U.S. Department
of Transportation

**Federal Railroad
Administration**

Locomotive-Based Top of Rail Friction Control Implementation Results and Issues

Phase 1: Atomized Spray/Friction Control Product

Office of Research and
Development
Washington, D.C. 20590

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Final Report

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13. ABSTRACT

This report documents the first phase of a test to determine what effect top of rail (TOR) friction modification has on rail surface friction, lateral curving forces, and train handling. In Phase 1, one type of TOR friction modifier and application system was evaluated, primarily on coal trains operating over a 120-mile segment which featured curves up to 10 degrees and gradients up to 2.2 percent. Results showed that lateral curving forces could be reduced up to 50 percent, when the TOR system was properly operated and maintained. During the TOR implementation period, no adverse train handling issues were noted. This work was conducted under the Track Train Interaction Program Element within the Federal Railroad Administration's Research and Development Strategic Plan. During Phase 2, another TOR friction modifier and application system will be evaluated under the same conditions.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
		AREA		
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	m^2
mi^2	square miles	2.60	square kilometers	km^2
	acres	0.40	hectares	ha
		MASS (weight)		
oz	ounces	28.00	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.90	tonnes	t
		VOLUME		
tsp	teaspoons	5.00	milliliters	ml
Tbsp	tablespoons	15.00	milliliters	ml
fl oz	fluid ounces	30.00	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.80	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
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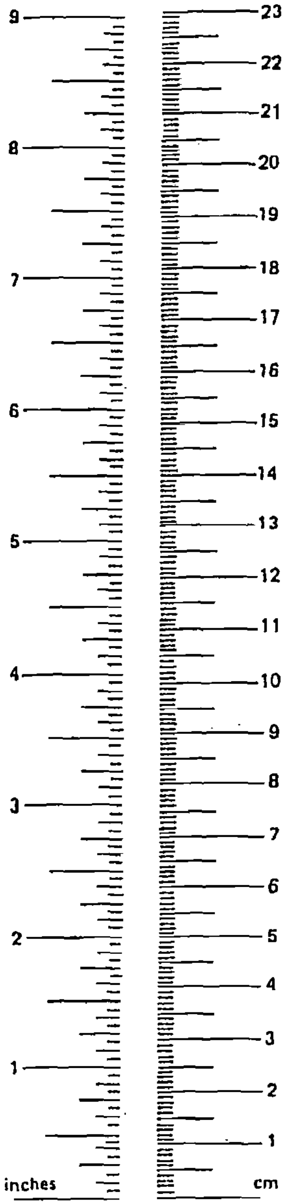
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
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cm	centimeters	0.40	inches	in
m	meters	3.30	feet	ft
m	meters	1.10	yards	yd
km	kilometers	0.60	miles	mi
		AREA		
cm^2	square centim.	0.16	square inches	in^2
m^2	square meters	1.20	square yards	yd^2
km^2	square kilom.	0.40	square miles	mi^2
ha	hectares (10,000 m^2)	2.50	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.10	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36.00	cubic feet	ft^3
m^3	cubic meters	1.30	cubic yards	yd^3
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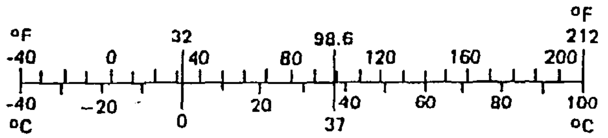

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* 1 in. = 2.54 cm (exactly)

Executive Summary

Previous work conducted by the Federal Railroad Administration and the Association of American Railroads demonstrated significant fuel savings and control of curving forces when prototype top-of-rail (TOR) friction modification systems were operated. These demonstrations were conducted in either closed loop or limited field sites. To provide more definitive measures of TOR's effect on lateral curving forces in revenue service applications, on operation with helper locomotives, and on train handling and general TOR system performance, five locomotives equipped with operating TOR friction modification systems were monitored on a 25-mile section of the CSX Transportation, Inc. railroad. In addition, a short concept demonstration was conducted on a 14-mile section of the Norfolk Southern railroad. Data was collected to monitor changes in rail friction, lateral curving forces, and train handling.

Test results show that, while the front portion of a TOR-equipped train exhibits a greater force reduction than at the rear, lateral forces in sharp curves were reduced up to 50 percent, even though conventional gage-face lubrication was also present and locomotives were applying sand. During the controlled period, a significant amount of manual override, adjustment, and equipment monitoring was needed to ensure proper output necessary to provide reliable application. This produced the observed 50-percent reduction in curving forces. No adverse train handling effects were reported during the test periods.

In general, the friction control product reduced the friction coefficient of dry rail from a level at or above 0.5 μ to within the target range of 0.30 μ to 0.35 μ. In addition, the friction control product used in this test apparently has the ability to increase friction to 0.30 μ when existing conditions are below this value, which can improve the lateral curving performance of cars. Regarding remaining friction modifier present after the passage of a TOR-equipped train, data showed that following trains not equipped with TOR systems rapidly removed the excess TOR friction product from the rail, with only one or two non-equipped TOR trains receiving any benefit from this remaining friction modifier.

Also noted was the need for some additional equipment development to improve reliability so that full TOR implementation can be accomplished without the need for constant monitoring. In particular, further development is needed to eliminate nozzle clogging.

Based on observations from these tests, and from previous experiments, the following represent some general requirements for ensuring effective TOR implementation:

Extensive training for locomotive inspectors to ensure that they know how to properly inspect and adjust TOR systems.

Regular feedback on rail conditions from track inspectors, including evidence of excessive or insufficient friction control product, to help locomotive repair and operating departments keep TOR systems properly maintained and adjusted.

Long-term monitoring of lateral curving forces at truck performance detector sites to determine if overall TOR system operation is effective.

Periodic field measurement and inspection of rail friction as part of an effective TOR monitoring program. The monitoring program should also include review and evaluation of historical trends to help determine desired practices for system adjustment and operation.

Continued monitoring and inspection of wayside lubricators to achieve adequate gage face lubrication and to control rail wear.

Results from these and previous tests suggest that the economic benefit of locomotive-based TOR friction control can be significant when a substantial number of trains are equipped with properly operating and adjusting systems. The benefits would be realized through reduced fuel consumption, reduced rail and wheel wear, and reduced track damage in curves due to lower lateral forces. These benefits can be expected, provided TOR lubrication systems are reliable and can be maintained with modest effort.

Acknowledgements

A large number of individuals contributed to the successful implementation of this effort. The combined, cooperative support allowed performance to be monitored over time and documented.

A number of CSX personnel contributed to this effort. Marty Clifton of the research department provided field support and monitored most of the runs when TOR units were in operation. Wes Ketchem provided signal department assistance in establishing the load station and periodic field assistance to repair the site. Additional support was provided by George Melodini, Jim Beyerl, and K. Wilson, and numerous personnel in the CSX operating and transportation departments who assisted in coordinating locomotive allocations to support these demonstrations.

Portec Rail Products personnel assisted with high-speed tribometer data collection and system refilling, and included Ward Powel, Bruce Wise, and Kevin Adkins. Data reduction of the high-speed tribometer data was performed by George Clem.

KLS/Lubriquip provided significant field support during installation and implementation by Ray Niemczura and Brian O'Toole.

Kelsan Technologies personnel Don Eadie and John Cotter assisted with field support to ensure the friction modifier was properly stored and applied.

NS support for the cooperative CSX/NS demonstration test included assistance from Bob Blank, Kevin Conn, Scott Keegan, and Don Cregger.

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1.0 INTRODUCTION

1.1 BACKGROUND

With the Class I railroads now spending approximately $3.2 billion per year on fuel, even a small percent reduction in fuel usage can represent a significant savings. Thus, any practical, cost-effective method for reducing fuel consumption is of interest – and thus the main reason for examining the practicality of top of rail friction modification (TOR) systems. These systems are designed to apply a substance (a friction modifier) to the top of the rails to lower the wheel to rail friction, and thus reduce the energy needed to pull a train. Unlike the lubricants commonly applied to the gage face of the rail (mainly in curves) friction modifiers are intended to provide low friction when wheels are in a purely rolling mode and moderate friction when wheels are in a braking mode (attempting to slide).

In most TOR experiments to date, a locomotive-mounted system applied a friction modifier to the top of rail behind the last locomotive axle. To prevent possible adverse effects on locomotive traction of following trains (when high friction levels are often needed), the friction modifier was applied in controlled quantities and was designed to be used up (or consumed) as the train passed. Some friction modifiers have since been designed to remain on the rail after the passage of a single train, without adversely affecting traction, as is the case for the friction modifier tested for this report.

Tests conducted from 1997 through 1999 documented the energy-saving potential of TOR systems, with revenue service testing showing a fuel reduction of about 10 percent for loaded coal trains and 5 percent for empty trains. [1,2,3] Tests conducted at the Transportation Technology Center also showed the potential for up to 50 percent reduction in lateral curving forces, along with associated reductions in wheel and rail wear. In addition, these tests provided some observations of train handling effects, of train stopping distances, and some discussion of practical issues in employing TOR systems. One observation from previous testing is the need for good control in applying friction modifiers to prevent adverse train handling effects, avoiding excessive TOR application and maintaining consistent application on both rails.

Because energy savings were demonstrated, with no apparent adverse train handling effects when the systems were functioning as intended, the decision was made to further explore TOR systems in revenue service applications. While many aspects needed examination, this next phase of testing would focus on their effect on lateral wheel-rail forces in curves, on rail surface friction after the passage of TOR-equipped trains, on compatibility with gage-face lubrication, on the effects on helper locomotives at the end of trains, and otherwise, to gain further insight on how to effectively employ these systems.

Most of the testing documented here was conducted on CSX Transportation, Inc. (CSXT), with funding provided jointly by the Federal Railroad Administration (FRA) and the Association of American Railroads (AAR). The CSXT tests would be conducted in two phases. In each, CSXT would provide one type of TOR application system and one friction modifier, with five locomotives equipped with each system. A few tests were also conducted on Norfolk Southern

(NS) using a borrowed CSXT locomotive equipped with a TOR system. This report documents results of the NS tests and the first phase of the CSXT tests

1.2 OBJECTIVE

The main test objective was to monitor the effects of locomotive-mounted TOR systems on:

- Rail friction
- Lateral curving forces
- Train handling

In addition, some observations would be made of general system performance and reliability, of the interaction of TOR friction modification with conventional rail gage face lubrication in curves, of maintenance issues, and of other aspects of practically implementing TOR systems.

1.3 APPROACH

The general approach was to test each of the two TOR system and friction modifier combinations at separate times to ensure that any differing performance characteristics between the two would be evident and to make any necessary TOR system troubleshooting during the tests easier. Trackside (curve force) data was collected at a sharp curve (7 degrees on CSXT, 8 degrees on NS) to help ensure that any curve force effects due to the TOR system would be evident. To determine if repeated passes of the TOR system appeared to produce any residual top of rail friction effects, top of rail friction over the test segments was measured with a high speed tribometer before the tests and after periods of testing.

All TOR-equipped trains were either loaded or empty coal unit trains. Tests were conducted on selected segments of track (25 miles long on CSX and 14 miles long on NS) with frequent curves as sharp as 10 degrees.

1.4 SCOPE

Tests documented here were made with one TOR application system (Lubriquip Trackmaster® Onboard Top of Rail Delivery System), and one friction modifier (KELTRACK®). These were purchased by CSXT as a package system. The system was tested as supplied and operated per suppliers' instructions, with no design alterations made during the tests.

Curve force data came from one trackside instrumentation site on both CSX and NS, with train speeds at the site about 10 to 15 mph on CSX and up to 25 mph on NS. No measurements of fuel usage or wheel or rail wear were made during these tests. Tests on CSX were conducted over several months and for one day on NS.

2.0 SYSTEM DESCRIPTION – PHASE 1

2.1 APPLICATION SYSTEM

The application system used by CSXT during the Phase 1 demonstrations was the Lubriquip Trackmaster® Onboard Top of Rail Delivery System, manufactured by Lubriquip, Inc. of Cleveland, Ohio, (formerly known as KLS or KLS–Lubriquip). Each system includes a Trackmaster LLIC™ Controller, a 50-gallon reservoir, a circulating pump driven by a 74 volt brushless DC motor, two "metering boxes," which house stepper motor driven gear pumps that control the flow of friction modifier to the top of the rail, delivery nozzles, and miscellaneous plumbing and wiring. The Trackmaster TOR system incorporates several unique design features, and therefore the design has been submitted to the US Patent and Trademark Office for patent protection. The application is pending.

The Trackmaster system is fully automatic. The Trackmaster LLIC™ (last locomotive in consist) controller monitors various locomotive systems, such as train line air pressure, locomotive speed, and dynamic brake, throttle and reverse positions. While operation is automatic, certain features such as application rates are user selectable. Using the various inputs, the controller determines when application of the friction modifier is desirable or not, such as when the brakes are being applied. Furthermore, the technique used by the Trackmaster LLIC controller automatically senses the locomotive position in the train so that friction modifier is only applied after the last driving wheels in the train. This prevents wheel slip on the locomotive(s) while the fluid dries and provides full TOR benefits to all axles on the trailing cars. Figure 1 is a schematic of the Trackmaster system. For the CSXT tests, nozzles were not mounted on the rear trucks because the locomotives usually operate in back-to-back pairs; thus, the trailing truck is always at the front of the locomotive.

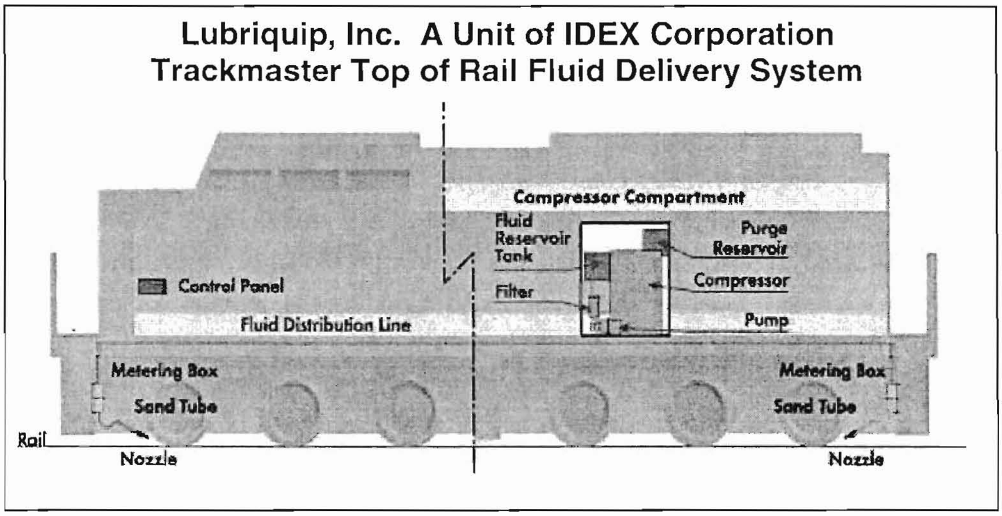

Figure 1. Typical Mounting Locations for Phase 1 Locomotive-Based TOR Components
(For Phase 1 CSXT demonstrations, nozzles were mounted only on the lead (front) truck.)

Most of the components in the Lubriquip Trackmaster TOR system are universal in design. The exceptions are the nozzle mounts and reservoirs, which necessarily are custom designed for the particular locomotives on which the system is installed. The CSXT test locomotives were General Electric GE-AC4400 units of recent vintage. The reservoirs were mounted in the air compressor rooms.

2.2 FRICTION CONTROL PRODUCT

The friction control product used in this test is a KELTRACK® Onboard Locomotive Product, developed and produced by Kelsan Technologies Corp. of Vancouver, B.C, Canada. It is a water-based suspension of friction-modifying solids that physically resembles a water-based latex paint. It does not contain oil or grease lubricants. When applied as an atomized spray onto the top of rail, the water rapidly evaporates under the action of the first few wheels. This leaves a thin, dry uniform film across the wheel-rail contact patch, which provides an intermediate coefficient of friction on the top of the rail. The material, when dry, is engineered specifically to provide a friction level that is believed to be optimal (0.35 μ), and which will not impair traction or braking. This controlled friction level is, in turn, the reason for reduced lateral forces and tractive energy consumption.

The friction control product also incorporates technology that produces a film with enough durability to last for as many wheel passes as possible (maximum retentivity). This technology enhances the film strength and adherence to the rail. As designed, the material is NOT intended to be worn off or otherwise removed by the end of the train, but rather to remain on the rail and provide as much benefit as possible to subsequent trains that may not have a TOR application system.

The frictional characteristics of the film are also designed to provide "positive friction." This means that as creepage increases, the friction of the film increases. This reduces corrugation onset and wheel squeal in curves. The technology involved in the friction modifier is broadly patent protected.

2.3 REFILLING AND INSPECTION

Each locomotive is equipped with a 50-gallon reservoir, which under normal operations is expected to last 4–6 weeks before requiring refilling. As the application system can be inhibited during periods of air brake application, and may (at the railroad's discretion) be inhibited during dynamic braking, speeds less than 10 mph, and throttle settings less than notch 5, the average amount of lubricant applied per mile of operation will vary considerably by route. A route with steep downgrades requiring significant time in dynamic brake mode will result in very little product being applied, while the return run, at speeds over 1 mph with the throttle setting 5 or greater, might apply the friction control product for the entire distance. This allows a very slow train pulling a grade to still apply friction control material as long as speeds are greater than 1 mph and throttle setting is 5 or higher.

