Transportation Test Center

FAST/HAL RAIL PERFORMANCE EXPERIMENT AND OVERVIEW

AAR REPORT R-796
FRA/ORD-91/24

ASSOCIATION OF AMERICAN RAILROADS

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Facility for Accelerated Service Testing
Heavy Axle Load Program

02-Track-Train Dynamics

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13. Abstract

The Rail Performance Experiment, conducted at the Facility for Accelerated Service Testing, Transportation Test Center, Pueblo, Colorado, was performed to evaluate the effect of increasing axle loads, from 33- to 39-tons, on the fatigue and wear performance of rails, ground rails, and welds. Four ancillary tests constituted this experiment: The Rail Wear Test; The Rail Fatigue Test; The Rail Grinding Test; and The Rail Welding Test.

The increased axle load did cause increased rail wear rates in terms of wear in inches per million gross tons of accumulated tonnage. Under totally dry operations, the increase in wear occurred as elevated vertical wear on the high rail of the curve. Under lightly lubricated conditions, the lateral and the head height wear rates of the high rail both increased.

The effect of increasing axle loads on the fatigue performance in lubricated curves was not clear. Intermediate strength rails performed noticeably worse under HAL's in two cases, and performed better in another case. One rail type, which did not develop defects by 160 MGT under 33-ton axle loads, developed several detail fractures by 145 MGT of 39-ton axle loads.

In the Rail Grinding Test, four different rail grinding practices were used in a 6-degree lubricated curve: conditioned under non-lubricated operations; ground to a worn profile; asymmetrically ground; and as-rolled. Fatigue defects developed in the ground worn, asymmetric, and as-rolled profiles. The conditioned rail did not develop defects.

Electric flash butt and thermite welds were used to join test rails for the HAL test. Flash butt weld failure rates increased during HAL testing. These failures were primarily due to horizontal web cracks. A significant increase in thermite weld failures occurred in the high rails of curves during testing. Horizontal web cracks and head shelling were the two primary causes of failure.

14. Subject Terms

Rail Fatigue, Rail Wear, Rail Grinding, Rail Welding, MGT, Heavy Axle Load, High Tonnage Loop

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Enclosed is a copy of AAR Report No. R-796, "FAST/HAL Rail Performance Experiment and Overview." This report is based on tests conducted at the Facility for Accelerated Service Testing (FAST) to evaluate the effect of increasing axle loads, from 33- to 39-tons, on the fatigue and wear performance of rails, ground rails, and welds. Four ancillary tests constituted the experiment: The Rail Wear Test; the Rail Wear Test; the Rail Fatigue Test; the Rail Grinding Test; and the Rail Welding Test. Included at the end of the report is an overview of all rail tests conducted on the FAST High Tonnage Loop (HTL).

I am confident that you will find the information in this report useful. Should you have any comments on it, please let me know.

Sincerely,

Roy A. Allen
Assistant Vice President

cc: G. H. Way
S. B. Harvey
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REPORT BRIEF

FAST/HAL RAIL PERFORMANCE EXPERIMENT AND OVERVIEW

R-796

November 1991

Past increases in wheel loads on North American railroads have caused concern in the industry regarding their effect on rail and rail weld performance. Axle load increases from 33 tons to 39 tons at the Facility for Accelerated Service Testing (FAST) have demonstrated some adverse affects on rail performance. These Heavy Axle Load (HAL) tests were conducted by the Association of American Railroads, Transportation Test Center (TTC), Pueblo, Colorado, in conjunction with the Federal Railroad Administration.

The FAST facility has a 2.7 mile oval railroad, known as the High Tonnage Loop (HTL), on which the tests are conducted. Rail performance observations were first made on the HTL from 1985 to 1988 under tonnage applied by a 33-ton axle load coal train. From 1988 to 1990 observations were made with tonnage applied by a 39-ton axle load train.

Four subordinate tests constituted the Rail Performance Test: Rail Wear; Rail Fatigue; Rail Grinding; and Rail Welds. Results from the Rail Wear Test suggest that, in relatively sharp curves while under the influence of light lubrication or totally dry conditions, gage face wear does increase with increased axle loads. There is a benefit (longer rail life) which can be gained by using premium rail metallurgies under 33-ton axle load traffic. With increased axle loads (39-ton) and under lightly lubricated conditions, this benefit decreases. However, with increased axle loads and under totally dry conditions, the benefit increases.

In lubricated curves in which rail life is limited by the development of fatigue defects, the effect of increased axle loads on rail life is not clear-cut. Intermediate strength rails which developed fatigue defects under 33-ton axle loads, performed noticeably worse under HALs in one case, and performed about the same under HALs in another case. One rail type which did not develop defects by 160 MGT under 33-ton axle loads developed numerous detail fractures by 145 MGT.

Four different rail profile grinding practices were used in a 6-degree curve, with the intent to evaluate practices which perform best under fully lubricated conditions and HAL testing. The four practices which constituted the test were (1) conditioned by dry operations, (2) ground to a worn profile, (3) asymmetrically ground, and (4) as-rolled. Shells developed in the ground worn and as rolled profiles. Detail fractures developed in the asymmetric profile while the conditioned rail did not develop defects. Results may have been affected by the nature of the rail placed in test.

Electric flash butt and thermite welds were used to join test rails for the HAL test. Flash butt weld failure rates slightly increased during HAL testing with welds primarily removed because of horizontal web cracks. A significant increase in thermite weld failures occurred in the high rails of curves during HAL testing. Horizontal web cracks and head shelling were the two primary causes for the removal of the standard carbon welds during HAL testing.

Copies of the AAR Report: "FAST/HAL Rail Performance Experiment and Overview," are available from the Document Distribution Center, Chicago Technical Center, 3140 South Federal Street, Chicago, Illinois 60616. The AAR report number is R-796; the price is $10.00 for member railroads and $100.00 for nonmembers. Illinois residents please add 8% sales tax. The cost includes surface mail postage if mailed within North America. There will be a surcharge for any overseas mail. Checks should be made payable to the Association of American Railroads. This report was issued in November, 1991. A report list is available upon request.

EXECUTIVE SUMMARY

Past increases in wheel loads on North American railroads have caused concern in the industry regarding their effect on rail and rail weld performance. Axle load increases from 33 tons to 39 tons at the Facility for Accelerated Service Testing (FAST) have demonstrated some adverse affects on rail performance. These Heavy Axle Load (HAL) tests were conducted by the Association of American Railroads, Transportation Test Center (TTC), Pueblo, Colorado, in conjunction with the Federal Railroad Administration.

Rail performance observations were first made on the High Tonnage Loop (HTL) from 1985 to 1988 under tonnage applied by a 33-ton axle load coal train. Then from 1988 to 1990 observations were made with tonnage applied by a 39-ton axle load coal train.

Four subordinate tests were conducted on the HTL, a 2.7 mile track, at FAST. These tests included the Rail Wear Test, the Rail Fatigue Test, the Rail Grinding Test, and the Rail Welding Test. Generally, at TTC, rail wear tests are conducted in a curve on the HTL where little lubrication is applied on the high rail of that curve. In such a scenario, rail wear rates are high due to abrasion at the wheel/rail interface. Rail fatigue tests are conducted in curves that carry a substantial level of lubrication on the high rail of the curve. In this scenario, wear is trivial and the development of fatigue limits rail life. Rail grinding tests are fatigue tests which evaluate different rail grinding practices. Finally, rail weld tests include evaluating a weld's resistance to wear and fatigue.

Results from the Rail Wear Test suggest that in relatively sharp curves, under the influence of light lubrication or totally dry conditions, wear rates increase with increased axle loads. Under totally dry operations, the increase in wear occurred as elevated vertical wear on the high rail of the curve. Under lightly lubricated conditions, the lateral and the head height wear rates of the high rail both increased. There is a benefit (longer rail life) which can be gained by using premium rail metallurgies under 33-ton axle load traffic. With increased axle loads and lightly lubricated conditions, this benefit decreases. However, with increased axle loads and totally dry conditions, the benefit increases.

In lubricated curves, increased axle loads affected expected rail life by the development of contact fatigue defects. Intermediate strength rails that developed fatigue defects under 33-ton axle loads performed noticeably worse under HALs in one case, and performed about the same under HALs in another case. Another rail type, made with a clean steel process, did not develop defects by 160 MGT under 33-ton axle loads and but developed numerous detail fractures by 145 MGT of HALs. Finally, rail manufactured by an old AREA standard hardness of 248 Bhn survived from 60 to 132 MGT of 33-ton axle loads and only survived 37 MGT of 39-ton axle loads.

Four different rail profile grinding practices were used in a 6-degree curve, with the intent to evaluate practices which best perform under fully lubricated conditions and HAL testing. The four practices which constituted the test were conditioned rail initially subjected to 15 MGT of totally dry (nonlubricated) operations; rail ground to the naturally worn profile occurring on the HTL; asymmetrically ground; and as-rolled. Shells developed in the ground worn and as rolled profiles. Detail fractures developed in the asymmetric profile while the conditioned rail did not develop defects. Results may have been affected by the nature of the rail placed in test.

Electric flash butt and thermite welds were used to join test rails for the HAL test. Flash butt weld failure rates slightly increased during HAL testing and welds were primarily removed because of horizontal web cracks. A significant increase in thermite weld failures occurred in the high rails during HAL testing. Under 33-ton axle loads and by 65 MGT, 29 percent of thermite welds installed in the high rails of curves had failed. This figure increased to 67 percent under HAL's meaning the failure rate more than doubled. Horizontal web cracks and head shelling were the two primary causes for the removal of the standard carbon thermite welds during HAL testing.

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INTRODUCTION

Rail performance tests have been conducted at the Transportation Test Center (TTC), Pueblo, Colorado, on the Facility for Accelerated Service Testing (FAST), High Tonnage Loop (HTL) since its installation in 1985. The first HTL experiment, under which rail tests were conducted, was the Defect Occurrence and Growth Test (DOG).[1] The primary objective was to evaluate wear and fatigue differences between various rail metallurgies when exposed to dry or lubricated operating conditions. This test accumulated over 160 MGT of 33-ton axle load traffic from June 1985 until March 1988. Figure 1 shows the HTL layout.

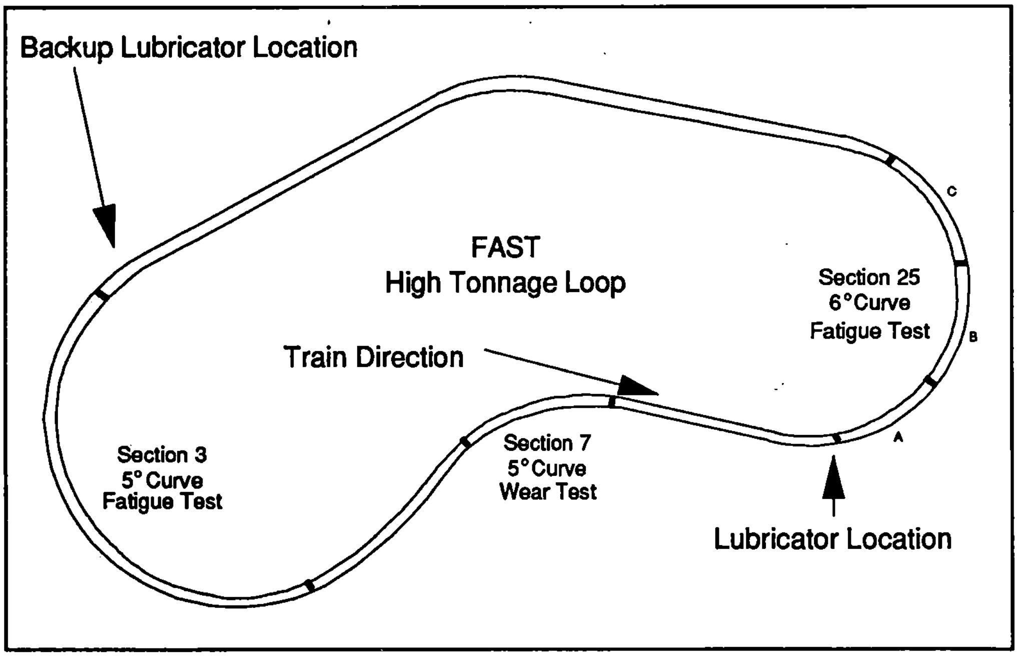


Figure 1. FAST HTL

The Heavy Axle Load Experiment (HAL) was initiated on the HTL in July 1988. The purpose of the rail performance portion of this experiment was to investigate the effect of 39-ton axle loads (HALs) on rail/weld fatigue and wear, especially as compared to the effects of 33-ton axle loads. At the time of this report, HAL testing had accumulated 160 million gross tons (MGT).

Rail performance tests have been divided into four subordinate performance tests: Rail Wear; Rail Fatigue; Rail Grinding; and Rail Welds. This paper contains sections describing the results of each subordinate test as well as an overview of all HTL rail performance tests conducted. The overview also incorporates rail performance research conducted elsewhere.

Rail wear tests are conducted to determine a rail's resistance to metal particulate loss on the rail running surface from wheel/rail abrasion. Rail fatigue tests determine a rail's resistance to surface or subsurface rupture caused from cyclic loading from passing wheels. Rail grinding tests are fatigue tests which, instead of evaluating different rail types, evaluate the effects of different rail grinding practices. Finally, rail weld tests include evaluating a weld's resistance to wear and fatigue.

The HTL has been operated under a lubricated regime, except for special controlled non-lubricated periods. When operations started in 1985, only the outside rail of the HTL was lubricated. Track grease was applied to the gage face and gage corner of the high rail in Section 24 with a wayside lubricator (Figure 1). After one year of this type of lubricated operation, the FAST train derailed in Section 28. The derailment was attributed to the differential in top of rail friction between the highly lubricated outside rail and the dry inside rail. This differential created high truck turning moments which lead to rail fastener weakening and eventual rail roll-over. To reduce the differential friction, a light oil was applied to the top of the inside rail. The standard operating procedure now is to lubricate the high (outside) rail in Section 25 and apply light oil to the top of the low (inside) rail.

Due to the methods of lubrication on the HTL, rail fatigue tests have been conducted in Sections 03 and 25 while rail wear tests have been conducted in Section 07. Section 25 is a 6-degree curve with 5 inches of superelevation, and Sections 03 and 07 are 5-degree curves with 4 inches of superelevation. Under the highly lubricated conditions on the outside rail, rail wear rates are extremely low which in turn makes wear evaluation difficult. Fatigue is common where lubrication is present on high rails of curves as in Sections 25 and 03.

Section 07 was originally selected for rail wear testing because the high rail (inside rail of the HTL) of that curve was not lubricated at all, and wear rates were very high. After the derailment in Section 25, and subsequent application of light oil to the inside rail, the high rail in Section 07 was contaminated. Other contamination of the inside rail came from the train being turned every 3 MGT and lubrication on the wheels being carried over from the outside to the inside rail. Even with slight contamination of the high rail, Section 07 lubrication conditions approach that of a dry track, and wear rates are elevated enough to make valid comparisons in relatively short time frames.

The special non-lubricated periods previously mentioned consisted of two periods which were completed consecutively between the 33-ton axle load and 39-ton axle load tests. The 33-ton axle load dry test, which came at the end of the 33-ton axle load lubricated test, lasted for 10 MGT and was followed by a 15 MGT period of the 39-ton axle load dry test. At the time of operation, FAST engineers hoped that rail wear rates could be established for all curves of the HTL (Sections 03, 07 and 25).

Throughout the entire HTL operation, the train operated at 40 mph in a counter-clockwise direction. At this speed, the train was 2 inches over balance speed for both the 33- and 39-ton axle load test. The FAST\HAL train consisted of four or five 4-axle locomotives and 70-80 loaded 125-ton hopper cars. Part of the standard operating procedure was that the train be turned every 3 MGT and operated in a clockwise direction for 30 laps. During the clockwise operation, the wayside lubricators were turned-off to allow lubrication levels to drop and make flaw detection runs more accurate. This procedure was adopted for the benefit of rail fatigue tests because the train reversal places a beach mark on growing fatigue defects. These beach marks can then be used to determine fatigue crack growth rates.

PART I - RAIL WEAR TEST

1.0 OBJECTIVE

The objective of this experiment was to determine the effect of increasing axle loads from 33-tons to 39-tons on rail wear rates. Another objective was to investigate the wear resistance of various types of rails relative to a standard carbon "control" rail.

Gage face wear is the predominate form of wear at FAST's Section 07 and is the focus of Part 1 of this report. However, rail head height wear and rail corrugation growth data is also presented.

2.0 PROCEDURE

Rails were installed in Section 07, monitored for wear under both 33-ton and 39-ton axle loads, and removed from test when steady wear rates were established or when rails became too worn for safe train operations.

A special dry wear period, described in the introduction of this report, was also conducted on the normally lubricated curves of Sections 03 and 25. During these periods, rail wear was monitored under 10 MGT of 33-ton axle loads and 15 MGT of 39-ton axle loads.

2.1 DATA COLLECTION

Rail wear measurements were normally taken at 15 MGT intervals and included gage wear measurements, head height wear measurements, and longitudinal rail profiles. Brinell hardness measurements were also performed to determine original rail hardnesses, and dynamic loads were collected at specific locations.

2.1.1 Gage Face Wear

The gage face wear device, shown in Figure 1, is used to determine gage wear on the high rails of curves. Referencing the top and the field side of the rail head, a dial indicator reading on the gage face is taken 5/8 inch below the running surface. Accuracy of the readings is plus or minus 0.003 inches. Data is recorded at different MGT intervals and is entered into a computer database. Wear rates are calculated by a computer program, which statistically positions a linear regression line through a scattergram of the data collected over several million gross ton (MGT) intervals. Figure 2 is a sample scattergram with the regression line and slope of that line. The slope of the line indicates wear rate in inches/MGT.

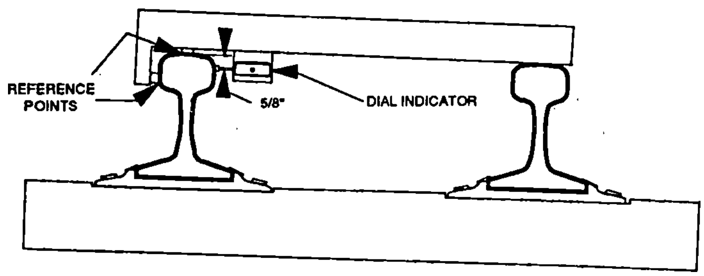


Figure 1. Gage Face Wear Measurement

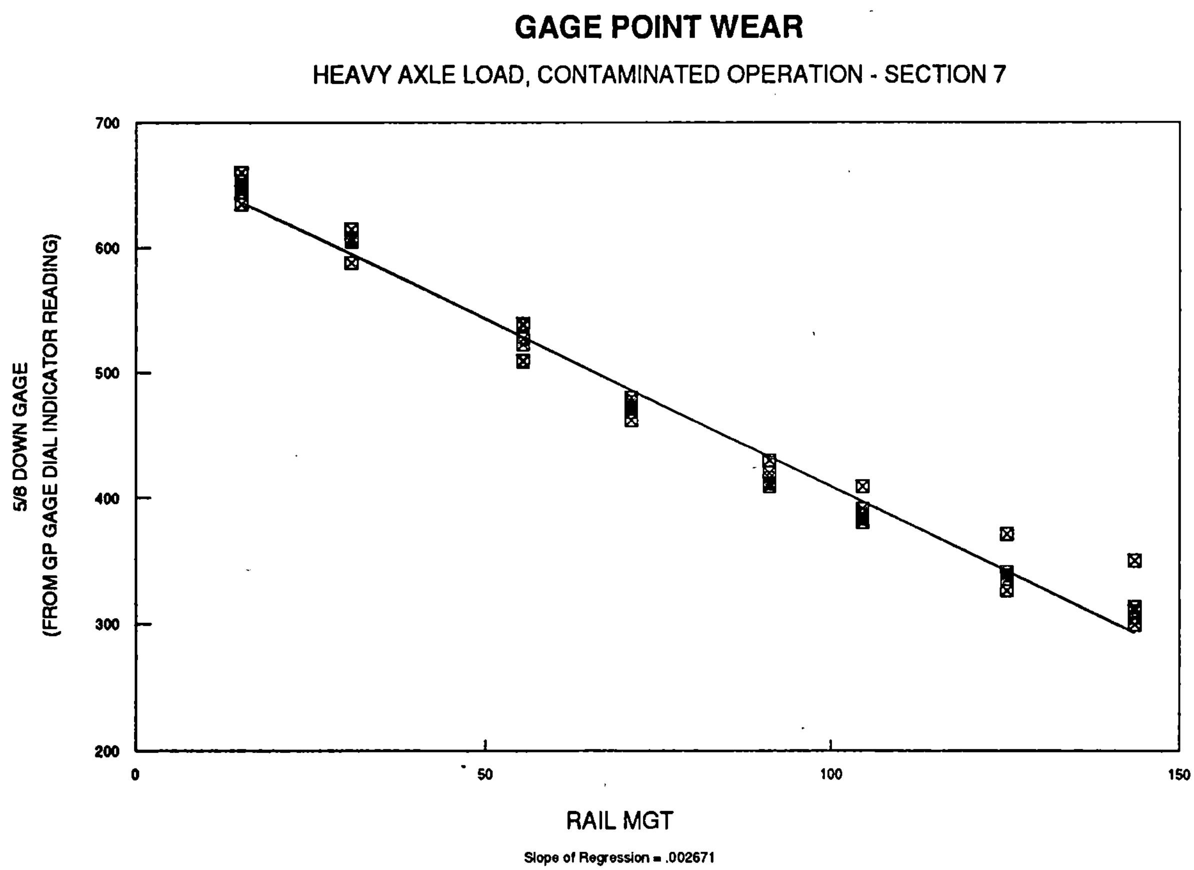


Figure 2. Scattergram With Regression

2.1.2 Head Height Loss

The head height loss instrument, shown in Figure 3, takes a direct measurement at the center of the rail head. This device references the base and web of the rail and also has an accuracy of plus or minus 0.003 inches. Data is collected for high and low rail of curves and processed as with the gage face wear data.

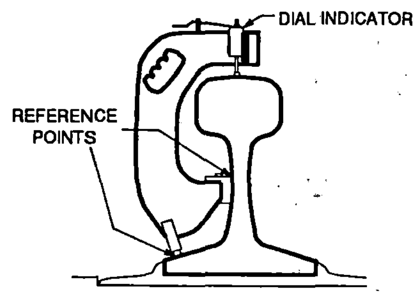


Figure 3. Head Height Loss Measurement

2.1.3 Longitudinal Rail Profiler

The Longitudinal Rail Profiler (LRP machine) records a 1 meter longitudinal tracing of a rail's running surface onto a 10-inch strip chart. Vertical fluctuations are magnified by 7.87 times so that .05 inch in change is reflected as 1 millimeter (mm) on the strip chart. The LRP machine is used to record corrugation wavelengths and depths, or welded rail end batter.

2.1.4 Brinell Hardness

Brinell Hardness (Bhn) is taken on the running surface of rail with one of two hardness testers. Both testers are portable and provide a 3,000 kilogram (kg) load on a 10 mm ball; one is pumped manually, while the other is automatic. Measurements are taken when the rail is new, and periodically thereafter.

2.1.5 Dynamic Load Measurements

Dynamic load measurements are used to determine wheel loads a rail at a particular location of track is actually being exposed to. These measurements are accomplished with the use of strain gages placed on the rail. Though readings from these gages may not be representative of what is happening throughout a particular section, they are very accurate for specifically selected sites. This technique was used for load measurements in corrugated rail.

2.2 TEST LAYOUT

All rails in this test (RE 136, RE 132, or RE 133) were donated by numerous rail manufacturers worldwide to the FRA/AAR FAST program. Section 07, a 5-degree curve, is 1,000 feet long which allowed up to eight types of rail (120 feet each) to be tested concurrently. Figure 4 illustrates rails which were previously tested and under what conditions. The position of each rail within the curve, which is shown on the left side of this figure, shows the approximate location of the rail in Section 07. Position 1 is the first rail in the curve the train passes over when traveling in a counterclockwise direction.

Several rail changes have occurred since the beginning of the HTL and are also shown in Figure 4. For example, the Alloy HH (Off-Line) 360 rail was installed at 10 MGT of the 33-ton axle load test. This rail remained in test through the contaminated 33-ton axle load test, the dry 33-ton axle load test, the dry 39-ton axle load test, and the contaminated 39-ton axle load test. It was removed after 70 MGT of 39-ton axle load testing and replaced by the standard 283 Bhn rail.

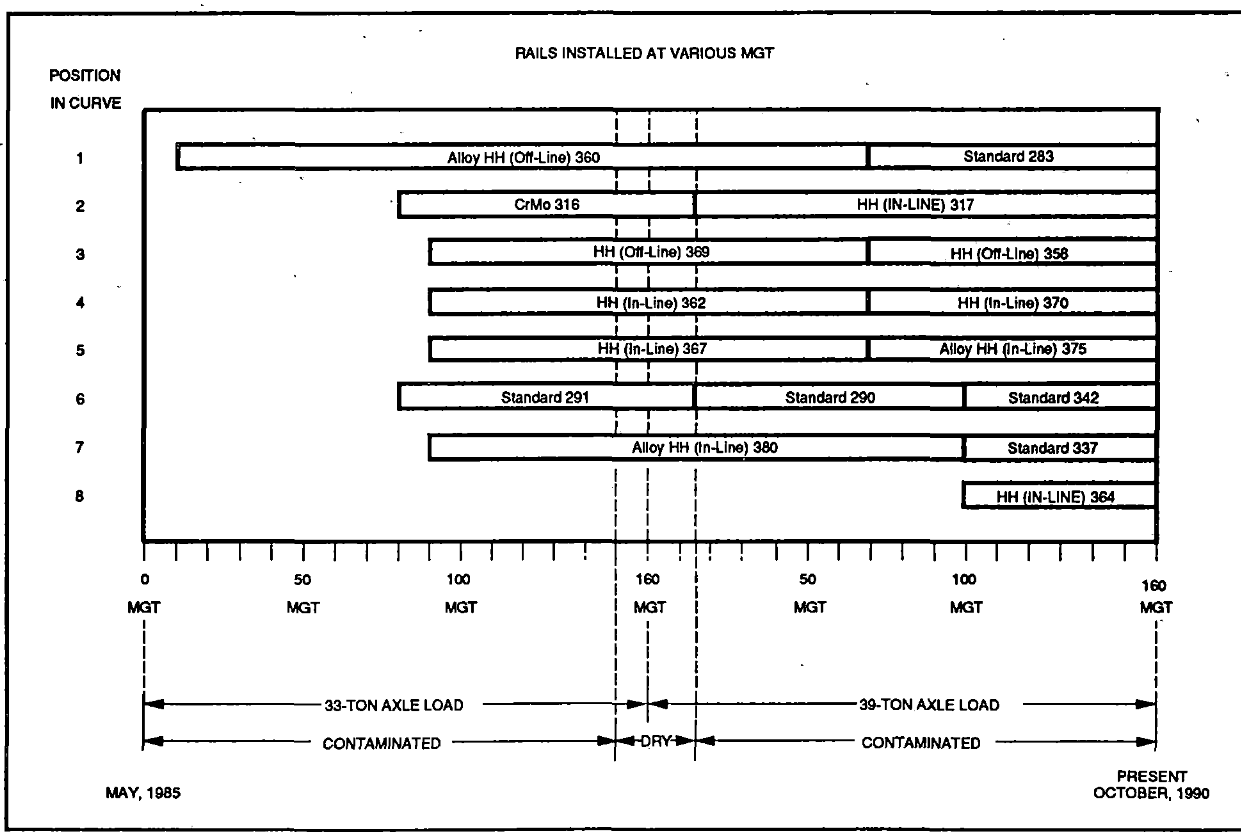


Figure 4. History of Rail in HTL Section 07

3.0 RESULTS

3.1 GAGE FACE WEAR

Wear results from the two non-lubricated periods of the usual fully lubricated curves of Section 03 and 25 were very questionable. There are two reasons for this. First of all, in lubricated curves, the pattern of wear is very different from non-lubricated curves. In fact, wear rates are so low that some metal flow exists on the gage face of many rails in these lubricated curves. Sufficient exposure to dry wear is required to produce conformal wheel/rail profiles and steady state wear rates. Second, the 39-ton axle load test introduced wheels with new AAR 1:20 profiles, both 38 inch Class B (Bhn 277 min to 341 max) and 38 inch Class C (Bhn 321 min to 363 max). These new profiles and hardnesses were different from the 33-ton axle load test wheels (36" class U wheel sets, Bhn ≈ 249-273) with worn profiles. The two dry periods did not have enough tonnage in Sections 3 and 25 to produce the conformal profiles needed for valid wear rate comparisons. This data is excluded from wear analysis in this report.

Table 1 lists the various rails, their hardness as tested at TTC, and gage face wear rates collected from 1986 to 1989 in Section 07. In evaluating wear results, this report concentrates on the rails which were in track under all four operating conditions; that is, the first seven rails listed in Table 1. The standard 291 Bhn rail was replaced at the end of the dry test period with standard 290 Bhn rail. For comparison purposes, these two rails will be considered the same. Three main groups of rail types were included in the test: (1) the standard and the CrMo rails -- controlled cooled (CC) rail, (2) the in-line and off-line head hardened (HH) rail, and (3) the in-line and off-line alloy head hardened (Alloy HH) rail.

Table 1. Gage Face Wear Rates

RAIL		DRY OPERATIONS		CONTAMINATED OPERATIONS	
Metallurgy	Hardness	33-Ton Axle Load Test In./1000 MGT	39-Ton Axle Load Test In./1000 MGT	33-Ton Axle Load Test In./1000 MGT	39-Ton Axle Load Test In./1000 MGT
Alloy HH (Off-Line)	360	*0.968	2.406	1.371	2.323
CrMo (CC)	316	3.368	4.283	2.812	-
HH (Off-Line)	369	2.857	3.275	1.914	2.513
HH (In-Line)	362	2.923	2.957	1.768	2.323
HH (In-Line)	367	2.894	2.448	1.476	2.143
Standard (CC)	291	3.315	-	2.604	3.243
Alloy HH (In-Line)	380	2.493	2.519	1.067	2.081
Standard (CC)	283				2.039
HH (In-Line)	317				2.846
HH (Off-Line)	358				2.165
HH (In-Line)	370				1.826
Alloy HH (In-Line)	375				1.975
Standard (CC)	342				2.261
Standard (CC)	337				3.025
HH (In-Line)	364				2.457

*Extremely low wear rate discarded from analysis

As expected, the performance of the rails within each category was similar. The CC rails had the highest wear rates followed by the HH rails and the alloy HH rails. There is one rail that was an exception to the categories, but in only one of the four operating periods. The alloy HH 360 rail had a much lower wear rate (.968 in./1,000 MGT) during the dry 33-ton axle load test than the alloy HH 380 (2.493 in./1,000 MGT). It was expected that the alloy rails would wear moderately less than the other HH rails. But the alloy HH 360 performed so much better that it is suspected that unforeseen, and so far unknown factors, had come into play which resulted in lower wear rates. This extremely low wear rate will be discarded from the analysis.

As indicated, one of the objectives of this experiment was to compare the wear performance of different metallurgies. This can be done by looking at the gage face wear figure of merits. A figure of merit (FM) is calculated by dividing the control rail wear rate by other rail wear rates. For example, during the contaminated 33-ton axle load test, the gage FM for the alloy Bhn 380 is calculated by dividing the standard 291 Bhn rate of 2.604 in./1,000 MGT by the alloy wear rate of 1.067 in./1,000 MGT. The resulting FM of 2.4

means that the alloy rail performed 140 percent better, or would last over twice as long as standard rail under the 33-ton axle load contaminated condition. If wear rates for standard rail were unavailable for use as the control rail, CrMo rail rates were substituted.

Table 2 summarizes all Section 07 gage face wear FMs (a complete FM listing is located in Appendix C; Table C1). Under contaminated operations and 33-ton axle loads, the HH rails increased rail life from 30 percent to 80 percent over standard rail, while the alloy HH rails increased life 90 percent to 140 percent. Under contaminated 39-ton axle loads (HALs), these same rails increased life 30 percent to 50 percent and 40 percent to 60 percent, respectively. This data suggests, under contaminated conditions, increasing axle loads reduce the benefit (in terms of increased rail wear life) of HH and alloy HH rail over standard rail.

Table 2. Gage Face Wear Figures of Merit

RAIL METALLURGY	DRY OPERATIONS		CONTAMINATED OPERATIONS	
	33-Ton Axle Load Test (FM)	*39-Ton Axle Load Test (FM)	33-Ton Axle Load Test (FM)	39-Ton Axle Load Test (FM)
CC	1.0	1.0	1.0	1.0
HH	1.1 to 1.2	1.3 to 1.7	1.3 to 1.8	1.3 to 1.5
Alloy HH	1.3	1.7 to 1.8	1.9 to 2.4	1.4 to 1.6

*CrMo was used as control rail.

Dry operations generated different results. During the 33-ton axle load test, HH rails increased rail life only 10 percent to 20 percent, and alloy HH rail increased rail life by 30 percent. Under 39-ton axle loads, HH rail increased life 30 percent to 70 percent, while alloy HH increased life 70 percent to 80 percent. Therefore, the benefit of using HH and alloy HH rail over standard rail under totally dry conditions increased with increased axle loads.

Review of the FMs is appropriate for relative rail performance, but it does not display the actual effect of increasing axle loads on individual rails. Table 3 summarizes the penalty factors encountered from increasing wheel loads from 33 tons to 39 tons under both dry and contaminated conditions. Penalty factors (PF) are calculated by dividing the 39-Ton Axle Load Test wear rate by the 33-ton axle load wear rate (a complete PF table is in Appendix C; Table C2).

Table 3. Gage Wear Penalty Factors for Increasing Axle Loads

RAIL METALLURGY	DRY OPERATION (PF)	CONTAMINATED OPERATION (PF)
CC	1.2	1.2
HH	.85 to 1.1	1.3 to 1.5
Alloy HH	1.0	1.7 to 2.0

Under dry conditions, increasing the axle load increased the gage face wear rate of CC rails by 20 percent, of HH rails by -15 percent to 10 percent, and of alloy HH by zero percent. Therefore, increasing the axle load from 33 tons to 39 tons (approximately 18%) increased the wear rate of standard rail proportionally, but had no apparent affect on HH and alloy HH rails.

A possible explanation for this can be offered. Under totally dry conditions and 33-ton axle loads, wear rates were extremely high no matter what type of rail was being used. This can be seen in the Table 2 in which all the FMs are near 1. When the axle load was increased, the wear of the HH and alloy HH rails remained approximately the same (see Table 3). This suggests that the wear was a surface condition and not caused from subsurface metal flow (crushing), i.e., the wear overcame any crushing of the gage. However, the softer standard rail, which is more susceptible to crushing, encountered both crushing and surface wear. Thus, the wear rate of the CC increased, but not in the premium rails.

Under contaminated operations, the CC rail wear again increased proportionally with wheel load at 20 percent. However, the HH and alloy HH rail, which showed no increase of wear with increased load under dry conditions, did show an increase with contamination. The HH rail wear rate increased 30 percent to 50 percent and the alloy HH rate increased 70 percent to 100 percent. Under contaminated conditions, increasing the axle loads increased the wear of premium rails more than standard rails. Surface wear is not high enough to overcome crushing; therefore, increasing the load would increase the wear rate.

3.2 HEAD HEIGHT LOSS

The gage face wear data gives an incomplete picture of the wear that took place in Section 07. Comparisons of high and low rail head height loss PFs for increasing axle loads may help give a clearer picture. Table 4 lists all the head height loss rates encountered in Section 07 that can be used for these comparisons.

Table 4. Section 07 Head Height Loss Wear Rates

RAIL METALLURGY	ORIGINAL BRINELL HARDNESS	33-TON AXLE LOAD TEST DRY OPERATION (In./1000 MGT)		39-TON AXLE LOAD TEST DRY OPERATION (In./1000 MGT)		33-TON AXLE LOAD TEST CONTAMI-NATED OPERATION (In./1000 MGT)		39-TON AXLE LOAD TEST CONTAMI-NATED OPERATION (In./1000 MGT)	
		High Rail	Low Rail	High Rail	Low Rail	High Rail	Low Rail	High Rail	Low Rail
Alloy HH (Off-Line)	360	1.101	0.514	1.857	0.546	0.242	0.085	0.440	.0780
CrMo (CC)	316	1.740	2.186	2.234	1.250	0.741	0.282	-	-
HH (Off-Line)	369	0.488	0.755	1.128	0.334	0.263	0.201	0.506	0.221
HH (In-Line)	362	0.727	0.941	1.299	0.540	0.293	0.165	0.516	0.167
HH (In-Line)	367	0.474	0.401	1.533	0.460	0.273	0.172	0.517	0.234
Standard (CC)	291	1.701	1.900	-	-	1.039	0.472	1.462	0.436
Alloy HH (In-Line)	380	0.430	0.479	1.437	0.162	0.251	0.192	0.463	0.143
Standard (CC)	283							0.874	0.369
HH (In-Line)	317							0.522	0.177
HH (Off-Line)	358							0.285	0.127
HH (In-Line)	370							0.116	0.035
Alloy HH (In-Line)	375							0.105	0.031
Standard (CC)	342							0.751	0.367
Standard (CC)	337							1.414	0.570
HH (In-Line)	364							0.374	0.216

Table 5 summarizes the head height loss PF ratios of 39-ton axle load wear rate to 33-ton axle load wear rate (a complete PF listing is located in Appendix C; Table C3). Under dry conditions on the high rail, increasing the axle load resulted in an increase in head height loss in all cases. The CC rate increased 30 percent, the HH increased 80-220 percent, while the alloy HH rate increased 70-230 percent. However, the low rail head height loss decreased in most cases for CC, HH, and Alloy HH rail. As discussed earlier, gage face wear remained approximately the same under dry conditions and increased axle loads.

This indicates that high rail head height loss may become a critical factor of rail life under HALs. Also, the suggestion that surface wear overtakes any crushing under dry conditions is not valid for head height loss as it is for gage face wear.

Table 5. Head Height Loss Penalty Factors for Increasing Axle Loads

RAIL METALLURGY	DRY OPERATION		CONTAMINATED OPERATION	
	High Rail (PF)	Low Rail (PF)	High Rail (PF)	Low Rail (PF)
CC	1.3	0.6	1.4	0.9
HH	1.8 to 3.2	0.4 to 1.1	1.8 to 1.9	1.0 to 1.4
Alloy HH	1.7 to 3.3	0.3 to 1.1	1.8	0.7 to 0.9

High rail head height loss PFs under contaminated operations are very similar to the dry period PFs. The head height loss increased in all cases, again especially for HH and alloy HH rail. These PFs are also comparable to the gage wear PFs in Table 3. Increasing the axle loads under contaminated conditions increased the gage face wear and head height loss nearly the same. However, the PFs for the low rail, which are all near 1.0, suggest head height loss remained about the same.

3.3 CORRUGATIONS

Throughout the history of the HTL, Section 07 has been susceptible to corrugations on the high rail of the curve. During operation of the 33-ton axle load test, these corrugations were observed to begin at a joint or a battered weld in standard rail and then to carry through the remainder of the rail as tonnage was accumulated. There are no exact records of corrugation development, but the longer the rail remained in service, the deeper the corrugations became until the rail eventually had to be ground. Corrugations were also noticed in HH rails, but they were light and did not become worse with tonnage. A strip chart recording from the LRP machine is shown in Figure 5. This LRP was taken on standard carbon rail after 71 MGT of contaminated 33-ton axle operation and was the only corrugation data taken during the period. The test site chosen had the deepest corrugations. Assuming the corrugations began to develop immediately with train operations, and a corrugation depth of .09 inches after 71 MGT, the growth rate is .0013 in/MGT.

