Evaluation of Track Performance Under 39-ton Axle Loads

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ABSTRACT
Evaluation of track components to enhance their safety and utility under heavy axle loads has continued at the Facility for Accelerated Service Testing (FAST). A test of rails developed to provide better wear and rolling contact fatigue (RCF) resistance began in 2010. Rails produced in Europe, North America, and Asia, and next generation rail developed through Association of American Railroads’ research are included in this evaluation. Differences in rail wear and the development of RCF among the various rail types are becoming evident.

Half-frame concrete ties, conventional concrete ties, and modified concrete ties have accumulated 240 million gross tons (MGT). The half-frame ties provide about twice the resistance to lateral movement compared to conventional ties. One of the conventional tie test zones has under-tie foundation pads, and it continues to show more ballast migration than other test zones. After 370 MGT, softwood ties with cut-spike plates have shown the least gage restraint in the wood tie test. Screw spikes in one test zone were replaced with high-strength screw spikes due to numerous broken spikes.

Innovative rail welding methods developed by various suppliers are being evaluated. Second generation thermite, head repair welds have accumulated up to 160 MGT. None of these head repair welds have been removed compared to approximately 40 percent of earlier head repair welds removed by 100 MGT.

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Testing of concrete bridge spans continues; four spans installed in 2003 have accumulated 975 MGT, and a prototype span installed in 2011 has accumulated 20 MGT. The prototype span is a hybrid composite span with a tied-arch design that has the potential to substantially lower the weight of short to mid-length concrete spans.

A number 11 partial flange bearing turnout frog has accumulated 330 MGT on the mainline side and 4 MGT on the diverging side. Lateral impacts from the back of wheels striking one of the guard flares are disturbing frog alignment; mitigation methods are being considered.

A new, longer consist comprised of 110 aluminum coal cars and three EMD SD 70M or 70 MAC locomotives has increased efficiency, tonnage accumulation, and reduced fuel consumption at FAST.
INTRODUCTION
Testing at the Facility for Accelerated Service Testing (FAST) has been a mainstay in the Association of American Railroads’ (AAR) heavy axle load research (HAL) program since 1988, but the program has continually evolved to meet the changing needs of the industry. This evolution continues, and there have been significant changes in, and additions to, the program at FAST in the past year.

The experiments and tests that are conducted at FAST are continually reviewed by industry research committees to ensure that they are meeting current needs and are preparing the way for future requirements. Though the types of components being tested may be the same as were tested several years ago, current tests reflect industry needs as railroads continue to improve the safety and efficiency of their businesses.

A different train (Figure 1) is now operating at FAST. The Union Pacific (UP) Railroad provided 110 current generation 315,000-pound gross rail load aluminum coal cars for use at FAST.

Figure 1. Test Train at FAST
The new cars allowed the retirement of the 40-year-old steel cars that had been used at FAST since 1988. Component failures and maintenance costs for these steel cars were increasing, and the cars were no longer representative of the industry’s current coal fleet. The new train should enhance safety, increase productivity, and reduce maintenance costs. Norfolk Southern, UP, and CSX have provided the use of modern, high-horsepower, fuel-efficient EMD SD 70M or SD 70 MAC locomotives. These locomotives replace older, less efficient GP-39 and GP-40 locomotives. Fuel
consumption has been reduced by about 20 percent since the introduction of the new locomotives.

The modern control systems on the locomotives also facilitate the unmanned train operations that are now standard practice at FAST. Most train operations are now without personnel in the cab. The test controller activates the computer control system, which then controls throttle position and train braking. The test controller can also stop the train remotely.

The FAST train is operated on the High Tonnage Loop (HTL), a 2.7-mile track comprised of tangents, short spirals, and 5- and 6-degree curves (Figure 2). Train operating speed is 40 mph which results in overbalanced speed operations; the curves are balanced at about 33 mph. Operation is bi-directional, with approximately 50 percent in each direction.