Additionally, the Trackmaster LLIC controller prevents running the pumps dry by switching the system into "standby" mode when low level is sensed. Thus, no issues regarding empty tanks were encountered. For full-fleet implementation, special pressurized tanks located wayside at strategic locomotive refueling depots would be used. For this demonstration period, patented CHI-TECH nitrogen charged containers provided by Portec Rail Products was used (Figure 2). These tanks were located at strategic refueling locations and were used for refilling TOR equipped locomotives with friction control product. Each tank had a capacity for 250 gallons of the Kelsan friction control product. By use of special fittings, the pressurized CHI-TECH system allowed quick and spill-free filling, without the need for buckets and liners. When empty, the tanks were shipped to a bulk-refilling site and returned. Pressured wayside tanks were used to fill the onboard reservoirs so that pumps and associated electrical or air power would not need to be installed at the field sites.

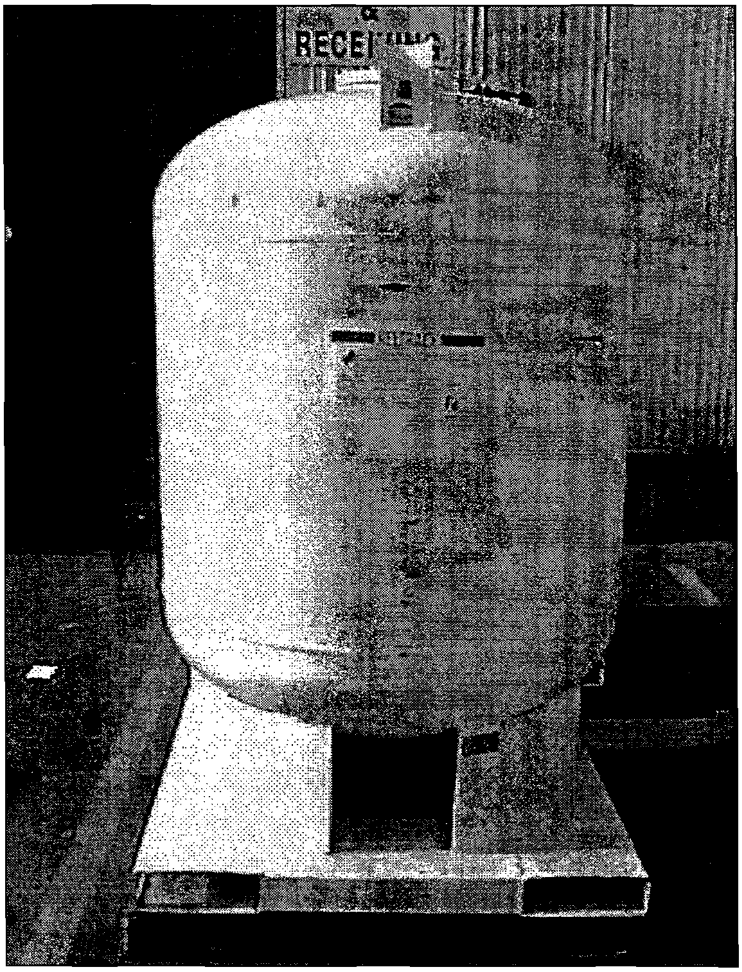

Figure 2. Pressurized Bulk Refilling Tank, CHI-TECH System, Provided by Portec Rail Products

3.0 TEST DESCRIPTION – CSXT TESTS

3.1 TEST SITE

For this test, CSXT offered the 96-mile line between Grafton, West Virginia, and Cumberland, Maryland, as Figure 3 shows. A 25-mile section of line (Figure 3, dotted lines) was thoroughly monitored for purposes of this study. This segment, which is between MP 242 and 267, is primarily double tracked. A detail of the main double track section (MP 242 to MP 252) is shown in Figures 4a and 4b. Of the two tracks, loaded coal trains operate in the eastbound (EB) direction, primarily on track No. 2, which is the upper track shown in Figures 4a-b. A daily mixed freight and light helpers also operate over this track. To determine the effects on train curving forces, a force monitoring station was installed on track 2, MP 251.7.

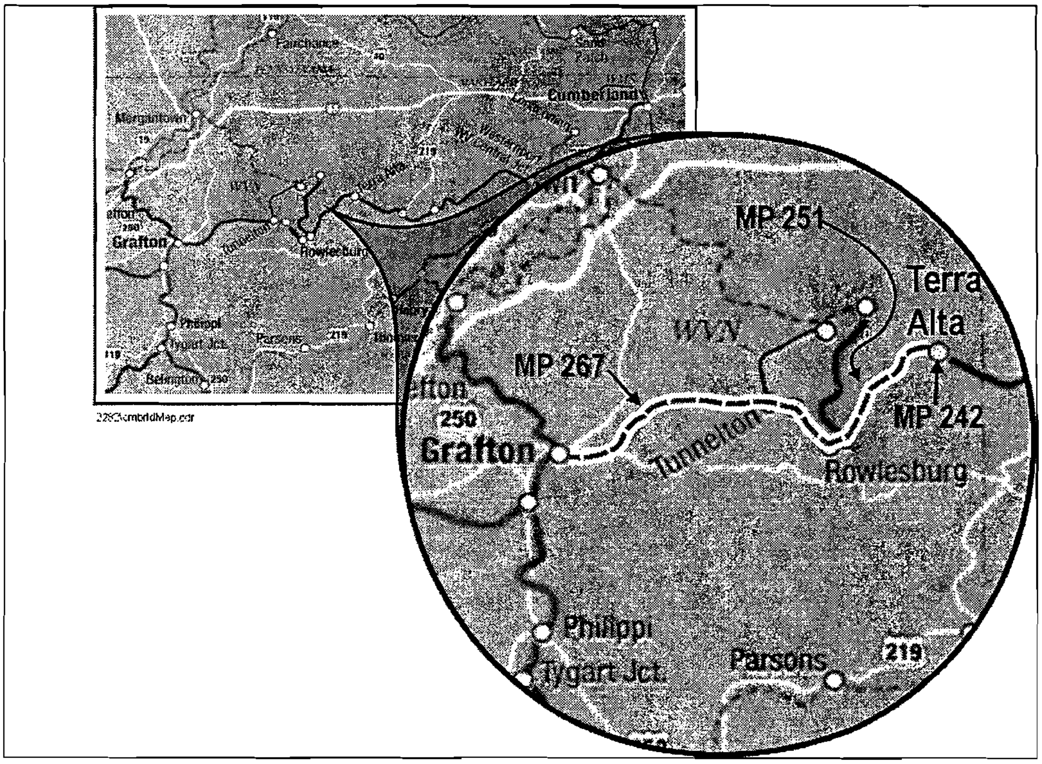

Figure 3. Map of the Grafton – Cumberland Coal Route

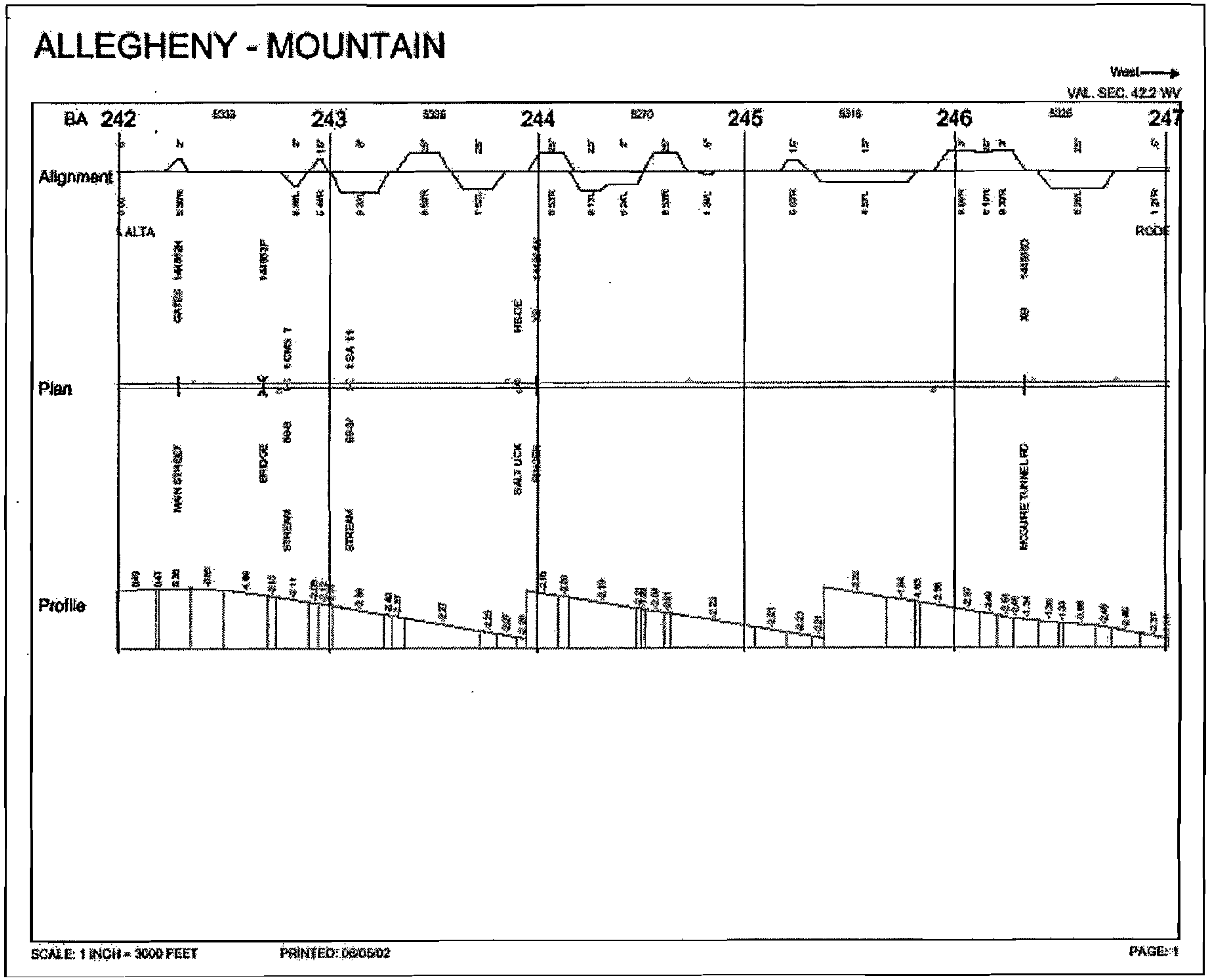

Figure 4a. Track Chart MP 242 to 247

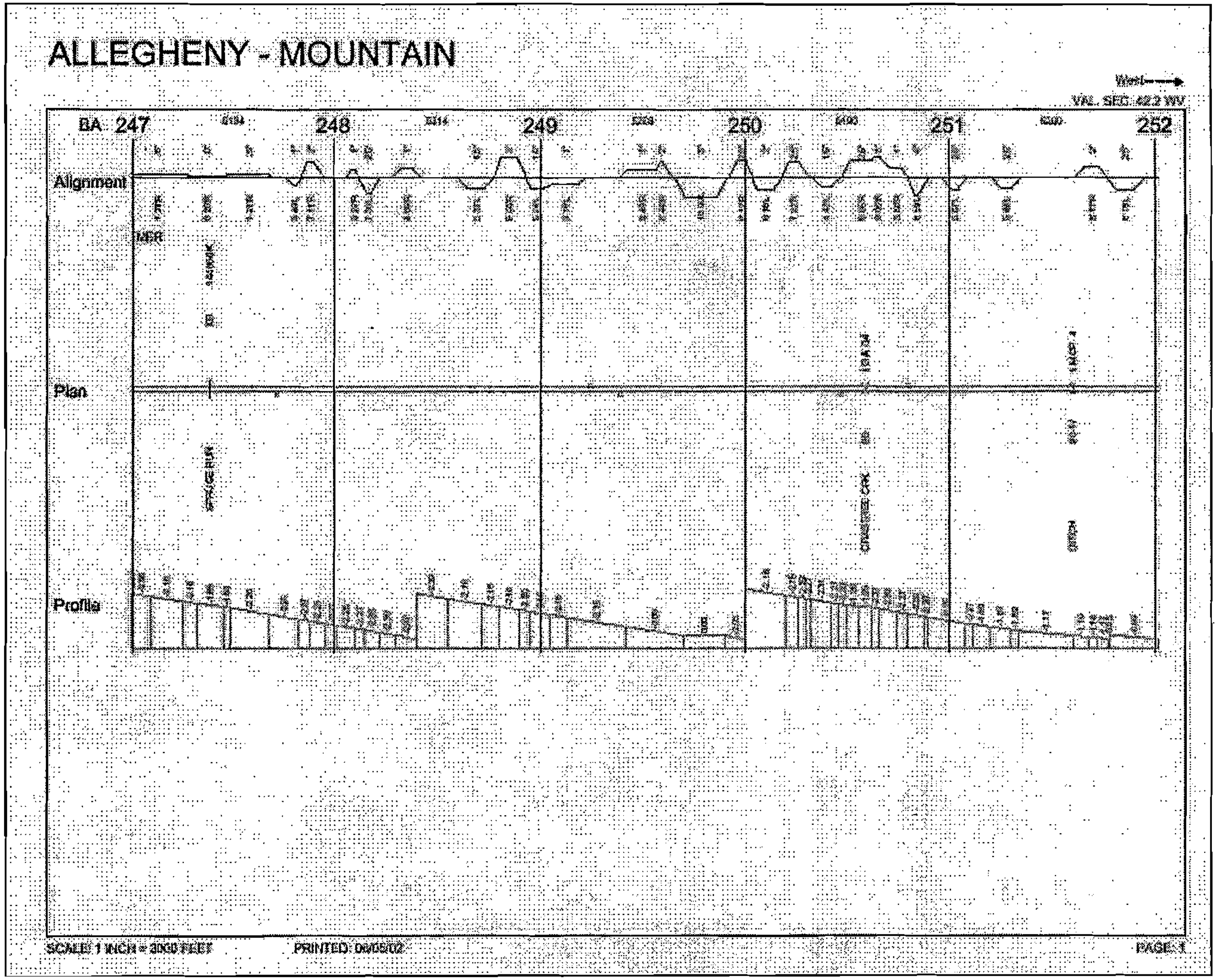

Figure 4b. S Track Chart MP 247 to 252, Showing Area Surrounding Load Monitoring Station at MP 251.7

3.2 INSTRUMENTATION AND DATA COLLECTION

With the cooperation of CSXT and AAR funding provided by the AAR Strategic Research Initiatives Program, a measurement site was established to monitor performance of key parameters and to track changes to friction and curving forces as TOR friction control was introduced.

Key data collected and monitored for this evaluation included:

- Wayside lateral and vertical (LN) forces EB mainline
- Rail friction — gage face and top of rail
- Train speed and length (cars)
- Changes in train operating policies
- Helper locomotive performance
- Crew comments and observations

The lateral force monitoring station was installed on a 7-degree curve near MP 251.7. The EB mainline was selected because most traffic is loaded coal trains traveling up a 2.4-percent grade. The grade at the measurement site reduces to approximately 1.8 percent for a short distance, but is between 2.2 and 2.4 percent on either side. Figure 5 shows an overall view of the measurement location.

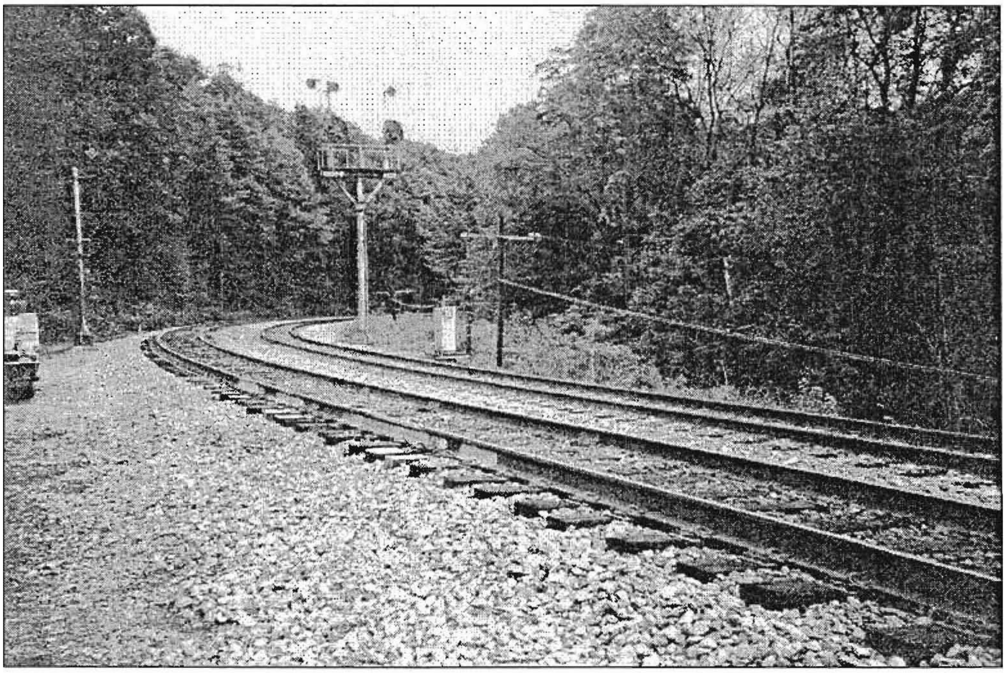

Figure 5. UV Monitoring Station Site at MP 251.7

For each train passing the site, a data file is created containing vertical and lateral load information. A summary of average load is produced for each train, which is utilized for long-term trend analysis. The data file for each train also contains information on direction, speed, load, and number of cars. When needed, lateral load data for each individual axle in a specified train can also be obtained. The force station runs continuously, with data collection automatically triggered and sent to TTCI for analysis.