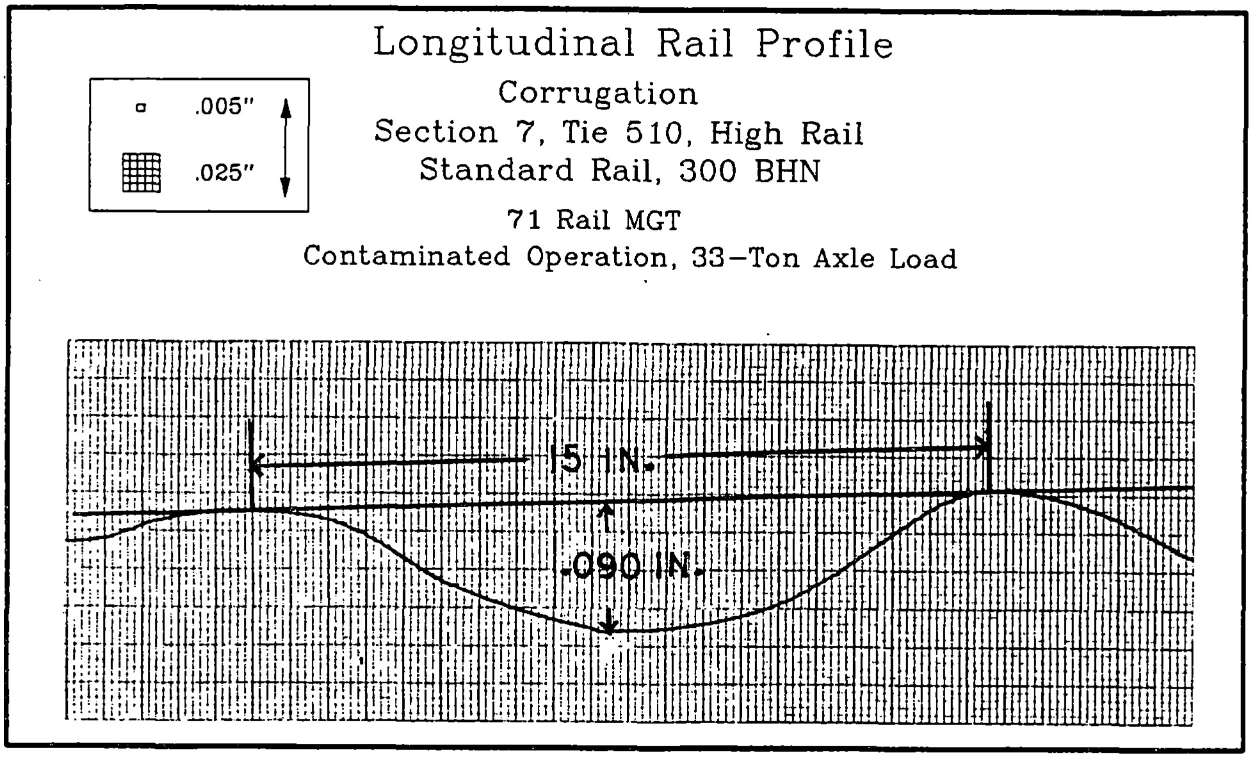


Figure 5. Corrugation Strip Chart 33-ton Axle Load

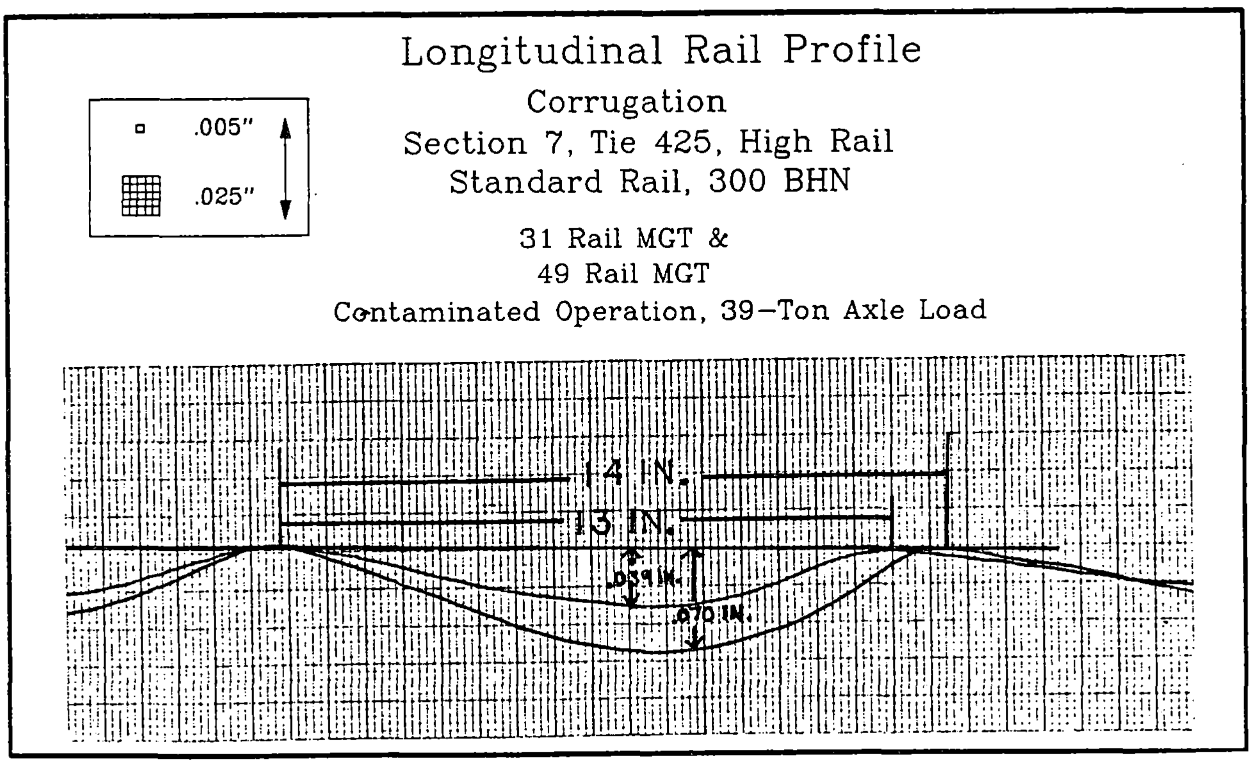


Figure 6. Corrugation Strip Chart 39-ton Axle Load

Under contaminated 39-ton axle loads, corrugations in rail (with the same hardness of the previously discussed rail and in nearly the same location) were first noticed near rail joints after 5 MGT, and within the rail itself at 10 MGT. That is to say the corrugations began nearly as soon as the rail was installed and showed signs of rapid development as tonnage accumulated. Figure 6 displays the LRPs taken at the worst corrugations in this rail and at two intervals: 31 and 49 MGT. A later LRP could not be taken as the rail was ground at 49 MGT. The rate of corrugation growth shown on this chart increased from .0013 in/MGT at 0 to 31 MGT to .0017 in/MGT at 31 MGT to 49 MGT, and averaged at .0014 in/MGT. This indicates that the growth rate increases as the corrugation depth increases.

In the lubricated sections of the HTL, 33-ton axle load corrugation records were not kept. However, it has been observed that rails with Bhn of 280+ were in track in Sections 25 and 03 for up to 150 MGT with no heavy corrugations. Also, rail with Bhn of only 269 became extremely corrugated by 60 MGT in these same curves. Under 39-ton axle loads, corrugations in Section 25 have been confined to joint locations in standard rail and have not become severe. In Section 03, however, standard rail (similar to that in Section 07) became corrugated under 39-ton axle loads as in Section 07.

It has been observed that corrugation wave lengths change with accumulated tonnage as shown in Figure 6. The 31 MGT corrugation, 13 inches long, grew to 14 inches by 49 MGT. The two strip charts were overlaid with no actual reference point, i.e., one point was matched over the other for a reference. Therefore, the actual movement of the corrugation peaks and valleys in relation to the rail and to each other has not been determined.

To determine the rail load environment in the corrugated sections, vertical load data was collected from corrugation peaks and valleys in Section 07. Strain gages were applied to the rail at two peaks and two valleys with depths of .070 inches to .080 inches. A special consist of cars from both the 33- and 39-ton axle load tests then passed over the gages at 40 mph. The vertical load data gathered is displayed in the exceedance plot of Figure 7.

The most striking result of the corrugation load data is the difference between the peak and the valley loads. Peak and valley loads for the 33 kip wheel ranged from 11 kips to 35 kips and from 32 kips to 80 kips, respectively. Wheel loads for the peak and valley under 39 kip wheels ranged from 19 kips to 43 kips and from 65 kips to 93 kips, respectively. The increase of 6 kips in static wheel load resulted in a increased maximum load at the peaks of 8 kips and at the valleys of 13 kips.

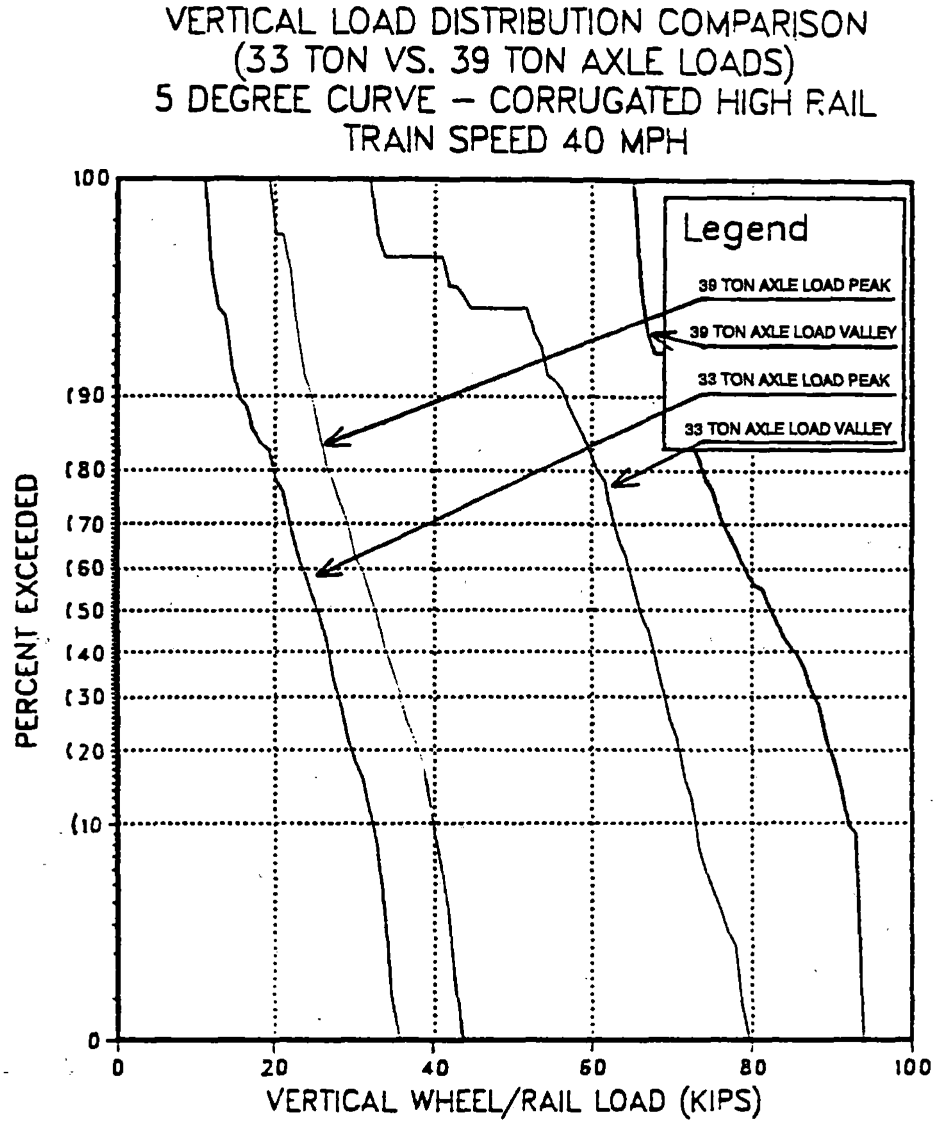


Figure 7. Dynamic Vertical Load Data

4.0 CONCLUSIONS

Several important wear comparisons between 33- and 39-ton axle loads have come from the HTL tests. These observations have implications for revenue service.

The evaluation of Section 07 wear results suggests that increasing axle loads from 33 tons to 39 tons under contaminated conditions:

1. reduced the rail life benefit (in terms of gage face wear) offered by premium rails over standard rail,
2. increased the rate of high rail head height loss and had little affect on low rail head height loss, and
3. relatively increased the rate of high rail head height loss nearly the same as the rate of gage face wear.

Increasing axle loads under totally dry conditions:

1. increased the rail life benefit (in terms of gage face wear) offered by premium rails over standard rails,
2. increased the rate of high rail head height loss and reduced low rail head height loss rates, and
3. increased the rate of high rail head height loss relatively more than the rate of gage face wear.

The 6 kip increase in wheel load caused vertical loads in the bottom of .070 inches to .080 inches corrugations to increase from maximums of 80 kips under 33 kip wheels to 93 kips under 39 kip wheels.

PART II - RAIL FATIGUE TEST

1.0 OBJECTIVES

The objective of the HAL Rail Performance Fatigue Test was to compare the effects of 39-ton axle loads on rail fatigue occurrence to those of 33-ton axle loads.

2.0 PROCEDURE

The Rail Fatigue Test took place mainly in Section 25 at FAST. The procedure for rail fatigue testing was to place rail in track under lubricated conditions and monitor fatigue defects in the high rail of the curve. The rail was not ground unless it was part of a special grinding test. Lubricators were placed at the beginning of Section 25 to create varying lubrication levels throughout the curve; i.e., high levels at the beginning, moderate/high levels in the center, and moderate/low levels at the end of the curve. Higher lubrication levels were expected to increase the initiation of rail fatigue defects. Section 25 was divided into three segments during the 33- and 39-ton axle load tests, A, B, and C, as shown in the HAL test layout in Figure 1. Segments A and C were fatigue tests in which rails were duplicated to determine the effect of lubrication level. Segment B was a grinding test. Rails have always been duplicated in Segments A and C in case there was an affect from lubrication level on fatigue.

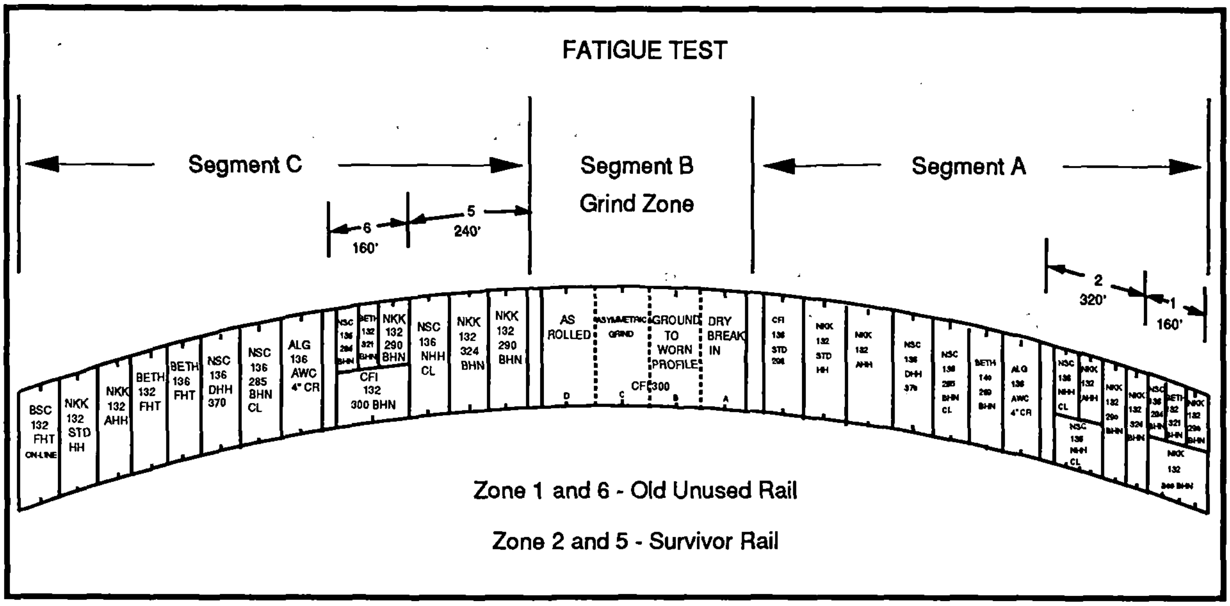


Figure 1. Section 25, Old Unused and Survivor Rail at Start of 39-Ton Testing

2.1 DATA COLLECTION

Ultrasonic rail flaw inspections are made every 3 MGT. TTC's rail flaw detection vehicle can detect fatigue defects in the form of detail fractures as small as 3 percent of the rail head area. If a flaw is detected in test rail, it is logged into a database and inspected by ultrasonic mapping with a hand held ultrasound unit for the remainder of its life. The data is used to determine how many and what type of defects a rail had, when they occurred and how fast they grew. These efforts are particularly useful for the fatigue test in Sections 03 and 25 since Section 07 rail has yet to develop a fatigue defect in the rail itself.

2.2 MATERIALS

Rails for the fatigue tests were donated by various manufacturers. The standard rails had a hardness specification of 269 Bhn minimum, while the head hardened rails had no Bhn specification. In preparation for the 33-ton axle load fatigue test, four rails of each metallurgy and manufacturer were placed in the high rail of Section 25; two rails in Segment A, and two rails in Segment C. Fatigue defects in the form of shells and detail fractures developed in many of the standard rails, but very seldom in the head hardened rails. The results suggested that differential lubrication levels had little or no affect on the number of defects developed in Segments A and C; therefore, this report does not distinguish between these two segments.

As stated, the main objective of the HAL Rail Performance Fatigue Test was to compare the effects of 39-ton to 33-ton axle loads. In order to do this, the same type of rail had to be installed in each test. This was done by setting aside some of the rail originally donated to the DOG Test and later installing it in the HAL Test. There was a very limited number of these "old unused" rails since the original number donated was small. Along with the old unused rails, some of the rails that had not produced defects during the 33-ton axle load test were left in track for continued testing under 39-ton axle loads. These "survivor rails" were left in to increase the number of comparable rails as well as to see the effect of 39-ton axle loads on 33-ton conditioned rail.

Table 1 lists the old unused rails and the survivor rails, their average hardnesses as tested, and the total number of each that were in track during the 33- and 39-ton axle load tests. For example, there were four Bethlehem 321 Bhn rails in the high rail of Section 25 during the 33-ton axle load test, but only two during the 39-ton axle load test. All the survivor rails were reinstalled for the 39-ton axle load test and therefore had the same number in both tests. The population of these rails is small which must be kept in mind in drawing conclusions based on fatigue results.

Table 1. Number of Old Unused and Survivor Rails

RAIL METALLURGY	NUMBER OF RAILS IN TRACK DURING 33- AND 39-TON AXLE LOAD TESTS	
	33-Ton Axle Load Test	39-Ton Axle Load Test
Old Unused:		
NSC Standard 284	4	4
BETH Standard 321	4	2
NKK Standard 290	4	2
Survivor:		
NSC HH 371	4	4
NKK Alloy HH 390	4	4
NKK Standard 324	4	4
NKK Standard 290	2	2

When defects in test rail became severe enough to remove from track, some of the test rail was removed with it. Some test rail was also removed when rail end welds failed. This caused a decrease in the sample size of the rail as the test progressed. During the 39-ton axle load test, field weld failures became more common than in the 33-ton axle load test and in turn adversely affected the sample size. Also, the 39-ton axle load test sample was smaller to begin with.

3.0 RESULTS

Table 2 lists the Fatigue Test results from the old unused rails and shows rail type along with the average accumulated number of detail fractures (DF) and shells per rail at 150 MGT of 33-ton and 145 MGT of 39-ton axle loads. The NSC 284 rail had three DFs and 0.5 shells per rail at 150 MGT of 33-ton axles. Under 39-ton axle loads, it had three DFs and five shells at 145 MGT. The 39-ton axle loads seemed to have a very detrimental effect on this rail, especially in the form of shells. Thirty-nine ton axle loads were also very detrimental to the NKK 290. This rail developed no defects at all during the DOG test, but averaged 1.5 DFs per rail under 39-ton axle loads. Increased axle loads did not seem to be detrimental to the Bethlehem rail, possibly because of its higher hardness. This rail had three DFs and 2.75 shells per rail during the 33-ton axle load test, but only 1.5 DFs and two shells per rail during the 39-ton axle load test. Of the three rail types tested, two performed noticeably worse and one performed noticeably better under HALs.

Table 2. Rail Fatigue Performance Under 33- and 39-Ton Axle Loads

RAIL METALLURGY	33-TON AXLE LOAD TEST 150 MGT		39-TON AXLE LOAD TEST 145 MGT	
	DFs/ Rail	Shells/ Rail	DFs/ Rail	Shells/ Rail
NSC Standard 284	3.0	0.5	3.0	5.0
BETH Standard 321	3.0	2.75	1.5	2.0
NKK Standard 290	0	0	1.5	0

Another observation was made on some old unused rail which is not listed in Table 2. The rail was old AREA standard 248 Bhn, which was in all segments of Section 25 during the 33-ton axle load test, and was in the leading end of Section 03 during the 39-ton axle load test. Section 03 (5-degree curve with moderate lubrication) is a less severe curve than Section 25 (6-degree curve with heavy lubrication). Rails placed in Section 03 are expected to last longer than similar rails in Section 25. The old standard 248 Bhn rail had to be removed from the 33-ton axle load test anywhere from 60 MGT to 132 MGT. Under 39-ton axle loads, this same rail had to be removed from Section 03 at 37 MGT. Being placed at the beginning of Section 03 instead of further into the curve may have contributed to the rapid degradation of this rail, under 39-ton axle load testing.

Table 3 lists the defects that occurred in the rail that survived the 33-ton axle load test and was installed in the HAL Test. Two of the surviving metallurgies were the standard NKK rails. The NKK 324 was actually a low alloy rail while the NKK 290 (also an old unused rail) was actually an extra clean standard rail, i.e., it was cleaner than most rails. Since these rails produced no defects during the 33-ton axle load test, they were installed as survivors in the HAL. The other two survivors were head hardened rails which had been in track since the start of the HTL. The standard rails were in track for only 295 MGT because they were taken out during the two dry run periods. For example, in the left column of Table 3, all the rail had accumulated 150 MGT of lubricated 33-ton axle loads. In the right column, the standard rails had 295 MGT (150 MGT 33-ton and 145 MGT 39-ton axle loads) while the head hardened rails had 320 MGT (150 MGT, 33-ton axles, lubricated; 10 MGT, 33-ton axles, dry; 15 MGT, 39-ton axles, dry; and 145 MGT, 39-ton axles, lubricated).

The NSC HH 371 developed a shell in the first 150 MGT of the 33-ton axle load test. This was unusual and was the only defect any of the survivor rails developed during the test. As this rail continued in test under 39-ton axle loads, it developed a DF. As the NKK 324 continued under 39-ton axle loads, it developed .5 shell and .25 DF per rail. The NKK 290 performed about the same as the old unused NKK 290; developing 1.25 DFs but no shells. The only rail to survive without any defects was the NKK alloy HH.

It is difficult to determine from these results what the effect of 39-ton axle loads was on the survivor rail. The defects that occurred under heavy axle loads could be a result of total accumulated tonnage or of the 39-ton axle loads. It can be said, however, that rails which seldom developed fatigue defects under 33-ton axle loads began to fatigue when later exposed to 39-ton axle loads.

Table 3. Fatigue Defects Survivor Rail 150 MGT of 33-Ton Loads and Subsequent 145 MGT 39-Ton Loads

RAIL METALLURGY	33-TON AXLE LOAD TEST 150 MGT (Add 10 MGT more for HH Rails)		39-TON AXLE LOAD TEST ADDITIONAL 145 MGT (Add 15 MGT more for HH Rails)	
	DFs/ Rail	Shells/ Rail	DFs/ Rail	Shells/ Rail
NSC HH 371	0	0.25	0.25	0.25
NKK Alloy HH 390	0	0	0	0
NKK Standard 324	0	0	0.25	0.5
NKK Standard 290	0	0	1.25	0

4.0 SUMMARY AND CONCLUSIONS

Several important rail fatigue comparisons between 33- and 39-ton axle loads have come from the HTL tests as follows:

1. The low alloy and extra clean standard rails that survived the 33-ton axle load test with no defects began to develop shells and detail fractures when subsequently exposed to HALs.

2. Intermediate strength standard rails, which developed fatigue defects under 33-ton axle loads, performed noticeably worse under HALs in one case, and performed slightly better under HALs in another case.

3. One old unused extra clean standard rail, which did not develop defects by 160 MGT of 33-ton axle loads, developed numerous detail fractures by 145 MGT of HALs.

4. Old standard 248 Bhn rail which survived 60 to 132 MGT of 33-ton axle loads only survived 37 MGT of 39-ton axle loads.

Due to the small sample size available for this test, it is difficult to draw conclusions on the effect of increasing axle loads. However, the observations suggest that increasing axle load does reduce rail fatigue life for standard non heat-treated rails. This especially seems to be the case for the standard 248 Bhn rail. Though this rail type is no longer manufactured for major railroads, it is still abundant in revenue service.

If the increasing axle loads were to reduce rail life, it seems likely that this reduction could be offset by the improvement in rail metallurgy. That is, railroads have operated 33-ton axle loads on rail manufactured with non-current processes. Now that rail metallurgy has been improved with new processes, it is able to support a heavier load.

PART III - PILOT RAIL GRINDING TEST

1.0 BACKGROUND

Rail grinding has been performed in the United States and on other railroads throughout North America, generally as a means to correct or eliminate rail anomalies on the running surface of the rail head. This method of maintenance termed, "corrective grinding" is normally performed only after the surface defects have occurred on the rail surface. The defects that normally are responsible for maintenance grinding are (1) spalling and head checking on the high rail, and (2) excessive metal flow on the low rail. With heavier axle loads (33-ton and higher), combined with rail lubrication, corrective grinding provides only a temporary fix to rail surfaces since it only reshapes the rail head. It does not remove internal rail head fatigue, and its affect on prevention of internal fatigue is unknown.

Since lubricated testing began during 33-ton axle load testing at FAST, rail wear of the gage face has seen a significant decrease in the curves. Consequently, with a reduction in rail wear the occurrences of subsurface defects has increased. Previous tests at FAST have shown that higher wear rates of rail not only reduce surface defects but also suppress internal defects, i.e., detail fractures and shelling. Railroads are now adopting preventive grinding programs aimed at reducing internal rail defects before they have an opportunity to form in the rails. This new, more scientific approach to rail profile grinding has been implemented by railroads and is designed to extend rail service life. Rail grinding programs are primarily intended to (1) shift the wheel loads from the gage corner of the rail running surface by asymmetric grinding patterns, (2) prevent areas of high localized contact stresses by grinding worn profiles more conforming to the wheel geometry; therefore, distributing the internal stresses more uniformly into the rail cross section, and (3) grind at predetermined intervals and rates constantly shifting the critical internal stresses thereby not allowing time for microcracking to occur.

One of the preventive rail grinding experiments undertaken at FAST is asymmetric profiling. The asymmetric profile was designed by AREA Rail Committee 4 to help reduce shells and detail fractures. The intent of the experiment was to validate the occurrences of shell defects which occurred in similar ground test rail during the previous 33-ton axle load test at FAST. During 33-ton axle load lubricated testing at FAST, a basic approach was taken to reduce the occurrences of shelling and detail fractures under lubricated operation. A small portion of the rail gage corner of the high rail was ground off a segment of rail in the 6-degree curve of Section 25 (Figure 1). The low rail was not ground. The intent of this gage corner grind was to unload the gage corner of the high rail by minimizing the contact at the wheel throat/rail gage corner interface in an attempt to reduce shelling and detail fractures. As it turned out this grinding approach did not prevent the formation of shells and detail fractures but caused a slight increase in the rate of occurrences of shells and detail fractures. Instead of the traditional single plane shells normally found in unground rails at FAST a new biplanar shell developed in the rails as a result of the two point contact produced from the gage corner grind.[1]

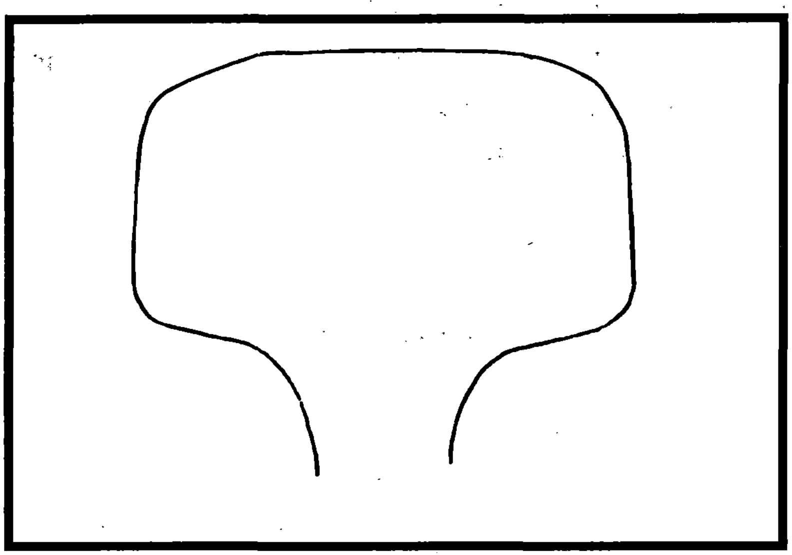


Figure 1. High Rail Gage Corner Grind 33-Ton Axle Load Testing

This pilot grinding experiment was intended to establish directives and sort out discrepancies as what to expect during future rail grinding tests at FAST. This paper describes the fatigue performance of four different profiles in standard carbon rail. It also describes the particular problems encountered at FAST during the test. The test spanned a period of 145-160 MGT under 39-ton axle loads at FAST.

2.0 OBJECTIVE

The objective of this test was to evaluate rail grinding practices and determine which grinding frequency, rate and profile will extend rail fatigue life.

3.0 PROCEDURE

Four different rail profiles were selected for testing in Section 25, a 6-degree lubricated curve, on the HTL (Figure 2). The test zone was divided into four subsections each 160 feet long and were designated A, B, C, and D. Each subsection contained a different rail profile, which is described in Figure 3. Rails chosen for the test were standard carbon 133

RE with an average hardness of 300 Bhn. The entire 640 feet of rails on the high and low rails were manufactured from the same heat creating a test zone in which the rail chemistry and hardnesses were nearly identical. Subsection A rail contained a conditioned profile, as shown in Figure 4a (service worn), which was developed during the initial 15 MGT of dry operation on the HTL under 39-ton axle loads. The conditioned profile was conformal to the average FAST wheel profile. Subsection B profile (Figure 4a) was a ground worn profile which was intended to replicate the conditioned dry worn profile. The low rails were also ground to match the dry worn low rails. Because of inconsistencies in the FAST rail grinder, the required ground worn profile (Subsection B) was not fully achieved until 47 MGT. Initially too much metal was ground off the gage corner of the rail and was not fully corrected until 47 MGT. The Subsection A dry worn rail profile also had a natural worn-in gage face whereas the Subsection B ground worn profile rail initially did not.

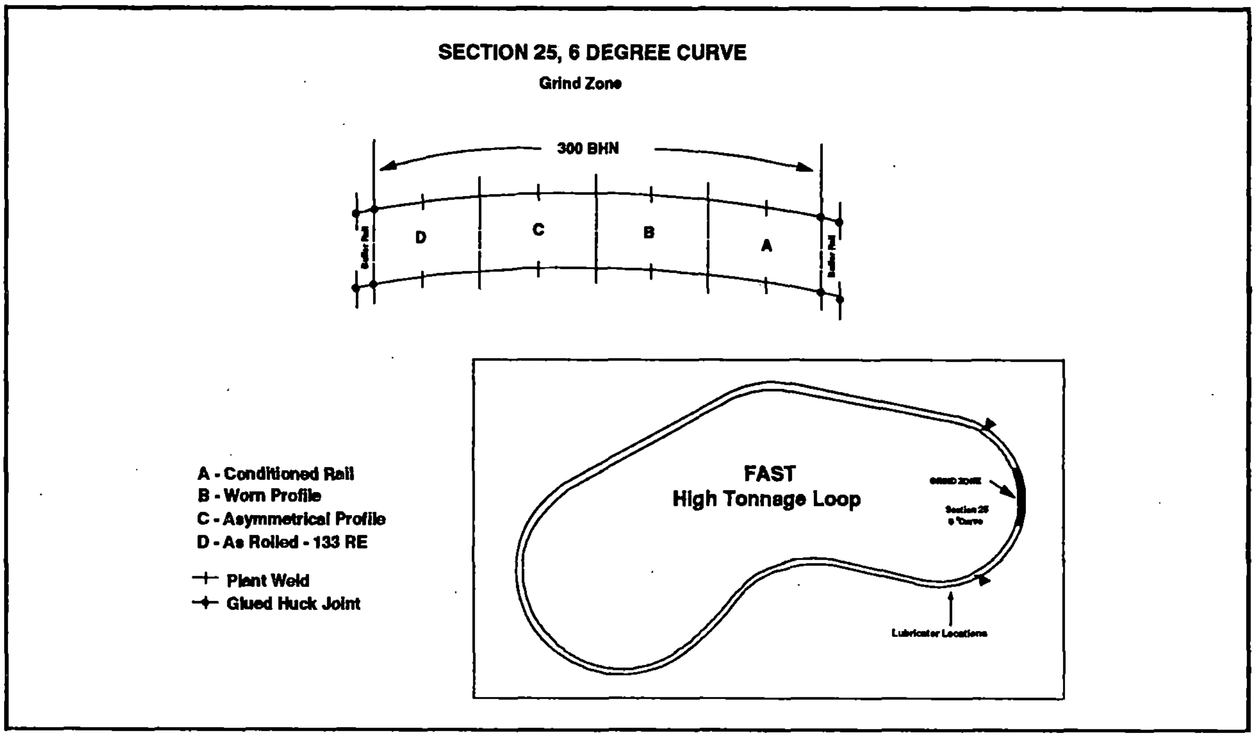


Figure 2. Layout of Grind Zone in High Tonnage Loop

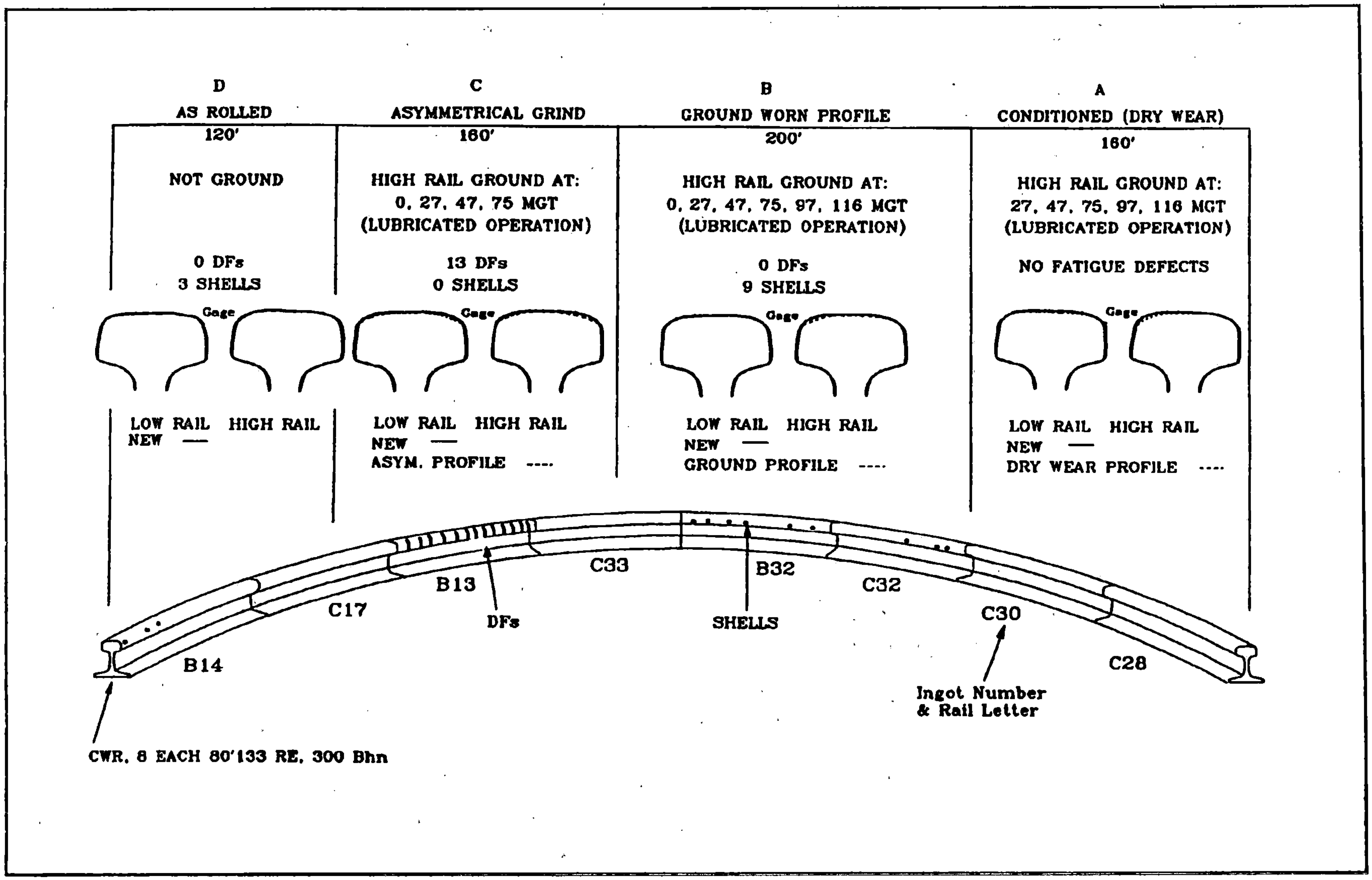


Figure 3. Grind Zone -- High Rail of HTL Section 25

The profile in Subsection C (Figure 4b) was ground to an asymmetric pattern on both the high and low rails. A 1.25 inch contact path was ground onto the running surface of the rail. The center line of the contact path was offset from the center line of the rail 1/8 inch toward the field side of the low rail and 1/8 inch toward the gage of the high rail. The intent of the asymmetric profile was to help steer the trucks away from the gage corner of the high rail to relieve gage corner loading. Subsection D (Figure 4b) was installed to act as a control rail for Subsections A, B and C. It was installed in the "as rolled" condition and was worn-in "naturally" under lubricated operation during the test. The control rail was to be used as a base line in which all other profiles could be compared when evaluating their fatigue performance. Figures 4a and 4b show the rail profiles as they looked at the start of 39-ton axle load lubricated testing.

