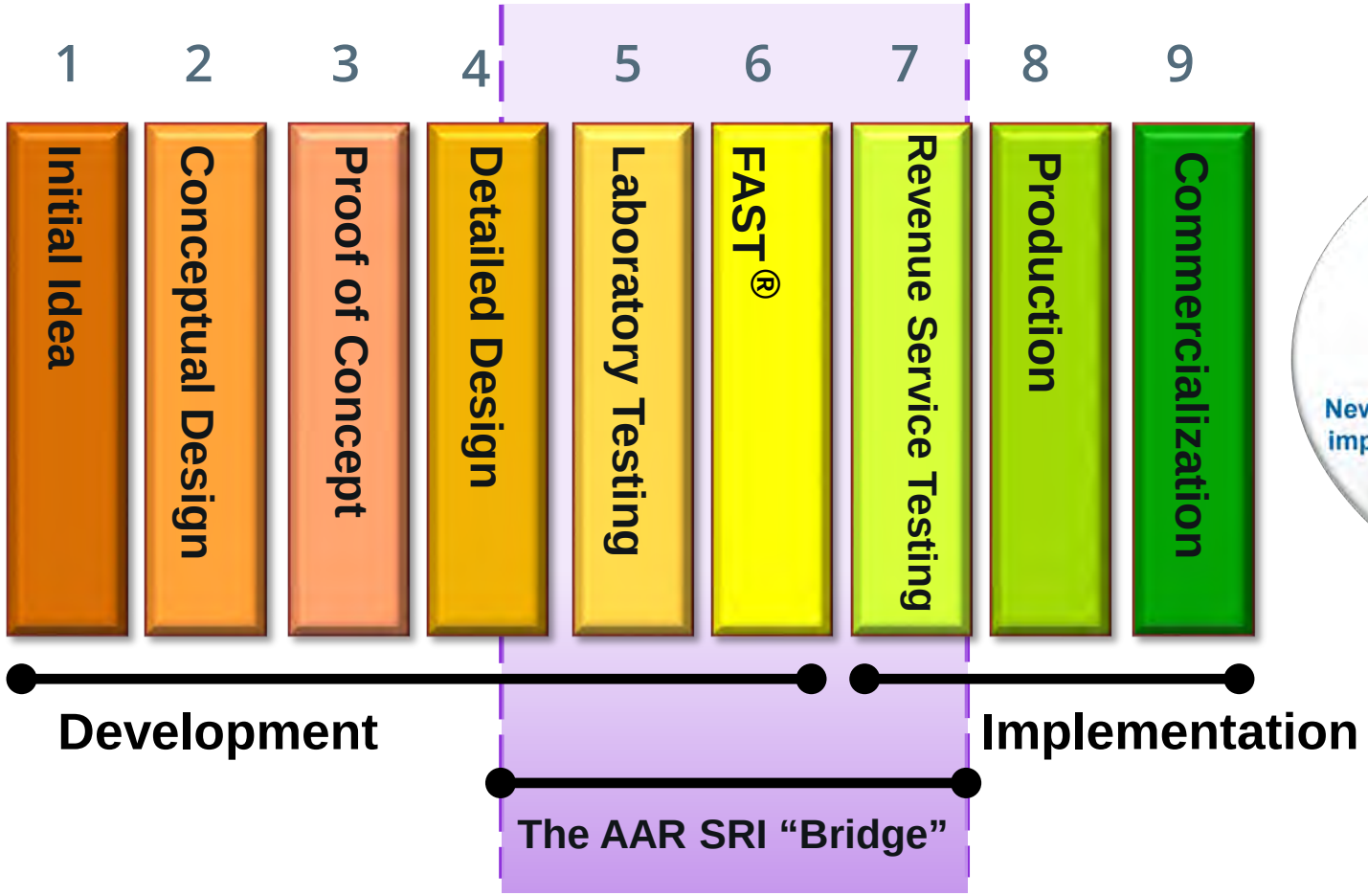
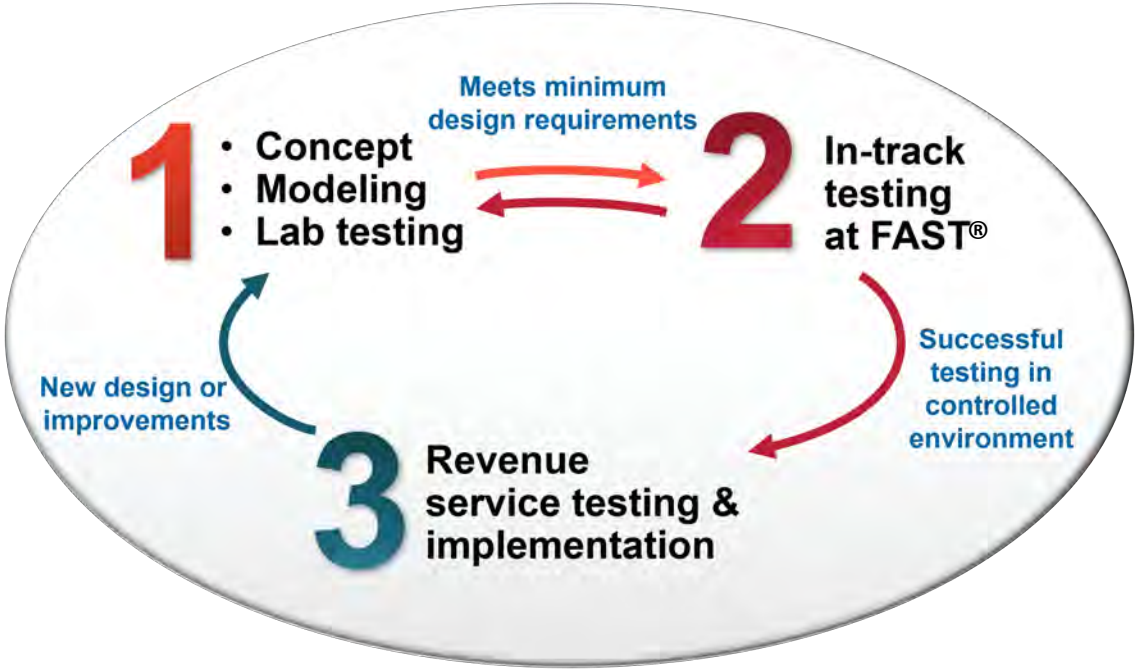
Technology Assessment & Implementation

Technology Readiness Level (TRL) Map





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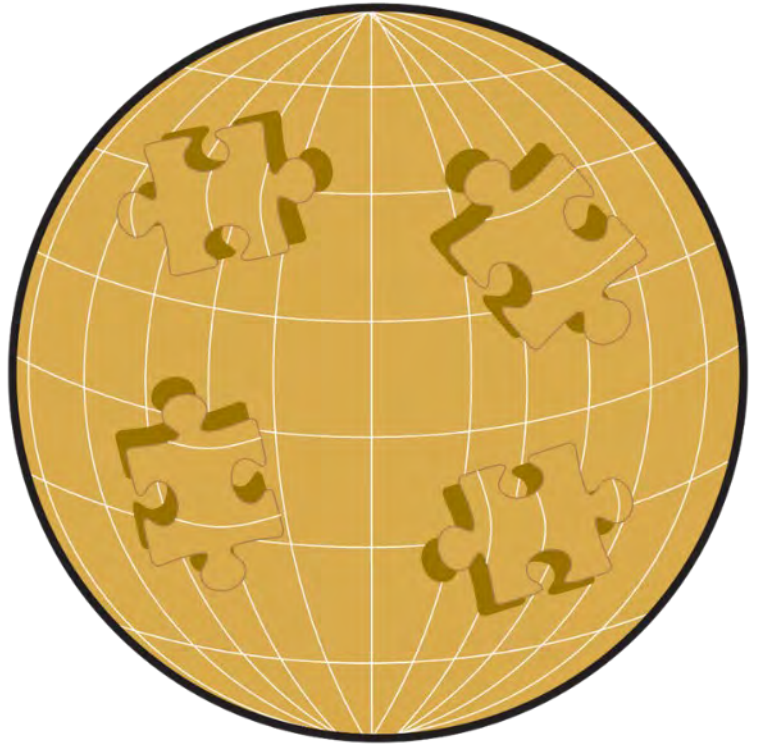
Grand Challenge in Railway Engineering

- **Projects recommended by AAR Technology Review Advisory Panel (TRAP) and AAR Research Committee**
- **A family of initiatives fostering innovation to address key issues impacting the safety, reliability, and efficiency of freight rail operations in North America**
  - Solving complex, critical rail industry existing challenges
  - Increasing scientific knowledge base of the rail industry
  - Capitalizing on the potential of existing technologies



GRAND CHALLENGE
INITIATIVE

Grand Challenge Project Topics

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1

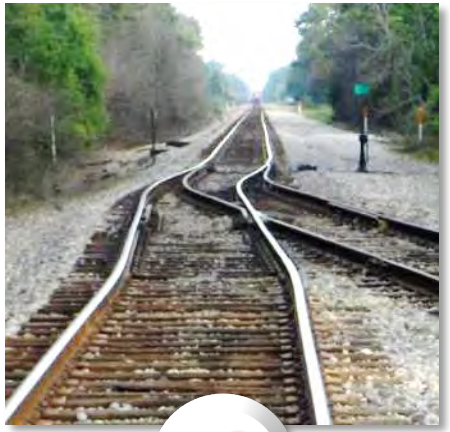
In-motion Full Rail Section Inspection using NDE methods

2

In-motion Full Wheel Tread Inspection using NDE methods

3

In-motion Axle and Bearing Inspection using NDE methods



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Novel ways for force/ stress measurements

Other Topics

- Technological approaches to railway resiliency related to extreme weather events
- Efficient data fusion and predictive analytics approaches
- Efficient and reliable inspection methodologies and approaches for sub-structure systems
- Open ideas and new technologies

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Proposal Selection & Approval Process

All projects undergo a competitive RFP and rigorous independent review process

AAR University Programs TRAP reviews and recommends projects/proposals

Since 2020, MxV Rail has supported 12 out of 61 proposals through AAR SRI University Programs

Current Funded Grand Challenge Projects

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University of Missouri
University of Illinois Urbana-Champaign
The University of Utah

In-situ Rail Neutral Temperature (RNT) Measurements

Michigan State University

Hybrid Rail Inspection Approaches

SIU Carbondale Southern Illinois University

In-Motion Rail Base Inspection

Virginia Tech

In-Motion Wheel Inspection

UCSD ExpMech/NDT/SHM Lab

3D Imaging of Internal Rail Flaws

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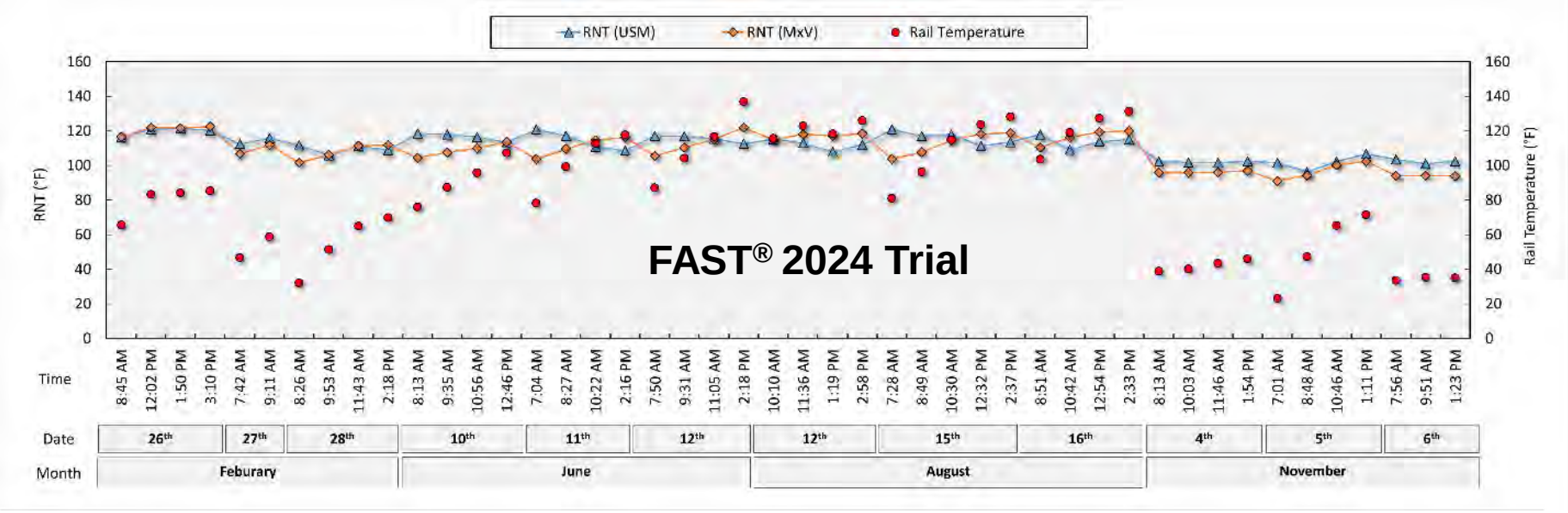
University of Missouri – PI: Dr. Glenn Washer

- **Develop an ultrasonic stress measurement (USM) technology for in-motion stress measurements to determine/predict the rail neutral temperature (RNT) and assess track buckling risk**
  - Field and controlled laboratory tests have demonstrated a high correlation for the rail temperature and ultrasonic birefringence
  - The average error during FAST® trials was found to be less than 3°F with a standard deviation (σ) of less than 7°F



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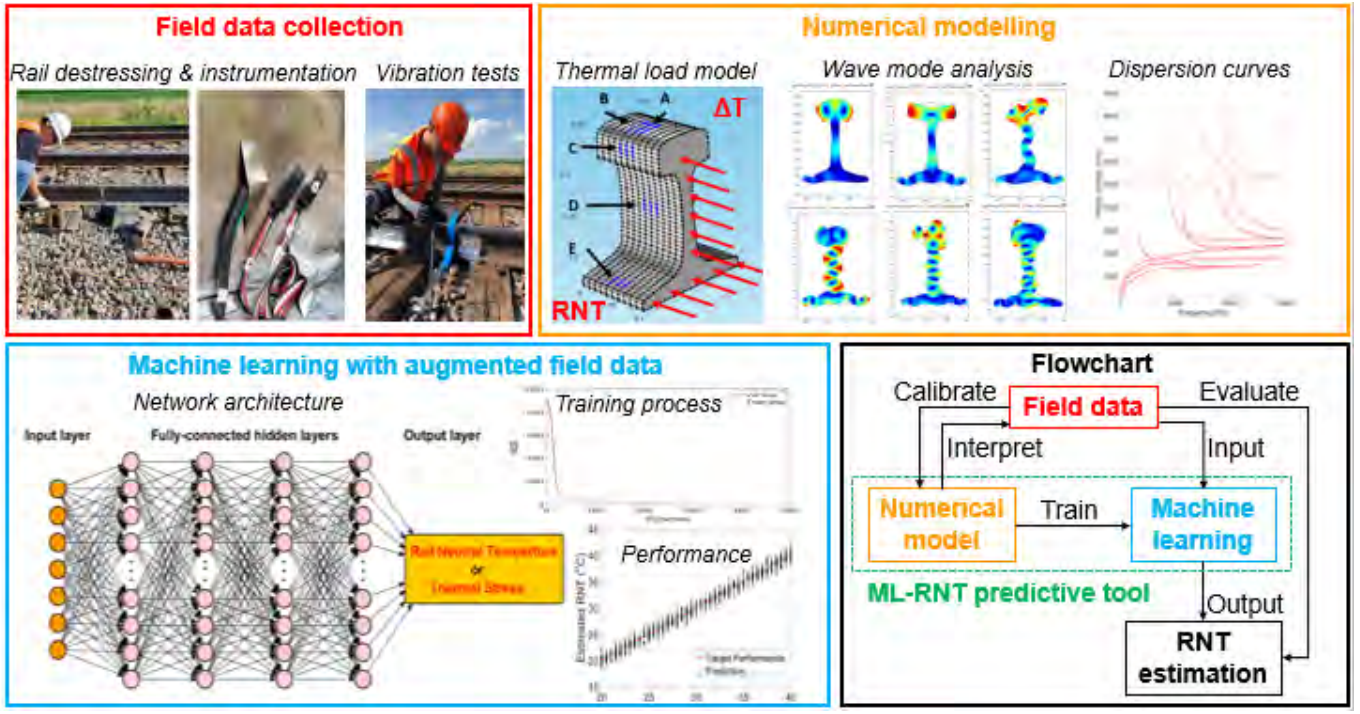
University of Utah / UIUC – PI: Dr. Peter Zhu

- **Determine in situ machine learning-based RNT predictive tool without the need of reference measurement at zero stress state with a reasonable accuracy (±10°F)**
  - Develop a portable local resonance and temperature measurement system that employs mechanical impacts
  - Perform long-term local resonance monitoring over 6-month period to verify the performance of the machine learning-based RNT predictive tool

Utah / UIUC in situ RNT Predictive Tool Framework



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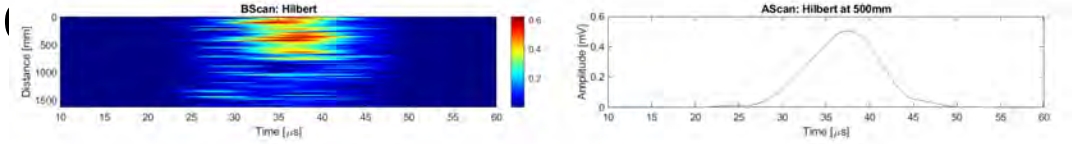
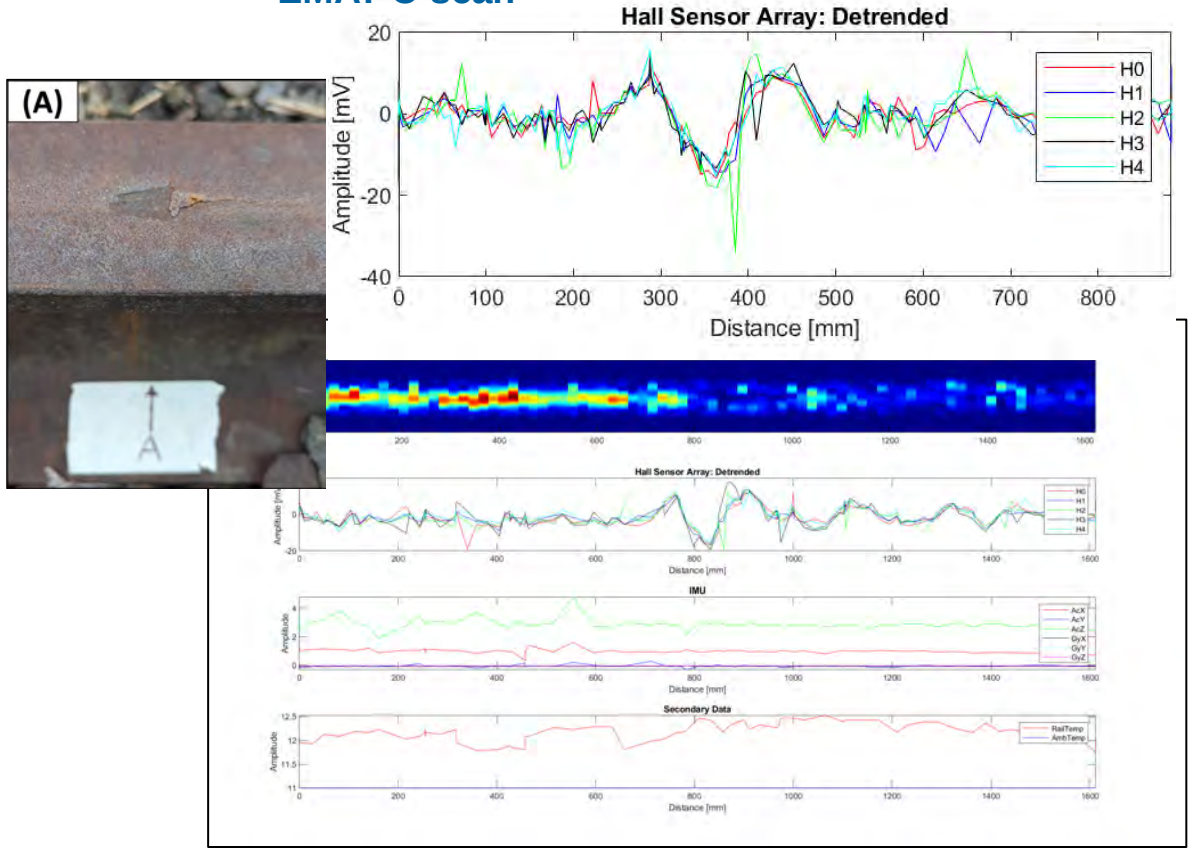
Michigan State University – PI: Dr. Yiming Deng

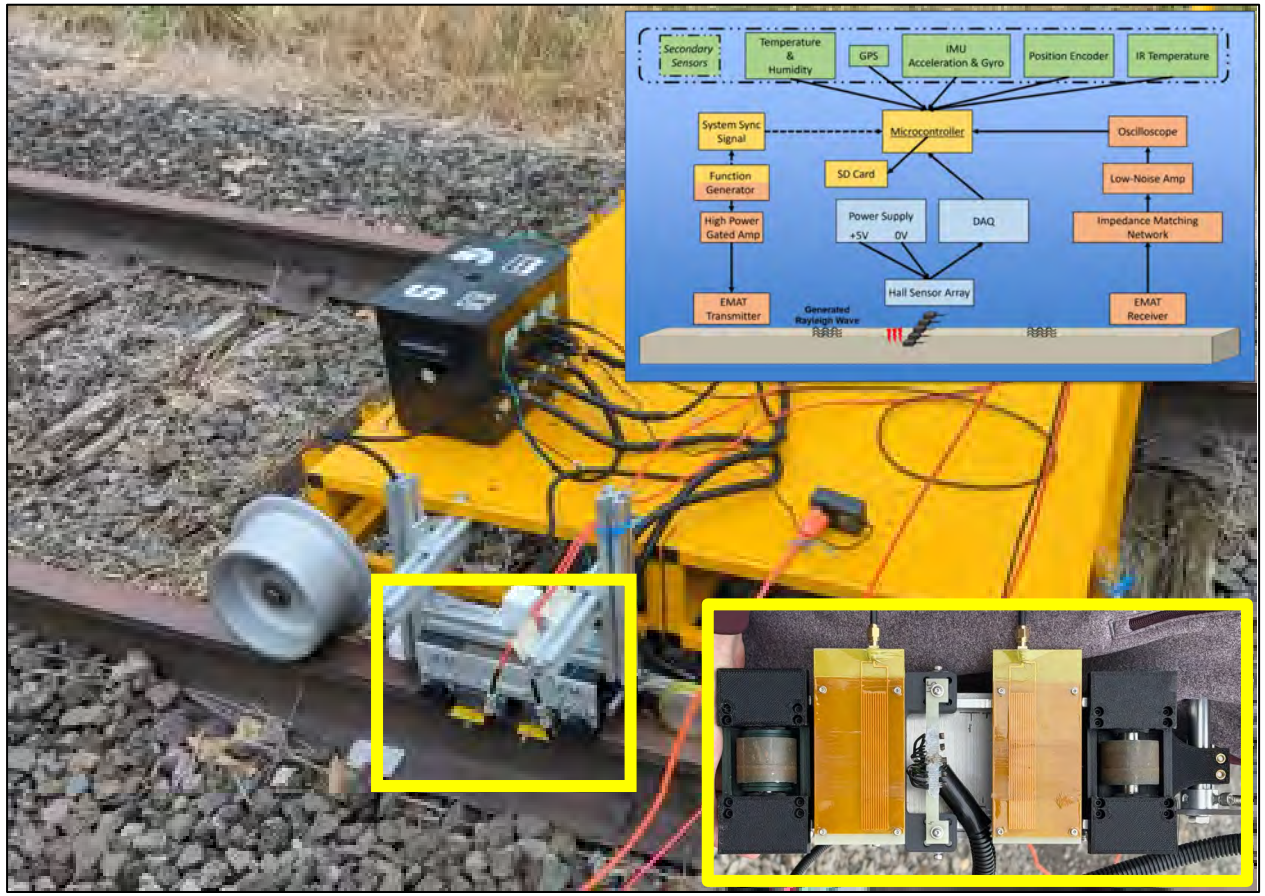
- **Develop a multi-wave hybrid non-contact electromagnetic and ultrasonic sensing method for in-motion real-time rail fatigue crack**



EMAT C-scan



MSU Hybrid Sensing Trolley



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Southern Illinois University – PI: Dr. Philip Chu

- **Develop in-motion rail base inspection system using line scanning thermography**
  - First field trial conducted in Q4 2024

SIUC IR-TRAIN cart

Real-time IR Video

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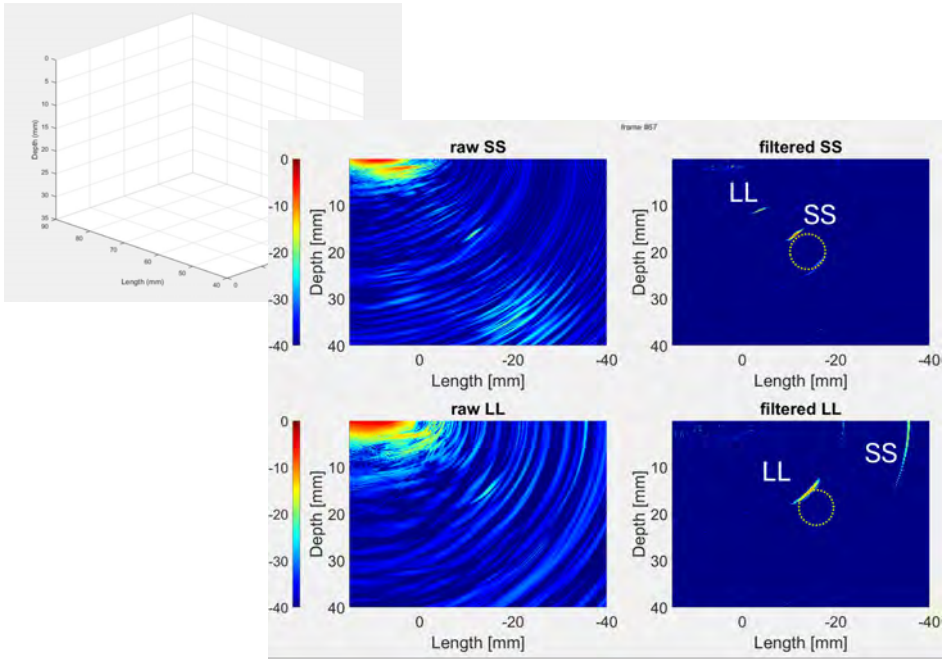
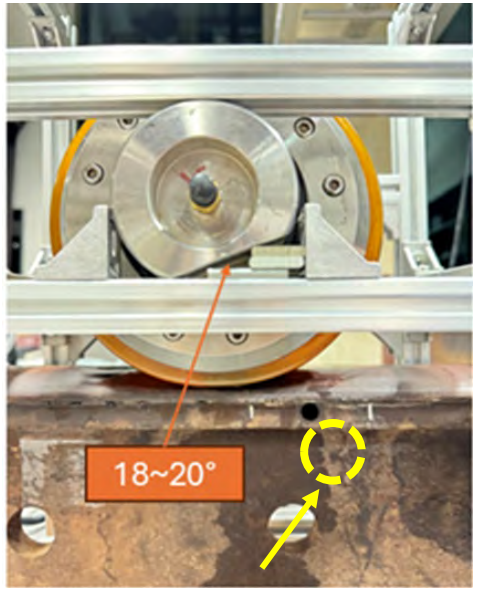
University of California San Diego – PI: Dr. Francesco Lanza di Scalea

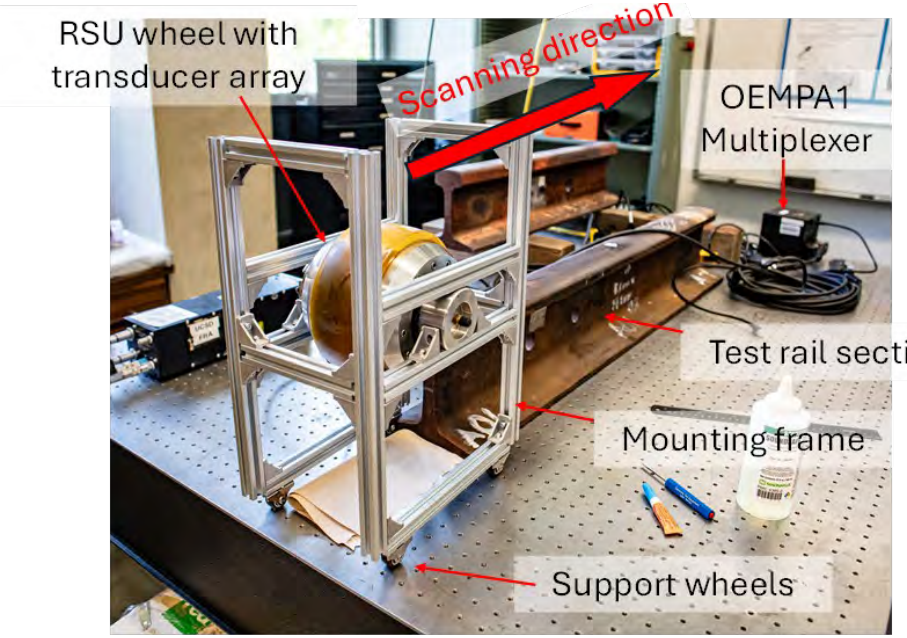
- **Develop in-motion 3D internal rail flaw imaging/ sizing technology**
  - Employs phased array ultrasound (PAU) synthetic aperture focusing techniques (SAFT) principles
  - Current focus is towards enhancing defect detection/ sizing using subaperture technique and recursive singular value decomposition (SVD) filter



Enhanced PAU Imaging



Side Drilled Hole



Portable PAUT RSU Platform

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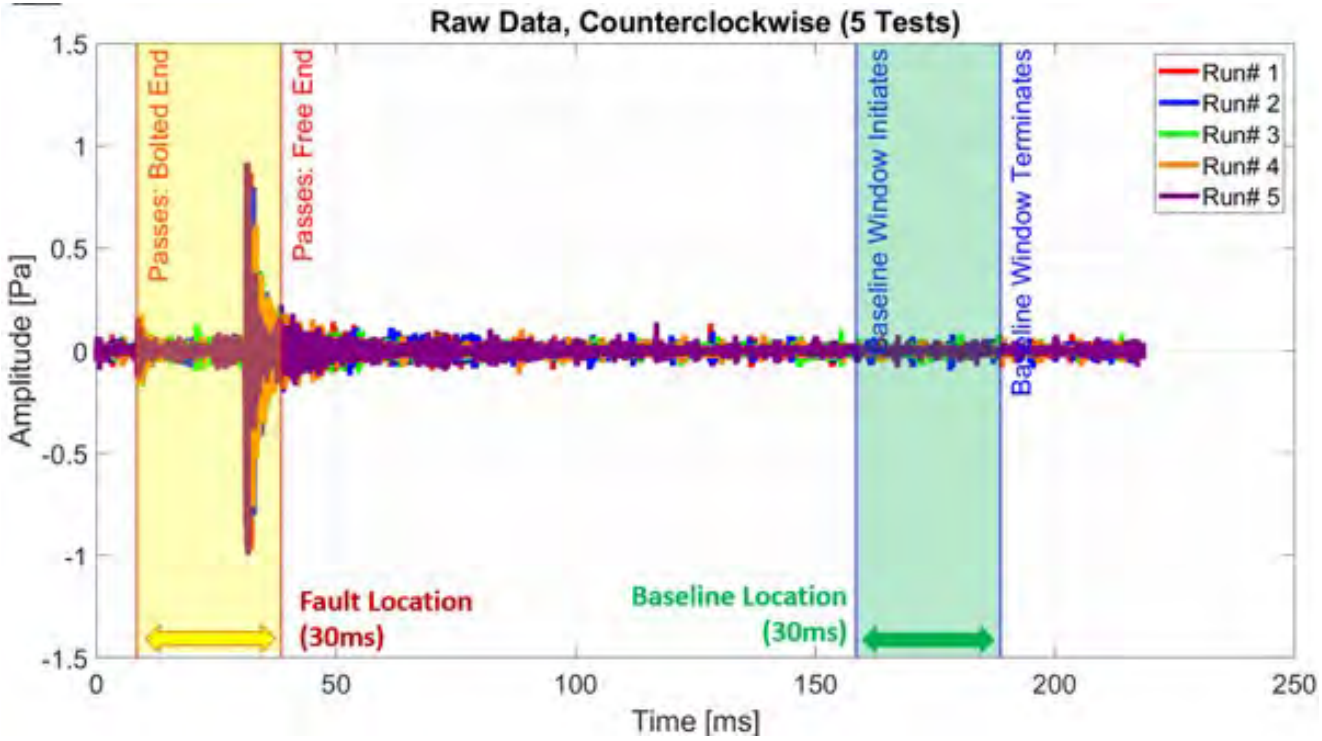
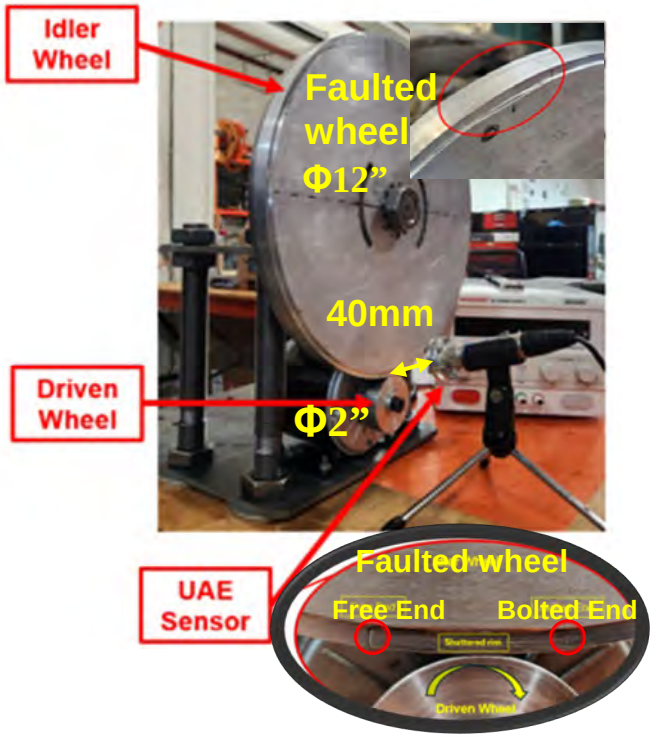
Virginia Tech – PI: Dr. Mehdi Ahmadian

- **Develop ultrasonic acoustic emission (UAE) methods for in-motion wheel crack detection**
  - Dynamic rig with the faulted wheel mounted at the top, driven by a DC motor at the bottom, and the UAE sensor located close to the contact location

VT UAE Test Results



VT UAE Test Setup



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University Days

- **Acquaint university researchers and students with MxV Rail research programs**
- **Focus on Grand Challenge research topics and projects**
- **Exposure to real-world application research and testing**
- **2025 University Day: 2nd week of August**

Acknowledgements

- University Partners
- Technology Review Advisory Panel (TRAP)
- MxV Rail Team

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Click titles to jump to presentation

Technical Sessions - Infrastructure

Infrastructure (AM) | Fortino A/B

FAST®	Christopher Johnson
Analysis of Broken Welds	Ananyo Banerjee
Crosstie and Fastener Research	Yin Gao

Infrastructure (PM) | Fortino A/B

Ballast & Subgrade Research	Stephen Wilk
Advances in Rail Research	Ananyo Banerjee
Bridge Research	Christopher Johnson

FAST®

Christopher Johnson, P.E.
Scientist

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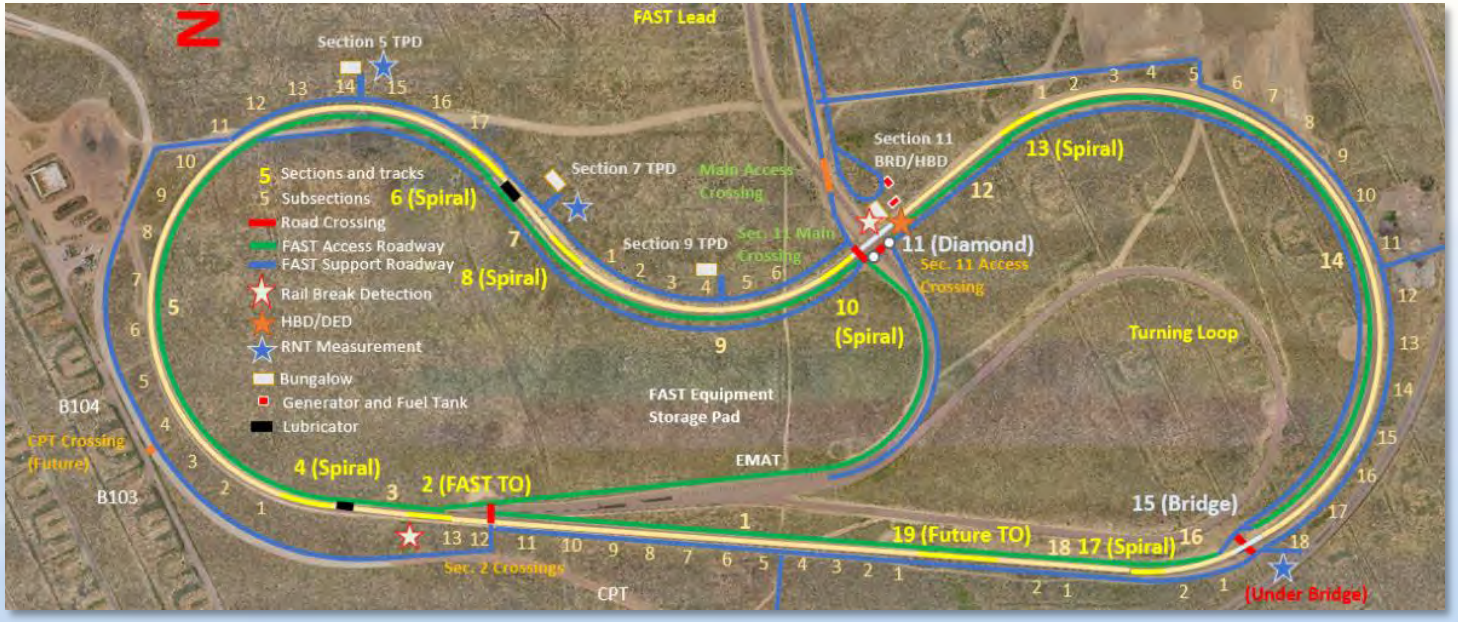
What is FAST?

- **Facility for Accelerated Service Testing**
  - Heavy Haul Test Track
  - 2.8-mile loop
  - 18,000-ton train
    - 315,000-pound cars
  - Annual accumulation
    - 140 million gross tons
    - 21,000 miles
      - 50+ tests



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FAST Objectives

High Tonnage

Heavy Axle Loads

EFFECTS

Track Degradation

Mitigation Strategies

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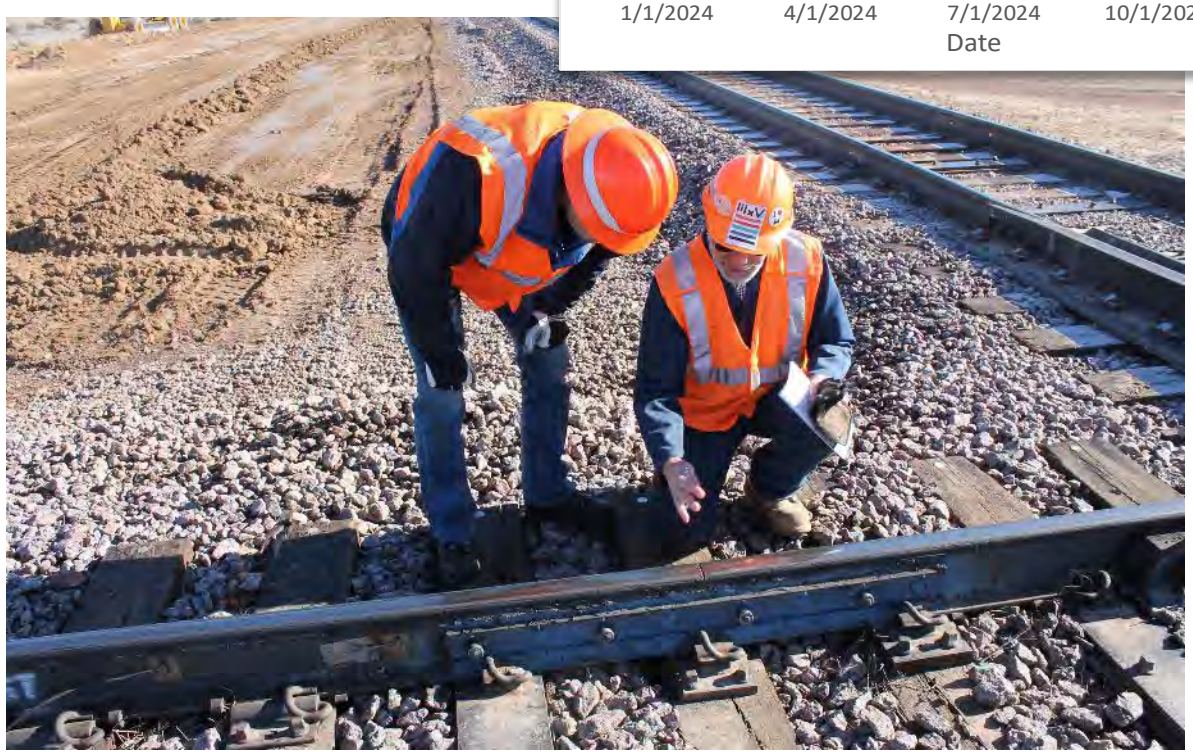
FAST Objectives

- **Rapid tonnage accumulation**
- **Controlled environment**
  - Well-planned and executed evaluations
- **Valuable information**
  - Qualified component performance
  - Root causes
  - Mitigations



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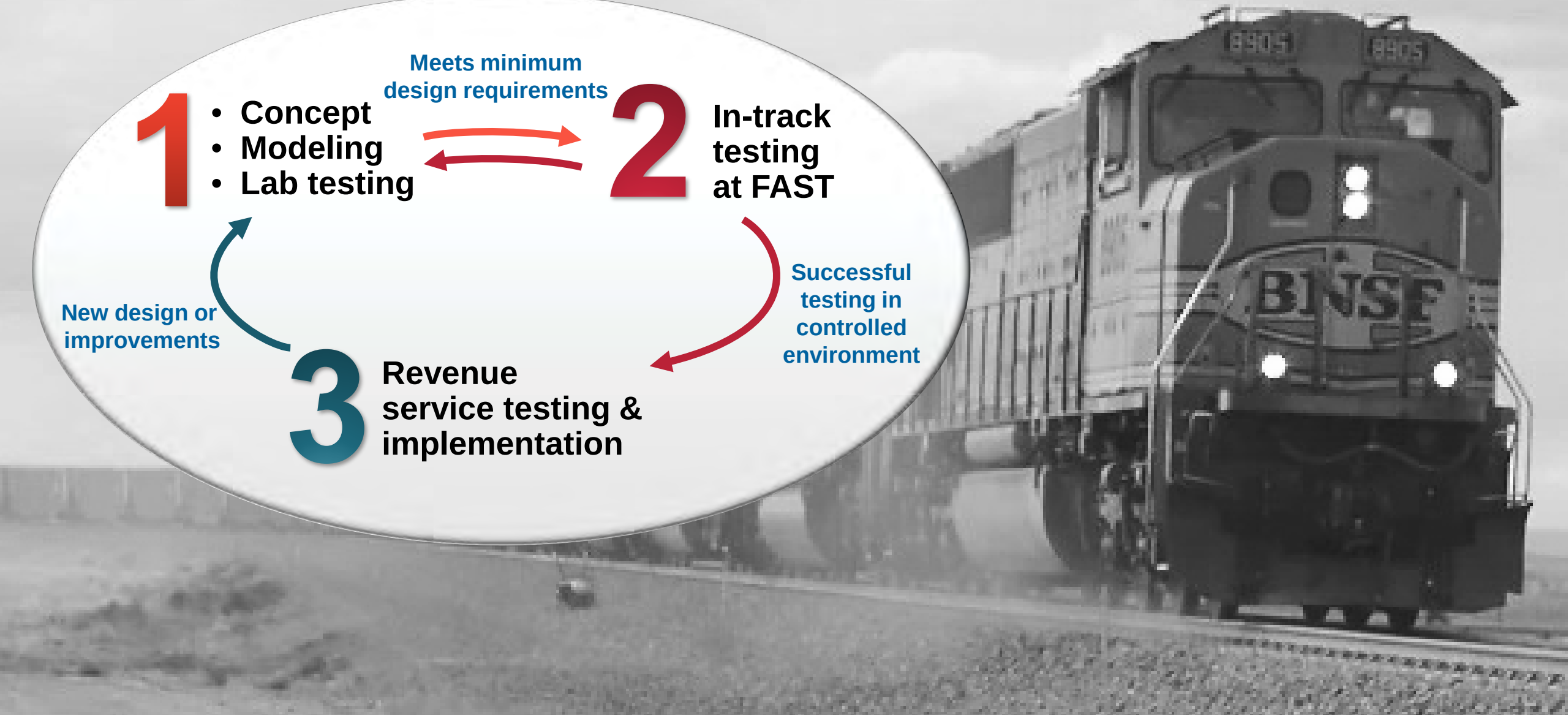
Pathway to Implementation



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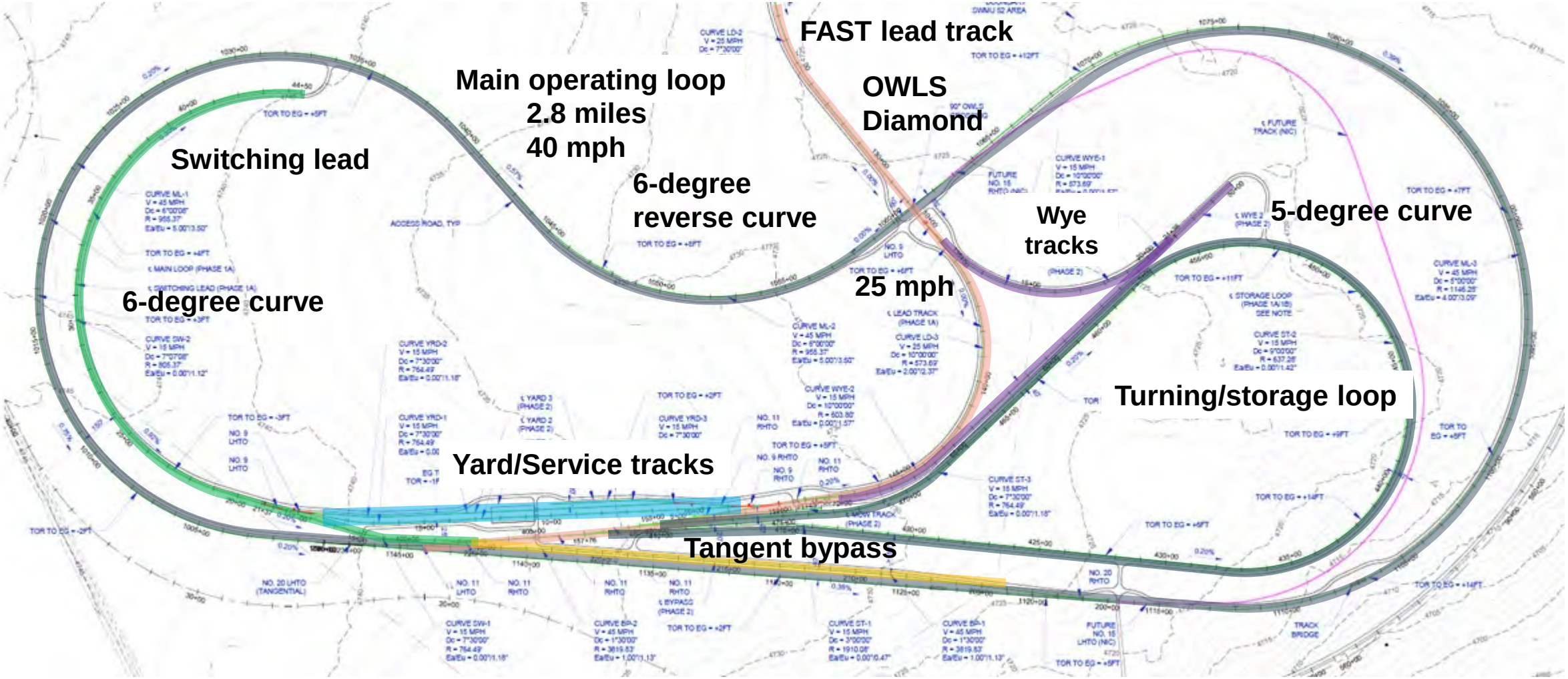
FAST Map



Operations Summary

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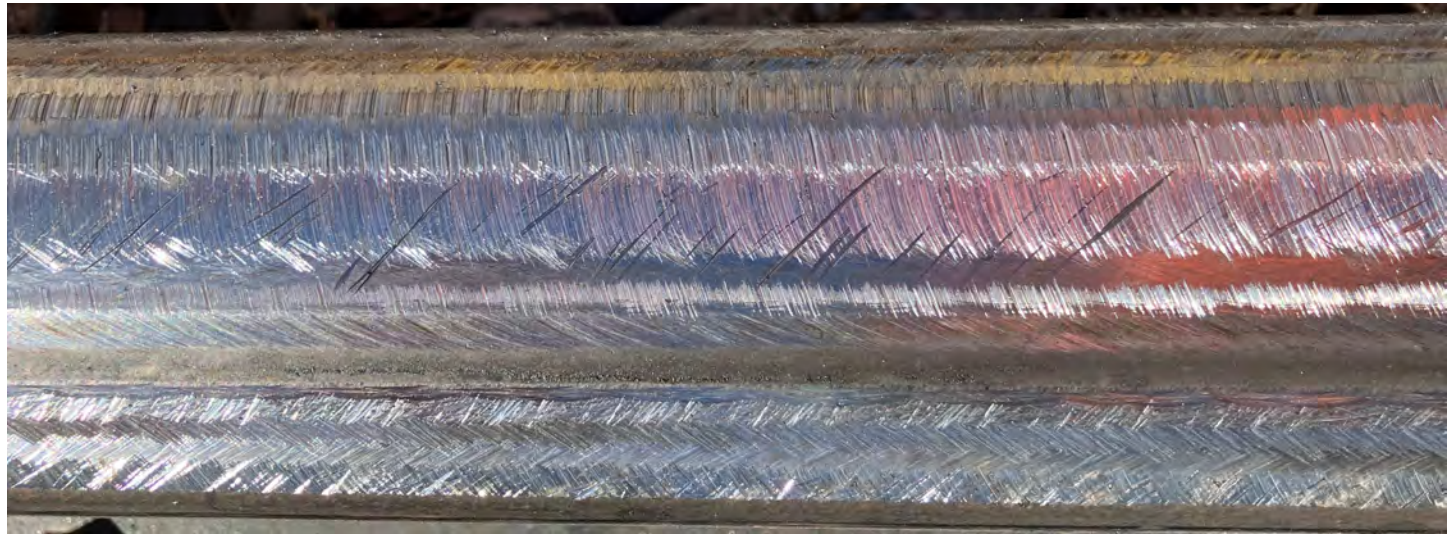
- **Operations at new FAST began in 2023**
- **140 MGT in 2024**
  - Split spring and fall seasons
- **30 MGT YTD in 2025**
  - 140 MGT goal
- **Distributed power operations**

Improvement

- **Storage loop construction**
  - Improved train performance
- **Rail grinding**
  - Address surface condition
  - Restore rail profile



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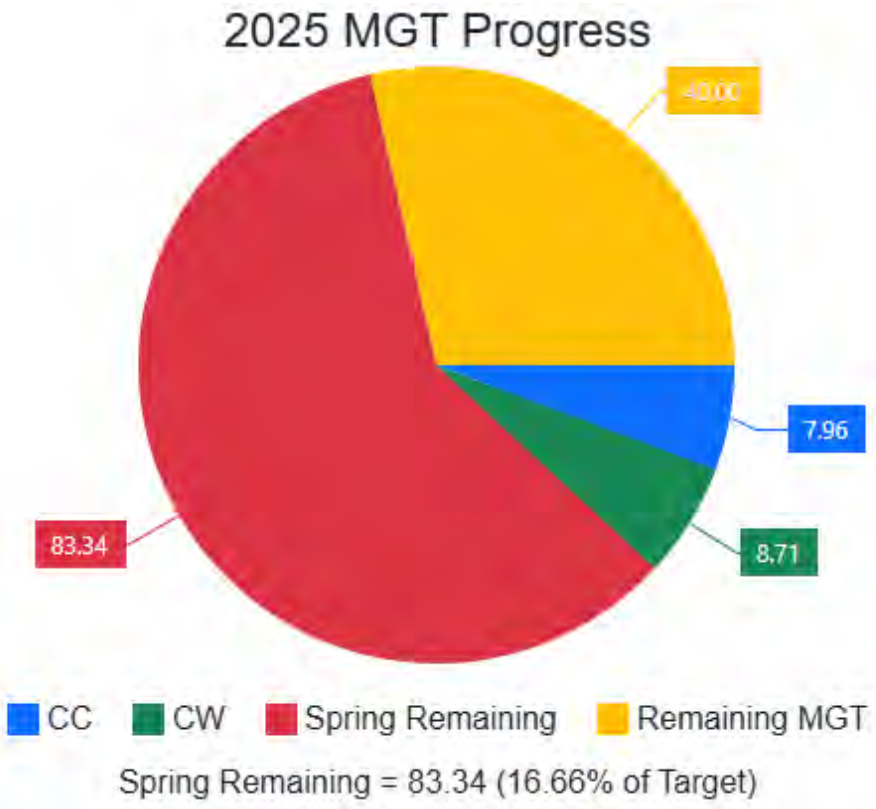
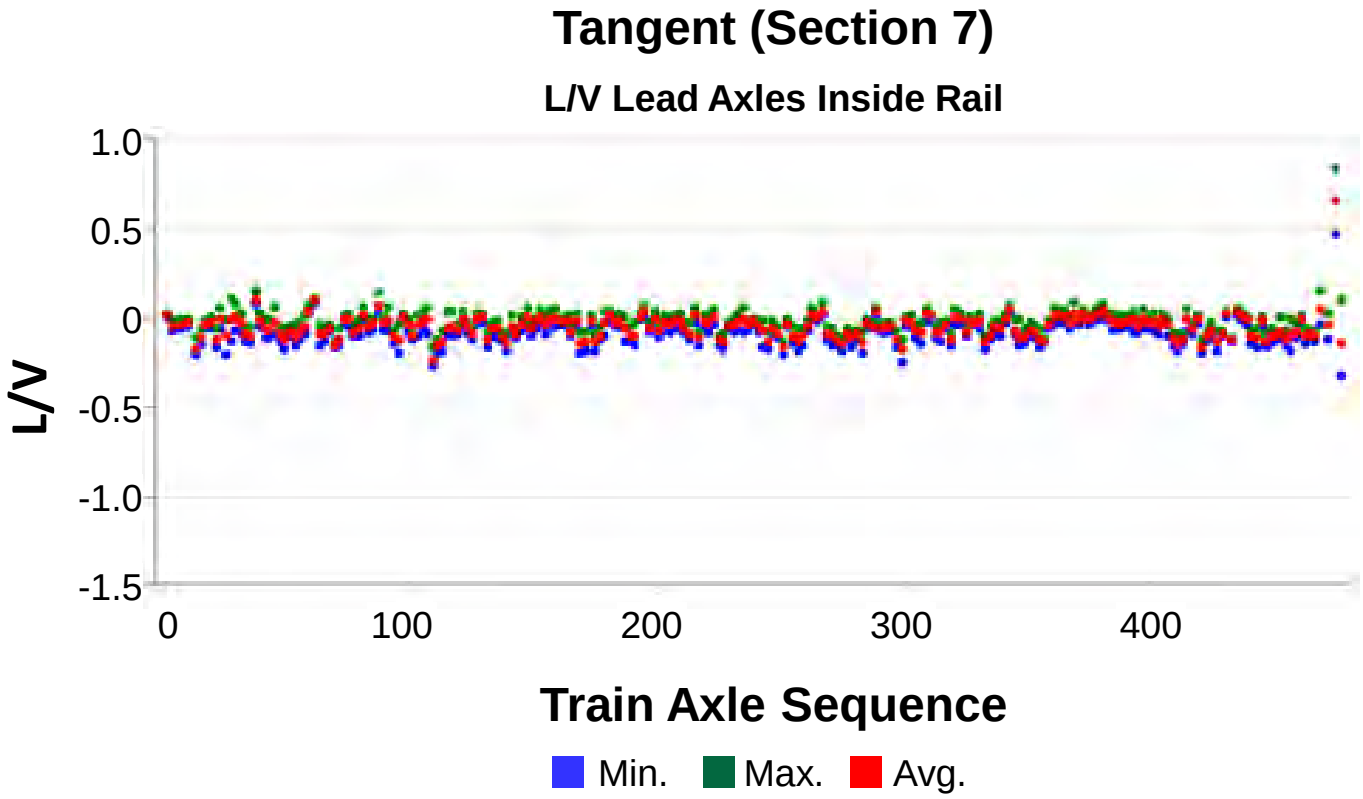
- **FAST internal records for statistics and testing**
  - Operational data visibility





FIRST

- **Inspection and inventory**

Visual Track Inspection

Summary

- 0.09 MGT since last visual track inspection.
- 2/20/2025 is last visual track inspection date.
- 1 operating days since last visual track inspection.
- 4 calendar days since last visual track inspection.

View All Findings

Start New Inspection

View Inspection Summary

Open Inspections	
Track Inspection ID	Inspection Start Date

Rail & Weld Defect Inspection Summary

Create New | Load Removed Defect(s)

Max Records To Load 50 | Load | View Map

Export

1 2 Page Size:

	Track Defect ID	Defect Location (Section, Subsection, Tie)	Side	Date Defect Found	Direction of Inspection	Defect Type	Current Length (in)	Current Width (in)	Current Height/Depth (in)	Current Transverse Fissure (TD) %	Weld Number	Weld Manufacturer	Previous Length (in)	Previous Width (in)
Add New Measurement	124	05-11-081	Inside Rail	2/21/2025	CC	Web Defect	0.7	0.7			90	MxV Rail In-Track Weld	0.7	0.5
Add New Measurement	123	14-06-040	Inside Rail	2/21/2025	CC	Web Defect	0.7	0.3			4083	Plant Weld		
Add New Measurement	122	14-05-108	Outside Rail	11/1/2024	CW	Transverse Fissure (TD) - DF		0.2	0.5	1.6	30	MxV Rail In-Track Weld		0.2
Add New Measurement	121	09-01-048	Outside Rail	11/1/2024	CW	Transverse Fissure (TD) - Rev		0.2	0.2	0.6	628	MxV Rail In-Track Weld		

Track Maintenance Log

Select work type... | Create New | Show Initial Inventory

Max Records To Load 50 | Load

1 2 3 4 5

Task ID	Task Date	Work Type	Cause	Rail Side	Start Section	Start Subsection	Start Tie	End Section	End Subsection	End Tie	Weld Number
2028	2/20/2025	Weld Removal	Failure	Outside Rail	14	16	89				40
2027	2/20/2025	Weld Removal	Failure	Outside Rail	6	1	73				3141
2026	2/18/2025	Weld Removal	Failure	Outside Rail	14	10	19				119
2025	2/18/2025	Other Track Maintenance	Maintenance	N/A	14	6	70	14	8	1	
2024	2/18/2025	Other Track Maintenance	Maintenance	N/A	5	8	40	5	10	12	
2023	2/18/2025	Other Track Maintenance	Maintenance	N/A	1	12	116	1	13	4	
2020	2/14/2025	Other Track Maintenance	Test	N/A	5	8	76	5	10	20	
2019	2/5/2025	In-Track EFB Weld Install	Test	Outside Rail	14	12	89				5081
2018	2/5/2025	In-Track EFB Weld Install	Test	Outside Rail	14	12	99				5080
2017	2/7/2025	Thermite Weld Install		Inside Rail	1	1	1				

1 2 3 4 5

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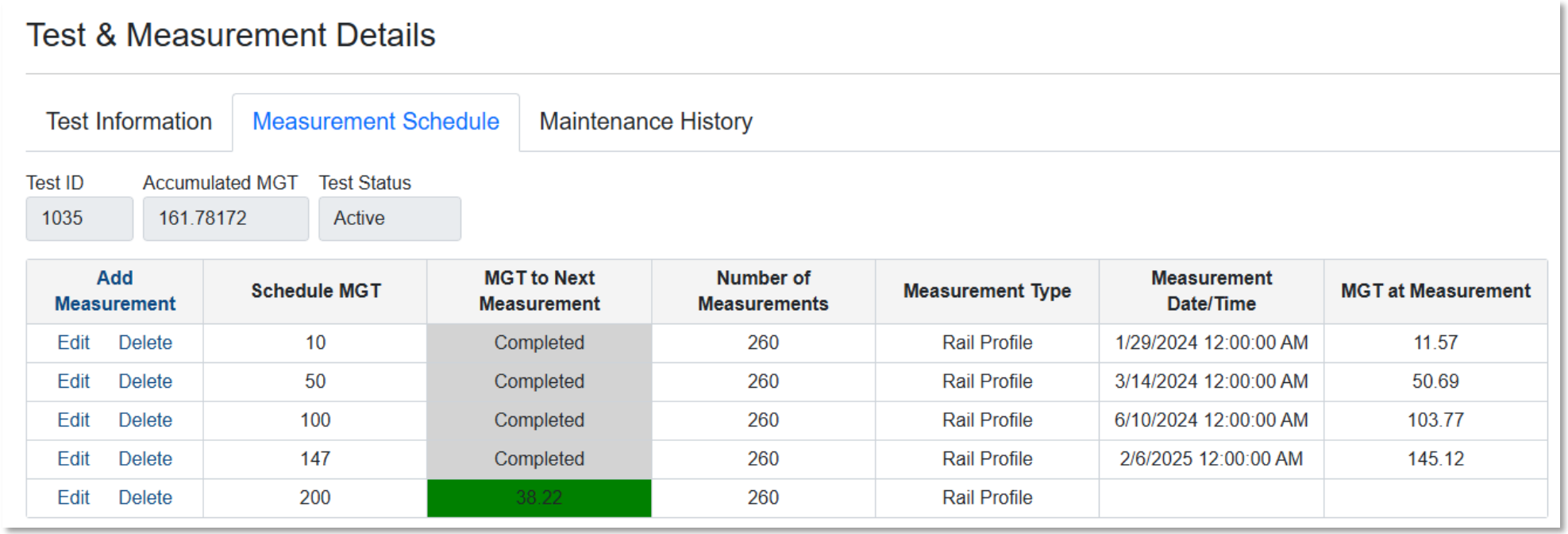
- **Test tracking**



Test & Measurement Details

Test Information | Measurement Schedule | Maintenance History

Test ID	Accumulated MGT	Test Status
1035	161.78172	Active

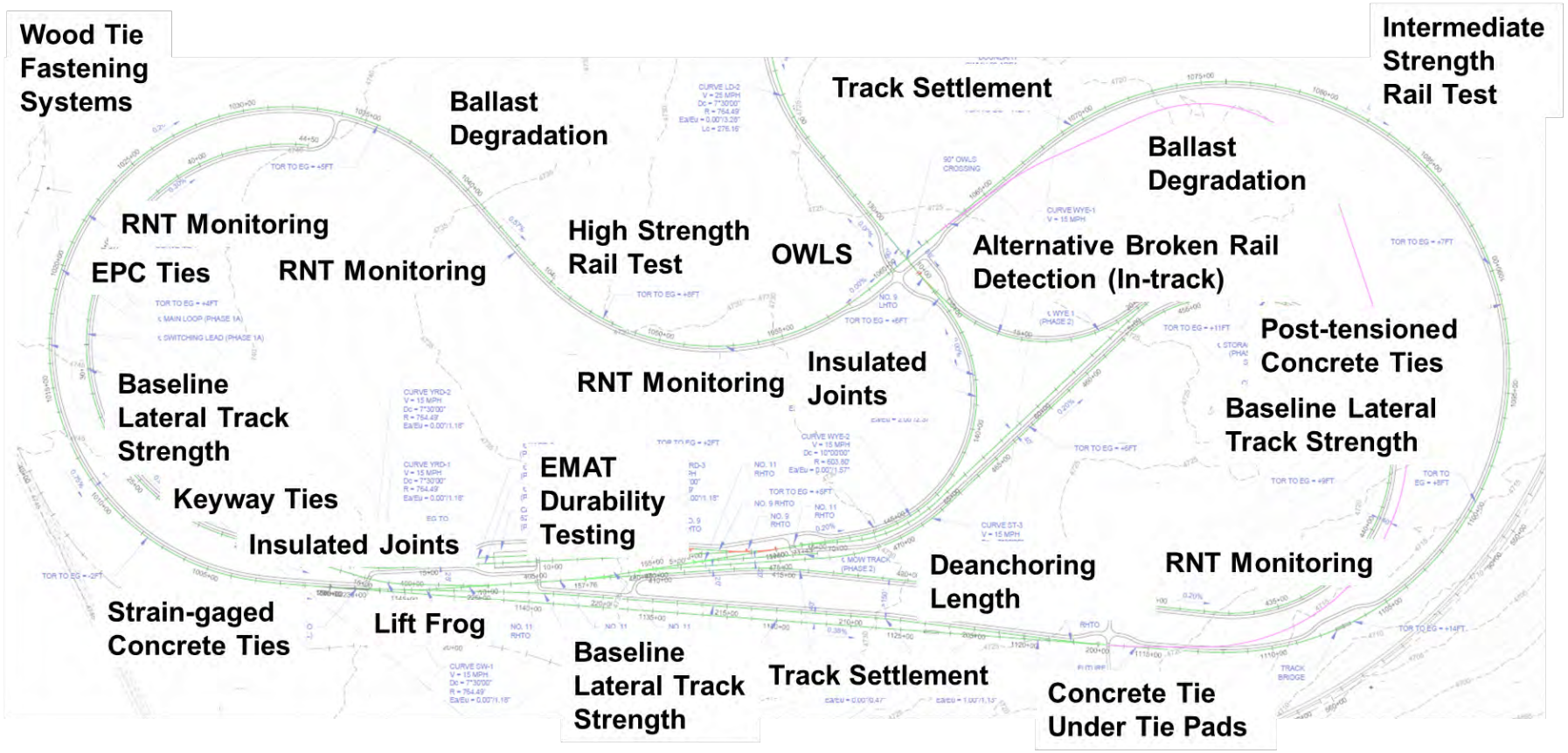
Add Measurement	Schedule MGT	MGT to Next Measurement	Number of Measurements	Measurement Type	Measurement Date/Time	MGT at Measurement
Edit Delete	10	Completed	260	Rail Profile	1/29/2024 12:00:00 AM	11.57
Edit Delete	50	Completed	260	Rail Profile	3/14/2024 12:00:00 AM	50.69
Edit Delete	100	Completed	260	Rail Profile	6/10/2024 12:00:00 AM	103.77
Edit Delete	147	Completed	260	Rail Profile	2/6/2025 12:00:00 AM	145.12
Edit Delete	200	38.22	260	Rail Profile		

- **Finding new uses for collected data**

Testing

Test Layout

- **Conducted 52 tests at FAST in 2024**
  - An increase from the 31 planned tests
  - SRI
  - Commercial
  - Other AAR



Rail Tests

- **2023 high strength rail testing**
  - Six suppliers, seven rail types
  - Unlubricated reverse curve
  - 155 MGT YTD
    - Ground at 145 MGT

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Rail Tests

- **2021 intermediate strength**
  - Lubricated curve
  - 437 MGT
  - Ground at 334 and 427 MGT

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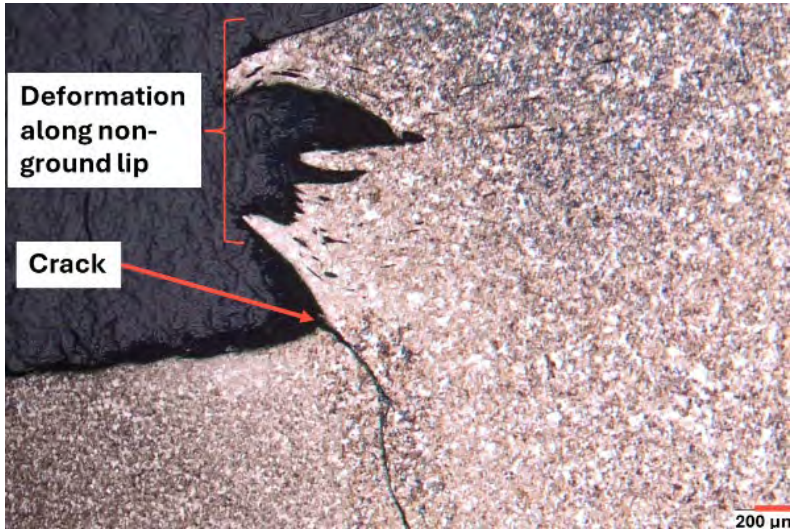
Welds

- **Head repair welds**
  - Installed without defects
- **31 broken welds in 2024**
  - All rail and weld breaks saved for analysis
  - Weld preparation and grinding important



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Special Trackwork

- **One-way low speed (OWLS) diamond**
  - Longer ramps for testing higher speeds
  - Deformations on mainline rails
  - Broken bolts
- **#11 Turnout with lift frog**
  - Normal wear
- **Insulated joints**

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Ties and Fasteners

- **Multiple test zones**
- **Concrete ties**
  - Use in transition zones
- **Timber ties**
- **Composite ties**

Ballast and Subgrade

- **Baseline measurements**
  - GPR
  - Commercial ground characterization
  - Ballast sampling
  - Settlement
  - Lateral track strength
- **Long term track settlement**
  - Initial and post trackwork
  - Diamond and transition zones

