A World of Change:

1st Annual
AAR Research Review
November 6-9, 1995

Transportation Technology Center

VOLUME 1: FAST/HAL TEST SUMMARIES

U.S. Department of Transportation

Federal Railroad

25 - R& D Management

Association of American Railroads
Transportation Technology Center
Pueblo, Colorado

C. ORTH

ACKNOWLEDGMENT

The FAST Program continues to be made possible through the dedicated efforts of many individuals and companies. The annual operating funding of $4.2 million comes jointly from the Association of American Railroads and the Federal Railroad Administration. Significant donations of materials and equipment are supplied by member railroads and supply companies. This saves the FAST program over $1.8 million in operating expenses each year.

Recognition is also given to the dedicated support staff at the Transportation Technology Center. Their support, along with staff support at AAR headquarters in Washington, D.C., is essential to the successful operation of FAST. Finally, we would like to thank the FAST Steering Committee for the overall technical direction provided from its members of railroad, supply and governmental representatives.

The success of the FAST Program is made possible through the combined support of all these people, and the financial assistance received.

FAST Facility for Accelerated Service Testing

HAL Heavy Axle Load

Association of American Railroads

Transportation Technology Center

U.S. Department of Transportation
Federal Railroad Administration

FOREWORD

Welcome to *A World of Change:* 1st Annual AAR Research Review, November 6-9, 1995. Our four-day event focuses on four aspects of the activities carried out by the Association of American Railroads' Research and Test Department at the Transportation Technology Center (TTC), in Pueblo, Colorado.

This two volume set, FAST/HAL Test Summaries and AAR Research Review, serves as a written record of our formal discussions during the event. We hope it continues to serve your reference needs for many months to come.

You will have the opportunity to participate in an open house of the Facility for Accelerated Service Testing, heavy axle load track structure and train consist, review the technical results of the heavy axle load program with our project managers, receive current information on the full range of R & T's strategic research initiatives, and observe the entire complement of facilities and equipment now resident at TTC.

The Research and Test Department has been in a year of transition. As we bring 1995 to a close, we complete a major chapter in AAR's history of R & T activity. For the first time we have the full complement of analytical capacity, laboratory test machinery, full scale track and vehicle test facilities and comprehensive skills at one location. The recent name change to the Transportation **Technology** Center reflects the creation of a truly unique world class railroad research, development and test staff and facility that will meet the rail industry's technology expectations for the 21st Century.

On behalf of the entire AAR staff, our research partners from government and industry, our member railroads, and our contributors and supporters we appreciate your attendance...thank you for coming.

CONTENTS

INTRODUCTION TO THE HEAVY AXLE LOAD IMPLEMENTATION
AAR Strategic Research Initiative No. 4
by Semih F. Kalay

Increased axle loads represent an attractive means of increasing efficiency and productivity in revenue service. A potential 5 percent reduction in the annual diesel fuel costs for bulk and intermodal traffic, due to less energy consumption per ton mile, could by itself result in annual savings of $95 million. Through testing and analysis, the Association of American Railroads'(AAR) research into the impact of heavy axle loads on track maintenance requirements has helped the railroad industry gain the economic benefits of hauling larger capacity cars safely and efficiently. Results from Phases I and II of heavy axle load operations, at the Facility for Accelerated Service Testing (FAST), show that 39-ton axle loads are economically beneficial in many services, but the track penalty may be as much as 30 percent, if conventional equipment and track materials are used.

There are three projects under this strategic research initiative: (1) further research into new suspension systems for HAL traffic in FAST operations, (2) development of alternative substructure improvement techniques to reduce substructure failure under HAL, and (3) monitoring of revenue service performance under HAL. These improvements will allow the industry to introduce still further increases in axle loadings safely and economically by reducing HAL costs and ensuring the timely identification and correction of problems. A summary of the three projects follows:

FAST/HAL PROGRAM

The goal of the FAST/HAL program is to determine the reduction of track maintenance and degradation with a train equipped with HAL cars and advanced truck designs. Another goa l is to determine the effect of HAL traffic on existing track materials.

Phase II of the program has investigated the effects of HAL traffic on track performance using a train equipped with conventional three-piece trucks. With this train, costs associated with HAL operation over track constructed with conventional and premium components have been documented. Improvements in truck suspension design may offer additional reductions in cost associated with track maintenance requirements under HAL traffic.

In Phase II 300 MGT of traffic were generated. This included operating additional tonnage over track materials that previously had exhibited a full life cycle, along with evaluation of new and improved materials. Phase II results are included in this document.

In Phase III, a train of 60-75 HAL cars will be equipped with improved truck designs and operated to generate track degradation and maintenance data. This data will be used to perform an economic analysis to identify the cost benefits associated with HAL traffic using advanced suspension designs. The initial 100 MGT of Phase III will make direct comparisons with track performance data generated with conventional trucks. Phase III operations will continue for approximately 475 MGT to document the long term track degradation for HAL traffic using advanced suspension designs.

TRACK SUBSTRUCTURE ASSESSMENT

Track substructure assessment will determine causes of and solutions for track subgrade support failure under heavy axle loads by providing a rapid in-situ subgrade test to determine the soil strength. The project also seeks to determine the substructure support characteristics and how much support varies along the track by means of a rail deflection-based measurement obtained by a moving vehicle. The end products expected to come out of this project are recommended practices to minimize the effects of HAL on subgrade maintenance costs, and development of methods to relate track support to track maintenance requirements.

Subgrade stability has a large influence on the ability to maintain track geometry. With an increase in axle loads, subgrade performance becomes increasingly important. Soils which can withstand the current loading environment may be overstressed by HAL. With current methods of subgrade investigation, it has been necessary to excavate a trench to test subgrade strength and estimate in-situ properties. This trenching only extends down a few feet into the subgrade. The cone penetrometer test (CPT) offers a non-destructive, quick and reliable method which can test to depths of 20 feet or more. Recent tests at FAST showed that marginal track substructure conditions may require surfacing maintenance at intervals as low as 13-15 MGT. This represents a three-fold increase in track surfacing costs leading to a major increase in HAL operating costs.

With the CPT technique, a cone is continuously advanced into the subgrade while the resistance to penetration with depth is monitored and recorded. The adequacy of the existing amount of granular material over the subgrade can be assessed and recommendations made regarding the most appropriate maintenance remedy based on the findings.

Also it has been shown that the variation of track deflection along the track provides a direct measure of the substructure support stiffness and its variability. A rail deflection based measurement taken with a moving vehicle, along with the CPT, could provide essential information for deciding upon the most appropriate maintenance remedy. The rail deflection measurement will add even more capability to this diagnostic and remediation procedure.

In 1995, a production version of the CPT was completed and tested at TTC. The test vehicle has since been used on Conrail, AMTRAK, and the Burlington Northern to determine the extent of a soft subgrade along and under the track. Work in 1996 will include the completion of a survey of North American subgrade strength conditions and the analysis of economic benefits and assessment of alternative substructure improvements. Outer year deliverables include the incorporation of rail deflection and CPT subgrade measurements in overall diagnostic test, and the survey of revenue track support conditions using rail-deflection based measurement procedure

HAL Revenue Service Evaluation

The HAL revenue servie evaluation will determine the effects of HAL traffic on the track infrastructure and mechanical components and to alert the industry to potential problem areas and refine the economic analysis of HAL traffic.

Several railroads have begun the implementation of heavy axle load operations. Based on the results of AAR's initial economic analysis, 286K gross weight vehicles have been selected for this implementation into the industry.

The areas of particular importance and focus are those which cannot be addressed adequately at FAST. The specific test areas include wood and concrete crosstie performance, track degradation with respect to marginal subgrade strength locations, turnouts, and bridges. The vertical and lateral load environments, including impacts, are also being monitored as the HAL traffic is introduced.

An increased knowledge of the effects of HAL traffic on track infrastructure will allow for strategic maintenance planning. Predictions of failures from unsatisfactory components for this load environment will also be possible.

Test sites have been established on several of the AAR member railroads. Baseline (263K traffic) data has been and continues to be collected. The implementation of HAL traffic will most likely be a gradual one. The AAR plans to continue monitoring the progress of this implementation throughout this process. Changes in degradation rates as the loads are increased will be sought. This data will provide the basis for the economic evaluation of HAL operations which will follow.

Work in 1995 includes an update of life of rail-bound manganese frogs in heavy haul service, which has been under evaluation for three years. Two revenue service bridges are also under investigation to assess the effects of heavy axle loads on bridges. The HAL revenue service evaluation project is being planned to end in 1997, unless further monitoring is required.

FAST HISTORY AND OPERATION OVERVIEW

INTRODUCTION TO FAST/HAL PROGRAM ...Richard P Reiff

To the North American railroad industry, FAST, the Facility for Accelerated Service Testing, means track testing. Since its inception in 1976, over 1.5 billion tons of traffic have been operated over a closed loop of track under carefully controlled and monitored conditions. Countless labor-hours have been expended in train operation, track maintenance, measurement, documentation efforts, and data analysis.

The intent of this conference is to provide participants with an overall background to the FAST program and, specifically, a detailed review of results from the last three years of testing. During this period, a controlled set of experiments has been conducted to determine the engineering impact to premium track components when subjected to heavy axle loads. Data from these trials is being made available to the industry to provide component performance information as an aid in determining the most safe, reliable, and efficient method of operating a railroad system with heavy axle loads.

Particular emphasis at this conference will be on the effects that heavier axle loads have on track materials and maintenance procedures.

BRIEF HISTORY OF FAST

In September 1975, a report recommending a facility to study wear and fatigue of railroad track and equipment was issued by the Association of American Railroads (AAR) and the Federal Railroad Administration (FRA). The following spring, track construction began at the High Speed Ground Test Center, Pueblo, Colorado. The first loop covered 4.78 miles (Figure 1) and utilized some of the existing Train Dynamics Track to reduce construction costs.

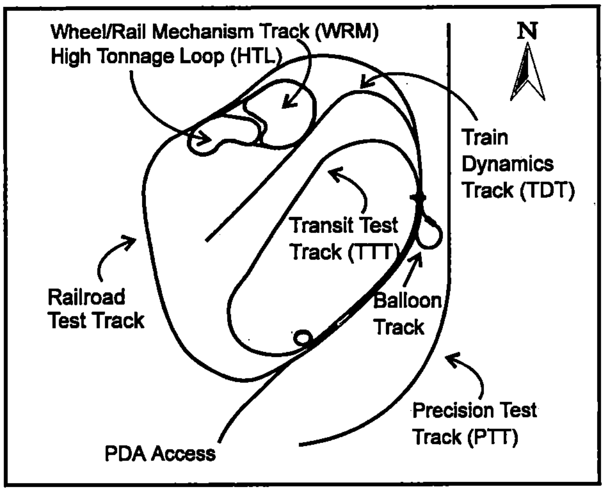


Figure 1. Test Tracks at High Speed Ground Test Center, Pueblo, CO, Showing General Location of FAST

On September 22, 1976, the first FAST train began accumulating tonnage on the dedicated test track. Since that time, a test train in various configurations and under a variety of test conditions has continued to operate.

The original FAST program was sponsored by the FRA, with all operating and measurement costs being the responsibility of the government. The railroad industry contributed significantly to the program by providing technical assistance and equipment, and by transporting materials for construction and maintenance.

After 1977, government emphasis at the test center shifted away from high speed transportation to research of conventional transportation modes. The testing center was renamed, Transportation Test Center (TTC), and in late 1982, government policy changed the operational procedures making the AAR solely responsible for its operation and maintenance. (Recently the research and test site was renamed the Transportation Technology Center and is still maintained and operated by the AAR.)

FAST also continued to change. The annual FAST program operating budget had steadily decreased over a period of five years and, by 1985, it was apparent that the expense of operating a full train over the 4.78 mile track was no longer affordable. To permit continued operation of FAST, a cut-off track was proposed, designed, and constructed using AAR funds (Figure 2).

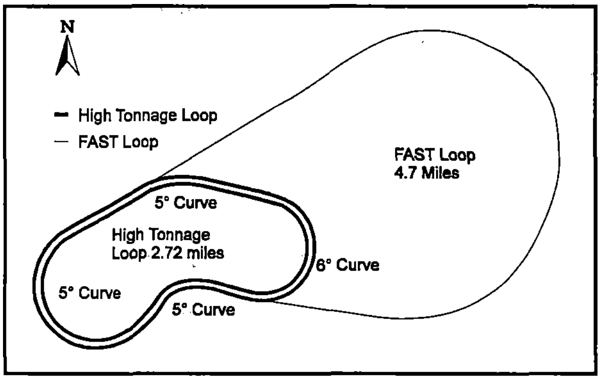


Figure 2. High Tonnage Loop

The cut-off track, approximately 1.3 miles, effectively reduced the loop from 4.78 miles to 2.7 miles. The new loop, named the High Tonnage Loop (HTL), consisted of one 6-degree curve and three 5-degree curves. All curves in the loop utilized spirals 300 feet long. As with the original loop, the HTL was divided into a number of test sections, which made inventory, maintenance, and measurement activities easier to document.

Completion of the HTL in June 1985, significantly reduced operating costs and allowed continuation of the FAST program using the original 33-ton axle load consist.

Since 1976, FAST has monitored tonnage applied to all test sections. This is accomplished by having every car and locomotive weighed and assigned a control number. This number is used to monitor daily train consist makeup and, when combined with the lap count for each shift, allows an accurate determination of applied tonnage over the loop. Each train operation is monitored in such a fashion, except for occasional work trains used for ballast dumping, rail unloading, or other track maintenance support functions.

Details of HTL Operations 33-ton Axle Load Phase

Along with the HTL came minor changes to the method of train operation. At the start of the HTL operation, a major rail fatigue test was initiated that required different operating characteristics than was used before. Train operation under the previous FAST policy controlled train direction so that both clockwise and counterclockwise operations were balanced. But on the HTL, the train operated counterclockwise. The main reason was that lubrication, applied from a wayside lubricator, could be controlled from one location. (A calcium soap base lubricant with 11 percent graphite had been utilized at all wayside lubricators at FAST.) The combination of single directional operation and the use of wayside lubricators created the intended differential in the lubrication — more near the lubricator, less at distances remote from the lubricator. By installing like or identical rail sections at various locations around the loop, the effect of different lubrication levels could be assessed.

The shorter length of the HTL, 2.7 miles opposed to the original 4.78 miles, necessitated a major change in the signal system. The original signal system configuration was composed of a basic 3 block, direct current track circuit design. It utilized conventional, off-the-shelf signal components. Signal spacing on the HTL, however, prevented the proper function of this system. Block lengths, which were relative to the length of the train, were so short that the locomotives would be continuously operating on a yellow approach. The signal system, which was solely used for broken rail detection, not block control of trains, was redesigned to function only as a broken rail detector.

As a result of the revised system, the outside and inside rails of the loop were fully insulated from each other making each rail its own independent signal loop. One master insulated joint was installed at a location on the outside and inside rail. Independent power supplies feed each circuit, with each loop of rail becoming its own continuity check circuit. Due to the short blocks, only a red (stop) or green (proceed) indication is now given. By using switch control boxes and additional insulted joints at turnouts, signals will also display red if a switch is thrown for an incorrect route. This revised signal system has been successful in detecting broken rails, joints, and improperly aligned turnouts since its installation.

Another variation initiated with the start of the HTL was to lubricate only the outside rail of the loop. Previous tests were conducted by altering operating periods of lubricated rail (both rails) and dry rail. Typically 40 MGT of lubricated operation was followed by 10 to 15 MGT of dry rail, a sequence repeated over a number of cycles. The new rail fatigue test required a long-term (150 or more MGT) period of fully lubricated rail, without extended dry operation. Such a long lubricated test period would have prohibited the testing and evaluation of rail in the dry mode.

By only lubricating the outside rail, and leaving the inside rail dry, the one reverse curve (Section 07) on the HTL would have a dry gage face and offer a site for evaluating dry wear characteristics (Figure 3). As the train was turned end-for-end on a scheduled basis (but operated only in the counterclockwise direction), some contamination of the inside rail was observed immediately after train turning, but then rapidly disappeared.

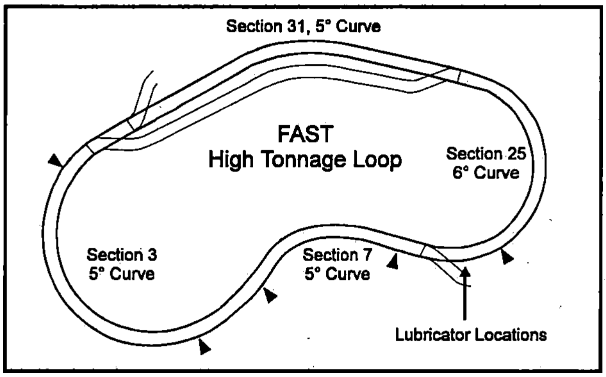


Figure 3. Lubricator Locations on the High Tonnage Loop

In July 1986, a major derailment occurred with the FAST train when the inside rail overturned, after exiting the spiral in Section 25. Although track in this area was visibly in good condition, subsequent measurements located several pockets of weak gage restraint. A number of tests conducted to determine the cause of the rail overturning found that under extreme differentials of high rail to low rail lubrication (high rail over lubricated, low rail extremely dry) a high truck turning moment could be obtained especially with locomotives in traction. Results suggested that this high moment accelerated the fatigue of wood tie fastener support near the derailment area, until rail rollover occurred. Results of this study are reported in AAR report R-712, "Effect of Track Lubrication on Gage Spreading Forces and Deflections," by K.J. Laine and N.G. Wilson, August 1989.

To eliminate, or at least reduce high differences of lubricant effectiveness between high and low rails without severely impacting the rail wear test, a very small amount of lubrication was required on top of both the high and low rails. Since the high (outside) rail of the loop was already lubricated, a small amount of contamination was placed on top of the low (inside) rail of the loop. This was accomplished by installing some modified Fuji roller lubricators on cars kept near the end of the train. These lubricators were configured to lubricate the wheel tread (NOT THE FLANGE) with a very small amount of lubricant.

As an added safety check, gage widening "tell tales" were installed at a number of locations around the FAST/HTL loop (Figure 4). The tell tale is a small spring loaded device that provides an indication of maximum gage widening at that location caused by the action from a passing train. The track inspectors at FAST routinely monitor these devices to see if excessive gage widening is occurring. This provides a safety check and gives advance notice of impending loss of gage holding ability.

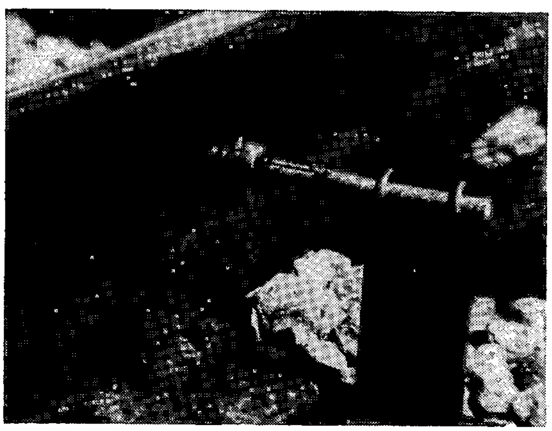


Figure 4. Tell Tale Installed on the HTL

Background and Need for the HAL Test Program

The completion of the 33-ton axle load (100-ton car) phase of the HTL occurred March 28, 1988. A total of 160 MGT was operated in the HTL configuration, while those parts of the HTL that utilized the original FAST loop had a total of 1023 MGT.

Until this time, the FAST consist was made up entirely of 100-ton-capacity cars, which resulted in a weight on rail of 263,000 pounds per car. Occasionally a few 89-foot flatcars, tank cars, and other less than 100-ton capacity cars were operated for special tests.
The 100-ton car, as it is commonly referred to, has an axle load of 33-tons. The standard for such equipment includes 36-inch diameter wheels, 6 ½ by 11-inch wheel bearings and a truck wheel base of 5 feet 6 inches (see Figure 5); this is the maximum weight on rail that is currently accepted for unrestricted interchange of equipment in North America.

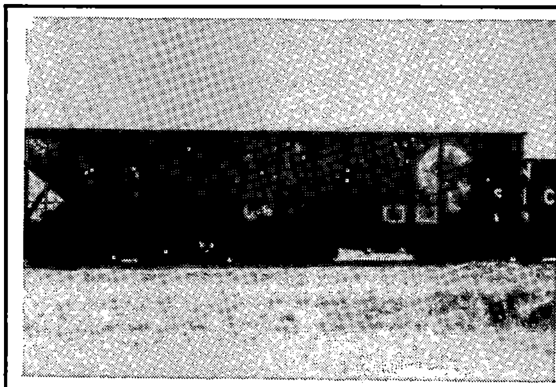


Figure 5. Typical 100-ton Capacity Car

The industry Vehicle Track System (VTS) group became involved with HAL testing in 1988. Under VTS direction, experiment plans were revised to incorporate current industry concerns. The FAST Steering Committee recommended that the operation of the HTL continue, but that the train weight be increased to a 39-ton axle load. The purpose of the continuation would be to document the effect of heavier cars on existing tract structures since some do exist and operate daily in North America. Examples include the Detroit Edison coal train, which consists of 125-ton-capacity equipment. These cars have larger wheels (38" diameter), larger bearings (7"x12") and a longer truck wheel base (6'), as shown in Figures 6a and 6b. Table 1 summarizes the differences between 100- and 125-ton capacity cars.

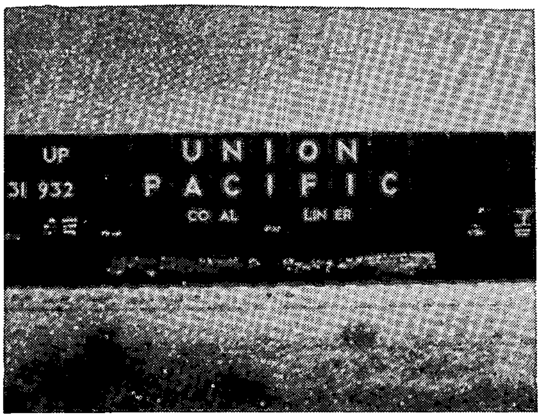


Figure 6a. Typical 125-ton Capacity Open Top Gondola

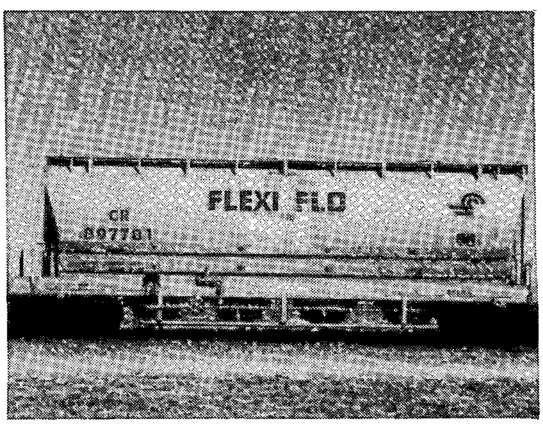


Figure 6b. Typical 125-ton Capacity Covered Hopper Car

Where heavier axle load cars are already in operation, they are not the sole traffic over a line. For this reason it is impossible to determine the exact damage factor that the heavier car load applies to the track. Maintenance prediction, for lines that may soon see a large amount of these heavier cars, is therefore difficult to determine. Thus, in order to obtain a better understanding about such degradation and performance models, the HTL is operated using a heavier car.

Table 1. Differences Between 100- and 125-ton Capacity Cars

COMMON NAME	ACTUAL CONFIGURATION
100-ton car	100 tons of lading 31.5 tons of empty car weight 131.5 tons on the rail 263,000 lbs on the rail 33,000 lbs per wheel (33 kips) 36" diameter wheel (33-ton axle load)
125-ton car	124.5 tons of lading 33 tons of empty car weight 157.5 tons on the rail 315,000 lbs on the rail 39,000 lbs per wheel (39 kips) 38" diameter wheel (39-ton axle load)

The Heavy Axle Load (HAL) testing program was initiated in 1988. Until then, all FAST operations were funded solely by the FRA. For the first time in the history of the FAST program, funding for train operation use and data collection was supplied from both FRA and AAR funds. Guidelines for experimental goals were established as follows:

- Utilizing 125-ton equipment, repeat as near as possible the basic experiments conducted with 100-ton equipment during the final 160 MGT of the HTL.

- The only major variable was to increase the axle load; thus car type, train speed and configuration, and track layout would remain the same.
- Data would be collected to determine the effect, if any, on increasing the axle load.
- Data would also be collected to assist in validating existing track performance and deterioration models.

HAL TEST SCHEDULE AND PARAMETERS

Plans for the HAL experiment were prepared after reviewing the results of the 160 MGT of 100-ton traffic on the HTL. Minor changes were made where results indicated a change in test procedures was needed, or where direct back-to-back comparisons could not be made. In some cases, where comparative data was simply not available, new test plans were drawn up.

Track rebuilding efforts began in April 1988, and a completed loop was made available for testing in early July. The track loop for the HAL Test was essentially the same as that for the 33-ton axle load (HTL) period, with the exception of adding a "by-pass track" (Refer back to Figure 3). The loop was divided into test zones, which were identified by numbers.

The by-pass track, or siding, provided additional operating configurations and testing opportunities. The primary purpose of the by-pass was to permit operation over turnouts in both the straight-through and diverging route directions. FAST schedules called for 20 percent to 30 percent of the traffic to operate over the by-pass, thus applying tonnage to diverging route turnout components.

An added benefit to this type of operation was that it allowed track experiments to be conducted that required small but controlled dosages of traffic between measurement and inspection cycles. It was possible to operate as little as one train or as much as one full shift (0.01 to 1.35 MGT) during any given shift over the by-pass, thus affording selected track experiments controlled increments of tonnage between inspection periods.

After track rebuilding efforts were completed in August 1988, train operation began immediately. Small increments of MGT accumulation required by the Ballast Test, located on the main loop, resulted in low MGT accumulation rates during the first month. Rapid accumulation of tonnage began in October 1988, with the first 15 MGT of the HAL program operating in a dry, no lubrication mode.

The initial dry mode was operated for several reasons:

- To obtain early dry-wear-rate data for "quick look" purposes
- To break-in rail and wheel profiles to a "worn" shape
- To provide a conformal worn rail/wheel profile on selected test rails for rail fatigue information

The 15 MGT dry mode was completed in January 1989. By design, a large amount of test rail was replaced to allow installation of "lubricated only" rail in support of fatigue testing. At the same time, a large amount of transition rail was replaced due to excessive wear observed during the dry operation.

Fully lubricated operation was initiated in March 1989, and continued until an additional 135 MGT was applied on April 20, 1990. During this period a number of interim measurements were taken, minor rebuilds were performed, and a major turnout was replaced. A total of 160 MGT of HAL (39-ton) traffic was applied to the loop.

HAL Track Description

A detailed description of the HAL loop, initial experiments and an overview of train operation are contained in the *HAL Booklet*, 1989. The contents of this booklet have been reproduced in this document — *Track Test Zones: Description of HTL Track Sections.* (Refer to this section for detailed descriptions of track sections, experiments, measurements and other items.)

FAST/HAL TRAIN MAKEUP/OPERATION

The HAL train consists almost entirely of 39-ton axle load cars, as detailed above. Train length varies from 60 to over 75 HAL cars, with the addition of up to five standard 33-ton axle load (100-ton capacity) cars for mechanical test purposes. The 33-ton axle load cars were included for wheel wear control measurements and carried known defective bearings in support of mechanical tests.

Under normal conditions, four or five 4-axle locomotives (B-B truck configuration) were used to pull the consist; an example is shown in Figure 7.

These usually consisted of EMD GP38 and GP40, and GE U30B locomotives loaned to the FAST program by AAR members. On occasion, due to locomotive maintenance requirements, a rental or TTC locomotive was used to ensure adequate horsepower. Six-axle (C-C) locomotives were used in the consists only during special test runs or as a work train. Train speed, after the initial "check-out lap" was held to 40 mph, with an average range of 38 mph to 42 mph which results in a 2-inch under balance. The 5-degree curves were built with 4 inches of superelevation, while the 6-degree curve was built with 5 inches of superelevation. All elevation was run-out within the length of the 300-foot spirals.

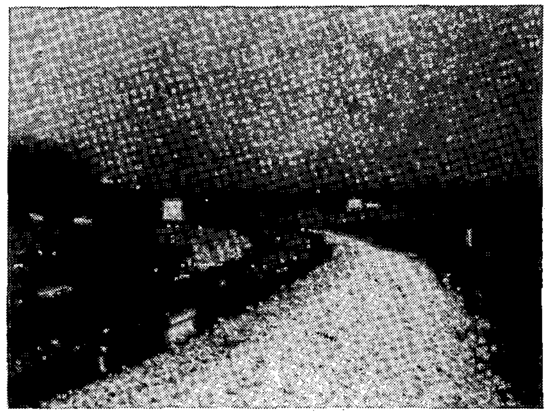


Figure 7. Typical HAL Train in Operation

Most train operation during the HAL testing occurred during early morning, third shift hours. Generally train operation was started at or near midnight and continued until 8 to 9 a.m., unless a broken rail or other defect required an earlier stop. The night operation was conducted for two major reasons:

1. Rail Temperature: Due to the short loop and 40 mph operation, the time between last car and locomotive passage for the next lap was about 2¼ minutes. The rail did not have sufficient time to cool, and daytime rail temperatures of over 160-degrees Fahrenheit had been recorded. This led to some track instabilities, buckles, and other problems. Night operation, without the added heat load of the sun, eliminated most track instability problems.

2. Track Time for Maintenance Crews: Spot and "housekeeping" maintenance requirements, which will be discussed in the track maintenance section, soared

during the HAL Test as compared to the conventional axle load period. The night operation allowed daily access to the track to perform maintenance functions.

During a typical eight-hour shift, 100 to 120 laps could be accumulated; however, due to a significant problem with broken welds, many lap counts ranged between 65 to 90, and even lesson occasion. This translates to about 0.6 to 1.35 MGT per eight-hour shift, depending on train length, Train mileage, for a 65 to 120 lap shift, would range from 175 to 325 miles.

All cars were inspected every third shift of full operation, or within a 500 to 700 mile interval. Locomotive maintenance followed standard railroad daily, and 30- and 90-day inspection cycles.

Details of Current HAL Train Operation, Lubrication Application and Control

FAST train operation sequences are designed to provide an even wear to all truck orientation. Train direction is reversed every 2 MGT, and train orientation is reversed every 4 MGT. Field lubrication is maintained at all times except for a dry down every 3-4 MGT in support of rail flow ultrasonic inspections.

Lubrication levels around the loop were recorded using TTC's Lubricant Level Gage (often dubbed the goop gage). This device (Figure 8) is used by the track inspector to monitor the visible level of lubricant on the gage face of the rail. Although this device will in no way determine lubrication effectiveness, since the same lubricant was used at all times during both the 33- and 39-ton axle load tests, the values recorded can be used to determine amounts of lubricant present.

The normal maximum lubricant level desired, as measured by the goop gage, is a +10. The rail at the beginning of the 6-degree curve, nearest the lubricator, had significantly more lubrication averaging +20 to +30.

Track Inspection Policy

The FAST/HTL loop is inspected continuously during operations and after every 2 MGT of operation during daytime periods.

During train operating periods for the HAL Test, which generally occurred at night, one track worker inspected and adjusted the lubricators. The second track worker constantly searched for any damage to the track, change in support conditions, broken components or loose bolts. By using road vehicles equipped with extra lights, this inspection was carried on continuously throughout the shift.

Additional information on track conditions was received from the onboard train crew. Due to the short nature of the loop, the crew soon learns the "feel" of the track and becomes aware of any changes. Using radio contact, the ground inspector can readily be directed to a suspect area and ensure that an adequate track is being operated over.

The night crew had access to hand tools and some track machinery, which allowed them some repair capability, In some cases, such as a field weld failure, a two-worker crew was insufficient to pull rail gaps together, and operation of the train was suspended; however, most of the time minor repairs could be made and the train operation continued. Such repairs were made only in areas where experiment plans allowed, not where support data or measurements were needed.

The nighttime track inspectors monitored the entire loop, and, through inspection logs, documented areas that required immediate remedial repair, as well as areas of concern. Thus, items such as heavily corrugated rail, which might be causing undo ballast damage under train action, were noted for detailed daytime inspection.

The daytime track inspectors would make a detailed inspection, on foot, of the entire loop every 3 MGT, in conjunction with the ultrasonic inspection cycle. They would note all items requiring repair in the following categories: (1) fix immediately, and (2) schedule for repair.

Items such as missing fasteners, clips, and bolts would be in the "fix immediately" category. Other long-term planning items like tie replacement needs and grinding requirements would be in the "schedule for repair" category.

The track supervisor would advise the experiment monitor of repairs needed in test section areas, especially if such repairs might have damaged or altered measurement sites. When required, pre- and post-maintenance measurements were obtained in order to quantify the effect of the activity.

Track was generally allowed to degrade until it neared the FRA Class 4 limits. Such standards were monitored by the EM80 track geometry car (Figure 10) along with the above outlined visual/manual track inspection. In some locations, where no test was designated, the track inspectors and foremen were free to maintain track before Class 4 limits were met, depending on other work loads.

Track geometry car inspections are scheduled after every 5 MGT of operation to allow general monitoring of changes to gage, surface, line, and cross level. Extra inspections with the EM80 car are scheduled

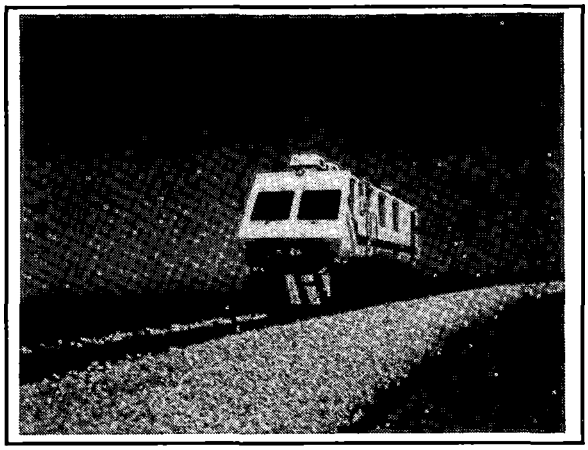


Figure 10. EM80 Track Geometry Car

before and after specific maintenance functions, such as surfacing and lining, when such activities are over specific test zones.

An important item to note is that the track was not allowed to degrade below a level designated safe. Proper maintenance was always completed so that the track could sustain at least 1.3 MGT of additional traffic. Because of this, FAST may be defined as being "over maintained," a policy enacted and followed since 1976. On a revenue railroad, a turnout frog, for example, may be recorded as requiring grinding. Typically a 40 to 50 MGT per year line may operate 10 to 20 trains moved during a 24-hour period between maintenance windows. Deferring maintenance in this example by one, two, or even three days generally will not cause an unsafe condition or undo damage to the item.

However at FAST, unless special conditions exist, one must plan for "worse case and best efficiency" train operations. Thus up to 135 laps (or train passes) of a fully loaded train, 12,500-ton, could be operated before the next maintenance window. With this in mind, using the frog grinding example described above, repairs would have been initiated for metal removal in advance to ensure that damage to the frog from excessive loop formation did not occur.

For this reason, all track degradation limits must be sufficiently high to allow for the anticipated extra degradation that a 1.3 MGT loading would apply at a given location. To permit this safety factor, certain items were prematurely maintained to ensure that a safe track structure would be available for an entire operating shift. Any comparison with other periods at FAST can be made with similar track maintenance limits in mind. The only change during the HAL Test was that, in some cases, the HAL train caused higher degradation rates at joints and other anomalies. This higher rate required extra caution when determining how far defects should be allowed to degrade before applying corrective maintenance efforts.

Interim Rebuilding/New Tests

During the course of the last 300 MGT of HAL operation, a number of minor changes to the original test configuration were made. As test components wore out or sufficient data was obtained on original items, new materials were placed in track.

Placing most track components in the original HAL Test required that the item already be in general use by the railroad industry. As stated in the original HAL goals, the purpose for the initial HAL Test was to determine the effect of the HAL train on track and train components. While new and experimental components were not always restricted, the budget for HAL dictated that the first priority was to evaluate the effect of heavier axle loads on conventional track materials and structures.

After the initial 160 MGT of HAL traffic, several major test components were added to the original configuration, which included:

- Tangential geometry — swing nose turnout on concrete
- Evaluation of spring frogs
- Evaluation of crossing diamonds/frogs
- Construction of low track modulus zone
- Installation of laminated wood ties

A summary of the 300 MGT extension follows. Detailed descriptions of each test, along with results, will be presented by the FAST engineering staff responsible for continuing this program

General Observations of the Last 300 MGT of Traffic

Results reported at the October 1990 open house indicated that heavier axle loads could be operated over conventional track, but that more rapid and severe deterioration would occur. Areas showing the most immediate impact included rail, turnouts, welds, and spot maintenance. Other areas of the track indicated possible effects, but could not be adequately defined in the limited 160 MGT period. Therefore, the FAST program was extended by 300 MGT to better define these areas, which include rail grinding, track support/maintenance, wood ties, concrete ties and ballast. Improved components have also been evaluated, especially in areas where a definite impact from HAL traffic was noted. Advanced design turnout geometry, frog materials, improved field welds, various rail metallurgies and heat treatments, and monitoring of subgrade loads under a variety of support conditions are included for the components tests.

The following papers will describe results of 300 MGT of applied traffic. All experiments were conducted under the same conditions and constraints. These include the following major considerations:

1. All traffic was made up of loaded cars and locomotives. No empty or light cars were operated for any extended period of time.

2. All trains were operated at 40 mph except for the first and last daily train pass, and when a slow order (10 to 15 laps at 25 mph) pass was needed for testing purposes. All curves were elevated for the same 2-inch overbalance condition.

3. Traffic direction is balanced for clockwise and counterclockwise direction.

4. All operation was conducted with the outside rail fully lubricated and the inside rail slightly contaminated at all times. Every 3 MGT, dry-downs were conducted; however, some trace of gage face lubrication remained at all times, even after the dry-down.

5. Under normal operating conditions, train brakes were not used. Occasionally, when the signal system detected a broken rail, a standard 10 psi to 15 psi brake pipe reduction was made to stop operation. Other than that, air brakes were rarely used to control train speed.

6. All equipment contained conventional design mechanical components, with three-piece trucks

7. The TTC is located in the high plains of Colorado where natural moisture is relatively low — approximately 11.5 inches per year. Subgrade support conditions are almost ideal for track construction; firm, sandy, and well-drained soil. The winter season generally sees little in the nature of freeze/thaw cycles. Winter snows usually evaporate in one to three days, with relatively little moisture seeping into the ground.

Phase III Description

To date, all 33- and 39-ton axle load traffic has been applied using conventional, standard three-piece freight car trucks. The HAL train has essentially been 100-ton type equipment "scaled up." This includes larger bearings, wheels and reinforced car bodies. However, there has been no change in suspension design from conventional equipment. The resulting dynamic loads into the track have been shown to be quite high, suffering in many cases from a basically crude suspension.

The future direction of FAST includes the complete replacement of existing trucks with those of improved design but still supporting a 39-ton type axle load. The design of these trucks is intended to reduce dynamic loads into the track structure.

Phase III of FAST is presently scheduled to start in late 1995 and will repeat selected experiments on the track to determine the actual reduction in component wear, fatigue, and track maintenance, when a HAL train of "advanced" suspension is operated. Thus the most recent operation of HAL will become the new baseline for comparing future data under a train of superior trucks.

DESCRIPTION OF EXPERIMENTS

1995 FAST/HAL PROGRAM DESCRIPTION OF EXPERIMENTS

Experiments that have been implemented as part of the FAST/HAL Program are as follows:

Rail Profile Grinding Experiment: The objective of the Rail Profile Grinding Experiment is to determine the effects of rail grinding on the fatigue and wear life of premium rails under 39-ton axle loads. This test is located in the two main curves of the HTL, Sections 25 and 03. High rails on both curves are well lubricated to produce fatigue defects and keep rail wear to a minimum. Premium head-hardened 133-RE rail was installed in the spring of 1994 and has accumulated 100 MGT of HAL traffic. The rail was purchased at the direction of an industry oversight committee and represents current and future rail purchases. The test rail has been divided into seven zones with each zone being ground to a specific profile at specific tonnage intervals. Grinding practices were selected to represent those of major railroads.

A "quick look" rail fatigue test is also being conducted as part of this experiment. The fatigue performance of standard ingot-cast rails under the standard truck train has been documented. To record the influence of advanced truck designs on rail fatigue, 320 feet of identical rail has been installed at the beginning of Section 25. This rail will be left in track until it fatigues or wears out.

Rail Wear Experiment: The Rail Wear Experiment has been a mainstay of testing at FAST. Section 07, the HTL's reverse curve, is slightly lubricated on the high rail and the low level of lubrication allows for relatively high rail wear rates. Rails from manufacturers worldwide have been installed to determine wear rates on various rail types.

A quick look rail wear test will be conducted to determine effectiveness of advanced truck designs in reducing rail wear. Wear rates on identical rails will be established under the standard and advanced truck design consist.

Weld Test: Thermite weld tests are being performed to evaluate weld performance under heavy axle loads. A variety of modifications in thermite welds is being evaluated. These modifications include improvements in weld chemistries, mold designs, and detailed weld installation procedures.

Thermite welds are inspected for both surface and subsurface fatigue. Visual, ultrasonic, and magnetic particle inspections are performed on the welds as required. Other periodic inspections include surface hardness tests and longitudinal rail profiles, which quantify batter in the weld area.

Tie and Fastener Experiment: The objective of the Tie and Fastener Experiment is to determine behavior and performance of concrete and wood ties, along with various types of rail fasteners in a heavy axle load environment. The secondary objective is to collect data that can be used to validate existing mathematical models for use in predicting fastener performance under heavier axle loads. Test zones are established in the 5-degree and 6-degree curves of the HTL.

The Wood Tie Experiment includes three separate areas of investigation: (1) wood tie species performance, (2) fastener performance, and (3) gage restraint ability. Measurements include track geometry, tie plate cutting, static lateral rail deflections and dynamic lateral rail deflections. Measurements of dynamic lateral wheel forces will be taken in the test locations to characterize the load environment in the test area. The data will be analyzed to determine the behavior of the tie/fastener system as a function of tonnage accumulation. Gage retention of the wood tie equipped with cut spikes and direct fixation fasteners will also be analyzed.

The Concrete Tie Experiment includes two separate areas of investigation: (1) concrete tie performance, and (2) concrete tie rail seat abrasion.

The objective of the Concrete Tie Performance Experiment is to determine behavior and performance of concrete ties in a heavy axle load environment. The test zone is located in Section 03, a 5-degree curve, on the HTL. Measurements include track geometry, visual inspections, and dynamic rail loads and deflections. The data will be analyzed to determine the behavior of the tie/fastener systems as a function of tonnage accumulation.

The objective of the Concrete Tie Rail Seat Abrasion Experiment is to determine the methods and material combinations, for in-field repair and manufacturing processes, that are effective in preventing, reducing or stopping rail seat abrasion. The abrasion experiment is located in two zones in Section 03, on the HTL. Zone 1 consists of 315 ties with 64 sub-sections. Zone 2 consists of 76 ties with 14 sub-sections. These ties are sprayed with water daily during train operations to provide sufficient moisture to trigger the abrasion process.

Measurements include profiles taken with a modified CXT abrasion gage, visual inspection, and photo documentation of all rail seats. Measurements were taken at 0, 50, and 100 MGT, and 100 MGT cycles thereafter. The data will be used to determine which materials and/or processes are most effective in preventing or stopping abrasion.

Turnout, Frogs and Crossing Experiment: Turnouts are evaluated for component performance under 39-ton axle loads. Turnouts under test include an AREA geometry No. 20 with premium components and a No. 18.5 tangential geometry turnout with asymmetrical switch points and swing-nose frog.

Measurements of load environment, geometry degradation, vehicle response, and turnout stiffness are performed at specific levels of tonnage accumulation.

The by-pass track permits operation on both sides of the turnouts, with a minimum of 20 percent of the traffic on the diverging routes. Since the traffic on the HTL is bi-directional, both turnouts are exposed to facing point and trailing point traffic. Load data is collected through the turnouts using instrumented wheel sets. Track geometry is measured periodically over the turnouts.

Testing of individual frogs, including rail-bound manganese frogs, European design frogs, and spring-rail frogs, is performed at various locations around the HTL. Swing nose frogs may be installed at a future date. The objective of this test is to compare the performance of the various frogs. Criteria include wear rates and maintenance requirements.

Crossing diamond testing was initiated during Phase II. To date, manganese insert crossings, solid manganese crossings, and three-rail bolted crossings have been tested. The objective is to quantify performance of both standard and premium component crossings under HAL traffic. While there is no corresponding data from the 100-ton tests, instrumented wheel set data from both 100-ton and HAL cars is used to quantify and compare impact force levels over the crossings. Other criteria include maintenance requirements and component life.

Low Track Modulus (LTM) and Load Path Evaluation Experiments: To determine track geometry performance under heavy axle loads, a LTM test zone and a high track modulus control zone were designed and constructed on the HTL in 1991. The purpose of the LTM zone was to simulate lower-end, but not worst case, mainline track support conditions. The LTM zone was constructed by excavating a 5-foot deep by 12-foot wide trench under the track in Section 29 and backfilling the trench with high plasticity clay. The nominal track modulus of the LTM is 2,000 lb/in/in and the control zone average modulus is 5,000 lb/in/in. Measurements include track geometry, dynamic wheel forces from instrumented wheel sets, top of rail elevations, and static vertical rail displacements to be used in track stiffness and track modulus calculations.

As part of the Load Path Evaluation Experiment, the LTM and control zones were equipped with instrumentation to measure vertical load path characteristics. A measurement cell was installed in both zones to collect vertical rail force, vertical rail seat force, and ballast/subgrade pressure data. Load path data was collected under a consist of equal numbers of 33-ton axle load and 39-ton axle load vehicles.

TRAIN OPERATION

A fleet of high side gondolas, covered hopper cars and tank cars is loaded to a gross vehicle weight on the rail of 315,000 pounds. Normally, the consist includes 65 to 85 HAL cars plus no more than an additional 10 percent 100-ton cars. Four or five 4-axle locomotives are used to power the train at a steady 40 mph, resulting in an overbalance condition of approximately 2 inches on the curves.

The train operates an average of four days per week, with one day set aside for track maintenance and car inspection and repair. A typical day of train operation produces approximately 1 MGT of tonnage on the track and 270 miles on the cars. Every 5 MGT, track geometry data is collected for experimental and maintenance purposes. An ultrasonic rail flaw inspection vehicle is operated at 3 MGT intervals.

The train operates in both directions on the loop and car orientation is reversed periodically to equalize wheel wear.

SUMMARY AND DESCRIPTION OF MEASUREMENTS

Measurements required by each experiment are conducted periodically, usually triggered by a specified accumulation of tonnage. The various measurements taken at FAST are as follows:

Railhead Profile: Transverse railhead profiles are taken with a Miniprof rail profilometer.

Rail Hardness: Two measurement devices are used to measure Brinell and surface hardness.

Tie Plate Cutting: The height of the tie plate relative to top of the tie is measured with a self indexing fixture.

Track Inspection: A walking inspection of all test zones is made every 1 MGT to 3 MGT.

Lateral/Vertical Fail Force: Dynamic vertical and lateral wheel loads are measured with strain gage circuits mounted on the web and base of the rail.

Dynamic Rail Deflection: Displacement transducers measure railhead and base lateral displacement relative to the tie.

Track Geometry: Track geometry is measured with an EM80 track geometry car.

Vertical Track Stiffness/Track Modulus: A known vertical load is applied to the rail and the resultant vertical rail deflection is measured. Stiffness and modulus values are calculated from the deflection.

Spike Pullout Resistance: A load cell is used to measure the force needed to pull the spike from the tie.

Single Tie Push Test (STPT): Force needed to displace individual ties laterally through the ballast section is measured with special fixture.

Ballast Sieve Analysis: Gradation analysis of ballast per the ASTM C136 modified procedure.

Loaded Track Profile: Top of rail elevation is measured under the wheel of a fully loaded car.

Unloaded Profile: Top of rail elevation measured relative to a fixed benchmark.

Liquid and Plastic Limit: ASTM standards D423 and D424 are used to determine soil liquid and plastic limits.

Instrumented Tie Plate: Rail seat force on wood ties is measured with instrumented tie plates.

Subgrade Pressure: Pressure cells installed in the subgrade directly beneath ties measure dynamic vertical pressures

Continuous Wheel Load Measurement: Instrumented wheel sets are utilized to measure vertical and lateral wheel loads, and axle torque.

Gage Widening: Static lateral and vertical loads are applied to both rails simultaneously producing a 0.5 L/V ratio, and the total lateral displacement of the rails are measured relative to the tie.

Concrete Tie Rail Seat Profile: The depth and profile of the concrete tie rail seat is measured relative to a non-wearing surface to quantify rail seat abrasion.

Rail Flaw Monitoring: The rail is inspected for internal defects using ultrasonic equipment.

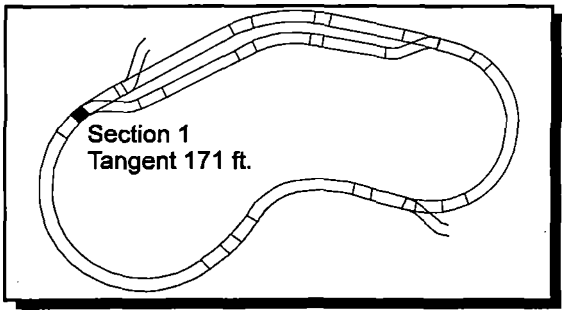
Wheel Profile: The Miniprof wheel profilometer is used to measure wheel profiles.

Metallurgical Evaluation: Selected rails and wheels exhibiting internal and/or surface defects are submitted to macroscopic inspection, metallography, hardness profiles, scanning electron microscopy and x-ray analysis.

