Track Design for Heavy Haul Railroads: A retrospective of North American Experience

Steve Wilk
Dave Davis
Outline

- History of U.S. Freight Railroad Design (1800s to today)
- U.S. Freight Design Considerations
- General Infrastructure Design
- Specific Design Experience
- Maintenance Planning
- Conclusions
History of U.S. Freight Railroad Design
(1800s to today)
Evolution of Freight Track Structure

- Guideway for mine’s coal wagons to transnational networks hauling passengers and freight
- 1800s – design experimentation
- 1900s to 2000s – Improved materials and technologies
Modern Track Structure - Purpose

- Provide a guideway for vehicles
- Distribute load to subgrade

Contact Stress Distribution

Wheel-Rail Contact Stress
~ 100,000 psi

Rail Bending Stress*
< 25,000 psi

Tie Bearing Stress*
< 200 psi

Ballast Bearing Stress*
< 85 psi

Subgrade Bearing Stress
< 20 psi
Increase in Axle Loads

- Key driver of modern track design over past century is the gradual increase in axle loads
  - Previous designs cannot withstand modern load environments
- Significant increase in 1960s to today

![Graph showing North American Car Capacity over Past Century](data:image/png;base64,iVBORw0KGgoAAAANSUhEUgAAAuAAAACwCAYAAAA0c3DAAAACXBIWXMAAA7DAAAD0CrSTAAAlwY1PRAAAAD3P05fAAAACxZFB99IAAAAAsS+ackAAAABdmpZDAAAASW2ZDAAA85P05fAAADyUK5PlAAAAAElFTkSuQmCC)
1960s and 1970s

- 70- to 100-ton capacity (200k to 263k pounds)
- Railroad track system in decline due to financial condition of railroads
- Largely empirical evaluation
- Weak points quickly exposed
  - Foundations
  - Rail wear
  - Turnouts
1980s

- 100-, 110-, 125-ton capacity (268k, 286k, 315k pounds)
- Railroad track system in good shape due to financial recovery
  - Staggers Act gave railroads pricing power
  - Government investment (4-R money to help rebuild railroads)
  - Industry initiative to prepare for future axle load increases
Association of American Railroads (AAR)
Strategic Research Initiative (SRI) Program

• Railroad industry driven research
• Research objectives:
  – Improve railroad safety, reliability, and efficiency
• Research topics:
  – Rail, ties & fasteners, ballast & subgrade
  – Welds, bridges, special trackwork, RNT
  – Rolling stock and components
  – Vehicle-track interaction
  – Signal and train control

(Index 2000 = 100)

Train accidents: ↓ 33%
Grade crossing collisions: ↓ 31%
Employee injuries: ↓ 52%

% change in rate from 2000-2020. 2020 is preliminary. Source: FRA
AAR

• Industry trade group representing Class 1s, Amtrak, and some regional commuter railroads

• Some industry statistics
  – 160,000 miles of track
  – 1.622 billion tons hauled
  – $70 billion in revenue
  – $13 billion capital invested

• Largest railroad network in entire world
SRI Research: What Gets Accomplished?

- Problem Diagnosis
- Product Testing/Designs
- Inspection Methods
- Life Predictions
- Maintenance
- Maintenance Planning

Enhanced, Systemwide Network Reliability

www.TTCI.tech

Wholly-owned subsidiary of AAR
• SRI research, support for standards & committees

Track, Vehicle & WRI Analysis

On-Location & On-Demand Support

Software & Modeling

Failure & Derailment Analysis

Standards & Regulation

Communications & Train Control

Testing, Monitoring Instrumentation & Test Design

Specialized Training

Laboratory & Track Testing

Beyond Rail

©2021 TTCI - 13
U.S. Freight Design Considerations
What To Get Out of This Presentation

• Complexity of railroad environment
  – Simple components but complex interactions

• Not how to design, but important considerations when designing
  – Successful railroad design requires more than just sound structural behavior