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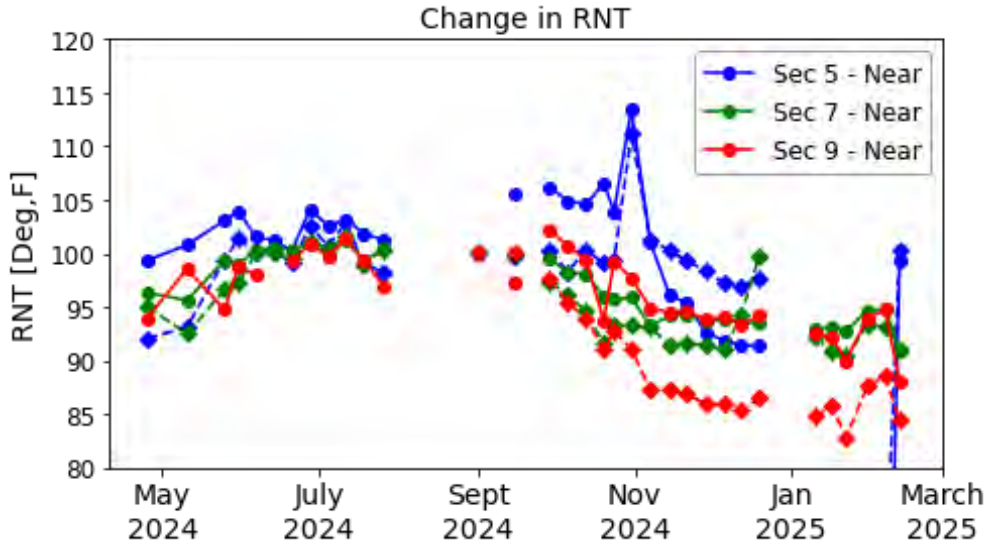
RNT and Track Stability



- **Monitoring RNT changes over time**
  - Winter versus summer RNT
  - Train operations
  - Curvature
  - Post-destressing
- **Train forces in rail**

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Bridge

- **Two-span bridge**

South span testing tapered glu-lam ties

North Span replaced with ballast deck beam span

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Mechanical and Inspection

- **HPW-2 and HPW-3 wheel tests**
  - 36- and 38-inch wheels
- **EMAT wheel inspection**
- **EMFI RCF measurement**

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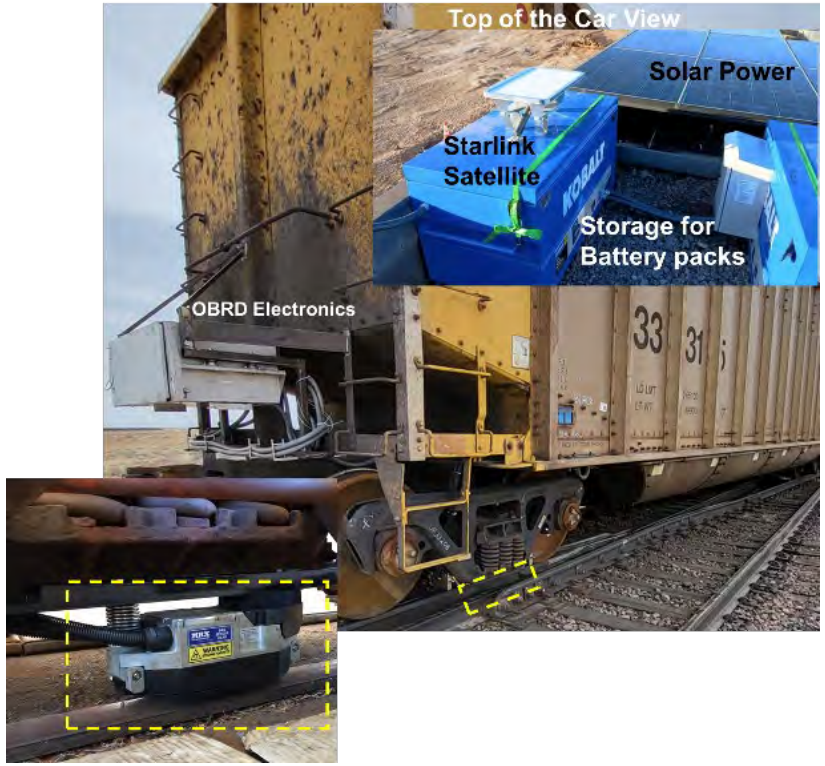
Broken Rail Detection

- **Three systems under evaluation: one trackside and two onboard**
- **Compared to MxV Rail BRD system**



Commercial

- **Mechanical, Track, Inspection**
- **Support product development**
- **Controlled, independent evaluation**

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Conclusions

- **FAST fully operational**
  - Improvements as required
- **Increasing number of tests**
- **Proof testing in a heavy axle load environment**
  - Improved component performance
  - Reduced risk

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Acknowledgements

- FAST Operating, Maintenance, Instrumentation and Engineering teams
- Railroad and supplier support

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Analysis of Broken Welds During 2024 Operations

Ananyo Banerjee, PhD
Principal Investigator II, Rail Infrastructure
Resource Manager of NDE-Metallurgy Group

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Overview

- **Background**
- **Broken welds from Facility for Accelerated Service Testing (FAST®)**
  - Overview of failures from 2024 operations
  - Electric flash butt weld failures
    - Common failure modes and findings
  - Thermite weld failures
    - Common failure modes and findings
- **Other broken welds**
- **Future work**

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Background

- **Welding Research Objectives**
  - Identify root causes of weld failures
    - Metallurgical reasons
    - Operational conditions and human factors
  - Evaluate performances of EFB welding processes, thermite charges, equipment and manufacturers
    - Develop pre- and post-weld treatment strategies
    - Improve welding guidelines and supporting efforts for best practices

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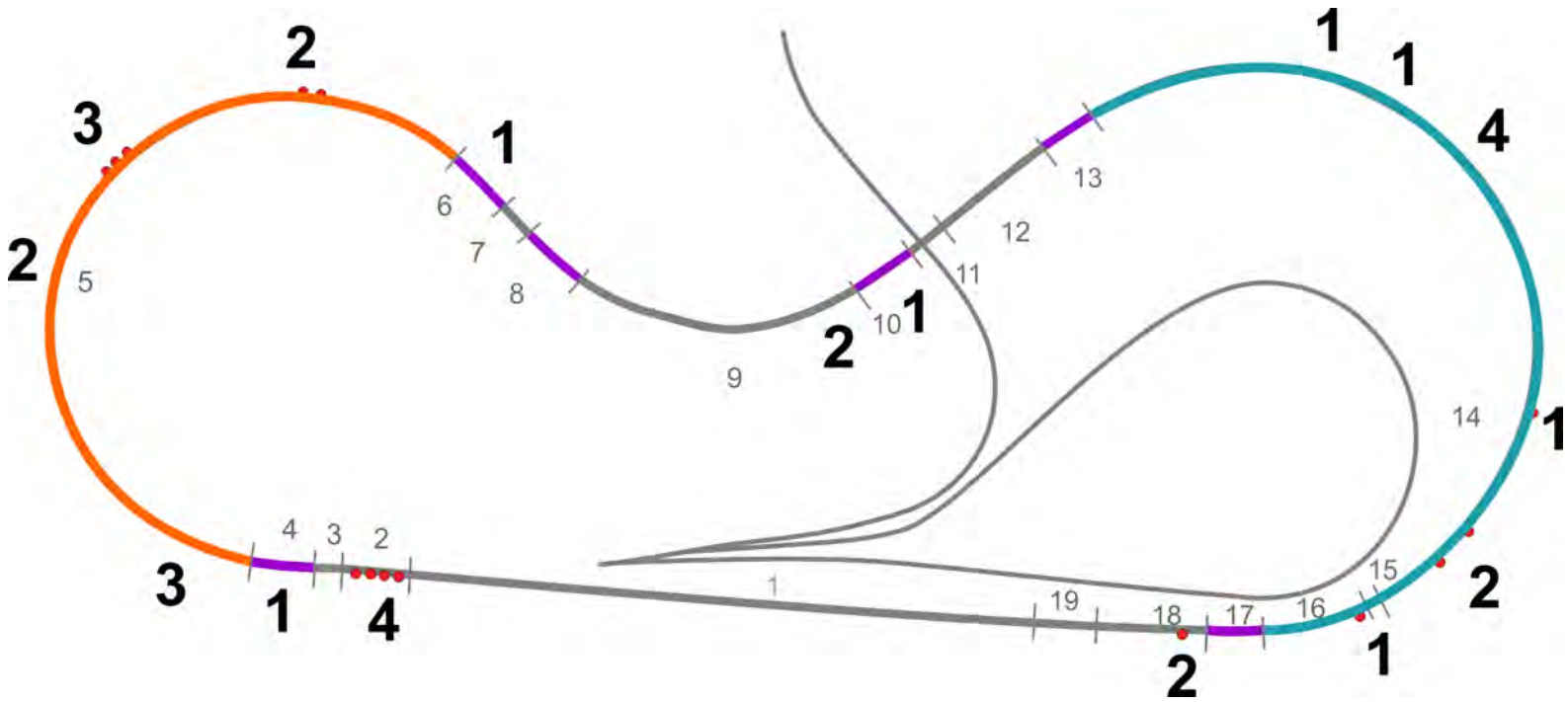
Broken Welds at FAST – Locations

- **2024 operations**
  - Accumulated 145 MGT through the end of 2024
  - Weld breaks: 31, Rail base breaks: 1
    - First break happened at 51 MGT

Facility for Accelerated Service Testing (FAST®)



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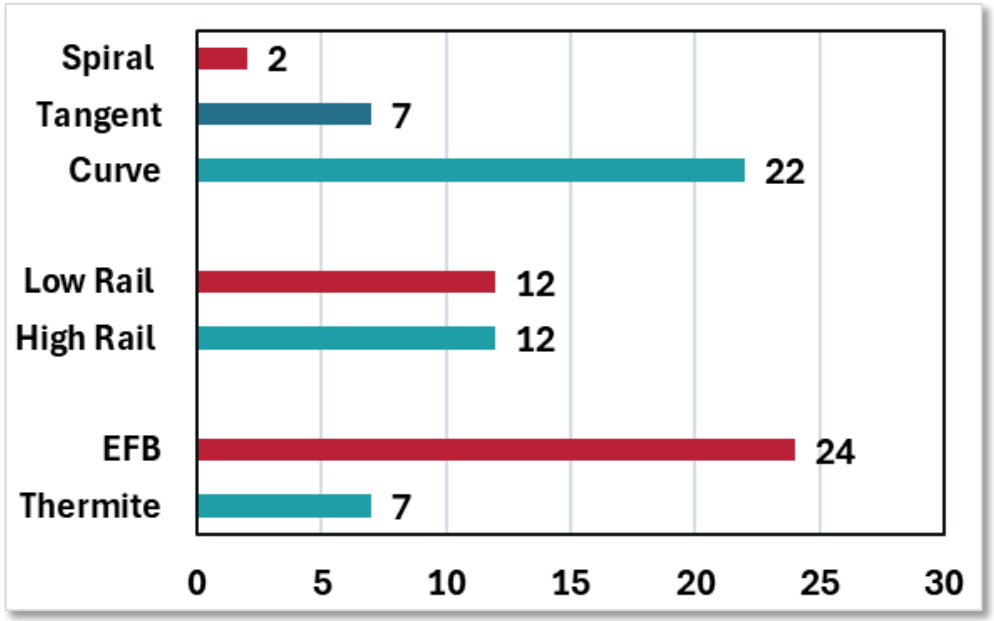
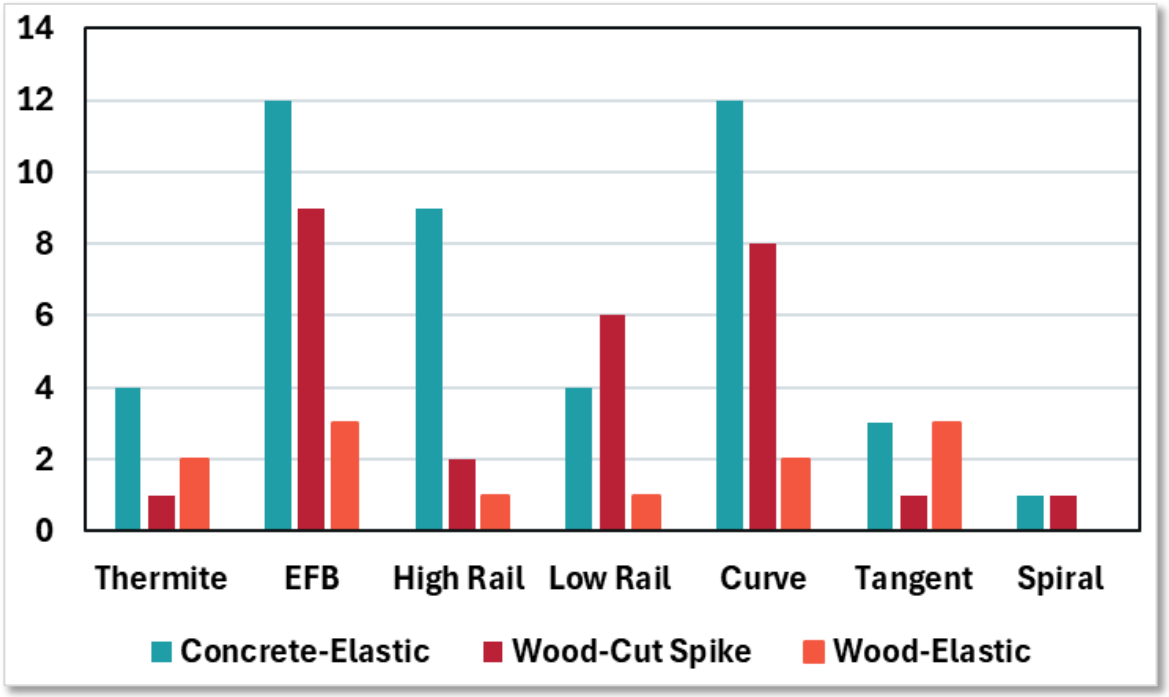
Distribution of FAST Weld Breaks

- **71% broken welds were found in curves**
- **24 EFB (77%) and 7 thermite breaks**
  - 16 breaks on concrete ties
  - 15 breaks on wood ties: 10 on cut spikes, 5 on elastic fasteners





Electric Flash Butt Weld Failures

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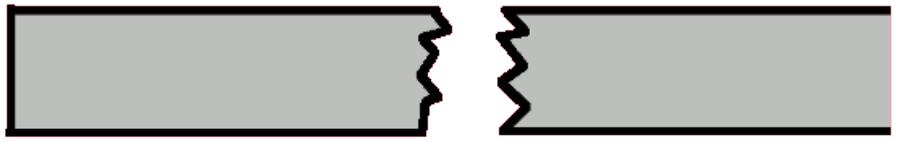
Electric Flash Butt Welding

- **Joining rails with no foreign material**
  - Rail ends are heated and then joined with forging forces – variant of friction welding
  - Needs vehicle with high power to do welding in track; not easily portable
  - Time and forces are critical



https://commons.wikimedia.org/wiki/File:Animation_of_flashing_operation_in_Flash_Butt_Welding.gif

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EFB Weld Breaks – Stress Risers

- **Insufficient post-weld grinding caused stress risers at the head/web fillet**
  - Fused metal forming a lip that was not removed during grinding

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EFB Weld Breaks – Stress Risers

- **Few weld failures linked to stamp marks and branding on the rail which were not removed by pre-weld grinding**

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EFB Weld Breaks – Other Failures

- **Many breaks linked to sharp changes in profile along the web; linked to improper post-weld grinding**

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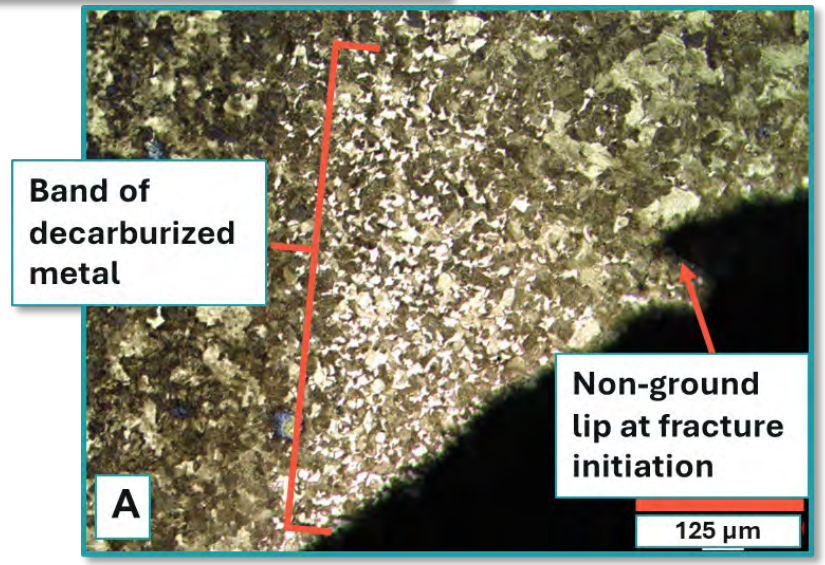
EFB Weld Breaks – Microscopic Analysis

- **Sharp changes in profile are often crack initiation points; soft band of ferrite observed in one weld break**



Thermite Weld Failures

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Thermite Welding

- **Adding molten steel to gap between rails**
  - Exothermic process generating molten temperature of iron
    - $Fe_2O_3 + 2Al = Al_2O_3 + 2Fe + 850$ kJ(805.6 BTU)/mole
  - Portable welding technique for repairing rail/weld breaks

Mold Setup

Pre-Heating

Welding

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Thermite Breaks – Porosity/Voids

- **Five out of seven failures showed shrinkage porosity and voids due to the lack of heat during weld solidification**
  - Lack of sufficient pre-heating
  - Moisture in molds, not removed during pre-heating

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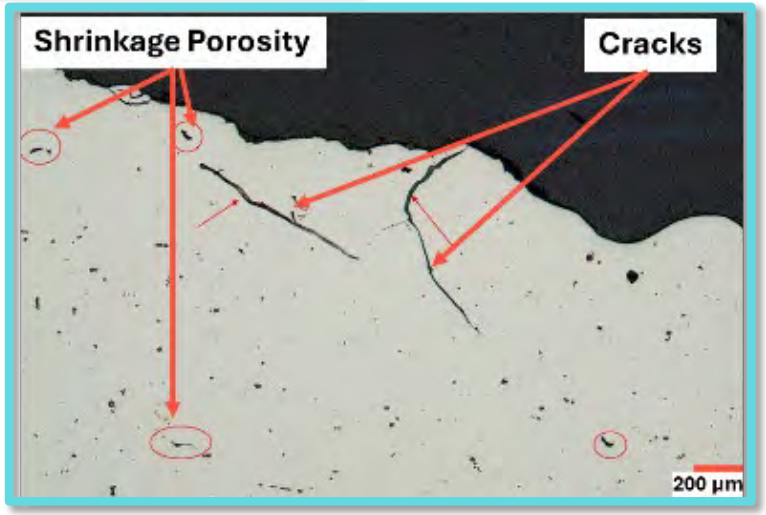
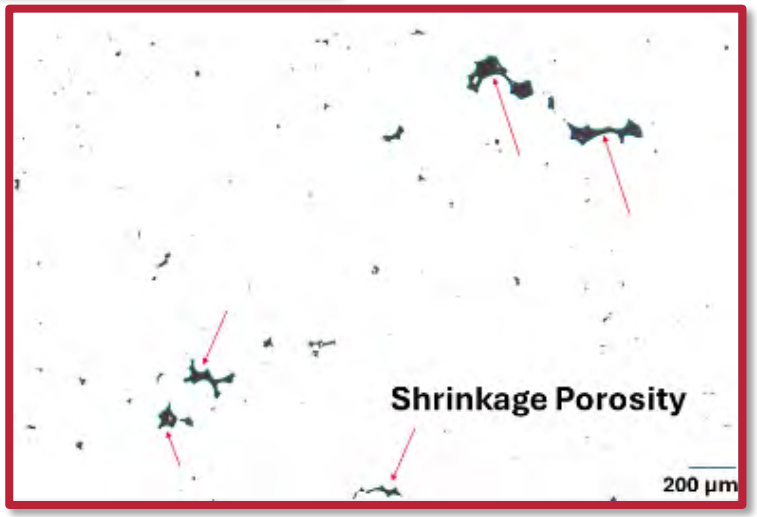
Thermite Breaks – Porosity Analysis

- **Lack of solidification caused shrinkage porosity leading to cracks**





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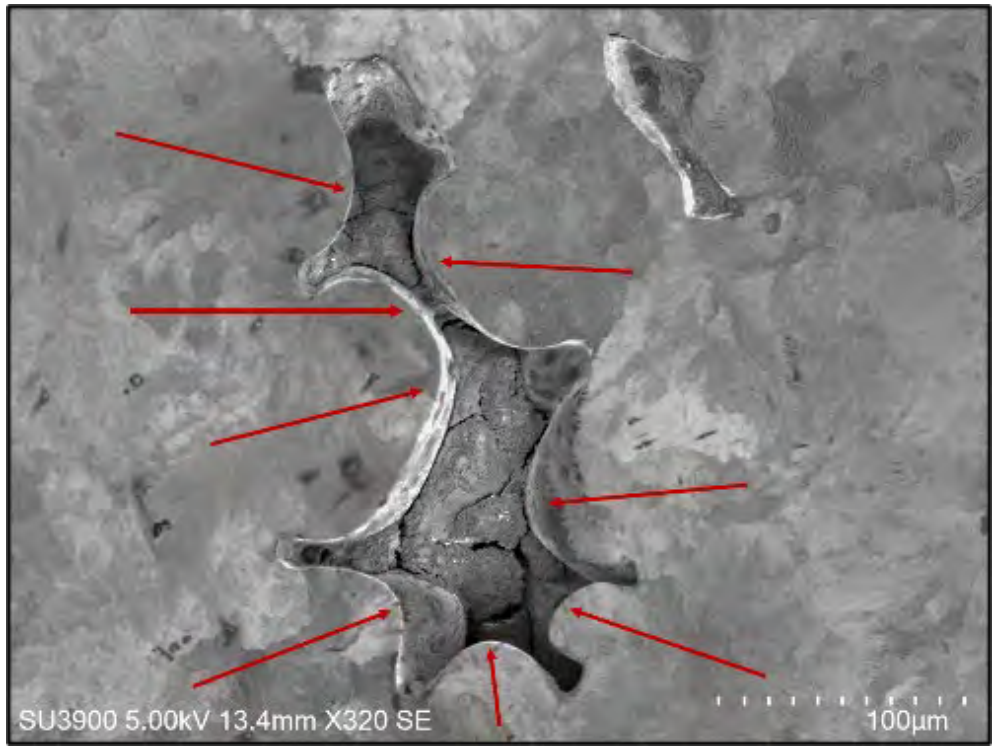
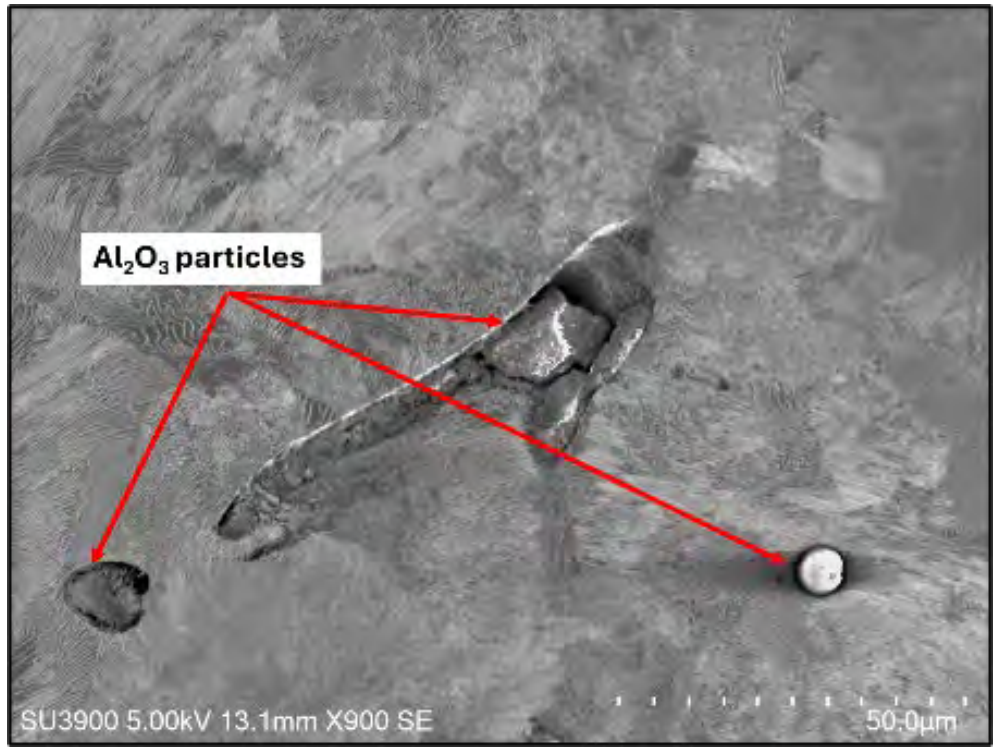
Thermite Breaks – Microscopic Porosity Analysis

- **Lack of solidification observed in five weld breaks**
  - Red arrows on left image show circular edges of molten metal that failed to fuse together due to lack of pre-heating
  - Alumina globules getting trapped as molten metal froze; not enough heat allowing alumina to diffuse into the slag





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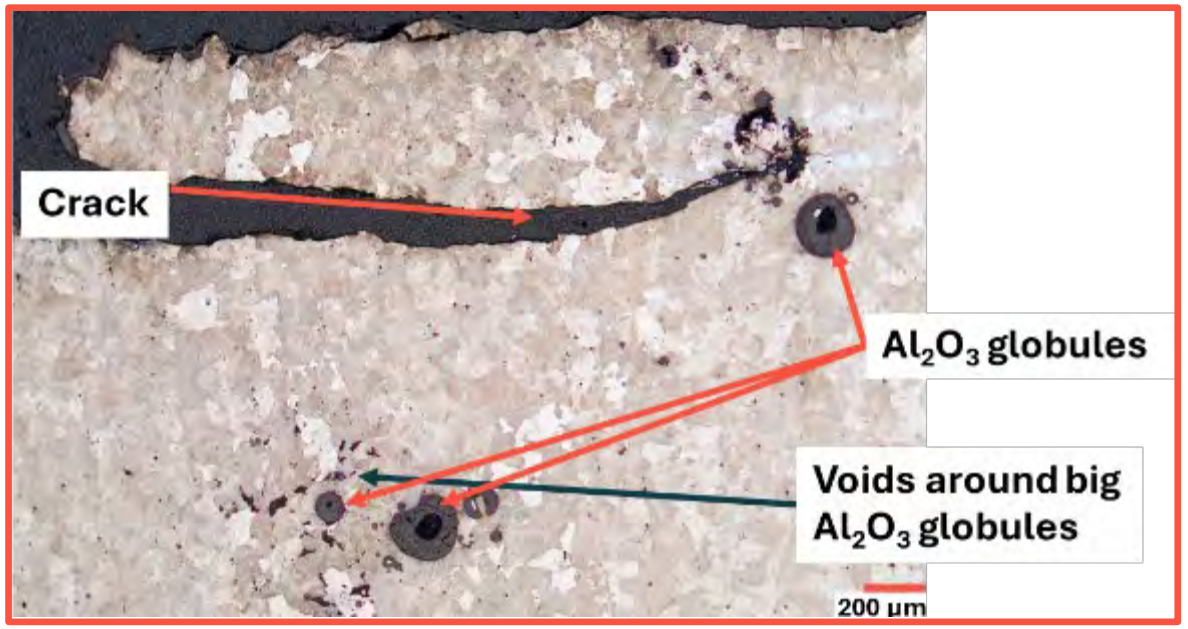
Thermite Breaks – Inclusions/Voids

- **Two out of seven failures showed entrapment of large alumina (Al_2O_3) particles near crack initiation**



Weld Failure Analyses Outside of FAST

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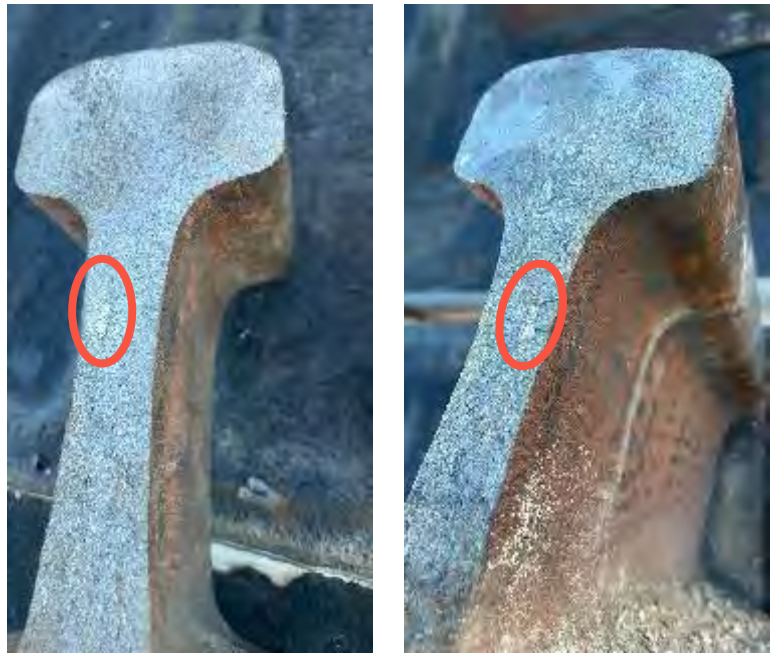
Other Broken Welds

- **Weld research focused on “innie-outie” (concave-convex) failures in EFB welds**
  - Fourth “innie-outie” failure in High Speed Loop (HSL)
    - Sub-zero temperatures involving high carbon premium low alloy rails without train movement

Fourth innie-outie break in HSL



Previous innie-outie breaks in HSL (TD 24-004, April 2024)

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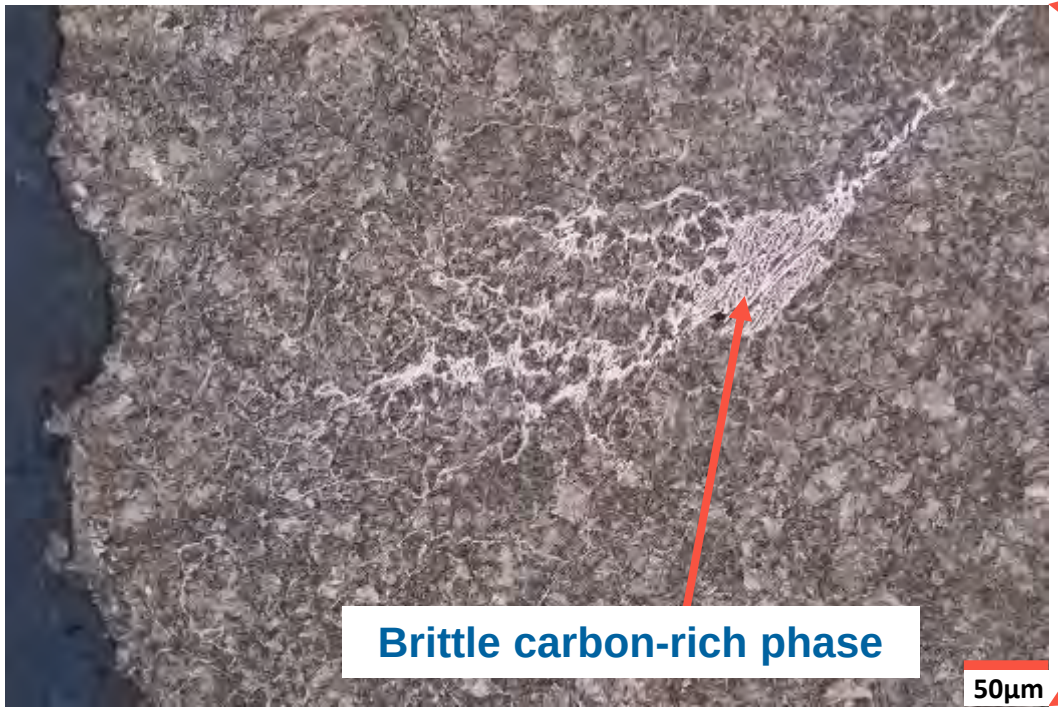
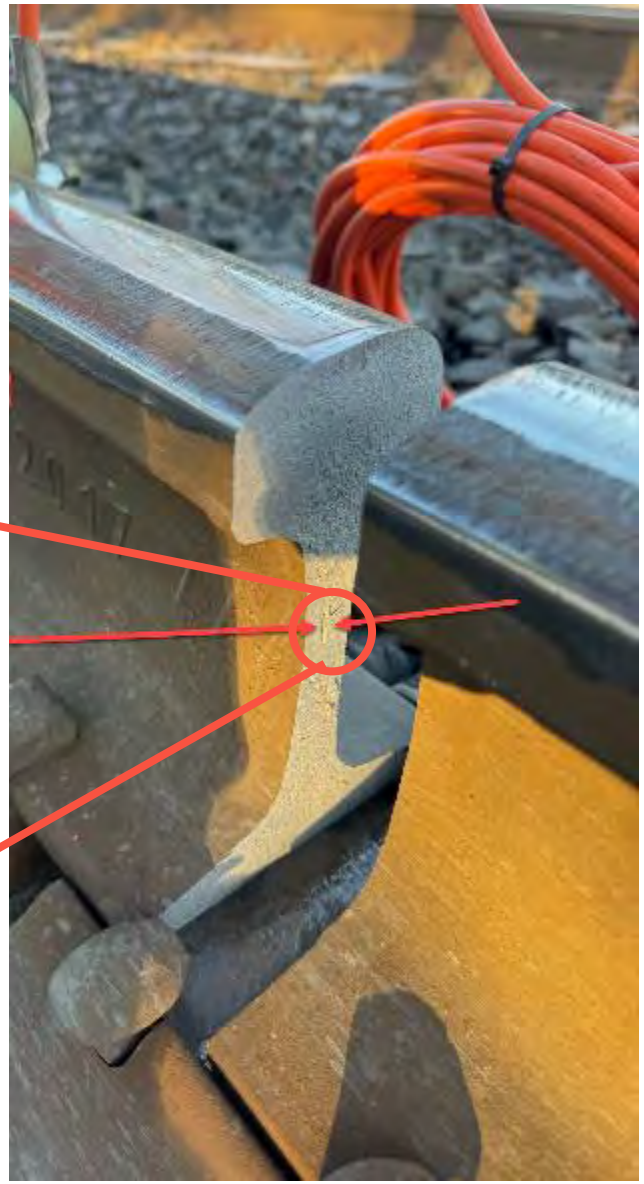
Other Broken Welds

- **Weld research focusing on innie-outie (concave-convex) failures in EFB welds**
  - Ongoing work with railroads on innie-outie failures involving alloyed rails





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Conclusions and Future Work

- **Conclusions**
  - Lack of proper grinding to remove stress risers was a major reason for EFB weld failures
  - Thermite failures were mostly due to formation of voids and shrinkage porosity caused by lack of sufficient heat during the thermite process

- **Future Work**
  - Analyzing bending stresses causing failures in head/web fillet
  - Effects of welding parameters on innie-outie failures

Acknowledgements

- MxV Rail Non-Destructive Evaluation (NDE)-Metallurgy team: Brian Lindeman, John Krasovic, Denise Valdez, Kerry Jones, and Survesh Shrestha
- FAST track crew, data science and instrumentation staff
- AAR’s Strategic Research Initiatives (SRI) Program

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Crosstie and Fastener Research

Yin Gao, Ph.D.
Principal Investigator I

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Overview

- **Objectives**
- **Crosstie and Fastener Tests at FAST®**
- **Tests and Measurements Update**
  - Track Gage Monitoring
  - Track Modulus Test
  - Concrete Ties Interspersed with Wood Ties
  - Spike Holding Power for Composite Ties
  - Evaluation of Glulam Ties for Turnouts
- **Closing Remarks**

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Objectives

- **Evaluate performance of new and existing designs in ties and fasteners**
- **Improve understanding of tie and fastener failure mechanism for best practices in maintenance and inspection**

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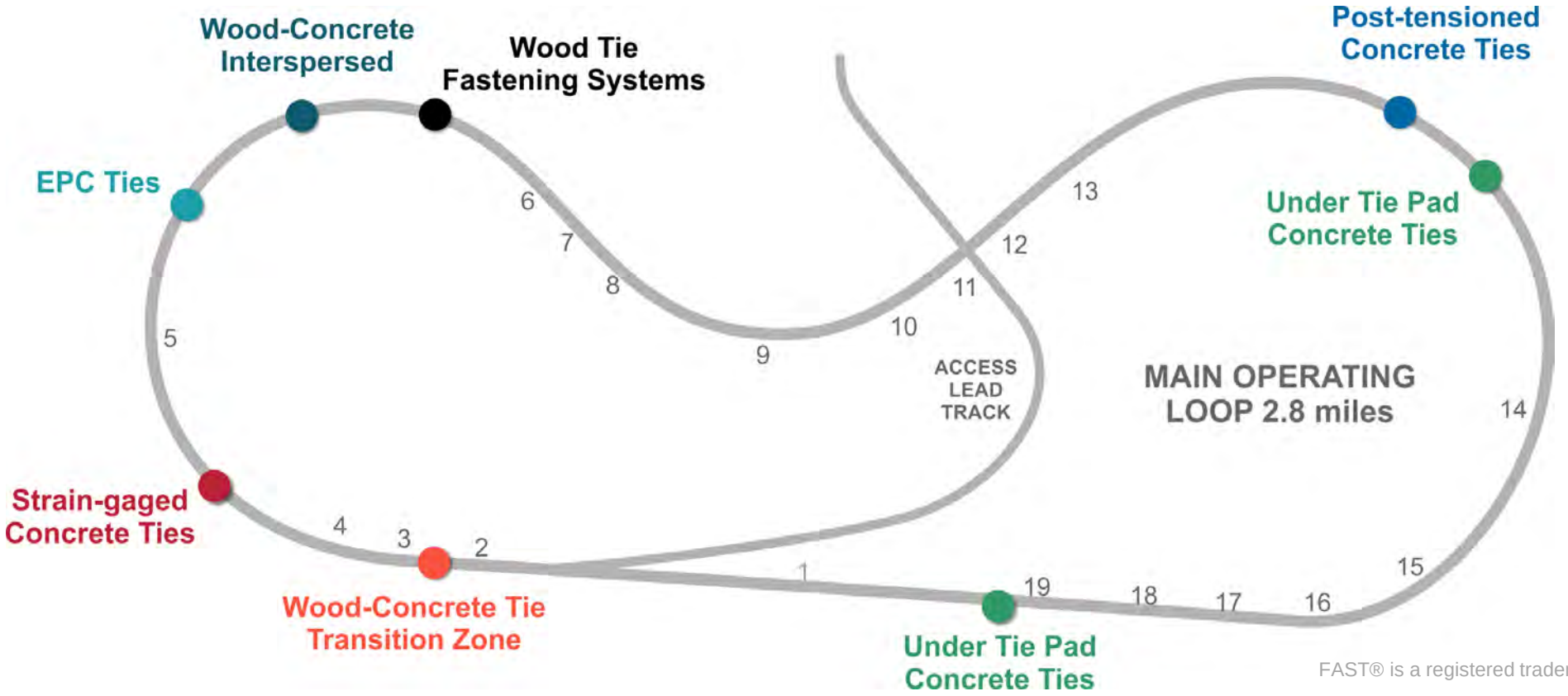
Crosstie and Fastener Tests at FAST®

- **Tests at various locations around the loop**
  - Most tests installed in November 2023
  - Mainly on two curves (5- and 6-degree)
  - Over 145 MGT by the end of 2024



FAST® is a registered trademark of MxV Rail

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Crosstie and Fastener Tests at FAST

- **Tests at various locations at FAST**
  - Tie type, fastener type, various configurations
  - Concrete tie tests
    - Concrete ties interspersed with wood ties
    - Strain-gaged concrete ties
    - Post-tension concrete ties
    - Under tie pad concrete ties
    - Wood-concrete transition zone

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Crosstie & Fastener Tests at FAST

- **Tests at various locations at FAST**
  - Wood tie fastening systems
  - Engineered polymer composite ties

Tie Plate	Fastener Type	Anchor Condition
14-in. Curve block	Cut Spike	EOTA
16-in. Curve block	Cut Spike	EOTA
16-in. Elastic fastener	Cut Spike	N/A
16-in. Elastic fastener	Cut Spike	ETA
18-in. Elastic fastener	Screw Spike	N/A
18-in. Elastic fastener	Screw Spike	ETA
18-in. Elastic fastener	Screw Spike (New Spike Type)	N/A
18-in. Elastic fastener	Cut Spike	N/A
18-in. Elastic fastener	Cut Spike	ETA
18-in. Elastic fastener	Cut Spike	ETA (New Anchor Type)
16-in. Rolled plates	Cut spike	EOTA

* ETA: every other tie; EOTA: every other tie

Tests and Measurements Update

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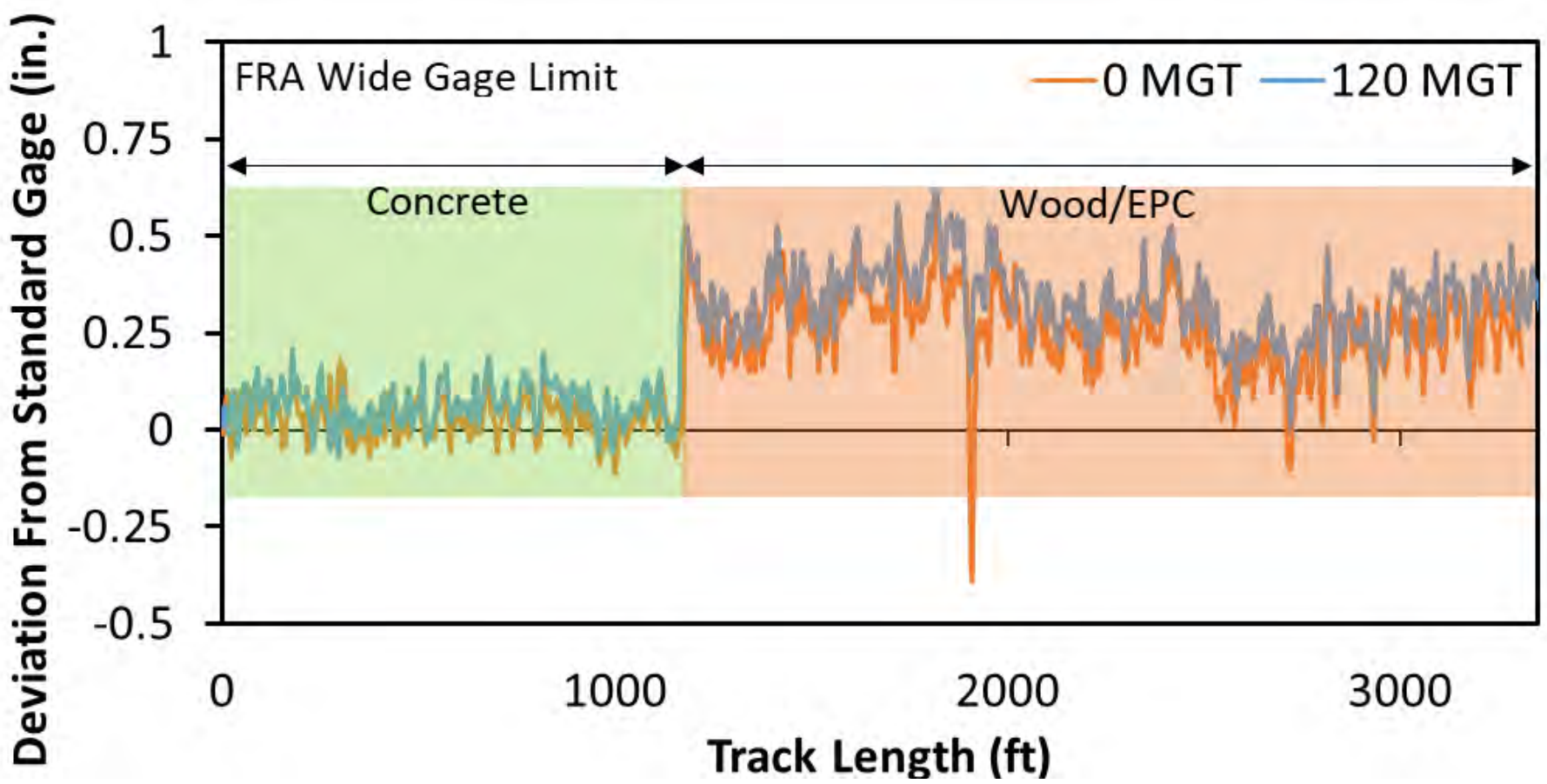
Track Gage Monitoring

- **Track gage collected by track geometry car**
  - Minor change over the initial 120 MGT (less than 0.1 inch)



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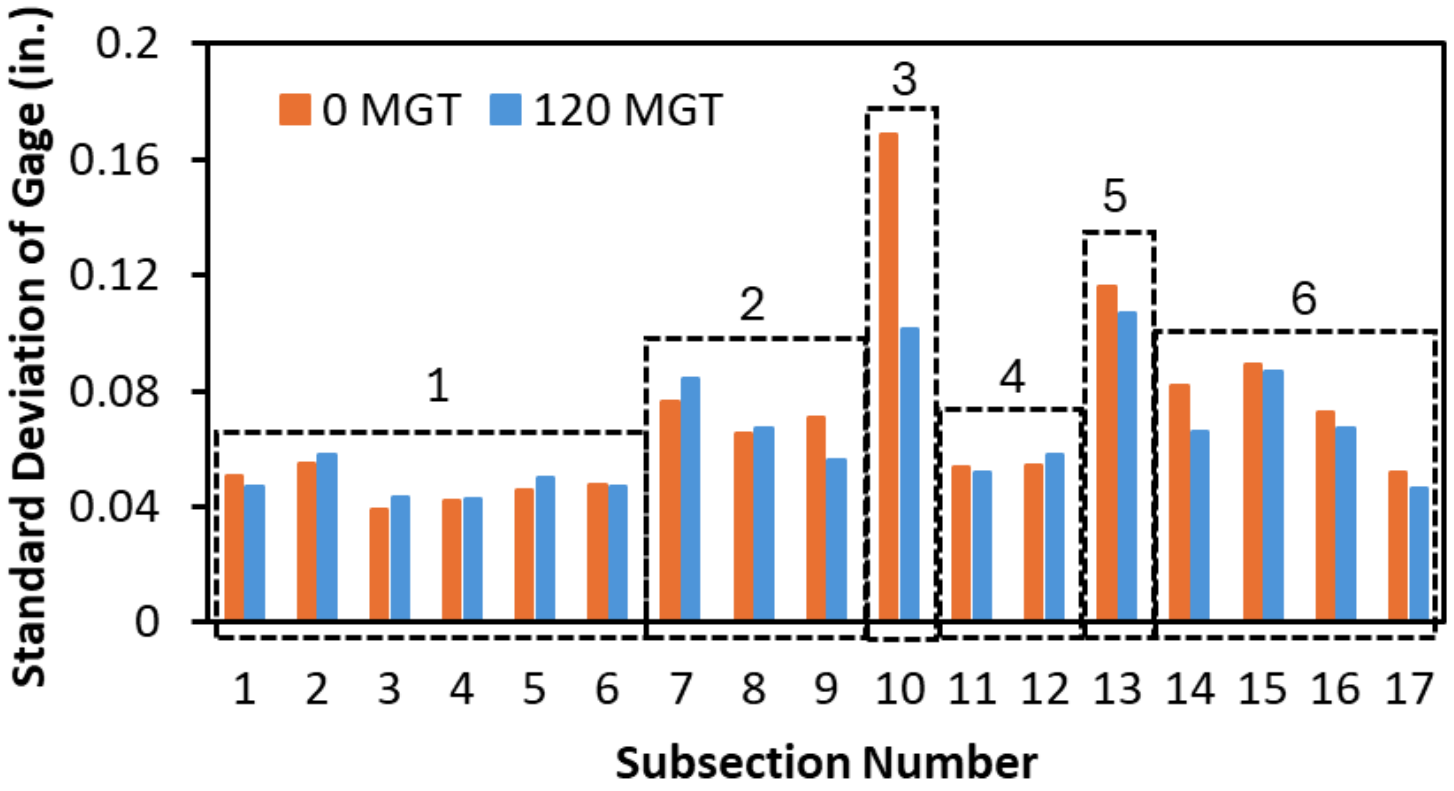
Track Gage Monitoring

- **Track gage collected by track geometry car**
  - Concrete ties presented the least variation in track gage, while the composite tie and interspersed concrete/wood ties had the largest variation



1. **Concrete ties**
2. **wood ties with AREMA plates**
3. **Composite ties with AREMA plates**
4. **Wood ties with curve block plates**
5. **Interspersed concrete/wood ties**
6. **Wood ties with elastic fasteners**

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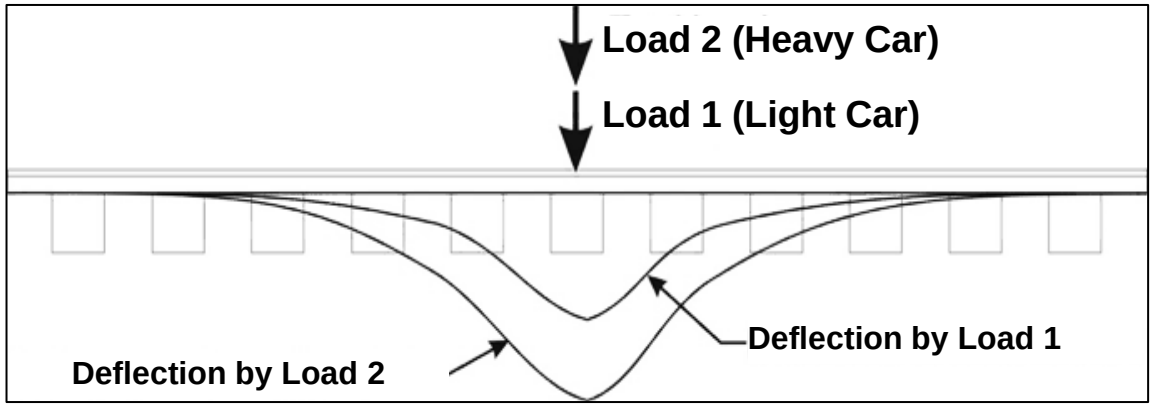
Track Modulus Test

- **Conducted on different tie and fastener types at FAST using light and heavy cars**
  - Deflect track with light and heavy cars
  - Account for slack in track
  - Isolate effect from voids
  - Need to deal with load superposition



Sussmann, 2011

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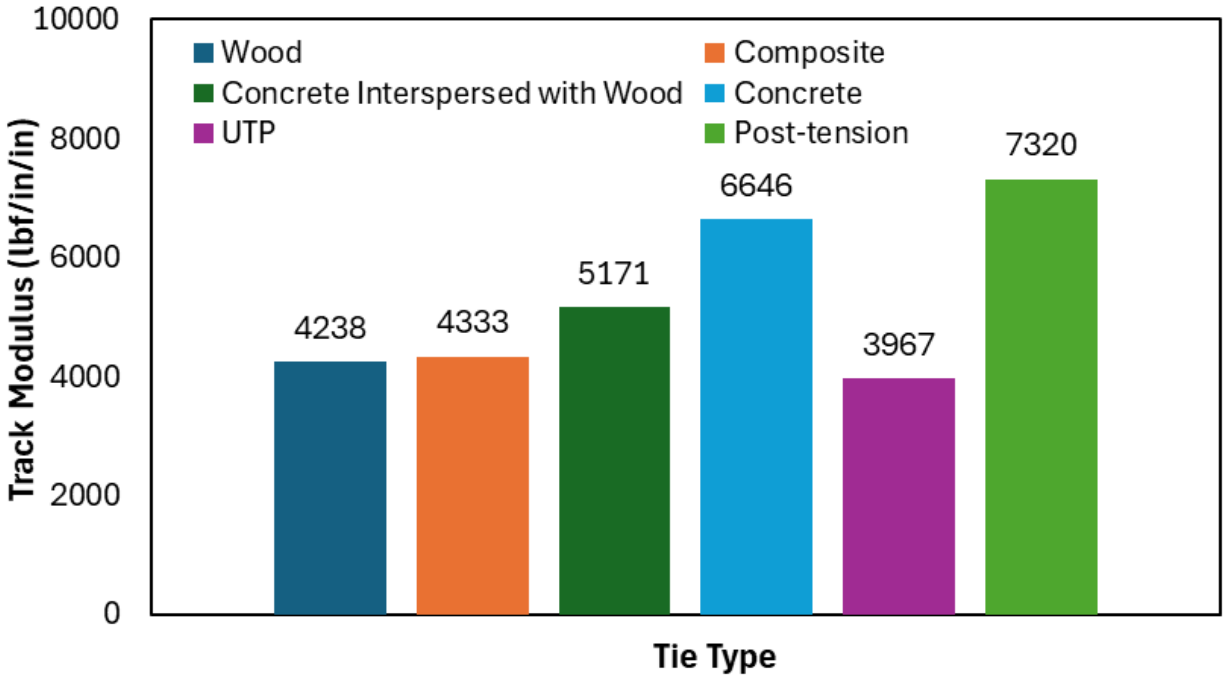
Track Modulus Test

- **Effect of Tie Type**
- **Effect of Fastening Systems**
- **Effect of Subgrade Conditions**



Wood Tie Fastener Type	Modulus (lbf/in/in)
Concrete – Embankment	6,358
Concrete – In Situ Subgrade	9,339
Wood – Embankment	4,066
Wood – In Situ Subgrade	4,712
Wood – AREMA Plates	3,968
Wood – Curve Block	3,989
Wood – Elastic Fastener Plates	4,756

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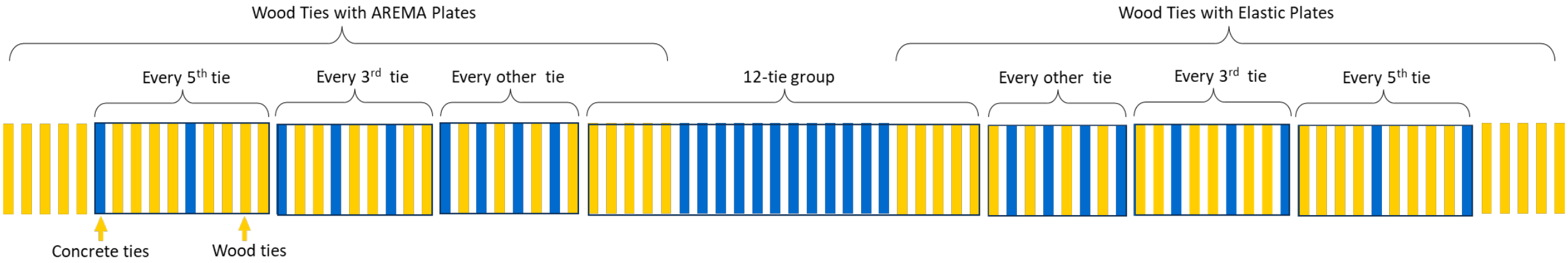
Concrete Ties Interspersed with Wood Ties

- **76-tie interspersed section**
  - Wood ties with standard AREMA plates
  - Wood ties with elastic fastener plates with cut spikes
  - A 12-tie consecutive concrete tie zone



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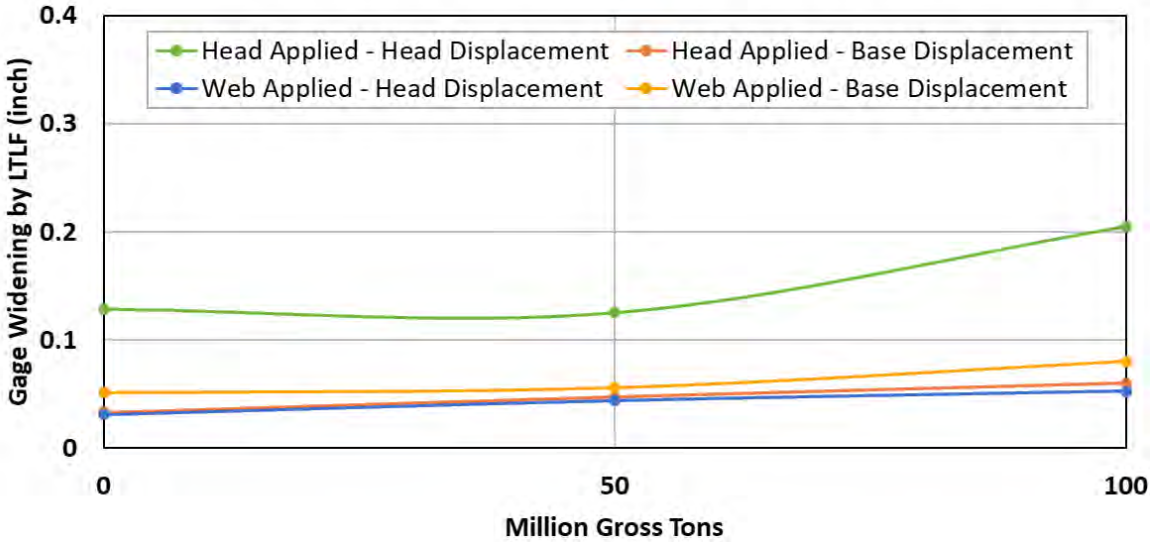
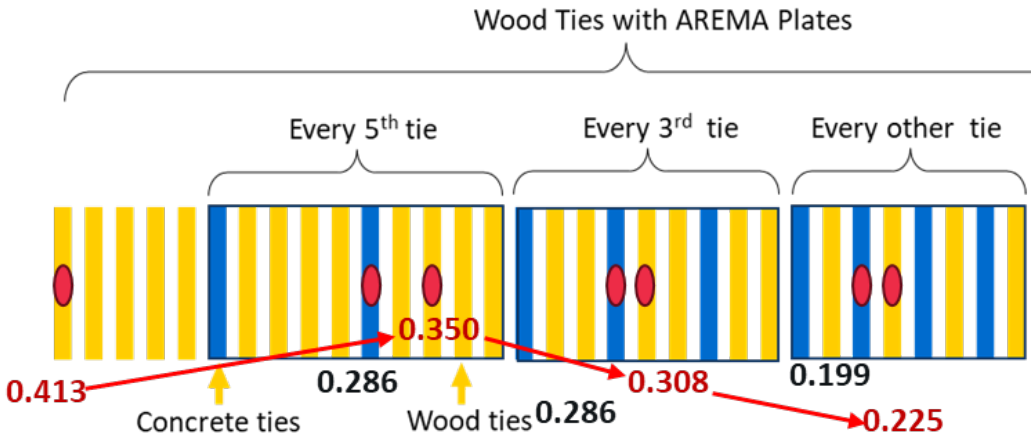
Concrete Ties Interspersed with Wood Ties

- **Track gage holding strength test**
  - Average 0.2-inch gage widening under gage spreading load
    - Interspersed with wood ties with AREMA plates: 0.2 to 0.35 inch
    - 12-tie consecutive concrete tie zone: 0.1 to 0.2 inch
    - Interspersed with wood ties with elastic plates: 0.1 to 0.2 inch
  - 0.4- to 0.45-inch gage widening for wood ties with cut spikes





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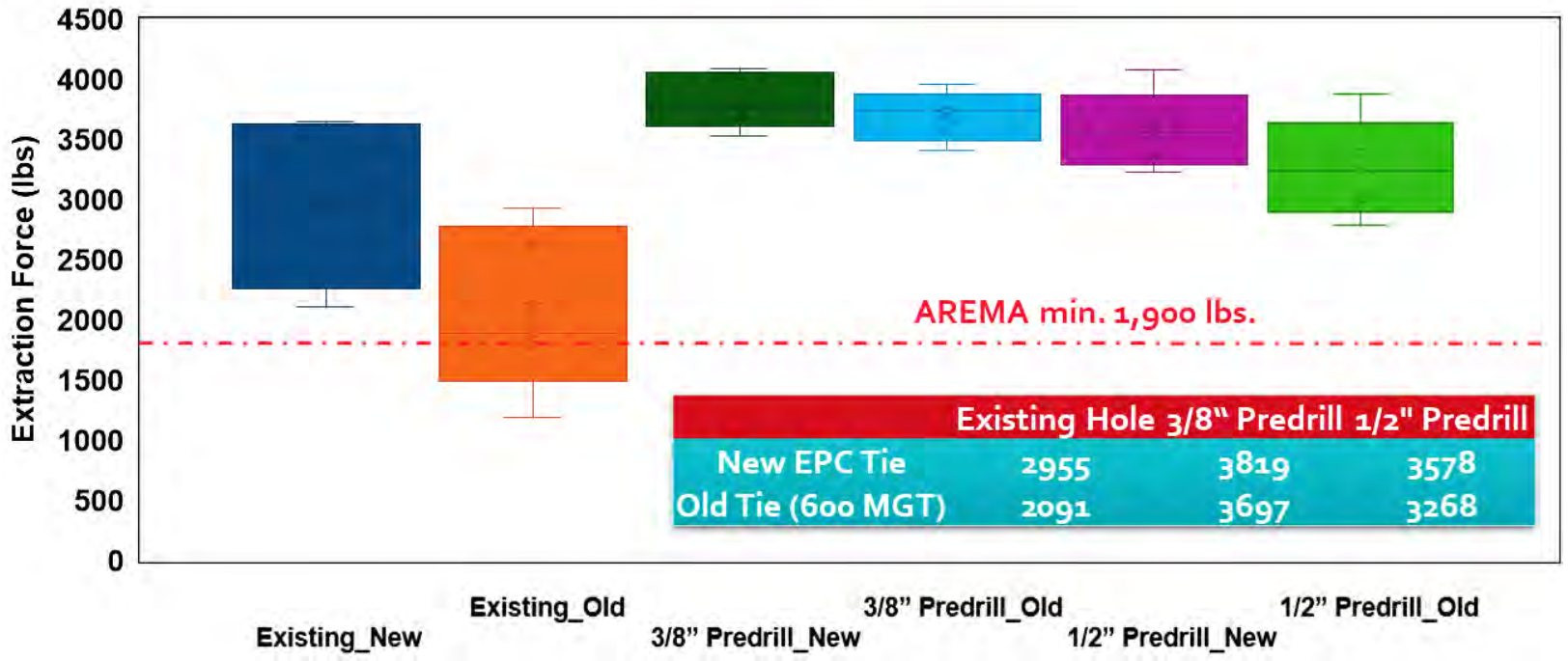
Spike Holding Power for Composite Ties

- **New composite ties versus old composite ties**
  - Old ties were from previous facility, over 600 MGT
- **Existing hole (1/2 in.) versus new holes (1/2 in. & 3/8 in.)**
  - All test cases (eight samples per test) met the AREMA minimum 1,900-pound spike holding force



	Existing Hole	3/8" Predrill	1/2" Predrill
New EPC Tie	2955	3819	3578
Old Tie (600 MGT)	2091	3697	3268

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Evaluation of Glulam Ties for Turnouts

- **Glue-laminated (glulam) ties versus solid-sawn wood ties**
- **A pair of No. 20 turnouts in a crossover**
  - September 2024 initial installation and inspection
  - One with glulam wood ties
  - One with solid-sawn wood ties (as a control for comparison)

Glulam Tie

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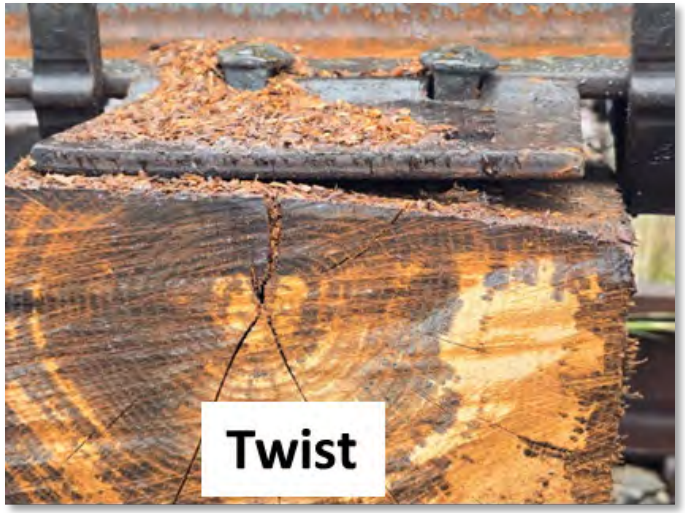
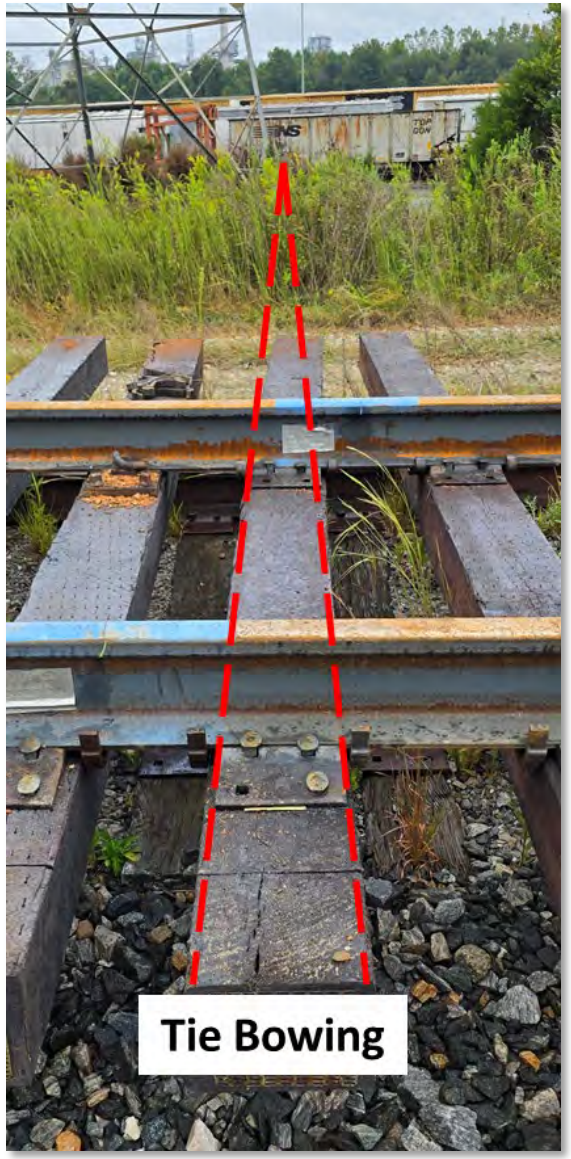
Evaluation of Glulam Ties for Turnouts

- **Visually, glulam ties are straight and have better quality than solid-sawn ties**
  - No warp, twist, split found on any glulam ties
  - Splits, twist and bowing found on solid-sawn wood ties
  - Long solid-sawn ties (>102 in.) tend to have more quality issues than regular solid-sawn ties
  - Glulam ties are heavier (larger cross section), and tie surface is more slippery when wet





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Closing Remarks

- **All the tie and fastener test zones were maintained track geometry of the Class 4 track under the HAL traffic at FAST after 145 MGT.**
- **The track modulus is affected by tie and fastener types, as well as subgrade conditions.**
- **Concrete ties interspersed with wood ties provided better track gage holding strength compared to wood ties with AREMA tie plates.**
- **Both new and old EPC ties met the specification of spike holding power without spike plugging materials.**

Acknowledgements

- Class I railroads and Tie TAG
- Tie and fastener suppliers
- AAR's Strategic Research Initiatives Program
- MxV Rail Team (Track, Instrumentation, Data Science Teams)

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Ballast and Subgrade Research

Stephen Wilk, Ph.D.
Principal Investigator II

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Substructure SRI

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1 Lateral Track Strength

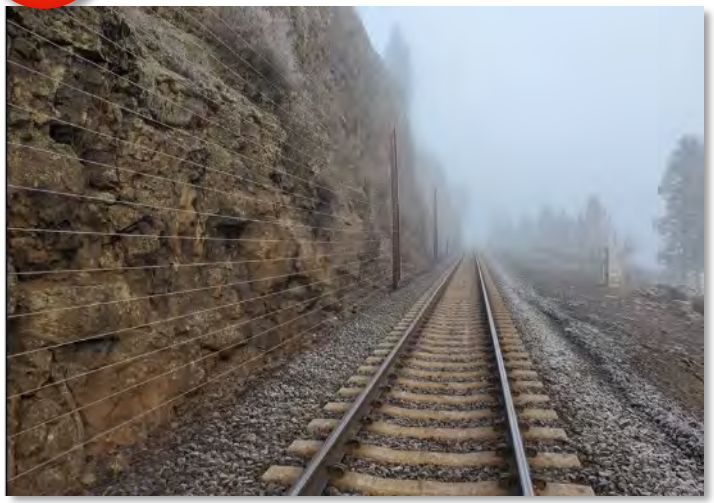
2 Ballast Maintenance

3 Ballast Degradation

4 Effect on other Components

5 Subgrade Remediation

6 Infrastructure Resiliency



Overview

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1 Reclaimed Ballast Characterization

2 Ballast Condition and Concrete Tie Life

Topic 1: Reclaimed Ballast Characterization

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Ballast Reclamation

- **Ballast reclamation is process of putting used ballast that passes gradation specifications back into track**
  - Undercutting: 0 to 30%
  - Shoulder Cleaning: 0 to 70%
- **Tradeoffs:**
  - Benefits: Saves material costs, transport costs, and avoids bottlenecks (**well defined**)
  - Potential Issues: Used ballast may reduce performance (**not well defined**)

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2022-2024 Study

- **Exploratory study to characterize reclaimed ballast characteristics using laboratory methods**
  - Isolate defined parameters but not as representative of revenue service performance
- **Partnered with University of Illinois at Urbana-Champaign**
  - Shape Characteristics, shear testing, settlement testing, and drainage testing
  - NS donated ballast: new, spoils, reclaimed (cleaned spoiled), 30/70 mixture, 50/50 mixture

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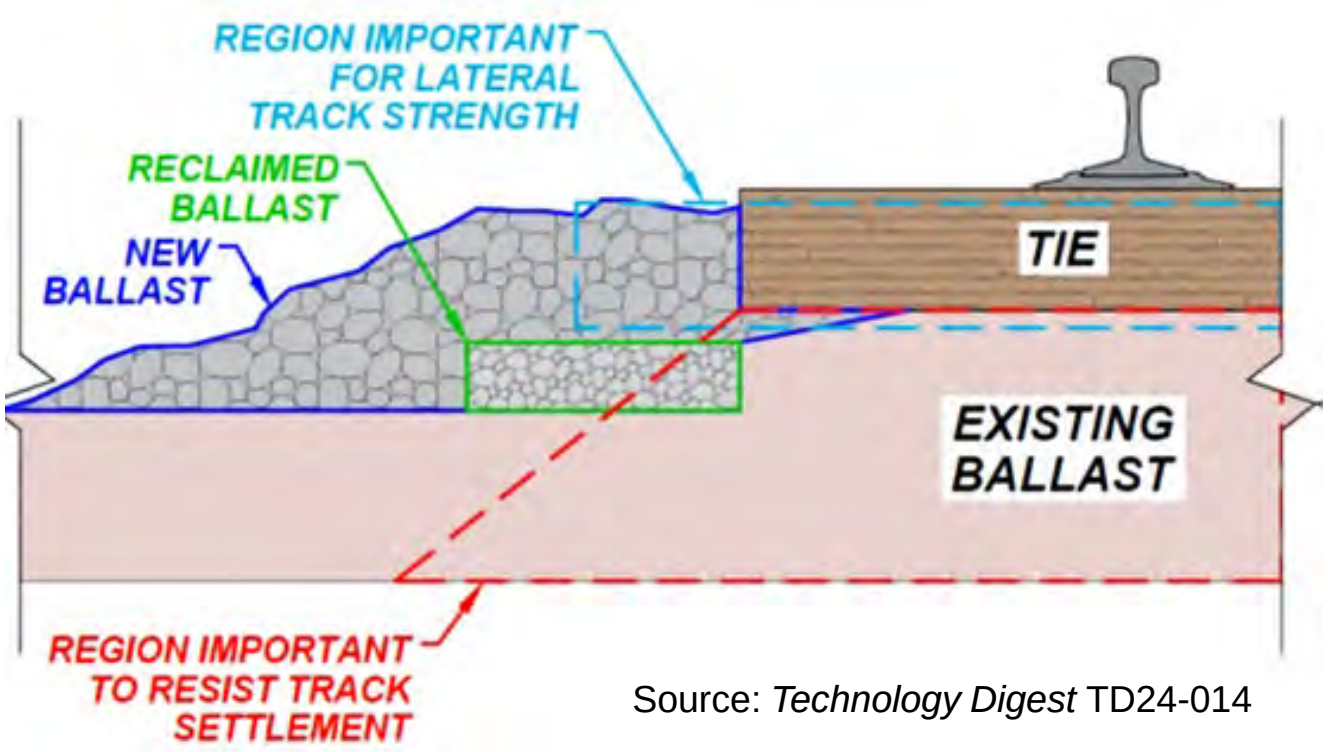
High-level Findings



Source: *Technology Digest* TD24-014

- **Lateral track strength loss estimated to be minimal (1-3%)**
  - Placed below important zone
  - Mixture with clean ballast increase strength
  - Shoulder only 20-25% of LTS
- **Testing showed no obvious issues with settlement or drainage**
- **Place reclaimed ballast as far from tie as possible**

Topic 2: Effect of Ballast Condition on Concrete Tie Life

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Effect of Ballast Condition on Concrete Tie Life

- **Question: How does ballast condition affect concrete tie life?**
- **Long-term goals:**
  - Quantify concrete tie life in various environment
  - Assess degradation trends and predict tie failure
  - Optimize tie life with ballast maintenance

Why Concrete Ties?

