

Ref. 95-2
FRA



U.S. Department
of Transportation
**Federal Railroad
Administration**

Field Testing of High Degree Revenue Service Track for Buckling Safety Assessment

Office of Research
and Development
Washington, DC 20590

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DOT/FRA/ORD-92/02
DOT-VNTSC-FRA-95-2

Final Report
January 1995

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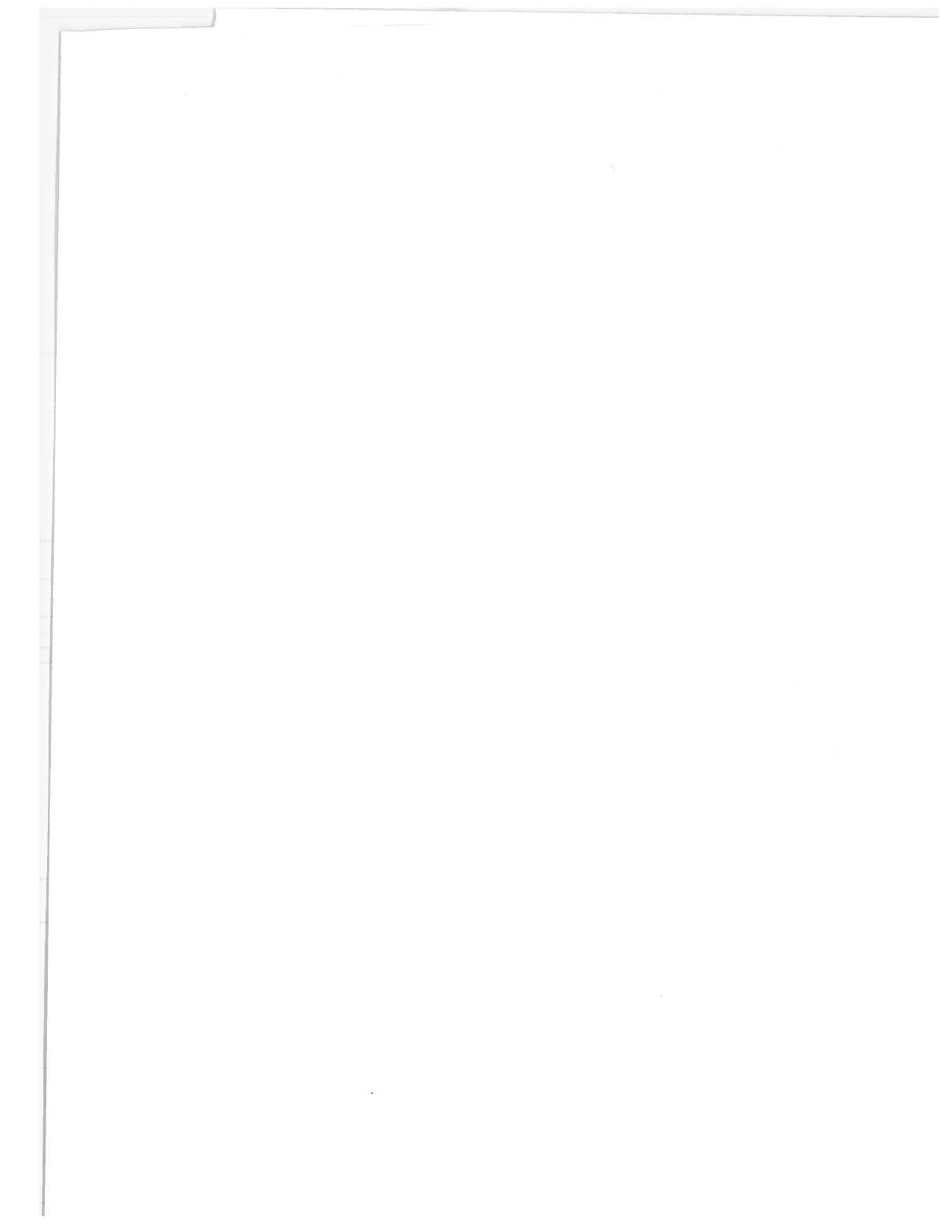
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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE January 1995		3. REPORT TYPE AND DATES COVERED Final Report February 1990 - August 1991	
4. TITLE AND SUBTITLE Field Testing of High Degree Revenue Service Track for Buckling Safety Assessment				5. FUNDING NUMBERS R5011/RR519	
6. AUTHOR(S) D. Thomson ¹ , G. Samavedam ¹ , W. Mui ² , A. Kish ²					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Foster-Miller, Inc. ¹ 350 Second Avenue Waltham, MA 02154				8. PERFORMING ORGANIZATION REPORT NUMBER DOT/FRA/ORD-92/02	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. DOT/RSPA Volpe National Transportation Systems Center ² 55 Broadway, Kendall Square Cambridge, MA 02142				10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT-VNTSC-FRA-95-2	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the National Technical Information Service, Springfield, VA 22161				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This report presents the results of a field study of high degree curves in continuous welded rail (CWR) territory. This program was conducted at two test sites: a 10 degree curve on the Atchison, Topeka, and Santa Fe (ATSF) Railroad near Sante Fe, NM, and a 12 degree curve on the Norfolk Southern (NS) Railroad near Bluefield, WV. The work presented here is part of a major investigation carried out by the Volpe National Transportation Systems Center, for the Federal Railroad Administration (FRA), on thermal buckling of CWR track, with the objective of developing guidelines and recommendations for buckling prevention. The field data collected included rail strain and temperature, rail radial movement, and tie lateral resistance in winter, spring, and summer conditions. Based on strain and temperature data, variations in rail neutral (zero force) temperatures are calculated. Seasonal neutral temperature shifts on the order of 20°F and diurnal shifts on the order of 5°F were typically recorded. The neutral temperature variations due to the rail radial movement (radial breathing) are evaluated. The lateral resistance test results indicated an increase in resistance as a function of traffic volume. Using the neutral temperature data and the track lateral resistance measured in the field tests as inputs, the track buckling potential has been evaluated using the Volpe Center's computer model. The predicted buckling response has been correlated with the observed buckling incidents on some of the track sections.					
14. SUBJECT TERMS Railroad, Continuous Welded Rail, Buckling, Thermal Effects				15. NUMBER OF PAGES 105	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified		18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified		19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	
				20. LIMITATION OF ABSTRACT Unlimited	



PREFACE

This report presents the results of field tests on 10 and 12 degree curved continuous welded rail (CWR) track, conducted on the Atchison, Topeka, and Santa Fe (ATSF) railroad in Sante Fe, NM, and the Norfolk Southern (NS) railroad in Bluefield, WV. The work is a part of the Volpe National Transportation Systems Center's track stability research program being conducted for the Federal Railroad Administration for the purpose of developing safety guidelines and specifications for the prevention of track buckling-induced derailments.

Thanks go to Messrs. R.N. Harbuck, T. Hernandez, A. Quintana, and W. Martinez of ATSF and Messrs. T.P. Painter, J. Gearhart, E. Otey and D. Cregger of NS for their participation in and support of this test program.

A major part of this work was performed under OMNI Contract No. DTRS-57-89-D-00009, TTD No. VA 1026, awarded by the Volpe Center. This report is prepared under OMNI Contract No. DTRS-57-93-D-00028, TTD No. VA 3201. The work was sponsored by the United States Department of Transportation, Federal Railroad Administration, Office of Research and Development, Washington, DC.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

- 1 inch (in) = 2.5 centimeters (cm)
- 1 foot (ft) = 30 centimeters (cm)
- 1 yard (yd) = 0.9 meter (m)
- 1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

- 1 square inch (sq in, in²) = 6.5 square centimeters (cm²)
- 1 square foot (sq ft, ft²) = 0.09 square meter (m²)
- 1 square yard (sq yd, yd²) = 0.8 square meter (m²)
- 1 square mile (sq mi, mi²) = 2.6 square kilometers (km²)
- 1 acre = 0.4 hectares (he) = 4,000 square meters (m²)

MASS - WEIGHT (APPROXIMATE)

- 1 ounce (oz) = 28 grams (gr)
- 1 pound (lb) = .45 kilogram (kg)
- 1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

- 1 teaspoon (tsp) = 5 milliliters (ml)
- 1 tablespoon (tbsp) = 15 milliliters (ml)
- 1 fluid ounce (fl oz) = 30 milliliters (ml)
- 1 cup (c) = 0.24 liter (l)
- 1 pint (pt) = 0.47 liter (l)
- 1 quart (qt) = 0.96 liter (l)
- 1 gallon (gal) = 3.8 liters (l)
- 1 cubic foot (cu ft, ft³) = 0.03 cubic meter (m³)
- 1 cubic yard (cu yd, yd³) = 0.76 cubic meter (m³)

TEMPERATURE (EXACT)

$$[(x-32)(5/9)] \text{ } ^\circ\text{F} = y \text{ } ^\circ\text{C}$$

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

- 1 millimeter (mm) = 0.04 inch (in)
- 1 centimeter (cm) = 0.4 inch (in)
- 1 meter (m) = 3.3 feet (ft)
- 1 meter (m) = 1.1 yards (yd)
- 1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

- 1 square centimeter (cm²) = 0.16 square inch (sq in, in²)
- 1 square meter (m²) = 1.2 square yards (sq yd, yd²)
- 1 square kilometer (km²) = 0.4 square mile (sq mi, mi²)
- 1 hectare (he) = 10,000 square meters (m²) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

- 1 gram (gr) = 0.036 ounce (oz)
- 1 kilogram (kg) = 2.2 pounds (lb)
- 1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

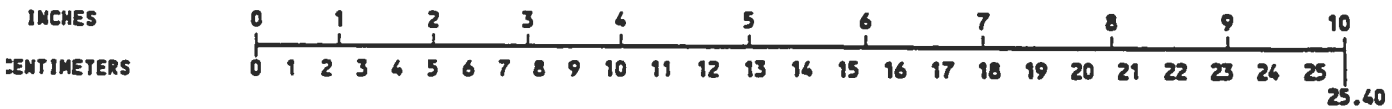
VOLUME (APPROXIMATE)

- 1 milliliter (ml) = 0.03 fluid ounce (fl oz)
- 1 liter (l) = 2.1 pints (pt)
- 1 liter (l) = 1.06 quarts (qt)
- 1 liter (l) = 0.26 gallon (gal)
- 1 cubic meter (m³) = 36 cubic feet (cu ft, ft³)
- 1 cubic meter (m³) = 1.3 cubic yards (cu yd, yd³)

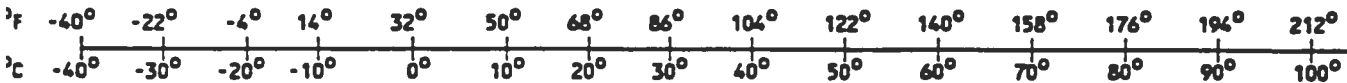
TEMPERATURE (EXACT)

$$[(9/5) y + 32] \text{ } ^\circ\text{C} = x \text{ } ^\circ\text{F}$$

QUICK INCH-CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price \$2.50. SD Catalog No. C13 10286.

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LIST OF SYMBOLS AND ABBREVIATIONS

α	Coefficient of Linear Thermal Expansion (6.4 $\mu\text{in}/\text{in}/^{\circ}\text{F}$ for Rail)
A	Rail Cross Section Area
ATSF	Atchison, Topeka, and Sante Fe
C	Track Curvature in Degrees
CWR	Continuous Welded Rail
ΔR	Radial Movement in Inches
ΔT_N	Change in Neutral Temperature
E	Modulus of Elasticity (30E6 psi for Rail)
ϵ_c	Current Rail Strain
ϵ_i	Indicated Strain
ϵ_{ml}	Indicated Strain due to Radial Movement
ϵ_{mt}	True Strain due to Radial Movement
ϵ_o	Reference Strain at Zero Rail Force
ϵ_t	True Strain
EOTA	Every Other Tie Anchored
ETA	Every Tie Anchored
F_L	Limit Lateral Resistance of a Tie
F_P	Peak Lateral Resistance of a Tie
μ	Poisson's Ratio (0.3 for Rail)
MGT	Million Gross Tons
NS	Norfolk Southern
P_{rail}	Rail Force
R	Curve Radius in Inches
SG	Rail Force Strain Gauge
STPT	Single Tie Push Test
T_c	Current Rail Temperature
T_N	Neutral Temperature
TS	Test Section
W_L	Tie Lateral Deflection at Limit Resistance
W_P	Tie Lateral Deflection at Peak Resistance

EXECUTIVE SUMMARY

During the periods of February to August 1990 and January to August 1991, field testing and data analyses were performed to evaluate the track buckling potential of typical continuous welded rail (CWR) high degree curve revenue service track. Field testing was performed near Santa Fe, NM, and Bluefield, WV, to monitor changes in rail neutral temperature and rail radial movement and to evaluate track lateral resistance. These data were correlated with known track work and damage to explain changes in neutral temperature. Analysis was done with the dynamic buckling model to compare model predictions with observed field behavior.

The neutral temperature, defined as the temperature at which the net longitudinal force in the rail is zero, was directly determined from rail mounted strain gauges and temperature probe data. These results were correlated with measurements of the rail radial displacement, which is a contributing parameter of neutral temperature variation of high degree curves. These measurements were made during winter, spring, and summer to evaluate seasonal factors.

Track lateral resistance was measured at both sites using a single tie push test (STPT) device. The test sites were each subdivided into three test sections for comparison of lateral resistance under either recently tamped or consolidated conditions. Data was collected during spring and summer both to monitor increasing lateral resistance as a function of tonnage and to evaluate seasonal variation influences.

Buckling predictions were made using the Volpe Center's dynamic buckling model and the neutral temperature and track lateral resistance. These predictions were correlated with field results and observations of track condition. In the one case where a buckling incident occurred, the model predictions correlated well with the recorded incident.

1. INTRODUCTION

Continuous welded rail (CWR) track buckling potential is essentially governed by rail longitudinal force, track lateral resistance, rail size, track curvature, and track misalignments. The compressive rail force is primarily due to rail temperature increase over its neutral temperature.

The rail neutral temperature can shift from the installation temperature due to rail vertical, longitudinal, and lateral displacements caused by vehicle and thermal loads, and maintenance operations. Previous field tests on revenue service track and at the U.S. DOT Transportation Test Center (TTC) in Pueblo, CO, which is operated by the Association of American Railroads (AAR) under contract to DOT, have measured neutral temperature shifts on tangent and low degree curves (≤ 7.5 deg). Buckling potential on these tracks has been evaluated by direct buckling tests at TTC, and the test data have been correlated with the theoretical model predictions.

No significant data exist for evaluation of the buckling potential on high degree (> 7.5 deg) CWR track. Unlike in the foreign railroads, particularly the European, where the maximum curvature of CWR is restricted to 5 degrees, high degree CWR curves do exist on U.S. railroads. High degree curve CWR track apparently experiences significant maintenance problems due to the rail radial breathing in and out of the curves as the temperature changes. Theoretically, uniform outward movements could be beneficial to the track, as they tend to reduce the rail compressive force at high temperatures. In practice, these movements are not uniform and induce alignment defects, which may lead to eventual buckles. Furthermore, large radial movements due to seasonal changes can reduce the track lateral resistance itself. Prevention of track movement would require unduly large lateral and longitudinal resistance. Thus, the high degree CWR track is subject to complex parameter variations; buckling predictions need to include these parameters and influences.

1.1 Objectives of the Field Tests

- To study and compare the behavior of two high degree curves in different geographical locations (hence, different peak rail temperatures), at different annual traffic volumes measured in million gross tons (MGT) (hence, presumably operated at different lateral resistance levels)
- To monitor the rail force over a period covering winter, spring, and summer conditions, and thus determine the rail neutral temperature shifts on a diurnal/seasonal basis
- To monitor rail radial movements and evaluate the rail breathing influence on the neutral temperature shifts

- To determine the lateral resistance under tamped, “as-is,” and consolidated conditions, and also to monitor changes in the lateral resistance over time
- To estimate the buckling potential on the basis of the measured parameters, using the Volpe Center's theoretical dynamic buckling model.

2. FIELD TESTS

2.1 Test Sites

Based on the forgoing objectives, two test sites, one near Santa Fe, NM, and another near Bluefield, WV, were selected. The Santa Fe site is about 7,000 ft above sea level, and its ambient temperatures range from 0° to 110°F, whereas in Bluefield, the range is typically 10° to 100°F, approximately. Further, the Santa Fe site has a low annual traffic volume of 9 MGT, while the Bluefield site has 68 MGT annually. The sites have some history of track buckles.

2.1.1 Santa Fe, NM - ATSF Railroad

This site was located on the Atchison, Topeka, and Santa Fe (ASTF) Railroad, east of Santa Fe, NM, near I-25 between Sands and Blanchard, at mile posts 796 to 797. Track characteristics were:

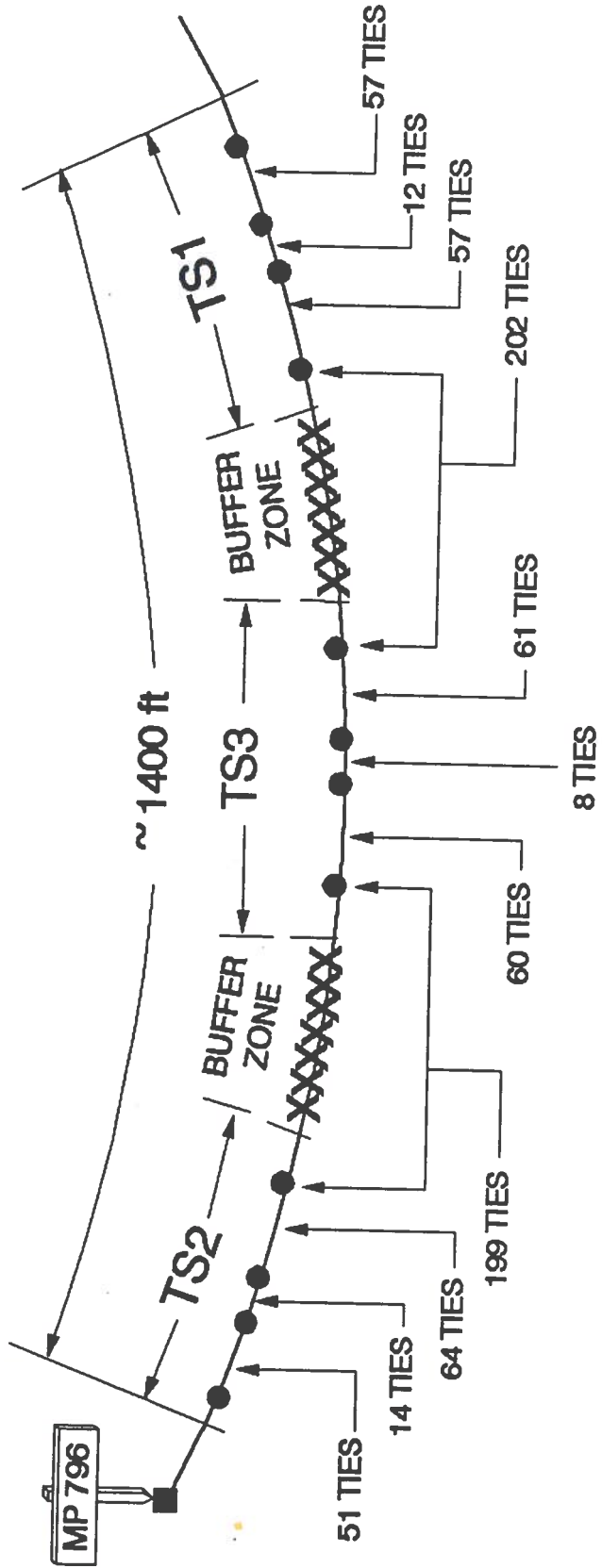
- Rail: 132 lb CWR
- Curvature: 10 degrees
- Ballast: Mix of hard rock and Pueblo slag
- Ballast shoulder: 14 to 16 in.
- Crib: Full
- Ties: Wood, approximate spacing 20 in., average condition
- Anchoring: Every other tie (EOTA)
- Speed: 20 mph freight, 25 mph Amtrak
- Tonnage: 9 MGT
- Curve length: \approx 1,300 ft
- Single track territory
- Superelevation: 2.5 in.

Three test sections (TS) were partitioned at this site as shown in Figure 2-1, which also gives the strain gauge and rail movement benchmark locations.

2.1.2 Bluefield, WV - NS Railroad

This site was located on the Norfolk Southern (NS) Railroad, northwest of Bluefield, WV, near Rte. 52 between Keystone and Vivian, at mile posts 390.2 and 390.6. Track characteristics were:

- Rail: 136 lb CWR
- Curvature: 12 degrees
- Ballast: Granite
- Ballast shoulder: 10 to 16 in. high rail; 4 to 12 in. low rail
- Crib: Full



• STRAIN GAUGE AND SURVEY LOCATIONS ON HIGH AND LOW RAILS

Figure 2-1. ATSF - Santa Fe Test Zone Layout

- Ties: Wood, approximate spacing 20 in., good condition
- Anchoring: Every tie (ETA)
- Speed: 25 mph freight
- Tonnage: 68 MGT
- Curve length: \approx 2,000 ft
- Double track territory
- Superelevation: 3.5 in.

The three test sections selected at this site are shown in Figure 2-2.