• No “One Size Fits All”
  – Wide range of track conditions require wide range of solutions

• Avoid Siloing
  – Railroad track is a system, and each component is influenced by the behavior of surrounding components
  – Railroad components wear and degrade over time so must account for all profiles across component lifespan
Key Drivers of U.S. Freight Design

- **Increase in axle loads**
  - Loading increases across entire track infrastructure

- **New materials**
  - Significant improvements in metallurgy over past 40 years

- **Iterative design improvements**
  - Gradual improvements over time by learning from previous designs
Common U.S. Freight Design Considerations

• U.S. railroads a legacy system with large investments in current practices
  – Equipment, procedures, and practices
• Any new designs must be interchangeable with previous designs and serve previous functions
  – New designs generally involve tradeoffs
• New designs should attempt to minimize maintenance down-time and time replacement with other relevant components
  – Two birds with one stone
• Assume long testing process
  – Railroads are a severe loading environment and field testing will likely identify any design issues
General Infrastructure Design
SRI Infrastructure Topics

Program Manager
Scott Cummings

Bridges
Chris Johnson
Duane Otter
David Linkowski

Rails
Ananyo Banerjee

NDT
Anish Poudel
Matt Witte
Kerry Jones
Brian Lindeman

Ties and Fasteners
Yin Gao

Data Analysis
Tony Sultana
Silvia Galvan-Nunez
Kenny Morrison

Substructure
Steve Wilk

Welds
Ananyo Banerjee

Special Trackwork
Duane Otter
Chris Johnson
Ben Bakkum
Steve Wilk

©2021 TCI - 19
Rail Design

- Incremental improvements in rail life and quality (less defects and better wear resistance)
  - Larger sizes
  - Improved metallurgy
  - Improved detection techniques

Detected by NDE method and removed from track
Tie & Fastener Design

- Many unique and premium products
- Align design with appropriate location and condition
Ballast Design

- Ballast cannot be manufactured
- Increased loading required
devoping specifications to identify higher quality rock
  - Granite and traprock
  - Ballast abrasion
  - Minimum 12-inch depth
  - Full shoulder and crib
  - Importance of drainage

AREMA (2019)

La Abrasion Test
(Tutumluer et al. 2021)
Subgrade Design

- Typically, reactive fixes
- Highly specialized at issue areas
Weld Design

• **Improved welding materials**
  – Goal is to increase weld life to reduce frequency of track repair

• **Thermite:**
  – Does not require power source
  – Portability
  – Adds material to rail gap

• **Electric flash butt:**
  – Longer life; no foreign material
  – Consumes material
  – Needs power source
Specific Design Experience

Track Design for Heavy Haul Railways

Insulated Joints:
- **Divide the track into traffic blocks (pre-CBTC)**
  - Installed in pairs
  - For electrically simpler designs, only one needs to function
- **Mechanical rail joints**
  - Structurally weak butt joint
- **A chronic problem**
Insulated Rail Joints for Heavy Haul Railways

Insulated Joints - Problem! What Problem?

- In the early 2000s there was no agreement that there was a problem
  - “This is a chronic problem we lived with”
  - Booming coal traffic raised the profile of this problem
    - Eastern railroad (60 MGT/yr) – replaces IJs on 4-year cycle; similar to rail life in curves
    - Western railroad (200 MGT/yr) – replacing IJs annually; rail service life is five times longer
      - A leading cause of train delay
- ~2000 AREMA IJ life survey – 230 MGT
  - Shorter service life than non-insulated rail joint
  - Shorter service life than mainline turnout frogs
Effects of HAL on Bonded IJ Performance

Failure Modes Analysis

• Bonded IJ failures in HAL Service
  – Service disruption is likely outcome
  – Fail-Safe occurrences: not one of the major track related derailment causes
    ▪ Redundant design
    ▪ Signal system (electrical) failure likely first
  – Most common failure is epoxy debonding related
    ▪ Glue line “unzips” from center of joint outward
      o Broken bolt
      o Electrical short
      o Pull-apart
Insulated Joint Failure Modes Analysis