- **Ballast condition affects degradation and life of most track components**
- **Concrete Ties:**
  - Parallel efforts in “Tie and Fastener” SRI
  - Many concrete ties approaching 40-year life
  - Easier to isolate ballast effect
  - Recent ability to quantify aspects of concrete tie condition using track-based inspection systems

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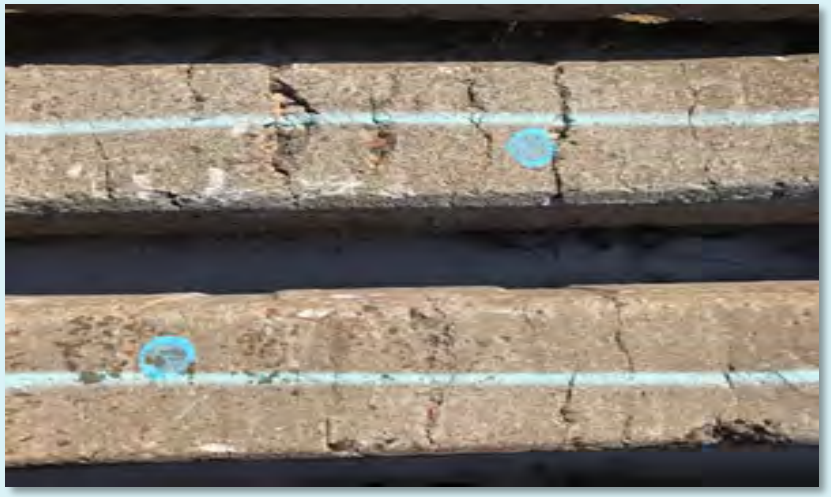
Concrete Tie Failure Modes: Center Cracking

- **Concrete tie life affected by all failure modes but this study emphasizes center cracking**

Shoulder Wear

Rail Seat Deterioration

Cracking/Breaking



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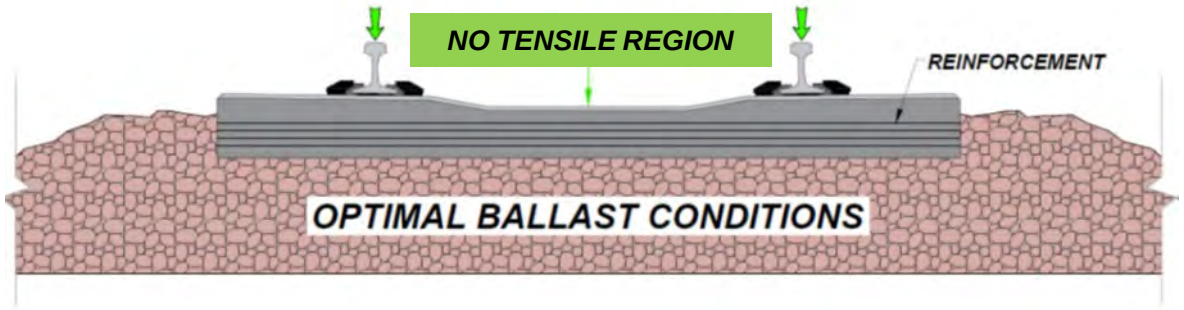
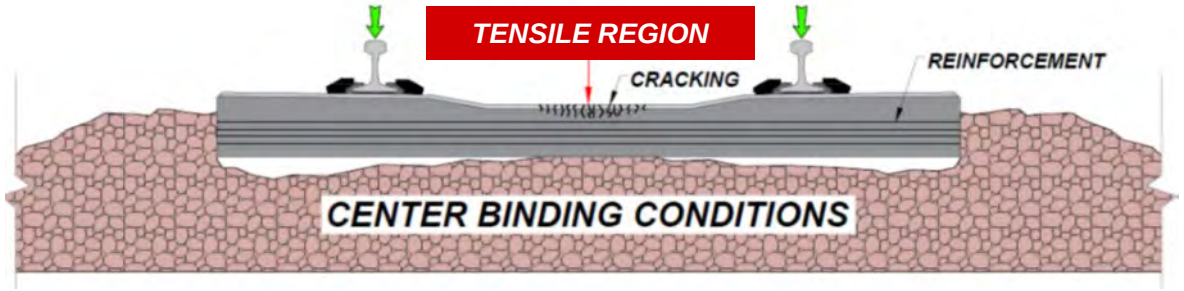
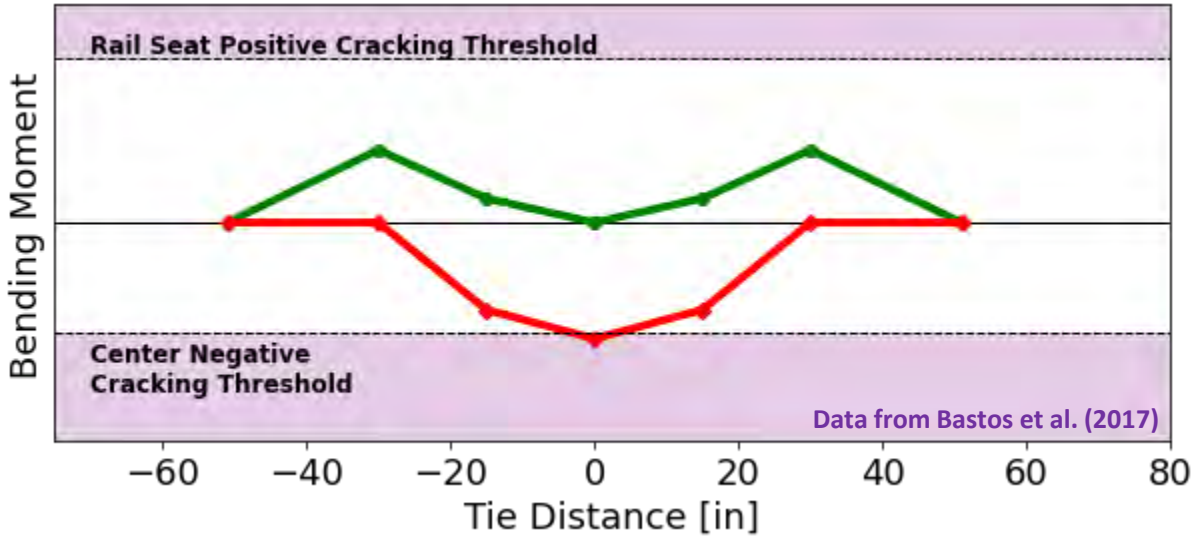
Center Cracking

- **Center cracking often attributed to center-binding ballast condition**
- **Center-binding often attributed to ballast experienced greater settlement**
  - Fouled ballast, skin lifting, long surfacing cycles
- **Pre-stressed concrete tie designed not to crack under typical loads and ballast support**







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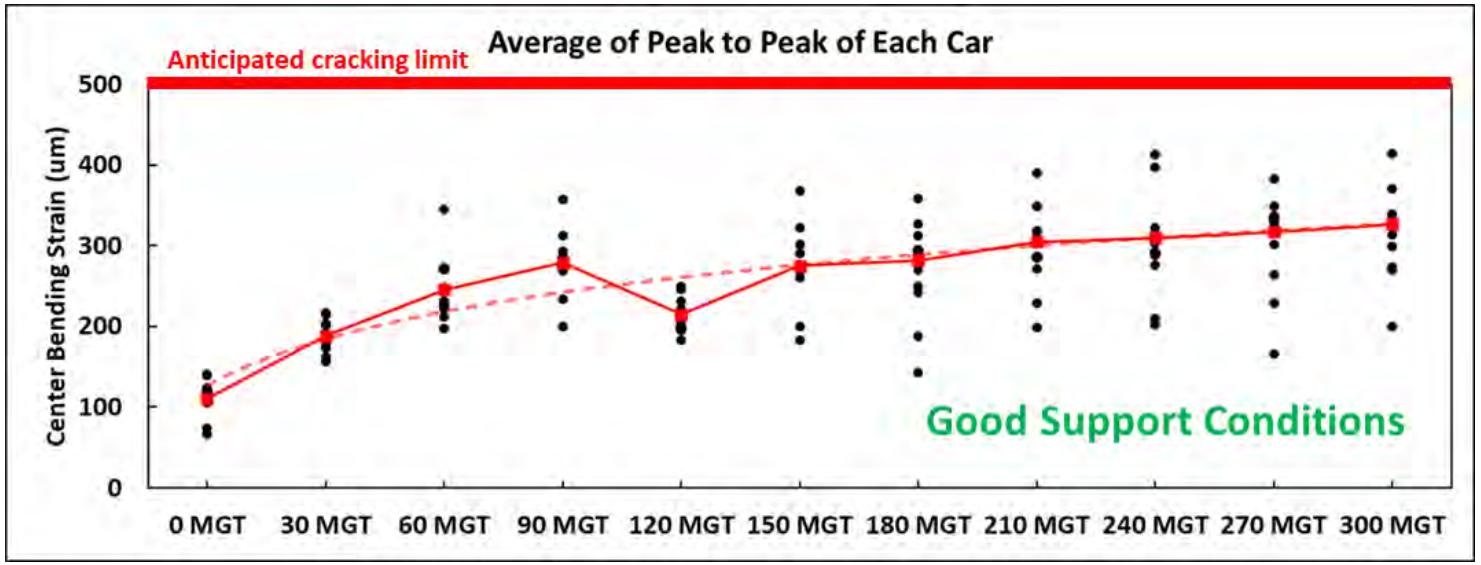
FAST® Testing: Center Bending with MGT

Range of center bending strain from 10 concrete ties at FAST over a 300 MGT surfacing cycle



- **FAST test showed center bending strains ranging from 200 to 400 um, below the anticipated 500 um cracking limit from laboratory tests**
- **FAST typically represents good support conditions**

FAST® is a trademark of MxV Rail.

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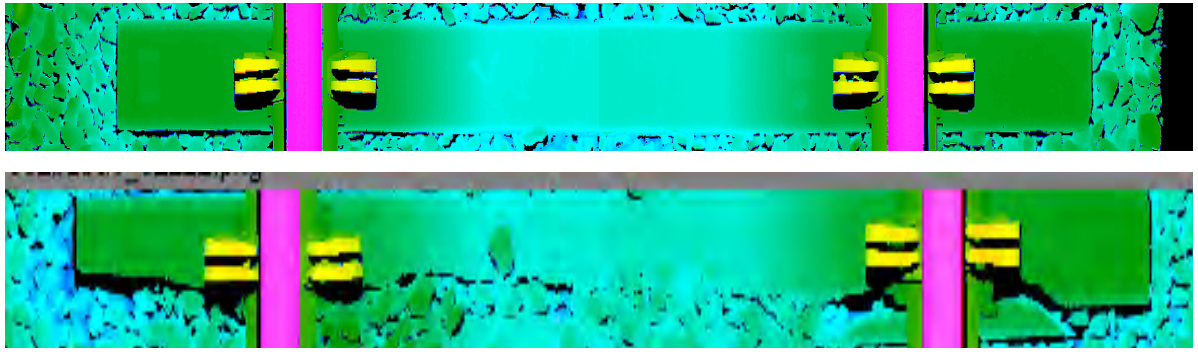
Concrete Tie Scanning

- **Track-based systems to grade concrete ties**
- **Immediate Uses**
  - Understand concrete tie condition over subdivision/system
- **Long-Term Uses**
  - Degradation projections (tie life)
  - Interactions with other track-based inspections (ballast, track geometry)

Track-based concrete tie identification and grading



Bankston and Wilk, 2023 (AREMA, IHHA)

2023 Study Details

- **> 1 million concrete ties from five subdivisions**
- Installation date, tonnage
- **Track Geometry and Ground Penetrating Radar (GPR)**

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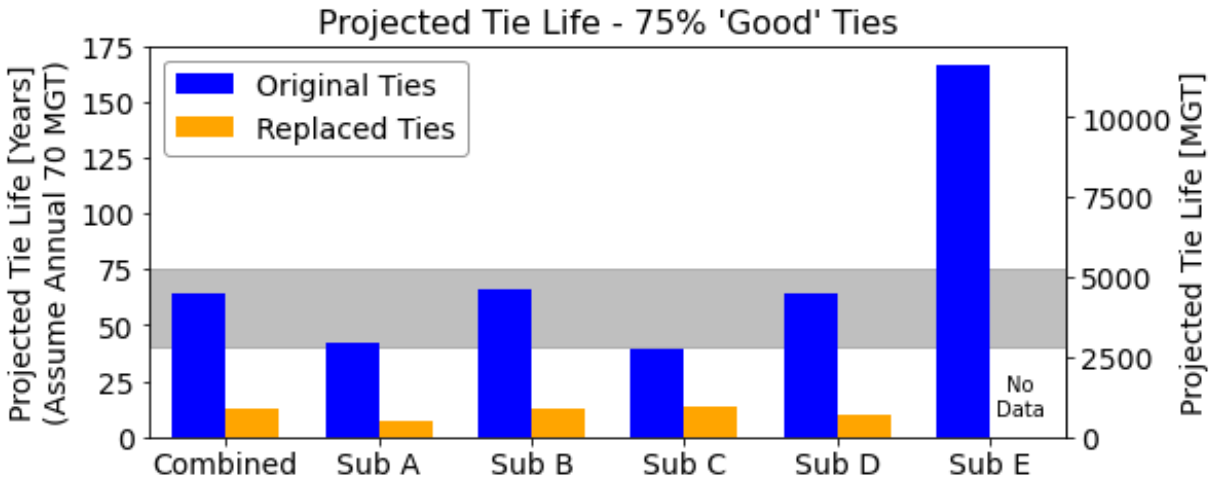
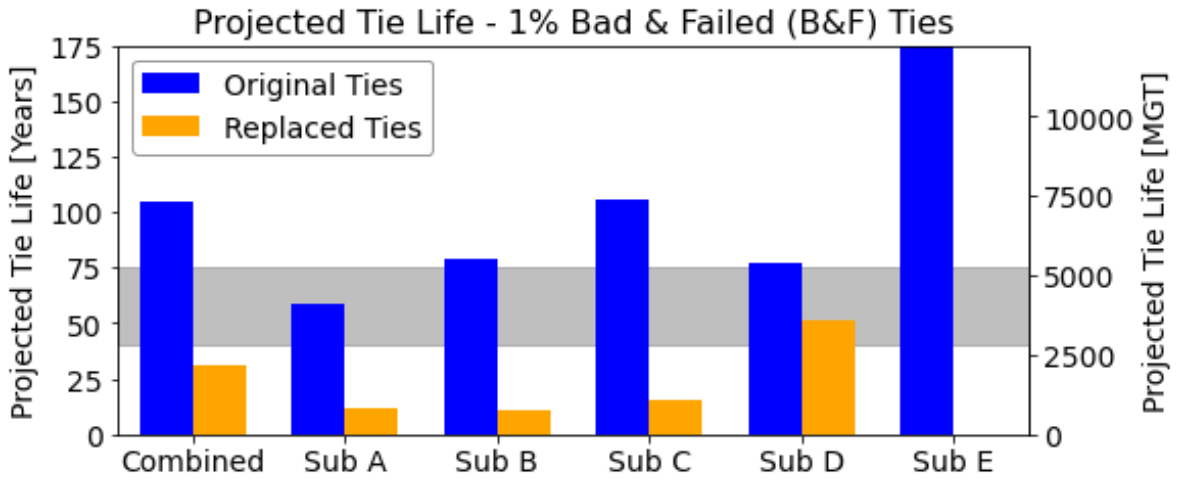
Concrete Tie Life Study





Source: *Technology Digest* TD23-022

Key Findings

- **Significant difference in concrete tie life between “original” and “replaced ties”**
- **“Original” ties between 45 to 75 years (2,800-5,200 MGT)**
- **“Replaced” ties between 10 to 14 years (700-1,000 MGT)**
- **What is explanation for difference between “original” and “replaced”**
- **No indication of maximum tie life of 40-50 years**

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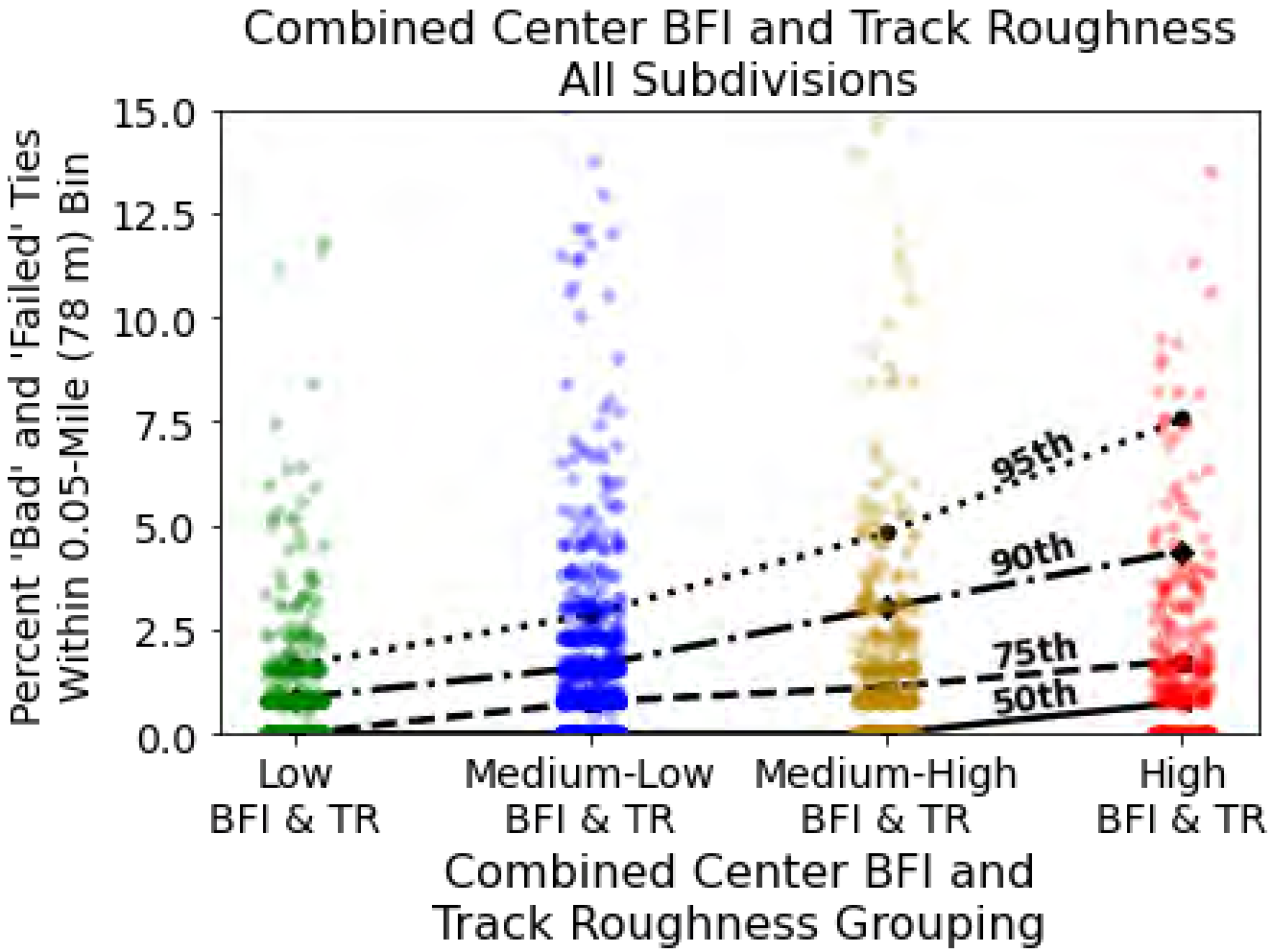
Parameters Relating to Concrete Tie Condition



Key Findings

- **Track with high center BFI and track roughness (surface profile) has a greater likelihood of more “bad” or “failed” ties**
- **Difficulty isolating relationship due to other factors**

Source: *Technology Digest* TD23-024

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Field Testing

- **Road crossing approach with mud pumping and “moderately” cracked concrete ties**
  - Line consists of loaded and empty unit trains
- **Timeline:**
  - Pre-Maintenance Measurements: June 2024
  - Undercutting and Surfacing: August 2024
  - Post-Maintenance Measurements: December 2024

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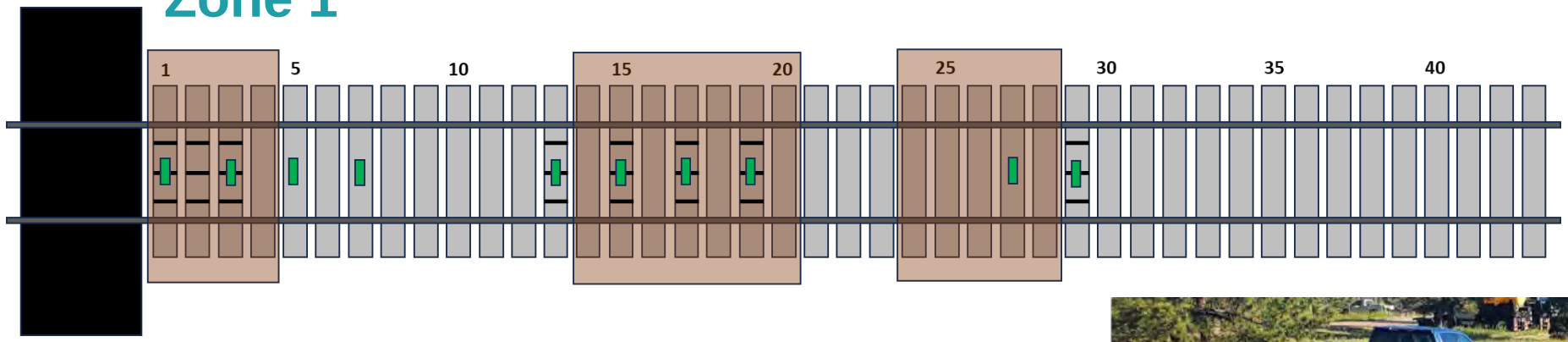
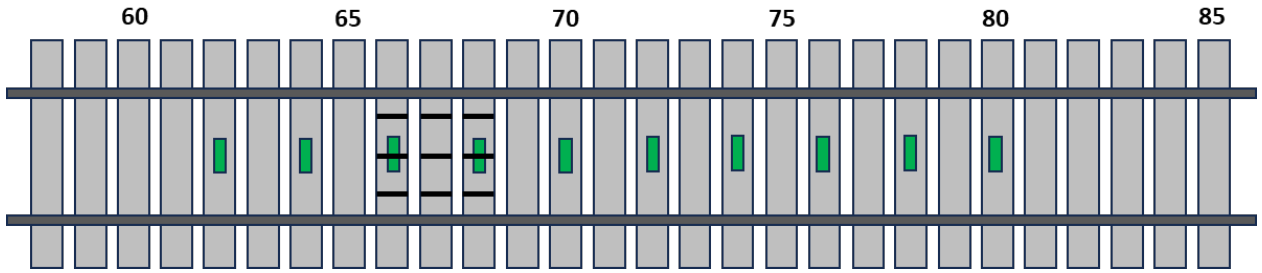
Test Layout

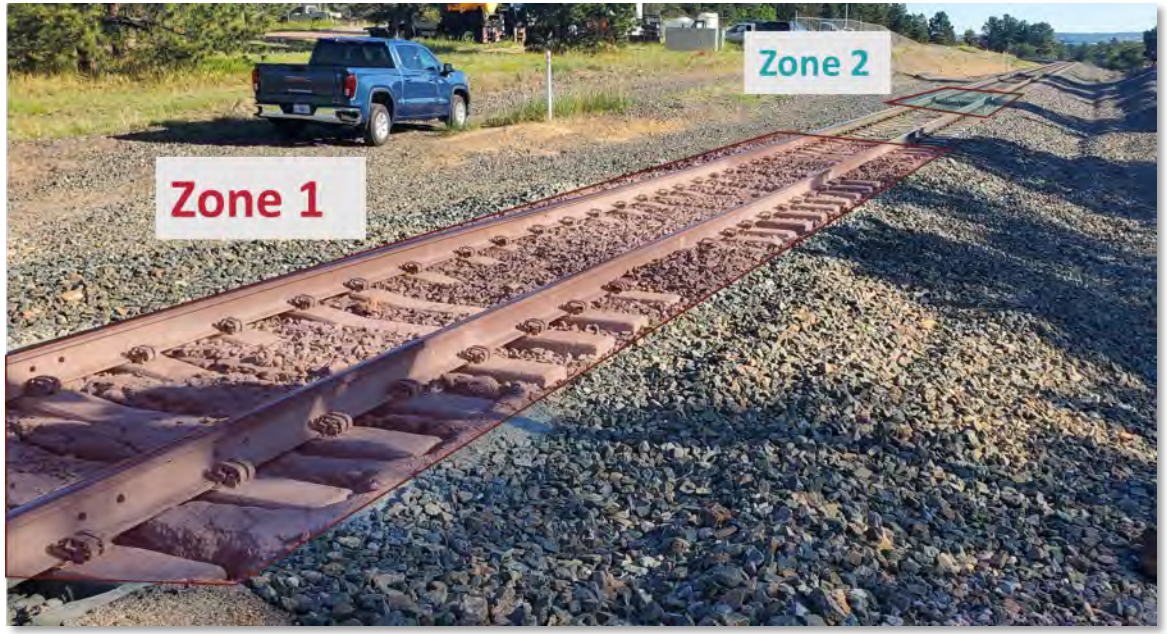
Mix of cracked/non-cracked concrete ties in range of support conditions

Zone 1



Zone 2





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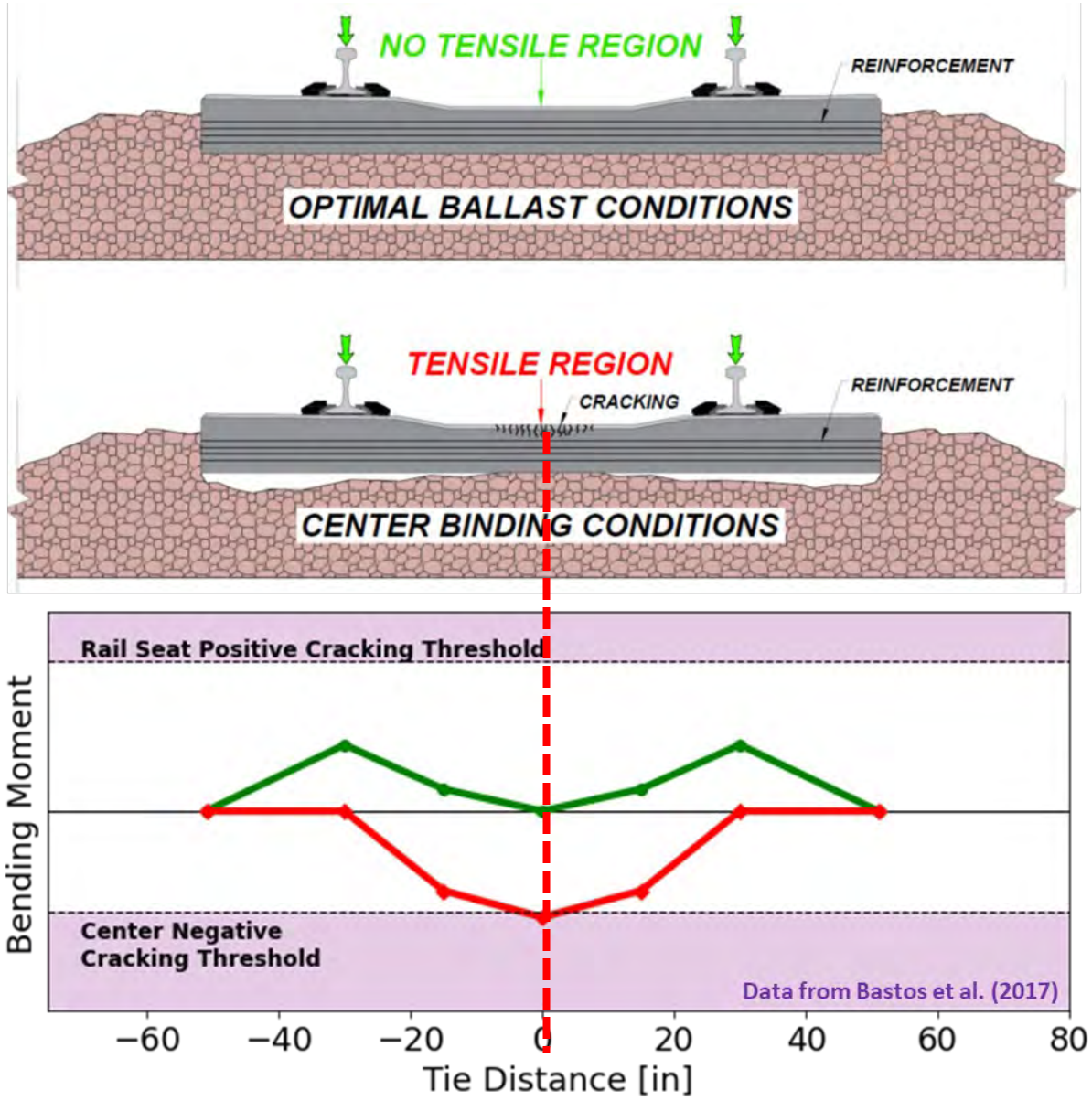
Instrumentation

- **20 strain gauges measure maximum center negative bending strain**



Trip #1 Results: Pre-Maintenance

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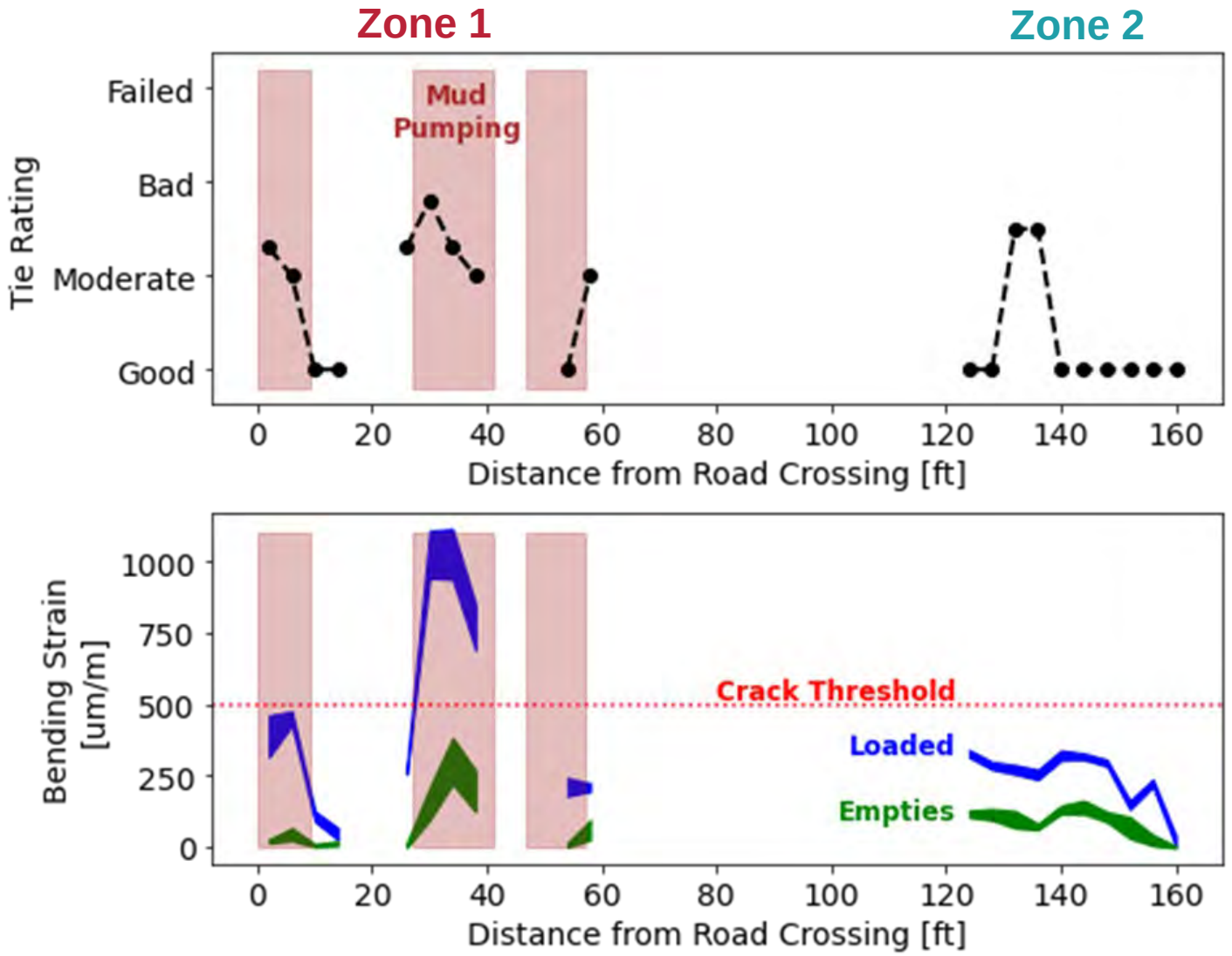
Key Findings

- **Strong relationship between ballast conditions and bending strain**
- **Significantly more bending from loaded cars than empties**



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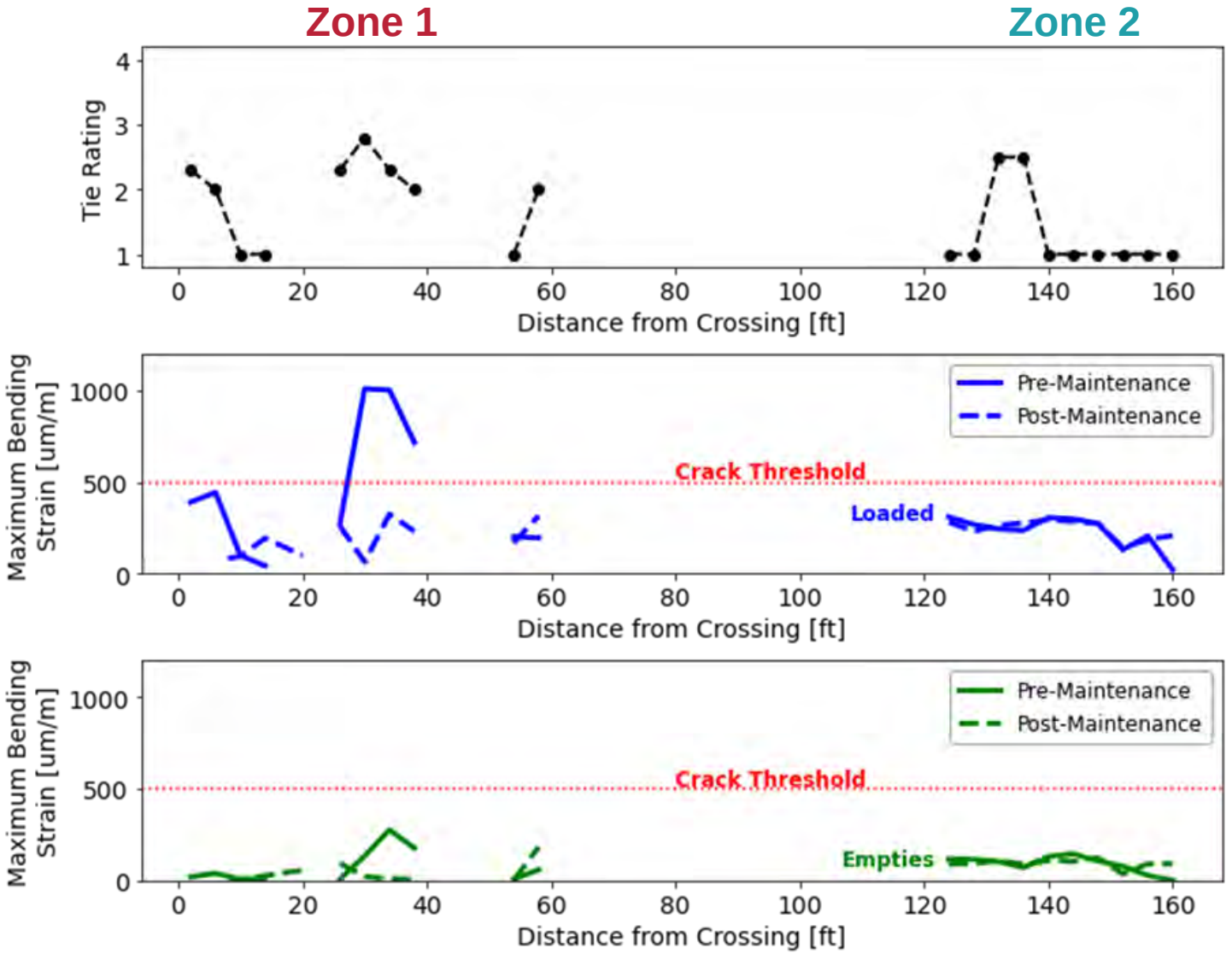
Trip #2 Results: Effects of Undercutting/Surfacing

Key Findings

- **Undercutting/surfacing removed surface mud and track pumping**
- **All concrete ties to within or below optimal bending levels**
- **No indication that “moderately” cracked ties shed load and likely due to expanding mud**



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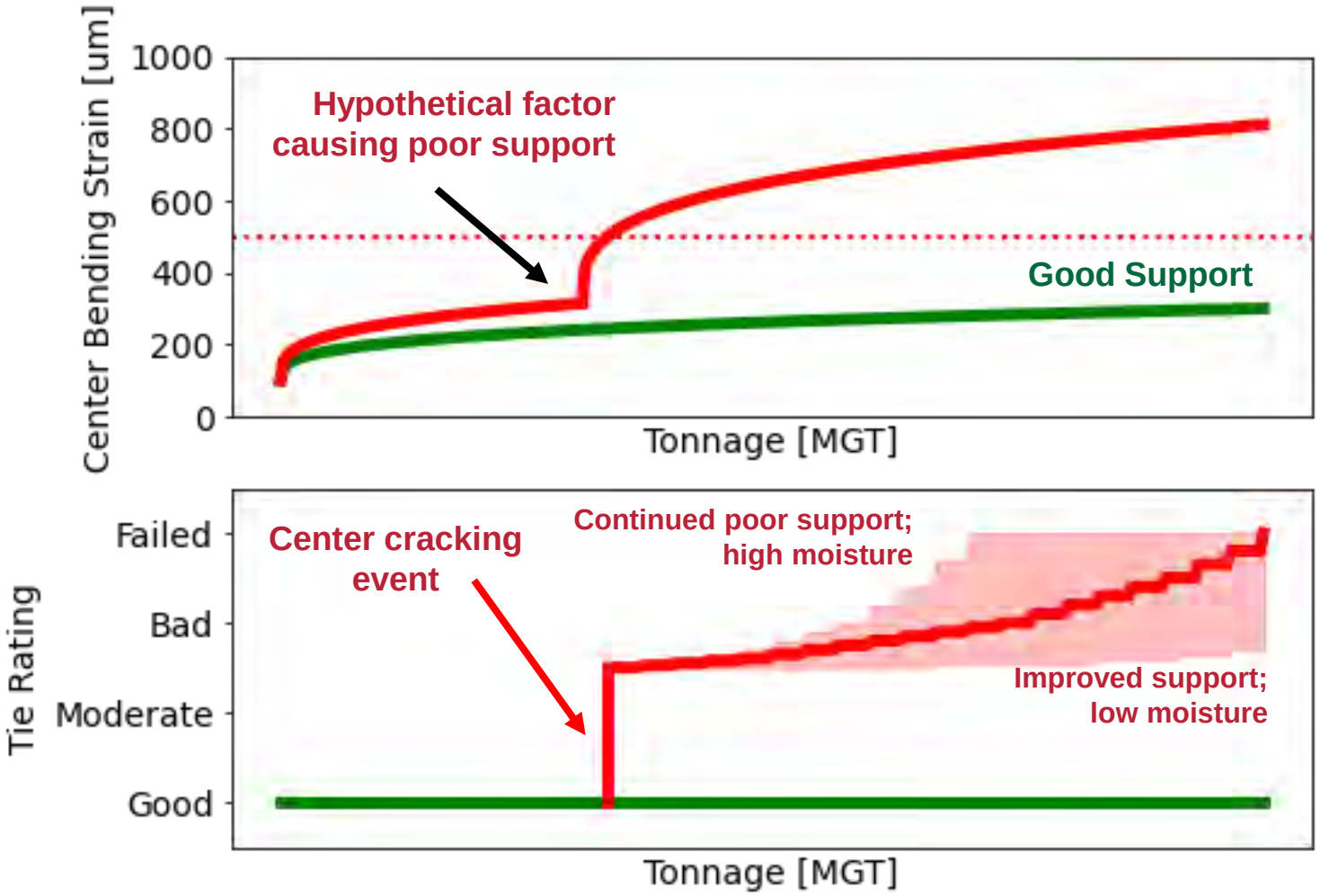
Key Takeaways

Concept of Degradation Model



Good Support

- **Typically, within optimal bending ranges and will not develop centering cracking**
- **Lifespans may be quite long in these circumstances**
- **Majority of ties in service**

Poor Support

- **Cracked concrete ties more suspectable to further degradation**
  - Further cracking from deteriorating support conditions
    - Weather and water infiltration (rainfall, freeze/thaw, drainage)
- **Degradation trends unknown**

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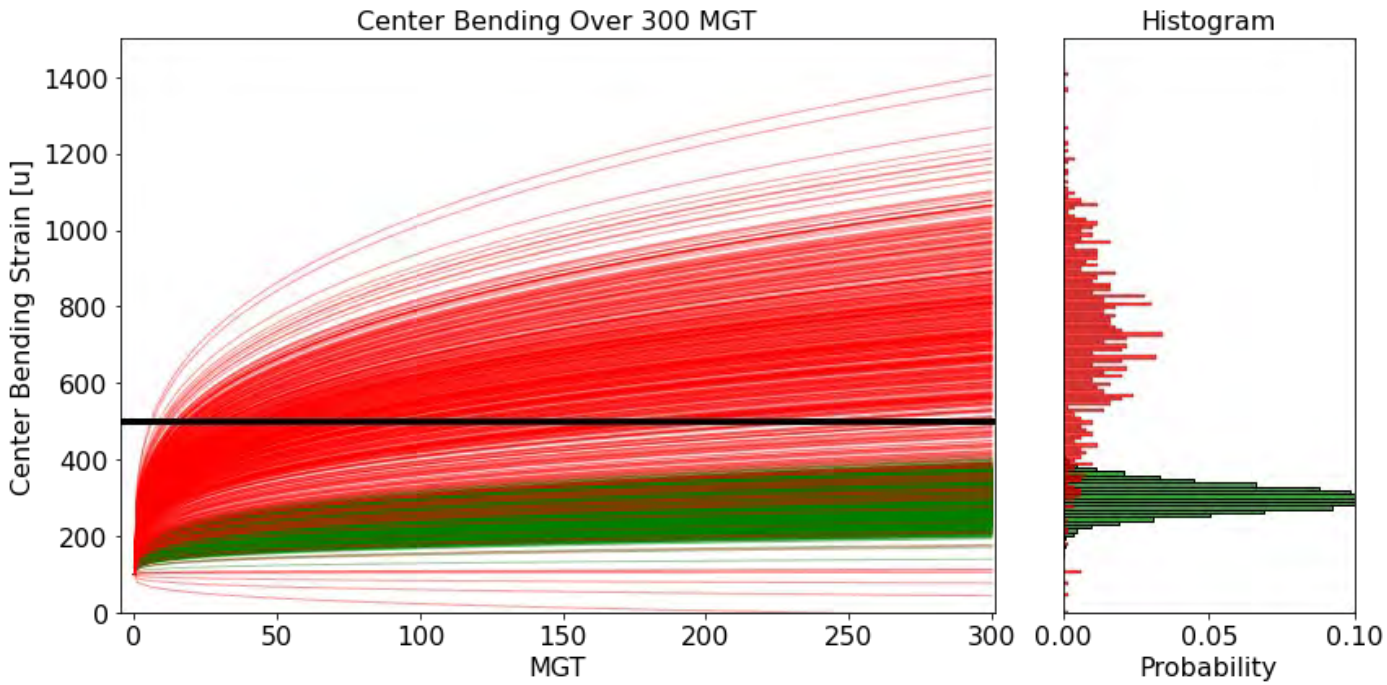
Paths Forward – Concrete Tie Life Modeling

- **Concrete Tie Initial Center Cracking Model**
  - Forecasts % cracked concrete ties (initial cracking)
  - Probabilistic model
  - Inputs of surfacing cycle and support condition distributions
- **Deterioration Models**
  - Forecasts deterioration of already cracked ties
- **Combine with other failure modes**
- **Validation and Improvement**



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Summary

- **Ballast Reclamation**
  - Reclaimed ballast has reduced ballast characteristics but reduction of key performance metrics (e.g., lateral strength) is estimated to be minimal
- **Ballast Condition and Concrete Tie Center Cracking**
  - Multiple studies at FAST and revenue service suggest concrete ties in good ballast conditions remain in optimal bending levels and are not anticipated to center crack. This can lead to tie lives much longer than 40 years.
  - Center cracked ties may follow multiple degradation paths and performance is likely dependent on ballast support and climate/drainage (water infiltration).

30TH ANNUAL Association of American Railroads RESEARCH REVIEW

ASSOCIATION OF AMERICAN RAILROADS

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Acknowledgements

- BNSF: (local crews, Adam Bankston)
- NS: (Steve Bosela)
- Substructure Technical Advisory Groups
- MxV Rail Engineering: Yin Gao & Duane Otter
- MxV Rail Instrumentation: Mike Vazquez & Adom Simpey

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Advances in Rail Research

Ananyo Banerjee, PhD
Principal Investigator II, Rail Infrastructure
Resource Manager, NDE-Metallurgy Group

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Overview

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- **Background**
- **Rail Tests at FAST®**
  - Intermediate strength (IS) rail test
    - Before and after grinding analysis
  - High strength (HS) or premium rail test
    - Updates on ongoing test
- **Rolling Contact Fatigue (RCF) Simulator Tests**
  - Analysis of grinding facets and ridges on rails
    - Tests and Finite Element Modeling (FEM)
- **Conclusions and Future Work**

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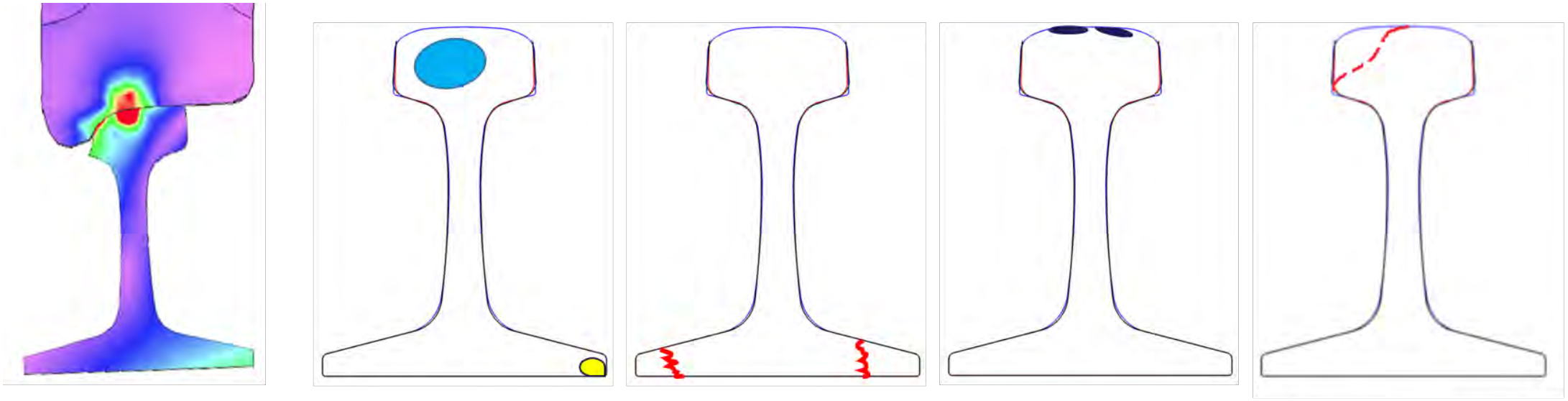
Background

- **Purposes of rail research**
  - Evaluate performance of latest high strength (HS) and intermediate strength (IS) rails under heavy axle loads
  - Evaluate fatigue behavior influencing surface and internal defects as a function of rail head wear for different rail sizes/sections



Rail Stresses | Fatigue Defects | Base Corrosion | RCF, Spalling | Wear

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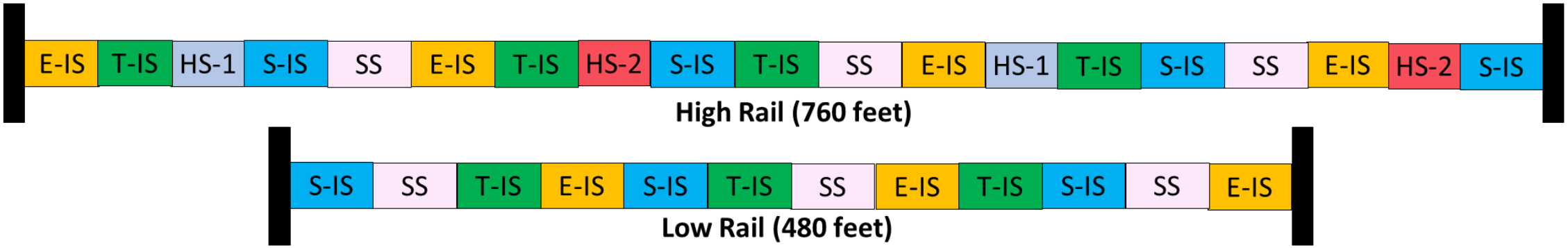
IS Rail Test at FAST

- **Test has accumulated over 400 MGT**
  - Test happening on 5-degree lubricated curve
  - No gage corner shells or fatigue defects in the head through 400 MGT
  - One base break in low rail, four weld defects through 400 MGT
  - Grinding done four times with pre- and post-grind assessments



T-IS Třinecké železárny (TZ) IS Rail

S-IS Steel Dynamics IS Rail

E-IS EVRAZ Rocky Mountain Steel IS Rail

SS Standard Strength Rail (USA)

HS-1 High Strength Rail 1 (USA), Only on high rail

HS-2 High Strength Rail 2 (USA), Only on high rail

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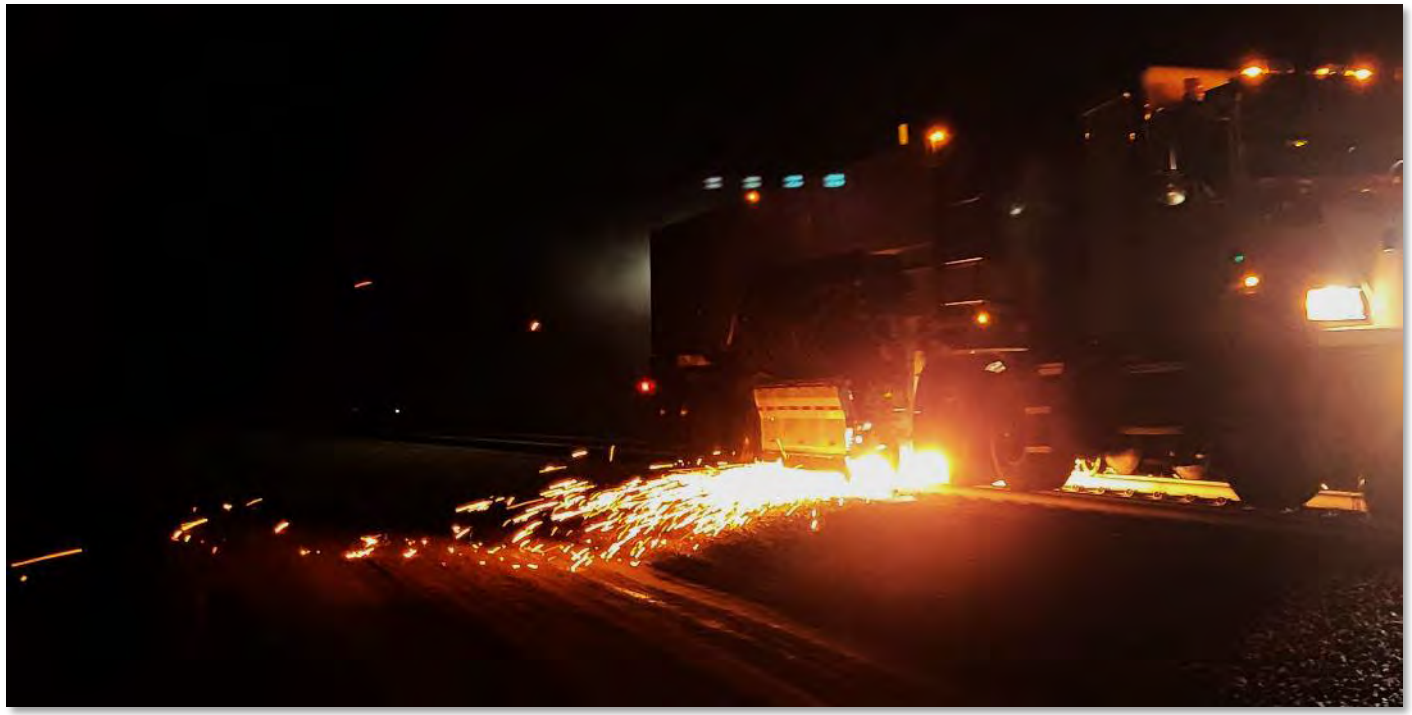
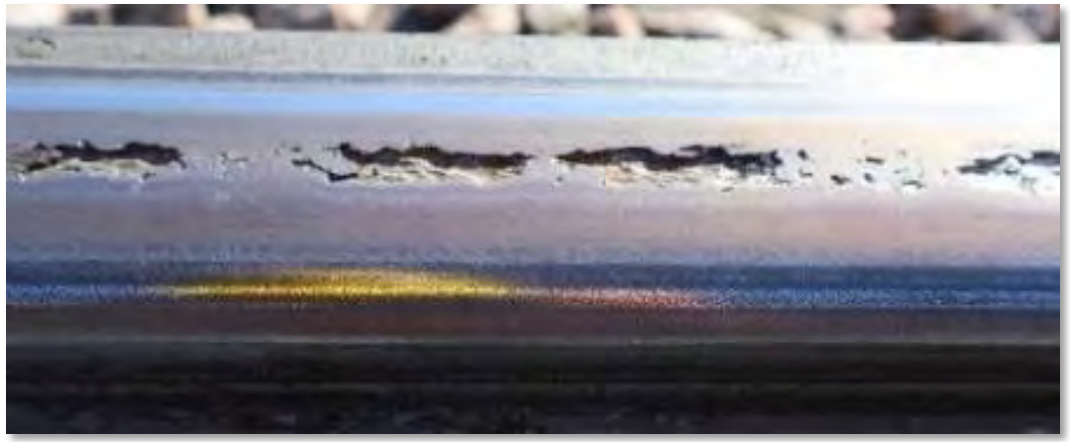
IS Rail Test at FAST

- **Last grinding at 336 MGT; heavy grind for RCF removal**
  - *Technology Digest* TD 24-019 published on latest results



Grinding at 336 MGT in IS rail test zone



RCF on high rail before grinding

RCF on low rail before grinding

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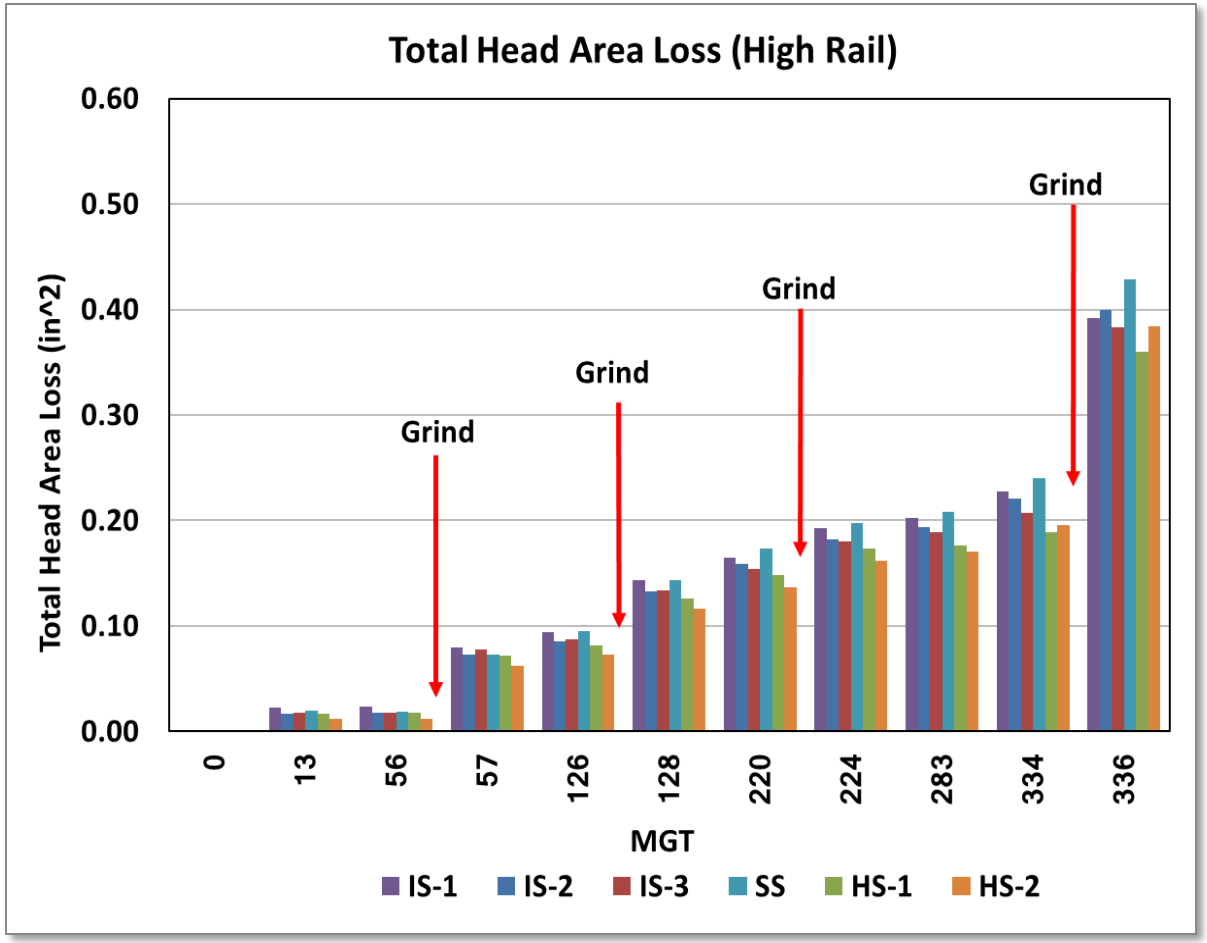
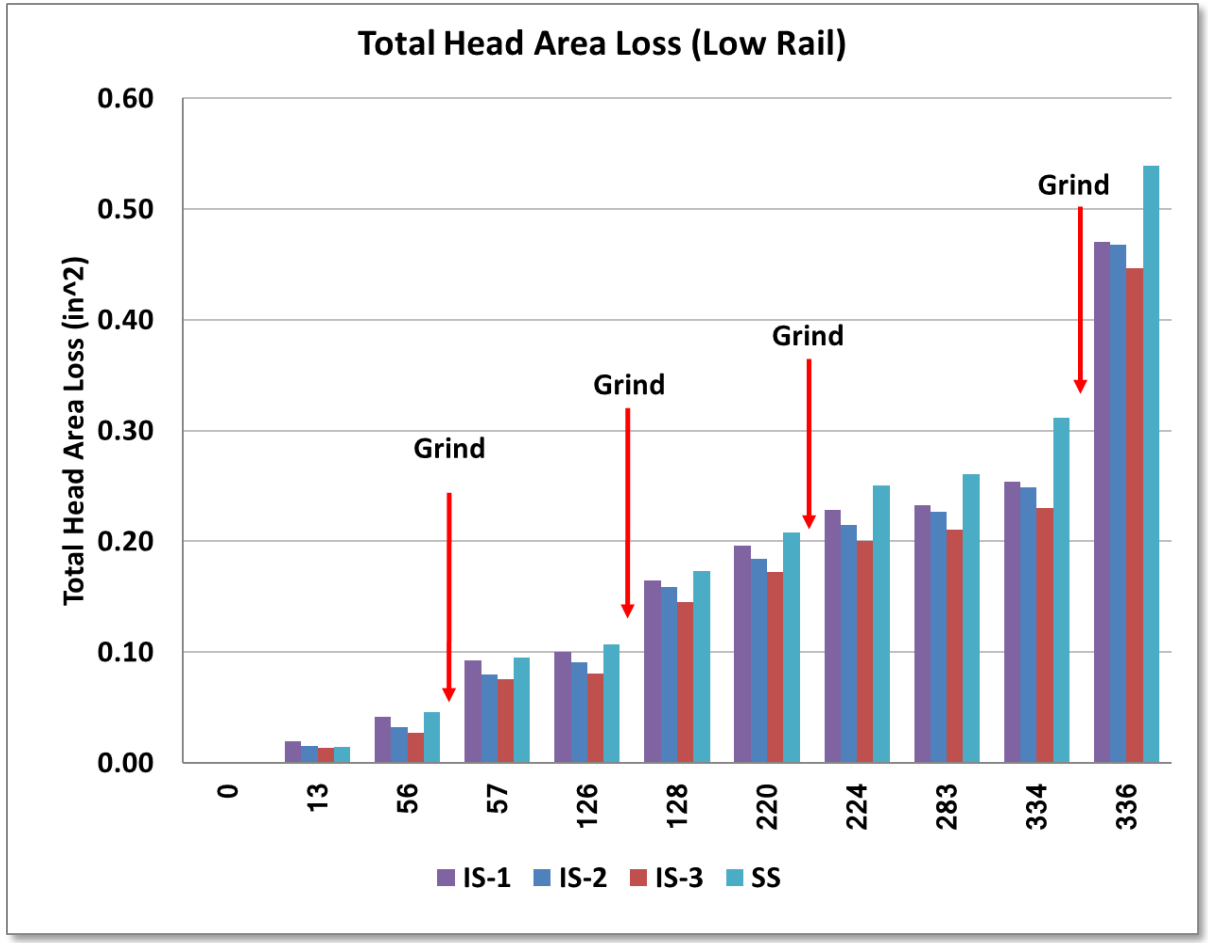
IS Rail Test at FAST

- **Grinding at 336 MGT had more metal removal than previous grinds**





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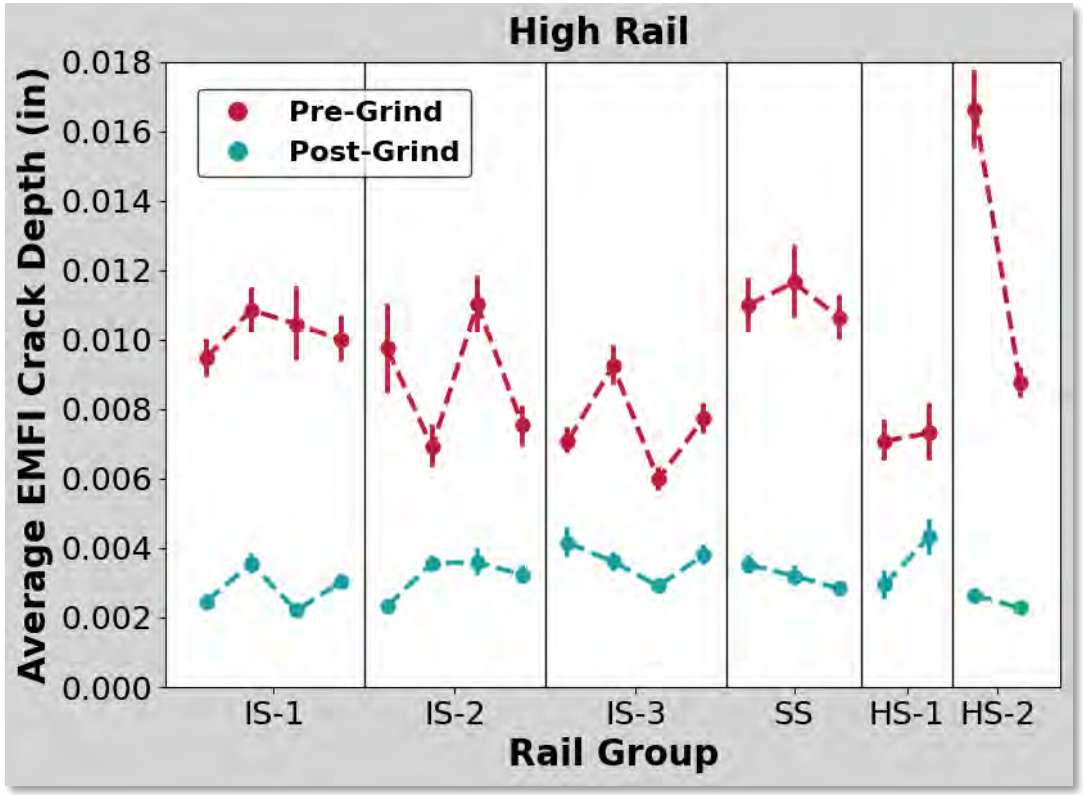
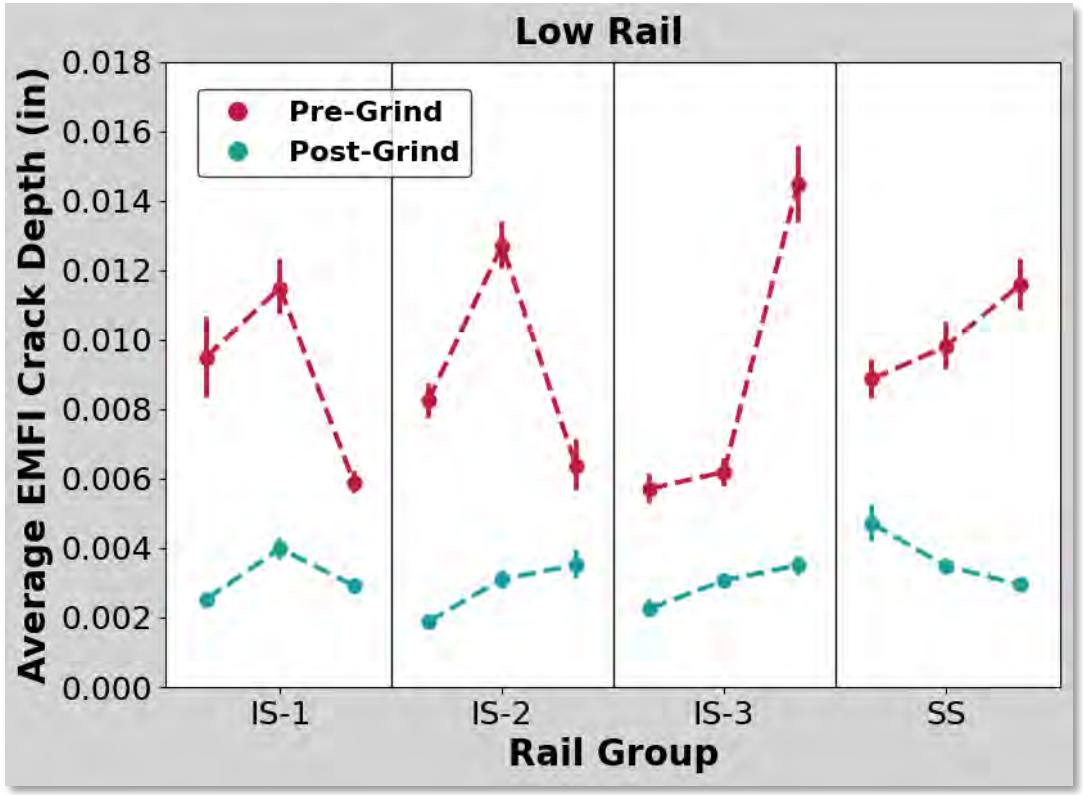
IS Rail Test at FAST