2.2 Test Measurements and Instrumentation

2.2.1 Rail Force

Longitudinal force in the rail was monitored using full (4-arm) strain gauge bridges welded to the rail web at the neutral axis. Rail temperature readings were taken, using a portable rail thermometer, at a total of 24 gauge locations at each site. Strains were monitored with a Vishay P-3500 portable strain indicator. Using the strain and temperature of the rail, the change in rail longitudinal force can be calculated against zero force readings obtained by cutting the rail.

Note: All strain values shown in this report and used in equations are full bridge indicated microstrain (ϵ_i). The true microstrain (ϵ_t) may be determined as follows:

$$\epsilon_t = \frac{\epsilon_i}{2(1 + \mu)} \quad (2-1)$$

where

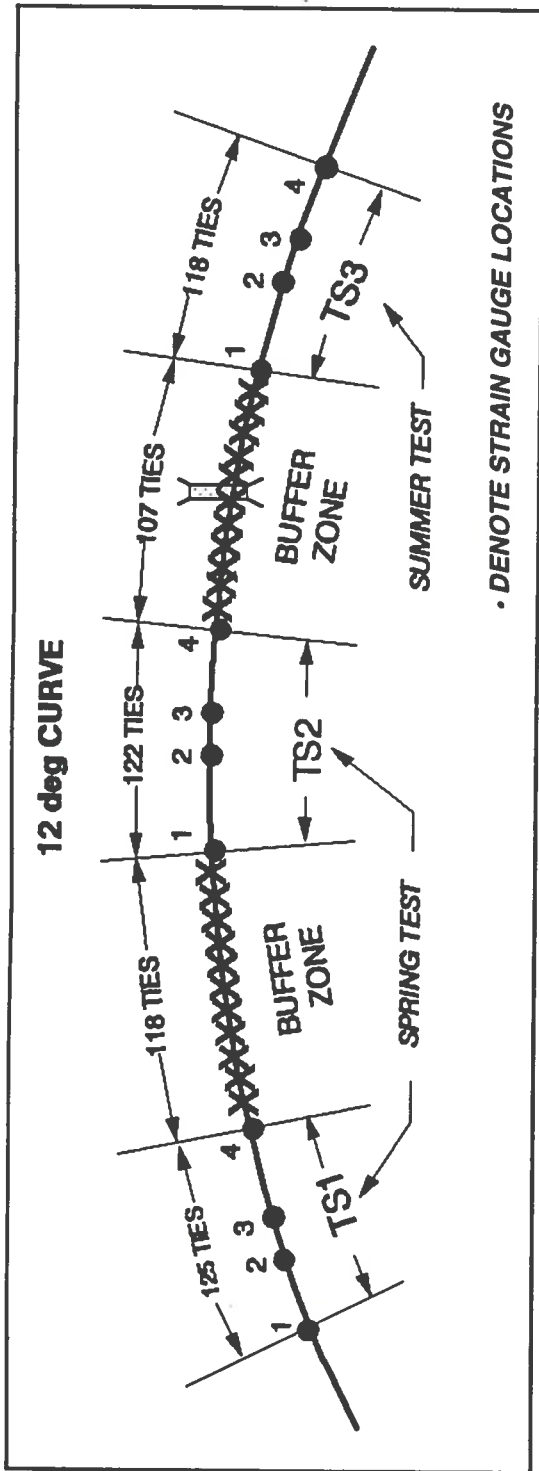
μ = Poisson's Ratio (0.3 for rail)

2.2.2 Rail Movement

Movement of the rail in the radial direction was measured using a special device designed for this purpose (Figure 2-3). Benchmark posts were cemented in the ground near the track. The radial movement of an etched point in the rail was measured directly from the benchmark to the rail.

2.2.3 Track Lateral Resistance

The single tie push test (STPT) device includes instrumentation for measuring the lateral resistance of the ties. The load applied is measured by a pressure transducer, which monitors the hydraulic pressure. The movement of the tie is measured with a linear potentiometer-type transducer attached to the rail. These two measurements are plotted against each other



TEST SECTION (TS1)	BUFFER ZONE
- SG 1-2 (58 ties)	(BETWEEN TS1 and TS2)
- SG 2-3 (8 ties)	- 118 ties
- SG 3-4 (59 ties)	BUFFER ZONE
TEST SECTION (TS2)	(BETWEEN TS2 and TS3)
- SG 1-2 (56 ties)	- 107 ties
- SG 2-3 (9 ties)	
- SG 3-4 (57 ties)	
TEST SECTION (TS3)	
- SG 1-2 (48 ties)	
- SG 2-3 (8 ties)	
- SG 3-4 (62 ties)	

Figure 2-2. NS - Bluefield Test Zone Layout



Figure 2-3. Radial Measurement Device

during the test using a portable x-y plotter. The STPT device is shown moving a tie in Figure 2-4.

2.3 Field Work

2.3.1 Phase I: 1990

Initial test site visits were made to Santa Fe on 12 February 1990 and to Bluefield on 5 March 1990. During these visits, the strain gauges were applied to the rail. Steel posts were cemented into the ground to serve as rail movement benchmarks. Initial strain readings and rail location measurements were recorded.

Second test site visits were made to Santa Fe on 2 April 1990 and to Bluefield on 23 April 1990. During these visits, strain readings and rail movements were recorded over a three-day period. The rails were cut in TS1 and 2 to obtain the strain readings for zero stress. STPTs were conducted in TS1 and 2. TS1 was tamped prior to these tests to provide a comparison between tamped and "as-is" lateral tie resistance.

Third test site visits were made to Santa Fe on 25 June 1990 and to Bluefield on 6 June 1990. These additional visits were made primarily to replace the steel cover plates which protect the strain gauges. At this time, rail strain and radial movement data were recorded.



Figure 2-4. STPT Device

Fourth test site visits were made to Santa Fe on 23 July 1990 and to Bluefield on 30 July 1990. During these visits, rail strain and radial movement data were recorded. The rails were cut in TS3 to obtain initial readings for zero stress. STPTs were conducted in TS1 and 3. TS1 was tested to provide a comparison between its tamped condition in the spring and its consolidated condition in the summer.

2.3.2 Phase II: 1991

The first on-site data collections of 1991 were made in Santa Fe on 29 January and in Bluefield on 4 February. During each of these visits strain readings and rail movements were recorded over a two-day period.

The next on-site visits were made to Bluefield on 1 April 1991 and to Santa Fe on 3 April 1991. Both rails had been replaced in Bluefield due to substantial wear; a final strain reading was taken to check zeros and the test was terminated. Strain and rail movement data were collected in Santa Fe over a two-day period.

Subsequent Santa Fe site visits and measurements were made on 21 May, 16 July, and 13 August 1991. On the final visit on 13 August 1991, track lateral resistance was measured using the STPT device. A total of 29 STPTs were conducted throughout the three test sections, for comparison to data from the previous year. Strain and rail movement data were also recorded over a three-day period.

A summary of field work is shown in Table 2-1.

Table 2-1. Summary of Field Work

Visit	Date	ATSF - Santa Fe, NM	NS - Bluefield, WV
1	2/12/90 - ATSF 3/5/90 - NS	<ul style="list-style-type: none"> - Strain gauges applied - Steel benchmarks cemented into ground - Initial rail location measurements taken 	Same as ATSF
2	4/2/90 - ATSF 4/23/90 - NS	<ul style="list-style-type: none"> - Rail strain and temperature recorded - Rail movement recorded - Rails cut and zero strains recorded in TS1 and TS2 - TS1 tamped prior to STPTs - STPTs conducted in TS1 and TS2 	Same as ATSF
3	6/6/90 - NS 6/23/90 - ATSF	<ul style="list-style-type: none"> - Rail strain and temperature recorded - Rail movement recorded - New cover plates installed 	Same as ATSF
4	7/23/90 - ATSF 7/30/90 - NS	<ul style="list-style-type: none"> - Rail strain and temperature recorded - Rail movement recorded - Rails cut and zero strains recorded in TS3 - STPTs conducted in TS1 and TS3 	Same as ATSF
5	1/29/91 - ATSF 2/4/91 - NS	<ul style="list-style-type: none"> - Rail strain and temperature recorded - Rail movement recorded using new radial measurement device 	Same as ATSF
6	4/1/91 - NS 4/3/91 - ATSF	<ul style="list-style-type: none"> - Rail strain and temperature recorded - Rail movement recorded 	<ul style="list-style-type: none"> - Zero strains taken on rail after removal for replacement - Test terminated
7	5/22/91 - ATSF	<ul style="list-style-type: none"> - Rail strain and temperature recorded - Rail movement recorded 	
8	7/16/91 - ATSF	<ul style="list-style-type: none"> - Rail strain and temperature recorded - Rail movement recorded 	
9	8/13/91 - ATSF	<ul style="list-style-type: none"> - Rail strain and temperature recorded - Rail movement recorded - STPTs conducted in all three test sections - Test terminated 	

2.4 Related Information

2.4.1 Instrumentation Damage

Two instrumentation problems partially affected the execution of this test program. The most significant of these was the extensive strain gauge damage that occurred at the Bluefield site between the first and second visits. Due to apparent vandalism, all of the gauges in TS3, and three of the gauges in TS2 had their wires cut. Of these 11 gauges, three were damaged permanently and the other eight had to be directly wired to the indicator box for reading. A second problem developed with the steel cover plates that protected the strain gauges. Track vibration proved to be too great for the clamps to hold the plates in place. Thus, a new cover plate attachment was designed and installed during the third site visits. This new cover plate assembly, shown in Figure 2-5, performed very well.

2.4.2 Track Work Problems

During this five-month testing period of Phase II, maintenance work was performed on the rails at both test sites. This work affected rail force and movement, and caused significant abrupt changes in the test data.

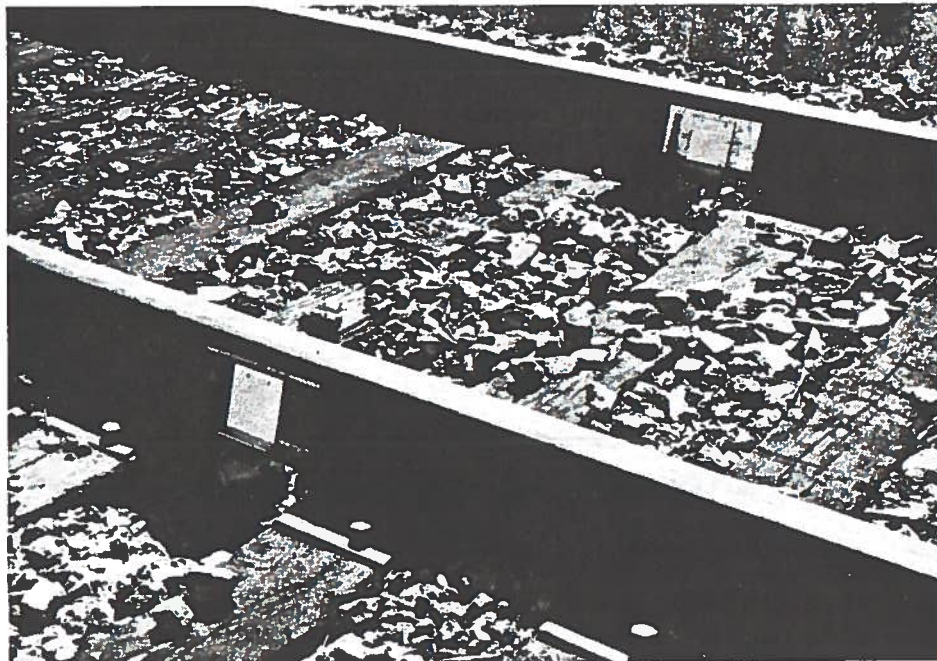


Figure 2-5. New Cover Plate Assembly

2.4.3 Santa Fe

During the second visit to Santa Fe, rail work was performed for our tests. Both rails were cut in TS1 and 2 to obtain the strain at zero stress. These rails were then rewelded. In addition, TS1 was tamped as per the test requirements. Between the third and fourth visits, a significant increase in the ambient temperature caused several rail kinks. Both rails were cut at 200 ft to the east of TS2 to relieve minor kinks. These rails were then welded. Likewise, both rails were cut at 400 ft to the west of TS1 to relieve many minor kinks, two major kinks in TS1, and a major kink to the west of the cuts near a bridge. Rail jacks were used to line up the track at the major kinks. Six inches of the high rail and 5 in. of the low rail were removed before the rails were rewelded. In September 1990, the railroad crew installed Pandrol clips between TS3, strain gauge (SG) 4 and TS1 SG 2 on the high rail; this installation was not part of the test requirement. In June 1991, defective welds were found in TS1 and TS3. Sections of rail were removed and secured with bolted joints. Rail work at the ATSF site is summarized in Figure 2-6.

2.4.4 Bluefield

During the second visit to Bluefield, rail work was performed both for and in addition to our tests. Both rails were cut in TS1 and 2 to obtain the strain at zero stress. These rails were then welded. In addition, TS1 was tamped, lined, lifted, and given additional ballast.

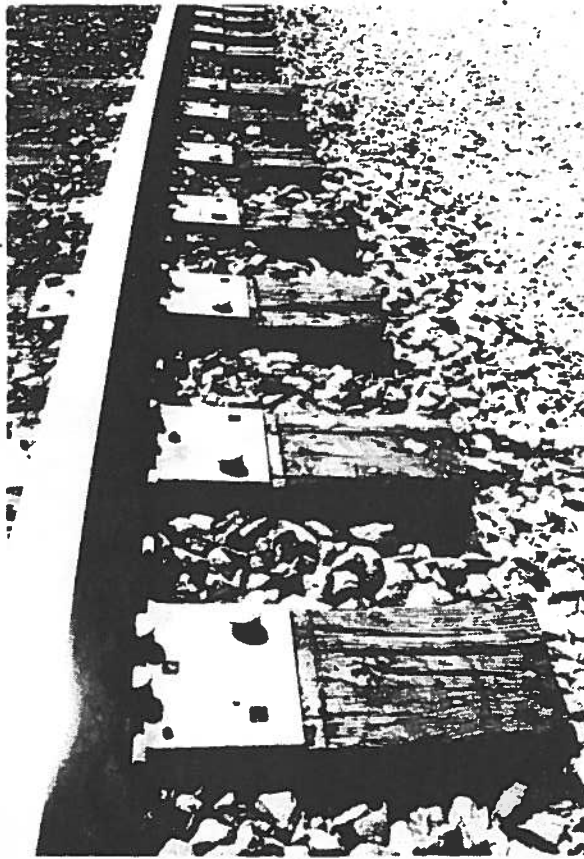
Between the third and fourth visits, a significant increase in the ambient temperature caused several problems, primarily during the last week in June. In TS1, the tie plates were repositioned 1 in. outward for alignment. In TS2, the low rail broke and a 41-ft section was cut out and replaced but not welded. Since it remained a bolted joint, the neutral temperature was no longer an appropriate measure for this section. In addition, tie plates on the low rail were moved to tighten the gauge from 57-1/2 in. to 56-1/2 in. (Figure 2-7). Between TS2 and 3, the rail broke at midnight and again, a 41-ft section was replaced and secured with bolted joints. In TS3, a crack in a high rail weld (Figure 2-8) was discovered and a 37-ft section, between strain gauges 3 and 4, was replaced and secured with bolted joints. This work is pictorially summarized in Figure 2-9.

Testing at this site was terminated when the rail section, which was originally installed in 1981, was replaced in 1991. As a result of the high degree of curvature, the high rail was significantly worn after 700 MGT of traffic. As shown in Figure 2-10, the low rail maintained its width at 3 in. while the high rail was worn to a substantially reduced width of 2-1/4 in. This curve's stability was also potentially affected by the fact that typically only a 6-in. ballast shoulder on the inside and a 12-in. ballast shoulder on the outside of the curve are permitted, to facilitate drainage and prevent rain water flooding.

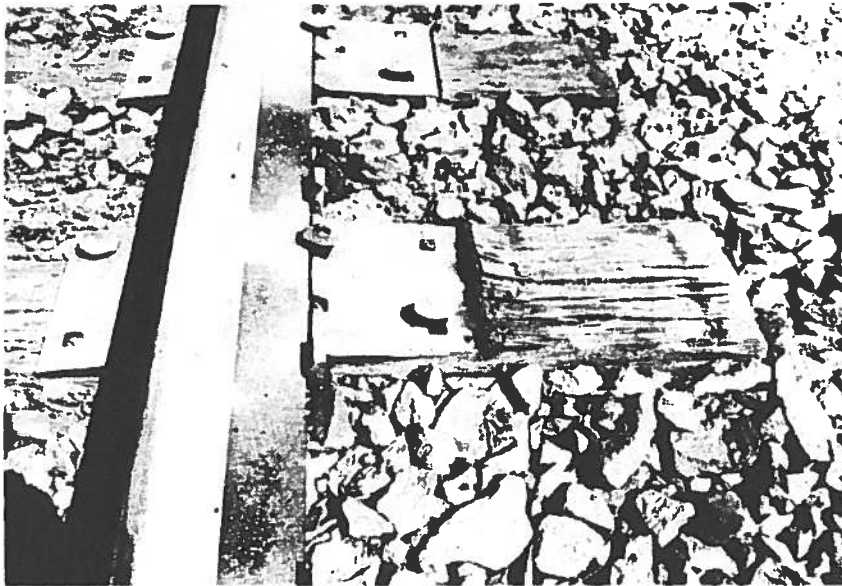
1990	FEBRUARY	Strain Gauge Installation at ATSF Test Site (Total of 24)
	APRIL	<ul style="list-style-type: none"> • Rails cut and rewelded at TS1 and TS2 (as part of test) • Tamped track at TS1 • Buckle occurrences at TS1
	JUNE	Post Buckled Maintenance
	JUNE	<ul style="list-style-type: none"> • Rail cut (6" from HR), (5" from LR) - both cuts about 400' away from TS1 • Rail jacks used to line the track back at TS1 buckles • Rails cut and rewelded at TS3 (as part of test) • Pandrol clips installed in late Sept 1990 from TS3-s.g.4 to TS1-s.g.2 on high rail
	JULY	
	SEPTEMBER	
1991	JUNE	<ul style="list-style-type: none"> • Rail plug installed (bolted in only) at TS3 low rail between s.g.3 and s.g.4 (34' long) • Rail plug installed (bolted in only) at TS1 low rail at s.g.3 and before s.g.4 (39' long) <p>(See below)</p>
		<p>• Strain Gauge</p> <p>• Rail Plugs First Week of June (Not Welded)</p>
1992	JUNE	<ul style="list-style-type: none"> • Tie replacement activity