Figure 2. HTL and FAST Experiments

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EXPERIMENTS AT FAST
Rail Performance Evaluation

Rail tests have been part of the FAST program since its inception. These tests provide information on rail performance for use in purchasing decisions and for improving future generations of rail. Because U.S. railroads are spending more than $3 billion per year to renew and maintain rail, increasing the service life and decreasing the life-cycle costs of modern rail steels is of great importance to them. In 2010, nearly 2,000 track-feet of new state-of-the-art rail was installed in two 5-degree curves at FAST for performance evaluation under HAL. Testing in the controlled and well-maintained environment of FAST allows accelerated testing while minimizing test variables.

Premium Rail
The latest rail test at FAST includes 10 high-hardness (413 HB average) premium rails developed to provide better wear and rolling contact fatigue (RCF) resistance, which were provided by manufacturers in North America, Europe, and Asia. In addition to commercially developed rail, an experimental rail developed in a collaborative effort between Transportation Technology Center, Inc. (TTCI) and the University of Pittsburgh and produced by voestalpine AG is also being tested. This experimental rail, designated as 400NEXT, was produced with chemistry and thermo mechanical processing intended to maximize cleanliness and to minimize the development of pro-eutectoid cementite. Studies at the University of Pittsburgh showed that inclusions and pro-eutectoid cementite could contribute to the development of RCF cracking. Table 1 lists the suppliers and types of premium test rails.

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<th>Supplier</th>
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<td>ERMS Rail Mill (USA)</td>
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<td>VAS 1, VAS 2, voestalpine 1 &amp; 2 400NEXT</td>
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Table 2 shows the mechanical properties for the test rails. Initial tests were conducted at TTCI, and two independent laboratories verified the results. The table shows the independent laboratory results. All rails met American Railway Engineering and Maintenance-of-Way Association (AREMA) recommendations for hardness and ultimate tensile strength of premium rail. Some rails did not meet the requirements for elongation or yield strength.

### Table 2. Mechanical Properties of Premium Rails

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| AREMA Recommended Minimums | 120 | 171 | 10* | 120 | 171 | 10* |

*Up to 5% of the order may be less than 10% elongation if the purchaser’s authorized representative and supplier agree, but in no case may the elongation be less than 9%.

The premium rails were installed in a 5-degree nonlubricated curve. Figure 3 shows rail wear (area loss) for the rails on the high rail of the curve through 140 MGT. Note that the 400NEXT rail was installed later than the other test rails, and thus, has accumulated less tonnage.
The rail with the most wear has worn about 20 percent more than the rail with the least wear; however, previous testing has shown that relative wear can change as tonnage accumulates. These results should be considered as preliminary. All rail types are showing some RCF after 140 MGT, but some rails are showing more than others. Figure 4 shows examples of premium rails with RCF.

Intermediate Hardness Rail
Intermediate hardness (340 HB average) rails from several manufacturers were installed in a lubricated 5-degree curve and are also being tested. Table 3 lists the types and suppliers of the
intermediate test rails. These rails are intended to provide satisfactory performance under moderately demanding conditions, but at a lower cost than premium rail. Figure 5 shows rail wear (area loss) for the rails on the high rail of the curve through 140 MGT.

Table 3. Intermediate Test Rails

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<td>IH, IH HS, SS Intermediate Hardness, Intermediate Hardness High Strength, Standard Strength</td>
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<td>Lucchini Rail Mill (Italy)</td>
<td>IH Intermediate Hardness</td>
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<td>Mittal Rail Mill (USA)</td>
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<td>Panzhihua Rail Mill (China)</td>
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<td>Trinecké Zelezárny Rail Mill (Czech Republic)</td>
<td>TZ Trinecké Zelezárny</td>
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</table>

Figure 5. Intermediate Rail Wear

There is more variability in the wear rates of the intermediate rail than in the premium rail; there is also more variability in the hardness’s of the intermediate rails. Note that despite the higher
hardness of the premium rails, the average wear for the intermediate rails is less than one-half that of the premium rails, illustrating the effectiveness of rail gage-face lubrication in reducing rail wear.