- **RCF changes observed visually and using electro-magnetic field imaging (EMFI) method**

EMFI RCF assessment before and after grind on high rail (left) and low rail (right)





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HS Rail Test at FAST

- **Test has accumulated close to 200 MGT**
  - Seven new rail types, five unused rails from 2018 FAST test as comparison
  - Test is on 6-degree unlubricated curve with no direct lubrication

Layout of HS Rail Test at FAST (1120 ft of test rails on high and low)

VU	Voestalpine UHC-XR (Austria)
EA	EVRAZ APEX G2 (USA)
NH	Nippon HE-X (Japan)
OA7, OB7, OJ7, ON7, OV7	2018 Unused sticks Arcelor-Mittal (A), British Steel (B), JFE (J), Nippon (N) and voestalpine (V) rails

JE	JFE Type E (Japan)
JF	JFE Type F (Japan)
SM	Saarstahl MHH (France)
CC	Cleveland Cliffs AHH (USA)

High Rail																									
40'	OJ7	NH1	JF1	OA7	EA1	VU1	CC1	JE1	SM1	JF2	EA2	OV7	NH2	CC2	SM2	VU2	ON7	JE2	JF3	CC3	EA3	NH3	SM3	JE3	VU3	OB7	40'
Low Rail																											
40'	VU7	NH4	JF4	CC7	EA4	VU4	CC4	JE4	SM4	JF5	EA5	VU8	NH5	CC5	SM5	VU5	CC8	JE5	JF6	CC6	EA6	NH6	SM6	JE6	VU6	VU9	40'

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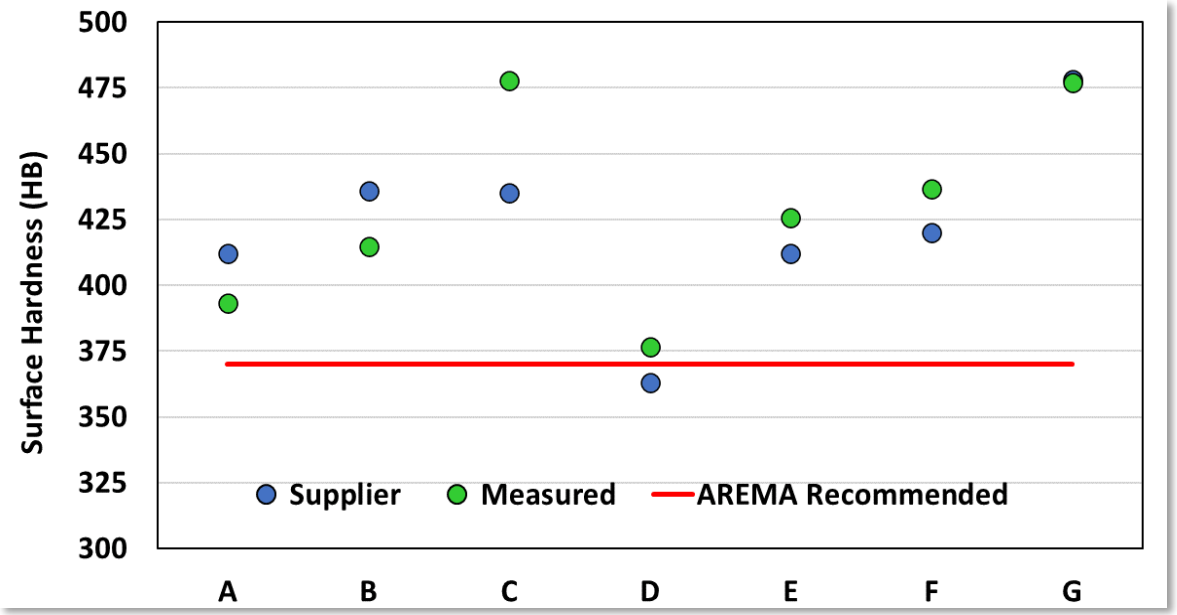
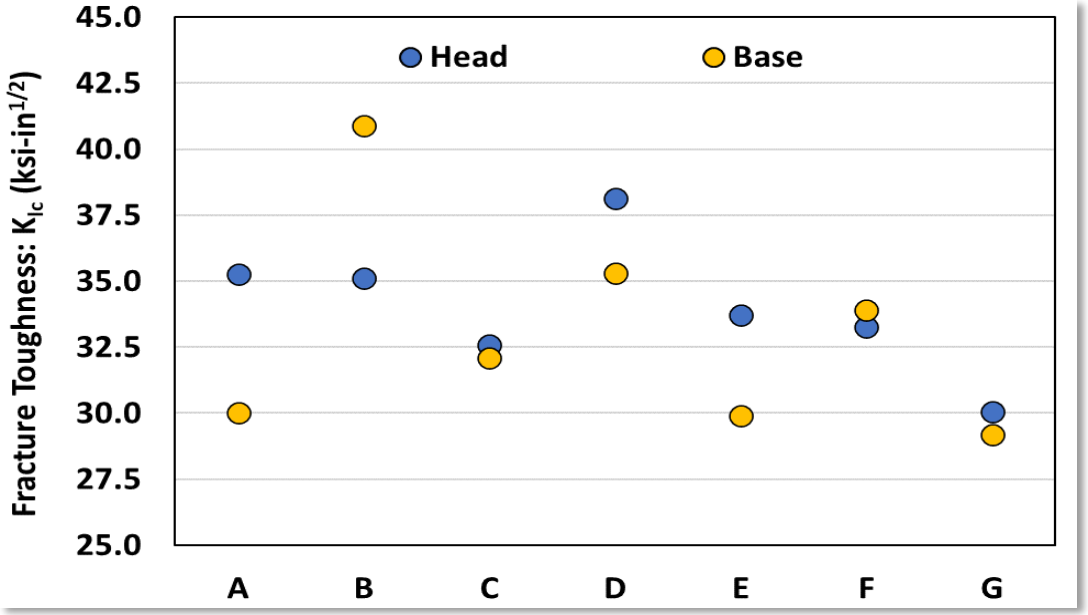
HS Rail Test at FAST

- **Mechanical and metallurgical properties analyzed**
  - Variation of 100 Brinell hardness between hardest and softest rail types

Surface hardness comparison among seven HS rail types



Fracture toughness comparison among seven HS rail types



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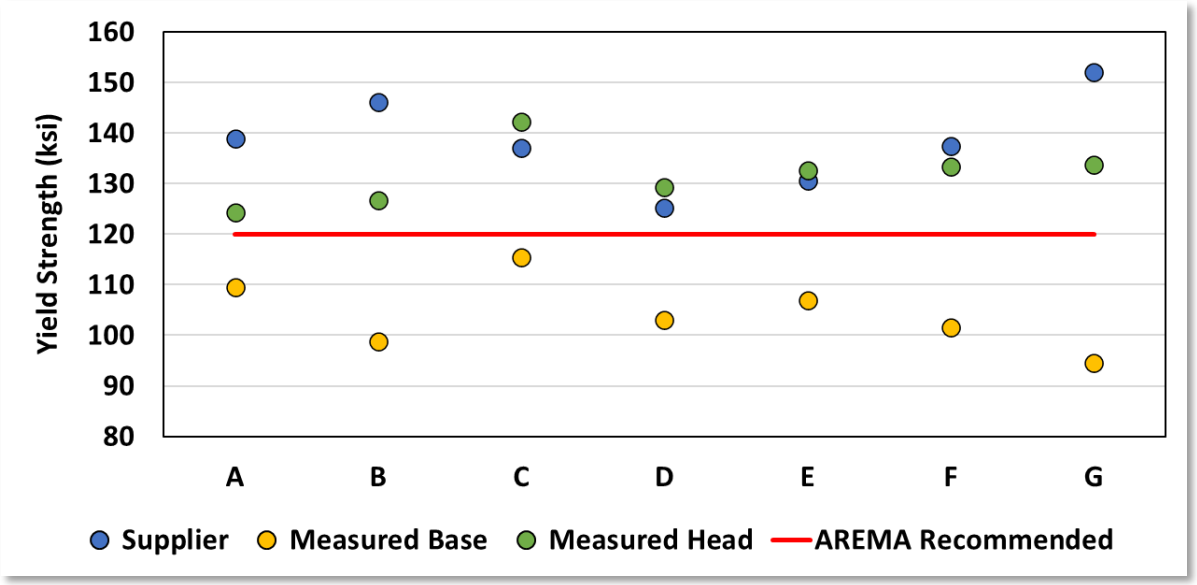
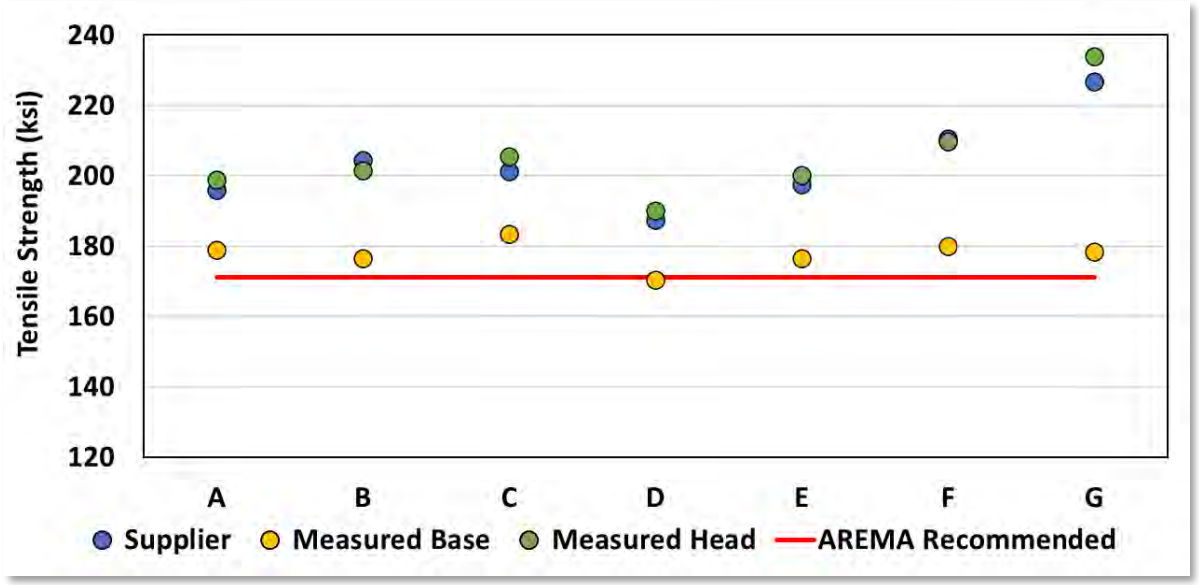
HS Rail Test at FAST

- **Mechanical properties indicate large differences between rail types**
  - *Technology Digest* TD 24-001 published

Yield Strength Comparison among 7 HS Rail Types



Tensile Strength Comparison among 7 HS Rail Types



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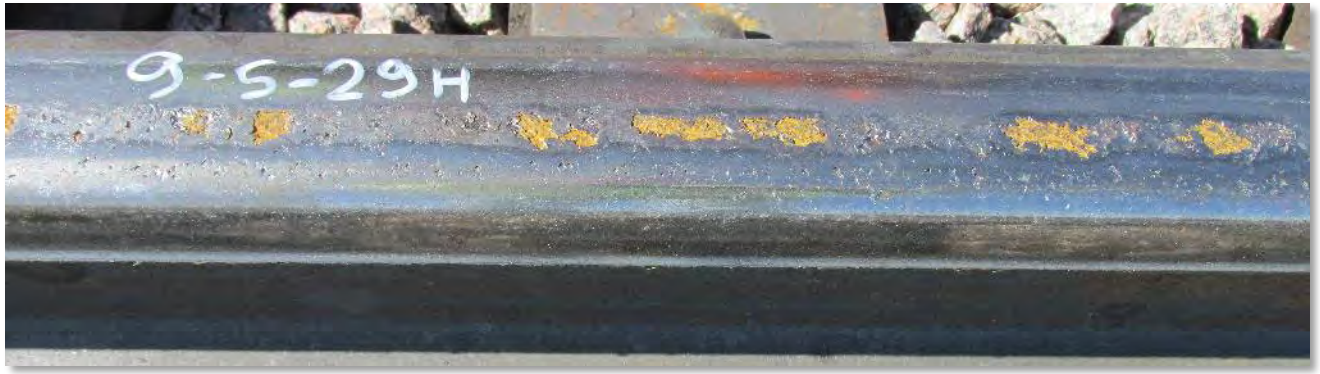
HS Rail Test at FAST

- **Test has accumulated close to 200 MGT**
  - First grinding at 145 MGT exposed some sub-surface RCF
  - No defects on any rails; no weld breaks through end of 2024



Same location on high rail before (top) and after grind (bottom)

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Rolling Contact Fatigue Simulator (RCFS)

- **Purpose:** Predicting damage on wheel and rail; analyzing RCF forming mechanisms due to various track conditions and third body layers

- ✓ Wheelsets (28- to 41-in. diameter) rolling on rails (115 to 141 lb./yard) at standard gage
- ✓ 144,000 lbs. (72-ton axle load) vertical, 84,000 lbs. lateral and 44-milliradian yaw angle capacity
- ✓ 4-ft. stroke with 6 degrees-of-freedom (DOF) rail carriage table motion; 1 DOF (rotation) for wheelset
- ✓ 3.5 mph speed with high accuracy displacement, angle, force and moment control
- ✓ Laser-based profile measurement systems and cameras

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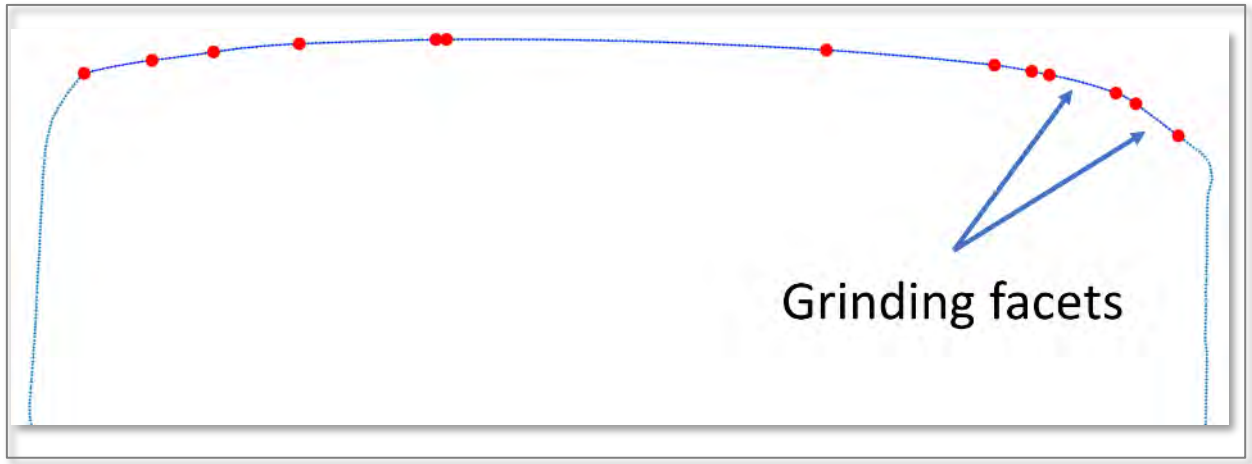
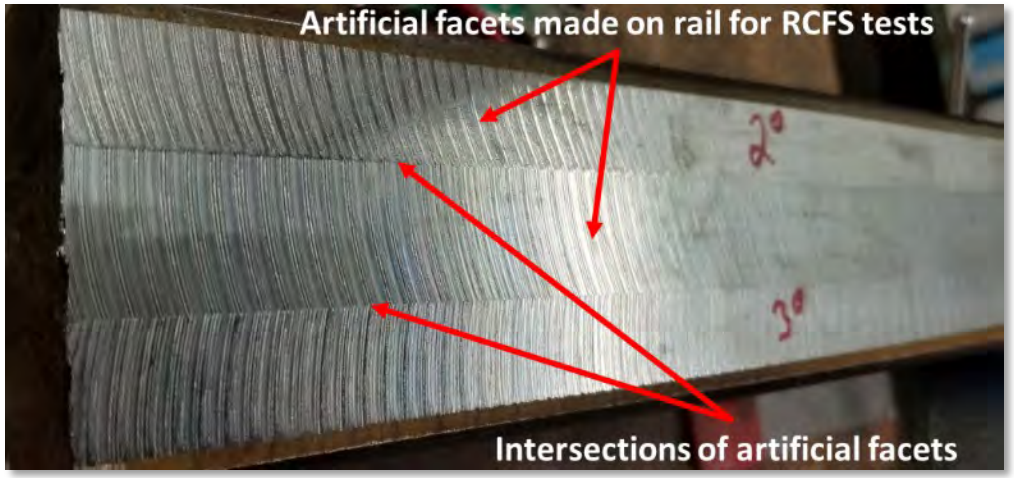
Analysis of Rail Grinding Facets

- **Hypothesis: Facets left by grinding stones on a rail intersect to form ridges that initiate RCF due to high stresses**
  - Artificial facets created on rails using horizontal milling
  - Wheel ran over ridges to initiate RCF
    - Angle-of-attack: 4-6 milliradians

Red dots showing ridges in between grinding facets on a rail profile measured on track



Artificially machined facets and angles simulating grinding for RCFS tests



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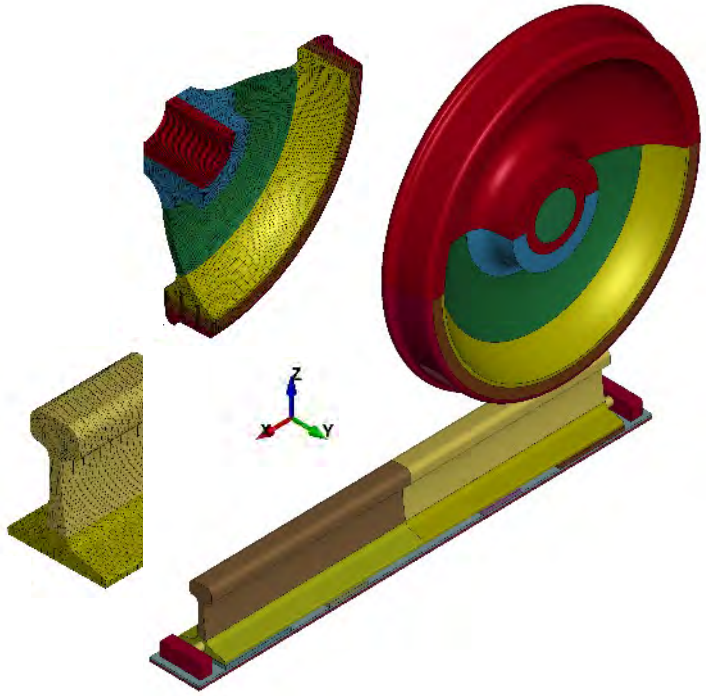
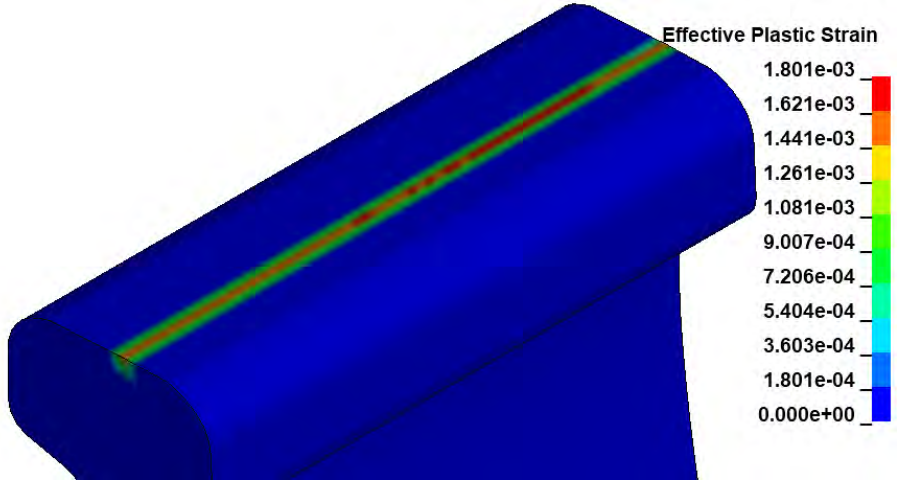
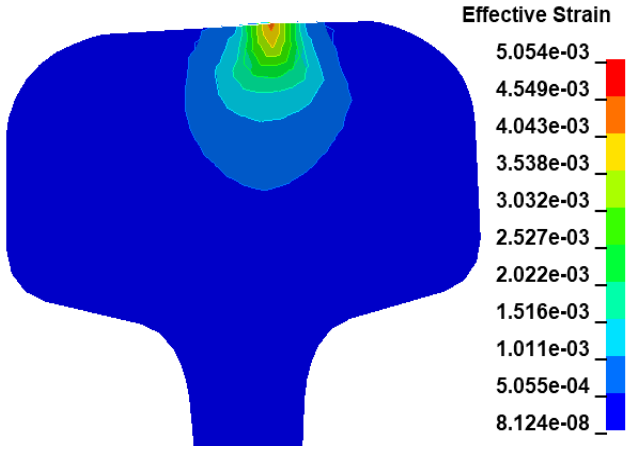
Analysis of Rail Grinding Facets

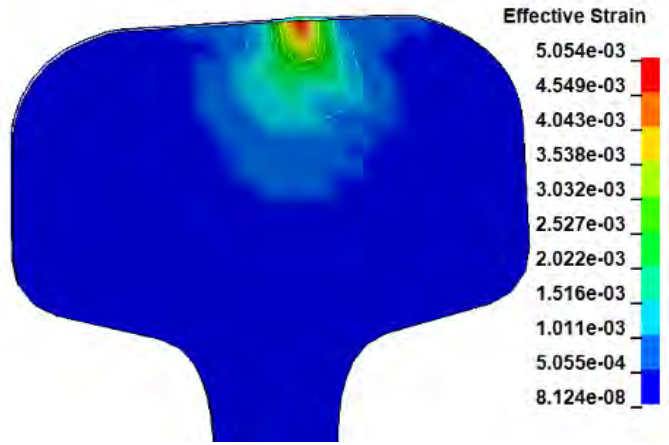
- **FEM includes 36-inch wheel on 52-inch-long 136 RE rail**
  - Sharper facet angles: 3.5 to 6.5 degrees
  - Constant friction of 0.5 maintained at the wheel/rail interface



Finite Element Model (FEM)







Effective strain under 1 load cycle (left & top) and 4 load cycles (right)

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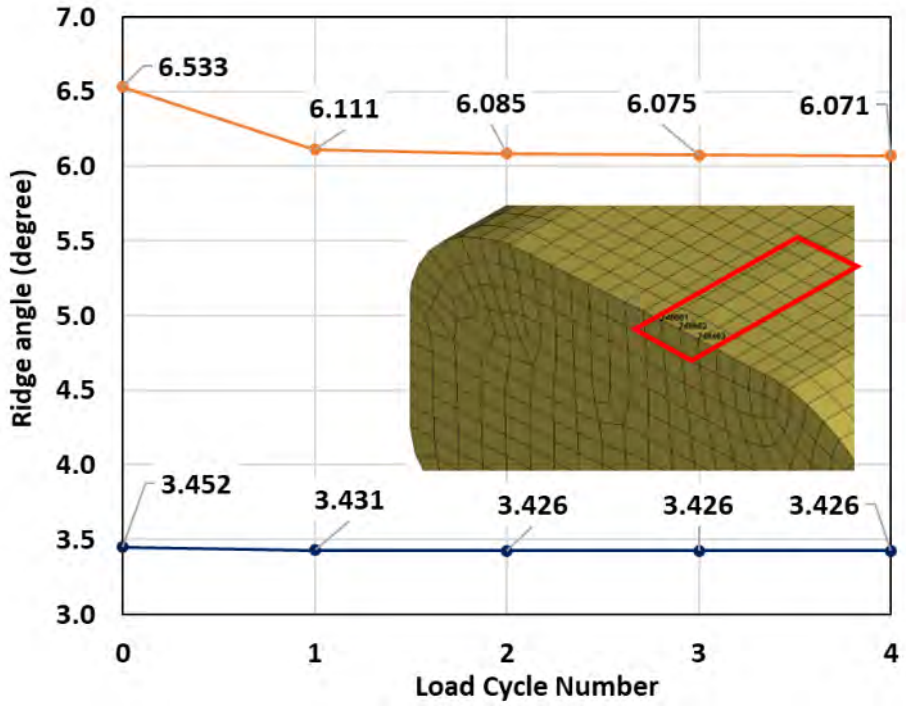
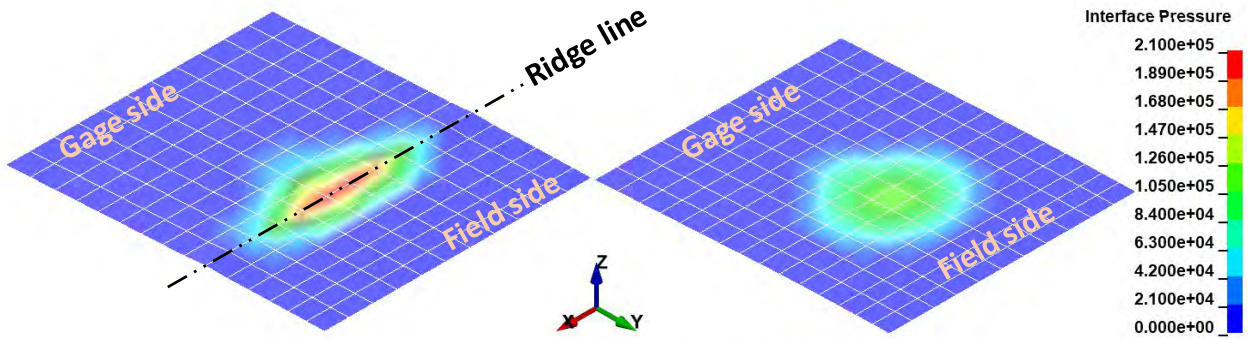
Analysis of Rail Grinding Facets

- **FEM Analysis: *Technology Digest* TD23-027 published**
  - Results show contact pressure decreases as ridge wears
    - 7.1% reduction in the first 4 cycles for the 6.5° ridge angle
    - Contact pressure reduction caused contact patch change

Changes in ridge angle (3.5° & 6.5°) between facets in FEM after four load cycles



Contact pressure reduction causing contact patch change in the original ridge location



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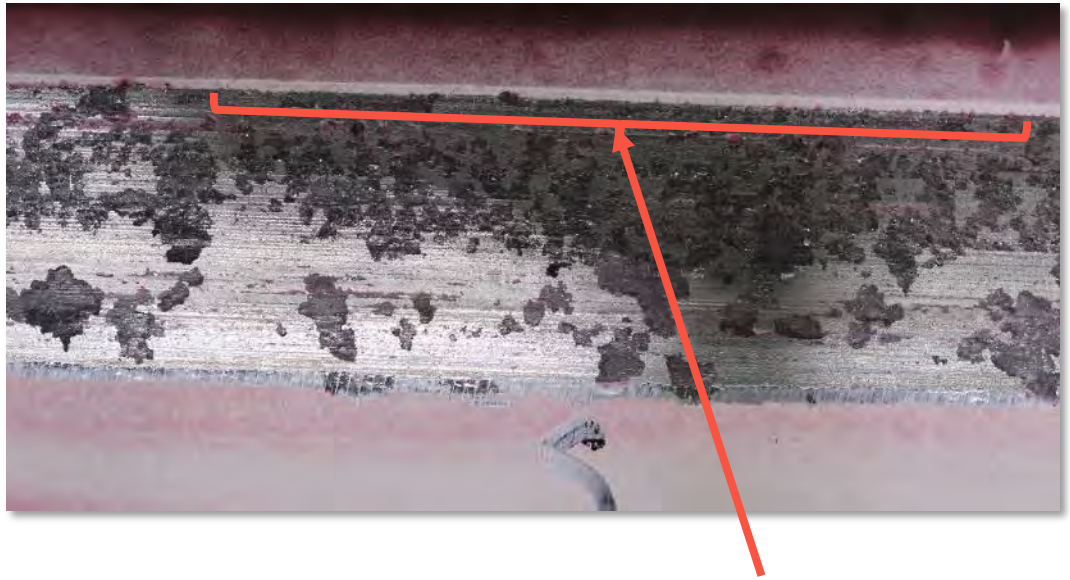
Analysis of Rail Grinding Facets

- **RCFS Tests**
  - Ridges between facets plastically deformed and wore
    - Wear was fast in the initial 50,000-60,000 cycles
  - Contact band widened over 140,000 cycles
  - RCF initiated later but not at the original ridge

High rail at 10k cycles (left) and at 130k cycles (right)



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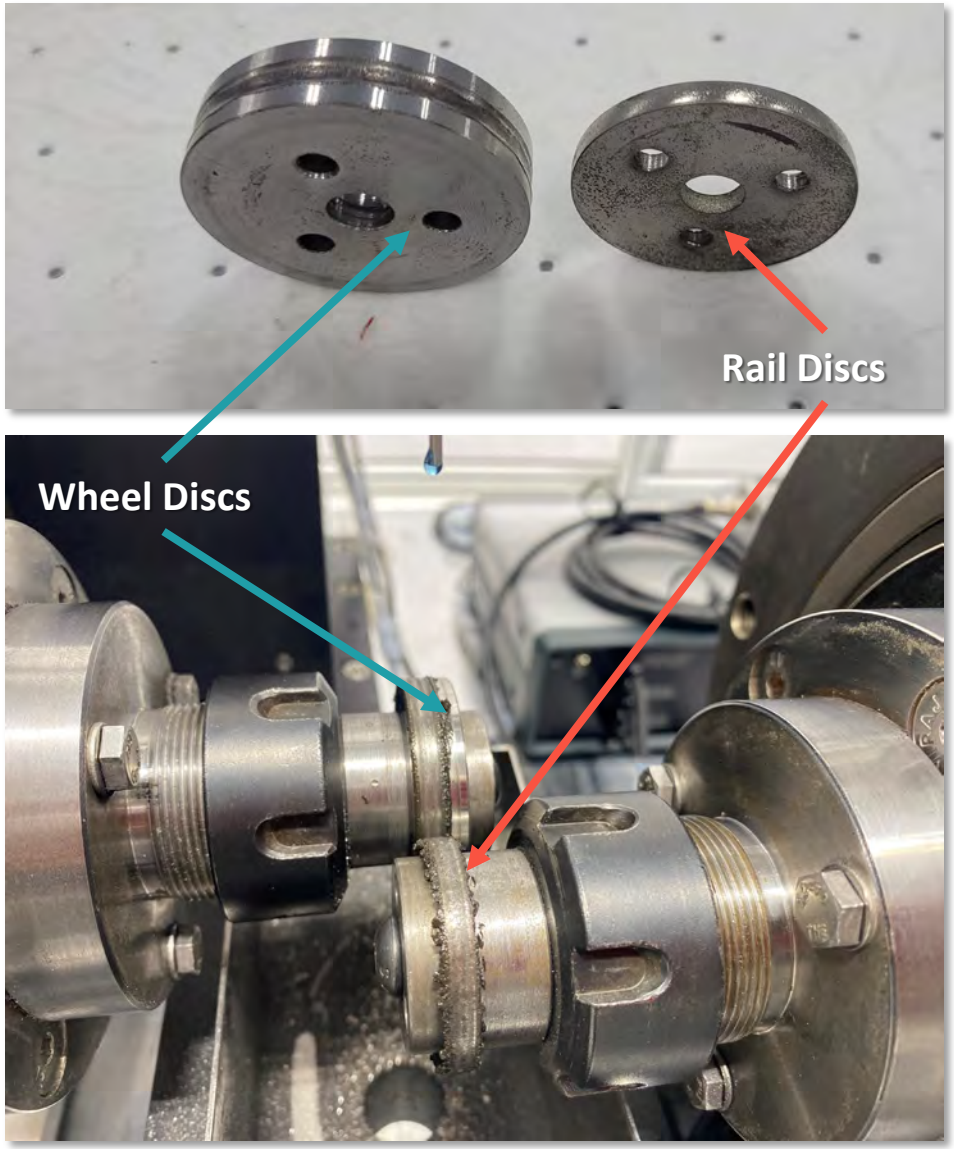
Conclusions and Future Work

- **FAST Rail Tests**
  - Conclusions
    - IS rails showing good fatigue performance
    - HS rail test started with seven rail types. Some rails have hardness > 450 Brinell and yield strengths > 140 ksi
  - Future Work
    - Twin disc testing of rails: Analyzing effects of depth of head hardening on wear and RCF response

Twin Disc Testing



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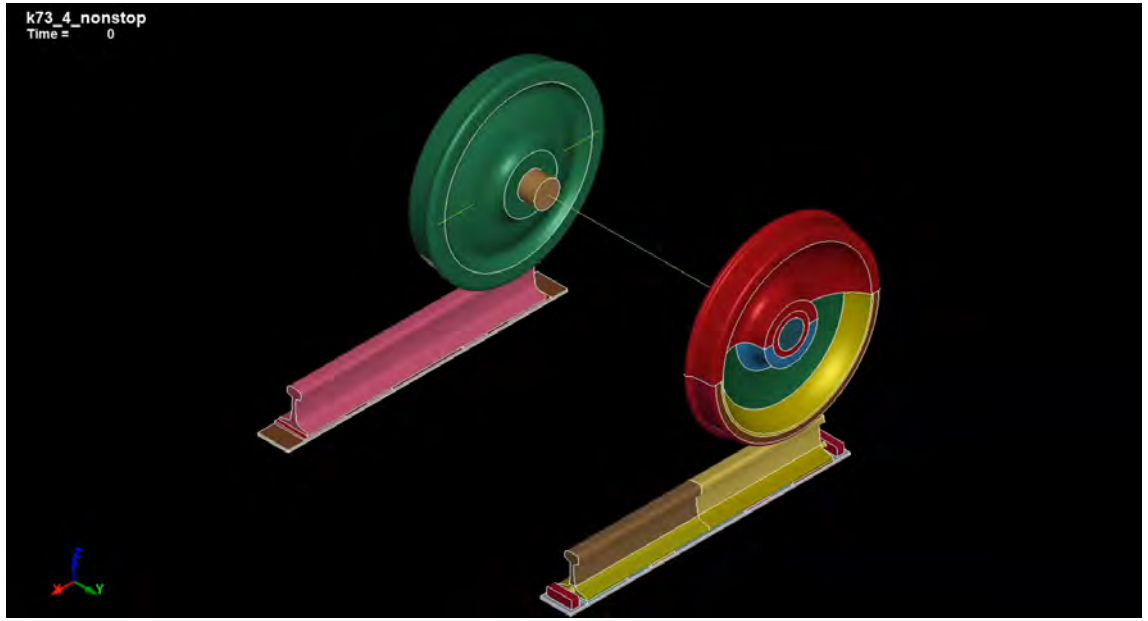
Conclusions and Future Work

- **RCFS tests and FEM analyses**
  - Conclusions
    - Intersecting facets form sharp ridges that can cause high contact stresses
    - Ridges wear fast leading to contact stress reduction
  - Future Work
    - Rails with multiple facet angles from in-track grinding to be tested next
    - FEM development ongoing with added capabilities (wheelset on both rails)



Acknowledgements

- Rail manufacturers
- MxV Rail RCFS team
- FAST track crew, Data Science and Instrumentation staff
- AAR's Strategic Research Initiatives Program

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Bridge Research Update

Christopher Johnson, P.E.
Scientist

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Bridge Systems Overview

- **Objectives**
  - Evaluate legacy bridge designs
  - Develop, evaluate, and implement
    - Best practices for bridge fitness for service assessments
    - New bridge design and maintenance strategies

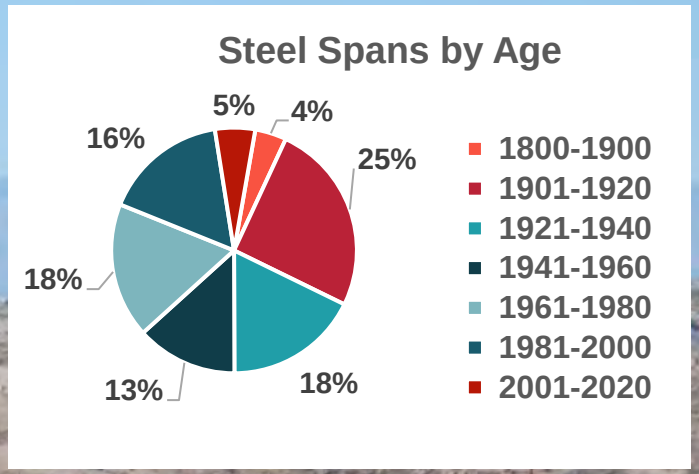

Photo by Rich Reiff

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Fitness for Service of Through Structures

- **Through structure:**
  - Supporting members extend above the track level

Photos courtesy Karl Rethwisch

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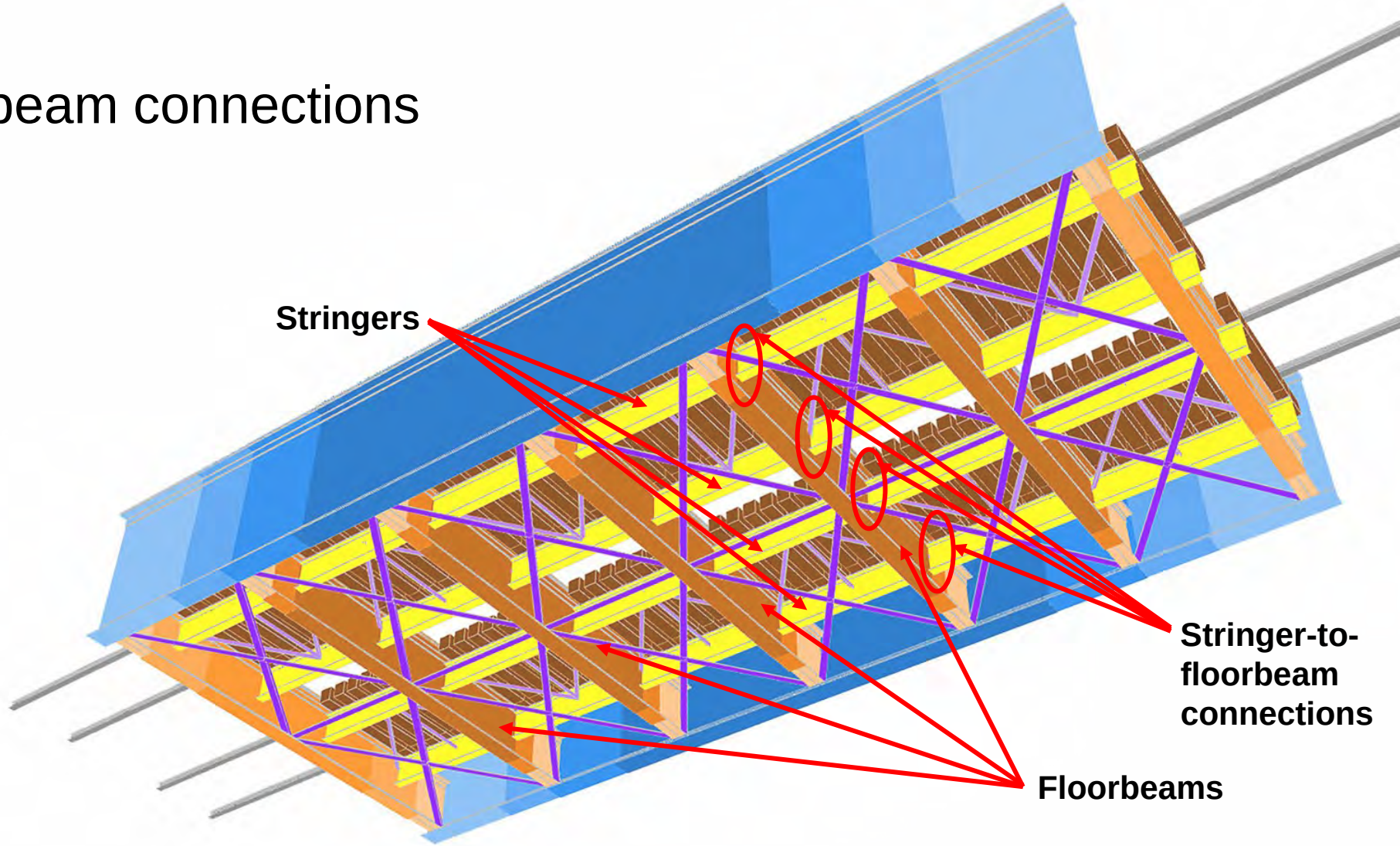
Fitness for Service of Through Structures

- **Focused on the floor system**
  - Stringers
  - Stringer to floorbeam connections



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Fitness for Service of Through Structures

- **Field testing**
  - Strains and deflections

Stringer to Floorbeam connection

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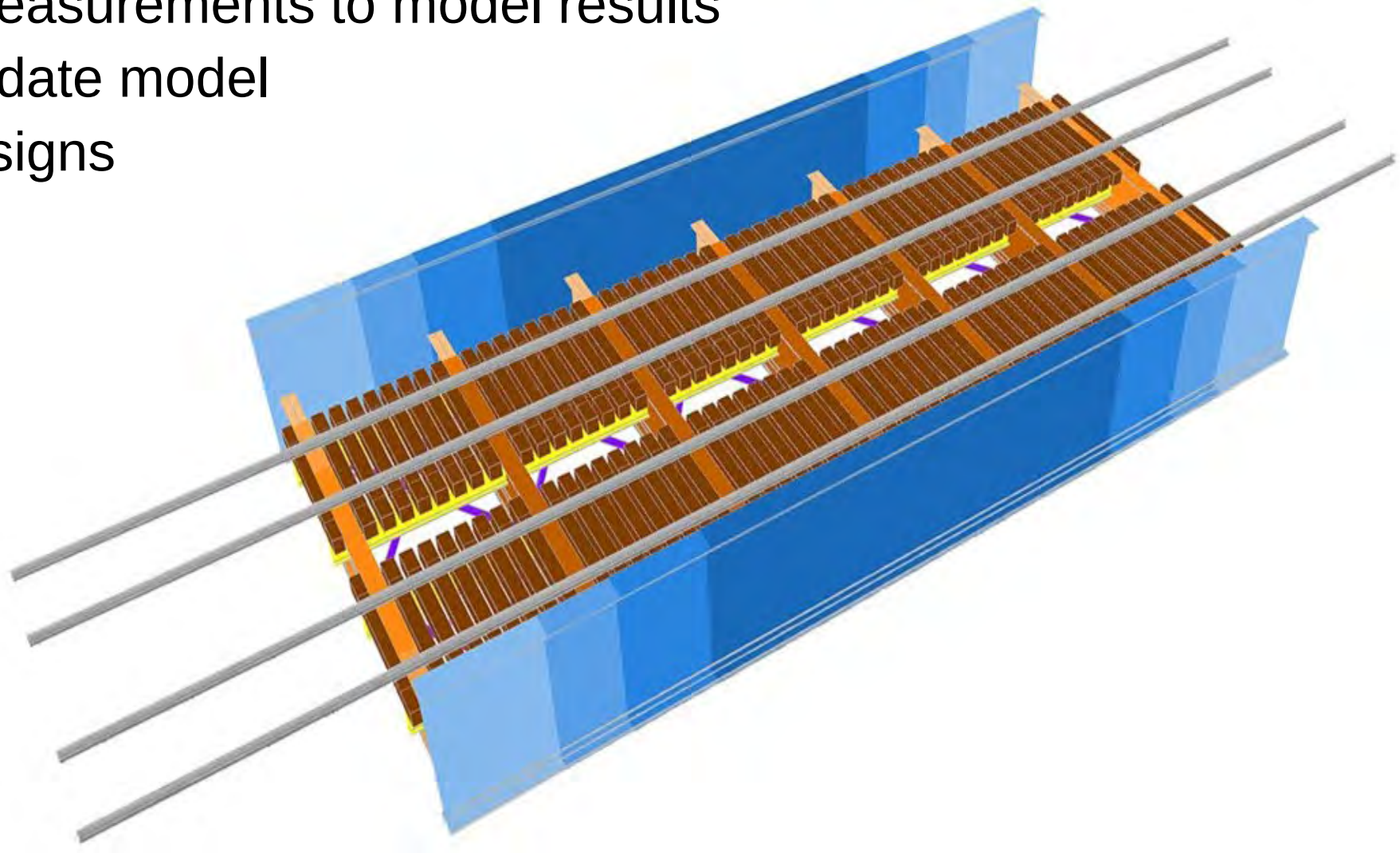
Fitness for Service of Through Structures

- **Future work:**
  - Compare field measurements to model results
  - Calibrate and update model
  - Assess other designs



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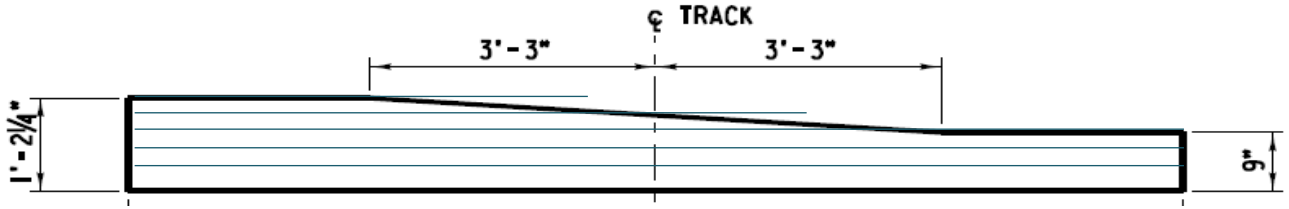
Tapered Glulam Bridge Ties



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Tapered Glulam Bridge Ties

- **Installed for nine years**
  - Under traffic for seven years
  - > 750 MGT
- **Ties in good condition overall**
- **Individual laminations in tapered cut starting to become more visible**

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Tapered Glulam Bridge Ties

- **Broken screw spikes**
  - 16-inch plates with screw spikes and elastic fasteners
  - Approximately 650 MGT
    - ~50 MGT at new location
  - Primarily in gage side of outside rail
  - Also seen in regular track ties at lower MGT

FAST® Bridge As Built

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FAST® is a trademark of MxV Rail

North Span:
- 31 ft. 6-in. DPG E-58
- Superelevated span
- Constant height ties

South Span:
- 30-ft. 1912 DPG E-61
- Level span
- Superelevated ties

FAST Bridge Now

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North Span:
- **31 ft. 6-in. 2025 BM E-80**
- **Ballast Deck**

South Span:
- **30’ 1912 DPG E-61**
- **Level span**
- **Superelevated ties**

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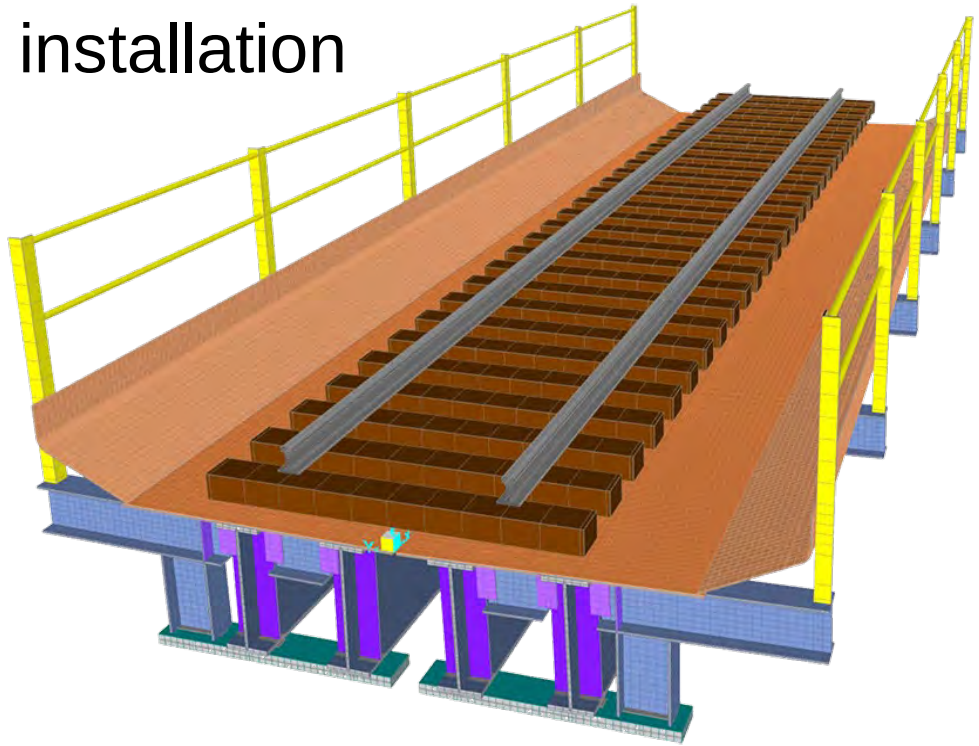
NSBA Span Background

- **National Steel Bridge Alliance**
  - Part of the American Institute of Steel Construction
- **Developed design for new short-span steel bridge**
  - Design freely available to railroads (and others)
  - Simplified fabrication, transportation and installation
    - Rolled beams and plates
    - Welded or bolted construction
    - Minimize fatigue susceptible details
  - More qualified fabricators available
  - Guided and reviewed by advisory group
    - Includes railroad, fabricator and supplier members



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Design Details/Differences

- **Rolled beam railroad bridges are a common design**

Photo courtesy Karl Rethwisch

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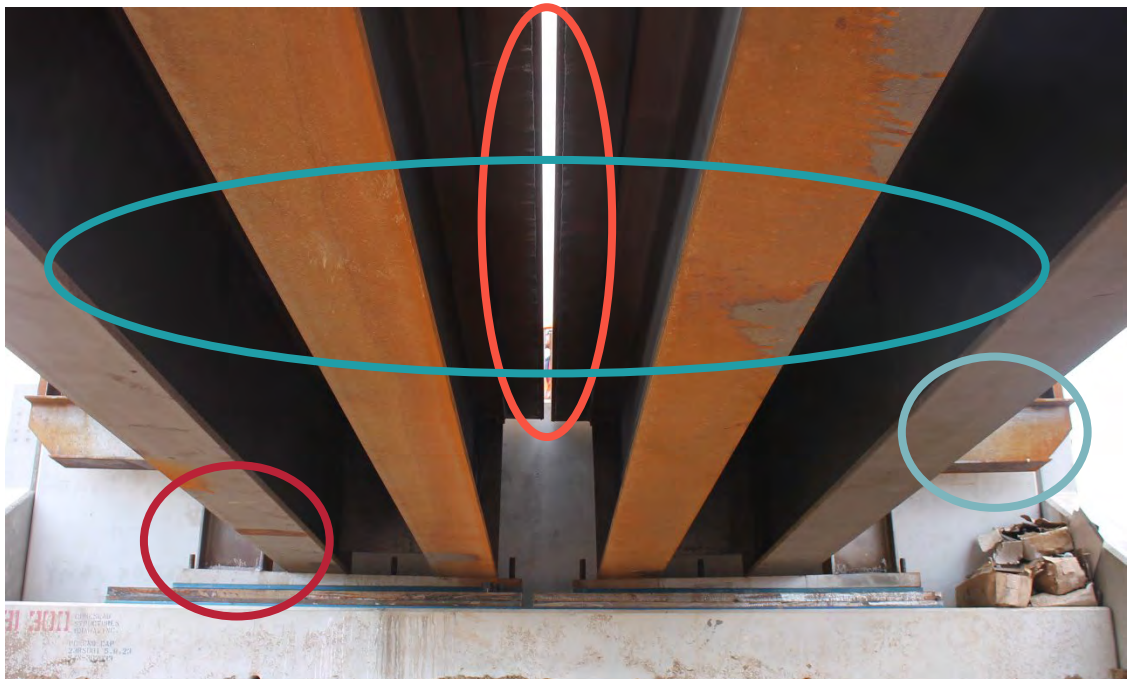
Design Details/Differences

- **Four main differences from common designs to investigate**
  - Separate units under each rail
  - No intermediate cross-frames or diaphragms
  - End frame anchorage for lateral loads and overturning
  - Curb design



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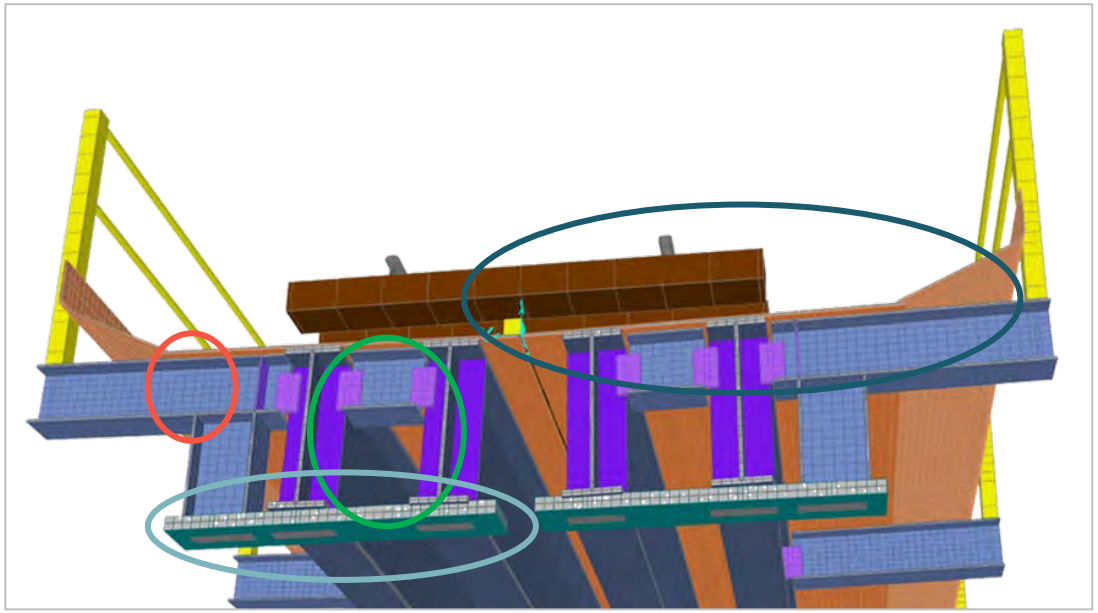
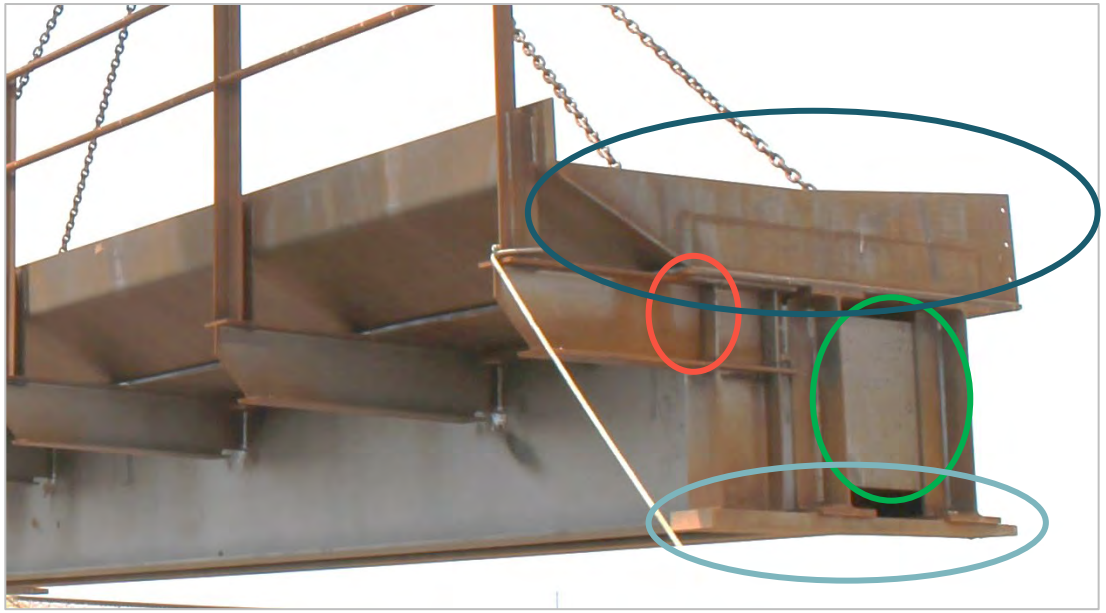
Modifications for FAST

- **Intended for tangent track**
  - up to 45 feet
- **FAST span 32 feet long**
  - 5-degree curve
- **Additional stiffeners**
- **Full depth end diaphragms**
- **Custom sole plates**
- **End ballast dams**





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Span Changeout

Span arrival

Old span removal

Bearing modifications

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Unit 1 Installation

Setting Unit 1

Unit 1 in place

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Unit 2 Installation

Unit 2 installation

Unit 2 in place

©2025 MxV Rail

Installed

Installed

©2025 MxV Rail

©2025 MxV Rail

Other Details

Modified ballast end dam

Center drain ballast retainer

Welded outrigger

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Ballast and Track–Initial Ballast

Testing Under Traffic

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- **40 MGT**
- **E-68 loading (315,000-lb. cars)**
  - E-80 design
- **Instrumentation**

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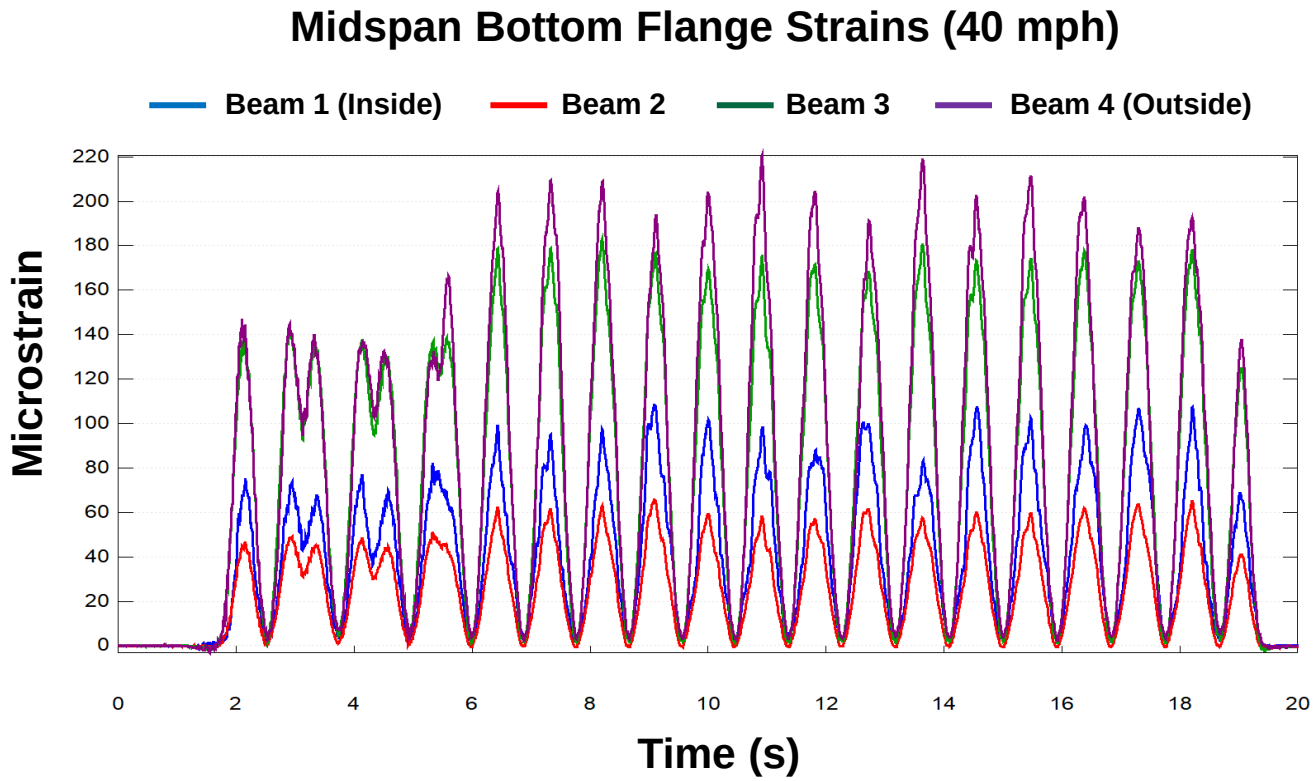
Results: Bottom Flange

- **Measured strain at quarter-points and midspan**
- **Span length < FAST car inner axle spacing**
- **One cycle per car, 117 cycles per train**



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Results: Bottom Flange

- **Stress varies by beam due to curvature and speed**
- **Each cycle up to 6.5 ksi under typical 315K FAST cars**
- **AREMA Fatigue Category B**
  - Constant Amplitude Fatigue Limit: 16 ksi
  - “Infinite” fatigue life; over 200 years at FAST

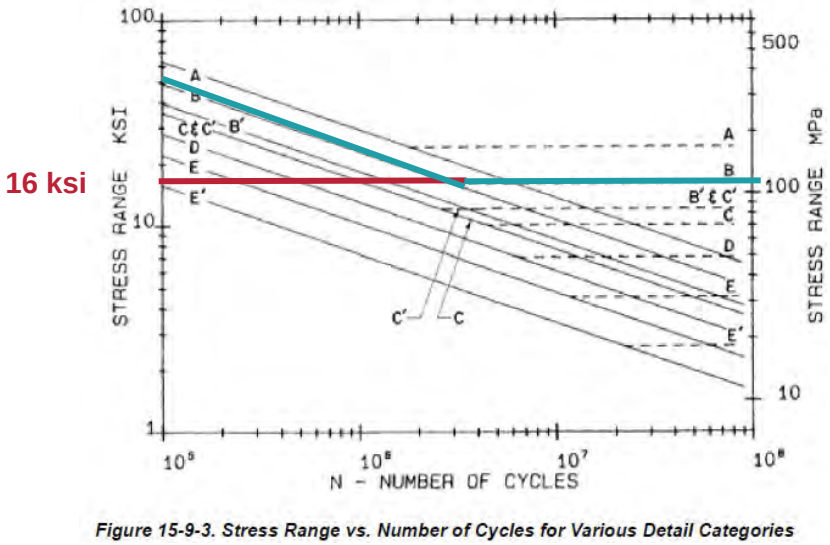
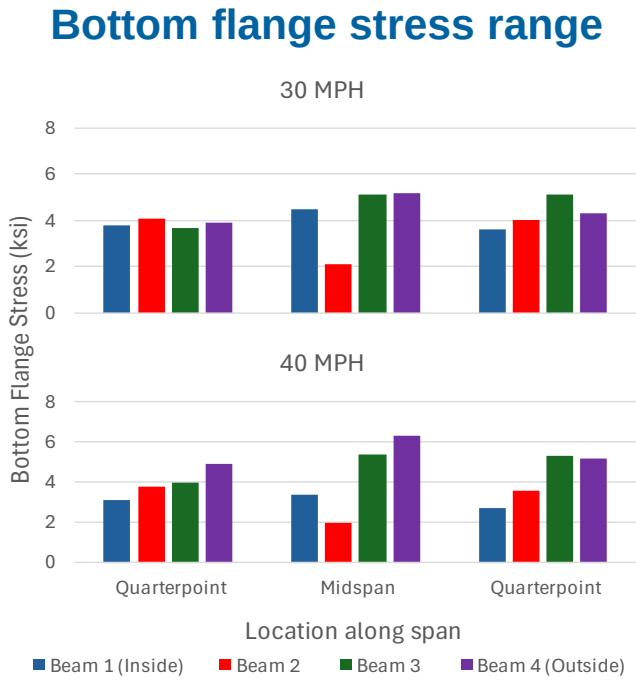


Figure 15-9-3. Stress Range vs. Number of Cycles for Various Detail Categories

Source AREMA 2024 MRE



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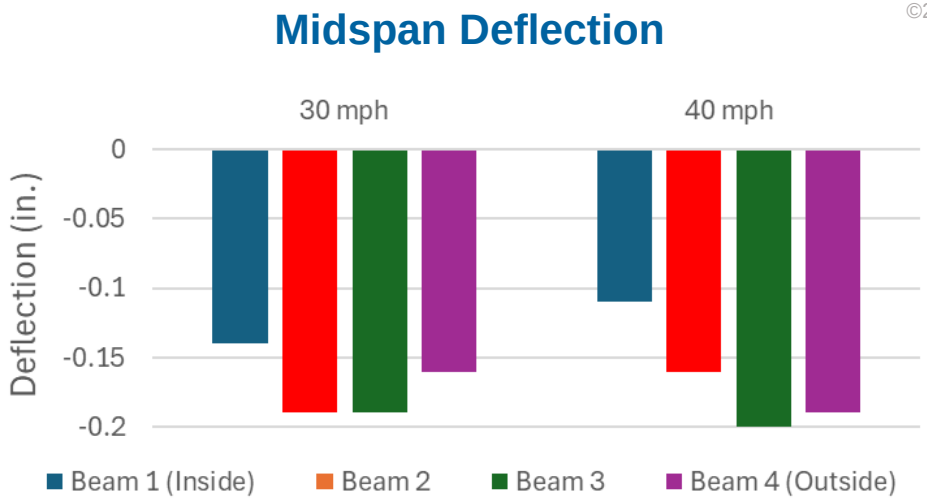
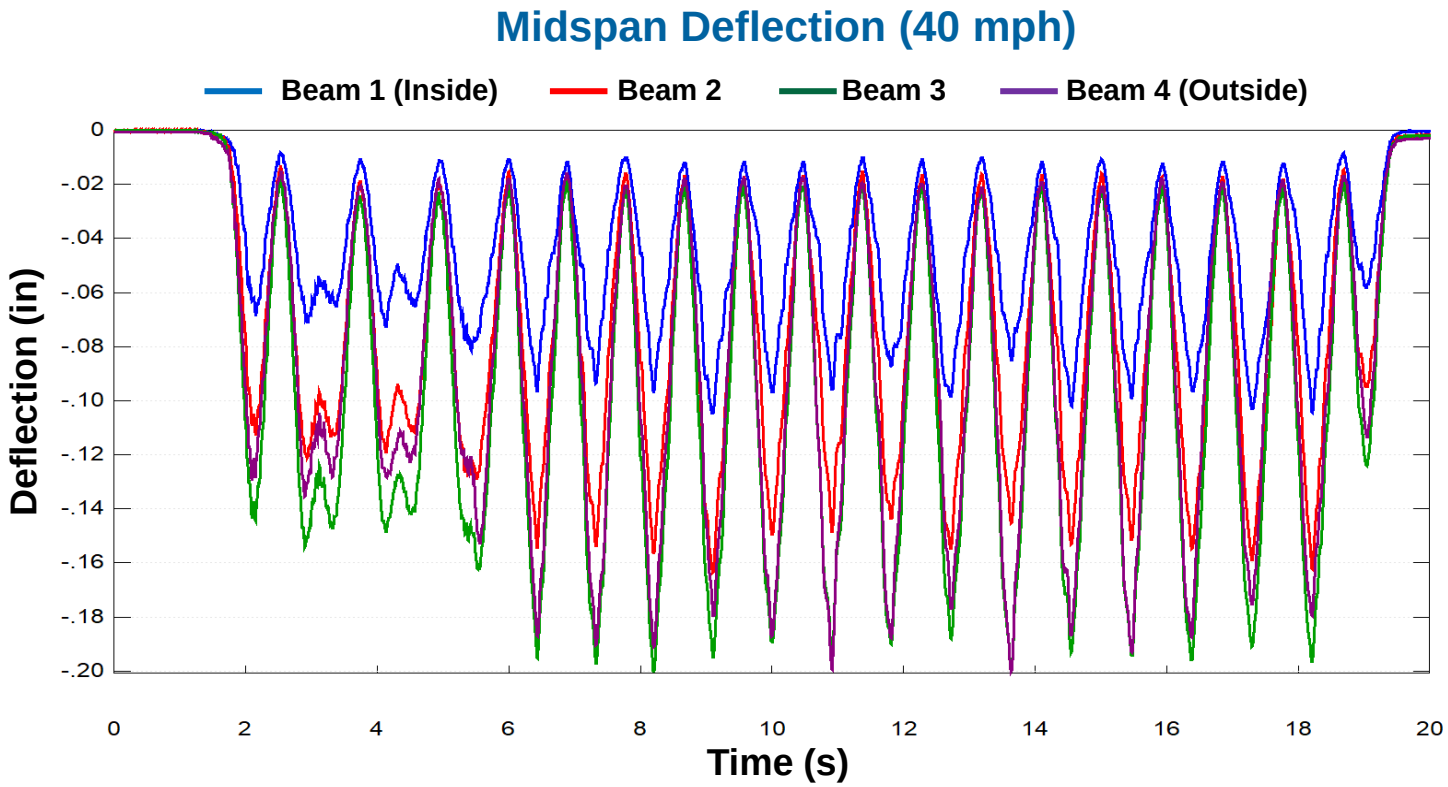
Results: Deflection

- **Maximum midspan deflection**
  - Outside beams: 0.19 in.
  - Inside beams: 0.20 in.
- **AREMA limits deflection**
  - L/640
  - 0.58 in. for 31-ft. span