307-DTS-95190-1

Figure 2-6. Track Work in Santa Fe, NM



a) LOW RAIL



b) HIGH RAIL

Figure 2-7. Rail Gauge Adjustment - Bluefield, WV

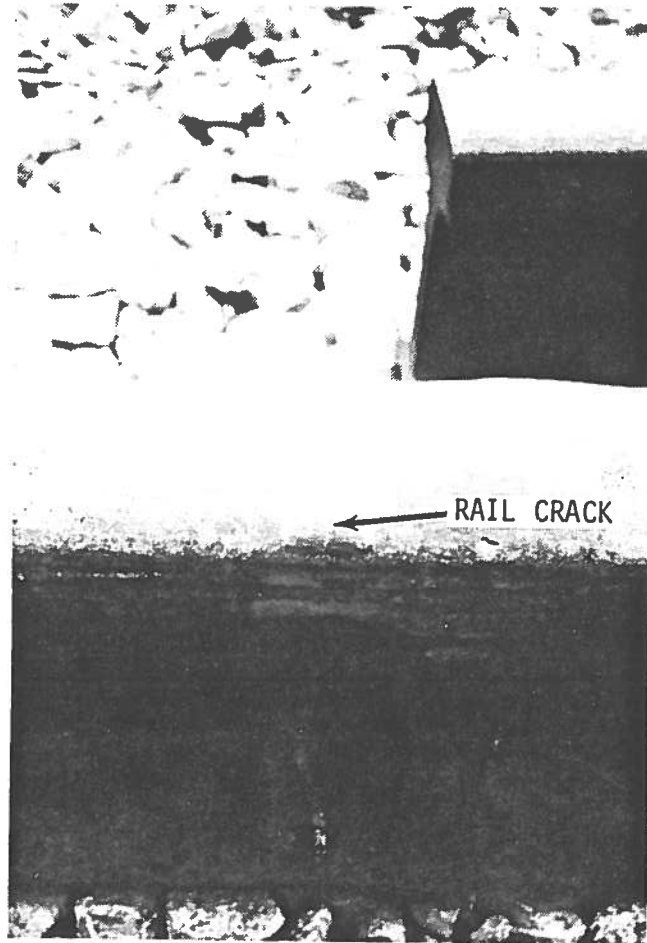
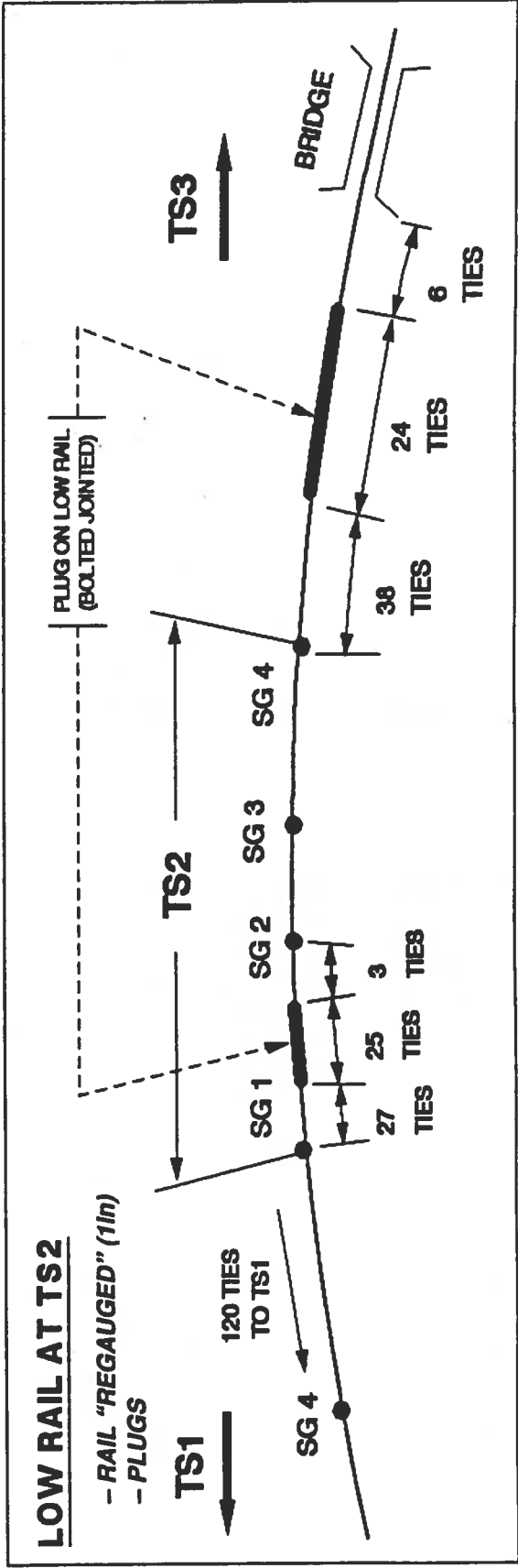
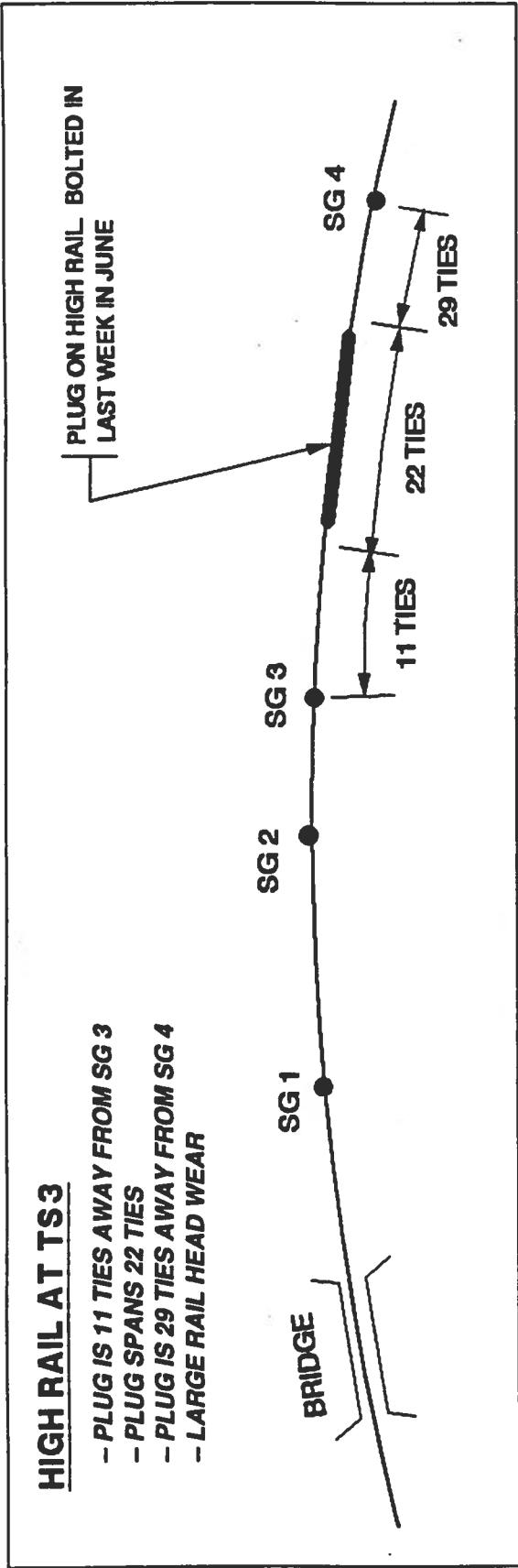
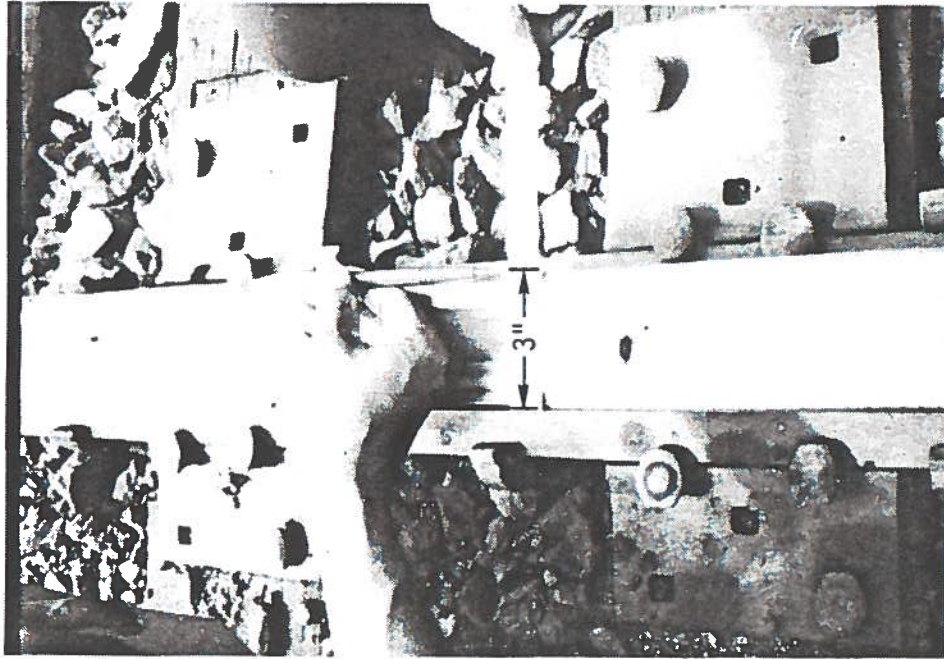


Figure 2-8. Crack in High Rail in Test Section 3 - Bluefield, WV

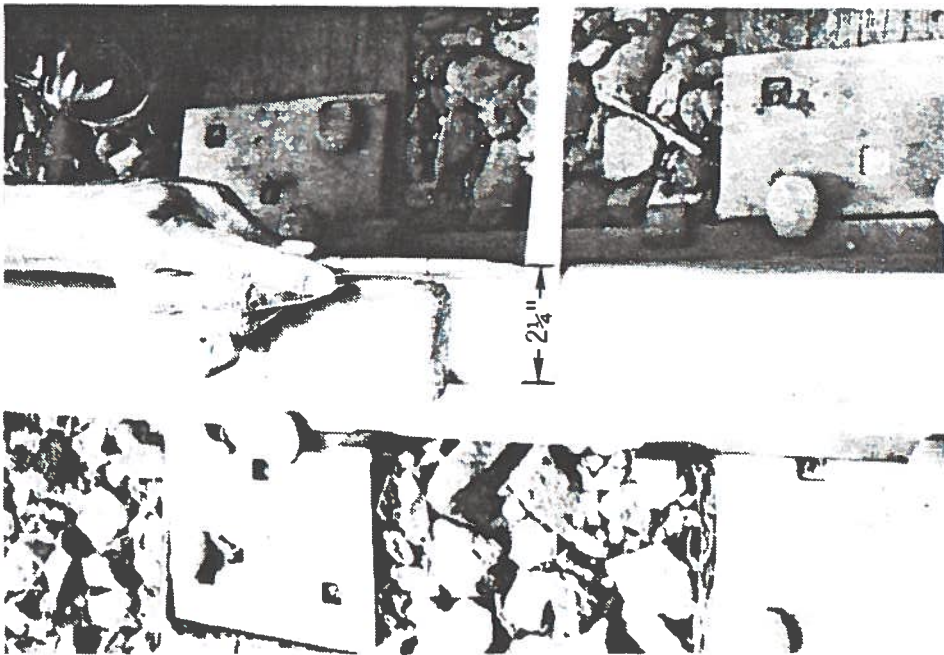


NOT TO SCALE

Figure 2-9. Track Work in Bluefield, WV



b) LOW RAIL (3 in.)



a) HIGH RAIL WORN (2-1/4 in.)

Figure 2-10. Rail Wear in Test Section 2, 136 lb Rail Installed in 1981 - Bluefield, WV

3. TEST DATA

This section presents summaries of the data collected at the test sites. Rail force and neutral temperature are calculated from the rail strain and temperature raw data to provide information of practical interest. All the raw data on strain, temperature, and radial movement, are presented in Appendix A. STPT data from three separate site visits are also summarized in this section.

3.1 Rail Force

The rail strain and temperature were recorded to monitor the rail force and, consequently, the neutral temperature of the rail (T_N), which is the rail temperature at which the net longitudinal force in the rail is zero. The greater the difference is between T_N and the actual rail temperature, the greater the force will be in a fully constrained rail. Since the rail temperature will go through a daily cycle, the rail force will exhibit a similar progression in CWR.

Figures 3-1 through 3-3 show this force cycle for several full days in each of the three ATSF test sections during 1991 (Phase II). When force was calculated as an average of the high and low rails a solid data point is shown, with an open point indicating data from only one rail. These figures provide a large amount of supporting information in addition to the variation of rail force, which is calculated using equation 3-1, shown below. The data collection time is also shown, which indicates that rail force typically peaked between 1:00 pm and 2:00 pm each day. The average rail temperature for each point is provided for reference along the x-axis, however, the data is actually plotted at data collection intervals along the date scale shown above the x-axis. Also shown is the variance of neutral temperature (ΔT_N) within each data collection day.

The plot for TS1 (Figure 3-1) shows an average force for both rails from January to May 1991, and for the high rail only from July and August (the low rail contained a bolted joint during those two months). Figure 3-2 shows the data from TS2 as an average of both rails throughout. The plot for TS3 (Figure 3-3) is similar to that for TS1 in that the low rail contained a bolted joint during July and August. The bolted joints permit rail thermal expansion and thus serve to relieve the force buildup. During the testing, gaps on the order of 1/4 in. in the rail bolted joints were observed to close due to thermal expansion during the day. It should be noted that plots were not made of the NS data as several bolted joints were used at this site and the test was terminated early in 1991.

The rail force (P_{rail}) is calculated by measuring the current rail strain (ϵ_C). The rail force in pounds is then calculated from the following equation:

$$P_{\text{rail}} = \frac{(\epsilon_C - \epsilon_0)AE}{2(1 + \mu)} \quad (3-1)$$

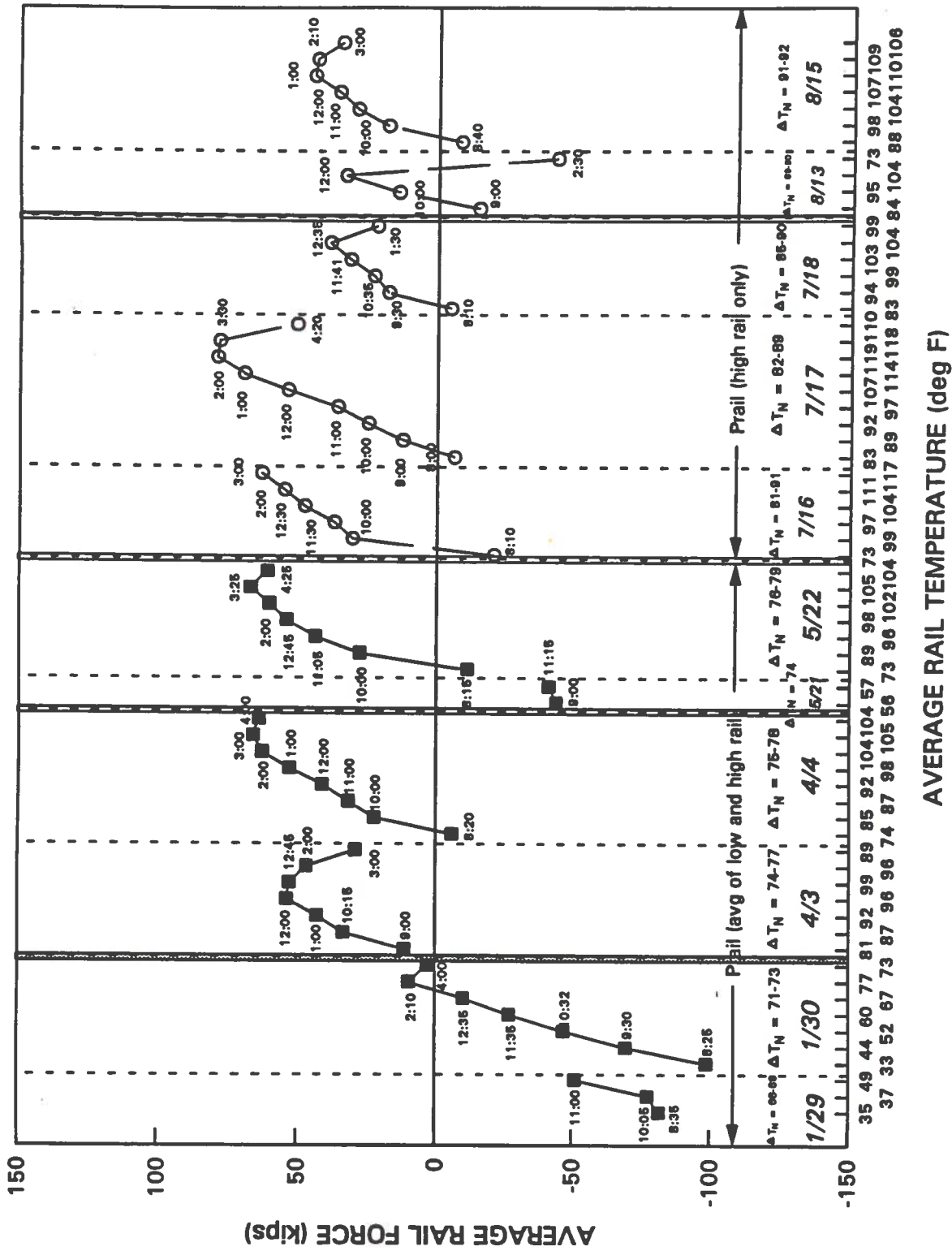
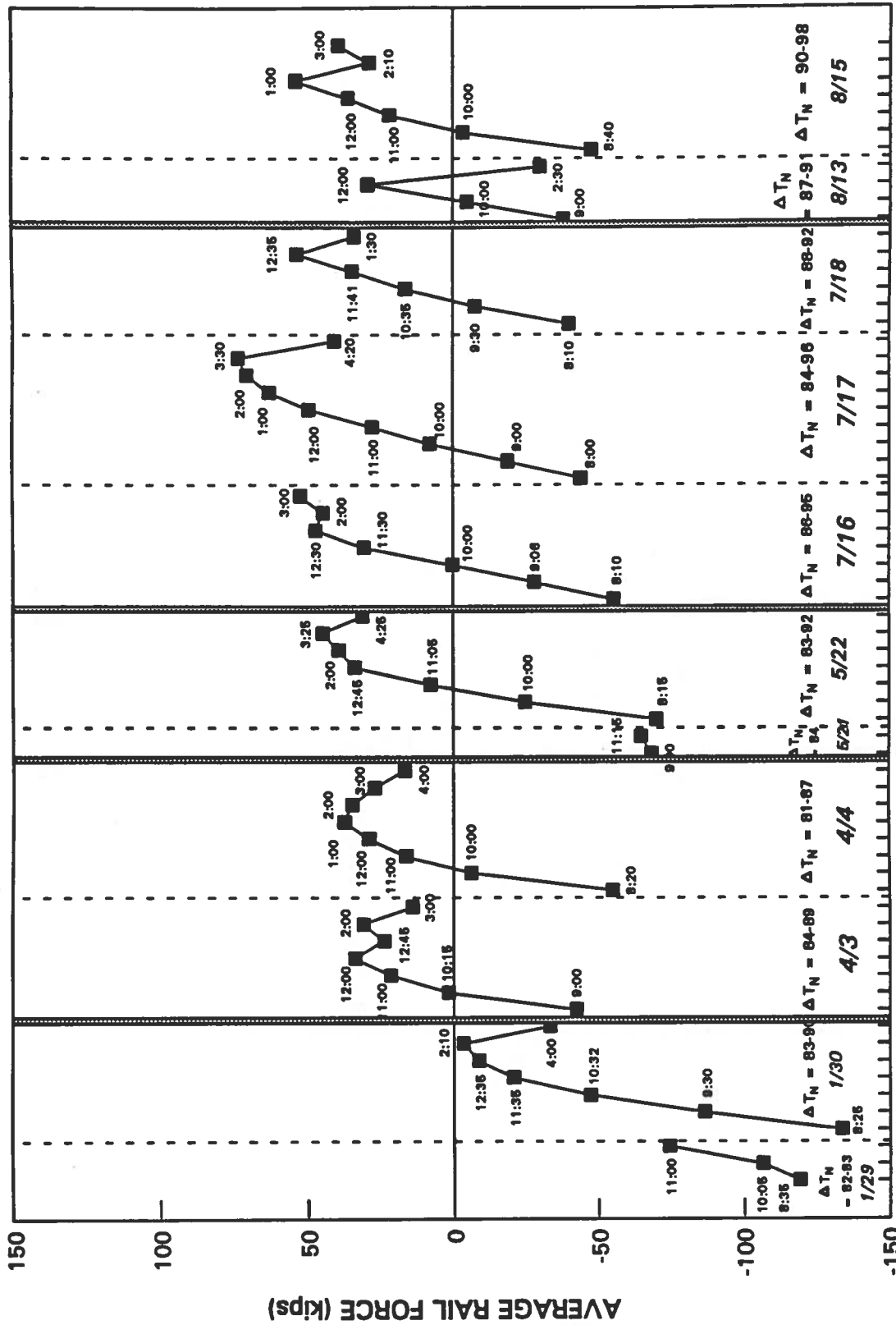


Figure 3-1. ATSF - Santa Fe, NM: Rail Force versus Rail Temperature at TS1 During 1991 (Phase II)



AVERAGE RAIL TEMPERATURE (deg F)

Figure 3-2. ATSF - Santa Fe, NM: Rail Force versus Rail Temperature at TS2 During 1991 (Phase II)

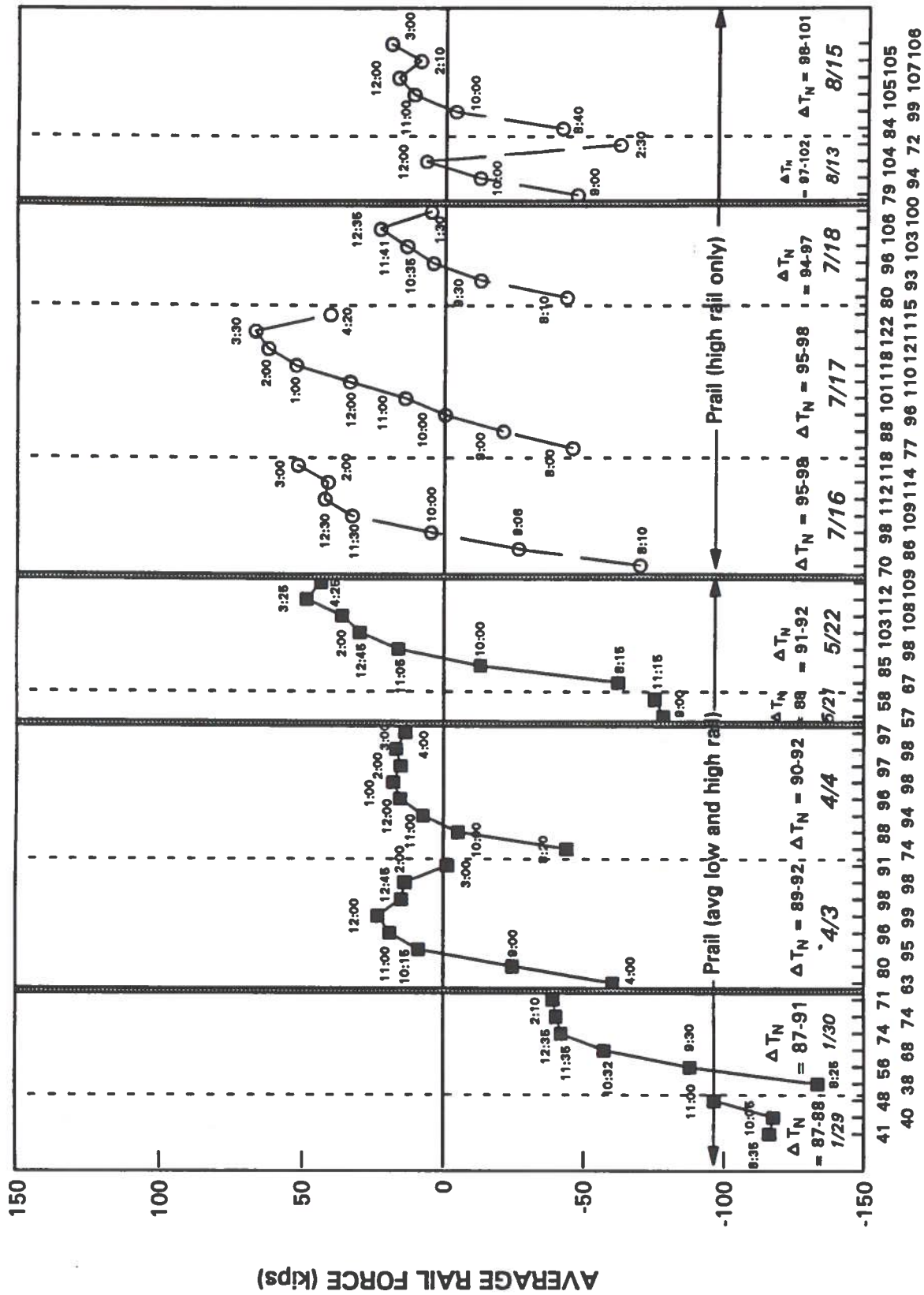


Figure 3-3. ATSF - Santa Fe, NM: Rail Force versus Rail Temperature at TS3 During 1991 (Phase II)

where

μ = Poisson's ratio (0.3 for rail)

ϵ_0 = Reference strain at zero rail force (recorded when rail was cut)

A = Rail cross section area (12.95 in.² for 132 lb rail, 13.35 in.² for 136 lb rail)

E = Modulus of elasticity (30E6 psi for rail)

The peak rail force, which is critical for track buckling, was captured on all data collection days shown in Figures 3-1 through 3-3. Since all data was taken after dawn, the full range of rail force was not recorded. However, it can be seen that the range of rail force is typically at least 100 kips on a sunny day. Further, this large range is found under winter, spring, and summer conditions, independent of the absolute rail temperature. Therefore, it is preferable for the neutral temperature to be near the middle of the daily range in all seasons to minimize the likelihood of track buckling and tension failure.