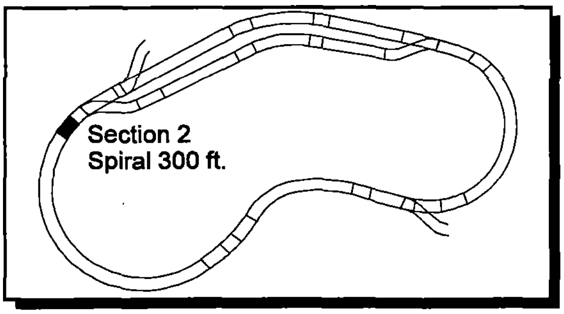
TRACK TEST ZONES

DESCRIPTION OF HTL TRACK SECTIONS

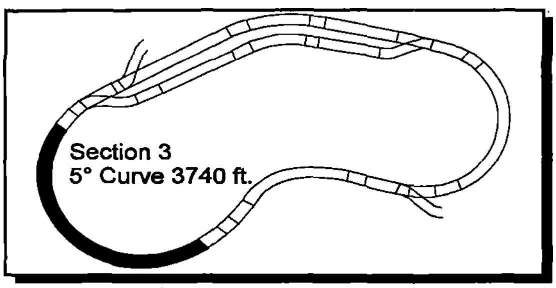
The typical HTL track structure consists of continuous welded rail fastened to wood ties with cut spikes and fully box anchored at every second tie. Included in specific test zones are concrete ties, jointed rail, and elastic type rail fasteners. A description of each section follows:



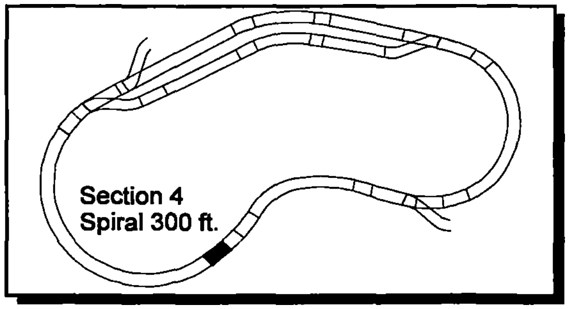
Transition Zone/Available for Testing Location of Hot Bearing Detector



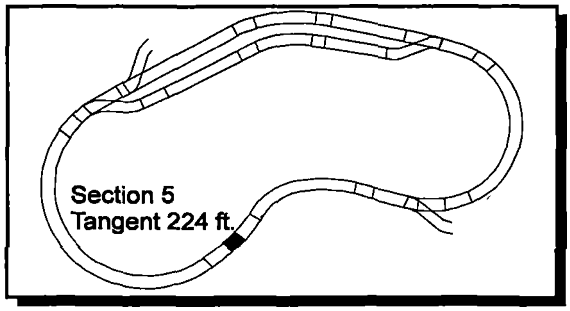
Transition Zone/Available for Testing



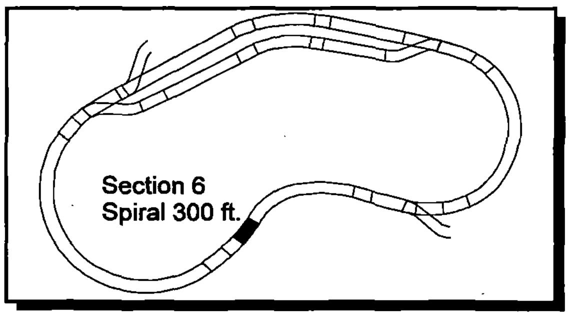
Location of Ballast, Rail Performance and Concrete Tie Experiments



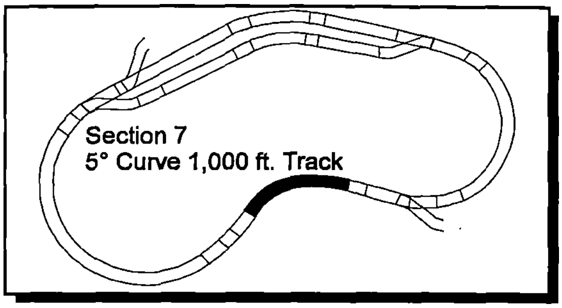
Transition Zone/Available for Testing, Future Site of Steel Tie Test



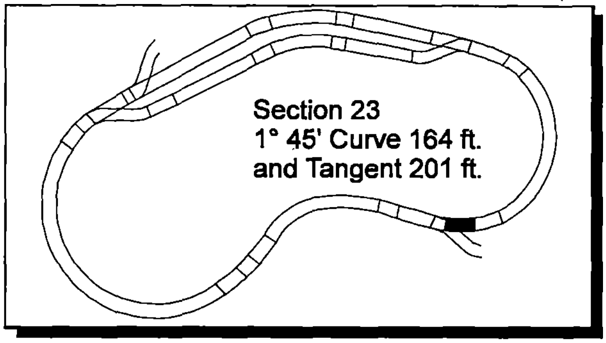
Location of Alternate Hot Bearing Detector, Future Site of Steel Tie Test



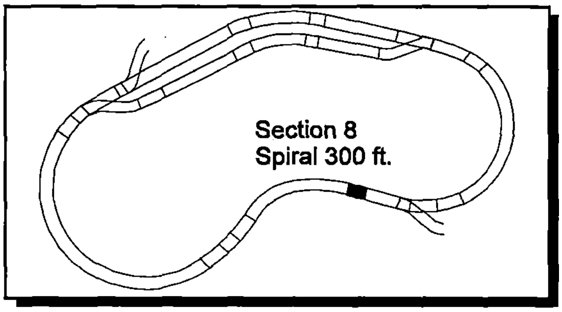
Transition Zone, Future Site of Steel Tie Test



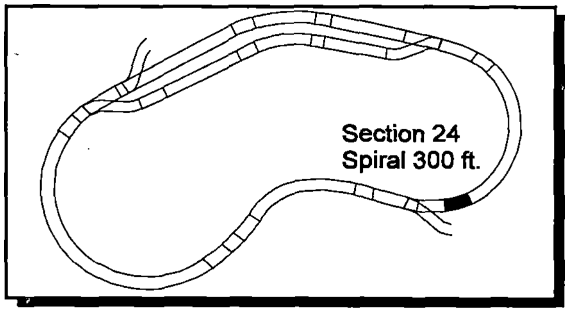
Location of Tie and Fastener and Dry Rail Performance Experiments



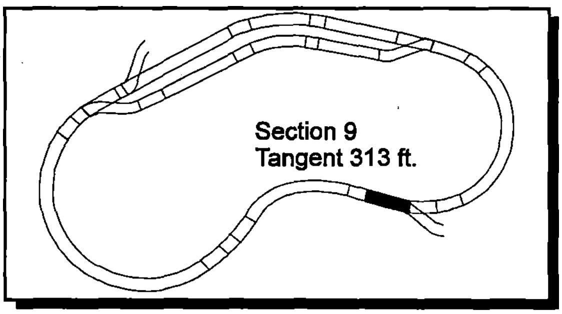
Wayside Rail Lubricator



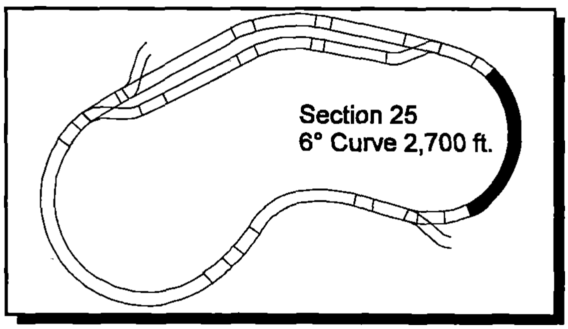
Transition Zone



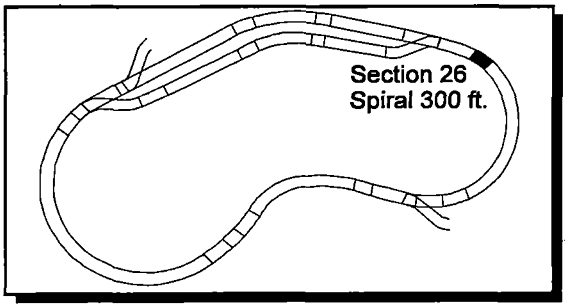
Transition Zone/Available for Testing



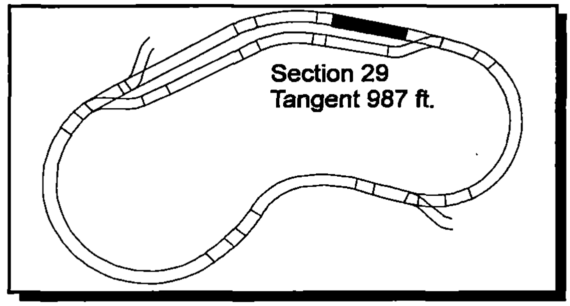
Road Crossing and No.10 Turnout



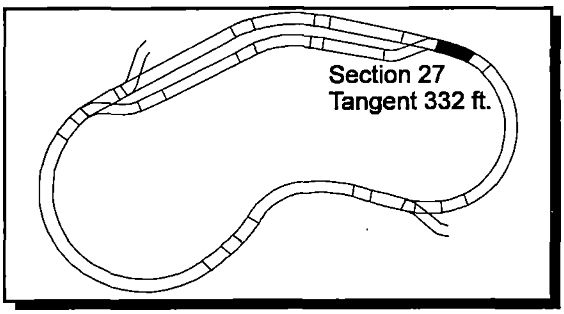
Location of Rail Grinding Performance, Wood Tie and Fastener Experiments



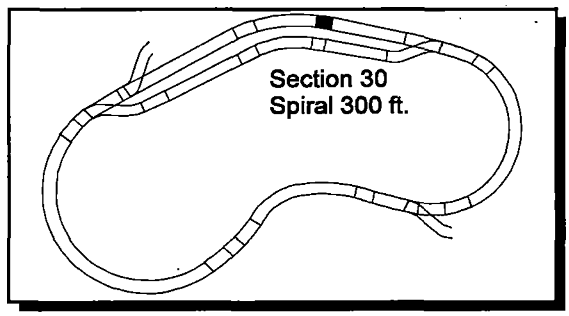
Transition Zone



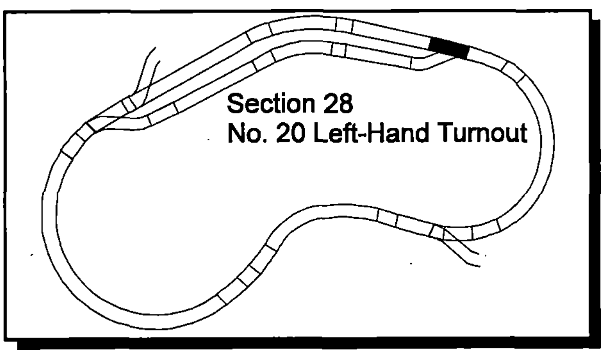
Location of Low Track Modulus Test and Load Path Evaluation



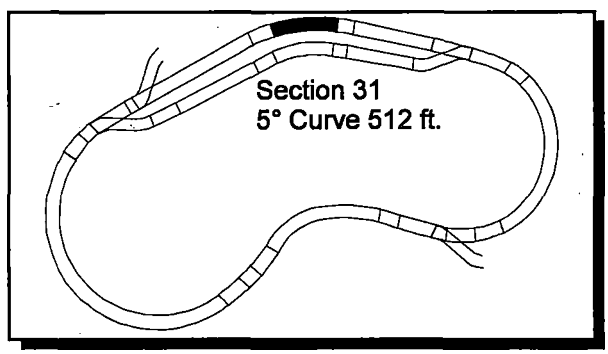
Location of Frog Performance Test



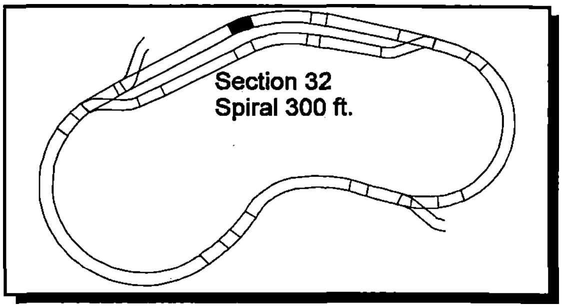
Transition Zone/Available for Testing



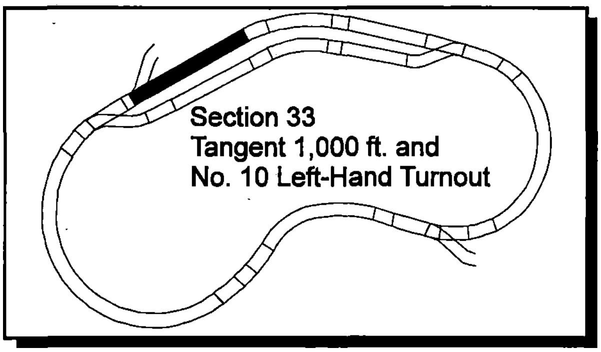
Turnout Experiment Location (AREA No. 20)



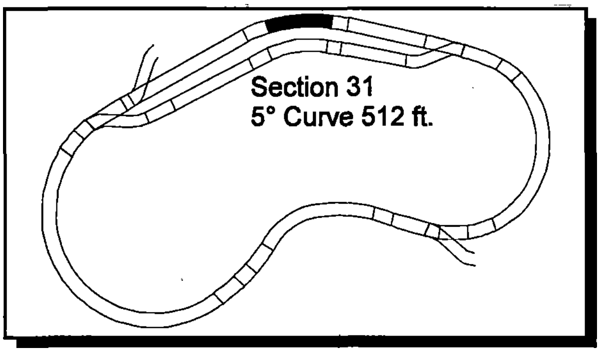
Location of Tie and Fastener Test, Azobe Wood, Concrete, and Thermite Weld Tests



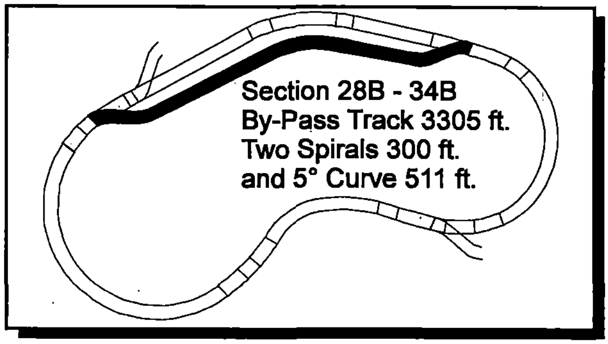
Transition Zone/Available for Testing



Location of Control Zone--Track Modulus and Load Path Evaluation, Experiment and Frog Casting Performance Test, and Tangent Concrete Ties



Location of Tie and Fastener Test, Azobe Wood, Concrete, and Thermite Weld Tests



Location of the Ballast Resistance Characterization Experiment

SAFETY CONSIDERATIONS

High volume, high mileage train operation can be very informative, but must be conducted safely. To ensure safety of personnel and equipment, visual inspections of the consist and car components are performed on a regular basis. All safety procedures comply with the AAR and FRA safety standards as appropriate.

The safety oriented measurements are as follows:

Wheels

Every car and locomotive wheel is measured for flange thickness, flatness and height, and rim thickness. Visual inspections are made to detect cracked or broken flanges; thermal cracks in the flange, tread or plate; built-up, grooved, shelled or slid-flat treads; cracked, broken, burnt, shattered or spread rims; overheated wheels; cracked or broken plates or hubs.

Axle Journal Roller Bearings

The journal roller bearings are checked for grease loss, and loose or missing cap screws.

Roller Bearing Adapters

During regular shop maintenance, safety checks are made for adapter crown wear, pedestal roof wear above the adapter, thrust shoulder wear, and machined relief wear.

Trucks

Friction castings, side frames, and bolsters are checked for deterioration.

Air and Hand Brake

Train crews check for cracked or bent pipes, fittings and valves; defective or loose hoses; broken shoe keys; piston travel and inoperative air brakes; inoperative hand brakes; and worn brake beams, levers, guides, or bends.

Center Plates

During maintenance periods, crews check for vertical wall wear on both body and truck plates, horizontal surface wear and vertical linear weld cracks on the truck center plate. In additional to the regular maintenance intervals, inspections are required for body center plate cracks and weld connection cracks.

Side Bearings

Inspections are conducted for required side bearing clearances, cracks in the truck side bearing cages, wear in the body side bearing wear-plates and loose or bent body side bearing bolts.

Brake Shoes

Inspections are made prior to operation for cracks, breaks or excessively worn shoes.

Coupler and Carrier Wear Plates

Coupler shank plates and carriers are checked for cracks.

Couplers

During regularly scheduled maintenance, head and knuckles, shank length, butt thickness, knuckle wear, and draft key wear are checked to ensure the components meet minimum standards. Coupler body and shank are checked for cracks, bends, and breaks.

Miscellaneous Components

Minimum standards examinations of brake steps, sill steps, handholds, ladders, center sill, body bolsters and structural welds are conducted.

General

A primary and backup hot bearing/hot wheel detector unit is utilized to monitor the train during each pass around the loop. The locomotives are also equipped with radio communication to advise the crew if a shutdown is necessary.

A broken rail detector system utilizing a modified track circuit system is in constant operation to detect broken or separated rails. This system also detects improperly lined switches.

EXPERIMENT SUMMARIES

"Results of Rail Wear Tests at FAST,"
by Jon S. Hannafious

Summary

In a cooperative effort, the Association of American Railroads (AAR) and Federal Railroad Administration (FRA) are conducting rail tests at the Transportation Technology Center (TTC), Pueblo, Colorado. This effort is being done to quantify the effect of heavy axle loads on wear performance of different rail types.

Tests conducted at the Facility for Accelerated Service Testing (FAST) on the lightly lubricated 5-degree curve in Section 07 yielded the following results:

- High rail gage wear rates were initially high, but declined once the rail had "worn in."
- High rail gage wear is the predominant form of wear in Section 07.
- Standard rail was the only rail to crush (exhibit metal flow not at wheel/rail contact) and develop corrugations.
- Rail hardness can be used to predict wear rates; i.e. increasing hardness reduces wear rates.
- Wear results produce a forecasted wear life of 272 MGT for standard rail (hardness of 308 Brinell) on the high rail. Forecasted wear life of head hardened rail ranges from 338 to 588 MGT.
- Wear life of rails at FAST can be compared/contrasted to those in revenue service by considering lubrication conditions, rail grinding, wheel profiles, and operating conditions.
- Wear life of rail was increased up to a factor of 14 with lubrication.

The 5-degree test curve has 4 inches of superelevation. The FAST train operates at 40 mph, 6 mph over the balance speed (or 1.6 inches cant deficiency). High rail fatigue is very rare in this curve for three reasons: (1) the rail quickly wears to a conformal wheel/rail shape, which minimizes contact stresses, (2) the protective work hardening layer on dry worn rail has been shown to be deep (deeper than on lubricated rail), and (3) gage wear causes the rail to wear out before it fails in fatigue.

INTRODUCTION AND CONCLUSIONS

Rails from worldwide manufacturers were donated to the FAST program to conduct the Rail Wear Test (see Table 1). All rails were head hardened, except the CF&I standard rail, which was installed as a control. One uncommon head hardened rail was the NKK Damage Resistant, which has a softer rail head center designed to inhibit surface-fatigue spalling.

Hardness results, shown in Table 1, reflect the field corner regeon of the railhead after it had been in service. Rockwell "C" measurements were taken in this location as it was the only surface area of the worn rails that had no work hardening from service exposure. The small area requirement of the Rockwell test allowed the work hardened area to be avoided. Results were then converted to Brinell using the conversion table developed by CF&I for rail steels, shown at the end of this paper.

Wear rates, which are listed in Table 1 in inches per 1,000 MGT, were calculated after 84.6 MGT of traffic had accumulated. For example, if the Sydney rail on the high side of the curve could be left in track for 1,000 MGT, it would be expected to wear laterally 1.48 inches and vertically 0.30 inch.

Wear Rates Initially Decline with Accumulated Tonnage

All rails in test experienced high initial wear rates. In Figure 1, the relative width measurement results (measured at the 5/8 gaging point) of two sample rails, the NSC DHH and the Rodange HH, are plotted as a function of MGT. A best fit line was added between each measurement interval and the wear rate calculated from the slope of that line (inches/1,000MGT) is listed. The lateral wear rate of both rails decreased with tonnage up to at least 12 MGT as the profile wore in and the rail work hardened. Initial wear rates of all rails would have likely been lower had the new rail profile been identical to the worn rail profile. The Rodange rail had a lower initial hardness than the NSC, and the rails had different as-rolled profiles. Both of these factors influenced initial wear rates.

Table 1. Donated Rails (as located in track) and Test Results

Rail Mfg	Rail Section	Mfg Process	Bhn	Gage Face Wear Rate (In/1,000 MGT)	High Rail Wear Rate (In/1,000 MGT)	Low Rail Wear Rate (in/1,000 MGT)
Sydney (FHH)	136-4 CN	Off-line "Fully" Head Hardened	366	1.48	0.28	0.30
Hayange (HH)	136 RE	Off-line Head Hardened	368	0.85	0.15	0.22
Thyssen (HH)	136-10	Off-line Head Hardened	342	1.35	0.26	0.24
CF&I (Std)	136-10	Control Cooled	308	1.84	0.69	0.54
NKK (THH)	136-10	In-line "Tough" Head Hardened	349	1.08	0.18	0.19
NKK (DR)	136-10	In-line Head Hardened "Damage Resistant"	373*	1.02	0.23	0.29
NSC (DHH)	136-10	In-line "Deep" Head Hardened	347	1.12	0.21	0.21
Rodange (HH)	136-10**	In-line Head Hardened	321	1.37	0.32	0.39

***Hardness at top center of railhead measured 346 Bhn**
**** Modified 136-pound rail section**

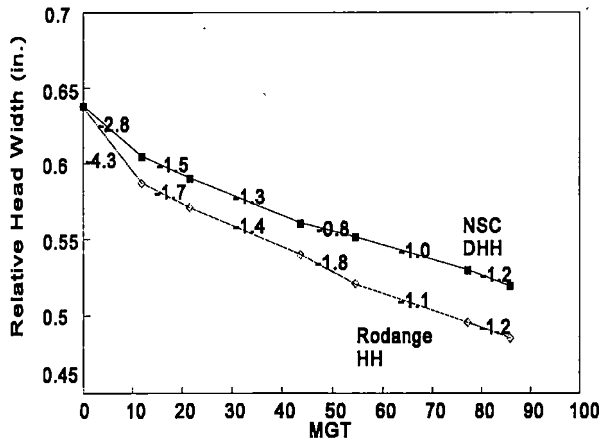


Figure 1. Gage Wear Rates throughout Test

Test rails included four rolled sections. Contact geometry between FAST worn wheels varied with new rail profiles. To eliminate the effects of the initial profiles as a variable and to make resulting wear rates comparable, the wear rates listed in the table were calculated without the first data point; i.e the data used for wear rate calculations were collected from 12 MGT to 85 MGT.

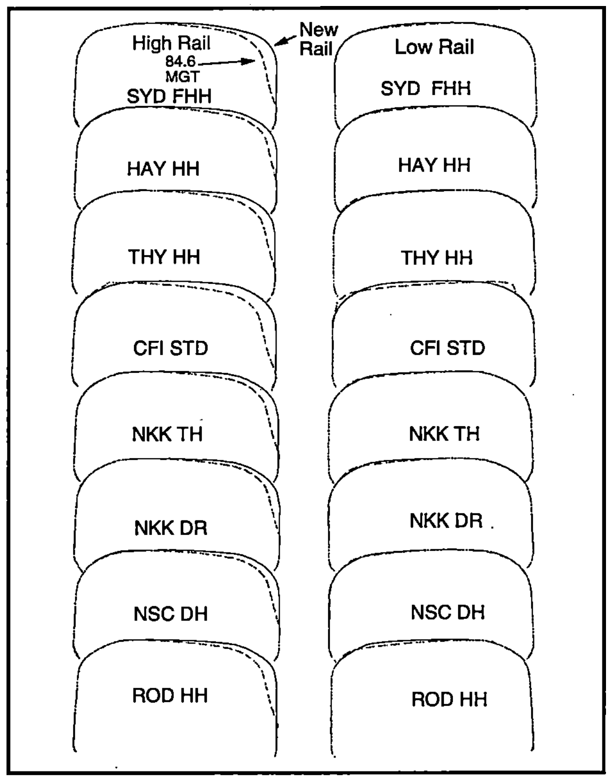


Figure 2. Worn Profiles Overlayed with New Rails and Profiles after 84.6 MGT

Though the initial profiles of the various sections varied, they all wore to the same shape. This shape is reflected in worn profiles in Figure 2, which has overlays of the new rails and profiles collected after 84.6 MGT. This figure also shows the relative amount of wear each rail type encountered during the test.

Gage Wear is Predominant Form of Wear

Wear rates listed in Table 1 are illustrated in Figure 3 to show the relative difference in gage and vertical wear rates. On the premium rails, the gage wear rate is from three to six times the vertical wear rates of either high or low rails of the curve. The standard rail gage wear rates are only 2.5 to 2.5 higher than the vertical wear rates. The fact that vertical wear on low rails is a major issue in revenue service will be explored further in the discussion of forecasted rail life.

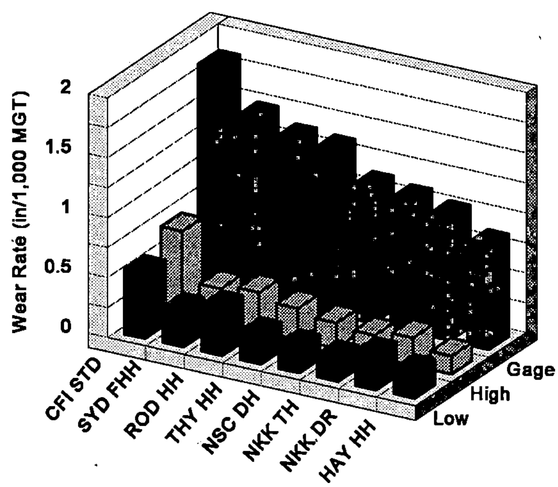


Figure 3. Wear Rates -- Gage, High & Low Rail Vertical

Standard Rail Crushes and Corrugates

Relatively higher vertical wear on standard rails points to a heavy axle load issue: Standard rail is "crushing" under the heavy loads while the premium rails are able to withstand the vertical forces. Further proof of this is illustrated in Figure 2, with the standard rail the only one with metal flow to the field side of the head where there is no wheel/rail contact. Standard rail was the only rail with gross head deformation (crushing). Increasing the hardness of the rail from 308 (standard) to 321 (Rodange) seems to bring the rail out of the plastic flow range of Heavy Axle Load Operations.

Not only was the standard rail the only one to crush, it was the only rail to corrugate. Corrugations were observed in the control rail at 15 MGT with wavelengths from 12 to 18 inches. Measurements collected at 21.8, 67.0, and 84.6 MGT, illustrated in Figure 4, depict how the corrugations grew with tonnage. By 84.6 MGT, corrugations were as deep as 0.11 inch. None of the head hardened rails had developed visible corrugations during the 84.6 MGT test period. Vertical force measurements collected on corrugated rail under 125-ton cars were as high as 95 kips in the trough of .070-inch corrugations. Figure 5 illustrates a surface fatigue defect (deep spall) typical of many that developed in the troughs of the corrugations, likely in part due to high dynamic vertical forces.

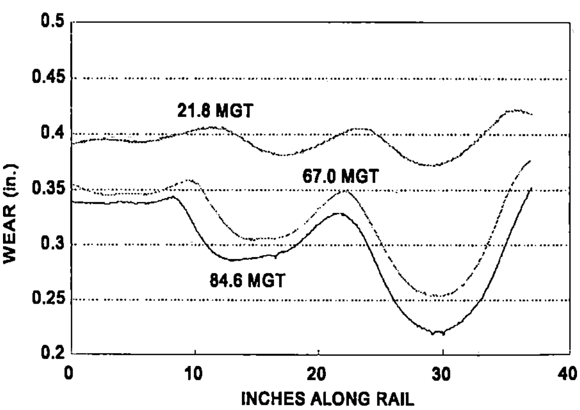


Figure 4. Longitudinal Rail Profile

Figure 5. Surface Fatigue Defect

Rail Hardness Can Be Used To Predict Gage Wear Rates

Gage wear rates are plotted as a function of hardness in Figure 6. Included is a best fit line through the various wear rates with rail hardness used as the independant variable. A respectable correlation coefficient of .84 resulted, as long as the Sydney rail was left out of the analysis. This suggests that increasing hardness reduces wear rates at a linear rate in the range of hardness included in the test. It appears in Figure 6, however, that decreasing hardness below approximately 320 Bhn will result in an exponential rise in wear rates. This possibility is supported by the crushing of the CF&I rail only, a mode not experienced by the harder rails.

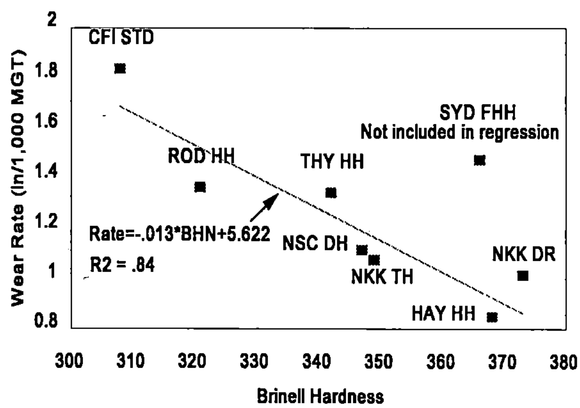


Figure 6. Gage Wear Rate vs Rail Hardness Excluding Sydney Rail in Regression Analysis

With the Sydney included, the correlation dropped to a poor 0.54. The poor correlation with Sydney rail included is due to a disagreement between hardness and wear rate of this rail. Sydney rail was measured with one of the highest hardnesses, but also had the highest gage wear rates of the premium rails. No good explanation can be offered for this behavior, but there are two conceivable possibilities knowing that the wear rates are correct: (1) the high rails were softer than the low rails, which were measured for hardness (high rail samples were not available at report time). This is unlikely because the Sydney rail also exhibited the highest wear rate of all premium rails on the low rail; (2) or the metallurgical properties of the Sydney rail are different from the other rails, though this is also unlikely.

Forecasted Rail Life

The wear rates listed in Table 1 can be used to predict the limit of rail life on this curve due to wear. Figure 7 illustrates the forecasted life of the test rails — the amount of tonnage a rail can be exposed to before accumulating ½ inch of wear at the location of the wear measurement. The ½-inch measurement was selected as it represents a considerable amount of wear, both in the gage face and head height directions.

In the test curve, gage wear limits rail life on the high rail, and head height loss of either rail is not a critical issue. On the high rail, the control rail has a projected life of 272 MGT while the Hayange HH rail is forcasted to last 588 MGT. These lives, slightly higher than those typical of rail life in revenue service, are low due to the light lubrication conditions of the high rail.

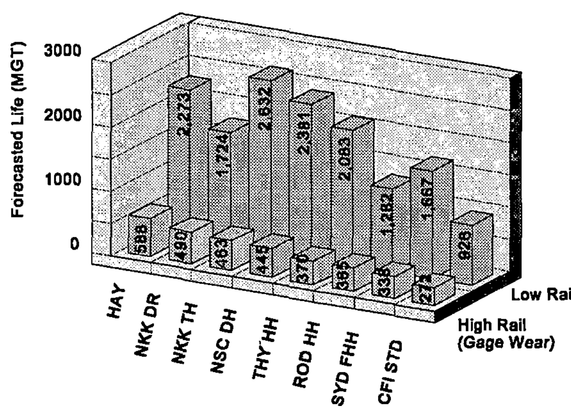


Figure 7. Forcasted Rail Life -- High and Low Rail

On the low rail, the control rail has a projected wear life of over 900 MGT and the NKK THH rail has a projected wear life of over 2,600 MGT. These long lives are likely due to operation of the FAST train overbalance speed and high lubrication levels of the low rail. These projected lives assume no fatigue failures will develop.

Forecast life results can be compared and contrasted with revenue service experience. On high rails, an outside observer might expect rail life to be lower in Section 07 since this curve is intentionally lubricated only lightly. However, lubrication conditions in revenue service often end up like those in Section 07. Rail grinding and hollow tread wheels also reduce high rail wear life in revenue sevice. On low rails in revenue service, there are areas where trains operate below balance speed and head height loss of the low rail is a critical issue. In such instances, low rails may be replaced at 2 to 3 times the rate of high rails, and high rails are often transposed to low rails because they have encountered substantial gage wear with minimal height loss. Other conditions that may accelarate low rail wear include poor lubrication, hollow tread wheels that increase contact stresses, and rail grinding which has been demonstrated to only increase wear rates. Table 2 summarizes the rail life comparisons between FAST and a typical revenue service curve and gives likely reasons for the similarities and/or differences.

Lubrication Increases Rail Wear Life

Another test curve at FAST has identical geometry and operating conditions as the wear test curve. However, this curve is well lubricated with coefficient of friction readings: high rail top (.25-.30), high rail gage face (.15-.20), and top of low rail (.30-.40). This curve also contains NKK THH rail.

In comparison, typical Section 07 readings: high rail top (.35-.40), high rail gage face (.25-.30), and top of low rail (.30-.35).

The wear life expected in the wear test is less than 500 MGT, while the same type of rail is forecasted to last almost 7,000 MGT in the well lubricated curve. This increase (x14) in wear life would likely be even greater if the rail in the wear test were totally dry.

Table 2. Comparison of Operating/Maintenance Conditions at FAST and In Revenue Service and Their Effect on Rail Wear Life.

		FAST	REVENUE SERVICE
Low rails have much longer life at FAST	Increased wear life due to:	-No rail grinding -Well lubricated rail -Over balance speed -Good wheel condition	N/A
	Decreased wear life due to:	N/A	-Rail grinding -Hard to lubricate low rail -Often under balance speed -Hollow tread wheels
FAST high rail life is similar to revenue service	Increased wear life due to:	-No rail grinding	N/A
	Decreased wear life due to:	-Poor lubrication (intentional)	-Often poor lubrication -Rail grinding -Hollow tread wheels

Hardness Conversion Chart for Rail Steel
(Courtesy of CF&I Lp.)

Brinell Hardness Number	**Hardness Vickers 30 kb**	**Rockwell "C" Hardness**
248	234	20
255	242	22
262	251	24
269	259	25
277	268	27
285	277	28
293	286	30
302	295	32
311	305	33
321	316	35
331	326	36
341	336	37
352	347	39
363	358	40
375	369	41
388	381	42
401	393	43
415	405	44

"Rail Grinding at FAST,"
by Jon S. Hannafious

Summary

After 100 MGT of testing with the heavy axle load (HAL) train on the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST), Transportation Technology Center, Pueblo, Colorado, results from the Rail Grinding Test show the following:

- Profiling a high rail of a curve with gage relief will result in increased gage wear. Maintaining such a two point contact profile will maximize the gage wear rate under given conditions.
- Frequent 12.5 MGT grinding intervals will result in accumulated gage relief (if gage corner is ground even very lightly) on a premium head hardened rail under well lubricated conditions.
- The first grind interval on a new rail results in appreciable vertical rail wear. Much of the head height loss of both high and low rails in the first 100 MGT can be attributed to the first grind interval.
- Grinding increases the natural wear rate of the rail; i.e., wear not including the metal removed from grinding itself.
- Two point contact grinding increases wheel set angle of attack and lateral curving forces.
- Low rail spalling is associated with wide gage and cut spike track, though not all such areas developed spalls
- Non-ground zones have remained spall free after 99.4 MGT (even in a wide gage area) and also have by far the least head height loss and gage face wear.
- A hands-off approach may be the best spall maintenance method

The Rail Grinding Test was designed to help determine the effects of grinding on the life of rail as it is limited by wear and fatigue. The test is being conducted in the two main curves of the FAST/HTL, Sections 25 (a 6-degree curve with 5 inches of elevation) and Section 03 (a 5-degree curve with 4 inches of elevation).

Both curves are well lubricated with coefficient of friction readings: high rail top (.25-.30), high rail gage face (.15-.20), and top of low rail (.30-.40). The FAST /HAL train, consisting of cars with 125-tons net loads, operates at 40 mph through both these curves, 6.2 mph overbalance speed in Section 03 (or 1.6 inches cant deficiency) and 5.5 mph over balance speed in Section 25 (or 1.7 inches cant deficiency).

INTRODUCTION AND CONCLUSIONS

A committee of rail grinding personnel from major railroads, the rail grinding supply industry, academia, the Association of American Railroads (AAR), and Federal Railroad Administration (FRA) have gathered over the last three years to discuss rail grinding issues. Part of the agenda of this committee was to design and oversee the FAST Rail Grinding Test. The grinding practices selected and the track layout are illustrated in Figure 1. Wear results after 99.4 MGT of testing are listed in Table 1.

GAGE CORNER RELIEF INCREASES GAGE WEAR

The amount of gage wear that occurred in 99.4 MGT listed in Table 1 is illustrated in Figure 2. The three grind zones in Section 25 (aggressive, moderate, and passive) all have the same amount of gage wear even though the grinding intervals vary from 12.5 to 75 MGT. This is likely due to the constant gage corner relief in all zones. Though the ground profiles vary slightly in the three zones, the gage corner of the high rails in all three zones is never contacted by passing wheels. Thus the dynamic behavior of passing trucks is the same.

The rails that are ground to similar profiles as those in Section 25 (Wood and Concrete Zones in Section 3) and then allowed to wear to the shape of the wheels have a lower wear rate. The initial gage relief in these zones is nearly gone when the rails are re-profiled every 50 MGT. Finally, those rails that are not ground (Control Zones and the Dry Wear Zone) have extremely low gage wear rates. Essentially, no gage face has developed in the Control Zones, and the Dry Wear Zone gage face developed during the initial 15 MGT of dry wear. These observations indicate that profiling a high rail of a curve with gage relief

Table 1. Wear in 99.4 MGT (0.001 inch) on 133 RE NKK HH Rail Includes Pre- and Post-Grind at 0 MGT

Section - Zone	Gage Wear* (.001 in.)	Head Height Wear - High Rail (.001 in.)			Head Height Wear - Low Rail (.001 in.)		
		Total	Grinding	Natural	Total	Grinding	Natural
25 - Aggressive	81	69	68	1	71	43	28
25 - Moderate	81	55	34	21	53	15	38
25 - Passive	86	40	23	17	61	27	34
03 - Control 1	0	1	0	1	19	0	19
03 - Wood	43	27	15	12	58	19	39
03 - Concrete	65	36	24	12	47	13	34
03 - Dry Wear	40**	12	0	12	45	18	27
03 - Control 2	5	7	0	7	30	0	30

*Gage wear is not directly affected by grinding; i.e., the side of the rail head is not ground
**Includes 15 MGT of light lubrication not experienced by other rails in test

will result in increased gage wear, and that maintaining such a two point contact profile will maximize the gage wear rate under given conditions. These results also indicate that where two point contact is maintained and the interval is varied, the resulting gage wear rates produced will be nearly identical.

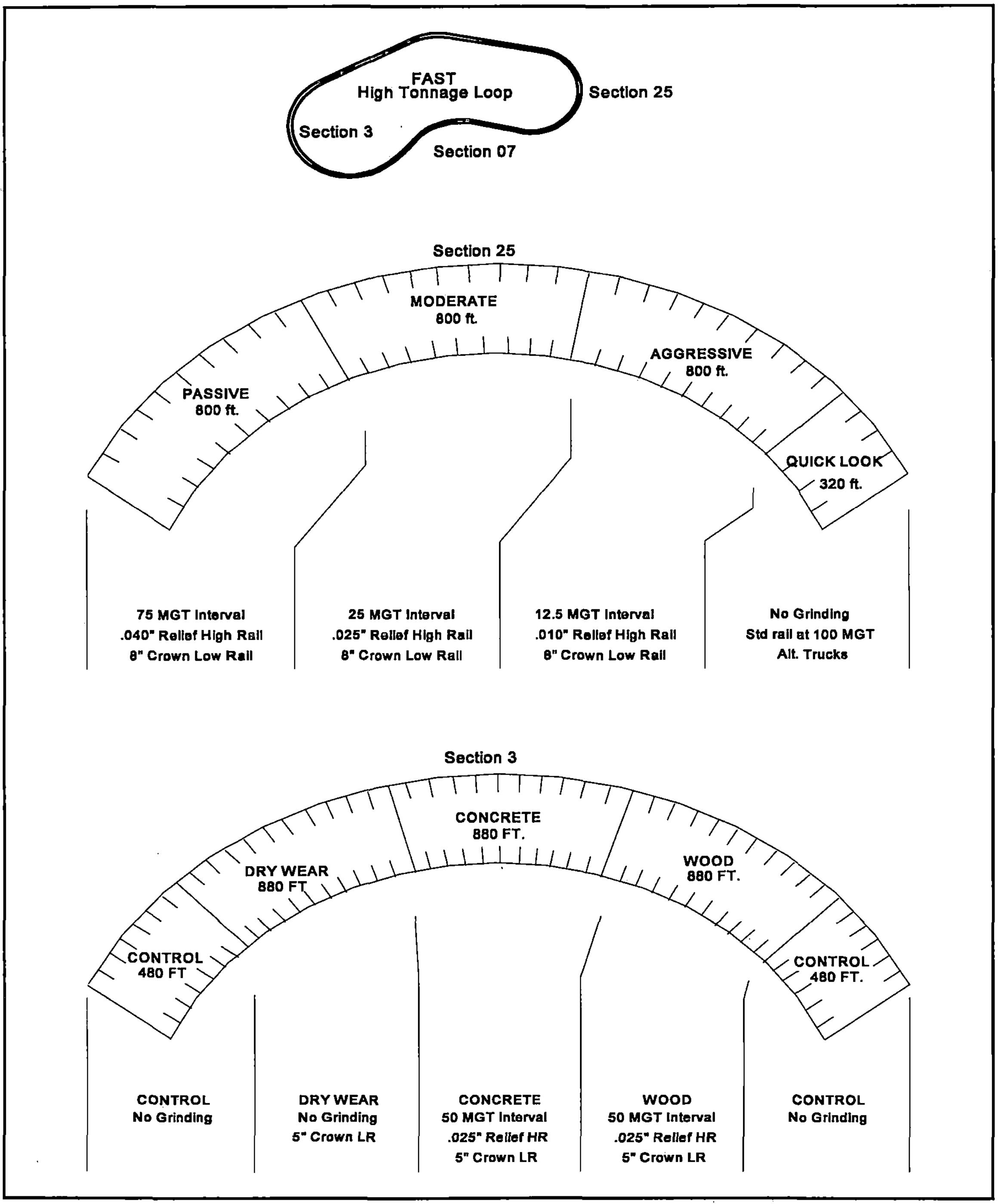


Figure 1. Layout of Grinding Test on the FAST/HAL

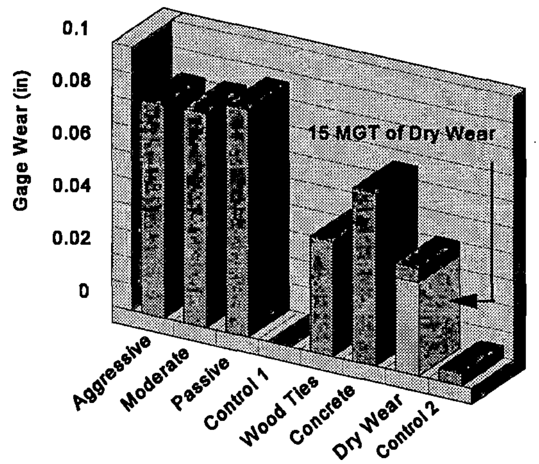


Figure 2. Total Gage Wear in Grinding Test Zones in 99.4 MGT

FREQUENT GRINDING INTERVALS RESULT IN ACCUMULATED GAGE RELIEF

A field observation made during the test is that very mild gage relief of high rails at 12.5 MGT intervals tends to accumulate. Even when only .010 inch to .015 inch is ground off the gage corner of a well lubricated, worn, head hardened rail, the rail does not wear to a naturally worn profile within 12.5 MGT. During the next interval, another light grind will result in more that the desired .010-inch relief. This was the experience at FAST, even though a very small (16 stone, 15 HP per stone) rail grinder is used. High grind speeds at 4 mph, light down pressure, and only five passes still resulted in accumulated gage relief.

THE FIRST GRIND INTERVAL RESULTS IN APPRECIABLE VERTICAL RAIL WEAR

Appreciable metal must be removed to establish a worn profile shape on new rail in the high side of a curve and to recrown the low side of the curve with center of rail contact. This amount is illustrated in Figure 3 which shows rail profiles of all test zones at 0 MGT, after being ground at 0 MGT (in the grind zones), and at 99.4 MGT. This figure also illustrates the overall wear that accumulated in each zone to date. Much of the overall wear during the first 100 MGT of the rail's life can be attributed to the first grind. Figures 4 and 5 illustrate the source of vertical wear on the high and low rails, respectively. Both the amount of rail ground off during the grind maintenance intervals and the amount of rail to wear naturally throughout the test are shown. Though the numbers are not included, nearly all the grinding wear illustrated came at the first grind interval when the high rail was ground to the worn profile shape, and the low rail was re-profiled to either an 8- or 5-inch crown radius.

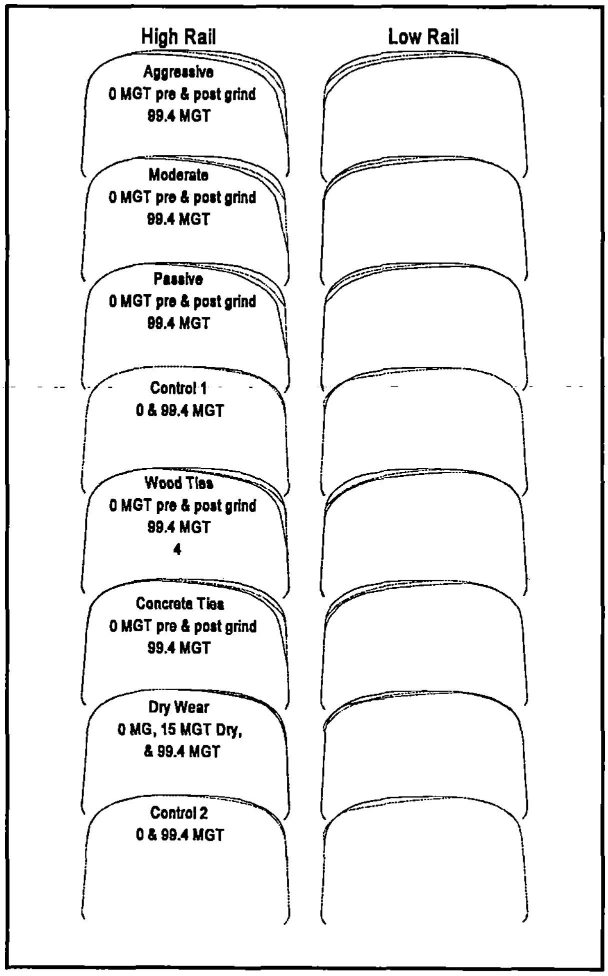


Figure 3. Profiles of Test Zones at 0 MGT and 99.4 MGT

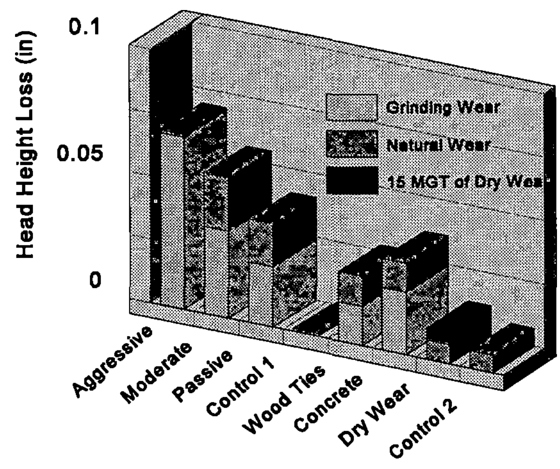


Figure 4. Head Height Loss of High Rails in 99.4 MGT

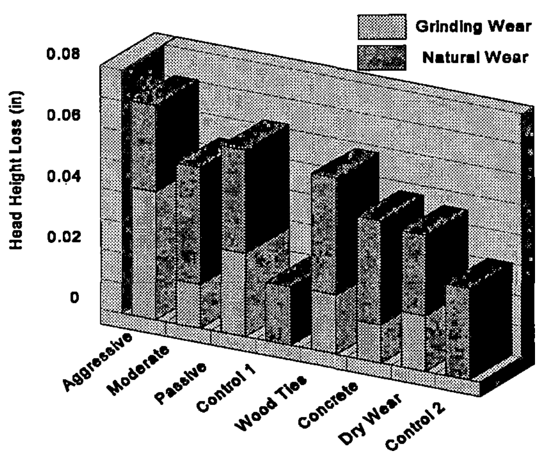


Figure 5. Head Height Loss of Low Rails in 99.4 MGT

GRINDING INCREASES THE NATURAL WEAR RATES OF THE RAIL

Figures 4 and 5 also show that natural wear rates (not including metal removed by grinding) are increased by grinding. Compared to the ground rails, the control rails and the dry worn rails had lower natural vertical wear rates on both the high rail and low rail. This may be for several reasons; e.g., the work hardened surface layer, which is very resistant to wear, is preserved on the non-ground rails; contact stresses are increased and bearing surface decreased on profiles ground to other than a naturally worn profile; and truck curving forces are minimized with non-ground profiles, or with ground profiles identical to naturally worn profiles.

TWO POINT CONTACT GRINDING INCREASES WHEEL SET ANGLE OF ATTACK AND LATERAL CURVING FORCES

In order to document grinding effect on vehicle dynamic behavior, wayside wheel set angle-of-attack and lateral force instrumentation were set up on worn non-ground rails (conformal wheel/rail contact) in the 6-degree curve of Section 25. The FAST consist passed over this data collection station at normal speed (40 mph) and under varying lubrication conditions (dry, high rail gage face lubricated, and both rails lubricated). The gage corner of the worn high rail was then relieved .040 inch by grinding (2 point contact), and the test repeated. The low rail was not ground. Average angle-of-attack results and average inside rail lateral wheel force results for the entire FAST consist are illustrated in Figure 6.

Subsequent to grinding, average angle of attack for both lead and trail axles of the FAST consist increased by about 1 mrad under almost all lubrication conditions. This indicates that less positive steering forces were being provided by the wheel sets due to high rail gage corner relief. In the exception condition, both rails were dry, and similar steering forces were being produced after grinding due to the dry flanging. Interesting to note is that the angle-of-attack rose after both rails were lubricated, though at the same time the lateral forces dropped appreciably for the lead axles.

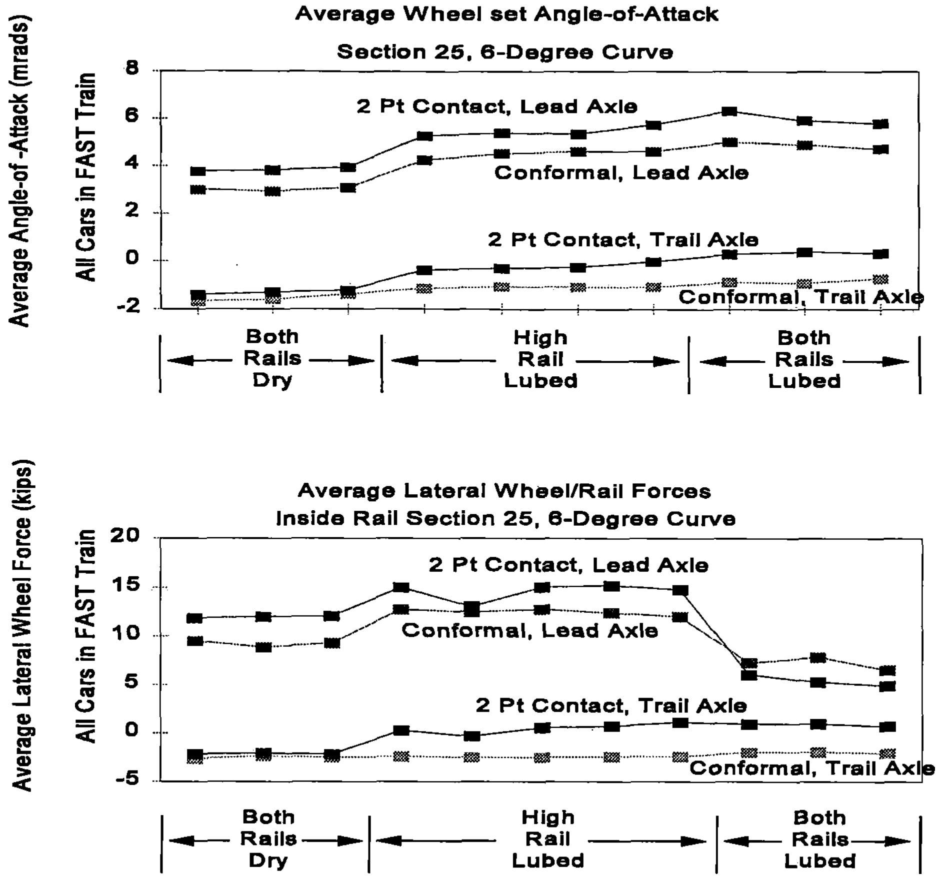


Figure 6. Angle-of-Attack and Lateral Forces before (Conformal) and after (2 point contact) High Rail Gage Corner Relief Grinding

Lateral forces, which are in part a function of low rail lubrication conditions, were highest when the low rail was dry. Under this condition, the ground profile lateral wheel forces always exceeded the non-ground forces, usually by about 2,500 pounds (or a truck side increase of 5,000 lbs). The worst condition was when the high rail gage face was lubricated, the low rail was dry, and the rail had been ground. In fact, at a time when lead axle lateral forces were highest, this condition brought positive forces from the trail axles (on average) which now contributed to gage widening. Before, the trail axles curbed gage widening. Lubricating both rails brought forces down and is the approach often taken in revenue service to control forces, especially where two point contact grinding is used. However, this can be viewed as a "Band-Aid" approach because the wheel set angle-of-attacks are highest under this approach and it will likely cause the most truck wear.

SPALLING IS ASSOCIATED WITH WIDE GAGE AND CUT SPIKE TRACK

Low rail spalling has developed in three areas of the test originally with cut spike track and wide gage: (1) severe spalling developed on the low rail of the Wood Tie Zone in Section 3 by 50 MGT, (2) spalling developed at the end of Section 25 in the passive zone and was heavy by 50 MGT, (3) light spalling developed in the Aggressive Zone and is not yet a concern. Gage measurement results at 50 MGT and 100 MGT for Sections 25 and 03 are illustrated in Figure 7 along with arrows marking the location of the spalled rail. Since the curves are a mixture of ties and fasteners, the cut spike zones are shown. Section 25, all wood ties, had three cut spike zones at 50 MGT that have been reduced and/or eliminated. Section 03 contains only cut spikes and concrete ties with elastic fasteners as illustrated.

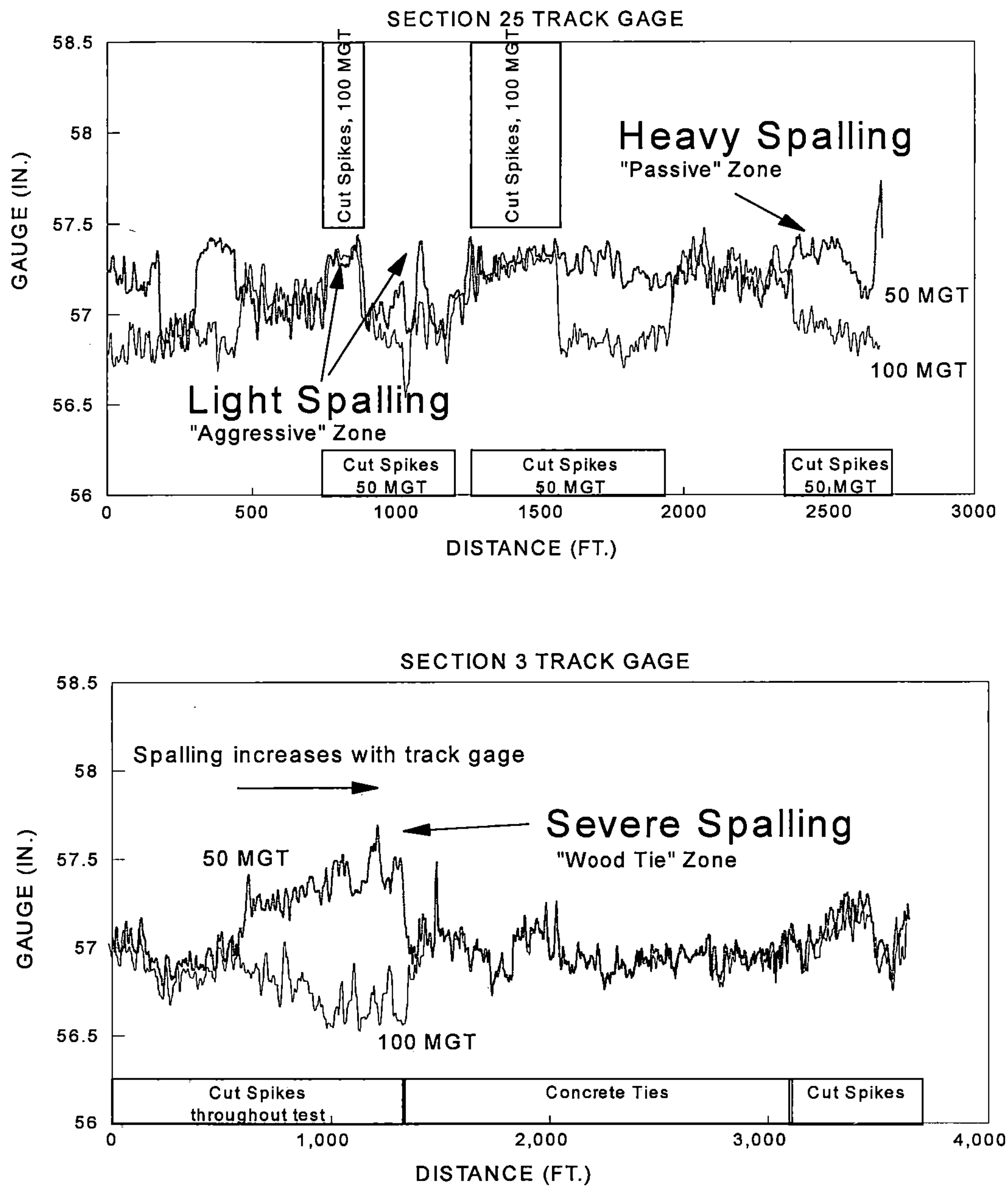


Figure 7. Track Gage in Test Sections and Spalled Rail Locations

The severe spalling in Section 03, illustrated in Figures 8 and 9, developed under excessively wide gage conditions of 57.5 inches. Though wheels at FAST are not known to be hollow, the natural convex shape at the rim of the wheel was riding directly on top of the 5-inch crown low rail (and directly over the spalls) as shown in Figure 10. When the Wood Tie Zone was regaged at approximately 55 MGT, only three of the 11 rails had spalled. However, the damage was apparently done. By 100 MGT, the spalling extended to all but two of the rails in the zone. It is worth noting that the spalling cannot be solely blamed on the 5-inch crown as the Concrete Tie Zone also has a 5-inch crown low rail and is exhibiting no spalling. Also after regaging and without any non-scheduled grinding, the spalling in the Wood Tie Zone appears to be less severe in the original three rails at 100 MGT than it did at 50 MGT.

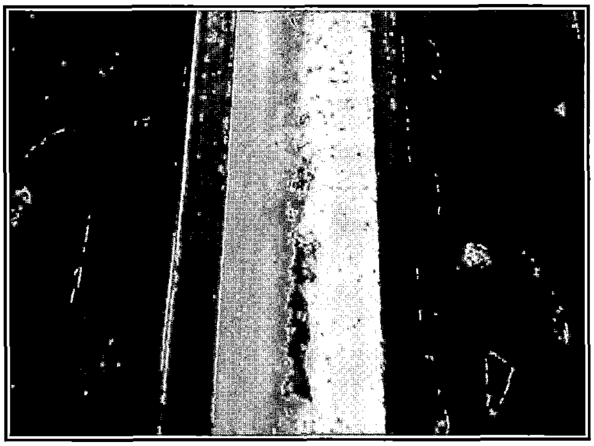


Figure 8. Spalling of Section 03 Low Rail in the Wood Tie Zone after 50 MGT

The heavy spalling in the Passive Zone of Section 25 appeared quite differently from that in Section 03. These spalls are located to the gage side of the low rail (which has an 8-inch crown radius) at the edge of wheel/rail contact. Reconstituted ties with cut spikes were originally in track in this area and have since been replaced by Pandrol fasteners and woodties. The reconstituted ties exhibited field side tie plate cutting and wide gage before being removed. Tie plate cutting likely rotated the low rail out and forced contact to the gage side of the rail and resulted in the spalling.