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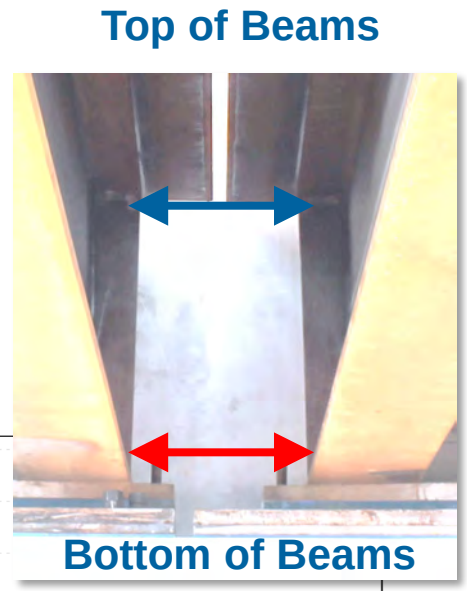
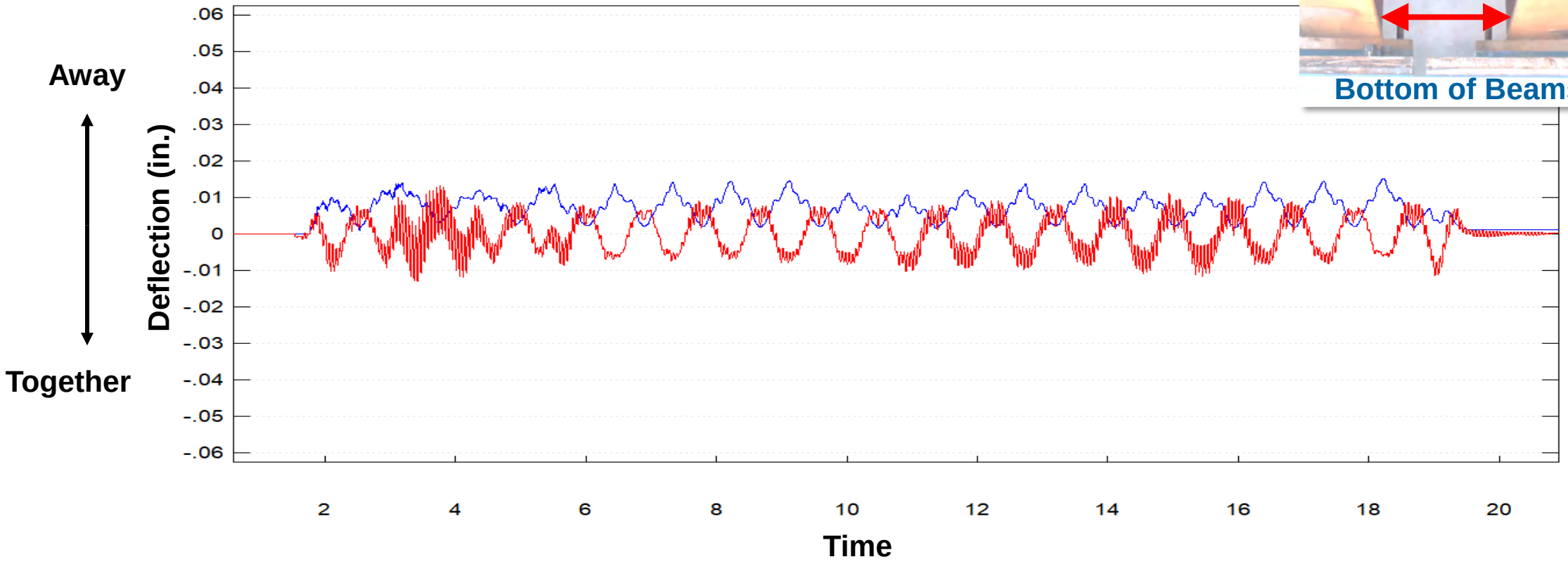
Results: Lateral Movement

- **Separate units move independently under load**
- **Measured lateral deflection between units**
- **Negligible movement**





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Summary

- **No significant movement between separate units.**
- **Comparable deflections and strains between beams without diaphragms.**
- **End frames and curb design require further study.**

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Conclusion

- **Bridge fitness for service expanding to through structures**
- **New design and maintenance strategies continue evaluation**
  - Tapered glulam bridge ties have over 750 MGT
  - Initial performance of new NSBA short span steel bridge promising

Photo courtesy Karl Rethwisch

Acknowledgements

- AAR Bridge TAG
- AISC/NSBA
- Fry Technical Services
- MxV Rail Track, Facilities and Instrumentation groups
- Duane Otter and Dante DeVencenty

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Technical Sessions - Mechanical

Mechanical (AM) | Fortino C

Bearing Performance and Integrity	Matt Wenger
Wheel Performance and Integrity	Corey Pasta
Inspection Technologies	Anish Poudel

Mechanical (PM) | Fortino C

Draft Systems Research	Adam Klopp
Brake Systems Research	Yi Wang
Wheel Profiles and Hunting	Ulrich Spangenberg

Bearing Performance and Integrity

Matt Wenger
Senior Engineer III

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Overview

- **Project Objectives**
- **Bearing Reconditioning Background**
  - Assembly overview
  - Inspection procedures
  - Common damage modes
- **Nondestructive Evaluation (NDE) for Bearing Inspection**
  - Rig testing results
- **Path Forward**
- **Additional Research**

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Project Objective

- **Improve the overall reliability and safety of bearings**
- **Evaluate methods to improve the reconditioning process**
- **Investigate the root causes of bearing performance degradation**

Bearing Reconditioning Overview

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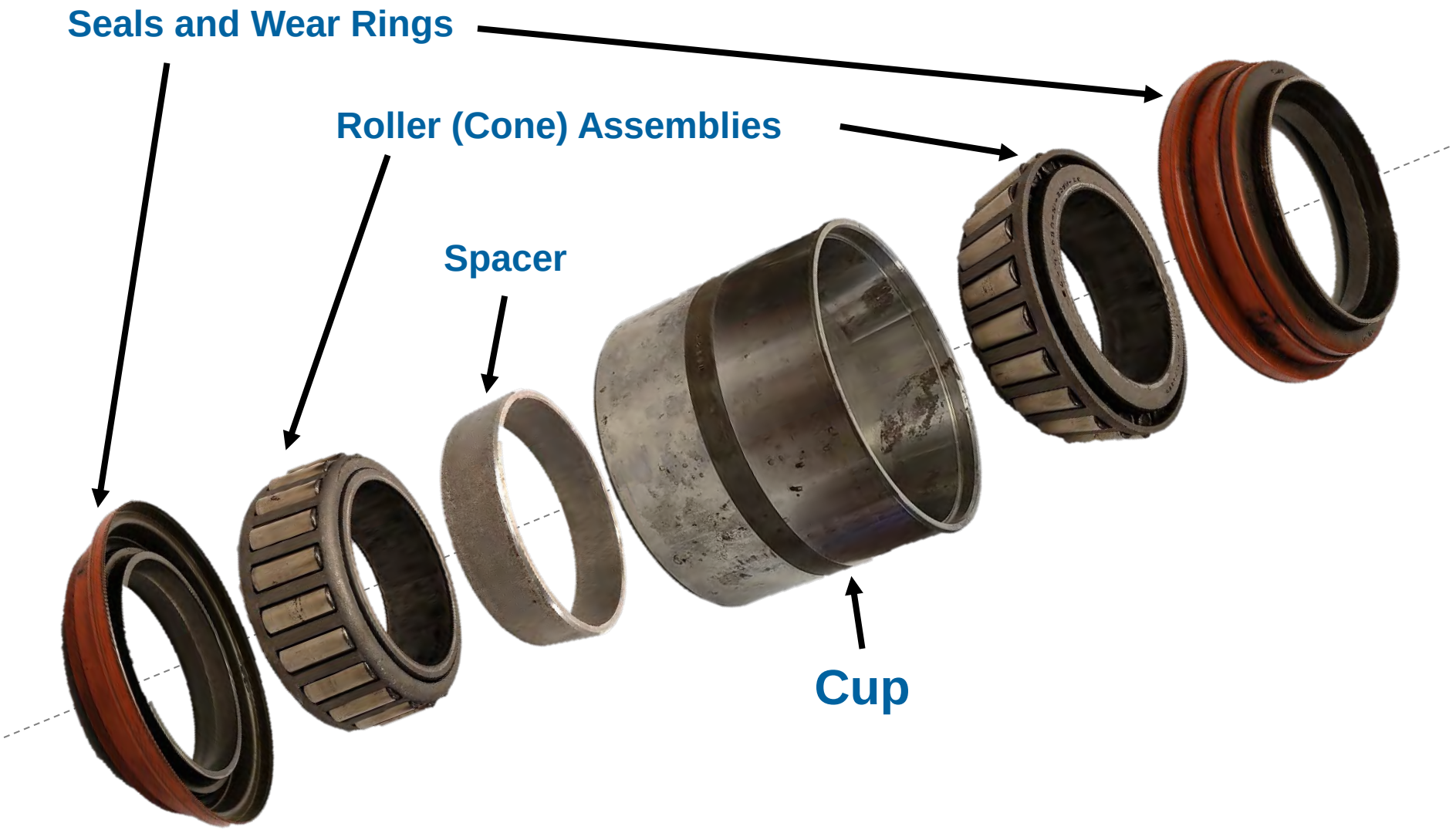
Bearing Assembly Overview



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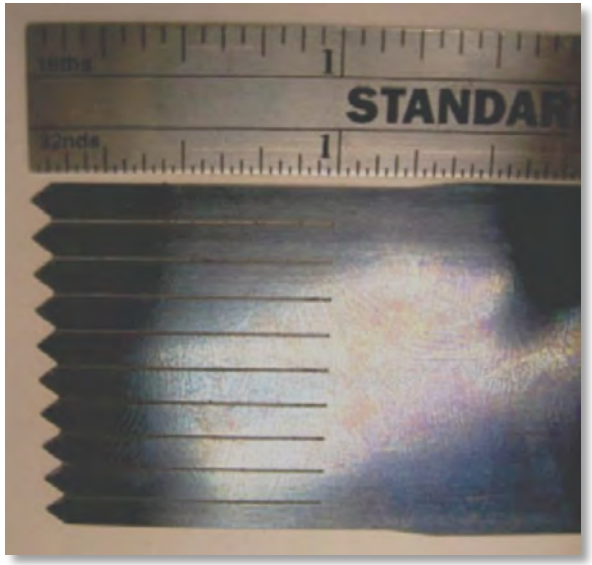
Reconditioning Inspection

- **Following teardown and cleaning, components are inspected individually per AAR MSRP H-II**

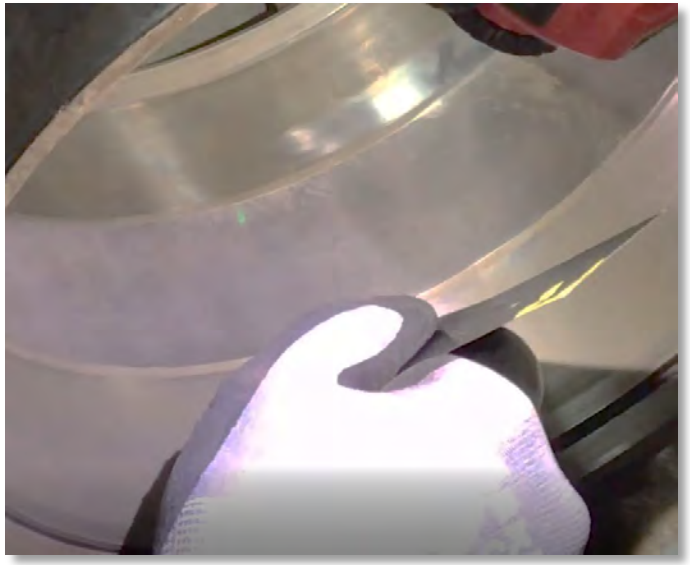
- **Roller assembly inspections:**
  - Back face wear
  - Cone bore diameter
  - Rollers and cage: Visual inspection
  - Raceways: “Feeler” gauge inspection

- **Cup inspections:**
  - Outer diameter
  - Seal counterbore diameter and out-of-round
  - Raceways: Visual inspection

“Feeler Gauge”/ “Surface Roughness Tester”



Inspecting cup raceway



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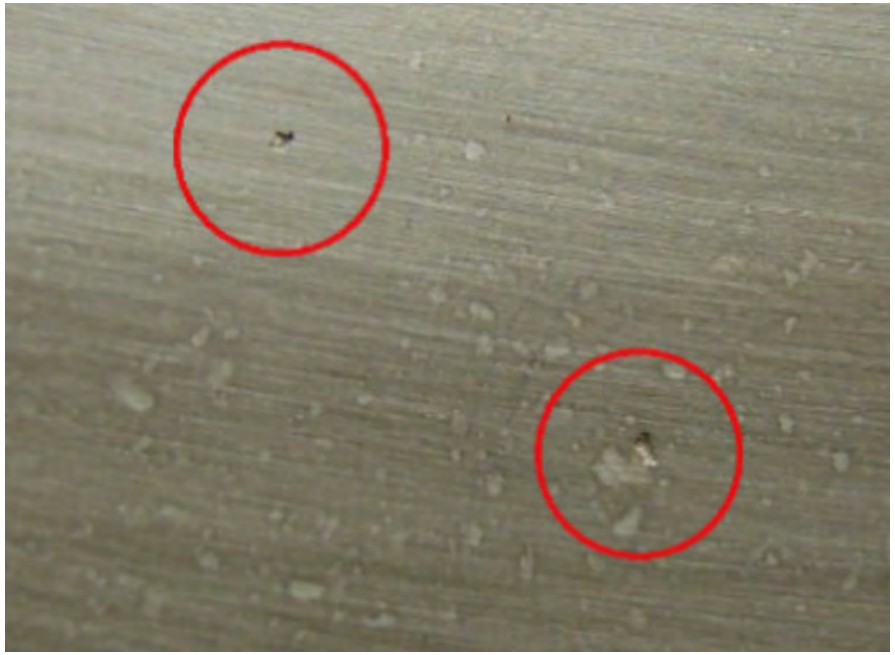
Common Damage Modes

- **Spalls**
  - Fatigue cracks found on rolling surfaces
  - Early indication of localized metal failure
    - Sharp edges become stress risers
    - Pieces break away, leaving new stress risers
- **Etching**
  - A type of corrosion caused by water or acidity in the bearing grease
    - Can vary from light staining (superficial) to deep pitting
    - Severe etching can lead to spalling

Pinhead spalls in middle of cup raceway



Superficial water etch

NDE Technology for Bearing Cup Inspection

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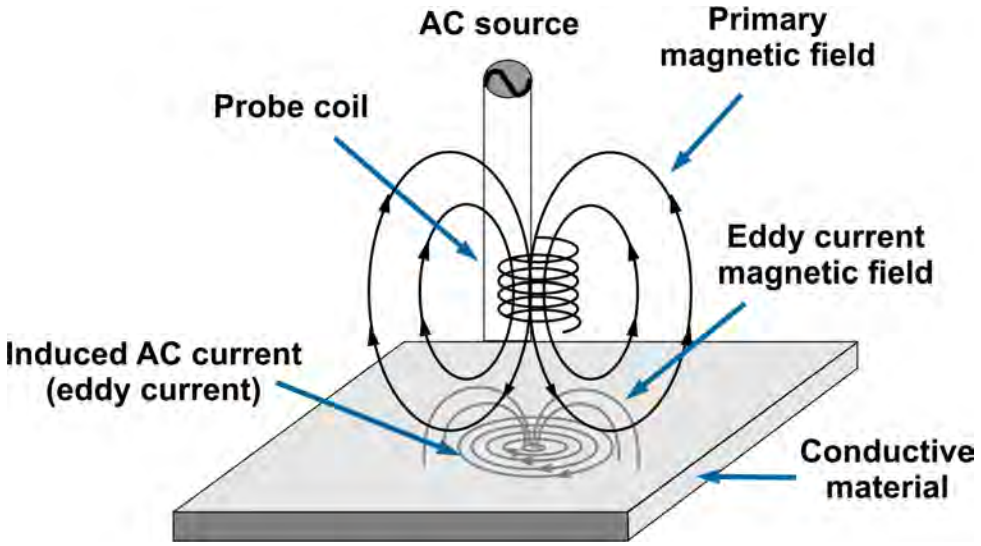
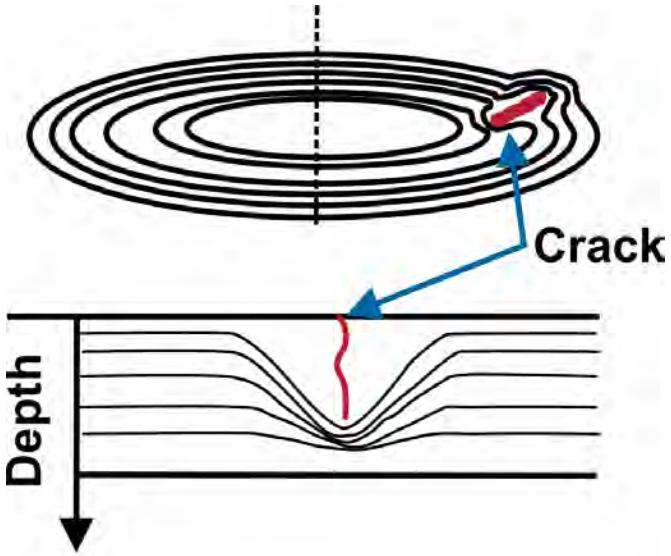
Eddy Current Testing (ET) Fundamentals

- **Eddy current NDE uses electromagnetic induction principals**
  - A coil within a probe is excited with alternating current
  - Eddy currents are induced within the sample material
  - Any discontinuities in the sample material impede eddy current flow
  - Changes in material impedance are detected by probe

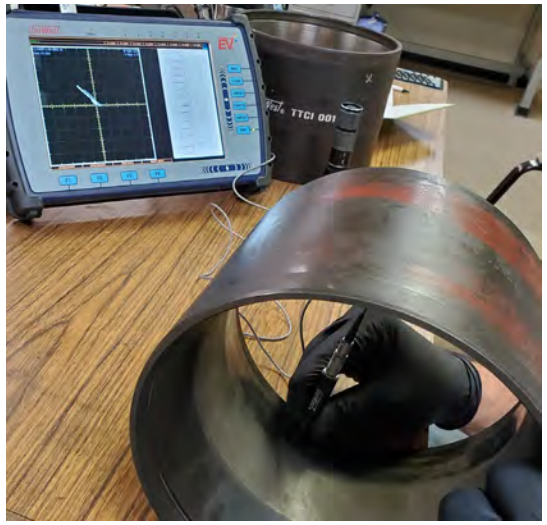
Principle of eddy current testing



Distortion of eddy current in presence of crack



Conventional single coil probe



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11/22

Eddy Current Testing (ET) Fundamentals

- **Eddy Current Array (ECA) technology uses several coils simultaneously**
  - ECA can inspect one cup raceway in approximately 30 seconds
  - Results are color-coded C-scans
  - Flexible ECA probes allow scanning of complex surfaces

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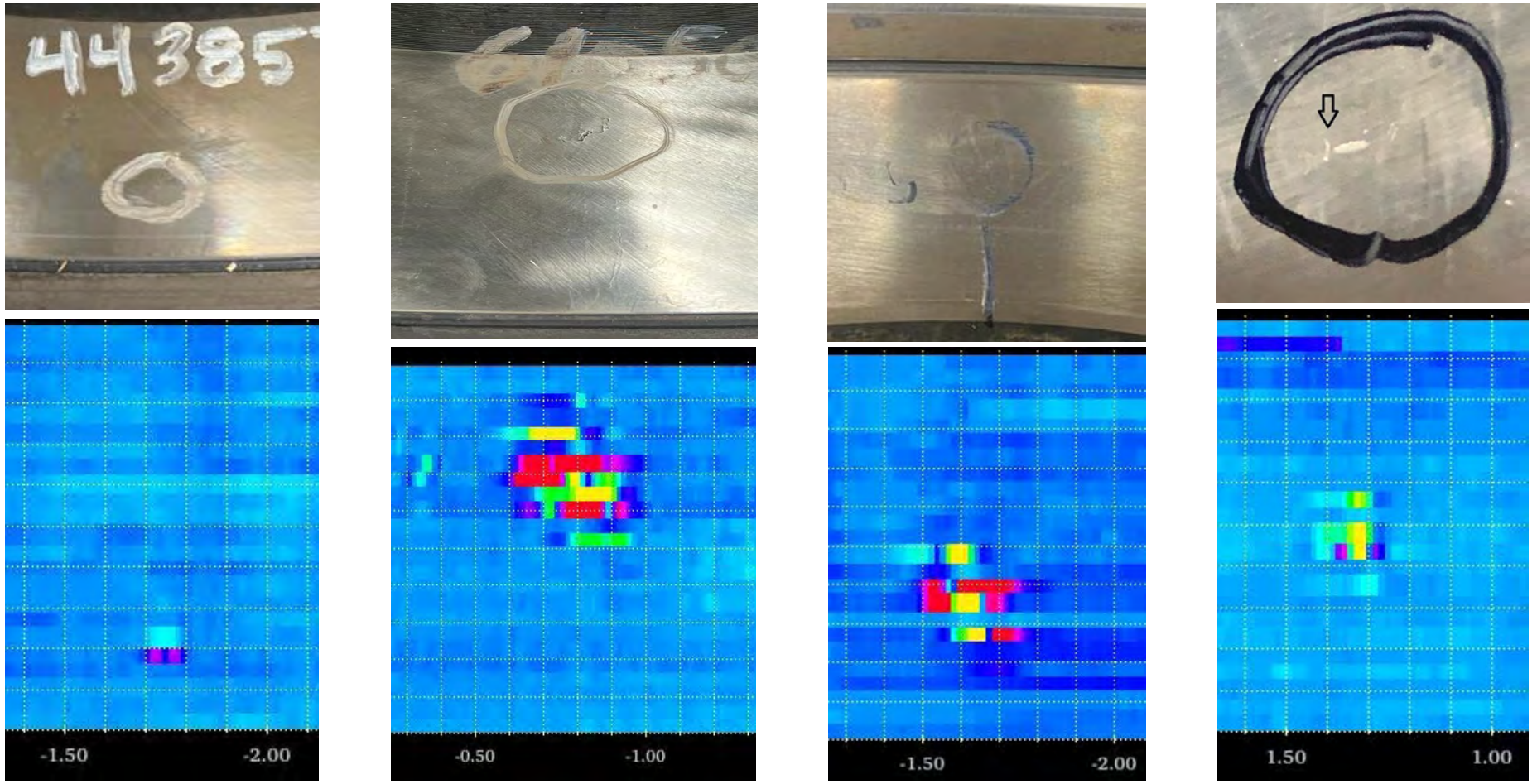
ECA Indications

- **Example ECA scans of cups with indications of surface or near-surface defects:**

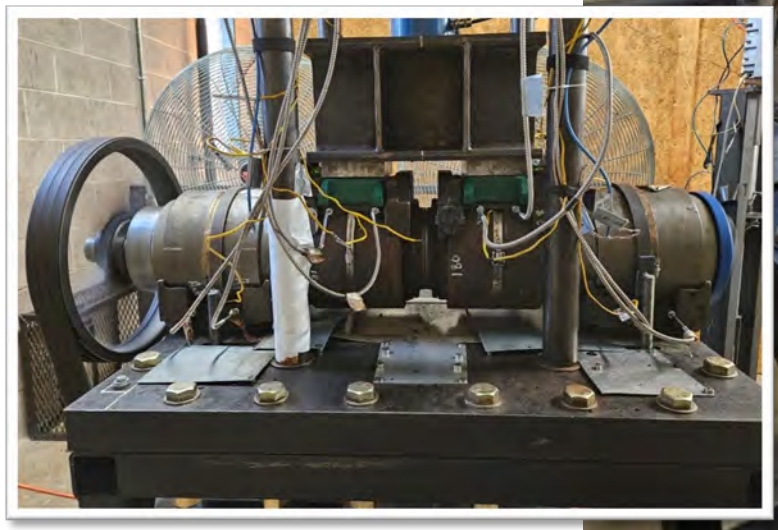
Raw reconditioned cup raceways (top) and corresponding ECA indications (bottom; x,y scale in inches)



ECA Validation through Rig Testing

Rig Test Parameters

- **Testing performed by University of Texas-Rio Grande Valley (UTRGV)**
  - Test duration: 240,000 miles
    - Teardown inspections every 60,000 miles
  - Vertical load: 34,400 pounds each
  - Equivalent train speed: 85 mph
  - Cups prevented from indexing
  - Vibration and temperature monitored continuously



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2024 Rig Testing: Water Etched Cups

- **Two sample sets selected for rig testing, each with superficial water etch**
  - Eight cups without ECA indications
  - Seven cups with ECA indications
    - Scanned 192 cups total to find seven candidates (3.6%)
      - Two other SRI studies have shown similar bearing cup indication rates:
        - Seven of 256 (2.7%) (FY 2021)
        - Eight of 252 (3.2%) (FY 2024)

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ECA Rig Test Validation Results

- **Total accuracy of ECA in predicting rig test outcome: 87%**
  - Six of seven cups with ECA indications spalled early in rig testing
  - Seven of eight cups without ECA indications did not spall throughout rig test
  - Strong correlation between ECA indication size and:
    - Resulting spall area
    - Spall initiation mileage
  - Results to be published in a 2025 *Technology Digest*
  - Previous ECA validation (2022) showed only 56% accuracy in predicting rig test outcome

Final NDE Error Matrix

Bearing Outcomes	Spall During Test	No Spall During Test	Total
ECA Indication	6	1	7
No ECA Indication	1	7	8

Results of Cups with ECA Indications

Cup #	ECA Indication Size (in^2)	Spall Area (in^2)	Spall Initiation Mileage	Total Test Mileage
1	0.003	0.00	N/A	111,220
2	0.062	4.37	18,000	48,691
3	0.034	3.49	15,100	62,529
4	0.048	0.95	9,980	17,121
5	0.046	1.98	<17,121	17,121
6	0.010	*	11,491	65,742
7	0.019	1.09	41,502	65,742

** Cup #6 had numerous small spalls spread out; area measurement was not possible*

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True Positive ECA Indications

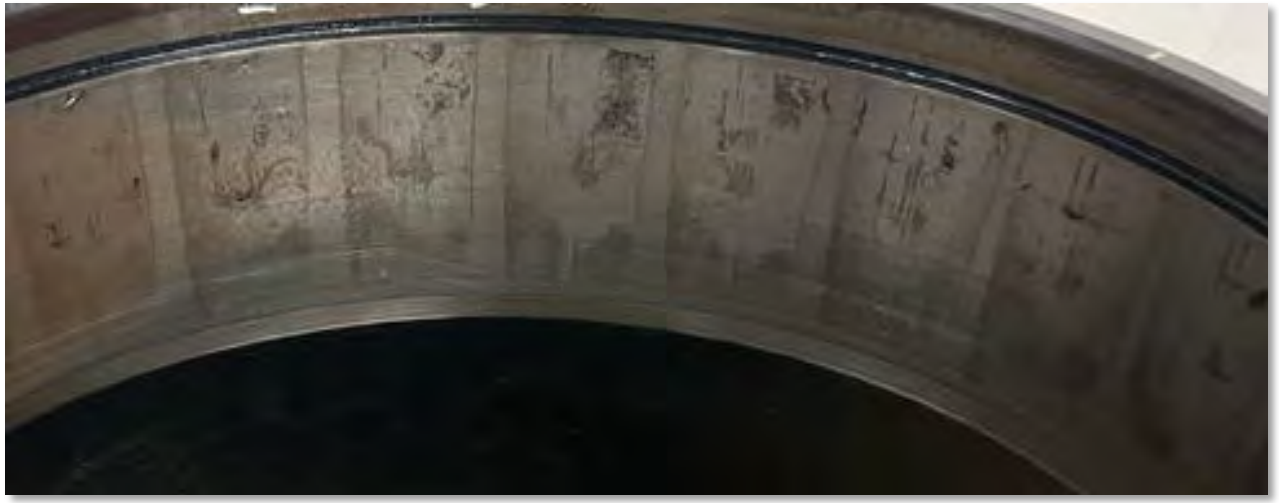
Cup #2 after 48.7k miles

Cup #3 after 62.5k miles

Cup #4 after 17.1k miles

Cup #5 after 17.1k miles

Cup #6 after 65.7k miles



Cup #7 after 65.7k miles

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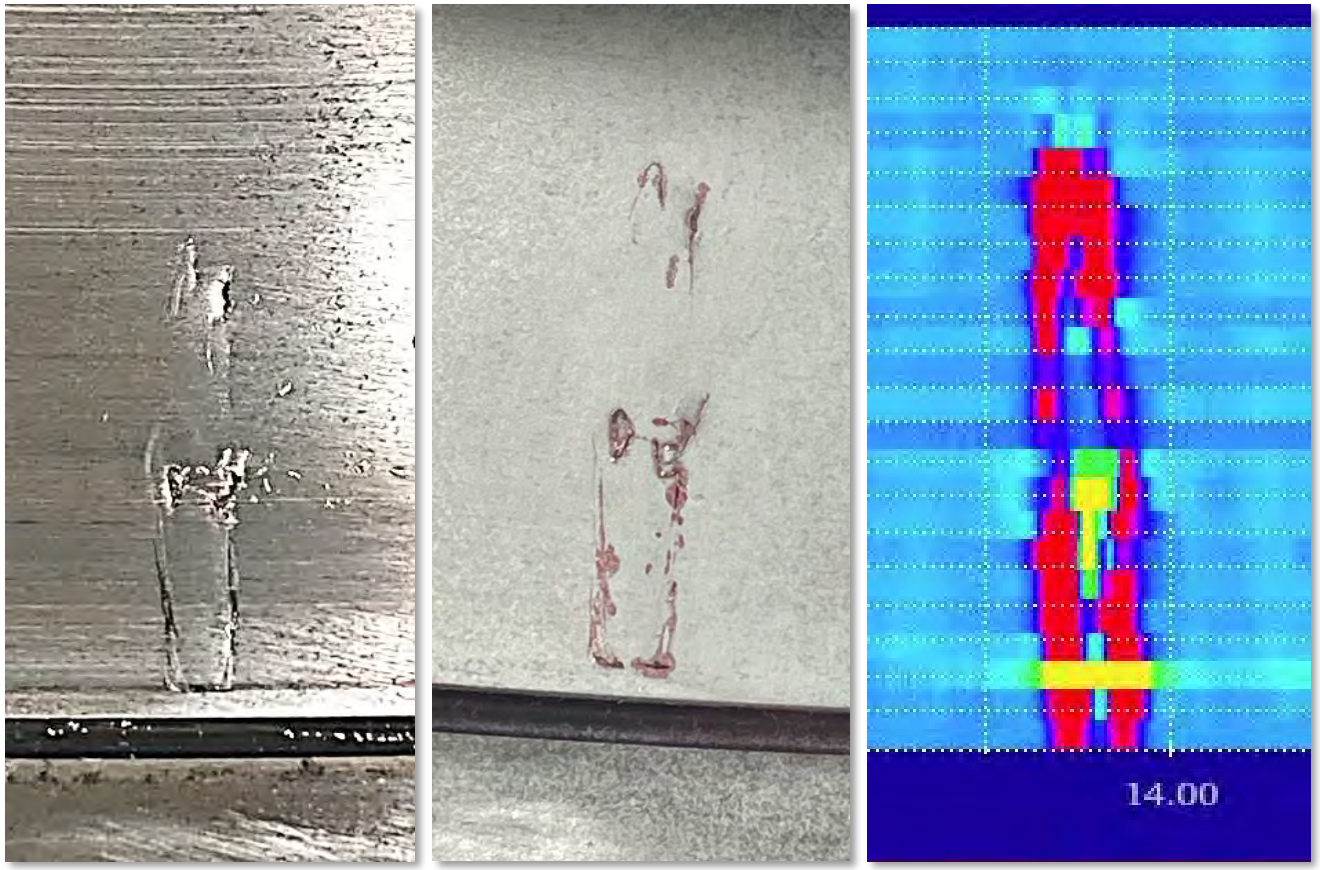
False Negative ECA Indication

Spalling on cup without ECA indication, dye penetrant, and post-test ECA scan



- **One of eight cups without ECA indications began to spall around 60,000 miles**
  - Spalling may have originated from incipient spall near edge of raceway
    - MxV Rail's current scan path is limited to the middle 1.2 inches of raceway
    - Future work will evaluate a wider array probe and edge effects

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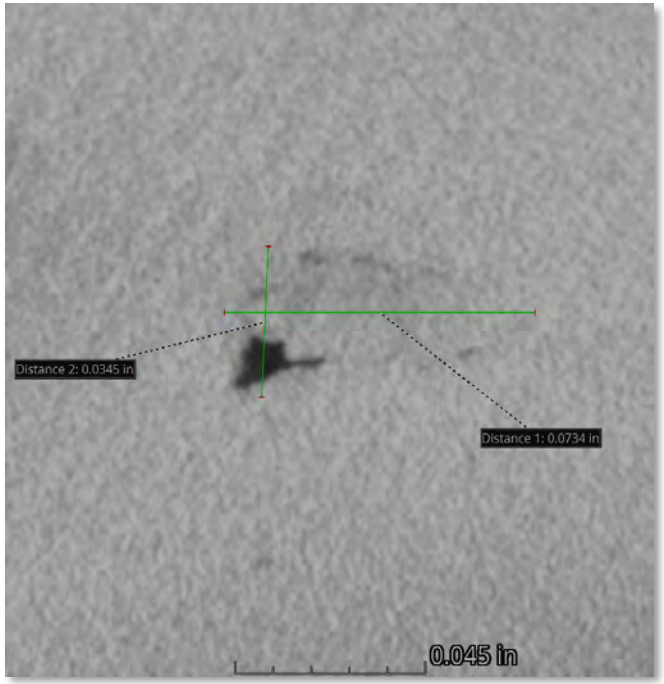
Path Forward

- **ECA Validation:**
  - Additional rig testing underway on cups with small ECA indications and without superficial water etch
  - Evaluate wider array probe to detect near-edge defects.
  - Ongoing destructive analysis of defects to understand root cause and damage propagation
    - Micro Computed Tomography (CT) scanning to quantify the minimum detectable defect size and subsurface depth

Micro CT image of defect



Cut sample undergoing Micro CT Scanning

Additional Research

- **Water ingress testing on MxV Rail's bearing rig**
  - Testing wide variety of isolated variables to determine the conditions that allow for water ingress
- **Degradation of bearing grease during periods of inactivity**
  - Investigating how long cars may safely sit idle and maintain proper lubrication properties

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Summary

- **Overview of reconditioning process**
- **ECA technology for bearing inspection**
- **Final results of water etch rig testing are drastically improved compared to previous validation**
  - ECA indications predicted rig test outcome 87% of the time

- **Path forward:**
  - Continue rig testing cups with smaller ECA indications
  - Continue destructive analysis to better understand limitations of ECA scans

30TH ANNUAL
Association of American Railroads
RESEARCH REVIEW

ASSOCIATION OF AMERICAN RAILROADS

MxV RAIL

Acknowledgements

- MxV Rail Team
- Progress Rail
- University of Texas – Rio Grande Valley

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Wheel Performance & Integrity

Corey Pasta
Scientist, Mechanical Research

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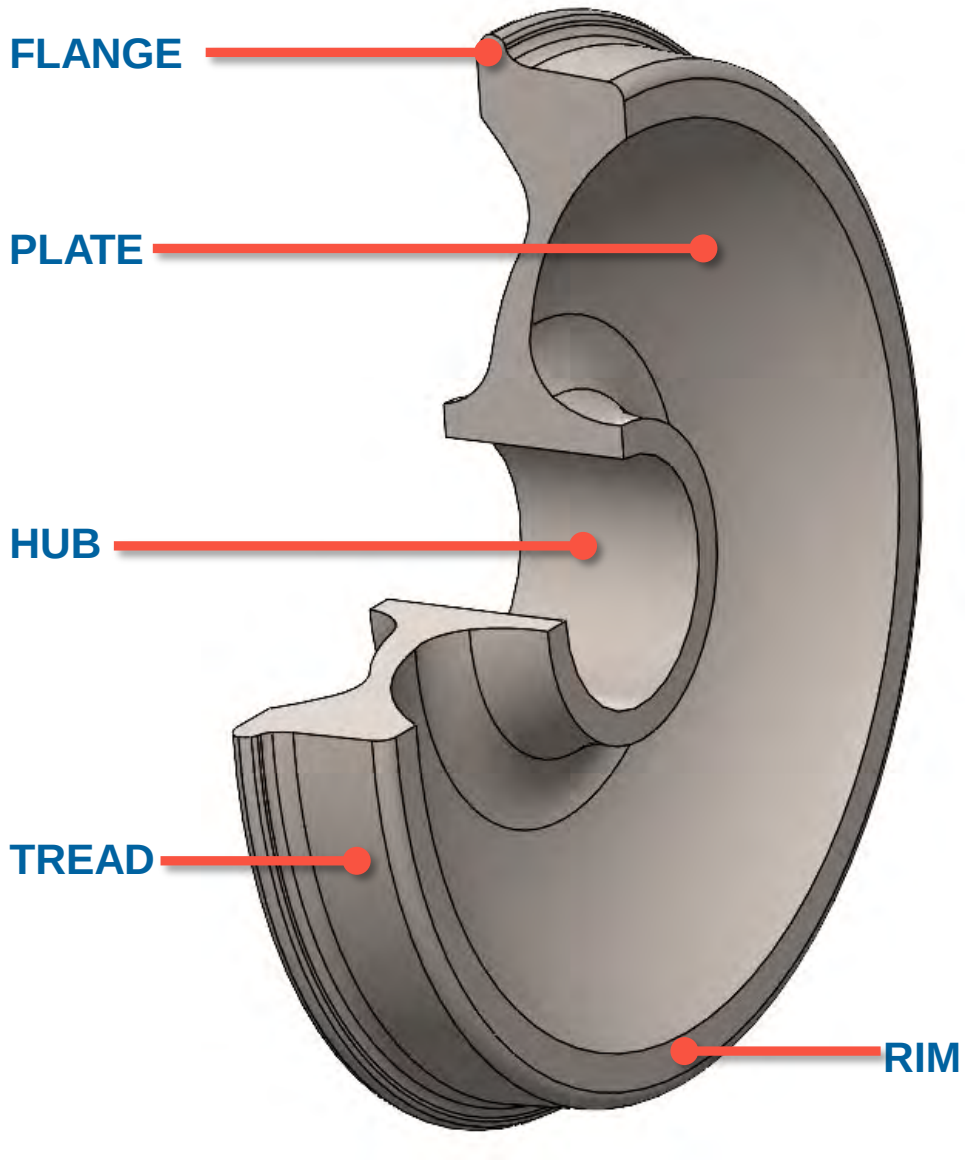
Overview

- **Research Objectives**
- **Wheel Life – Wear/Fatigue**
- **Historic Advances**
- **Research Updates**

Wheel Section View with Key Nomenclature



Research Objectives

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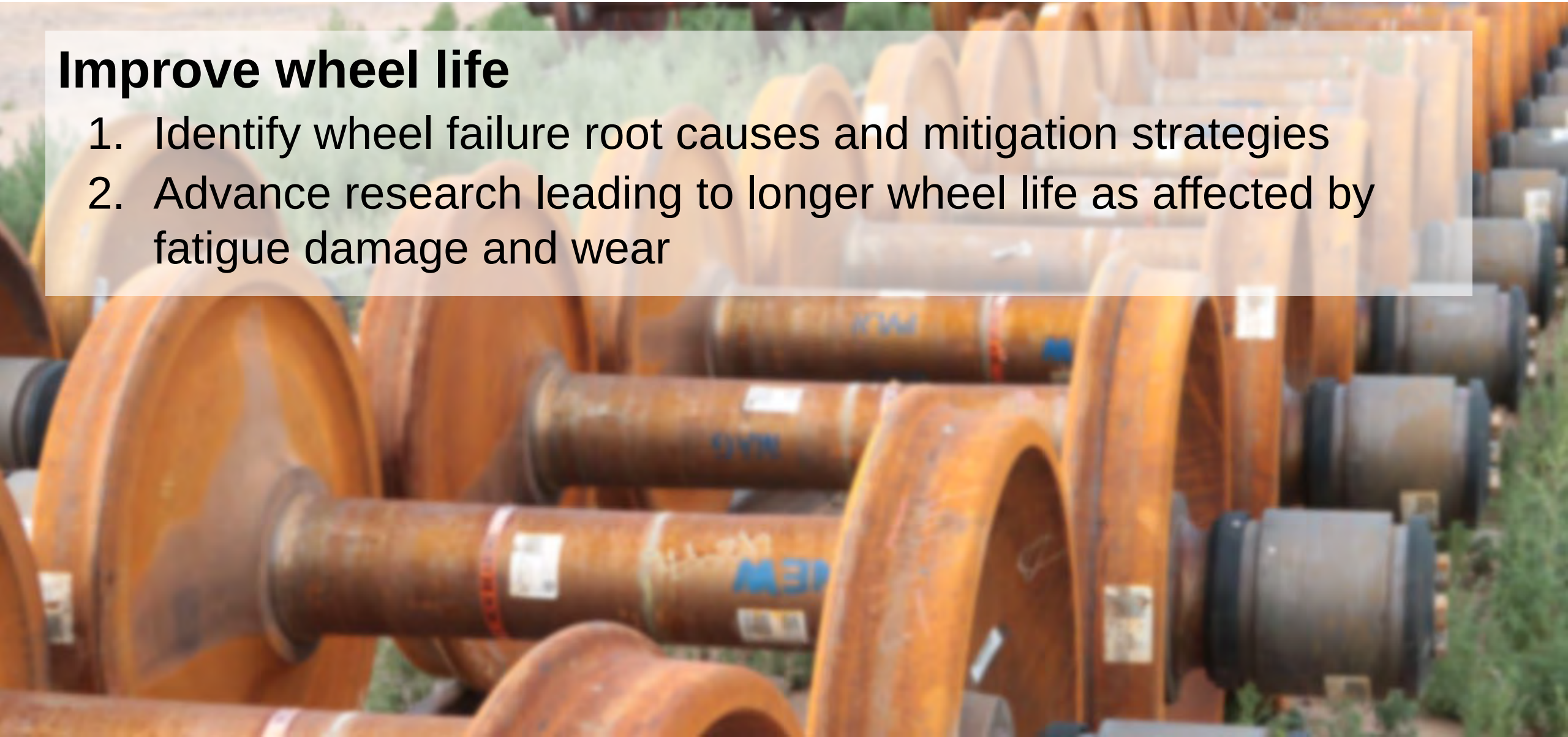

Improve wheel life

1. Identify wheel failure root causes and mitigation strategies
2. Advance research leading to longer wheel life as affected by fatigue damage and wear

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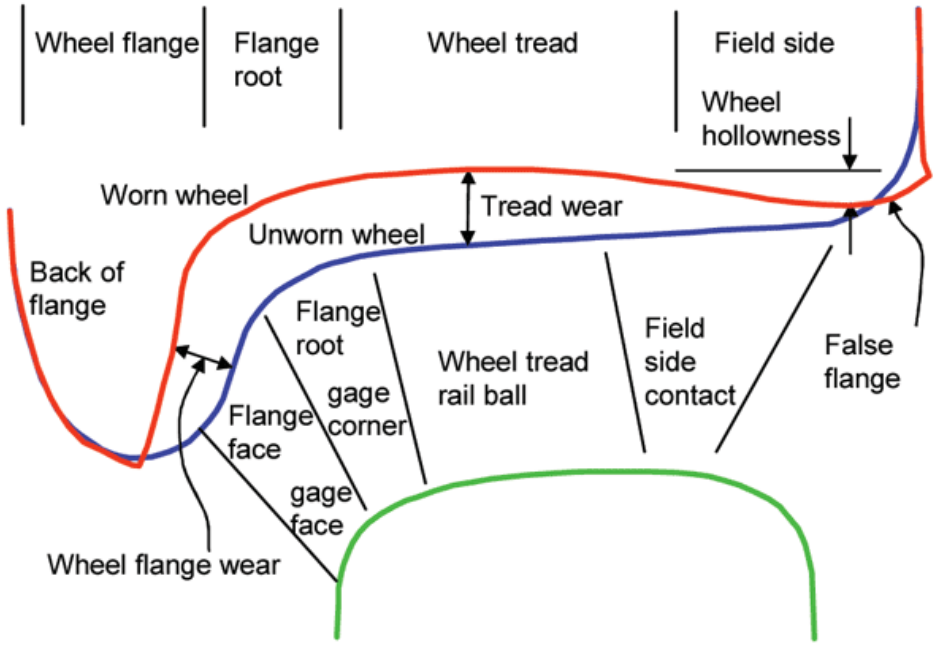
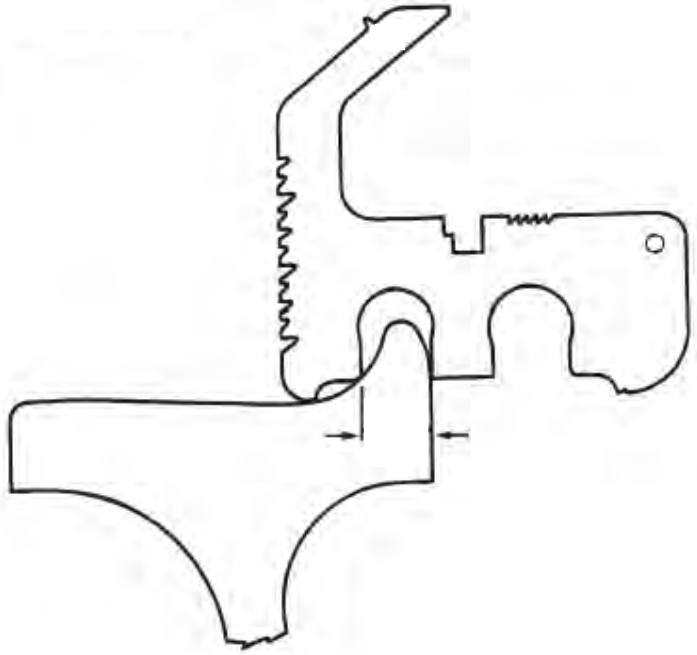
Wheel Life – Wear

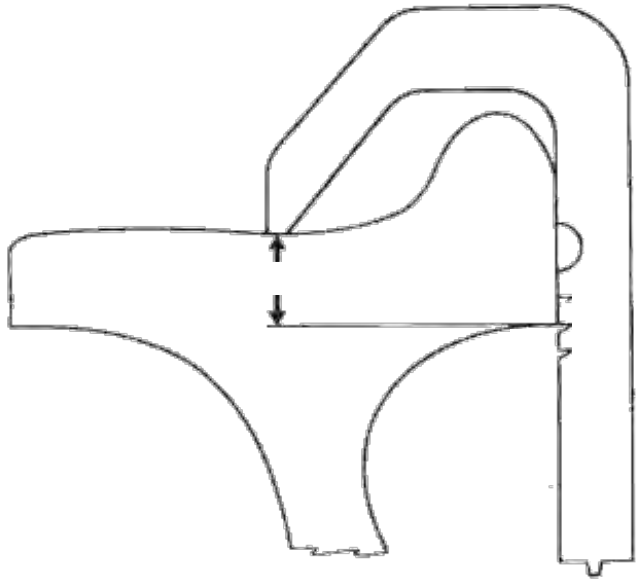
Wheel Wear



Thin Flange & Gauge



Thin Rim & Gauge



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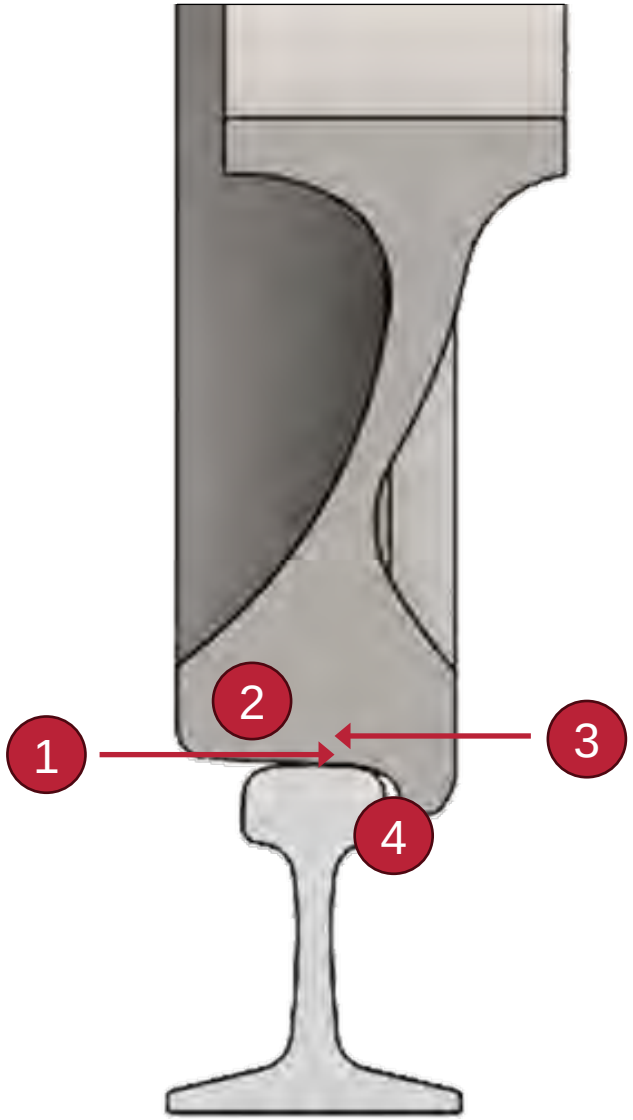
Wheel Life – Fatigue

Imminent Vertical Split Rim

Wheel Shelling
~5mm Below Tread Surface



Shattered Rim
~20mm Below Tread Surface

Cracked Flange

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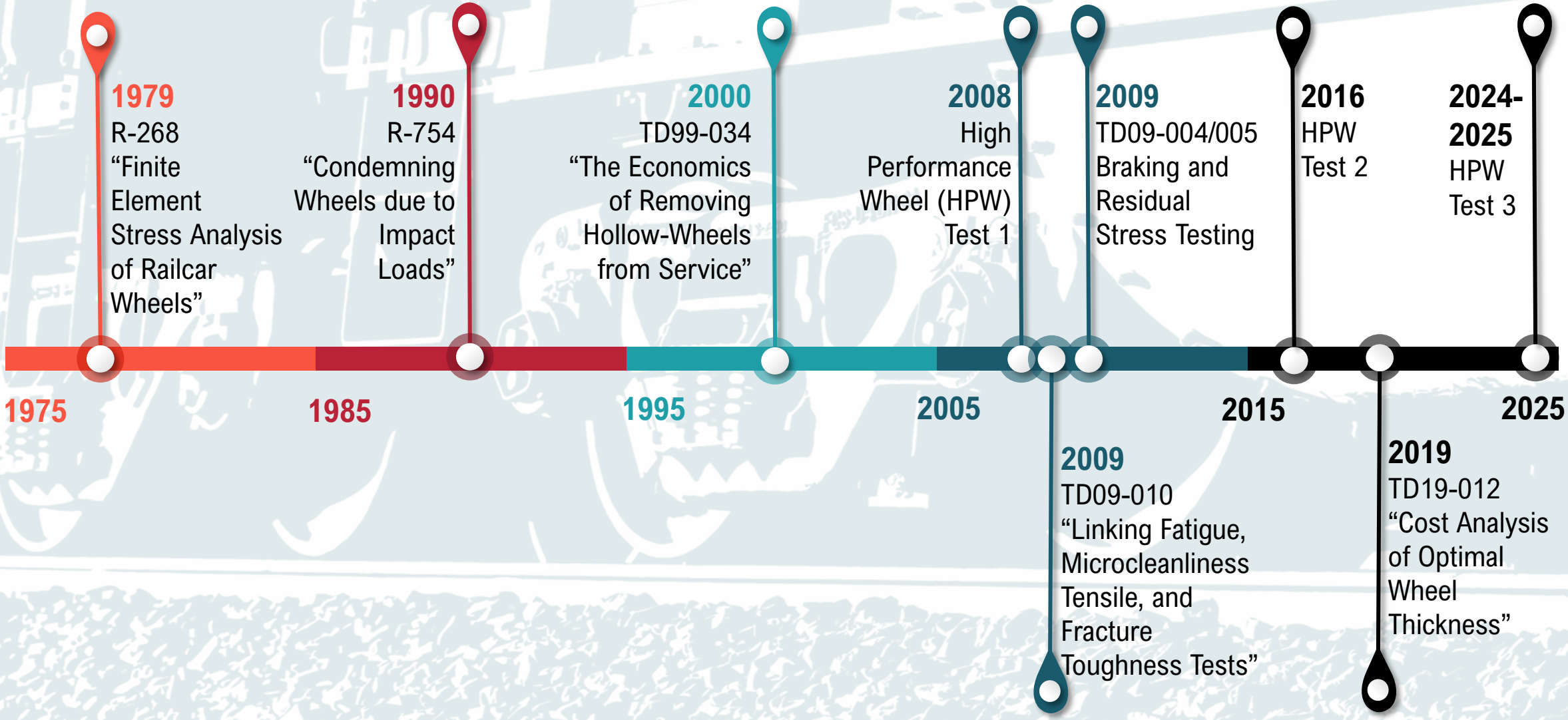
Wheel Research Advances & Project History



High Performance Wheel (HPW) Tests

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HPW Test 1

- FAST® testing began 7/2008
- 9 wheel types
- FAST testing ended 9/2016
- Revenue service test on Class 1 coal cars
- Test sunsetting in 2025

HPW Test 2

- FAST testing began 9/2017
- 14 wheel types
- FAST testing continues with 120k average wheel mileage. 40 wheelsets across 14 suppliers (wheel types)
- Revenue service test with 168 wheelsets, including 44 Class C on Class 1 grain cars

HPW Test 3

- FAST testing began 8/2024
- 3 wheel types*
  - All AAR approved
- FAST testing continues with 8.5k average wheel mileage
- Revenue service test planned for intermodal cars

*Fourth wheel type pending

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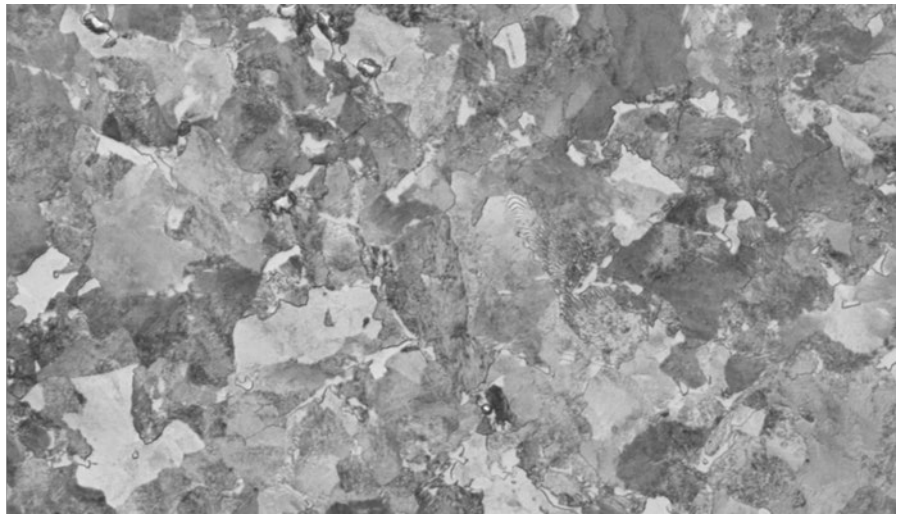
HPW Laboratory Testing

Property	HPW1	HPW2	HPW3
Chemical composition	✓	✓	
Microstructural analysis	✓	✓	
Microcleanliness	✓	✓	
Hardness	✓	✓	
Tensile properties	✓	✓	
Fracture toughness	✓	✓	
Rotating beam fatigue	✓	✓	
High temp. tensile	✓		
Residual hoop stress	✓		

Typical Pearlitic Microstructure



Microcleanliness Analysis
Red areas indicate voids, oxides or sulfides

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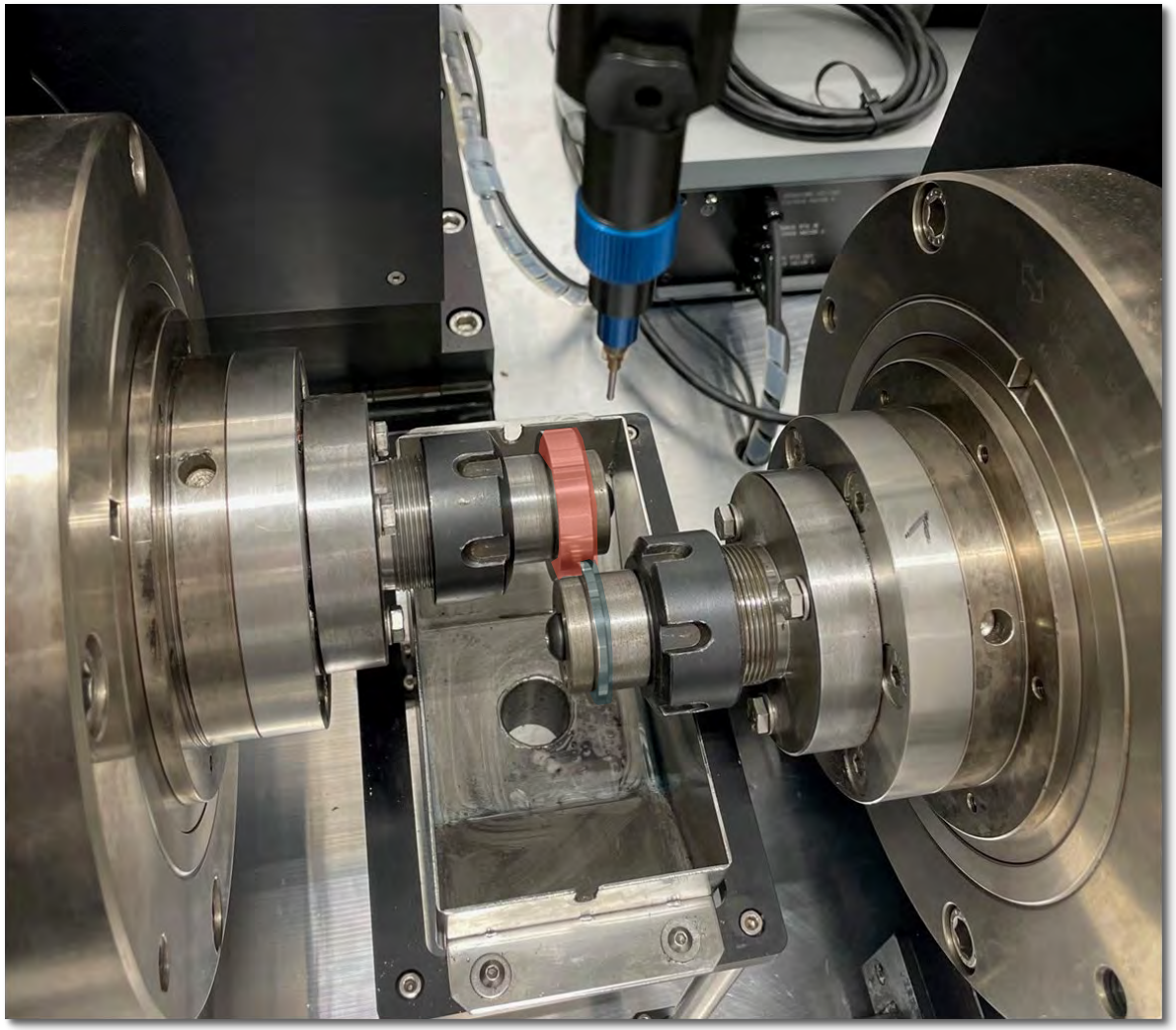
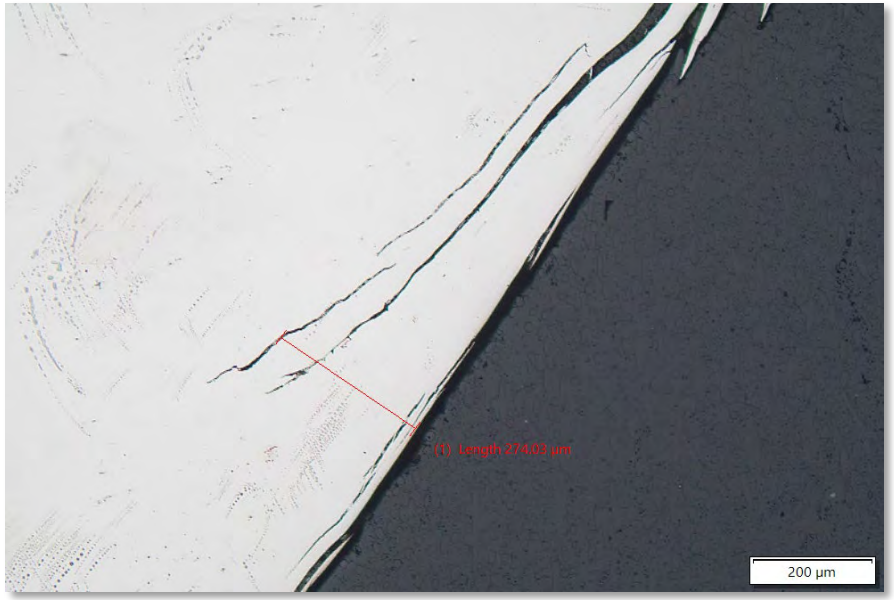
Recent Addition: Twin Disk Test Machine

MxV Rail Twin Disk Test Machine



Twin Disk Samples: Rail & Wheel Steels

Microscopic Image of Twin Disk Sample Post-Test



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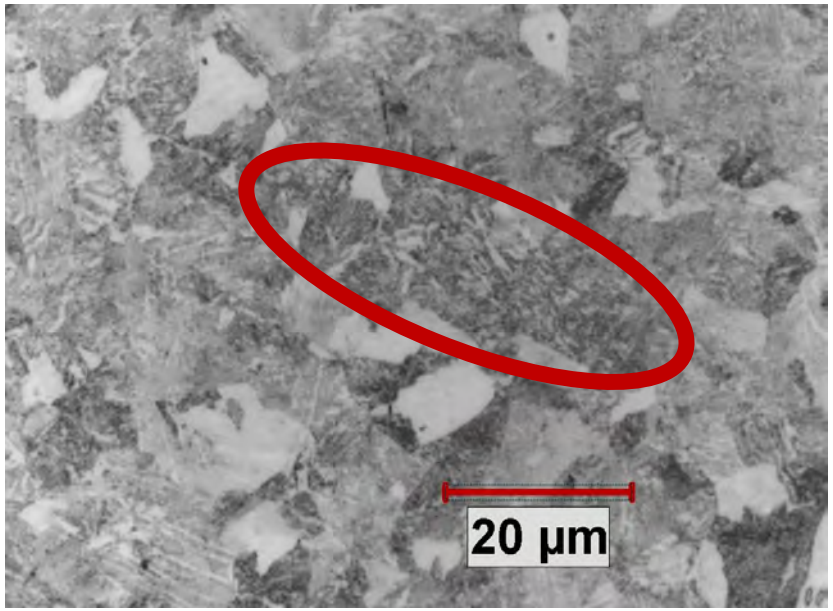
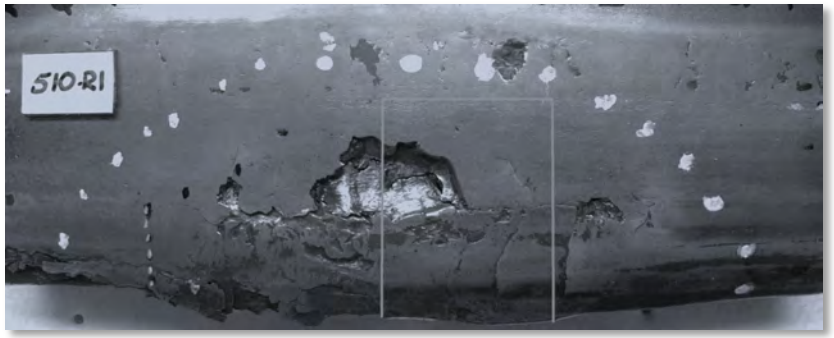
HPW Test 1

- **Key findings**
  - A wheel design with a pearlitic + bainitic microstructure was removed from the test due to early development of shattered rims
  - Performance not tied to any single factor
- **Operating condition challenges**
  - Normalizing wheel life for varying axle loads and operating conditions
  - Cars removed from revenue service test
- **Sunsetting of HPW1**
  - Statistical analysis of removal causes
    - Failure modes and wheel wear rates

Pearlite + Bainite



Example of Shattered Rim at FAST w/ Pearlite + Bainite Wheel Design



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HPW Test 2

- **FAST testing**
  - 10 FAST HPW2 wheelsets removed for cause (of 40 HPW2 wheelsets)
    - Eight for subsurface cracking
    - One shattered rim
    - One for shelling/spalling
  - Average of 120,000-miles
- **Revenue service testing**
  - Eight wheelsets removed (of 124 HPW2 sets)
    - 193,000 miles average
    - Cause data under review
- **Wear performance differences under evaluation**

Shattered Rim, HPW2 FAST Test

HPW3: Revenue Service Testing

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- **FAST**
  - Test wheelsets installed under 10 cars of similar design
  - 315,000-pound GRL, 38-inch wheels
  - 8,500 average mileage
  - No removals to date
- **Revenue service test plan**
  - Intermodal car, articulated truck
  - Accelerated mileage in challenging environment

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Acknowledgements

- Wheel Suppliers
- Union Pacific
- Kerry Jones, Brian Lindeman, John Krasovic, MxV Rail NDE-MET Team
- TTX

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Inspection Technologies

Anish Poudel, Ph.D.
Scientist
Research & Innovation

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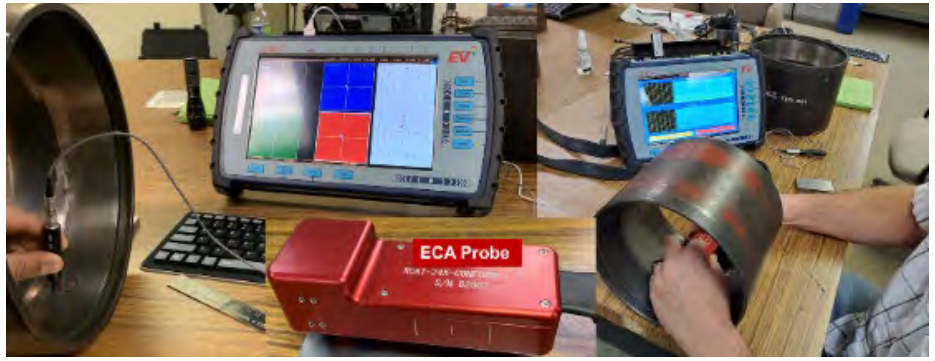
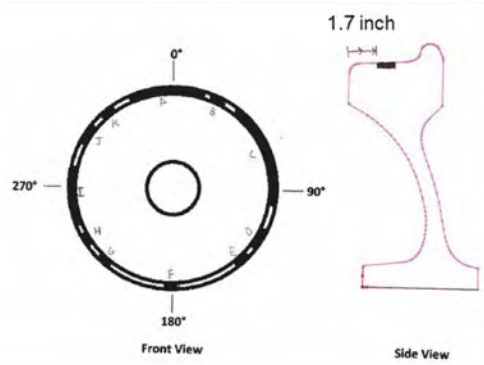
Overview

- **Wheel Inspection**
  - Broken wheel precursors
  - Existing inspection technologies
  - Electro-Magnetic Acoustic Transducer (EMAT) technology
    - On-track FAST® trials
    - Hand-held FAST trials
- **Axle Inspection**
  - Eddy current testing (ET) technology
  - Surface crack characterization
- **Bearing Cup Inspection**
  - Eddy current array (ECA) technology
  - ECA validations
- **Summary**
- **Acknowledgements**

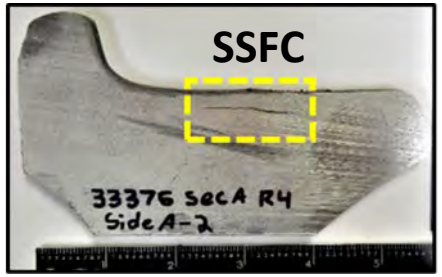


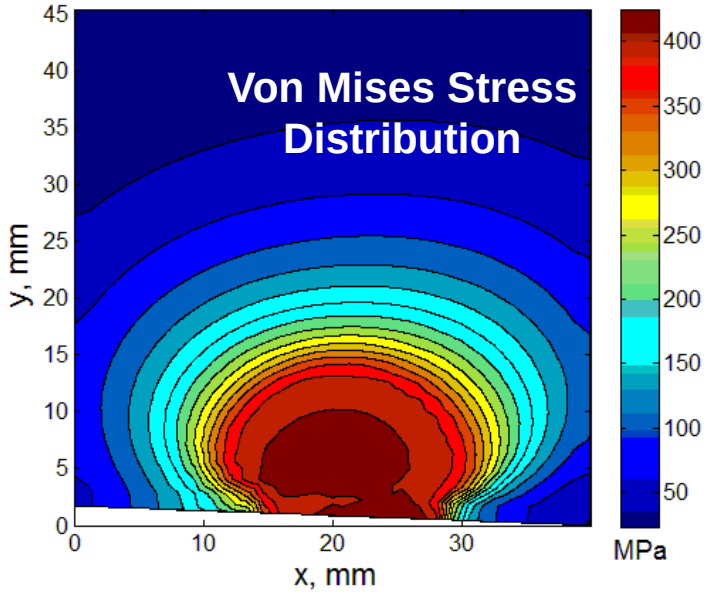
Broken Wheel Precursors

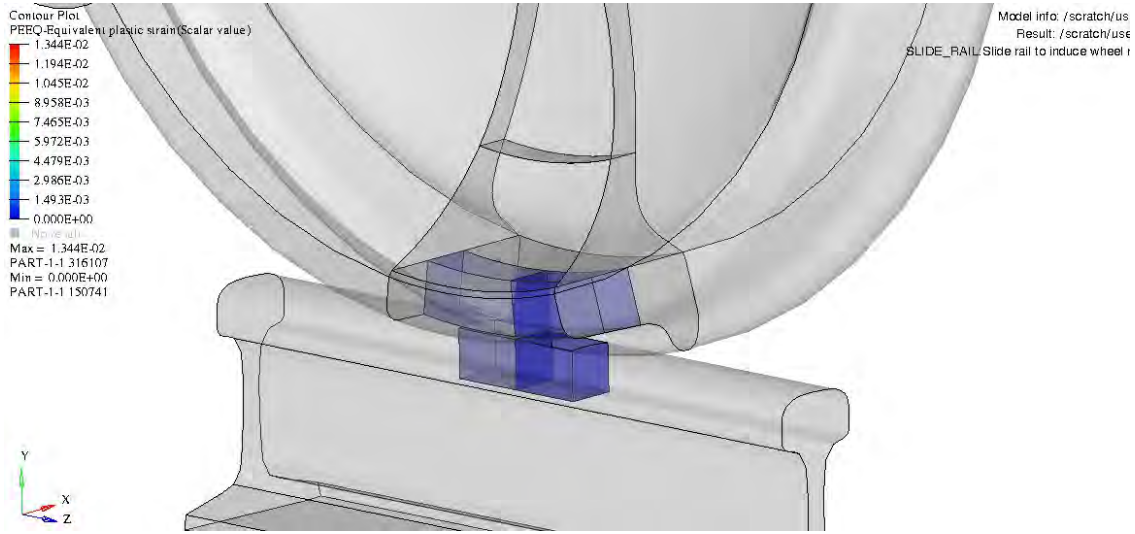
- **Broken wheels are results of sub-surface fatigue cracks (SSFC)**
  - Result of complex loading mechanisms and maximum shear stresses in the layer beneath the wheel surface
  - If present, non-metallic inclusions or voids act as stress risers and can accelerate fatigue cracks