Rail friction data was collected using a DMF/Portec Rail Products high-speed tribometer. This device measures top of rail and gage face friction continuously at speeds up to 25 mph, and produces a database of rail friction. Figure 6 shows the measurement wheels of the high-speed tribometer in use.

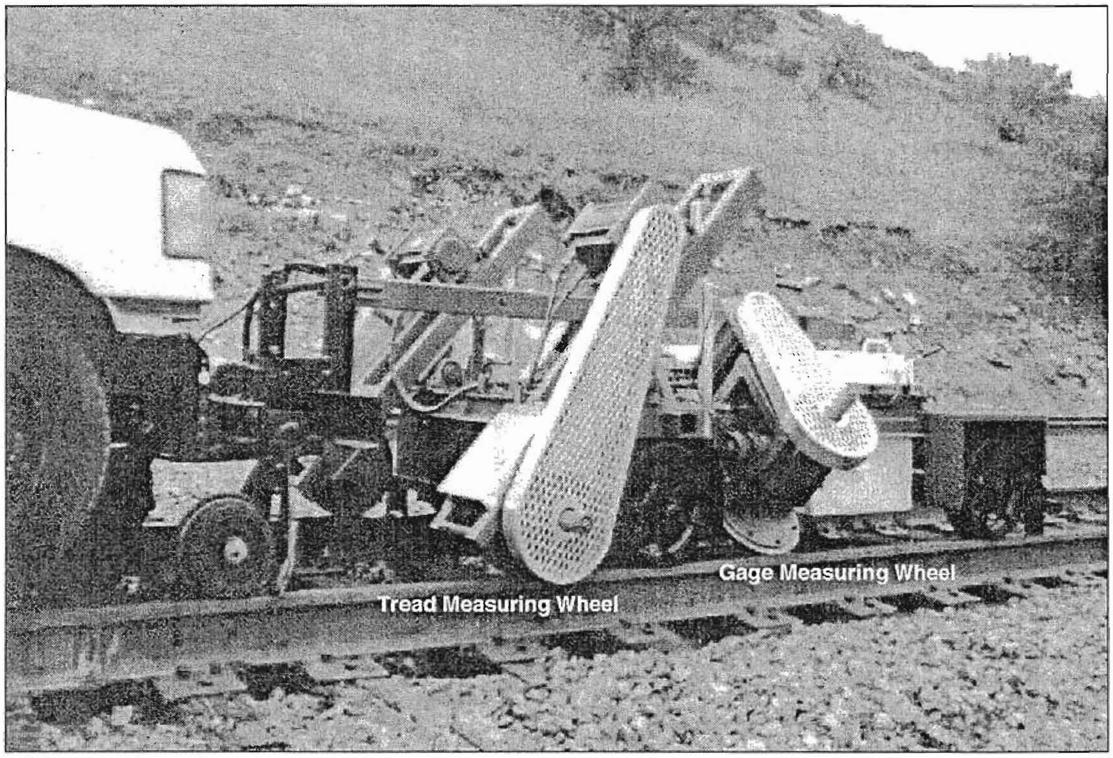

Figure 6. High-Speed Tribometer Used to Collect Rail Friction Data

CSXT's Research and Test Department personnel spent considerable time with local operating officials and train crews. Interviews and discussions were conducted to determine if any changes in operation or train handling were required with trains equipped with TOR systems. Both vendor and CSXT representatives rode many of the TOR-equipped trains between Grafton (MP 277) and Terra Alta (MP 242) to monitor system operation.

3.3 TOR SYSTEM INSTALLATION AND TRAIN OPERATIONS

Under efforts funded by CSXT, five GE-AC4400 locomotives were equipped with TOR application systems using the Lubriquip/Kelsan atomized spray concept at the Huntington, West Virginia shops. The first unit was equipped in August 2001, after which it was placed into service. Installation of the other four locomotives was delayed to allow:

1. CSXT locomotive shop personnel to recommend any changes to improve installation
2. CSXT field personnel and vendors to observe operation in the field to determine if any modifications were warranted.

After several months of operation, minor software and installation upgrades were suggested and were implemented by Lubriquip, after which TOR application equipment was installed onto the remaining four locomotives in the following sequence: Unit two was installed the last week of November 2001, unit three was installed the second week of December 2001, unit four was installed the third week of January 2002, and unit five was installed the third week of February 2002.

During December 2001, the first TOR equipped locomotive was made available to Norfolk Southern (NS) Corporation for a 1-day demonstration. A short test to verify reductions in lateral loads was conducted using a NS coal train. Information from this demonstration was used to adjust output rates for field implementation on CSXT.

During the period from March to May 2002, the five TOR-equipped locomotives were operated in general service on CSXT. The locomotives operated over a wide range of CSXT tracks to determine system reliability. To document the effect of multiple trains operating with TOR units, the five units were assigned to operate over the monitored site during a concentrated monitoring period. This was initiated mid-April 2002 during which time an additional high-speed tribometer measurement was made. During the CSXT tests, the TOR application rate for both rails was set for 60 ml/mile (regardless of train speed) for tangent rack and increased to 100 ml/mile during curving.

4.0 RESULTS: CSXT TESTS

Tests results cover:

- How the friction modifier appeared to have affected top of rail friction values, including evidence of residual product remaining after TOR-equipped train passage
- How the TOR system affected lateral curve forces at the test site
- Train handling observations
- Observations of equipment performance

4.1 FRICTION

4.1.1 Top of Rail and Gage-Face Friction - Before and During Testing

Rail friction measurements were taken over approximately 25 miles of track with a high-speed tribometer, which makes continuous measurements of both top of rail and gage-face friction. The ability to measure both rail tread and gage-face friction allowed some assessment of the extent to which conventional gage face lubrication may have interacted with top of rail friction modification.

Measurements were made twice before the TOR units were implemented, and once during a period when multiple passes with TOR-equipped trains were operated (April 2002). The pre-implementation measurement runs were conducted in April 2000 and again in December 2001. Because local weather (rain and snow) impacted the "as is" readings during the December 2001 run, producing localized segments of low friction, much of the data collected during this run was affected by very wet rail conditions. For this reason, most comparisons will be made between the April 2000 and April 2002 databases.

Figure 7 shows the baseline, pre-TOR implementation data for the 25-mile section (MP 242 to MP 267) in April 2000. The two upper lines in this figure are tread (top of rail) measurements, and the two lower lines are gage face measurements. Figure 8 shows the friction data over the same route during the TOR implementation, and although the gage and tread measurements are closer together here, the tread measurements are generally higher than the gage face measurements, especially between mileposts 248 and 258. Comparing the two periods suggests that dry rail readings (top of rail friction coefficients > 0.45 μ) were generally present during the "as is" baseline period, while during the TOR operation a top of rail friction of 0.3 μ to 0.35 μ was present in many locations. It should be noted that some heavy rain was experienced the evening prior to the inspection run in April 2002, and that some sections of track had no train operations after the rain, while others were subjected to at least one empty train pass. Track with no train passes had a film on the railhead during the friction measurement pass. Possible implications of this film are discussed below.

During both periods, gage face friction data suggested that many of the wayside lubricators produced marginal effectiveness, with reduced gage face readings only noticeable within 100 feet at most of the wayside lubricator locations. Figures 7 and 8 compress the entire 25 miles into one plot, masking subtle differences. Data is also available in a mile-by-mile format to show details and site-specific performance.

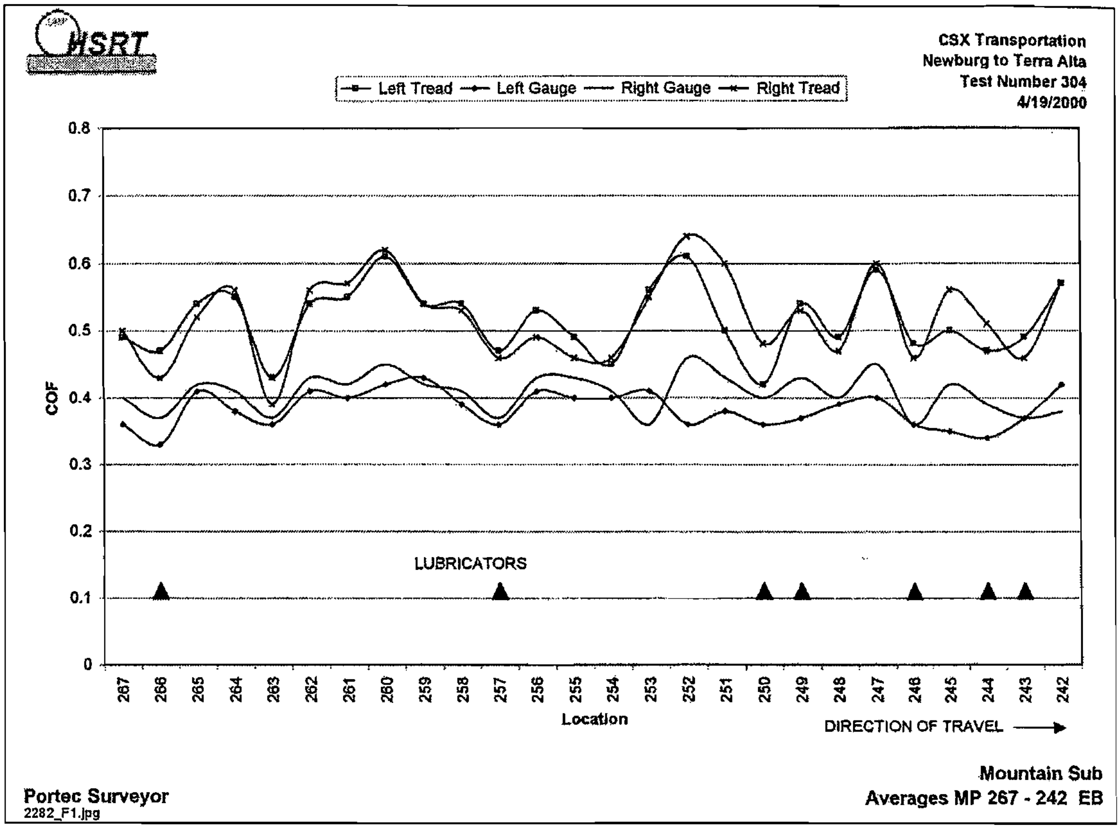

Figure 7. Rail Friction Map of 25 miles – Baseline Condition, April 2000

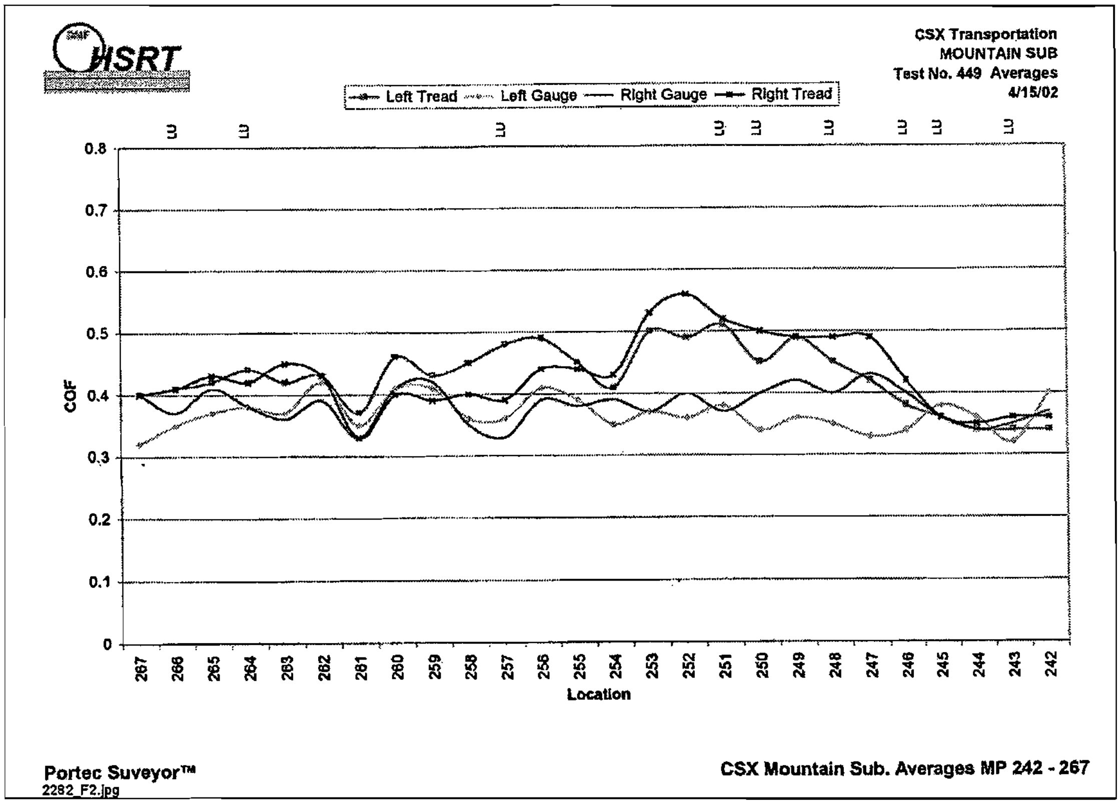

Figure 8. Rail Friction Map of 25 Miles – During TOR Implementation, April 2002

4.1.2 Friction in the 4,400-Foot Long Frostburg Tunnel

The one section of track within this 25-mile section that is not directly influenced by weather is inside the 4400-foot-long Frostburg Tunnel, between MP 261.1 and MP 261.9. Figures 9 and 10 show high-speed tribometer data for this segment collected for baseline conditions on April 2000 and during the TOR implementation stage in April 2002, respectively.

Examining the data in Figure 9 suggests the top of rail (two upper lines) was very dry (friction > 0.5 μ for most of the tunnel), while data in Figure 10 shows a marked drop in top of rail friction to a value of about 0.3 μ to 0.35 μ for the entire length of the tunnel. As no rain or other weather affected the rail, data suggests that the friction control product being applied by the TOR systems was producing top of rail friction to the desired level.