Figure 9. Close-Up View of Spalling in the Wood Tie Zone showing Metal Flow to the Field Side

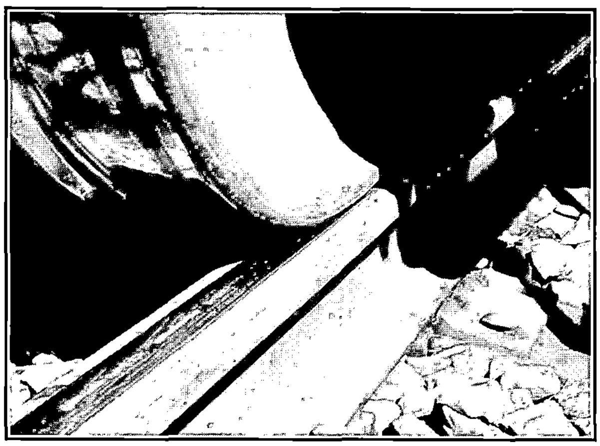


Figure 10. Rim Edge of a Passing Wheel Contacting Center of Low Railhead at Spalling Location (due to wide gage)

NON-GROUND ZONES PERFORMING BEST SO FAR

Non-ground zones have remained spall free after 99.4 MGT and also have by far the least head height loss and gage face wear. The Control Zone at the end of Section 03 has wide gage of 57.25 inches but has resisted spalling. In such a zone where profiles become naturally worn, dynamic truck behavior is better and thus the rail is more likely to perform better in this sense. There is a fear in revenue service that no grinding will lead to an overloaded gage corner, shelling, and catastrophic rail failures.

A HANDS-OFF APPROACH MAY BE BEST SPALL MAINTENANCE METHOD

AAR's experience suggest that low rail spalls do not cause catastrophic rail failures. Grinding out these defects often results in a tremendous decrease in the wear life of the rail. Often in revenue service, the defects return after being ground out. If the potential source for spalling is know; for example, wide gage or poor lubrication, it may be best to address the spalling through regular maintenance practices. Economically, it may even be better to leave the spalls in the rail.

According to the results of the wayside angle-of-attack and lateral force testing at FAST, grinding can contribute to spalling. Wheel sets that steer through a curve with minimized angles of attack are less likely to slip and cause slip related surface damage. Wheels steer better on a naturally worn high rail profile. Two-point contact under typical low rail lubrication conditions will increase lateral forces which are put into the track throught the wheel rail interface.

BACKGROUND

Rail Grinding and Control

Rail grinding is conducted with TTC's Pandrol Jackson 16 stone J-1, a switch and crossing grinding, Figure 11. The grinder is computerized with automatic patterns and grinding modes. During operation, rail grinder settings are called for from an inspector who bases the settings on what the shape of the rail is and what the desired profile is. Profile is checked with use of the Loram Bar Gage (Figure 12), for which FAST profile based templates were built at TTC specifically for this test.

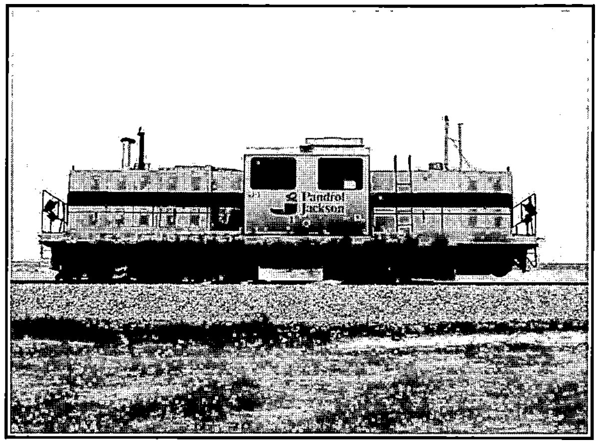


Figure 11. TTC's 16 Stone Pandrol Jackson Swith and Crossing Grinder (J-1)

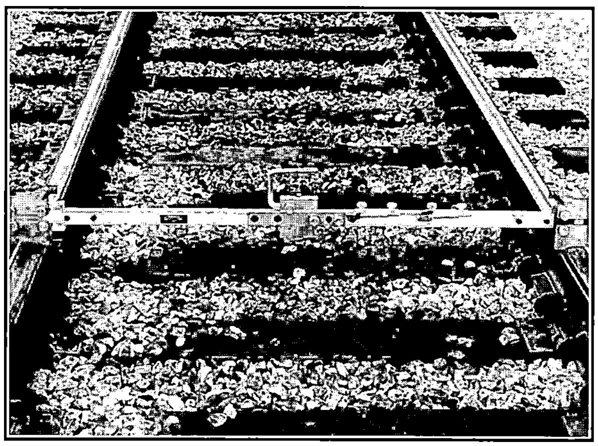


Figure 12. Loram Bar Gage used to Control Profiles at FAST (with special templates)

Test Layout

The Rail Grinding Committee was established under the direction of the FAST Steering Committee to address revenue service grinding issues at FAST .

The committee suggested that selected rail represent that being used now and in the future in revenue service. A modern steel rail specification was used and 133-RE NKK rail was selected. This was the first time in the history of FAST that rail was purchased for fatigue testing in the main curves of the FAST High Tonnage Loop.

Rail grinding practices in Section 25, illustrated in Figure 1, also represent revenue practices. "Aggressive" represents railroads who aggressively pursue grinding and have field conditions that allow for such a practice to be internally justified. "Passive" is used to represent a railroad that is unable, for whatever reason, to justify grinding more that once per year on even the heaviest lines. Section 03 was set up not to represent revenue service practices, but to help cover the matrix of rail grinding possibilities. There are two control zones for non-grinding comparisons. Concrete and wood ties were set up as a relative comparison of the rail performance on different support conditions. Maintenance practices (of the rail itself) in these two zones are identical. Finally, the Dry Wear Zone was designed to see how a rail would perform under lubricated conditions, if it were installed with a naturally worn profile. This rail was installed in the reverse curve on the HTL (see Figure 1) for the first 15 MGT of its life. Section 07 is only lightly lubricated on the high rail and wear rates are high. Thus the Dry Wear Zone rail was "worn in" when installed in the lubricated high rail of Section 03. The low rail of this zone was not worn in and has been installed in Section 03 from the start. The low rail of the Dry Wear Zone was initially ground to a 5-inch crown radius.

Low rails of Sections 25 and 03 are also controlled. Section 25 is ground entirely to an 8-inch crown similar to what is often used in revenue service. Section 03 was ground to a 5-inch crown in all but the control zones.

Fatigue at Fast

Standard chemistry 300 Bhn ingot rail has been installed in previous HAL tests at FAST in both Sections 25 and 3. These tests were conducted with the standard FAST heavy axle load train. Within 200 MGT, this rail had produced numerous shell defects, one of which is shown in Figure 13. Some of these shells turned down, as did the shell shown in Figure 13, into detail fractures (shown in Figure 14). Nearly all non-head hardened rails installed in the fatigue test curves at FAST eventually developed defects of the types shown. Head hardened rails have been much more resistant to these defects, some withstanding several hundred MGT and being removed with no defects. FAST experience tell us that NKK rail in the current test will not likely develop internal fatigue defects within 400 MGT. It will be several years before the final fatigue results of this test will be available.

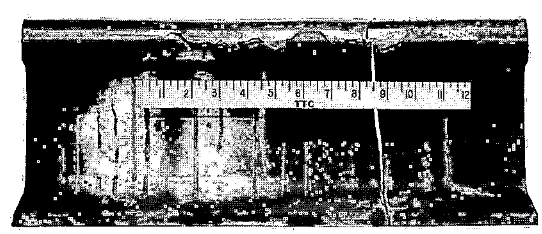


Figure 13. Shelling of Standard 300 Bhn Ingot Cast Rail under FAST HAL Testing

Some of the 300 Bhn ingot rail that was installed in previous tests was set aside. This rail will be installed in the "quick look" zone marked on Figure 1 in the fall of 1995 to see how it performs under FAST's advanced truck test train. Back-to-back fatigue results will be available to help measure the performance of the advanced truck test train.

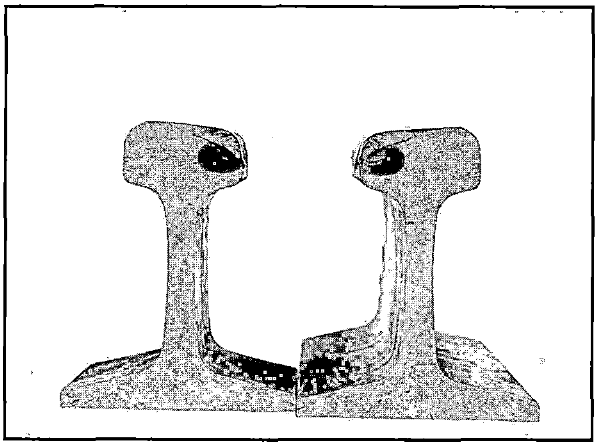


Figure 14. Detail Fracture Portion of the Shelling Defect Shown in Figure 13

"Thermite Weld Performance Under Heavy Axle Load Operations at FAST,"

by Greg Garcia

Summary

Thermite welds have been installed for both test and maintenance purposes at the Facility for Accelerated Service Testing (FAST), Transportation Technology Center in Pueblo, Colorado. When axle loads were increased, failure rates of thermite welds on the high rails of curves increased threefold. Subsequently, the AAR and the weld manufacturer set out to reduce the rate of weld failure and improve the reliability of welds under heavy axle load (HAL) operations. As a result, the failure rates (at 75 MGT of HAL testing) of standard thermite welds were reduced to 20 percent from 80 percent on the high rail and to 6 percent from 19 percent on the low rail.

Observations to date include:

- The expected life of standard and premium welds has increased.
- Premium thermite welds display a higher resistance to batter than standard welds.
- By limiting batter, the effects from it can be more readily addressed.
- Improvements in current mold designs provide a smoother web which reduces the grinding maintenance required at the web of the weld.

The performance of thermite welds, especially failure mode and tonnage at failure, has been documented under two operating regimes, 100- and 125-ton (HAL) unit trains. Standard track materials such as thermite welds generally are unable to withstand the increased stress generated by HALs. The thermite weld test, at FAST, was designed to evaluate existing and prototype welds with varying chemistries, mold designs and installation procedures.

The maintenance weld currently utilized at FAST has been changed from a standard to a premium weld (370 Brinell Hardness), which demonstrates a higher resistance to shelling under HALs (the main failure mode of standard welds at FAST). Discussions with railroad personnel suggest that web cracking, the primary failure mode of premium welds at FAST, is an issue in revenue service that still needs to be addressed.

INTRODUCTION AND CONCLUSIONS

Observations of thermite weld tests conducted at the Facility for Accelerated Service Testing (FAST) at the Association of American Railroads (AAR), Transportation Technology Center (TTC) in Pueblo, Colorado, show that 39-ton axle loads adversely affect the performance of standard thermite welds.

After identifying the need to improve reliability and thermite weld life, actions taken by both the manufacturer and the AAR have brought a substantial reduction in failure rates.

RESULTS

Performance testing of track components and materials at FAST was conducted under a 33-ton axle load train from 1985 until 1988. From 1988 until 1995, testing was conducted with a 39-ton axle load train (39-ton or heavy axle loads — HAL) in two phases. Phase I was conducted from July 1988 until June 1990 to investigate the performance of standard track materials/components under HAL traffic. Phase II was conducted from December 1990 until May 1995 to investigate the performance of premium materials/components under HAL traffic.

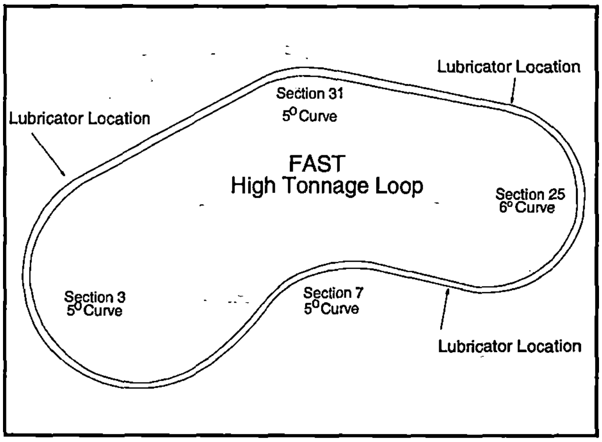


Figure 1. Map of HTL

During 100-ton car testing, 13 standard thermite welds were installed in the curves of the FAST High Tonnage Loop (HTL) (Figure 1.) Seven welds were installed on high rails and six on low rails. Of these welds, two failed on the high rail due to shelling of the weld material prior to 65 MGT.

HAL PHASE I TESTS

At the beginning of HAL Phase I, 36 standard thermite welds were installed in 5- and 6-degree curves on the HTL (Table 1).Twenty welds were placed in the high rail and 16 welds in the low rail. Table 1 lists the weld location by track sections, failure mode if any, and failure tonnage or tonnage when removed from track.

Table 1. Standard Thermite Welds in Test During HAL Phase I (High (H) and Low (L) Rail)

HTL Section	H/L	Failure Mode	MGT
03	H	Detail Fracture	81.7
03	H	Web Crack	41.2
03	H	Base Crack	36.3
03	H	Shelled	143.9
03	H	Shelled	36.3
03	H	Web Crack	45.2
07	H	Web Crack	36.2
25	H	Shelled	71.2
25	H	Shelled	71.2
25	H	Shelled	64.1
25	H	Shelled	29.2
25	H	Web Cracked	76.4
25	H	Shelled	50.1
25	H	Web Crack	22.4
25	H	Web Crack	56.4

Table 1. Standard Thermite Welds in Test During HAL Phase I (High (H) and Low (L) Rail) — Continued

HTL Section	H/L	Failure Mode	MGT
25	H	Shelled	58.8
25	H	Shelled	58.8
25	H	None	143.9
25	H	Shelled	55.5
31	H	Detail Fracture	56.2
03	L	Detail Fracture	143.9
03	L	Shelled	143.9
03	L	None	143.9
03	L	VSH, Shelled	143.9
03	L	Batter	48.8
03	L	Base Fatigue	84.4
03	L	Web Crack	80.4
25	L	None	143.9
25	L	Shelled	143.9
25	L	Web Crack	94.5
25	L	Detail Fracture	143.9
25	L	Battered	65.0
25	L	Web Crack	94.9
25	L	Shelled	143.9
25	L	None	143.9
31	L	Shelled	56.2

From Table 1 the following observations can be made:

High Rail

- All but one thermite weld was removed from track due to failure. (The final weld was removed due to a rail change.)
- Sixteen of the 20 welds evaluated had failed prior to 75 MGT (80 percent).
- The primary modes of failure were from shelling and horizontal web cracks.
- The average life for all welds in Phase I testing on the high rail was approximately 62 MGT (143.9 maximum).

Low Rail

- Thirteen of 16 thermite welds were removed from track due to failure. (Three welds were removed due to a rail change.)
- Three of the 16 welds evaluated had failed prior to 75 MGT (19 percent).
- The primary modes of failure were from shelling and horizontal web cracks.
- The average MGT for all welds in Phase I testing on the low rail was approximately 114 MGT (143.9 maximum).

HAL PHASE II TESTS

Due to the high failure rate of thermite welds during Phase I testing, FAST engineers set out to ensure better weld quality for Phase II. AAR welders were re-trained by the weld manufacturer in thermite weld installation. Subsequently, they were sent to general weld training school at the Burlington Northern facility in Kansas City. Finally, an AAR member railroad was invited to install their railroad's standard weld at TTC, allowing AAR's welders to observe. Though there were subtle differences in processes between AAR, the manufacturer, and the railroad, all agreed on the best procedures.

Meanwhile, the weld manufacturer adopted a new mold design aimed at reducing failures from web cracking. The mold provides for a smoother finish in the web and thus fewer fatigue initiation sites. All welds provided by the manufacturer now have this design.

Finally, to investigate weld performance under HAL traffic, combinations of standard and premium chemistries and/or standard or modified mold designs were installed in a dedicated weld test section of the HTL. The installation was monitored closely by the manufacturer's representatives.

Seventy-one thermite welds were installed for Phase II testing. Thirty-six welds were standard (16 on the low rail and 20 on the high rail). Table 2 identifies the weld location (Section 31), failure modes if any, and the accumulated tonnage prior to removal from track for either failure or rail change. Thirty-five of these welds were premium (18 on the low rail and 17 on the high rail). Table 3 identifies the weld location (Section 31), failure modes if any, and the accumulated tonnage prior to removal from track for either failure or rail change.

Premium thermite welds on the HTL have shown a high susceptibility to web failure. Since TTC designated the premium weld as the maintenance weld in October of 1993, there have been approximately 350 welds installed on the HTL. There have been 28 failures, and of the failures, 20 have been web failures. This is an 8 percent defect rate with 71 percent being web related. Discussions with revenue service personnel suggest that this is an important issue since they are experiencing similar failures.

The weld test has shown drastically different results with the variety of premium welds being evaluated. There have been 13 high rail and 4 low rail premium thermite weld failures. Twelve were due to shelling and only one can be classified as a web failure.

Table 2. Standard Thermite Welds in Test During HAL Phase II (High (H) and Low (L) Rail)

HTL Section	H/L	Failure Mode	MGT
31	H	Base Fatigue	23.1
31	H	Web Crack	49.7
31	H	Web Crack	49.7
31	H	Shelled	56.0
32	H	Still In Test	70.0
32	H	Still In Test	70.0
31	H	Still In Test	74.1
31	H	Still In Test	74.1
31	H	Still In Test	74.1
31	H	Still In Test	74.1
31	H	Rail Change	79.1
31	H	Shelled	79.1
31	H	Shelled	79.1
31	H	Shelled	79.1
32	H	Still In Test	101.5
31	H	Still In Test	101.5
31	H	Still In Test	101.5
32	H	Still In Test	101.5
31	H	Web Crack	113.2
31	H	Still In Test	153.2
31	L	Shelled	26.6
32	L	Still In Test	70.0
31	L	Still In Test	74.1
31	L	Still In Test	74.1
32	L	Still In Test	74.1
32	L	Still In Test	74.1
31	L	Rail Change	79.1
31	L	Rail Change	79.1
31	L	Rail Change	79.1
31	L	Rail Change	79.1
31	L	Rail Change	79.1
31	L	Shelled	79.1
31	L	Still In Test	101.5
30	L	Still In Test	101.5
32	L	Still In Test	102.3
31	L	Still In Test	153.2

From Table 2, the following observations can be made:

High Rail

- Eight of 20 thermite welds have been removed from track due to failure. (One weld was removed due to a rail change.)
- Four of the 20 welds failed prior to 75 MGT (20 percent)
- The primary modes of failure were from shelling and horizontal web cracks.
- Eleven welds remain in test on the high rail.

Low Rail

- Two of 16 thermite welds have been removed from track due to failure. (Five welds were removed due to a rail change.)
- One of the 16 welds failed prior to 75 MGT (6 percent).
- The only mode of failure was shelling.
- Nine welds remain in test on the low rail.

Table 3. Premium Thermite Welds in Test During HAL Phase II (High (H) and Low (L) Rail)

HTL Section	H/L	Failure Mode	MGT
31	H	TD	45
31	H	Pull Apart	46.4
31	H	Shelled	61.2
31	H	Shelled	65.8
32	H	Still In Test	70.0
31	H	Shelled	70.3
31	H	Shelled	70.6
31	H	Still In Test	74.1
31	H	Shelled	79.1
31	H	Shelled	79.1
31	H	Shelled	79.1
31	H	Shelled	79.1
31	H	Shelled	79.1
31	H	Shelled	79.1
31	H	Shelled	94.9
31	H	Rail Change	101.5
31	H	Still In Test	153.2
31	L	Base Fatigue	0.1
31	L	Base Fatigue	13.7
31	L	HSW	29.0
31	L	Rail Change	65.8
32	L	Still In Test	70.0
30	L	Still In Test	74.1
31	L	Still In Test	74.1
31	L	Rail Change	79.1
31	L	Rail Change	79.1
31	L	Rail Change	79.1
31	L	Rail Change	79.1
31	L	Rail Change	79.1
31	L	Rail Change	79.1
31	L	Shell	113.2
31	L	Still In Test	153.2
31	L	Still In Test	153.2
31	L	Still In Test	153.2
31	L	Still In Test	153.2

From Table 3, the following observations can be made:

High Rail

- Thirteen of 17 premium thermite welds have been removed from track due to failure.

- Six of the 17 welds failed prior to 75 MGT (35 percent).
- The primary mode of failure was shelling with one pull-apart and one TD.
- Four premium welds remain in test on the high rail.

Low Rail

- Four of 18 thermite welds have been removed from track due to failure. (Seven welds were removed due to a rail change.)
- Three of the 18 welds failed prior to 75 MGT (17 percent).
- The modes of failure were two base fatigue, one horizontal split web and one shell defect.
- Nine welds remain in test on the low rail.

BATTER

Batter results from localized changes in the metallurgical character of the rail, which occur in the vicinity of thermite welds. The welds observed in the thermite weld test at FAST have displayed both double dipper and peaked characteristics. The distinguishing factor is that the valleys from the double dipper configuration occur at the heat affect zones (HAZ) and the peaked configuration occurs outside of the HAZ.

The batter in the weld area is monitored by utilizing a Longitudinal Rail Profile (LRP) measuring machine. This machine measures along the longitudinal surface of the rail for a distance of 37.5 inches. A reading is taken every 0.01 inch which gives a total of 3,750 measurements at an accuracy of 0.001 inch at each location. The overall accuracy across the length of the machine is 0.005 inch. Hardness measurements are taken, in track, utilizing an Equotip Hardness Tester. The Equotip is a light penetrant, impact phase and rebound phase process with a Brinell hardness accuracy of +/-0.5 percent. Three hardness measurements are taken at seven locations for a total of 21 measurements per weld. The measurement locations are located at the center of the weld as well as 1 inch, 2 inches and 12 inches to each side of the weld.

The amount of batter has decreased with the utilization of premium and ultra-premium thermite welds. This decrease can be largely attributed to the higher hardness of premium welds. Comparisons made between test welds in track , after 72 MGT of traffic, show that, on the average, the premium welds displayed a 24-percent higher resistance to batter than did the standard welds. Figures 2 and 3 show a comparison between eight standard and eight premium welds along with the effect from batter since the last grind. As shown in Figure 2, the high rail welds displayed a lower effect from batter. And in Figure 3 the effect from batter appears to be more consistent with premium welds.

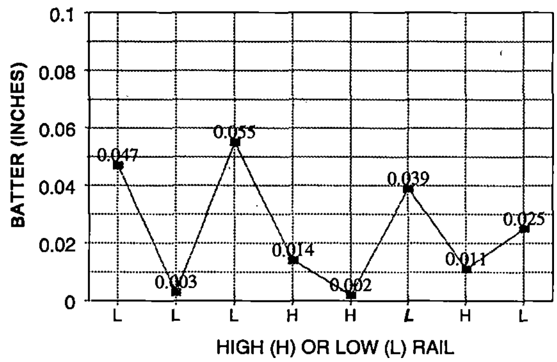


Figure 2. Standard Thermite Welds Showing Amount of Batter After 59 MGT

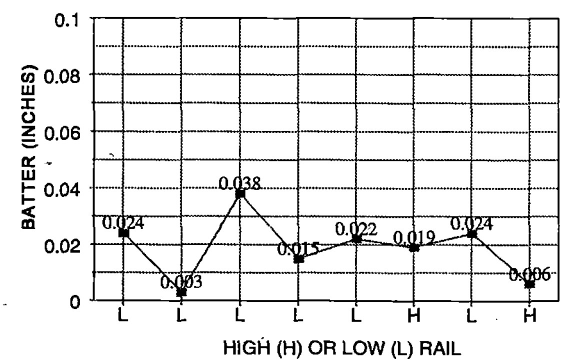


Figure 3. Premium Thermite Welds Showing Amount of Batter After 59 MGT

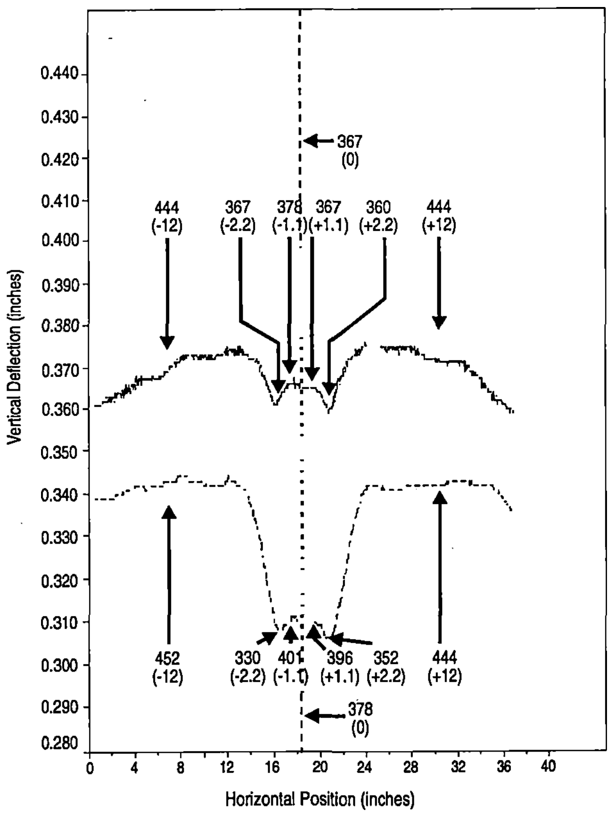


Figure 4. LRP's and Bhn's on a Standard Thermite Weld which was Air Quenched

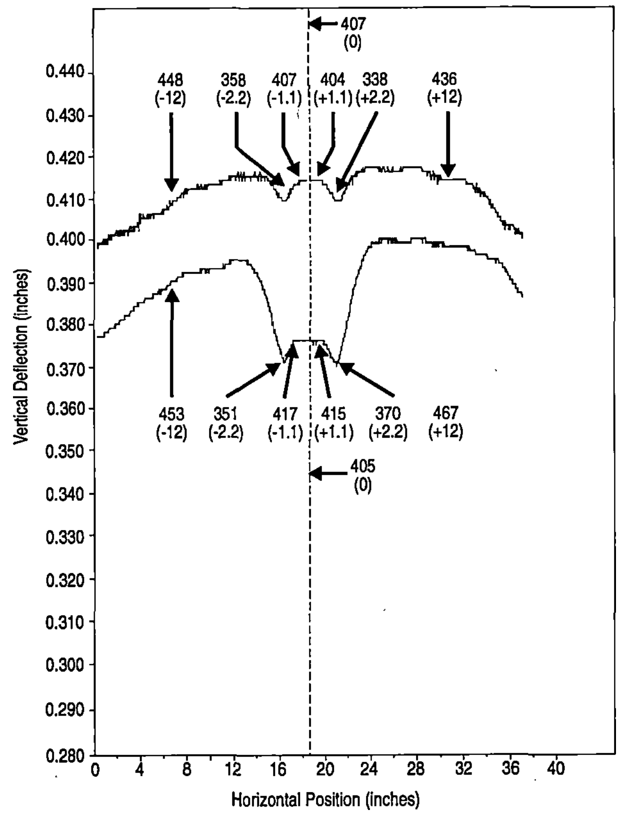


Figure 5. LRP's and Bhn's on a Premium Thermite Weld

Figures 4, 5, and 6 show the effect of batter and hardness on a standard thermite weld, a premium thermite weld, and an ultra-premium thermite weld.

The weld represented in Figure 4 is a standard weld with a standard mold which was air quenched. This particular weld can be summarized as follows:

- The weld was placed in track on August 14, 1992.
- The weld has accumulated approximately 74 MGT of heavy axle load traffic.
- The amount of batter incurred since the last grind is 0.055 inch after 59 MGT of traffic.
- The batter displayed can be classified as that of a double dipper configuration.
- The surface hardness at installation was 340 Bhn.
- The post grind surface hardness was 367 Bhn and
- The current surface hardness measures 378 Bhn.

The weld represented in Figure 5 is a premium weld with a standard mold. This particular weld can be summarized as follows:

- The weld was placed in track on August 19, 1992.
- The weld has accumulated approximately 76 MGT of traffic.
- The amount of batter incurred since the last grind is 0.038 inch after 59 MGT of traffic.
- The batter displayed can be classified as that of a double dipper configuration.
- The surface hardness at installation was 364 Bhn.
- The post grind surface hardness was 407 Bhn and
- The current surface hardness measures 405 Bhn.

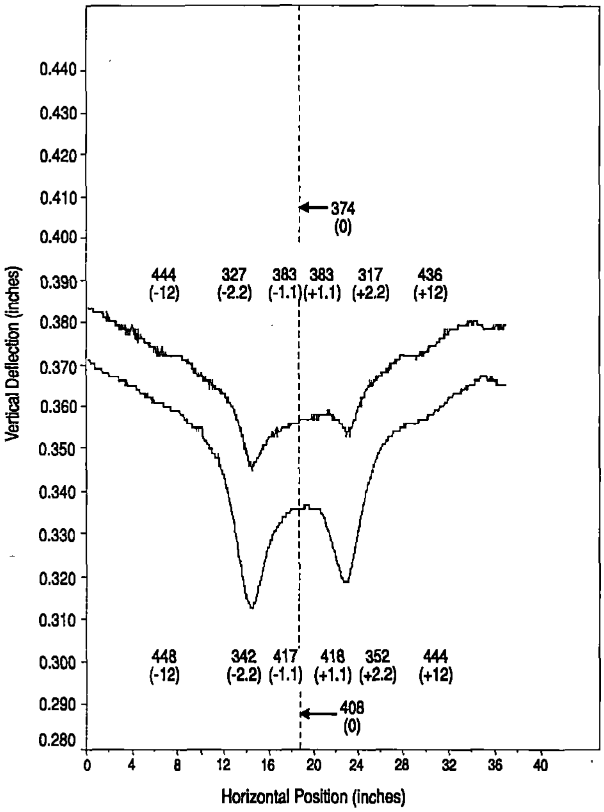


Figure 6. LRP's and Bhn's of an Ultra-Premium Thermite Weld (380+Bhn)

The weld represented in Figure 6 is an ultra-premium weld with a standard mold. This particular weld can be summarized as follows:

- The weld was placed in track on August 28, 1992.
- The weld has accumulated approximately 72 MGT of traffic.
- The amount of batter incurred during the last grind is 0.024 inch after 59 MGT of traffic.
- The batter displayed can be classified as that of a peaked configuration.
- The surface hardness at installation was 375 Bhn.
- The post grind surface hardness was 374 Bhn.
- The current surface hardness measures 408 Bhn.

There are 30 thermite welds still in test at FAST. These welds will continue to accumulate tonnage during Phase III of Heavy Axle Load Testing and will remain in test until either a rail change is required or they fail.

"Analysis of Wood Tie and Fastener Performance in a Heavy Axle Load Environment,"

by M. Carmen Trevizo

Summary

Test results from the jointly sponsored Association of American Railroad's/Federal Railroad Administration Heavy Axle Load (HAL) Wood Tie and Fastener Experiment at the Transportation Technology Center, Pueblo, Colorado, indicate that the amount of gage widening varies with wood species. The experiment, which has been in place on the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST) since the beginning of the HAL program(August 1988), is evaluating the effects of HAL traffic on wood tie and fastener performance.

Ties and fasteners are in test in three curves and one tangent section on the HTL. New wood species were added at the start of the second phase of HAL testing to evaluate underutilized tie resources, which may be used in future HAL revenue service. Results indicate the following:

- The amount of gage widening varied with wood species.
- Oak ties exhibited less gage widening than any other hardwood or softwood specie in test.
- Douglas fir ties, a softwood specie, retained gage to FRA Class 4 limits about 50 percent longer than other softwood species tested.
- The lateral load environment greatly influences gage widening.
- The failure mode in the Cedrite reconstituted ties was cracks in the rail seat area and not gage widening.
- Direct fixation fasteners provide more lateral rail restraint than the cut spike system at 0.4 lateral/vertical load ratio.
- Ties installed at 24-inch spacing have experienced more skewing than the same ties installed at 19.5-inch spacing.

INTRODUCTION AND CONCLUSIONS

The Heavy Axle Load (HAL) Wood Tie and Fastener Experiment sponsored by the Association of American Railroad's (AAR) and the Federal Railroad Administration at the Transportation Technology Center, Pueblo, Colorado, is evaluating the behavior and performance of various types of wood tie species and rail fasteners under 39-ton axle load traffic. The primary objective of the experiment is to quantify the long term behavior of wood ties and various types of rail fastening systems in a heavy axle load (39 kip static wheel load) environment. Comparisons, when possible, will be made with data collected during the 33 kip wheel load phase. The secondary objective is to collect data which can be used to validate existing mathematical models for use in predicting fastener performance under heavier axle loads.

TRACK LAYOUT

Different configurations of wood tie species and fasteners were installed on three curves and one tangent section of the High Tonnage Loop (HTL). The fastener experiment was installed in Section 07 (5-degree curve), and different configurations of wood tie species were installed in Section 25 (6-degree curve), Section 31 (5-degree curve), and Section 33 (tangent track). Test zone locations on the HTL are shown in Figure 1.

As part of the tie test, Douglas fir and oak ties were installed in August 1988 in the center of Section 25 at the start of the HAL program. Douglas fir and oak ties were also installed in Section 07 for the fastener test. After the start of the HAL program, additional wood tie species were installed in Sections 07, 25, 31, and 33 at different time intervals.

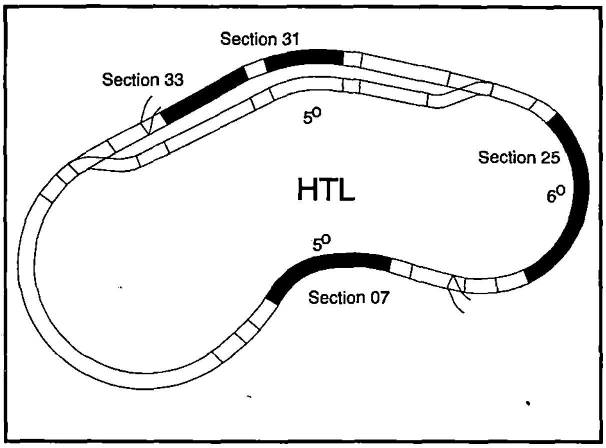


Figure 1. Test Zone Locations on the HTL

Section 07

Each test subsection was made up of 100 ties. All but one subsection was made up of 80 oak ties and 20 Douglas fir. Each subsection had one of the following fastening systems: cut spikes, double elastic spikes, Koppers, Safelok, or Pandrol fasteners. After 160 MGT of traffic the Koppers fastening system and ties were taken out of test[1] and replaced with six laminated ties equipped with cut spikes. The tie size in all of the subsections was 7"x9"x8'-6".

Section 25

Three subsections, 100 ties long, were in test in the center of Section 25 at the start of the HAL program. Each subsection was made up of 80 oak ties and 20 Douglas fir. The tie size in one section was 6"x8"x8'-6", while the tie size in the other two sections was 7"x9"x8'-6". Cut spikes were used in all three test sections.

After 160 MGT of HAL traffic, additional wood tie species were installed. The wood tie species installed consisted of Cedrite reconstituted ties, dowel laminated oak ties, hem fir, southern yellow pine, red maple, and CN soft and hardwood ties. At installation, cut spikes were used on all of the ties with the exception of the dowel oak laminated ties, where the Pandrol fastening systems was used.

Section 31
One hundred tropical hardwood, Azobe ties, were installed in Section 31 after 15 MGT of HAL traffic. The ties were spaced 19.5 inches on center. One half of the ties were equipped with cut spikes and the other half with Hoesch double elastic spikes. After 80 MGT of HAL traffic, 80 additional Azobe ties were installed. Half of the ties were equipped with Hoesch double elastic spikes and the second half with Pandrol plates and fasteners. These ties were installed 24 inches on center.

Section 33
One hundred Cedrite reconstituted ties were installed in Section 33 after 160 MGT of HAL traffic. The ties were spaced 24 inches on center and were equipped with the Pandrol fastening system.

MEASUREMENTS

Wood tie performance is based on results obtained from specific measurements. These measurements include lateral railhead and rail base displacement under static and dynamic loading, and track gage measured with EM80 geometry car. Track geometry degradation, maintenance requirements, and failures modes are also used to asses tie/fastener performance.

Dynamic Measurements
Wheel forces were collected in the three test curves, using wayside instrumentation to characterize the lateral load environment in the curve test locations. The wheel load data was collected using strain gages instrumented on the rail.

Static Measurements
Static gage widening was the measurement used to monitor tie and fastener degradation. The measurement is accomplished by statically applying a known vertical and lateral load to the rails and measuring the lateral railhead displacement. Forty thousand pounds of vertical load and 20,000 pounds of lateral load are applied to the rails producing a L/V ratio of 0.5. The static gage is calculated by adding the lateral railhead displacement of the high and low rails. The lateral railhead and base deflection are also used to derive rotation of the rail.

RESULTS

Lateral Load Environment
Due to the TTC's semi-arid climate, the majority of the ties exhibit minimal tie plate cutting, thus having little impact on tie performance. However, most of the tie degradation that does occur is attributed to gage widening. In spite of the numerous rail changes on the HTL, which required re-spiking, the lateral load environment appears to be the largest contributor to gage widening. Ties located in the higher lateral load environments were more susceptible to gage widening

Figure 2 shows the distribution of peak wheel lateral forces generated by the passing wheels on the three curve test locations, recently collected on the HTL. As shown in the distribution, about the first 40 percent of the lateral load data in the three curves is at or below 2.5 kips; however, the difference in the three locations is evident in the magnitude of the lateral loads for data above the 60th percentile. Lateral loads are highest in Section 25, followed by Section 31. The lowest lateral load environment was in Section 07. The higher lateral load environment in Section 25 is due to sharper curvature, differences in grinding profile, lubrication practices, and operating conditions on this section.

TRACK GAGE DEGRADATION

At the end of the first 160 MGT, there was no significant degradation in track geometry in the wood tie test zones; however, during the second phase of testing, which involved an additional 300 MGT of HAL traffic, track degradation was evident in several wood tie species.

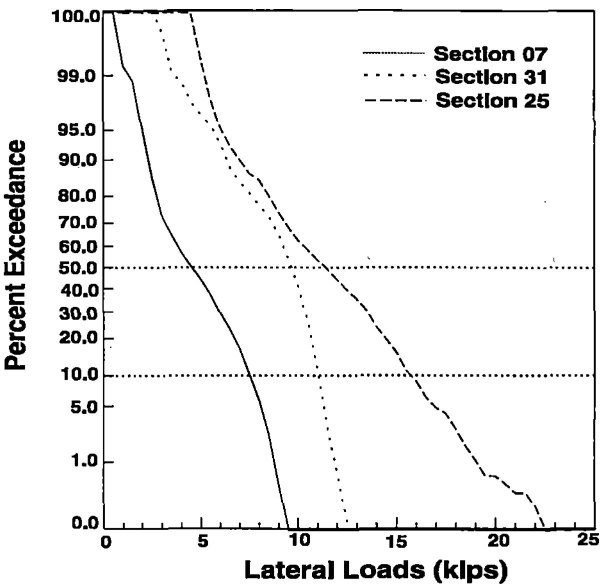


Figure 2. Lateral Wheel Forces

Figure 3 shows the track gage measured using the EM80 geometry throughout Section 25. The figure shows that all of the softwood species have gage widened more rapidly than the hardwoods. Track gage for all of the softwoods falls above the horizontal line. The reconstituted ties at the end of the section did not gage widen as rapidly as the other ties installed at the same time. However, because of rail seat cracking, they were removed from track.

Figure 3 shows the track gage measured using the EM80 geometry throughout Section 25. The figure shows that all of the softwood species have gage widened more rapidly than the hardwoods. Track gage for all of the softwoods falls above the horizontal line. The reconstituted ties at the end of the section did not gage widen as rapidly as the other ties installed at the same time. However, because of rail seat cracking, they were removed from track.

With an additional 160 MGT of HAL traffic, the Douglas fir and oak ties shown in the center of Figure 3 show less or about the same gage widening as the other hard and softwood ties. The Dougas fir in this section required re-gaging after 360 MGT of HAL traffic. However, the Douglas fir ties in Section 07, which had accumulated the same amount of tonnage, required no maintenance.

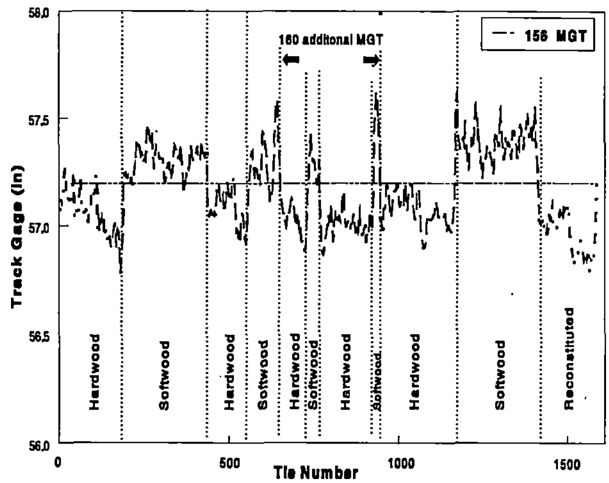


Figure 3. Measured Track Gage Using the EM80 Geometry in Section 25

Figure 4 shows track gage measured only on the Douglas fir and oak ties. The data shown reflects 424 MGT of accumulated HAL traffic. The two middle sections of Douglas fir ties, which are shown as a solid line on the plot, were re-gaged after 359 MGT of HAL traffic and retrofitted with Pandrol plates and coach screws. The Douglas fir tie section on the far right was re-gaged at 375 MGT and the cut spikes were retained. No change in gage widening between the two sections was noticeable at 424 MGT.

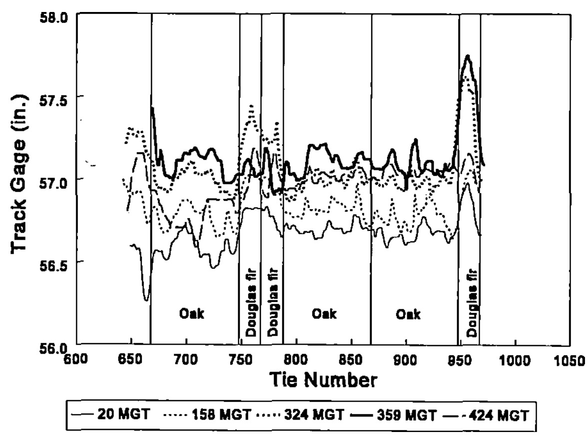


Figure 4. Measured Tack Gage in Section 25 for Douglas Fir and Oak Ties

Figure 5 shows the measured track gage on the Douglas fir and oak ties in Section 07. The highest measured gage is about the same for both Sections 07 and 25; however, about ½ inch of the measured gage in Section 07 is due to rail wear. When comparing measurements at 352 and 359 MGT, the extent of rail wear in Section 07 is noticeable. The rail was changed just prior to the 359 MGT measurement. Because the installation of new rail was performed without re-gaging the plates, the measured track gage in both the cut spike and direct fixation fastening system zones can be attributed to long term degradation.

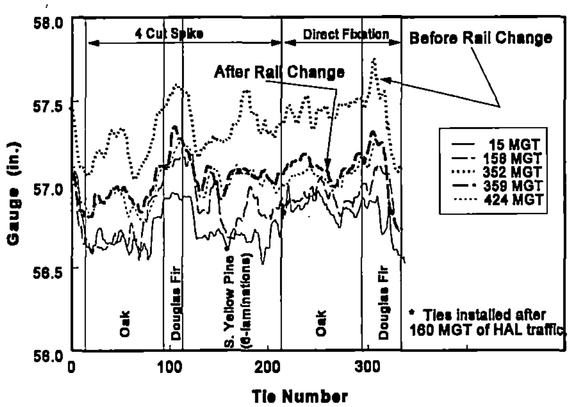


Figure 5. Gage in Section 07 -- Douglas Fir and Oak Ties Test Areas

In Section 25, track gage degradation was also significant in the hem fir and southern yellow pine ties installed at the start of the second phase of the HAL program. After 200 MGT of HAL traffic, the ties gage widened significantly and required re-gaging. In fact gage widening was so severe the track supervisor felt that re-plugging and re-gaging the ties with the existing cut spike system would bring about gage widening in a short time period. Thus, the ties were re-gaged and equipped with Pandrol plates, fasteners, and coach screws in an attempt to lengthen the re-gaging maintenance cycle.

Figure 6 shows the measured track gage for the hem fir and southern yellow pine. The change in track gage between 156 and 200 MGT of accumulated HAL traffic once again was due to re-gaging prior to the 200 MGT measurement.

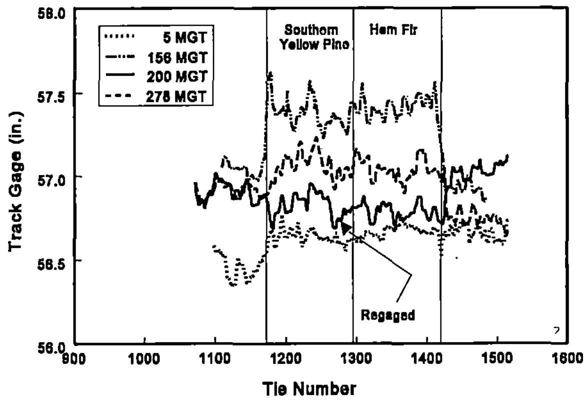


Figure 6. Accumulated Track Gage on the Southern Yellow Pine and Hem Fir Tie Sections

While Pandrol plates and coach screws improved gage retention of the ties, the coach screws were continually working out of the ties under traffic. In an attempt to remedy the problem, threaded coil inserts were used in the hold down hole. However the screws continued to work out wherever a split was present in the hold down hole. Tie splitting may have been too severe for this type of repair. The severe tie condition was accelerated by rail plugs installed during a period when rail fatigue caused numerous breaks.

After 460 MGT of HAL traffic, the majority of the ties in Section 25 will be replaced due to permanent damage from gage widening or severe split condition. The only ties that will remain in test, will be the oak ties installed at the start of the HAL phase.

TRACK STRENGTH

Track strength, a measurement used to monitor tie and fastener degradation, is determined by statically applying known vertical and lateral loads to the rails, while measuring the lateral railhead and rail base displacement. In Figure 7, railhead displacement measured on the hem fir and southern yellow pine ties is shown. The data, under 40,000 vertical and 20,000 pounds static loads, indicates that gage restraint increased after the installation of the Pandrol fastening system. The measured average lateral railhead displacement was about 50 percent less.

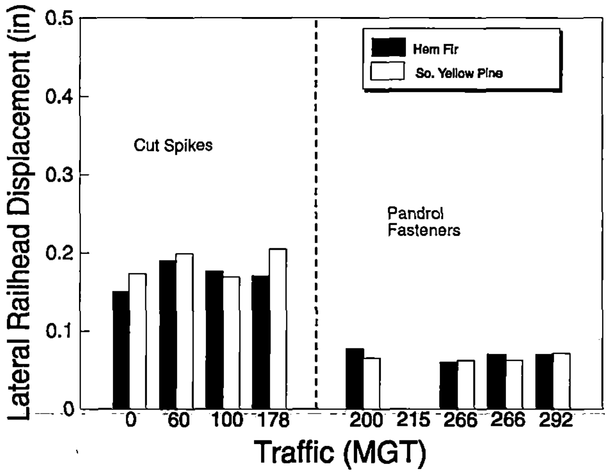


Figure 7. Lateral Railhead Displacement

The lateral railhead displacement measured on the different types of fasteners installed on the oak ties in Section 07 is shown in Figure 8. The lateral restraint provided by the cut spike system is less than that provided by the three different types of direct fixation fasteners. The lateral railhead displacement for the cut spikes varied throughout the test due to the rail changes that occurred. Whenever re-plugging occurs after rail changes, the lateral railhead displacement decreased. Very little change occurred throughout the test on the lateral restraint provided by the direct fixation fasteners in test. In the softwood ties, Douglas fir ties, the direct fixation fasteners also provided more lateral restraint than the cuts spikes.

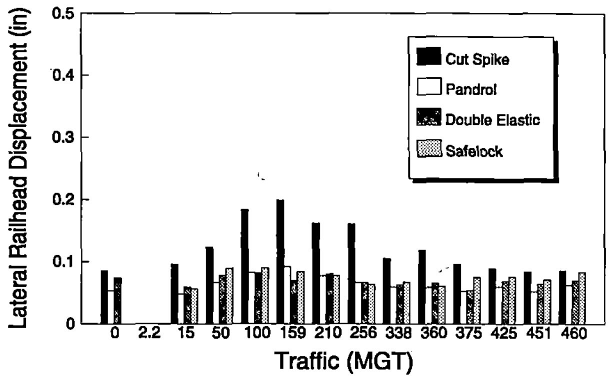


Figure 8. High Railhead Displacement on the Oak Tie — Section 07

TROPICAL WOOD SPECIES AND RECONSTITUTED WOOD CROSSTIES

Azobe ties installed with cut spikes and direct fixation fasteners have minimal gage widened since installation of the ties. The ties installed on 19.5-inch spacing were equipped with cut spikes and Hoesch double elastic spikes, while the ties installed on 24-inch spacing were equipped with Hoesch double elastic spikes, and Pandrol fasteners. Figure 9 shows the final track gage measurement taken on the four subsections. The ties spaced at 19.5 inches have accrued 245 MGT of HAL traffic, while the ties spaced at 24-inches have accrued 170 MGT of HAL traffic. The

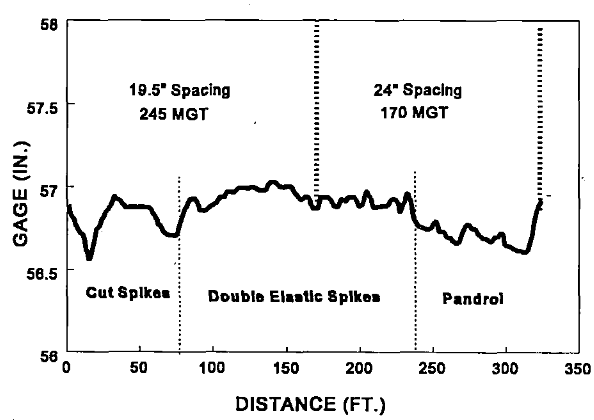


Figure 9. Track Gage for the Azobe Ties for Section 31 — Cut Spikes and Direct Fixation Fasteners

maintenance required in this section has been tie straightening because of tie skewing. The ties installed on 24-inch spacing have experienced more tie skewing than the ties installed on 19.5-inch spacing.

Lateral railhead displacement was also measured on the Azobe ties. The lateral restraint provided by the direct fixation fasteners on this hardwood is higher that provided by the cut spikes. Figure 10 shows lateral railhead displacement for the high rail for the cut spikes and double elastic spikes. Very little difference is measured in the lateral gage restraint on the Azobe ties installed on 24-inch spacing and equipped with two different direct fixation.

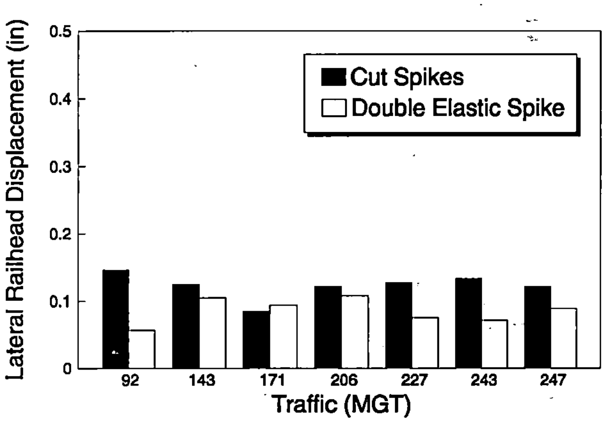


Figure 10. Average Lateral Railhead Displacement for the Azobe Ties 19.5-inch Spacing

Reconstituted Cedrite Ties

Three different Cedrite reconstituted tie subsections were installed in Section 25. The first subsection was installed from tie 90 to tie 185 and was equipped with the Pandrol fastening system and coach screws. The second and third subsections were 90 ties in length and were installed at the end of Section 25. The second subsection was equipped with the Pandrol fastening system and lock spikes, and the third subsection was equipped with standard AREA plates and cut spikes.

Gage widening was not a failure mode on the Cedrite ties while in test in Section 25. Track gage for the two subsections at the end of Section 25 is shown in Figure 11. The average track gage after 260 MGT of HAL traffic was about 57 inches. Re-gaging was not required while in test.

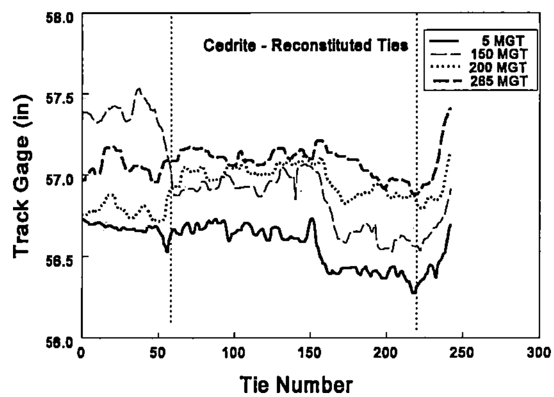


Figure 11. Track Gage for the Cedrite Reconstituted Ties in Section 25

Tie skewing was one of the problems encountered with these ties. Early on in the test, an attempt to straighten one of the skewed ties resulted in cracking at the center of the tie, thus, no further attempts were made to correct the problem on these ties. The ties installed at the beginning of Section 25, were removed from test after 178 MGT of HAL traffic because 90 percent of ties had cracks on the rail seat area. At this time no visible cracks were evident on the ties in the two remaining subsections located at the end of Section 25.

After 200 MGT of HAL traffic, on the skewed Cedrite ties at the end of Section 25, cracks were detected on the Pandrol plates. The skewing of the tie had pushed the Pandrol plate at an angle against the rail, initiating stress cracks on the plate corner that was in contact with the rail. Because the ties did not have visible cracks, they were not removed from test at this time. All of the Pandrol plates were removed from test to assure that no stressed plates were left in test. Standard AREA plates and cut spikes were used to replaced the Pandrol system, and each tie was box anchored to prevent further skewing. After an additional 65 MGT of HAL traffic, the ties in these two subsections also started to exhibit cracks in the rail seat area; therefore, they were removed from test. The ties were in test a total of 265 MGT of HAL traffic.

Figure 12 shows the fastener performance on the Cedrite ties tested in Section 25. The performance of direct lateral railhead displacement measured on the cut spikes is greater than that measured with direct fixation fasteners.

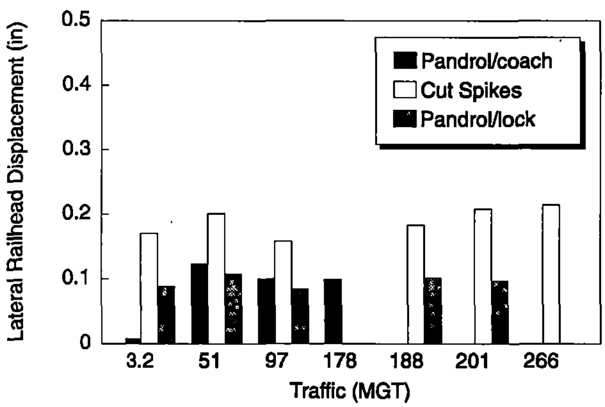


Figure 12. Lateral Railhead Displacement for the Cedrite Reconstituted Ties in Section 25

Cedrite ties were also installed in Section 33, a tangent test zone. The ties were installed on 24-inch spacing and equipped with the Pandrol fastening system and coach screws. These ties have not experience any failure modes and are still in test after 300 MGT of HAL traffic. The longer tie life in this section is most likely due to the lower lateral load environment in tangent zones. Measured median lateral loads in Section 33 are about 4 kips, while the mean lateral loads in Section 25 are about 12 kips. Ties will stay in test until a failure mode occurs.

FUTURE

All of the ties in Sections 07, 31, 33 and the oak ties installed in Section 25 at the start of the HAL program will remain in test. New ties will be installed in Section 25 to compare tie performance under the new improved trucks.

REFERENCES

1. Read, David M., "FAST/Wood tie and Fastener Experiment," *Proceedings: Workshop on Heavy Axle Loads*, Pueblo, Colorado, October 1990.