Rail grinding intervals and rates for Subsections A and B were predetermined before heavy axle load testing began. These profiles were scheduled to be ground at 20-25 MGT intervals. Total metal removal rates were not to exceed 2 millimeters (0.080") per 100 MGT. The asymmetric profile (C) did not have a predetermined grinding interval and was ground (reprofiled) only after the asymmetric pattern was lost due to service exposure. Subsection D would act as a control rail for the grind test and was not ground unless it was absolutely necessary.

All rails in the test zone were subjected to 145 MGT of loading over a period of 14 months. Subsection A had an additional 15 MGT because of its exposure to the dry operation. The test train consisted of up to seventy-five, 125-ton cars and four locomotives. Total weight averaged 12,500 tons. For the majority of the test, the consist operated in the counterclockwise direction, except at the end of each 3 MGT period when 30 laps were run in the clockwise direction. The 30 clockwise laps were always operated with the lubricators turned off to allow dry-down of the HTL, which would assure a better quality rail flaw inspection. In addition, the clockwise operation established "beach marks" on the surface of existing transverse fatigue defects in the test rails from which growth rates could be calculated.

Railhead profile measurements were taken at predetermined intervals using the Yoshida Profiler. These intervals were 20-25 MGT for Subsections A and B. Measurements in Subsection C were taken whenever the asymmetric pattern was worn away and required reprofiling, at which time they were taken before and after. Because of time constraints, post-grind profiles could not always be taken as scheduled but were taken as soon as possible thereafter. Subsection D outside rail went the entire test without any grinding and profiles were taken at the required FAST test measurement intervals of 30 MGT. Table

1 shows at which MGT period each subsection required grinding. In some cases the low rails in Subsections A and B did not always require grinding at the same interval of the high rail.

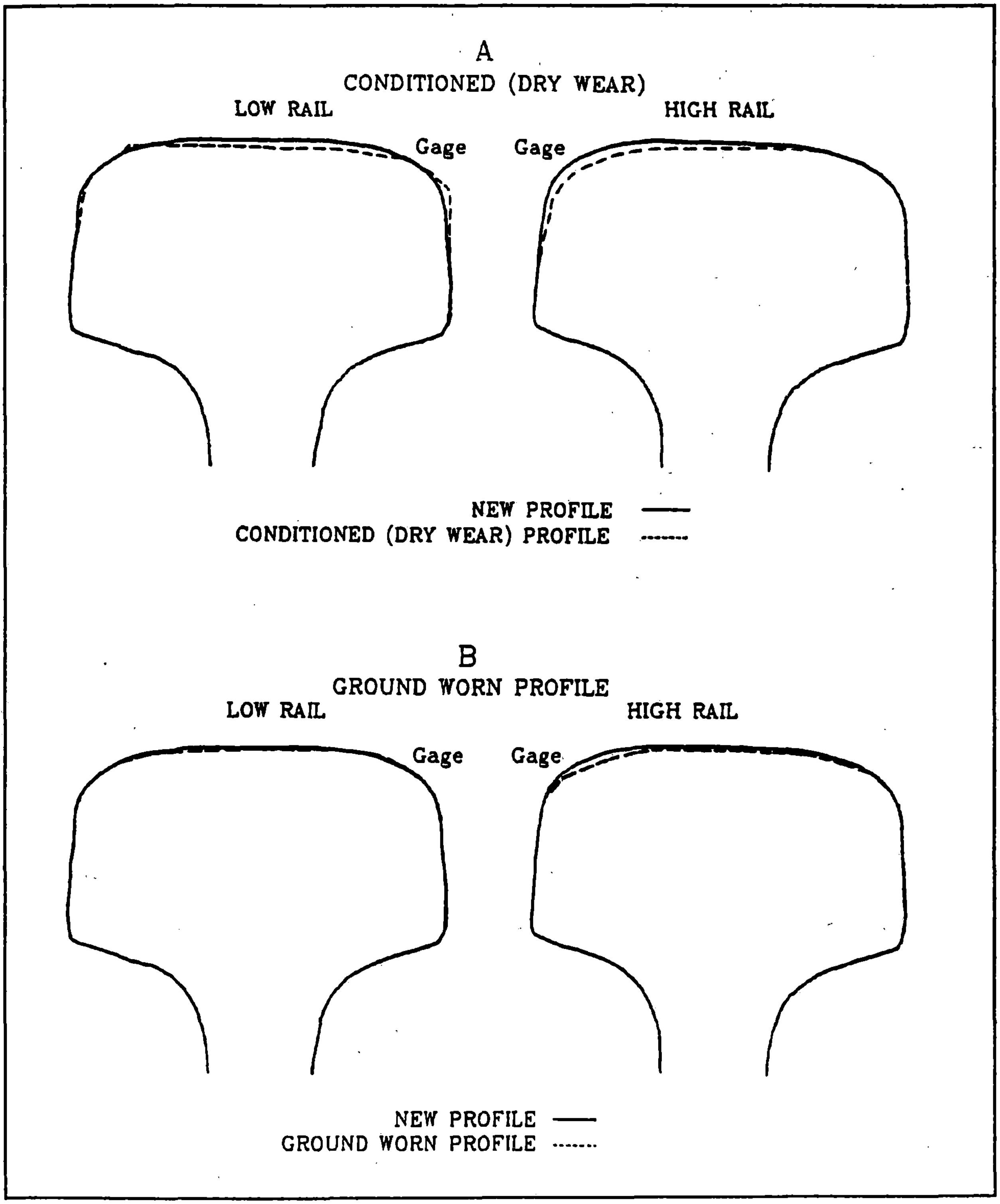


Figure 4a. Dry Wear and Ground Worn Profiles

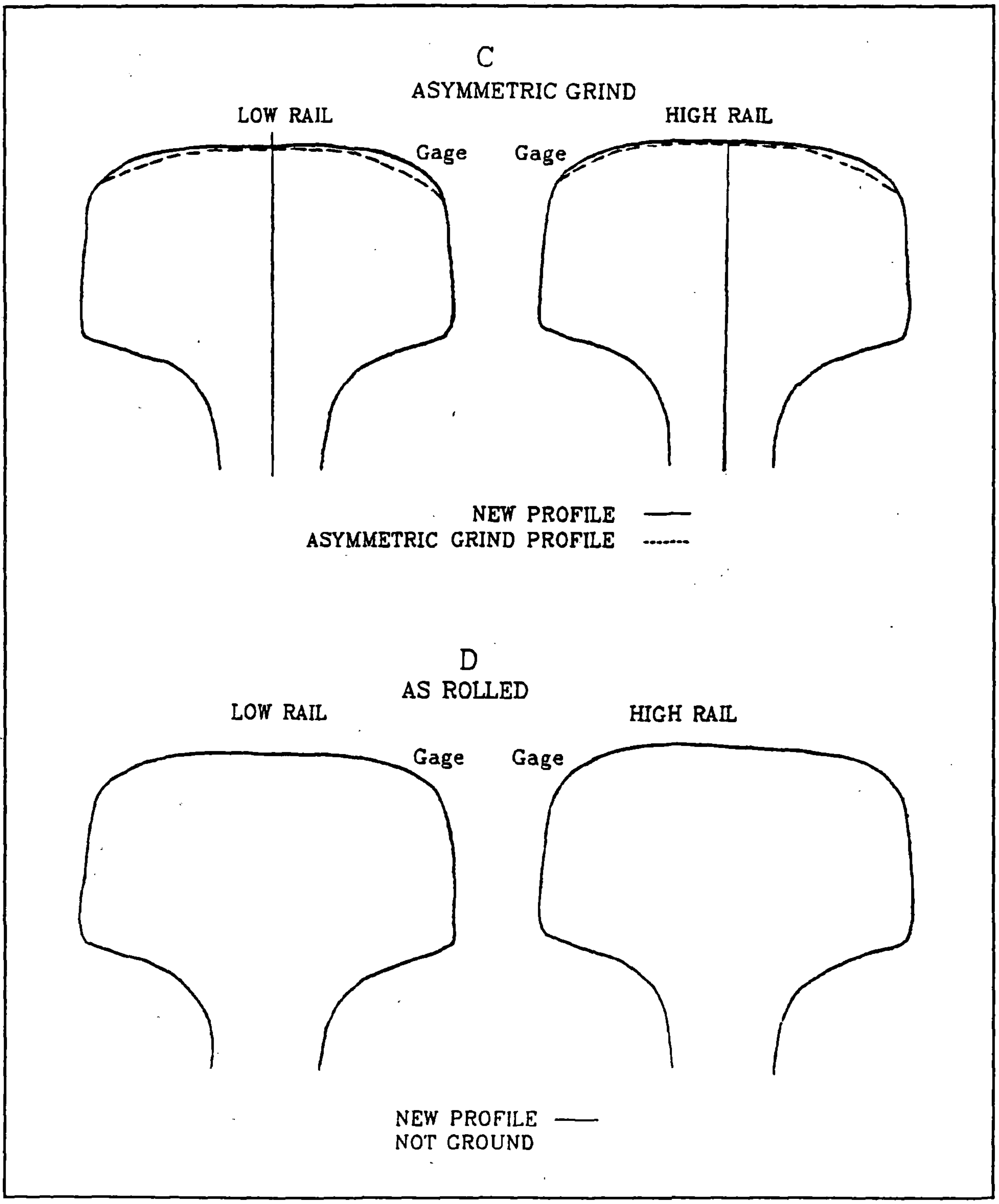


Figure 4b. Ground Asymmetric and As Rolled Profiles

Table 1. Traffic Accumulation Levels at which Rail in Section 25 was Ground

*SUBSECTION A CONDITIONED DRY WEAR		SUBSECTION B GROUND WORN PROFILE		SUBSECTION C ASYMMETRIC GRIND		SUBSECTION D AS ROLLED	
INSIDE	OUTSIDE	INSIDE	OUTSIDE	INSIDE	OUTSIDE	INSIDE	OUTSIDE
		01/10/89 0 MGT	01/10/89 0 MGT	01/10/89 0 MGT	01/10/89 0 MGT		
05/05/89 27 MGT	05/05/89 27 MGT	05/05/89 27 MGT	05/05/89 27 MGT	05/05/89 27 MGT	05/05/89 27 MGT		
06/15/89 47 MGT	06/15/89 47 MGT	06/15/89 47 MGT	06/15/89 47 MGT	06/15/89 47 MGT	06/15/89 47 MGT		
09/29/89 75 MGT	09/29/89 75 MGT	09/29/89 75 MGT	09/29/89 75 MGT	10/03/89 75 MGT	10/03/89 75 MGT		
10/27/89 84 MGT		10/27/89 84 MGT		10/27/89 84 MGT		10/27/89 84 MGT	
	01/24/90 97 MGT		01/24/90 97 MGT	01/25/90 97 MGT			
				02/08/90 104 MGT			
	03/01/90 116 MGT		03/01/90 116 MGT	02/27/90 114 MGT			
				04/05/90 138 MGT			

* Rail in Subsection "A" was subjected to 15 MGT more than shown.

4.0 RESULTS AND DISCUSSION

At zero MGT lubricated operation, Subsections B and C were ground to their respective profiles. Subsection A was not ground at this time. Subsection B was ground to match the dry worn profile of Subsection A. Subsection A had already seen 15 MGT of dry service and head checking had developed on the gage corner of the rail head. The head checking could be considered heavy, but no signs of gage corner spalling were yet detected. At 27 MGT of lubricated operation, profiles in Subsections A and B were both ground as scheduled. The grinding rate was predetermined to remove approximately 0.50 mm (0.020") of metal from the rail head at each grinding interval. Because of the limited capacity of the rail grinder this was not totally achieved and at most 0.25 mm (0.010") was removed. At the second grinding interval (27 MGT), light head checking was detected on the gage corner of Subsection B, and gage corner spalling had already developed in Subsection A. The asymmetric profile in Subsection C had worn away at 27 MGT and also required grinding at this time.

Profiles in Subsections A and B were ground at 47 and 75 MGT and followed thereafter in accordance with the 20-25 MGT grinding interval cycle. The asymmetric profile (C) also required grinding at these same intervals. Although the low rails in Subsection C required several more grinds during the duration of the test, the high rail was not ground again after 75 MGT as it kept its profile throughout the entire test up to 145 MGT. Table 1 gives the grinding intervals required for the four subsections.

Table 2 lists the shell and detail fracture defects as they occurred during the test. The shell defects did not occur until 83 MGT at which time one was detected in the ground worn profile. Four additional shells were reported in Subsection B at 123 MGT. At 143 MGT, 10 shell defects occurred in the rails in Subsection B. Three shells were detected at 143 MGT in the "as rolled" rails in Subsection D. The one shell located near tie 1017 in Subsection D may have formed as a result from being located near a bolted huck joint. The conditioned dry worn profile in Subsections A and the ground asymmetric did not initiate shells throughout the 143 MGT of testing.

Detail fractures were detected only in the ground asymmetric rails (C). The first detail fracture occurred at 75 MGT and a total of 13 occurred by 134 MGT.

Table 2. Size and Occurrences of Shell and Detail Fracture Defects

Shell Defects

SUBSECTION OUTSIDE RAIL	67 MGT	83 MGT	91 MGT	101 MGT	123 MGT	143 MGT
PROFILE B:						
25-0744	-	-	-	-	-	2.25"
25-0746	-	-	-	-	-	1.75"
25-0751	-	-	-	-	0.50"	0.50"
25-0777	-	-	-	-	-	1.00"
25-0789	-	-	-	*SPIKE	0.50"	1.00"
25-0811	-	-	-	-	-	1.50"
25-0812	-	0.50"	0.50"	0.50"	1.00"	1.25"
25-0813	-	-	-	-	0.50"	0.50"
25-0823	-	-	-	-	0.50"	REMOVED
PROFILE D:						
25-1008	-	-	-	-	-	1.25"
25-1011	-	-	-	-	-	3.00"
25-1017	-	-	-	-	-	JNT 0.25"

* Indication to small for measurement.

Detail Fractures

SUBSECTION OUTSIDE RAIL	MGT DISCOVERED	TD % (FIELD)	MGT REMOVED	TD % (LAB)
PROFILE C:				
25-0921	75.2	10	79.3	36.1
25-0914	112.9	26	112.9	19.2
25-0905	112.9	3	123.4	15.9
25-0911	122.6	3	123.4	12.1
25-0906	122.6	3	123.4	8.8
25-0899	128.5	3	134.5	12.8
25-0875	134.5	9	134.5	7.6
25-0876	134.5	15	134.5	11.2
25-0879	134.5	3	134.5	3.0
25-0882	134.5	32	134.5	21.7
25-0883	134.5	30	134.5	26.7
25-0884	134.5	9	134.5	9.0
25-0903	134.5	9	134.5	11.0

All rails used in the grinding experiment were manufactured from the B and C portion of ingot steel (Figure 3). Most of the detail fractures and shells that occurred were in the test rails that were manufactured from the B portion of the ingot. Rails manufactured from the C portion of the ingots formed very few defects (only 3 shells). On occasion, if impurities and oxide inclusions are not removed properly during the steel making process, concentrations of inclusions will generally be located near the top of the ingot where the B rails are manufactured. C rails are manufactured farther down into the ingot and generally are less apt to contain the high concentrations of inclusions found in B rails. As a result, rail cleanliness may be confounding the experiment. After the next phase of the HAL, the rails will be tested for metallurgical cleanliness in all of the test rails. It's possible rails that formed the high number of defects contained dense clusters of oxide inclusions. It's also possible the rails in the ground worn profile if properly ground before 47 MGT, may have delayed the formation of shell defects to beyond 123 MGT.

5.0 CONCLUSIONS

Rail cleanliness, at this time, is a big unknown and it's possible that this may have significantly affected the fatigue performance of the ground rails. With this in mind the following observations were made.

- Asymmetric profiles in Subsection C may have suppressed shell defects, but did not prevent the formation of detail fractures.

- Ground replicated worn profiles in Subsection B may have prevented the formation of detail fractures, but did not suppress shelling.

- Initial dry service exposure with subsequent grinding prohibited the formation of fatigue defects.

6.0 RECOMMENDATIONS

1. Continue grinding experiment into second phase of HAL.

2. Examine the effect of different grinding intervals and grinding rates.

3. Perform metallurgical inspection and analysis of samples removed from test to determine if rail cleanliness differences between Subsections A-D did exist and possibly influenced rail defect occurrences.

PART IV - RAIL WELD PERFORMANCE

1.0 BACKGROUND

In the past decade, the railroad industry in the United States has seen electric flash butt welding refined to a point where it has become the standard practice for welding rails into long continuous strands. As is commonly known, in standard carbon rails the mechanical strength of a flash butt weld will generally approach that of the rail base metal. Alloy rails can now be welded with a great deal of confidence whereas 10 years ago alloy welds were not entirely dependable and on many occasions ended up as service failures. Flash butt welds in head hardened rails can now be air quenched to a hardness similar to that of the rail thereby minimizing differential wear and maintaining a smoother running surface.

Flash butt welding is not always possible and rails sometimes must be joined by other means. Strands of continuous welded rails (CWR) once delivered to their field locations are usually joined together with thermite welds. In the past, mechanical joint bars were used to join CWR but could not provide adequate stiffness required for maintaining a smooth running surface. The low cost of thermite welds as well as the minimum labor and track time required to make a thermite weld makes them very desirable as a means to join rails. At FAST, thermite welding is not only used to join CWR, but also becomes necessary when installing rail plugs. It is also used as a tool to replace rail fatigue defects in rails.

In the early 1970's portable flash butt welding systems were introduced to the United States and Europe as another means to perform rail welding in the field.[2] Generally, welds made with this system perform similar to welds that have been welded with fixed (in-plant) systems.

2.0 OBJECTIVES

The primary objective of this test was to evaluate the service performance thermite and flash butt welds under 39-ton axle loads and to compare this performance with performance results of welds under 33-ton axle loads. The performance criteria for the welding test included one or more of the following:

A. Fatigue Defects

1. Shelling
2. Detail Fractures

3. Horizontal Split Webs
4. Base Failures
5. Vertical and Horizontal Split Heads

B. Wear

1. Rail End Batter
2. Surface Spalling

3.0 PROCEDURES

3.1 OPERATING PROCEDURES

The weld test was conducted at FAST on the High Tonnage Loop (HTL). The HTL is a 2.7 mile test track (shown in Figure 1). The outside rail of the HTL is lubricated wayside near the entrance of Section 25. The outside rail constitutes the high rails of Sections 25 and 03 and the low rail of Section 07. Rail/weld wear is suppressed in lubricated areas but fatigue occurrence is amplified. Therefore, any rail/weld failures in the high rails of Sections 25 or 03 were usually due to fatigue, while rail/weld wear was the predominate degradation factor in the high rail of Section 07. Section 07 is traditionally a non-lubricated curve where welded rail end batter and rail wear testing is done.

This test accumulated 145 MGT of 39-ton axle load. All welds installed in the HTL would have been exposed to this much service unless removed due to weld failure or failure of the rail surrounding the weld.

3.2 WELD TESTING PROCEDURES

3.2.1 Longitudinal Rail Profiles

Longitudinal rail profiles (LRP's) were taken on selected electric flash butt welds in the 5-degree curve in Section 07. Strip charts generated from the LRP's were overlaid to calculate welded rail end batter rates. Welded rail-end batter rates are expressed as the loss of surface (inches) per one MGT, or inches/MGT.

3.2.2 Weld Database

All new welds installed in the HAL test were monitored. Records were kept for installation date, failure type and date of failure if applicable, and accumulated tonnage. The records were logged into a database which was used to determine failure rates of welds at particular accumulated tonnages.

3.2.3 Weld Installation

Three types of welds were installed for this test: thermite welds, electric flash butt welds (EFBW), and portable electric flash butt welds (PEFBW). At the beginning of 39-ton axle load testing, there were approximately 85 thermite welds located throughout the HTL. Forty of these were new welds installed at the start of 39-ton testing and were used to join individual test rails to CWR in the test curves of Sections 03, 07, and 25. The remainder of the welds were either "used with unknown service history" or "new welds outside of the test zones." Fatigue data was collected on all welds in the HTL for purposes of generating a data base.

The weld chemical compositions and the procedures used for making standard thermite welds during the beginning of the 39-ton axle load test were the same as those used during the 33-ton axle load Defect Occurrence and Growth Test (DOG).[3] These identical procedures allow for performance result comparisons between the welds under the two axle loads. Later into the 39-ton axle load test, thermite welds were made using a new alignment procedure as directed by Orgo-Thermit, Inc. and the height of the weld crown was changed. These new weld procedures precluded weld performance comparisons with the previous 33-ton axle load test. Also, four new alloy thermite welds were installed in Section 03 and were tested independent of the standard welds.

Electric flash butt plant welds installed in Sections 03, 25, and 07 at the start of 39-ton axle load testing joined together a variety of standard carbon 300 Bhn rails and head hardened rails. A selected number of the head hardened welds were air quenched at the request of the rail manufacturers. EFBWs were only monitored for the required fatigue database information with the exception of test welds installed in Section 07, which were also tested with the LRP machine to measure their resistance to welded rail end batter.

Portable electric flash butt welds were also installed and LRP tested in section 07 (5-degree curve). A portable alternating current (AC) welder performed a number of welds in rails for testing. Existing strands of in-plant continuously welded 39 ft. rail were cut at selected 19-foot 6-inch centers of the rails and portable electric flash butt welds were installed. Every other weld in the CWR strand was a portable flash butt weld. This manner of weld layout allowed for direct comparisons between plant and portable weld performance.

4.0 RESULTS AND DISCUSSION

4.1 THERMITE WELDS

Particular close attention was paid to the new standard thermite welds installed in the four test curves, Sections 03, 07, 25, and 31. This was done in order to allow fatigue failure results to be compared to the previous DOG test results in which only welds in curves were monitored. Figure 1 illustrates the location of the forty new welds in the HTL as well as which welds had failed by 65 MGT. Tables 1A and 1B list the weld locations along with other information including: weld kit mold size and type (standard portion unless otherwise noted), rail section and metallurgy, rail temperature taken during the welding operation, and the type and MGT of the failure, if applicable. The table is divided in two parts: (1A) welds installed in high rail of curves, and (1B) welds installed in low rails of curves. Twenty-two of the initial 40 welds were installed in 5- and 6-degree curves in the high rails, with 20 of these being standard portion welds. The remaining 18 were in low rails of curves, with 16 of these being standard portion.

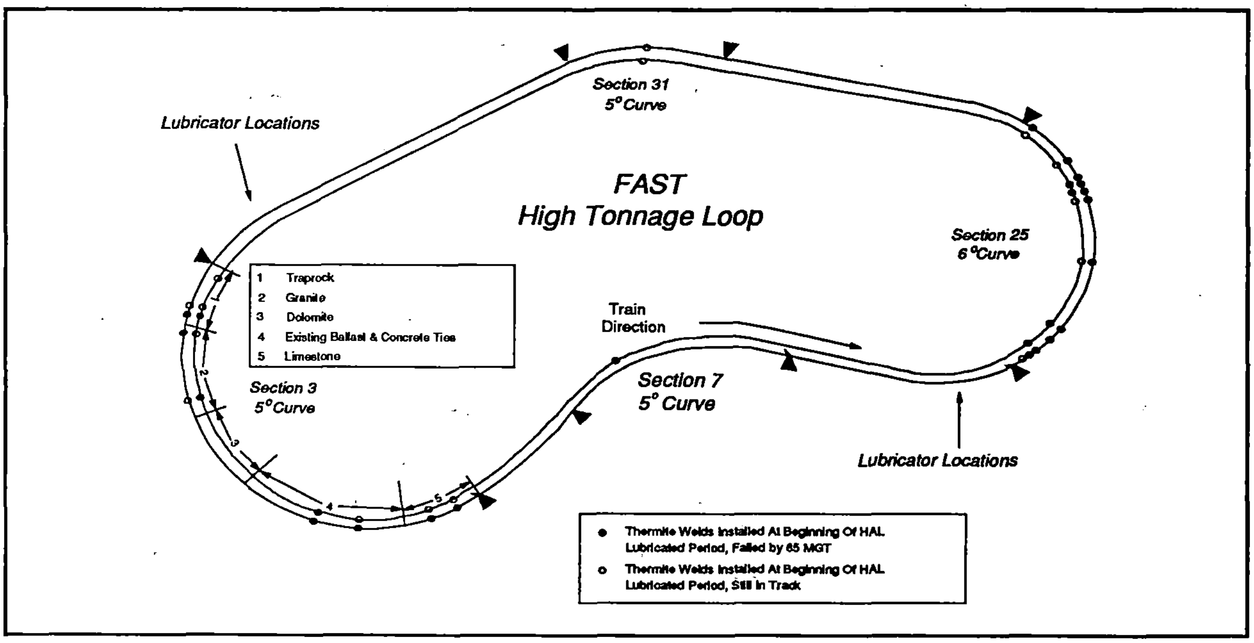


Figure 1. Location of Thermite Welds on FAST Track

Table 1A. Thermite Welds Installed in the High Rail of Curves at the Beginning of 39-Ton Axle Load Lubricated Testing

HTL SEC-TIE	KIT TYPE	RAIL METALLURGY	RAIL TEMP	FAILURE MODE	WELD MGT
03-0269	132/136	136 STD/132 STD	72	Detail Fracture	81.7
03-0316	136	132 STD/132 STD	67	Web Crack	41.2
03-0362	132/136	132 STD/136 STD	66	Base Crack	36.3
03-0743	136	132 HH/132 HH	50	Shelled	143.9
03-1536*	132 ALLOY	132 HH/132 HH	65	Web Crack	12.9
03-1674	136	136 HH/136 HH	42	Shelled	36.3
03-1859*	132 ALLOY	132 HH/132 HH	65	Web Crack	10.6
03-1995	136	132 HH/132 HH	-	Web Crack	45.2
07-0170	136	132 HH/132 HH	67	Web Crack	36.2
25-0046	136	132 STD/132 STD	45	Shelled	71.2
25-0070	132/136	132 STD/136 STD	55	Shelled	71.2
25-0093	132/136	136 STD/132 STD	58	Shelled	64.1
25-0182	136	132 STD/132 AHH	54	Shelled	29.2
25-0320	136	136 HH/140 STD	40	Web Crack	76.4
25-0726	136	133 STD/133 STD	52	Shelled	50.1
25-1134	132/136	132 STD/136 HH	39	Web Crack	22.4
25-1178	132/136	136 HH/132 STD	40	Web Crack	56.4
25-1225	136	132 STD/132 STD	60	Shelled	58.8
25-1249	132/136	132 STD/136 STD	66	Shelled	58.8
25-1332	136	136 HH/136 STD	40		143.9
25-1618	136	132 HH/132 FHT	72	Shelled	55.5
31-0251	136	132 STD/132 HH	87	Detail Fracture	56.2

20 standard welds were installed in high rail of curves, 14 failed by 65 HAL MGT, and 19 were removed or had defects by 144 MGT.

* Alloy welds were not included in failure rate calculations.

Table 1B. Thermite Welds Installed in the Low Rail of Curves at the Beginning of 39-Ton Axle Load Lubricated Testing

HTL SEC-TIE	KIT TYPE	RAIL METALLURGY	RAIL TEMP	FAILURE MODE	WELD MGT
03-0079	132/136	133 STD/136 STD	-	Detail Fracture	143.9
03-0268	132/136	136 STD/132 STD	77	Shelled	143.9
03-0315	136	132 STD/132 STD	79		143.9
03-0363	132/136	132 STD/136 STD	75	VSH, Shelled	143.9
03-0745	136	132 HH/132 HH	-	Batter	48.8
03-1537**	132 ALLOY	132 HH/132 HH	65	Web Crack	22.4
03-1677*	136	136 HH/136 HH	-		84.4
03-1858**	132 ALLOY	132 HH/132 HH	72	Web Crack	94.9
03-1998	136	132 HH/132 HH	-	Web Crack	80.4
25-0101	136	132 STD/132 STD	52		143.9
25-0343	136	136 HH/140 STD	72	Shelled	143.9
25-0751	136	133 STD/133 STD	63	Web Crack	94.5
25-1161	132/136	132 STD/136 HH	-	Detail Fracture	143.9
25-1206	132/136	136 HH/132 STD	33	Battered	65.0
25-1255	136	132 STD/132 STD	44	Web Crack	94.9
25-1364	136	136 HH/136 STD	54	Shelled	143.9
25-1653	136	132 HH/132 FHT	40		143.9
31-0265	136	132 STD/132 HH	89	Shelled	56.2

16 standard welds installed in low rail of curves, 3 failed by 65 HAL MGT, and 12 were removed or had defects by 144 MGT.

* Weld was removed because of rail maintenance.
** Alloy welds were not included in failure rate calculations.

Of the initial 20 standard welds installed in the high rails of curves, 14 of these failed by 65 MGT. By 144 MGT, 19 of the original 20 welds in the high rails were removed or had defects. The dominant modes of failure were web cracks and shelling. Although the shell defects did not cause catastrophic fracturing of the welds, they did require a cessation of operation of the FAST train to allow time for repair or removal of the weld. Repair of shelled welds usually involved 1-2 hours (depending on the severity of the shell) using electric arc weld repair. Usually immediate response was taken in the repair or removal of shells found in welds as rapid deterioration of the gage side of the rail head would occur under heavy axle loads. Of the 16 original welds installed in the low rails, three failed by 65 MGT. Twelve were removed or had defects by 144 MGT. Again, web cracks and shelling failures were the primary cause for removal.

Table 2 lists welds that were installed at the start of 33-ton axle load testing and also gives the failure type and accumulated tonnage at failure if applicable. The thermite weld population was small because most of the test rails in during the 33-ton axle load test were flash butt welded. Thermite weld test records for the 33-ton axle load testing are available up to 65 MGT, therefore, comparisons can only be made with 39-ton axle load up to this accumulated tonnage.

Table 2. Section 25 and 03 - Thermite Welds Installed at the Beginning of 33-Ton Axle Load Lubricated Testing

HIGH RAIL

HTL SEC-TIE	RAIL METALLURGY	FAILURE MODE	WELD MGT
03-0702	132 STD/136 STD		
03-0820	136 STD/136 STD	Shelled	65.0
03-0967	136 STD/132 STD		
25-0340	136 STD/136 STD		
25-0679	136 HH/136 STD		
25-0846	136 STD/136 STD	Shelled	56.0
25-1562	136 HH/136 STD		

7 Welds installed in high rail of curves; 2 failed by 65 MGT

LOW RAIL

SEC-TIE	RAIL METALLURGY	FAILURE MODE	WELD MGT
03-0700	132 STD/136 STD		
03-1150	136 HH/132 STD		
25-0098	132 STD/136 STD		
25-0328	136 STD/136 STD		
25-0846	136 STD/136 STD		
25-1616	136 STD/136 STD		

6 welds installed in low rail of curves; 0 failed by 65 MGT

One of the four high rail welds failed before 65 MGT in Section 25, while in Section 03, one out of three failed. No welds failed in the low rails of Sections 03 or 25 during the 33-ton axle load test.

4.2 ELECTRIC FLASH BUTT WELDS - FATIGUE

Approximately 195 new electric flash butt test welds were installed at the start of the 39-ton axle load lubricated testing in Section 03 (5-degree curve) and Section 25 (6-degree curve). Layouts illustrating the locations and rail metallurgies that the welds joined are shown in Figures 2 and 3. Of the 195 welds, 100 were in the high rail and 95 were in the low rail.

At the end of 145 MGT of testing, five welds failed in the high rails of Section 03 and 25 (five percent), while six failed in the low rails (four percent). Horizontal web cracks accounted for the bulk of weld failures. Table 3 lists the types of failures and the million gross tons at which the weld failures occurred.

Flash butt weld failures during the 33-ton axle load test can be seen in Table 4. A total of 175 flash butt welds were tested in Sections 03 and 25 at the start of the 33-ton axle load test, 91 welds were in high rails and 84 were in low rails. At the end of 160 MGT of lubricated testing, three high rail welds had failed (three percent) and three of the low rail welds had failed (four percent). Transverse defects and horizontal web cracks were responsible for most plant weld failures during 33-ton testing.

For both 5- and 6-degree curves, increasing the axle load from 33- to 39-tons increased the failure rate by 67 percent in the high rail welds and by 50 percent in the low rail welds.

4.3 WEAR OF ELECTRIC FLASH BUTT WELDS - (PORTABLE AND SHOP)

Fourteen portable electric flash butt welds along with 26 flash butt shop welds were tested in the 5-degree curve of Section 07. The high and low rail welds installed in Section 07 are listed in Tables 5A and 5B respectively. Also listed in the tables are: rail metallurgy; weld test location; the tonnage accumulated during 39-ton axle load testing; weld batter which occurred during that accumulated tonnage; and weld batter rate. Batter rates are determined by dividing the batter depth by the weld's service MGT. The top half of each table lists 8 welds that were exposed to 33-ton axle load testing and were carried over and exposed to 55.5 MGT of the 39-ton axle test. The bottom half of the table lists the portable and shop welds that were installed in Section 07 at 75 MGT of the 39-ton axle load test. Since no welds of this type were tested during the DOG test, comparisons cannot be made between weld performance under 33- and 39-ton axle loads.

The CWR strands containing the portable and shop welds were installed at 75 MGT of 39-ton axle load testing and currently have accumulated 67 MGT of testing. Some of the welds were air quenched and are designated with an asterisk in the tables.

The 8 high rail welds which had previous 33-ton axle load exposure tend to exhibit higher batter rates than the welds installed during 39-ton axle load testing. At the beginning of 39-ton axle load testing, batter already existed from 33-ton axle loads. Since batter accelerates with increased batter depth, the rates were naturally higher in this rail.

The low alloy in-line head hardened welds (1500 series) were installed at the start of 39-ton axle load testing and remained throughout the entire test. One of the low alloy welds (1506), in the high rail, developed a horizontal web crack and was removed at 136 MGT.

Six of the portable welds were mixed together with shop welds in standard 300 Bhn and induction head hardened CWR strands. Data in Table 5A suggests portable flash butt welds in standard carbon rail battered at rates slightly less than that of shop welds. The data also shows post weld air quenching of portable welds is beneficial in the induction head hardened high rails. The non-air quenched welds battered at rates two times higher than air quenched welds. Low alloy head hardened (AHH) 370 Bhn and standard head hardened (THH) 370 Bhn portable welds batter at similar rates (.0003 in. per MGT) in high rails.

In the low rail welds, batter rates were similar (approximately .0001"/MGT) for standard 300 Bhn, standard carbon induction head hardened, and THH 370 head hardened rails. Air quenching portable welds offered no benefits in low rail induction head hardened and THH 370 welds. Low alloy AHH 370 and low alloy HH (in-line) welds showed minimal batter rates. The low rail shop welds that was air quenched showed no benefits from air quenching.