• Debonding starts at the end-post
• Rust and metal to metal contact occurs
• Joint then “pulls apart”

• Typical start of failure
Insulated Bonded Rail Joint

- Unbuckling of the joint by debonding, tie fasteners, deflection, and bar/rail fasteners.
Insulated Bonded Rail Joint

- Longitudinal rail stress puts the joint in tension and debonding separates end-post contact.
Insulated Bonded Rail Joint

- Foundations deteriorate, ballast breaks down, mud pumping occurs, and tie/plate degrade
Insulated Bonded Rail Joint

- Batter and rail end shelling affects running surfaces that adds to IJ deterioration.
AAR Bonded IJ Research Matching Loads to Design Strengths

- **Standard**
- **Bigger bars**
- **Supported foundation**
- **Tapered joint**

**Epoxy Stress (psi)**

- Stronger Epoxy
- Existing Epoxy (new)
- Existing Epoxy (weathered)
Focus on Improving Existing Design with Better Materials and Processes

- Environmental effects are significant

![Chart showing comparison between new and weathered epoxy shear strength normalized.](chart.png)
Insulated Joints for Heavy Haul Railways

Remedies:

Better foundations

- Replace IJs as a panel
  - New ballast
  - New crossties
Insulated Joints for Heavy Haul Railways

Remedies:

Factory made IJ

- Rail is carefully prepped and epoxy is applied in a “clean room”
- Cured under controlled temperature and humidity
Suspended Foundation IJ Load Environment

- Thermal load in rail – measured up to 300 kips
- Vertical and longitudinal load add up during winter – causing more IJs to fail during winter
Supported Foundation IJ Load Environment

- **Bending and Thermal load in rail – counteracting**
  - Materials developed to insulate tie plate
- **Reduced maximum tensile loading**

![Diagram showing the relationship between bending, compression, tension, and thermal load.](image)
Evaluation of IJ Designs

• IJ System Approach… Super IJ

Bolts Insulated from Joint Bars

11” Wide Parallam Ties

Three -Tie -Plate

48” Long Joint Bars
Evaluation of IJ Designs

- LAP IJ: Structurally better

Shear stresses are one-third of conventional butt joint

Wheel impacts reduced to smooth rail – FAST test results
Insulated Joints for Heavy Haul Railways

Remedies

• Industry effort to improve service life
  – Railroads, suppliers and researchers
• 1990s: 200 MGT
• 2010s: 800 MGT
• Future: Eliminate IJs
Maintenance Planning
Lifecycle Management

- Railroad components have no set lifespan
  - Can vary significantly depending on environment and how well maintained
  - Example 1: Tie life can vary from 2 to 100 years depending on tonnage and climate
  - Example 2: Tie degradation can be greatly affected by local conditions such as nearby degraded ties, mud spots, and vehicle impact loading

- Forecast remaining component lifespan based on the current condition and degradation of that condition

Wood pole decay hazard risk (1 = lowest decay risk, 5 = highest) (image: osmose.com)
Condition-Based Maintenance

Track-Based Inspection

Maintenance

Condition Assessment

Forecasting

Data Lake

Enhanced, Systemwide Network Reliability
Conclusions and Lessons Learned
Conclusions and Lessons Learned

• Complexity of railroad environment
• Not how to design, but important considerations when designing
  – Successful railroad design requires more than just sound structural behavior
• No “One Size Fits All”
  – Wide range of track conditions require wide range of solutions
• Avoid siloing
  – Railroad track is a system, and each component is influenced by the behavior of surrounding components
  – Railroad components wear and degrade over time so must account for all profiles across component lifespan
TTCI - Contacts

Steve Wilk
Stephen_wilk@aar.com

Human Resources

Sherri Corpuz
Sherri_corpuz@aar.com
Thank you!

Transportation Technology Center, Inc.
55500 DOT Road
Pueblo, Colorado 81001
www.aar.com