"Concrete Tie Rail Seat Abrasion Test"

by Scott E. Gage and
Richard P. Reiff

Summary

During the past four years and 300 MGT of train operations, the Facility for Accelerated Service Testing (FAST)/Heavy Axle Load Program (HAL) at the Transportation Technology Center, Pueblo, Colorado, has evaluated a number of materials and components designed to resist or prevent abrasion. Results suggest that there are some combinations of pads which can reduce or prevent abrasion. Repair techniques which appear to survive HAL traffic are also available.

The following pad materials seem to offer promise in preventing abrasion:

- Dual durometer materials (hard and soft materials bonded to a single pad)
- Sandwich materials (multiple products such as a sealant, steel plate and resilient material on one pad)
- Convex rail seats

Many abrasion resistant pads may not provide a permanent solution. Instead, they may require replacement on a periodic basis during the life of the tie. Repairing rail seats and replacing tie pads between programmed rail replacement cycles can be a significant cost item. For this reason, the target life cycle between tie pad replacement should be the same as the rail at a given location.

Currently, a continuation of this test is being planned. With fewer test variations and a larger population of each product, it will be possible to determine the full life cycle of each promising technique.

INTRODUCTION AND CONCLUSIONS

During the past four years, a matrix of ties and materials intended to eliminate, control, or prevent concrete tie rail seat abrasion has been monitored as part of the Facility for Accelerated Service Testing (FAST)/Heavy Axle Load (HAL) program at the Transportation Technology Center (TTC), Pueblo, Colorado. This matrix of ties and materials include (1) rail seat treatments, (2) structural rail seat applications, (3) rail seat shape, and (4) tie pad composition and tie pad application. Presently over 370 ties (broken down into 76 sub-sections) are in test at FAST.

Results after 300 MGT of HAL traffic point to several promising solutions for preventing rail seat abrasion, as well as repair techniques designed to address areas where abrasion has already occured. However, many of the solutions that show promise, such as soft tie pads, have a limited life. It is uncertain if other materials showing promising performance have sufficient tonnage to be considered a permanent solution, or whether they must be periodically inspected and replaced.

WHAT IS RAIL SEAT ABRASION?

Concrete tie rail seat abrasion results when tie material under the tie pad is lost due to hydraulic action and motion transmitted from the rail as a train passes. The contributing factors in abrasion include a combination of water, sand and/or grinding residue at the tie pad-tie rail seat interface. Abrasion takes the form of localized breakdown of cement paste under the rail seat. Figure 1 shows the appearance of moderate abrasion in the field.

In revenue service, many of the following characteristics present at abrasion sites are also present in the FAST/HAL experiment:

- High annual tonnage
- Moisture
- Severe curvature and high lateral/verticle conditions
- Heavy axle loads
- Rail grinding
- Sand (from locomotive and/or wind blown)

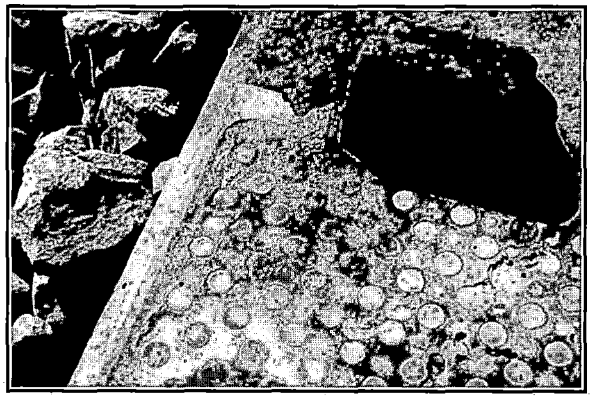


Figure 1. Appearance of Rail Seat Abrasion in the Field

IMPLEMENTATION

A number of new concrete ties and ties from revenue service with various amounts of abrasion were obtained and installed at FAST during the December 1990 track rebuild. A range of tie pads and repair techniques was introduced to this mix of concrete ties. At the time, and during subsequent phases of the abrasion test, tie and pad selection was accomplished under the direction of the ad-hoc Concrete Tie Rail Seat Abrasion Committee.

The abrasion experiment is located in two zones in Section 03, a 5-degree curve on the FAST/High Tonnage Loop (HTL) bracketing the existing Concrete Tie Experiment (Figure 2). Presently, Zone 1 is 630 feet long and consists of 315 ties with 64 sub-sections. Zone 2 is 136 feet long with 68 ties and 12 sub-sections. (A materials list for each of these zones is located at the end of this document.)

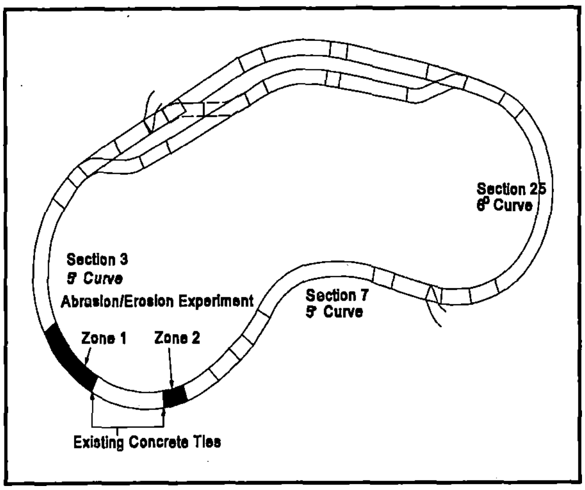


Figure 2. Rail Seat Abrasion Test Zones at FAST

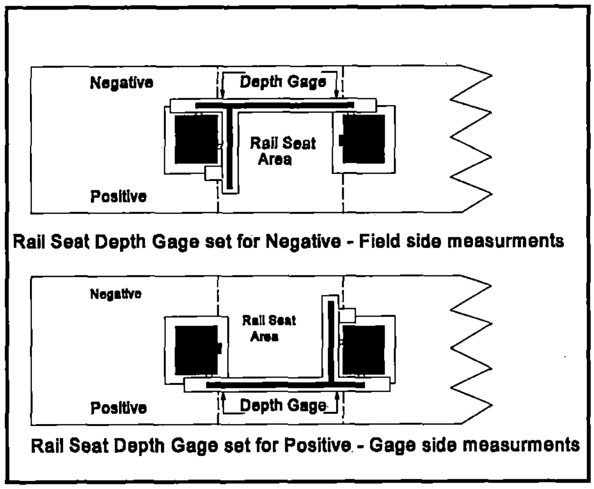


Figure 3. Modified CXT Abrasion Depth Gage

To help induce abrasion, the rail seat areas of the high and low rails are kept moist. During FAST/HAL train operations, the ties are manually sprayed with water to ensure that adequate moisture is maintained. Spraying this additional water adds approximately 21 inches of effective precipitation to the 11 inches of natural annual precipitation.

EVALUATION OF MATERIALS AT FAST

Major combinations of ties, tie pads, and repair techniques included variations in the following categories:

- Dual durometer tie pads (rubber and polyurethane)
- Reinforced rubber pads
- EVA tie pads (control)
- Urethane tie pads
- Various other tie pad materials
- Tie pad shape factors (flat, double dimple, Chevron)
- Tie pads bonded or glued to tie surface
- Tie pads with sealing rings built into pad
- Three-piece sandwich pads (foam gasket/steel plate/polyurethane tie pad)
- Steel plate cast into new tie
- Steel plate/epoxy repair
- Epoxy repair
- Variety of filler materials for repair
- Alternative insulator designs and materials
- Tie surface coatings
- Alternative concrete mixes
- Rail seat surface shape factors

Each system has been proposed according to its unique approach to solving the abrasion problem. For example, tie pads glued to the tie surface were evaluated based on their ability to prevent water, sand and other particles from entering and contaminating the rail seat/tie pad interface. This prevention measure would thereby eliminate the cause of abrasion. Because the pads did not remain "glued" to the tie surface, however, this solution did not reduce abrasion at FAST. Once a technique was determined a failure, it was replaced by a new system.

DATA COLLECTION

Few data collection cycles were available to measure the abrasion depth, primarily because rail had to be removed, tie pads individually picked up, and each rail seat cleaned before measurements could be taken. Initially, data was obtained on a 50 MGT cycle, then on a 100 MGT cycle. A modified CXT abrasion gage, which measures the perimeter area of the rail seat relative to the non-wearing tie surface, was fabricated (Figure 3). Because each rail seat had to be disturbed, the inspection and measurement process may have had an occasional adverse effect on how some pad combinations resisted abrasion.

Figure 4 shows a three-dimensional plot of typical abrasion data using the modified abrasion gage. As illustrated, the deepest abrasion generally occurs on the field side of the high rail, with the depth of abrasion reducing towards the gage side. This occurs because of lateral loads. Also notice the non-wearing reference points on the four corners of the profile.

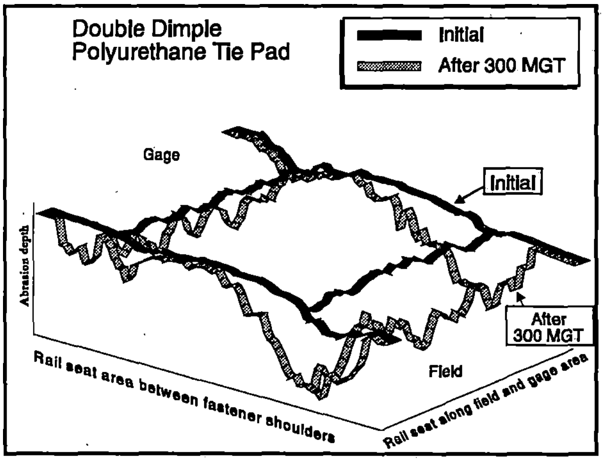


Figure 4. Conceptual Rail Seat Abrasion Data

RESULTS/OBSERVATIONS TO DATE

Based on the solutions under evaluation at FAST, it appears that abrasion can be controlled by certain combinations of pads and materials. However, the life cycle of these techniques is not known. Several solutions, including very soft pads, dual-durometer pads, and sandwich pads appear to either prevent or minimize the formation of abrasion. At this time though, they do not appear to be permanent solutions; they must be replaced during the life of the tie or rail installation.

Many of the softest rubber pads at FAST have shown no abrasion. But after 100 to 150 MGT of service, the pad has worn through or must otherwise be replaced. Table 1 summarizes data for a number of materials selected to show a sampling of good and bad performers.

Ideally, the life of abrasion eliminating materials should, at least match, if not exceed the rail replacement cycle. This would allow materials to be replaced at little incremental cost during routine, planned rail change-outs. If they must be replaced between rail replacement cycles, then a significant increase in cost will be incurred in track time, train delays, and labor effort to de-clip rail, raise and replace the pad, and replace the rail. Based on data collected to-date, the rail seat abrasion problem, although not "solved," can be managed if a proper combination of material and replacement protocol is selected.

Table 1. Performance Data for Various Abrasion Resistant Pads and Materials

Pad Type	MGT	Avg. Abrasion Depth	Abrasion Rate mm\100 MGT
Flat EVA	300	4.4 mm	1.47
Soft Rubber	142	1 mm	.7 *
Double Dimple Polyurethane	300	5.4 mm	1.8
3-Piece Sandwich	200	<1 mm	<.5
Convex Rail Seat	100	<1 mm	<.5

*Limited life,<150MGT

FUTURE

To determine which of the promising solutions have an adequate life cycle, selected pad materials will continue to be evaluated at FAST. The abrasion program has been reviewed for reconfiguration to improve long-term evaluation of a limited number of materials. The test conduct will be revised to allow a smaller number of material variables that have shown abrasion resistance to be evaluated, but in larger sections. This will permit a few samples from each matrix to be measured on a periodic basis and allow long-term evaluation of the most promising materials.

Table 2. ZONE 1 Concrete Tie Abrasion Experiment
Materials List
June 1995

Zone	Tie No.	Tie Type	No. in Test	Hardware	MGT	Comments
8A	870-874	FEC	5	Spring Clip/ Plastic	19.5	Installed May '94 Removed July '94
2C	875-879	CN 60C HD-8	5	Pandrol/ Rubber	300	Standard as cast
2B	880-884	CN 60C HD-8	5	Pandrol/ Urethane	300	Standard as cast one tie broken/removed
2A(B)	885-890	CN 60C HD-8	6	Pandrol/ EVA	300	Standard as cast
2A(A)	891-893	CN 60C HD-8	3	Pandrol/ Glued EVA	300	Standard as cast
4B	894-899	CN 60C HD-8	6	Pandrol/ Miner pads	172	Standard as cast
4A	900-904	Itisa HD-10	5	Pandrol/ DD Poly	172	Post-tension ties In HTL since '89 Installed for abrasion 12/92
20	905-907	CN 60B HD-8	3	Pandrol/ Rubber	300	RTR #40
2N	908-910	CN 60B HD-8	3	Pandrol/ Urethane	300	RTR #40
2M	911-914	CN 60B HD-8	4	Pandrol/ EVA	300	RTR #40
2L	915-919	CN 60B HD-8	5	Pandrol/ Rubber	300	Resurf-241
2K	920-924	CN 60B HD-8	5	Pandrol/ Urethane	300	Resurf-241
2J	925-929	CN 60B HD-8	5	Pandrol/ EVA	300	Resurf-241
2I	930-935	CN 60B HD-8	6	Pandrol/ Rubber	300	Chemor - 1984 tie

Table 2. ZONE 1 Concrete Tie Abrasion Experiment — continued
Materials List
June 1995

Zone	Tie No.	Tie Type	No.in Test	Hardware	MGT	Comments
2H	936-941	CN 60B HD-8	6	Pandrol/ Urethane	300	Chemor - 1984 tie
2G	942-946	CN 60B HD-8	5	Pandrol/ EVA	300	Chemor - 1984 tie
2F	947-952	CN 60B HD-8	6	Pandrol/ Rubber	300	Jeffamine - 1984 tie
2E	953-958	CN 60B HD-8	6	Pandrol/ Urethane	300	Jeffamine - 1984 tie
2D	959-964	CN 60B HD-8	6	Pandrol/ EVA	300	Jeffamine - 1984 tie
5C	965-974	CP CT5	10	Pandrol/ Convex rail seat/urethane	100	Standard as cast Special Insulators Installed 1/94
5B	975-979	CP CT5F	5	Pandrol/ 4 Urethane 1 CRP	100	Standard as cast Tie 977 with CRP pad Installed 1/94
5A	980-989	CP CT5	10	Pandrol/ Convex rail seat/urethane	100	Standard as cast Special Insulators Installed 1/94
1A1	OUT OF TEST	BN 100	3	McKay/Pad cast to rail seat		Installed 1/92 - 60.5 MGT Removed 11/93
1A(A)	990-994	CP CT3 HD-8	5	Pandrol/ Mobay	300	Standard as cast
1A(B)	995-999	CP CT3 HD-8	5	Pandrol/ Dual urethane	300	Standard as cast
1A(C)	1000-004	CP CT3 HD-8	5	Pandrol/ Dual rubber	300	Standard as cast

Table 2. ZONE 1 Concrete Tie Abrasion Experiment — continued
Materials List
June 1995

Zone	Tie No.	Tie Type	No. in Test	Hardware	MGT	Comments
1A(D)	1005-1009	CP CT3 HD-8	5	Pandrol/ Mobay	300	Standard as cast
1B(A)	1010-1014	CP CT3 HD-8	5	Pandrol/ Mobay	300	Jeffamine
1B(B)	1015-1019	CP CT3 HD-8	5	Pandrol/ Dual urethane	300	Jeffamine
1B(C)	1020-1021	CP CT3 HD-8	2	Pandrol/ Dual urethane	300	Jeffamine
1B(D)	1022-1024	CP CT3 HD-8	3	Pandrol/ Dual rubber	300	Jeffamine
1B(E)	1025-1029	CP CT3 HD-8	5	Pandrol/ Mobay	300	Jeffamine
1F(A)	1030-1032	UP 497 HD-10	3	Pandrol/ Epoxy/ steel plate	300	11/93 Pandrol repair replace 6 1/2 mm poly pad
1F	1033-1043	UP 497 HD-10	11	Pandrol/ 6 1/2 mm poly	300	Standard as cast
1G	1044-1049	UP 497 HD-10	6	Pandrol/ Poly	300	Jeffamine
1H	1050-1056	UP 497 HD-10	7	Pandrol/ Poly	300	Jeffamine
1I	1057-1063	UP 497 HD-10	7	Pandrol/ Dual rubber	300	Jeffamine
1J	1064-1069	UP 497 HD-10	6	Pandrol/ Poly w/glue	300	Standard as cast
1K(A)	1070-1071	UP 497 HD-10	2	Pandrol/ poly w/ seal ring	300	Standard as cast

Table 2. ZONE 1 Concrete Tie Abrasion Experiment — continued
Materials List
June 1995

Zone	Tie No.	Tie Type	No .in Test	Hardware	MGT	Comments
1K(B)	1072-1074	UP 497 HD-10	3	Pandrol/ Dual poly	300	Standard as cast
1L(A)	1075-1076	UP 497 HD-10	2	Pandrol/ Poly	300	Installed with neoprene below poly-wore away by 100 MGT
1L(B)	1077-1079	UP 497 HD-10	3	Pandrol/ Poly	300	Installed with BUNA below poly-wore away by 100 MGT
1W(A)	1080-1081	K11 1011 HD-10	2	Pandrol/ 4D - 2/93 4D - 3/94	300	Standard as cast 4D pads replace double dimple EVA
1W(B)	1082-1083	K11 1011 HD-10	2	Pandrol/ 4D - 2/93 4D - 3/94	300	Standard as cast 4D pads replace double dimple poly
1X(A)	1084-1086	K11 1011 HD-10	3	Pandrol/ 4D - 3/94	300	Standard as cast 4D pads replace rubber w/ seal ring
1X(B)	1087-1088	K11 1011 HD-10	2	Pandrol/ 4D - 2/93	300	Standard as cast 4D pads replace dual durometer rubber
1X(C)	1089	K11 1011 HD-10	1	Pandrol/ 4D - 3/94	300	Standard as cast 4D pads replace rubber w/ seal ring
1Y(A)	1090-1091	K11 1011 HD-10	2	Pandrol/ 4D - 2/93 4D - 3/94	300	Rail seat silene treated 4D pads replace double dimple EVA
1Y(B)	1092-1093	K11 1011 HD-10	2	Pandrol/ 4D - 2/93 4D - 3/94	300	Rail seat silene treated 4D pads replace double dimple Poly

Table 2. ZONE 1 Concrete Tie Abrasion Experiment — continued
Materials List
June 1995

Zone	Tie No.	Tie Type	No.in Test	Hardware	MGT	Comments
1Y(C)	1094-1095	K11 1011 HD-10	2	Pandrol/ 4D - 3/94	300	Rail seat silene treated 4D pads replace rubber w/ seal ring
1Y(D)	1096-1097	K11 1011 HD-10	2	Pandrol/ 4D - 2/93	300	Rail seat silene treated 4D pads replace dual durometer rubber
1Z(A)	1098	K11 1011 HD-10	1	Pandrol/ 4D - 2/93	300	Whole tie silene treated 4D pads replace double dimple EVA
1Z(B)	1099	K11 1011 HD-10	1	Pandrol/ 4D - 2/93	300	Whole tie silene treated 4D pads replace double dimple Poly
1O	1100-1109	BN 100	10	McKay/ Rubber	300	New rubber replaced Std. McKay rubber 2/94
1P	1110-1119	BN 100	10	McKay/ Sandwich	300	Standard as cast
1Q	1120-1131	BN 100	12	McKay/ Rubber	300	No air entrainment New rubber replaced Std. McKay rubber 2/94
1R	1132-1137	BN 100	6	McKay/ Rubber	300	Pyrament New rubber replaced Std. McKay rubber 2/94
1S	1138-1147	BN 100	10	McKay/ 8 mm EVA	300	Silica fume + air

Table 2. ZONE 1 Concrete Tie Abrasion Experiment — continued
Materials List
June 1995

Zone	Tie No.	Tie Type	No. in Test	Hardware	MGT	Comments
1T(A)	1148-1148	BN 100	2	McKay/ Poly	300	Standard as cast Installed with Neoprene/ wore away by 100 MGT
1T(B)	1150-1152	BN 100	3	McKay/ Poly	300	Standard as cast Installed with BUNA/ wore away by 100 MGT
1T(C)	1153-1157	BN 100	5	McKay/ Masti Cord	300	Standard as cast
1U	1158-1167	BN 100	10	McKay/ CRP glue/poly	300	Standard as cast
1V	1168-1177	BN 100	10	McKay/ 8 mm poly	300	Silica fume + air
2Y(A)	1178-1182	BN 100	5	McKay/ Sika flex	300	Standard as cast CRP rubber
2Y(B)	1183-1186	BN 100	4	McKay/ Epoxy	300	Standard as cast Poly

Table 3. ZONE 2 Concrete Tie Abrasion Experiment
June 1995

Zone	Tie No.	Tie Type	No. in Test	Hardware	MGT	Comments
7A(C)	1673-1674	Koppers	2	Pandrol/ 2 pc sandwich poly/poly	100	Standard as cast Special insulator set up Installed 2/94
7A(B)	1675-1677	Koppers	3	Pandrol/ 2 pc sandwich poly/Steel	100	Standard as cast Special insulator set up Installed 2/94
7A(A)	1678-1681	Koppers	4	Pandrol/ 3 pc sandwich	100	Special insulator set up Installed 2/94
3F	1682-1687	BN 100	6	McKay/ Std. EVA	170	Standard as cast OUT OF TEST
3E	1688-1693	BN 100	6	McKay/ Cast poly	170	Standard as cast Installed 2/01/93
3D	1694-1699	BN 100	6	McKay/ Steel plate cast in rail seat	170	Standard as cast Miner tie pads Installed 2/01/93
3C	1700-1705	BN 100	6	McKay/ Miner pads	170	Standard as cast Installed 2/01/93
3B	1706-1710	BN 100	5	McKay/ Double Crafco McKay poly	170	Standard as cast Installed 2/01/93 OUT OF TEST 1/94
3A	1711-1713	BN 100	3	McKay/ Single Crafco McKay poly	170	Standard as cast Installed 2/01/93 OUT OF TEST 1/94
3A(A)	1714-1715	BN 100	2	McKay/ Single Crafco Crafco rubber	170	Installed 2/01/93 New Crafco sealant and pad replace Crafco w/poly 1/94

Table 3. ZONE 2 Concrete Tie Abrasion Experiment
June 1995 — continued

2Z	1716-1725	BN 100	10	McKay/ McKay rubber	300	Standard as cast New rubber replace std 2/94
2X(B)	1726-1730	BN 100	5	McKay/ Epoxy & steel	300	More than 1.5 mm abrasion
2X(A)	1731-1735	BN 100	5	McKay/ Sika & steel	300	More than 1.5 mm abrasion
2W	1736-1745	BN 100	10	McKay/ McKay rubber	300	Epoxy repair New rubber replace std 2/94
2V	1746-1754	BN 100	9	McKay/ 3 pc. sandwich	300	Sandwich replaced rubber 2/94

"Frog Performance Under 39-ton Axle Load,"

by Joseph A. LoPresti

Summary

Five rigid No. 20 frogs and two No. 10 spring rail frogs have been tested on the High Tonnage Loop at the Transportation Technology Center's Facility for Accelerated Service Testing (FAST). A Voest-Alpine Vario frog had the longest life at 277 MGT. Next were the Bethlehem and Nortrak high integrity RBM frogs, with similar life spans at 203 MGT and 172 MGT, respectively. The Voest-Alpine vee-nose manganese frog suffered an early failure at 79 MGT, due to an inclusion in the casting. Both standard component frogs, a CNW standard RBM frog, and an IC No. 10. spring frog failed at 48 and 69 MGT, respectively, under 39-ton axle loads. The second spring rail frog, an NS frog made from premium components, remains in track after 42 MGT.

Maintenance demand was recorded for each frog. The Voest-Alpine Vario frog required 0.25 hour of maintenance per MGT of frog life. The Bethlehem frog needed 0.50 hour and the Nortrak frog 0.47 hour per MGT. The Voest-Alpine manganese frog had the highest maintenance requirements, 1.0 hour per MGT. The CNW frog required 0.30 hour per MGT, the IC No. 10 spring rail frog took 0.27 hour per MGT, and the NS spring rail frog required 0.37 hour of maintenance per MGT.

The test is being performed to monitor the performance of frogs under heavy axle loads as part of the Frog and Turnout Performance Experiment at FAST.

INTRODUCTION AND CONCLUSIONS

The performance of a variety of frogs under nominal axle loads of 39 tons is being monitored on the High Tonnage Loop at the Facility for Accelerated Service Testing, Transportation Technology Center, Pueblo, Colorado. Initially, five rigid No. 20 frogs were included in the test. Two No. 10 spring rail frogs were subsequently installed, and two No. 20 swing nose frogs will soon be installed.

Performance criteria include frog life and over-all maintenance demand of each frog. All maintenance performed and the amount of time the work required were recorded for each frog. When a frog was removed from the test, the cause of the removal and accumulated MGT at that time were recorded.

The Voest-Alpine vario frog had the longest life and lowest maintenance requirements. Next were the Bethlehem and Nortrack high integrity RBM frogs which had similar life spans and total maintenance needs. The Voest-Alpine vee-nose manganese frog suffered an early failure due to an inclusion in the casting. Both standard component frogs, a CNW standard RMB frog and an IC No. 10 spring frog, failed after limited tonnage under the 39-ton axle loads.

FROG LIFE AND MAINTENANCE

Table 1 lists the frog donor and type, and the failure that lead to the frog being removed from the test. Figure 1 shows frog life and the maintenance required per MGT.

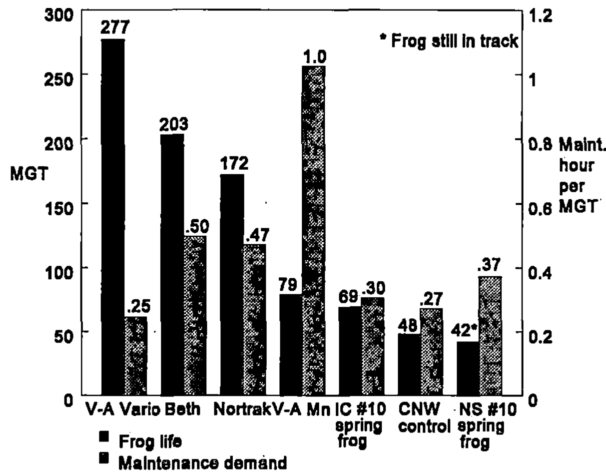


Figure 1. Frog Life and Maintenance Demand

Table 1. Frog Life and Failure Mode

Frog Donor and Type	Failure Mode	MGT
Nortrack High Integrity RBM	Cracked frog point, cracked heel rail	172
Voest-Alpine Vario	Crack at weld between vario point and rail	277
Voest-Alpine Vee-nose Manganese	Cracked frog point	79
CNW standard RBM	Cracked frog point	48
Bethlehem High Integrity RBM	Cracked frog point	203
IC Standard No. 10 Spring Rail	Cracked long point	69
NS Premium No. 10 Spring Rail	Still in track*	42*

Figure 2 shows maintenance hours as a function of MGT with notes at major maintenance occurances.

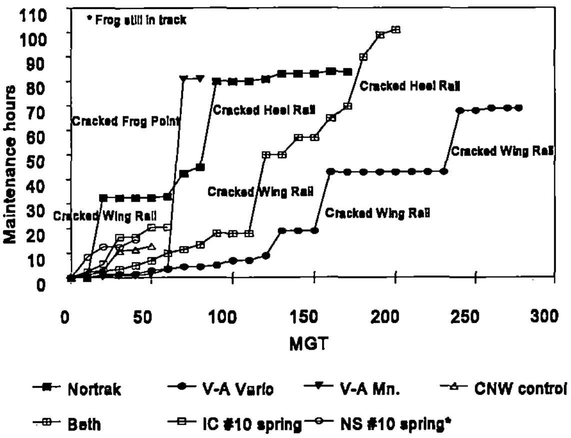


Figure 2. Maintenance vs MGT

Not every hour of maintenance work performed is reflected in Figures 1 and 2. For example, a wing rail on the V-A Vario frog failed at about 160 MGT. A new replacement was not available, so an old wing rail was installed. Maintenance on the old rail, which was needed to keep the frog in track until the new rail arrived, is not shown in either of the graphs.

The Nortrack frog required 84 hours of maintenance. Forty-one percent of the time was spent on wing rail repair and 48 percent on the heel rail. This frog was removed due to a crack 14 inches from the point. The crack was found to extend toward the heel of the frog during the repair. The heel rail was also found to be cracked at that time.

The V-A Vario frog had the longest life and required among the lowest maintenance hours required per MGT (69/277). Sixty percent of the time was spent on wing rail repair and replacement. Very little work was needed on the point of the frog which remained in good condition throughout the life of the frog. It was removed because of a crack at the interface between the maraged steel on the running surface of the point and the weld insert between the point and the heel rail (Figure 3). The alloy point cannot be welded directly to the rail steel (heel), so there is a small section of weld compatible steel between the two sections. The crack was ground until visual inspection indicated that it had been completely removed (about 1.5 inches deep). The area was then checked with dye penetrant which revealed that cracks were still present. Additional grinding followed the crack back into the rail steel, where it reached the separation between the two rails and V-A advised that repair was not practical.

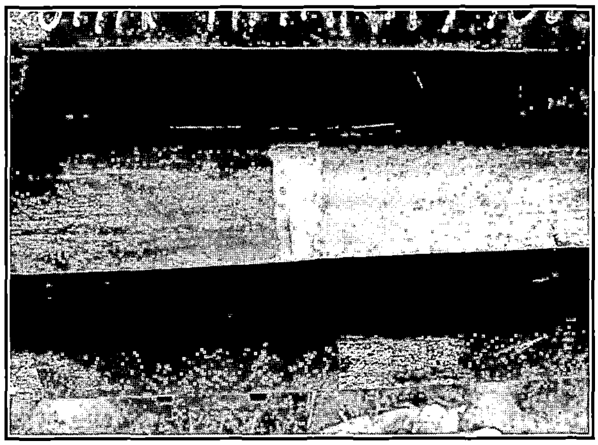


Figure 3. Crack in V-A Vario Frog

The V-A manganese frog needed 80 hours of maintenance. Almost all of the work was related to a crack in the point which initiated at an inclusion in the casting. The short life and high maintenance demand for this frog can be attributed to the inclusion.

Both the CNW control frog and the IC No. 10 spring rail frog were made of standard components. The materials were not able to withstand extended operations under HAL traffic, and both frogs failed after fewer than 70 MGT. The maintenance hours per MGT for these frogs were low because the failures occurred early in the lives of the frogs and were so extensive that repairs were not practical.

Sixty-two percent of the 13 hours of work done on the CNW frog were in repair of the manganese wing. The frog was removed from track when a crack developed 80 inches from the 1/2-inch point-of -frog (p.o.f.).

The Bethlehem frog lasted longer than any of the other RBM frogs, and required more total maintenance. Thirty-nine percent of the 101 hours was spent grinding and building up of the point. Thirty-two percent of the work was on the wing rail, and 14 percent on the heel rail. The frog was removed after several weld repairs on the point. The final repair was on a crack 12 inches from the 1/2 inch p.o.f. The crack extended the full depth of the point as seen with visual inspection. The frog was repaired and is kept on site as a back-up frog for one of the test turnouts.

The IC No. 10 spring rail frog required 20.5 hours of maintenance. Eighty-three percent of those were spent grinding and building up the long point rail. Almost all of the rest were grinding metal flow from the rails. The frog was removed after two weld repairs to a crack in the long point 39 inches from the 1/2- inch p.o.f. The weld cracked shortly after the second repair, and the frog was not reinstalled.

The NS No. 10 spring frog remains in track after 42 MGT of HAL traffic. It has required 15.5 hours of maintenance. Thirty-nine percent of work performed was needed to correct a problem caused by adjacent rail contraction. The frog was installed in warm weather. When the rail cooled and contracted, the spring wing rail would not close completely. This occurred even though the adjoining rail was box anchored 133 ties ahead of the frog and 46 ties behind it. The proximity of a test turnout prevented the placement of more anchors behind the frog. The problem was corrected by installing a plug in front of the frog. The mechanical joint was then able to take up the rail movement. Though this took care of the rail movement, the introduction of a discontinuity in the running surface is generally not advisable. Twenty-six percent of the work performed involves welding broken plates. The frog is constructed from premium rail, but the plate-work and design are standard. In addition to the work listed above, all of the frogs needed periodic tightening or replacement of bolts and tamping. The RBM frogs required periodic grinding of the point and manganese wings. Both points of the spring rail frogs were ground periodically.

FROG COMPONENTS

Three basic frog designs, with some differences in materials, have been tested. Figures 4, 5, and 6 show No. 20 railbound manganese, No. 20 European vee-nose, and No. 10 spring rail frogs, respectively. Table 2 summarizes the components used in the frog test.

FROG INSTALLATION

The five original frogs and guard rails were installed in the tangent track of Section 22 of the HTL in December, 1989, as shown in Figure 7. The frogs were located on the outside rail of the loop only. Since the outside rail of the loop is lubricated, there was some concern that frog performance might be affected by lubrication. Subsequent testing has shown that it is not. The frogs were located to primarily receive facing point traffic (the FAST train operated 90 percent of the time in a counterclockwise loop direction at 40 mph).

After the first 160 MGT of HAL operations (53 MGT on the original frogs), train direction was changed to bi-directional: 50-percent clockwise and 50-percent counterclockwise.

The train speed remained at 40 mph. Another lubricator was installed in Section 25 at the end of the curve opposite of the original lubricator. Frog 1 was moved to Section 09.

On May 6, 1991, after 35.0 MGT of bi-directional HTL operations, Frog 6 was installed in the HTL's Section 05.

Subsequently in July, 1991, after 50.9 MGT of bi-directional operations, Frogs 2, 3, and 5 were moved to Section 27. These frogs were moved to create space for the installation of a new tangential geometry turnout (see Figure 4). Frogs 1, 2, 3, 5, and 6 subsequently failed and were removed.

On September 7, 1994, Frog 7 was installed in Section 27 where it remains. Two new No. 20 swing nose frogs donated by the Union Pacific Railroad are scheduled to be installed later this year.

ACKNOWLEDGEMENTS

The author acknowledges the assistance of Nortrack Ltd., Voest-Alpine International, Chicago and North Western Transportation Company, Bethlehem Steel Corporation, Illinois Central Railroad Company, Norfolk Southern, and Union Pacific Railroad for donating the frogs used in this test.

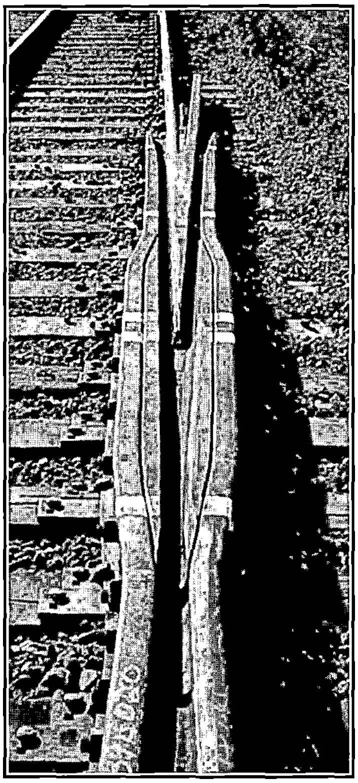


Figure 4. No. 20 Rail Bound Managanese

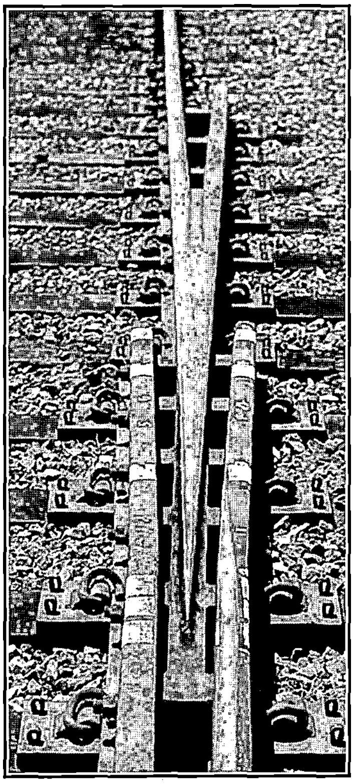


Figure 5. No. 20 Vee-Nose

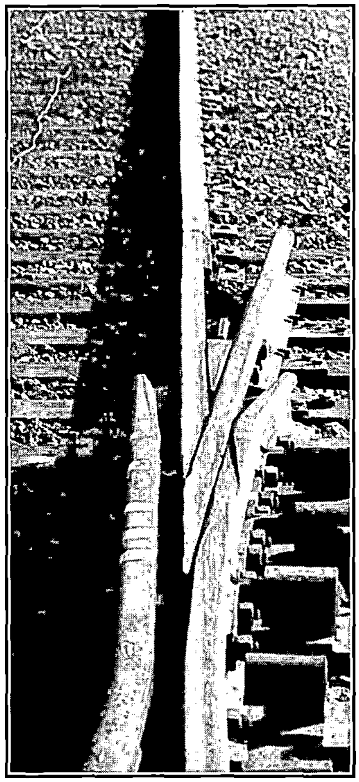


Figure 6. No. 10 Spring Rail

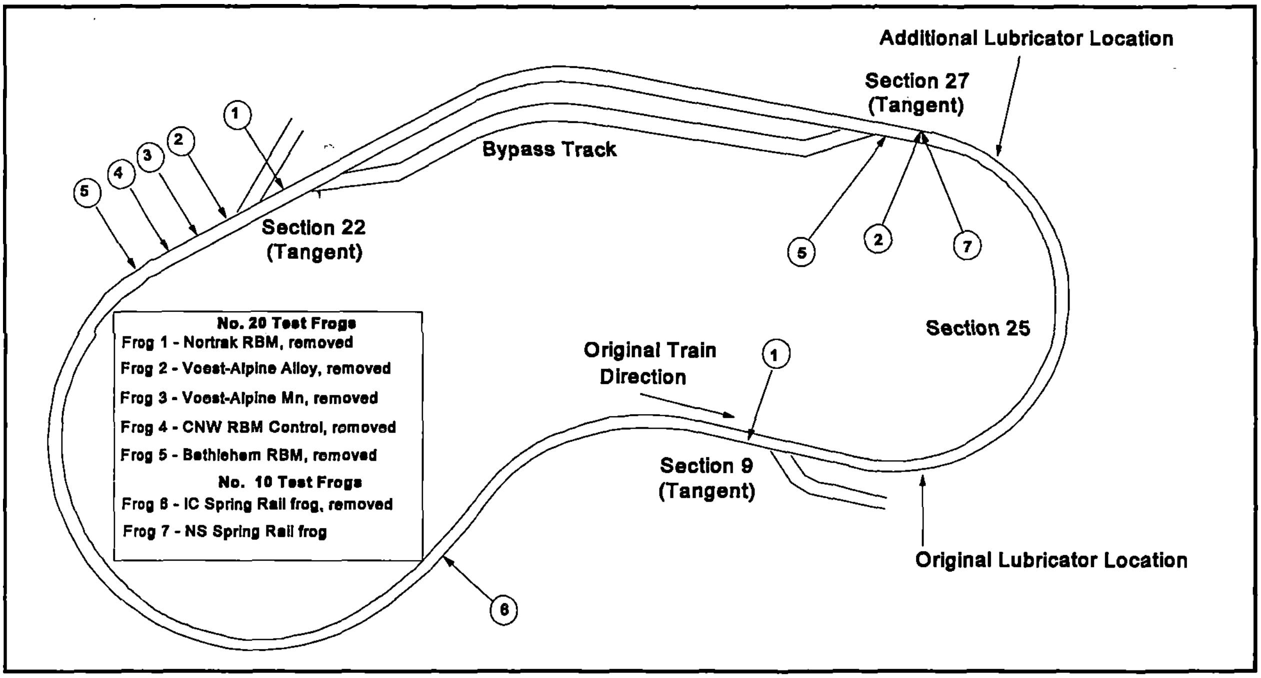


Figure 7. Location of Test Frogs on the FAST High Tonnage Loop

Table 2. Components for Frog Farm Test

Frog Number & Donor	Frog Type All No. 20 Except Frog 6 and 7	Wing Rail & Heelrail Rail Type	Frog Plates Spikes & Fasteners	Guard Rail Plates, Spikes, & Fasteners	Tie Centers, Hardwood Ties
Frog 1 Nortrack	AREA Railbound Manganese (EDH)	132 RE Fully Heat Treated	Manufacturer's Frog Plates w/ Pandrol Lock Spikes and Rail Clips	14'6" Bolted Tee-rail w/ Hook Twin Tie Plates and Lock Spikes	19.5 inches
Frog 2 Voest-Alpine Alloy	European Vee-nose, Alloy	UIC 60 Head Hardened	Manufacturer's Frog Plates w/ Pandrol Lock Spikes and Rail Clips	18'8" European Design Guard Rail & Plates Lock spikes	24 inches
Frog 3 Voest-Alpine Manganese	European Vee-nose, Manganese (EDH)	UIC 60 Head Hardened	Manufacturer's Frog Plates w/ Pandrol Lock Spikes and Rail Clips	18'8" European Design Guard Rail & Plates Lock spikes	24 inches
Frog 4 CNW Control Frog	AREA Railbound Manganese	136 RE Standard	Hook Twin Plates & Cut Spikes	22' Bolted Tee-rail Canted Plates Cut Spikes	19.5 inches
Frog 5 Bethlehem	AREA Railbound Manganese (EDH)	132 RE Fully Heat Treated	Hook Twin Plates & Cut Spikes	22' Bolted Tee-rail Canted Plates Cut Spikes	19.5 inches
Frog 6 IC	No. 10 Spring Frog	136 RE Standard	Manufacturer's Spring Frog Plates w/ Lag Screws, Hook Twin Plates & Cut Spikes	13' Bolted Tee-rail, Guard Rail Plates, Cut Spikes	19.5 inches
Frog 7 NS	No. 10 Spring Frog	136-10 Heat Treated	Manufacturer's Spring Frog Plates w/ Lag Screws, & Cut Spikes	22' Bolted Tee-rail Canted Plates Cut Spikes	19.5 inches

"Evaluation of Three Turnouts at FAST,"

by Joseph LoPresti

Summary

Three turnouts have been tested on the High Tonnage Loop at the Transportation Technology Center's Facility for Accelerated Service Testing (FAST) to monitor the performance of No. 20 or equivalent turnouts under heavy axle loads as part of the Frog and Turnout Performance Experiment at FAST. A standard component No. 20 AREA geometry turnout donated by Southern Pacific was removed from track after 106 MGT. As a result, maintenance demand was heavy.[1]

A premium component No. 20 AREA geometry turnout donated by Bethlehem Steel Corporation remains in track after 350 MGT. The switch points and stock rails were replaced after 250 MGT.

A No. 18½ tangential geometry turnout with a swing nose frog donated by American Track Systems and manufactured by Butzbacher Weichenbau Gesellschaft was rebuilt after about 130 MGT. All major running components were replaced with improved materials. As a result, it has been in track an additional 100 MGT.

Unlike an AREA geometry turnout with a rail-bound manganese frog, the tangential geometry turnout with a swing nose turnout generally reduces peak lateral and vertical forces. Vertical forces were found to be higher under a 125-ton car than under a 100-ton car, as expected. Lateral forces may not be higher under the 125-ton car.

INTRODUCTION AND CONCLUSIONS

The objective of the FAST Turnout Evaluation is to monitor the performance of No. 20 or equivalent turnouts under nominal 39-ton axle loads. Three turnouts, a standard component No. 20 AREA geometry turnout donated by Southern Pacific, a premium component No. 20 AREA geometry turnout donated by Bethlehem Steel Corporation, and a No. 18½ tangential geometry turnout with a swing nose frog donated by American Track Systems (ATS) and manufactured by Butzbacher Weichenbau Gesellschaft (BWG) of Germany have been tested on the High Tonnage Loop (HTL) at the Transportation Technology Center (TTC) in Pueblo, Colorado.

The criteria used to evaluate turnout performance include component failure, maintenance demand, and dynamic rail forces as measured by instrumented wheel sets. As testing progresses, critical events are recorded for each turnout. For example, if a component fails, the date and type of failure are recorded and photographs are taken. If maintenance is required, the date, type of maintenance, and level of effort in labor hours are recorded. Thirty-eight-inch instrumented wheel sets under a 125-ton car and 36-inch instrumented wheel sets under a 100-ton car are operated through both turnouts. Data taken includes continuous vertical and lateral forces on both wheels.

The reduction in lateral forces in the switch points of the No. 18½ tangential turnout compared to the AREA No. 20 turnout under 125-ton cars has previously been reported.[2] Subsequent instrumented wheel set tests have confirmed that lateral forces are generally lower in the tangential turnout. Peak vertical forces are also lower.

Testing which compared forces under 125-ton cars to those under 100-ton cars found higher vertical forces under the 125-ton cars as expected. Lateral forces may not be higher under the 125-ton car.

Replacing the original tangential geometry turnout with premium rail components substantially reduced maintenance requirements for the turnout. Premium components are needed to withstand heavy axle loads even with the reduced dynamic forces seen in a tangential turnout. The premium component AREA No. 20 has had lower maintenance requirements than the standard component AREA No. 20 turnout previously tested.[1]

The premium component AREA No. 20 remains in track after about 350 MGT of heavy axle load (HAL) traffic. The switch points and stock rail were replaced after 250 MGT. All running surface components on the tangential turnout were replaced after about 130 MGT. The turnout remains in track in relatively good condition after an additional 100 MGT.

INSTRUMENTED WHEEL SETS

Dynamic forces measured with instrumented wheel sets under 100- and 125-ton hopper cars going through a No. 20 AREA geometry turnout are shown in Figure 1. Train movement was facing point, diverging route. The forces shown are for the lead wheel on the closure rail of the turnout. Peak vertical forces measured under the 125-ton car were higher than those measured under the 100-ton car in the switch point and in the frog areas, as expected. Peak lateral forces were lower than expected under the 100-ton car in the switch points. A possible explanation is that the wheel was flanging, and there was no impact when the flange hit the switch point. An indication that this may have been happening is seen at the frog/guard rail area. The greatest force seen on the wheel is shown

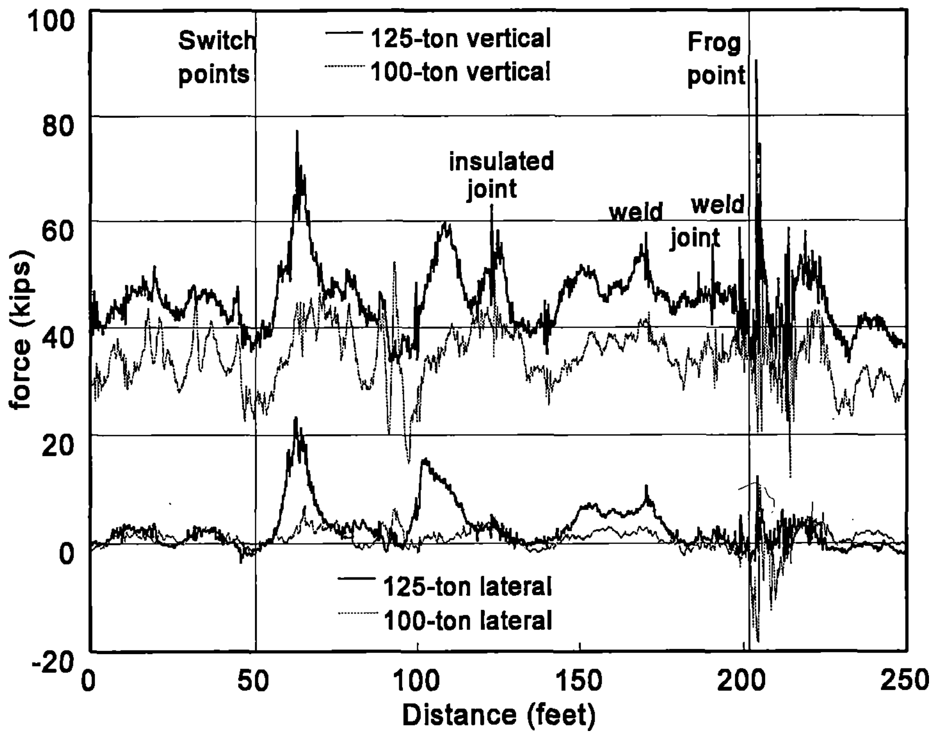


Figure 1. Vertical and Lateral Forces Measured in a No. 20 AREA Geometry Turnout

as a negative force where the guard rail catches the wheel and pulls it over. The negative sign indicates the direction of the force, pulling away from the flange. The high negative force is not seen under the 125-ton car at the guard rail, but high lateral forces in the switch point area are.

The same test train was operated in the same movement through the No. 18½ tangential geometry turnout. The forces measured on the lead wheel, closure rail are shown in Figure 2. Again, the vertical forces are higher under the 125-ton car than under the 100-ton car, but there is less difference between the two than in the AREA No. 20 turnout. The tangential turnout is a smoother turnout that induces less motion in the car. The swing nose frog in the turnout provides a smoother transition than the RBM frog in the AREA turnout. Both of these factors contribute to lower peak vertical forces and smaller differences between the 100-ton and 125-ton cars. The lateral forces are similar for both cars. Truck steering probably has more affect on lateral forces than axle load.

Peak forces for both turnouts are shown in Figure 3.

MAINTENANCE

Figure 4 shows maintenance hours as a function of MGT with notes at major maintenance occurances. Not every hour of maintenance work performed is shown in Figure 4. For example some of the concrete ties shipped with the turnout were defective, but usable. They were installed and used until replacements arrived. The installation of the replacements are not reflected in the graph.

Several field welds on the premium AREA No. 20 turnout had to be replaced at between 50 and 60 MGT. The welds were poured before premium quality weld kits were available, and began to shell and batter soon after installation. They were replaced when the new kits arrived. The hours are shown to illustrate the need for premium welds under heavy axle loads. If the improved kits had been available at the time of turnout installation, the major maintenance effort at the 50 to 60 MGT milestone would not have

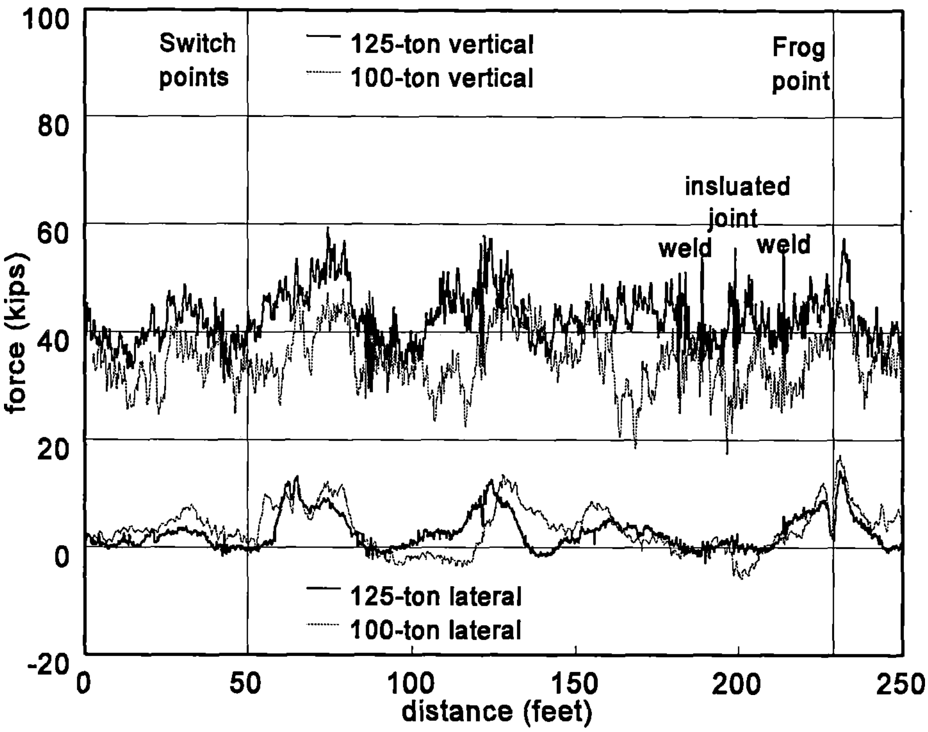


Figure 2. Vertical and Lateral Forces Measured in a No. 18.5 Tangential Geometry Turnout

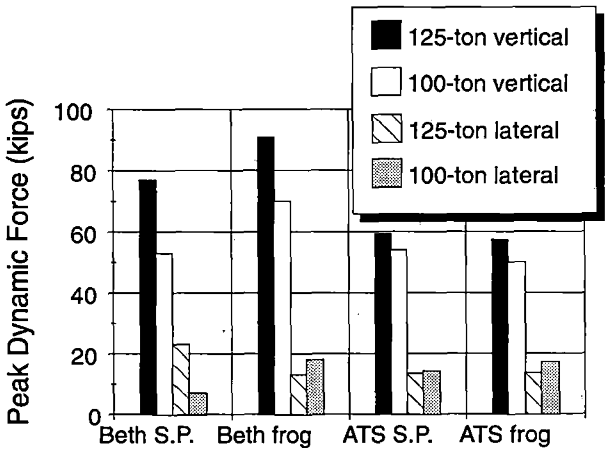


Figure 3. Peak Vertical and Lateral Forces in Both Turnouts

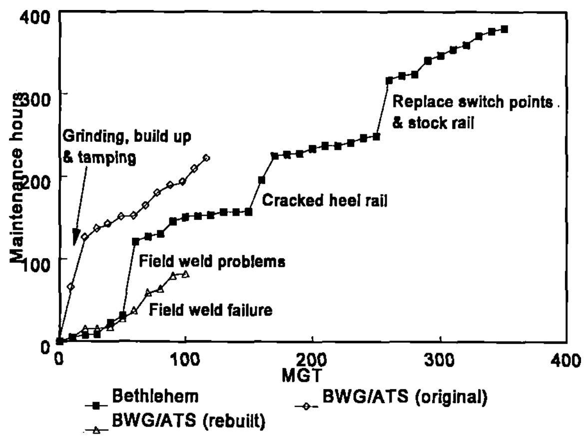


Figure 4. Maintenance vs MGT

been required. Routine maintenance on the turnout includes grinding and weld build-up of the manganese frog, tamping and alignment, grinding the rail, replacing broken bolts, and cleaning and lubricating switch points.

The original closure, stock, wing, and heel rail, switch points and moveable point frog of the tangential geometry turnout were hardened only in selected areas. The areas which were not hardened were not able to withstand HAL traffic, and suffered severe battering problems. The effort needed to address these problems is reflected in the steep slope of the line early in the life of the original ATS/BWG turnout.

The original running surface components were replaced after 132 MGT with fully hardened components. They have withstood the HAL traffic with much less maintenance than the original turnout.

Minor variations in the heat treatment of the components currently in the ATS/BWG turnout continue to cause some maintenance problems. Soft spots in the left switch point and both wing rails, which have led to battering, are not associated with any welds. The spots in the wing rails have been built-up with weld material, but will soon be replaced. The soft spot in the switch point has been ground, and will soon be hardened under the direction of ATS. Hardness readings at the soft spot in the switch point are shown in Figure 5. The locations of the soft spots are shown in
Figure 6.

BACKGROUND

The Turnout Performance Experiment began on the Facility for Accelerated Service Testing (FAST), High Tonnage Loop with the initiation of the Heavy Axle Load program in July 1988. The HTL has two locations that allow the installation of No. 20 turnouts. These locations are on each end of a siding (the bypass track), which was constructed in 1988. The locations of the turnouts tested are as follows: the standard component AREA geometry turnout, location 1; the premium component AREA geometry turnout, location 1; and the advance design tangential geometry turnout, location 2, are shown in Figure 7.