All of the intermediate hardness rails are also showing shallow RCF. However, there is less RCF than in the premium rails (in the dry curve) and less variability in the degree of RCF in the intermediate rails.

**Improved Strength Track**

More and more is being demanded of the track structure. The trend is toward heavier, faster, longer trains. Passenger trains and their attendant track-geometry requirements will share tracks with freight trains in increasing numbers. Maintenance windows will become even shorter as traffic increases. Innovative types of track structures are needed to meet the increased demand. New-design, heavy-duty concrete ties and state-of-the practice conventional concrete ties were installed at FAST as part of a test of improved strength track. The half-frame ties (Figure 6) have larger vertical and lateral footprints than conventional ties and have integral under-tie pads.

![Figure 6. Improved Strength Track with Heavy Duty Ties](image)
These features should reduce surfacing requirements and increase resistance to track buckling. Some of the more conventional concrete ties in test also have under-tie pads, which are intended to reduce the need for track maintenance.

The first 240 MGT of testing shows that the half-frame tie track is indeed very stable. Single tie push tests showed that it takes more than two times the force to push the half-frame ties laterally through the ballast compared to conventional ties. Some of the half-frame ties have developed minor cracks. Modifications have been made to the fastening configuration to reduce forces in the unreinforced portions of the ties where cracks occurred. No new cracks have developed in the modified ties. Four of the clips on the heavy duty ties have also cracked. One of the broken clips has been sent to the supplier for failure analysis. Figure 7 shows a broken clip.

Figure 7. Broken Clip on Heavy Duty Tie

There are also obvious differences in ballast movement and churning between tie types. The ballast in one of the zones has gradually migrated to the inside of the curve with accumulated tonnage. This zone was regulated to move the ballast back to the outside of the curve at about 80 MGT and 195 MGT, but ballast movement continues. The composition and stiffness of the under-
tie pads appears to be a contributing factor. The zone with the stiffest pads has shown the most ballast movement.

**Ties and Fasteners**

In 2008, over 1,000 hardwood, softwood, and concrete ties were installed at FAST. The softwood ties with cut-spike plates have shown the least gage restraint and the most gage widening after 370 MGT. Gage restraint provided by hardwood ties with elastic fasteners has been similar to that provided by concrete ties. Gage widening on plastic ties with approximately 1,000 MGT is similar to hardwood ties with comparable tonnage. Figure 8 shows gage widening (difference between loaded and unloaded gage) as measured by the AAR’s Track Loading Vehicle (TLV). The TLV applies a 33,000-pound vertical load and an 18,000-pound lateral load.

![Figure 8. Delta Gage Measured by the TLV](image)

Component failures have also been documented at FAST. Approximately 12 percent of the screw spikes in one of the test zones had fractured 2-3 inches below the spike head through 230 MGT. They also had more wear where they contacted the plate than other spikes (Figure 9). The screw spikes were European design and were softer than those typically used in North America.
These spikes were replaced with high-strength screw spikes. There have been no subsequent screw spike failures in that test zone. About one-fourth of the insulators in the concrete tie zones had cracked through 210 MGT. The insulators were replaced with improved insulators. No subsequent failures have been noted. The plastic tie zones exhibit more ballast churning than the wood tie zones, and more tie plates on the plastic ties have broken.

Figure 9. Broken and Worn Screw Spikes

Rail Welding
Ten second-generation thermite, head repair welds from Orgo-Thermit and Railtech Boutet (improvements based on earlier tests at FAST) have accumulated up to 160 MGT with no weld failures. For comparison, approximately 40 percent of the earlier head repair welds had been removed by 100 MGT. Repair welds have also been installed over electric flash butt welds and in rail directly over concrete ties. The repair welds installed over electric flash butt welds have accumulated 100 MGT, and two of the ten welds have failed. The eight welds over concrete ties have 60 MGT with one failure.
A new type of head repair weld is being tested this year at FAST. In 2011, seven electric flash head repair welds from the Holland Company were installed and have accumulated 95 MGT without weld failure. The welds were produced in a shop, and then installed at FAST. Work on an in-track system is underway. Figure 10 shows examples of thermite and electric flash head repair welds.