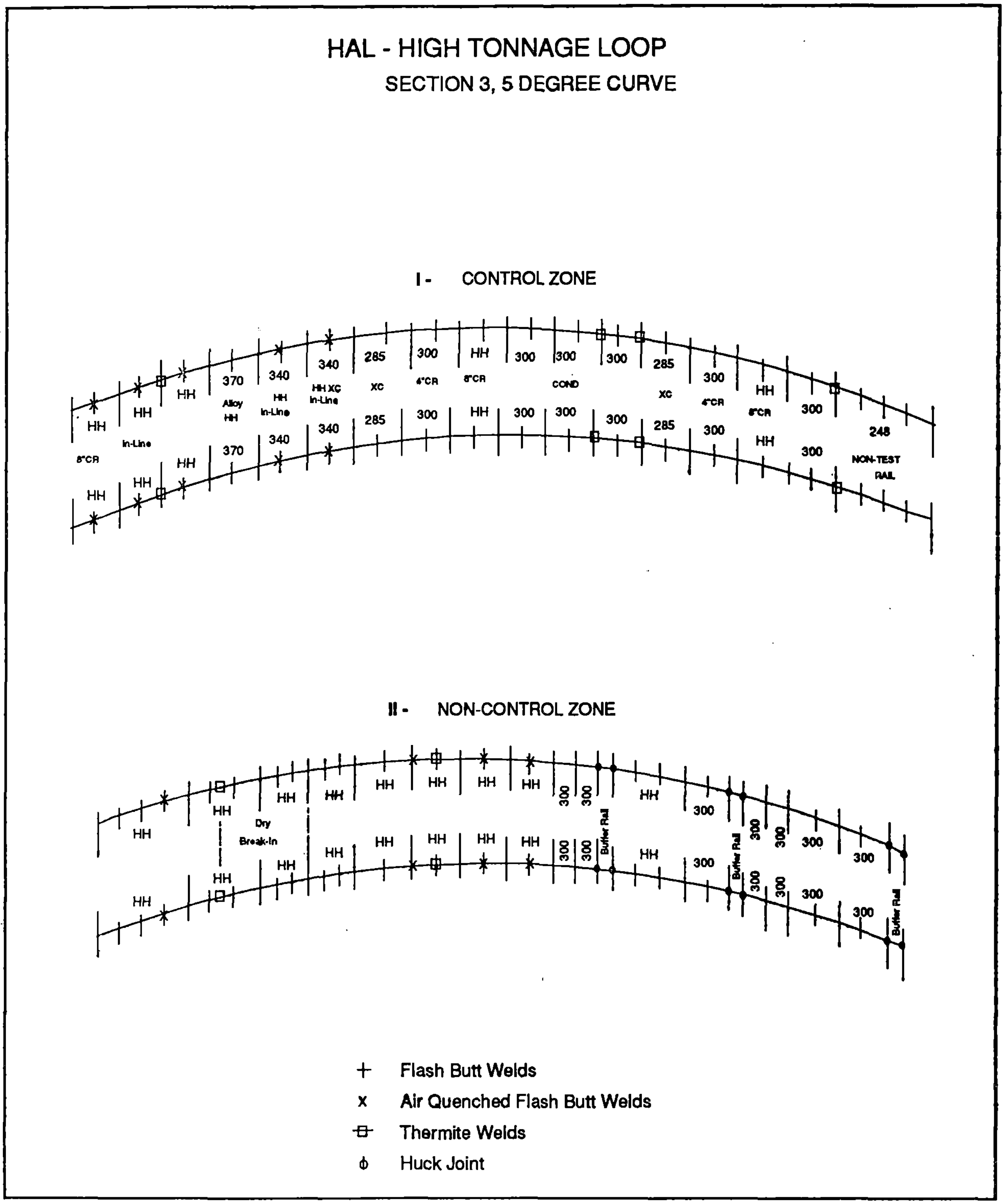


Figure 2. Weld Locations and Rail Metallurgies

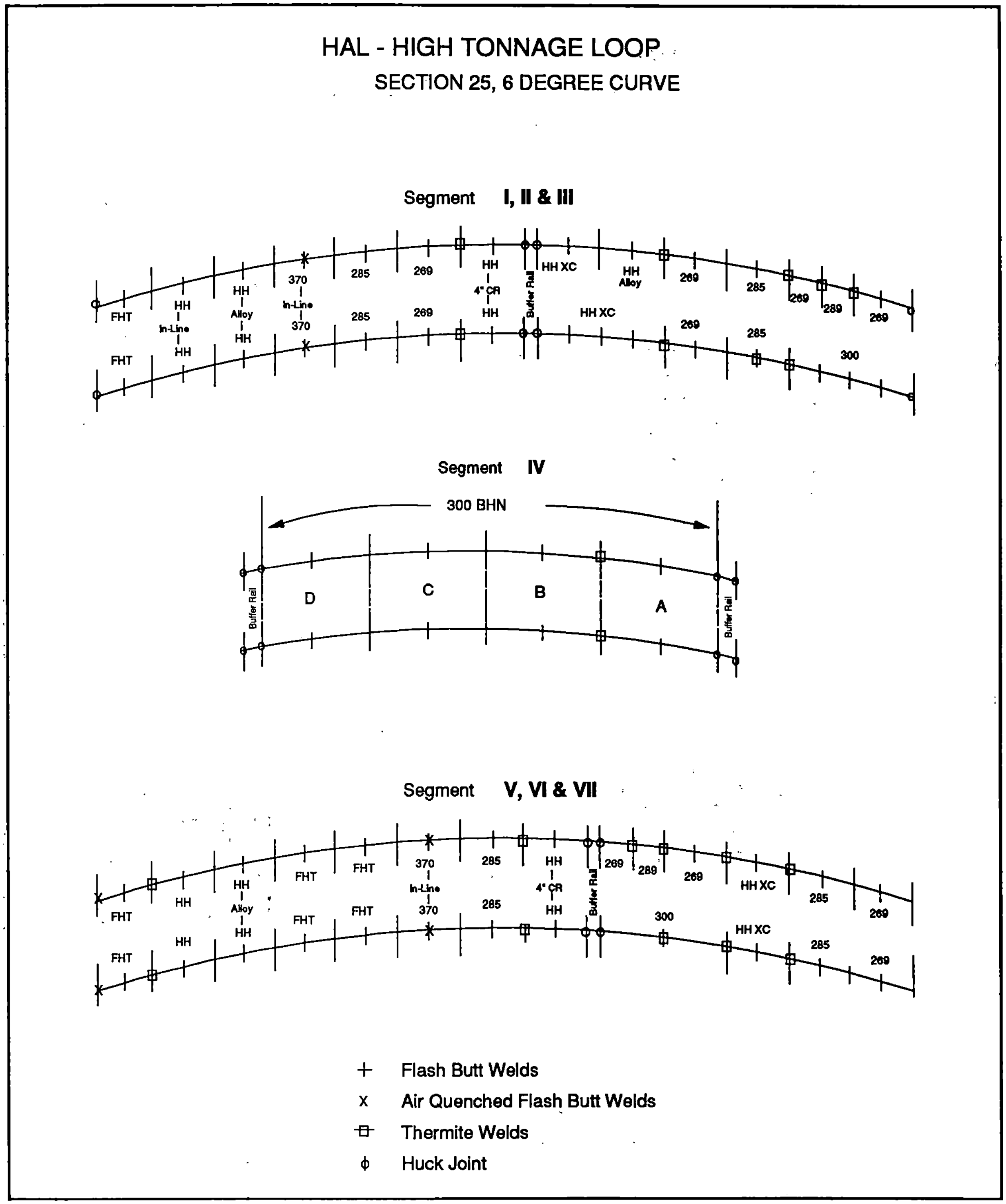


Figure 3. Weld Locations and Rail Metallurgies

Table 3. Failed Plant Welds 39-Ton Axle Load

HIGH RAIL

SEC-TIE	RAIL METALLURGY	FAILURE MODE	WELD MGT
03-0624	136 HH 340/136 HH 340	VERT SPLIT HEAD	140.6
03-0791	132 HH/136 HH	WEB CRACK	55.5
03-1516	132 HH/132 HH	WEB CRACK	99.3
25-1476	136 FHT/132 FHT	WEB CRACK	81.7
25-1548	132 AHH/132 AHH	WEB CRACK	121.3

100 Welds installed in high rail, 5 failed by 145 MGT

LOW RAIL

SEC-TIE	RAIL METALLURGY	FAILURE MODE	WELD MGT
03-0698	136 HH 340/132 HH	TD	103.2
03-1058	132 STD/132 STD	WEB CRACK	100.5
25-0053	132 HH 300/132 HH 300	UNKNOWN	91.2
25-1509	136 FHT/132 FHT	TD 20%	45.2
25-1533	132 FHT/132 FHT	TD 22%	138.2
25-1558	132 FHT/132 AHH	WEB CRACK	85.5

95 Welds installed in low rail, 6 failed by 145 MGT

Table 4. Failed Plant Welds 33-Ton Axle Load

HIGH RAIL

SEC-TIE	RAIL METALLURGY	FAILURE MODE	WELD MGT
03-0777	136 STD/136 STD	TD 41%	
25-1583	136 STD/136 STD	TD 22%	
25-0679	136 STD/136 NHH	SHELL	62.0

91 Welds installed in high rail, 3 failed by 160 MGT

LOW RAIL

SEC-TIE	RAIL METALLURGY	FAILURE MODE	WELD MGT
03-0810	136 STD/136 STD		
03-0906	132 STD/132 STD	WEB CRACK	94.0
25-0473	136 STD/132 STD	BATTERED	56.0

84 Welds installed in low rail, 3 failed by 160 MGT

Table 5A. Electric Flash Butt Welds in Section 07, 5-Degree Curve

HIGH RAIL

METALLURGY	TEST LOCATION	WELD TYPE	TOTAL MGT	BATTER DEPTH (IN.)	BATTER RATE (IN/MGT)
INDUCTION HH	1113	SHOP	55.51		0.0006
	1115	SHOP	55.51		0.0008
	1117	SHOP*	55.51		0.0003
	1121	SHOP*	55.51		0.0002
370 DHH	1309	SHOP	55.51		0.0003
	1311	SHOP	55.51		0.0001
370S DHH	1409	SHOP	100.00	0.0160	0.0002
	1414	SHOP	100.00	0.0310	0.0003
LOW ALLOY HH (IN-LINE)	1502	SHOP	139.00	0.0330	0.0002
	1506	SHOP*	136.00	0.0020	0.00001
300 Bhn	1705	PORTABLE	67.40	0.0000 **	
	1711	SHOP	67.40	0.0350	0.0005
INDUCTION HH	1805	SHOP	67.40	0.0240	0.0004
	1809	PORTABLE	67.40	0.0160	0.0002
	1813	SHOP	67.40	0.0220	0.0003
	1817	PORTABLE*	67.40	0.0040	0.0001
THH 370	1905	PORTABLE	67.40	0.0180	0.0003
	1911	PORTABLE*	67.40	0.0140	0.0002
LOW ALLOY AHH 370 (OFF-LINE)	2005	PORTABLE	67.40	0.0270	0.0004
	2011	PORTABLE	67.40	0.0140	0.0002

* AIR QUENCHED WELD
** INVALID BECAUSE OF METAL FLOW

Table 5B. Electric Flash Butt Welds in Section 07, 5-Degree Curve

LOW RAIL

METALLURGY	TEST LOCATION	WELD TYPE	TOTAL MGT	BATTER DEPTH (IN.)	BATTER RATE (IN/MGT)
INDUCTION HH	1116	SHOP	56.41		0.0002
	1118	SHOP	56.41		0.0001
	1119	SHOP*	56.41		0.0001
	1123	SHOP*	56.41		0.0002
370 DHH	1310	SHOP	56.41		0.0000
	1312	SHOP	48.81		0.0002
370S DHH	1412	SHOP	100.00	0.0160	0.0002
	1415	SHOP	100.00	0.0100	0.0001
LOW ALLOY HH	1504	SHOP	139.00	0.0060	0.00004
(IN-LINE)	1508	SHOP*	139.00	0.0000	0.0000
300 Bhn	1704	PORTABLE	67.40	0.0040	0.0001
	1710	SHOP	67.40	0.0040	0.0001
INDUCTION HH	1804	SHOP	67.40	0.0060	0.0001
	1808	PORTABLE	67.40	0.0040	0.0001
	1812	SHOP	67.40	0.0100	0.0002
	1816	PORTABLE*	67.40	0.0060	0.0001
THH 370	1904	PORTABLE	67.40	0.0040	0.0001
	1910	PORTABLE*	67.40	0.0100	0.0001
LOW ALLOY AHH	2004	PORTABLE	67.40	0.0000	0.0000
370	2010	PORTABLE	67.40	0.0020	0.00003
(OFF-LINE)					

* AIR QUENCHED WELD

5.0 CONCLUSIONS

5.1 THERMITE WELDS

- During 33-ton axle load testing, 29 percent of welds installed in the high rails failed by 65 MGT. There were no failures in the low rails of Sections 03 and 25.

- At 65 MGT of 39-ton axle load testing, the high rail failure rate was 67 percent, while the low rail failure rate was approximately 13 percent.

- For both Sections 03 and 25 high rail thermite welds, increasing the axle loads by 20 percent (i.e. from 33-ton to 39-ton axle load) increased the failure rate by 130 percent at 65 MGT of testing.

- As of 144 MGT, 95 percent of high rail welds had failed while 75 percent of low rail welds had failed.

5.2 ELECTRIC FLASH BUTT SHOP WELDS

- During 33-ton axle load testing, the total high rail failure rate for 5- and 6-degree curves was 3 percent, while the low rail failure rate was 4 percent.

- During 39-ton axle load testing, the high rail failure rate for 5- and 6-degree curves was 5 percent while the low rail failure rate was 6 percent.

- For both 5- and 6-degree curves, increasing the axle load by 20 percent increased the failure rate by 67 percent in the high rail welds and by 50 percent in the low rail welds.

- Horizontal web cracks were the dominate mode of failures for plant welds in 39-ton axle load testing, while both transverse defects and horizontal web cracks were responsible for plant weld failures during 33-ton testing.

5.3 PORTABLE ELECTRIC FLASH BUTT WELDS

Because of the limited number of portable welds in track during 39-ton axle load testing, firm conclusions cannot be derived from such a low population of test samples and trends can only be observed after 67 MGT of service.

- Portable welds in standard induction head-hardened high rails batter at rates less than that of shop welds.

- Low rail welds made with portable and shop flash butt welds batter at nearly identical rates.

- In induction head hardened high rails, non-air quenched portable welds display batter rates two times higher than welds which were air quenched.

- Low rail portable welds show no benefits from post weld air quenching.

OVERVIEW OF THE FAST/HAL RAIL PERFORMANCE TESTS

INTRODUCTION

The current Heavy Axle Load (HAL) tests are the outgrowth of three distinct preceding rail metallurgy experiments as well as of a crack growth experiment (FASTKRAX). In addition, rail wear and defect occurrence and growth studies were undertaken under 33 kip wheel loads as part of High Tonnage Loop (HTL) operation immediately before the introduction of the 39 kip wheel loads.

The results of the rail tests from the current HAL experiment have been reported in Part I through IV of this document. The authors have utilized some data from the earlier HTL experiments to provide wheel load comparisons. The intent of this overview is to take a somewhat broader view. It will examine the results from both the HTL (33 kip wheel load) and HAL (39 kip wheel load) experiments in greater detail and in the light of what has gone before in previous FAST experiments and as the result of research elsewhere into rail performance.

BACKGROUND

In order to understand the significance of the current results from the HAL experiment as well as the research approach undertaken, a brief review of salient findings from previous experiments will prove helpful.

Previous experiments have shown that wear rate measured both as side wear at the gage face (GF) and as vertical head height loss (HHL) are inversely related to initial hardness as illustrated in Figure 1. The variation in GF from the softest (260 Bhn) to the hardest (~380 Bhn) was about 5:1. Under the FAST test conditions of unbalance (2") and curvature (5°), the GF typically was about four times greater than the HHL. Lubrication applied to the gage face of the high rail in the test curve (but with likelihood of some contamination on the running surfaces of both high and low rails) was much more effective in suppressing GF than commercially available improvements in metallurgy; reductions in GF of over 100:1 for carbon rail were achieved in the FAST experiments. But the benefit ratio diminished with increasing initial hardness of the rail steel as shown in Figure 2. The presence of effective lubrication on the gage face of the high rail, even in the presence of some contamination on the running surface of the rail, caused the ratio of GF to HHL to drop to near unity. The extremely effective levels of lubrication achievable on the FAST loop generally would not be achievable in revenue service.

The extreme success in suppressing gage face wear at FAST by lubrication was accompanied, not surprisingly, by the development of rail fatigue (shell/DF) occurrence as the cause of rail replacement. The disparate lubrication conditions of the first two metallurgy experiments (RME I, initially dry and RME II, effectively lubricated from the start) prompted the use of an operating policy consisting of lubricated running interspersed with brief periods of dry running in the next experiment (RME III); the intent was to suppress fatigue defect formation, more nearly balancing wear life with fatigue life. The attempt was apparently successful; in the same 5-degree curve only one DF developed in approximately 230 MGT of operation (RME III) compared to 15 DF's in 230 MGT in RME II (the sources and manufacturing processes of rail as well as mix of metallurgies were somewhat different from one experiment to the other). Still it was not clear whether the apparent improvement in fatigue performance had come about from the metal removal itself or by adjustment of the rail profile to a more conformal configuration, both of which were the results of having interludes of dry running.

At the same time, the three dimensional rail fatigue model, PHOENIX, was being developed. Exercise of that model suggested that head loss at a rate near 2mm/100 MGT should enhance the rail fatigue behavior. In addition, improvements in rail steel metallurgical cleanliness were predicted by the model to have a potentially large beneficial effect on fatigue behavior.

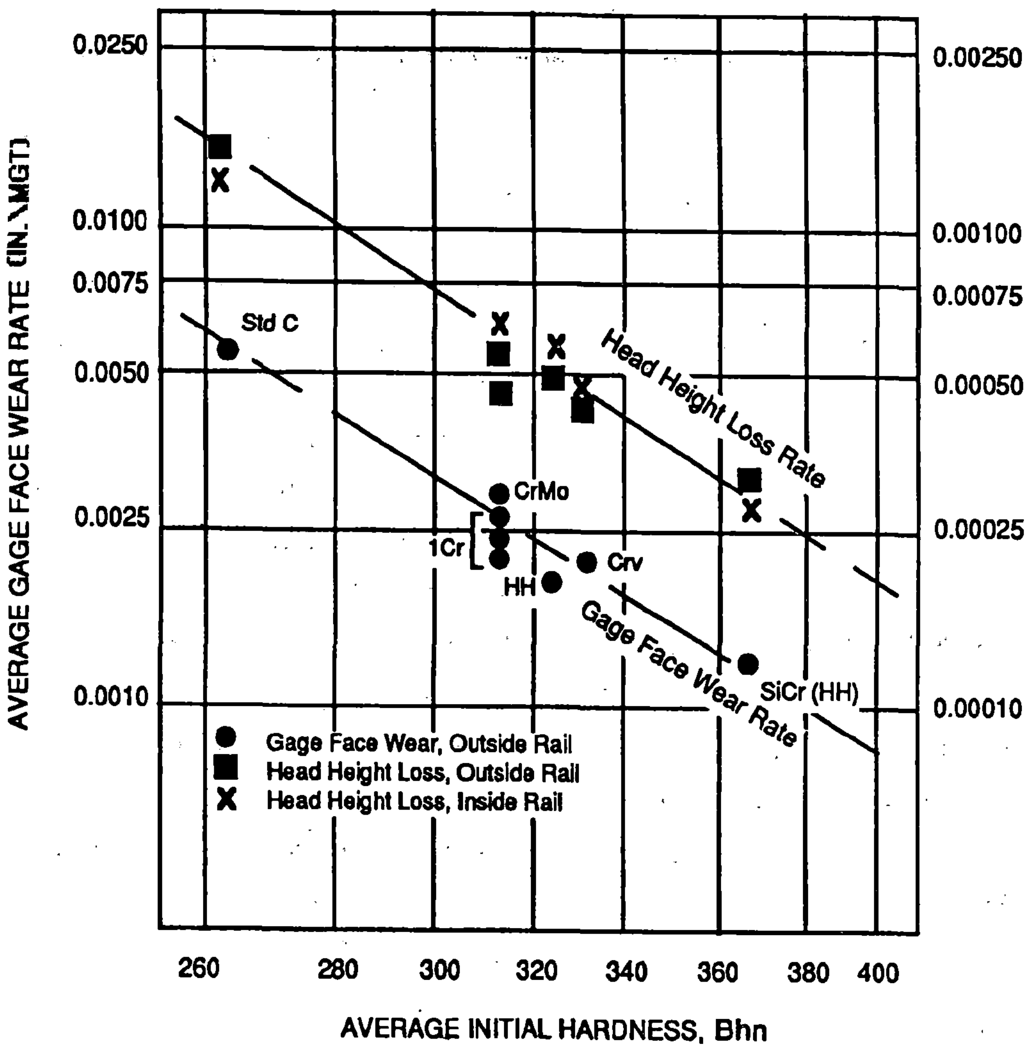


Figure 1. Average Wear Rates as a Function of Average Initial Hardness

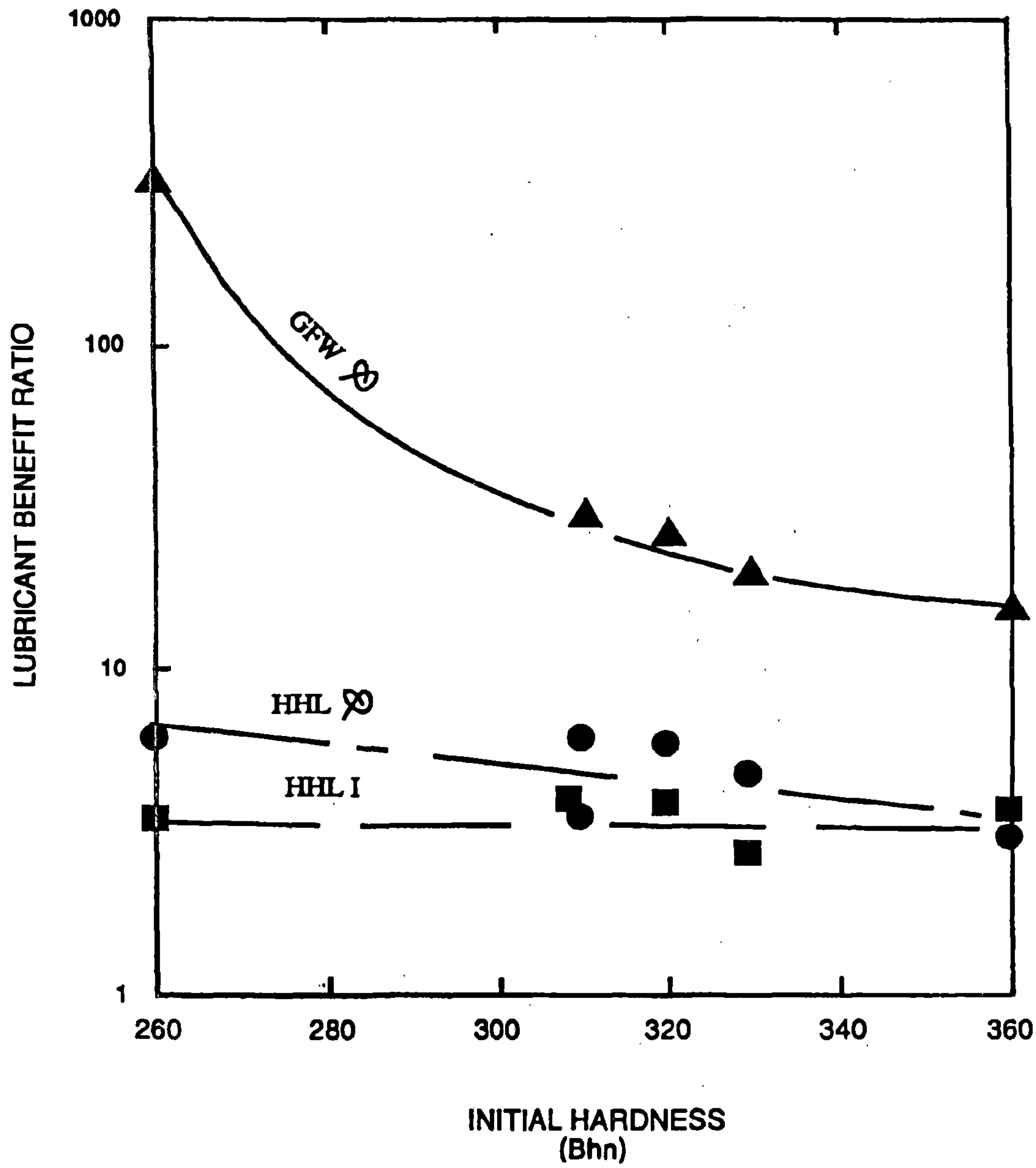


Figure 2. The Variation of Lubrication Benefit Ratio with Hardness

Thus, the focus of the next rail performance experiment was directed at continuing the evaluation of dry wear resistance for improved rail metallurgies that were becoming available commercially, and at evaluating the effects of metallurgical cleanliness and rail grinding on fatigue behavior. Perhaps, unfortunately, the occurrence of a derailment in the exit spiral of Section 25, necessitated the subsequent application of a small amount of lubricating oil to the running surface of the inside loop rail. This caused the results from Section 07 following the derailment not to be directly comparable with results obtained previously under very dry conditions.

Efforts were made to keep the same rails in test under both 33 kip and 39 kip wheel loads. In such cases, defect prone rails had to be replaced, not always in kind. New rails put into test at the introduction of the 39 kip wheel loads, but from the same heat as rails already in test, were referred to as old unused rails. In the fatigue portion of the test, comparison of rails already in test with those from the same heat introduced with the 39 kip wheel loads (old unused) allowed for some assessment of conditioning by the lighter loads.

In the 33 kip wheel load phase, rail which had been asymmetrically ground (high rail only) exhibited two features that prompted further examination in the pilot grinding test initiated at the introduction of the 39 kip wheel load. The two features were:

(a) significantly higher lubricated gage face wear rates than those of comparable rails having conformal profiles, and

(b) occurrence of bi-planar shells initiating under the unloaded portion of the gage corner (not contacted by the wheel).

The higher gage face wear rates occurring in the asymmetrically ground rail are illustrated in Figure 3 where the GF of carbon rails has been plotted against the ratio of GF to HHL. Segment A was closest to the lubricator while Segment C was at the opposite end of the curve. As lubrication effectiveness tended to diminish toward the opposite (exit) end of the curve, the GF and the ratio GF/HHL both increased. The asymmetrically ground rail exhibited GF's approximately twice as high as those observed in conformally contoured rail at the same level of GF/HHL ratio. Even so, the lubricated GF of the asymmetrically ground rail was still low, about one-fifth of that which might have been expected in the very dry condition.

Before proceeding further, it may be worthwhile to recall what the 33 kip wheel load tests have told us about the effects of metallurgical parameters upon fatigue defect initiation. Figure 4 illustrates how the rail defect occurrence behavior (total defects/rail) varies with three metallurgical parameters:

- Volume fraction of oxide
- Sugino Index (a measure of the clustering tendency of the oxide inclusions)
- Hardness in Bhn

Four data points are portrayed upon the figure; a fifth can be inferred. If the rail with the next lowest value of VFXSI/Bhn below the four shown were expected to produce its first fatigue defect just as the HTL test came to an end, its data point would occur at the circle shown at the lower left hand corner of the figure. Its presence there would suggest that the relationship between defect occurrence rate and the metallurgical parameter factor is not really linear on logarithmic axes but rather curves downward to the left implying an increasing dependency of defect rate on the metallurgical parameters. Considerable uncertainty exists in the exact form of the relationship because there is likely to be considerable statistical variability in defect occurrence in individual rails due to a small sample size. Representativeness of the cleanliness measurements is also uncertain as they have been determined from only a few examination planes. Nevertheless, the results have demonstrated experimentally the direct effect of metallurgical cleanliness on rail fatigue defect rate. The higher defect rate of some of the test rails has prevented their carry-over into the HAL phase of the experiment.

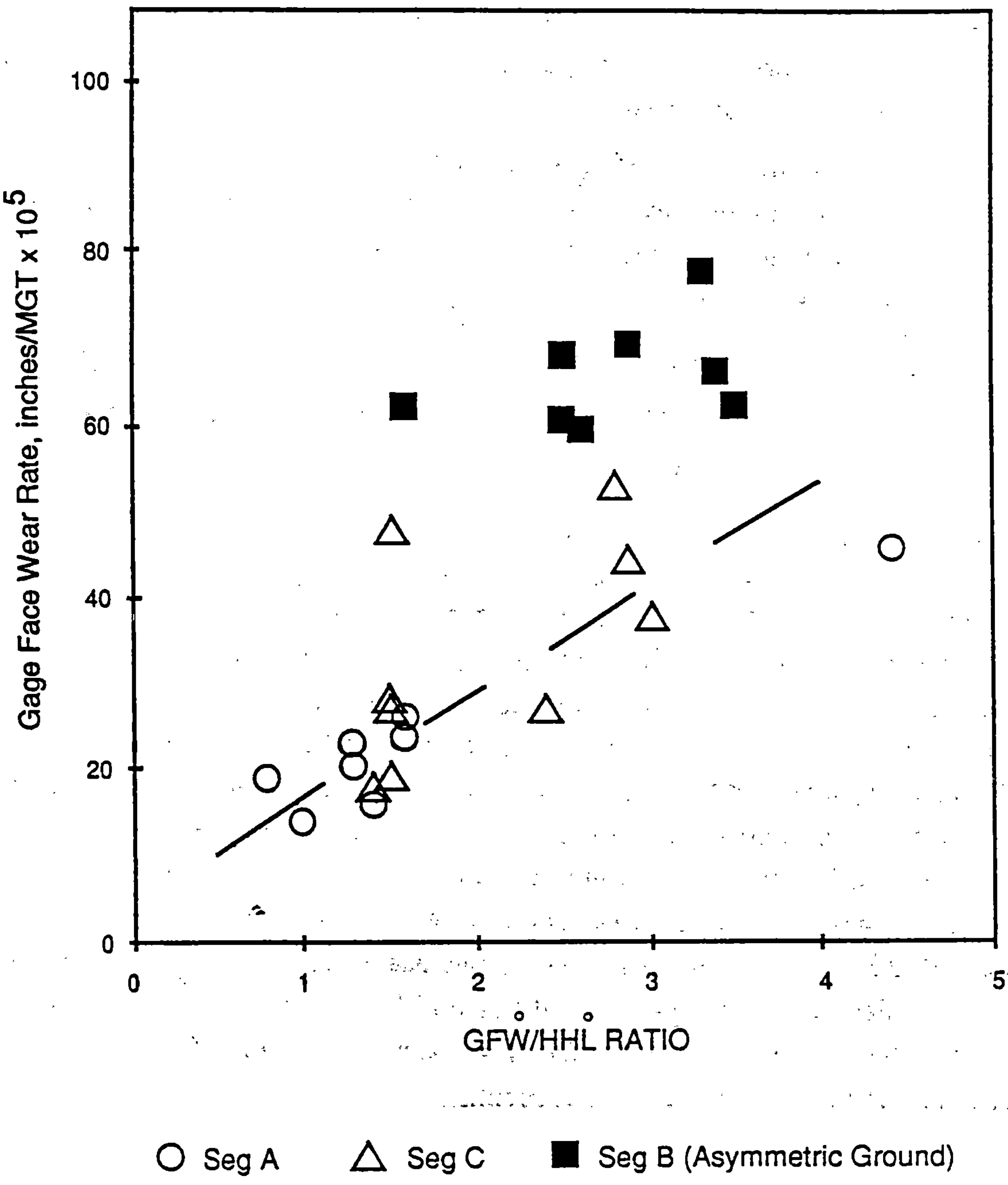
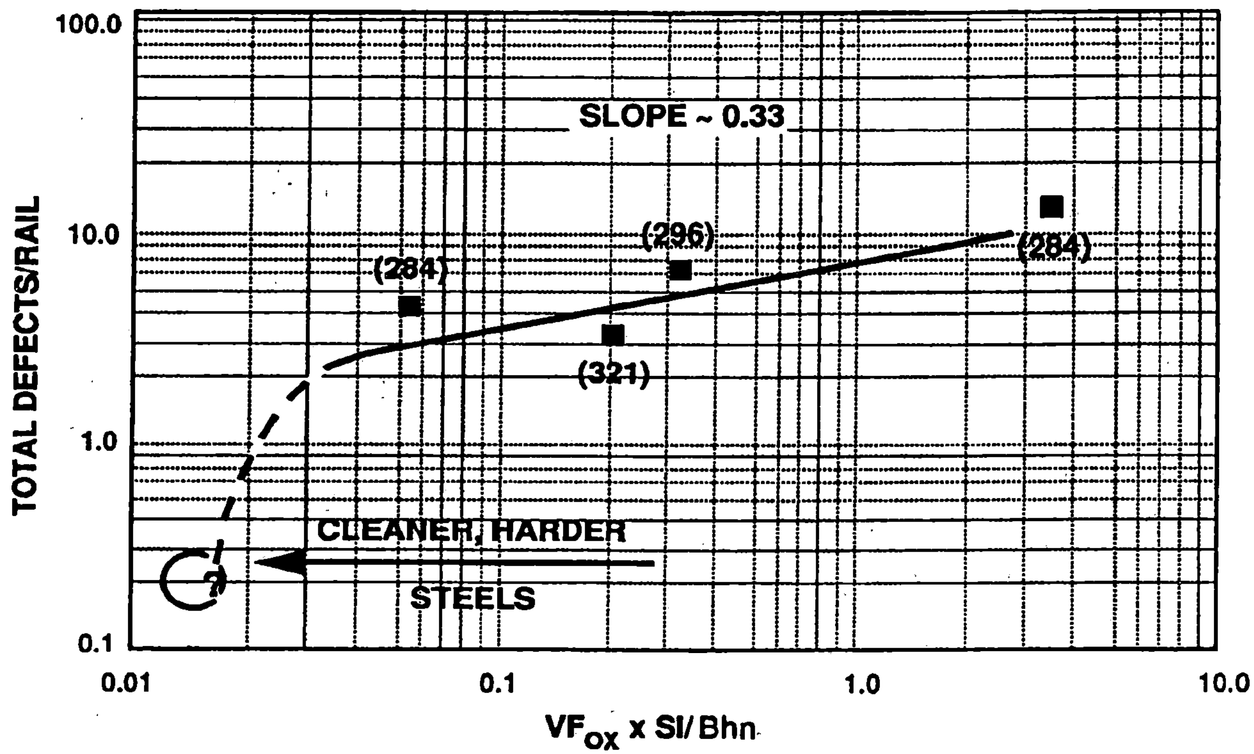


Figure 3. Lubricated Wear Rates, S25 33 KIP Wheel Load Test



VF_{OX} = Oxide Volume Friction
SI = Sugino Index (a measure of cluster length)
Bhn = Brinell Hardness

*Note: Numbers in parentheses are rail hardness in Bhn

Figure 4. Effect of Metallurgical Cleanliness and Hardness on Defect Rate

DISCUSSION OF RESULTS

As indicated previously, the results of the current HAL tests have been presented in Part I through IV of this document. The experimental information will not be repeated here. Rather, that data will be examined for its meaning in the light of the data from the HTL (33 kip wheel load) and other previous tests.

Section 07/Wear

The GF penalty factors resulting from the introduction of the 39 kip wheel loads have been plotted in Figure 5 as a function of position through the test curve in Section 07. This has been done to determine any position-in-curve (PIC) effects. The fact that the SiCrV HH rail at the entry to the curve exhibits a very different penalty factor from those of nominally comparable metallurgies (the HH and DHH rail) suggests that indeed a PIC effect has existed in the dry test phase. The contaminated condition curve also suggests the action of a less strong PIC effect. Thus, the question becomes what data can be considered most appropriate.

Some judgements about appropriateness can be made by arranging the data as shown in Table 1 using both the GF and HHL information to help test for consistency. Considering first the dry condition, the exceptionally low 33 kip wheel load GF of the SiCrV HH rail at the entry to the curve is to be noted. The low GF is reflected in an exceptionally low value of GF/HHL ratio. The CrMo rail, next in the curve, also exhibits a low 33 kip wheel load GF/HHL ratio by comparison with the other test metallurgies. These exhibit ratios much more like those observed in earlier experiments. Thus, it appears that some of the data for the SiCrV HH rail and possibly the CrMo rail is suspect. On this basis, the test seems to show that in the dry rail condition, head hardened rails have exhibited no increase in GF (measured in wear/MGT), with the change to 39 kip wheel loads. In the contaminated condition, the greater consistency of the GF/HHL ratios under both the 33 kip (100T) and 39 kip (125T) wheel loads suggests less influence of PIC effect. However, the GF/HHL ratios are greater for the 33 kip wheel load reflecting the effect of the 39 kip wheel load to increase HHL more than it does GF -- at least in the center position of the curve.

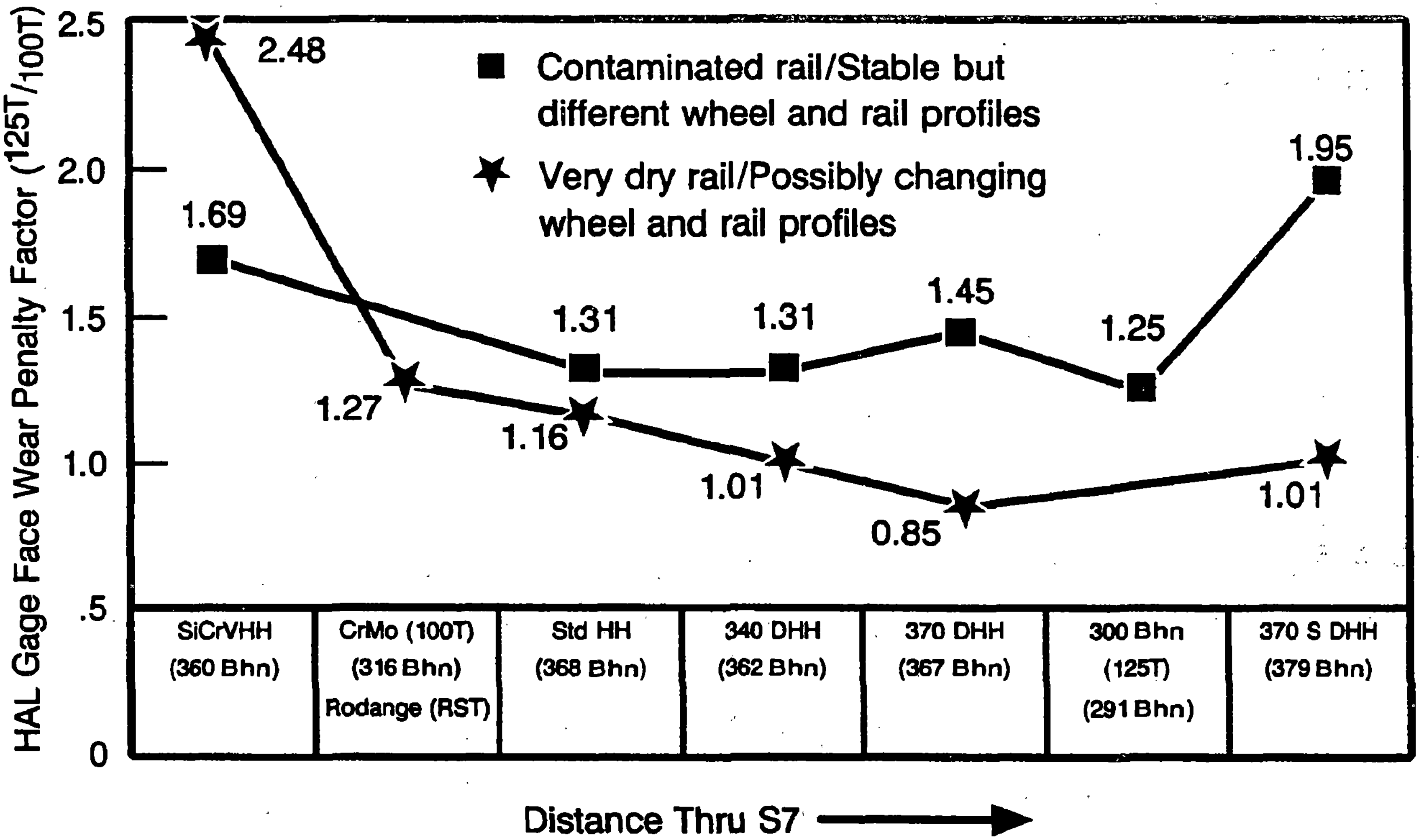


Figure 5. Variation of Penalty Factor with Position-In-Curve, Metallurgy, and Lubrication Condition

Table 1. FAST HTL Section 07 Wear Rates

	5/8 GAGE FACE WEAR RATES x 10^3				*GF/HH RATIO*				*HEAD HEIGHT LOSS RATE x 10^3*			
	DRY		*CONTAMINATED*		*DRY*		*CONTAMINATED*		*DRY*		*CONTAMINATED*	
METALLURGY	100T	125T	100T	125T	100T	125T	100T	125T	100T	125T	100T	125T
SiCrV HH	0.968	2.406	1.371	2.323	0.88	1.30	5.67	5.28	1.101	1.857	0.242	0.44
CrMo	3.368	4.283	2.812	—	1.94	1.92	3.79	—	1.740	2.234	0.741	—
HH (off line)	2.857	3.275	1.914	2.513	5.85	2.90	7.28	4.93	0.488	1.128	0.263	0.51
340 DHH	2.923	2.957	1.768	2.323	4.02	2.28	6.03	4.47	0.727	1.299	0.293	0.52
370 DHH	2.894	2.448	1.476	2.143	6.11	1.60	5.41	4.12	0.474	1.533	0.273	0.52
370 SDHH	2.493	2.519	1.067	2.081	5.80	1.75	4.25	4.52	0.430	1.437	0.251	0.46

Figures 6, 7, and 8 show how wheel load and lubricant contamination alter the benefit achievable by increased rail hardness. In Figure 6, the CrMo (39 kip wheel load) and SiCrV HH (33 kip wheel load) GFs are displaced well away from all of the rest of the data suggesting that these data are suspect. This was clear before for the SiCrV HH but was not so clear for the CrMo. Thus, these observations reinforce the view that in the dry phase the first two metallurgies at the entry to Section 07 have acted inconsistently from the rest of the rail in test and that the calculated wheel load penalty factors for them are suspect. The remaining data does seem to be self consistent suggesting that the wheel load change has had no effect on GF. The contaminated condition data shown in Figure 6 illustrates two significant events:

(a) Contamination has had a greater effect on reducing the GFs of the harder rails; this is opposite to the pattern of behavior usually observed in the past and currently observed in Section 25 when lubricant is applied liberally to the gage face of the high rail.

(b) The increased wheel load has diminished the effect of greater hardness on GF; this is consistent with laboratory wear tests simulating gage face wear which were run in the dry condition. It is not clear why the same effect was not noticed in the dry phase of the operation.

Figures 7 and 8 portray the behavior of the high and low rail HHLs respectively with increased hardness. The effect of increased wheel load to increase HHL is observed in all cases except for the low rail under contaminated conditions. With contaminated conditions, the low rail HHL was not altered at all by the wheel load change. The effect of contamination on HHL of both rails was to decrease the dependency upon hardness -- just the opposite of the effect on GF. And on both rails, the contamination has reduced the effect of wheel load by comparison with the behavior in the dry condition.