Hand UT flaw mapping







Stress Analysis of Wheel/Rail Contact

Broken Wheel

Existing Wheel Inspection Technologies

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- **Visible damage (broken)**
  - Vision
  - Laser
  - WILD Edge
- **Mechanical damage (surface)**
  - Strain gauge (WILDs)
  - Fiber optics
  - Accelerometer
- **Internal damage (cracks)**
  - Ultrasonic testing (UT)
  - EMAT

WILD Edge

Vision

Laser

Fiber Optics

Accelerometer

Strain Gauge

UT

EMAT

EMAT Principle

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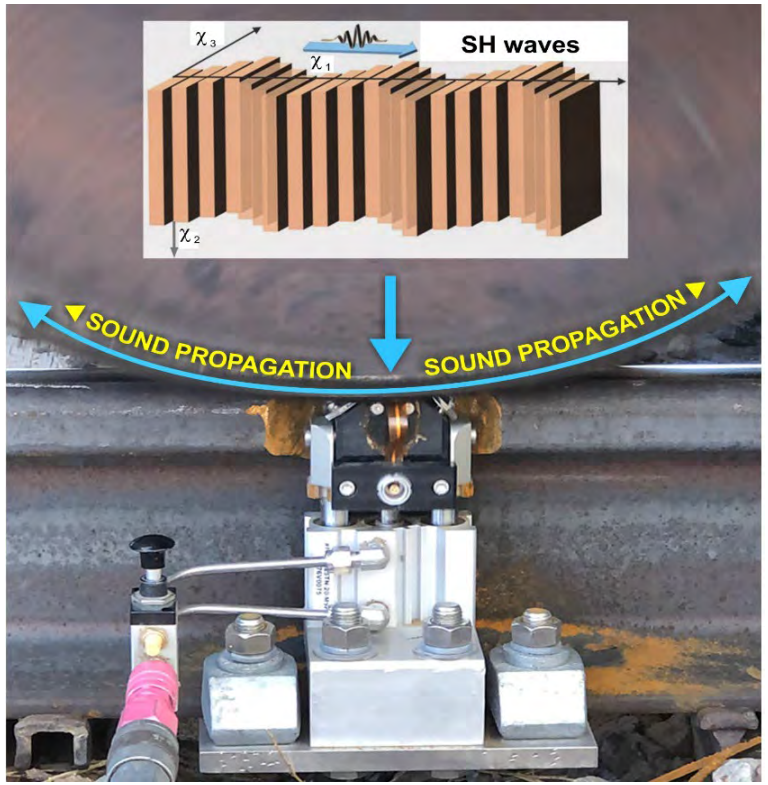
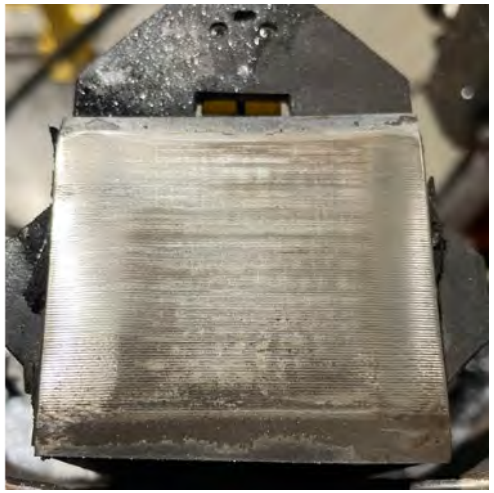
- **Generates ultrasound in the part using electromagnetic induction through two basic mechanisms, Lorentz force and magnetostriction**
- **Magnetostrictive patch-based EMAT**
  - Shear horizontal (SH) guided waves
- **EMAT sensor assembly sustained 2 million wheel passes (equivalent to 40 MGT) in a controlled rolling load machine tests (*Technology Digest* TD24-008)**



After 2 million passes



EMAT Signal Amplitudes

FAST® is a trademark of MxV Rail ©2025 MxV Rail

EMAT FAST® Initial Trials

- **Initial FAST installation and evaluation completed**
  - EMAT signal quality issues
    1. Locomotive traction motor electromagnetic interference
       - Resolved by grounding the EMAT system & adding appropriate hardware filters
    2. Wheel tracking issues
       - Resolved by installing U-69 guard rails
    3. Poor sensor compliance
- **Requires sensor modification**

Electromagnetic interference

Wheel lateral movement

Wheel lateral movement

Notched Track with guard rails

Innerspec is the provider of EMAT Technology

Hand-Held EMAT Trials

- **Initial evaluation conducted in FAST and hospital consist cars**
  - Signal quality/consistency issues
  - Requires sensor design changes

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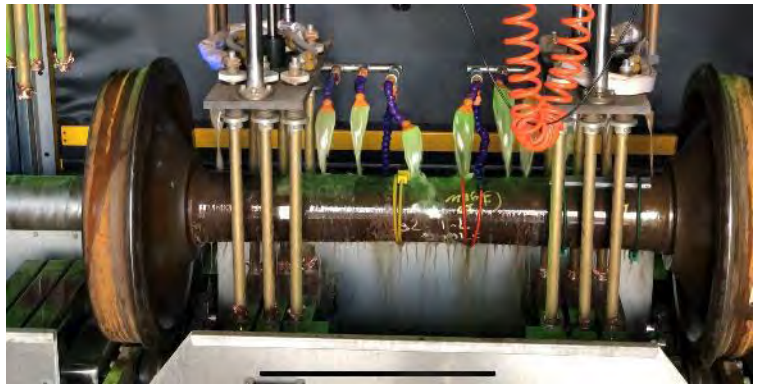
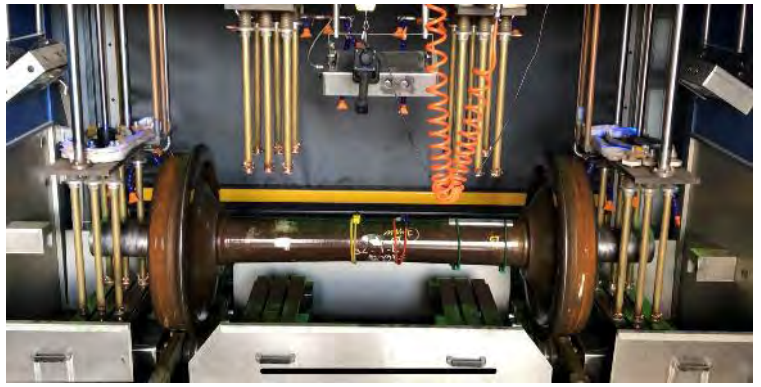
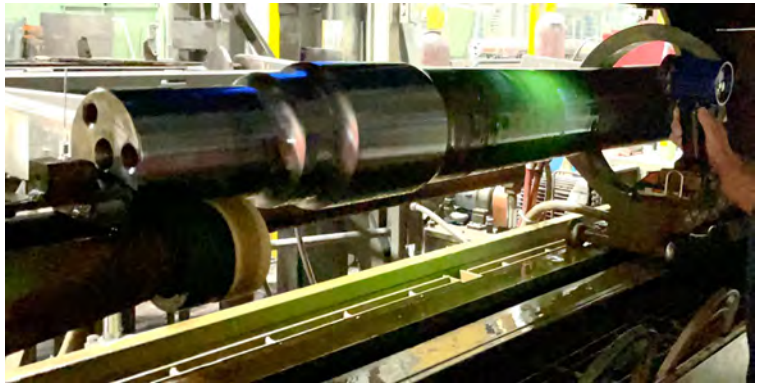
Axle Inspection Technologies

- **Primary goal is to help facilitate in the development of an in-motion automated cracked axle inspection system for revenue service applications**
- **Current shop application uses wet-magnetic particle testing (MT) approach**
- **Alternative automated NDE inspection technique that supports the shop application**
  - Replace/compliment current wet-magnetic particle testing (MT)
  - Demonstrate the capability with low false positives

Wet MT Approach







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Axle Journal Surface Cracks Characterization

- **Axle journal radius surface crack depths ranged from 2934µm to 110µm with average depths of 500µm (total 30 samples)**
- **Average axle journal radius hardness was around 94 Rockwell B (HRB) or 203 Brinell Hardness (HB)**
- **All surface cracks appeared to be transgranular (propagating through the grains of the material)**

Scanning Electron micrograph

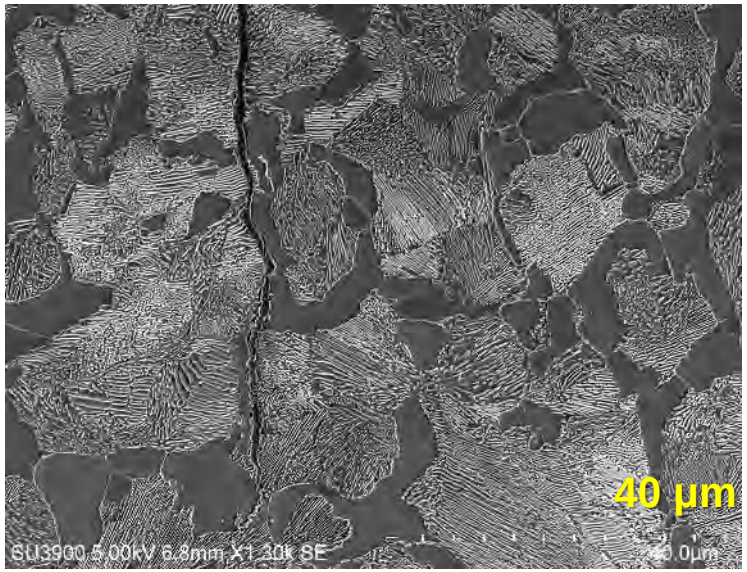
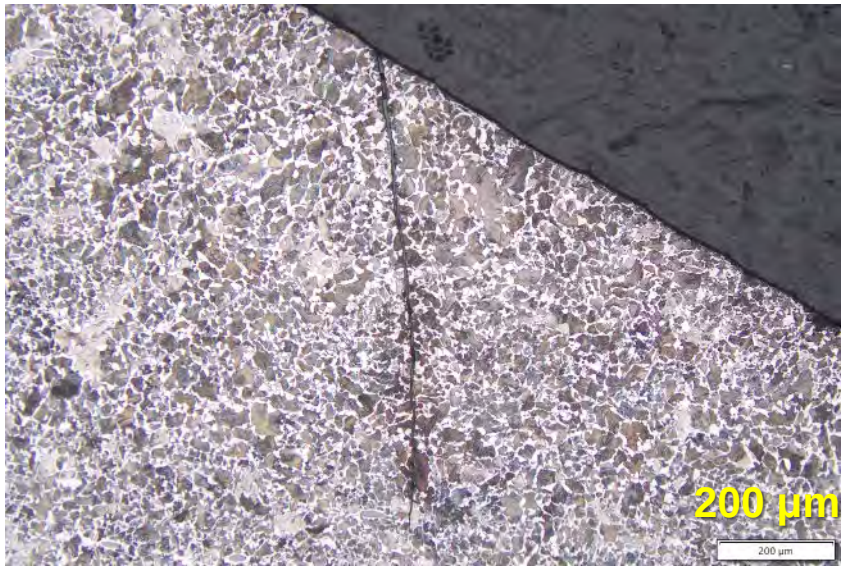
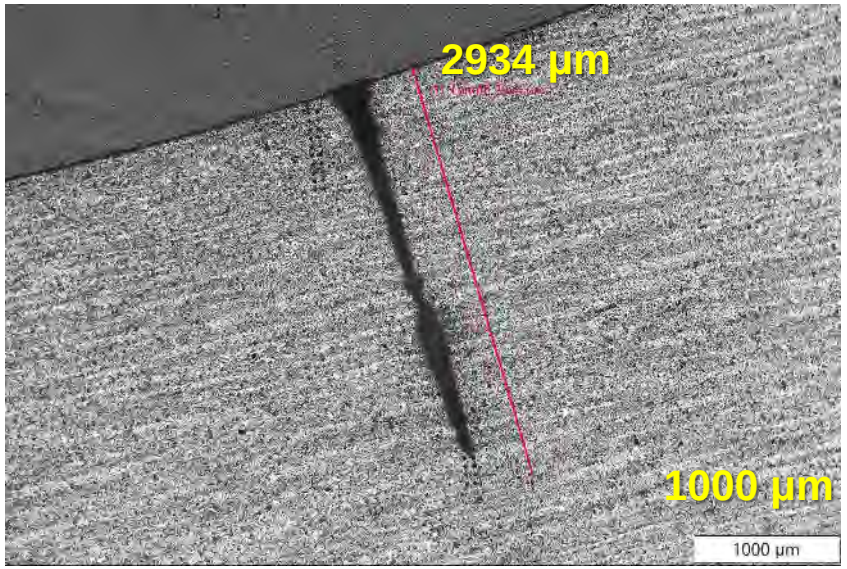


Photo micrographs





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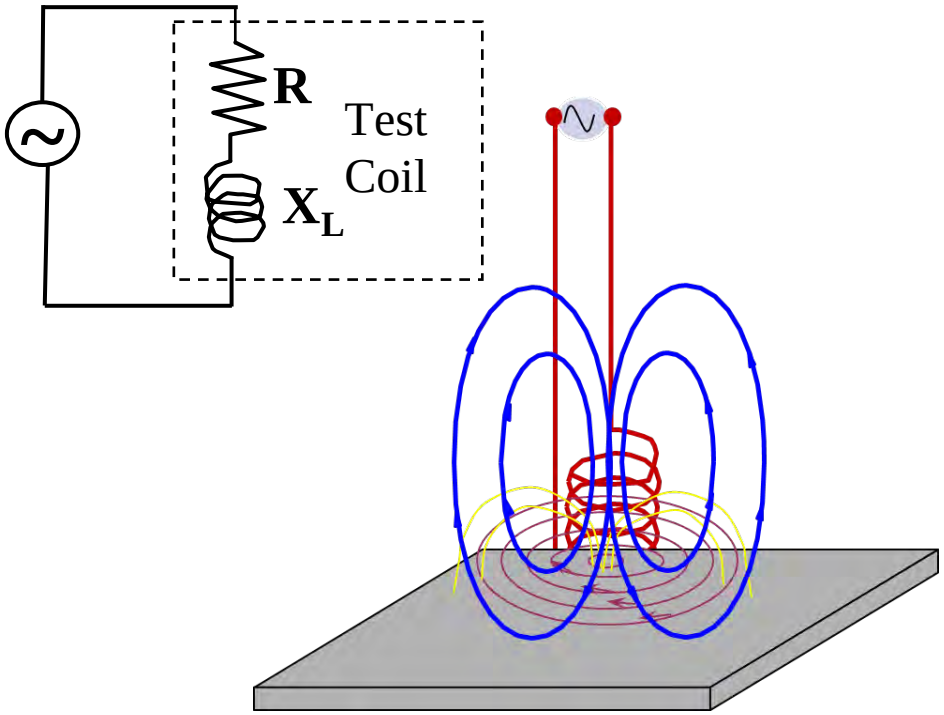
ET Principle

- **ET measures a loading effect (changes in electrical impedance) caused by variations (materials, cracks and flaws, liftoffs) in a conductive material**
  - Impedance (Z) in an eddy current coil is the total opposition in a coil
    - Z is made up of resistance (R) and inductive reactance (XL)



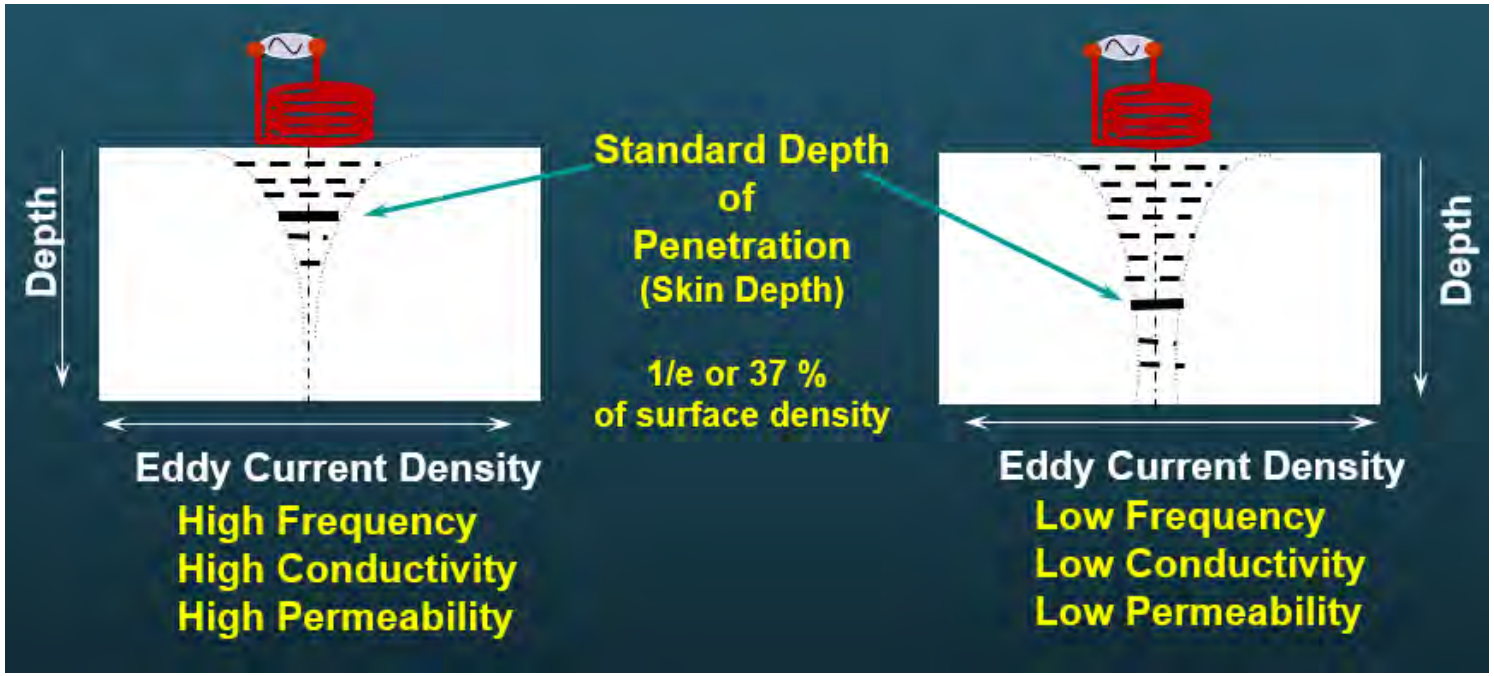


Photo Courtesy: www.nde-ed.org/

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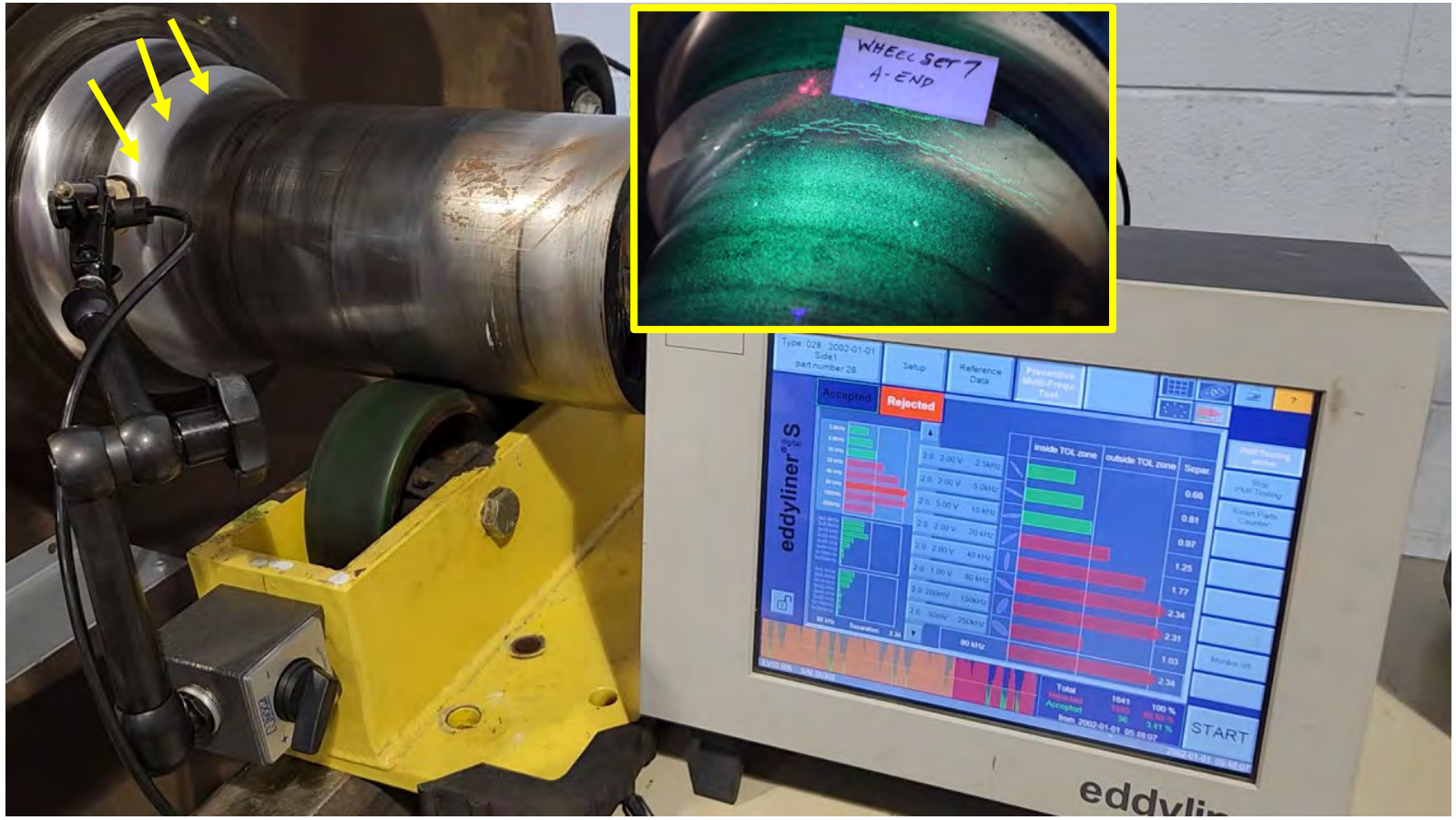
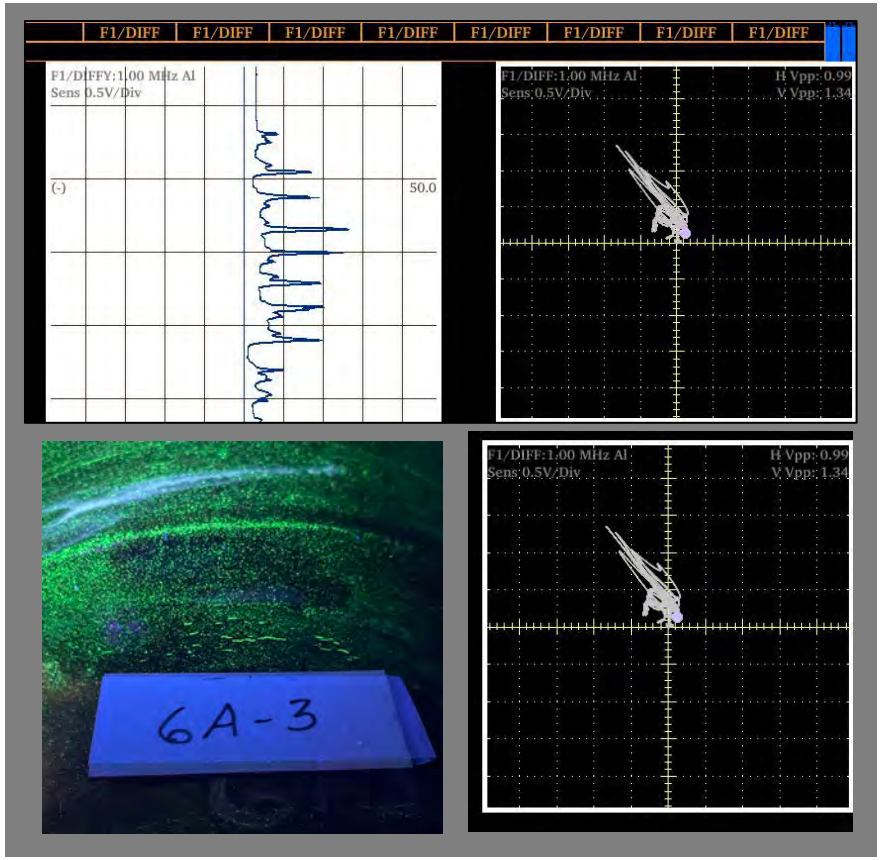
ET Inspection Technology for Axle Journal

- **Detects surface cracking as well as material changes at the microstructure level in journal radius of the axle**





Bearing Cup Inspection Need

- **Explore electromagnetic NDE methods to improve the current bearing reconditioning inspection process**
- **Develop understanding of what eddy current scans are physically detecting in the material**
  - Cracks (size and depth)
  - Microstructural changes
  - Others
- **Understand the difference between the indications that spalled during the rig test and those that did not**

Freight Car Bearing

Spalled Bearing Cup

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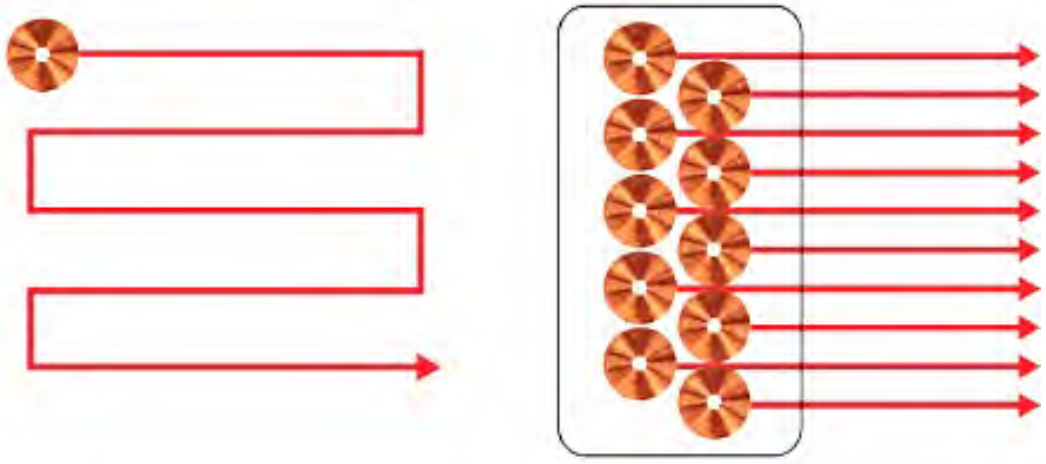
Eddy Current Array (ECA) Technology

- **Improves traditional ET using multiple coils in a single probe, enabling considerable area coverage in one pass without line-by-line scanning**
- **Each coil generates its magnetic field, and a unique multiplexing pattern avoids interference between coils**
- **Results are displayed as color-coded maps (C-scans), making inspection faster and easier to analyze**

Single-coil raster scan vs. array single pass



Pencil probe **Conformable ECA probe**

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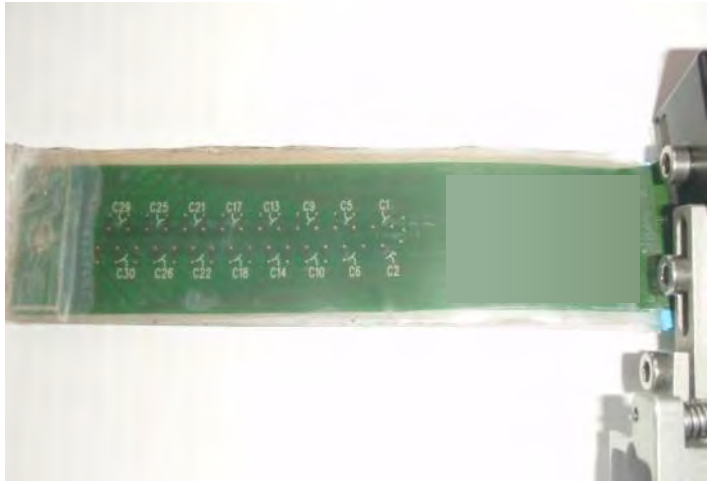
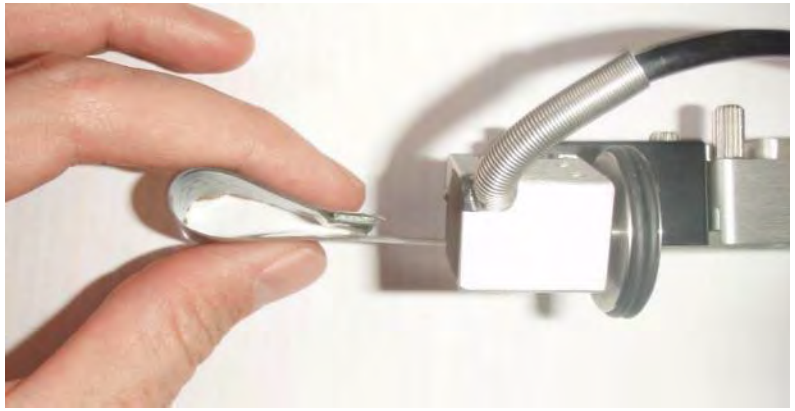
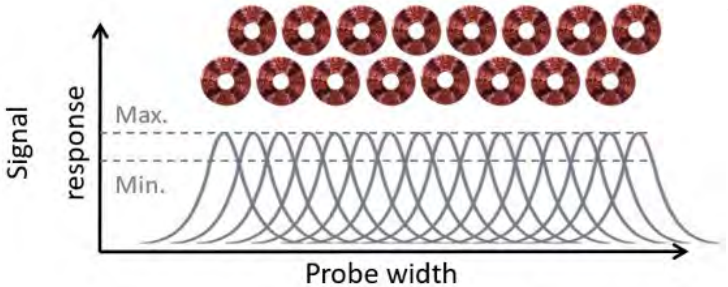
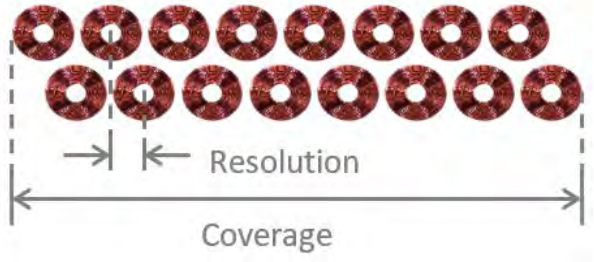
Flexible ECA Probe









- **24-circular orthogonal coil (0.072 in. or 1.8 mm) array, high-resolution**
- **Flexible (confirmable) array on a PCB film**
- **Frequency range: 200 kHz – 2 MHz**
- **Built-in multiplexer**
- **Coverage: 1.2 inch**
- **Resolution: 0.015 in. (0.3 mm) deep x 0.020 in. (0.5 mm) long x 0.003 in. (0.1 mm) width (flat plate) (2:1 aspect ratio)**
- **Position encoder for C-scan display of coverage**

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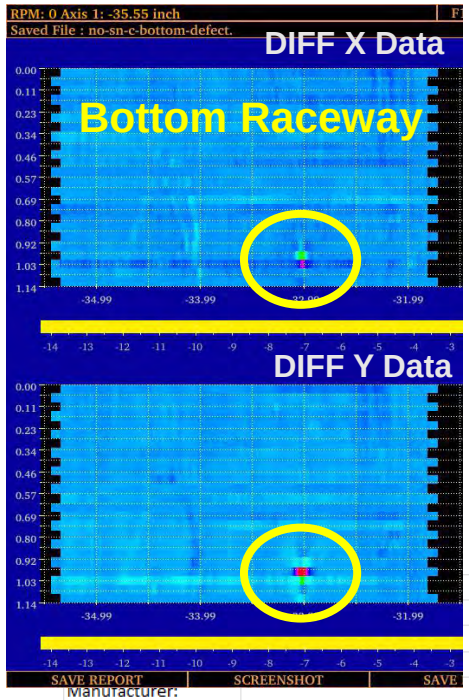
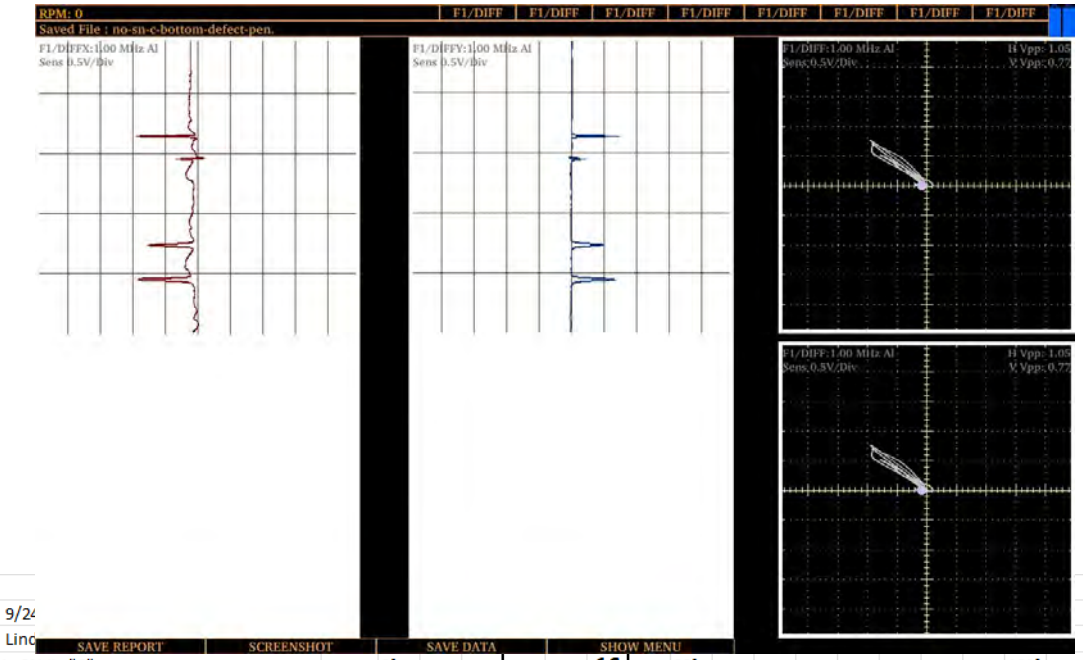
ECA / ET Results





No SN # - "C"

Manufacturer:	Timken	Height	0° 1	2	3	4	5	6	90° 7	8	9	10	11	12	13	14	15	16	180° 17	18	19	20	21	22	23	270° 24	25	26	27	28	29	30	31	32	Length
Comments:		0						16															13		14				15					0°	
1	large dimple repair	0.5																																	
2	shallow dimple repair	1.0																					Indication												Top/ Right
3	**large dimple repair**	1.5									12- light linear indications												13		14										
4	light indication lines	2.0					SAVE													1			CT						SAVE			2			
5	light indication lines	2.5																																	
6	light indication lines	3.0																																	
7	light indication lines	3.5																					SAVE												Center
8	light indication lines	4.0																																	
9	light indication lines	4.5																																	
10	**CRACK**	5.0									4		5		6	7	8	9					CRACK						Repair						
11	**strong indication - Defect**	5.5					CT				4		5		6	7	8	9						10						3					Bottom/ Left
12	Linear indication	6.0					11																CT						CT						
13	**indication but not a defect**	6.5																																	
14	strong indication with array- indication at a small spot with pen	7.0																																	
15	Save remainder		Manufacture Name starts at 0°																																
16	Save remainer							11																10					3						

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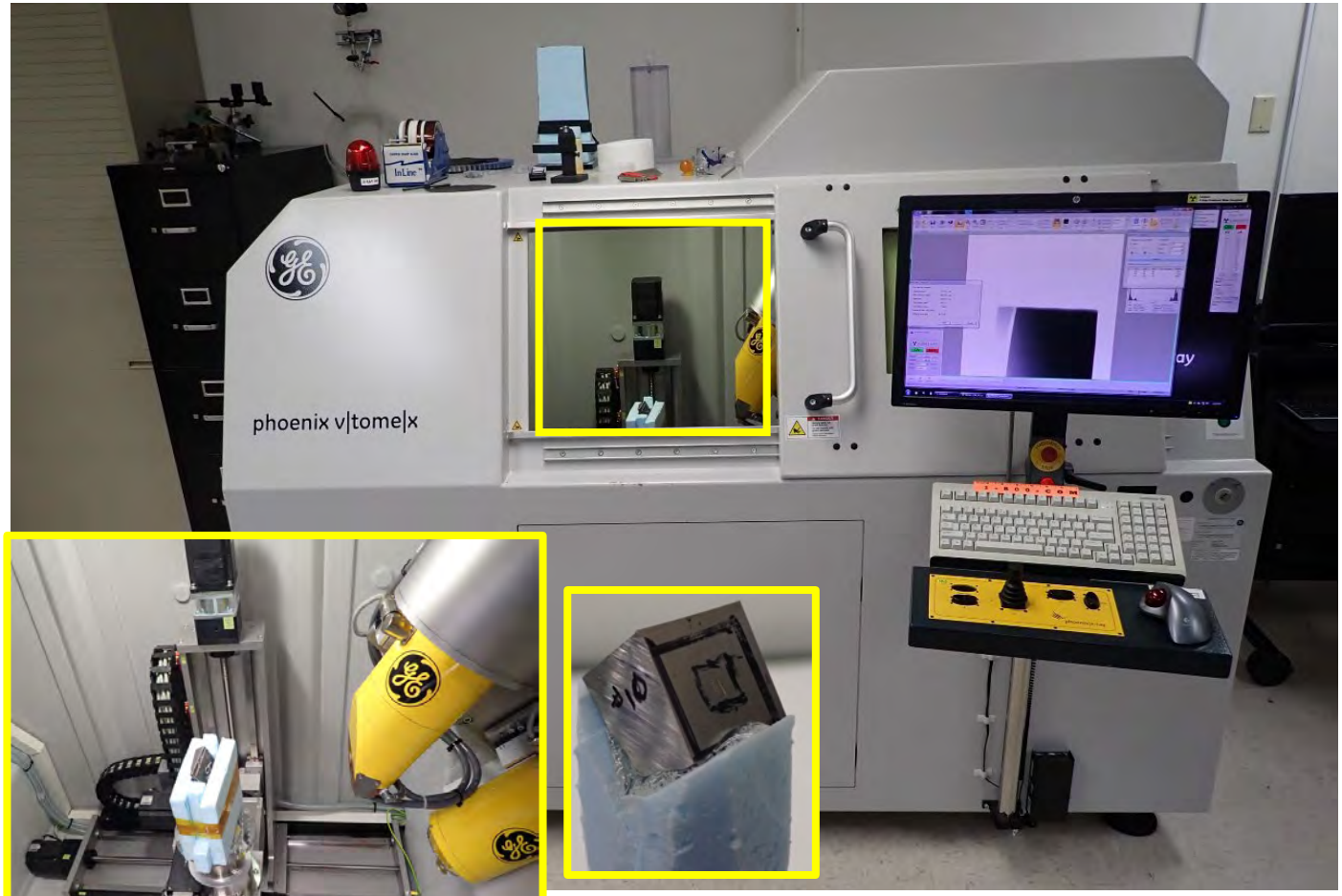
ECA Validation

- **X-ray computed tomography (CT) was used for ECA validation**
- **Sample size: 0.70-inch cube**

CT Scan Parameter

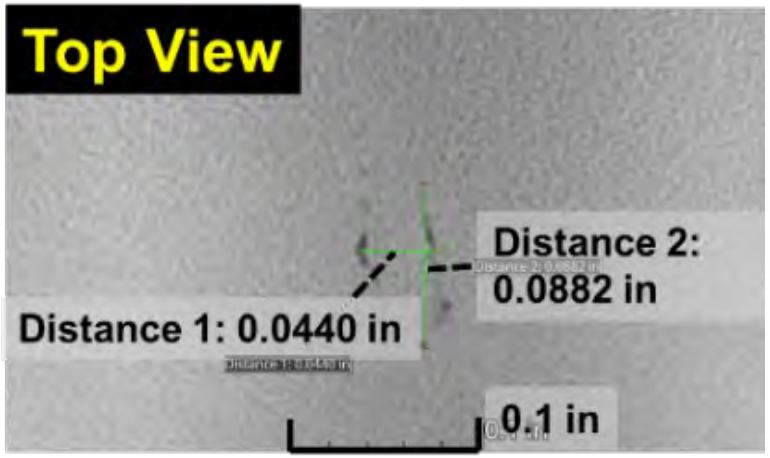
Sample ID	#10	#11	#12A/B
Focal Spot (µm)	39.775	19.35	19.35
Detector Pitch (µm)	100	100	100
Source-Detector distance (mm)	612.6	701.2	701.2
Source-Object distance (mm)	174	64.27	64.27
Magnification	3.52x	10.91x	10.91x
Voxel size (µm)	28.4	18.33	18.33
Total Projections	1150	1800	1800
Frame Averages	4 @ 0.5 FPS	4 @ 1 FPS	4 @ 1 FPS
Scan Time (hrs)	4.2	3.5	3.5

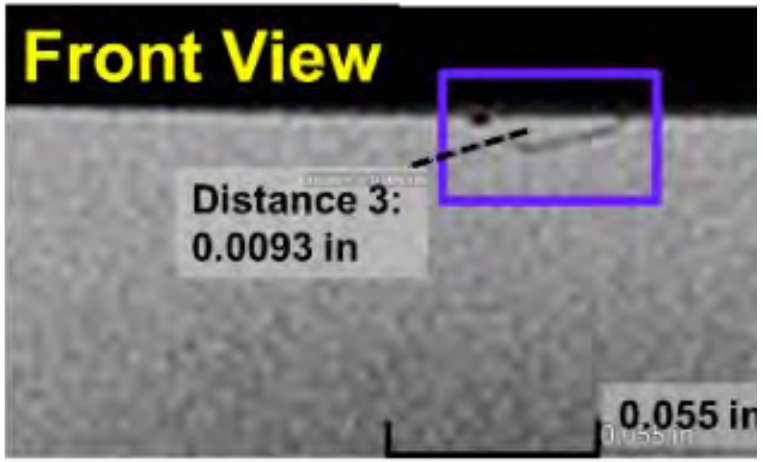


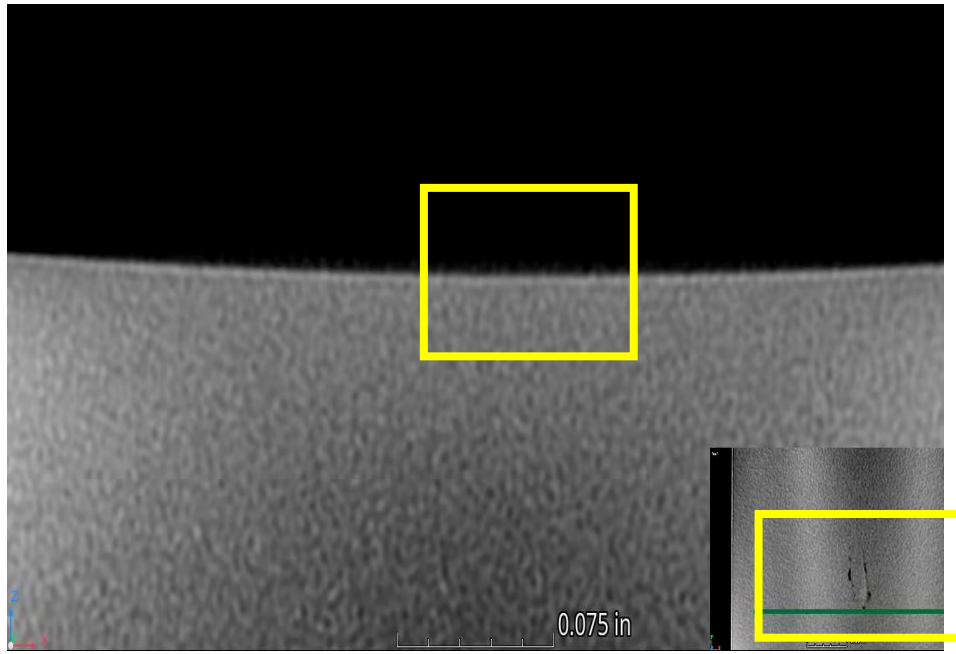
220kVp V|TOME|X GE CT Scanner

Contracted with The Aerospace Corporation

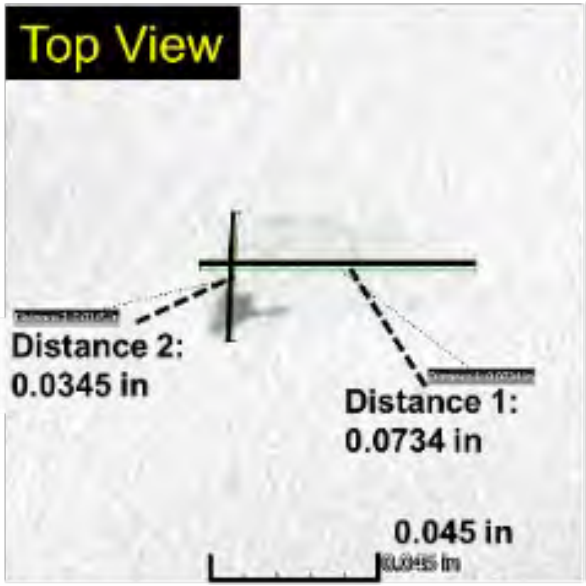
CT Scan Results

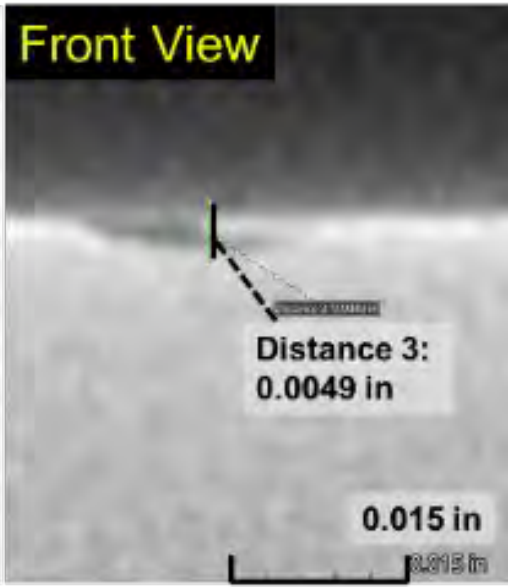




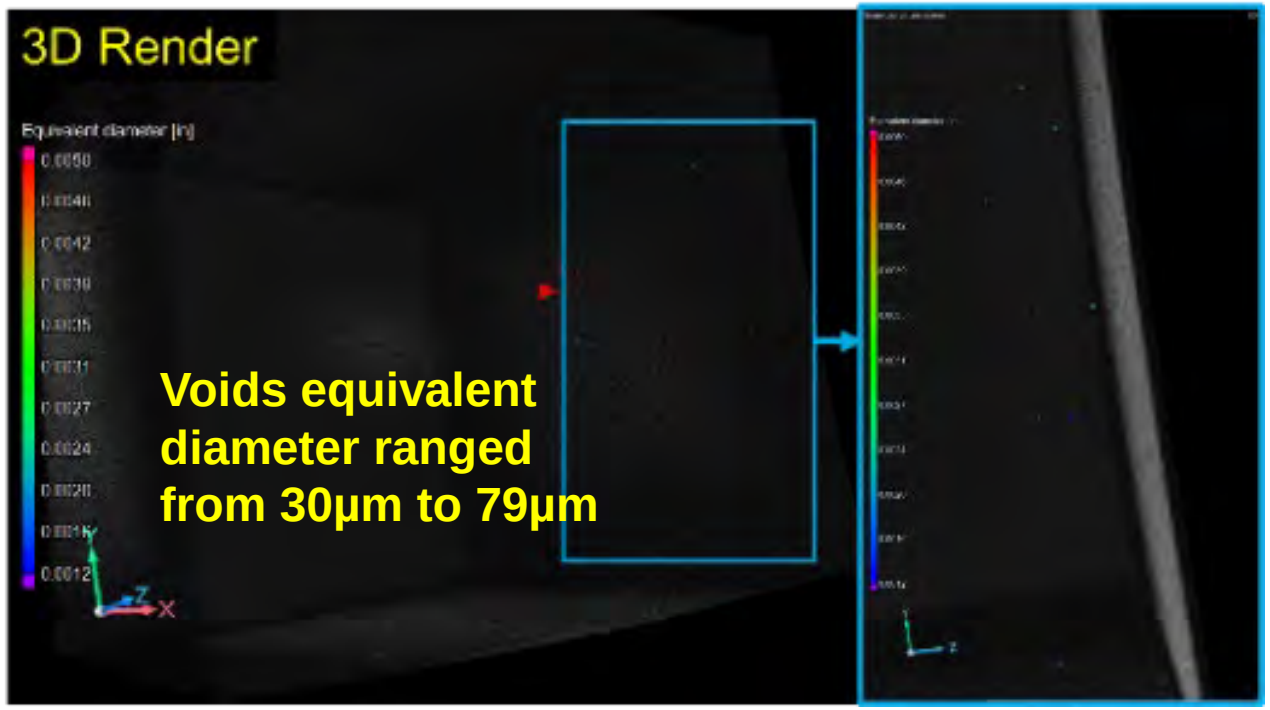


Sample 10





Sample 11



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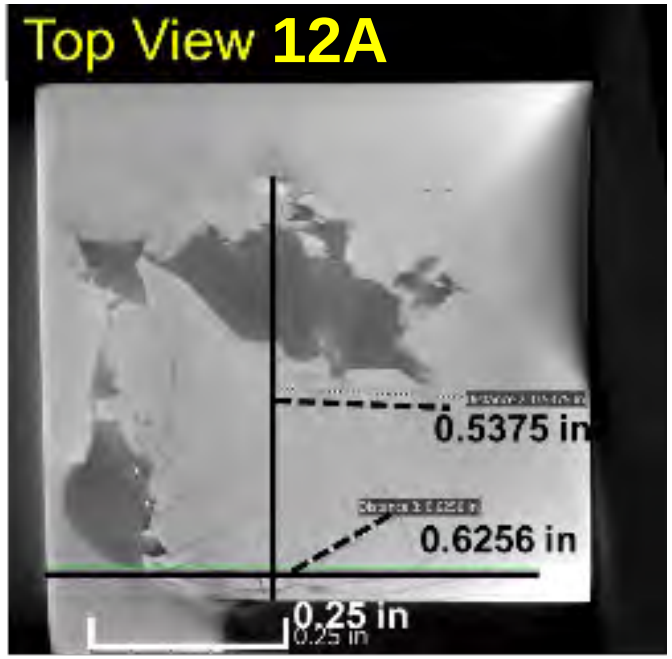
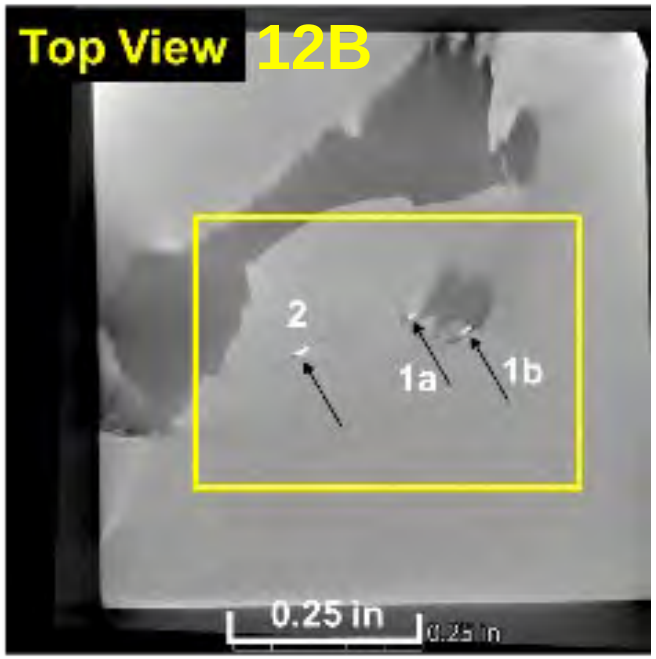
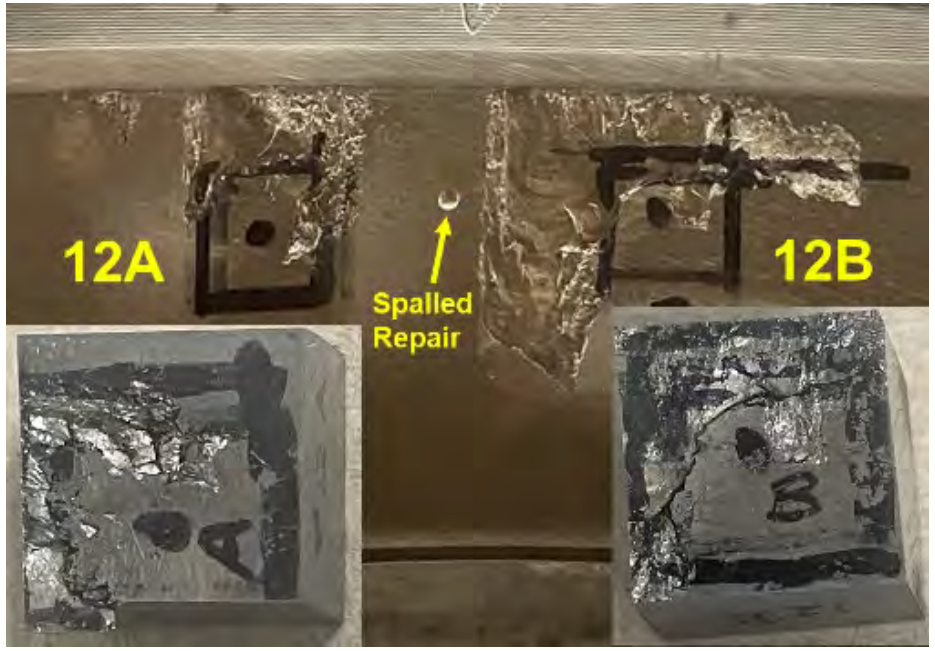
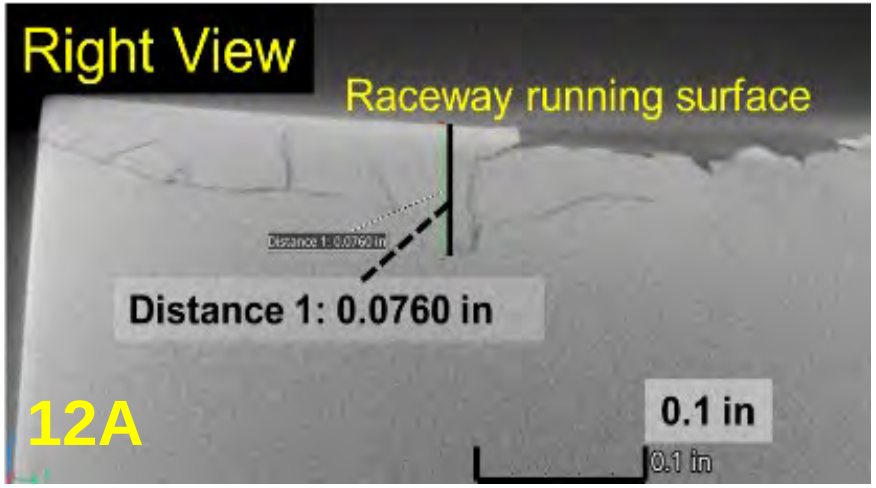
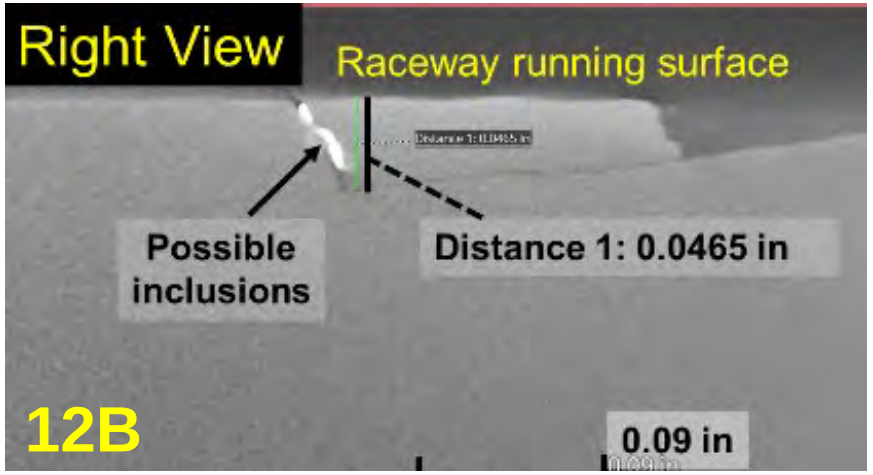
CT Scan Results- Sample 12

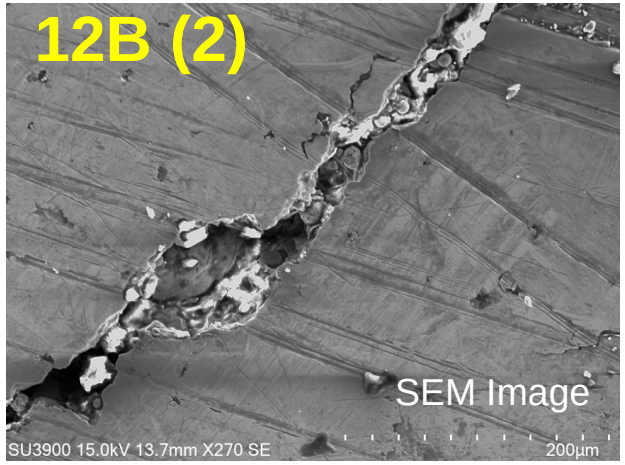












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Summary

- **The SRI program explores/facilitates development of inspection technologies for potential implementation by railroads**
- **Improvements in inspection technology improve rail safety and efficiency, and benefits employees and stakeholders**
  - Technology enables performance-based safety improvements
- **Technology not used in a vacuum; people are an important part of the equation**
- **Skilled people make things happen and get things done. Proper and standardize trainings are required for effectively implementing technologies**

Acknowledgements

- AAR Technology Advisory Groups
- AAR Research Committee
- Original Equipment Manufacturers
- MxV Rail NDE MET Team
  - Brian Lindeman
  - Survesh Shrestha
  - John Krasovic
  - Denise Valdez
  - Kerry Jones

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Draft Systems Research

Adam Klopp
Principal Investigator II

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Overview

- Project Objectives
- Draft System Standards
- Damage Prevention Standards
- Damage Prevention Impact Tests
- Concluding Remarks

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Project Objectives

- **Reduce draft system related service interruptions and increase train make-up flexibility by researching and improving draft system design and performance**
- **Improve draft system performance**
  - Impact energy management
  - Train action control
  - Limit in-train forces
- **Reduce service interruptions**
  - Component failures
  - Broken knuckles
  - Train separations

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Draft System Standards

- **Most draft systems are draft gears or end-of-car cushioning (EOCC) units**
- **AAR *Manual of Standards and Recommended Practices* (MSRP) requirements for these systems include:**
  - M-901 series for draft gears
  - M-921 series for EOCC units
- **Testing focused on impact energy absorption**

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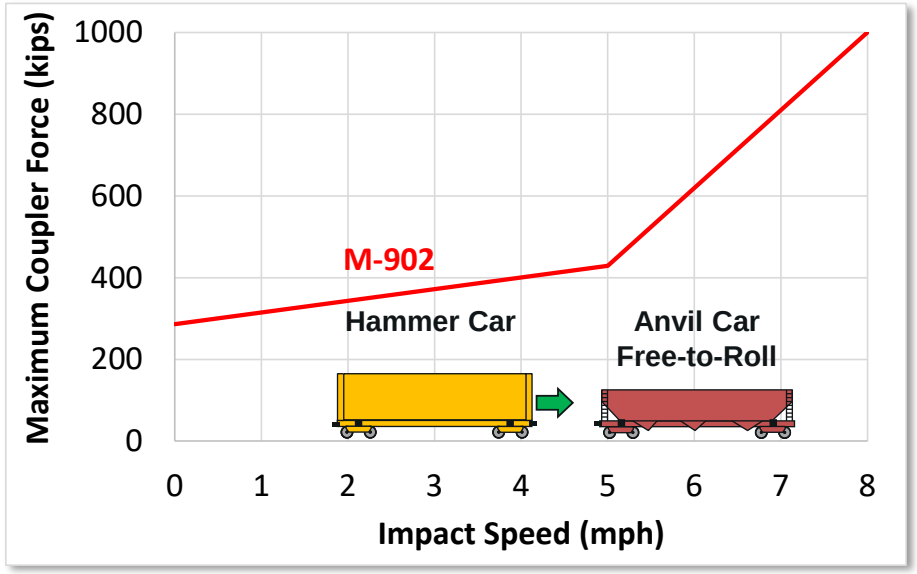
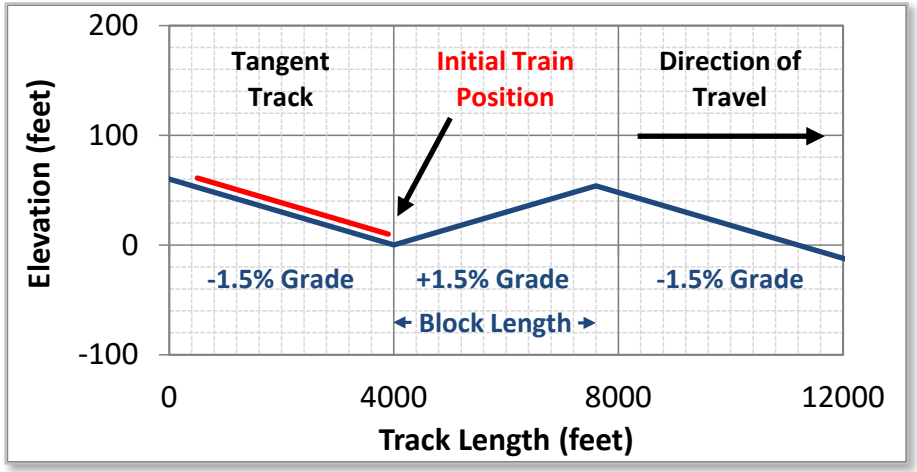
Updated Draft System Standards

M-902 Impact Test Coupler Force Limit



RP-906 Drifting Simulation



- **EOC Energy Management Task Force developed and implemented new standards for "hybrid" draft systems**
  - M-902: End-of-Car Energy Management Systems
    - Requirements for systems that are not draft gears or EOCC units
  - RP-906: Methodology for Multi-Car Drifting Simulations
    - Modeling to evaluate in-train draft systems performance

Damage Prevention Standards

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- **Current standards in the MSRP have a mechanical focus**
- **Series of functional impact requirements also exist that focus specifically on freight effects**
  - Closed Car Loading Standards (GIB No. 2)
  - Open Top Loading Rules (Sec. 1, Rule 36)

Damage Prevention Impact Tests

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8/21

- **Collaborated with Damage Prevention and Loading Services (DP&LS)**
- **Conducted boxcar impact tests with paper roll load to:**
  - Support the evaluation of current Damage Prevention Standards
  - Characterize the current impact environment experienced by cars
  - Evaluate the lading response to different draft system types

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Impact Test Measurements

- **60-foot boxcar loaded with paper rolls to 250,000 pounds and equipped with one of the following draft system types:**
  - Hydraulic 15-inch EOCC units
  - Dual draft gear “hybrid” systems
  - Standard draft gears
- **Measurements included:**
  - Car speed
  - Coupler force and displacement
  - Carbody accelerations
  - Paper roll accelerations

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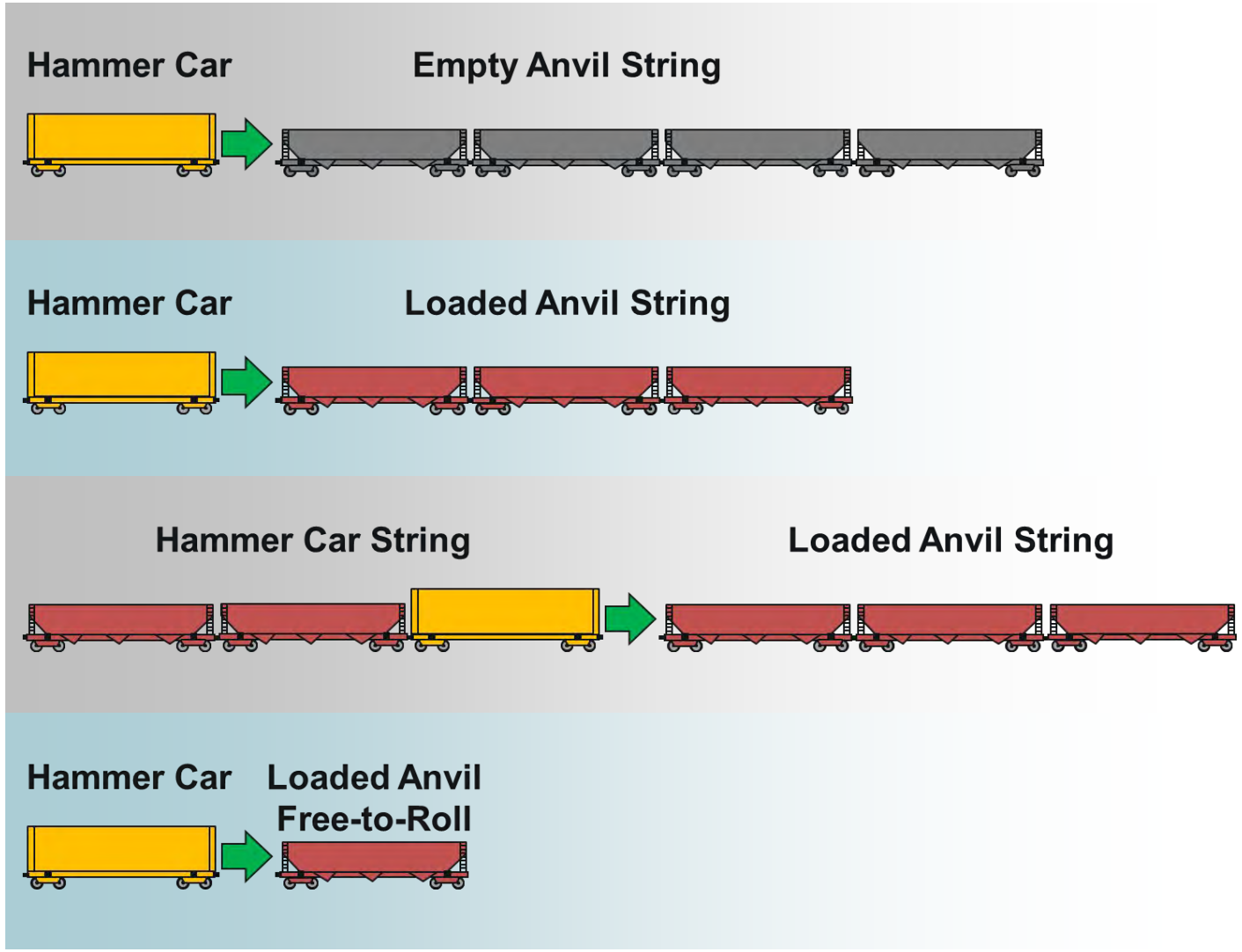
Impact Test Setup

1. **Impacts into Empty Anvil String**
   - Similar to Closed Car Standard Impact Test
2. **Impacts into Loaded Anvil String**
   - Similar to M-921B Impact Performance Test
3. **Impacts with three-car Hammer String**
   - Similar to flat switching event with multiple-car cut
4. **Impacts into Free-to-Roll Loaded Anvil Car**
   - Similar to new M-902 Impact Test



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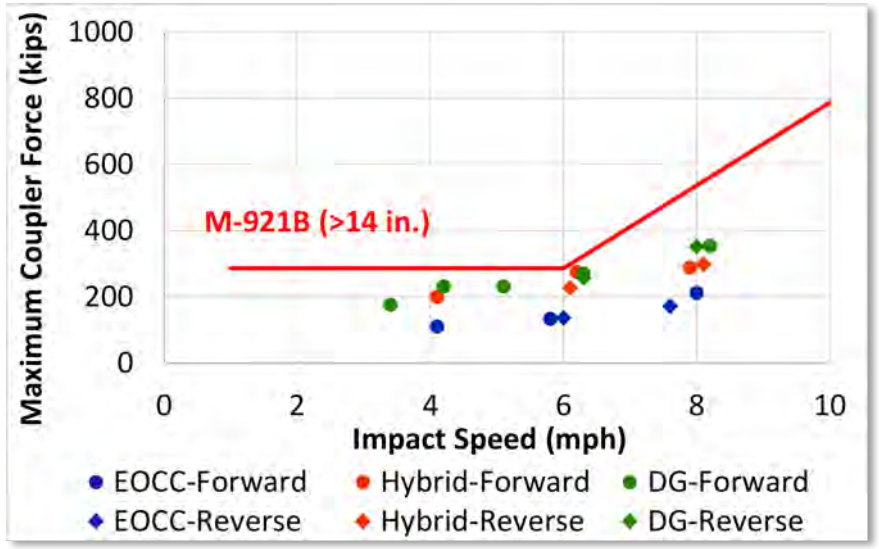
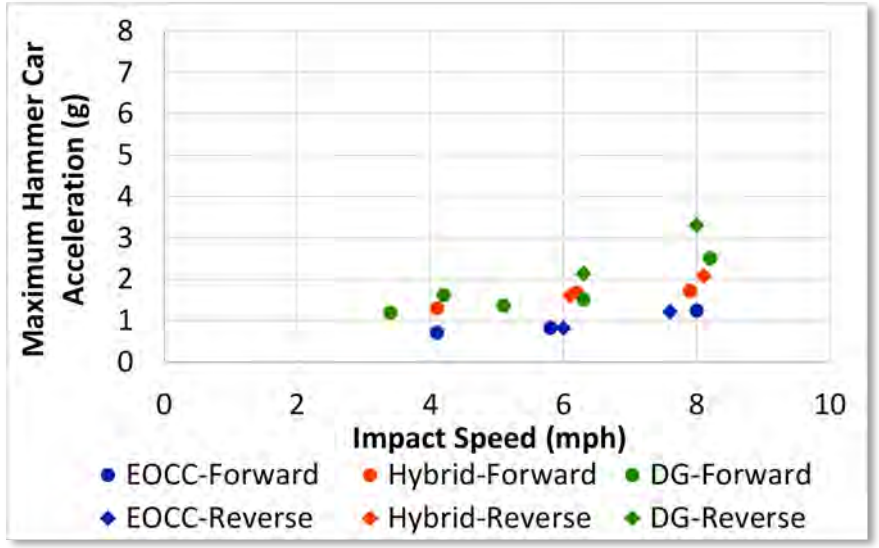
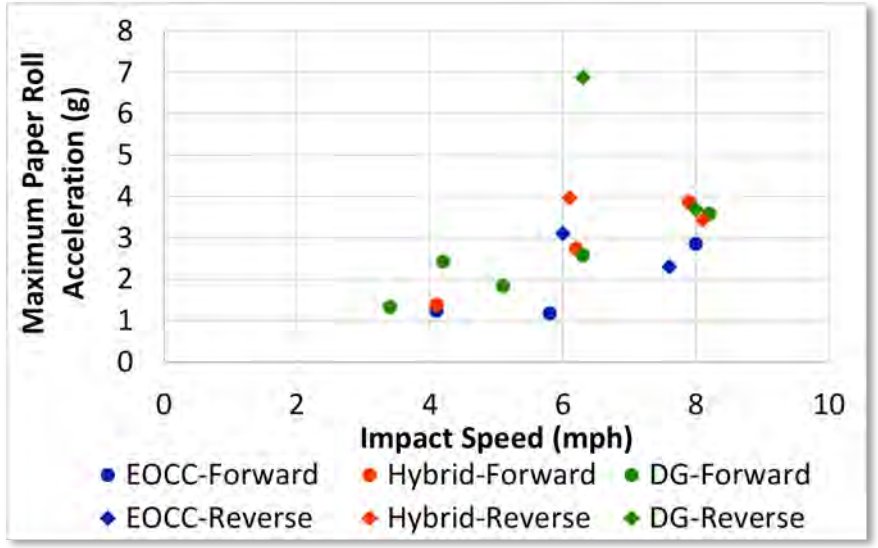
Results-Impacts into Empty Anvil String