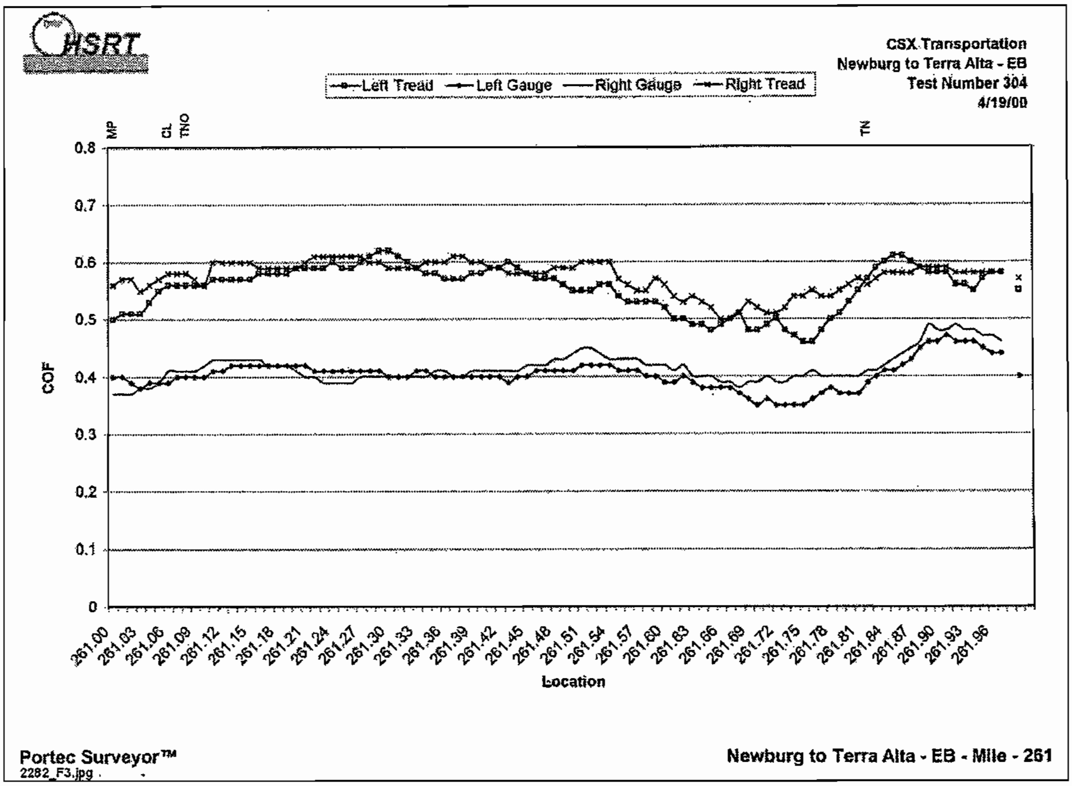

Figure 9. Rail Friction in Frostburg Tunnel (MP 261.1-261.9) during non-TOR Application Baseline Period April 2000

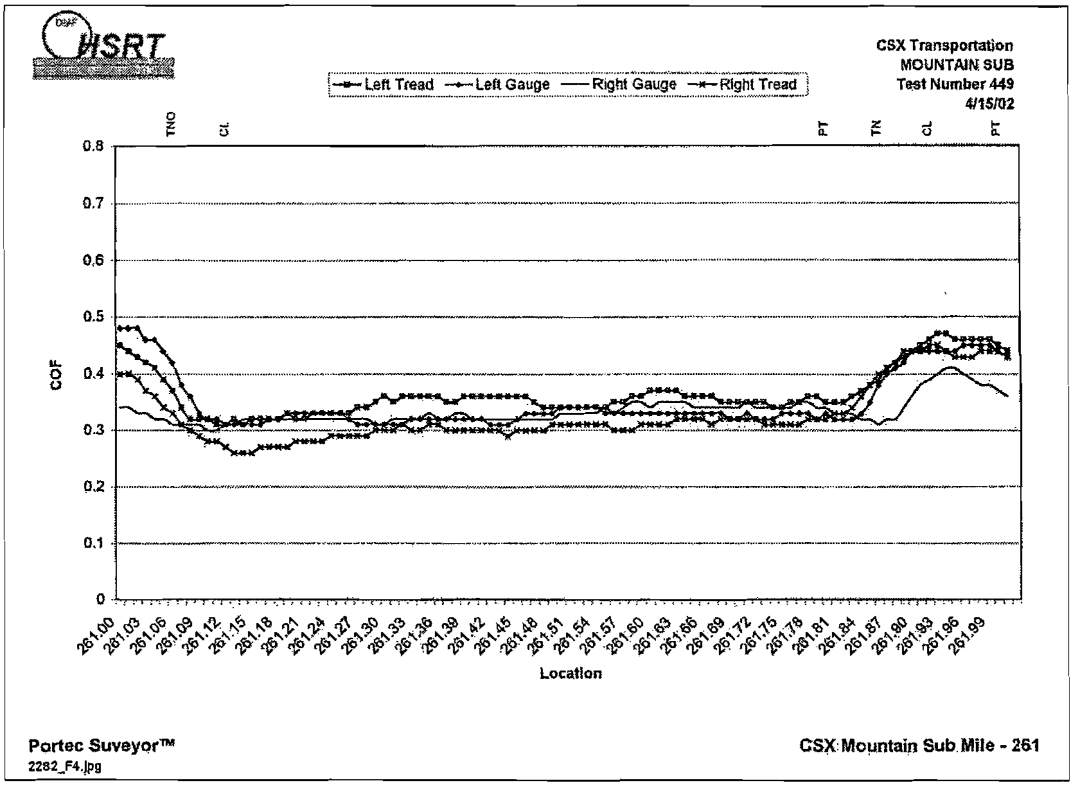

Figure 10. Rail Friction in Frostburg Tunnel (MP 261.1-261.9) during TOR Implementation Period April 2002

4.1.3 Friction Values due to Film Developed from Rain

A heavy rainstorm was experienced in the area the night before inspection was conducted in April 2002. The inspection was conducted during the day, during which no rain occurred, and the rail was not wet. Ongoing track work on the EB mainline had closed some sections of track, thus some locations had experienced trains operating before the tribometer inspection while others had not.

The segment between MP 242 and 254 was out of service and had not been subjected to any train traffic; however, a heavy-duty hi-rail crane had operated between MP 242 and MP 246 just prior to inspection. The track between MP 254 and MP 267 had experienced the passage of at least one empty train before the inspection.

This mix of train and hi-rail traffic produced rail with a fresh, shiny surface for all segments except MP 246 to MP 254. Examining the railhead at several locations along this last segment indicated a film of rust-like material had developed after the previous night's rainstorm. Data for a section of track in this area (MP 245 and 246) is shown in Figures 11 and 12 for the baseline time period, and Figures 13 and 14 for the TOR period. The predominant direction of traffic on this track is in descending milepost order (right to left on the figures).

Figures 11 and 12 indicate a drop in TOR friction from greater than 0.5 μ to a value of about 0.4 μ near the lubricator at MP 246 and MP 245. The 0.4 μ friction gradually returns to the dry levels of \greater than 0.5 μ about one-half mile farther up the grade.

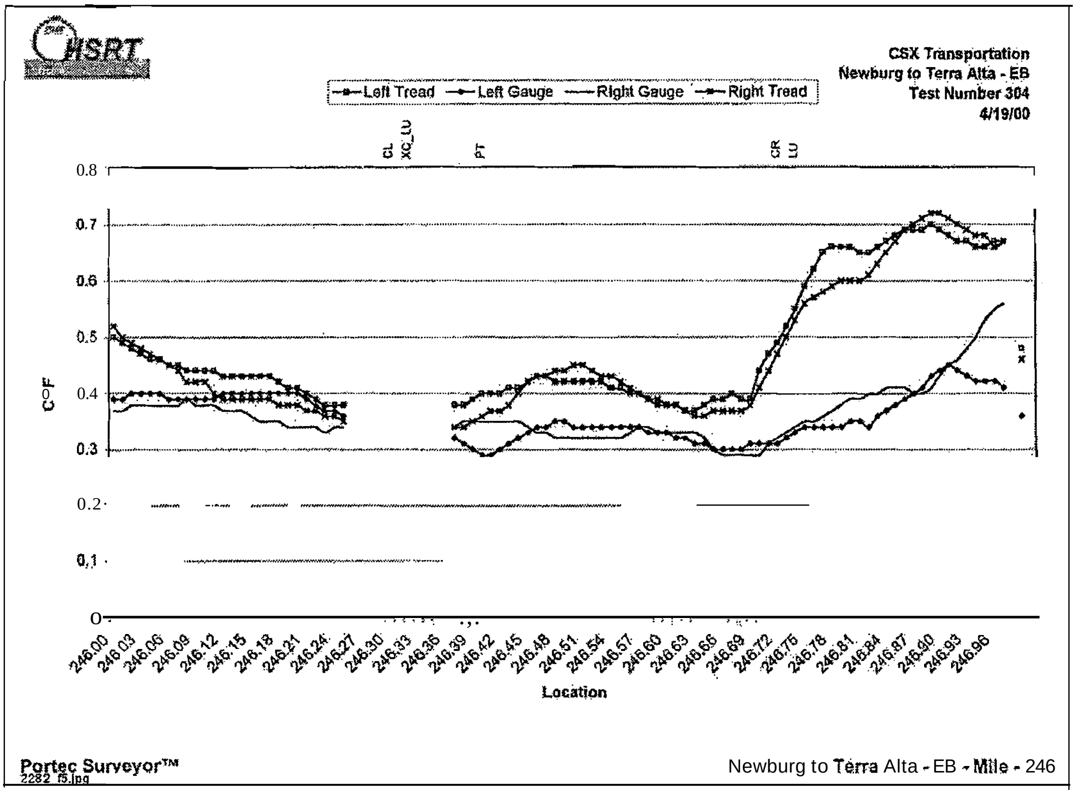

Figure 11. Rail Friction near MP 246 - Baseline Period

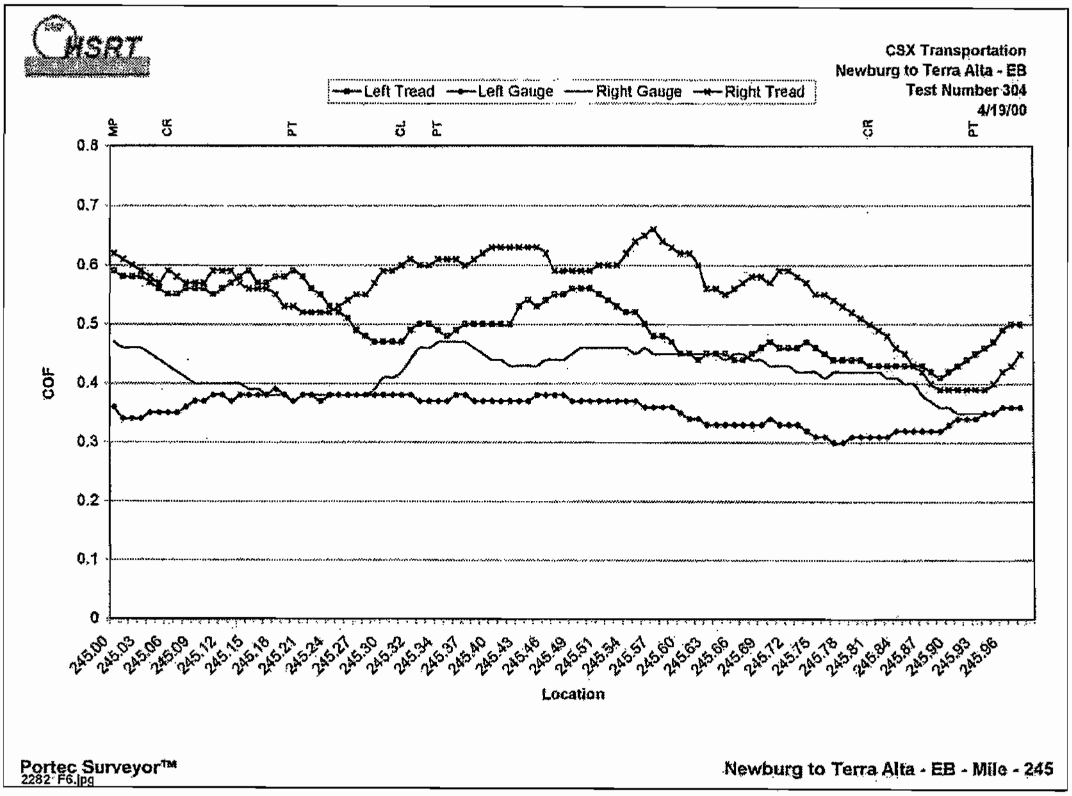

Figure 12. Rail Friction near MP 245 — Baseline Period

Figures 13 and 14 show the same sites as Figures 11 and 12 during the TOR application period. Referring to Figure 13, rail to the right of approximately MP 246.6 (increasing milepost order) exhibited the film described above, while rail to the left of MP 246.6 (descending milepost order) was wiped clean from passage of the hi-rail truck. Data shows that the top of rail friction remained at 0.33 μ to 0.38 μ for most of the remaining rail. This suggests that the friction control product being applied was having the desired effect on rail that was clean, while rusty rail affected tribometer data.

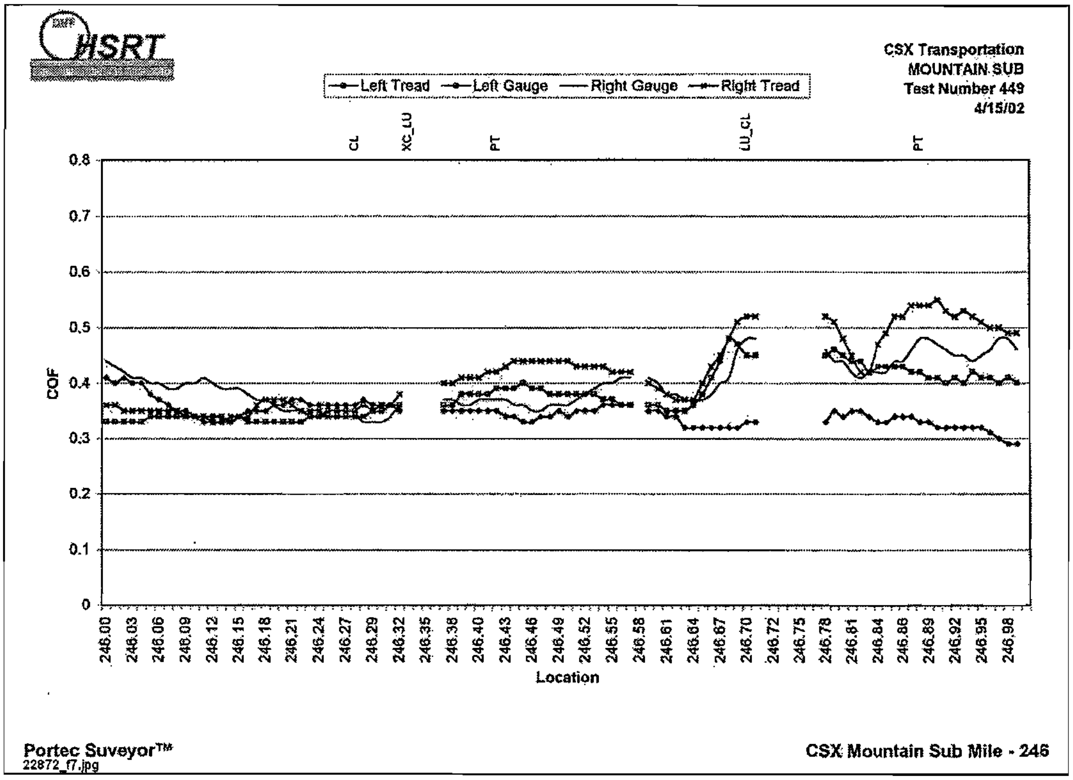

Figure 13. Rail Friction near MP 246 — During TOR Implementation Period

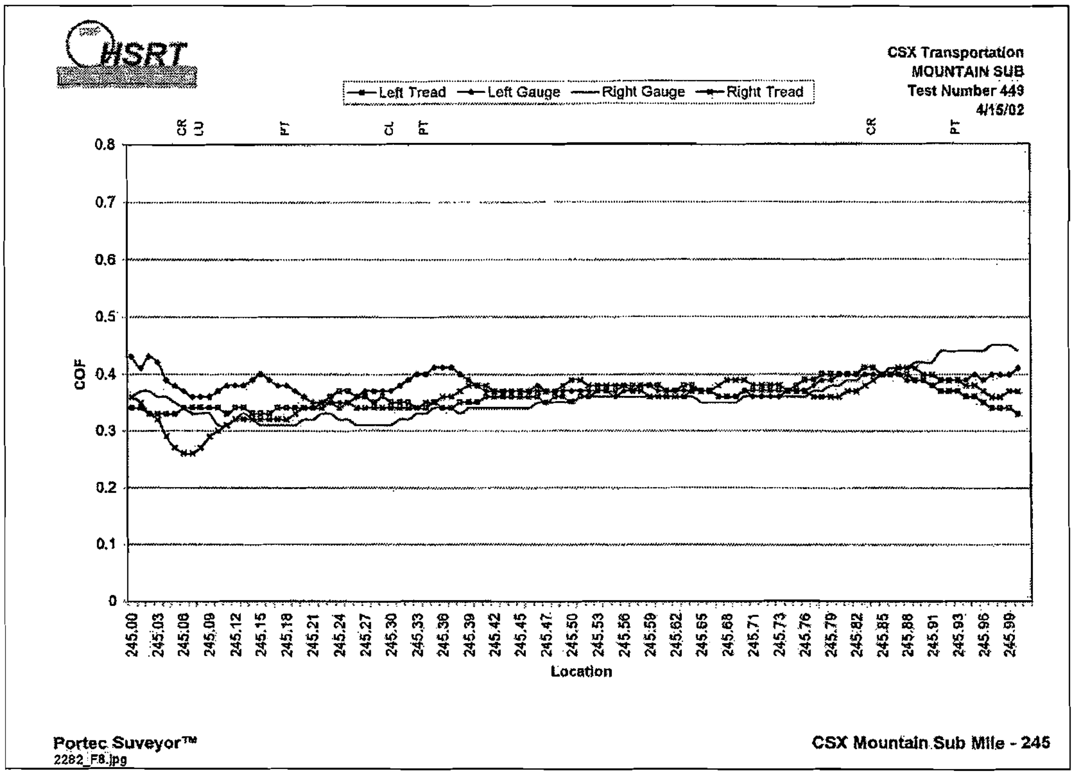

Figure 14. Rail Friction near MP 245 — During TOR Implementation Period

4.1.4 Wayside Lubricator Effectiveness

During the course of the two-year monitoring effort, some lubricators had been relocated. Also, different personnel had been assigned the responsibly for lubricator maintenance throughout this period, contributing to the difficulty in making comparisons over a long period. For these reasons, performance of wayside lubricators will be evaluated only from data collected during the April 2002 inspection.

The primary function of wayside lubricators is to reduce friction on the gage face of the high rail in curves, with little or no lubricant desired on the top of the rail. Examination of the friction data suggests that while some wayside lubricators were functioning properly, the majority had little or no effect on gage face or top of rail friction.

Examining Figure 13 shows that the lubricator at MP 246.7 was functioning, as friction values for the gage and top of rail dropped at the lubricator site. Farther up the grade from this location (in the direction of predominant traffic), the one rail near lubricators located at MP 243.9 and MP 243.3 (refer to Figure 15) exhibited a drop in friction at the gage face and top of rail. The distance of effectiveness was short, generally less than 0.2 miles. This pattern was repeated at several locations on this segment.