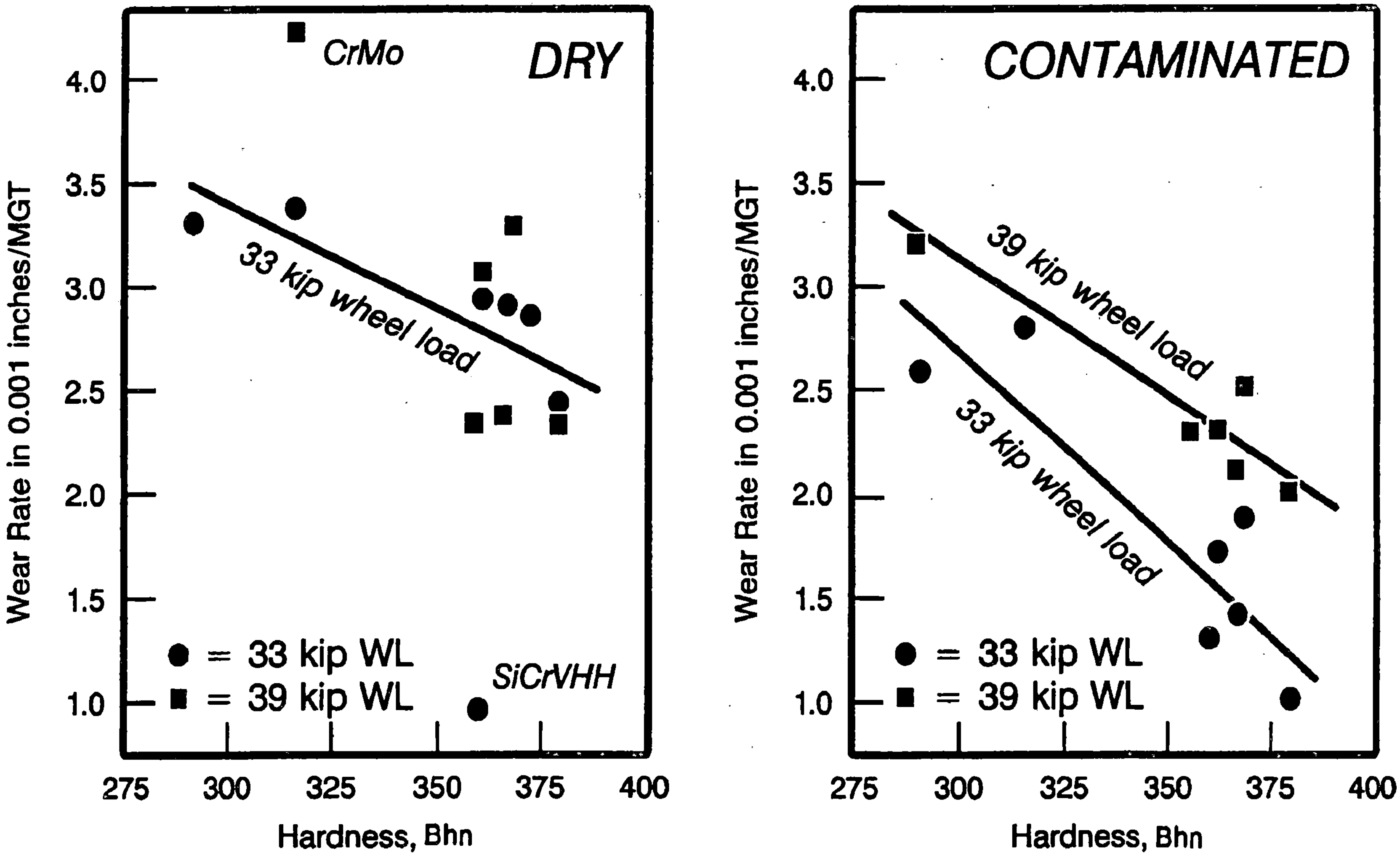


Figure 6. Gage Face Wear Rates as a Function of Hardness

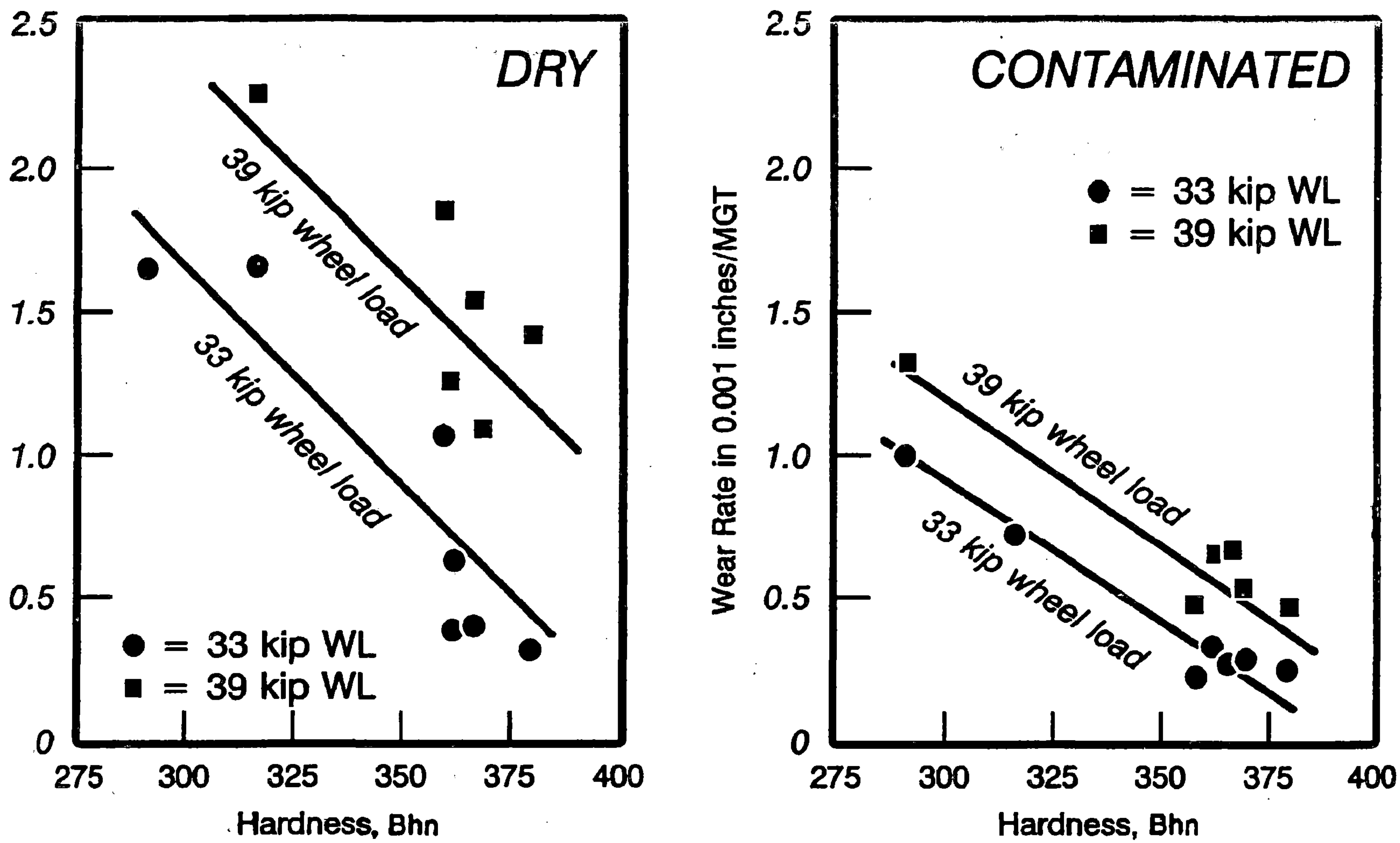


Figure 7. High Rail Head Height Loss Rates as a Function of Hardness

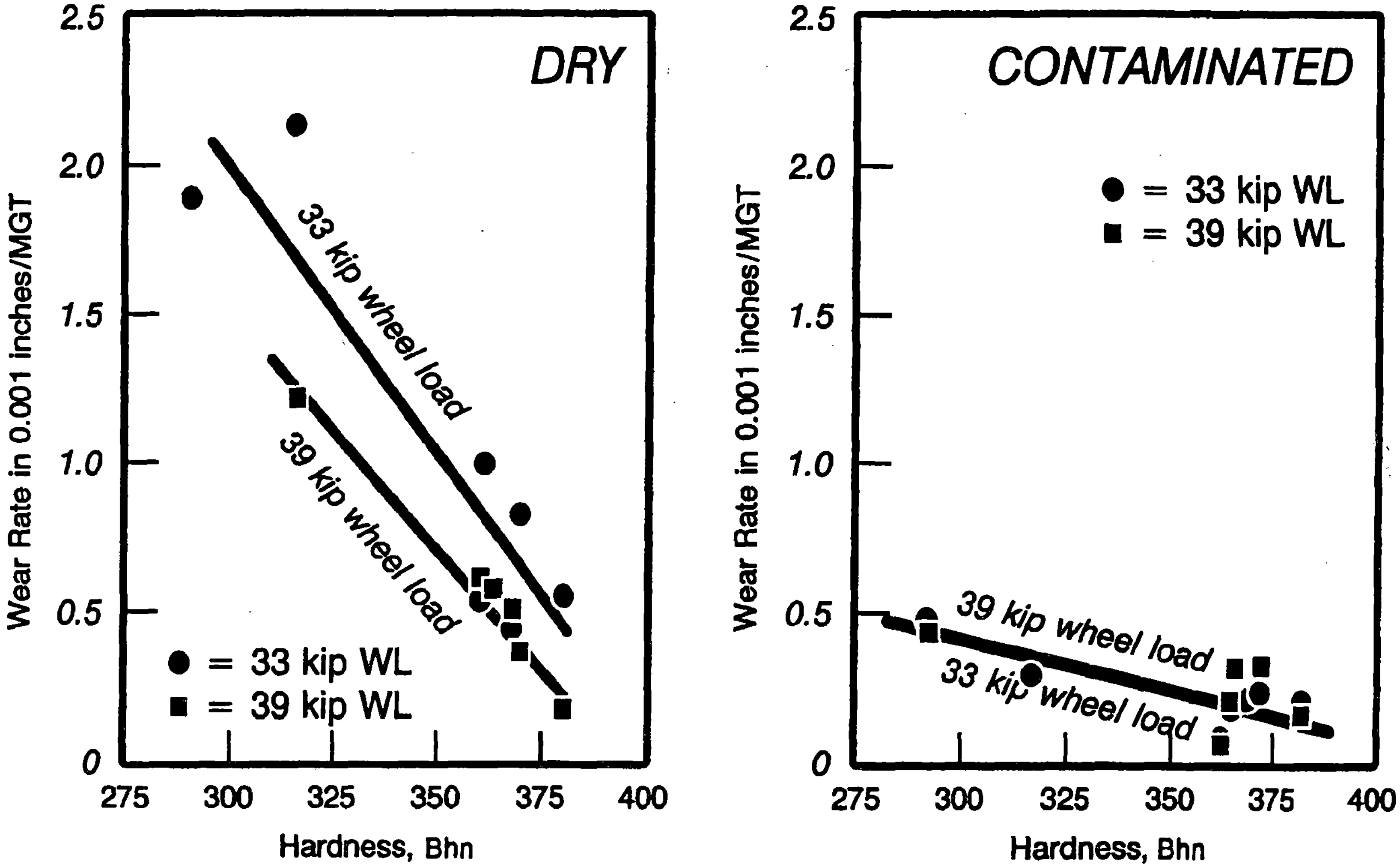


Figure 8. Low Rail Head Height Loss Rates as a Function of Hardness

Unfortunately, there is no tribometer data available for the 33 kip wheel load test phase to permit an assessment of the nature of contamination. But some tribometer data does exist for the contaminated part of the 39 kip wheel load phase and is presented in Figure 9. In spite of the fact that the lubricant (oil) applied to the inside loop rail (high rail in Section 07) was applied only to the ball, the greatest reduction of coefficient of friction has been on the gage face, though not entirely consistently throughout the entire October/November period shown. The coefficient of friction on the low rail had been lowered to about 0.3 fairly consistently for the two-month period. Presumably the source of that surface contamination is the gage face track-side lubricator at the entrance to Section 25 about two miles (in the direction from which the train comes) away.

It is not clear why such marked differences in wheel load dependence developed between the dry and contaminated conditions of operation. This difference in behavior is extremely troublesome because although the dry condition is well defined, the contaminated condition is not. Probably a nearly infinite variety of contaminated conditions can exist in revenue service. It is unclear that the FAST observations are applicable to all or even any of them.

Conceivably the wear behavior, especially GF behavior with wheel load change in both the dry and contaminated phases, could have been associated with wheel profile changes (and with them, the rail profile changes) and perhaps even wheel class mix changes. These profile changes occurred with the introduction of the heavier axle load cars and continued by wear and deformation throughout the progression of the tests. Figure 10 illustrates a typical set of rail profiles in the SiCrV HH at the entry to Section 07. The four profiles shown represent, from right to left on the gage face, contaminated (33 kip wheel load), dry (33 kip wheel load), dry (39 kip wheel load), and finally contaminated (39 kip wheel load). The effect of dry running was to cause a sharp transition from the gage face to the ball (marked by the letter A) permitting a clear-cut definition of the flange contact angle. Operation under contaminated conditions softened that transition as illustrated by the circled region marked B. Also, the region at the bottom of the gage face is shaped differently under 39 kip wheel load contaminated conditions than that observed under dry conditions.

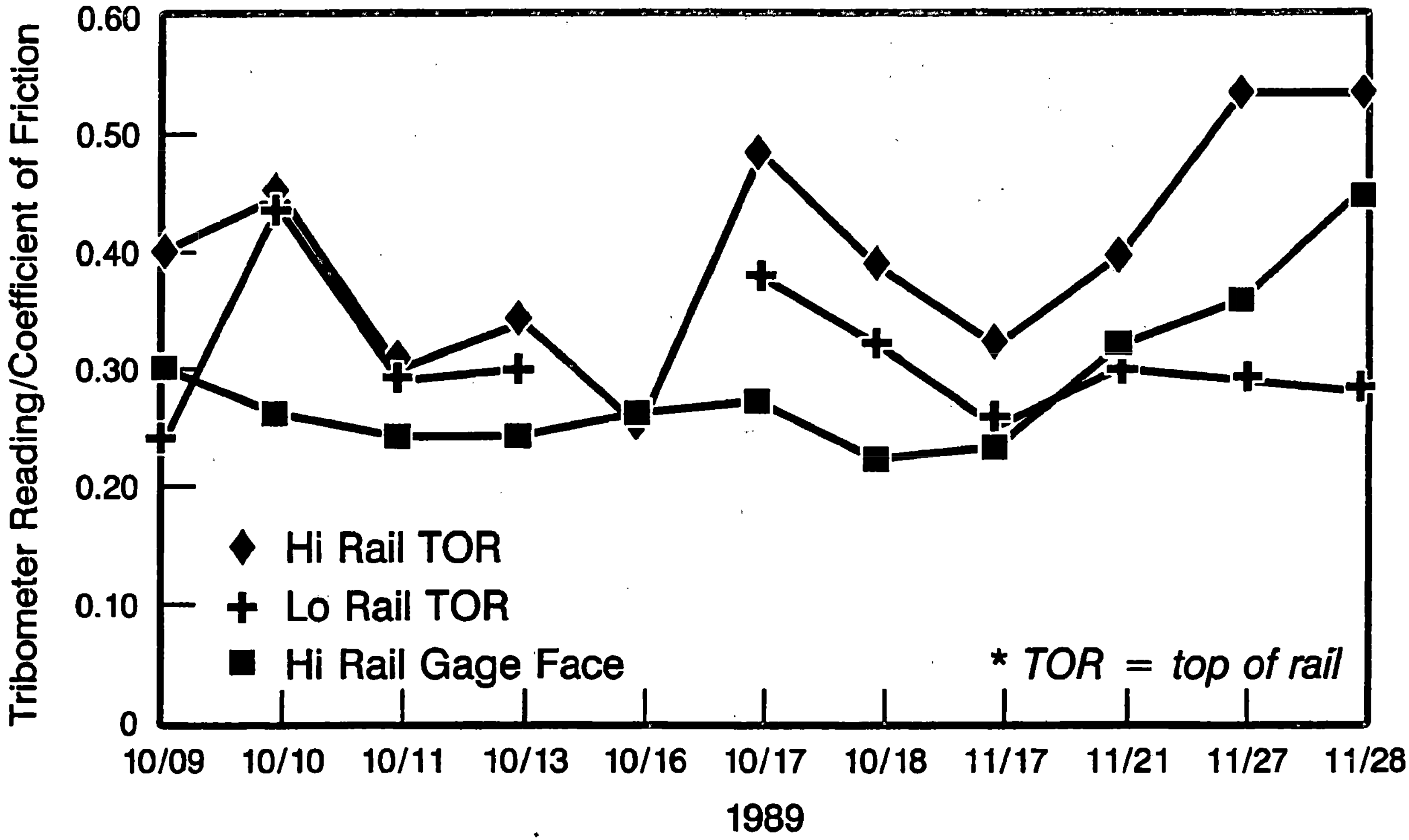


Figure 9. Tribometer Measurement of Rail Lubrication/Location 070093

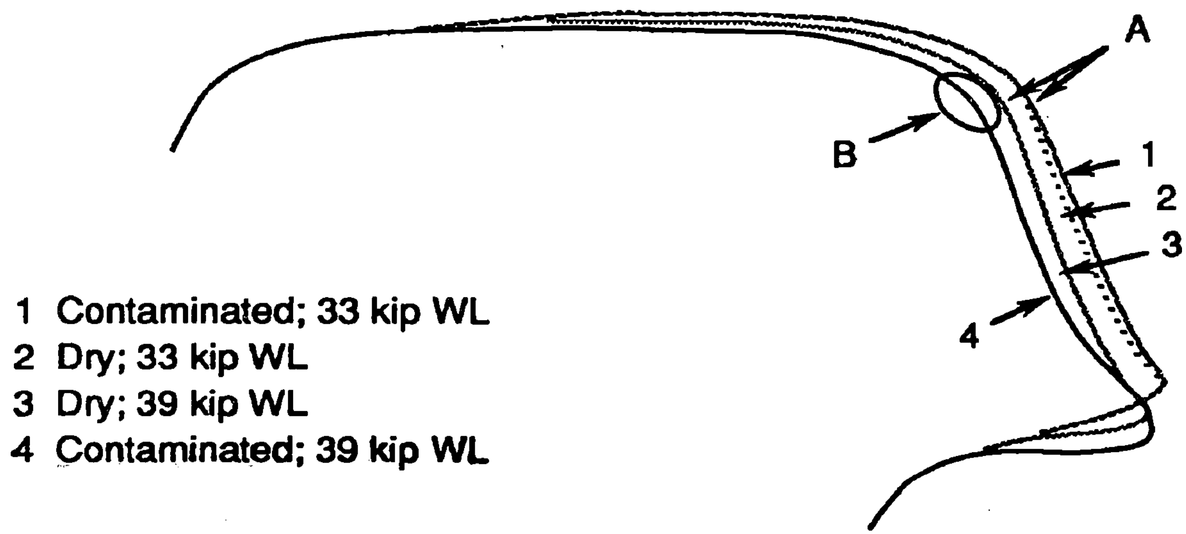


Figure 10. Profile Configurations in Section 25 SiCrV HH Rail at Various Times During the HTL and HAL Tests

Curving model analyses have been undertaken using the rail profiles shown in Figure 10 for the 33 kip and 39 kip wheel load contaminated conditions and the wheel profiles given by Bob Florom. The intent has been to determine if wheel and rail profile differences could have contributed to the GF changes which have been attributed to wheel load only. The results are tabulated below for a 5-degree curve with the following coefficients of friction: high rail ball, 0.35; low rail ball, 0.30; high rail gage face, 0.25.

	33 kip	39 kip
Train Resistance	2.07	1.59
T x U (ft-lb/ft)	60.5	33.5
Angle @ Flange Contact (°)	70.0	53.5

The results suggest that the rounding of the gage face/running surface transition with an ensuing decrease in the angle at flange contact should have reduced the wear rate and train resistance substantially. The opposite actually happened. Thus, although curving model analysis shows that wheel and rail profile differences could have contributed to the differences in GFs observed, the observed behavior in the contaminated phase is not in agreement with the analysis predictions.

Section 25

The rail fatigue tests were accomplished in Section 25 under consistent conditions of effective lubrication on the high rail. At approximately 3 MGT intervals, the train was run dry in the reverse direction to clean the rail for flaw inspection and to mark the boundaries of any DF's present in the rail. Two tests were undertaken in the section:

- Evaluation of the effects of metallurgical characteristics (metallurgical cleanliness and hardness)
- Pilot grinding test to confirm previous observations and to evaluate the TTC grinder capability to maintain profile and achieve needed metal removal rates

In the metallurgical characteristics evaluation test, some rails were carried through from the previous HTL (33 kip wheel load) test; these are referred to as survivor rails. Other rails from the same tests as rails previously in the HTL tests were introduced new into test at the beginning of the HAL test; these are referred to as old unused rails. Figures 11 and 12 illustrate how the 39 kip wheel loads have influenced the total defect occurrence behavior (defects/rail installed) by way of comparison with rails of the same type exposed to 33 kip wheel loads only. The NSC 269 old unused rail initially exhibited a defect occurrence rate similar to that observed in the HTL tests. But at 80 MGT the rate increased apparently only to slow down again after 100 MGT to a rate similar to that for the 33 kip wheel loading. Overall though, the defect occurrence rate was slightly more than twice as large under the 39 kip wheel loads. The Bethlehem 289 old unused rail behaved quite differently. From 60 MGT to 120 MGT, the rate was about the same as the overall rate under the 33 kip wheel loads. But above 120 MGT the rate seems to have dropped to zero (no additional defects were reported between 120 and 150 MGT). Thus for this rail type the overall defect occurrence rate has decreased by about 50 percent with increased wheel load.

It is not really likely that the defect occurrence of any steel would decrease with increased wheel load. Perhaps the differences are due to rail-to-rail variations (most probably in metallurgical cleanliness).

The defect occurrence behavior of the survivor rails is less subject to rail-to-rail variability effects because the same rails have been retained in test through both wheel load periods. Figure 13 portrays the defect occurrence behavior for three survivor rails; one old unused data set has been included for comparison. The NKK 269 and 285 rails produced no defects in the period of the 33 kip wheel load tests, but did begin to produce defects with the introduction of the 39 kip wheel loads. The rate was low at the start (150-240 MGT) but increased at 240-280 MGT. The 269 old unused and survivor rail behaved much the same on average suggesting that little conditioning due to 33 kip operation of the rail occurred. The NSC HH rails were considerably harder than the NKK rail shown, but nevertheless did produce one defect (in four rails) under the 33 kip wheel loads. The increase in defect occurrence rate was only slight through the 39 kip wheel load from 150 MGT to 290 MGT but a higher rate may have begun to appear at 300 MGT.

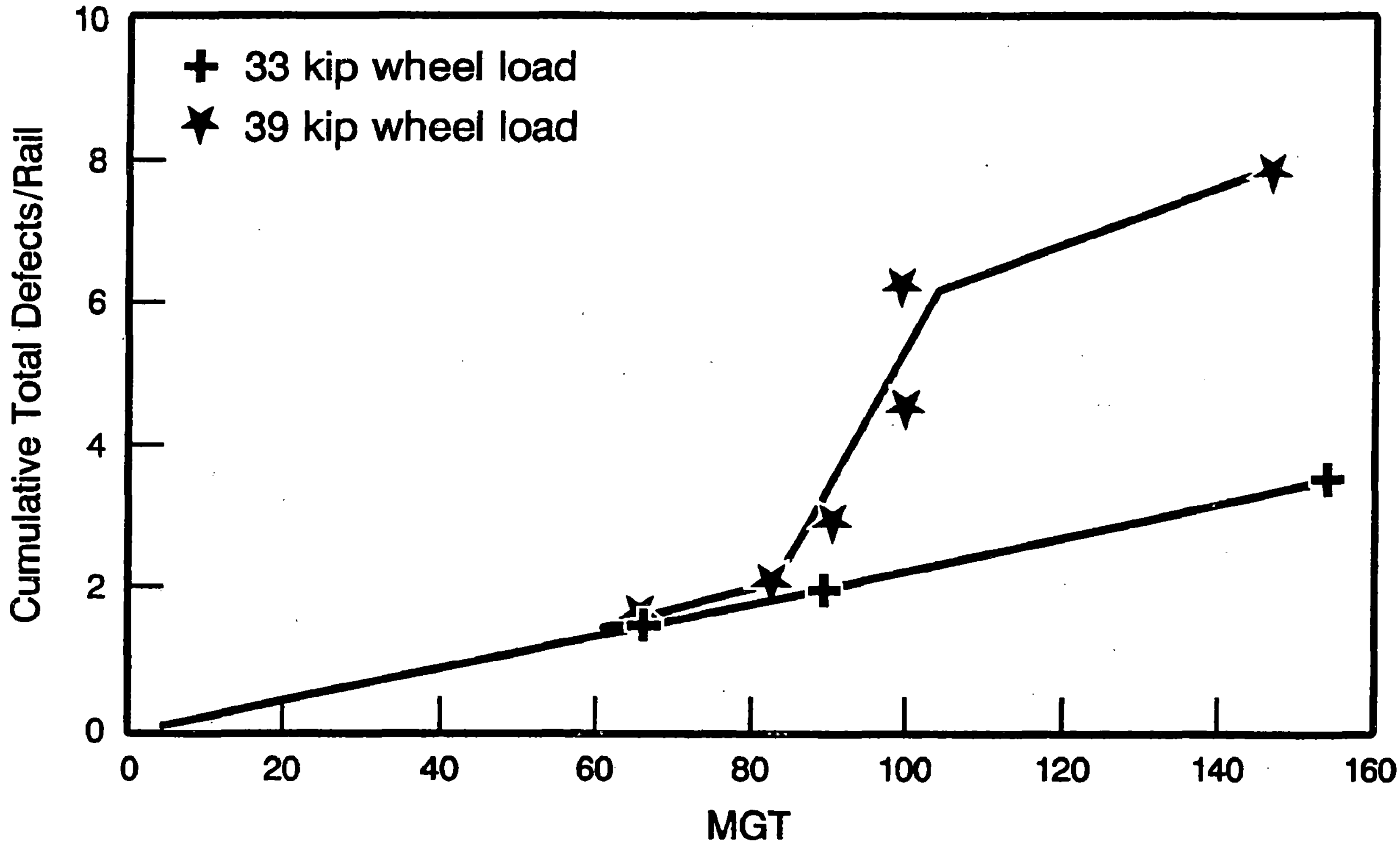


Figure 11. Fatigue Defect Accumulation Behavior as a Function of Service Exposure/NSC 169 Old Unused

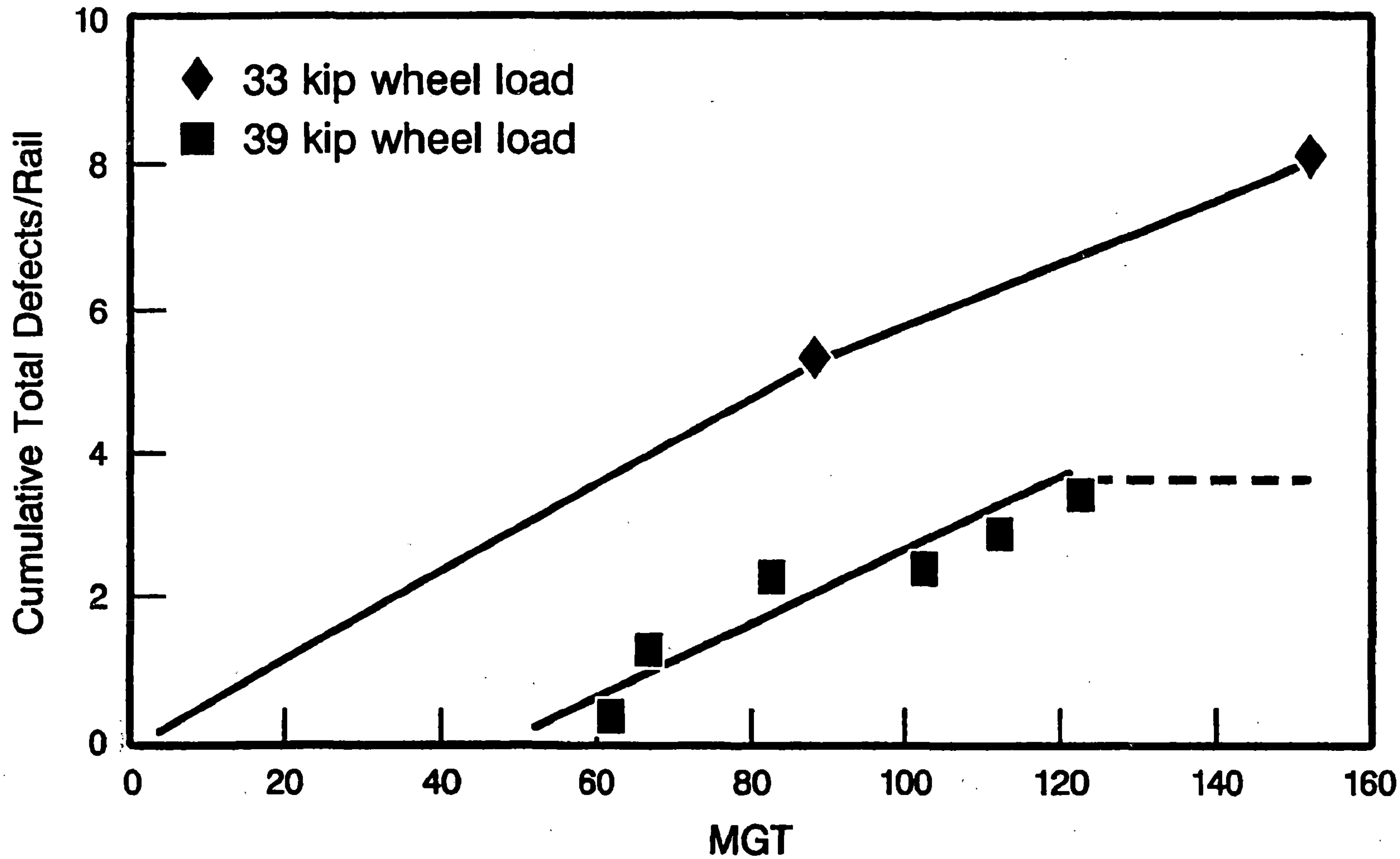


Figure 12. Fatigue Defect Accumulation Behavior as a Function of Service Exposure/Bethlehem 289 Old Unused

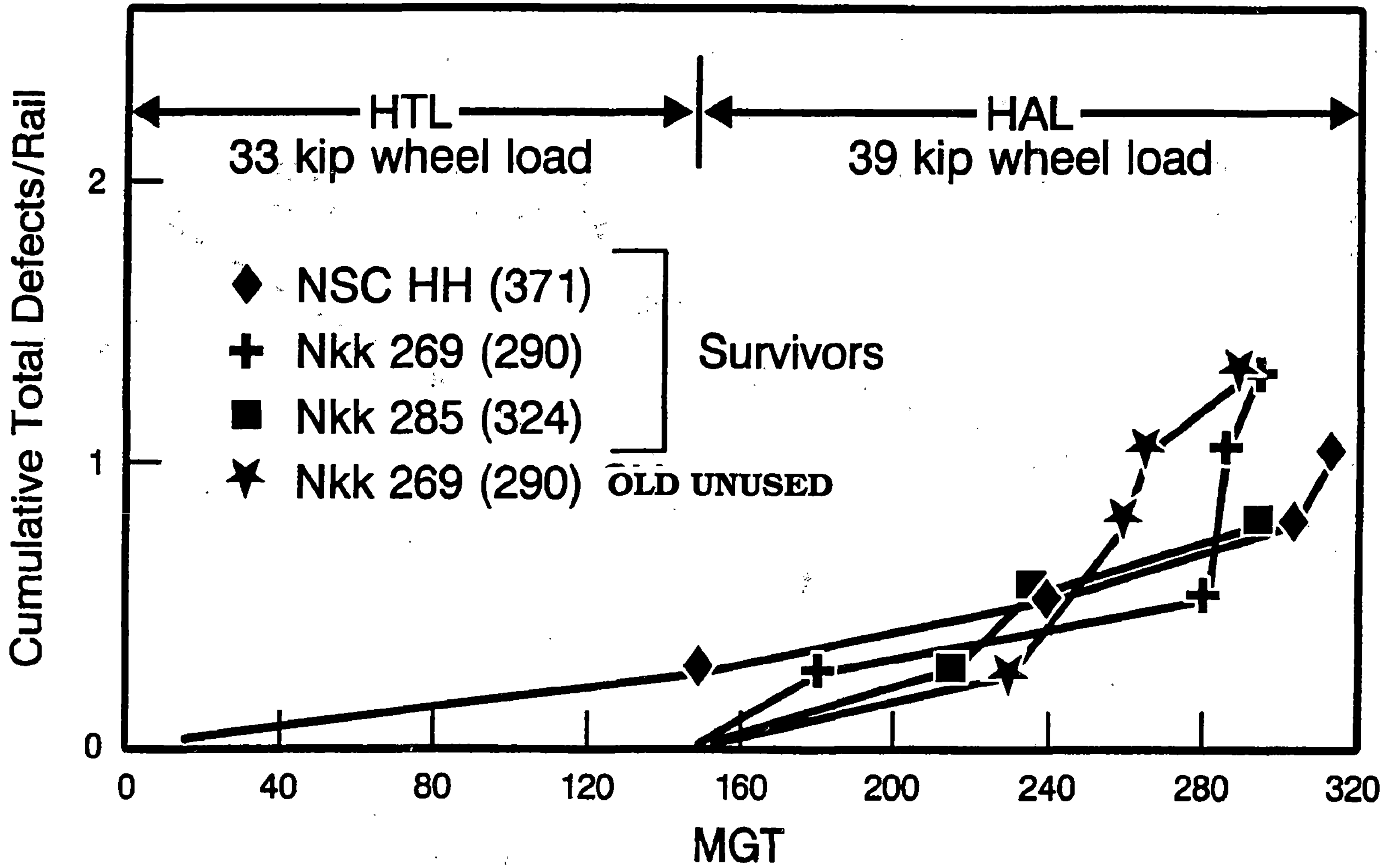


Figure 13. Survivor Rail Fatigue Defect Accumulation Behavior as a Function of Service Exposure

[redacted]

The effect of increased wheel load on defect occurrence behavior seems to depend upon hardness of the rail as shown in Figure 14. In the 150 MGT period under 39 kip wheel loads, a 390 Bhn rail would not be expected to exhibit an increase in defect occurrence rate. Were one to go beyond 150 MGT, it is likely that even the 390 Bhn rail would exhibit an increase in defect occurrence rate. Ideally Figure 14 should have been composed as relative defect occurrence rate for the 39 kip vs. 33 kip wheel loads as a function of hardness, but that was not possible because no defects formed in the NKK rails in 150 MGT under the 33 kip wheel loads.

The final parameter of concern in the metallurgical characteristic tests is crack growth rate. The crack growth curves for a typical cross section of rails that developed DF's under the 39 kip wheel loads as shown in Figure 15 with the results from 33 kip wheel loads tests superimposed as the shaded area. Generally, the growth behavior under the 39 kip wheel loads seems about the same as that observed under the 33 kip wheel loads.

Pilot Grinding Test

This test was undertaken to determine whether the bi-planar shells and higher gage face wear rates associated with the asymmetric rail profile observed previously in the HTL test could be reproduced. Also the intent was to determine whether the Test Center grinder could maintain a worn rail profile and achieve the necessary metal removal rates to accomplish a more elaborate grinding study. In this current HAL test, the asymmetric profile yielded the greatest number of fatigue defects and the naturally dry worn rail yielded no fatigue defects. The ground-to-worn and the as-initially-rolled profiles were intermediate in behavior. There were two obvious weaknesses in the test:

- Only two 80-foot rails were used for each profile.
- B and C rails were used in each test zone except in the naturally dry worn segment where only C rails were used.

Thus the population is too small and the confounding effect of B vs. C rails has made comparison of defect rates impractical.