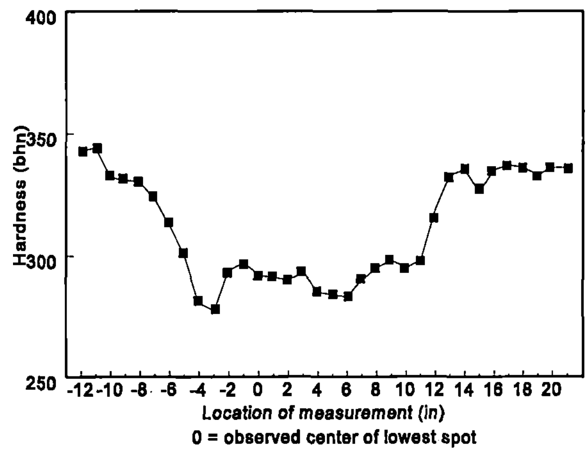


Figure 5. Hardness Readings

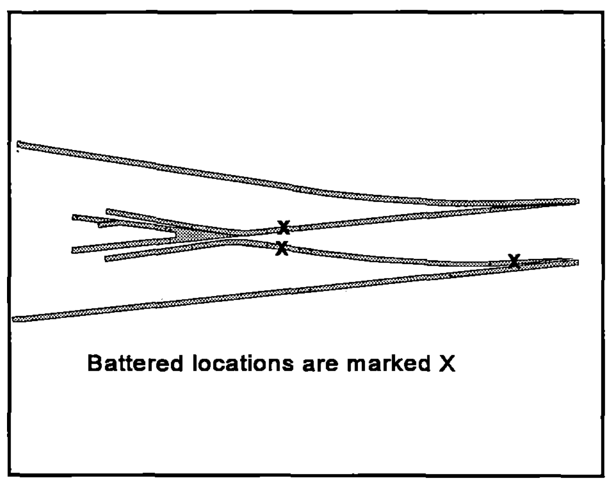


Figure 6. Locations of Soft Spots

The first turnout, donated by Southern Pacific Transportation Company (SP), consisted of standard components and was manufactured to AREA geometry specifications. This type of turnout is considered typical of those recently used in North American railroads and is still purchased by some. The SP turnout was assembled and installed at FAST in May 1988 and was removed in December 1989 after 106 MGT of service exposure.

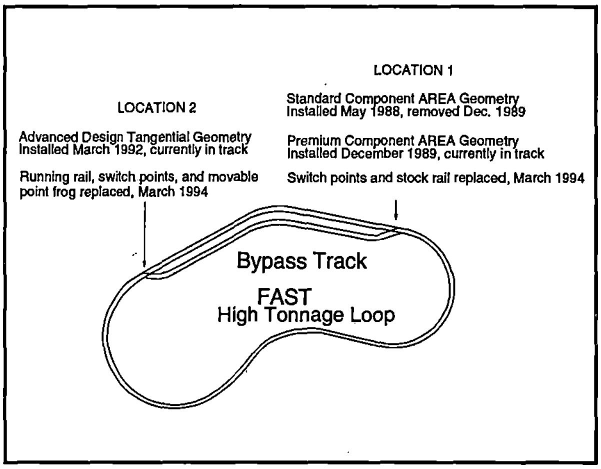


Figure 7. Turnout Locations on the High Tonnage Loop

The second turnout (Figure 8) was pre-assembled and donated by Bethlehem Steel Corporation (BSC). It consists of premium components and was manufactured to AREA geometry. This geometry is identical to the geometry of the SP turnout. Key premium components included thick web switch points; a high integrity explosive depth hardened frog casting; continuously welded fully heat treated rail; and Pandrol fasteners. The BSC turnout was installed in December 1989 and is still in track with over 350 MGT of service exposure. The thick web switch points were replaced with undercut FHT 132 RE switch points with reinforcing straps in March 1994.

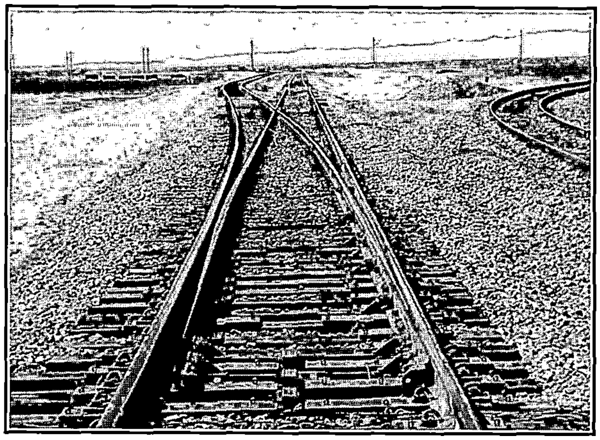


Figure 8. Bethlehem AREA No. 20 Turnout

The third turnout (Figure 9) was donated by American Track Systems (ATS) and manufactured by Butzbacher Weichenbau Gesellschaft (BWG) of Germany.

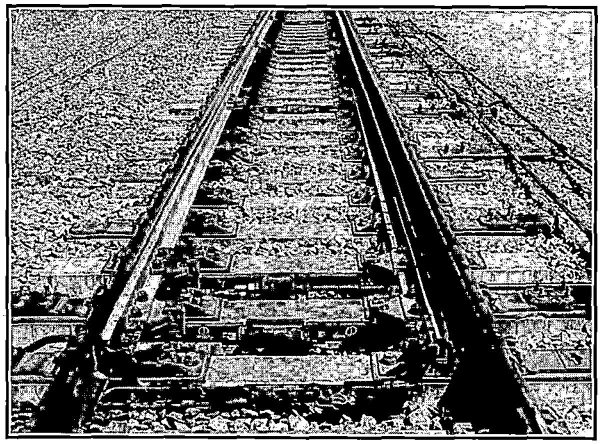


Figure 9. ATS/BWG Tangential No. 18½ Turnout

Construction of the ATS/BWG turnout was performed at FAST by FAST personnel. This turnout also includes premium components which differ from those in the BSC turnout. Key premium components include concrete ties; a movable point frog (Figure 10); full web asymmetric tangential geometry switch points; the Schwihag fastening system for the switch points; switch motors for both frog and switch point operation; and rail heat treated in key areas.

The original running surface components were replaced after about 130 MGT in early 1994 with components which were hardened on all running surfaces.

Table 1 lists the components used in the two turnouts remaining in track.

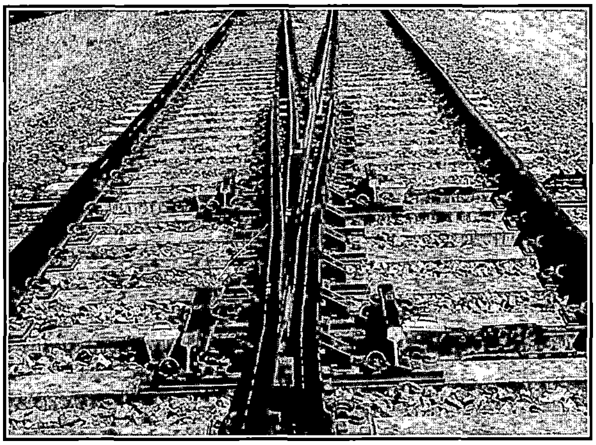


Figure 10. ATS/BWG Turnout Swing Nose Frog

ACKNOWLEDGMENTS

The author acknowledges the assistance of the Southern Pacific Transportation Company, The Bethlehem Steel Corporation, American Track Systems, and Butzbacher Weichenbau Gesellschaft for donating the turnouts used in this test.

REFERENCES

1. Read, David M., "FAST/HAL Turnout Performance Experiment," *Proceedings, Workshop on Heavy Axle Loads,* Pueblo, Colorado, October 1990, p 18-9.

2. Hannafious, Jon S., "Turnout Performance Experiment, " *Welcome to the FAST/HAL Open House Workshop, Phase II,* Pueblo, Colorado, September 15-16, 1992, P2-100.

Table 1. Turnout Components

BSC Number 20 Premium Component AREA Geometry	ATS/BWG Number 18½ Advanced Design Tangential Geometry
Pre-assembled AREA No. 20	No. 18½ assembled at TTC
Switch Radius = 3605.7 ft (1°35') Lead Radius (CL) = 3329.9 ft (1°43')	3937 ft. radius (1°27') tangent one tie ahead of p.s. and at heel of frog
156 ft. 1/2 in. lead	185 ft. lead
Hardwood ties	Sherman Abetong concrete ties
Bethlehem fully heat treated 132 RE stock*, closure, wing, and heel rails	CF&I HH 136-10 stock & closure rails* Thyssen HH 136-10 wing & heel rail*
Continuously thermite welded, except insulated joints	Continuously thermite welded except beveled insulated joints
Pandrol "e" clips throughout turnout with Pandrol lock spikes	Pandrol "e" clips throughout turnout on plates bolted to ties
Undercut FHT 132 RE switch points with reinforcing straps* •50 ft. 11 in. (Curved 39 ft.) •4 3/4 in. throw •Slide plates/Uniform risers •Rollers, no helpers •Bolted rail braces with screw spikes & bolt-less Pandrol rail braces with lock spikes •Screw spikes •Three gage plates •Floating heel blocks	Asymmetric heavy web "T" rail* •76 ft. 7 in. (tangential) •4 3/4 in. throw •Graduated risers •Three helper rods •Schwihag fastening system •Double Pandrol "e" clips •Floating heel blocks
	GRS model 5A switch motors
Manual throw	Movable point frog* •One helper
High integrity manganese steel frog casting gage plates (point and heel)	No guard rail
23 ft. hook flange guard rail	

* Original materials replaced March 1994

"FAST/HAL Phase II — Crossing Diamond Tests,"

by Duane E. Otter and
Joseph LoPresti

Summary

Five crossing diamonds have been tested on the High Tonnage Loop (HTL) at the Transportation Technology Center's Facility for Accelerated Service Testing (FAST).

An 89-degree standard component manganese insert crossing was removed from track after 1.9 MGT of heavy axle load (HAL) traffic. The castings were then explosion hardened and reversed. The original wing rails were replaced with premium rail. The rebuilt 89-degree crossing remains in track with 2.2 MGT.

A 62-degree three-rail bolted crossing with about 14 MGT of revenue service traffic was installed on the HTL after the rail ends at the crossing gaps had been repaired. It survived an additional 4.6 MGT. The running rails of this crossing were then replaced with premium rail. The crossing was reinstalled and lasted 29.4 MGT.

A 76-degree premium component solid manganese crossing survived 15.9 MGT with extensive weld repairs at 10.8 MGT.

Instrumented wheel sets were used to measure impact forces in the crossings under 100- and 125-ton cars at various speeds. The 125-ton car produced impacts that were equal to those for a 5 to 10 mph higher speed with the 100-ton car.

The higher the crossing angle, the greater the increase in wheel impact force with increasing speed. The impact forces generally increase linearly with speed through 40 mph. Average impact forces more than three times the static load were seen at 40 mph.

This test is being performed to monitor the performance of crossing diamonds under HAL's as part of the Frog and Turnout Performance Experiment at FAST.

PERFORMANCE RESULTS
STANDARD COMPONENT CROSSINGS

89-Degree Manganese Steel Insert Crossing

The 89-degree manganese insert crossing was subjected to 1.9 million gross tons (MGT) of HAL train traffic at FAST before being removed from track. The crossing battered at a very rapid rate. Vertical track geometry degraded rapidly as well. The train operating crew reported a very rough ride through the diamond. After the equivalent of about two days of operation over the crossing, train traffic was stopped and the diamond was removed from track.

Figure 1 shows the excessive amount of batter and metal flow, on both the insert castings and the wing rails, after 1.9 MGT of 39-ton axle load traffic. The batter rate on the casting was about 1/8 inch per MGT. The plastic deformation and metal flow resulted in a narrowing of the cross-direction flangeway to less than the AREA allowable. The deformation included yielding of the manganese steel casting walls, as measured using strain gages applied at various locations on the castings. This indicates that more than just a harder casting surface may be necessary to withstand HAL traffic. In addition, there was a significant loss of vertical track geometry, as the crossing settled with accumulating tonnage.

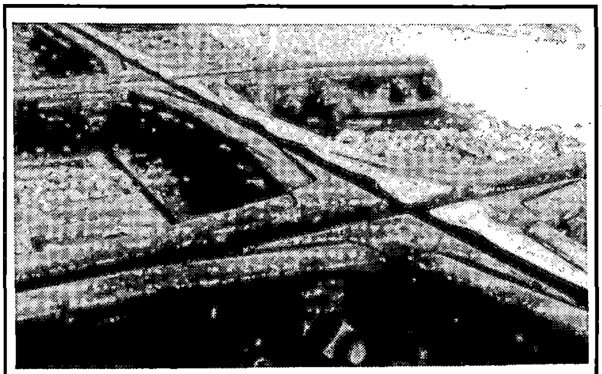


Figure 1. 89-Degree Crossing after 1.9 MGT of HAL Traffic

Given the extent of the damage to both the castings and the wing rails, and the rapid rate at which it occurred, it was deemed impractical and prohibitively expensive to attempt to repair the crossing and maintain it in track for any length of time.

62-Degree Three-Rail Bolted Crossing

The original 62-degree crossing (Figure 2) was subjected to 4.6 MGT of HAL traffic at FAST before being removed from track. The reason for removing the crossing from track was excessive damage to the rail ends at the gaps in the crossing. As might be expected, the rail ends downstream of the gap suffered the most severe damage after a day of train operation in one particular direction.

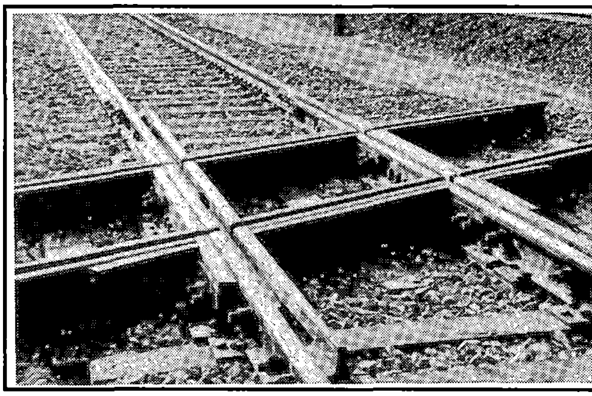


Figure 2. 62-Degree Three-Rail Bolted Crossing

The rail ends at the crossing gap required frequent repairs, particularly the down-stream ends. Most of the damage was in the form of plastic flow which needed to be ground off. Weld material was then used to build up the surface. Figure 3 shows a damaged rail end after 4.6 MGT of HAL traffic. Notice the extensive plastic flow and cracking. The cracks went so deep that very little of the original railhead material would have been left if the cracks were ground. Perhaps this rail end might have lasted longer if train operations were stopped before the damage had progressed this far, and a repair could still be made.

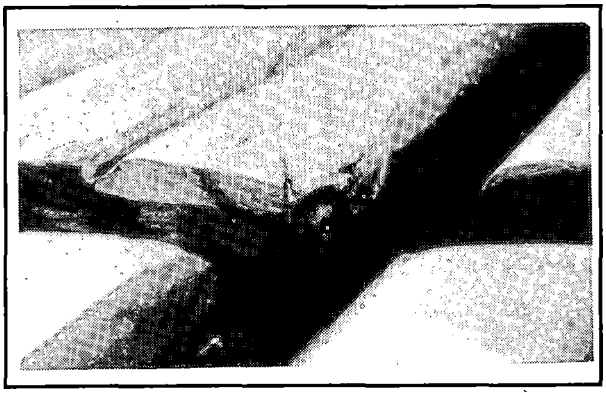


Figure 3. 62-Degree Crossing Rail End after 4.6 MGT of HAL Traffic

There was little loss of track geometry over the 62-degree crossing as tonnage was accumulated. The train operating crew reported no noticeable ride problems or geometry degradation through the diamond.

PERFORMANCE RESULTS - PREMIUM COMPONENT CROSSINGS

76-Degree Solid Manganese Crossing

The 76-degree solid manganese crossing survived a total of 15.9 MGT of HAL traffic at FAST (Figure 4). After 10.8 MGT of traffic, the crossing was removed from track to repair a crack in one of the castings. After the repair, the crossing was reinstalled and withstood an additional 5.1 MGT of HAL traffic. It was removed again due to additional cracks in the same casting. The new cracks were not in the repair welds or the associated heat affected zones.

During the first 10.8 MGT of service, the ballast beneath the crossing was hand tamped every 1 to 3 MGT. The ballast contained a high percentage of slag, which appeared to deteriorate rapidly beneath the crossing. When the crossing was reinstalled, after the casting repair, granite ballast was used to minimize track surface problems.

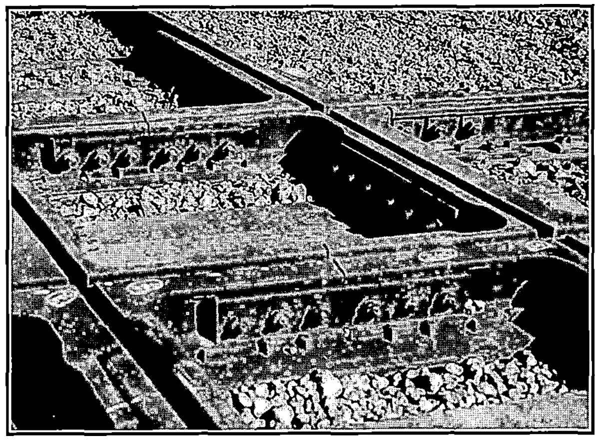


Figure 4. 76-Degree Solid Manganese Crossing

Aside from the out-of-track repair of the cracked casting, the crossing also required in-track maintenance. The gage corners of the running surface were ground lightly every 2 to 3 MGT to remove metal flow and maintain flangeway clearance. No build-up welding was performed during the first 10.8 MGT, although the batter was about 1/4 inch at each of the flangeway gaps. The battered ends were built up in conjunction with the casting repair. Other portions of the running surface performed well, with no corrugations or batter after 15.9 MGT of HAL traffic. During this period, eight of the torque-stud bolts came loose and were retightened using a conventional track wrench.

One of the four castings was cracked extensively enough to warrant removal of the crossing for repairs after 10.8 MGT. The crack extended across the full width of the base of the section (Figure 5) and up into the vertical walls of the casting. The crack was visible in the bottom of the flangeways.

Welders from Conrail and Santa Fe supervised and assisted in the repair of the crossing. The portion of the crack that was readily accessible from the bottom of the casting was weld repaired. But it was decided that repairing the cracks in the interior vertical walls of the casting would not be cost effective. Details of the weld repair are described elsewhere.[1]

The corners of the castings at all four flangeway intersections were also repaired at this time. Average batter was about 1/4 inch, with some metal flow and small cracks evident.

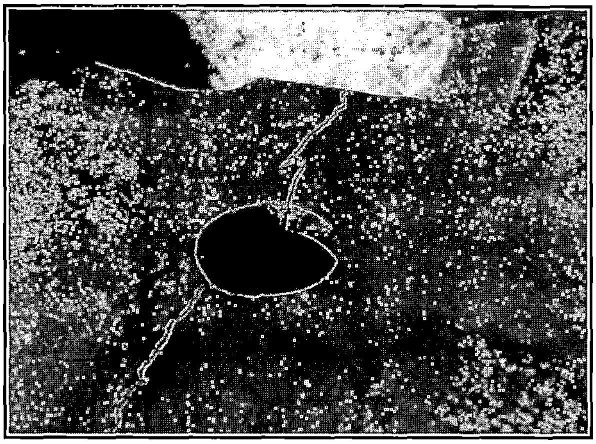


Figure 5. Crack in Casting of 76-Degree Crossing

Rebuilt 62-Degree Three-Rail Bolted Crossing

The rebuilt 62-degree crossing withstood 29.4 MGT of HAL traffic at FAST before being removed from track. The crossing was removed due to a head-web separation crack discovered during an ultrasonic inspection propagating from the flangeway gap on one of the running rails. At the time the crossing was removed, the crack was about ½ inch long. Other than this single crack, the crossing appears to be in excellent condition.

The FAST Special Trackwork working group has recommended that a new running rail be fabricated and the crossing be reinstalled for further testing at FAST.

Rail end batter at the flangeway gaps averages about 1/8 inch. The rail ends have been ground periodically to remove the slight amount of metal flow present, but no buildup welding has been done. Flangeway clearance is not a problem.

Rebuilt 89-Degree Manganese Insert Crossing

The rebuilt 89-degree manganese insert crossing has accumulated about 2.2 MGT of HAL traffic and remains in service at FAST. Thus far, no build-up welding has been performed. The casting has been ground to remove metal flow along the flangeways. Batter at the flangeway gaps is about 1/4 inch. The joints between the castings and the wing rail have also been slotted to remove metal flow. Some bolts have been retightened. The crossing, which has required tamping to maintain track surface, loses surfaces rapidly under the 40 mph HAL traffic.

COMPARISON

Figure 6 shows the total HAL tonnage carried by each of the crossings installed at FAST. Table 1 summarizes tonnage and reasons for removing each crossing.

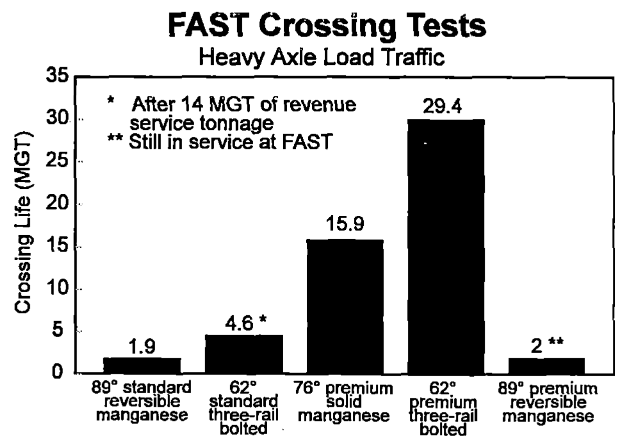


Figure 6. Life of Various Crossing Under HAL Traffic at FAST

Table 1. Summary of Crossing Performance Under HAL Traffic at FAST

Crossing	Life (MGT)	Reason for Removal
89-Degree Manganese Insert	1.9	Rail Batter and Corrugation
62-Degree Three-Rail Bolted	4.6	Battered and Cracked Rail End
76-Degree Solid Manganese	15.9	Cracked Casting
Rebuilt 62-Degree Three-Rail Bolted	29.4	Head-Web Crack in Rail End
Rebuilt 89-Degree Manganese Insert	2.2*	*Still In Track

Based on the tests conducted to date, the following three factors appear to be significant in determining the life and performance of a crossing under HAL traffic:

1. Hardness and depth of hardness of running surface
2. Crossing angle
3. Number of rail transitions through crossing

In general, the harder the running surface, the better the crossing performance. The explosion hardened castings and head-hardened wing rails in the rebuilt 89-degree crossing have already lasted longer than the original castings and standard wing rails. The head-hardened running rails in the rebuilt 62-degree crossing lasted longer than the original running rails.

The crossing hardness failure mode is an issue worth noting. Failure of the rebuilt 62-degree crossing with head hardened rail was due to a head-web separation crack at one of the flangeway gaps. This type of crack is not easily detected and can lead to a catastrophic railhead failure with little prior visible signs of distress. In all the other crossing failures, the damage was quite visible and was observed growing worse. This allowed sufficient warning to remove the crossings from track before they became unsafe for further train traffic.

The lower the crossing angle, the lower the impact forces and the better the crossing performance. To date, the 62-degree crossing has lasted the longest, not only because it has the lowest impact forces, but also because it had the hardest material. Further testing is needed to quantify the amount of life increase caused by each of these effects.

The fewer the transitions in rail surface, the better the crossing performance. The 89-degree manganese insert casting has four wing rail-to-casting transitions per running rail which must be maintained to prevent chipping and corrugation. The solid manganese and three-rail bolted crossings had much smoother running surfaces without these transitions. Therefore they were easier to maintain and provided fewer rail surface irregularities. Because of the many differences between the crossings tested to date, it is not possible to differentiate the extent of the rail hardness, crossing angle, and rail surface transition effects without further testing.

WHEEL IMPACT FORCES

Instrumented wheel sets were used to measure impact forces in several of the crossings due to 100-ton cars and HAL cars at various speeds. Figure 7 summarizes the wheel impact force data for HAL (315,000 lb) cars. Similarly, Figure 8 summarizes the impact force data for 100-ton (263,000 lb) cars. For each crossing, the impact forces increased with increasing speed. Each data point represents the average of at least 16 impact measurements. At zero speed, the static wheel loads are plotted. The test trains used to perform these measurements ran over the crossings at speeds from 10 to 40 mph in both directions for each speed. The instrumented wheel set data was sampled at a frequency of 512 Hz with 200 Hz filtering. There is also some mechanical filtering of the impacts due to the wheel mass between the gages and the wheel tread.

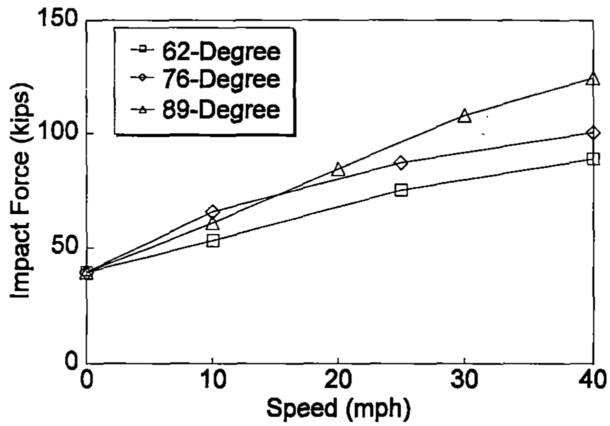


Figure 7. Average Crossing Impact Forces under HAL Cars

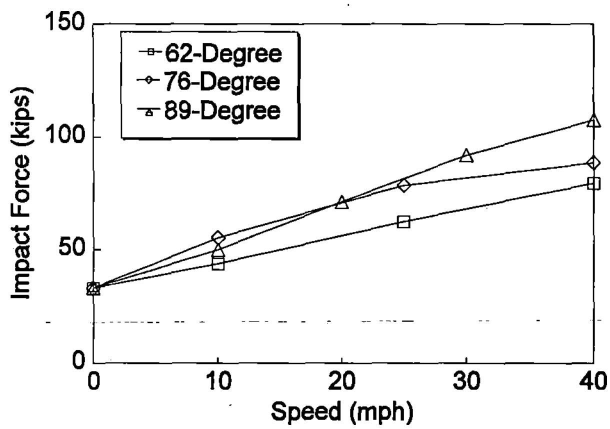


Figure 8. Average Crossing Impact Forces Under 100-Ton Cars

The higher the crossing angle, the greater the increase in wheel impact force with increasing speed. The impact forces generally increase linearly with speed through 40 mph. The nonlinearity in the responses for the 76-degree crossing may be due to the fact that the measurements were taken just after the completion of the repair and build-up welding on the casting material.

Nonlinearity may indicate working of the weld and/or casting material. The impact forces may also be a function of the amount of batter present on the crossing at the time of measurement.

Figure 9 shows a comparison of the wheel impact forces in the 89-degree crossing due to HAL and 100-ton cars. The HAL car produced impacts that were about equal to those for a 5 to 10 mph higher speed with the 100-ton car. At 40 mph, the average impacts are more than three times the static wheel load for both cars.

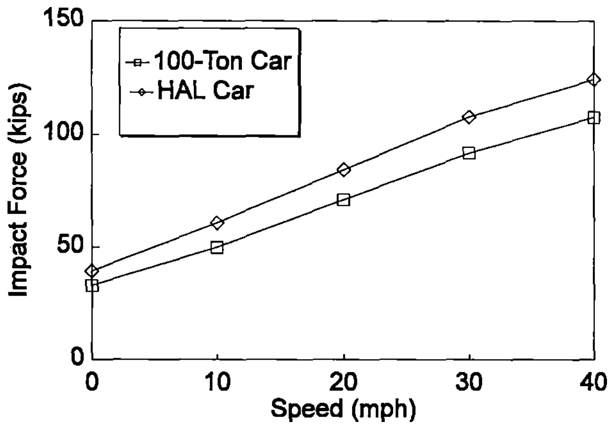


Figure 9. Average Impact Forces on 89-Degree Crossing

EFFECT OF CROSSING ANGLE

Crossing angle affects wheel/flangeway gap interaction in the following three ways:

1. At 90-degree crossings, both wheels of a wheel set negotiate the flangeway gap at the same time, causing simultaneous impacts on both wheels.

2. At crossings between 90 and about 60 degrees, each wheel crosses an effective gap. The transition from one running surface to the next while crossing the flangeway is not continuous. This causes an impact on the downstream end. The geometry for this case is shown in Figure 10.

3. At crossing angles less than about 60 degrees, the wheel is in contact with at least one running surface at all times. The lower the angle, the longer the transfer zone.

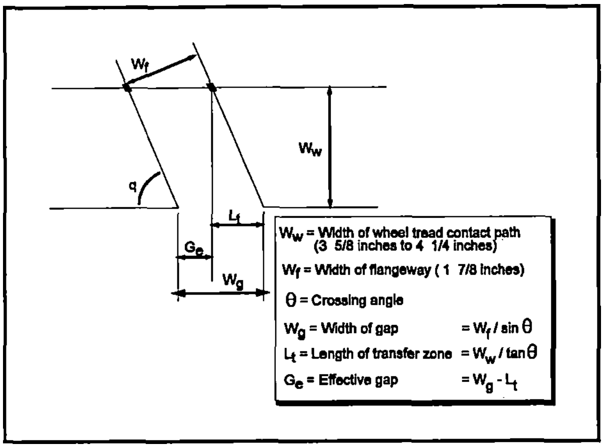


Figure 10. Flangeway Gap Geometry

Because a wheel set might not be centered while negotiating a crossing, there are minimum and maximum possible tread contact bands given standard wheel set and flangeway dimensions. The extreme case of a wheel set in contact with the guard rail is shown in Figure 11. The minimum possible tread contact width occurs on the wheel in contact with the guard rail. The maximum possible tread contact width occurs on the opposite wheel.

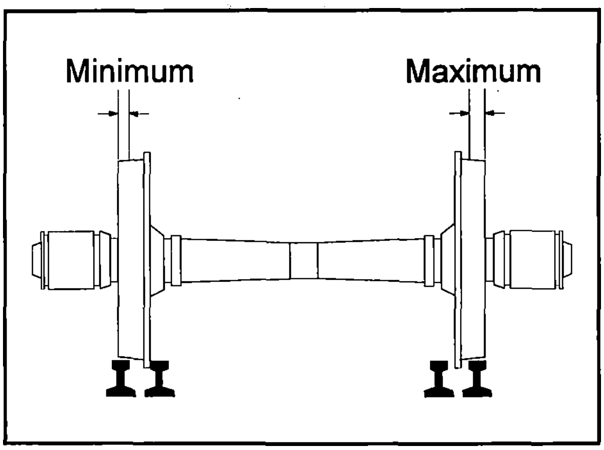


Figure 11. Minimum and Maximum Possible Wheel Contact Widths

For a 1 ⅞-inch flangeway, a wheel width of 5 ½ inches, and the maximum allowable flange back-to-flange back distance of 53 ⅜ inches, the minimum and maximum possible contact bands are 3 ⅝ inches and 4 ¼ inches, respectively.

The effective gap, using this range of wheel tread contact width, is shown in Figure 12 for different crossing angles. A negative gap shows that the wheel may be in contact with both sides of the gap at the same time. The wheel transfers weight from one side of the gap to the other without losing contact at angles lower than approximately 60 degrees. One would expect that the larger the effective gap, the larger the impact force at the frog due to a particular wheel. Therefore, realignment to reduce crossing angle may prolong crossing life. Further testing is needed to quantify this relationship though.

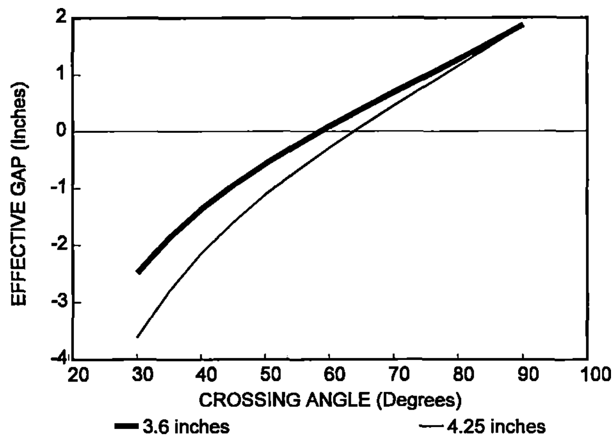


Figure 12. Effective Flangeway Gap for Various Crossing Angles

CROSSING DESIGN AND INSTALLATION

Figure 13 shows the location and installation date for each of the crossings installed at FAST

89-Degree Manganese Insert Crossing

The 89-degree manganese insert crossing was donated by the Atchison, Topeka, & Santa Fe Railway Company (ATSF). The crossing was constructed with 133-RE rail and manganese steel insert castings by the Conley Frog and Switch Company, using castings by ABC Rail. The insert castings were mechanically hardened. The crossing was designed for installation at Bonner Springs, Kansas, where ATSF tangent track crossed a 3-degree curve on the Union Pacific Railroad (UP). The crossing angle is 89 degrees, 20 minutes. The design follows AREA Plan Nos. 700F-80, 746-82 and 749-73. The ATSF abandoned their line before installing the new diamond, thus the unused crossing became available for testing.

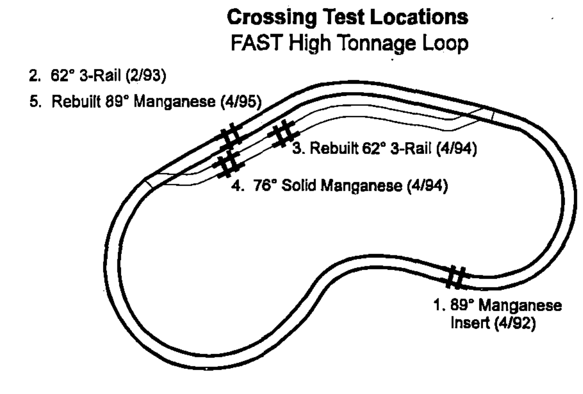


Figure 13. Locations of Crossing Diamond Tests on the HTL

The installation at FAST followed the manufacturer's recommendations. The diamond was placed on one 7" x 12" x 9' 0" and two new 7" x 21" x 12' 0" hardwood ties. The crossing was designed with the intent of the 3-degree curve route having heavier traffic than the tangent route. Ties are ordinarily laid in the direction of the heavier traffic; however, only the tangent route of the crossing could be installed, so the ties were perpendicular to the direction of traffic on the High Tonnage Loop (HTL). The crossing was installed on the manufacturer's plates with cut spikes. The five ties on either side of the crossing were new 7'x9"x9'0' hardwood ties. Ties farther away from the crossing were 7"x9'x8'6" softwood ties. Every tie in the section was box anchored.

The crossing was installed with bolted joints with 133-RE rail, as intended by the manufacturer. The rail surrounding the crossing was continuously welded. The ballast section had 12- to 15-inch shoulders, 2:1 slopes, and cribs full to the tops of the ties. The ballast was a mixture of granite, traprock, and slag.

Due to the track configuration at FAST and the lack of a crossing track, it was only possible to run trains in two of the four directions of traffic to which the diamond would normally be exposed.

89-Degree Crossing Rebuild

The 89-degree crossing was rebuilt using new wing rails fabricated from NKK 133- RE head-hardened rail, with a nominal Brinell hardness number of 370. Only the wing rails in the direction of traffic were replaced. The new wing rail pieces were made by the original manufacturer of the crossing, Conley Frog and Switch. The castings were reversed and explosion hardened by the original manufacturer of the castings, ABC Rail. Casting hardness was at least 350 Brinell after explosion hardening. The crossing installation was similar to the previous one, except for the location.

62-Degree Three-Rail Bolted Crossing

The 62-degree three-rail bolted crossing diamond donated by CSX Transportation was constructed by the Conley Frog and Switch Company using Bethlehem 136-RE fully heat-treated rail. The steelwork closely follows AREA Plan Nos. 700F-80 and 701-80. AAR personnel also performed the timber work following the AREA plans. There are no manganese castings. According to the AREA manual, this crossing design is recommended for use where speed does not exceed 60 mph and annual tonnage does not exceed 10 MGT.

The crossing was originally installed at Sampson City, Florida, where CSX tangent track crossed a tangent on the Norfolk Southern (NS). The crossing angle is 62 degrees, 14 minutes. The diamond was oriented with the CSX as the line of heavier traffic (mainline) and the NS as the branch line. The diamond was in service for approximately two years before the NS abandoned its line, making the crossing unnecessary. Revenue service tonnage over this crossing was about 14 MGT total on the CSX and less than 1 MGT total on the NS. Maximum train speed over the diamond was 40 mph on CSX.

Before installing the diamond in track at FAST, the rail ends on the mainline running rails were built-up to repair the damage sustained during the two years of revenue service traffic over the diamond. The hardness of the running rails after the build-up repairs ranged from 310 to 395 Brinell, with an average hardness of about 350.

The installation at FAST followed AREA Plan Nos. 700F-80 and 701-80 for the timber and steel work. The crossing was installed for FAST train operations over the route designed for heavier traffic. The branchline route was not connected to any other tracks. The crossing was installed on the manufacturer's plates with cut spikes. Hook twin tie plates were used for the skewed ties on the branchline stubs. The diamond was installed with bolted joints into track with 136-RE rail. On one rail, bonded insulated joints were used for track signal purposes. The rail surrounding the diamond was continuously welded. The ballast section had 12- to 15-inch shoulders, 2:1 slopes, and cribs full to the tops of the ties. A granite ballast was used.

Due to the track configuration at FAST and no crossing track, it was only possible to run trains in two of the four directions of traffic to which the diamond would normally be exposed.

62-Degree Crossing Rebuild

The ends of running rails on the route designed for heavier traffic were the only parts of the crossing that failed during the first test. AAR personnel fabricated new running rails from NKK 136-RE head-hardened rail and rebuilt the crossing. The hardness of the rail was measured at 365 Brinell. Six new pieces of running rail were replaced, for the direction of heavy traffic only. All other parts of the original crossing were used again.

76-Degree Solid Manganese Crossing

The 76-degree solid manganese crossing was donated by Conrail. It was manufactured by Pettibone-Ohio Corporation in March 1987, with three-shot explosion-hardened solid manganese castings on an integral base. The average of several hardness measurements of the casting was 340 Brinell. The leg and guard rails are Bethlehem 132 RE fully heat-treated. The steel work closely follows AREA Plan Nos. 771-80 and 700F-80. The bolts are Camcar Camrail high strength with torque studs attached for application. The crossing had not been in track before testing began at FAST.

The crossing was installed for FAST train operations over the route designed for heavier traffic. The branch line routes were not connected to any other tracks. On one rail, bonded insulated joints were used for signaling purposes. The other rail was installed with standard bolted joints. The rail surrounding the crossings was continuously welded. The ballast sections had 12- to 15-inch shoulders, 2:1 slopes, and cribs full to the tops of the ties. The ballast was a combination of granite and slag.

ACKNOWLEDGMENTS

The authors acknowledge the assistance of Conrail, CSX Transportation, and the Santa Fe Railway for donating the crossing diamonds used in this test. Walt Heide, Conrail's director of standards and track analysis, and John Baker, Santa Fe's manager of track standards, were instrumental in providing support for the repair of the 76-degree casting. The authors also acknowledge the assistance of Russell Hein of Conley Frog and Switch, and Gene Swansiger of ABC Rail for their companies' donations to the rebuilding of the 89-degree crossing.

REFERENCES

1. Otter, Duane E., and Joseph LoPresti "Testing a 76-Degree Crossing Under Heavy Axle Load Traffic," *Technology Digest*, TD 95-014, April 1995.

"Heavy Axle Load Ballast Experiment,"

by M. Carmen Trevizo

Summary

Four ballast materials — granite, traprock, limestone, and dolomite — were evaluated under the Heavy Axle Load (HAL) Ballast Experiment at the Facility for Accelerated Service Testing (FAST), Transportation Technology Center, Pueblo, Colorado. Each of these materials has been able to withstand the heavy axle load at varying accumulated tonnage in the FAST environment.

The objective of the experiment is to evaluate selected ballast materials relative to their ability to withstand the loads associated with 39-ton axle load traffic and, when possible, to compare their performance under 33-ton axle load traffic

Direct comparison of the particle breakdown for ballast tested under 33- and 39-ton axle traffic can be made for the limestone and granite ballast. An increase in particle breakdown and maintenance due to HAL is evident in the limestone ballast; however, it appears that degradation of the granite material is more dependent on accumulated tonnage than on increased axle load. One apparent drawback discovered during this experiment was that lower quality ballast, namely the dolomite and limestone, required an out-of-face surfacing before reaching 100 MGT of traffic. The dolomite ballast also required frequent spot maintenance in areas where profile anomalies were present. Results from the gradation analysis on samples removed from the ballast bins also show that the degradation increases significantly with tamping, as shown in the ballast bin gradation analysis.

INTRODUCTION AND CONCLUSIONS

The Association of American Railroads (AAR) in conjunction with the Federal Railroad Administration (FRA) are conducting the Heavy Axle Load (HAL) Ballast Experiment. The objective of the experiment is to evaluate selected ballast materials relative to their ability to withstand the loads associated with 39-ton axle load traffic and, when possible, to compare their performance under 33-ton axle load traffic.

Ballast material, with their varied mineral characteristics, may prove to be impractical or incapable of supporting traffic for a suitable length of time in a HAL environment. Ballast breakdown significantly contributes to track fouling, which plays a critical role in determining maintenance cycles.[1] The quality of the four ballasts used in the test ranged from good to marginal based on experience under conventional 100-ton equipment. Ballast materials were granite, traprock, limestone, and dolomite and are currently used in revenue service under 33-ton axle load traffic.

Test Locations and Layout

The test zones were located in Section 03, a 5-degree curve on the High Tonnage Loop (HTL) at FAST. This curve is 3740 feet long and has a superelevation of 4 inches. The track structure consists of continuous welded rail, wood and concrete ties, cut spike and direct fixation fasteners, with every other tie fully box anchored. The four ballast test zones were only located under the wood crosstie area, where the cut spike fastening system was in place. The concrete tie area, which was in the center part of the curve, was not used in the ballast test.

Upon installation of ballast, every third existing tie was replaced with a new hardwood tie. During testing, existing ties had to be removed periodically from track to retrieve ballast samples. These ties were then replaced with new ties after the sample was retrieved. Figure 1 shows the track locations of the four test zones

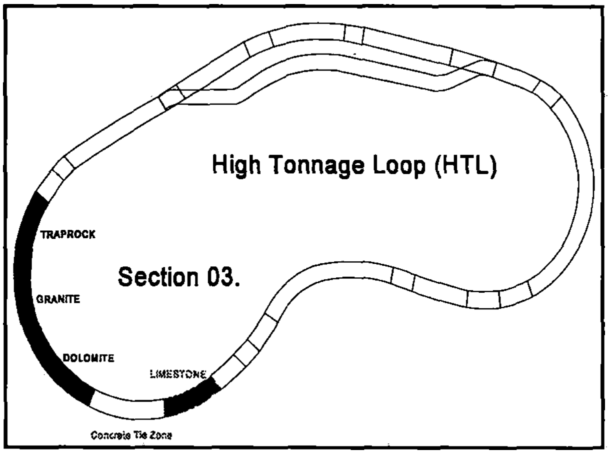


Figure 1. Ballast Test Zone Locations

Each of the four ballast test zones were subdivided into two subsections. One of the subsections was used to measure the track geometry retention of the ballast. Samples for ballast gradation analysis were removed from the second subsection. Since the ballast was disturbed when the ballast sample was retrieved, and because the tie was tamped after sampling, the sampling and the geometry retention zones were separated so that any changes in track geometry were due to the ballast performance and not ballast disturbance. Ties in the geometry zone were only replaced if failure occurred. Figure 2 shows the typical layout for each of the ballast test zones.

The limestone and traprock test zones were approximately 560 feet (350 ties) long, but the granite and dolomite test zones were 715 feet (440 ties) long. The additional length provided a larger ballast sampling area for the two ballasts.

Each ballast test section consisted of two transition zones, one geometry zone, one sampling zone, and one continuity zone. The transition zones were approximately 81 feet long and were located on the ends of each test ballast. The geometry zone was 162 feet long, and was located between the continuity and the transition zone. The ballast sampling zone was 162 feet long in the traprock and limestone sections, and 300 feet long in the granite and dolomite test ballasts. The continuity zone was 81 feet long and was used as the divider between the geometry and ballast sampling zones of each test ballast.

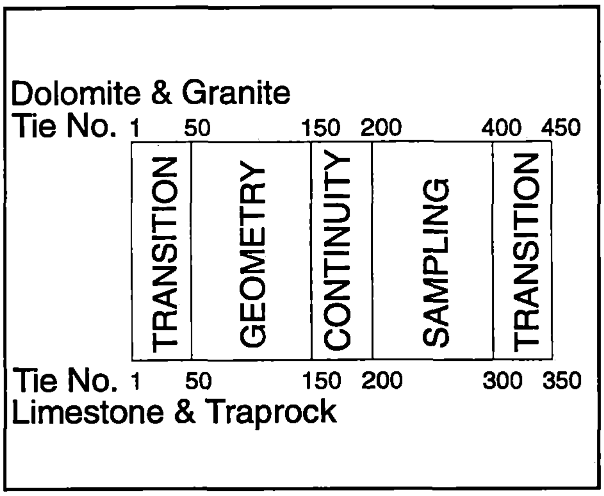


Figure 2. Typical Test Section Layout

The transition zones in the granite and dolomite test areas were used to install ballast bins. The bins were installed to determine ballast degradation due to dynamic loading from tamper damage.

The test ballast gradation specification recommended by the AREA Ballast Committee, and requested by the AAR for the ballast experiment was an AREA 4; however, the gradations of the four donated ballasts varied. The gradation for the granite and limestone ballasts was an AREA modified 3, while the traprock gradation was AREA 4, and the dolomite was an AREA 24.

Field Measurements

Ballast degradation and track geometry retention measurements were monitored at predetermined MGT cycles for each of the test ballasts. Measurements taken to monitor track geometry retention included loaded and unloaded profile elevations, ballast density, vertical track modulus, track geometry car measurements (alinement, cross level, profile, etc.), and instrumented wheel set force measurements.

Loaded track profile, a measurement of track settlement as a function of accumulated tonnage, was accomplished by reading the elevation of a short survey rod permanently attached to an end of an overloaded 100-ton car. The overloaded end resulted in a 39-ton static axle load.

The unloaded profile measurement was accomplished by reading top of tie elevations on five selected ties in the geometry subsection of each test ballast. Measurements were taken immediately outboard of the high and low rail seat area of the tie. Tacks were installed on the ties to ensure that measurement was always taken on the same location of the tie, and on a non-wearing surface.

Ballast density measurements were taken by lowering a nuclear density gage probe down to the ballast/subgrade interface through steel pipes that had been placed directly inboard of the rail seat area on five consecutive ties. The depth density-moisture gage, which measures sub-surface density using a probe containing a gamma source, and a gamma detector, was used on all ballast density measurements. To avoid backscatter when taking the readings, the probe was lowered through the steel pipe 3 inches above the ballast/subgrade interface.

Vertical track modulus is calculated by using the measured vertical track deflection under predetermined variable loads. The deflection used in the calculation is the difference between a light load (10 kips) and a heavy load (39 kips). The deflection is measured on a magnetic scale that is attached to the rail directly over the measured tie. The 605 car, a modified locomotive frame that applies single point loading on both rails to simulate a single axle loading, is used to apply loads ranging from 0 to 40,000 pounds in increments of 10,000 pounds. Vertical track displacement of the rail is taken at each of the load levels.

Track geometry retention was monitored with data collected using the EM80 track geometry measurement car. The EM80 measures gage, track profile, cross level, and alinement. Data is collected dynamically at a speed of 10 mph and under an axle load of 15-tons.

Dynamic vertical and lateral load data was collected with the 38-inch instrumented wheel sets. The vertical forces at the rail/wheel interface are a combination of the car 's static wheel load and the dynamic loads generated by the track geometry irregularities and imperfections, which occur in the wheel/rail running surfaces. Lateral rail forces are a combination of vehicle curving forces and dynamic forces induced by track geometry imperfections.[2]

LABORATORY TESTS AND ANALYSIS

Gradation analysis was performed to monitor the particle breakdown with accumulated tonnage on ballast samples removed from ballast bins and track samples.

Ballast samples were retrieved during the designated MGT schedule, and before and after out-of-face surfacing. Initially ballast samples, at each measurement cycle, were retrieved from the low rail of five random ties; however, after the 160 MGT of HAL traffic, the sample size was reduced to four ties due to the reduction in track sampling area. To capture any difference in ballast degradation between high and low rails, ballast samples were retrieved from under both rail seat areas after 1 MGT of HAL traffic.

To isolate the actual physical degradation of the ballast particles from contamination of subgrade or wind-blown material, ballast bins were installed directly under the rail bearing area of the ties and filled with a known gradation. Twenty bins were installed in one of the transition zone on the granite and dolomite test zones.

The sides of the ballast bins were made of sheet metal. A geotextile material was used for the bottom of the bins. The geotextile did not significantly alter the vertical support condition of the ballast contained in the bins, but kept the ballast samples drained, while isolating the ballast particle breakdown. The bins were covered with a sheet metal cover to prevent influences from other contamination sources. Each bin was filled with a pre-measured gradation. The gradation had less than 0.5 percent passing in the ¼ inch sieve. Five of the 10 bins were tamped at predetermined cycles. The other five bins were individually tamped after installation to simulate initial track installation.

There were several laboratory tests performed at the start of the ballast experiment on all of the four ballast materials: Soundness of Aggregate (magnesium & sodium sulfate), Los Angeles Abrasion, Clay Lumps, Friable Particles, Scratch Hardness of Coarse Aggregates, Unit Weight of Aggregate, Sieve Analysis, FAST Elongation Index Test, and FAST Flakiness Index Test. Results will be reported in a follow-up AAR report.

TEST IMPLEMENTATION

The ballast test zones in Section 03 were undercut down to the ballast/subgrade interface. The skeletal track was in place when a sub-ballast (dolomitic) material was installed. The rails and ties were not removed prior to the installation of the sub-ballast to avoid any adverse influence on the rail and weld test in place at this location four years before the start of the ballast test. The sub-ballast, made up of dolomite fines, was installed with an average depth of 8 inches under all four ballast test zones.

The ballast was then installed to an average depth of about 18 inches below bottom of tie on the low rail. The ballast depth was dictated by the surrounding track sections and variations in undercutter operation. Because only part of the curve was undercut, the track elevation in the undercut area had to be raised to the elevations of the adjoining track zones, keeping the experiments in the undercut area and the adjacent areas undisturbed.

After 15 MGT of HAL traffic over the ballast test zones, an investigation was conducted at different locations throughout the four ballast test zones to evaluate the condition of the sub-ballast layer. Density measurements, moisture content, density (Standard Proctor) tests, ballast, and sub-ballast depth measurements were performed. The seven trenches were excavated in the transition zones to avoid disturbing the geometry retention and ballast sampling zones.

The installed ballast depth measured across the seven trenches varied from 19 to 21 inches. This variation resulted from the non-uniformity of the switch undercutter that was used. Because of the short distance to undercutt and the limited time available for undercutting before the start of the test, a switch undercutter was used.

Since the sub-ballast material was installed uniformly, the difference in elevation that the undercutter had created during the undercutting operation was made up by the ballast depth to achieve a smooth top of rail elevation. Figure 3 shows the average ballast depth measured in all four ballasts during the investigation.

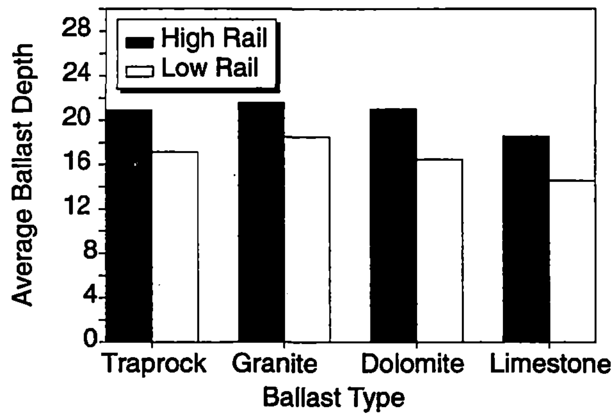


Figure 3. Average Ballast Depth

The measured sub-ballast depth varied from 7 to 9 inches. A total of 49 density readings were taken throughout the seven trenches. The sub-ballast layer was considered to be uniformly compacted since the coefficient of variation from the density readings was less than the 10 percent required for uniformity. The coefficient of variation was calculated by dividing the standard deviation by the mean density of the 49 density readings.

Once the test started, the geometry zone of each ballast was monitored for any track geometry retention loss. Once the zone fell below FRA Class 4 limit, the entire ballast section was surfaced out-of-face. To capture the geometry conditions of the track, measurements were taken before and after surfacing. Measurements frequency was followed as recommended by the AREA Ballast Committee.

Results from the experiments after the first 160 MGT of HAL traffic pointed out some specific areas of track components, which indicated that improvement was necessary. Some of these changes were made in Section 03. This included rail changes and selected tie replacement over a selected area of the curve. After the changes were made, the area over the granite, and part of the dolomite area, required surfacing. To prevent any biasing of the ballast performance on these two ballasts, all of the four ballast materials were surfaced out-of-face.

A growing concern in the railroad industry is concrete tie rail seat abrasion, thus this experiment was added to the HAL program after 250 MGT of traffic. The existing concrete tie area in Section 03 was extended to accommodate this experiment. This change eliminated the dolomite ballast test zone and reduced the limestone ballast test zone. The decision, agreed to by the FAST Steering Committee, took into account the higher level of daily maintenance required in the dolomite ballast during the last 10 MGT of the first 250 MGT of HAL traffic. The limestone continued with the original geometry retention zone undisturbed, however the tie sampling was eliminated. The ballast sampling continued in the transition zone adjacent to the geometry zone, and was also extended 10 ties into the spiral of Section 04.

The length of the granite and traprock was not changed. The tie sampling area, however, had been depleted due to the high sample frequency at the start of the test and to the spot maintenance required due to rail joints. Although the rail in this area was CWR, rail breaks were common, and rail joints were used as a temporary fix, until a field weld was installed. The few ties left undisturbed for ballast sampling were reserved for end of ballast life. Geometry retention measurements continued to be taken at this time.

After reaching 300 MGT, the majority of the rail in Section 03 was experiencing an increase in fatigue defects. Rail breaks were occurring at a high frequency and the welding crew was unable to repair them immediately. The number of rail joints and the length left in track increased significantly. Since the adverse effect of these joints on the individual ballast performance could not be quantified, the ballast experiment was terminated by concurrence of the FAST Steering Committee. End of ballast life of the three remaining ballast will be documented. Any tamping performed on this ballasts continues to be recorded for future use.

RESULTS

Geometry retention measurements varied with each type of ballast, while particle degradation from ballast track and bin samples showed an increase in degradation after 200 MGT of traffic. Ballast degradation was more pronounced in the dolomite and limestone ballast. However, the gradation analysis did show an increase in degradation in both the granite and dolomite ballasts with increased tamping.

Loaded and Unloaded Top-of-Rail Profiles

During the first 3 MGT of traffic, a large initial settlement occurred in all four ballast geometry test zones. The larger settlements in all four ballasts also followed out-of-face surfacing cycles. As seen in Figure 4, the granite ballast experienced less overall loaded track settlement.