3.2 Rail Neutral Temperature

The neutral temperature can be calculated by measuring the current rail strain and rail temperature (T_c). These are then compared to the zero force strain using the following equation:

$$T_N = T_c - \frac{(\epsilon_c - \epsilon_0)}{2(1 + \mu)\alpha} \quad (3-2)$$

where α = Coefficient of linear thermal expansion (6.4 μ in./in./°F for rail).

The variation of the neutral temperature over time is shown in Figures 3-4 through 3-6 for the three NS test sections and Figures 3-7 through 3-9 for the three ATSF test sections. On all plots, the high rail is designated by solid data points and a solid line and the low rail is designated by open data points and a dashed line. A dotted line is used to indicate the presence of bolted rail joints. The test implementation activity, when the rail was cut to establish the zero force reference strain readings, is indicated by a shaded section. Further shaded lines provide a break between Phase I (1990) and Phase II (1991) as well as between each site visit on the ATSF data plots. The rail temperature for each point is provided for reference along the x-axis, however, the data is actually plotted at data collection intervals along the date scale shown below the temperatures. Major testing and maintenance activities are also noted on the figures.

3.2.1 NS Railroad

In all of the test sections, major changes in neutral temperature could be attributed to maintenance or seasonal changes. Due to the limited data set, most notably on the damaged TS3 section, daily variations at the NS sites were more difficult to evaluate.