- **Results of empty anvil string impacts discussed in TD24-024**
- **Forces and accelerations lowest for EOCC units, highest for draft gears**
  - Similar trends for all impact sequences tested





Example-Impact into Empty Anvil String

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- **Boxcar equipped with 15-inch EOCC units**
- **Paper rolls continue moving forward after impact**
  - Forced to decelerate more quickly than the car
- **Generally increased paper roll movement for first reverse direction impact**

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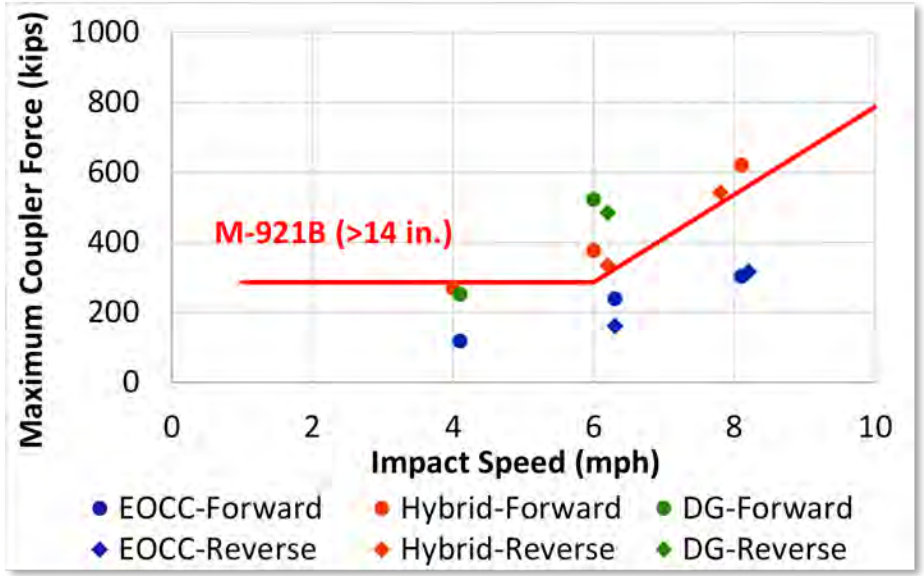
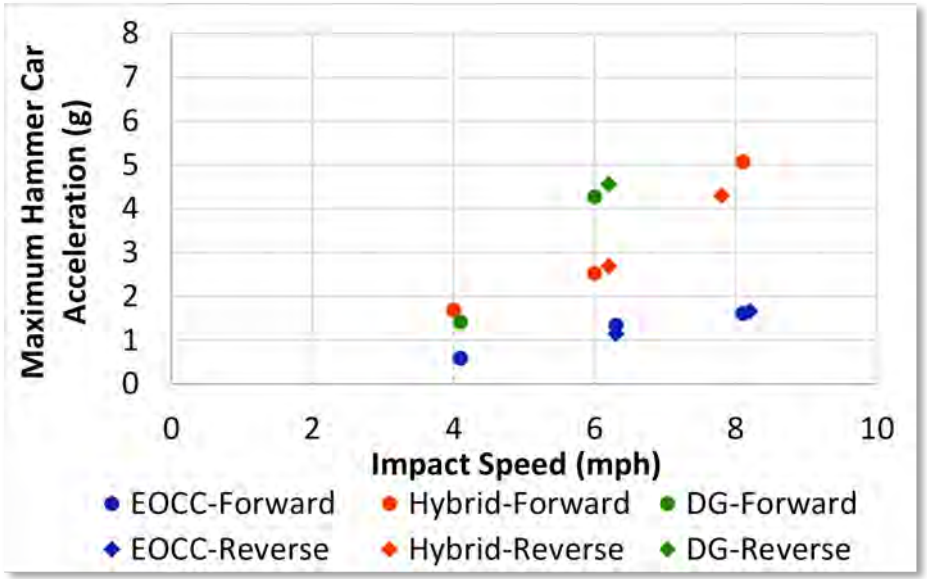
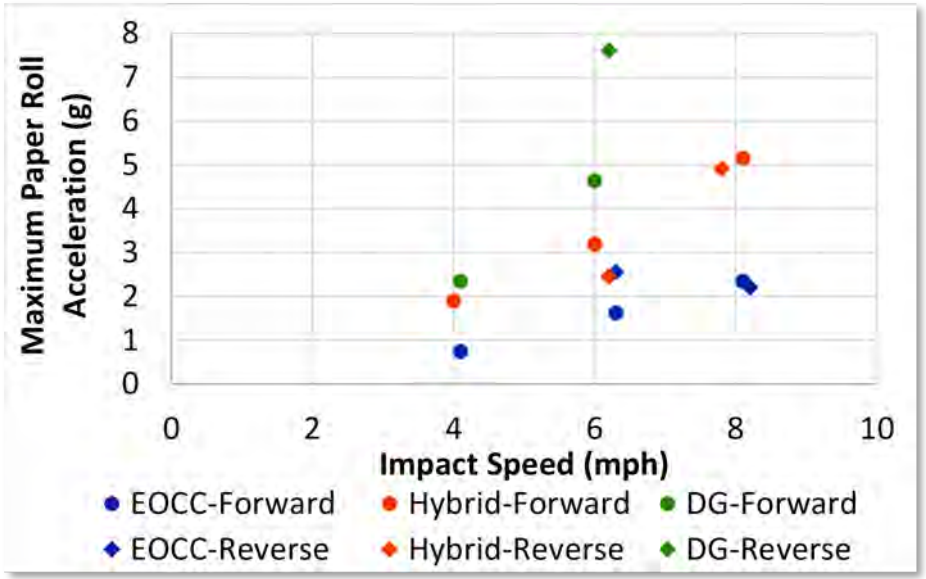
Results-Impacts into Loaded Anvil String

- **Higher forces and accelerations than empty anvil impacts**
- **Draft gear boxcar limited to 6-mph for subsequent impacts due to high car/paper roll accelerations**







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Example-Impact into Loaded Anvil String

- **Boxcar equipped with standard draft gears**
- **6-mph impact reverse direction**
- **High force, acceleration impact, due to:**
  - Higher anvil string weight
  - Draft system type

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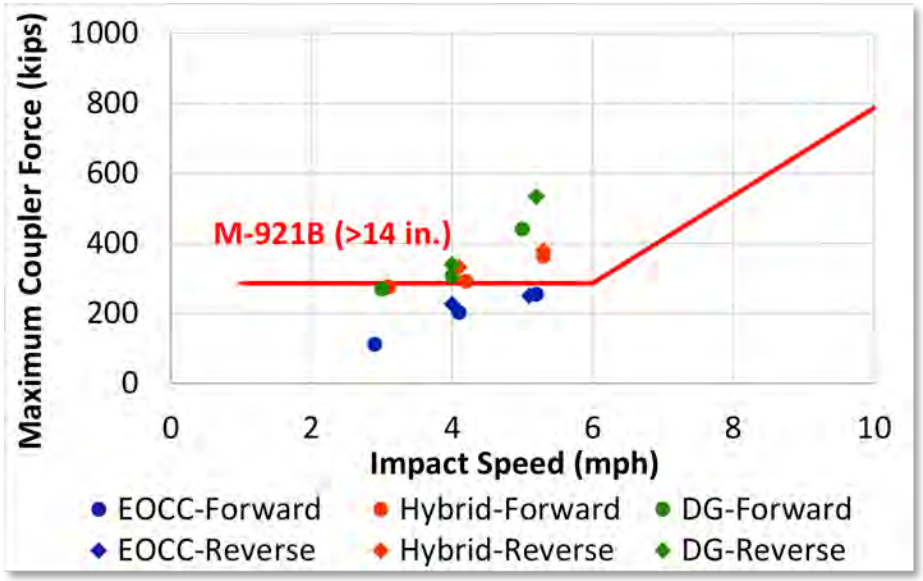
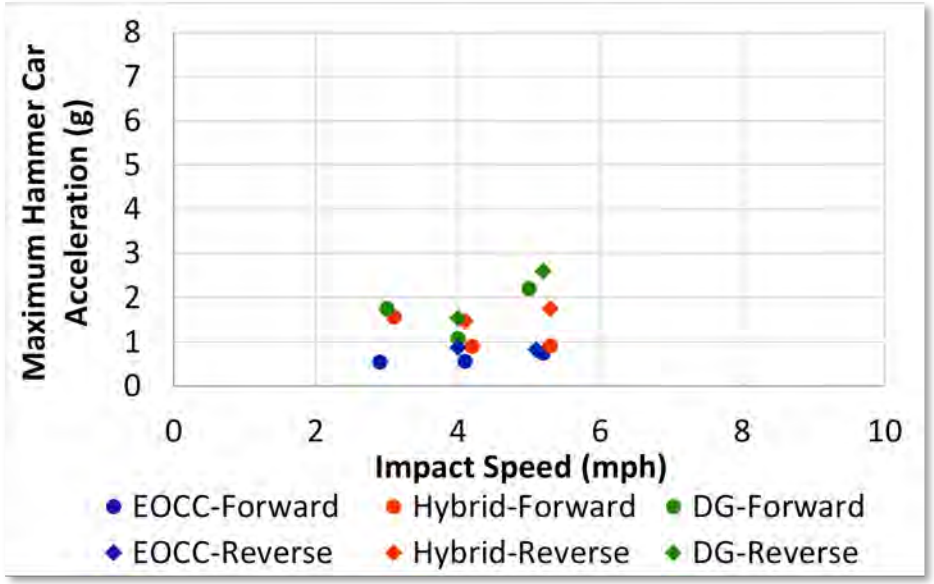
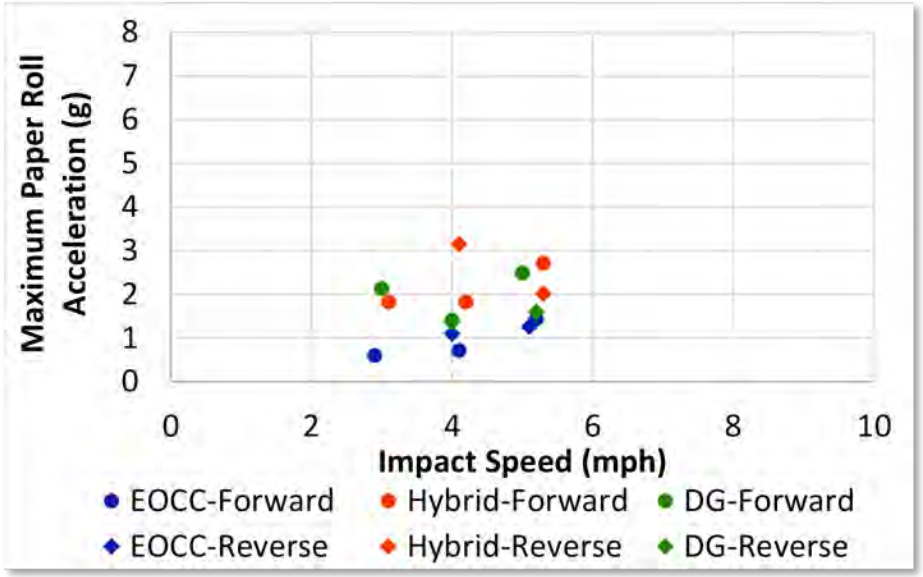
Results-Impacts with Three-car Hammer String



- **Higher forces at lower speeds for all draft systems tested due to:**
  - Increased mass of the moving hammer string
  - Exhausting available buff stroke at lower speeds





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Example-Impact with Three-car Hammer String

- **Boxcar equipped with hybrid dual draft gear system**
- **4-mph Impact reverse direction**
- **Despite higher coupler force, lower accelerations were measured**
  - Heavier hammer string continues moving forward after impact

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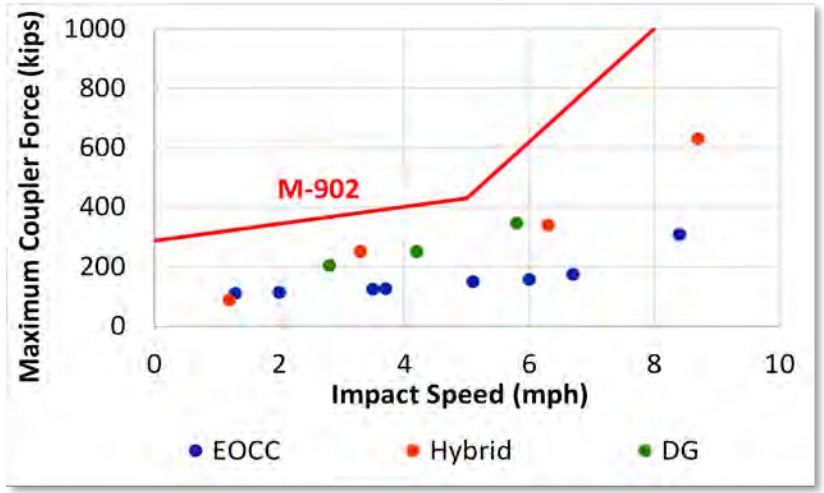
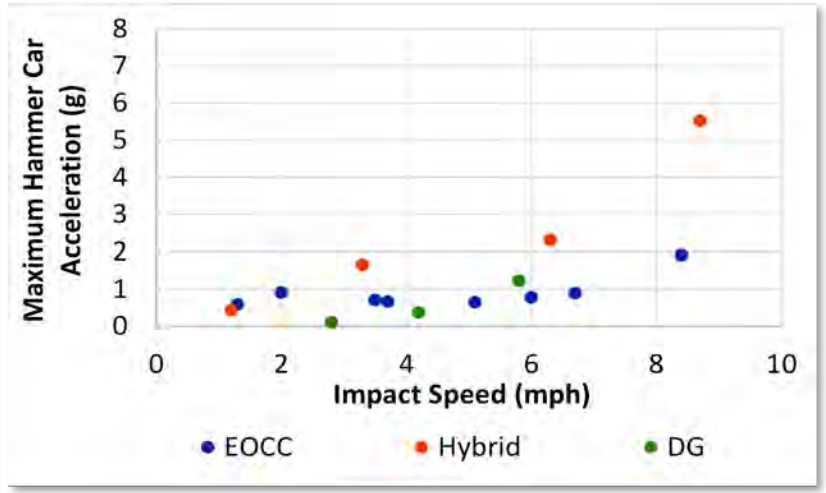
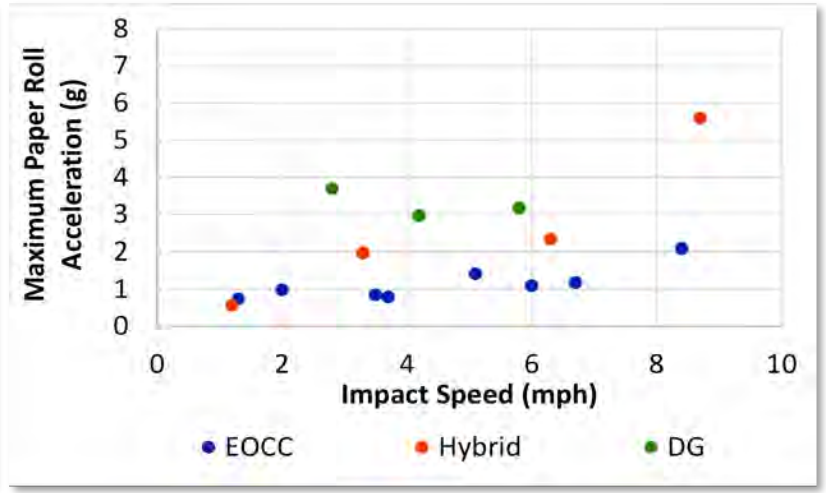
Results-Impacts into Free-to-Roll Anvil Car

- **Similar maximum forces and car accelerations as impacts into loaded anvil string**
- **Paper rolls compacted toward the struck end, especially when the boxcar contained draft gears**







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Example-Impact into Free-to-Roll Anvil Car

- **Boxcar equipped with hybrid dual draft gear system**
- **8-mph Impact (only forward direction)**
- **High coupler forces and accelerations, similar to loaded anvil string impacts**
  - Did not test draft gear boxcar to highest 8-mph speeds

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Freight Observations

- **Paper roll movement and damage was more significant for:**
  - Impacts into the loaded anvil string and free-to-roll anvil car
  - Boxcars containing draft gears and hybrids systems
- **Included outward lateral roll movement, crushed cores, core out-of-rounds, and roll chaffing**

Crushed core

Core out-of-round

Lateral movement into the doorway

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Conclusions

- **Impact coupler forces, carbody/paper accelerations, and paper accelerations generally lowest when the boxcar was equipped with EOCC units, highest with draft gears.**
- **Paper roll movement and damage more significant for:**
  - Impacts into the loaded anvil string and free-to-roll anvil car
  - Boxcars containing draft gears and hybrid systems
  - During first reverse direction impact in each series, while load transitions from compressed to uncompressed
- **Most severe test sequence was impacts into the loaded anvil string. Least severe was impacts into the empty anvil string.**

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Acknowledgements

- TTX Company
- Union Pacific Railroad
- EOC Energy Management Task Force
- MxV Rail staff

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Brake Systems Research

Yi Wang, Ph.D., P.Eng.
Principal Investigator

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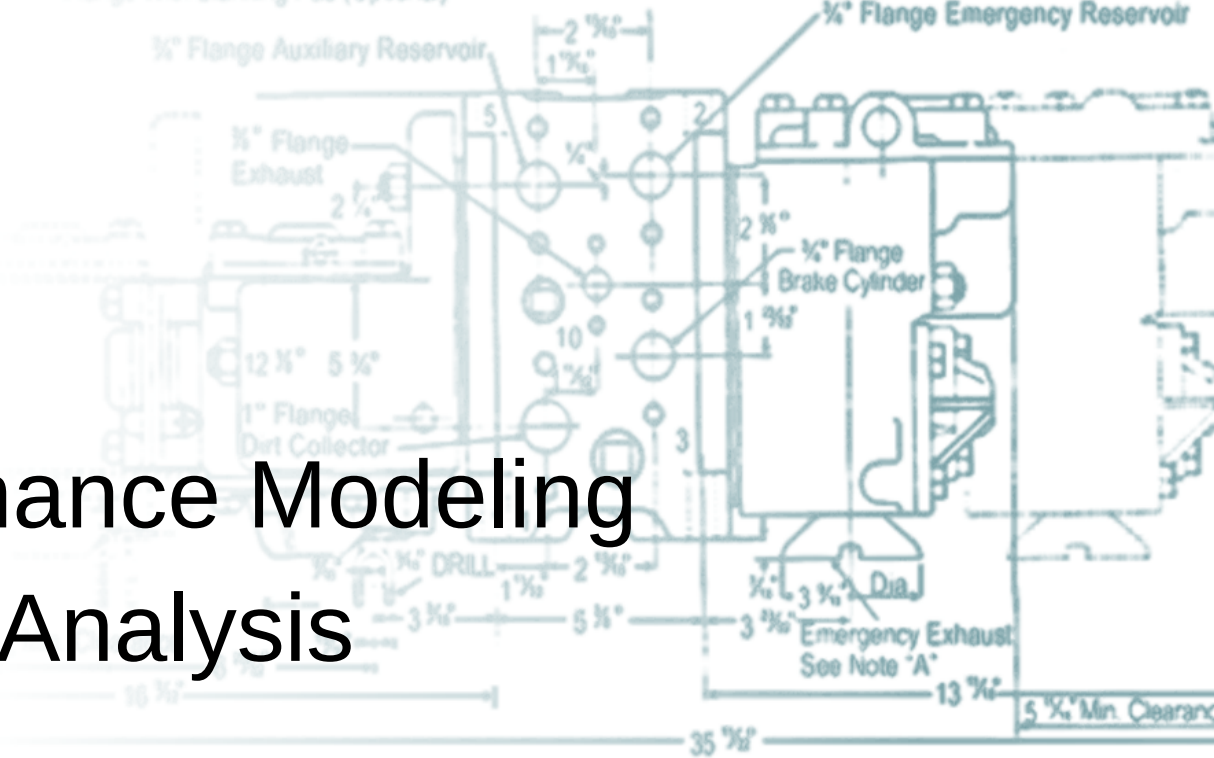
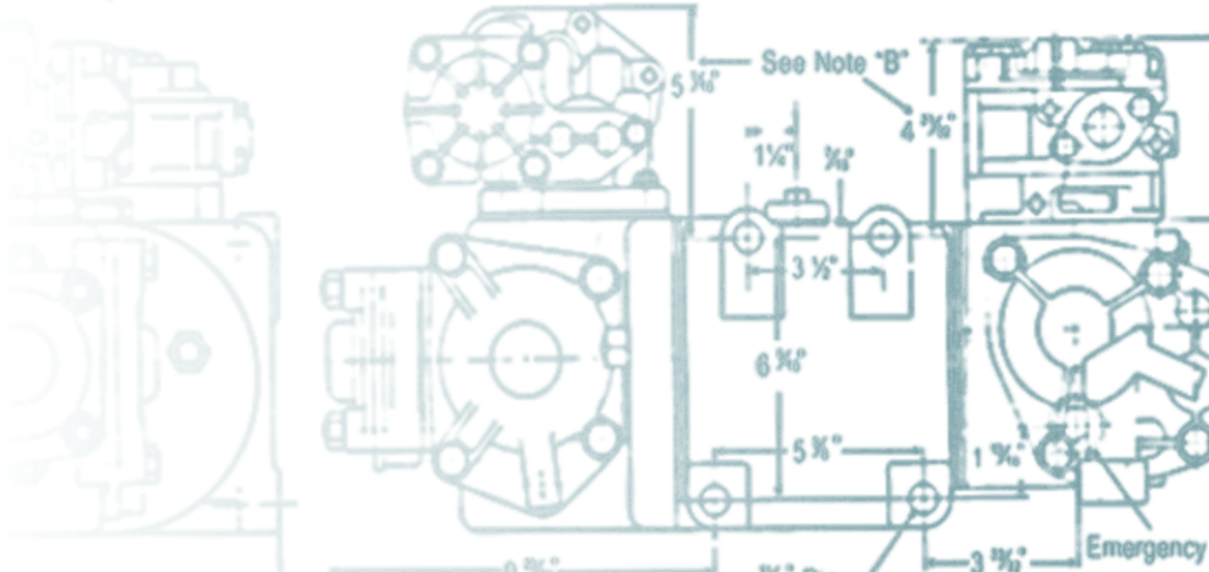
Overview

- **Introduction**
- Updates on Brake Performance Modeling
- Cold Wheel Process Data Analysis
- Ongoing Research
- Summary





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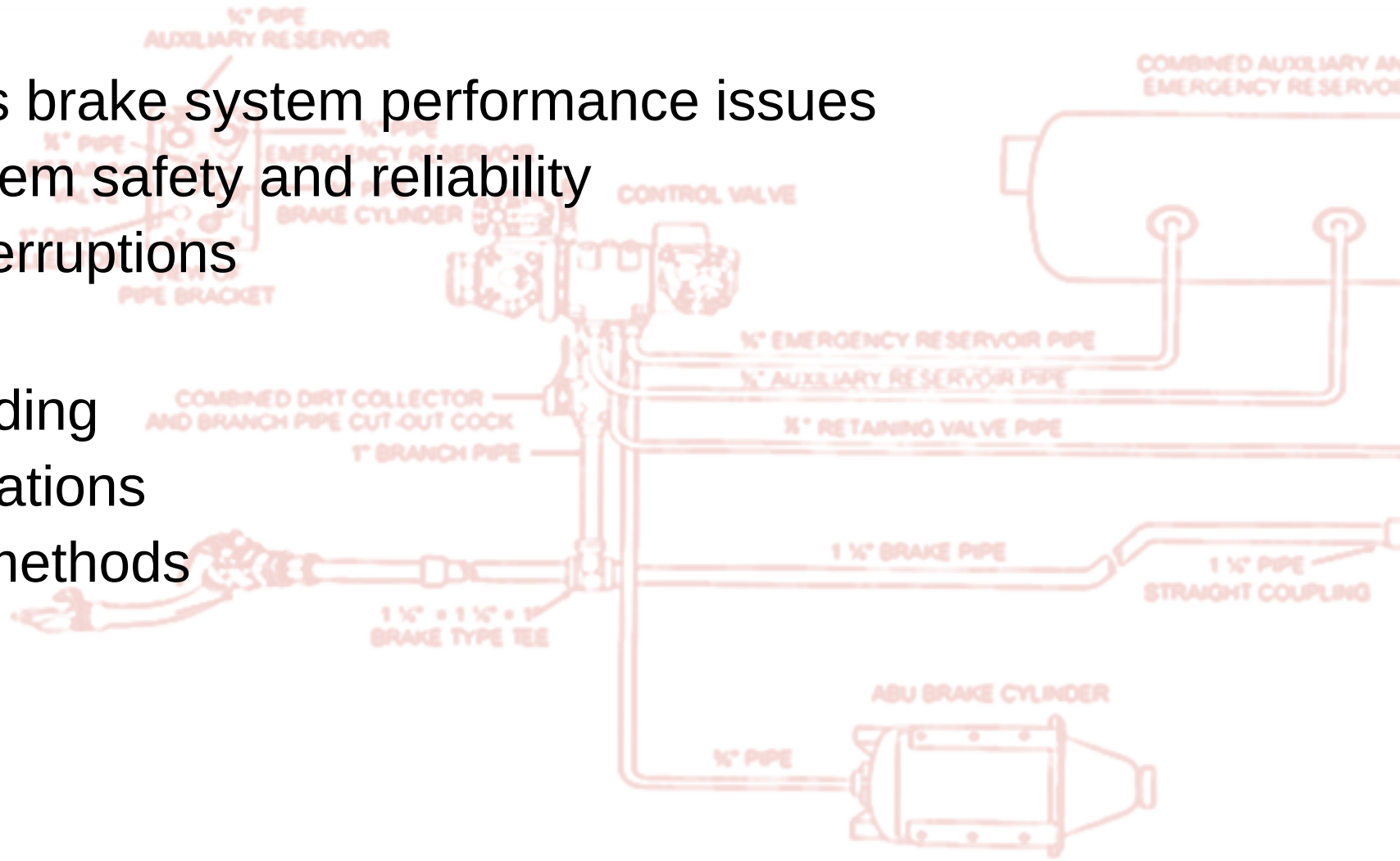
Brake Systems Research

- **Objectives**
  - Detect and address brake system performance issues
  - Improve brake system safety and reliability
  - Reduce service interruptions
- **Approaches**
  - Improve understanding
  - Support implementations
  - Explore tools and methods



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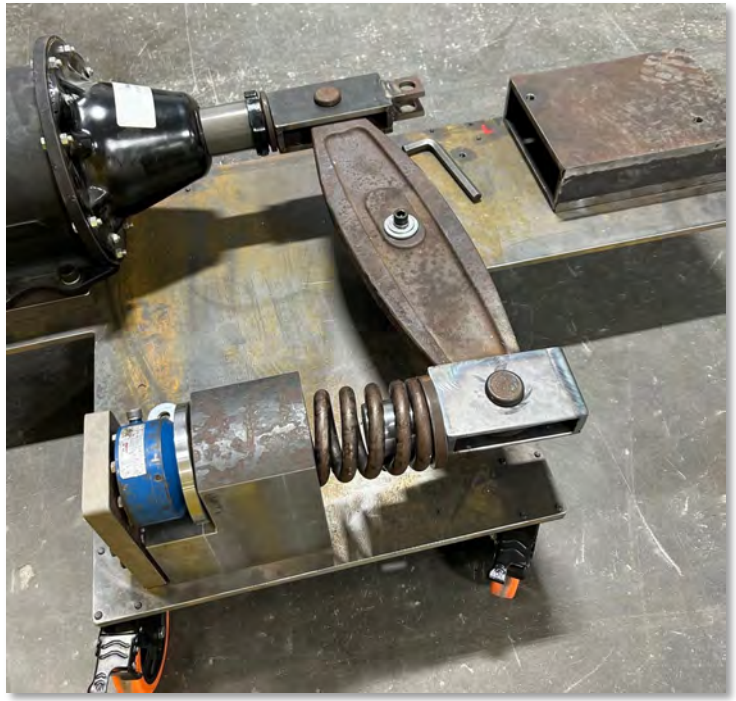
Ongoing Topics

- **Teardown of tested control valves**
- **Automatic secondary securement devices**
- **Survey of cross-industry research and methods**
- **Develop more advanced tools for brake system modeling**



Overview

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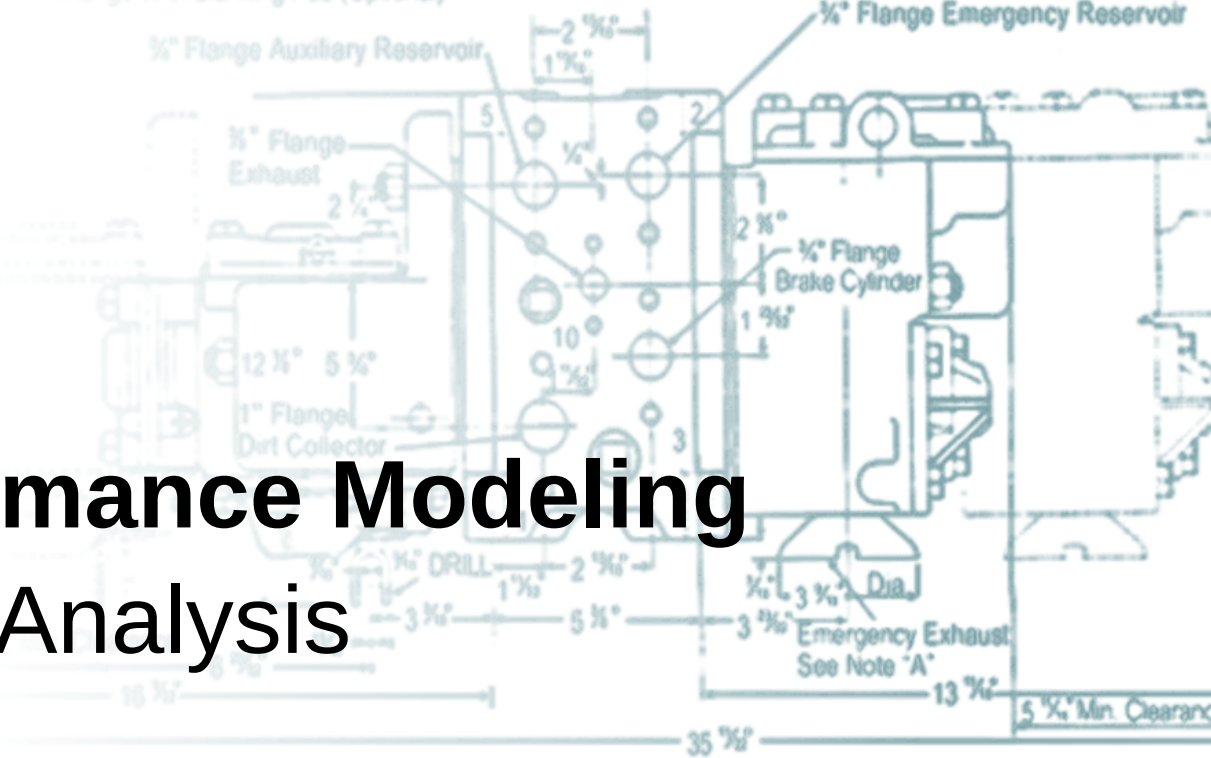
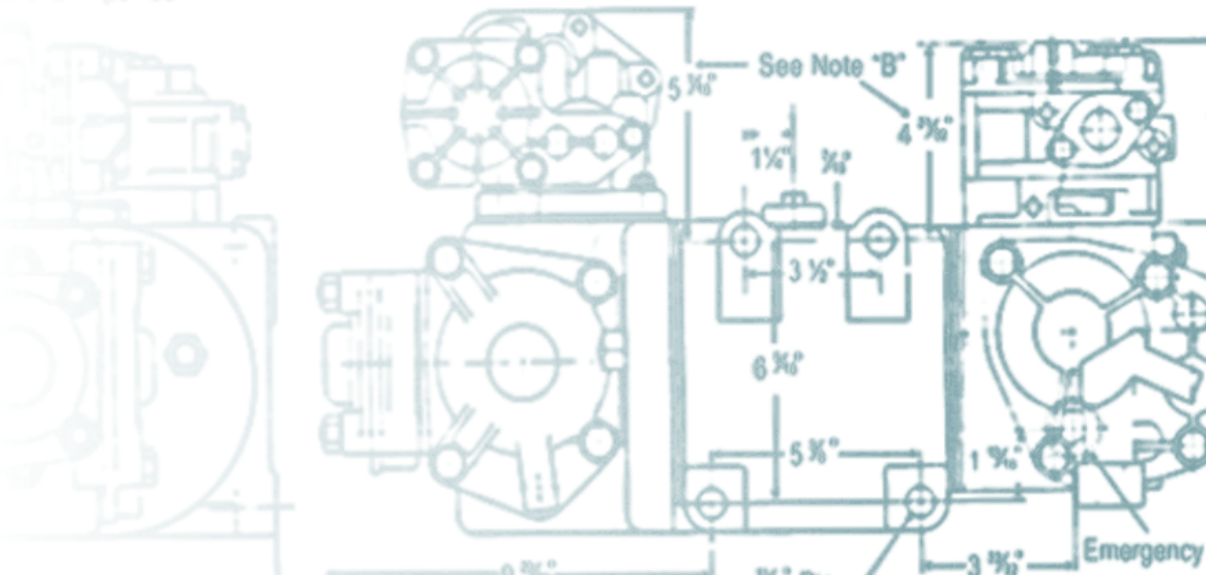
- **Updates on Brake Performance Modeling**
- Cold Wheel Process Data Analysis
- Ongoing Research
- Summary





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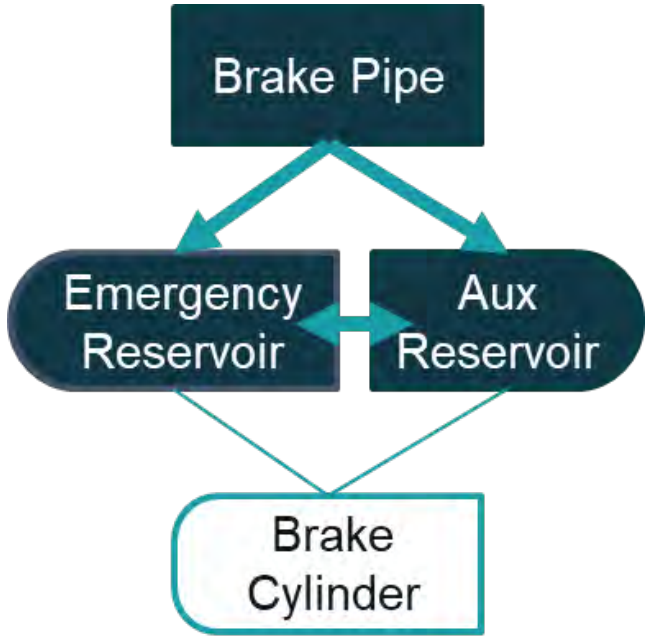
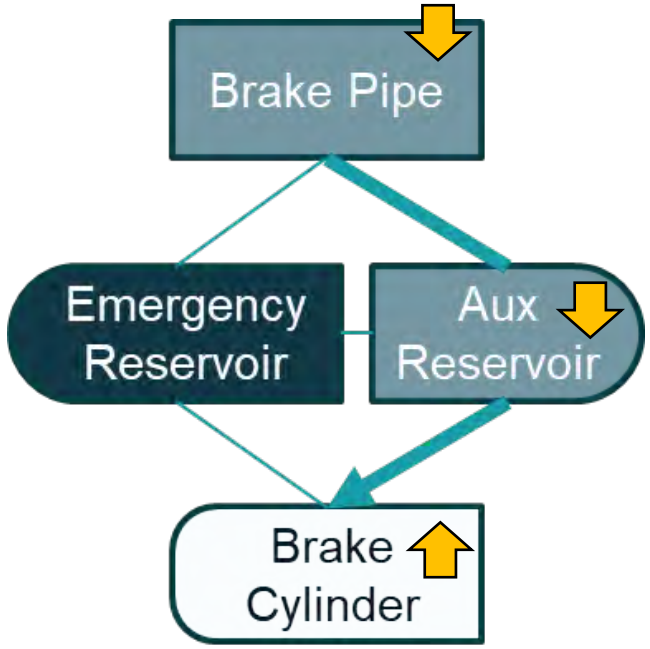
Recap

- **Relationship between pressures in the brake pipe (BP), auxiliary reservoir (AR), emergency reservoir (ER), and brake cylinder (BC)**
- **Flow of air through the control valve**

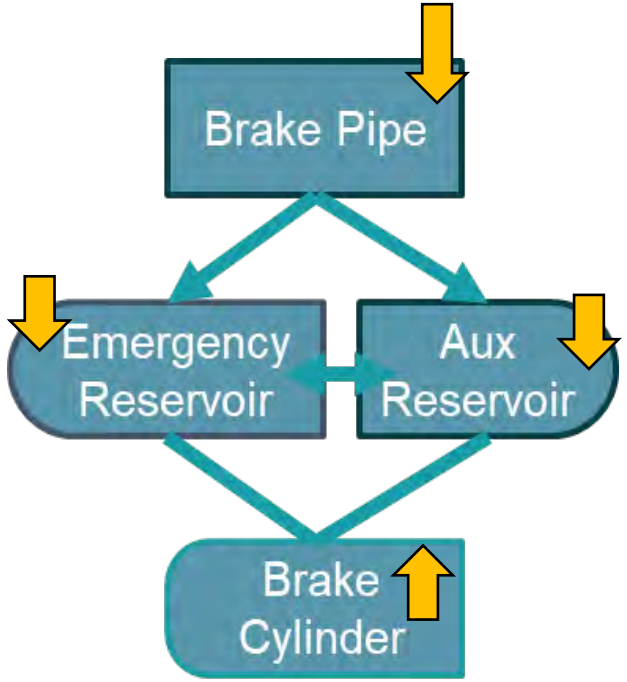
Brake charging/released, BP, ER, AR reach equilibrium



Service braking, AR pressure follows BP fills the BC



Emergency braking, BP rapidly goes to zero, ER, AR, BC reach equilibrium



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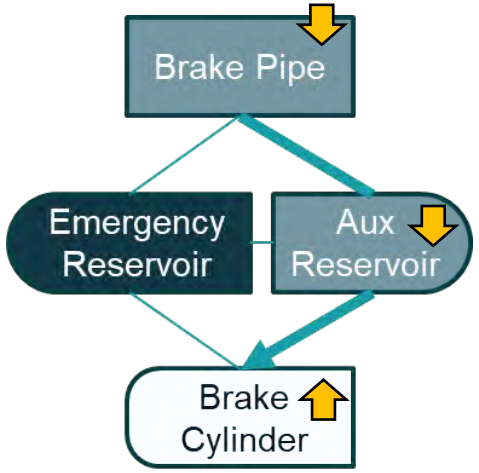
Recap

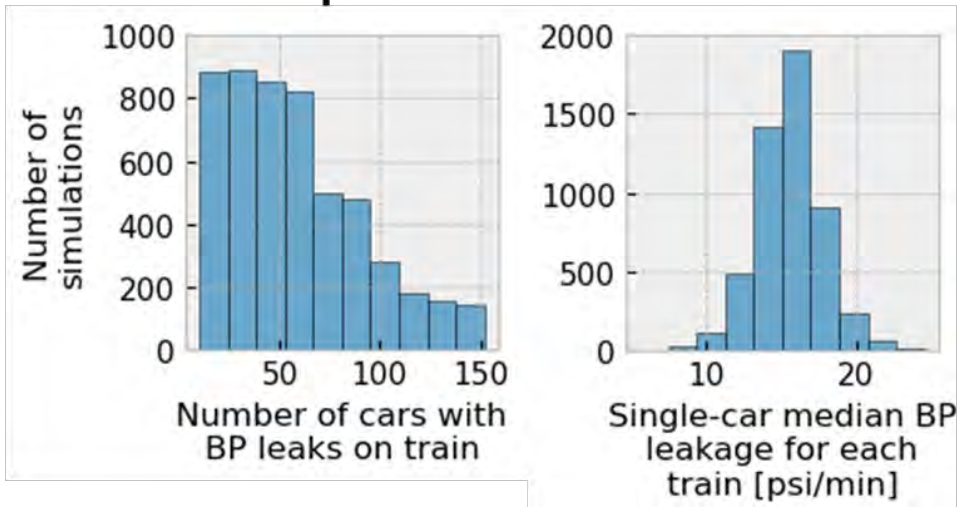
- **TOES™ simulations performed to model concentrated brake pipe (BP) leakage**
- **Effect on brake cylinder pressure discussed last year**
- ***Technology Digest* TD24-002 and TD24-012**



Leakage from BP reduces available air in the AR

200-car consists

Simulation inputs



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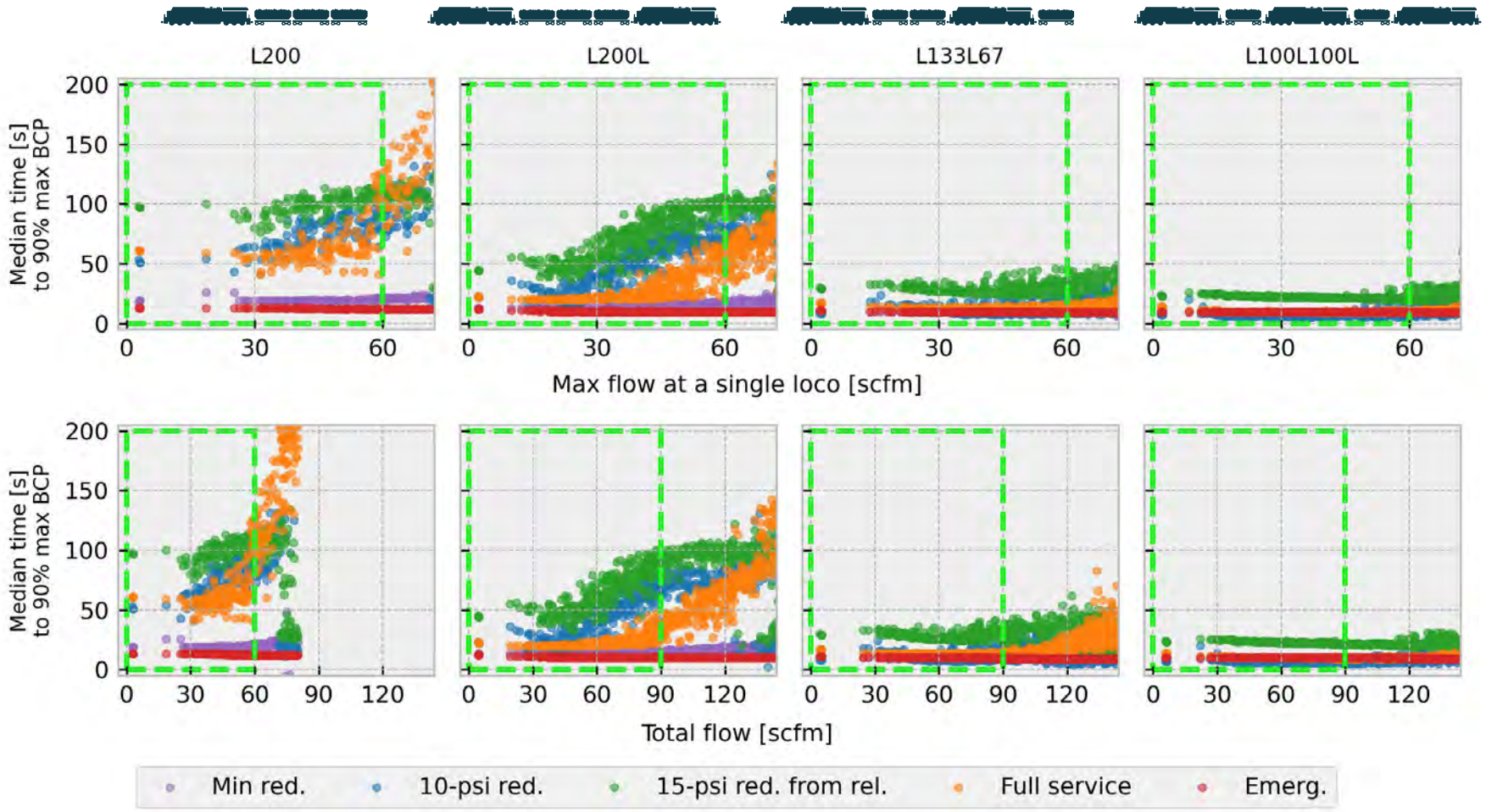
Brake Application

- **Faster on consists with shorter BP sections**
- **Lower values indicate better performance**



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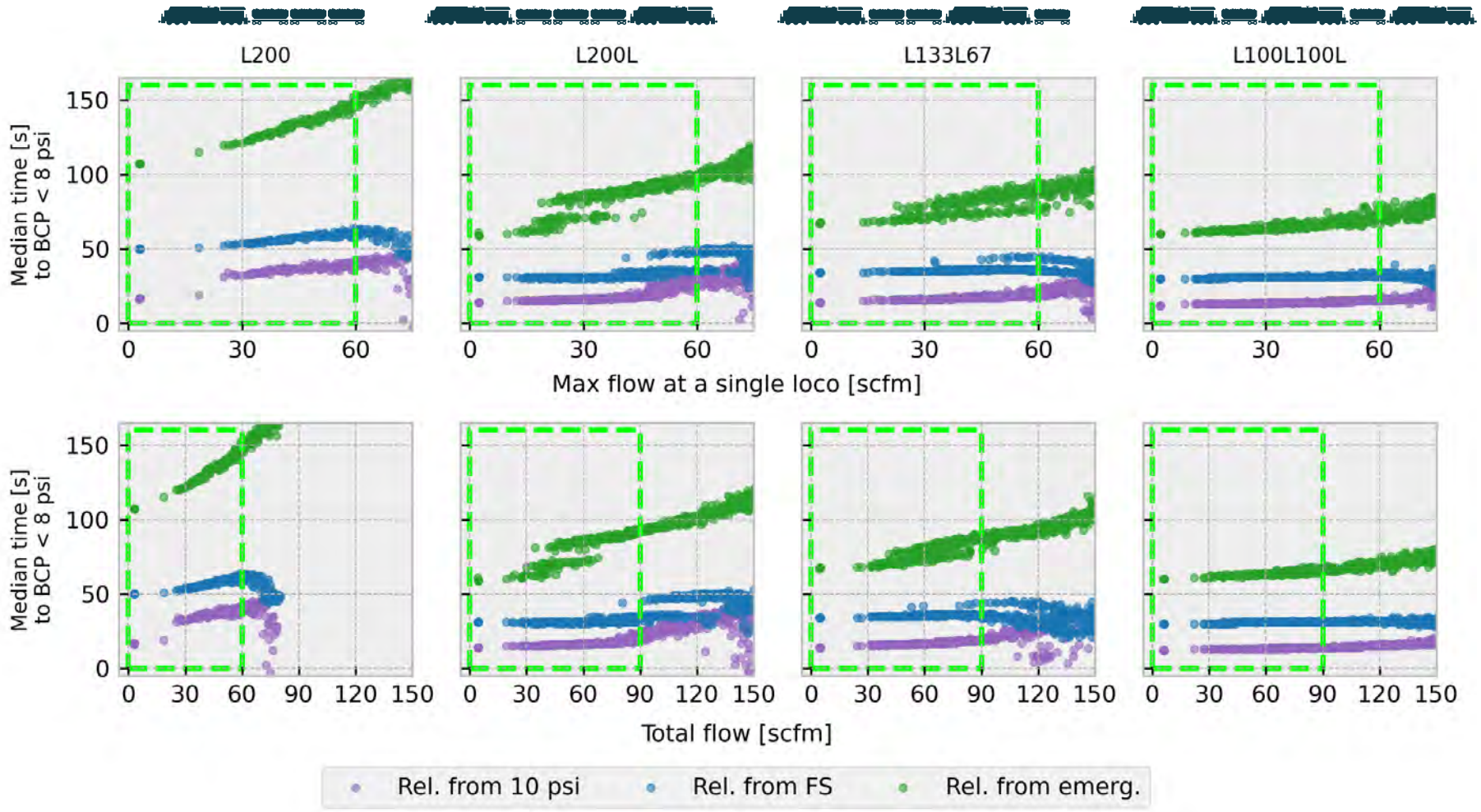
Brake Release

- **Faster on consists with shorter BP sections**
- **Lower values indicate better performance**



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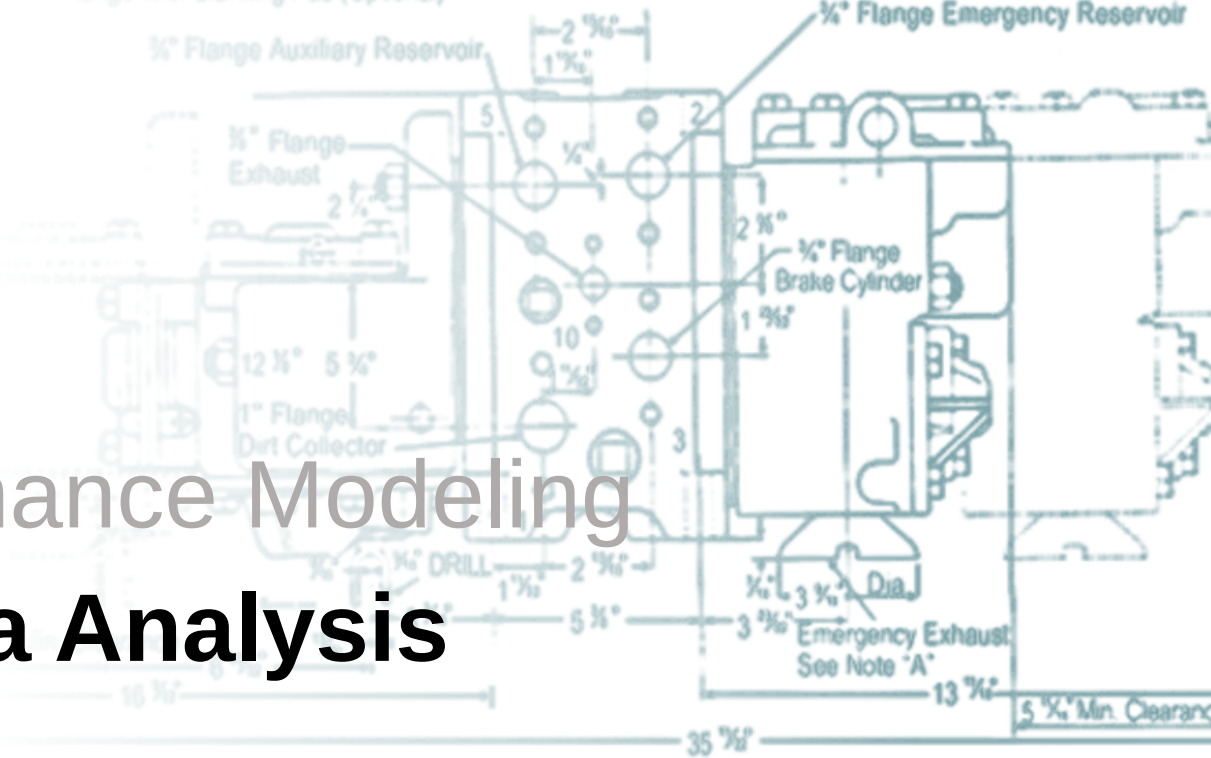
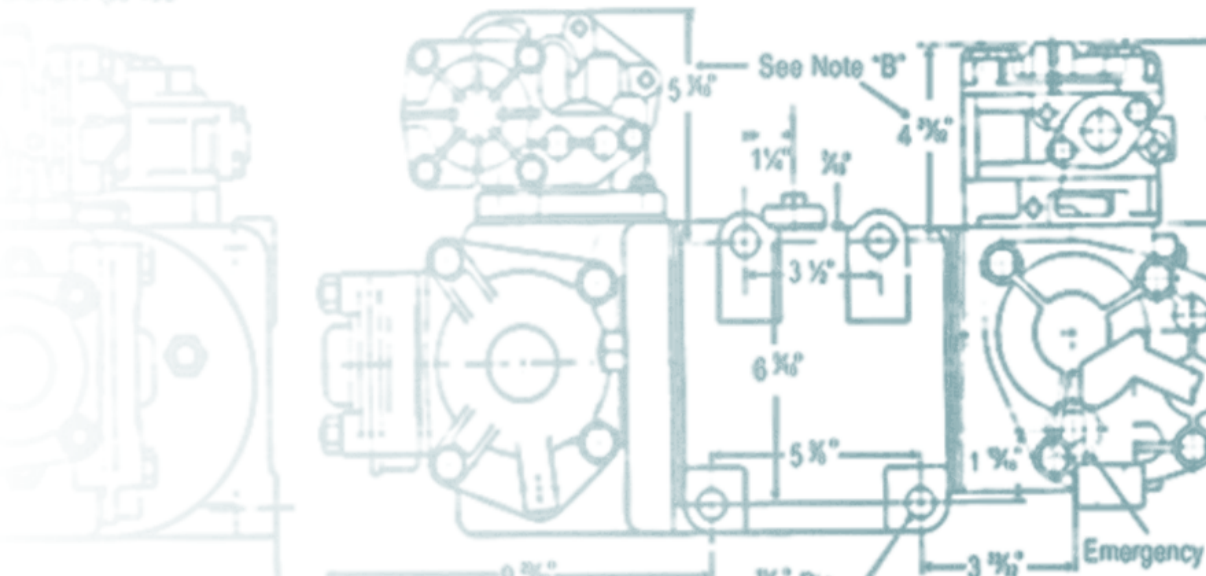
Results on Brake Application and Release

- **BP section length leads to different sensitivity of application and release signals**
  - More prominent away from air sources
- **These differences lead to differences in application and release timing**

Overview

- Introduction
- Updates on Brake Performance Modeling
- **Cold Wheel Process Data Analysis**
- Ongoing Research
- Summary





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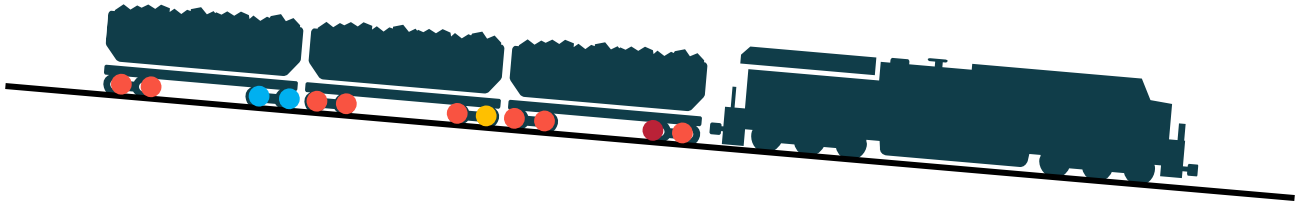
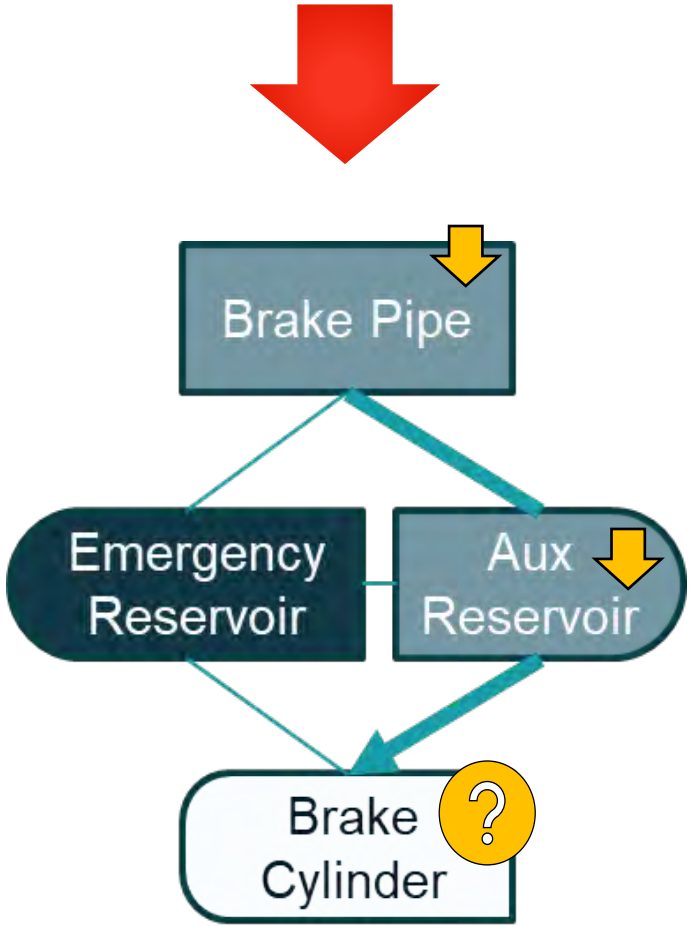
Cold Wheel Process

- **Identify ineffective brakes using wheel temperature**
- **Assess brake performance on moving trains at lower brake cylinder pressures than typical standing brake tests**





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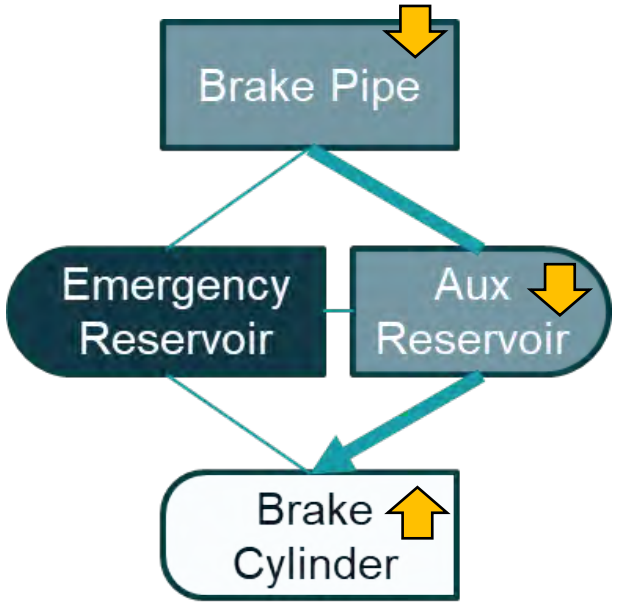
Cold Wheel Process

- **In practice, problem diagnosis not as straightforward**



Air flow path in service braking shown. Leakage from BP reduces available air in the AR.