The traprock and granite ballasts experienced less settlement than the dolomite and limestone ballasts during the first 160

MGT of HAL traffic. A substantial increase in track settlement is evident in the traprock ballast after the out-of-face surfacing at 160 MGT. The surfacing resulted from rail changes in part of Section 03. Performing the out-of-face surfacing cycle on the traprock, when it did not require it, appears to have had a detrimental effect on the ballast.

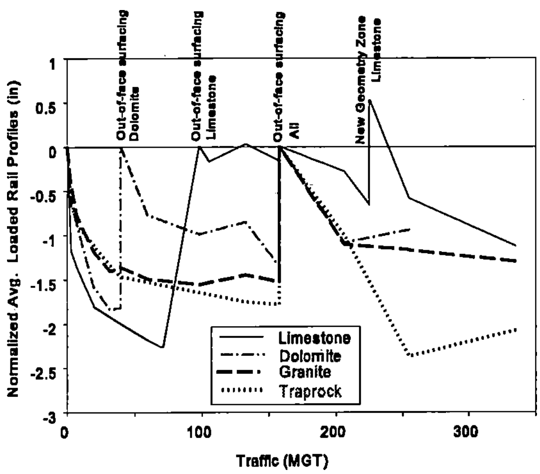


Figure 4. Loaded Profile Settlement — High Rail

When track settlement occurs, surface problems are not necessarily the outcome. However, if this settlement between the two rails is uneven, and/or profile deviations occur, maintenance requirement may increase. The maintenance required in both the dolomite and limestone ballast was due to uneven settlement between the two rails. The measured settlement was about 50 to 60 percent more on the high rail.

The ballast that required the most maintenance due to a loss of cross level was the dolomite. Track roughness is the calculated standard deviation of the loaded track profile measurement. Track roughness for the dolomite ballast was consistent in both the high and low rail, about 2 mm, for the duration of the test. The track roughness on the low rail of the limestone ballast was similar to the granite and traprock; however, the track roughness on the high rail was higher than the dolomite, about 3 mm. The granite and traprock ballasts, which required no maintenance, had a track roughness value of about 0.25 mm for both rails.

The unloaded track profile elevations in Figure 5 show an initial large settlement rate during the first 50 MGT of traffic. However, the settlement rate leveled off after the first 50 MGT.

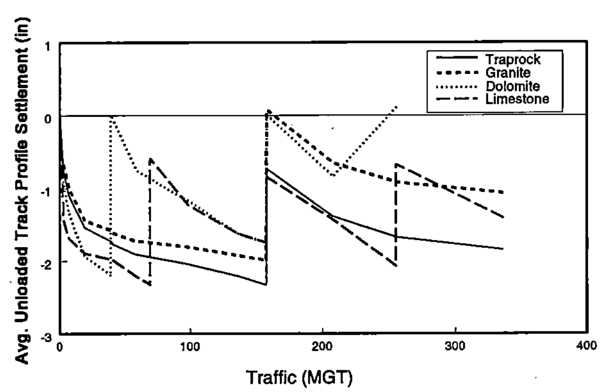


Figure 5. Average Unloaded Track Profile — High Rail

Density

Normalized ballast density shows an increase with tonnage. Once the ballast is disturbed by the out-of-face surfacing, the ballast density decreases and again starts to increase with tonnage. The dolomite ballast, which had the largest increase in ballast fines, also shows a higher density increase than the other three ballasts. The difference in ballast density can be seen in Figure 6.

Track Modulus

Data from the track modulus measurements reflect no major difference between the ballast materials in test. There appears to be a greater variation in track modulus with tonnage. Conditions that may have caused this change are surfacing operations and frozen ballast conditions. Some of the data was collected during the winter months, and during surfacing operations. The changes in modulus after the surfacing operations are clearly evident. The dolomite was surfaced out-of-face at 40 and 160 MGT, the limestone was surfaced at 70, 160, and 225 MGT, while the granite and traprock were surfaced at 160 MGT.

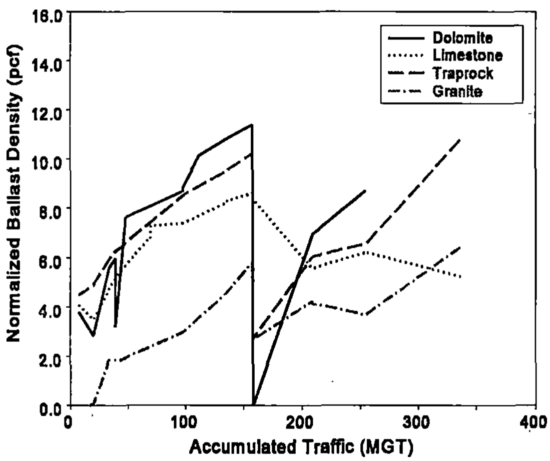


Figure 6. Normalized Ballast Density — High Rail

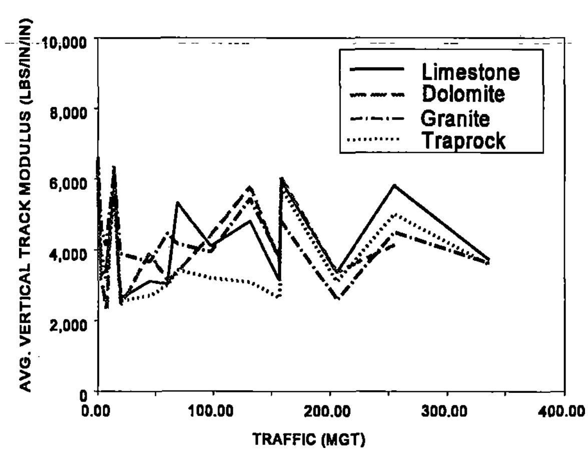


Figure 7. Average Vertical Track Modulus — High Rail

Figure 7 shows the average track modulus values for the high rail. The ranges for both the low and high rail were between 3,000 and 4,000 lb/in/in.

Sieve Analysis

Sieve analysis results for data collected for all four ballasts are shown in Figures 8 through 18 (placed at the end of this paper). Figures 8 and 9 show the results under 39-ton axle load traffice for the dolomite and granite ballasts, installed in ballast bins. Gradation results also show the damage due to tonnage and damage caused by tamper tools. Figures 10 through 13 compare the gradation analysis of the ballast tested under 33- and 39-ton axle load traffic. The 33-ton results were collected during the first ballast experiment at FAST.[4] Figures 14 through 18 compare the gradation analysis of the granite ballast tested under 33- and 39-ton axle load traffic. The 33-ton data was collected during the second ballast experiment at FAST.[2]

Ballast Bins

The ballast bins that were placed in the dolomite test zone remained in track only up to 40 MGT of HAL traffic. Before removal, the bins required daily tamping due to constant loss of track geometry in this area. The bins placed in the granite test zone did not experience any loss of geometry retention during the full 386 MGT of HAL traffic.

Figure 8 shows the sieve analysis results from the ballast bins in the dolomite zone removed after 46 MGT of HAL traffic. The control bins, which were tamped once after installation in track, show very little degradation. However, the bins that accrued the same tonnage and tamped at 0, 7.2 , 39 and 46.4 MGT show an increase in ballast breakdown. Because both the control and tamped bins were exposed to the same traffic application, were located in closed proximity, and were isolated from any contamination, a conclusion was made that the major difference in breakdown was generated by the cyclic tamping.

The ballast gradation analysis from the ballast bins in the granite test zone, shown in Figure 9, show an increase in the ballast breakdown in the tamped ballast bins. The granite ballast was exposed to an additional tamping cycle and additional 386 MGT. The measured granite ballast breakdown in the tamped bins was about the same as the measured breakdown in the tamped dolomite bins.

The ballast breakdown in the control bin shows no measurable breakdown. Again both the control and tamped bins were exposed to the same traffic and isolated from outside contamination. Reinforcing that tamping greatly increases ballast breakdown.

Ballast Samples

Ballast breakdown data results collected under 39- and 33-ton showed no major difference in most ballasts due to the increase in axle loads. Gradation analysis for these data are shown in Figures 10 through 13.

The ballast particle degradation under the 39-ton traffic is higher for the dolomite ballast. This difference may exist because ballasts originated from different quarries. Because the dolomite in the HAL test was removed from test early, results for 282 MGT of 39-ton traffic are compared with the data under 33-ton data, which has 350 MGT of traffic. The dolomite ballast used in the first ballast experiment had an AREA 4 gradation and originated from Illinois, while the ballast used in the HAL experiment had an AREA 24 modified gradation and originated from Wyoming.

Both limestone ballasts tested during the HAL and first ballast experiment originated from Indiana. However, an AREA 3 gradation was used in the HAL experiment, while the first ballast experiment had an AREA 4 gradation. The breakdown of the ballast, shown in Figure 11, is greater under HAL traffic.

The particle breakdown for the granite ballast tested during the first ballast appears to have been greater than that measured during the HAL experiment, shown in Figure 12. This difference may exist because the ballasts originated from two different quarries. The ballast for the first experiment originated from Wyoming and had an AREA 5 gradation, while the ballast for the HAL experiment originated from North Carolina and had an AREA 3 gradation.

Particle breakdown of the traprock ballast tested under 33- and 39-ton axle load traffic is shown in Figure 13. There is little difference in the particle breakdown on the traprock ballast tested during the first ballast and HAL ballast experiment. Both ballast had an AREA 4 gradation. The first ballast test traprock originated from Pennsylvania, while the HAL ballast originated from Massachussets.

Ballast particle breakdown was compared with ballast tested under 33-ton traffic using the granite ballast tested under HAL traffic. There appears to be no major increase in particle breakdown on the granite ballast tested under HAL traffic in comparison to the five granites tested during the second experiment. The granite ballast tested under 39-ton traffic had an AREA 3 gradation and originated from North Carolina.

The North Carolina granite, Granite I, had an AREA gradation between 3 and 4. Figure 14 shows the particle breakdown for both 33- and 39-ton axle load tests. There appears to be no increase in breakdown due to the increase in axle load.

There appears to be more particle breakdown on the Minnesota granite (granite II) tested under 33-ton traffic than granite tested under 39-ton axle load traffic, Figure 15.

There is little difference in the breakdown of the Georgia granite, Granite III, and the HAL North Carolina granite. Figure 16, shows the gradation analysis for both ballasts. The gradation difference between the HAL ballast, AREA 3, and the Georgia granite, AREA 24, is also evident.

Granite IV, Arkansas granite, and the HAL granite also show little difference in particle breakdown, shown in Figure 14. The Arkansas granite had an AREA gradation between 3 and 4.

The Wisconsin quartzite, Granite V, shows a greater particle breakdown under 33-ton traffic than the North Carolina granite ballast tested under HAL traffic. Gradation is shown in Figure 18.

CONCLUSION

All four ballast materials have been able to withstand the heavy axle load environment at varying accumulated tonnage in the FAST environment. The good performance of the ballast may be due to the semi-arid climate, which averages about 12 to 14 inches of precipitation a year, and the controlled environment; i.e, no lading contamination, at FAST.

Only limited comparisons between 33- and 39-ton axle load traffic can be made due to differences in the quarry source or gradation size in the ballasts tested at FAST. The limestone ballast tested during the first ballast experiment and the ballast tested under HAL traffic originated from the same quarry but had a different initial AREA gradation. Particle breakdown on this ballast type was higher under HAL traffic. However, there appears to be no difference in ballast breakdown between the North Carolina granite tested under 33- and 39-ton axle load traffic. Particle breakdown for this ballast appears to be more dependent on accumulated tonnage than on increase axle load.

One apparent drawback discovered during the HAL experiment was that lower quality ballast, namely the dolomite and limestone, required an out-of-face surfacing before reaching 100 MGT of traffic. The dolomite ballast also required frequent spot maintenance in areas where profile anomalies were present.

Results from the gradation analysis on samples removed from the ballast bins also show that the particle breakdown increases significantly with tamping cycles.

REFERENCES

1. Wah Tung, Kok. "An Investigation of the Causes of Railroad Ballast Fouling." Geotechnical Report No. AAR 89-359P. Graduate School of the University of Massachusetts, May 1984.

2. Heiss, J. "Ballast Testing at FAST: 1976-82," FRA/ORD-84/18, August 1984.

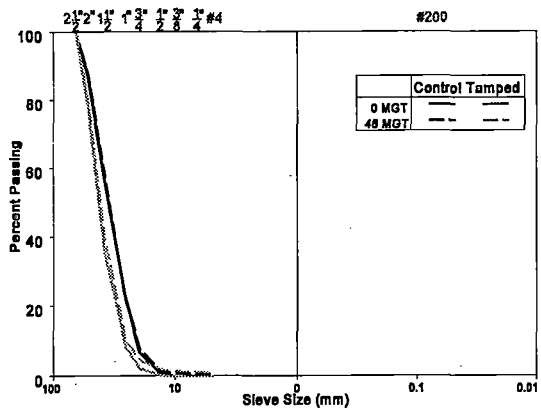


Figure 8. Gradation Analysis on Dolomite Ballast Removed from the Ballast Bins

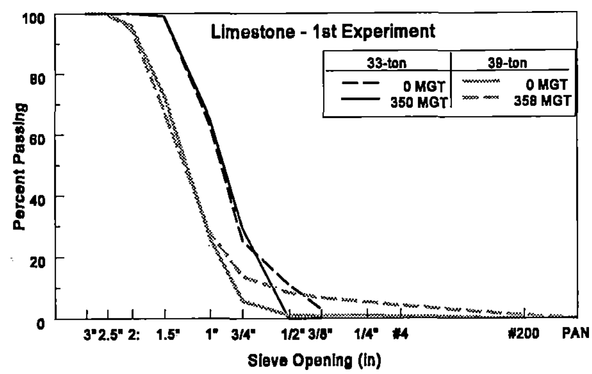


Figure 11. Limestone Gradations — 1st Experiment/HAL Experiment

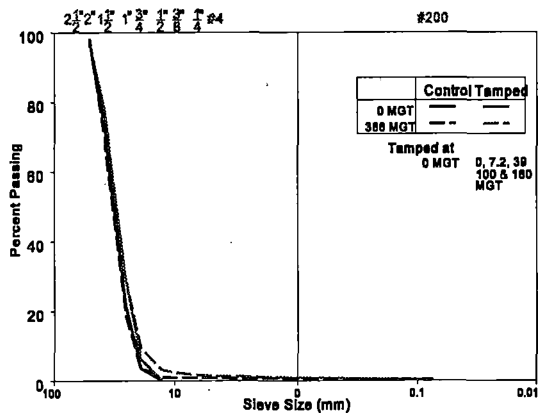


Figure 9. Gradation Analysis from Granite Ballast Removed from Bins

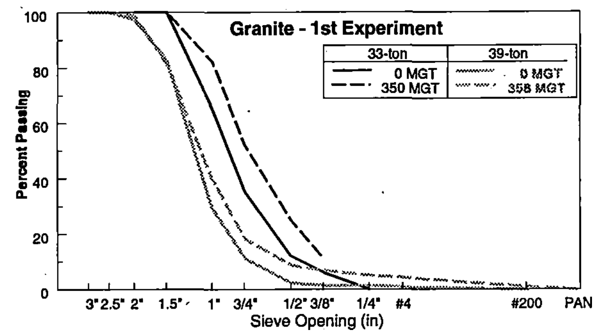


Figure 12. Granite Gradation — 1st Experiment /HAL Experiment

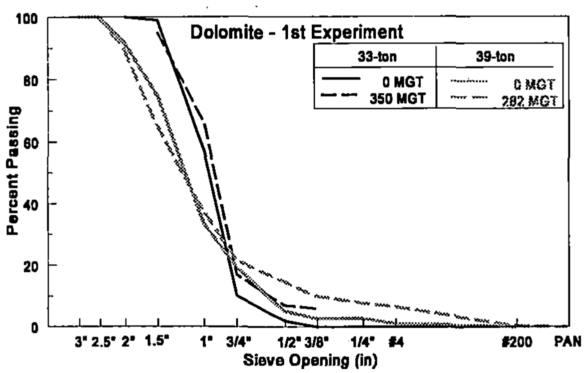


Figure 10. Dolomite — 1st Experiment/ HAL Experiment

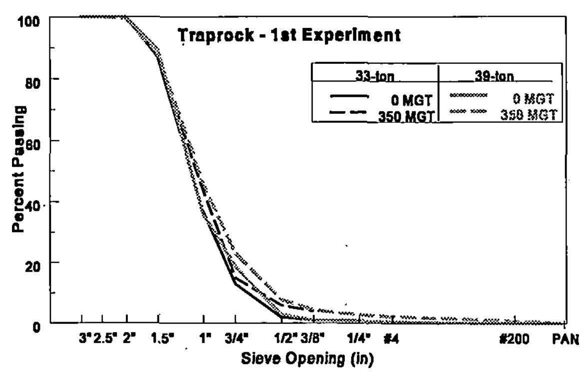


Figure 13. Traprock Gradations — 1st Experiment/HAL Experiment

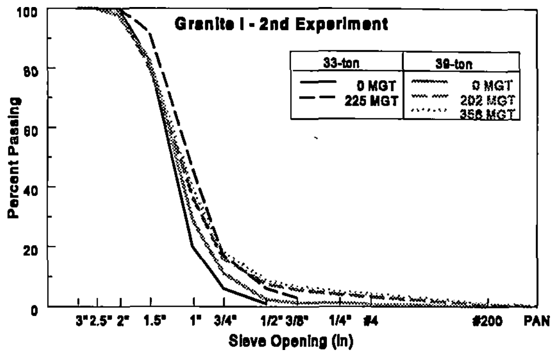


Figure 14. Granite I Gradation — 2nd Experiment/HAL Experiment

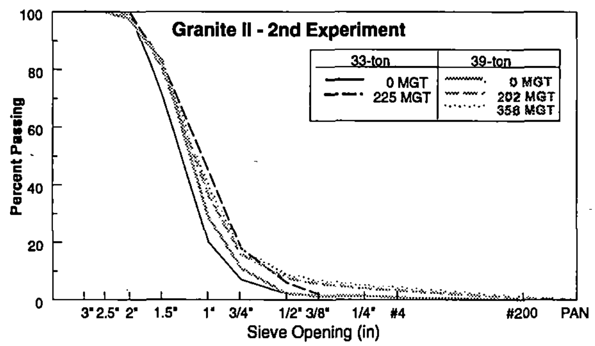


Figure 15. Granite II Gradation — 2nd Experiment/HAL Experiment

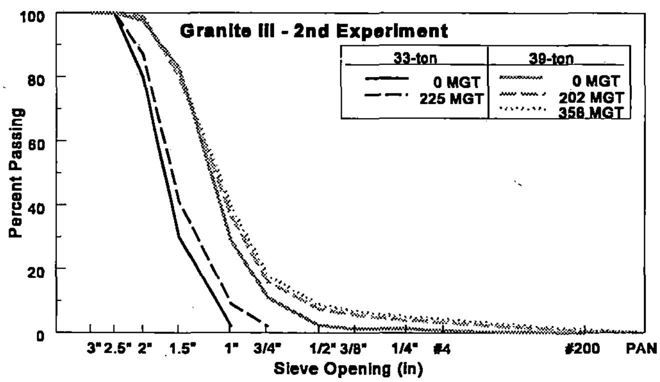


Figure 16. Granite III Gradation — 2nd Experiment/HAL Experiment

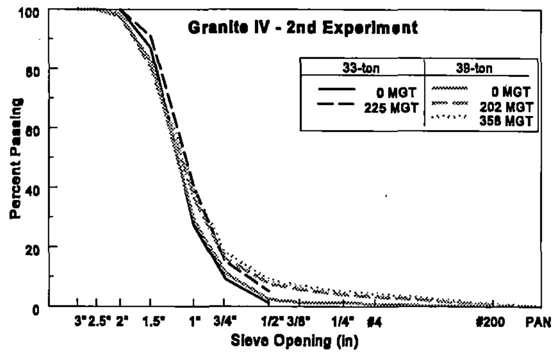


Figure 17. Granite IV Gradation — 2nd Experiment/HAL Experiment

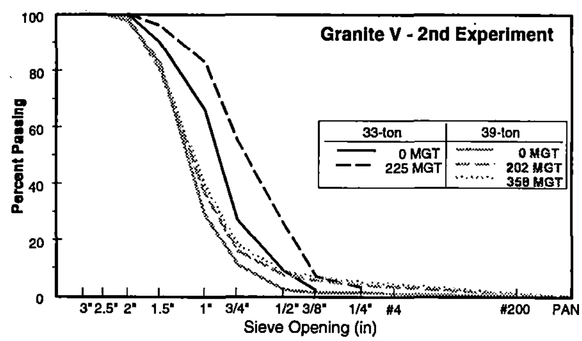


Figure 18. Granite V Gradations — 2nd Experiment/HAL Experiment

"Low Track Modulus and Load Path Evaluation Experiment Summary,"

by David M. Read,
M. Carmen Trevizo and
Dingqing Li

Summary

A low track modulus (LTM) test zone (nominal track modulus of 2,000 lb/in/in) was installed in 1991 to determine heavy axle load effects on low stiffness track. Results indicate that track modulus less than 2,000 lb/in/in is not adequate for sustained operation of 39-ton axle loads. Track modulus between 2,000 lb/in/in and 2,500 lb/in/in was marginal for heavy axle loads, requiring frequent maintenance cycles.

Subgrade pressures of 10 psi to 20 psi were measured under the heavy axle load consist in both soft and firm subgrades. These pressures exceed the strength of many low strength soils. Other test results show that a strong relationship exists between track profile geometry and vertical wheel forces from standard three-piece trucks. This data will be useful in evaluating advanced truck designs at the Facility for Accelerated Service Testing (FAST).

The original LTM design included 12-inch ballast and 6-inch subballast layers over a low-strength clay subgrade. Surfacing to correct cross-level deviations was required at 10 to 15 MGT intervals during the first 60 MGT of operation over the zone. At 60 MGT, the subballast thickness was increased to 15 inches to reduce stresses in the subgrade. Initial geometry degradation of the rebuilt zone was minimal until 9 MGT, when the profile and cross-level deteriorated significantly as the HAL train operated during a heavy rain. The zone was surfaced and traffic resumed; however, rapid geometry degradation continued and the zone was removed from service at 14 MGT for investigation and correction.

INTRODUCTION AND CONCLUSIONS

The natural silty-sand soil at the Association of American Railroad's (AAR) High Tonnage Loop (HTL) in Pueblo, Colorado provides an excellent subgrade for railroad track support. Consequently, the track modulus and stiffness of the HTL is believed to be higher than much of revenue track. Although the relationship between track modulus and track performance has not been firmly established, it is likely that much track maintenance expense is related to deficiencies in the track substructure which allow large deflection under load. To gain as complete a determination as possible of track performance under heavy axle loads (HAL), a low track modulus (LTM) test zone was designed and constructed on the HTL at the AAR's Transportation Technology Center (TTC) in 1991. The purpose of the LTM zone was to simulate lower-end, but not worse case, mainline track support conditions. A track modulus of 2,000 lb/in/in was used as the target value for the LTM design and construction. A control zone with modulus of approximately 5,000 lb/in/in was also established.

In addition to quantifying track geometry degradation, the LTM and control zones were equipped with instrumentation to measure vertical load path characteristics. A measurement cell was installed in both zones to collect vertical rail force, vertical rail seat force, and ballast/subgrade pressure data. Load path data was collected under a consist of equal numbers of 33- and 39-ton axle load vehicles.

Test results indicate that track modulus of less than 2,000 lb/in/in will not support sustained operations of 39-ton axle load traffic. Subgrade pressures of 10 to 20 psi were measured in both the LTM and control zones under HAL cars, which exceeds the strength of many subgrade soils.

DESCRIPTION OF TEST ZONES

The LTM and control zones are located in Sections 29 and 33, respectively, in the HTL (Figure 1). The LTM zone (600 feet long) and the control zone (475 feet long) are both located on tangent track. The HTL bypass track is located adjacent to the zones on 20-foot track centers.

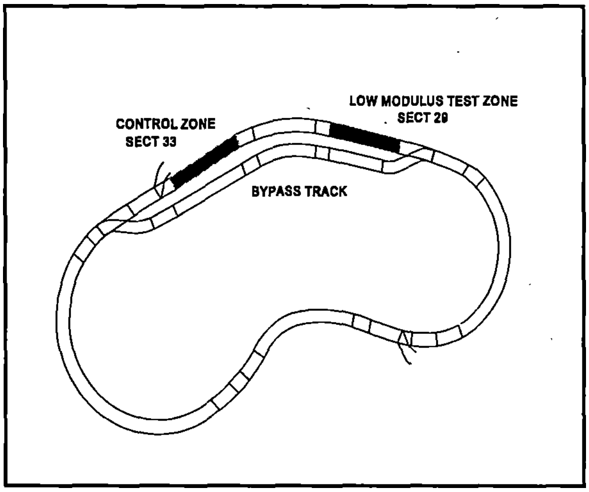


Figure 1. Location of LTM and Control Zones on the HTL

Track components above the subgrade are identical in both zones and include:

- 136-pound Continuous Welded Rail (CWR).
- 7"x9"x8'6" hardwood ties (primarily second-hand) with cut spikes, AREA tie plates, and every other tie box anchored.
- Granite ballast, AREA 4 gradation.
- Six-inch thick subballast layer of well-graded sand with gravel.

The control zone was constructed on the existing HTL subgrade. Tonnage over the control zone subgrade at the time of construction was in excess of 1,000 MGT.

LTM Zone Design

The concept of the LTM design was to modify the existing subgrade in Section 29 to create a track segment with a nominal modulus of 2,000 lb/in/in. GEOTRACK (an elastic multi-layer model for the analysis of railroad track structures under vertical wheel loading) analysis was used to evaluate various design parameters.[1] The analysis predicted that the target track modulus was possible by installing a 5-foot-thick layer of low stiffness clay beneath the subballast. The analysis assumed resilient modulus of the existing subgrade to be 15,000 to 30,000 psi and resilient modulus of the clay as 2,000 to 3,000 psi.

As shown in Figure 2, the final design specified that the clay be placed in a 12-foot wide by 5-foot deep trench located symmetrical to the track center line. The sides and bottom of the trench were lined with a 20-mil PVC liner to prevent loss of clay moisture to the surrounding soil. A 6-inch-thick layer of compacted subballast material was placed on top of the clay.

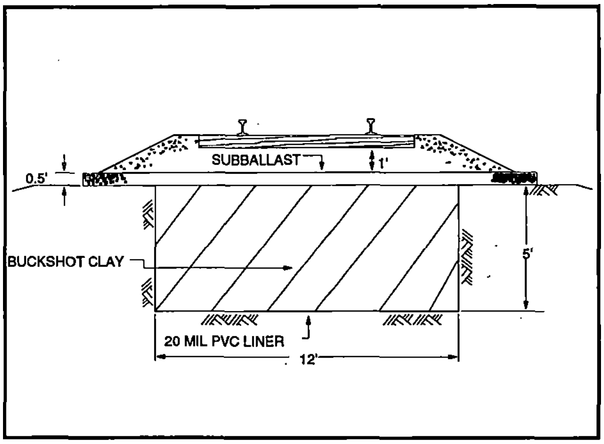


Figure 2. LTM Zone Cross Section

The clay selected for the trench was a high plasticity clay obtained from the Vicksburg, Mississippi, and known locally as "buckshot" clay. The Army Corps of Engineers Waterways Experiment Station (WES) in Vicksburg had used this soil extensively for pavement research and its properties were well defined. Sample data provided by WES[2] characterized the clay as follows:

- High plasticity clay, CH by the Unified Soil Classification System with 97 percent passing No. 200 sieve
- Plasticity Index (PI) 38 to 45 and Liquid Limit (LL) 58 to 68
- 2.71 Specific Gravity
- 92 lb/cu ft maximum dry density and 23 percent optimum moisture content (standard Proctor)

Lab tests indicated the resilient modulus of the clay to be in the range of 2,000 to 3,000 psi at 30 percent moisture content and deviator stress of 10 psi.[3] These values were consistent to the resilient modulus values used in the analysis.

The LTM zone was constructed by removing the existing rail, ties and ballast and excavating the trench. The clay was installed in nominal 12-inch lifts at 30 to 33 percent moisture content using a small bulldozer to spread and compact the clay. The average track modulus of the LTM and control zones measured immediately after construction was 2,400 lb/in/in and 6,900 lb/in/in respectively. These values were calculated using the track stiffness between applied single point loads of 10,000 and 40,000 lb to remove non-linearity in the stiffness curve due to slack in the track structure.

LOAD PATH EVALUATION

As the LTM and control zones were being constructed, instrumentation was installed in each to measure the distribution of dynamic vertical forces transferred to the track structure. The instrumentation array is shown in Figure 3 and included the following transducers:

- Rail mounted strain gages to measure vertical rail force
- Instrumented tie plates to measure vertical rail seat force
- Pressure cells located beneath the rail seat at the subgrade/ subballast interface to measure subgrade pressure

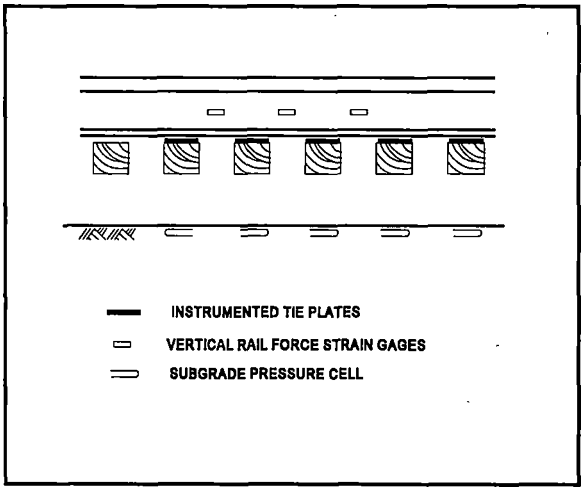


Figure 3. Typical Load Path Evaluation Instrumentation Layout

Data was collected four times between 1991 and 1995. The consist included a block of fourteen 33-ton axle load cars and a block of fourteen 39-ton axle load cars during each measurement cycle. Approximately 10 train passes of data were collected per measurement cycle.

The distribution of 33- and 39-ton axle load vertical rail forces measured in the LTM and control zones are shown in Figures 4 and 5. The data represent all rail forces measured during the four measurement cycles. The data also reflect the 20-percent static wheel load increase and indicate a relatively low dynamic component due to track or wheel imperfections.

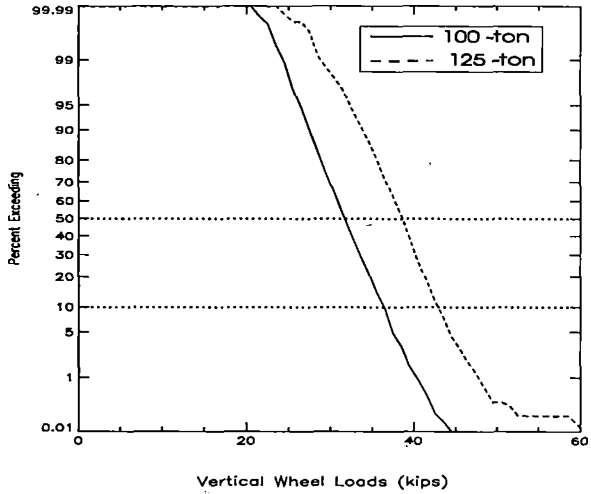


Figure 4. Vertical Rail Force Distribution for LTM Zone

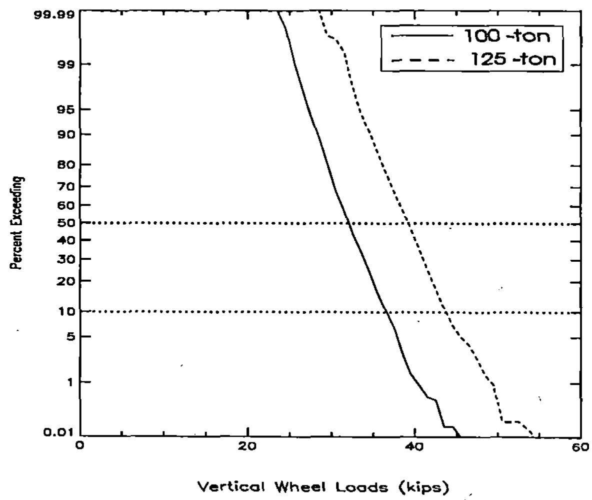


Figure 5. Vertical Rail Force Distribution for Control Zone

Vertical force at the rail seat also increased about proportionally to the axle load with 39-ton axle load cars generating about 16 percent higher forces than the 33-ton cars. In Figure 6, distribution of rail seat forces measured under 125-ton cars in the control and LTM zones during the four measurement cycles are compared. Consistently lower forces were measured in the LTM zone due to the lower track stiffness. The rail seat force at the 50th percentile level is 12 percent lower in the LTM zone and 17 percent lower at the 90th percentile level.

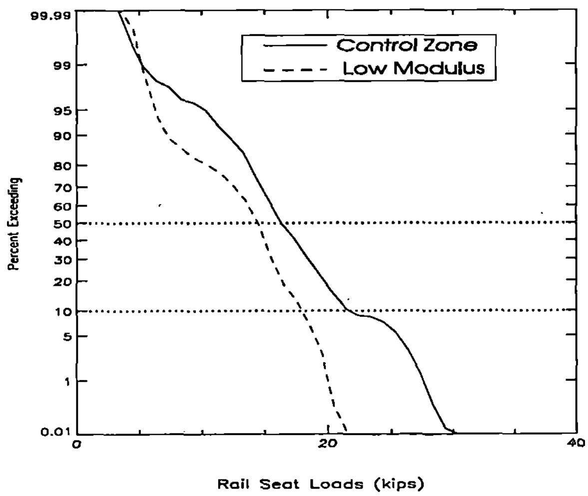


Figure 6. Rail Seat Force Distribution

Distributions of vertical subgrade pressures measured under 33- and 39-ton axle loads in the LTM zone are shown in Figure 7. As was true for the rail and rail seat forces, the increase in subgrade pressure of 15 percent was roughly equal to the increased axle load. Despite the lower track stiffness, however, the LTM subgrade pressures were not significantly lower than the control zone pressures, a trend noted with the rail seat forces and which is theoretically correct. There is no immediate explanation for the lack of pressure difference between the two zones, other than potential difference in ballast/subballast depth between the locations which could effect the pressure at the subgrade.

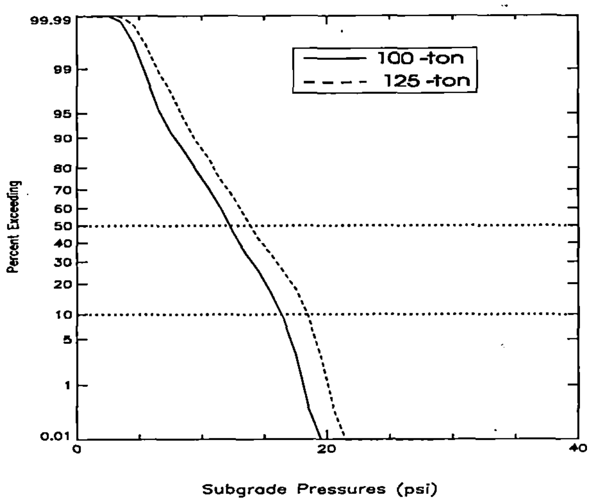


Figure 7. LTM Subgrade Pressures

LTM subgrade pressures were measured in 1995 directly after the zone had been surfaced and lined. The post-tamp pressures were higher than pressures measured during the previous cycles when the track had accumulated some tonnage after tamping (Figure 8).

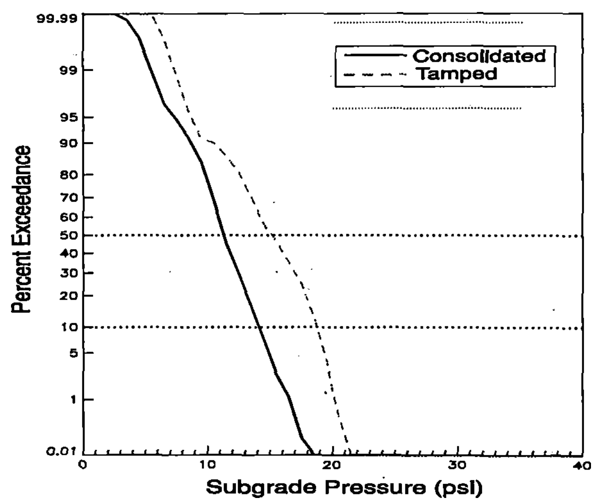


Figure 8. Effect of Tamping on Subgrade Pressures in LTM Zone

Impact Load Investigation

An investigation was performed in 1993 to measure the effects of rail impact loads, as produced by a wheel flat or battered weld, on subgrade pressure. To generate the load, a flat spot, or "divot" was ground into the rail head directly over a pressure cell tie. The depth of the flat was 0.080 inch and the length corresponded to a 19-inch radius (38-inch wheel diameter) as shown in Figure 9.

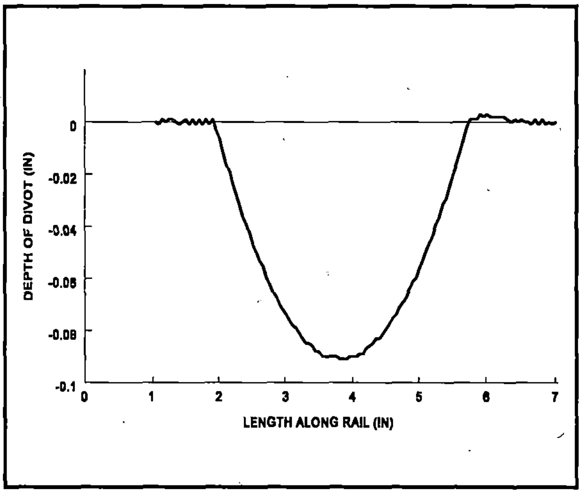


Figure 9. Longitudinal Profile of Rail Flat Spot

Subgrade pressures were first measured on the smooth rail, and then with the divot installed. Subgrade pressures increased on the order of 50 to 60 percent with the flat spot in the rail. The increase was consistent for both 33- and 39-ton axle load vehicles.

The 50th and 90th percentile values for the vertical rail force, vertical rail seat force and vertical subgrade pressures measured during the Load Path Evaluation are summarized in Table 1.

LTM TRACK GEOMETRY, TRACK MODULUS AND DYNAMIC WHEEL FORCE SUMMARY

HAL train operations began over the LTM zone in late 1991. At 12 MGT, the zone required surfacing due to cross-level deviations exceeding 1.5 inches. The zone required surfacing to correct cross-level exceptions again at 28, 37, 48 and 60 MGT. Geometry degradation in the control zone was not significant during the 60 MGT period. In Figure 10, the cross-level standard deviations measured in both zones with a Plasser EM80 track geometry vehicle are plotted as a function of tonnage. The profile (62-foot chord mid-ordinate offset) standard deviations are similarly plotted in Figure 11. As shown in Figures 10 and 11, LTM geometry maintenance was required at an average rate of 12 MGT. The relationship between cross-level deviation amplitude and track modulus as measured in the LTM and control zones is plotted in Figure 12.

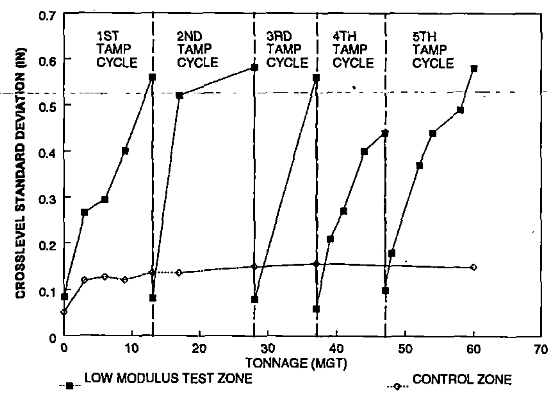


Figure 10. LTM Cross-Level Degradation as a Function of Tonnage

Table 1. Summary of Load Path Data

	Percentile	LTM Zone		Control Zone	
		33-Ton Axle Loads	39-Ton Axle Loads	33-Ton Axle Loads	39-Ton Axle Loads
Vertical Rail Force (kips)	50th	31.5	36	32.1	36
	90th	39	43.5	39	44
Vertical Rail Seat Force (kips)	50th	13	15	14.6	16
	90th	14.5	19.3	18.7	24.2
Vertical Subgrade Pressure (psi)	50th	12	13.5	9.4	11
	90th	16.4	18.5	14	15.4

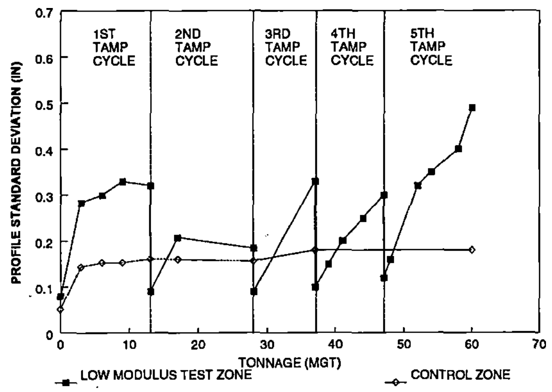


Figure 11. LTM Profile Degradation as a Function of Tonnage

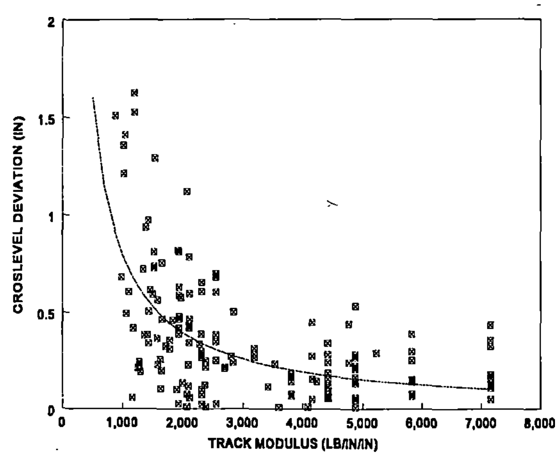


Figure 12. Relationship of Cross-Level to Track Modulus

The data points in Figure 12 represent the cross level value measured at the track modulus measurement locations in both zones. The data was taken over the 60 MGT period. Figure 12 reinforces the intuitive notion that track support and geometry performance are related.

Instrumented wheel sets were used four times during the 60 MGT period to measure dynamic wheel forces in the test zones. Two wheel sets were located in the lead truck of the same 39-ton axle load car during each measurement cycle. The truck was a standard three-piece variable damped truck, identical to most of the trucks in the HAL consist at that time. Track geometry was recorded each time the wheel set data was taken. In Figure 13, the relationship between dynamic vertical wheel force and track profile roughness is shown by plotting the wheel force standard deviation as a function of the profile standard deviation. Since data was taken on several occasions, dynamic force was measured under a fairly wide range of profile conditions. This data will be useful when comparing the performance of advanced design trucks with conventional trucks during the third phase of the HAL program.

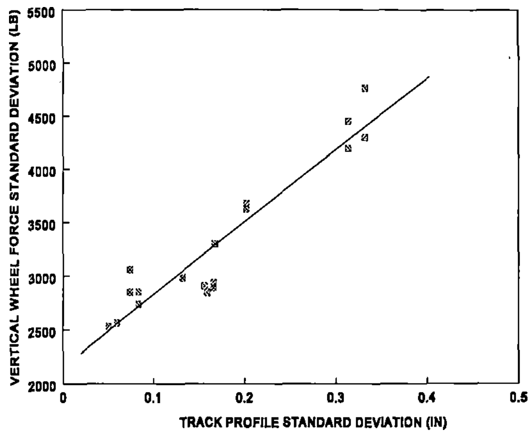


Figure 13. Relationship of Vertical Wheel Force Dynamics to Track Profile

60 MGT LTM SUBSTRUCTURE INVESTIGATION AND RECONSTRUCTION

At 60 MGT, an investigation was performed to determine the cause of the geometry degradation. Several cross trenches were opened revealing that clay was being squeezed outward from under the rail seat and tie ends, a condition referred to as subgrade progressive shear.[4] To reduce stresses in the subgrade, the original granular layer thickness of 18 inches was increased to 27 inches (12-inch ballast and 15-inch subballast). The track granular layer design model was used to determine the thickness required to reduce subgrade stresses to less than 12 psi.[5]

The new design was implemented by removing the existing track, including ballast and subballast sections, reshaping the clay surface and installing the thicker subballast layer. The subballast was placed in three lifts of 4 to 6 inches and was compacted with a vibratory roller.

FAILURE OF THE RECONSTRUCTED ZONE

Traffic resumed over the rebuilt zone with little evidence of geometry deterioration, indicating that subgrade stresses were reduced by the thicker granular layer. At 9.3 MGT, however, heavy rainfall during train operations caused a sudden increase in cross-level and inside rail profile deviations.

The zone was surfaced the day following the rain and traffic resumed. However, the geometry again degraded rapidly with traffic even though there had been no further precipitation. The inside rail was out of profile and cross level specification at 14 MGT, or less than 5 MGT after the surfacing.

The zone was removed from service and another investigation was performed to determine the cause of the track instability. Cross trenches were dug at five locations and measurements of ballast and subballast depth as well as profiles of the clay surface were taken at each location. The cross trenches revealed a great deal of free water within the subballast layer, especially under the inside rail. Measurements of clay moisture content showed no significant change since installation. Plastic deformation of the clay surface beneath the inside rail was also apparent.

It was concluded that the combination of the adjacent HTL bypass track, the impermeable clay layer beneath the subballast and the relatively low permeability of the subballast material and surrounding silty-sand native soil forced all the water to drain to the outside ballast shoulder. The relatively slow drainage allowed water to accumulate in the subballast under the inside rail.

Highway pavement research has shown that the presence of free water in a granular layer designed for structural purposes greatly limits the ability of the layer to distribute and reduce applied stresses to the underlying layer.[6]

Excessive free water in the subballast may have caused increases in train induced subgrade stresses. The higher stresses initiated plastic deformation of the clay surface resulting in track profile and cross-level deterioration. Once initiated, the deformation process became self-sustaining since water collects and is trapped in subgrade pockets or ruts at the subgrade surface. Surfacing the track in this condition provides only short term improvement as the cause of the support instability has not been corrected. With the LTM zone, the geometry was out of specification within 5 MGT of surfacing the zone.

Granular layer thickness design can be used to prevent over-stressing of weak subgrades and is a possible method of upgrading problem subgrades for HAL traffic. The design allows most of the granular layer thickness to be made up of subballast material rather than the more expensive ballast aggregate. However, as the LTM experience suggests the subballast layer can be a source of ongoing track instability if excessive free water is allowed to accumulate.

RESULTS

Results of the Load Path Evaluation and LTM experiments are as follows:

1. Track modulus less than 2,000 lb/in/in is not recommended for sustained operations of 39-ton axle loads. Modulus of between 2,000 lb/in/in and 2,500 lb/in/in should be considered marginal for HAL operations, with frequent maintenance cycles to be expected.

2. Vertical subgrade pressures measured under 39-ton axle load vehicles were in the range of 10 psi to 20 psi in both zones. The difference in subgrade stiffness did not have a significant effect on subgrade pressures, therefore, pressures in excess of 10 psi should be expected under HAL traffic.

3. Subgrade pressures increased 50 to 60 percent under impact forces generated by a 0.080-inch flat spot in the running surface of the rail head when compared to subgrade pressures under a smooth running surface.

4. Subgrade pressures measured directly after surfacing of the LTM zone, showed a 30- to 35-percent increase over pressures measured before surfacing.

5. Dynamic vertical wheel forces from a standard 3-piece, variable damped truck increased linearly with track profile roughness. The rate at which the forces increase with profile degradation will serve as a baseline for the evaluation of advanced truck design performance.

REFERENCES

1. Selig, E.T. *FAST Low Track Modulus Site Design*, AAR Consultant Report, August 1991.

2. Coleman, D.M. *Results of Laboratory Testing on Vicksburg Buckshot Clay*, AAR Subcontractor Report, October 1990.

3. Thompson, M. *Vicksbuurg Clay Resilient Modulus Testing*, AAR Consultant Report, December 1990.

4. Selig, E.T. and John Waters, *Track Geotechnology and Substructure Management*, Thomas Telford, 1994.

5. Li, D. *Railway Track Granular Layer Thickness design Based on Subgrade Performance Under Repeated Loading*, Ph.D. Dissertation, University of Massachusetts, 1994.

6. Cedergren, H.R. *Seepage, Drainage, and Flow Nets*, John Wiley and Sons, Third Edition, 1989.

"FAST HAL Alternative Suspension Systems Project,"

by Curtis L. Urban

Summary

As a result of a three-year effort which began in 1992, the Association of American Railroad's (AAR) Strategic Research Initiative test program titled "Alternative Suspension Systems Project" has successfully selected and re-equipped the Facility for Accelerated Service Testing (FAST) train at the AAR's Transportation Technology Center in Pueblo, Colorado, with three advanced truck designs for Phase III.

The intent of the project was to evaluate and quantify the improvements of advanced truck designs, install them into the existing FAST train and demonstrate improvements over the existing three-piece truck designs currently installed in the FAST train. At the peak of the investigation, 10 advanced truck designs were considered. All of these designs were modeled using NUCARS, some were tested on the High Tonnage Loop (HTL) at FAST, and through a limited number of Chapter XI test regimes, were used to select the trucks for Phase III of FAST.

From this research three advanced trucks were selected:

- Standard Car Truck's (SCT) heavy duty (HD) S-2-HD cross bracing design with variable column damping and a D5 suspension with double side coils and a primary suspension shear pads.
- Buckeye Steel Casting's XC-R VII design with constant column damping equipped with a D5 suspension hydraulic dampers and a primary suspension
- American Steel Foundries' (ASF) AR-1 constant column damping with a D5 suspension, hydraulic dampers and primary suspension shear pads.

In the next phase of FAST, the intent is to further quantify the operating and economic benefits of 39-ton axle loads by examining the degradation of the track structure using improved three-piece trucks. With this knowledge, the industry can answer the long standing question "Is it economical to operate 39-ton axle loads with improved equipment?"

INTRODUCTION AND CONCLUSIONS

As a result of a three-year effort that began in 1992, the Association of American Railroad's (AAR) Strategic Research Initiative test program titled "Alternative Suspension Systems Project" has successfully selected and re-equipped the Facility for Accelerated Service Testing (FAST) train at the AAR's Transportation Technology Center (TTC) in Pueblo, Colorado, with three advanced truck designs for Phase III. All of these designs were modeled using **NUCARS**, tested on FAST High Tonnage Loop (HTL), and through a limited number of Chapter XI test regimes, to select the trucks for Phase III of FAST.

The intent of the project was to evaluate and quantify the improvements of advanced truck designs, install them into the existing FAST train and demonstrate improvements over the existing three-piece truck designs used during FAST Phase II. Out of 10 advanced truck designs considered, the following three advanced trucks were selected:

- Standard Car Truck's (SCT) heavy duty (HD) S-2-HD cross braced design with variable column damping, D5 suspension with double side coils, and a primary suspension
- Buckeye Steel Casting's XC-R VII design with constant column damping equipped with a D5 suspension, hydraulic dampers, and a primary suspension, and
- American Steel Foundries' (ASF) AR-1 constant column damped design equipped with a D5 suspension, hydraulic dampers, and a primary suspension.

TRUCK MIXTURE

All remaining 55 high-sided gondola cars loaned to the AAR by the Union Pacific Railroad (UP) are equipped with the advanced truck designs. The remaining FAST fleet made up of 23 39-ton axle load tank cars are currently undergoing retrofitting. Due to time restraints, and test schedules imposed on the FAST program, only four AR-1 cars will be equipped in the train. The remaining cars will be made up with a 50-50 split of S-2-HDs and XC-R VIIs designs.

The FAST Steering Committee and the AAR directed the selection process which consisted of a four phase approach: (1) soliciting designs, (2) **NUCARS** modeling evaluations, (3) initial prototype evaluation conducted on the FAST High Tonnage Loop (HTL), and (4) abbreviated Chapter XI test for final selection. Figures 1-3 , which consist of FAST HTL and Chapter XI tests conducted from July to November 1994, are examples of the on-track test results obtained from the three trucks selected for FAST.

The trucks' manufacturers assisted TTC technicians during the initial installation process to ensure that the trucks were installed properly.

FAST HTL TEST RESULTS

Figure 1 shows the loaded curving test results from the test conducted on the FAST HTL. It represents an exceedence plot of lateral wheel set forces collected using two 38-inch instrumented wheel sets with a worn wheel profile for the entire FAST 2.72 mile loop. The runs were collected using the standard FAST lubrication conditions. Friction levels on the gage face ranged from 0.15-0.2 and both high and low rail head values ranged from 0.4-0.45. Friction readings were obtained at three locations (Sections 3, 7, and 25) around the loop during testing. *Note: All tests were conducted with the same instrumented wheel sets.*

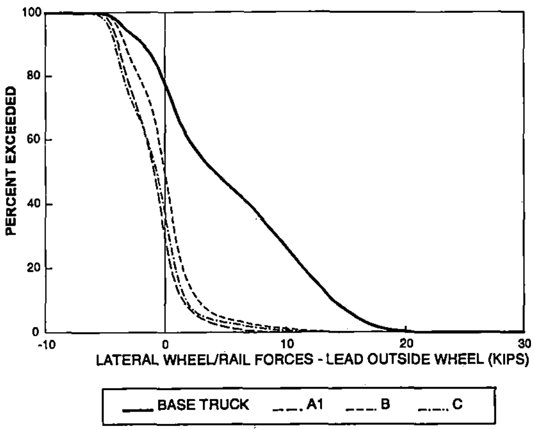


Figure 1. FAST HLT Test Results Lateral Wheel/Rail Force Distribution for the Entire FAST Loop

Refer to the description below for Figure 1.

A1 - American Steel Foundries AR-1 Radial Steering Design

B - Standard Car Truck's S-2-HD Cross-Frame Design

C - Buckeye Steel Casting's XC-R VII Design

FAST Base car - National Casting's Super C-1 Wedgelock Design

The average degree of curvature for the FAST loop was computed to allow for comparisons with other track tests. The FAST loop is made up of 5,183 feet of 5-degree curve, 2700 feet of 6-degree curve, and approximately 2,400 feet of spiral curves and turnouts. The remaining 6,486 feet are tangent track sections. This results in an average curvature of 3.35 degrees for the loop.

Figure 1 shows the wheel/rail forces for the lead axle outside rail. The percent exceedence distribution plot is an indication of the range of forces and the percentage of data greater than the minimum values indicated. These results show the significant improvement in curving performance of the three advanced designs when compared with the base car/truck design.