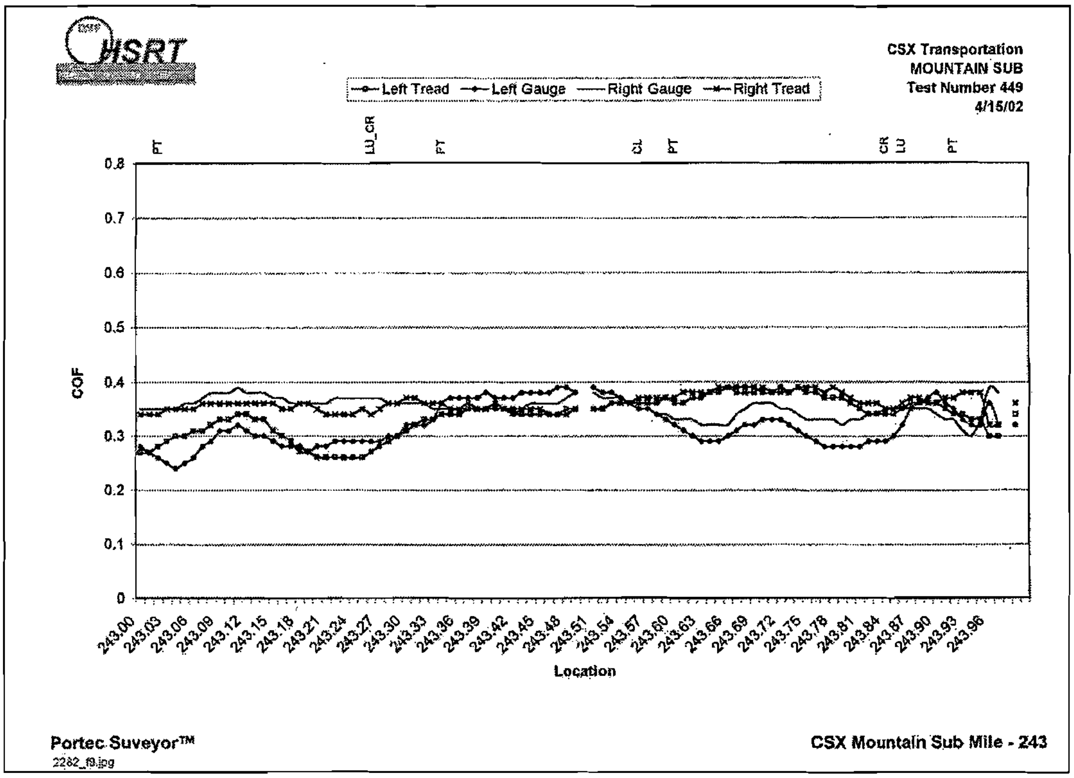

Figure 15. Rail Friction Patterns from Wayside Lubricators at MP 243.3 and 243.9

The short distance that wayside lubricators affected friction (both top of rail and gage face), along with the generally high friction observed on the gage face, is an indication that these systems have not been optimized. At most locations at or near a wayside lubricator, the gage face friction was never lower than 0.28 μ, and effectiveness was limited to very short sections of curves.

Because the primary focus of this program was to determine the effectiveness of locomotive-based TOR systems, the possible interference or interaction from wayside lubricators with top of rail friction modification needed to be documented. Data suggests that because wayside lubricator output rates were not optimized, no conclusions could be reached in regards to their influence on TOR systems. An additional effort to optimize wayside lubricator location, operation, and/or lubricant is suggested but is beyond the scope of this project.

4.2 LATERAL CURVING PERFORMANCE

While friction was measured over a distance of 25 miles, lateral curving performance was monitored at one single location. Friction data is shown for "spot" periods of time, while curving force data is monitored continuously and shows long-term trends. Curving performance data is presented to show the change in lateral forces generated by trains during different periods.

The database for this measurement system contains a significant amount of information. Forces for individual axles, both high and low rail, along with train averages can be statistically evaluated. As each train is different and will apply forces as a result of specific car types and conditions, for purposes of this report, the average lateral force for every train passing the site over a long period will be used to show trends. Changes in TOR friction will be seen as long-term changes in averages.

A recalibration of the force-measuring site was required after some damage occurred to the strain gages in late 2001. To allow comparison of train performance without adjusting for changes in calibration, lateral force data from December 2001 to May 2002 is used. This covers a portion of the baseline period and when numerous trains equipped with functioning TOR units operated past the site. For comparison purposes, lateral forces are shown in the following data summaries. Wheel forces (vertical loads) generally ranged from 33 to 36 kips for all trains included in these plots and figures. The average force for loaded coal trains operating over this site is shown in Figure 16, and Table 1 lists all trains operated with a TOR equipped locomotive during this same period. Notes and comments are included to identify shorter trains, trains with TOR equipment problems, and other conditions that might affect lateral forces. All trains equipped with a TOR system are noted with a "TOR" flag in Figure 16. It should be noted that not all trains shown on Table 1 are included in the time history plot in Figures 16, 17a and 17b. Data was not included if a train was known to have a disabled or non functional system, if the position of the locomotive was incorrect and the system would not function, or if the train configuration/type was not similar to those making up the baseline.

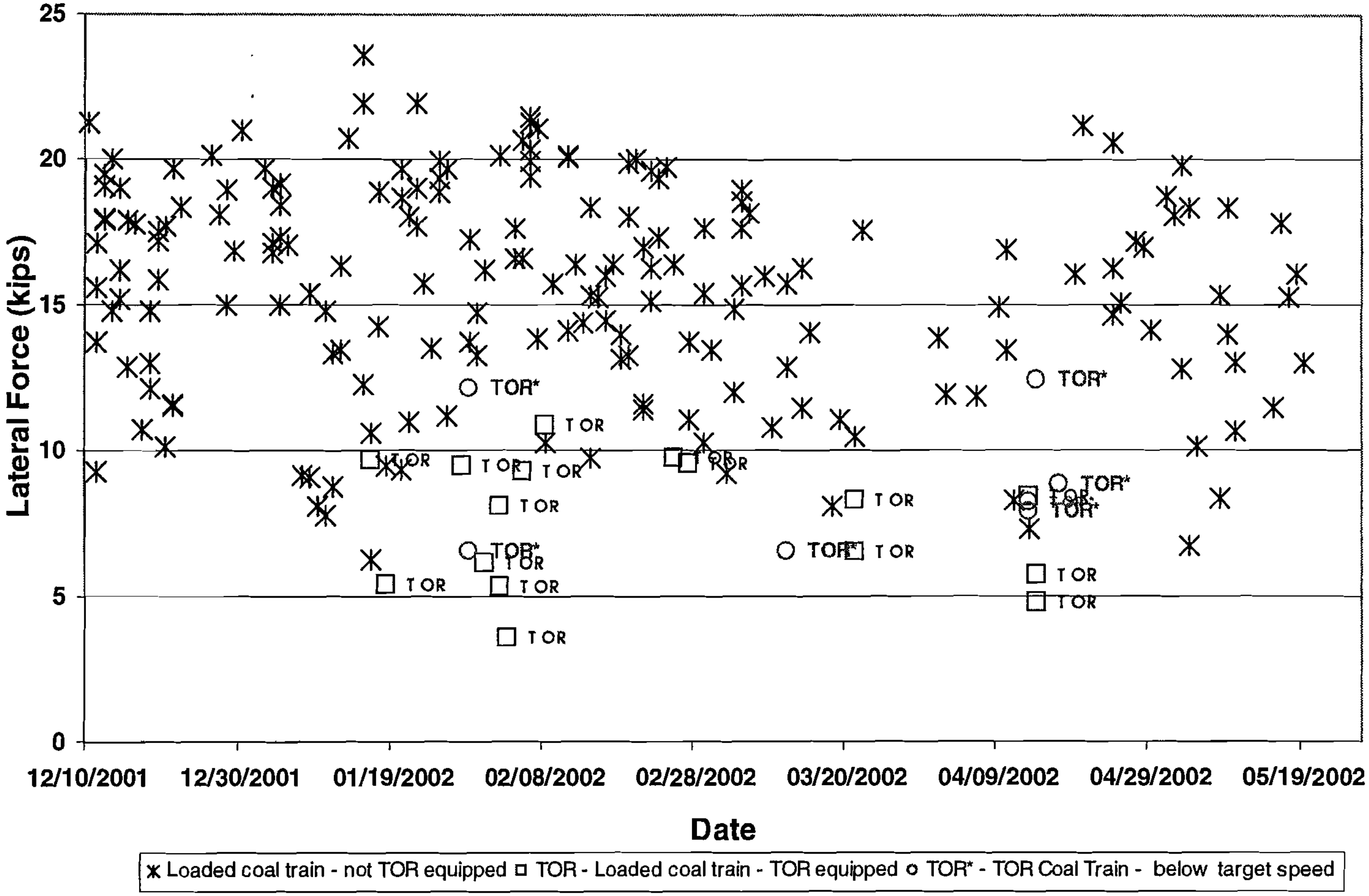

Figure 16. History of Low Rail Lateral Forces for Loaded Coal Trains – December 2001 to May 2002
(Trains equipped with TOR application systems are noted as "TOR.")

Table 1. List of TOR-Equipped Trains Operating over the Load Monitoring Site

DATE	TRAIN ID	LEAD LOCO	TRAIL LOCO	LOADS	TIME	TONS	REMARKS
01/16/02			CSXT 0514	84	14:37	12745	
01/18/02	V63317	CSXT 0531	CSXT 0514	82	10:42	11079	
01/18/02	U82217	CSXT 0509	CSXT 0501	80		10300	DID NOT WORK
01/19/02			CSXT 0514	75	5:35		SNOW ON RAIL
01/28/02	U82227	CSXT 0541	CSXT 0514	75	20:35		ALSO CSXT0503-ISOLATED
01/28/02	U82328	CSXT 0515	CSXT 0537	81	3:17	10777	ALSO CSXT0538-ISOLATED
01/29/02	U83328	CSXT 0541	CSXT 0514	82	20:03	10753	
01/31/02	U83330	CSXT 0526	CSXT 0521	82	15:55		
02/01/02	V65131	CSXT 0515	CSXT 0537	75	20:23	9796	
02/02/02	V65401	CSXT 0523	CSXT 0514	79	8:32	10334	
02/03/02	U82202	CSXT 0509	CSXT 0501	80	10:36	10308	
02/05/02	T86105	CSXT 0523	CSXT 0514	80	17:13	19950	
02/08/02	U82206	CSXT	CSXT 0537	78	1:27		
02/25/02	U82224		CSXT 0514	75	16:38	12477	
02/25/02	V61025	CSXT 0509	CSXT 0501	81	21:54		
02/26/02	U82326	CSXT 0526	CSXT 0537	80	21:31	12248	
02/27/02	V63327	CSXT 0526	CSXT 0537	80	22:49		
03/05/02	Q31603	4LOCOS	CSXT 0521?	30	14:35	4515	31 EMPTY-NOT COAL TRAIN
03/13/02	Q31611	4LOCOS	CSXT 0514	55	18:43	7003	NOT COAL TRAIN
03/13/02	U82212	CSXT 0060	CSXT 0537	75	22:54	9635	
03/19/02	V65117		CSXT 0517	75	12:30	9814	NOT WORKING-
03/19/02	Q31617	CSXT 0545	CSXT 0537		17:05		537 2ND IN CONSIST OF 5
03/21/02	U82219	CSXT 0530	CSXT 0517	75	1:47	7660	
03/21/02	U83320	CSXT 0531	CSXT 0521	79	9:30	10339	
04/13/02	W51612	CSXT 0518	CSXT 0514	82	2:30		
04/13/02	U83312	CSXT 0545	CSXT 0537	82	11:10		
04/13/02	U82212	CSXT 0516	CSXT 0501	75	17:00		
04/14/02	Q31612		CSXT 0514		2:15		
04/14/02	W51014	CSXT 0539	CSXT 0521	25	6:00		LIGHT RAIN
04/14/02	V65113	CSXT0042	CSXT 0537	80	11:30		HEAVY RAIN
04/16/02	V63316	CSXT 0150	CSXT0501	77	23:00		
04/17/02	V62917	CSXT 0472	CSXT 0514	80	13:45		
04/18/02	U82215	CSXT 0522	CSXT 0517	74	4:00		
04/18/02	V62918	CSXT 0472	CSXT 0514	80	15:00		
5/2/2002	V61302	CSXT 0522	CSXT 0517	81	18:30	10554	
5/3/2002	V61303	CSXT 0539	CSXT 0521	78	18:00	10073	
5/7/2002	V61307	CSXT 0153	CSXT 0514	80	12:30	10221	

The force monitoring site database collects information on all trains, including empty and mixed freight, as well as light helper locomotives passing the site. For comparison purposes, most trains shown in Figure 16 meet the following requirements, with other trains selected from the database:

- Loaded coal trains only (average axle load > 60,000 lbs)
- Trains between 70 and 90 cars in length
- Trains passing the load station with average speeds of 10.0 mph to 13.5 mph
- Eastbound trains

To more clearly show the effects on lateral forces when frequent TOR-equipped trains were operated, two expanded time scale lines are shown in Figures 17a and 17b. Figure 17a shows the period from January 24 to February 15, 2002, and Figure 17b shows the period for the month of April 2002. During the operation of TOR-equipped trains, some trains were shorter or operated faster than those stated in requirements, but were included to show overall effects. Trains not meeting the above requirements are noted with asterisks in Figures 17a and 17b.

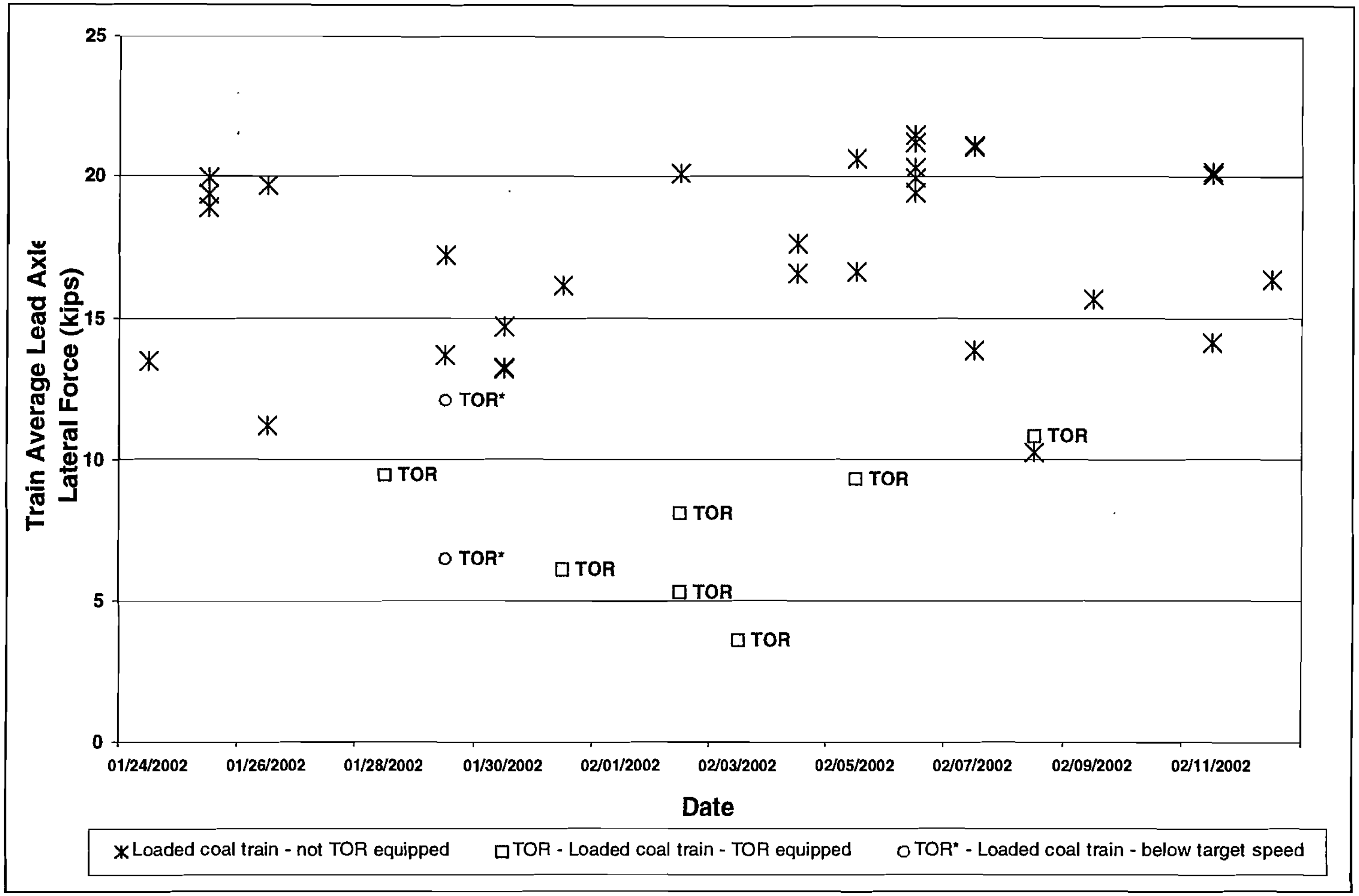

Figure 17a. Detailed Low Rail Lateral Force Performance During TOR Implementation Stage — January 24 to February 15, 2002