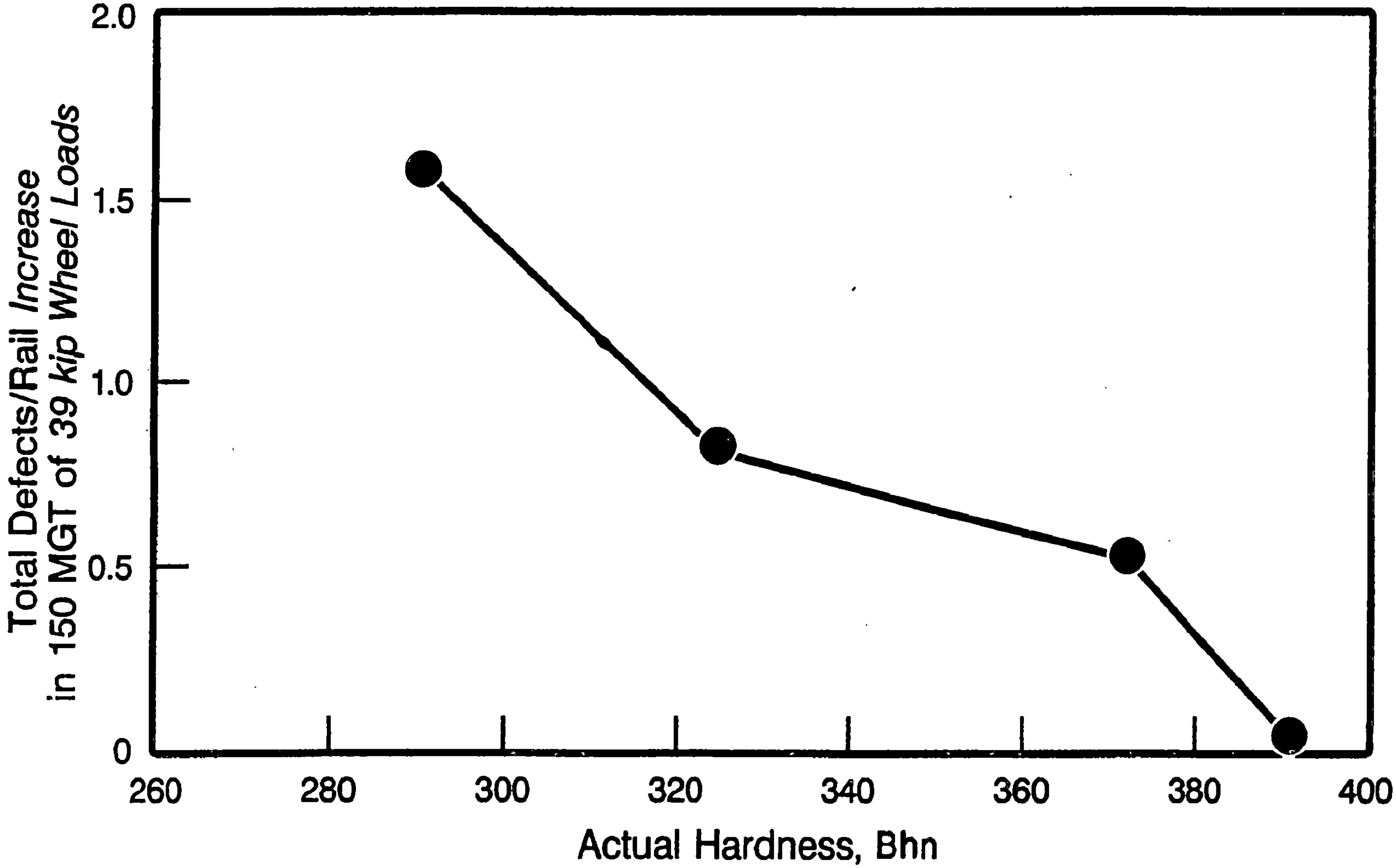


Figure 14. Additional Fatigue Defect/Rail Increment Due to 39 Kip Wheel Loads (in 150 MGT)

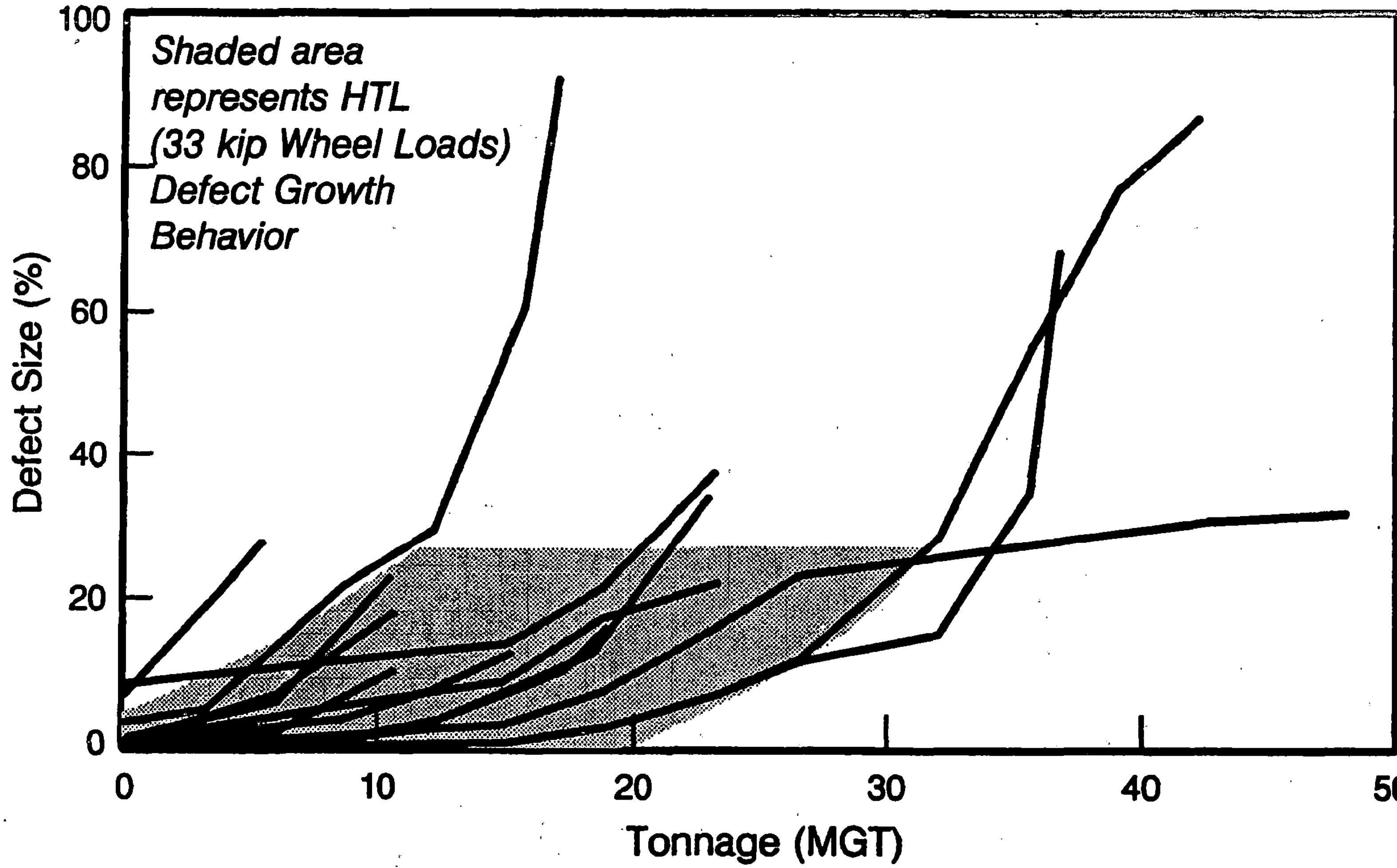


Figure 15. Trsansverse Defect Growth Behavior

However, answers to the original questions can be provided. Bi-planar shells were again observed to be associated with the asymmetric profile. Figure 16 shows the appearance of the bi-planar shell with its origin under the relieved (by grinding) portion of the ball. All of the shell/DF's that formed in the B rail were located unusually close to the surface (about 0.2" deep) and exhibited only very short shell growth before turning to DF's. The origin of the shell appeared to be at an oxide inclusion as shown in Figure 17. The prompt turning of the shell to a DF after only a brief period of longitudinal growth is consistent with an analytical model of shell growth. It predicts that the closer the shell initiates to the surface the shorter will be the shell growth before turning occurs and the greater will be the turning tendency. This is demonstrated in Figure 18.

The asymmetric profile has again been associated with a higher lubricated GF, as illustrated in Figure 19. The lowest overall GF occurred with the as-rolled 133 RE rail profile. The wear rates of the dry-worn and ground-worn rails (segments A and B respectively) seem unusually high considering the intended conformality (and single point) of contact. Figure 20 shows why. The rails in the first two segments were supposed to have been ground to create (segment B) and maintain (segments A and B) a worn profile. But the profile actually ground initially on these rails was asymmetric. Figure 21A shows that in the period in which an asymmetric profile existed on the rails in segments A and B the gage face wear rate was quite high (0.0009" to 0.0012"/MGT). After the profile was corrected to what it was supposed to be (near 50 MGT), the wear rate diminished to about 0.0001"/MGT in these two segments. Figure 21B illustrates the consistently high gage face wear rate of the asymmetric profile (segment C) and the low wear rate of the as-initially-rolled profile (segment D). There is a brief period of about 20 MGT shown in the figure at the beginning where the configuration of the as-initially-rolled profile was undergoing change before any gage face wear occurred at the 5/8-inch gage point. Even though the lubricated GF of the asymmetrically ground is apparently higher, the rate is still about only 1/3 that expected for the dry condition.

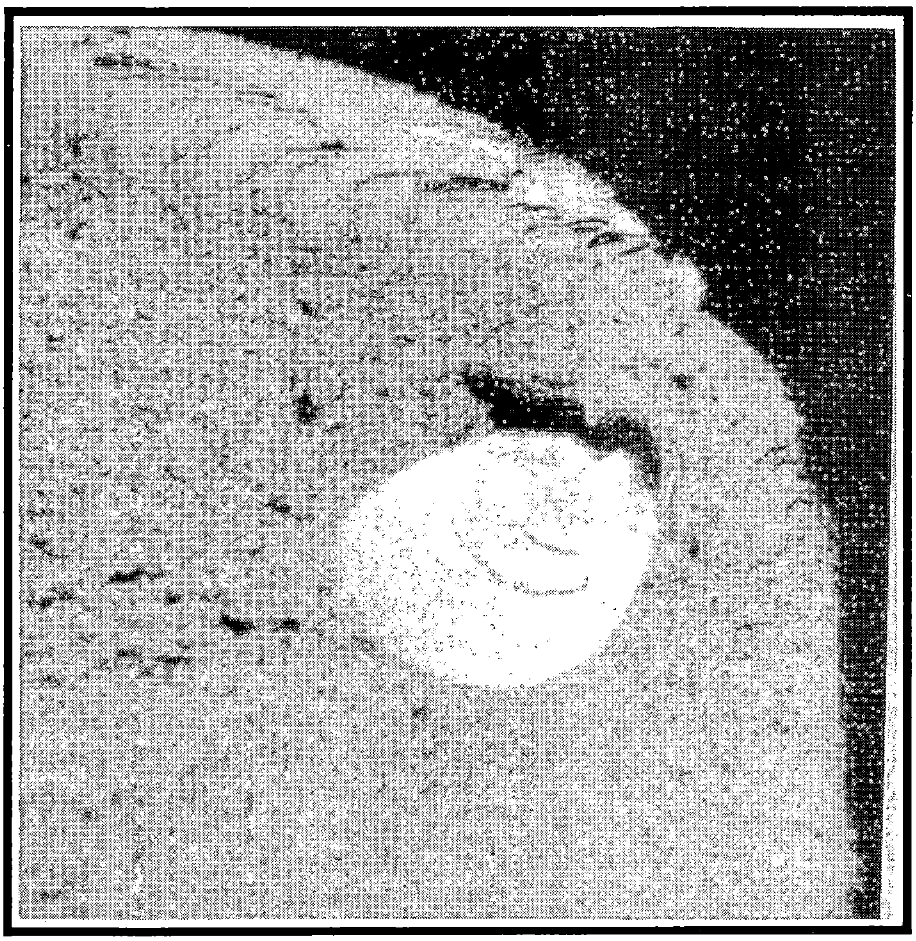
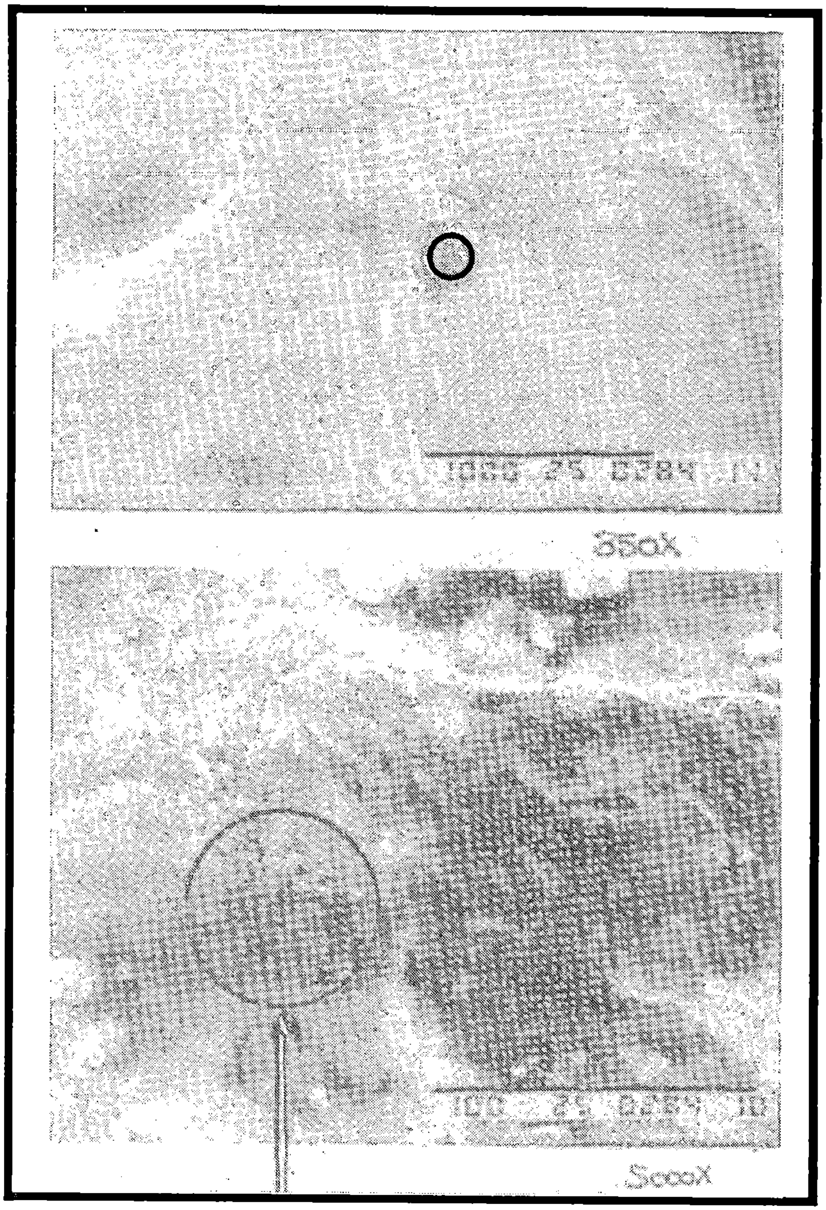


Figure 16. Bi-planar Shell/DF Occurring Beneath Gage Corner of the Asymmetrically Ground Rail



Al_2O_3 Inclusion

Figure 17. Fractographic View of Bi-planar Shell Origin

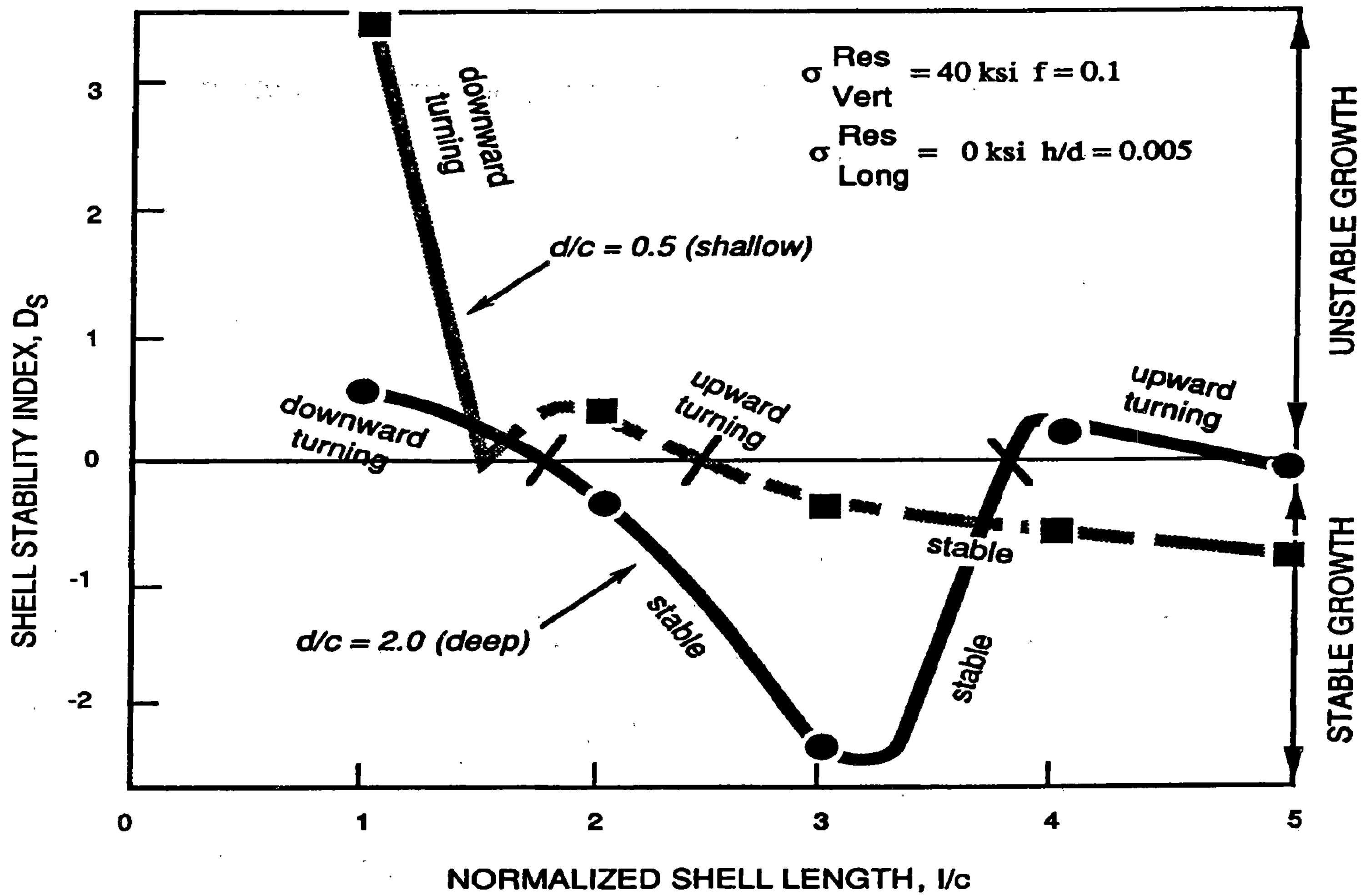


Figure 18. The Effect of Shell Depth on Shell Turning Parameter as a Function of Shell Length

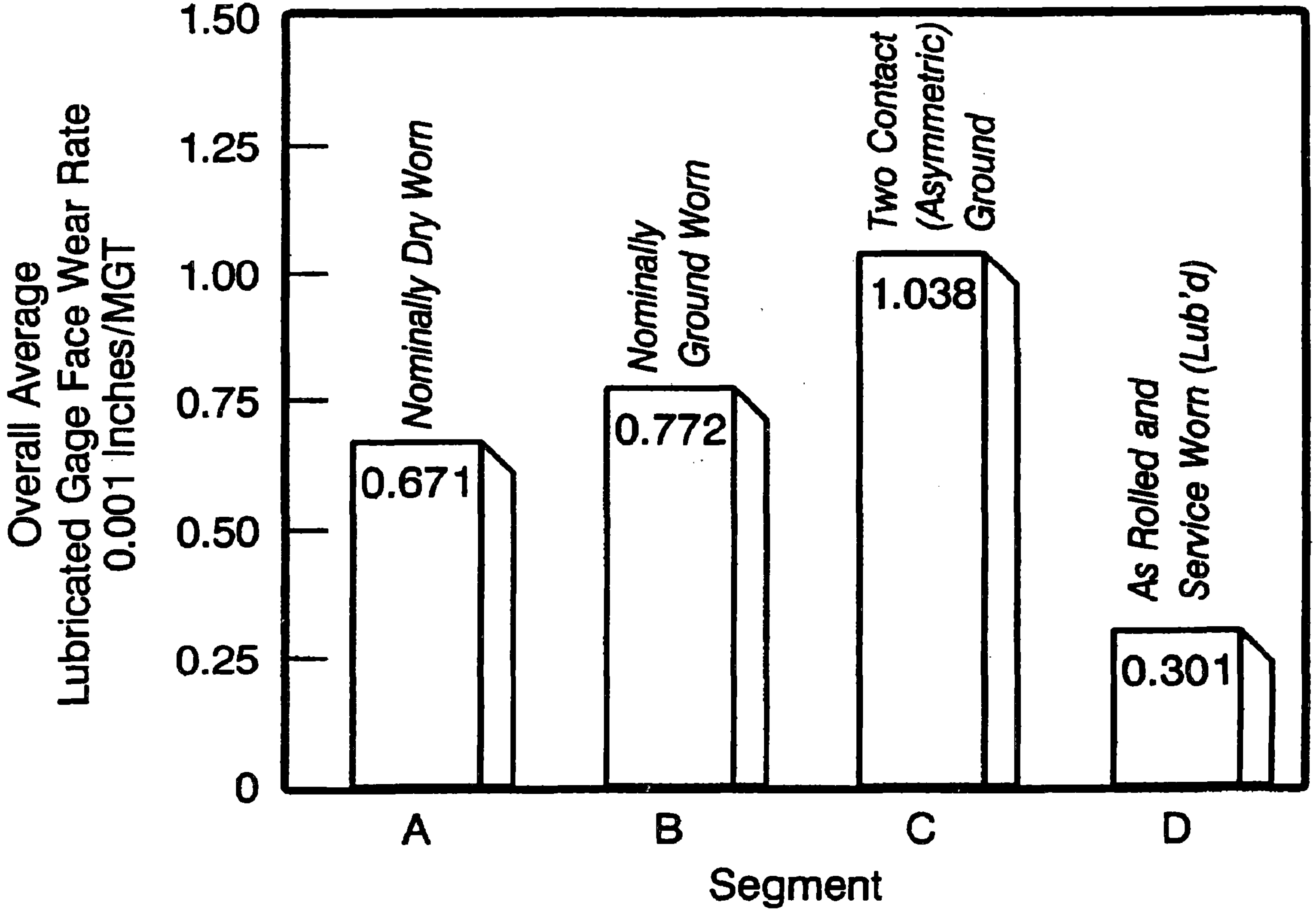
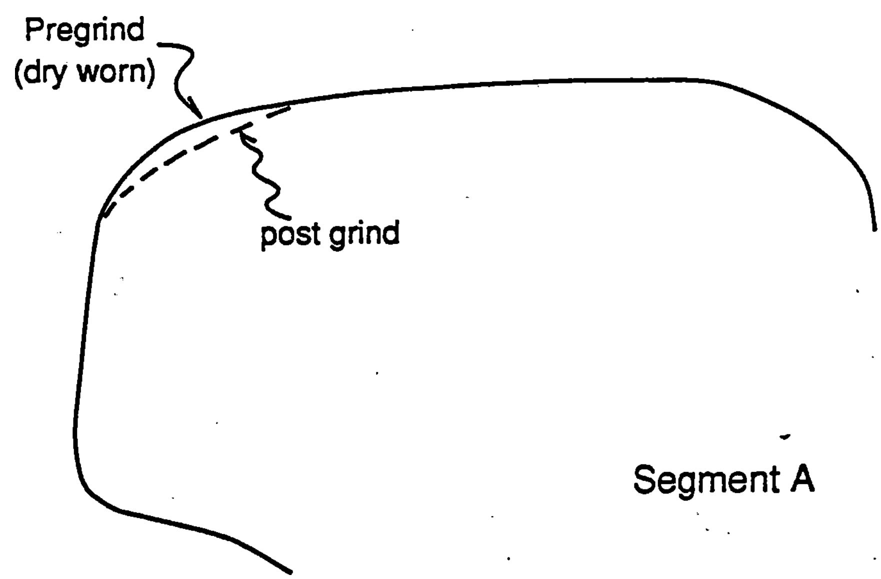


Figure 19. Comparison of Lubricated Gage Face Wear Rates in the Pilot Grinding Test Zone



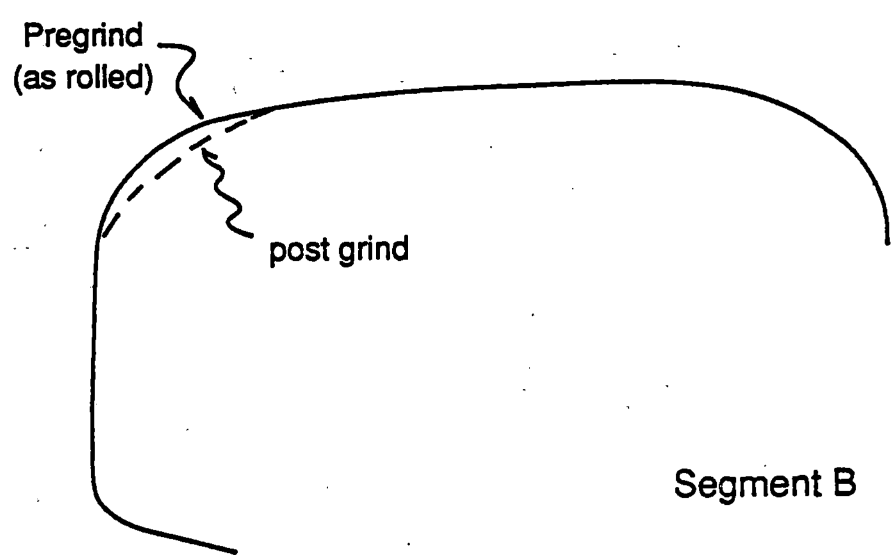


Figure 20. Asymmetric Profile Initially Ground on Rail in Segments A and B

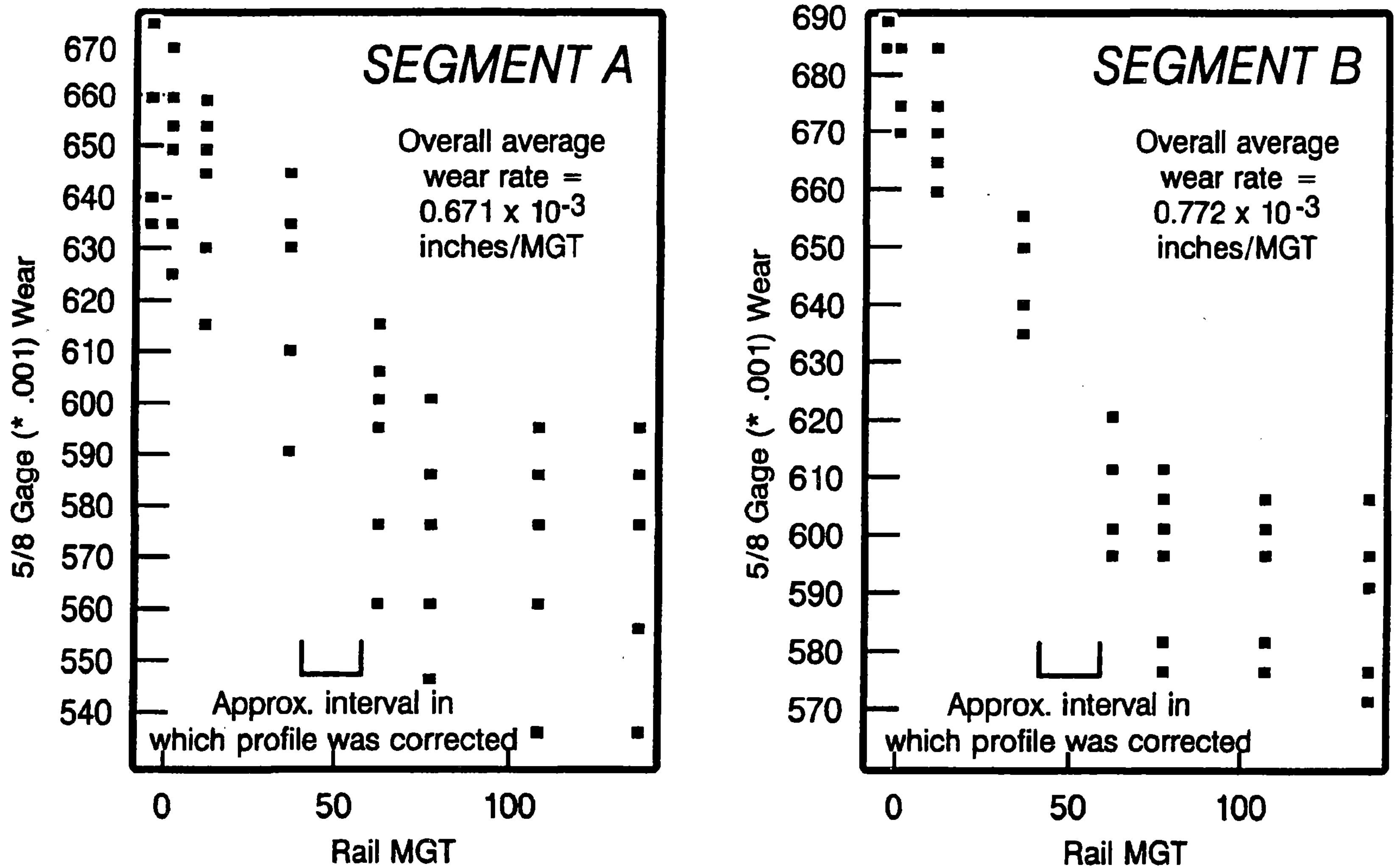


Figure 21a. Wear in the Pilot Grinding Test Zone

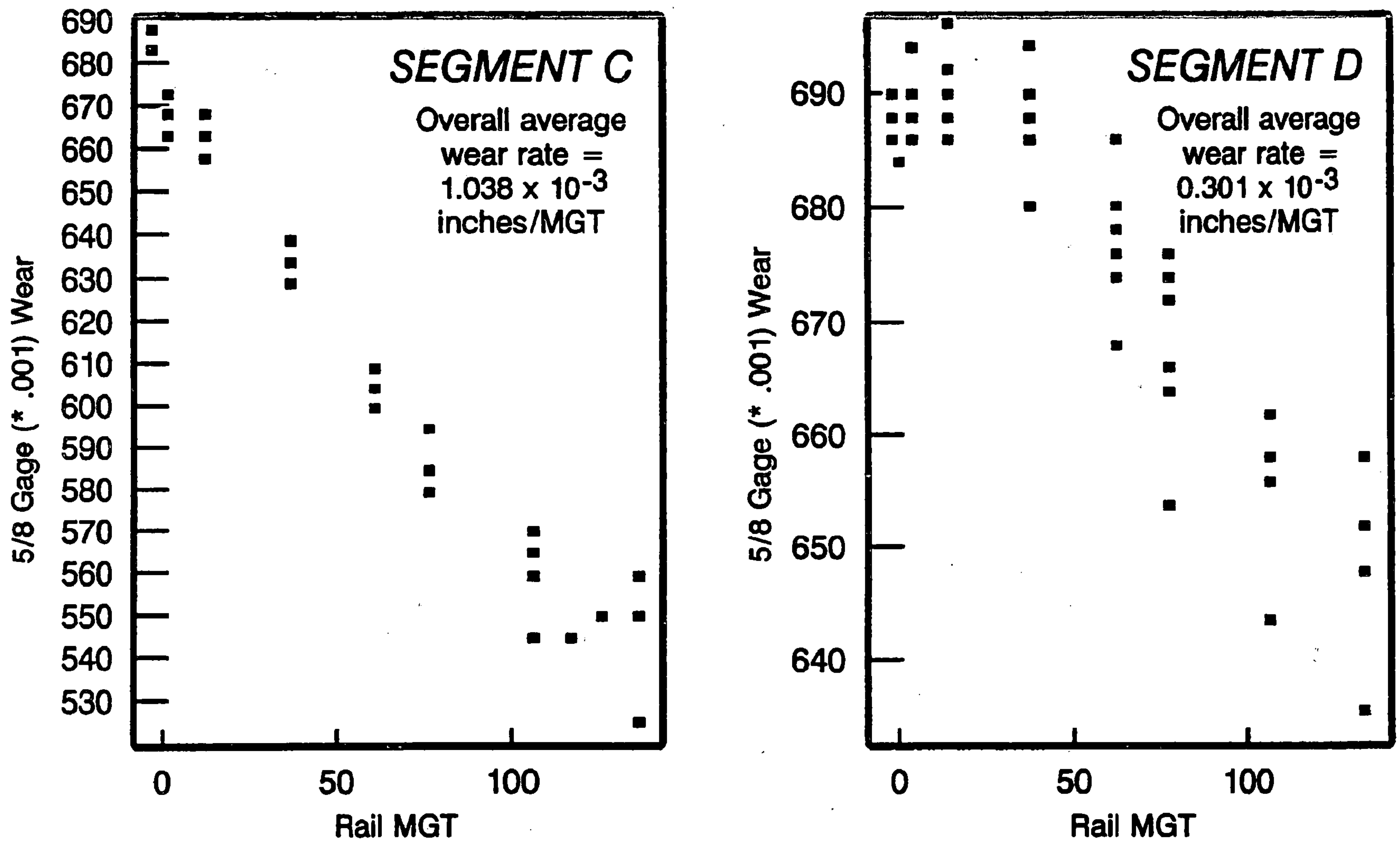


Figure 21b. Wear in the Pilot Grinding Test Zone

One final observation is relevant. It was intended to grind segments A and B to the worn profile removing about 2 mm/100 MGT. Head height loss measurements suggested that the removal rate was much closer to 1 mm/100 MGT.

Thus, the results of the pilot grinding test were a mixed bag. The occurrence of bi-planar shells and the existence of a higher GFs were confirmed in the asymmetric profile test segment. But the unbalanced mix of B and C rails may have confounded the defect occurrence rate results (along with the small size of the experiment). Grinding a worn profile with the available 4 stone/rail grinder turned out to be a greater challenge than expected. Reliable removal of the specified amount of metal requires much better precision of measurement that was at first practiced.

CONCLUSION

Increased wheel loads seem to cause very different effects on the gage face wear rate depending on the character (lubrication extent) of the wheel/rail contact. Even for head height loss rates, the character of the wheel/rail contact appears to play an important role. In each case it is not clear why the disparate behavior occurs. The effects of wheel and rail profile differences remain uncertain as well. Nevertheless, gage face wear rates appear to increase between 0 and 40 percent for a 20-percent increase in wheel load.

The effect of wheel load on the fatigue defect occurrence rate has been shown most reliably to depend upon hardness with the carbon rails (near 300 Bhn) showing large increases and rails near 390 Bhn showing no increase in the duration of the test. The pilot grinding test confirmed that bi-planar shells and higher gage face wear rates can occur in asymmetrically ground rails under FAST test conditions; i.e., non-conformal profile conditions. Future experiments designed to study the effect of grinding must have a bigger population size with a balanced rail mix and much greater care must be paid to profile control and removal rate determination.

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2. American Railway Engineering Association Advisory Committee. "Rail and Trackwork Welding," *The Track Cyclopedia*, Chapt. 15, 10th Ed., Simmons-Boardman, Omaha, NE, 1985.

3. Brave, G. and Hannafious, J. "Field Welding at FAST," Quarterly Report #033

APPENDIX A

FAST HISTORY, OPERATION AND MAINTENANCE OVERVIEW

by

Richard P. Reiff

INTRODUCTION

To the North American railroad industry, FAST, the Facility for Accelerated Service Testing, means track testing. Since its inception in 1976, well over 1 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.

This appendix provides readers with an overall background to the FAST program. During the last 4 years, a controlled set of experiments has been conducted to determine the engineering impact to track and mechanical components when subjected to a controlled increase in applied axle loading. 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.

Particular emphasis has been 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, (now the Transportation Test Center). The first loop covered 4.78 miles (Figure 1) and utilized some of the existing Train Dynamics Track to reduce construction costs.

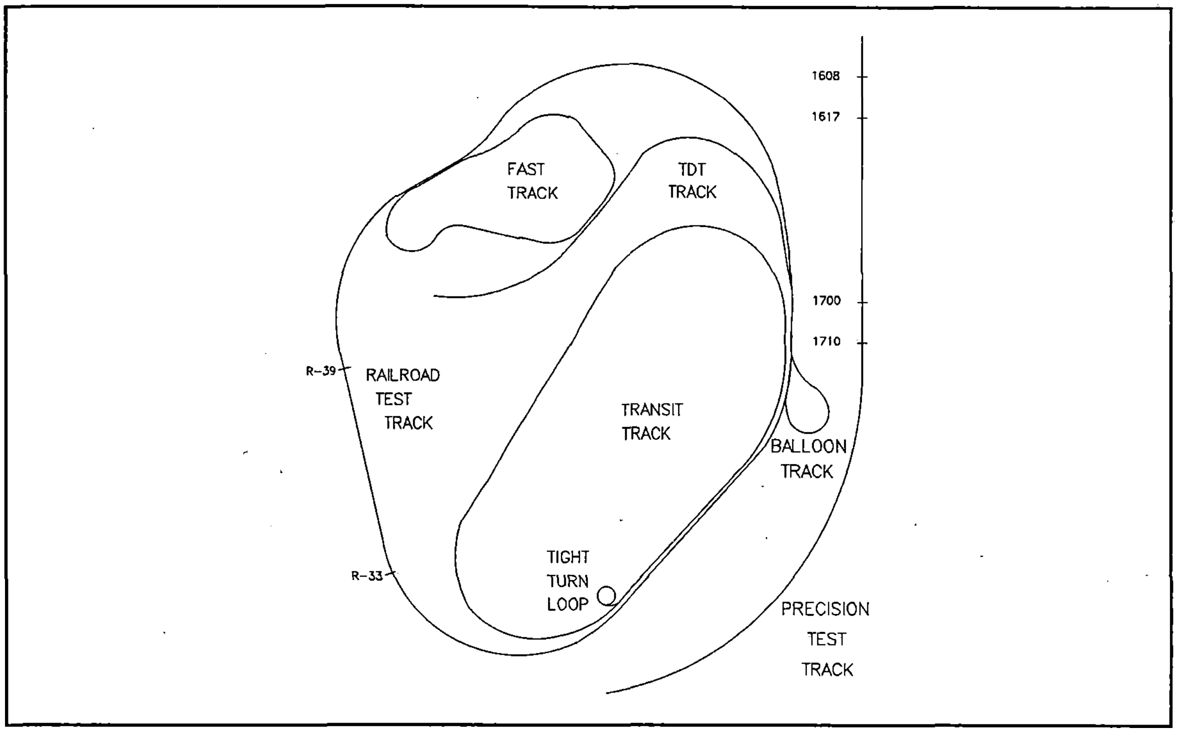


Figure 1. Test Tracks at High Speed Ground Test Center, Pueblo, CO, Showing General Location of FAST

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.

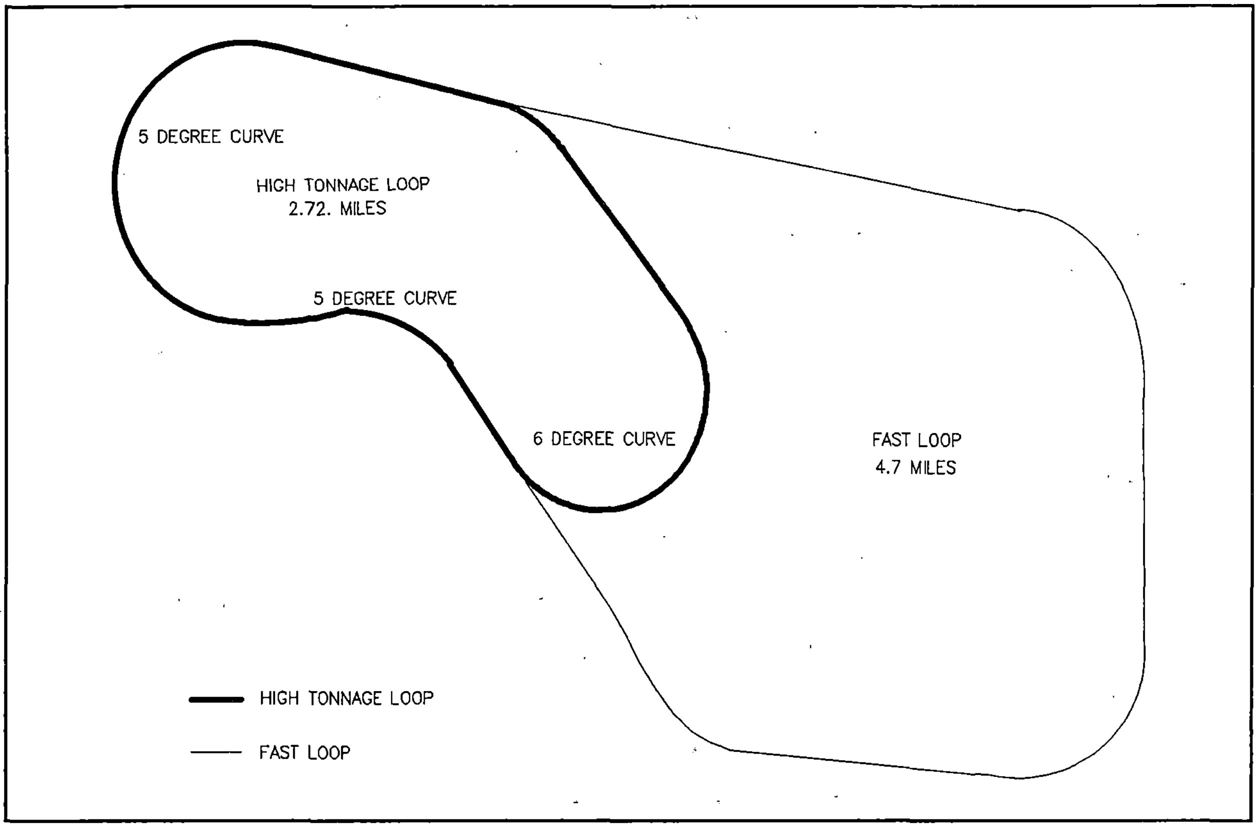


Figure 2. High Tonnage Loop

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.