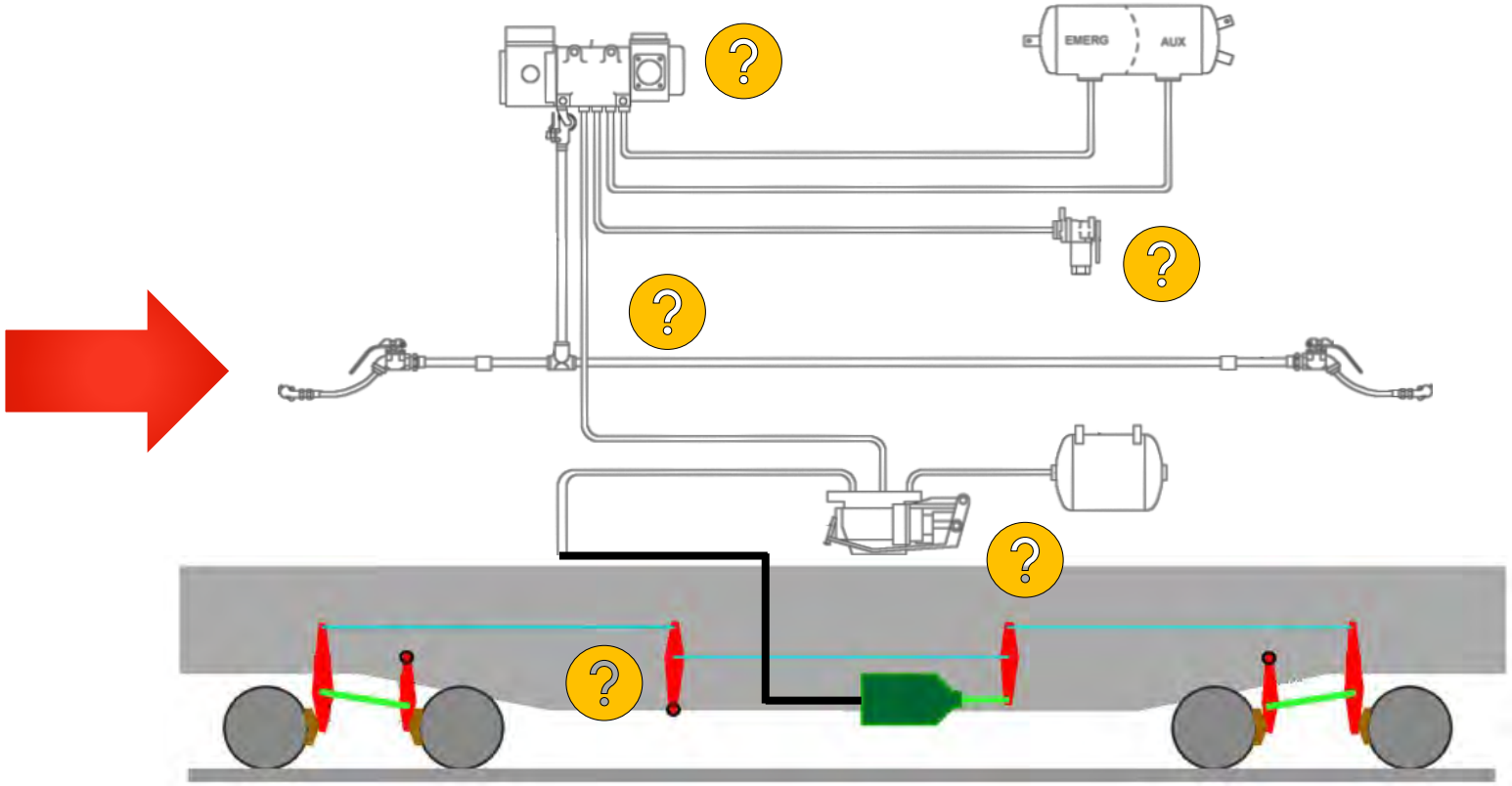


Figure adapted from: AAR S-400 and Harpwolf at English Wikipedia, CC BY-SA 3.0, via Wikimedia Commons

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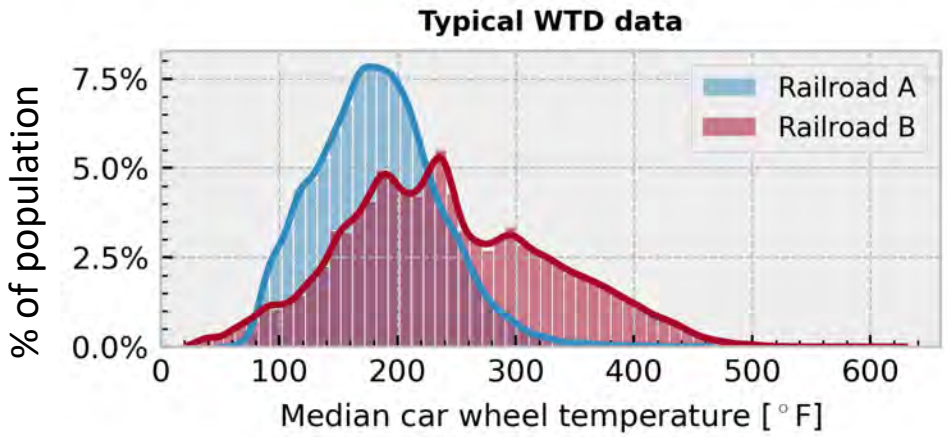
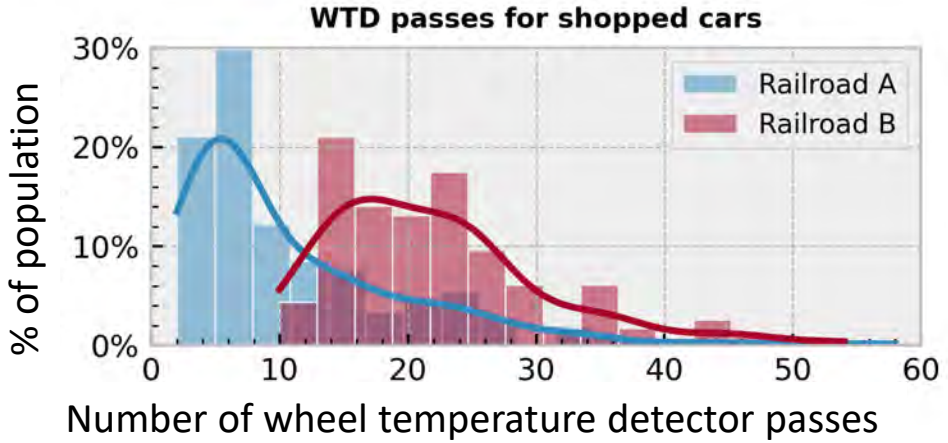
Evaluation of Process Effectiveness





- **Goal: evaluate effectiveness of cold wheel processes**
- **Wheel Temperature Detector (WTD) and repair data from two railroads**
  - Different methodologies
- **Factors considered:**
  - Average train wheel temperatures
  - Individual car wheel temperatures
  - Train handling
  - Repair job codes

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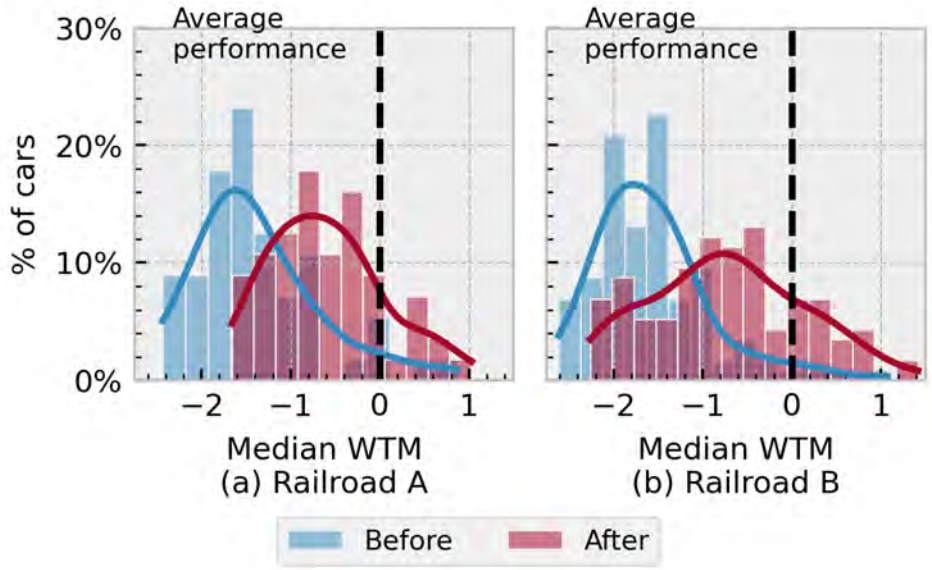
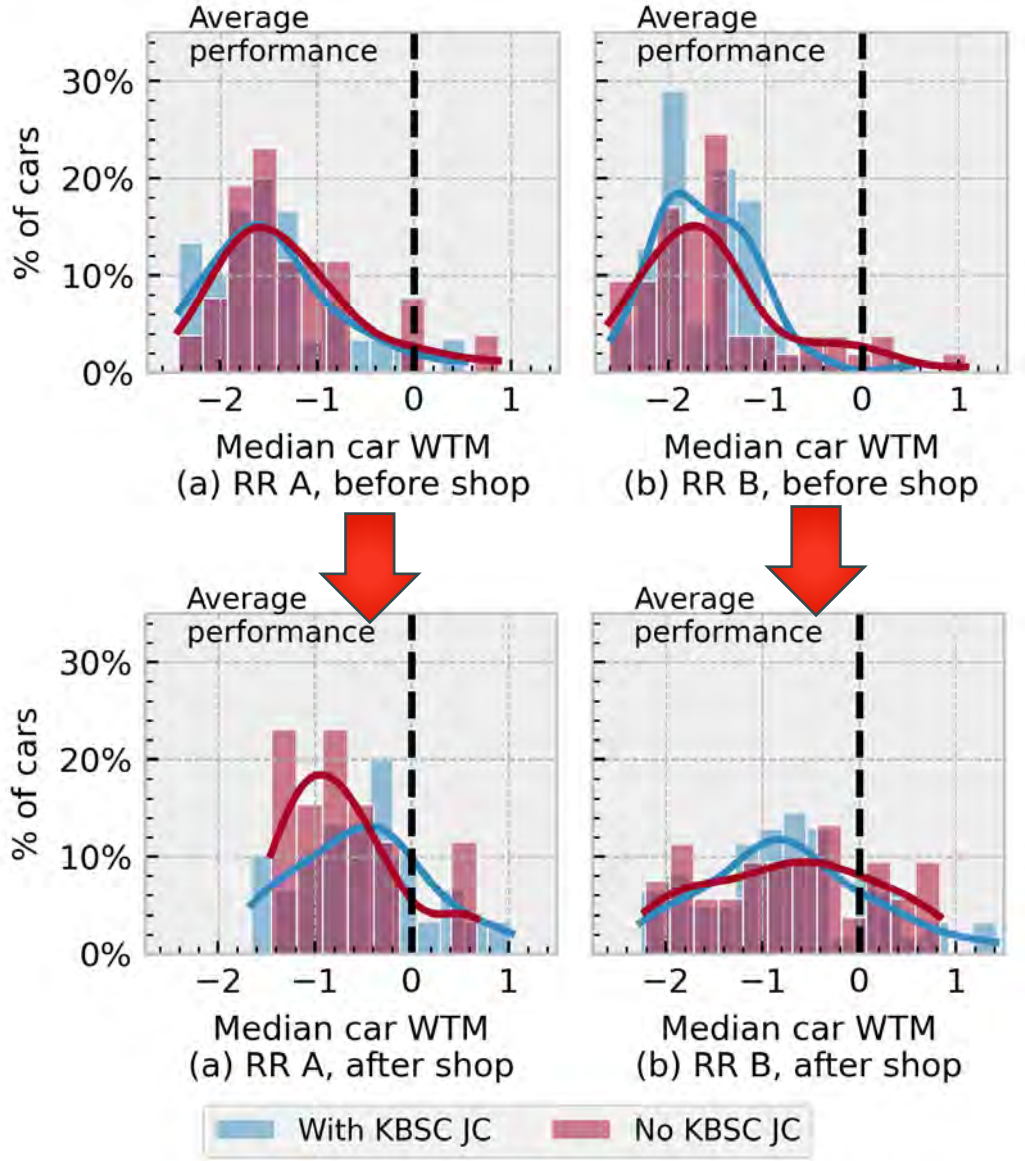
Findings

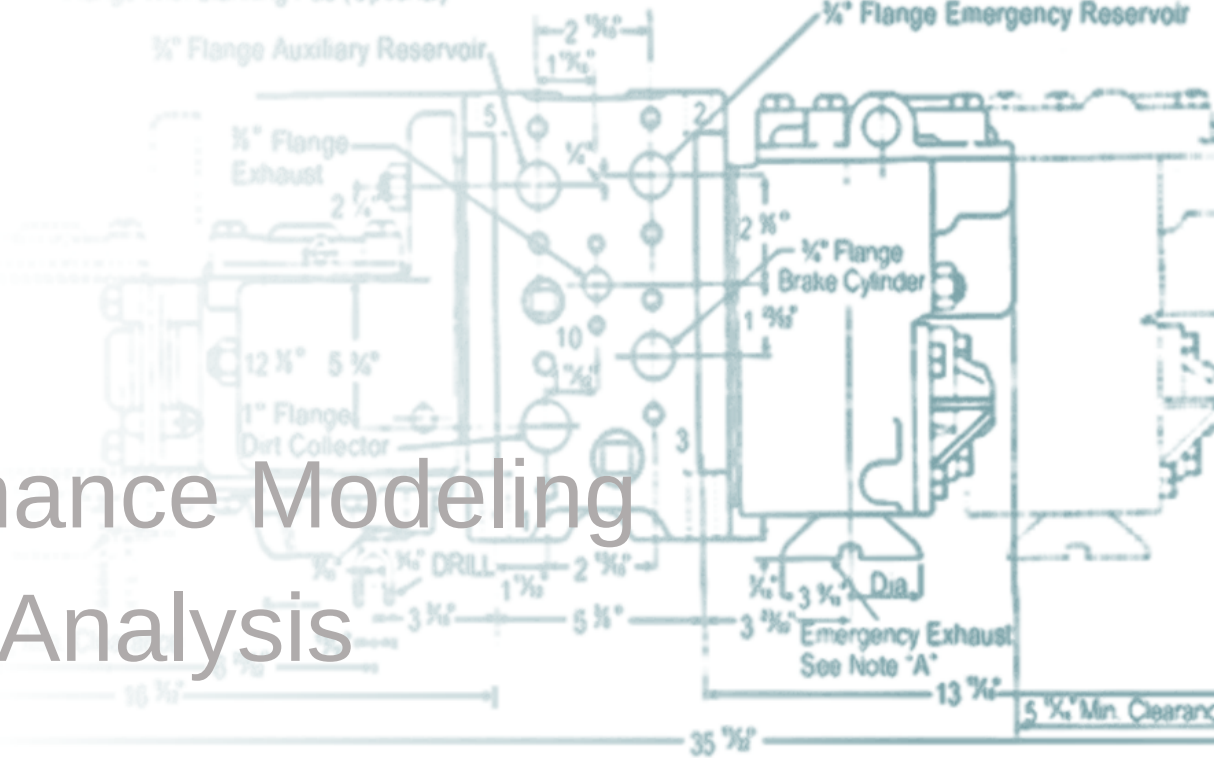
- **Common practice of categorizing repairs by job codes (JC)**
  - whether directly related to key brake system components (KBSC)
- **Comparisons used normalized wheel temperature metrics (WTM)**

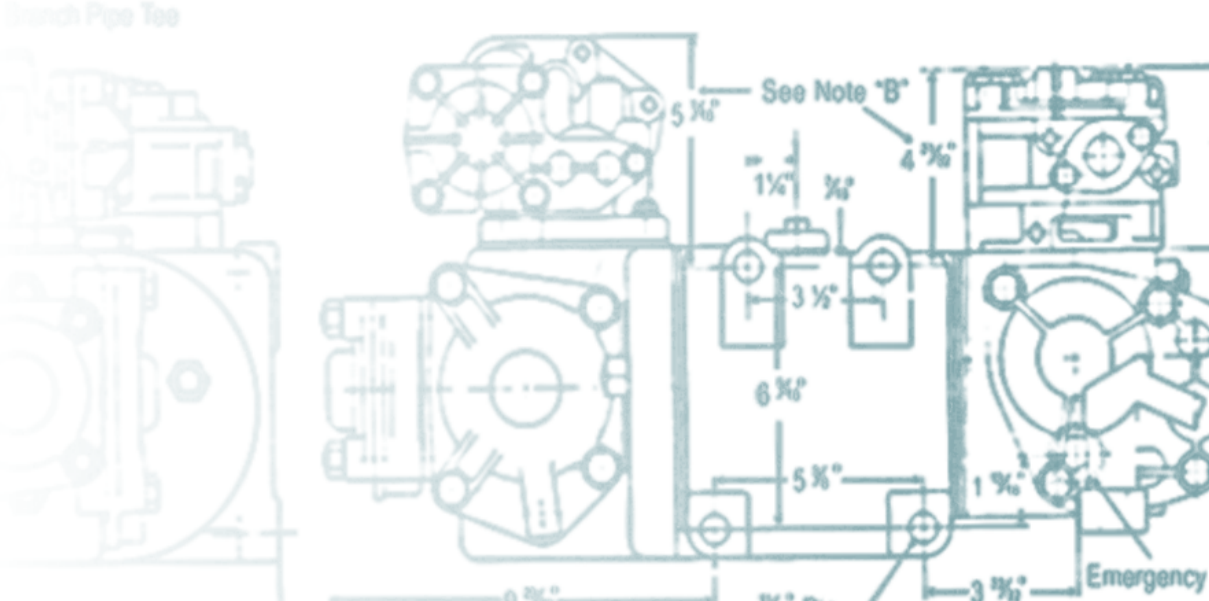




Overview

- Introduction
- Updates on Brake Performance Modeling
- Cold Wheel Process Data Analysis
- **Ongoing Research**
- Summary





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Automatic Secondary Securement Devices

- **Testing automatic secondary securement devices (ASSD) to support the AAR Brake Systems Committee**
- **Three manufacturers, two types**
  - ASSD mechanically locks the brake piston
  - Locking and unlocking are based on brake pipe pressure
  - Manual release possible

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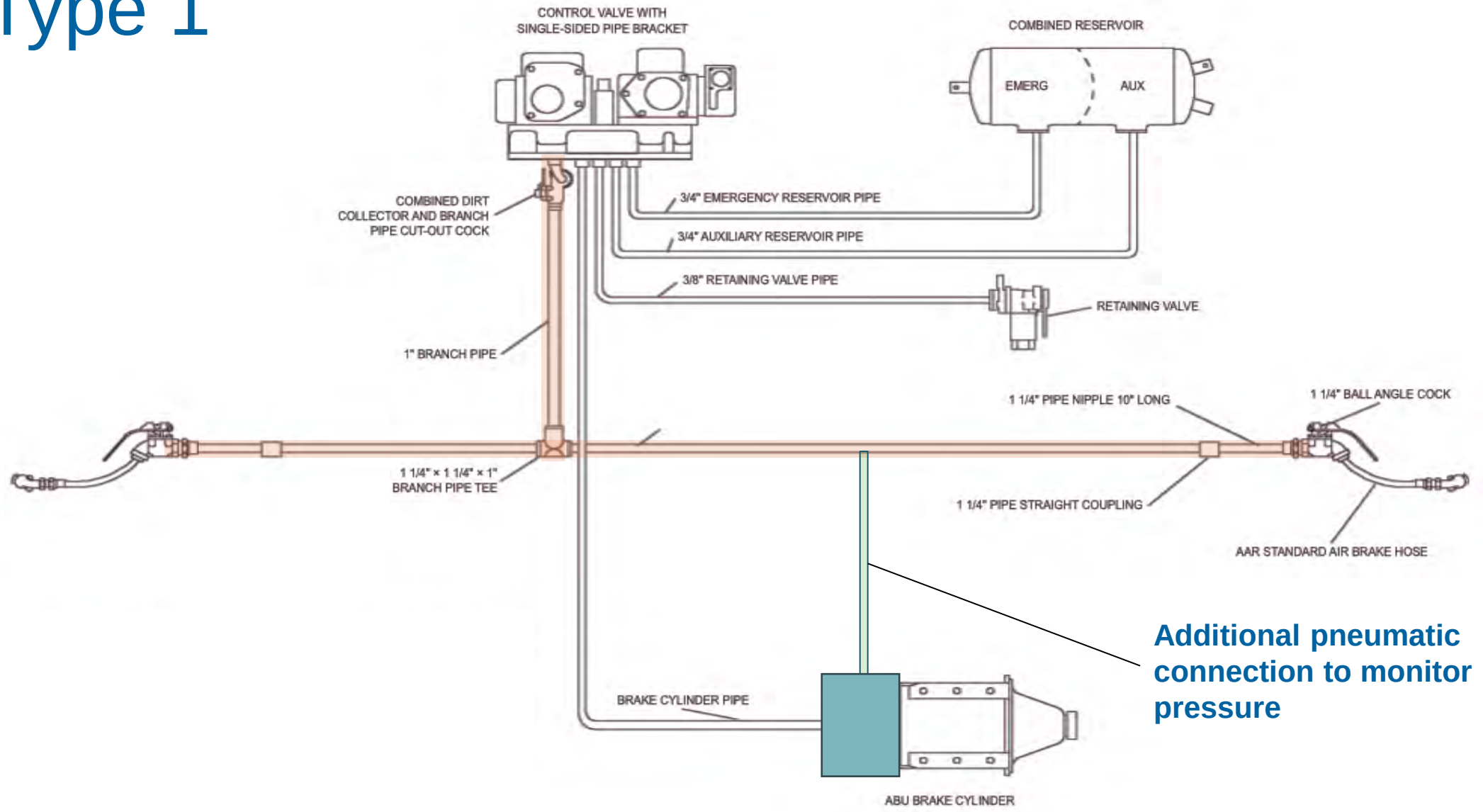
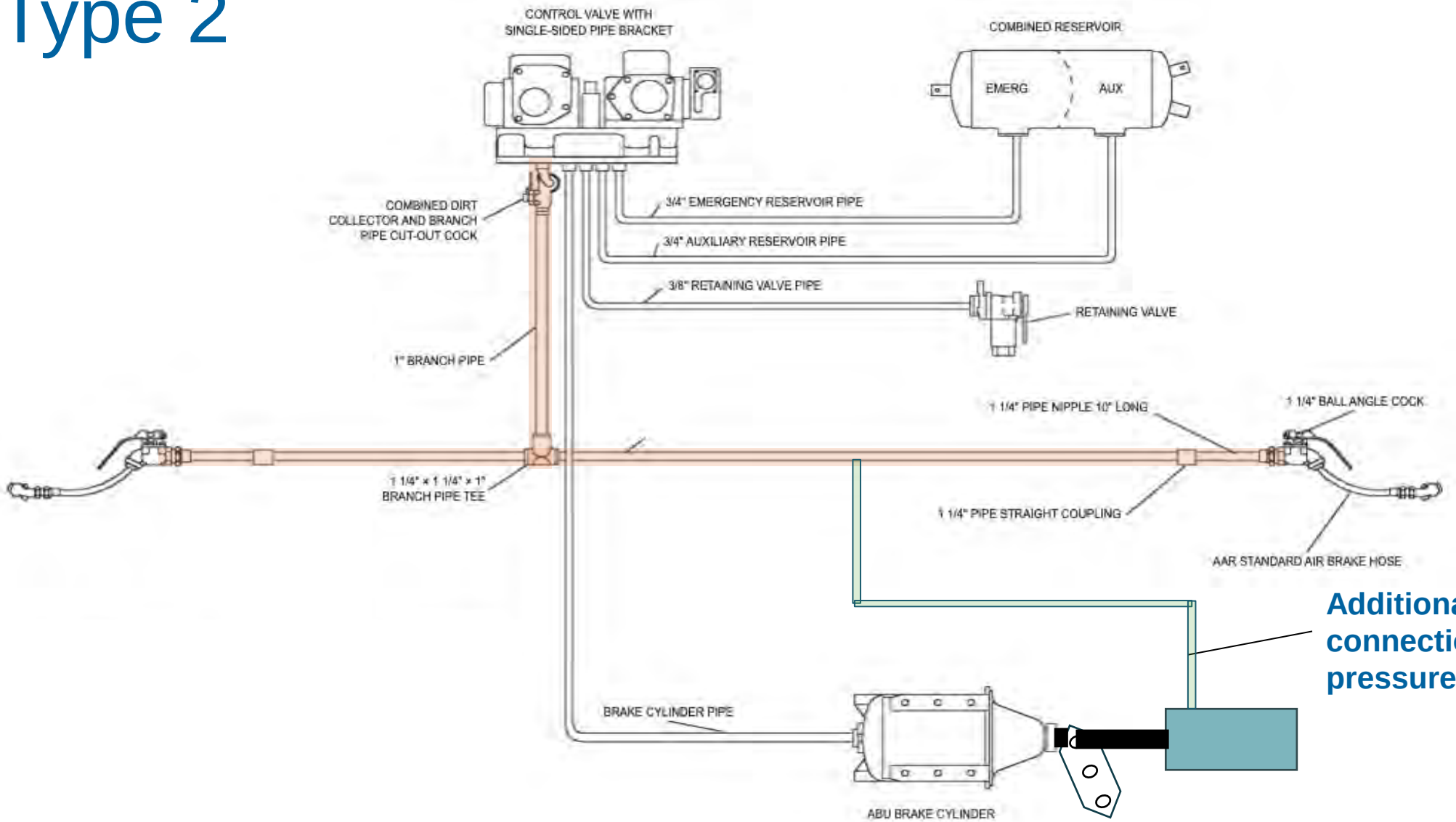
Type 1



Additional pneumatic connection to monitor BP pressure

Type 2



Additional pneumatic connection to monitor BP pressure

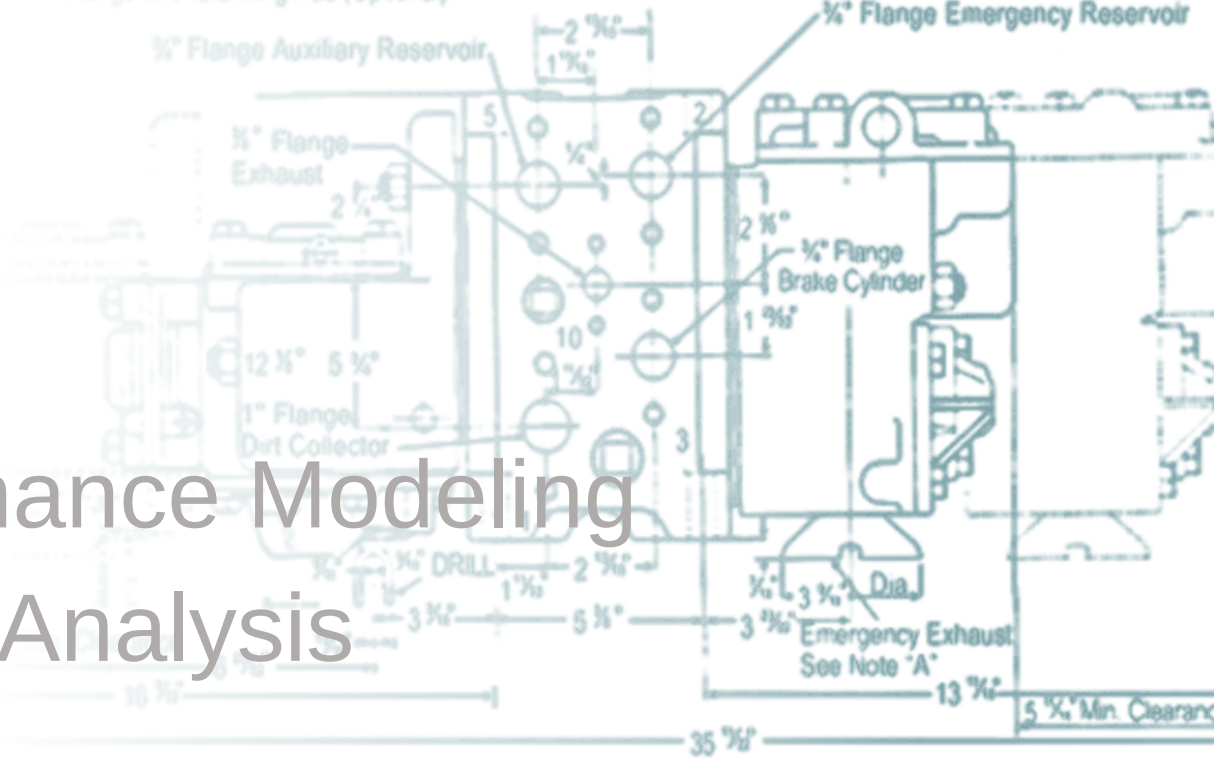
Test Plan

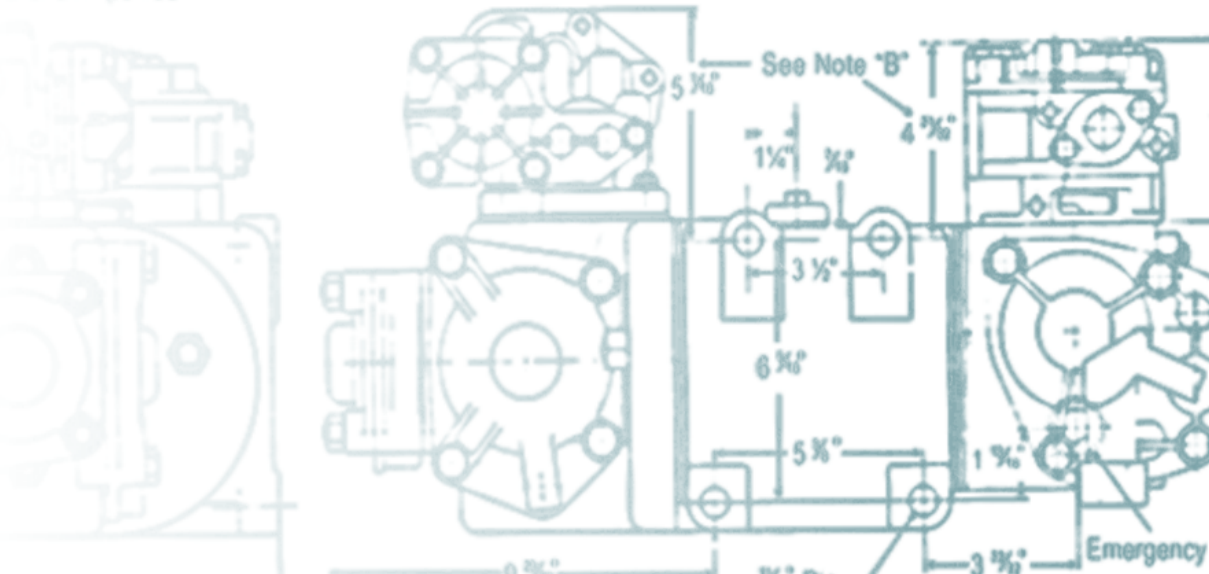
- **Lab testing**
  - Continuously cycle through different ranges and rates of braking
- **Testing at FAST®**
  - Simulate revenue service environment in FAST train
  - Fewer actuations of ASSD

FAST® is a registered trademark of MxV Rail

Overview

- Introduction
- Updates on Brake Performance Modeling
- Cold Wheel Process Data Analysis
- Ongoing Research
- **Summary**





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Summary

- **Leakage modelling using TOES™**
  - Number and placement of air sources both affect brake performance
- **Cold wheel process data analysis**
  - Statistically significant improvement in brake performance regardless of the job code applied
- **Automatic secondary securement testing**
  - Lab and field testing planned to support AAR Brake Systems Committee

Acknowledgements

- MxV Rail colleagues
- Railroads and supplier community

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Wheel/Rail Profile Design and Maintenance

Ulrich Spangenberg, Ph.D.
Principal Investigator, Vehicle/Track Interaction & Instrumentation

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Introduction and Background

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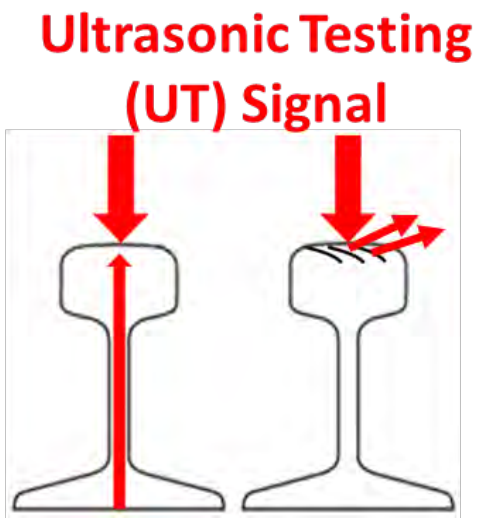
Project Objective

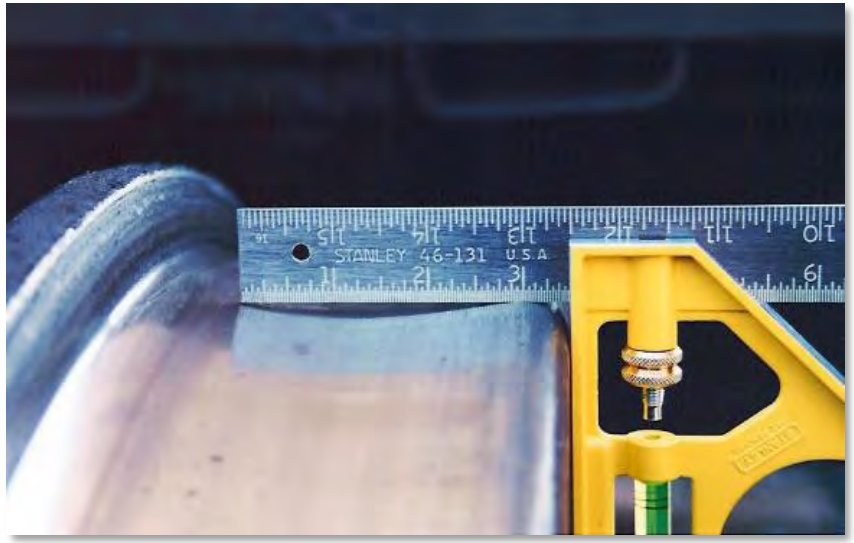
- **Single greatest material cost is related to wheels and rails**[1]
- **Extend service lives of wheels and rails by reducing wear and rolling contact fatigue (RCF)**
- **Improve the margin of safety against derailment**

Rolling contact fatigue (RCF)

“Loss of Bottom”



Wheel hollow wear



1. International Heavy Haul Association (IHHA), “Guidelines to Best Practices for Heavy Haul Railway Operations: Management of the wheel and rail interface”, International Heavy Haul Association, Virginia Beach, 2015.

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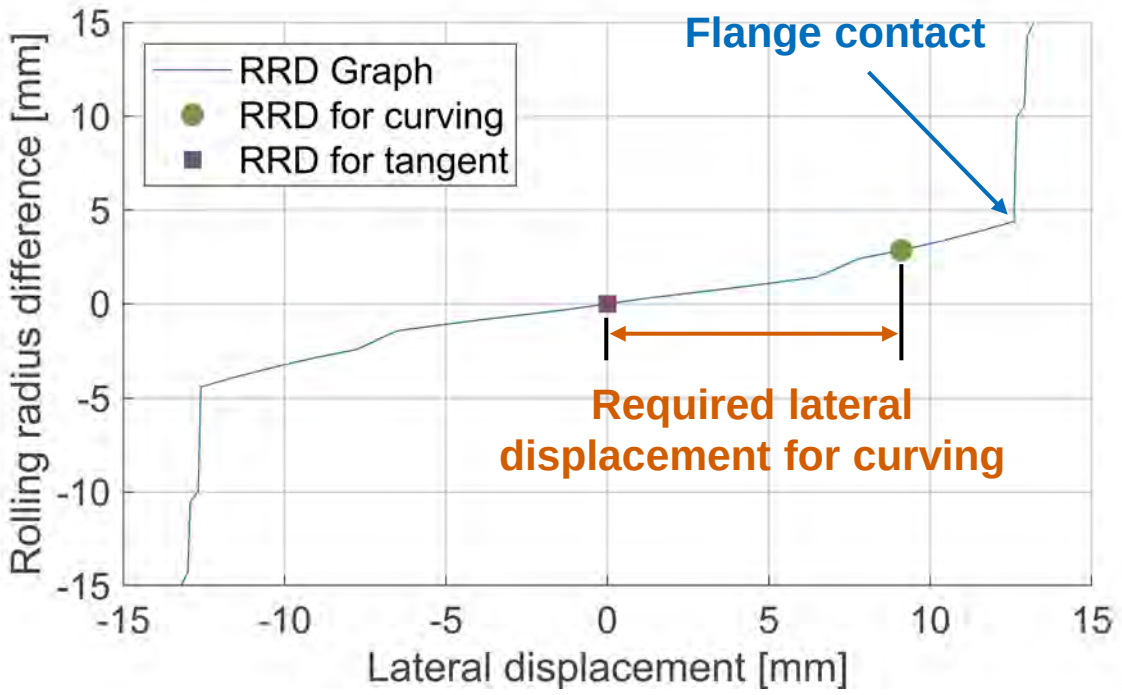
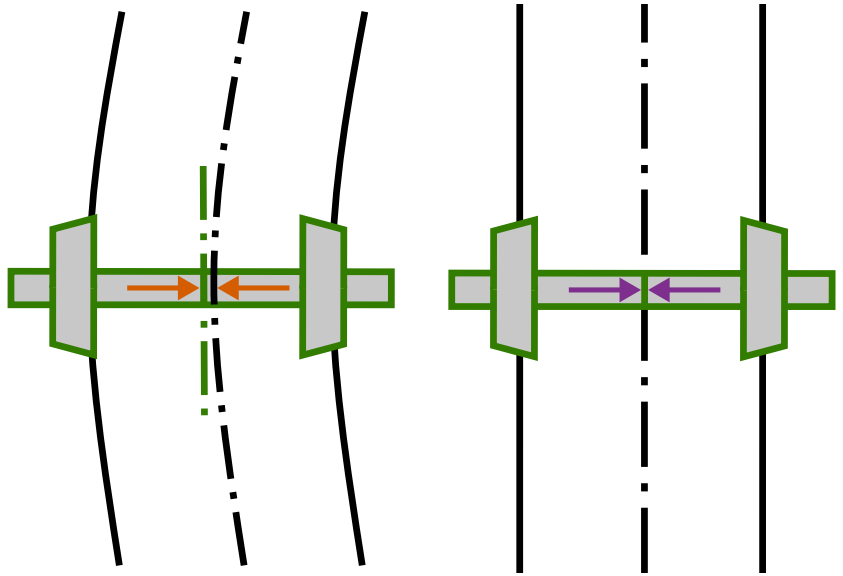
Introduction to Hunting

- **Coning of wheels generates rolling radius difference (RRD) that:**
  - Improves steering and reduces flange wear
  - Allow a wheelset to find its equilibrium
  - Allow a wheelset to remain centered on tangent track



Curving and tangent lateral displacement at equilibrium



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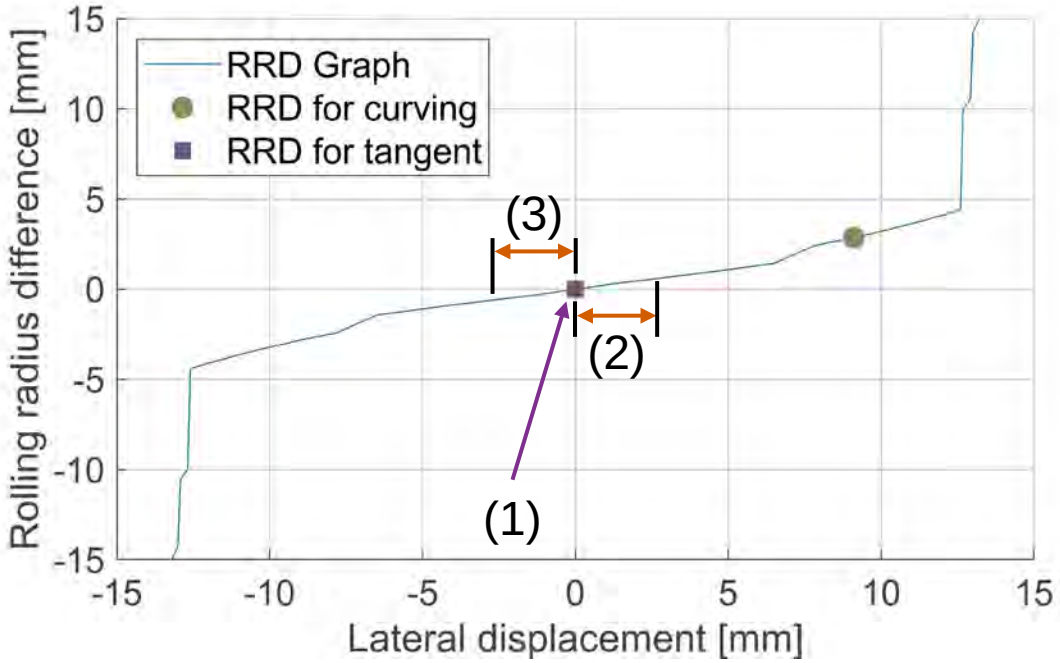
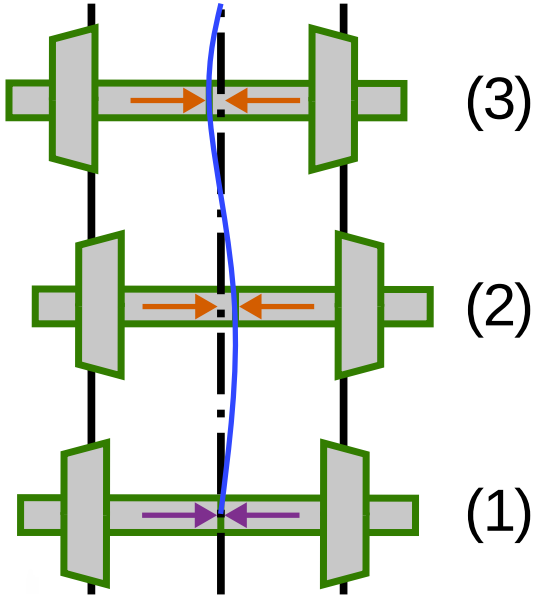
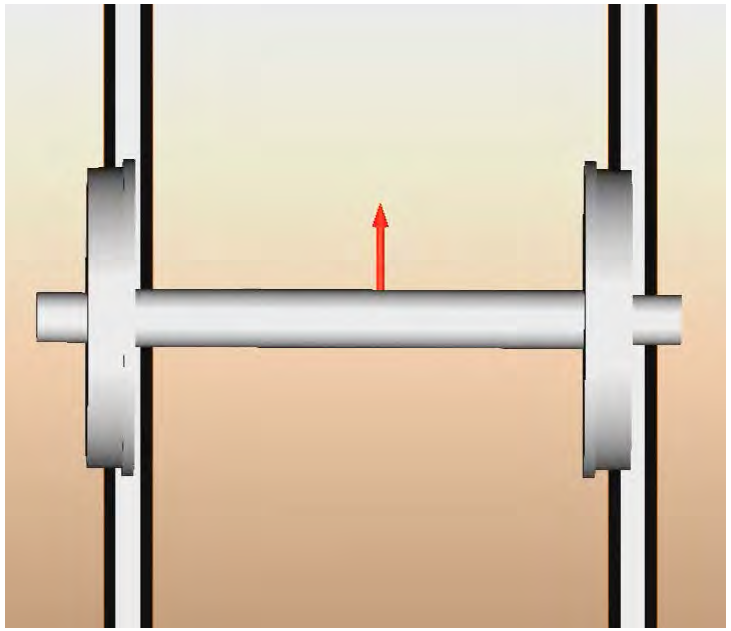
Introduction to Hunting

- **Result of coning on tangent is hunting for the equilibrium position**





Exaggeration of wheelset hunting



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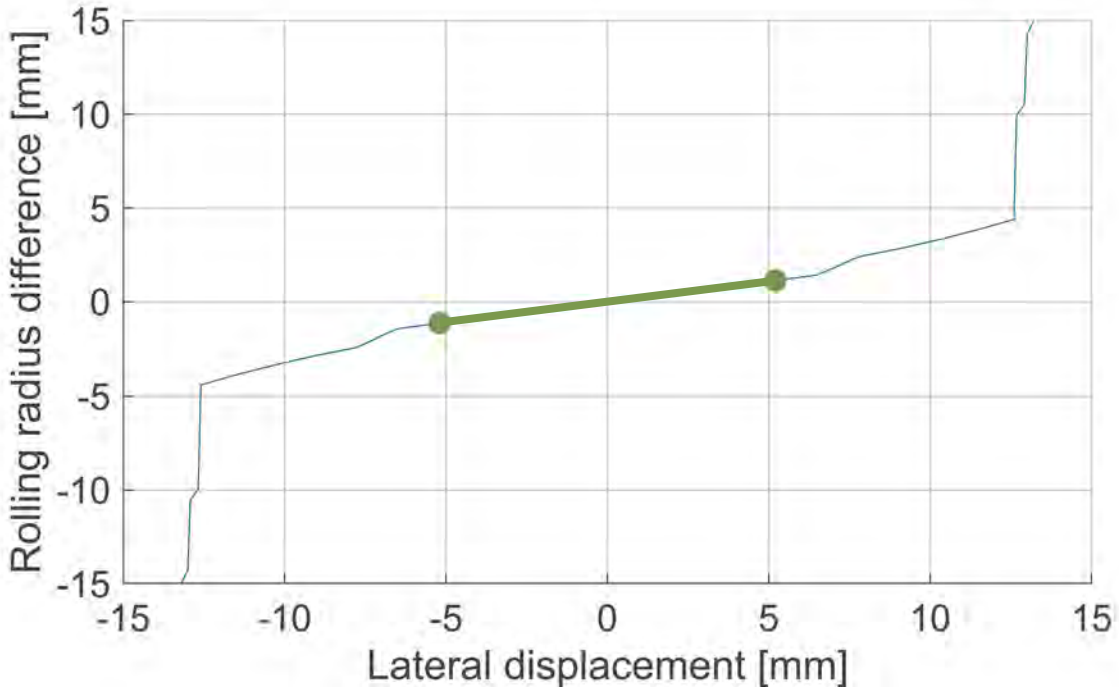
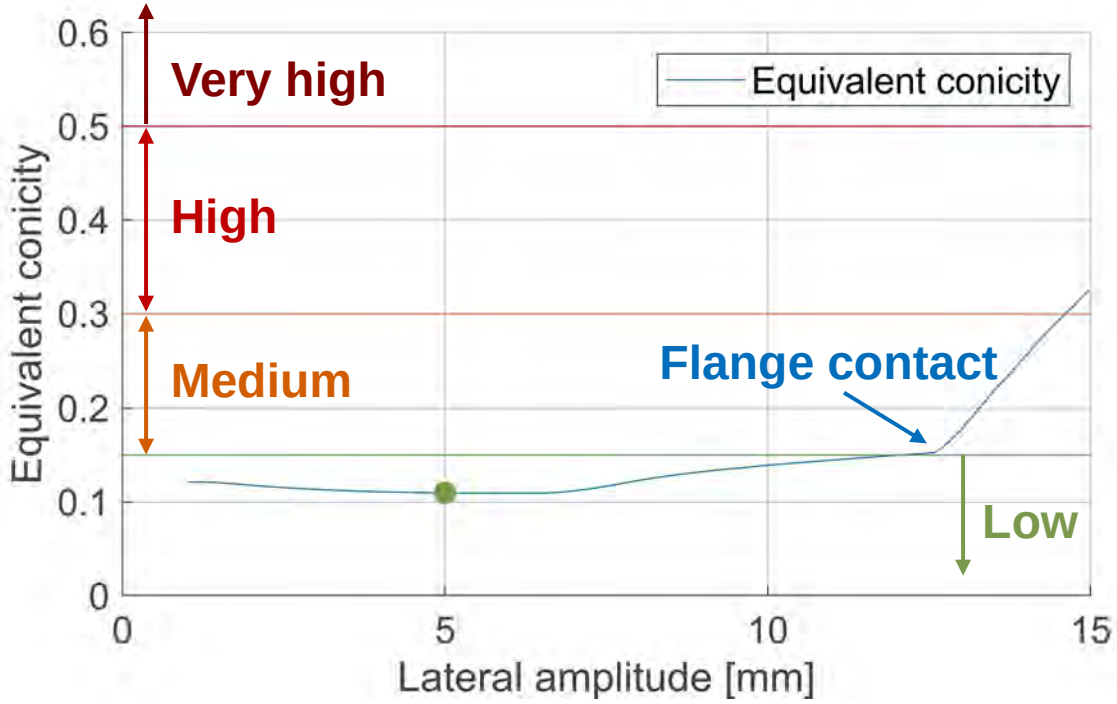
Introduction to Hunting

- **Equivalent conicity:**
  - Related to the slope of the RRD function
  - Lateral amplitude of ~0.12 inch (3 mm) is used to indicate likelihood of hunting





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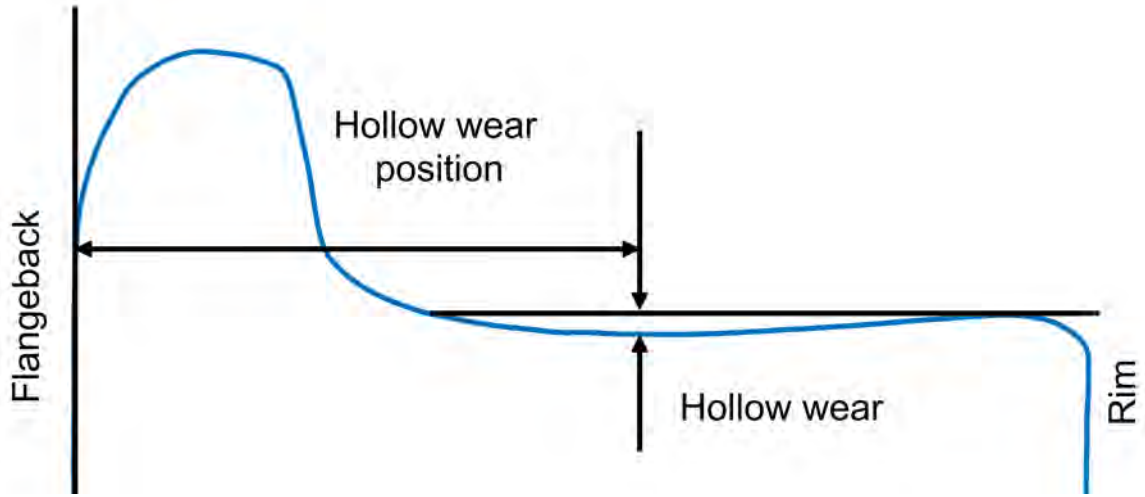
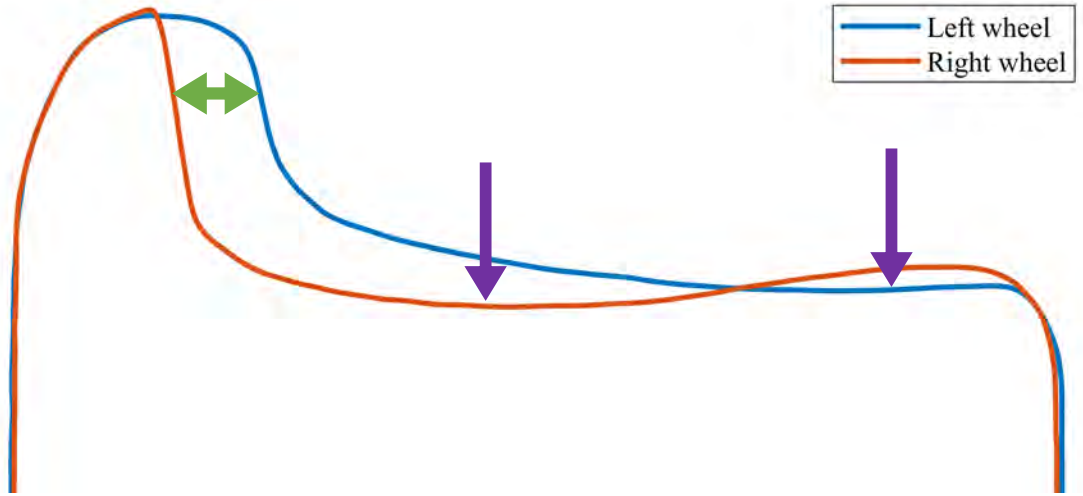
Introduction to Hunting

- **Likelihood of hunting reported to increase with increasing hollow wear**
- **Ongoing effort to determine root cause of asymmetric wheel wear**
- **Hunting oddities observed while investigating asymmetric wheel wear**

Calculation of hollow wear and position



Example of asymmetric hollow wear



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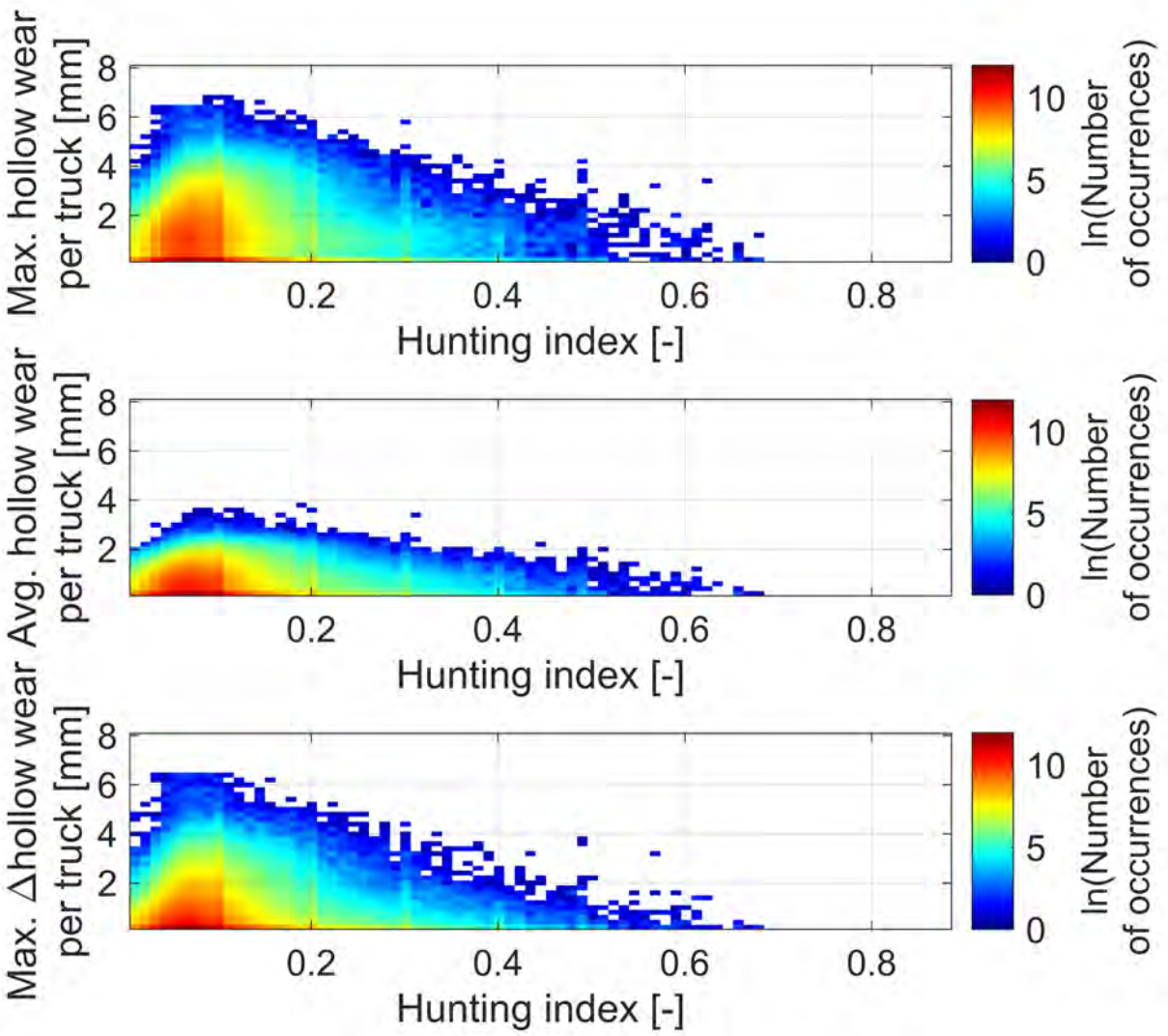
Introduction to Hunting

- **Analysis of asymmetric hollow wear showed:**
  - More hollow worn wheels are more stable
  - More asymmetry in hollow wear is also more stable
- **Objective: Identify worn profile characteristics prone to hunting**

Hunting index relation to hollow wear



Method

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Method

- **Simulation analysis with NUCARS®**
- **Straight track, single 0.25-inch lateral perturbation over 50 feet**
- **Reducing velocity method, 80 mph to 10 mph in 140 seconds**
- **Measured wheels from 14 in-service cars and KR wheel**
- **Seven unique rail profile pairs**
  - Three tangent rail templates and four measured rails from M-976 hunting zone
- **Empty hopper car and intermediate covered loaded hopper car as per M-976**

NUCARS® is a registered trademark of MxV Rail

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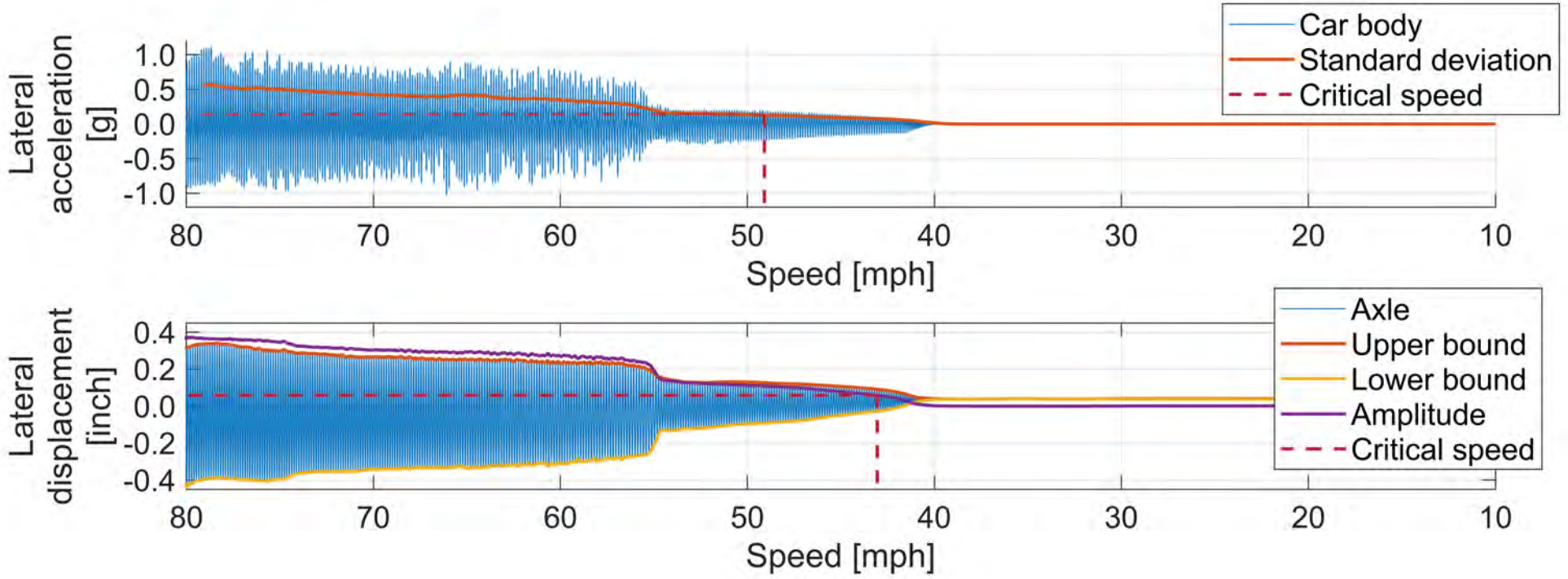
Method

- **Hunting threshold/critical speed found at speed where:**
  - Lateral acceleration ≤ 0.13 g, using 2-mph segments
  - Lateral amplitude ≤ 0.06 inch (1.5 mm), only if amplitude was > 0.12 inch (3 mm) at the start
  - Neither criteria triggered, critical speed set to 80 mph

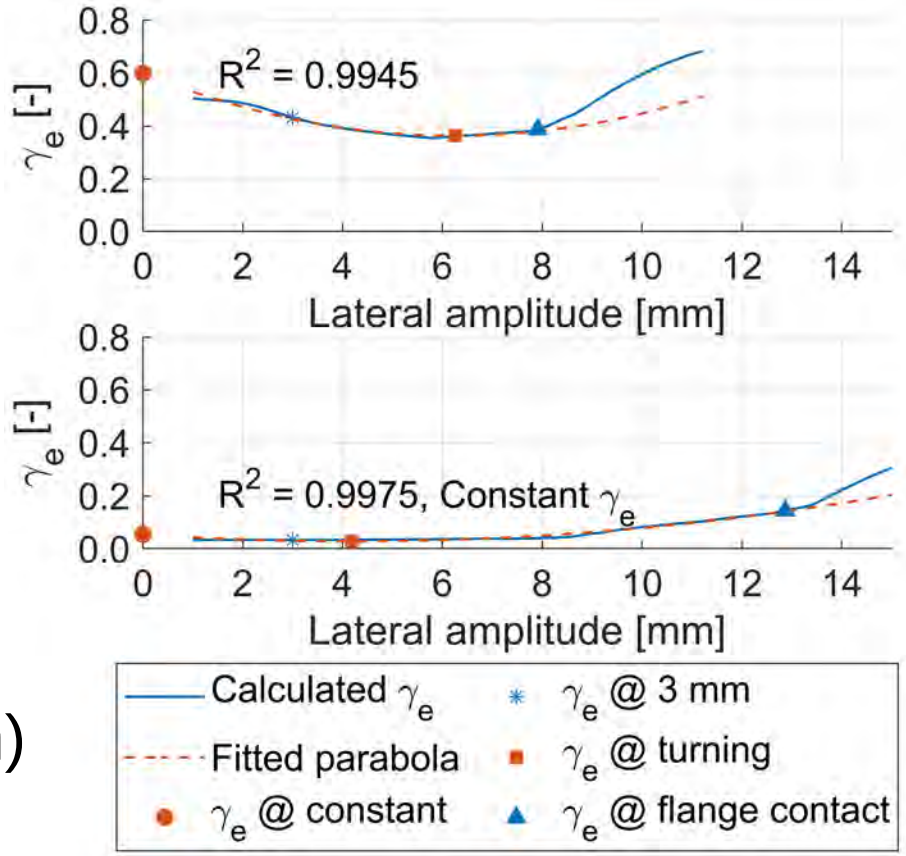


Results

Likelihood of Hunting

- **The equivalent conicity (γ_e) at ~0.12 inch (3 mm) to assess likelihood of hunting**
  - Evaluated γ_e according to UIC 519[2]
  - Looked at other methods:
    - Turning point of fitted parabola
    - Ordinate intercept of fitted parabola
    - γ_e at flange contact
    - Constant vs. non-linear γ_e function
    - Oscillation damping by profiles
    - Non-linear parameter[3]
    - Contact point difference at ±0.12 inch (±3 mm)

Examples of calculated and fitted γ_e



[2] UIC Code 519. *Method for determining the equivalent conicity*. 1st Ed. Paris: International Union of Railways, 2004.
[3] Polach, O. and D. Nicklisch. Wheel / rail contact geometry parameters in regard to vehicle behaviour and their alteration with wear. *Wear* 2016; 366–367: 200–208.

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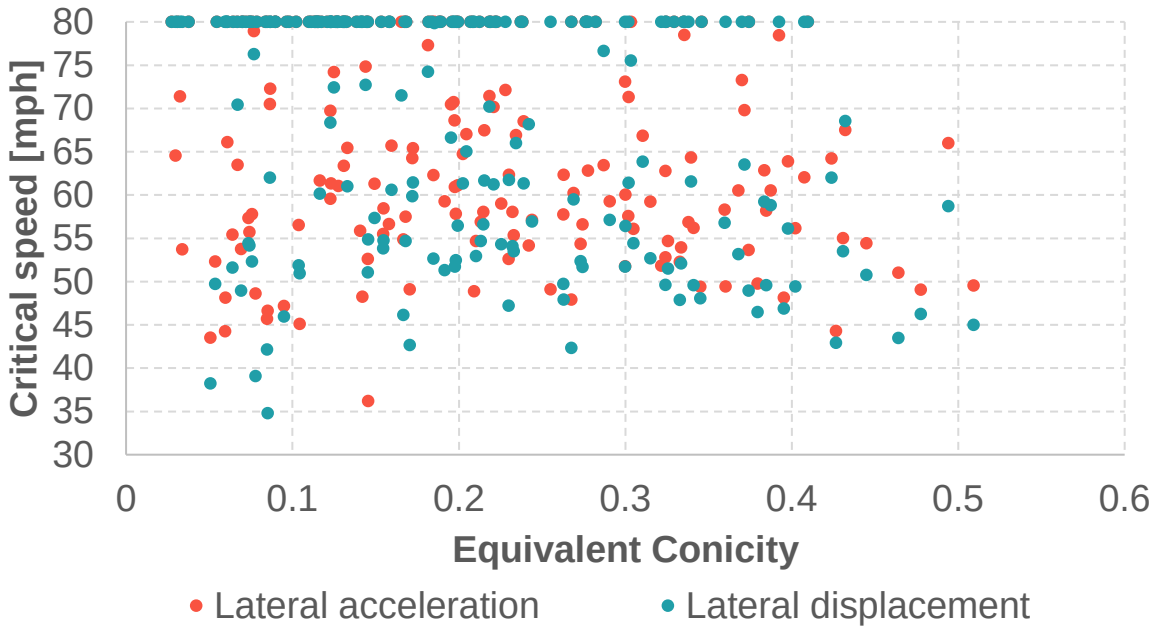
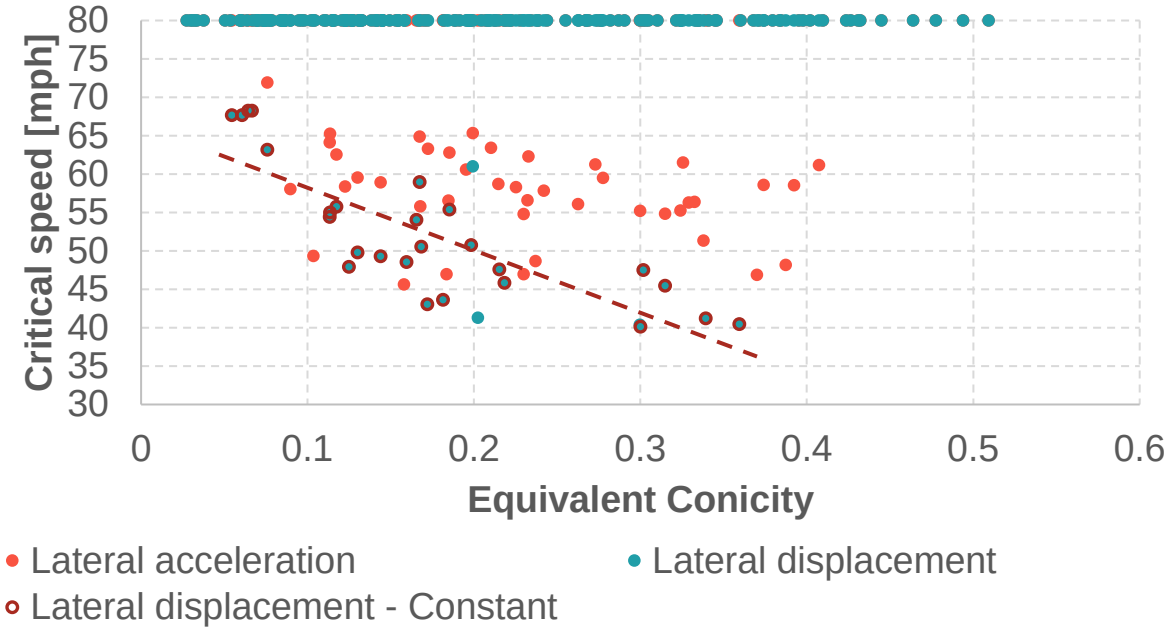
Likelihood of Hunting

- γ_e and critical speed, unrelated, empty
- γ_e and critical speed, related, loaded, lateral displacement criteria only
- Constant γ_e agreement with loaded hunting

Minimum critical speed for truck, empty condition

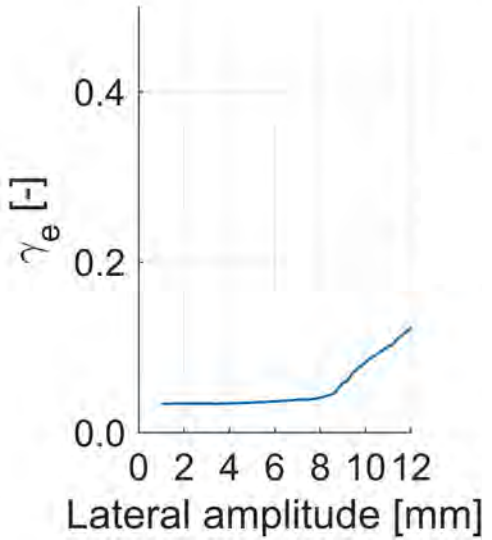


Minimum critical speed for truck, loaded condition

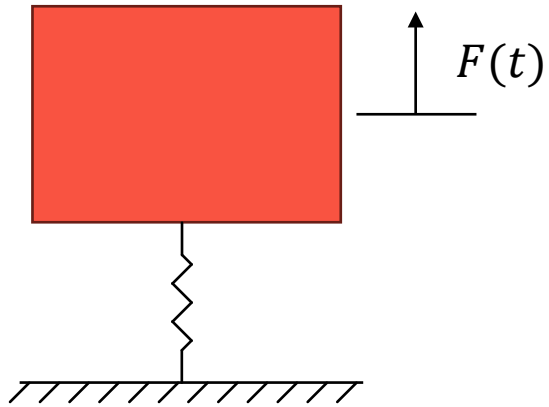


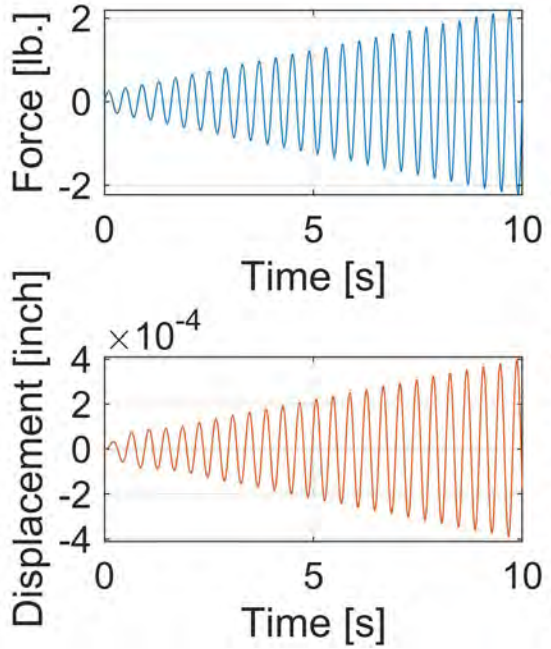
Likelihood of Hunting

- **Constant γ_e, linked to loaded hunting**
- **Klingel formula describes wavelength (L) of hunting**
  - Constant γ_e = constant L



$$L = 2\pi\sqrt{\frac{lr_0}{\gamma}}$$





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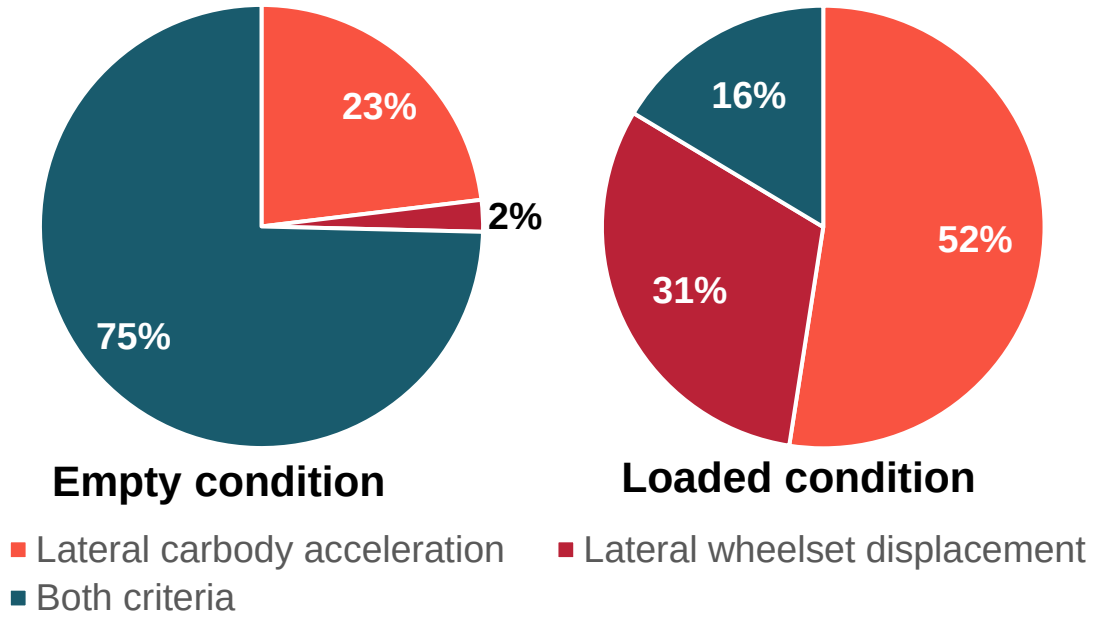
Likelihood of Hunting

- **Results per truck and load condition**
  - 29 unique trucks
    - 90% occurrence of hunting in empty condition
    - 79% occurrence of hunting in loaded condition
    - 72% occurrence of hunting in both conditions

Hunting occurrences identified by each criteria



Wavelengths of hunting per criteria

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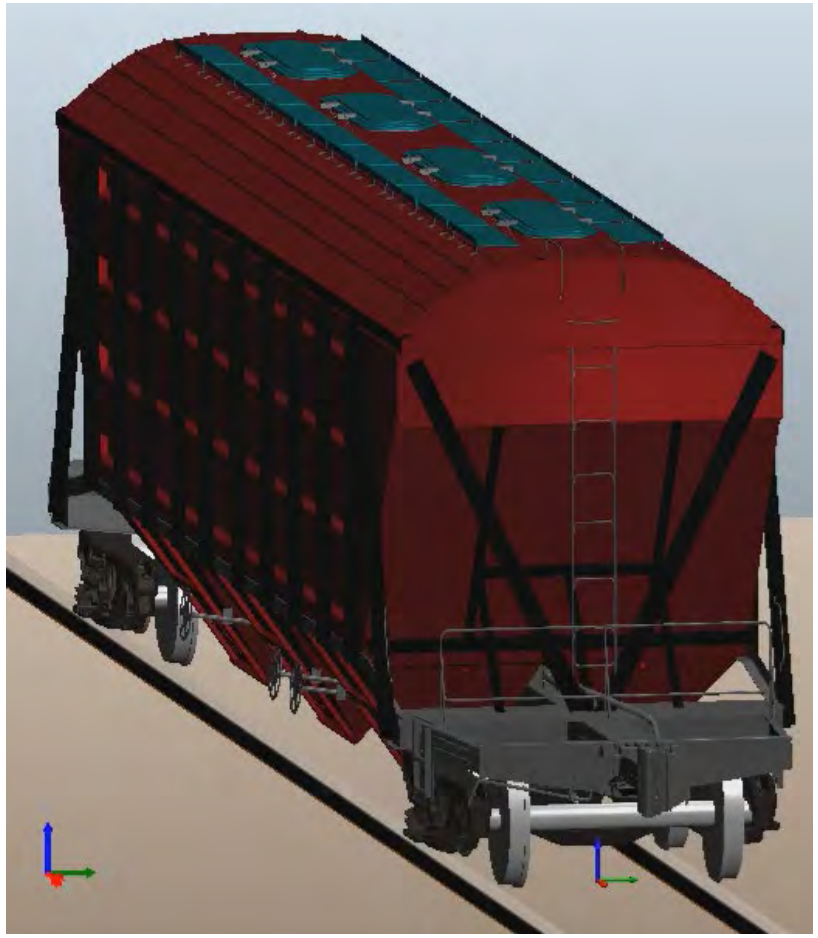
Likelihood of Hunting

- **Lateral acceleration criteria more sensitive to low amplitude, short wavelengths**

Low amplitude, short wavelengths



High amplitude, long wavelengths

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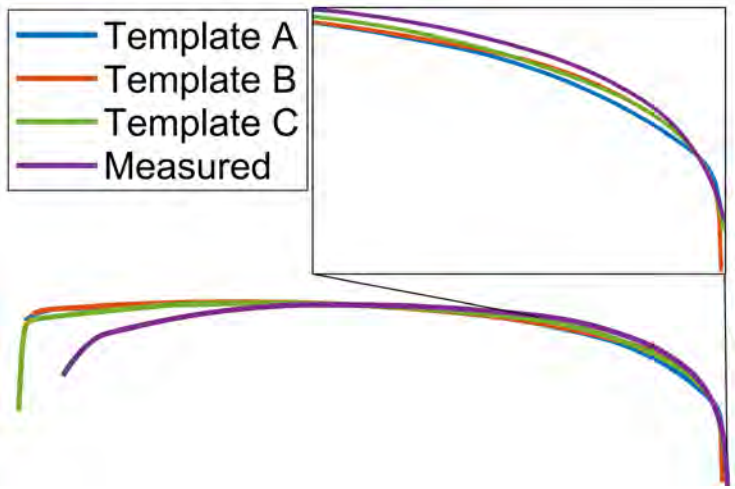
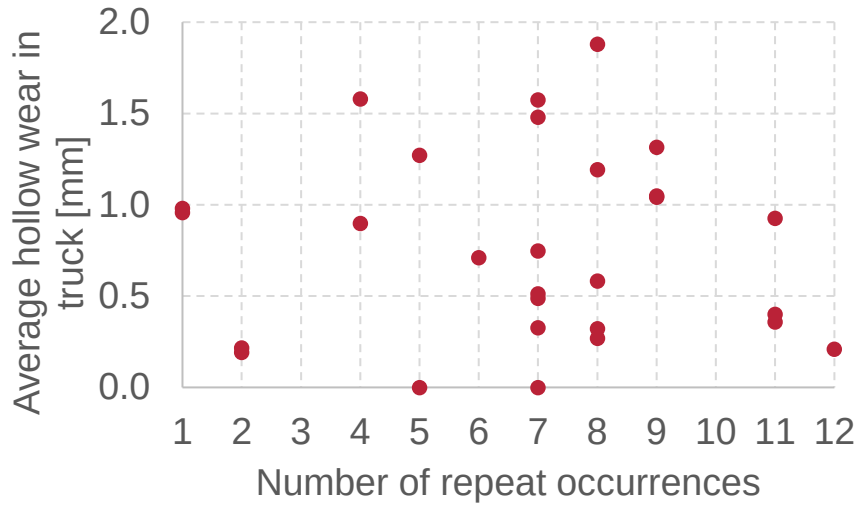
Profile Features and Hunting

Comparison of rail profiles



Hollow wear and occurrence of hunting



- **Hunting occurrences on rail profiles:**
  - Measured: 70%
  - Template A: 8%
  - Template B: 10%
  - Template C: 12%
- **Some wheel profiles showed more hunting occurrences than others**
- **Hunting occurrences unrelated to hollow wear in truck**

Conclusions

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Conclusions

- **Standard practice of γ_e at 3 mm inaccurate predictor of critical speed or hunting.**
  - Wayside systems relying on γ_e to manage hunting trucks are not suitable for North American freight operations.
- **Lateral acceleration: Low amplitude, short wavelengths in loaded condition with worn profiles.**
  - Not suitable criteria for use when identifying hunting of worn wheels.
- **Lateral displacement: High amplitude, long wavelengths, suitable for loaded condition with worn profiles.**
  - Criteria that should be used to identifying hunting of worn wheels and is more relevant for wayside systems.

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Conclusions

- **Loaded hunting sustained by constant equivalent conicity.**
  - Loaded hunting can be treated by grinding rail profiles that produce non-linear γ_e.
- **Rail profiles with smaller crown radii resulting in gage shoulder relief are less prone to hunting.**
  - Design and grinding of such rail profiles to improve hunting stability.
- **Unidentified characteristic of worn wheel profile driving hunting performance.**
  - Maintaining wheelsets for hollow wear will not eliminate hunting.

Acknowledgements

- Kenny Morrison
- Walter Rosenberger (Retired, MxV Rail)

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