![Figure 10. Thermite Head Repair (left) and Electric Flash Head Repair (right) Welds](image)

Maintenance rail welding has changed at FAST. Previously, thermite welds were used for all day-to-day rail welding. Thermite welds are relatively easy and inexpensive to install, but typically have substantially shorter lives than rail. UP donated an in-track electric flash butt welder for use at FAST, which has reduced the number of thermite welds and the number of service failures. Regular maintenance grinding of remaining thermite welds has reduced weld batter and increased weld life.

**Concrete Bridges**

A new type of concrete bridge is being tested at FAST. The hybrid composite concrete bridge is a tied-arch design that reduces the weight of a span. The first span tested at FAST was a 30-foot bridge span. Preliminary testing showed that its design was capable of supporting 315,000-pound cars, but the original deck was insufficient for HAL. The deck was replaced, and the span accumulated 240 MGT before it was removed. It performed as expected, with deflections similar to reinforced concrete. The 30-foot span was removed in May 2011, concurrent with the installation of a new, 42-foot hybrid composite concrete span (Figure 11).
The original 30-foot box-girder span was reinstalled, while the 42-foot high-strength concrete span formerly in track was replaced with the new hybrid composite concrete bridge span.

Other concrete bridge spans being tested at FAST are performing well through nearly 1,000 MGT. Ballast depth on one of the bridges was recently reduced from 12 inches to 8 inches for the first of a series of tests on the effects of ballast depth. Earlier tests showed that using tie materials and ballast mats to modify track modulus is an effective method of lowering the stress state and reducing track maintenance requirements.

Flange Bearing Turnout Frog
Removing or lessening the rail discontinuities often associated with special trackwork is one way of reducing dynamic loads. Carrying a car on its wheel flanges over a smooth surface instead of on its wheel treads over a gap in the rail can dramatically reduce impacts. Much of the preliminary work on high-angle flange bearing crossing diamonds was done at FAST. More recently, two flange bearing turnout frogs have been tested. Figure 12 shows one of the frogs. The frog installed on the main line of the HTL has accumulated 330 MGT on the mainline side, and about four MGT on the diverging side. The average life of conventional railbound manganese frogs in this location is 150
MGT. Instrumented wheelset tests showed that dynamic forces on the mainline side of the turnout were reduced by about 70 percent compared to conventional turnout frogs, and that cars can be safely operated over the diverging route on flange bearing turnout frogs at speeds up to 15 mph. It has been difficult to maintain lateral track alignment at the frog. Measurements of lateral movement during train operations indicate that the proximity of the frog to curves on each side (some trucks are still misaligned when they reach the frog), in combination with short, steep guard flares are contributing to the problem. When the misaligned wheels strike the guard flares, the impact moves the frog laterally. Wear patterns and wheel contact locations on the test frogs at FAST have provided the suppliers information that has since been used to improve the design of the frogs.

![Figure 12. Locomotive Approaching and Traversing Flange Bearing Turnout Frog](image)

**CONCLUSION**

Railroads must continue to develop cost-effective ways to safely increase capacity. Increased axle loads have historically been one of the means that railroads have used to do this. Funded by the AAR and the industry, research at FAST has helped minimize the adverse effects of increased axle loads, and it will continue to do so. FAST provides the industry with a valuable facility for the development and evaluation of innovative track components. It provides a facility for testing components with the unproven potential to provide improved performance. Tests are regularly conducted...
updated at the direction of railroad committees to assure that the program meets the changing needs of the industry.
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Figure 7. Broken Clip on Heavy Duty Tie