Of particular interest is the maximum force levels in the 5 to 50 percent range. At the 50 percent level, the base car is at approximately 5 kips of lateral load while the advanced suspensions are slightly negative or zero. This indicates that the new designs are steering and from the lateral loads of the

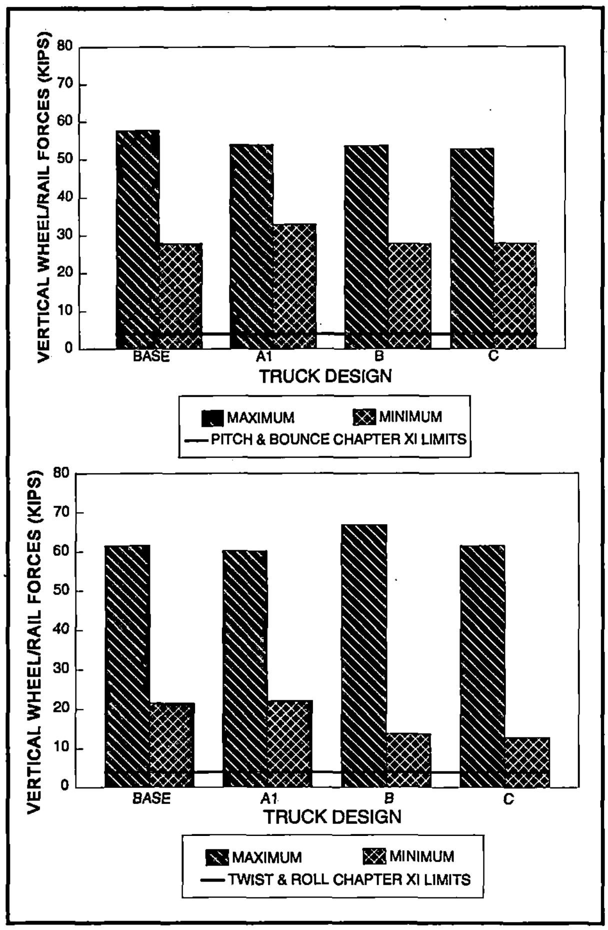


Figure 2. Pitch and Bounce and Twist and Roll Test Results: Maximum and Minimum Vertical Wheel/Rail Forces at 40 mph

trailing axles (Not Shown) are not warping. All of the designs were equipped with primary suspensions which provided some level of passive steering and vertical force attenuation at the bearing adapter. Other designs, not accepted as the final three, showed performance in the range between these advance designs and the base car levels.

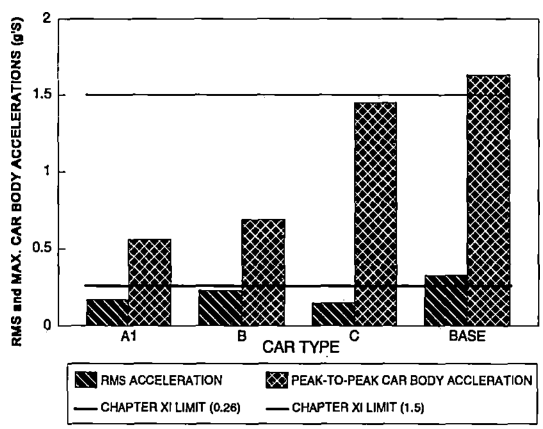


Figure 3. Hunting Test Results: Maximum Lateral Car Body RMS Accelerations and Maximum Peak-to-Peak Lateral Car Body Accelerations

During all phases of testing, wayside lateral and vertical wheel/rail forces as well as angle-of-attack (AOA) measurements were taken. The measurements obtained in Section 25 at tie number -1165, occurred on a 6-degree left hand curve. The rail profile at this location is ground to ensure two-point contact between the wheel and rail. This sets up an ideal test condition to ensure that the trucks tested can negotiate track section with the worst of conditions. The steering forces can be severely hampered depending on the severity of the two-point contact grind. All measurements taken in this section showed that the advance trucks selected had improved performance when compared to other designs.

Pitch and Bounce, and Twist and Roll Test Results

Pitch and bounce and twist and roll are Chapter XI safety evaluation test regimes conducted to ensure that the vehicle/truck combination can damp out any unwanted oscillations. The vehicle is operated at speeds ranging from 10 mph to 70 mph over a set of perturbed test sections to initiate the desired response. The test sections are constructed on the Precision Test Track with 10 in-phase (pitch and bounce) 39-foot vertical sinusoidal 0.75-inch amplitude inputs, or 10 out-of-phase (twist and roll) inputs. All of the selected designs passed the Chapter XI tests.

The pass/fail criterion for pitch and bounce requires that no vertical wheel forces drop below 10 percent of the static load. The criteria for twist and roll also requires that the vertical wheel forces must remain above the 10 percent static level and that the car body roll angle does not exceed 6 degrees peak-to-peak. Figure 2 shows the test results obtained at 40 mph. This is of particular interest to the FAST program because the standard operating speed is 40 mph.

Keeping in mind that the test results are obtained from 10 repeated track perturbations not likely to occur at FAST, all trucks performed nearly the same. Also, Trucks A1 and C are equipped with hydraulic damper whereas Truck B is not.

Lateral Stability (Hunting)

Hunting is initiated by lateral shifts of the wheel set relative to the rail. This introduces a rolling radius difference between the wheels, thereby causing a yaw angle. The wheel set that moves toward the flange then has the greatest rolling radius which causes the wheel set to steer toward the opposite rail. Eventually this sets up an uncontrolled dynamic oscillation that increases with speed.

These tests were also done to ensure that the use of primary suspensions did not degrade the trucks' ability to damp out unwanted lateral oscillations during tangent track or high speed operations. All tests were conducted with an empty UP- high sided gondola car currently used at FAST.

All of the advanced trucks passed the Chapter XI test for hunting stability except the base truck. These tests were conducted on the Railroad Test Track from stations R-39 to 33 using an identical car body and set of AAR-1B wheel profiles. Only the trucks were changed from test to test. To ease interpolation of the results, the Chapter XI safety limits for RMS and peak lateral car body accelerations have been added. The criterion for pass/fail is that car body Root Mean Square (RMS) lateral accelerations cannot exceed 0.26 and car body accelerations cannot exceed 1.5 peak-to-peak, for a 2000 foot section of track.

POTENTIAL BENEFITS

Repeatability

The friction wedge arrangement is a cheap and inexpensive method of providing damping to the standard three-piece truck. But for years, the industry has been plagued with problems caused by using friction wedges to control dynamic oscillations. These wedges can provide a sufficient amount of damping for a given level of oscillation. As the oscillations increase beyond a level where the damping provided by the friction wedge is insufficient, the dynamic oscillations will increase without bound. This might be acceptable given that the service is bulk commodities where the only concern is the occasional derailment, but it is certainly not acceptable for autorack or intermodal service.

The friction wedge provides both damping and a measurable amount of truck squaring. As the wedge wears the damping and squareness of the truck diminishes with time, the net effect is reduced performance and reliability with wear on the standard three-piece truck design.

The advanced truck designs include devices to improve vertical performance such as hydraulic dampers and long travel constant contact side bearings. Steering has been improved with the use of radial and cross bracing arrangements. All of these devices with time will allow for a more repeatable and reliable level of performance.

Cost benefit analysis presentations for the Heavy Axle Load of Advanced Freight Trucks Project have been given on several occasions by the AAR. Preliminary economic analysis conducted using test data indicates net present value (NPV) savings of up to $9,000 per car set. The bottom line for this type of analysis is paying a larger premium up front to save dollars in the future. These saving are in the form of reduced fuel consumption, repairs to track and trucks, and wheel/rail life. Preventing derailments and possible loss of life offer cost savings which are immeasurable.

Reduced Curving Resistance

When the new test trucks were initially installed into the train, wayside lateral, vertical wheel/rail forces and AOA measurements were taken to ensure that the trucks were operating properly. An energy study to measure the curving and tangent resistance of 10 cross-frame trucks against 10 conventional three-piece trucks was included in these initial tests. Data was obtained for the entire FAST loop and two tangent test sections on the Railroad Test Track. From these initial test there was a 25 to 30 percent reduction in the force required to pull the consist on dry rail.

There is a direct correlation between reduced coupler force and reduced lateral wheel rail forces. Reduction of lateral forces during curing indicates reduced wheel/rail wear, fastener fatigue, tie plate or concrete shoulder wear, and ballast degradation. With reduced track damage, there is an equivalent reduction in truck and car body wear and fatigue.

Truck A1 (ASF's AR-1) is a passive radial steering design which is a slight modification of the DR1 design from years past. ASF has re-engineered the 33-ton axle load design into the current 39-ton axle load application. The design utilizes a standard three-piece Ride Control Truck© with constant column damping and the proper modifications to the side frames to allow for the addition of the steering arms. The steering arms are connected to the wheel set at the bearing adapters location and are in the shape of a C. The steering arms mounted on the lead and trail axles are then in turn connected to each other via a steel pin and rubber bushing arrangement in the rod through the area of the bolster. This arrangement provides a high inter-axle shear stiffness and low inter-axle bending stiffness. The overall suspension can then be "tuned" using a range of primary pad stiffness values. Standard roller side bearings are also part of this design.

Truck B (SCT's design) utilizes a standard variable column damped Barber S-2-C design that has been upgraded to a more robust heavy duty version, the S-2-HD. This particular design has an added feature, the cross-brace which was first introduced to the industry by Roy Smith during his Urban Transportation Development Corporation (UTDC) days. The cross-brace connects the left and right side frames together via a set of steel tubular frame members. The addition of the cross-frame, effectively increases the warp/shearing stiffness of the truck. The effective stiffness can then be "tuned" by the use of rubber washers at the side frame attachment points to acquire the desired performance. The resulting cross frame is soft in torsional and vertical bending to allow the three-piece truck to load equalize. A primary suspension in the form of a rubber shear pad has been added at the bearing adapter to side frame location to provide passive steering and vertical force attenuation. Roller side bearings are also utilized in this design.

Truck C (Buckeye's XC-R VII design) is a conventional three-piece truck with constant column damping. The added feature is an increased friction wedge surface area and a larger control coil force that results in an increased squaring stiffness. Hydraulic dampers and constant contact side bearings with roller assist are also used in this design to reduce car body roll. Primary suspensions with the appropriate stiffness have been added to provide some passive steering and vertical force attenuation.

Base Car (National Castings Super C1 Wedgelock) was the base truck used for all the 39-ton axle load tests conducted on the FAST HTL before November 1995. This is a 1970 design with constant column damping equipped with a D5 suspension. As the test progressed in later years, a mixture of Super C1's and other truck designs were incorporated.

When the cars first arrived at TTC, they were equipped with CCSB, but were later changed to roller side bearings. This allowed for a direct comparison between test results obtained with the 33- and 39-ton axle load equipment. Nearly all of the cars in the 33-ton axle load test were equipped with roller side bearings.

TRUCK SELECTION PROCESS

The FAST test program is an industry supported test program started in 1976 with the backing and financial support of the major railroads, suppliers, Federal Railroad Administration (FRA), and the AAR. The original mission was devoted to documenting and investigating track and mechanical damage utilizing standard 33-ton axle load three-piece truck equipment. For the past several years, however, the FAST HTL track degradation test program has concentrated on track performance using 39-ton axle load cars equipped with standard three-piece trucks. These tests have been conducted on standard and premium track component structures at the TTC.

The FAST Steering Committee, currently chaired by Stan J. McLaughlin (UP), directs all the research and approves the test budgets for FAST. The committee is a unique group made up of railroad officials, railroads suppliers, FRA officials, AAR research managers and AAR engineers. In late 1991, the committee approved the following selection process to acquire the new trucks to be used in Phase III of FAST:

The selection process includes a four-phase approach: (1) design soliciting, (2) NUCARS modeling evaluations, (3) prototype evaluations using mini-tests conducted on the FAST HTL, and (4) an abbreviated Chapter XI test for final selection.

In late 1991, solicitations were made to the railroad industry and truck manufacturers for design proposals. Six truck designs were accepted by the FAST Steering Committee for evaluation using the NUCARS model and reported to the FAST Committee in November 1992.

NUCARS is the AAR's multi-body computer simulation model capable of examining almost any new or existing truck/car design over a wide range of track inputs. The model was used to examine the designs over a wide range of rigid body modes including operations on the FAST HTL and all Chapter XI regimes. The AAR's Mechanical Division M-1001 Chapter XI test procedures for the certification of new and untried cars was used to evaluate the performance of each truck design. The following dynamic performance regimes were evaluated:

- Pitch and Bounce
- Twist and Roll
- Dynamic Curving
- Steady State Curving
- Curve Entry/Exit
- Yaw and Sway

Initial Nucars Modeling

From the initial NUCARS evaluations, only two designs passed, showing only a marginal improvement over the current design. The manufacturers were then asked to reevaluate their design(s) and resubmit them by March 1993. The AAR received 10 designs from various manufacturers and suppliers that could not participate in the first investigation but were ready for this submittal. The AAR again reevaluated the designs using NUCARS and reported the results to the committee in May 1993. All 10 concepts were accepted for mini-test evaluations at FAST. Seven of the original 10 trucks proposed were tested.

First Mini-Test 1993

From July 21 through October 5, 1993, the new prototype concepts were evaluated at FAST in a mini-test consist. The mini-test train was operated for 14,000 miles of endurance and brake-in testing on the HTL. This phase of the evaluation was intended to verify NUCARS predictions in the selection process, monitor and measure the trucks performance and wear-in period, access first-hand the maintainability and identify any design deficiencies.

Improved curving performance was achieved by some of the proposed truck designs. However, higher component wear was noted in the trucks that showed improved curving performance. Curving performance data, including lateral and vertical rail force and wheel-set AOA were collected in the 6-degree curve of the HTL. Wheel flange wear was also documented for each design. The mechanical integrity of each design was also evaluated through daily inspections of critical truck components. The mini-tests resulted in the following conclusions.

- The curving performance results obtained for each truck design during the on-truck test were consistent with NUCARS modeling predictions.

- A number of designs demonstrated improved curving performance as compared to the truck designs currently being operated under the HAL cars. The improvements included reductions in lateral wheel/rail force and wheel set AOA. The reduction in lateral wheel/rail force and wheel set AOA should translate into reduced damage to the track structure.

- The remaining truck designs showed little or no improvement in terms of curving performance as compared to the truck designs currently being operated under the HAL cars. Utilizing these designs would translate into only slight reductions in damage to the track structure.

- The alternative trucks that demonstrated improved curving performance also showed the largest amount of component wear, while those designs that showed little or no improvement in curving performance showed slight amounts of wear.

- The alternative trucks that demonstrated improved curving performance also showed the largest amount of component wear, while those designs that showed little or no improvement in curving performance showed slight amounts of wear.

Even though improvements in curving performance were achieved by some of the designs, it was necessary for the manufacturers and suppliers to make modifications to correct the wear and/or performance issues identified in mini-test. The AAR presented the results from this phase of testing to the FAST Steering Committee in the fall of 1993. With approval of the FAST Steering Committee, the AAR asked the truck manufacturers and suppliers participating to again re-evaluate their design(s). This time they were asked to perform the NUCARS analysis with the aid of the AAR, report the NUCARS findings by February 1994, and deliver new prototype hardware to TTC by April 1994.

Second Mini-Test '94

Six modified alternative designs were operated in a mini-test consist from May to July 1994 for 10,000 miles starting in the spring of 1994. The curving performance and vertical dynamics of each design were also evaluated during the 10,000 mile operating period.

Based upon the wayside measurements obtained from the 10,000 miles of operation, all designs were approve for additional testing over limited Chapter XI perturbed track sections. Again, the guidelines in the

AAR's Mechanical Division M-1001 Chapter XI procedures for the certification of new and untried cars were to be used to evaluate the performance of each truck design. The test results (Figures 1-3) were presented to the FAST Steering Committee in the fall of 1994. Based upon this information and additional test results, the committee selected three advanced truck designs to be installed in the FAST train for the next phase of the HAL program.

TRUCK PURCHASE

The trucks were purchased by the FRA and the AAR as a combined industry effort. The FRA acquired the truck castings and hardware to make them functional and the AAR purchased the premium hardware. Wheel sets, bearing brakes as well as other expendable items were provided with the current FAST budget.

ACKNOWLEDGMENTS

AAR/TTC wishes to thank ASF, Standard Car Truck, and Buckeye Steel Castings for their support during this project. Special thanks to Buckeye Steel Casting for interrupting their casting schedule to produce the trucks in a timely manner.

REFERENCES

Klauser, P.E.,R.L. Florom, and C.L. Urban. "On-track Test Results for the Heavy Axle Load Alternative Suspension Program," Working Paper. *Unpublished*

Hargrove, M.B., and T.S. Guins. "Economic Evaluation of Advanced Trucks," Presentation at the Freight Car Truck for the 21st Century, Urbana, Champaign, Illinois, September 1994.

Kalay, S.F., R.L. Florom, and C.L. Urban. "Vehicle Track Systems, Program Review," November 1993.

Klauser, P.E., J. Rismantab-Sany, and C.L. Urban. "Vehicle Dynamics Predictions for the Heavy Axle Load Alternative Suspension Program," WP-165. March 1994

Klauser, P.E., J. Rismantab-Sany, and C.L. Urban. "Interim Report- Vehicle Dynamics Predictions for the Heavy Axle Load Alternative Suspension Program," Working Paper, November 1992, *unpublished.*

" Introduction of HALTraffic (286 Cars) on Revenue Service Lines: A Preliminary Analysis,"

by M. Carmen Trevizo, John D. Mazza, Duane E. Otter, and David D. Davis

Summary
Preliminary results of the Association of American Railroad's (AAR) Heavy Axle Load (HAL) Revenue Service Monitoring Program suggest that the effects of HAL traffic on revenue service lines are very similar to those experienced on the High Tonnage Loop (HTL) at the Transportation Technology Center (TTC), Pueblo, Colorado. The AAR's goal is to monitor the degradation of track and track components in revenue service and/or in environments not found on the HTL at TTC's Facility for Accelerated Service Testing (FAST). This will allow the AAR to detect and advise the industry of HAL traffic related findings not seen at FAST.

A variety of tests are being conducted in selected revenue service lines to address the following areas of concern: concrete tie performance, performance of wheels and bearings, bridge performance, turnout and component performance, wood tie degradation, and track degradation on a low modulus subgrade.

Data collected yielded the following results:

- Wheel load data sampled in 1995 on the Chicago and North Western (CNW) Powder River Subdivision and CSX Transportation (CSXT) Coal River Subdivision showed that about 13 percent of the loaded unit trains on the CNW and 10 percent on the CSXT had an average car weight per train above 286 kip. Wheel loads are being measured to monitor HAL traffic and to correlate with measured degradation rates.
- Concrete tie measurements at the rail seat area show that tie bending strains are relatively low. However, the increase in bending strains at the tie center is evident with the increase in axle loads. The increase in tie center bending strains due to the increase in axle load on the HTL (39-ton) ranged from 15 to 35 percent, while the increase in center bending strains in revenue service (36-ton) ranged from 20 to 40 percent. Lateral loads appear to have a big influence on the tie center bending strains.
- No tie degradation was measured during the three years that the Norfolk Southern wood tie test site was monitored. Lateral wheel loads measured on this 5.1-degree curve are comparable or less than those measured on a comparable curvature on the HTL track. There was very little difference in gage strength between 1993 and 1995 measurements. Because track was well maintained in this area by plugging and re-spiking any high spikes, nominal track gage degradation was measured.
- The CNW Powder River Subdivision is using premium quality Nos. 10 and No. 20 frogs to achieve longer frog life.

INTRODUCTION AND CONCLUSIONS

The Association of American Railroads (AAR) Heavy Axle Load (HAL) Revenue Service Monitoring Program is evaluating the introduction of HAL traffic (286 kip cars) on revenue service lines. The program was initiated in 1992 with the primary goal of monitoring track environments not found in the High Tonnage Loop (HTL) at the Transportation Technology Center's (TTC) Facility for Accelerated Service Testing(FAST).

A variety of tests are being conducted in selected revenue service lines to address the following areas of concern: concrete and wood tie performance, performance of wheels and bearings, bridge performance, turnout and component performance, and track degradation on a low modulus subgrade. Wheel loads are also being measured to monitor the rate at which HAL traffic is introduced and to correlate with measured degradation rates.

LOAD MONITORING

To quantify the loads over the line as HAL traffic is introduced, load monitoring stations have been installed on two different revenue service lines. One site located on a single track of the Chicago and North Western (CNW) Powder River Subdivision sees both loaded and empty coal trains. The second site located on a single track of the CSX Transportation (CSXT) Coal River Subdivision sees the same type of traffic. At each site, an automated load monitoring station collects continuous wheel load information on the passing trains.

The CNW Powder River Subdivision is almost exclusively unit coal trains. The loads, which make up about 80 percent of the tonnage, all move eastward, while the empties, which make up the remaining 20 percent of the tonnage, move westward. Track speed is 45 mph for loaded trains and typical train length is about 110 cars.

On the CSXT Coal River Subdivision, which is almost exclusively unit coal trains, the loads move in the northward direction and the track speed is 25 mph for loaded trains. Typical train length is about 200 cars.

AVERAGE CAR WEIGHT

Figure 1 shows a histogram of the distribution of average car weight per train for coal trains sampled between April 1994 and May 1995 under normal operating conditions on the CNW. Because the histogram has a valley centered about 278 kips, this car weight was selected as a break point between conventional trains and HAL trains (i.e., all loads above 278 kips are considered to be from HAL cars). Note that the number of trains loaded to above 286 kips per car is significant.

The distinction between trains with average car weights of 263 kips and 286 kips is not as well defined as one might expect. It is likely that some trains of 286-kip cars are not being fully loaded, and/or that some trains of 263-kip cars are being overloaded. Either of these practices could contribute to the significant number of trains loaded at intermediate levels.

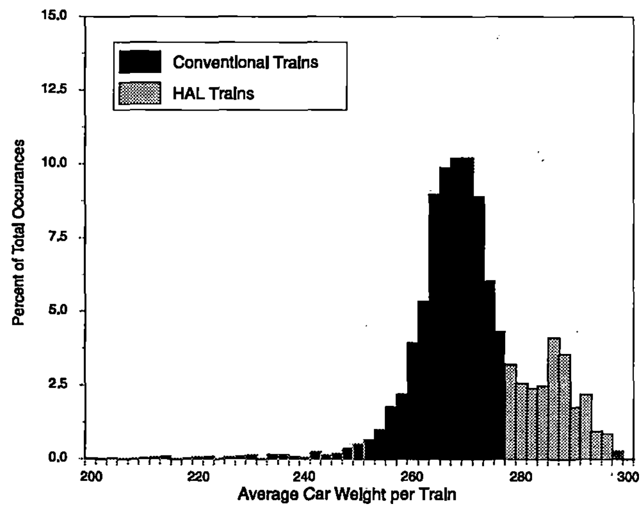


Figure 1. Histogram of Average Car Weight per Train on the CNW

Figure 2 shows a histogram of the distribution of average car weight per train for coal trains sampled between April and May 1995 under typical operating conditions on the CSXT. The break point for conventional and HAL cars is different on the CSXT line than that measured on the CNW (278 kips). Data shown in Figure 2 suggests that there are either a number of overloaded conventional cars or under loaded HAL cars. The break point for the HAL cars for this line is approximately 286 kips.

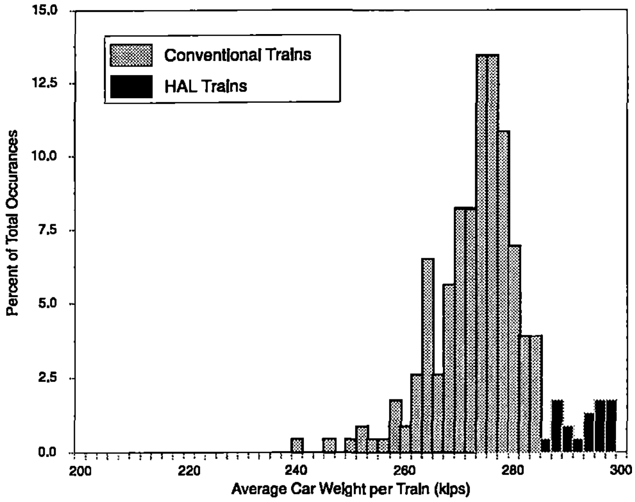


Figure 2. Histogram of Average Car Weight per Train on the CSXT

Depending on train handling, a road crossing located near the approach of the CSXT load station can significantly affect car dynamics, thus influencing the measured vertical wheel loads. To eliminate the car dynamics variable from the data, additional instrumentation was installed in an area where car dynamics were minimal. The data shown on the graph includes only the data collected after the additional instrumentation was installed.

Figure 3 shows a cumulative distribution of average car weights per train for the same data shown in Figures 1 and 2. On the CNW, 90 percent of the trains have an average car weight per train above 263 kips; 13 percent have an average car weight above 286 kips. While on the CSXT, about 94 percent of the trains have an average car weight per train above 263 kips; and about 10 percent have an average car weight above 286 kips. The highest observed average car weight for one train was nearly 300 kips.

Figure 4 shows the percentage of all HAL trains with gross rail loadings above 278 kips for both lines. The fluctuations in monthly percentages may be due to a variety of factors, such as train cycle times, policy changes, operating conditions, and mine loading practices. The rate at which HAL cars are introduced into revenue service continues to increase with time.

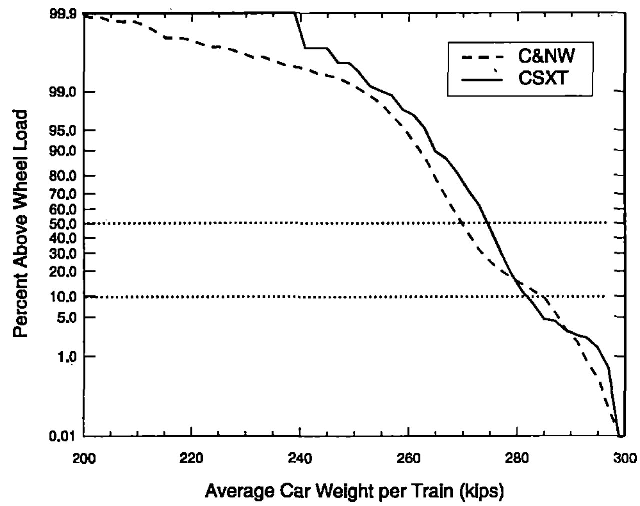


Figure 3. Distribution of Average Car Weight per Train on the CNW and CSXT

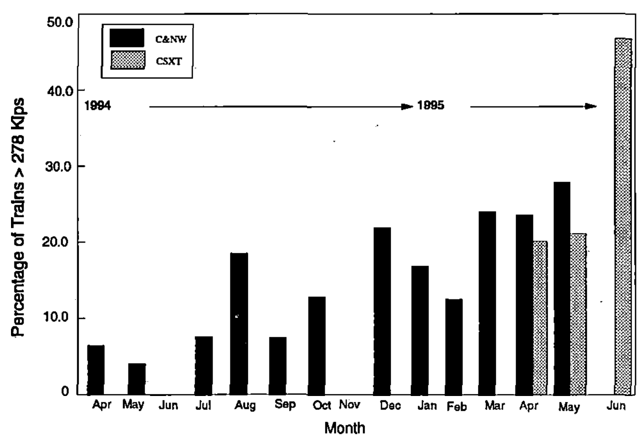


Figure 4. Percent of Trains Exceeding 278 Kips on the CNW and CSXT

AVERAGE WHEEL LOADS

Figure 5 shows the cumulative distributions of wheel loads measured for HAL trains for both the CNW and the CSXT. Mean wheel loads for the measured HAL trains on the CNW was 36 kips and 35 kips on the CSXT. Ten percent of the wheel loads on the CNW exceeded 45 kips, and 10 percent of wheel loads exceeded 48 kips on the CSXT.

While the highest measured vertical wheel load on the HAL trains for the CNW was 85 kips and 66.7 kips on the CSXT, the highest measured vertical wheel load on the conventional trains was 73 kips on the CNW and 60.2 kips on the CSXT. These high values were probably generated by wheel impacts. The highest measured lateral loads on the CSXT for HAL trains was 29.4 kips, and 24.3 kips for the conventional trains.

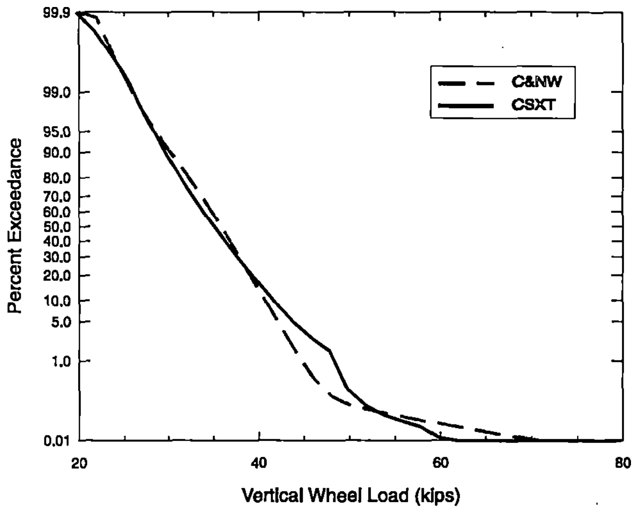


Figure 5. Vertical Wheel Load Distribution for Loaded Cars on the CNW

The static wheel load of a HAL 286-kip car is 35.7 kips. Considerable variations in wheel loads in both load station sites are most likely due to uneven loading, as well as car dynamics through the measurement zone. Table 1 provides a summary of vertical and lateral wheel load statistics. Note that the CNW load station is located on a typical curve for this line, a 1.5-degree curve; therefore, the lateral wheel loads are very low. Because the load station is located on an 8.4-degree curve, lateral wheel loads on the CSXT are much higher.

Table 1. Lateral and Vertical Wheel Load Statistics

Mean (kips)	100-Ton Cars	HAL Cars
Vertical Wheel Loads		
CNW	33.0	35.5
CSXT	33.1	35.6
Lateral Wheel Loads		
CNW	1.3	1.0
CSXT	6.1	7.9

The load station on the CNW was modified, additional vertical track circuits were installed and the lateral circuits removed. Only the vertical loads were measured since the measured lateral loads were so low. The new setup, which includes seven consecutive cribs instrumented with vertical rail circuits, provides about 65 percent coverage of the wheel circumference and allows for the capture of impact loads. Figure 6 shows the measured impacts loads on the CNW during the last 6 months.

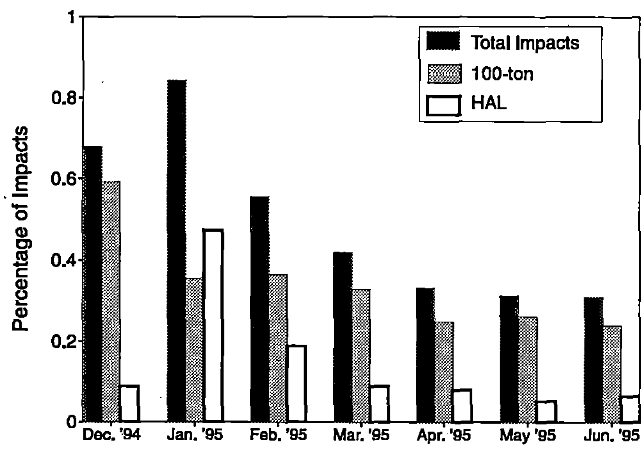


Figure 6. Percentage of Measured Impacts on the CNW above 60 kips

CONCRETE TIES

Concrete tie bending strain data is being collected on two lines to monitor tie performance under HAL traffic. The data is collected over 3 or 4 days once a year on the CSXT's James River Subdivision near Eagle Rock, Virginia, and on the BN's Spanish Peaks Subdivision near Mayne, Colorado. Tie bending strains are measured on two tie designs on the CSXT line and on a single tie design at the BN test site for comparison of several types of ties.

Data collected at both sites in 1993 and 1994 only captured conventional 100-ton traffic. But in March 1995, data was collected on several HAL trains at the CSXT site. The 6.1-degree curve has a track speed of 40 mph. Figure 7 shows the distribution of tie center bending strains, comparing a HAL train to a conventional train collected at this time. A bimodal distribution of the data is evident in the graph. While the high strain segment reflects the peak strains generated by a pair of coupled trucks, the low strain segment reflects the peak strains of the four individual axles. There is a noticeable increase in the bending strain magnitudes with the HAL train which may lead to a decrease in tie life.

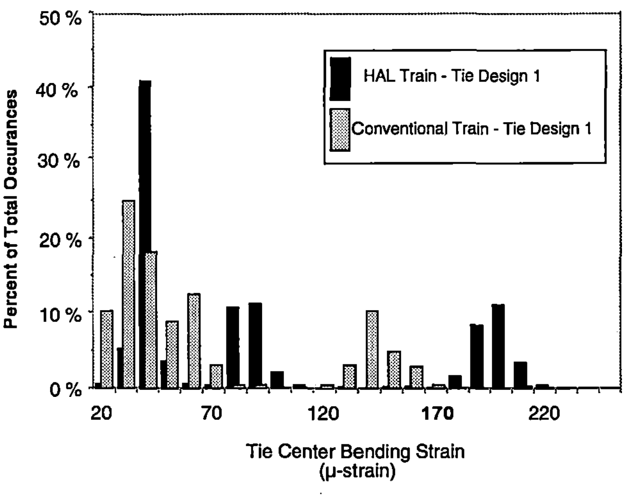


Figure 7. Histogram of Concrete Tie Center Bending Strains on the CSXT

Because the tie bending strains measured on the rail seat area are significantly less than those measured on the tie center, no significant differences were measured between conventional and HAL traffic on the rail seat area. Figure 8 shows the distribution of the concrete tie center bending strains under a conventional and HAL train at the concrete test site.

The median tie center bending strain measured under HAL trains is 60 microstrains, while 10 percent of center bending data measured exceeded 220 micro strains.

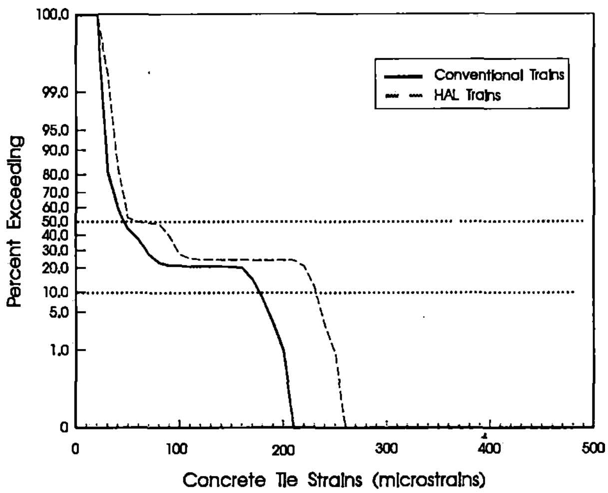


Figure 8. Distribution of Concrete Tie Center Bending Strains

In October, 1994, concrete tie strain gage instrumentation was added to the load station on the CSXT Coal River Subdivision near St. Albans, West Virginia. The curve is 8.4-degrees and has a track speed of 25 mph. The addition of this site allows continuous collection of concrete tie data, rather than the once-a-year collection performed on the two concrete test sites. A database of the measured concrete tie bending strain data on this site will allow for long-term monitoring of the tie performance as HAL traffic is increased. Figure 9 shows a slice of the time history for data collected under a HAL train at the load station site.

Lateral gage spreading forces influence tie center bending.[1] As much as 15 percent of the tie center strain measured at FAST can be attributed to gage spreading forces. Ties measured in revenue service and on the HTL were of different manufacturers but had a similar tie design. At a later date, gage spreading forces and center bending strains on this revenue site will be analyzed and reported.

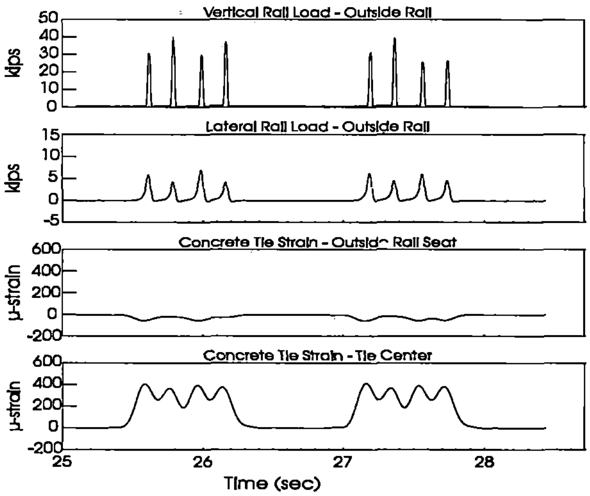


Figure 9. Time History of Data Collected at CSXT

WOOD TIES

The objective of this experiment is to study the possible effects that introducing HAL traffic may have on track strength performance. This includes the lateral restraint capabilities of the typical spike-fastened wood ties in revenue service with varying curvature and climate environments.

The test curve chosen is located on the Norfolk Southern Roanoke-Bluefield line, which carries coal and mixed freight with an annual tonnage of about 140 million gross tons. The curve is constructed of mixed hardwood ties with cut spikes, has a 5.1-degree curvature and a 25 mph track speed. Track gage strength and dynamic rail load and deflections have been taken over the past three years. As a result of track maintenance performed in the summer of 1995, when rail, selected ties, and the cut spike system were replaced, the curve is now equipped with the Pandrol fastening system.

Figure 10 shows very little difference between the unloaded and loaded track gage strength measured in 1993 and 1995. Because track was well maintained in this area by plugging and re-spiking any high spikes, nominal track gage degradation was measured.

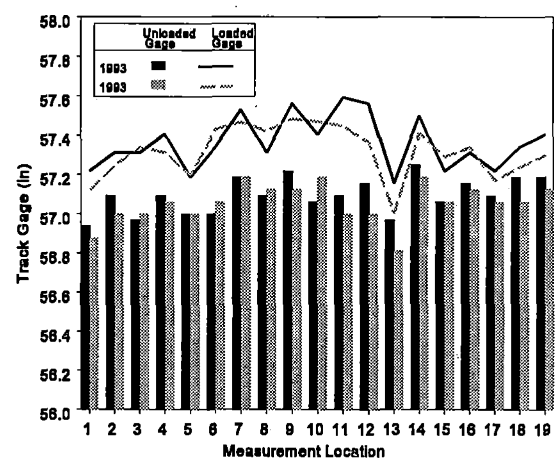


Figure 10. Track Gage Measurements on the NS

Figure 11 shows a time slice of the vertical, lateral and railhead displacement taken under a HAL train in 1995. There is an increase in lateral load magnitude from one truck to another, which may be due to a heavier car or skewed axles. This lateral load increase is also reflected in the increase of lateral railhead deflection. The increase in lateral loads and railhead displacement may influence tie life.

Figures 12 and 13 show the distribution of the lateral and railhead displacement measured on four trains in 1994 and 1995. The small difference between the two cycles in wheel lateral load and displacement may be due to the loading of the train, train speed, train handling or measurement error.

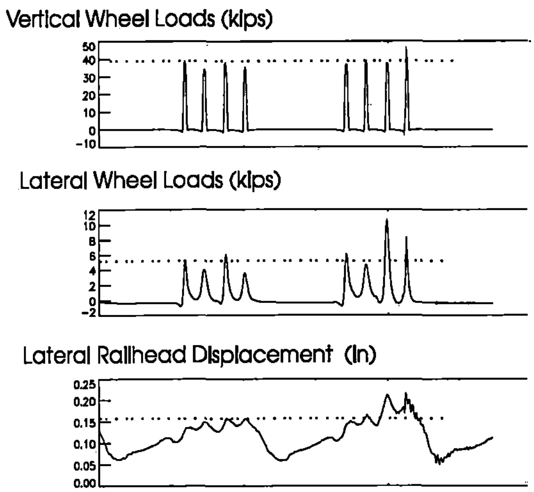


Figure 11. Dynamic Data Collected under HAL Train on the NS

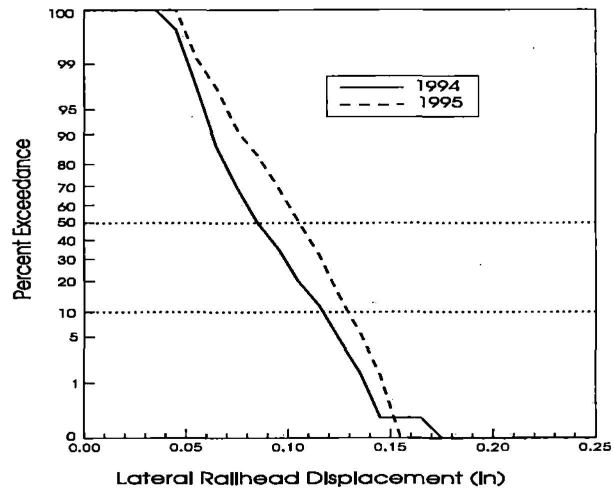


Figure 13. Distribution of Railhead Displacement on the NS

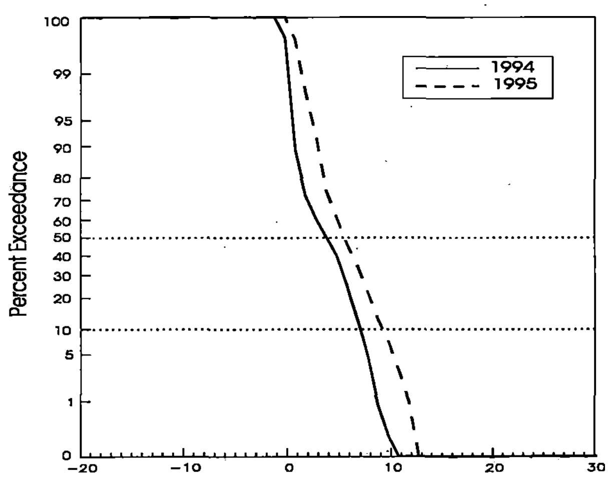


Figure 12. Distribution of Wheel Lateral Loads on the NS

TURNOUTS

The Union Pacific Railroad (UP) is using premium quality No. 10 and No. 20 frogs to achieve longer frog life on the former Chicago and North Western (CNW) Powder River Subdivision. Results from maintenance data collected as part of the AAR's Heavy Axle Load Revenue Service Monitoring Program is presented below.[2,3,4]

No. 20 Rail-Bound Manganese Frog Life

Figure 14 shows the average life in million gross tons (MGT) of standard and high-integrity No. 20 rail-bound manganese (RBM) frogs on this line. Many high-integrity frogs are still in service, so a Weibull analysis was used to account for tonnage still accumulating over those frogs. On the average, high-integrity No. 20 frogs are lasting almost three times longer than standard frogs.

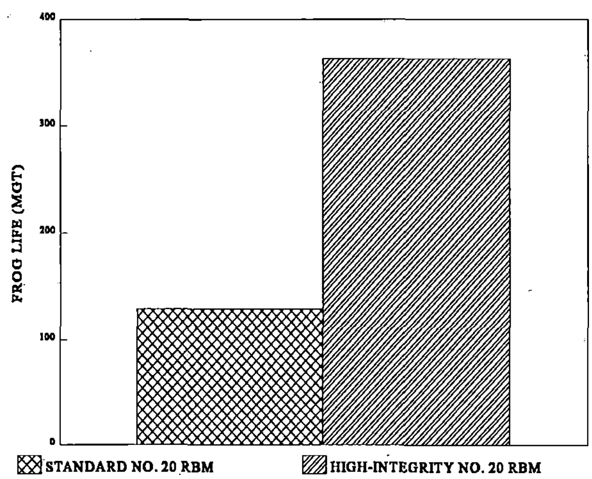


Figure 14. Average Life of Standard and High Integrity Frogs

High-integrity frogs were first installed in 1990 on this line. The castings have thicker walls, more risers and less porosity as compared to standard frog castings. Premium rail is used for the wing rails in high-integrity frogs, as compared to standard rail in the standard frogs. Other factors such as improved maintenance practices and the use of heavier base plates with elastic fasteners may also contribute to this increased frog life.

Figure 15 shows that the orientation of a frog with respect to the direction of heaviest tonnage appears to make a small difference in the average life of No. 20 frogs. Tonnage is split about 80 percent in one direction, and 20 percent in the opposite direction on this heavy haul route. For both standard and high-integrity No. 20 RBM frogs, the average life for frogs in facing point turnouts is somewhat less than for frogs in trailing point turnouts, with respect to the heaviest tonnage direction. These figures are based on 40 standard frogs and 45 high-integrity frogs. Of the high-integrity frogs, only 11 have failed to date. As tonnage continues to accumulate and additional frogs fail, these figures may change.

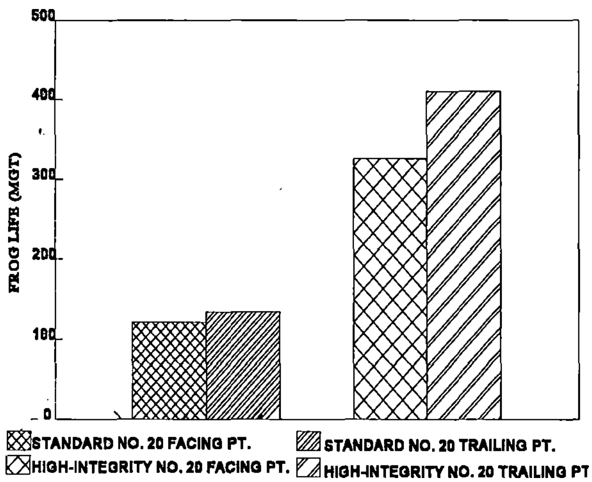


Figure 15. Average Frog Life - Facing and Trailing Point

As shown in Figure 16, two premium spring-rail frogs are lasting about eight and 11 times longer than the average life of standard No. 10 RBM frogs on this line. Both of these spring-rail frogs remain in service and continue to accumulate tonnage. These two frogs have seven wing rail hold-downs instead of three for a standard American Railway Engineering Association (AREA) design. They also have larger base plates and several braces ahead of the toe. They are protected by 39-foot guard rails on the mainline side instead of the 16.5-foot guard rail for a standard AREA design. The frogs are constructed of fully heat-treated rail and use a flexing wingrail (*RT&S*, March 1995, p. 29).

The fact that premium components, like the high-integrity No. 20 RBM frogs and the premium No. 10 spring-rail frogs, perform much better than standard components in heavy haul service complements the experience at the Facility for Accelerated Service Testing (FAST).

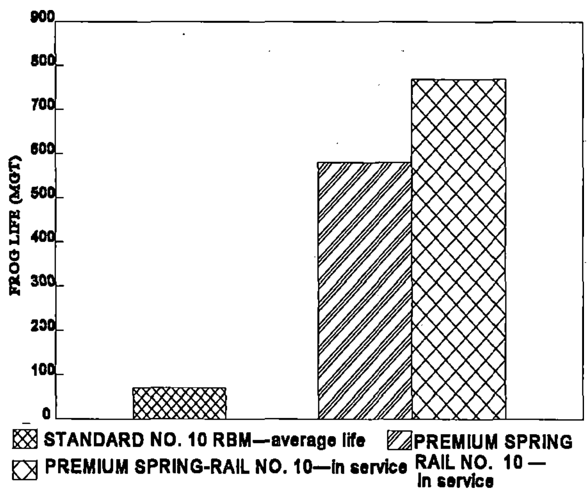


Figure 16. Life of No. 10 Frogs

Frog failures on this line are typically due to plastic flow, cracking, and spalling of the running surface. Frogs are removed from track when local maintenance forces judge them to be more economical to replace than repair by grinding and welding in the field. The welders keep maintenance records which provide some insight into the nature of the in-track repairs that are made during the life of a frog. On high tonnage lines such as this, repairs are often done in intervals between trains. Thus, in-track repairs may create less train delay than frog replacement. When the deteriorated area becomes too large, the frog is replaced.

Because of the operating pattern on this line, the weld repairs occurred almost exclusively on the frog nose and the main wing. The side wing, used by diverging route moves, suffered little damage. The loaded trains usually hold the main line when two trains meet. Only empty trains use the diverging routes. The number of nose and wing repairs was about equal. Repair locations on the wing range from about 20 inches ahead of the tip of the frog nose to about 40 inches behind the tip, with the majority centered near the tip of the frog. Repairs on the frog nose ranged from the tip to about 40 inches towards the heel. Again, the majority were near the tip of the frog. Average repair lengths were about 15 inches on the wing and 19 inches on the nose of the frog.

The wide range of repair areas suggests that the lateral location of the wheel on the rail and frog is not fixed, nor is the lateral location of the contact area on the wheel. The effects of hollow tread or "false flange" wheels are present in this data. Comparison of the locations of consecutive repairs on the nose and main wing showed that repaired areas almost always overlap. Possible explanations include:

- Weld repairs are incomplete. Not all of the damaged material is replaced.

- The weld material is inferior to the original casting.

- The weld repair process damages the underlying material.

- While the repair locations vary from frog to frog, traffic on a given frog tends to damage the same areas, before and after repairs.

The effect of traffic direction on weld repair was investigated and found to be negligible. Standard No. 20 RBM frogs that had loaded facing point moves behaved in the same manner as frogs with trailing point moves.

Traffic and Train Operations

Frog performance can be quite different on lines with different traffic mixes, train speeds, operating practices, and maintenance procedures. It is important to know the conditions for the frog results presented here. Data has been collected over the past 12 years by the CNW on the Powder River Subdivision, between Horse Creek, Nebraska, and Shawnee Junction, Wyoming. Traffic is almost exclusively unit coal trains. While loads make up about 80 percent of the tonnage, all moving eastward, empties make up the remaining 20 percent, moving westward.

Speed limit on the line was originally 40 mph in each direction, but over the past four years it has been raised to 45 mph for loads and 50 mph for empties. At the time this data was last updated, the speed limit was being raised to 60 mph for both loads and empties. Speed is limited to 25 mph through the diverging routes of No. 20 turnouts.

As a general practice, loads hold the main track and empties take the siding when trains meet. Therefore, none of the No. 20s carry more than about 20 percent of the tonnage over the diverging route.

Traffic on this line was nearly all 100-ton cars with 33-ton axle loads until about 1992. Since then the amount of HAL traffic with 36-ton axle loads has gradually increased. It is estimated that about 20 to 25 percent of the traffic in 1995 will be HAL traffic.

Over the years, the CNW made several improvements in frog maintenance on this line, including installation of longer guard rails, frog gage plates, larger frog base plates, and elastic fasteners. Warped switch ties are promptly replaced. Tamping, welding, and grinding practices are continuously improving.

REFERENCES

1. Gage, S. and Duane E. Otter, "Preliminary Results of Concrete Tie Strain Measurements at FAST," AAR, *Technical Digest*, TD-022 , September 1995.

2. Otter, Duane E., "Life of Rail-Bound Manganese Frogs in Revenue Heavy Haul Service," AAR *Technology Digest* TD 94-001, January 1994.

3. Davis, David D., "Performance of Weld Repairs on Rail-bound Manganese Frogs in Heavy Haul Service," AAR, *Technology Digest* TD 95-002, February 1995.

4. Otter, Duane E., "Life of No. 10 and No. 20 Frogs in Revenue Heavy Haul Service," AAR, *Technology Digest* TD 94-001, March 1995.

"HAL Substructure Investigation Using Rapid, Non-Destructive Techniques,"

by Steven Chrismer and Joseph LoPresti

Summary

As part of a program to determine the nature of track substructure problems and to recommend the best remedial action, the Association of American Railroads has developed an on-track vehicle which houses a rapid, non-destructive subgrade test apparatus known as a cone penetrometer. Although still in the planning stage, another rapid, non-destructive diagnostic tool being developed is a moving vehicle which continuously measures track deflections under load.

The cone penetrometer test (CPT) vehicle has been used to investigate the cause of excessive maintenance requirements on three member railroads. The data obtained is being used to determine the strength of the subgrade, the adequacy of the granular layer thickness over it, and the extent of weak soil deposits under and along the track. CPT data can be used as a guide to select the most appropriate maintenance remedy. This is one of the tools that can be used to asses the potential benefits of adding more ballast, modifying the soil in place, removing and replacing the subgrade with better material, or adding hot-mix asphalt over the weaker layer.

Deflection data can determine whether the problem resides in the ballast/subballast (granular layer) or in the subgrade. The running deflection measurements can first be used over long track distances to identify whether the problems are granular or subgrade related. Then, for locations with apparent subgrade problems, the CPT can be called in for a more detailed assessment. The deflection and CPT data are also used to decide when and whether more intrusive techniques (such as cross-trenching) are needed to further identify the problem.

INTRODUCTION AND CONCLUSIONS

As part of a program to determine the nature of track substructure problems and recommend the best remedial action, the AAR has developed an on-track vehicle which houses a rapid, nondestructive subgrade test apparatus known as a cone penetrometer. Work is also progressing on a vehicle designed to determine track maintenance needs by measuring vertical track deflection.

Because the source of track roughness is usually not apparent from the track surface, the engineer needs a fast and reliable diagnostic tool to determine the cause of the roughness and to make the best maintenance choice. While the cone penetrometer test (CPT) vehicle provides such a tool mainly for the subgrade, the track deflection-measuring vehicle will further assist the engineer to distinguish between ballast/subballast, and subgrade failure. With these results, the most appropriate maintenance technique can be selected which not only addresses the symptoms of track roughness, but also the cause.

CONE PENETROMETER TESTING

The source of the problem is not always addressed if tamping is routinely prescribed as a catch-all response to rough track. However, repeated tamping (especially in locations where it provides only short-term improvements) drives up maintenance costs as tonnage levels increase and track capacity shrinks. A lower life cycle cost, which requires information on the substructure, can often be achieved by addressing the underlying cause.

With the track-mobile CPT vehicle (Figure 1), the railroads now have a means to determine the depth and longitudinal extent of the problem soil, its strength, the adequacy of the granular layer thickness above it, and the effectiveness of a given solution. Subgrade is evaluated by measuring the pressure or resistance against a cone that is pushed through the track substructure in the zones shown. The vehicle weight, approximately 30,000 pounds, is used as the reaction mass while the cone is advanced using a hydraulic push frame mounted inside the vehicle. The frame can be moved laterally to position the cone between the rails.

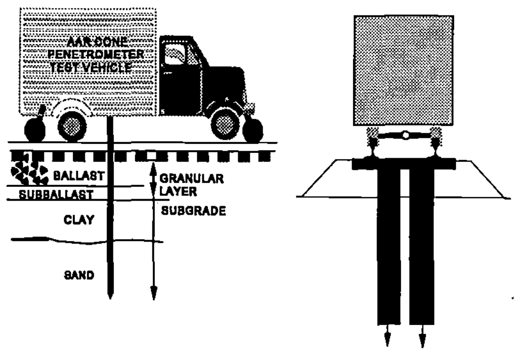


Figure 1. CPT Vehicle and Probing Locations

Figure 2 offers an example of how the CPT results can provide a unique insight into the cause of track instability. Although the track surface was rough, the cause of the instability was not apparent from outward appearance. The ballast surface was clean and seemed to be relatively thick. However, the tip resistance measurements illustrate that the clean ballast layer is very thin with a soft layer just under the ties. Excavations in the track revealed that the clay had pumped up from the subgrade, migrated through the ballast voids, and mixed with the ballast just under the ties.

CPT data can be used to determine the likelihood of the two most prevalent soft subgrade failure modes of progressive shear and excessive plastic deformation. Progressive shear is shown in Figure 3a where the soil is squeezed out under the ties. The resulting subgrade profile often has the largest depression just under the tie ends where the shearing stresses are usually the largest. For this subgrade failure mode, the subgrade strength just under the granular layer is of primary concern.