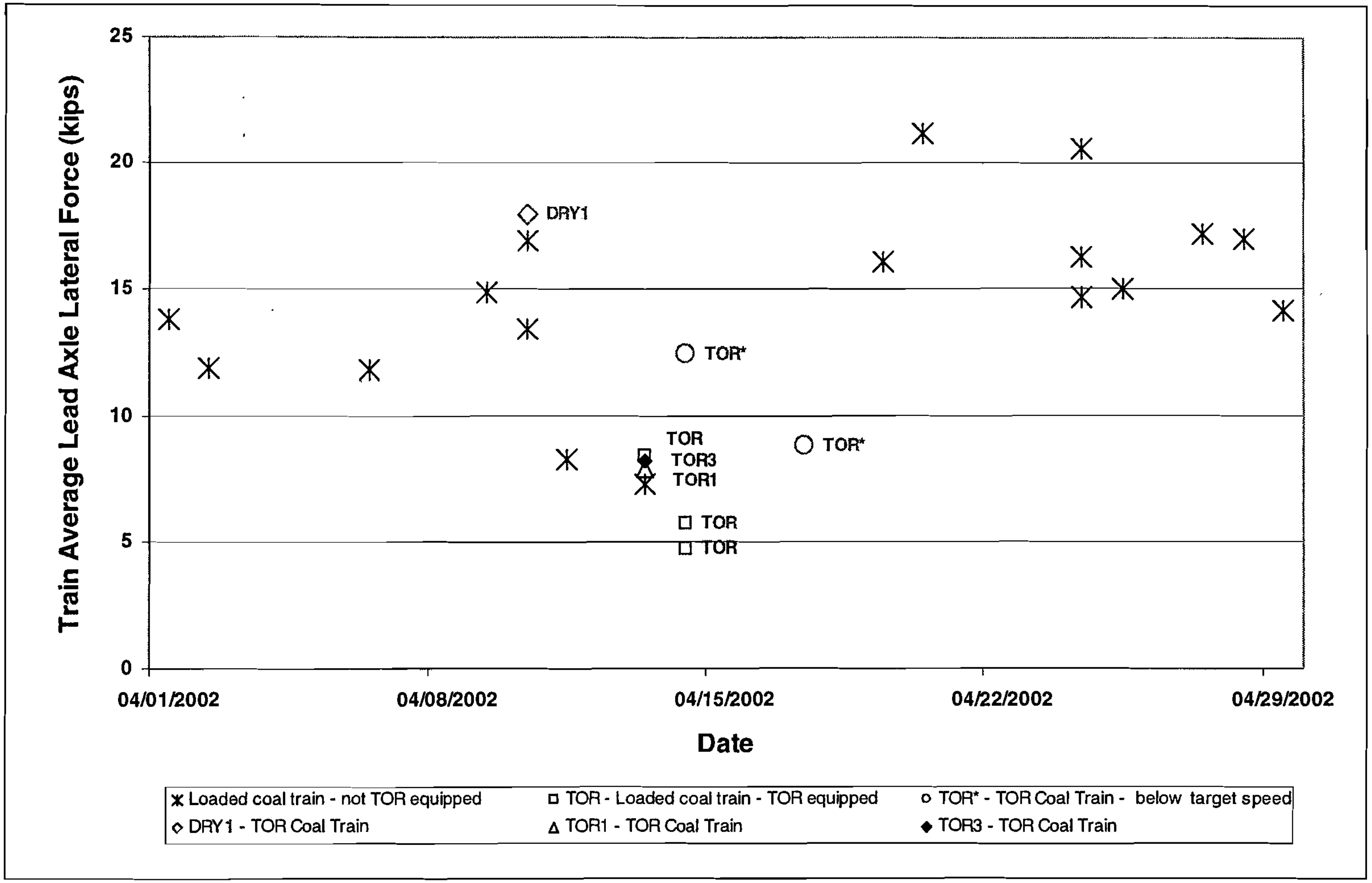

Figure 17b. Detailed Low Rail Lateral Force Performance During TOR Implementation Stage — April 2002

The force-monitoring site also collects detailed train performance data, allowing forces applied by each axle to be evaluated. Figure 17b shows footnotes for trains operating on April 10 and April 13. These are noted as Dry1, TOR1, and TOR3. Figures 18–23 show forces for every axle for each car, both high and low rails, for each of the trains Dry1, TOR2, and TOR2, as noted in Figure 17b.

Data for the train noted as Dry1 is from a non TOR-equipped train operating just a few days prior to implementing several trains equipped with operating TOR systems. The axle-by-axle lateral force performance for train Dry1 is shown in Figures 18 and 19. Data for the first TOR-equipped train, designated as TOR1, is shown in Figures 20 and 21, and for the third TOR-equipped train later that day in Figures 22 and 23. In all cases, for each pair of data plots corresponding to a given train the figures represent lateral forces for high and low rails, respectively.

Dry1 train data shown in Figures 18 and 19 show lateral forces for each axle of a non TOR-equipped train and is considered typical performance during the wayside only lubricated period. Trains operating past this location are well below balance speed as exhibited by the significantly higher lateral forces observed on the low rail (Figure 19) compared to the high rail (Figure 18).

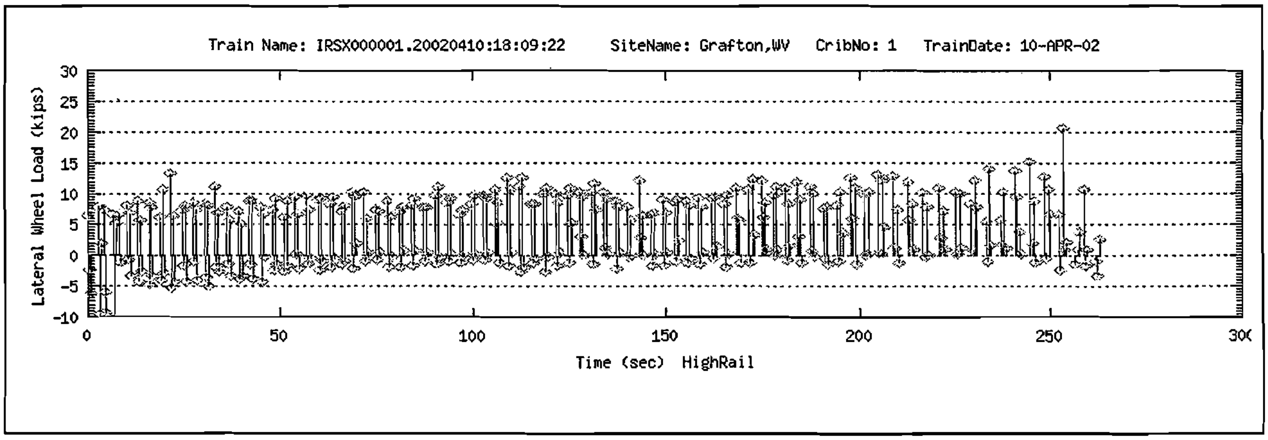

Figure 18. High Rail Lateral Force History of One Train During Baseline Period — Train Pass at 6:09 p.m. on April 10, 2002

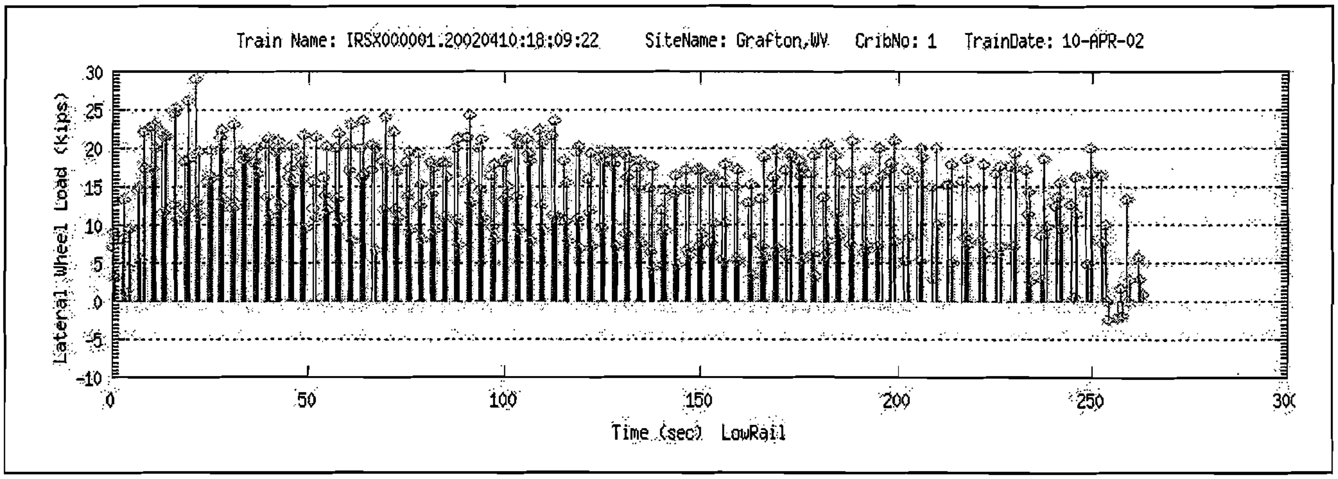

Figure 19. Low Rail Lateral Force History of One Train During Baseline Period — Train Pass at 6:09 p.m. on April 10, 2002

The first of several TOR-equipped trains operating sequentially went past the site at approximately 2:40 a.m. on April 13. (Figures 20 and 21) Examining Figure 20 (high- rail lateral forces) shows a definite front to rear differential in lateral forces, with the front of the train exhibiting much lower forces than the rear. Figure 21 shows low rail forces, which are higher than the high rail, and a small but noticeable front to rear train force differential.

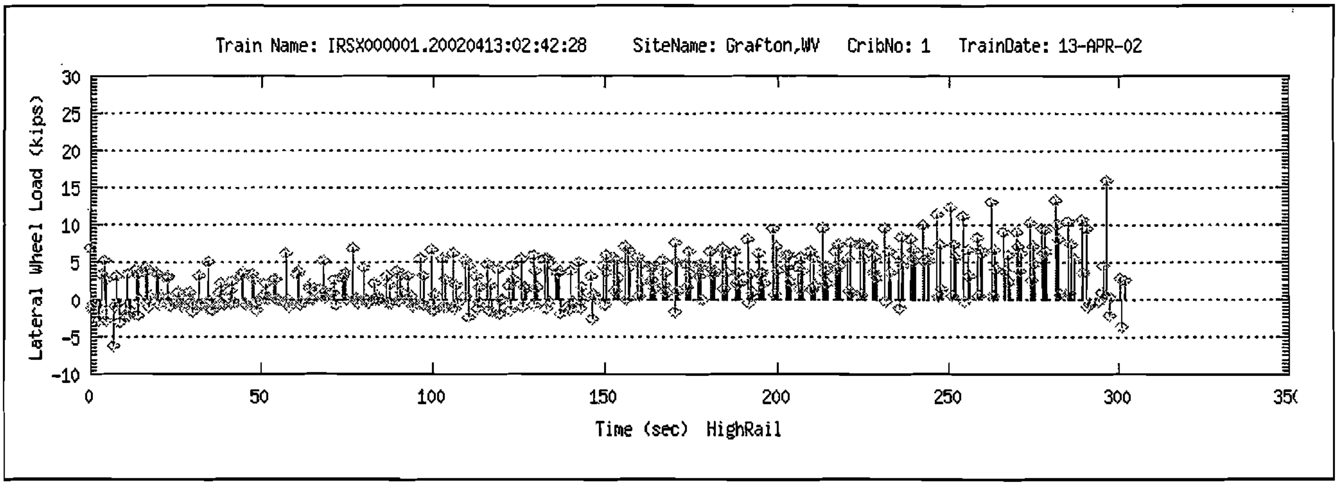

Figure 20. High Rail Lateral Force History of First Train During TOR Implementation Period — Train Pass at 2:40 a.m. on April 13, 2002

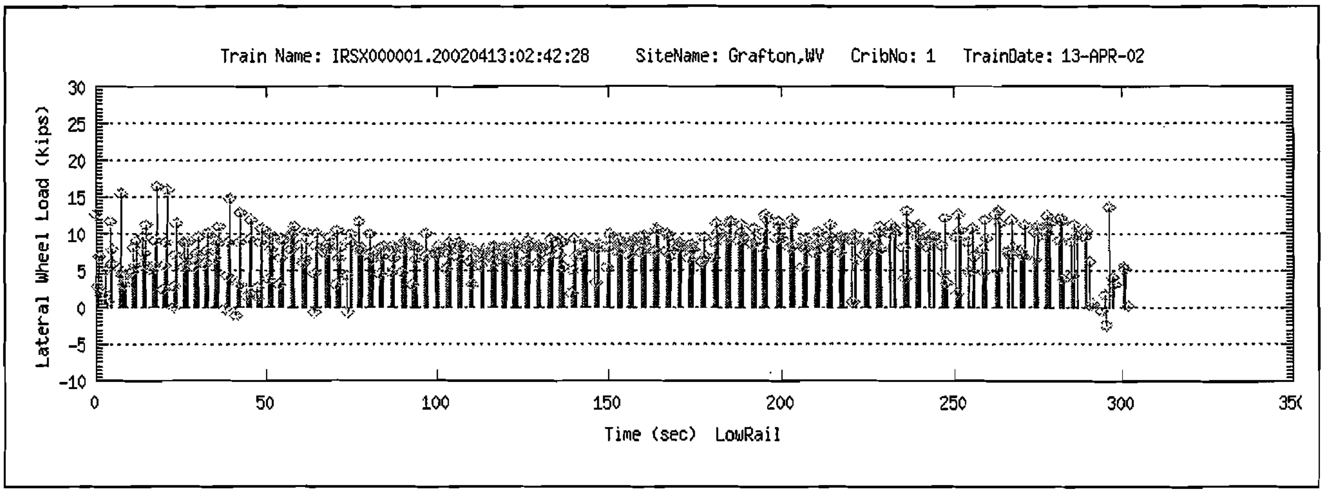

Figure 21. Low Rail Lateral Force History of First Train During TOR Implementation Period — Train Pass at 2:40 a.m. on April 13, 2002

Figures 22 and 23 represent the lateral forces applied by train TOR3, which was the third consecutive TOR-equipped train that passed this location. Examining Figure 22 (high-rail data), the front to rear differential is still apparent, and the overall forces are lower at the front of the train than the rear. Low rail data (Figure 23) shows more discernable front to rear differential when compared to data from TOR1 (Figure 20).

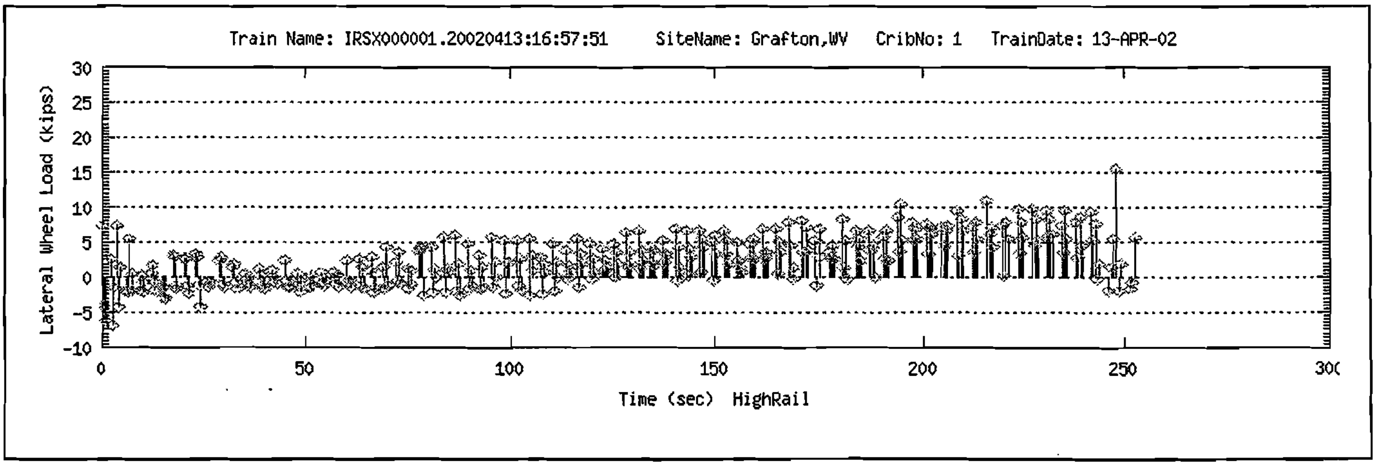

Figure 22. High Rail Lateral Force History of Third TOR-Equipped Train During TOR Implementation Period — Train Pass at 5:00 p.m. on April 13, 2002

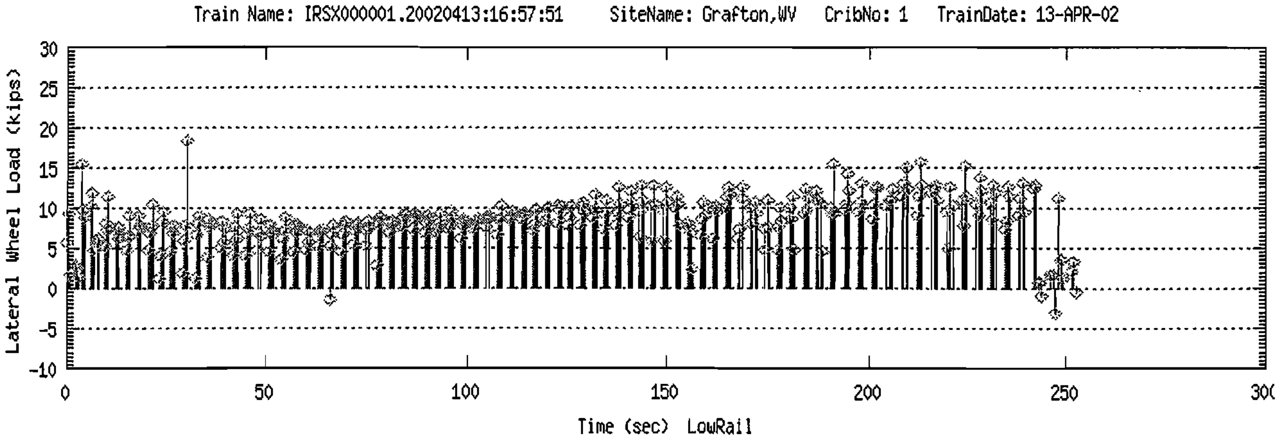

Figure 23. Low Rail Lateral Force History of Third TOR-Equipped Train During TOR Implementation Period — Train Pass at 5:00 p.m. on April 13, 2002

Note that the average lateral force applied for train TOR1 was slightly lower than that for TOR3. This could be a result of different car types, train characteristics, speeds, or other parameters. For this reason, absolute average train values of lateral forces cannot always be used to determine effective TOR operation.