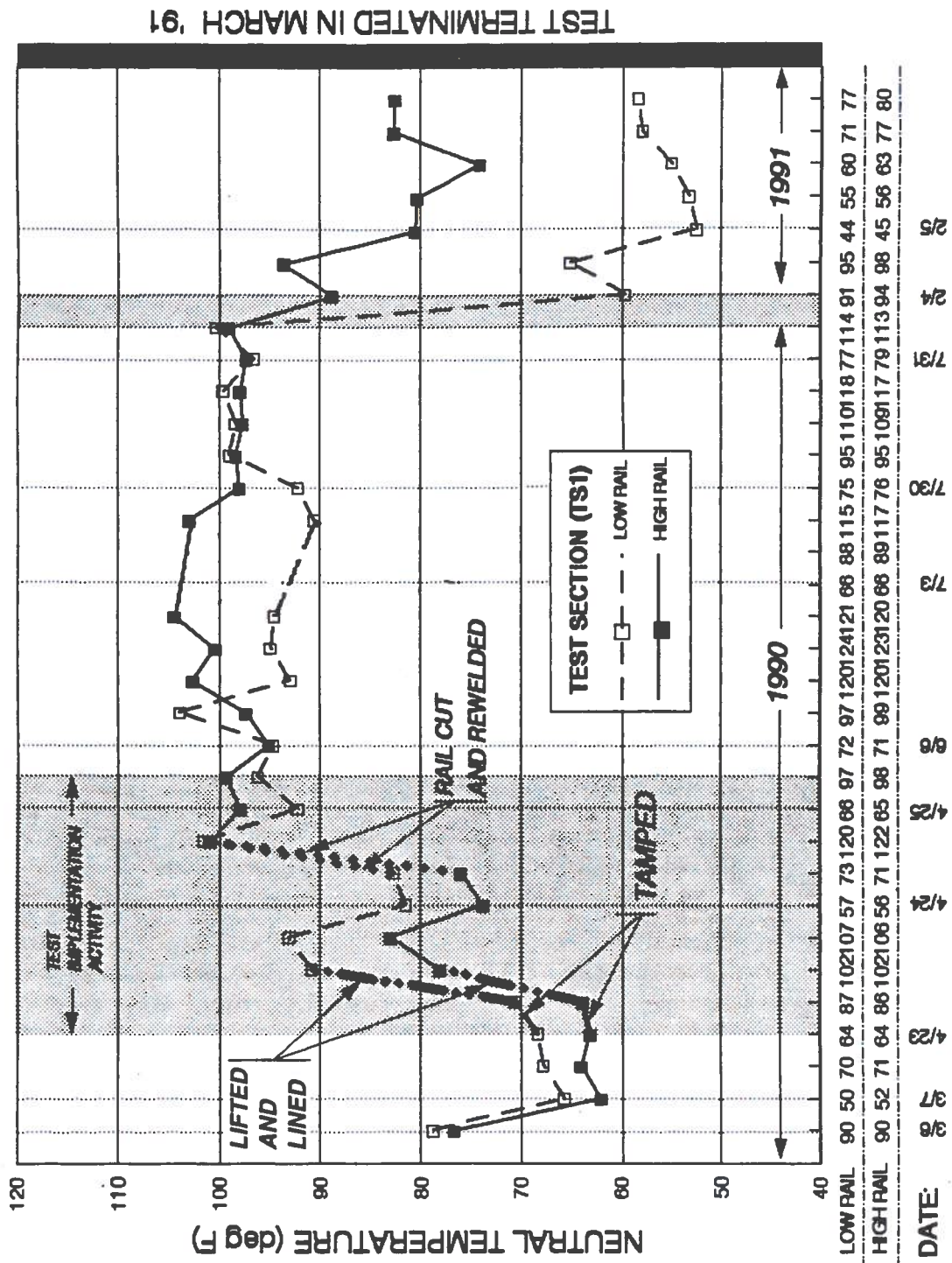


Figure 3-4. NS - Bluefield, WV: Neutral Temperature at TS1

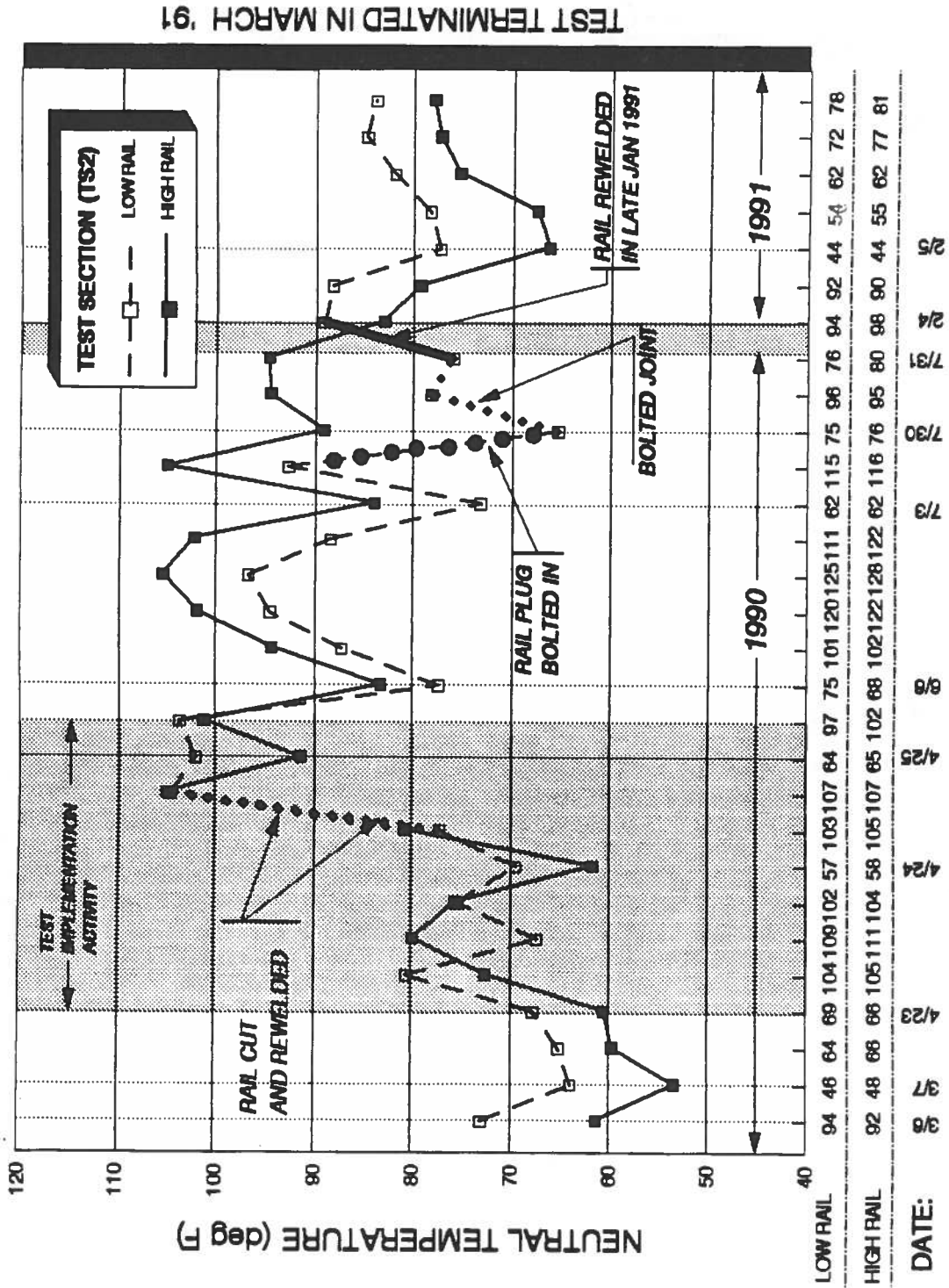


Figure 3-5. NS - Bluefield, WV: Neutral Temperature at TS2

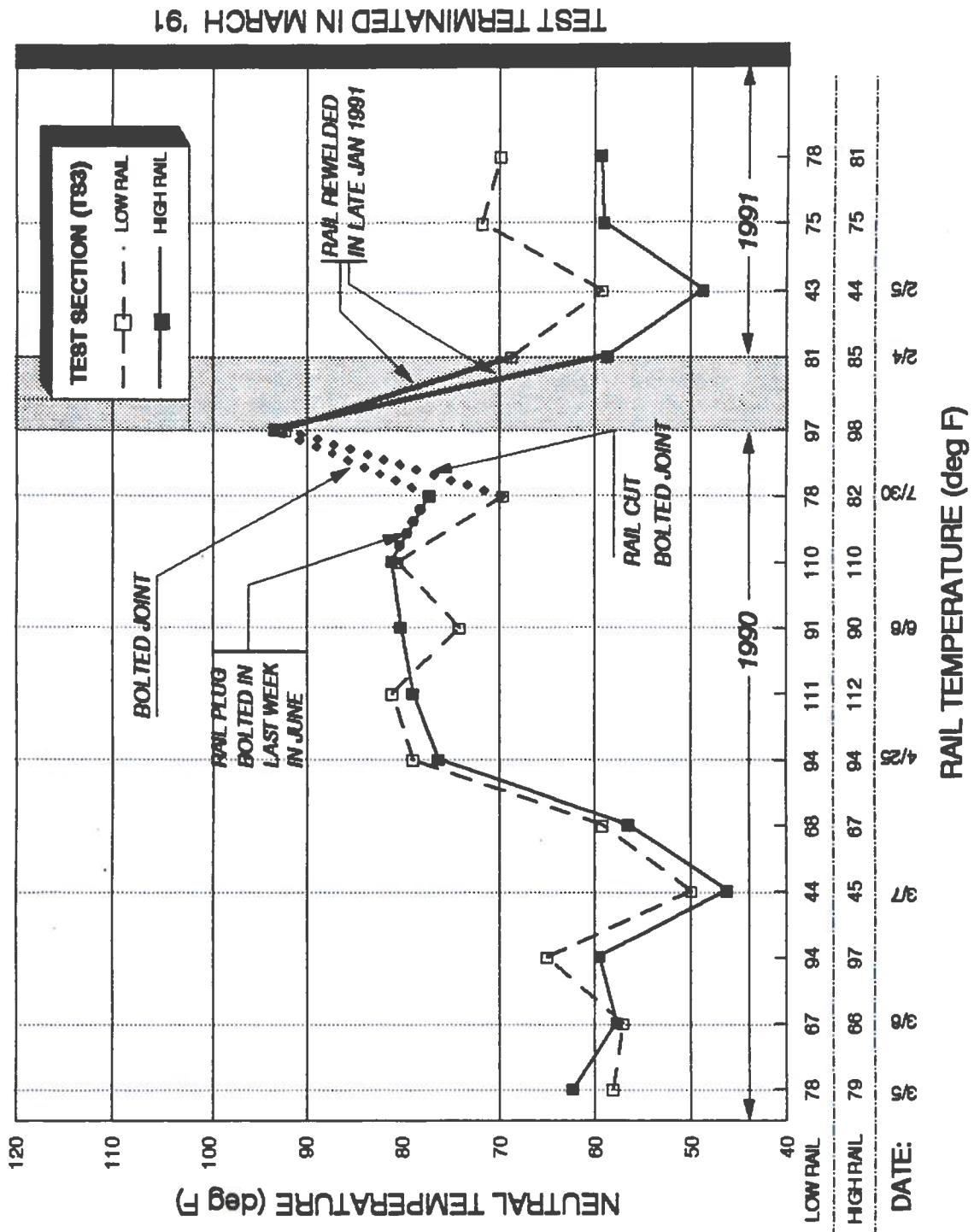


Figure 3-6. NS - Bluefield, WV: Neutral Temperature at TS3

REVENUE SERVICE BUCKLING STRENGTH EVALUATION TESTS - ATSF
RAIL NEUTRAL TEMPERATURE VARIATION SUMMARY

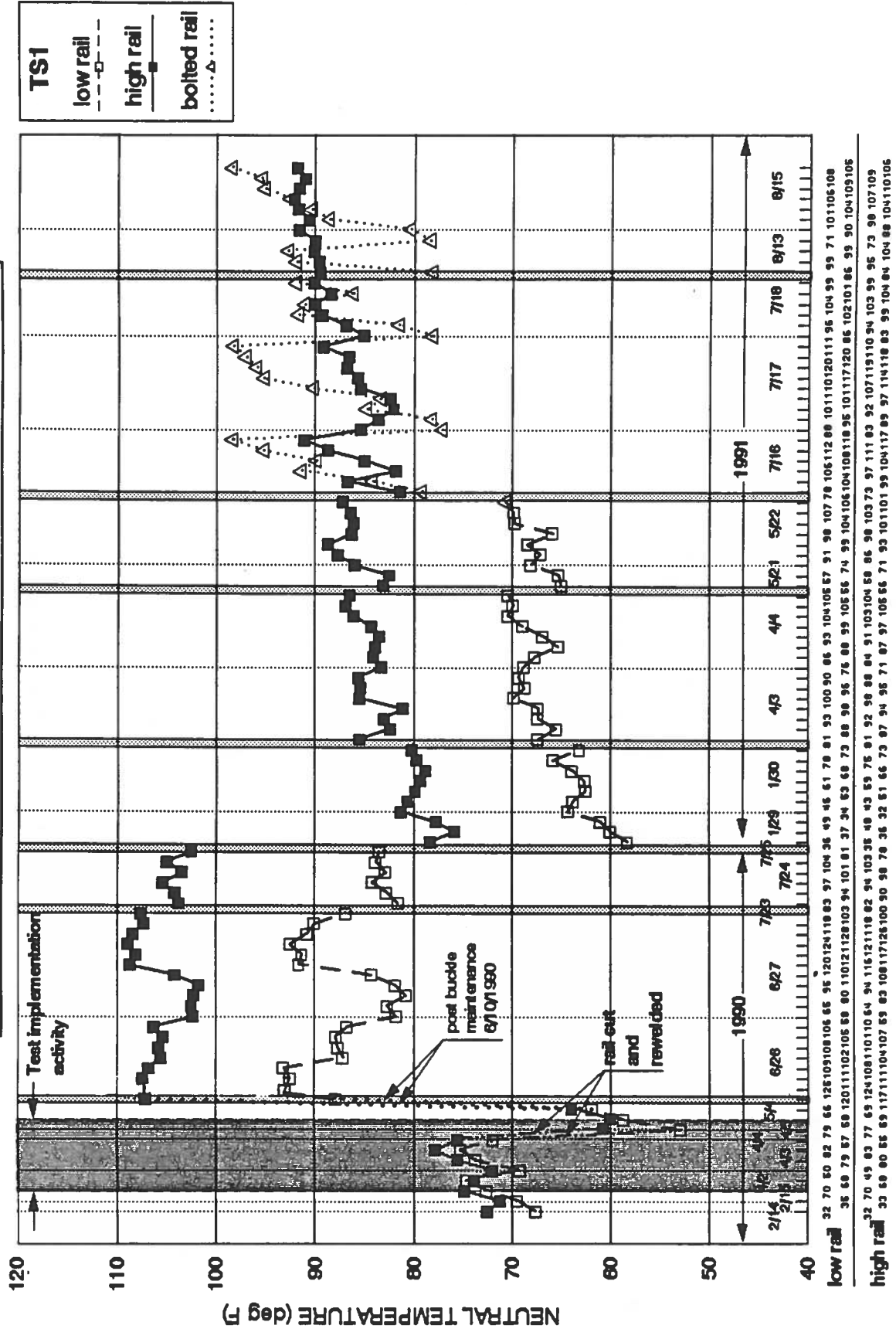


Figure 3-7. ATSF - Santa Fe, NM: Neutral Temperature at TS1

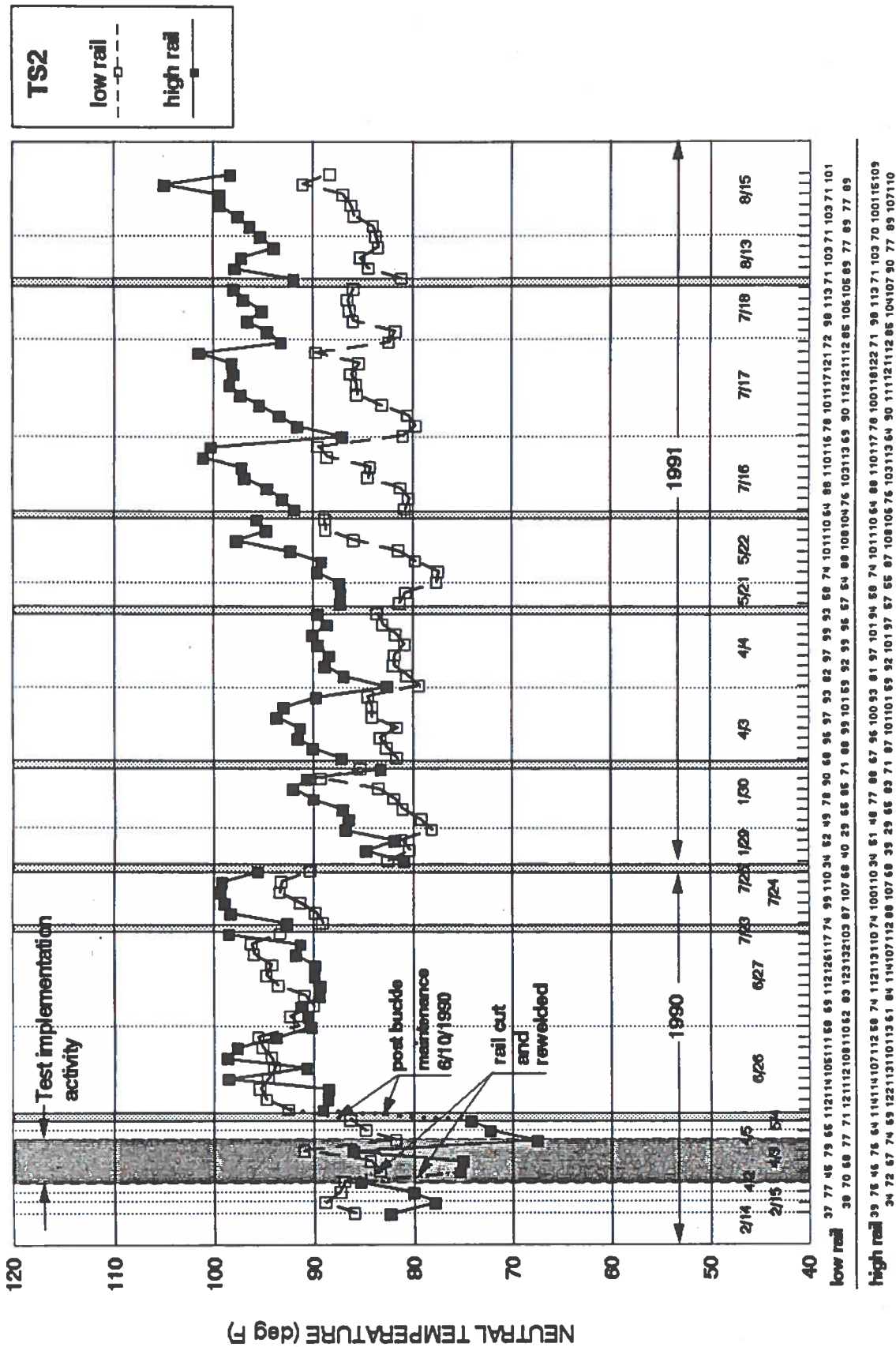


Figure 3-8. ATSF - Santa Fe, NM: Neutral Temperature at TS2

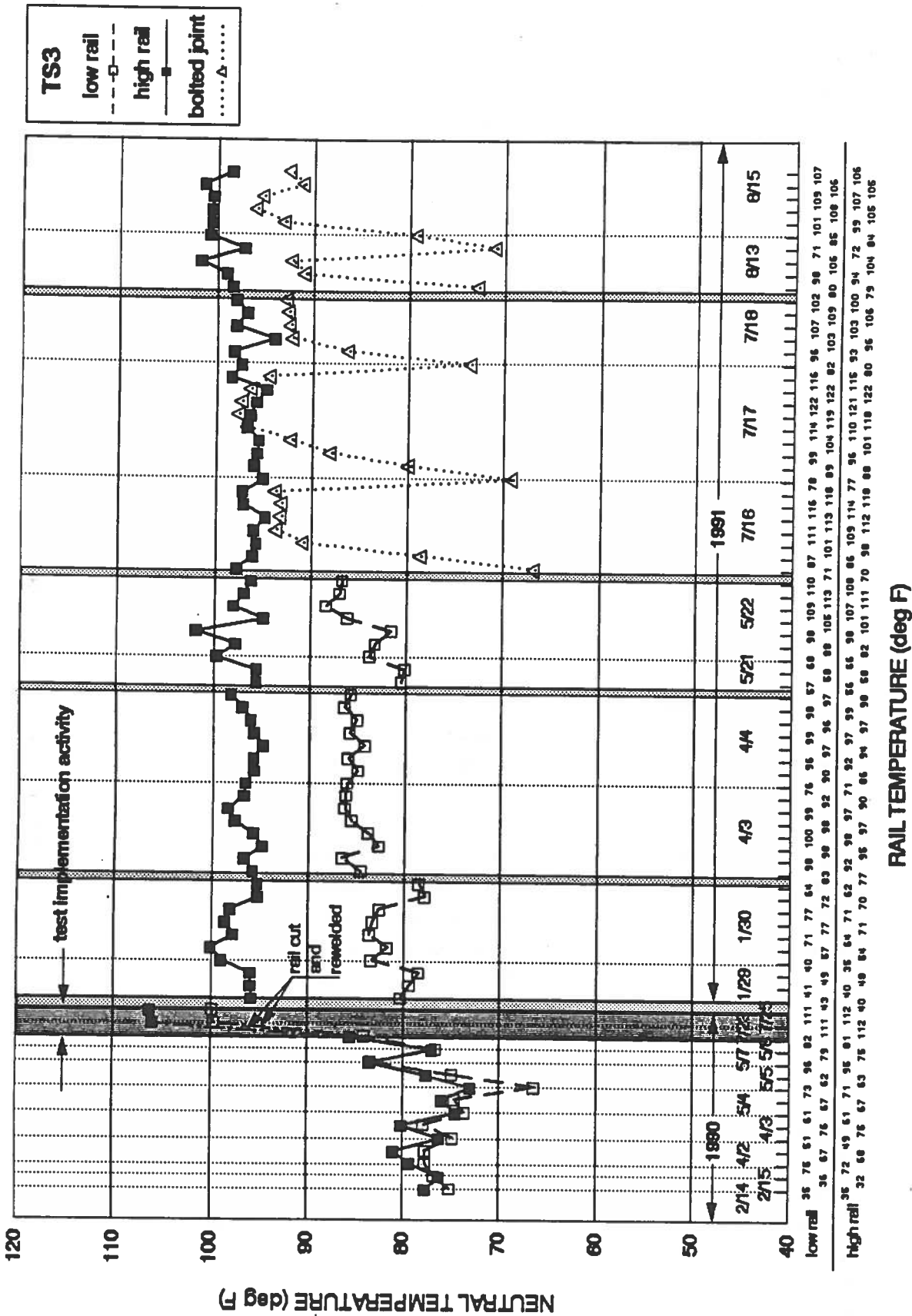


Figure 3-9. ATSF - Santa Fe, NM: Neutral Temperature at TS3

The neutral temperature variation for TS1 at the NS site is shown in Figure 3-4. During the test implementation period, the track was tamped, lifted, and lined, thus the neutral temperature was raised as the rail moved radially outward. The rails were then cut to obtain the zero force reference strain. Following rewelding of the rails, which set the neutral temperature at approximately 100°F, the neutral temperature remained fairly constant throughout the remainder of the Phase I (1990) testing, with typical daily variations of less than 5°F, while the rail temperature range was as much as 50°F. Track lateral resistance measurements, which are discussed in subsection 3.4, indicate that a high level of ballast consolidation was achieved by July 1990 in this section, which was tamped in April. This consolidation would support the constant neutral temperature, which was observed in June and July.

Between July 1990 and February 1991, there was, as would be expected, a substantial decrease in the average ambient temperature. This decrease would result in a high tensile force in the rail, especially at night, and apparently caused the track to shift radially inward. Such movement is the most likely explanation for the observed decrease in neutral temperature over this period. It is not inherently obvious why the low rail neutral temperature decreased substantially more than the high rail neutral temperature. The test in this section was terminated in March 1991 with the replacement of the rail.

The neutral temperature variation for TS2 at the NS site is shown in Figure 3-5. During the test implementation period, the rails were cut to obtain the zero force reference strain. The rewelding of the rails on the same day as the rewelding of the TS1 rails set the neutral temperature at approximately 105°F. However, unlike TS1, the neutral temperature in TS2 varied substantially over the remainder of 1990, with daily variation of as much as 20°F.

As was the case with TS1, the ambient temperature decrease between July 1990 and February 1991 led to a reduction in the neutral temperature in the continuous high rail. It appears in the figure that the low rail neutral temperature actually increased during this same period, however, the rail contained a bolted joint prior to rewelding in January 1991. Thus, the comparable neutral temperature in July 1990 is not a meaningful parameter. The test in this section was terminated in March 1991 with the replacement of the rail.

The neutral temperature variation for TS3 at the NS site is shown in Figure 3-6. The rails were not cut in this section to obtain the zero force reference strain until July 1990. After some substantial daily variance in March, the rail neutral temperature remained fairly constant from April to June prior to the rail cutting and the addition of bolted joints on both rails during late June 1990. The zero reference strains were recorded in July 1990 but the rails were not rewelded in January 1991. The February 1991 data shows a 10°F variation in neutral temperature as the rail temperature changes by 30°F. This variation is similar to that recorded in TS2 during the same period and in TS3 during March 1990, and may be caused by decreased track lateral resistance due to ballast thawing. The testing in this section was terminated in March 1991 with the replacement of the rail.

3.2.2 ATSF Railroad

The large data set from the ATSF test site permits a reasonable evaluation of both daily and seasonal neutral temperature variations, as well as changes due to maintenance activities. Comparisons of the same seasons from successive years are also made.

The neutral temperature variation for TS1 at the ATSF site is shown in Figure 3-7. During the test implementation period of April 1990, the section was tamped and then the rails were cut to obtain the zero force reference strain. The rails were rewelded on a cool morning and the neutral temperature was set at approximately 60°F. High ambient temperatures in June 1990 resulted in high compressive forces in the rails with low neutral temperatures. These forces, combined with the low lateral resistance due to recent tamping, resulted in buckling of the track in this section. Maintenance procedures subsequently increased the neutral temperature of both rails. Daily neutral temperature variations of 5° to 10°F were recorded through June and July 1990 while the track lateral resistance was still relatively low.

During the period of July 1990 to January 1991, when no data was collected, there was a substantial decrease in the average ambient temperature. As was the case at the NS test sites, this temperature change led to high tension forces in the rails and likely resulted in radially inward movement of the track. Consequently, a substantial decrease in the neutral temperature was recorded in both rails. It is interesting to note that the change in neutral temperature was similar (~25°F) in both rails, with the low rail neutral temperature remaining approximately 15°F lower than that of the high rail. This is to be expected, since the cross ties maintain a constant gauge between the rails; thus, any radial movement should be the same in both rails. Therefore, the change in neutral temperature, not the neutral temperature itself, should be the same for both rails, providing that no other maintenance activities are performed.

For all of the Phase II (1991) test dates, the neutral temperature showed minimal daily variations of less than 5°F. Over the entire test period from January to August 1991, the total gradual increase of the neutral temperature was less than 15°F. This slow increase was likely due to ambient temperature increases, which resulted in high compressive forces in the rails. These forces, combined with the lateral forces due to train passage, likely led to some radially outward movement of the track and, subsequently, to increases in the neutral temperature. Replacement of a section of the low rail in June 1991, due to a defective weld, ended the relevant neutral temperature monitoring of this rail because bolted joints were used. As can be seen in the figure, the neutral temperature increased along with the rail temperature and maintained a nearly zero force condition in this rail.

The neutral temperature variation for TS2 at the ATSF test site is shown in Figure 3-8. During the test implementation period of April 1990, the rails were cut to obtain the zero force reference strain. These rails were rewelded with higher neutral temperatures than TS1 (approximately 70°F for the high rail and 80°F for the low rail). The high June temperatures,

which led to the buckling in TS1, also caused some minor sunkinks to the east of TS2. To relieve these kinks, both rails were cut and rewelded and the TS2 neutral temperature was reset to approximately 95°F in both rails. This neutral temperature remained fairly constant, with typical daily variations of less than 10°F, for the remainder of the Phase I testing.

During the period of July 1990 to January 1991, the neutral temperature decreased in both rails in the same manner as was discussed for TS1. Since the summer of 1990, neutral temperature was not as high in TS2 as it was in TS1, the reduction in TS2 neutral temperature was only 10°F.

For the Phase II (1991) testing period, the daily variation of neutral temperature was substantially greater in TS2 than it was in either TS1 or TS3. While the increase in average neutral temperature over the period was less than 15°F and similar to TS1, the typical daily variations were 10° to 15°F. This variation is particularly pronounced in the high rail, which is subjected to the lateral forces due to train passage as well as the thermal forces. It is possible that Pandrol fasteners used in TS1 and TS3 in 1991 could have constrained the rail more effectively than the wood tie anchors in TS2.

The neutral temperature variation in TS3 at the ATSF site is shown in Figure 3-9. The rails were not cut in this section to obtain the zero force reference strain until July 1990, when cutting and rewelding resulted in neutral temperatures above 100°F in both rails.

No data was taken following the rewelding of TS3 in July 1990, until January 1991, when the neutral temperature had decreased in both rails in the same manner as was discussed for TS1. While the neutral temperature decreased for both rails, it is not obvious why the low rail decreased by 20°F while the high rail only decreased by 10°F. Both rails exhibited very small daily variations (typically 2° to 3°F) in neutral temperature for the entire Phase II (1991) test period. As with TS1, replacement of a section of the low rail in June 1991, due to a defective weld, ended the neutral temperature monitoring of this rail.

3.3 Track Radial Movement

Rail longitudinal force is affected not only by the change in rail temperature, but also by the movement of the rail as a result of the thermal or train passage forces. As the force increases, the track tends to move to relieve the force. As mentioned previously, radially outward movement will relieve force throughout a section and consequently raise the neutral temperature of the rails. This movement can be assisted by train passage. Longitudinal movement of the rail along the track may also occur influencing the rail force distribution.

Limited Phase I test data of the radial movement at the NS test sites are shown in Figures 3-10 through 3-12. The high scatter of this data is due to the inaccuracy of the original measurement system, as discussed in the analysis to follow in subsection 4.2. The data from the ATSF test sites are shown in Figures 3-13 through 3-15. The Phase II (1991) data shows

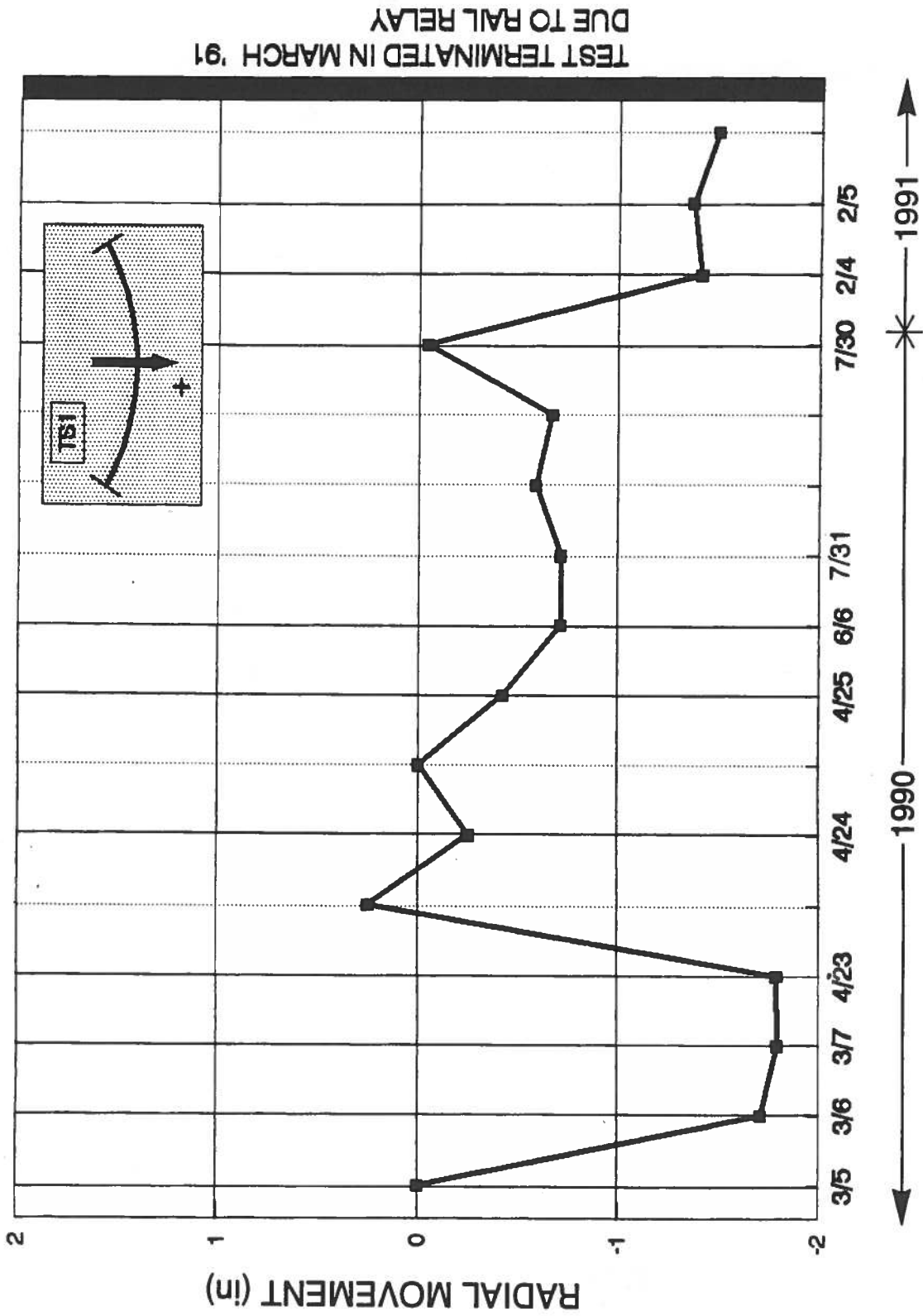


Figure 3-10. NS Rail Radial Movement Variation Summary (TS1)

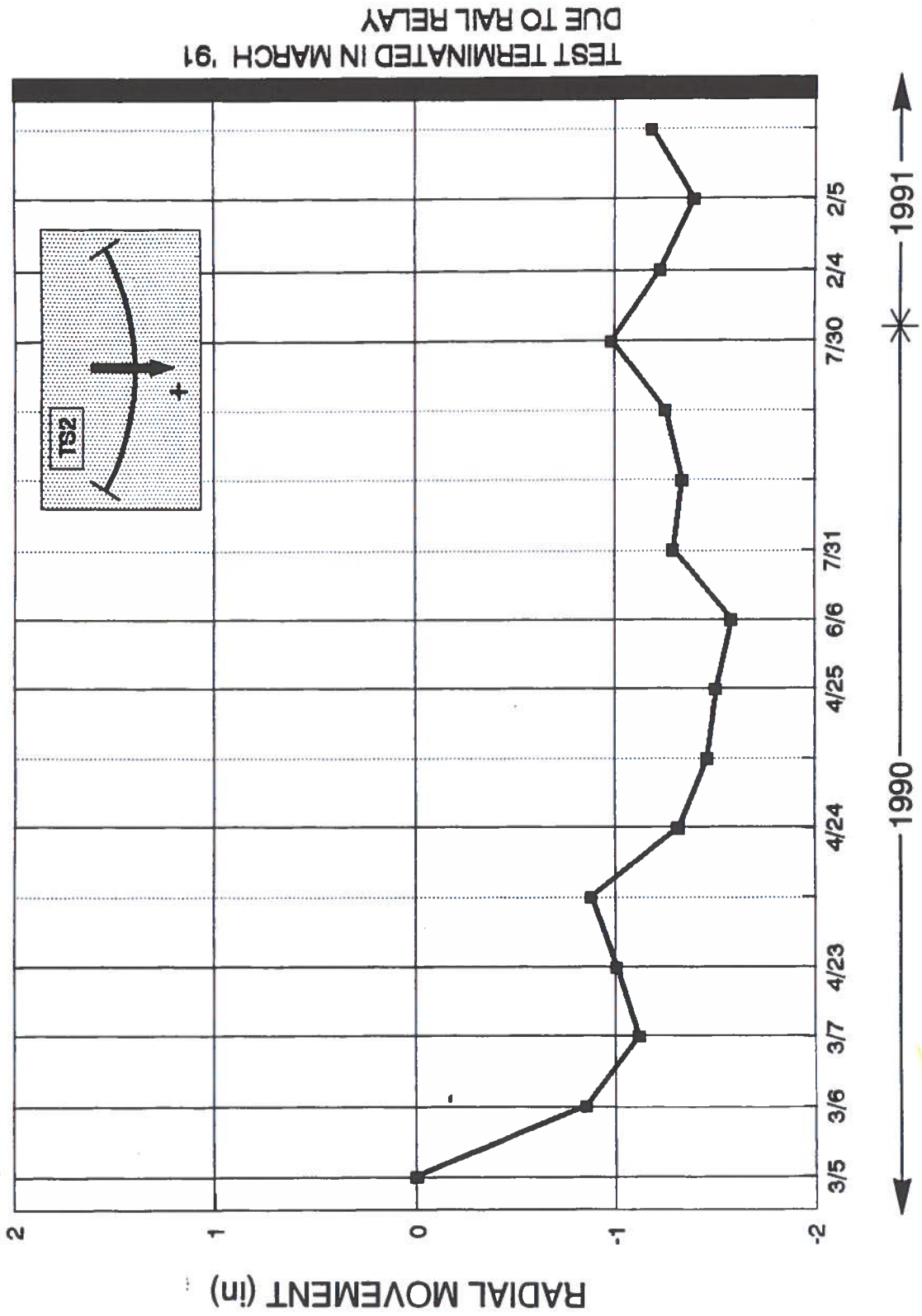


Figure 3-11. NS Rail Radial Movement Variation Summary (TS2)