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 loop was no longer affordable. To permit continued operation of FAST, a cut-off track was proposed, designed, and constructed using AAR funds (Figure 2). 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. The train operated only counterclockwise on the HTL. 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 has 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 a 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 as the block lengths would be so short, relative to the length of the train, that the locomotives would be continuously operating on a yellow approach. The signal system, which was solely used for broken rail protection and 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 rail of the loop was fully insulated from each other, and each rail became 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 insulated 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.

Another variation initiated with the start of the HTL was to lubricate only the outside rail of the loop. Previous tests were conducted by alternating 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, with this 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 7) 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 rapidly disappeared.

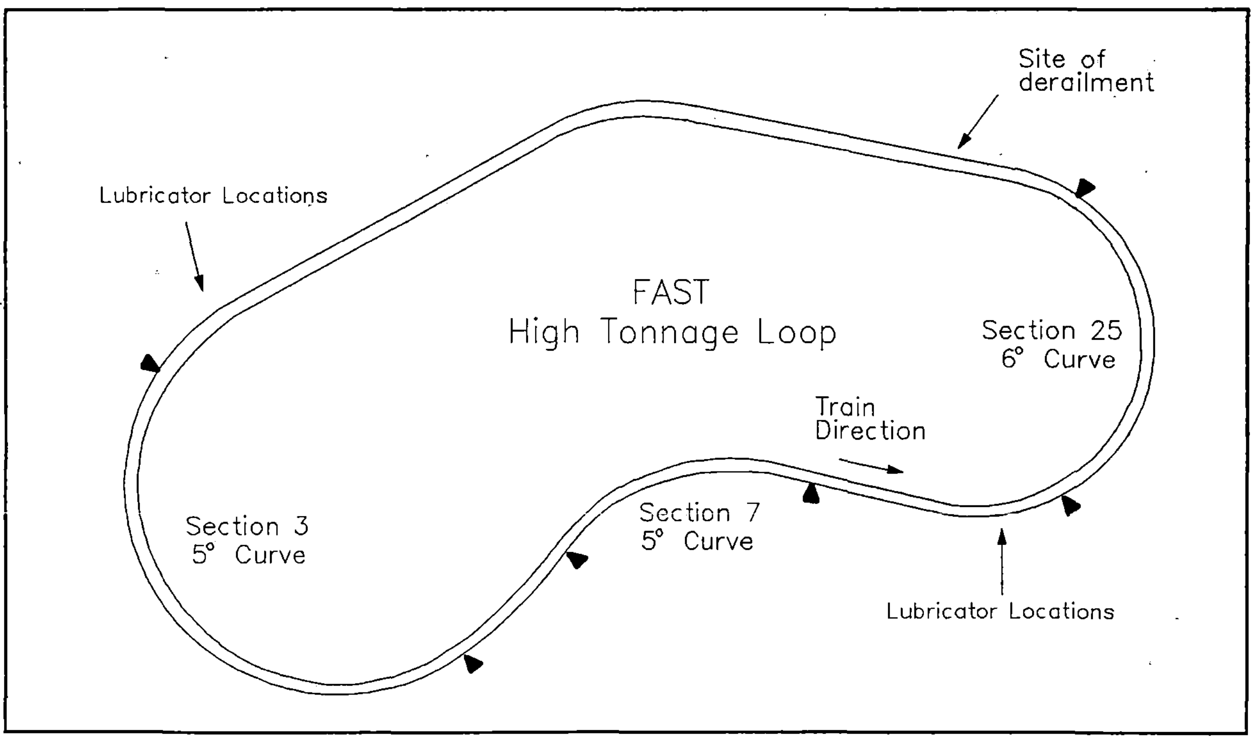


Figure 3. Lubricator Locations on the High Tonnage Loop

In July 1986, a major derailment occurred with the FAST train when the inside rail, after the exiting spiral in Section 25, overturned. Although track in this area was visibly in good condition, subsequent measurements located several pockets of weak gage restraint. A number of tests were conducted to determine the cause of the rail overturning. It was determined 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. It was 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, it was decided to place a small amount of contamination 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 due to the action from a passing train. The track inspectors at FAST routinely monitor these devices and check to see if excessive gage widening is occurring. This provides a safety check and gives advance notice if impending loss of gage holding ability is occurring.

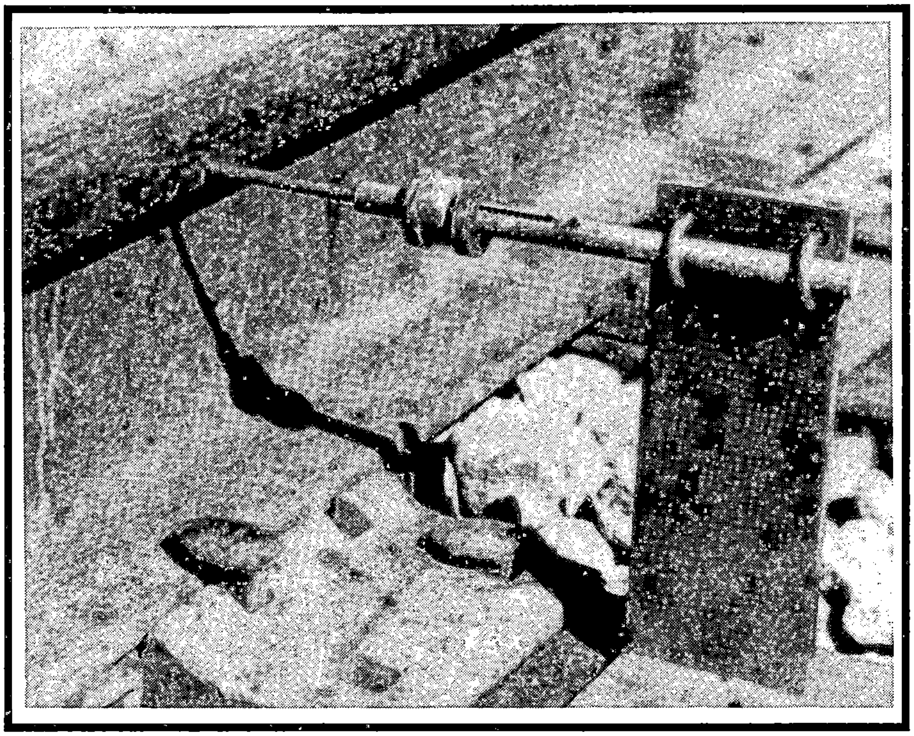


Figure 4. Tell Tale Installed on the HTL

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.

Up 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 1/2 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.

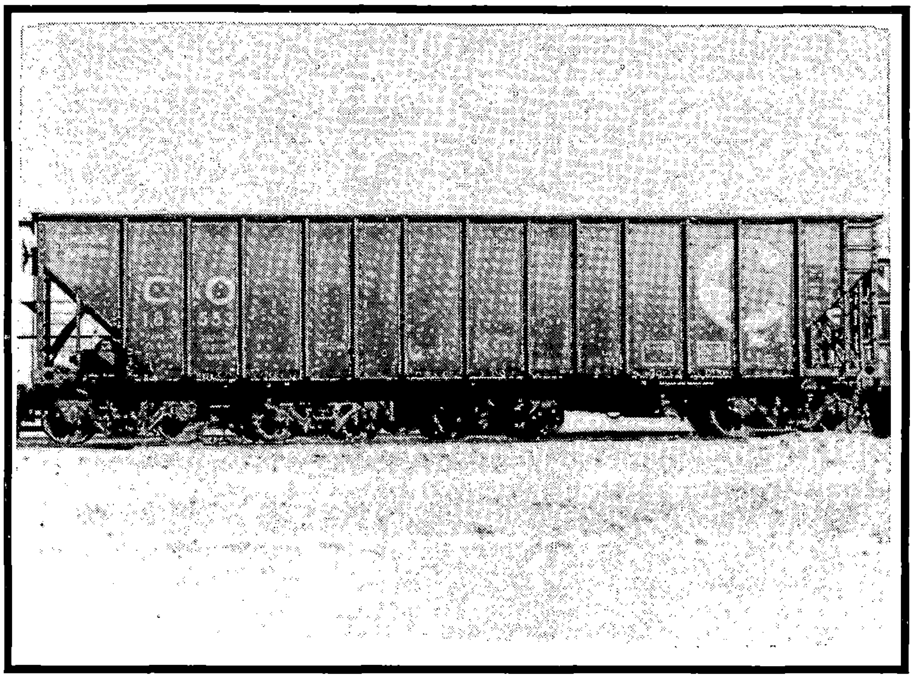


Figure 5. Typical 100-ton Capacity Car

The industry Vehicle Track Systems (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 track 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" X 12") and a longer truck wheel base (6'), as shown in Figure 6a and 6b. Table 1 summarizes the differences between 100- and 125-ton-capacity cars.

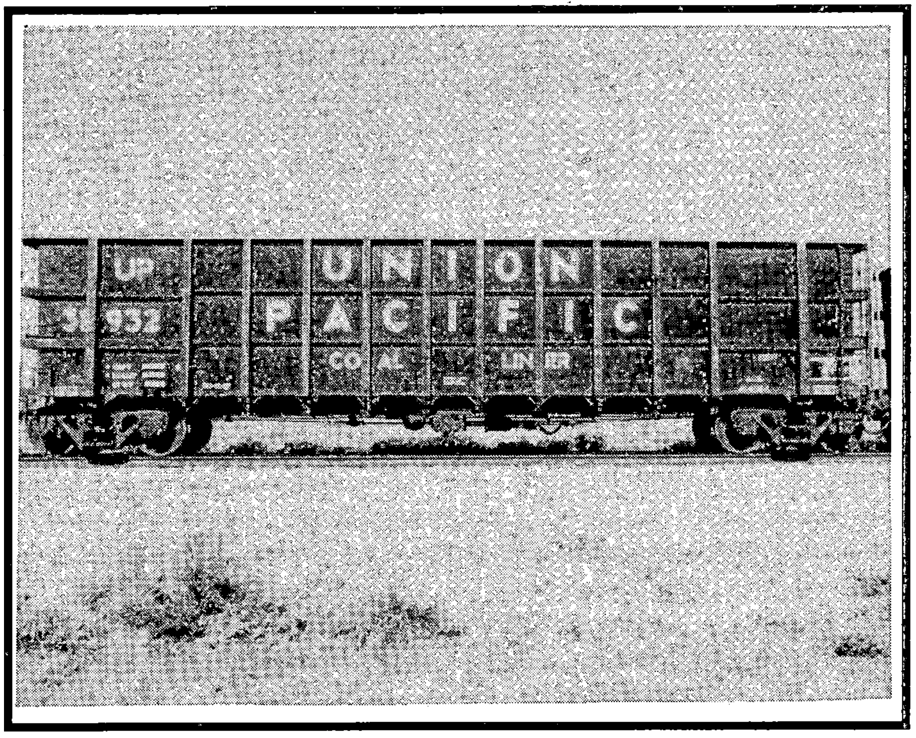


Figure 6a. Typical 125-ton Capacity Open Top Gondola

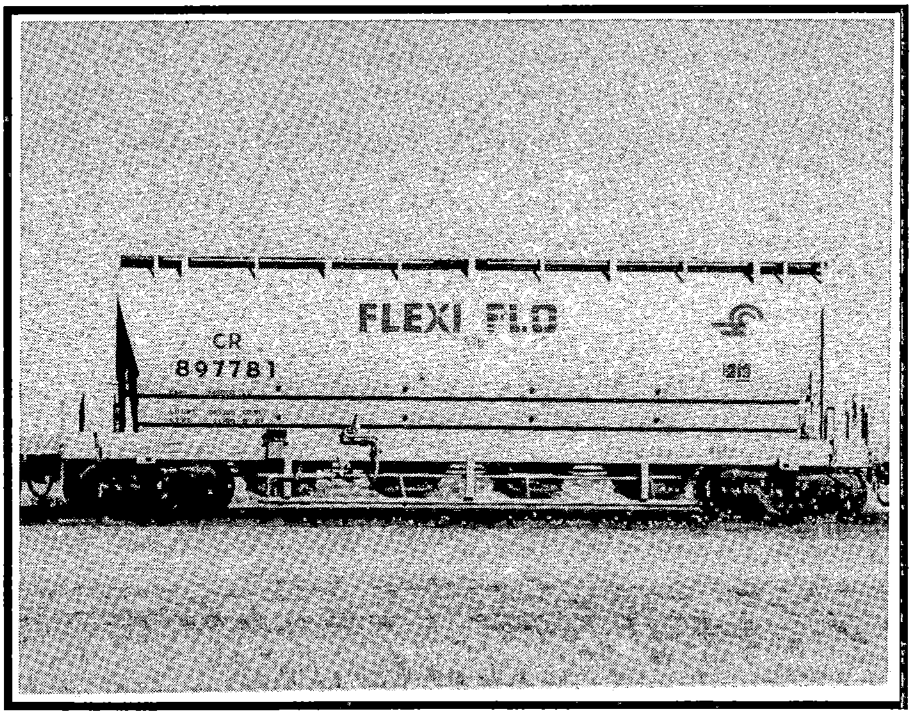


Figure 6b. Typical 125-ton Capacity Covered Hopper Car

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

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 wear rates, and fine tune track degradation and performance models, it was decided to operate the HTL using a heavier car.

The Heavy Axle Load (HAL) testing program was initiated in 1988. Up until this point in time, 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 a possible the basic experiments conducted with 100-ton equipment during the final 160 MGT of the HTL.

- The only major variable was to be that of increasing 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

HAL experiment plans 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" (Figure 7). The loop was divided into test zones, which were identified by numbers.

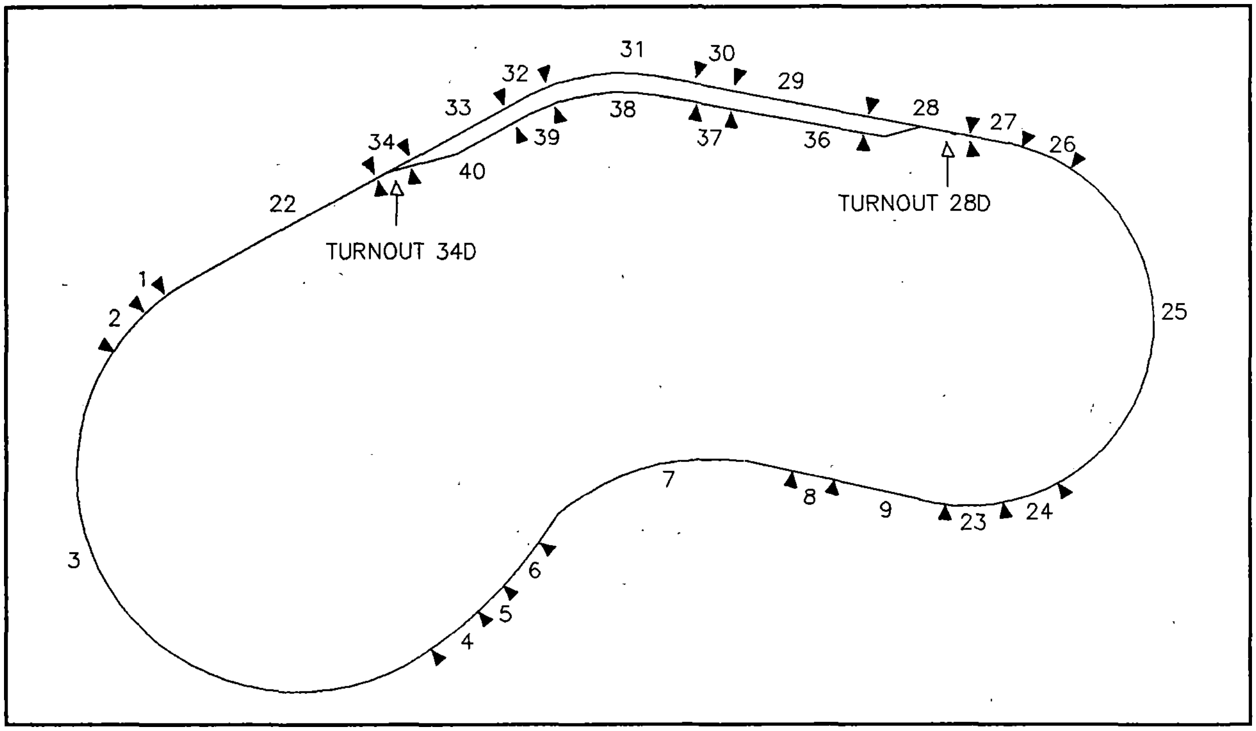


Figure 7. Map of HTL with By-Pass Track Added at Start of HAL Operations

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 that required small but controlled dosages of traffic between measurement and inspection cycles to be conducted. 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, minor rebuilds, and the replacement of a major turnout occurred. 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 Appendix B. 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 varied 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 8.

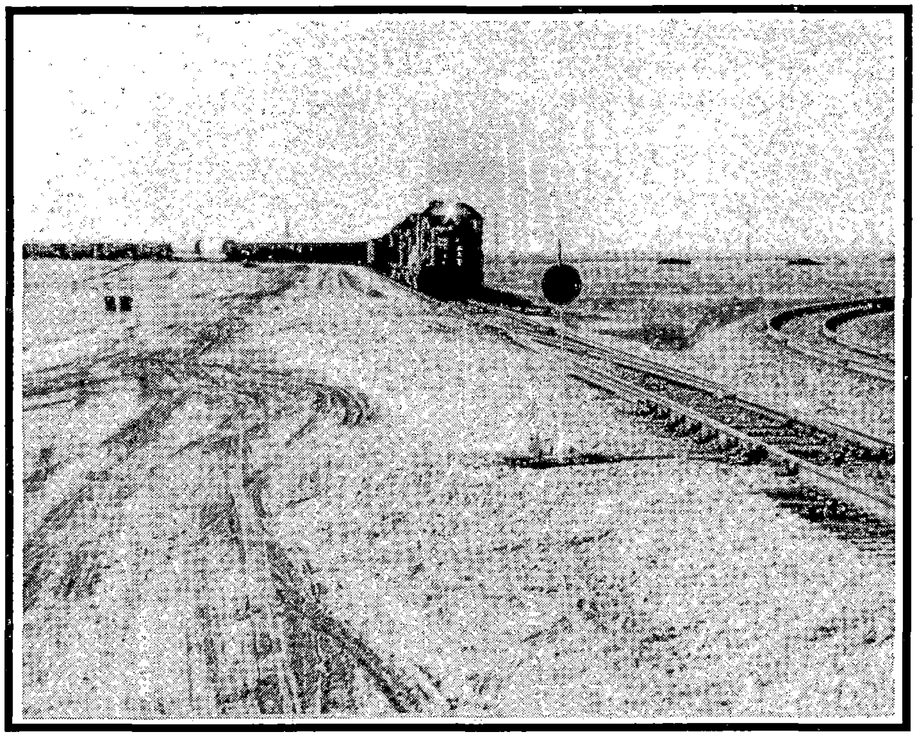


Figure 8. Typical HAL Train in Operation

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 consist 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. All curves were balanced so that at 40 mph a 2-inch underbalance condition occurred; that is, the high rail was loaded more than the low rail. 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.

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 2 1/4 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: As will be discussed later in this document and in the track maintenance section, spot and "housekeeping" maintenance requirements soared during the HAL Test as compared to the conventional axle load period. The night operation allowed daily access to the track in support of 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 on occasion even less. 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 HAL Train Operation, Lubrication Application and Control:

As stated previously, train direction was primarily counterclockwise, with the following exception:

After every 3 MGT of operation (+/- 1 MGT), the wayside lubricators were turned off and the power run around the loop to the rear of the train. Then up to 30 laps (no more than 0.35 MGT) were operated in a reverse (clockwise) direction with no lubrication added to the track. The clockwise dry-down operation served two purposes:

1. It removed excess lubricant from top of the rail to aid in ultrasonic inspections

2. It provided beach marks (growth rings) which are used to monitor and track the initiation and growth of internal rail defects, especially shells and transverse defects

After completion of the ultrasonic rail inspection, generally every 3 MGT, the train was turned end-for-end, and reset for a counterclockwise operation. Upon restarting train operation, the wayside lubricators were reconnected and full lubrication was usually obtained within 15 to 20 laps. The main lubricator providing the basic lubrication was located in Section 24 (a spiral) just before the beginning of the 6-degree curve.

During periods of cold weather, a backup lubricator, located in Section 1 about halfway around the loop from the main lubricator, was used to establish and occasionally maintain required levels of lubrication (Figure 3).

Lubrication levels around the loop were recorded using TTC's Lubricant Level Gage (often dubbed the goop gage). This device (Figure 9) 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.

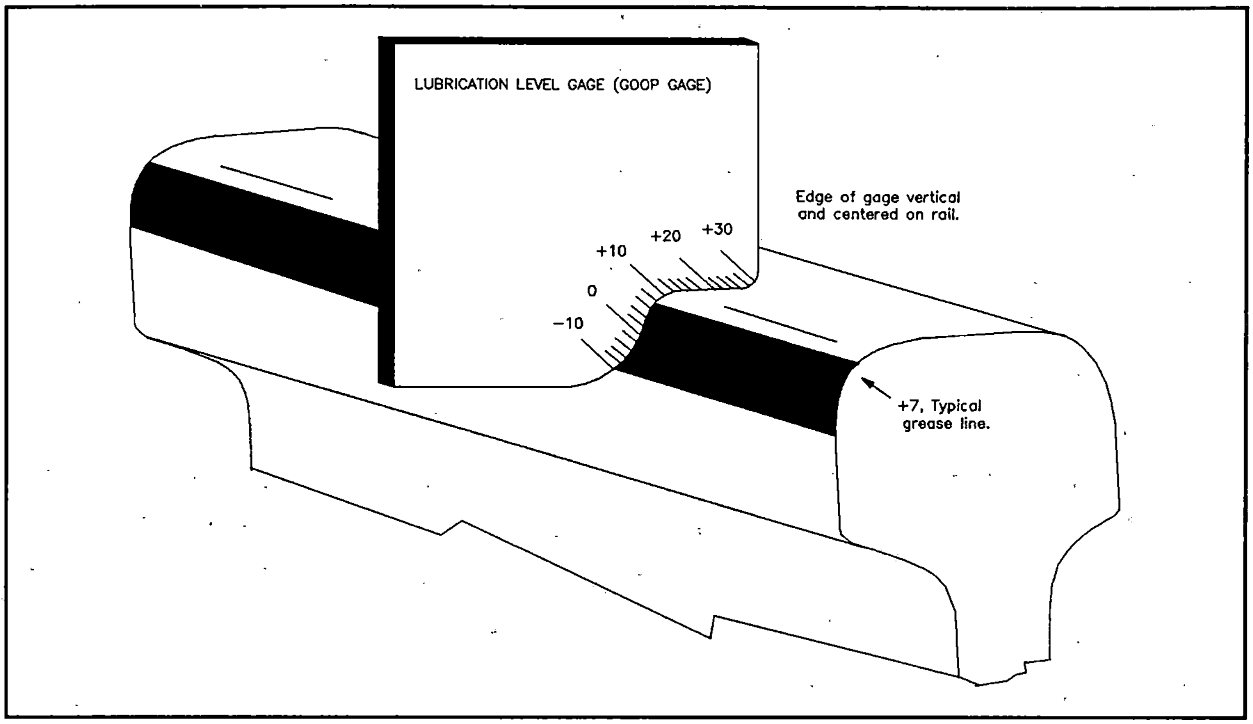


Figure 9. TTC's Lubricant Level Gage (Goop Gage)

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 was utilized to inspect and adjust the lubricators. The duty of the second track worker was to constantly rove and look 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. By use of 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.

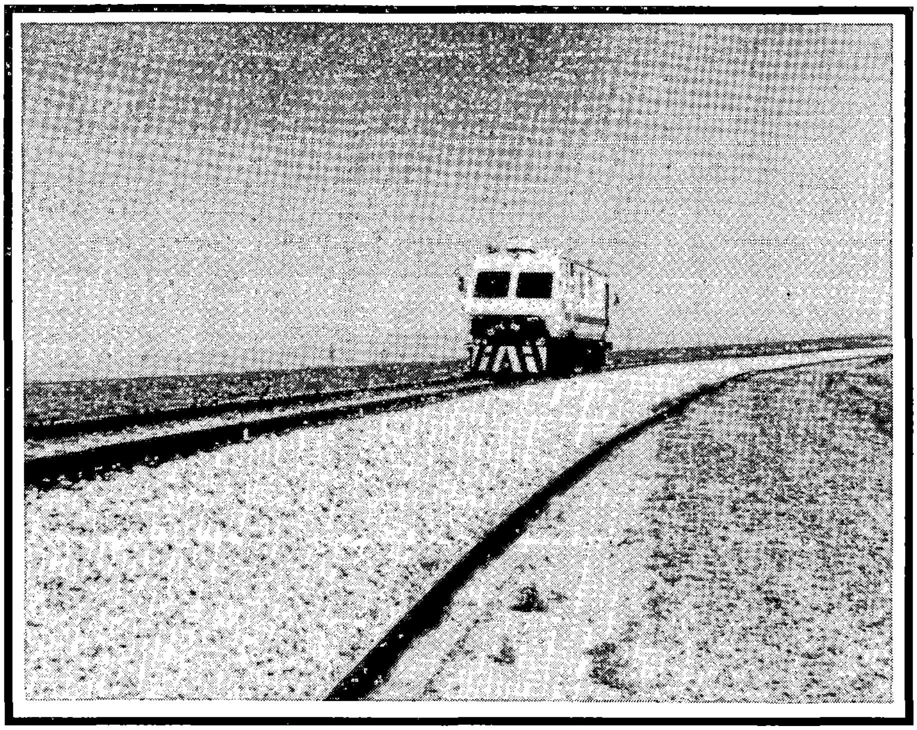


Figure 10. EM80 Track Geometry Car

Track geometry car inspections are scheduled after ever 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 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 train moves 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 "worst 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, with 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 lip 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 160 MGT 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.

A guideline for placement of most track components in the original HAL Test was that the item was already to 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.

Major test components that were added to the original configuration included:

- Replacement of the original AREA standard design #20 turnout with a state of the art heavy duty turnout with the same overall AREA geometry
- Addition of post tensioned concrete ties
- Addition of concrete ties designed for tangent track
- Addition of Azobe hardwood ties
- Installation of a Frog Casting Quality Test zone

The follow-on test program, in the form of at least a 100 MGT extension, will place more emphasis on new and improved materials that are designed to better withstand the effects of the HAL train environment.

General Observations after 160 MGT of Traffic

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 superelevation cant deficiency condition.

3. Ninety percent of the traffic was in one direction (counterclockwise); 10 percent went clockwise. This was accomplished in 300 lap/30 lap increments.

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. Most 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.

Comparisons between 160 MGT of 33-ton and 39-ton experiments were made with the same gross tonnage applied. For comparison purposes, all track related data is tied into this net applied load. As the axle loads were different for the two periods, a different number of cyclic loadings occurred to obtain the same applied tonnage. The 39-ton axle load period had approximately 16 percent fewer loading cycles for the same 160 MGT period as the 33-ton axle load test configuration (Table 2).

Table 2. Differences in Cyclic Loading for 33- and 39-ton Axle Load Periods with the Same Net 160 MGT on the Track

33-TON AXLE LOAD TEST	39-TON AXLE LOAD TEST
15,850 Trains	13,370 Trains
4,820,000 Rail Loading Cycles	4,065,000 Rail Loading Cycles
114 Million Tons of Lading Hauled	120 Million Tons of Lading Hauled

Note: Track loading for equivalent 160 MGT application of track load using 4 locomotives, 72 car average train. Heavier car required approximately 16% fewer trains to apply same loading onto the track, and hauled approximately 5% more net tonnage.

Major Items Showing Significant Impact during the HAL Period

Quality control of maintenance activities became even more important at FAST during the HAL period. The higher axle load caused even minor deviations and anomalies to degrade at a rate faster than before, thus workmanship during repair cycles was critical.

Track maintenance items could not be deferred to the extent permissible under the lighter load. Even small anomalies would often grow rapidly, when left to be repaired by the next shift.

All track work required careful blending and transition into adjacent areas. Sudden transitions must be avoided to prevent introducing bounce modes in vehicles, which could initiate additional degradation at other locations. Uniform support conditions, with little or no change in resulting track geometry, afforded the lowest track maintenance effort.

The surface condition of the rail became even more critical. Joint batter, welds and mechanical joints, (Figure 11), and rail corrugations (Figure 12) occurred more often and grew more rapidly under the HAL program. Metal flow at rail ends and frogs required significantly more maintenance effort than before.

Field weld failures (Figure 13) played an important part in the efficiency of operation during the HAL Test. Frequent failures, which were not observed during the 33-ton phase, resulted in a significant impact to train operations. The need for improved quality control during the welding process as well as improved welding techniques and materials to withstand the heavier axle loads was noted. The standard mix content of most field welds often lead to excessive batter, especially when used on 300 Brinell hardness (Bhn) and heat treated rails of standard chemistry.

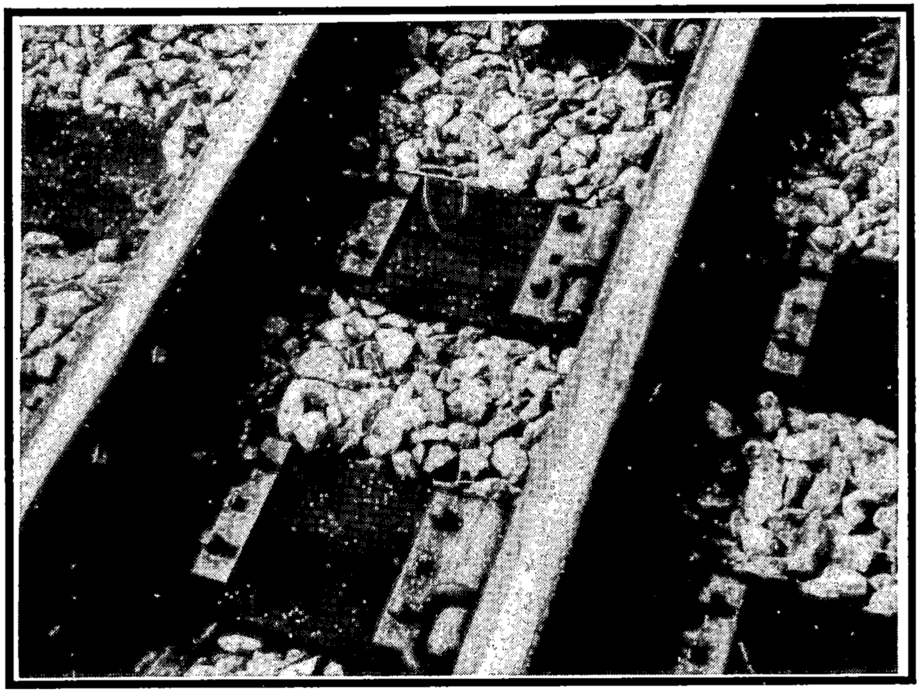


Figure 11. Typical Welded Rail Joint Batter

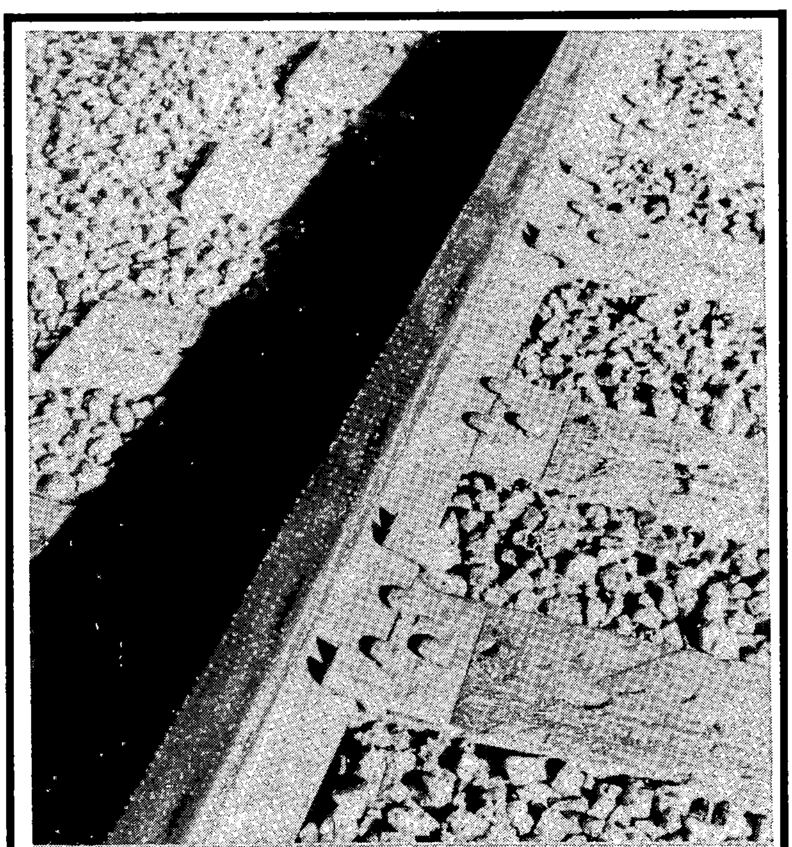


Figure 12. Typical Corrugations

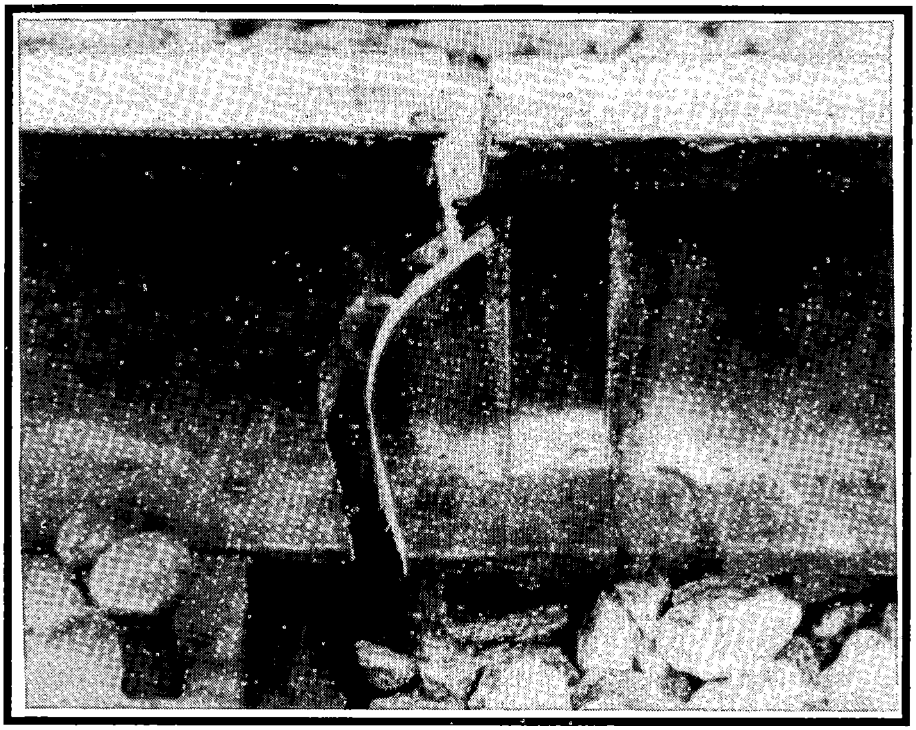


Figure 13. Typical Broken Field Weld

Under the HAL train operation, turnouts were second to field weld failures in the area of increased track maintenance. As with conventional field weld material, standard rail and frog components exhibited the shortest life and highest amount of maintenance and repair (Figure 14). Overall, turnouts required a significant increase in spot maintenance, grinding, and buildup requirements.

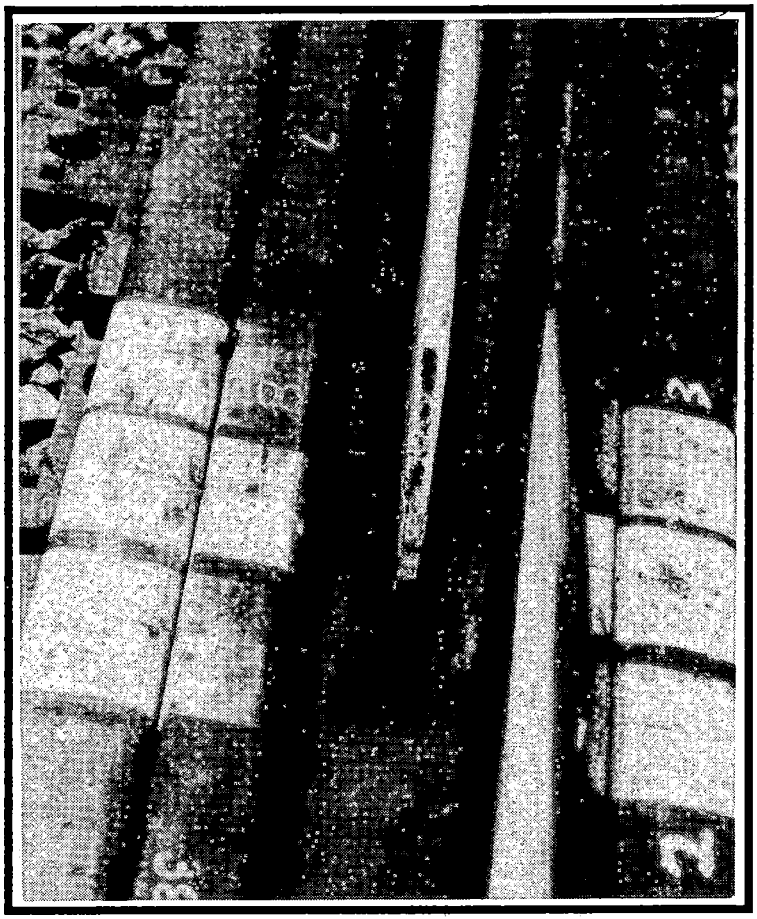


Figure 14. Typical Worn Frog Components

The overall track maintenance effort increased, with the following areas showing the highest demand.

1. Out of face grinding for corrugation control

2. Increased welding requirements

3. Immediate attention required for spot surfacing needs

4. Increased failure rate of field welds

In general, corrugations on tangent track, especially where standard rail was in place, became very common during the HAL Test. The increase in dynamic loads, due to vibrations, often required additional spot maintenance in these areas.

The heavier car emphasized problems using the lighter axle load geometry car. Low spots and pumping track areas, observed under traffic by the track inspectors, would not always show up as full depth defects on track geometry car inspection reports. The use of heavier geometry cars or heavier axle loads on geometry measuring equipment may eliminate this anomaly.

Many areas of the HTL were not totally rebuilt before starting the HAL train operation. In such areas, for example, where wood ties remained in place from the previous test period, more rapid tie degradation and higher replacement requirements than during a similar period with the lighter axle load were noted. Track inspectors had a more difficult time determining remaining tie life during the HAL train period, as the wood tie's ability to hold gage appeared to decline more rapidly, and with less visual indication. Hidden defects in the ties tended to degrade more rapidly, and with less visual warning, necessitating the replacement of more ties during cyclic renewals to ensure a safe operation.

The above observations are based on areas where back-to-back comparisons between 33- and 39-ton axle load data is available. A number of other test results from the 39-ton axle load phase include: localized cracking of selected concrete ties, early replacement of a standard turnout, and failure of one wood tie fastening system. Results from these tests cannot be compared to equivalent results under 33-ton axle loads at FAST simply because they were not under controlled tests during the HTL comparison phase.