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Figure 10. Thermite Head Repair (left) and Electric Flash Head Repair (right) Welds

Figure 11. Hybrid Composite Concrete Bridge Span

Figure 12. Locomotive Approaching and Traversing Flange Bearing Turnout Frog

Table 1. Premium Test Rails

Table 2. Mechanical Properties of Premium Rails

Table 3. Intermediate Test Rails
Evaluation of Track Performance Under 39-ton Axle Loads

Joseph A. LoPresti, Principal Investigator
Transportation Technology Center, Inc.,
a subsidiary of the Association of American Railroads
Increased axle loads
- Increased capacity — greater need as traffic increases
- Operational cost savings
- Increased track maintenance and renewal costs

FAST/HAL objective: Investigate performance of improved track components under HAL cars
- Mitigate adverse effects of HAL/extent component lives

FAST facilitates implementation of HAL

Improved safety
- Reduced derailments caused by component failure

Improved efficiency
- HAL reduces the number of trains, reduces congestion, increases asset utilization
FAST/HAL Implementation

- Cars and locomotives provided by railroads
- 105–115 315,000-lb coal gondolas
- 100–130 trains per night
  - 40 mph
  - 1.5–2.0 MGT per night
- 110–130 million gross tons per year
High Tonnage Loop (HTL)
2.7 mile
5° and 6° curves

- Interspersed Concrete Ties
- Thermite Head-Repair Welds
- Track Transitions
- Over-tie Switch Rods
- Insulated Joints
- Concrete Slab Track
- Coal Fouled Ballast
- Rail Joints
- Machine Vision Car Inspection
- Rail Performance
- Flange Bearing Turnout Frog
- Steel Bridge
- Concrete Bridges
- Concrete Ties
- ½ Frame Concrete Ties
- Ties (wood, plastic, concrete) and Fasteners
- Electrical Rail Bonds
- Rail Performance
- Ballast Gradation
- Rail Joints
- Machine Vision Car Inspection
- State-of-the-art Turnout
- Machine Vision Car Inspection
- Concrete Ties
Rail and Rail Welds

Problem size
- U.S. Class I railroads spent over $3 billion on rail in 2009
  - 562,000 tons of new rail laid
  - Rail life (MGT) has increased by more than 50 percent since 1994, but increase in yearly tonnage can mean shorter replacement interval

Safety
- Rail related defects No.1 or No. 2 in cost/cause of derailments
  - Weld defects ≈ 1/3 of total
  - Weld defects No. 1 cause of service failures for some railroads
Premium Rail Test at FAST

Conditions
- 5° curve
- 4-inch superelevation
- No direct lubrication

Rails
- 136-8 RE rail
- 412 HB average
- Evraz RMSM
- Corus
- JFE
- ArcelorMittal
- NSC
- voestalpine
- Panzhihua
- voestalpine 400NEXT

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Preliminary Premium Rail Wear

Average High Rail Wear Area

Rail Wear [mm^2]

Rail Type

ERMS
CORUS
NIPPON
JFE-A
JFE-B
MITTAL
PG4
VAS-1
VAS-2
400NEXT

32 MGT
60 MGT
89 MGT
140 MGT
Intermediate Rail Test at FAST

Conditions
- 5° curve
- 4-inch superelevation
- GF rail lubrication

Rails
- 136-8 RE
- 339 HB average
- Evraz RMSM
- TZ
- Panzhihua
- Corus
- ArcelorMittal (Spain)
- Lucchini

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Preliminary Intermediate Rail Wear

Average High Rail Wear Area

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<td>60 MGT</td>
<td>89 MGT</td>
<td>140 MGT</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

[Graph showing the average high rail wear area for different rail types and MGT values.]
More wear on high rail of nonlubricated premium rail than lubricated IH rail – especially on gage face.
Varying amounts of RCF evident in all rail types