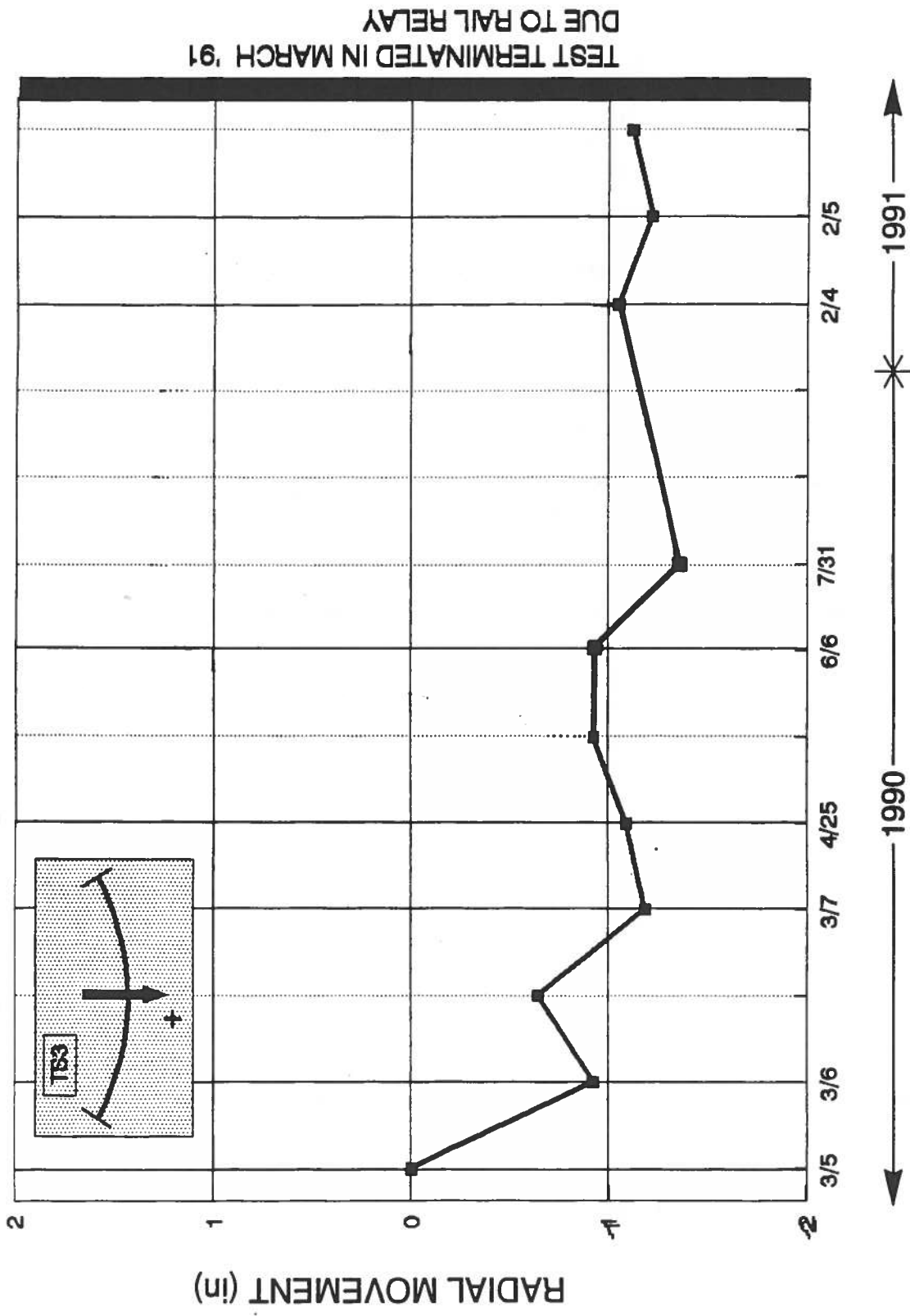


Figure 3-12. NS Rail Radial Movement Variation Summary (TS3)

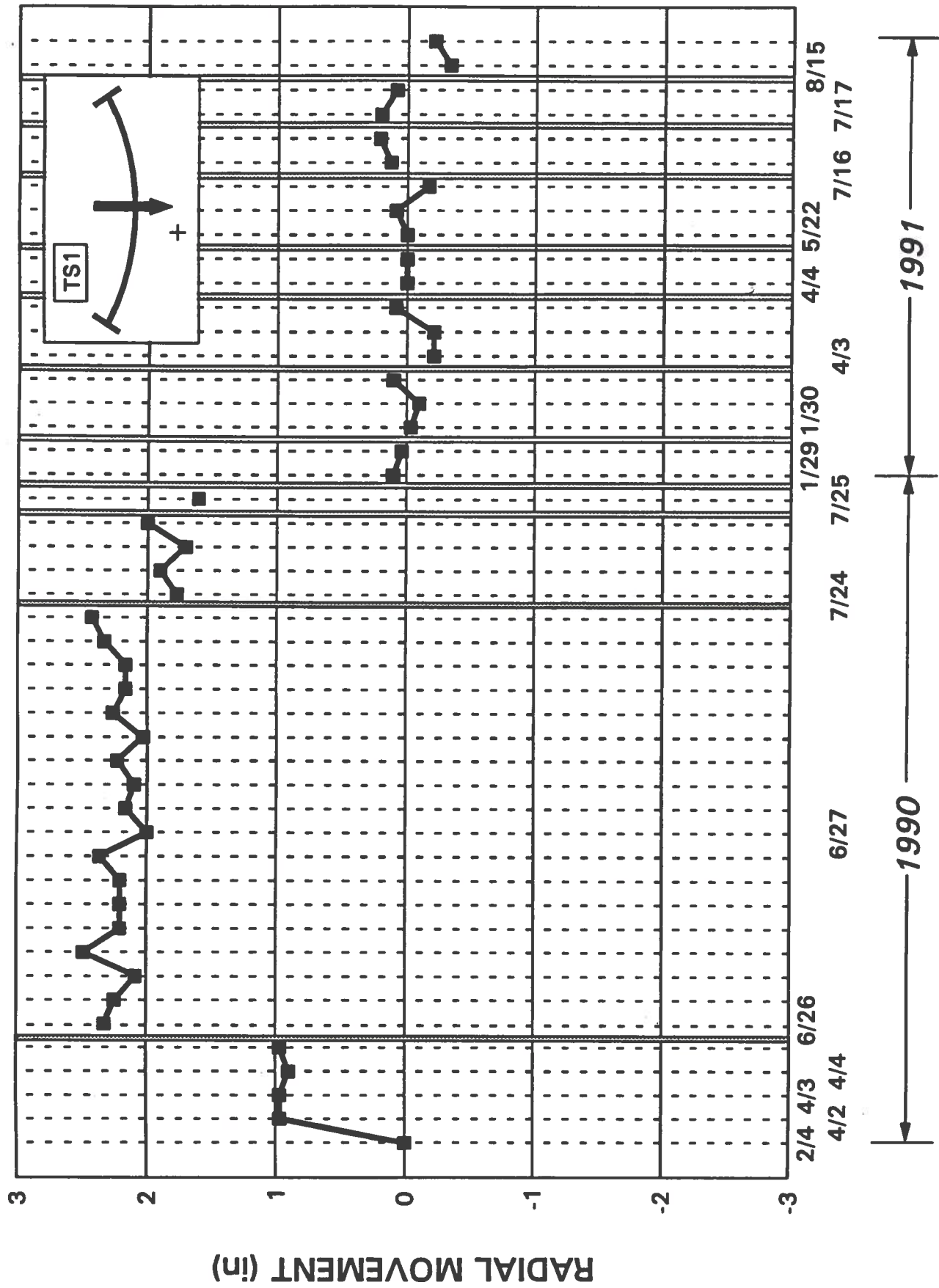


Figure 3-13. ATSF Rail Radial Movement Variation Summary (TS1)

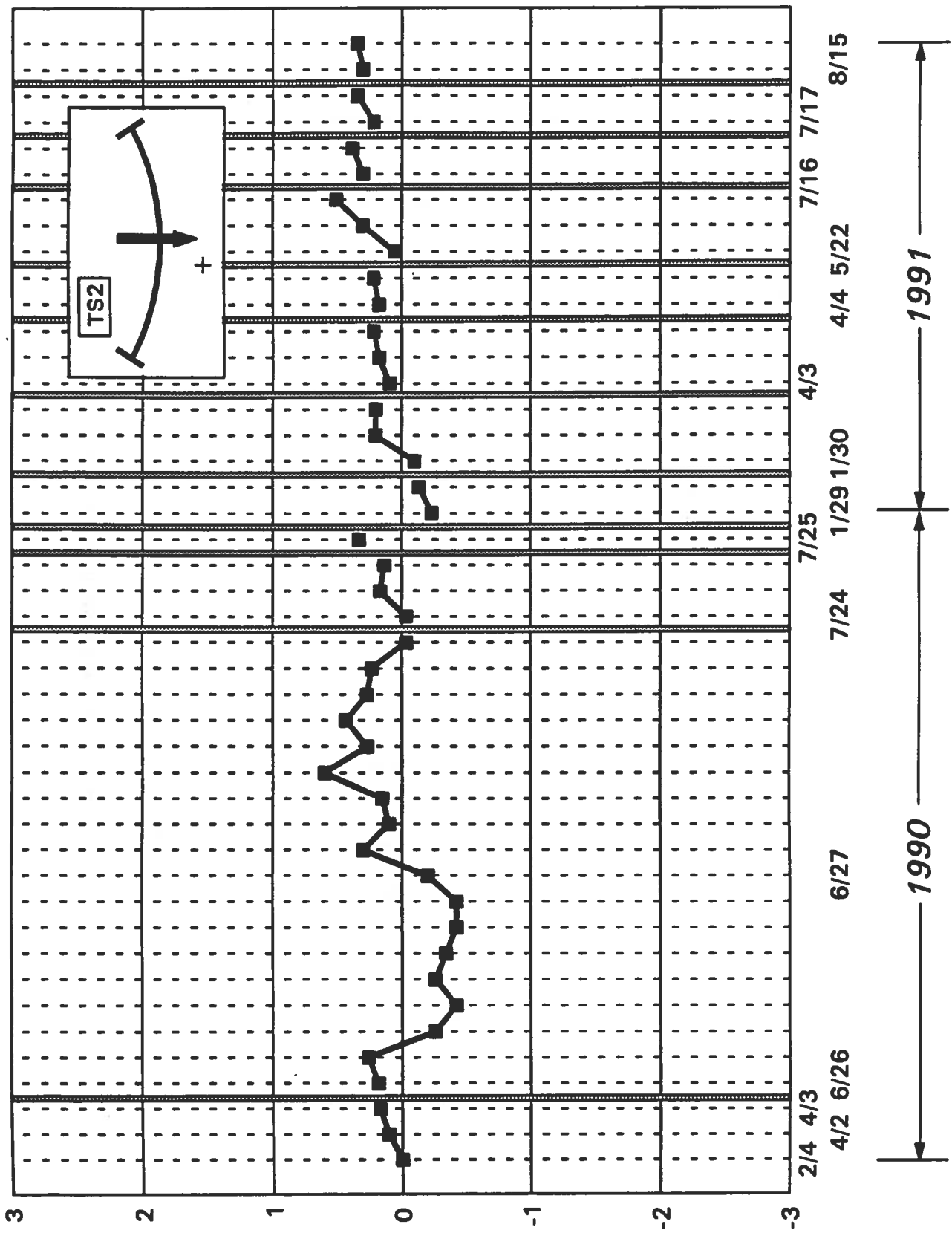


Figure 3-14. ATSF Rail Radial Movement Variation Summary (TS2)

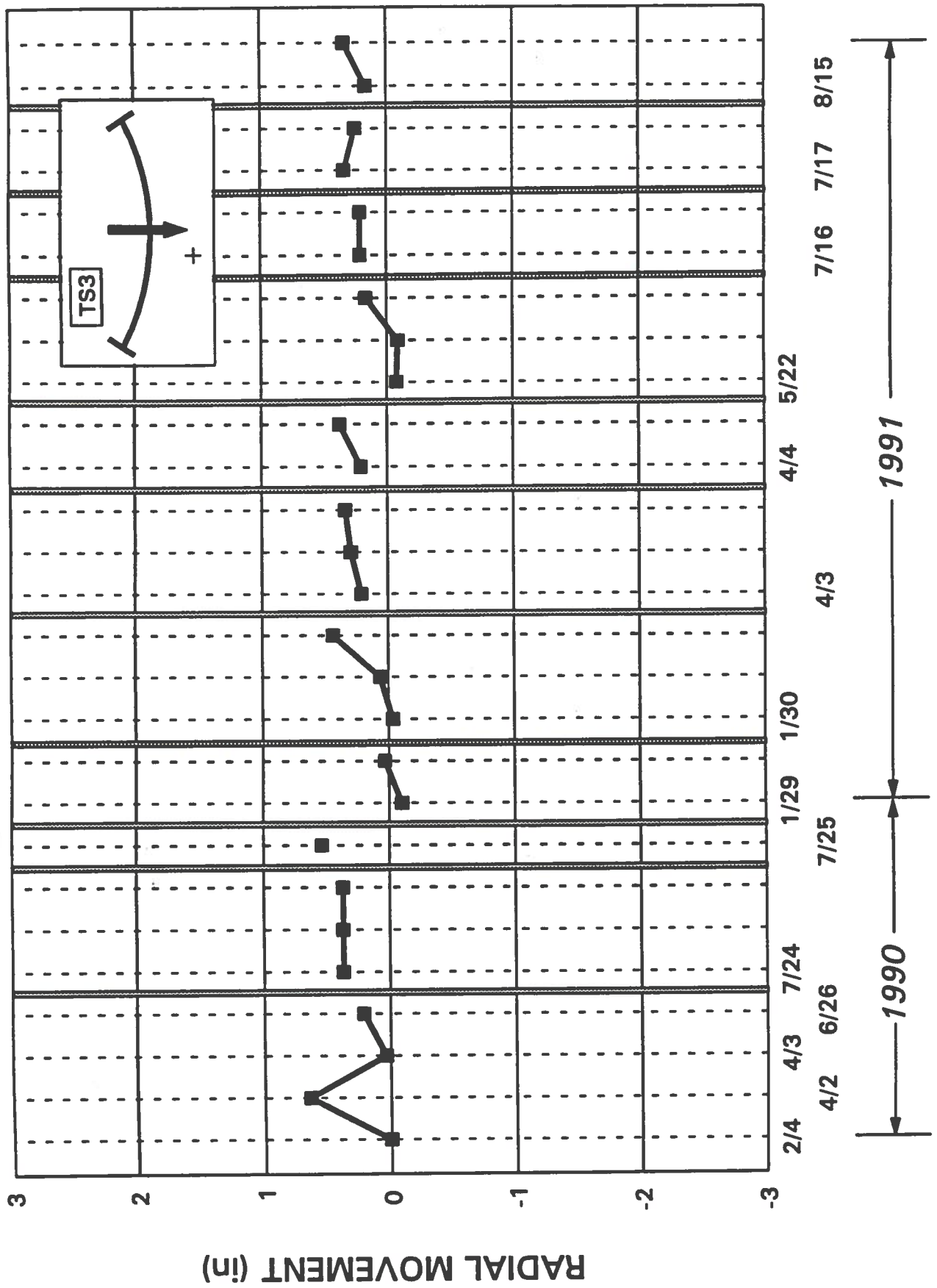


Figure 3-15. ATSF Rail Radial Movement Variation Summary (TS3)

substantially less scatter than the Phase I data and correlates reasonably well with the strain gauge data within the accuracy of the measurement system, as discussed later.

The relationship between radial movement of the track and the force in the rails can be expressed in terms of the rail strain. Since all strain data recorded in this test program is expressed as indicated strain, as discussed in subsection 2.2, the *indicated* strain due to track radial movement (ϵ_{m_i}) is calculated as follows.

The *true* strain due to track radial movement (ϵ_{m_t}) is expressed as:

$$\epsilon_{m_t} = \Delta R / R \quad (3-3)$$

and,

$$R = [12 \text{ in.} \times 100 \text{ ft} \times 360^\circ / C] / 2\pi \quad (3-4)$$

where:

- C = Track curvature in degrees
- ΔR = Radial movement in inches
- R = Curve radius in inches

combining,

$$\epsilon_{m_t} = \frac{2\pi C \Delta R (1E6 \mu\epsilon / \epsilon)}{360 \times 100 \times 12} = 4.63 C \pi \Delta R \quad (3-5)$$

from equation 2-1,

$$\epsilon_{m_i} = 2(1 + \mu)(4.63 C \pi \Delta R) = 12 C \pi \Delta R \quad (3-6)$$

where ϵ_{m_i} is expressed in microstrain

Thus, the radial movement data can provide a comparison to the recorded strain data and may be able to explain shifts in the neutral temperature. Complete tables of the rail movement data are given in Appendix A.

3.4 Track Lateral Resistance

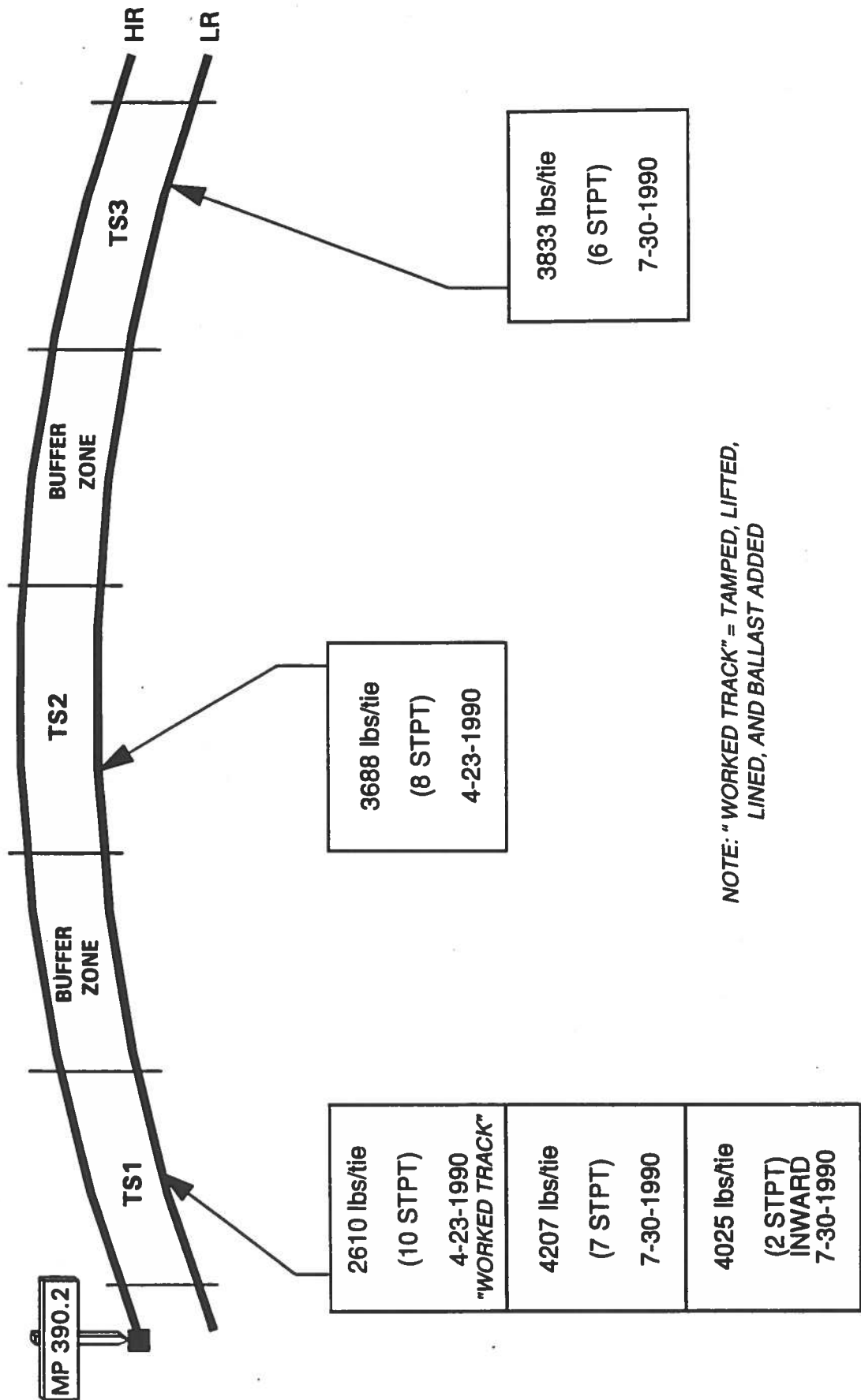
Track lateral resistance is defined as the load required to move the tie in the ballast, in the lateral direction. This lateral resistance, determined by performing the STPT, is one of the fundamental parameters controlling track lateral stability under thermal and vehicle loads. This parameter is one of the inputs for the Volpe Center's computer model, used here to predict the CWR buckling strength.

Using the procedure defined previously in subsection 2.2, applied load versus tie displacement, plots were generated for each tested tie. As shown in the typical plots in Appendix B, a maximum "peak" load (F_p) will be reached, usually after 0.25 to 0.50 in. of tie displacement. The load will then drop to a constant "limit" load (F_L), usually after 3 to 6 in. of tie displacement. The peak and limit loads are nearly equal in low resistance ties, but the peak can be 2 to 3 times greater than the limit in high resistance ties. A summary of the STPT results is given in Table 3-1. For each site, test section, and ballast condition tested, the average peak and limit loads and the tie displacements at these loads are shown. The standard deviation of each data set and the number of ties in the data set are also provided. Figures 3-16 and 3-17 summarize the data pictorially to more clearly show the lateral resistance distributions of both test sites.

The lateral resistance increased at different rates at the two sites as a function of traffic volume. Correlation of this data with the track tonnage is discussed in subsection 4.3.