These and other results were presented at the Workshop on Heavy Axle Loads, Pueblo, Colorado, October 16-17, 1990.

OVERALL TRACK MAINTENANCE IMPACT

Under the conditions of the FAST loop, the percentage of daily "spot" or "housekeeping" track maintenance effort increased significantly when compared to the axle load increase. Labor hours increased over 60 percent compared to an axle load increase of 20 percent.

The increase in spot maintenance requirements was determined by collecting records of all daily track maintenance activities recorded by field personnel. Each "routine" maintenance requirement, that is, an activity not associated with special requests due to experiment objectives, was assigned a standard labor hour rate. For example, each time a low joint required tamping a standard rate of 0.5 labor hours was applied while to repair a broken weld a standard rate of 16 labor hours per occurrence was applied. Also excluded were major component changeout efforts, such as major rail replacements due to wear, new test component installations, and other "capital improvement" work.

By eliminating the special request maintenance items, such as replacement of a weld due to laboratory analysis requirements, only those maintenance activities directly associated with track degradation were monitored. The use of standard labor hour rates for each activity also eliminated many of the inherent "unique" situations found at FAST. At FAST many maintenance activities require special care due to adjacent instrumentation, the need for pre- and post-measurements, and position of special test materials. Use of the standard labor hour rates permits the total maintenance demand to be normalized for comparison purposes.

The test loop was subjected to a number of changes during the course of the 33- and 39-ton axle load experiments. Both experiments, however, started out with track in approximately the same condition and with similar materials. As tonnage was applied, track materials were changed and new test materials installed, thus making direct comparisons more difficult as the programs progressed. Due to these changes comparisons after the initial 85 MGT are unreliable.

Figure 15 indicates the cumulative labor hours of effort for the following basic track maintenance categories: joint maintenance, rail maintenance, surface and lining operations, turnout maintenance, and miscellaneous. A total effort in labor hours is also shown. These values represent the total number of standardized labor hours for each maintenance category required to keep the track in the same general condition for the initial 85 MGT of each test train period.

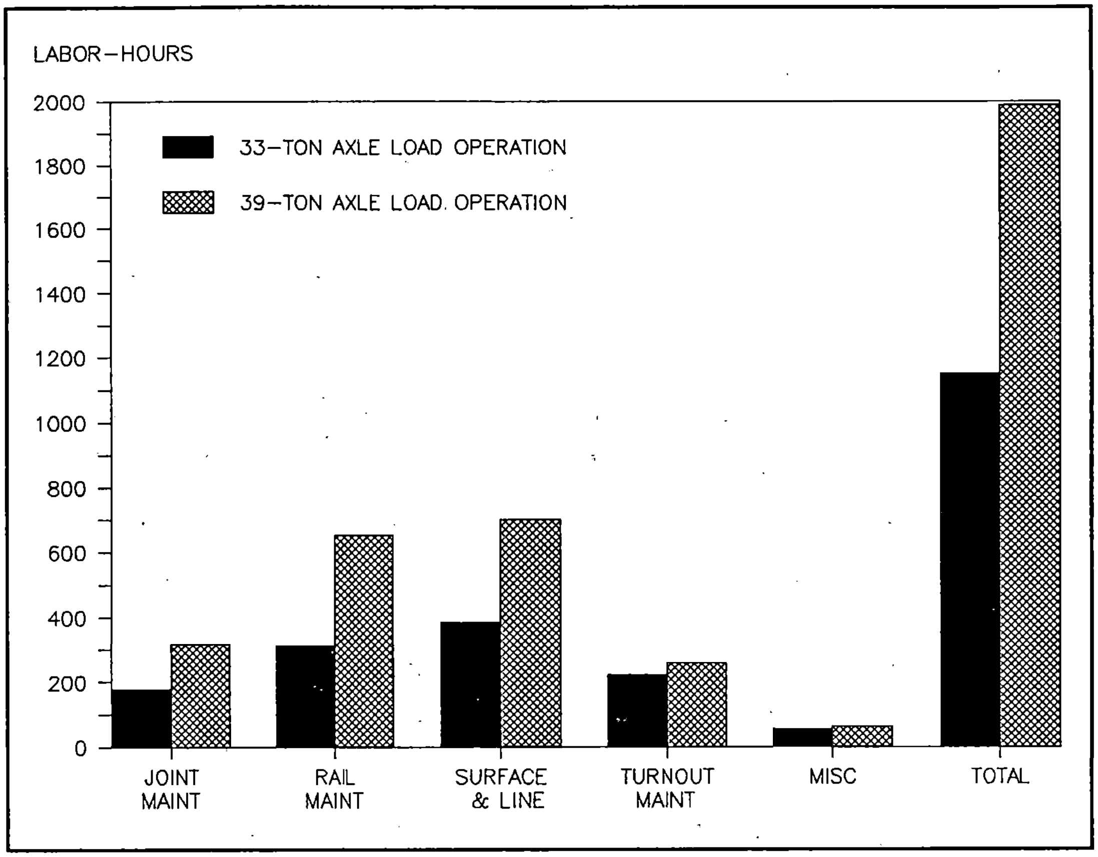


Figure 15. Breakdown of Track Maintenance Effort

Figure 16 shows the cumulative labor hour maintenance data by MGT for each test train period. For reference, the total labor hours for the 3-ton axle load test are shown beyond the 85 MGT base comparison period. Data beyond the initial 85 MGT baseline is shown for the 39-ton axle load test period. Labor hour maintenance totals continued at about the same rate per MGT as tonnage was accumulated to 100 MGT.

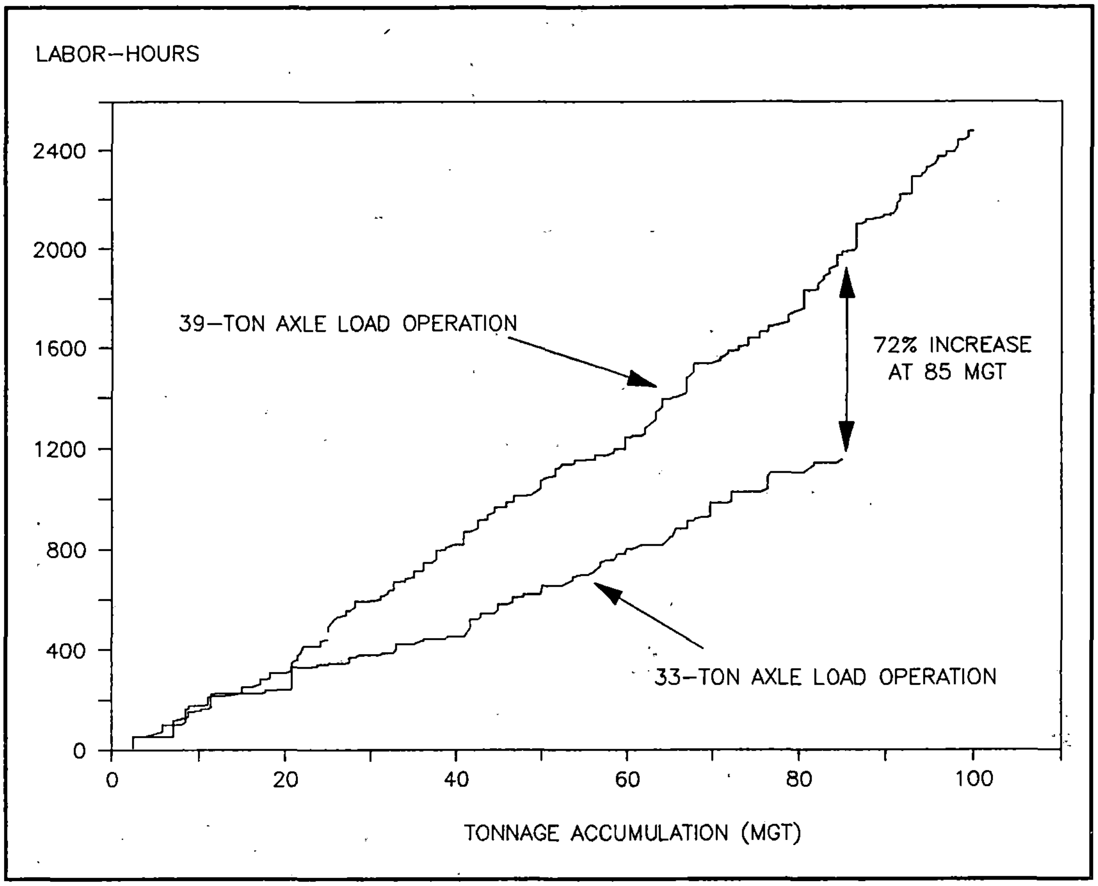


Figure 16. Track Maintenance Effort as a Function of Tonnage

The difference in cumulative labor hours after 85 MGT between 33- and 39-ton axle load test periods indicates a 72 percent increase due to the heavier axle load. Caution must be used in interpreting this data, as a significant error band in the total figures does exist. These labor hours represent spot maintenance demand, and as such is often dependent on the discretion of the field track supervisor. The data does not represent long-term replacement demand, such as out of face tie renewal, ballast work, or other capital investment related activities. The spot maintenance efforts represent comparison of activities needed to keep similar track at the same general geometry level during two periods of axle loads.

The long-term effects of rail wear, ballast work, wood and concrete tie life, fastener life and other capital intensive efforts have not been fully developed, but as the information and data trends indicate, the effect is not nearly as dramatic as the 72-percent increase in spot maintenance demand.

Results at FAST indicate that conventional track structure, as utilized by the majority of North American railroads, can survive 39-ton axle loads with some basic strategies which include:

- An increase in the attention to track maintenance detail and quality of work is required.
- Improved uniformity of work in blending repairs into the adjacent existing track structure will reduce non-uniform and impact loads.
- Areas of high impact forces, such as at frogs and within turnouts, require premium materials to withstand repeated loads
- Where premium materials are not used, such as in existing track that is to be subjected to a high percentage of increased axle loads, faster capital replacement will occur

Areas of Track Requiring Improvement

A number of basic areas of improvement have been identified for future evaluations. These are areas that could withstand the increased axle loads but required a disproportionately higher level of maintenance, based on FAST experience.

In areas where continuously welded rail (CWR) is utilized, which is the case in the majority of heavy mainline in North America, two major areas of improvement were identified:

1. The performance of field and shop welds declined significantly under the HAL train. In all cases weld batter must be reduced to lower the degradation of ballast and ultimately surface and lining demands. In the case of thermite type field welds the failure rate as well as batter rate was observed to be unacceptably high.
2. Where field welds are not practical or possible, such as at insulated joints or emergency plug repair sites, joint maintenance becomes critical. Emergency bolted plugs require immediate replacement with field welds when possible.

In areas where jointed rail is in place, early replacement with CWR is very desirable. Where complete replacement of jointed rail is not possible, or where programmed upgrades to an existing secondary line require operation over jointed track for a period of time, the FAST experience suggests the following:

- Eliminate jointed rail on curves. The few areas on FAST where jointed rail existed on curves resulted in significant track geometry degradation and high maintenance.
- In areas where jointed rail exists, repair of bent rail ends and loose fitting or worn bars must be completed immediately. Ballast memory was a higher problem under the HAL train than in previous FAST operations.
- Repeated tamping of joints, especially with certain ballasts that tended to become rounded with degradation, is ineffective. Repair of the rail surface problem (bent rail ends or joint bars) was required before a joint maintenance problem could be reduced.

Rail quality has improved over the last decade to where standard rail of 300 Bhn is usual for most installations, and premium rail of 340 Bhn and higher is found on most curves. Comparisons using 248 Bhn rail as a base are not directly applicable as many railroads have already eliminated this older rail on curves. There are cases, however, where older rail is still present on tangents of main lines and careful inspection may be needed before operating a significant amount of HAL type traffic. In the category of running surface materials, the following areas of improvement are suggested:

- Field inspections suggest that rail that corrugates easily should be eliminated or it will require increased out-of-face grinding maintenance. Corrugations on tangent track became common on the FAST loop in areas where older rail (less than 300 Bhn) was utilized. Even where 300 Bhn rail was used in tangents, corrugations were noted; especially, in turnouts. The requirement for premium rail in tangents needs to be investigated as a potential means of reducing grinding requirements.

- In turnouts, top quality materials are desirable. On FAST, the use of non-premium materials will lead to early failure along with high maintenance and repair costs. Rapid degradation was noticed where non-heat treated rails were used in components such as frog wing rails.
- Improved turnout geometry and component strength should be investigated to reduce spot maintenance requirements.
- Once started, the surface degradation leads to a rapid degradation of other components or adjacent areas, requiring spot maintenance activities to be scheduled on a frequent basis.

The items summarized above deal mainly with the ability of materials and components to withstand the heavier load.

<u>General Maintenance Policies of Railroads in the Daily and Cyclic Inspection, and the Maintenance Duties of Track Personnel</u>

Results of the FAST/HAL investigation point to the following areas where improvements to these duties would be beneficial where a large number of HAL type traffic is to be operated:

- Lower tolerance for deferred maintenance was noted. Small anomalies tend to degrade much faster under the HAL environment, thus reducing the allowable time between locating and repairing such defects.
- Improved methods of locating these minor defects will probably be needed, especially with automated track geometry systems. The need to identify small surface related defects, such as engine burns, low joints and other housekeeping requirements is increased.
- For long-term maintenance planning, wood tie integrity measurements are needed.
- Finally, once the above items are located, better tools for spot maintenance repairs may be needed. Spot work such as welding, grinding, and tamping of rail surface will take on even more importance with HAL traffic.

The major thrust of the HAL program to date has been to document the effect on track component wear and track maintenance requirements with increased axle load. Track, of course, does not degrade significantly by itself. The vehicles that operate over the rails are the major cause of this deterioration. The present FAST consist was selected for a number of reasons; however, the major factor was that the mechanical design of car bodies and trucks were very similar to that used for the previous test periods. Thus, the only main variable would be the axle load, allowing back-to-back comparisons between previous FAST tests with the least number of input variables.

Review of the results to date indicates that some areas in the mechanical equipment side need additional investigation, along with long-term research and development. With the existing train, which is made up of equipment designed and built in the late 1960s, allowable defects in components, especially the wheels, must be investigated under direction of the Vehicle Track Systems Committee. These include:

- Size of allowable wheel flats
- Limits of out of round wheels
- Limits of allowable surface defects, such as spalls and shells

These items may lead directly to increases in dynamic loads into the track structure, especially at the rail and tie level. Limiting the allowable size of such defects could result in a significant increase in the life span of the rail, tie and fastener. The extent to which these loads are transferred to various components in the track structure is not fully documented; however, additional investigations are planned.

Alternative car and suspension designs also need to be investigated. By reducing the impact and dynamic loads into the track structure, life of track components could be increased. Areas in mechanical design that need to be investigated include:

- Evaluate the effect of reducing unsprung mass. With a larger wheel diameter (and subsequent heavier wheel mass) the HAL car is already at a disadvantage, when compared to the conventional car. Additional design work in the suspension area may help reduce this effect.

- Premium trucks, which not only improve curving performance but reduce vertical dynamic forces, have been and should be evaluated.

- The effect of axle spacing, articulated cars and other designs should be investigated. The existing HAL train applies vertical loads at specified truck and car axle spacings, which are different than that of "double stack" and other alternate car designs.

Summary of Limitations

The future investigations, for both track and mechanical components, are based on the results from the existing FAST loop configuration, train operating policies, track maintenance standards and equipment designs. The results must be reviewed with some specific limitations in mind. These were stated in detail during the introduction section, and apply to all FAST test results to date. Limitations of the current test suggest changes that may be included in future test programs. These include:

- Variable speeds, with resulting different overbalance and underbalance conditions on curves should be investigated.
- Since the HAL program has been conducted with equipment manufactured in the 1960s, new mechanical equipment technology, including suspension, truck design, and wheel spacing, will be evaluated.
- Traffic mix of FAST is all loaded traffic, with no light cars or empties. The percentage of HAL traffic on some revenue lines may not be a high percentage of the overall tonnage.
- FAST produces a relatively mild environment for in-train forces. The effects of heavy braking (air and dynamic), and results from train forces from slack run in, grades and speed changes have not been addressed. Such forces will play a role not only in mechanical component fatigue life, but in forces that must be absorbed by the track structure as well.
- The dry climate at FAST, coupled with the stiff subgrade, may have reduced some of the track degradation effects of the HAL train. Future investigations will include a "low modulus support" track segment that is intended to evaluate the effects that HAL has on track geometry retention.

FUTURE

The results of the 33- and 39-ton axle load experiment have been presented in this document. The ongoing extension, which is utilizing the same train configuration and operating modes, started in late 1990.

This extension is being operated primarily to address some of the specific areas of track components that indicated immediate improvement was needed. Two major areas in this category include turnouts and field welds. Other test areas, such as fatigue of rail, grinding and ballast life, did not exhibit a full life cycle during the initial 160 MGT, and additional operations will be required to complete experiment objectives. Finally, the performance of some components, although adequate, could still be improved. The installation of a full matrix of tests to evaluate new and improved fastening systems, ties, rail and other track components will allow the evaluation of such items to continue.

Future FAST/HAL investigations will need to incorporate advanced technology in mechanical equipment designs. The program goals will be to monitor the effects of such equipment on existing as well as other improved track components. This will allow the engineering staff to determine the effect that such designs will have, if any, on overall operating and maintenance costs of a Heavy Axle Load system.

APPENDIX B

1990 HEAVY HAUL WORKSHOP AND FAST/HAL PROGRAM DESCRIPTION OF EXPERIMENTS

DESCRIPTION OF EXPERIMENTS

Below is a summary of the experiments that have been implemented to meet the objective of the HAL Program.

Rail Performance Experiment

The Rail Performance Experiment is one of the major tests currently being performed at FAST. The objective of this experiment is to determine the effects of 39-ton axle loads on rail wear, rail defect occurrence and growth, corrugation occurrence, metal flow, and weld batter.

This test is concentrated on the high rail of the three main curves of the HTL. The lubrication of the outside rail dictates that fatigue tests occur in Sections 25 and 3. Rail wear testing is performed in Section 7 due to the dryness of the high rail.

Rails of varying cleanliness, chemistry, hardness, and profiles were installed to see how they affect the test parameters. Cleanliness pertains to the volume and type of inclusions in the steel; chemistry refers to the chemical make-up of the steel. The hardness of the rails varies from 269 Brinell (old standard practice) to 370 Brinell (in-line head hardened practice), and rail profile generally pertains to the crown radius of the rail head, *i.e.*, how round or how flat the rail head is.

Though most of the rail was new at the beginning of the test, some had previous exposure to traffic. This includes conditioned rails with 150 MGT of 33-ton axle load exposure and "dry break-in" rails with 15 MGT of nonlubricated 39-ton axle load exposure. Also, some of the new rail installed was the same type that was tested during the 100-ton car test. The 100-ton and the 125-ton test results on this particular rail can and will be compared with each other.

A special rail grinding/conditioned rail experiment is being performed in Section 25. This test consists of four test zones: (1) rail with 15 MGT of dry 39-ton axle load exposure, (2) rail with a profile ground to match a worn profile, (3) asymmetrically ground rail, and (4) rolled rail. This test will be used to determine whether rail fatigue life can be improved by conditioning the rail with dry exposure, grinding the profile for "artificial wear," or grinding an asymmetrical rail profile pattern to alter the wheel/rail contact geometry.

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 environment. The experiment includes three separate areas of investigation: (1) wood tie and fastener performance, (2) gage restraint ability, and (3) concrete tie and fastener performance.

Test zones are established in the 5- and 6-degree curves of the HTL. Measurements include track geometry, fastener stiffness, tie plate cutting, visual inspections of concrete ties, and dynamic rail loads and deflections.

The data will be analyzed to determine the behavior of the tie/fastener systems as a function of traffic accumulation (MGT) and compared to performance under the 100-ton consist.

The experiment also addresses the ability of wood ties with cut spike fasteners to maintain gage.

Measurements of dynamic lateral wheel force and lateral rail deflection will be taken at various locations on the HTL at various increments of MGT accumulation to characterize the dynamic performance of the various systems. The dynamic vertical and lateral wheel loading of the test zones will also be characterized on a regular basis.

Turnouts and Frogs

Early in the 100-ton test, turnouts were evaluated for component performance. A similar experiment is being conducted during the HAL phase with two #20 turnouts.

The experiment will measure the load environment, geometry degradation, vehicle response, and stiffness of the turnouts at specific levels of tonnage accumulation.

The by-pass track will permit operation on both sides of the turnouts, with a minimum of 20 percent of the traffic on the diverging side of the turnout. Since the traffic on the HTL is primarily unidirectional, one turnout is exposed to predominantly facing point movements and the other to trailing point traffic. Load data is collected through the turnouts using an instrumented wheel set and rail mounted strain-gage circuits. Dynamic lateral, vertical, and longitudinal rail deflections are taken at the point and heel of switch, and at the point of frog and guard rail area. Vertical and lateral track stiffness measurements are taken at selected points throughout the turnout.

A test of newer design turnouts using moveable point frogs and concrete ties may be also be implemented.

As part of the turnout and frog test, a "frog farm" was recently installed in the tangent track of Section 22. The five isolated frogs (frogs not in turnouts) consist of three rail-bound manganese and two European designed frogs. The objective of this test is to compare the performance characteristics of the frogs. Criteria include insert wear rates and maintenance time demanded. The inserts were radiographed prior to installation to determine inclusion and void content. These results will be used in performance evaluations.

Track Irregularity

The Track Irregularity Experiment is designed to determine track geometry degradation at rail profile irregularities such as battered welds and joints.

The affect of vehicle dynamics, specifically roll and bounce motions, on track degradation will be observed. The key parameters being measured are applied wheel loading as measured with an instrumented wheel set and rail mounted strain gage circuits, and track geometry. Supporting data includes longitudinal rail profile and vertical track stiffness.

Ballast Resistance Characterization

The Ballast Resistance Characterization Test will define the rate at which track lateral resistance as provided by the ballast section is restored with traffic, after disruption of the ballast section by maintenance.

Ballast Test

A comprehensive ballast experiment compares performance of granite, limestone, traprock, and dolomite ballasts, with results obtained during the 100-ton phase. A test zone of each ballast type is established on a 5-degree curve, and varies in length from 570 to 900 feet.

Each test zone contains approximately 8 inches of sub-base material between the subgrade and the ballast section, and a below tie ballast-depth of 12-15 inches at the low rail. Track geometry, loaded track profile, track settlement, sieve analysis, ballast density, and vertical track modulus are measured in each zone.

Ballast degradation, track strength, and track geometry are the parameters used to evaluate ballast performance as a function of MGT accumulation.

Subgrade Test

The potential for subgrade failure is one of the more troubling issues in evaluating track performance under heavy axle loads.

Available analytical models have not been validated for axle loads of 39-tons. One hypothesis predicts linear increases in subgrade pressures and deformations while another postulates a non-linear increase resulting in additional maintenance requirements. The potential for complete subgrade failure also exists.

To provide validation data, pressure cells and extensometers, which measure subgrade deflection, have been installed at two sites on the HTL. Test site is located on tangent track with slag ballast. The site is on a fill area with a below tie ballast depth of 18 inches.

Unlike the other HAL experiments, the 100-ton comparison is not based on early FAST data, but on subgrade pressures and deflections acquired during the final months of the 100-ton operation. This was done to obtain as closely as possible the same soil moisture and compaction levels between programs.

Mechanical Components Performance

During the initial stages of the HAL Program, a wheel wear evaluation will be conducted as a part of the Mechanical Component Performance Experiment. The objective is to determine the wear rate and fatigue behavior of the 38-inch, class C wheels expected to be used in revenue service with heavy axle loads. A few class C, 36-inch wheels with 33-ton axle loads will be inserted into the HAL consist for comparative purposes.

The test consist will include three HAL cars equipped with standard three-piece trucks, and three 100-ton cars equipped with standard three-piece trucks.

TRAIN OPERATION

A fleet of high side gondolas and covered hopper cars has been obtained and loaded to a gross vehicle weight on the rail of 315,000 pounds. To replicate the center of gravity typical of these cars in revenue service, the gondolas are loaded with a lightweight aggregate material with a density similar to coal and the covered hoppers filled with sand to simulate concrete.

Normally, the consist includes 65 to 85 HAL cars plus the three 100-ton cars of the Mechanical Components Test. 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 three days per week, with two days set aside for track maintenance, and car inspection and repair. A typical day of train operation produces 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 a counterclockwise direction on the loop, except for 30 laps every 3 MGT when the train is reversed. The reversal of direction alters the shape of rail defect growth rings, permitting accurate tracking of defect growth rates. 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:

Rail Head Profile

The Yoshida rail head profilometer is used to record a 1:1 copy of the rail head profile.

Rail Hardness

Two measurement devices are used to measure Brinell and surface hardness at several points at the top of the rail head.

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 Rail 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 rail head and base lateral displacement relative to the tie.

Track Geometry

Track geometry is measured with an EM80 track geometry car.

Vertical Track Stiffness

A known vertical load is applied to the rail and the resultant vertical rail deflection measured.

Spike Pullout Resistance

A load cell is used to measure the force needed to pull the spike from the tie.

Single Tie Push Test

A load cell is used to measure the force needed to displace individual ties laterally through the ballast section.

Ballast Sieve Analysis

Gradation analysis of ballast per the ASTM C136 modified procedure.

Ballast Flakiness Indices

Classification of ballast particles having a thickness dimension less than 60 percent of nominal particle size.

Ballast Elongation Indices

Classification of ballast particles whose length is greater than 180 percent of nominal particle size.

CIGGT Shape Factor Test

Ballast particles retained on a specific sieve are measured for smallest width and longest dimension. Shape factor is the ratio of the sum of the longest dimension to the sum of the shortest width.

Ballast Density

A nuclear density probe is inserted into a steel pipe which has been installed through the tie and ballast to 3 inches above the subgrade/ballast interface to measure the ballast density.

Loaded Track Profile

The top of rail elevation is measured under the wheel of a fully loaded car.

Level Net

Top of tie elevation is taken immediately outboard of both rails. Tacks are used to ensure subsequent measurements are taken at the same location.

Subgrade Classification

Laboratory tests are performed in accordance with the ASTM D2487 standard to classify soil for engineering purposes.

Moisture Content

Laboratory tests are performed in accordance with the ASTM D2216 standard to determine the soil moisture content.

Liquid and Plastic Limit

The ASTM standards D423 and D424 are used to determine the liquid and plastic limits of the soil.

Instrumented Tie Plate

The rail seat load on wood ties is measured with instrumented tie plates which have been calibrated in track.

Dynamic Soil Measurements

The dynamic response of pressure cells and extensometers installed in the subgrade under the ties is monitored.

Static Soil Measurements

The measurement is accomplished by loading the track incrementally to a maximum of 50,000 pounds at each tie where subgrade pressure transducers have been installed.

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.

Longitudinal Rail Profile

A profilometer traces the rail head profile in the longitudinal direction for a length of 36 inches.

Goop Gage

A template is used to measure lubrication position on the gage side of the rail head.

Rail Flaw Monitoring

The rail is inspected for internal defects using ultrasonic equipment.

Rail Corrugation

Running surface degradation of rails and welds are monitored using the longitudinal rail profilometer.

Dynamic Corrugation

Strain gage circuits are mounted on the web of the rail to measure the load at the corrugation valley and the peak.

CN Profilometer and Snap Gage

A CN profilometer is used to collect wheel profile data and a TTC snap gage measures wheel area loss.

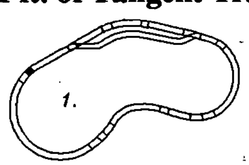
Metallurgical Evaluation

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.

DESCRIPTION OF HTL TRACK SECTIONS

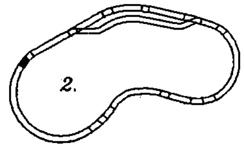
The typical HTL track structure consists of continuous welded rail fastened to wood ties with cut spikes and fully box anchored at every second tie. Included in specific test zones are concrete ties, jointed rail, and elastic type rail fasteners. A description of each section follows:

Section 1
171 ft. of Tangent Track



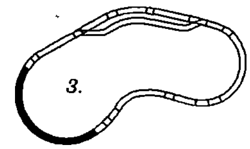
Transition zone/available for testing.
Location of hot bearing detector.

Section 2
300 ft. Spiral



Transition zone/available for testing.

Section 3
3740 ft. of Track on a 5 Degree Curve



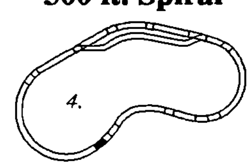
Location of Ballast, Rail Performance and Tie and Fastener Experiments.

Rail performance measurements include gage point wear, head height loss, metal flow, rail head profile, rail hardness, welded rail end batter, LRP, goop gage, rail flaw monitoring, wheel force data, track geometry, and corrugation.

Tie measurements include track geometry, rail fastener stiffness, rail loads, dynamic rail deflection, tie plate cutting, and static track gage.

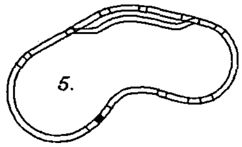
Ballast measurements include ballast sampling, particle indices, ballast gradations, loaded profiles, level net, ballast density, track geometry, and vertical track modulus.

Section 4
300 ft. Spiral



Transition zone/available for testing.

Section 5
224 ft. of Tangent Track



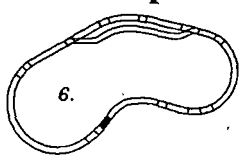
Location of Subgrade Experiment and Frog Casting Performance Test.

Measurements include static and dynamic subgrade pressure and deflection.

The subgrade material will be classified in the laboratory and tested for moisture content, liquid and plastic limits.

Location of hot bearing and acoustic bearing detector.

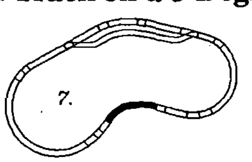
Section 6
300 ft. Spiral



Location of Ballast Resistance Characterization Test.

Measurements include lateral ballast resistance as measured with the single tie push test.

Section 7
1002 ft. of Track on a 5 Degree Curve

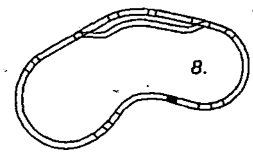


Location of Tie and Fastener and Rail Performance Experiments.

Tie measurements include tie plate cutting, fastener stiffness, rail loads, dynamic rail deflections, track geometry, and static track gage.

Rail wear measurements include gage point wear, head height loss, metal flow, rail head profile, rail hardness, welded rail end batter, LRP, and rail flaw monitoring.

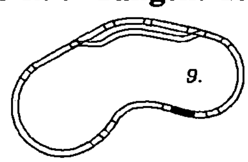
Section 8
300 ft. Spiral



Location of Ballast Resistance Characterization Experiment.

Measurements include lateral ballast resistance as measured with the single tie push test.

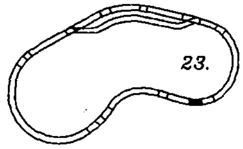
Section 9
313 ft. of Tangent Track



Road crossing and #10 turnout.

Proprietary test of uncased 12 inch and 36 inch pipes buried under railroad track.

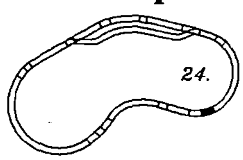
Section 23
164 ft. of Track on a 1 Degree-45 Minute Curve
and
201 ft. of Tangent Track



Frog Casting Performance Test.

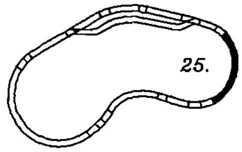
Wayside rail lubricator.

Section 24
300 Ft. Spiral



Transition zone/available for testing.

Section 25
2692 ft. of Track on a 6 Degree Curve

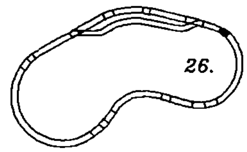


Location of Rail Performance, Ballast Resistance Characterization and Tie and Fastener Experiments.

Tie measurements include tie plate cutting, fastener stiffness, rail loads, dynamic rail deflections, track geometry, and static track gage.

Rail performance measurements include gage point wear, head height loss, metal flow, rail head profile, rail hardness, welded rail end batter, LRP, rail flaw monitoring, goop gage, track geometry, wheel force data and corrugation.

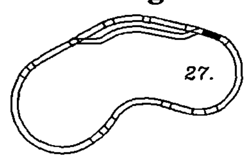
Section 26
300 ft. Spiral



Location of Tie and Fastener Experiment.

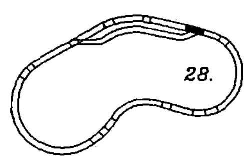
Measurements include static gage widening.

Section 27
332 ft. of Tangent Track



Location of Frog Casting Performance test.

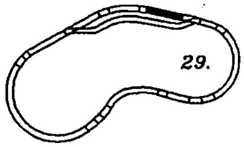
Section 28
#20 Left Hand Turnout



Location of Turnout Experiment.

Measurements include rail/wheel loads, dynamic rail deflections, lateral and vertical rail stiffness and track geometry.

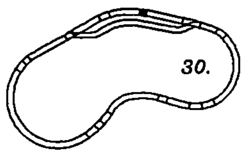
Section 29
987 ft. of Tangent Track



Location of Track Irregularity Experiment

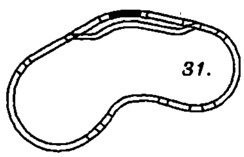
Measurements include rail/wheel loads, dynamic rail deflections, vertical track stiffness and track geometry.

Section 30
300 ft. Spiral



Transition zone/available for testing.

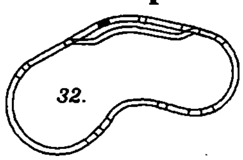
Section 31
511 ft. of Track on a 5 Degree Curve



Location of Tie and Fastener Test.

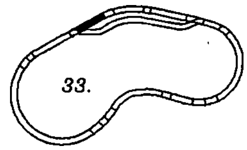
Measurements include tie plate cutting and track geometry.

Section 32
300 ft. Spiral



Transition zone/available for testing.

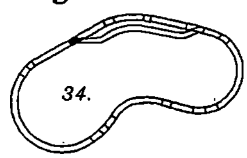
Section 33
517 ft. of Tangent Track



Location of Ballast Resistance Characterization Experiment and Frog Casting Performance Test.

Measurements include lateral ballast resistance as measured with the single tie push test.

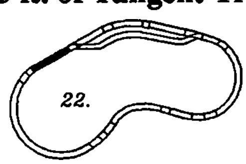
Section 34
#20 Right Hand Turnout



Location of Turnout Experiment.

Measurements include rail/wheel loads, dynamic rail deflections, lateral and vertical rail stiffness, and track geometry.

Section 22
715 ft. of Tangent Track

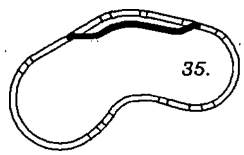


Location of Ballast Resistance Characterization Experiments and Frog Farm Test.

Measurements include lateral ballast resistance as measured with the single tie push test.

Frog Farm Test measurements include Brinell hardness and cross section profiles of the frogs.

Sections 28B - 34B
By-pass Track
1187 ft. of tangent track, 2 - 300 foot spirals, and 511 ft. of track on a 5 degree curve



Location of the Ballast Resistance Characterization Experiment.

Measurements include lateral ballast resistance as measured with the single tie push test.

DATA COLLECTION AND REPORTING

The various data are collected on magnetic tape/disk or recorded manually on a data form, then transferred to a data base on TTC's mainframe computer. All the dynamic data collected under the train is saved in digital format; the digitizing frequency being 1000-1500 samples per second. The tracings from the different profilometers are also digitized as XY coordinates to permit computer generated profile shapes and the computation of area loss. The track geometry data is digitized at one sample per foot of track.

Interim reports describing progress of the various experiments will be issued, along with a final report. These reports will be published by the FAST program and information as to their availability can be obtained through the FRA program office -- (202) 366-0464.

During the time the experiments are active, the TTC staff is planning to host several "open house" seminars so that interested parties can visit TTC and receive an up-to-date assessment of experiment progress, including a walking tour of the HTL. The seminar schedules will be published in the various railroad trade journals. If more information is required, interested parties should contact the FAST Program Manager at (719) 584-0581.

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 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.

Miscellaneous Components

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

Center Plates

During regular 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 addition 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.

General

A 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 is also detects improperly lined switches.

APPENDIX C

Tables of Figures of Merit and Penalty Factors

in Section 07 of the HTL

Table C1.
Section 07 Gage Face Wear Figure of Merit
(Control Rail Wear Rate/Wear Rate)

Rail Metallurgy	Original Brinell Hardness	33-Ton Axle Load Test Dry Operation	39-Ton Axle Load Test Dry Operation	33-Ton Axle Load Test Contaminated Operation	39-Ton Axle Load Test Contaminated Operation
Alloy HH (Off-Line)	360	-	1.8	1.9	1.4
CrMo	316	1.0	1.0	0.9	-
HH (Off-Line)	369	1.2	1.3	1.3	1.3
HH (In-Line)	362	1.1	1.4	1.5	1.4
HH (In-Line)	367	1.1	1.7	1.8	1.5
Standard (Control)	291	1.0	-	1.0	1.0
Alloy HH (In-Line)	380	1.3	1.7	2.4	1.6
Standard	283				1.6
HH (In-Line)	317				1.1
HH (Off-Line)	358				1.5
HH (In-Line)	370				1.8
Alloy HH (In-Line)	375				1.6
Standard	342				1.4
Standard	337				1.1
HH (In-Line)	364				1.3

Table C2.
Section 07 Gage Face Wear Penalty Factors
(39-Ton Axle Load Wear Rate/33-Ton Axle Load Wear Rate)

Rail Metallurgy	Brinell Hardness	Dry Operation	Contaminated Operation
Alloy HH (Off-Line)	360	-	1.694
CrMo	316	1.272	-
HH (Off-Line)	369	1.146	1.295
HH (In-Line)	362	1.012	1.301
HH (In-Line)	367	0.846	1.452
Standard (Control)	291	-	1.245
Alloy HH (In-Line)	380	1.010	1.950
Standard	283		
HH (In-Line)	317		
HH (Off-Line)	358		
HH (In-Line)	370		
Alloy HH (In-Line)	375		
Standard	342		
Standard	337		
HH (In-Line)	364		

Table C3.
Section 07 Head Height Loss Penalty Factors
for Increasing Axle Loads
(39-Ton Axle Load Wear Rate/33-Ton Axle Load Wear Rate)

Rail Metallurgy	Bhn	Dry Operation		Contaminated Operation	
		High Rail	Low Rail	High Rail	Low Rail
Alloy HH (Off-Line)	360	1.7	1.1	1.8	0.9
CrMo	316	1.3	0.6	-	-
HH (Off-Line)	369	2.3	0.4	1.9	1.1
HH (In-Line)	362	1.8	0.6	1.8	1.0
HH (In-Line)	367	3.2	1.1	1.9	1.4
Standard	291	-	-	1.4	0.9
Alloy HH (In-Line)	380	3.3	0.3	1.8	0.7

FAST/HAL Rail Performance Experiment and Overview, 1991
Association of American Railroads, Glenn Brave, Jon Hannafious, Roger Steele, USDOT, FRA

ASSOCIATION OF AMERICAN RAILROADS

U.S. Department of Transportation
Federal Railroad Administration