Research into mechanical causes under way
Railhead Repair Welds

- Repair of head defects without altering rail neutral temperature

Thermite railhead repair — testing at FAST
- Second generation – 140+ MGT, 0/10 failures
- Repair of EFB – 85+ MGT, 2/10 failures
- Repair over ties – 35+ MGT, 1/8 failure
Railhead Repair Welds

- Electric-flash slot weld
- Testing at FAST
- Laboratory produced prototype welds
- Installed Jan. 2011
- Section 3
- 6 welds in high rail
- 2 welds in low rail
- ~95 MGT to date
- No Failures
**Improved Track Strength**

*Half Frame, Conventional, and Modified Concrete Ties*

- **Safety**
  - Improve track stability, buckling resistance and gage restraint
  - Maintain alignment for HAL and high-speed passenger traffic

- **Efficiency**
  - Reduce life cycle costs
Half-frame Ties Increase Lateral Track Strength

- Tie pushes, 2 and 150 MGT
- Standard tie resistance increased with tonnage
  - 3800 lbs at 2 MGT
  - 4300 lbs after 150 MGT
- Half-frame
  - Continues to exceed machine capacity 10,000 lbs
Ballast Migration

Some standard ties show more ballast migration
- Most migration in one standard tie zone w/under tie pad
- Varies by type of fastening system and pad type
- Half-frame ties continue to show minimal migration
- No TGC related maintenance needed
Issues with Half-Frame Ties

- Cracks on end tabs (ears)
  - 6 of 95 ties w/8 clips/tie
  - 0 of 95 ties w/4 clips/tie
  - Solution: replace dual field side clips with single clip

- Four Broken clips
  - Clip strength? More deflection with softer pads?

- Transverse cracks near center of tie
  - Center binding? Tie strength?
Objective — Evaluate Tie and Fastener Systems:
- Safety and Efficiency
- Reduce Life-Cycle Costs
- Improve performance — gage restraint, alignment, and extend life of tie and fastener systems under HAL

HW — Hardwood
SW — Softwood
DF — Direct Fixation
CS — Cut spike
GRMS Data after 255 MGT
33,000-lb vertical load, 18,000-lb lateral load
Screw Spike Failures

- One supplier, 25 of 50 ties
- 3 inches below top of tie
- Gage strength measurements did show weak track
  - GRMS, Static track gage
  - Little plate movement
  - Found by track inspector
- Cause: Soft spikes
- Solution: Replace with HH screw spikes
  - Ties moved 2 inches
  - Alternate left/right
Broken Insulators – Concrete ties

- Broken or cracked insulators
  - Field side only
  - ~ 20% noted
  - Both “conventional” suppliers
- Found by visual inspection
- Typical of what is seen at revenue sites
- New design insulators installed
  - No issues to date
Flange Bearing Turnout Frogs

- Two frogs tested at FAST

Progress Rail

VAE Nortrak
Flange Bearing Turnout Frogs

Dynamic force reductions on mainline side

![Graph showing dynamic force reductions on mainline side](image)
Loaded and empty cars can operate safely up to 15 mph.
Current (mainline) tonnage life of FAST frog over 2x average of RBM frogs in that location
No exceedence of Chapter 11 criteria up to 15 mph
Parallel ramps help equalize vertical load across wheelset
Longer, shallower guard flares should reduce lateral impacts and lateral frog movement (mainline traffic)
New Design Concrete Bridge

- New production version HCB span installed at FAST
  - Professionally produced fiberglass shells
  - Concrete work by a Class 1 railroad supplier
  - Innovative new bolt-on polymer-concrete ballast curbs
  - Integrated cells in each half span
  - Stiffening fin added to concrete arch
  - Additional deck reinforcement
  - BNSF installation after 1-2 years proof testing at FAST
Conclusions

- Increased axle loads historically used to increase capacity
  - Next increase???
- Current axle loads can place high demands on track components
- Research at FAST has mitigated effects of previous increases
  - Can help prepare for future increases