Table 3-1. Summary of STPT Results from Both Test Sites

Site	TS	Condition	F _p Peak (lb)	Std. Dev. (lb)	W _p Displace- ment (in.)	No. of Ties	F _L Limit (lb)	Std. Dev. (lb)	W _p Displace- ment (in.)	No. of Ties
Santa Fe, NM	1	Tamped-Spring	1,477	214	0.52	11	1,032	200	4.2	11
		Summer	1,966	292	0.81	9	1,361	140	4.4	9
		Summer-Inward	1,512	270	0.23	4	987	163	4.17	4
	2	Spring	2,834	409	0.41	16	1,575	198	4.8	16
		Summer	3,038	330	0.4	4	1,900	374	4.9	4
	3	Summer	2,420	301	0.35	9	1,585	195	4.4	9
1-3	Spring	1,833	125	0.37	3	1,467	170	4.6	3	
Bluefield, WV	1	Tamped-Spring	2,610	530	0.58	10	1,538	308	4.5	8
		Summer	4,207	410	0.52	7	1,729	262	4.5	7
		Summer-Inward	4,025	75	0.9	2	1,900	-	-	-
	2	Spring	3,688	463	0.34	8	1,613	322	3.58	8
	3	Summer	3,833	672	0.28	6	1,285	235	4.18	6
Santa Fe, NM	1	Summer '91	2,686	899	0.6	9	1,278	322	4	9
	2		4,030	874	0.4	11	1,688	232	4	8
	3		3,356	903	0.5	8	1,857	256	3	7



NOTE: "WORKED TRACK" = TAMPED, LIFTED, LINED, AND BALLAST ADDED

Figure 3-16. NS Track Lateral Resistance (STPT) Summary

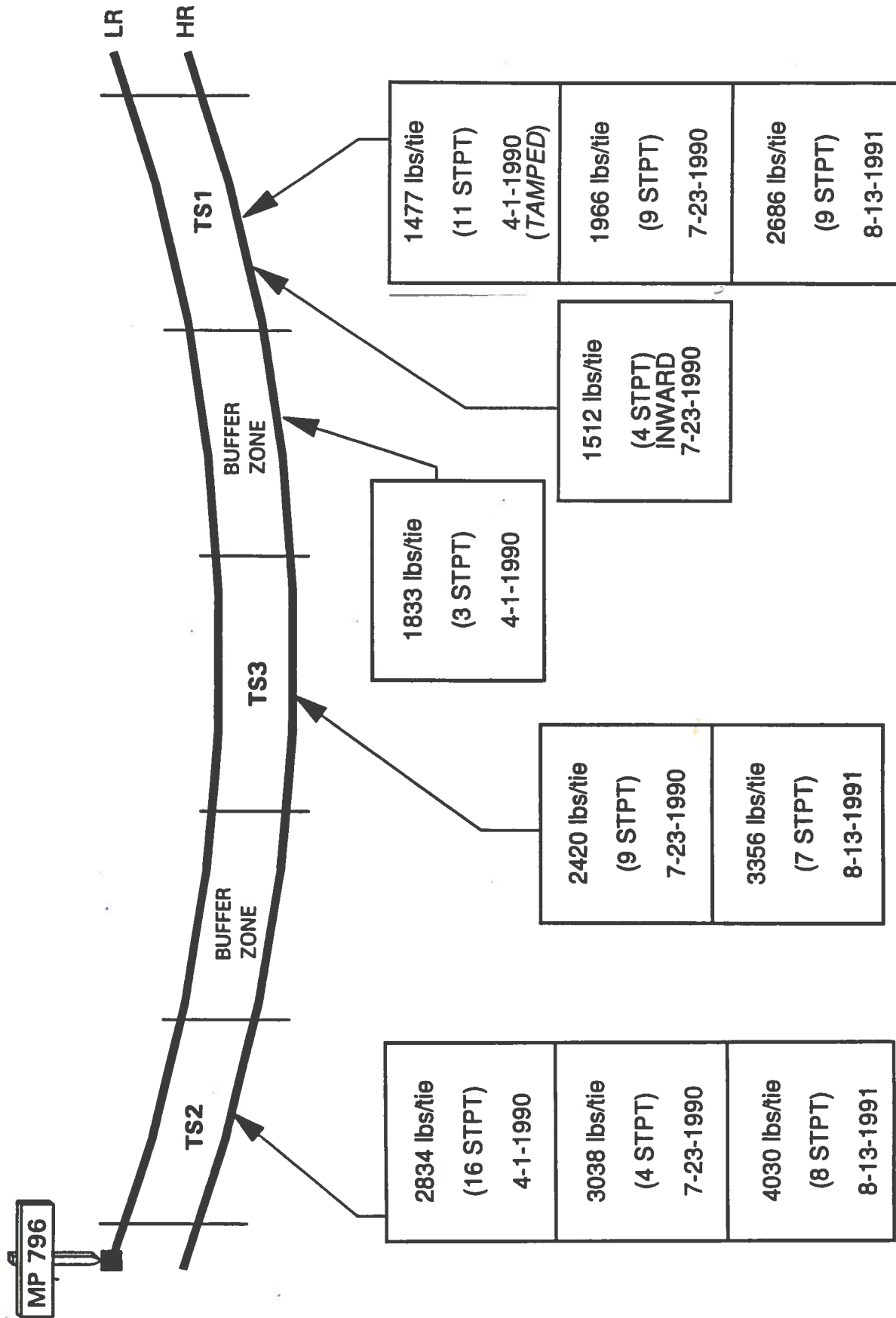


Figure 3-17. ATSF Track Lateral Resistance (STPT) Summary

4. DATA ANALYSIS

This section presents an evaluation of the results of the field test program. The data collected, namely (1) rail strain and temperature, (2) track radial movement, and (3) track lateral resistance, are utilized to characterize the following four primary aspects of track performance.

1. Rail neutral temperature, which was calculated from the rail strain and temperature data and presented previously in Section 3, is evaluated to assess daily, seasonal, and abrupt changes.
2. Radial breathing, which affects changes in rail neutral temperature, is compared with the evaluation from 1 to quantify the contribution of this movement to the recorded neutral temperature shifts.
3. Track lateral resistance is evaluated to compare the ballast consolidation rates at the two test sites and to provide input to the analysis in 4.
4. Track buckling potential is analyzed using the Volpe Center's dynamic buckling computer model with the above data, and the resulting predictions are compared with field observations.

As noted in Section 3, the complete strain, temperature, and movement raw data are presented in Appendix A.

4.1 Rail Neutral Temperature

Changes in the rail neutral temperature were observed throughout the test program and were shown previously in Figures 3-4 through 3-9. While most daily variations were typically on the order of 5°F, large daily variations on the order of 20°F were recorded in TS2 at the NS site. Primarily, the large shifts in neutral temperature were due to either seasonal temperature changes or track maintenance work. Table 4-1 provides a summary of the typical daily and seasonal variations in neutral temperatures recorded at each test site. These changes are most clearly evident at the ATSF site due to the substantially greater amount of data collected. However, summer-to-winter neutral temperature decreases are also found in the NS data, most notably in TS1.

The significant reductions in neutral temperature from summer to winter were partly due to the high neutral temperatures set by cutting and welding the rails in the late spring or summer of 1990. The data from the extended testing at the ATSF site indicate that an uncut rail will maintain a neutral temperature on the order of 85°F with seasonal fluctuations of less than 10°F. This is indicated by the data from 1991 and the data from April 1990 prior to rail cutting.

Table 4-1. Daily and Seasonal Neutral Temperature Variations

Norfolk Southern (NS)		Average Neutral Temperature (F)					Daily Variation (F)	
Test Site	Mar 90	Apr 90	Jun/Jul 90	Feb 91	Jul/Aug 91	1990	1991	
TS1	65	65/100*	85	90		5	<10	
TS2	65	75/105	95**	80		20	10	
TS3	60	80	80/***	60		5	10	
Atchison, Topeka, and Sante Fe (ATSF)								
Test Site	Apr 90	Jun/Jul 90	Jan 91	Apr 91	Jul/Aug 91	1990	1991	
TS1	75/60	105	80	85	90	5-10	5	
TS2	85/75	95	85	85	90	<10	10-15	
TS3	75	80/105	95	95	100	5	<5	
* The two Tn values represent before and after cut and weld								
** The neutral temperature at NS-TS2 varied greatly								
*** Rail not welded after cutting								

A summary of the shifts in neutral temperature due to track maintenance operations is provided in Table 4-2. In each test section, the rails were cut to obtain the zero force reference for the strain gauges. Due to low temperatures at rail welds in TS1 and TS2 at the ATSF site and high ambient temperatures in June 1990, a few buckles occurred in these test sections and substantial post-buckle maintenance was performed to realign the track radically outward and thus raise the neutral temperature in these sections. Unfortunately, the track crew's decision to use bolted joints in the rails at both sites prevented continuous tracking of seasonal changes. Since the bolted joints permit free expansion and contraction of the rail at the joints, the concept of neutral temperature is not applicable. Although these joints potentially reduce the likelihood of track buckling, the advantages of CWR are no longer realized.

4.2 Radial Breathing Contribution to Neutral Temperature Shift

The significant neutral temperature shifts observed in subsection 4.1 can be attributed in part to radial movement of the rail. Recall equation 3-6,

$$\epsilon_{m1} \approx 12C\pi\Delta R$$

where C is the curvature in degrees, ΔR is the radial movement in inches, and ϵ_{m1} is the change in indicated microstrain. Further, recall equation 3-2,

$$T_N = T_c - \frac{(\epsilon_c - \epsilon_0)}{2(1 + \mu)\alpha}$$

which may be rewritten as,

$$\Delta T_N = \frac{\Delta \epsilon}{16.64} \tag{4-1}$$

where $\Delta \epsilon = \epsilon_c - \epsilon_0$

using the rail properties of $\mu = 0.3$ and $\alpha = 6.4 \times 10 \mu\text{in./in./}^\circ\text{F}$.

Thus, the change in neutral temperature ($\Delta T_N = T_c - T_N$) due to radial movement (ΔR) may be directly expressed as follows:

$$\begin{aligned} \Delta T_N &= \frac{12C\pi\Delta R}{16.64} \\ &\approx 0.723 C\pi\Delta R \end{aligned} \tag{4-2}$$

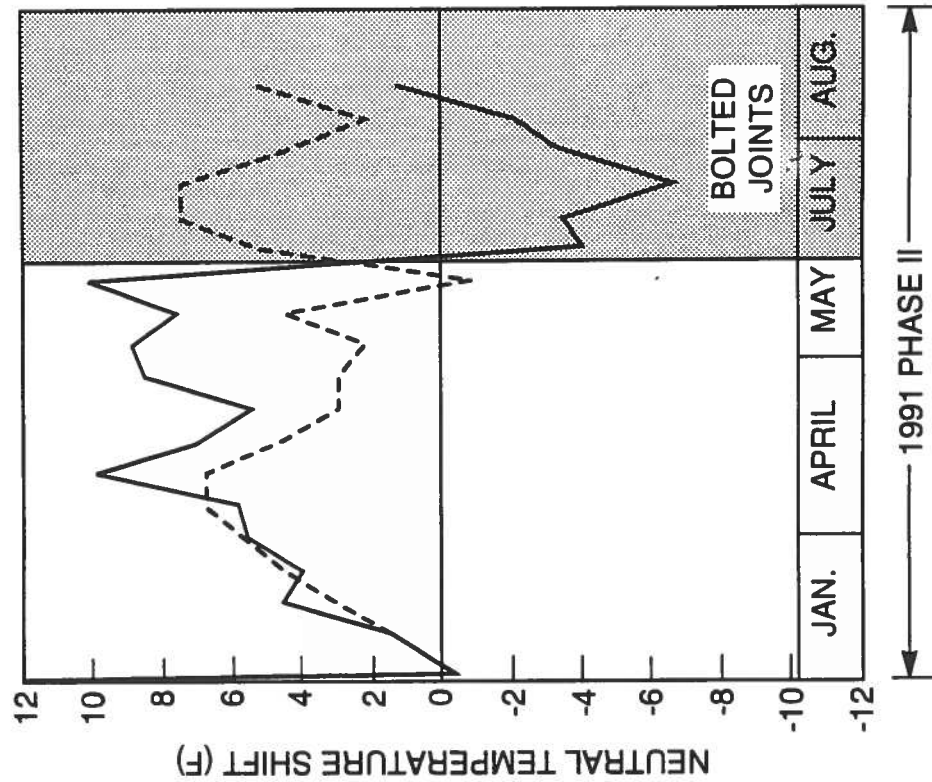
Table 4-2. Neutral Temperature Variations due to Maintenance Procedures

Norfolk Southern (NS)				
Test Site	Date	Neutral Temp. (F)		Maintenance Action
		Before	After	
TS1	Apr-90	65	85	Track lifted and lined
	Apr-90	80	100	Rails cut and welded for zero force measurement
TS2	Apr-90	75	105	Rails cut and welded for zero force measurement
	Jul-90	95	N/A *	Bolted joint installed in the low rail
	Jan-91	N/A	80	Low rail welded
TS3	Jun-90	80	N/A	Bolted joint installed in the high rail
	Jul-90	80	N/A	Bolted joint installed in the low rail
	Jan-91	N/A	60	Both rails welded
Atchison, Topeka, and Sante Fe (ATSF)				
TS1	Apr-90	75	60	Rails cut and welded for zero force measurement
	Jun-90	60	105	Post-buckle maintenance
	Jul-91	70	N/A	Bolted joint installed in the low rail
TS2	Apr-90	85	75	Rails cut and welded for zero force measurement
	Jun-90	75	95	Post-buckle maintenance
TS3	Jul-90	80	105	Rails cut and welded for zero force measurement
	Jul-91	85	N/A	Bolted joint installed in the low rail
*N/A - Neutral temperature is not an applicable concept due to the bolted joint				

Figures 4-1 through 4-3 show the total neutral temperature shift, as indicated by the strain gauges, and the contribution of radial movement toward the neutral temperature shift, as calculated above, for the test data from the ATSF site. Within the limited movement data, it can be seen that the radial movement typically accounts for the majority of the neutral temperature shift.

The Phase I data collected in 1990 was simply measured using a tape measure and plumb bob. Analysis of this data indicated that this measurement technique was not sufficiently accurate. The Phase II data collected in 1991 was measured with the new device shown in Figure 2-3. The improved accuracy of this measurement system yielded data that was typically in agreement with the strain gauge data. Thus, the NS data is not shown, as no Phase II measurements were made on radial movement at this site.

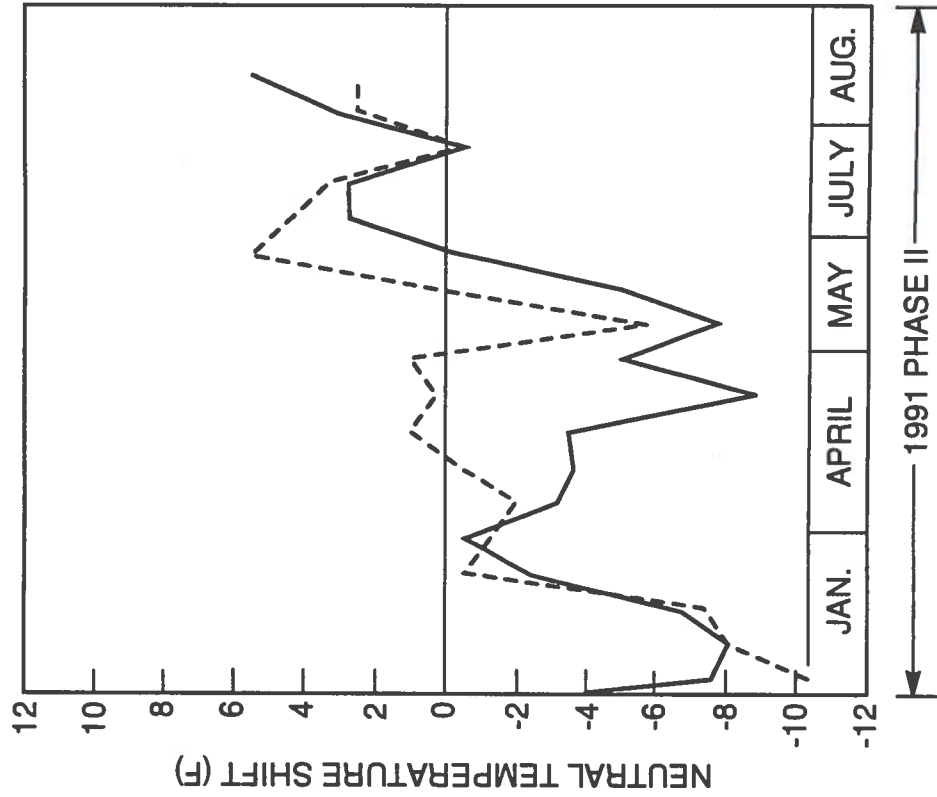
While radial movement is usually the most significant factor contributing to rail force relief, some of the data indicates the presence of other contributing factors. Most significantly,



--- CONTRIBUTION DUE TO RADIAL MOVEMENT
 — TOTAL NEUTRAL TEMPERATURE SHIFT

214-DTS-9718-1

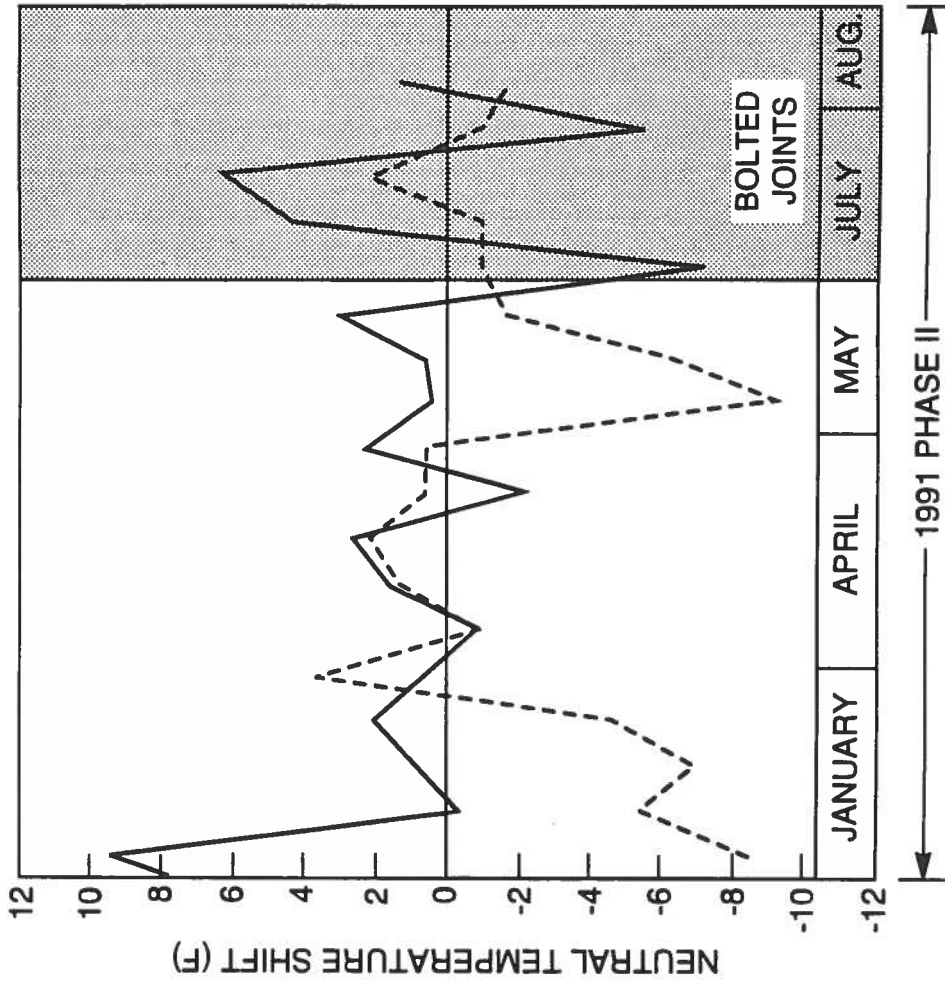
Figure 4-1. ATSF TS1 Rail Movement Correlation



--- CONTRIBUTION DUE TO
 RADIAL MOVEMENT
 — TOTAL NEUTRAL
 TEMPERATURE SHIFT

214-DTS-9718-2

Figure 4-2. ATSF TS2 Rail Movement Correlation



--- CONTRIBUTION DUE TO RADIAL MOVEMENT
 — TOTAL NEUTRAL TEMPERATURE SHIFT

214-DTS-9718-3

Figure 4-3. ATSF TS3 Rail Movement Correlation

neutral temperature would also be influenced by rail longitudinal movement, which was not recorded in the tests. Table 4-3 summarizes the contribution of the radial movement and provides a physical explanation when it is evident from the test data and observations.

4.3 Track Lateral Resistance

The STPT data was shown previously in Table 3-1. The average rate of increase of lateral resistance over the entire test period was found to be 90 lb/MGT for ATSF and 120 lb/MGT for NS, although data was not taken at fine intervals of MGT to truly characterize the nonlinear increase in resistance. This is in agreement with the fact that the overall resistance at NS was consistently larger than that at ATSF. A significant amount of coal dust was also visible in the ballast at the NS site, which may provide a more binding formation.

The results of the STPTs are discussed below for each test site.