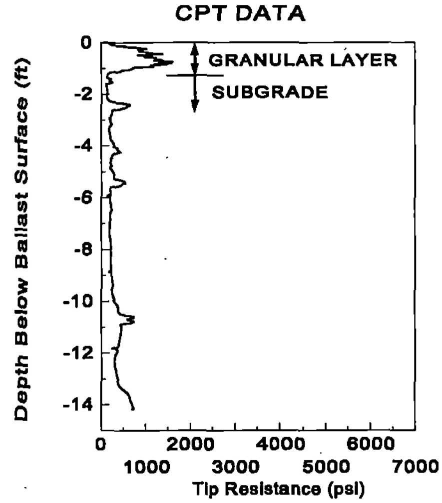


Figure 2. CPT Profile Over Weak Track

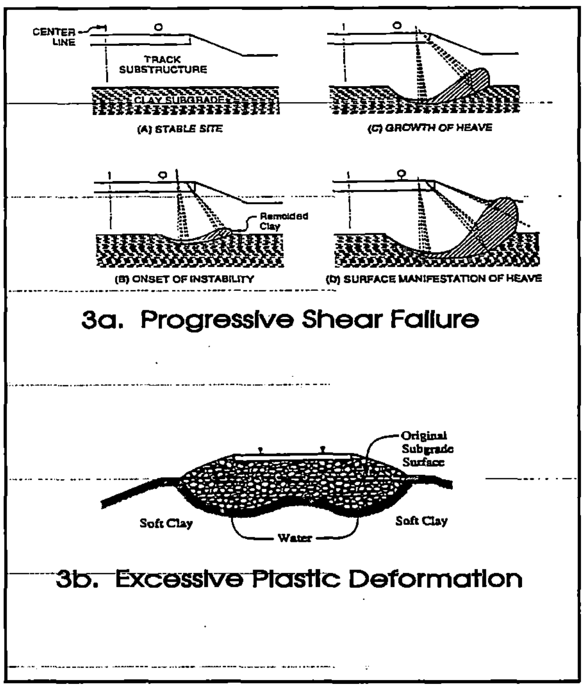


Figure 3a and 3b. "Soft" Subgrade Failure Modes

Whereas progressive shear is concentrated in the upper few feet of subgrade, excessive plastic deformation (Figure 3b) can result from soil strain over a considerable depth. Analyses with the GEOTRACK model, a three-dimensional, multi-layer model to predict the elastic response of the track structure, have shown that significant elastic and permanent subgrade strain can develop over as much as 25 feet. To assess the potential of this failure mode, the CPT should be able to penetrate to this depth. It is not necessary to determine if the soft subgrade extends beyond this depth or if a harder layer is just beyond, because neither resilient or permanent strain are significantly affected.

Another use of CPT data is to predict track stiffness or modulus. The modulus of the subgrade largely controls that of the track. Research by Ebersohn and Selig has shown that tip resistance often correlates well with subgrade modulus, as shown in Figure 4. This relationship was determined from four investigations with widely varying track super- and substructure conditions. With an estimate of subgrade modulus from this correlation, models such as GEOTRACK can be used to estimate the track deflection and modulus.

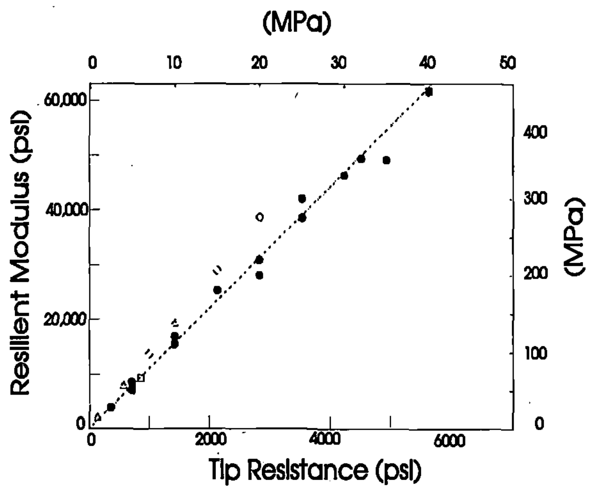


Figure 4. Tip Resistance and Resilient Modulus Relationship

Placing hot mix asphalt (HMA) between the ballast and subgrade is sometimes used to reduce the stresses on the underlying weaker materials. However, research has shown HMA to be of little benefit in reducing stresses if the weaker layer is more than about 3 feet under the subgrade. The CPT may be used to first determine if such a weaker layer is present and within this distance.

MAKING THE RIGHT TRACK MAINTENANCE CHOICE

Distinguishing Between Ballast and Subgrade Failure

Track deflection under load is a good indicator of substructure support and how it changes along the track. Figures 5a and 5b shows the deflections from both a small seating load used to close the voids between the tie bottom and the ballast, and a larger "total" load. The difference between these two deflections is called the contact deflection because the tie is assumed to be in full contact with the ballast. This contact deflection is primarily the elastic deflection of the substructure layers, and therefore indicates the support stiffness and its variance along the track.

In Figures 5a and 5b, the track, which, in both examples, is rough and in need of maintenance, shows considerable variation in support conditions. What is not immediately clear is the extent to which the problem is in the ballast or the subgrade. As a later investigation would show, the maintenance problems at these two sites are from two distinct failure conditions (in the ballast and in the subgrade respectively) and require very different maintenance remedies. However, this could have been determined by reviewing the deflection data in the manner shown below.

The track failure in Figure 5a is caused by a heavily fouled ballast. As the plots suggest, changing deflections are due mainly to variations in voids under the tie with the tie seating loads (variations in tie-ballast support) and not from the contact deflection. Data indicates that the contact load deflection, which is primarily indicative of subgrade conditions, was fairly firm and only gradually varying at this site.

On the other hand, because the track in Figure 5b had relatively large variations in contact load deflections, subgrade strength variation is the foremost problem to be addressed. Variations in seating and total load deflections resulted primarily from non-uniform subgrade support, and were not due to the ballast. This was confirmed by excavations which showed that the subgrade was failing at different rates at various locations due to strength variability.

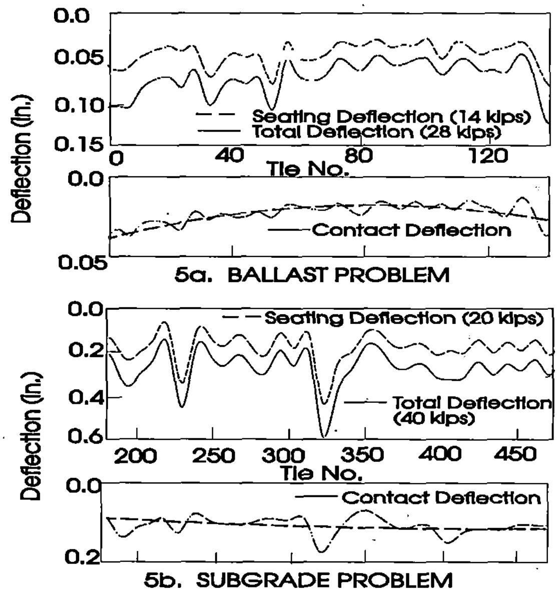


Figure 5. Determining Maintenance Needs From Track Deflection Data

To Tamp, or Not to Tamp

Raising the track and tamping more ballast under the ties is often used as a means to increase the depth of ballast between the tie and the weaker underlying layer. However, it is not clear how much the tamping cycle will be improved by the added ballast and reduced stresses on the subgrade. In an attempt to quantify this improvement, CPT data and a granular depth design model by Li and Selig were used to obtain the relationship shown in Figure 6.

To define the relationship and obtain the curves shown, the granular design model was used to determine the ballast depth required for varying subgrade strength values. Certain combinations of ballast depth and subgrade strength gave the same amount of predicted subgrade strain. This equivalent strain is interpreted as equivalent tamping cycles and provides the contour lines shown in Figure 6.

As more field data is collected from CPT work, this relationship will be refined and modified. For now, however, it is offered as a method to determine the potential benefit of tamping, or to show that another maintenance technique may be more economical than continued tamping.

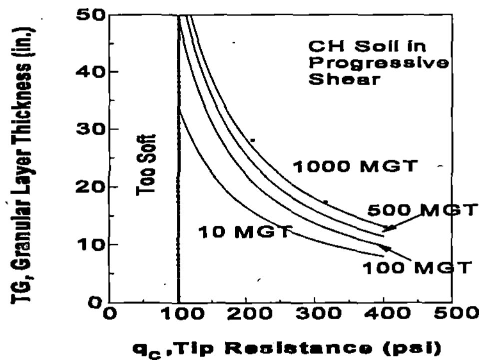


Figure 6. CPT Data Used to Predict Maintenance Frequency

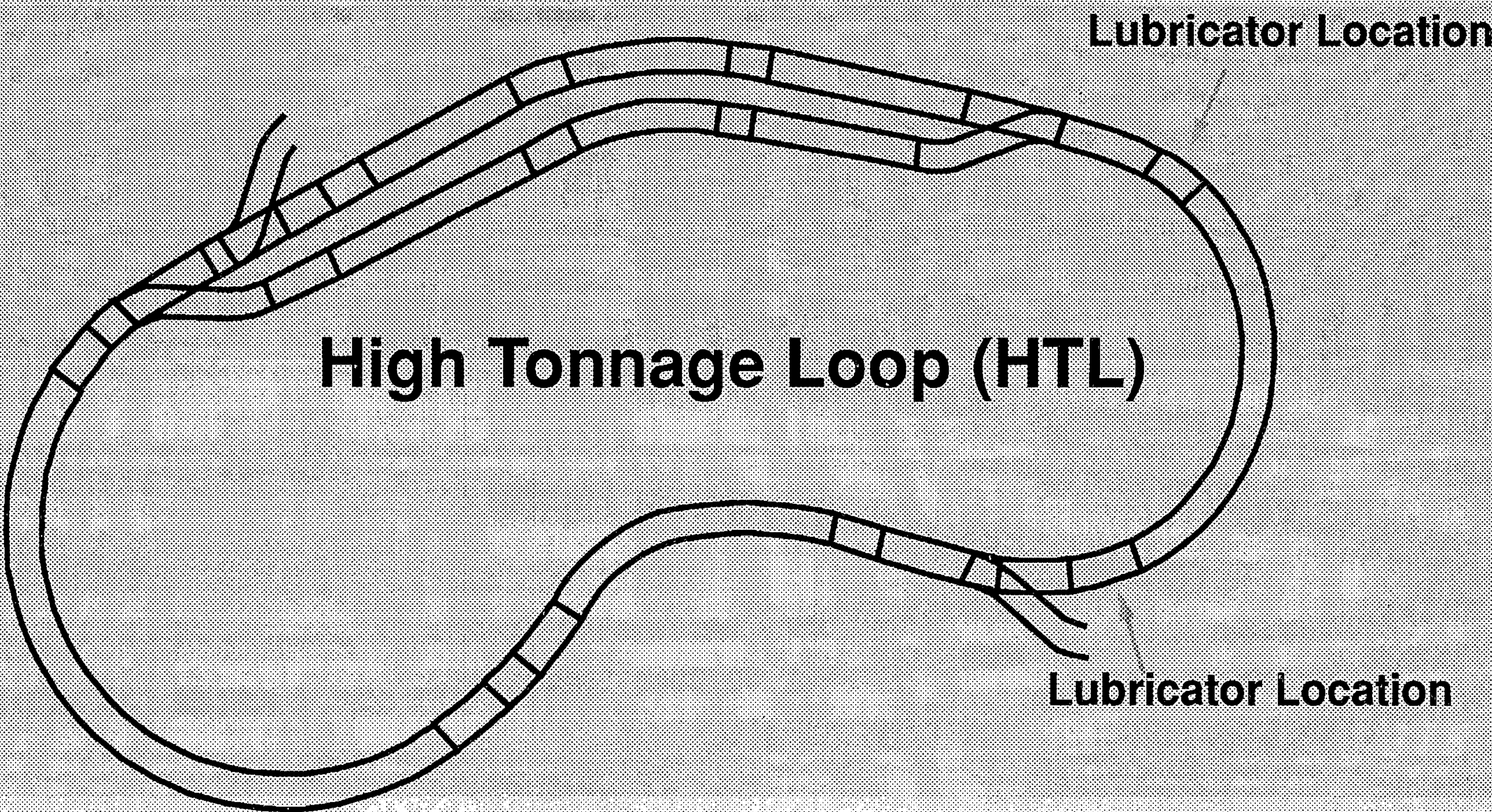
PHASE III PREVIEW

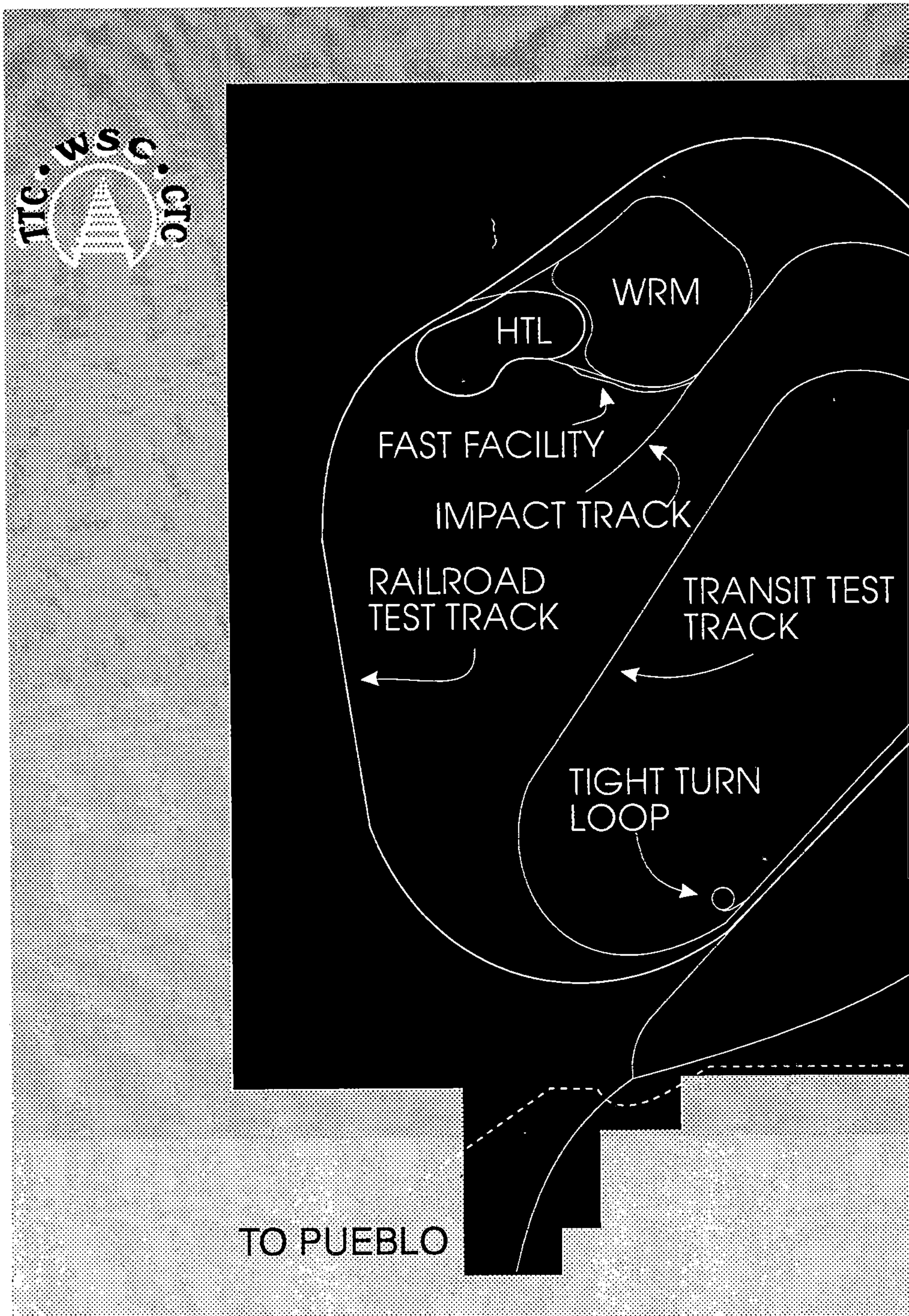
Summary of FAST/HAL Phase II

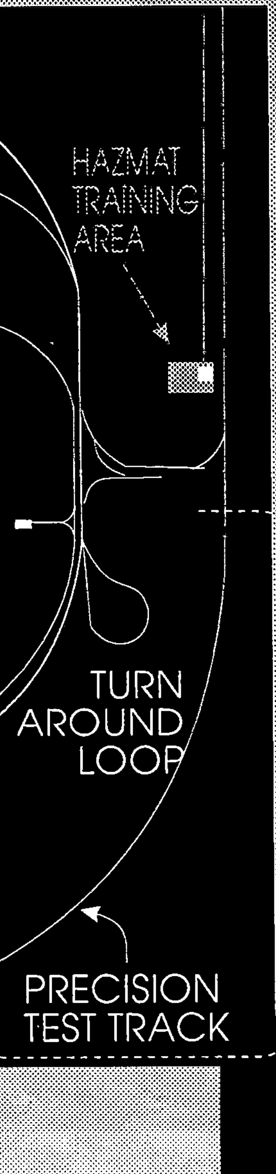
Operating HAL traffic over improved track materials

R.RIEFF/PHASE01

Summary of FAST/HAL Phase II




TTC • WSC • CTC
WRM
HTL
FAST FACILITY
IMPACT TRACK
RAILROAD
TEST TRACK
TRANSIT TEST
TRACK
TIGHT TURN
LOOP
TO PUEBLO



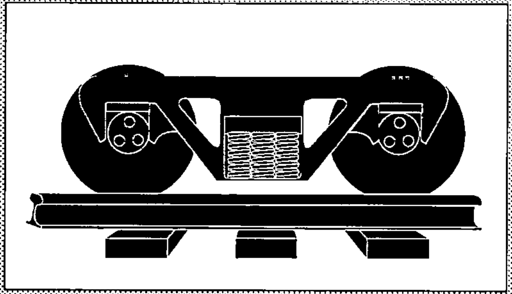
Test Tracks

Reiff\06map.cdr

FAST Heavy/Axle Load Program

Phase I

Complete 160 MGT

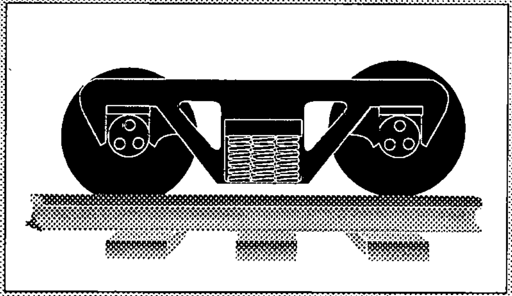


Conventional trucks

Conventional track

Phase II

Complete 300 MGT

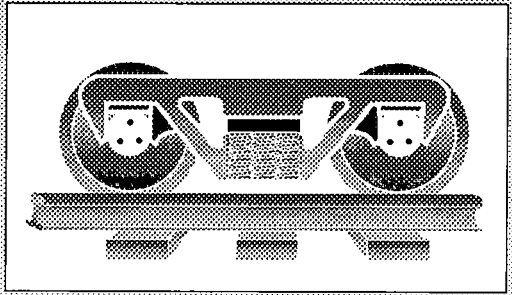


Conventional trucks

Premium track

Phase III

Starts Oct. '95



Improved suspension

Premium track

01f_hal.cdr

Summary of Results - Phase 1

- HAL traffic technically feasible on conventional track
- Increased degradation rates
- Increased degradation severity

Summary of FAST/HAL Phase II

Phase 1 - Specific areas of concern in the track

- Thermite welds
- Life of special trackwork - frogs, turnouts, crossings
- Track over marginal support
- Fatigue in older, standard process rail
- Deferred maintenance practices

Phase 1 - Specific areas of concern in the track (cont'd)

- Other areas required additional tonnage to evaluate HAL
  - wood ties
  - concrete ties
  - ballast
  - fatigue of premium rail

Summary of FAST/HAL Phase II

Phase 2 Findings - Results of improved track materials

Rail

- Heat treated rail shows considerable advantages
  - wear
  - surface fatigue
  - corrugations
  - profile maintenance
- Lubrication remains important in extending rail life
  - continues to show minimum 10:1 gage wear advantage
- Grinding policy needs to consider
  - wheel/rail profile
  - gage retention-lubrication/track strength

Summary of FAST/HAL Phase II

Rail - continued

- Initial results of extended operations over HH rail
  - no internal fatigue in first 100 mgt
  - best wear rates on "no-grind" rails
  - long term operations needed
  - surface fatigue noted in isolated areas of wide gage

R.RIEFF/PHASE01

REIFF\PHASEA5

Summary of FAST/HAL Phase II

Phase 2 Findings - Results of improved track materials
Welds

- Significant improvement in thermite weld behavior
  - quality control of welding personnel/training
  - improved weld materials
  - improved weld molds
  - improved weld procedures
- Accomplished with little or no increase in cost and time

Summary of FAST/HAL Phase II

Phase 2 Findings - Results of improved track materials

- Special trackwork - turnout frogs
  - Alternative shapes - V-nose vs AREA
  - Premium materials offered significant life
  - Repair techniques on special materials
  - In track repair costs vs replacement

Summary of FAST/HAL Phase II

Phase 2 Findings - Results of improved track materials

Special trackwork - turnouts

- Premium materials offer significant improvements
  - AREA turnout with standard vs premium materials
- Advanced geometry still requires premium materials of adequate strength
- HAL loads need uniform running surface hardness

Summary of FAST/HAL Phase II

Phase 2 Findings - Results of improved track materials

Special trackwork - crossing diamonds

- Premium materials offer significant improvements
- Shape/angle a critical issue in crossing life
- Alternative concepts should be investigated

Summary of FAST/HAL Phase II

Phase 2 Findings - Results of improved track materials

Wood Ties

- Hardwood ties offer significant gage widening resistance
- Softwood ties with cut spikes have limited life
- Premium (DF) fasteners can greatly extend tie life
- Tie life dependent on localized lateral load enviroment

Summary of FAST/HAL Phase II

Phase 2 Findings - Results of improved track materials

Concrete Ties

- No increased cracking due to HAL
- Rail seat abrasion an issue regardless of axle load, but appears to accelerate with increased loading
- There are mitigation techniques that appear to prevent abrasion, however life cycle has not been documented

Summary of FAST/HAL Phase II

Phase 2 Findings - Results of improved track materials

Ballast

- Little effect of HAL of performance of ballast
  - running surface anomalies continue to be an issue
  - tamping efforts contribute to ballast degradation
- Good ballast under 100 ton axle loads will perform under HAL

Summary of FAST/HAL Phase II

Phase 2 Findings - Results of improved track materials

Track support system

- Stiff, firm support shows little effect of HAL traffic
  - long term surfacing requirements
  - track geometry degradation rates
- Poor support shows significant HAL effects
  - non uniform degradation
  - spot maintenance at joints, anomalies
  - significant maintenance under lower track modulus

Phase III FAST/HAL Goals & Plans

Evaluate new suspension prototyepses	Completed 1995
Re-equip train with new trucks	Completed Late 1995
Rebuild track for Quick look test restart with new train	Late 1995
Upgrade long term test as materials become available	Ongoing 1996
Complete 100 MGT w/ new trucks	1995 - late 1996
Continue train operations w/ new trucks	Beyond 1996

R. REIFF\PHASE3\GOALS95

Phase III FAST/HAL Goals & Plans

- The FAST program wishes to acknowledge support provided by:
  - Member Railroads
  - Supply Industry
  - FRA
  - Committees/working groups
- Without their generous support this program would not be possible

R.REIFF\PHASE3\f95goal1.cdr

Summary for long term ongoing Track Evaluations

Some of the new track tests to be installed

- Ties - Steel
  - Interspaced with wood / gradual introduction
  - Out of face
- Ties - Wood
  - Alternative / under utilized species

R.REIFF\PHASE3\F95GOAL4

Summary for ongoing Track Evaluations

Some of the new track tests to be installed

- Rail - Grinding / Fatigue
- Ties - Concrete
  - Tie life
  - Rail seat abrasion prevention / mitgaten techniques
- Ties - Wood
  - Premium fasteners on conventional species
  - Laminated ties
- Turnouts - Long term performance

R.REIFF\PHASE3\f95goal3

Summary of Quick Look Track Tests

- Load Path
  - Rail to Subgrade
  - Feed models to aid in prediction & economic evaluation
- Top of Rail Performance
  - Mechanical joints/plug under deferred maintenance conditions
- Field Weld End Batter
  - Standard process

Quick Look Tests

- Provide industry with observations of new suspension effect on track life
  - Repeat key tests
  - Monitor materials with highest sensitivity to track performance
- Utilize last 100 MGT / first 100 MGT of old / new truck data
- Provide indication of truck effect on key track componentswithin first year after starting operation with improved trucks

Summary of Quick Look Track Tests (cont.)

- Ties & Fastener Systems
  - Dynamic gage widening with cut spikes on wood ties
  - Southern Yellow Pine with cut spikes as primary control
  - Concrete ties - fasteners and tie strains
- Rail Wear
  - Standard to premium rails
- Track Maintenance/Geometry on Low Modulus Zones
- Turnout Components - Frogs

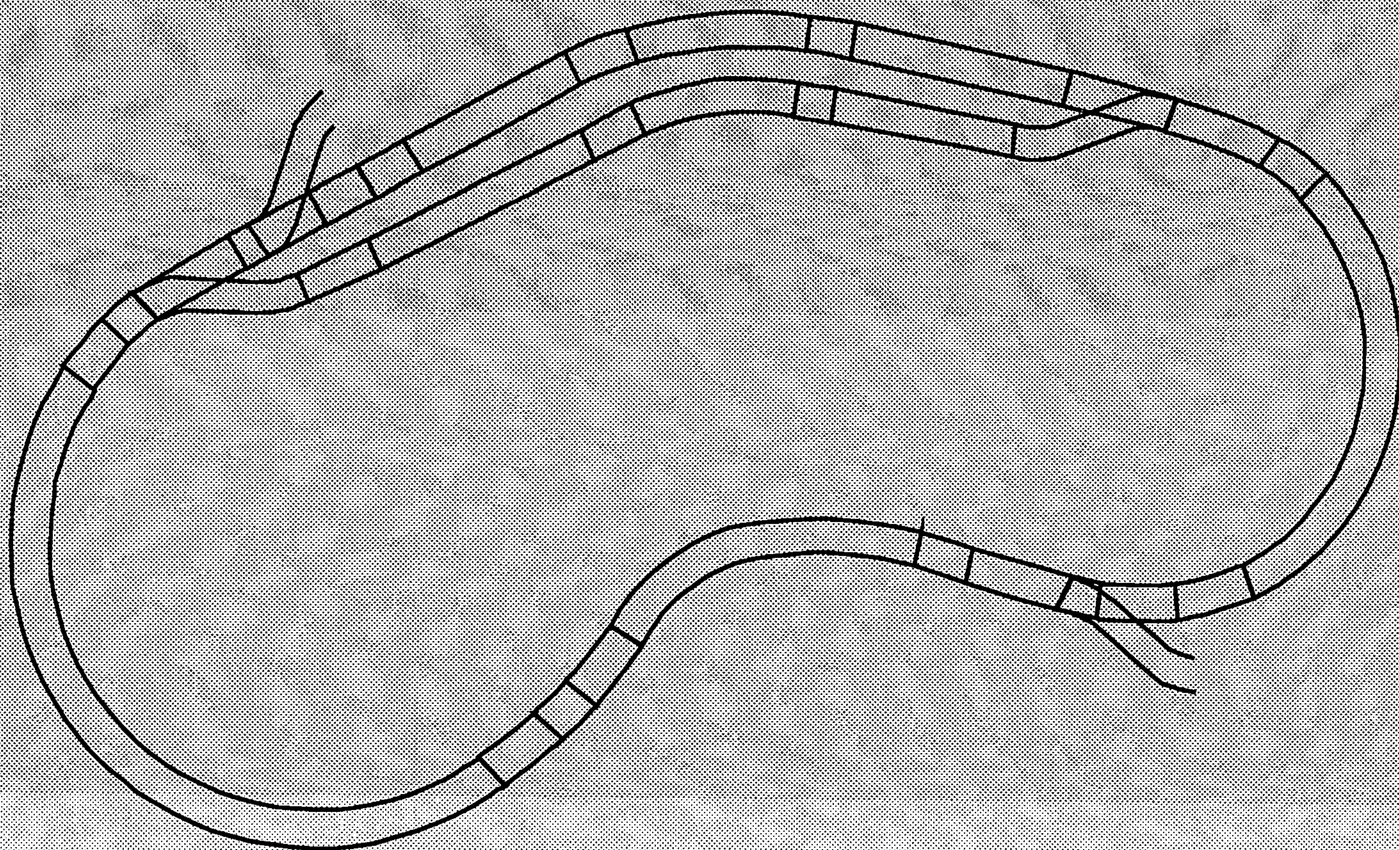
R.REIFF\PHASE3\QLOOK2

Future HAL Track Test Matrix

- Effect of New Suspension - "Quick Look"
- Continuation of Ongoing Evaluations
- New / Improved Products
- Other Areas Where HAL Becomes a Concern

R. REIFF\PHASE3\HALTEST

High Tonnage Loop (HTL)



R.REIFF\PHASE3\HLTMAP

Track Tests That Primarily Address Effects Of New Suspension

- Considered to be most Sensitive to Changes in Truck Performance
  - Load Path
  - Wood Ties / Tie Fasteners
  - Concrete Tie Strains
  - Rail Wear
  - Turnout Components - Frog Casting Performance
  - Track Geometry/ Low Modulus
  - Field (Thermite) Weld Performance
  - Mechanical Joint Batter

R.REIFF\ PHASE3/QKLOOKPT

HAL SUMMARY

OPERATING HEAVY AXLE LOADS: OBSERVATIONS AFTER 460 MGT

...Richard P. Reiff

In 1988, the Facility for Accelerated Service Testing (FAST) program replaced a train of 100-ton capacity cars (33-ton axle loads) with cars of 125-ton capacity (39-ton axle loads) to conduct controlled tests and evaluations of heavy axle load (HAL) traffic at the Transportation Technology Center. Before 1988, an extensive data base was made of track performance under conventional loads (100-ton capacity/33-ton axle loads) and different track materials. The HAL program was initiated to compare track performance under the two-axle loads. Initial effects of HAL traffic on conventional track materials was documented in the October 1990 *Proceedings: Workshop on Heavy Axle Loads.* Subsequent HAL operations were conducted with improved track materials in an effort to optimize the economics of operating with increased loads. Results to date indicate that the economics of HAL traffic are improved by the use of premium track components, but route specific restrictions, including bridges, must be evaluated before unrestricted increased axle loads can be operated.

To date, the HAL program has applied 460 MGT of traffic over a variety of track components in two distinct operating phases. Phase I, conducted from 1988 to 1990, provided baseline performance of standard track components under HAL cars equipped with standard truck designs. Phase II continued the HAL operation with the same train over improved track components. In addition, new tests were incorporated to address areas where previous results indicated that HAL traffic might be of concern, such as the effects of HAL traffic on subgrade. During the second phase, 300 MGT was applied. Future operations will evaluate the effect of improved truck suspensions on reducing track damage, while maintaining the same 39-ton axle load.

The engineering conference disseminates information on areas of the track structure that indicated the highest need for upgrading during the two phases of operation. It has been shown in revenue service that operating an occasional HAL load has little apparent effect in track degradation, thus operation of 39-ton axle loads is technically feasible. The economic issues of full HAL implementation include safety and reliability in service.

Each corridor where the operation of HAL traffic is to be considered can be viewed as a site specific case. The existing condition of rail, turnouts, frogs, bridges, ties, fasteners, ballast, and subgrade will be important in the overall consideration of how safely and economically HAL traffic can be moved. There is no single yes or no answer.

PHASE I OBSERVATIONS

Results of the first 160 MGT of traffic indicated that HAL traffic can be carried over standard track, but with increases (in certain cases a significant increase) in degradation rates and severity. Certain inspection and maintenance methods deemed acceptable under 100-ton traffic became marginal with continued HAL operations.

Data obtained during Phase I suggested several areas of specific concern: thermite welds, turnouts and special trackwork, track with marginal support conditions, and rail fatigue where older rail might still be in place. Other areas of the track structure exhibited little accelerated degradation during the first 160 MGT, and thus required extended operation to determine long-term effects (if any) of HAL operation. These components included wood and concrete ties, fasteners, ballast, tangent rail life and improved designs of turnouts. Some evaluations, such as the rail grinding test, have been restarted using state of the art materials to address performance issues likely to be encountered on today's heavy haul track.

Although evaluations are being conducted for a number of track components, the FAST budget does not allow every facet of HAL operations to be considered. Bridges have always been a major concern, and are being treated separately due to their unique, site specific nature. The environment at the TTC is relatively dry, and the effects of other climates is being considered by AAR through off-site testing on selected revenue railroads. In some cases, the cost of components has limited the variations and quantities available at FAST, thus revenue service sites have been selected to supplement the data from FAST.

HIGHLIGHTS OF RECENT TEST RESULTS

Details of each major test will be disseminated during the technical review session. Each evaluation will include a description of the experiment objective, layout, measurement methodology and frequency, closing with a discussion of observations, findings and recommendations for implementation when HAL traffic is being considered. Both FAST and off-site data will be reviewed. A summation of the economic benefits and penalties of introducing HAL traffic will be presented.

The order of presentations will be conducted in the sequence that loads are transmitted from the wheel: rail, ties, fastener, ballast, and subgrade. System evaluations, such as turnouts, frogs, load path transfer, track maintenance, and degradation will be introduced separately.

RAIL

Rail is the first point of contact between the wheel and the track structure, and can thus be extremely sensitive to increased loads. Standard rail continues to show significant surface deformation and increased wear compared to head hardened rail. Under marginal lubrication conditions of one 5 degree test curve, corrugations of over 0.1 inches developed in standard rail after 67 MGT of traffic, whereas heat treated rail showed no such surface degradation in the same time frame. Gage face and head height wear rates of head hardened rail indicates a life double that of standard (285-300 Bhn) rails of similar chemistry. Newly installed rail wore faster in the initial stages of operation. Once a conformal wheel/rail profile was formed rail wear rates were reduced. This suggests that a more optimal new rail profile might be appropriate.

As with previous observations at FAST, lubrication plays a dominant role in controlling wear. Identical rail located in other areas of FAST under full lubrication exhibits a wear life of up to 10 times longer than in the marginally lubricated wear test curve.

Rail grinding using state-of-the-art head hardened rail under controlled conditions has been under evaluation for only 100 MGT, during which no internal fatigue on ground or un-ground rail was observed. Initial observations during this period indicate that rail not ground (but kept under full lubrication) exhibited less wear than that of rail undergoing a variety of grinding policies. Surface fatigue was noted only on the center top running surface of the low rail, and only in areas where degradation of wood ties allowed wide gage to occur. This may have been a result of wider gage altering the intended low rail wheel/rail contact geometry conditions.

During the past decade, manufacturers have continued to provide improved rail. Future evaluation of HAL traffic over heat treated rail will determine benefits in long term wear and fatigue resistance of rails of 340 and greater BHN.

RAIL WELDING

When 70-ton cars were replaced by 100- ton cars, a significant amount of the increase in track maintenance was attributed to joint failures such as bolt hole cracking. Since that time mechanical joints in heavy traffic mainlines have generally been replaced with welded rail. Thermite welds are often utilized to join quarter mile strings in the field to form CWR and are an important component in the track structure.

During the controlled evaluation between coventional and heavy axle loads in Phase I, the life of thermite welds exhibited a higher failure rate than during the previous 33-ton axle load operation, and was a cause of much concern. Evaluation of welds made with improved chemistries, mold designs, and improved installation techniques has shown that significant improvements in the life of thermite welds can be obtained.

Working with weld manufacturers, FAST engineers have installed and evaluated samples of improved welds. Welds with these improvements have exhibited longer average life than previously observed under 33-ton axle loads with little or no increased product cost. Quality control during the preparation and installation process continues to play a significant role in obtaining this increased life.

SPECIAL TRACKWORK

Locations where running surface anomalies occur show accelerated degradation under HAL traffic. Running surface discontinuities in turnouts, crossing frogs and insulated joints are among common intentionally occurring anomalies, all of which exhibit increased degradation over that of surrounding track.

Turnout Frogs: The HAL program has evaluated maintenance demand on number 20 frogs fabricated from a variety of materials, as well as limited evaluation of frog designs. Similar data has been obtained from a revenue service railroad, and results support findings from FAST; that is, using improved materials can offer significantly increased life and reduced maintenance labor efforts.

Evaluation of a limited sample of frogs at FAST fabricated with high integrity castings offered a significant increase in life between failure/major rebuild efforts. Premium materials and alternative shape factors, such as a V-nose frog, also exhibited an increase in life, when compared to conventional AREA frogs and materials. On the down side, certain premium materials are difficult or impossible to repair by conventional welding techniques. Such materials have shown long life but may not always offer the lowest life cycle cost if multiple rebuilding efforts on a frog are considered.

Turnout Designs: Recent AAR studies indicate that relatively minor differences in turnout geometry, such as curvature, tangential designs, and lead lengths can result in reduced dynamic loads and improved ride quality. These changes offer the potential of significant reductions in differential wear and fatigue, as well as maintenance. However, at FAST, the use of premium materials appear to offer more potential improvement than geometrical design differences. Earlier FAST/HAL results comparing identical geometry AREA number 20 turnouts indicated significant improvement simply through the use of premium materials. A follow-on evaluation of a tangential geometry turnout featured a swing nose frog and concrete ties. Initial results indicate that for the installations at FAST, premium materials of adequate strength for HAL traffic played a greater role than an improved geometry design in reducing degradation.

During the initial phases of operation, immediately after installation, the tangential advanced design turnout placed in FAST required a significant amount of rail related maintenance. The rapid rail surface degradation was due to inadequate hardening of the running surface. This result was observed in spite of reduced dynamic loads from the improved geometry. After replacing all rail components in the turnout with materials that had exhibited adequate performance under HAL traffic from other evaluations, turnout maintenance has been reduced significantly. Minor variations in heat treatment of special components continue to cause some maintenance problems.

Crossing Frogs: A subset of special trackwork components includes crossing frogs. Although these represent a very small (and localized) population of the track structure, they are a high maintenance item. In many cases they are located in areas where alternatives, such as bridges, turnouts, or track realignment are not a viable option due to adjacent physical constraints.

Results to date have shown similar trends in performance due to material characteristics. Premium materials featuring very hard/tough characteristics offer improved performance over conventional material crossing frogs. However, the life of such frogs, even with premium materials, is still limited under HAL traffic and additional improvements are needed. Limited efforts into alternative crossing frog designs are being investigated.

TIES

Two primary material variations, wood and concrete, have been evaluated to date in the HAL program. A reconstituted wood tie, which had previous performance history under heavy haul conditions, is the only other manufactured tie material evaluated to date. Steel ties will be evaluated in the future.

Wood ties: Tie performance at FAST is conducted in a relatively dry environment. Accelerated rotting, fungus growth and other degradation conditions encountered in other parts of North America do not occur during the life of tests at FAST. The primary failure modes experienced in the HAL program are tie splitting and gage widening from spike kill due to repeated rail changes.

To date, oak ties have exhibited the least amount of gage widening of any type of tie utilizing cut spikes. Softwood ties have indicated a higher gage widening rate (using conventional fastening systems), with Douglas fir showing the best performance. The use of direct fixation fasteners, when installed on new ties or those with little degradation, offers a noticeable improvement in life. Track strength (gage restraint) is significantly improved with such fastening systems.

Lateral loads play an important role in determining wood tie degradation rates, especially under heavy axle loads. At FAST, as in revenue service, lateral load environment can be influenced not only by degree of curvature, but train type, track lubrication, grade, and other operating conditions. Thus the most severe lateral load environment in a given territory may not always be at the sharpest curve. Local conditions should be evaluated when the need exists to set priorities for track upgrade projects, such as when the number of direct fixation fasteners or premium ties being installed is limited.

Concrete ties: To date, only limited cracking of concrete ties, at the beginning of the HAL operation, has been observed. No failures or inadequate performance due to tie breakage has occurred. Tie center bending strains are between 15- and 35-percent higher levels under HAL cars, and could affect long-term fatigue life of ties.

Of greater concern is the occurrence of concrete tie rail seat abrasion, which if left unchecked can lead to loss of fastener hold down capabilities. Evaluations of a number of repair techniques as well as materials designed to prevent abrasion from initiating indicate some solutions appear to have promise; however, repair and equipment solutions evaluated at FAST have insufficient tonnage to determine their life cycle.

Once started, abrasion rates appear to accelerate with accumulated tonnage, making repair techniques an important part of concrete tie life management. In order to reduce cost impacts, the life of abrasion resistive components should match rail replacement cycles.

FASTENERS

Conventional spikes and direct fixation fasteners have not shown significant component failures under routine HAL operations at FAST. The loading environment, on occasion, produces very high lateral load impacts, which can eventually lead to fastener failures. The performance and failure mode of new fastener systems must be evaluated to determine appropriate inspection and repair techniques needed to ensure safe operations.

BALLAST

Perhaps the one track component that indicated the least impact from increased axle loads is in the area of ballast. Isolated running surface anomalies (engine burns, joints, etc) which produce localized impacts can have a great effect on the performance of certain ballast materials.

If a particular ballast has exhibited marginal strength or performance characteristics, then impacts under HAL operations can result in significant localized degradation and the need for spot maintenance. A ballast, which performs better than others under conventional axle loads, will tend to also perform better than others under HAL traffic. Although none of the ballast materials evaluated at FAST failed during the 460 MGT of Phases 1 and 2, some did exhibit higher particle degradation rates. Tamping efforts contributed more to ballast particle breakdown than increased axle loads. As most of the tamping efforts at FAST were in conjunction with localized running surface anomalies, quick repair of rail joints is a necessity in avoiding long range ballast problems.

Deferral of spot maintenance often will lead to long-term track surface problems. Operating significant amounts of HAL traffic requires that deferred maintenance policies be reduced to prevent development of localized track problems. Otherwise, ballast life appears to be dependent on total applied tonnage, with little effect or change from the increased axle loads.

TRACK SYSTEM EVALUATION

To determine the effect of HAL traffic on the total track system performance, the response of several components must be monitored at the same time. The first of such evaluations at FAST is the load path monitoring effort, which provides basic information on how the wheel loads are transmitted through the track structure into the subgrade. Data collected from this evaluation was utilized to assist in design of a track support system of marginal strength, as part of the need to bracket the performance data base for HAL traffic.

Load Path: The load path evaluation monitors rail/wheel loads and the subsequent transmission at various component interface points (tie plate/tie, tie/ballast, etc) until it is distributed into the subgrade. Data has been obtained with a variety of wheel loads and equipment designs. New designs of equipment which often feature non-traditional axle spacing, can result in significantly different load patterns and severity being transmitted to the subgrade.

Data suggests that the increased loading from HAL traffic is evident at all locations within the track structure, from the rail to the subgrade. However, subgrade support conditions have a significant influence on measured pressure differentials observed at various depths, resulting in variations to track performance. Impact loading, from flat wheels or rail surface anomalies, can also be noted at different levels in the subgrade. Also, different wheel base/truck spacings affect the load seen at the subgrade level.

These observations emphasize the concern of deferred maintenance. For instance, temporary joints remaining in track for long periods after a rail break is a common deferred maintenance practice. If not repaired immediately such conditions could lead to very rapid and localized degradation of the ballast especially when operating heavier axle loads.

Low Track Modulus Test: During the initial HAL operation, little or no influence was noted on out of face track surfacing requirements (outside of areas where localized anomalies occurred; i.e, joints). The implications were that HAL traffic could be operated with little or no increased cyclic surfacing maintenance. The railroad engineering community suggested that this might be an incorrect assumption, due in part to the generally uniform and stiff support conditions at FAST.

To address this issue, a lower support track known as the low track modulus (LTM) section was created to monitor maintenance and degradation rates of marginal track under HAL operation. As suspected, the LTM zone exhibited increased degradation rates and required extensive maintenance. Additional data provided a relationship between track surface conditions and dynamic wheel loads. Design and thickness of the granular layer between ballast and subgrade, along with moisture content of this material, played an important role in ultimate surface degradation rates.

Although no comparison with 33-ton axle loading can be made as far as maintenance demand, HAL traffic on marginal support should be a concern by operating railroads. Subgrade strength in revenue sites is site specific, and can vary from location to location. In addition, where support conditions might be just barely sufficient for loads transmitted from 33-ton axle loads, 39-ton axle loads can, in some cases, "tip the scales" and create a condition whereby subgrade failure may be imminent.

Results of the LTM test will be utilized in future operations to determine performance of the advanced suspension trucks. Current data suggests that areas where track support is or might be considered marginal should be evaluated in detail to determine if the incremental increase to HAL wheel loads will create an unacceptably rapid degradation of the track.

MANAGING THE TRACK SUPPORT SYSTEM BY OPERATING HAL TRAFFIC WITH PREMIUM TRACK MATERIALS

Summary observations: Heavy axle load traffic can be operated over modern, conventional track built with premium materials with controllable increases to maintenance costs. To do so, the use of premium materials is essential. The proper combination of premium rail, fasteners, ties, and ballast will function as a system to reduce differential deflections and spot anomalies. If such anomalies occur, they can rapidly create areas of higher dynamic loads, which will result in significantly increased maintenance. Thus deferring of maintenance can lead to accelerated and long term damage to the track.

The use of head hardened rail, which exhibits a high resistance to the formation of corrugations and metal flow, or which is periodically ground to remove such anomalies, is required to prevent running surface defects. When joined in the field with thermite welds made with proper controls, CWR can provide the smooth surface needed. If a weld failure occurs, immediate replacement welds, not mechanical joints, are required to prevent impact loads from degrading ties, fasteners and ballast.

Proper rail/wheel lubrication used in conjunction with wear resistant head hardened rail will extend rail life and limit damage to ties and fasteners from rail change activities. The use of direct fixation fasteners on wood ties will reduce the effects of spike killing during rail changes. Where concrete ties are utilized, the use of materials (pads, insulators, etc) to resist rail seat abrasion is essential. If rail seat abrasion has already occurred, repair techniques such as epoxy/steel plates have indicated a long life. Good quality ballast continues to be a requirement. If ballast life/quality is considered to be marginal under current operations, HAL traffic will not show significant changes in degradation except where rail surface anomalies are allowed to remain. In such cases, marginal ballast can be expected to exhibit increased spot maintenance requirements.

Finally, overall track support/subgrade conditions should be evaluated. Marginal support, especially when moisture conditions can create non-uniform track modulus, will be susceptible to significant track settlement and frequent maintenance cycles. Analysis of subgrade support conditions must be performed in order to determine the proper maintenance and remedial action to eliminate continued problems in the affected areas.

HAL ECONOMICS — PHASE II UPDATE

The economic implications of operating HAL traffic reported in the October 1990 *Proceedings: Workshop on Heavy Axle Loads* indicated that only a marginal benefit could be obtained. Actual benefits were very route specific.

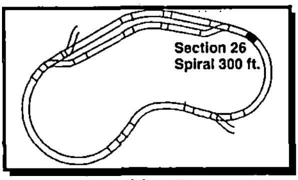
Phase II's economic analysis was improved in several areas. The primary area included data from the evaluation of improved track materials tested. The principal areas of track maintenance savings were a result of improved field welds and a reduction of turnout maintenance. The economic analysis also was affected by improved track deterioration models and improved calibration of deterioration models from both Phase II and the addition of revenue service information.

For this study, the economic analysis was performed for a typical eastern and western coal route. The economic results are service and route specific; therefore, individual railroads must analyze their own particular route and service alternatives.

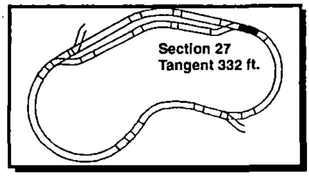
The overall impact of the improved track materials was to improve the economics of HAL equipment. Although the economics improved both the 286,000- and 315,000-pound equipment, the current 286,000-pound equipment continues to show a slightly lower cost per net ton mile than 315,000-pound equipment.

Future HAL operations will address additional reduction in track damage with HAL traffic using improved truck designs. Reduced dynamic loads should result in reduced maintenance, wear of components, and extend the fatigue life of track materials. Other areas of operation, including crew, car/locomotive, capital and maintenance costs, fuel, and bridges can significantly influence the economic of HAL traffic.

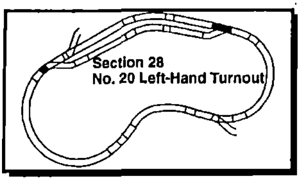
The net effects of these parameters are presented in a separate document provided at the conference.



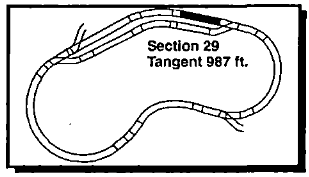
Transition Zone



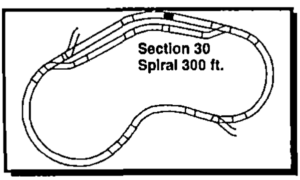
Location of Frog Performance Test



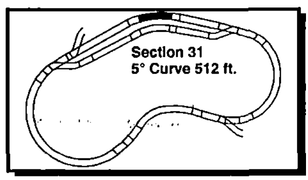
Turnout Experiment Locations



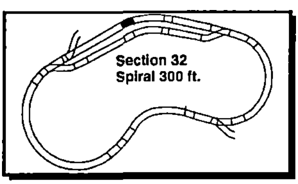
Location of Low Track ModulusTest
and Load Path Evaluation



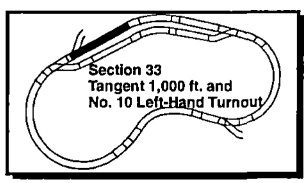
Transition Azobe / Available for Testing



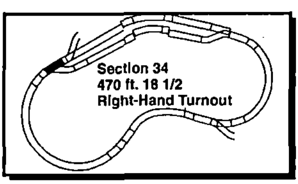
Location of Tie and Fastener Test,
Azobe Wood, Concrete,
and Thermite Weld Tests



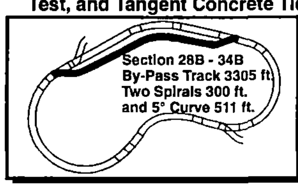
Transition Zone / Available for Testing



Location of Control Zone — Track
Modulus and Load Path Evaluation
Experiments, Crossing Frog Performance
Test, and Tangent Concrete Ties



Location of Tie and Fastener Test,
Azobe Wood, Concrete, and
Thermite Weld Tests



Location of the Ballast Resistance
Characterization Experiment

FAST Open House Track Self-Guided Inspection

Welcome to the 1995 AAR Engineering Conference FAST track and train inspection. Enclosed you will find a map of the FAST loop and a summary of each test zone.

During each inspection day (Monday/Wednesday), AAR/FAST engineering staff will be stationed around the loop wearing white hard hats. They are available to address your questions regarding track tests, results, materials and operations.

Additional staff will be on-hand at the FAST facility building to answer questions on mechanical/truck aspects of the program. Advanced truck manufacturing representatives selected for the next phase of FAST will also be available.

SAFETY
During all track and train inspections please wear a hard hat and safety glasses. These items are available in the Operations building main conference room and should be returned after inspections are complete.

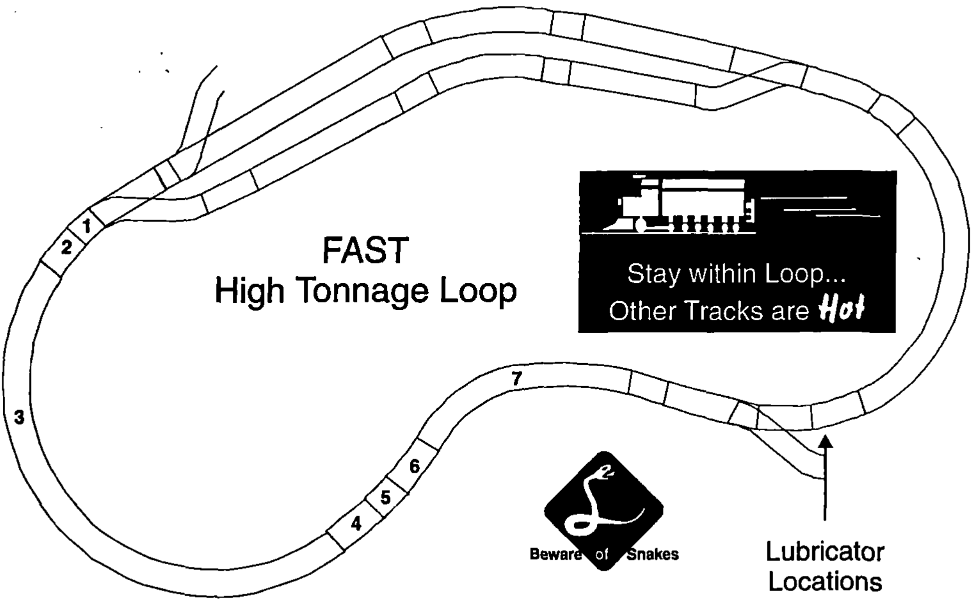
Caution: Please watch for rattle snakes. Also, be alert for high speed train moves on adjacent tracks.

LUNCH AND BREAKS
Served at FAST.
Lunch from 12:00 to 1:00 p.m. Refreshments at 10:30 and 2:00 p.m.

TRANSPORTATION
Vans will shuttle visitors between the Operations (Core area parking lot at the TTC main entrance) and FAST facility buildings, and to any location around the FAST loop.

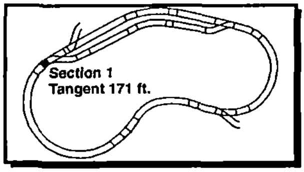
PHONES
The limited number of phones available at the FAST facility and Operations buildings will be clearly identified by signs.

Thank you for visiting the Transportation Technology Center. We trust your inspection will be both educational and enjoyable!

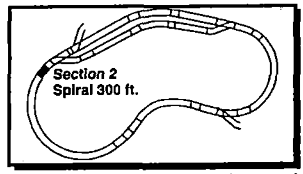


Description of HTL Track Sections

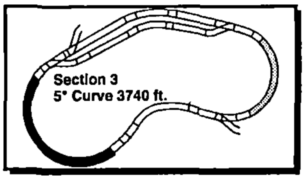
The typical HTL track structure consists of continuous welded rail fastened to wood ties with cut spikes and fully box anchored at every second tie. Included in specific test zones are concrete ties, jointed rail, and elastic type rail fasteners. A description of each section follows:



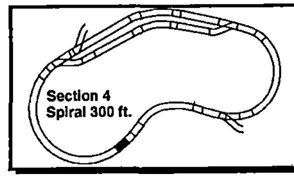
Transition Zone/Available for Testing
Location of Hot Bearing Detector



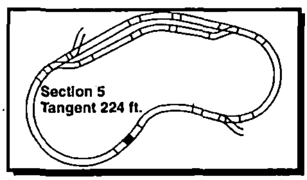
Transition Zone/Available for Testing



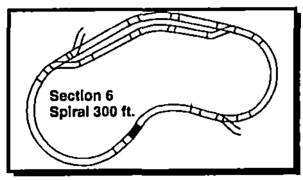
Location of Ballast, Rail Performance
and Concrete Tie Experiments



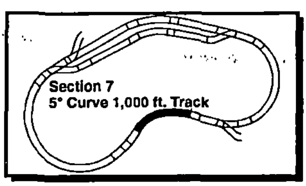
Transition Zone/Available for Testing,
Future Site of Steel Tie Test



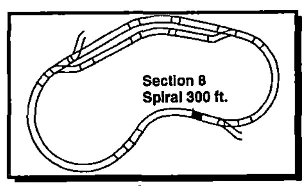
Location of Alternate Hot Bearing
Detector, Future Site of
Steel Tie Test



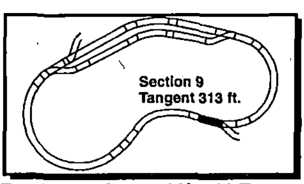
Transition Zone, Future
Site of Steel Tie Test



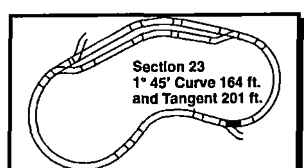
Location of Tie and Fastener and
Dry Rail Performance Experiments



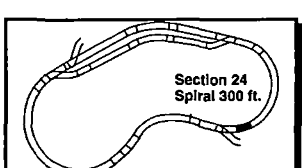
Transition Zone



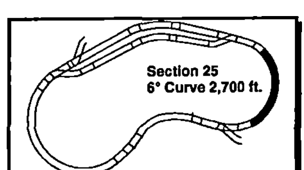
Road Crossing and No. 10 Turnout



Wayside Rail Lubricator



Transition Zone/Available for Testing



Location of Rail Grinding Performance,
Wood Tie and Fastener Experiments