A better understanding of the possible reductions in overall curving forces can be seen by examining Figures 24 and 25. These figures show lateral curving performance of lead and trailing axles, for low rail and high rail (respectively), baseline, and TOR periods. This data represents the average curving force for a typical train during the baseline period (no active TOR) and for a typical train during the TOR implementation phase. These typical trains are shown in Figures 18 and 19 (baseline) and Figures 22 and 23 (TOR).

At this curve, low rail lateral loads were higher than the high rail, with low rail curving forces during the baseline period about 9.1 kips, while the low rail was over 18.4 kips. The introduction of TOR reduced lead axle forces by 50 percent on both the high and low rails, while trailing axles exhibited a small reduction on the low rail (11.1 kips to 9.2 kips, or about 17 percent). The high rail exhibited a small increase in trailing axle curving forces, from -0.27 kips to 1.1 kips (an increase of 500 percent, but at an insignificant level).

By combining lead and trailing axles for each location, the truck side forces can be estimated. These also exhibited a reduction, approximately 40 percent on both the low and high rails. The values shown in Figures 24 and 25 are from two distinct trains. Cases could be found for a single train where the reduction in curving forces is higher than that shown in this example, or, in other cases, where an increase in curving forces could be noted with the introduction of TOR systems. The average lead axle low rail curving force for each individual train observed during the 6-month monitoring period (Figure 16) shows that some TOR-equipped trains produced higher curving forces than non TOR-equipped trains.

These examples have been highlighted to emphasize that the results of any one single train cannot be used to determine performance of TOR, but an average over a period of time is needed. Over the time period observed, TOR equipped trains produced curving forces averaging 40 percent lower than typical non-equipped trains, with some producing loads significantly less.

During this period, railroad and/or vendor personnel rode virtually every TOR equipped train, from Grafton to at least mile 40, to monitor output and when possible ensure proper operation of the application equipment. Occasionally, this required the application system to be adjusted, cleaned, or repaired before the start of train operations. Under normal railroad operating conditions, such monitoring would not be feasible; thus output from some TOR systems would not be adequate. Gains in system reliability are necessary to eliminate the need for manual override and monitoring. Until this is accomplished, some trains will be applying an incorrect pattern or insufficient amount of product. Therefore, a more typical and achievable average reduction in curving forces is expected to be 20 to 30 percent.

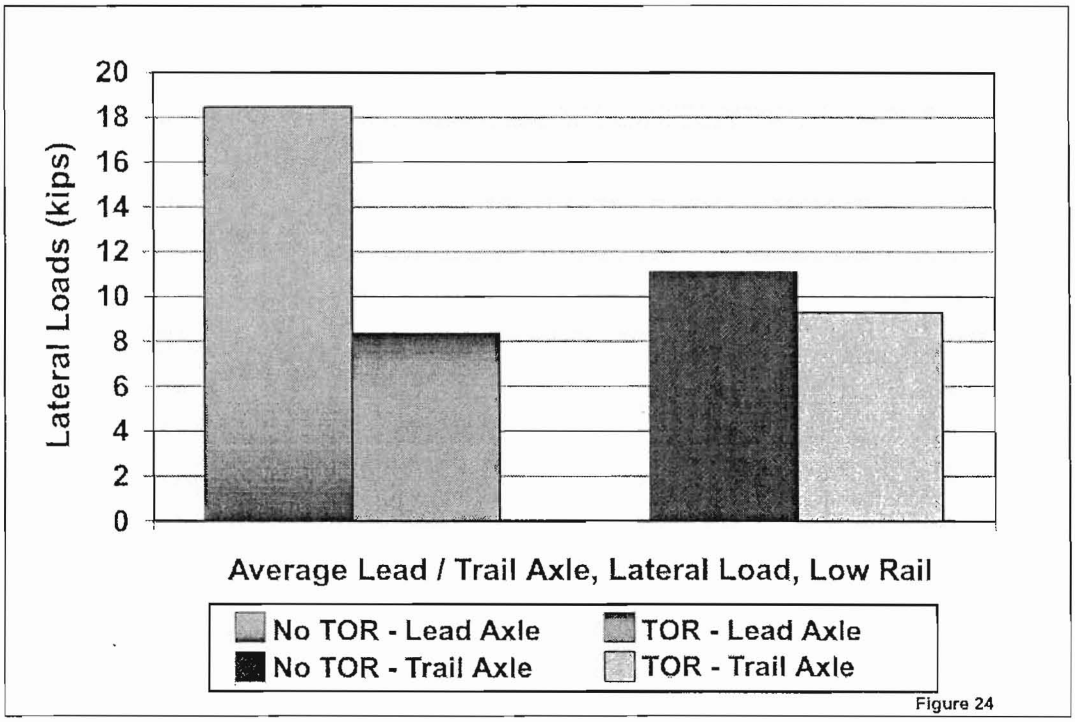

Figure 24. Low Rail Force Data from a Typical Baseline and TOR Equipped Train for both Leading and Trailing Axles

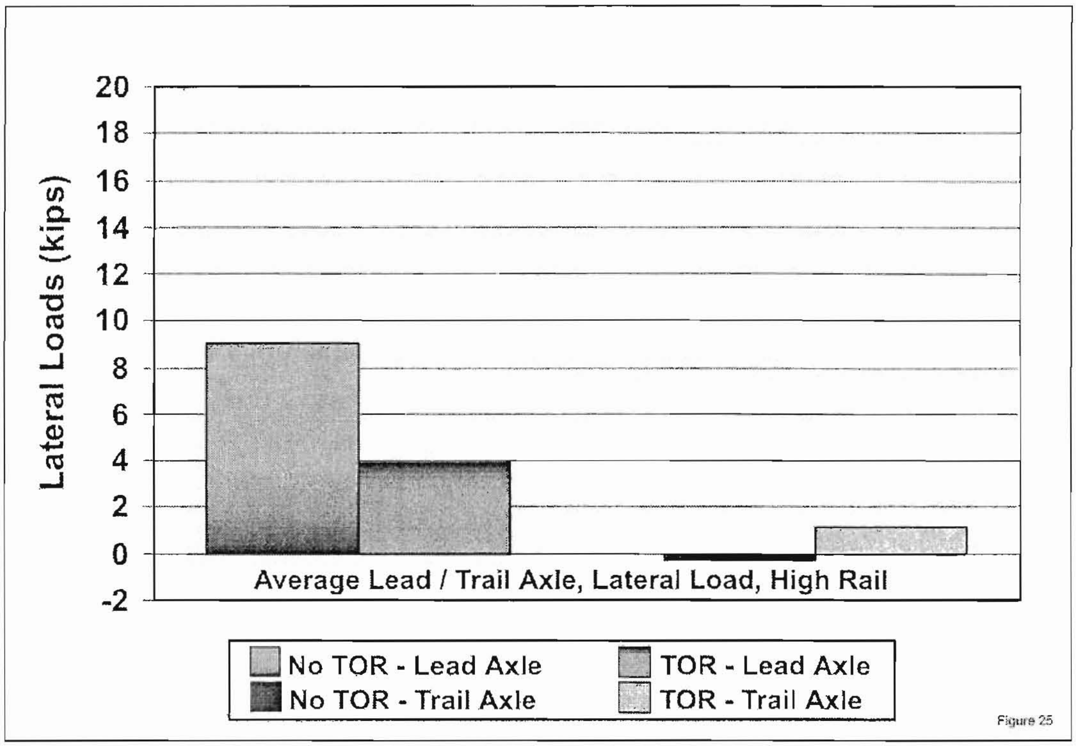

Figure 25. High Rail Force Data from a Typical Baseline and Second TOR Equipped Train for both Leading and Trailing Axles

Data shown in Figures 18 to 23 suggest:

- TOR-equipped trains exhibited reduced curving forces on both high and low rails.
- The head ends of TOR-equipped trains show a larger reduction in lateral loads than the tail end.
- Multiple passes of TOR-equipped trains produced a gradual build-up of a small reserve of material, which resulted in reduced lateral forces from other TOR-equipped trains.
- Material built up from multiple TOR-equipped trains (at the test application rate) reduced the lateral forces on only one or two following trains not equipped with an operating TOR system.
- Trends in lateral forces, not the value produced by an individual train, must be utilized to determine overall TOR system application effectiveness.

Not every train noted as being equipped with a TOR unit (refer to Figure 16) produced lateral forces in the lowest ranges. Some equipped trains reported mechanical problems with the TOR system (refer to section 4.4) and were not applying any friction control product to the rail. For example, inspection of one TOR-equipped train, after operating past the measurement site (February 3), was found to have an inactive system. Also, the variability between trains during the baseline period is significant, and the forces generated by any single train may not be sufficient to conclusively determine if the TOR system was operating correctly. Multiple trains, however, develop a trend that can be used to determine system effectiveness.

The trend in lateral forces during periods when a majority of the trains were equipped with TOR systems (mid to end of April) shows lower values than during an equivalent period when trains were not equipped with TOR systems. Also, TOR-equipped trains show a front to rear differential in lateral curving forces, with the front of the train exhibiting lower forces than the rear. This suggests that a force-monitoring station can be used to determine if a TOR system is functioning.

Trains not meeting the requirements listed in section 4.2 were excluded from the database to allow comparison of lateral forces. Lateral/vertical (L/V) ratio data for these trains can be estimated by using a typical 36-kip vertical force. Other, lighter axle trains have been ignored as they are much more variable. The majority of the traffic is associated with the more uniform, heavily loaded coal trains. As shown in Figures 20-23, during the passage of TOR-equipped trains, lateral forces are generally less than 15 kips, with a few cars exhibiting 17 kips. This would produce L/V ratios of less than 0.5. During the passage of the baseline train (Figures 18-19), many cars exhibited lateral forces of 25 kips to 30 kips, resulting L/V of 0.75 to 0.83, which is in the range where track damage (particularly gage-widening) can be significant.

A functioning TOR system should produce a front to rear differential in lateral forces, and the average lateral force for a train would be less than the total average of the fleet of trains over the same site that were not TOR equipped. A train consisting entirely of unique car or truck types, or containing a significantly different load may result in the entire train producing a higher or lower lateral force.

4.3 TRAIN HANDLING ISSUES

During the TOR test monitoring period, from January 2002 through May 2002, no train handling issues or complaints from train crews were reported or received by CSXT engineering staff. This time period includes two-weeks where virtually every EB loaded coal train operating over the measurement site was equipped with an operating TOR unit.

CSXT train operations for coal trains are generally uniform, with most loaded coal trains operating with two to three locomotives at the head end, 85 loaded hopper cars, and all trains equipped with two rear end pusher units. During normal operations, the pusher units are in full throttle position during most of the upgrade movement, including past the load measuring station site. Normal operations allow application of sand, and in most cases, passing trains were observed to have operating locomotive sanders at both the head and rear of the train. This sanding is a routine occurrence, and may have lead to some removal of residual friction control product from the rail.

No evaluations were made with repeated train passes when the sanding function was deactivated. During this period, no locomotive wheel slip of the pusher or head end power was reported, and the lateral force reductions reported during TOR operations were realized with sanding as a routine occurrence.

4.4 EQUIPMENT RELIABILITY ISSUES

The applicator and friction modifier used during Phase 1 implementation had been tested extensively during previous demonstrations conducted at the TTC. Results from previous demonstrations were summarized in a report that listed improvements required for successful implementation in revenue service.[1] The equipment and materials used in the field implementation on the CSXT represent revised products after the vendors upgraded their equipment and addressed the issues identified in earlier tests.

Observations and feedback from field personnel during 6 months of operating the five systems in revenue service suggest four issues that remain to be addressed. These include occasional occurrences of:

- Unreliable feedback from the reservoir level sensor
- False high pressure indications causing system shutdown
- Occasional clogging of the nozzle – internal and external, both during operation and after long dwell time of no use.
- Spillage or leakage during the refilling process

Reservoir level indicator: Occasionally, an incorrect (low) reading of the friction modifier level occurred, which shut down the system. To work with this fault, technicians bypassed the level sensor during the implementation tests. During the observational phase of this test, there was no chance of running out of product as frequent manual inspections were conducted, and the Trackmaster LLIC controller does not allow TOR dispensing if low or no level conditions are indicated. In actual implementation, however, a false "low" level indication could result in incorrect filling requests, but actual overfilling of the system could not occur due to the mechanical float valve incorporated into the fill port of the TOR reservoir. Investigation of an alternative or revised design is suggested to prevent nuisance interruption of TOR delivery.

High-pressure sensor: The application system uses regulated air pressure off the locomotive main reservoir system and pressurized lubricant. Normal operating pressure of the application system is relatively low. To avoid damage or incorrect application, should the system clog or excessive pressure be applied to hoses, the system sensors will shut down the operation. An automatic reset is incorporated to retry a specific number of times before shutting down the system. The cause and location of the false high-pressure indication needs to be addressed.

Nozzle clogging: Occasionally a clogged nozzle was noticed during the implementation demonstrations. This occurred both "statically" and "dynamically." Typically when clogging was an issue, it was found to be internal after the locomotive was static for extended periods of time, while external clogging occurred during operations.

Internal clogging: Occasionally clogging inside of the nozzle assembly occurred after periods of short and extended non-use. This might occur after the locomotive was stationary overnight to several days between runs. A check for internal clogging was conducted by manually activating the test mode while the locomotive was static at the fueling rack. If little or no friction control product was observed to be applied to the rail, then internal clogging was usually found to be the problem. Such clogging occurrences were rare and were solved by disassembling the nozzle and clearing orifices and parts.

External clogging: External clogging occurred dynamically and was occasionally experienced during times when the TOR system was active and operating. System operation would normally be verified at the locomotive ready track prior to a run. Test crews normally rode all TOR equipped runs as observers for the first 40 to 100 miles eastward out of Grafton, West Virginia. On rare occasions, even though the system was observed to work properly at the start of the run, it was noted to be plugged or not spraying properly when the test crew departed the train after the 40- to 100-mile ride. This external clogging did not totally block the spray, but a buildup of friction control material around the nozzle orifices (air and material delivery holes) would cause the spray pattern to divert from its intended target. Simply wiping off the orifice solved this problem.

The unique characteristics of the friction modifier and its associated carrier along with the nozzle design may have contributed to the internal and external clogging issues. The vendors (application system and friction control product) are addressing this issue with alternative designs intended to prevent clogging.

Bulk Refilling System: Railroad feedback from using the pressurized refilling system suggested instances where the quick disconnect fitting was not easy to use. Spillage or leakage during the refilling process, due to incorrect alignment of the fitting, was reported. Improved alignment and fittings that do not spray the friction control product if the system is not properly connected should be investigated.

5.0 NORFOLK SOUTHERN TESTS

Through the cooperation of the NS Corporation, a one-day demonstration of a TOR-equipped locomotive was conducted on their line near Roanoke, Virginia. The demonstration was conducted in December 2001 as a prelude to implementing all five locomotives on CSXT.

A test train of 89-loaded coal hopper cars was used, operating back and forth over a 14-mile section of curved track. To facilitate movements, two locomotives were placed at each end of the train, with the west end having the CSXT-TOR equipped unit. By utilizing this configuration (along with two train crews), reverse movements back and forth along the 14-mile section of track were accomplished with minimum delays. Figure 26 shows the test configuration.

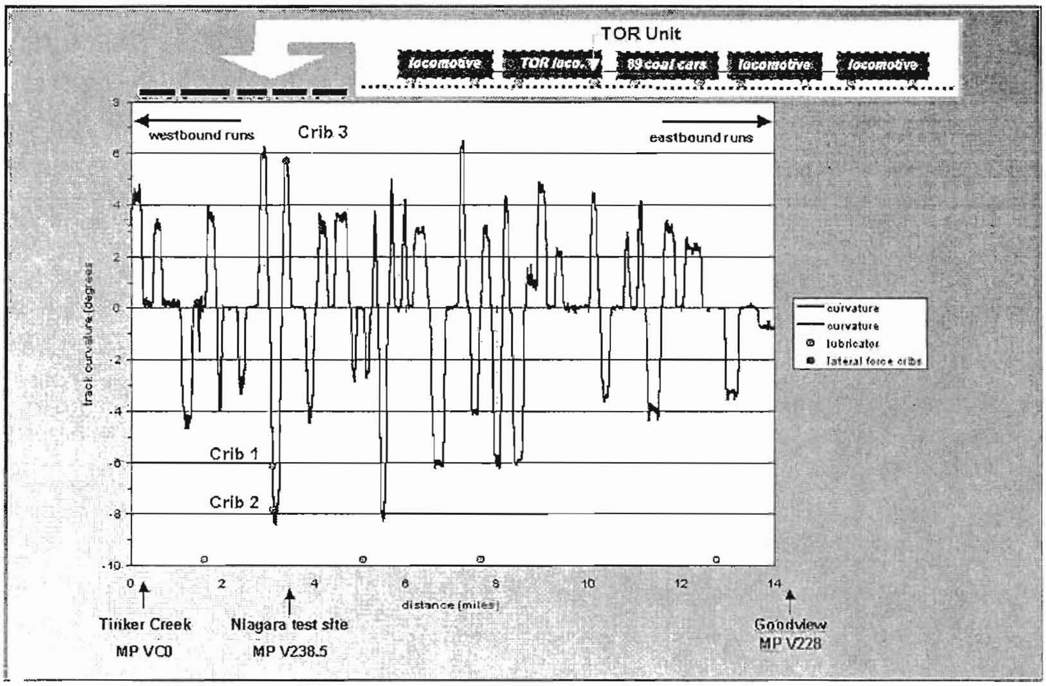

Figure 26. Diagram of NS Test Site and Train Configuration Used for TOR Evaluation

The train was configured such that during westbound (WB) runs the CSXT unit was the trailing locomotive in the head-end locomotive consists. This permitted the TOR unit to apply the Kelsan friction control product to the rail during selected WB runs. All EB passes were conducted using power on the opposite end of the train, and no TOR application was permitted. The train was operated between MP VC0 and MP V228 (14 miles). NS installed lateral force monitoring stations were located at an 8.0-degree right-hand and 5.4-degree left-hand reverse curve around MP V238.5. For purposes of this report, lateral force performance observed at the 8.0-degree right-hand curve will be discussed. Test train speed over the site was controlled to about 25 mph for all passes.

The day before testing, nearby wayside lubricators were readjusted to minimize the potential for gage-face lubricant migration onto the top of the rail. Test runs for this evaluation followed the sequence outline in Table 2.

Table 2. Test Run Sequence for NS TOR Demonstration

Train Pass No.	Train Direction	TOR Operation On/Off	Notes
1	EB	OFF	Initial pass – EB dry baseline
2	WB	OFF	WB dry baseline
3	EB	OFF	EB – Dry baseline
4	WB	ON	WB – first TOR active pass
5	EB	OFF	No active TOR, residual from 1 active TOR pass
6	WB	0N	WB – second TOR active pass
7	EB	0FF	No active TOR, residual from 2 active TOR passes
8	WB	ON	WB – third TOR active pass
9	EB (not a test train)	Not TOR Equipped	130 car loaded train passed site
10	EB	OFF	EB – pass after 130 car train
11	WB	OFF	WB – last pass for test

Figure 27 shows the lateral force data collected by NS research and test personnel on the high rail of the 8-degree curve. A number of performance issues regarding TOR application can be observed by evaluating data on this plot. However, the primary concern related to this implementation evaluation project is the effect of multiple train friction product buildup. Long-term reliability and maintenance issues of the TOR system were secondary as vendor and railroad representatives inspected and adjusted the system before testing.

During the first WB TOR application pass, the system did not activate properly and had to be manually activated by test personnel on board the locomotive. This occurred about 3 miles from the lateral force monitoring site. Data collected at the site, however, showed a significant drop in lateral curving force; thus, improper system operations were not directly affect the data collected at the force measuring site. During subsequent runs, no operating problems occurred.

Examination of lateral forces for passes 1-3, all non-TOR baseline runs, show consistent forces, with at least 30 percent of the total axles exhibiting lateral forces exceeding 10 kips. Pass 4, which was the first run with the TOR system activated, indicated an immediate and significant drop in lateral forces, with only 8.4 percent exceeding the 10-kip level. Also, as can be observed by examining Figure 27, lateral forces at the front of the train were significantly lower than at the rear, which follows the pattern observed at other sites where one pass of a TOR train has been monitored.

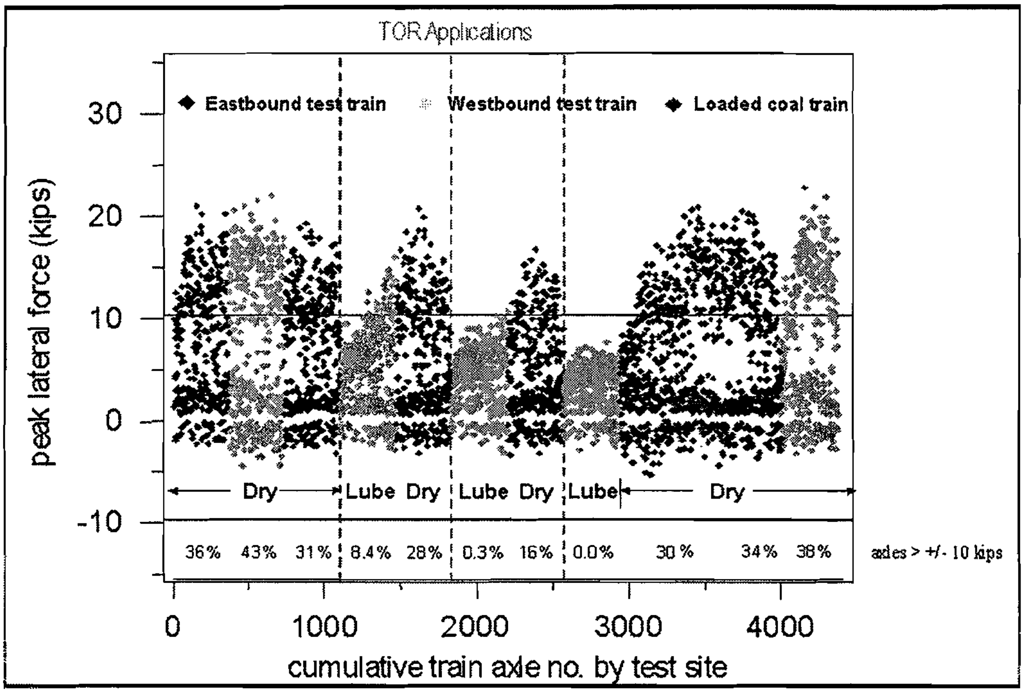

Figure 27. Lateral Force Station Data: High Rail, Crib 2, 8-Degree Curve on NS Showing Effect of Multiple TOR Train Passes on Lateral Forces (data collected and reduced by NS)

The “peaked” pattern of lateral forces generated during Pass 5, which is the reverse back-up move, suggests several items. Note that during the backup move, the first cars to pass the site were from the east end of the train consist, which was the farthest from the TOR applicator.

- The east end of the train, which was drier than the front, received some benefit from residual material remaining on the rail.
- The west end, which was closest to the TOR applicator, also received some benefit; in this case, from material built up on the wheels.
- The center of the train received the least benefit as the residual product remaining on the rails had disappeared, while at the same time residual product remaining on the wheels was more effective near the front (applying end) of the train.

Data from Pass 6, the second WB TOR application pass, indicated even more product was being built up on rails and wheels, as less than 0.3 percent of the total axles exceeded the 10-kip lateral load threshold. Pass 7, the non-TOR EB backup move, again exhibited a peak in forces at the middle of the train, with lower forces on the front and rear. For Pass 8, the final WB TOR application pass, forces for the entire train were well below the 10-kip threshold, with only a small differential effect at the head of the train.

Overall, the set of TOR runs 4, 6, and 8 and intermediate dry runs 5 and 7 show a progression of fewer percentage of axles exceeding the 10-kip threshold: the TOR runs dropping from 8.4 percent exceeding to 0 percent exceeding, and the dry runs 5 and 7 changing from 28 percent to 16 percent exceeding 10-kips. This suggests that some residual friction control product remained on the rail, and perhaps the wheels as well.

Pass 9 was not the test train, but instead a 130 car loaded revenue coal train that was allowed to travel past the measurement site. Data suggests that some residual lubricant/friction modifier was on the rail as the front of the this train exhibited a reduction in lateral forces, while the remaining cars performed similar to the non-TOR baseline test train runs of passes 1-3.

Pass 10 was the non-TOR EB backup move, which behaved similar to the dry baseline passes of runs 1-3, with the exception that the cars nearest the TOR equipment exhibited a slight reduction in forces when compared to the remainder of the train. These are the cars shown on the far right side in Figure 27. After this move, rail inspection indicated a film or oil was present on the top of rail. This material was not noticed after previous passes.

As the source of this contaminant was not known and track and crew time limits for additional testing were being exhausted, it was decided to operate the final WB pass (No. 11) with no TOR application. (Subsequent to the test, an outside laboratory analyzed the sample of oil residue obtained from the top of the track, along with representative samples of summer and winter grades of trackside greases, and oil from the onboard flange unit. Results indicated that the contaminant was most likely the trackside grease). Data for this last pass suggests that, as with pass 10, some residual product remained on wheels closest to the TOR-equipped end of the train. However overall average forces were similar to the baseline passes 1-3.

Other observations made by NS's Research and Test Department during the test were:

- No adjustment of the nozzles was required during the test.
- Multiple passes of TOR-equipped trains tended to build up friction modifier on the rail.
- Continued operation of a TOR-equipped train built up more friction modifier on the wheels nearer to the application equipment than at the end of train.
- The passage of one non-equipped train cleaned off virtually all residual friction modifier.
- The buildup of friction modifier on the rail observed during this test did not impact locomotive tractive effort or train braking.
- The application rate used for this demonstration was likely too high for multiple trains equipped with TOR units, but may be adequate if only an occasional TOR-equipped train is operated.
- Reliability of the applicator system needed addressing. (Note: The interruption of TOR application observed during the NS test resulted from a "time out" function in

the Trackmaster LLIC program when the locomotive controls were changed from "dynamic braking" setting to "normal throttle" setting. Lubriquip identified and corrected the program anomaly immediately and the problem has not since occurred.)

The vendor used the results of this demonstration to recommend application rates for the CSXT implementation demonstration where multiple TOR-equipped trains were to be operated in succession. These revised application rates (discussed in Section 3.3) were intended to produce reduced lateral forces yet not build up excessive friction modifier on the rail that might impact train operations.

6.0 CONCLUSIONS

Results of observing implementation of five TOR-equipped locomotives suggest that significant reductions in lateral forces can be achieved through properly operating and maintaining such systems. Controlled periods when multiple trains equipped with operating TOR systems passed over a territory suggest the following:

Lateral Forces

- Lateral forces in sharp curves can be reduced in the range of 20 percent to 30 percent, even when conventional gage-face lubrication is also used. Sometimes individual trains exhibited higher or lower savings, depending on site specific conditions and train handling, wheel profile and speed variations.
- The front portion of a TOR-equipped train exhibits a greater reduction in lateral forces than the rear.
- Locomotive sanding does not prevent achieving substantial reductions in lateral forces in curves when using the Kelsan friction modifier.
- The reduction in curving forces observed due to TOR implementation can be monitored using a number of different data bases and measurement methods. During closed loop testing, the use of lateral load data was supplemented by rail friction, drawbar (energy), and train handling monitoring systems.
- The use of lateral curving data is widely used as it provides information on forces being introduced to the track structure, which is the primary reason for track degradation and wear. Experiments monitoring the effect of track loading and subsequent component performance suggests that by reducing curving forces savings can be obtained in rail and wheel wear, track damage, energy and derailment potential. Utilizing the average lateral load is one of many ways of quantifying TOR performance. Other variations include separate evaluation of low or high rail curving performance, evaluating multiple, single axle or truck side force performance, angle of attack, etc. Each may be more appropriate for specific purposes or monitoring methods.
- The relationship between curving forces and track wear or degradation is not necessarily linear. Reducing lateral loads by 50 percent will not necessarily result in a 50 percent

reduction in wear. Other parameters, such as gage face lubrication and wheel rail profile, may have a greater influence on rail wear than curving forces.

- These other methods (monitoring energy, rail wear, etc.) require significantly more expensive measurement methodology and require more controls and conditions to be monitored for a long period of time. In order to provide a cost effective method of determining if the TOR system was operating, the use of curving forces was selected. The user must determine that benefits are of sufficient magnitude that implementing TOR can be justified, or if other methods of monitoring the effectiveness of TOR may provide more appropriate information.

Train Handling

- At the test application rate (60 ml/mile for tangent track and 100 ml/mile in curves), no train handling problems were reported with:
  - TOR-equipped trains
  - Following non-TOR-equipped trains, from any possible remaining friction modifier on the rails
  - From any trains, due to possible buildup of this friction control product from repeated passage of TOR-equipped trains

TOR Film Durability

- Trains not equipped with TOR systems rapidly removed the excess TOR friction product from the rail. Data showed that only one or two non-equipped TOR trains received benefit from a buildup of friction control product (from previous TOR-equipped trains).
- At the test application rate of 60 ml/mile for tangent track and 100 ml/mile in curves, helper units at the end of the train (when applying sand) apparently removed any small amount of friction modifier remaining on the rail under the last cars.

Rail Friction Values

- The friction control product generally reduced the friction coefficient of dry rail from a level at or above 0.5 μ to the target range of 0.30 μ to 0.35 μ.
- The friction control product used in this test apparently has the ability to increase friction to 0.3μ when existing conditions are below this value, which improves the lateral curving performance of cars. And further, through consistent application on both rails, curving forces should be minimized.

Performance Monitoring

- Effectiveness of the product could be evaluated by:
  - Measuring rail friction
  - Measuring the lateral forces from passing trains

Equipment Performance

- Some additional development in equipment reliability is needed to allow full implementation without the need for constant monitoring.
- With the nozzle design evaluated, visual and working inspections, along with frequent cleaning of external surfaces, were required during every locomotive refueling opportunity. From a practical standpoint, this is not an option for revenue implementation.
- The vendor has been using the test results to redesign the nozzle to eliminate external clogging and to extend time required between inspections and cleaning.

Based on observations from these tests, and from previous experiments, the following represent some general requirements for ensuring effective TOR implementation:

- Extensive training for locomotive inspectors to ensure that they know how to properly inspect and adjust TOR systems.
- Regular feedback on rail conditions from track inspectors, including evidence of excessive or insufficient friction control product, to help locomotive repair and operating departments keep TOR systems properly maintained and adjusted.
- Long-term monitoring of lateral curving forces at truck performance detector sites to determine if overall TOR system operation is effective.
- Periodic field measurement and inspection of rail friction as part of an effective TOR monitoring program. The monitoring program should also include review and evaluation of historical trends to help determine desired practices for system adjustment and operation.
- Continued monitoring and inspection of wayside lubricators to achieve adequate gage face lubrication and to control rail wear.

Results from these and previous tests suggest that the economic benefit of locomotive-based TOR friction control can be significant when a substantial number of trains are equipped with properly operating and adjusting systems. The benefits would be realized through reduced fuel consumption, reduced rail and wheel wear, and reduced track damage in curves due to lower lateral forces. These financial benefits can be expected, provided TOR lubrication systems are reliable and can be maintained with modest effort.

7.0 RECOMMENDATIONS

Generally, top of rail friction modification systems are still in the developing stages, and many aspects of employing them effectively and optimally still need to be explored. In addition to evaluating various friction control products, TOR systems, and TOR application rates, there is a need to better understand the optimum combination of TOR and conventional gage-face lubrication, a balance, which may vary with different territories, traffic patterns, and with the particular TOR and lubrication systems employed. Also to be determined is the effect of TOR systems during rain, snow, or other adverse weather conditions.

With respect to the TOR system evaluated here, further work is needed to eliminate nozzle clogging. In fact, both the application system and friction control product vendors have been working on this issue. The spray pattern is controlled using air jets to direct the friction control product to the rail, and it was found that air moving in and around the nozzle contributed to the clogging problem. A number of simulations using computer modeling have been conducted to modify the nozzle designs. This effort includes wind tunnel testing of improved designs, of which a revised version has been patented and is being introduced into revenue service. Monitoring of revised nozzles is ongoing by CSXT and vendor representatives, and performance of the revised design should be documented.

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