Table 4-3. Summary of Rail Radial Movement Contribution to Neutral Temperature Shift at ATSF

Test Section	Dates	Comments
TS1	All 1990	Poor correlation due to measurement device.
	1/29/91 to 4/4/91	Radial movement within 1/8 in. of total T_N shift.
	5/21/91 to 5/22/91	Radial movement within 1/4 in. of total T_N shift.
	7/16/91 to 8/15/91	No correlation due to bolted joints.
TS2	All 1990	Poor correlation due to measurement device.
	1/29/91 to 4/3/91	Radial movement within 1/8 in. of total T_N shift.
	4/3/91 to 4/4/91	Shift apparently not related to radial movement.
	5/21/91 to 5/22/91	Radial movement within 1/4 in. of total T_N shift.
	7/16/91 to 8/15/91	Radial movement within 1/8 in. of total T_N shift.
TS3	All 1990	Poor correlation due to measurement device.
	1/29/91 to 1/30/91	Shift apparently not related to radial movement.
	4/3/91 to 4/4/91	Radial movement within 1/4 in. of total T_N shift.
	5/21/91 to 5/22/91	Shift apparently not related to radial movement.
	7/16/91 to 8/15/91	No correlation due to bolted joints.

4.3.1 ATSF Railroad

In the spring of 1990, TS1 was tamped and subsequent STPTs indicated that the average lateral resistance peak was reduced to 1477 lbs/tie. The tests performed in TS1 indicate that from spring to summer 1990, the resistance had not increased dramatically. This is due to the low rail tonnage and may also be due to the lining of the track in late June 1990. The tests in TS2 and TS3 indicate a higher resistance than TS1 since no track work was performed in these test sections. The test results from August 1991 indicate that the lateral resistance has increased in all sections at a similar rate. However, as mentioned previously, the low tonnage is unable to consolidate the ballast sufficiently to provide high lateral resistance. The following subsection (4.4) will discuss the effects of this lower lateral resistance on track buckling.

4.3.2 NS Railroad

In the spring of 1990, TS1 was also tamped, lined, and lifted, and subsequent STPTs indicated that the lateral resistance average peak was reduced to 2610 lbs/tie. This resistance is substantially higher than that recorded at the tamped ATSF site. This difference may be due to several factors, including ballast type, shoulder width, and variables in the tamping operation.

The tests performed in TS1 in 1990 indicate that from spring to summer, the ballast consolidated back to the pre-tamping state. The resistance may also have increased in other sections. The increase, between spring and summer 1990, of the track lateral resistance at NS, in the tamped section (TS1), was three times greater than the increase rate measured at ATSF TS1, primarily due to the higher traffic volume at the NS site.

4.4 Buckling Potential Evaluation

The Volpe Center's dynamic buckling model was utilized to evaluate all six test sections at the two test sites using track lateral resistance data from the STPTs, neutral temperature data from the strain gauges, and an assumed misalignment amplitude of 1.5 in. The model predicts $T_{B,MIN}$, the lower critical buckling temperature increase at which buckling can occur with sufficient external energy input, and $T_{B,MAX}$, the upper critical buckling temperature increase at which buckling will occur with zero external energy input. Thus, the potential for buckling exists when the sum of $T_{B,MIN}$ and the rail neutral temperature (T_N) exceeds the temperature of the rail (T_{rail}).

The evaluation of each test site is summarized in Table 4-4. The minimum margin of safety for the three ATSF test sites occurred in June 1990. The three NS test sites were evaluated for the same time period for comparison. Additionally, TS1 and TS2 and the NS sites were evaluated for April 1990 when the minimum margin of safety existed for these sections.

The low neutral temperature at ATSF TS1, combined with the low lateral resistance due to recent tamping and low traffic, resulted in a low maximum allowable temperature of 117°F

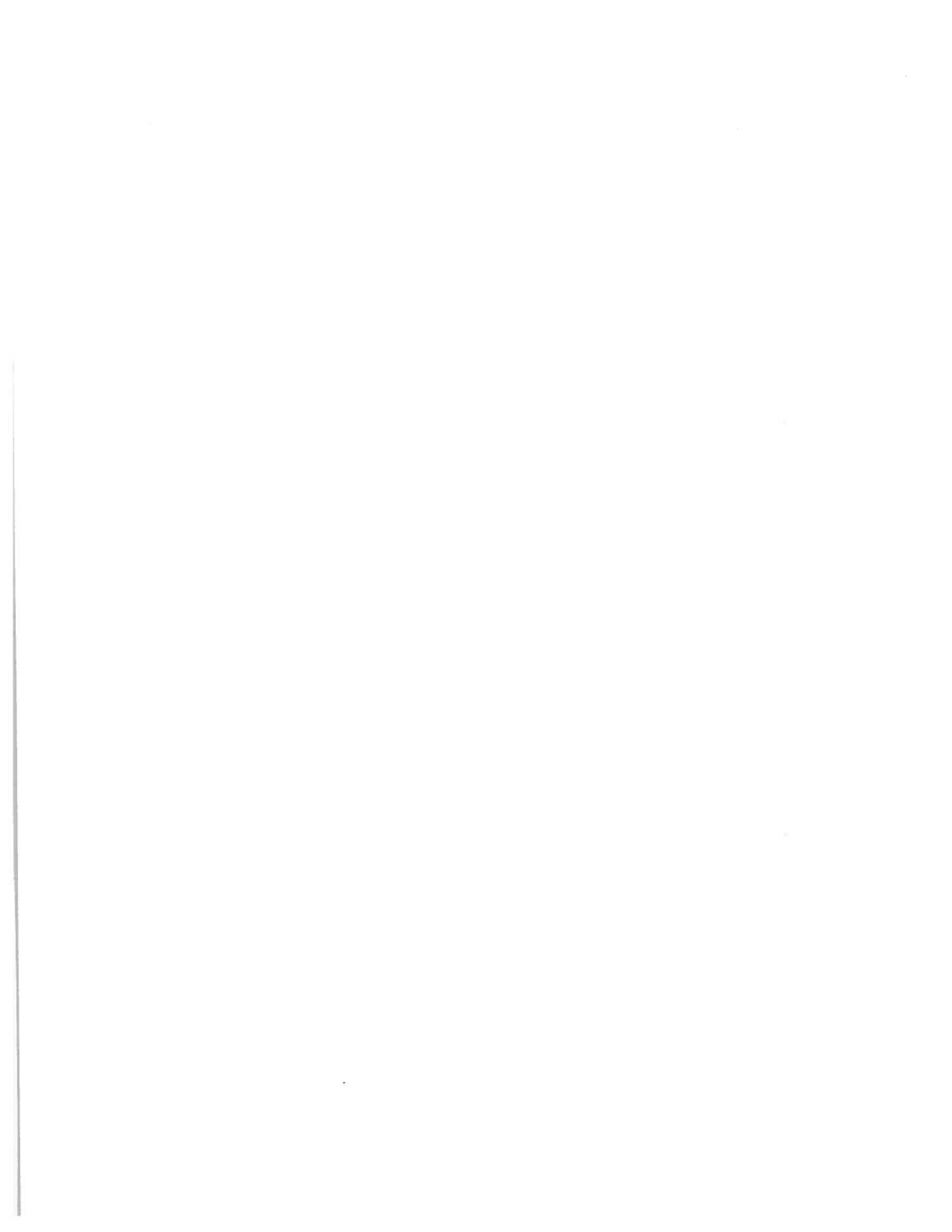
Table 4-4. Safety Margin at Each Test Section

Site	ATSF						NS					
	TS1	TS2	TS3	TS1	TS1	TS2	TS1	TS2	TS2	TS2	TS3	
	Jun-90	Jun-90	Jun-90	Apr-90	Jun-90	Apr-90	Jun-90	Apr-90	Jun-90	Jun-90	Jun-90	
Min Lateral Resistance (lbs/in)	90	150	120	130	180	180	190	170				
Min Buckling Temperature (T _{bmin})	54	64	60	67	79	79	81	76				
Neutral Temperature (T _n)	63	74	82	75	95	70	95	80				
Max Temp Allowable (T _{bmin} + T _n)	117	138	142	142	174	149	176	156				
Max Rail Temperature (T _{rmax})	135	135	135	115	128	115	128	128				
Margin of Safety	-18	3	7	27	46	34	48	28				
Notes:	1. Buckling occurred at ATSF TS1 on 10 June 1990											
	2. Minimum margin of safety occurred at NS on 23 April 1990											
	3. All temperatures are in deg F											
	4. T _{bmin} is calculated from the computer program											

during June 1990. Rail temperatures during June at this site were measured as high as 135°F on a day in which the ambient temperature reached 105°F. Consequently, the track buckled in this test site on 10 June 1990. Following this event, the rail was cut, destressed, and rewelded at a sufficiently higher neutral temperature.

TS2 and TS3 at the ATSF site also experienced the high rail temperatures of TS1. However, due to higher lateral resistance and higher neutral temperature, a slight margin of safety was maintained and buckling did not occur within these sections. The effect of lateral resistance is particularly evident in TS2, where there would have been a negative margin of safety and buckling would have been likely to occur had the section been tamped to the same low resistance as TS1. The effect of neutral temperature is evident in TS3, which was not cut and rewelded in April 1990 and thus had a higher T_N than the other two sections. If this section had the same low neutral temperature of TS1, buckling would have been likely despite the higher lateral resistance.

The high lateral resistance of the NS track typically resulted in a much lower buckling potential (much higher margin of safety). The lowest margin of safety apparent during the test period occurred in April 1990 at TS1, after tamping but prior to destressing of the rails. However, even after tamping, STPTs indicated a lateral resistance of 130 lb/in. Thus, a margin of safety of more than 25°F was maintained. By June 1990, when the highest rail temperatures were recorded at the site, the high traffic had consolidated the ballast and substantially increased the minimum buckling strength. Further, the rail destressing in April increased the neutral temperature and thus a large margin of safety is apparent. The high lateral resistance and moderate neutral temperatures in the other test sections also consistently resulted in high margins of safety throughout the test program.



5. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be drawn on the basis of the field test data and analysis presented in the previous sections.

5.1 Conclusions

1. Rail neutral temperature shifts in high degree curved tracks can be significant. Shifts due to seasonal effects are typically on the order of 20°F and in one extreme case a shift of 40°F was recorded. Shifts on the order of 5°F typically occur daily due to diurnal changes in rail temperature. However, in one test section, diurnal changes of 20°F were recorded.
2. Due to drainage requirements, adequate ballast shoulder was not always provided on the inside of some curved portions to prevent rail pulling in due to tensile loads. To increase the neutral temperature and reduce the misalignments, the track was realigned outward (larger radius) at some sites. The nighttime cooling of rails, together with general low resistance in the radially inwards direction, due to the minimal ballast shoulder, did occasionally offset the advantage of this outward realignment and the misalignments reappeared in the track.
3. Likewise, adequate ballast shoulder could not be maintained on the outside of some superelevated curved sections. These curved portions moved outward radially on hot summer days, and occasionally problems arose in the form of unacceptably large lateral misalignments at hard spots such as bridge abutments.
4. Radial movement of rails contributed to shifts in the neutral temperature and were measurable in the field. In one extreme case, a seasonal shift of 1.1 in. was recorded. One inch of radial movement theoretically corresponds to a neutral temperature change of 22°F on 10 degree track.
5. Tamping of the tracks dropped the lateral resistance to about 55 percent of the untamped value in the curve. Whereas at one site the resistance was quickly recovered due to the high traffic volume (5.7 MGT/month) of traffic, at another site the resistance rose to only about 65 percent of the untamped resistance after three months. The low traffic volume (0.8 MGT/month) at the second site could keep the tamped track under low resistance over a long period in some sections.
6. Track lateral resistance measured by STPT at both sites showed a drooping softening characteristic for consolidated ballast, similar to those observed previously at TTC. For tamped tracks, the peak and limiting values approach one another at values of about 1000 lb/tie. For consolidated track, the ratio of peak to limiting values can reach two or higher, depending on the level of consolidation.

7. By early spring, the CWR track does not seem to regain the neutral temperature lost during the winter due to inward radial movement. The rail temperatures reach significantly high values, increasing the buckling potential in the spring.
8. The combination of low neutral temperature and reduced lateral resistance after tamping could precipitate buckling on a hot day. Such buckling incidents did occur at some of the tested sites. A neutral temperature of 60°F was obtained after cutting and welding at one site. The rail temperature was anticipated to be low for subsequent weeks. Rail temperatures over 125°F were in fact reached, and these exceeded the theoretically allowable temperature, resulting in a few buckling incidents. Rail distressing, which raised the neutral temperature to greater than 90°F, reduced the problem significantly at this site.

5.2 Recommendations

1. The industry should be encouraged to utilize the following available instrumentation and hardware for improved monitoring of the safety of CWR track: (a) The STPT fixture should be simplified for rapid evaluation of resistance and spot checking of the ballast consolidation. The simplified STPT will have a green and red indicator for a minimum level of specified resistance; (b) At spots where the rails are cut for distressing, etc., the neutral temperature can be monitored using the strain gauge and portable strain indicator system; (c) Using reference pegs and a measuring tape, the radial movements of high degree curves can be monitored at selected locations.
2. The rail temperature should be regularly measured so that seasonal records of the typical local maximum temperatures can be developed. These records could be used by the track crew to properly select a rail temperature for welding after a rail has been cut.
3. Additional field tests should be conducted on high degree curve CWR, where maintenance operations can be restricted. The program presented in this report was hampered to some extent by the numerous maintenance operations, conducted at both sites, not related to buckling situations.
4. A similar field test program should be conducted on curved, CWR, concrete tie track to characterize track performance with these ties. The rail strain and temperature should be recorded periodically to quantify diurnal and seasonal neutral temperature variations. Further, the track lateral resistance and radial movement should be measured to fully assess the track performance.

APPENDIX A
Test Data

RAIL STRAIN DATA FROM SANTE FE, NM															
SECTION 1															
High Rail															
Date	Amb	Time	1			2			3			4			Comments
	Temp		Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	
2/14/90	37		1316	37.3	67.4	315	32.4	72.5	-44	32.5	72.4	414	33.1	74.8	
2/15/90	20		1229	33.2	68.5	358	31.5	69.1	-10	35.4	73.3	431	31.5	72.2	
4/02/90	56		1730	69.8	75.0	895	70.6	75.9	540	69.1	73.9	1024	73.5	78.5	
4/02/90		4:00	1759	68.0	71.5	881	67.1	73.2	513	68.1	74.5	963	69.9	78.6	
4/03/90	45	9:00	1454	47.8	69.6	590	48.0	71.6	242	49.7	72.4	687	48.7	74.0	
4/03/90			1921	80.9	74.7	1062	80.0	75.3	692	80.2	75.9	1142	77.9	75.9	
4/03/90		4:15	1953	83.7	75.5	1072	85.0	79.7	702	81.0	76.1	1159	80.5	77.4	After Tamping
4/04/90		8:15	1496	54.3	73.6	644	54.4	74.8	283	56.0	76.3	743	55.3	77.2	Before High Rail Cut
4/04/90			1817	75.7		983	75.5		620	74.6		1108	81.5		Zero, after Cut
4/05/90			1859	60.3	57.8	1261	77.6	60.9	888	76.8	60.7	1142	64.3	62.3	After Welding
5/04/90	48	11:30	1787	57.2	59.0	933	58.3	61.3	640	59.9	58.7	1050	59.8	63.3	Jon's Data
5/04/90	55	3:00	1925	67.0	60.5	1049	68.0	64.0	504	69.0	76.0	1153	68.4	65.7	Jon's Data
6/26/90	95	10:25	1924	111.8	105.4	1161	117.2	106.5	783	117.5	107.7	1300	117.9	106.4	
6/28/90	92	5:35	1816	106.1	106.2	1048	108.4	104.5	680	111.8	108.2	1203	112.9	107.2	
6/27/90	60	5:40am	1072	58.9	103.7	269	59.4	102.3	-110	58.5	102.4	359	58.0	103.0	Begin Full Day Test
6/27/90	65	6:40	1144	62.5	102.9	351	63.9	101.9	-19	64.8	103.2	458	64.8	103.9	
6/27/90	68	7:18	1481	85.5	105.7	672	83.7	102.4	278	81.7	102.3	723	81.1	104.2	
6/27/90	84	8:25	1644	92.5	102.9	857	93.4	101.0	471	93.8	102.8	940	95.3	105.4	
6/27/90	89	9:29	1840	106.8	105.4	1058	108.5	104.0	665	107.2	104.5				Train Prevented #4
6/27/90	92	10:45	1888	111.7	107.4	1109	115.7	108.1	732	116.1	109.4	1245	118.1	109.9	
6/27/90	95	12:00	1920	115.8	109.6	1137	116.3	107.0	755	117.3	109.2	1270	119.8	110.1	
6/27/90	98	1:00	1997	120.1	109.3	1200	121.4	108.4	815	121.2	109.5	1321	122.8	110.0	
6/27/90	105	2:00	2093	128.2	111.6	1292	126.5	107.9	896	125.6	109.0	1396	128.3	111.0	
6/27/90	95	2:57	2012	121.9	110.2	1188	118.7	106.4	778	117.8	108.3	1264	118.7	109.3	End Full Day Test
7/23/90	66	9:20am	1449	83.2	105.3	680	84.5	102.7	289	84.4	104.3	790	85.4	104.5	
7/23/90	82.8	12:08	1654	97.8	107.6	879	100.0	106.3	485	100.8	108.9	990	102.4	109.5	
7/24/90	73	9:00	1409	79.3	103.8				251	81.6	103.8	767	83.0	103.5	
7/24/90	81	10:00	1582	91.9	106.0				387	90.2	104.2	897	91.8	104.5	
7/24/90	78	11:00	1599	93.3	106.4				422	93.5	105.4	938	95.7	105.9	
7/24/90	83	12:00	1689	99.1	106.8				522	97.6	103.5	1018	98.9	104.3	
7/24/90	82	1:00	1756	102.3	106.0				578	102.5	105.0	1079	104.8	106.5	
7/25/90	73	8:00am	1355	80.5	108.3				215	78.2	102.5	717	80.8	104.3	
1/29/91	35	8:35	980	34.0	84.3				-101	34.9	78.2	391	35.7	78.8	
1/29/91	30	10:05	1046	36.4	82.7				-37	36.3	75.8	457	37.6	76.7	
1/29/91	38	1:00	1260	50.5	84.0				132	48.4	77.7	597	48.4	79.1	
1/30/91	38	8:25	844	30.6	89.1				-195	32.3	81.3	321	34.9	82.2	
1/30/91	39	9:30	1032	41.3	88.5				-10	42.8	80.7	526	46.1	81.1	
1/30/91	40	10:32	1222	51.7	87.5				145	51.3	79.8	675	53.3	79.3	
1/30/91	45	11:35	1411	62.4	86.8				289	59.4	79.3	786	58.9	78.3	
1/30/91	49	12:35	1535	70.9	87.8				409	66.2	78.9	880	65.5	79.2	
1/30/91	55	2:10	1688	81.4	89.2				542	75.1	79.8	984	75.6	83.1	
1/30/91	49	4:00	1647	77.8	88.0				491	72.5	80.3	914	69.2	80.9	
4/03/91	60	9:00	1642	79.6	90.1				543	80.9	85.5	1058	87.2	90.2	Begin Full Day Test
4/03/91	73	10:15	1787	86.6	88.4				692	86.8	82.5	1224	89.4	82.4	
4/03/91	72	11:00	1870	93.5	90.3				760	91.5	83.1	1284	92.6	82.0	
4/03/91	73	12:00	1950	98.0	90.0				840	94.4	81.2	1359	98.2	83.1	
4/03/91	77	12:45	1932	100.3	93.4				832	98.3	85.6	1339	101.0	87.1	
4/03/91	69	2:00	1893	97.2	92.6				784	95.3	85.4	1301	98.3	86.7	
4/03/91	69	3:00	1785	84.9	86.8				662	88.2	85.7	1161	89.9	86.7	End Full Day Test
4/04/91	51	8:20	1519	61.2	79.1				422	71.4	83.3	933	73.8	84.3	Begin Full Day Test
4/04/91	63	10:00	1709	82.2	88.7				618	84.0	84.1	1116	84.6	84.1	
4/04/91	64	11:00	1787	86.9	88.7				668	86.8	83.9	1191	89.2	84.2	
4/04/91	69	10:00	1857	92.4	90.0				739	90.7	83.5	1242	93.4	85.3	
4/04/91	73	1:00	1957	98.8	90.4				831	97.1	84.4	1315	98.5	86.1	
4/04/91	75	2:00	2034	105.2	92.2				902	103.1	86.2	1378	103.6	87.4	
4/04/91	72	3:00	2050	103.4	89.4				914	104.6	86.9	1402	104.9	87.2	
4/04/91	72	4:00	2008	104.5	93.0				906	103.8	86.6	1408	103.7	85.7	End Full Day Test
5/21/91	59	9:00	1293	56.7	88.2				176	56.4	83.1	674	56.4	82.5	
5/21/91	61	11:15	1299	57.4	88.5				204	57.5	82.5	691	57.6	82.7	

RAIL STRAIN DATA FROM SANTE FE, NM																		
SECTION 1																		
High Rail																		
Date	Amb	Time	1		Neut		2		Neut		3		Neut		4		Neut	Comments
	Temp		Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Temp	Temp		
5/22/91	56	8:15	1420	72.5	96.4				366	70.8	86.1	887	70.9	84.2				
5/22/91	64	10:00	1738	87.4	92.1				591	86.0	87.7	1161	86.9	83.7				
5/22/91	70	11:05	1856	94.4	92.1				693	93.1	88.7	1298	95.5	84.1				
5/22/91	74	12:45	1945	98.2	90.5				805	97.5	86.4	1359	100.4	85.3				
5/22/91	75	2:00	1968	103.1	94.0				863	100.8	86.2	1406	104.1	86.2				
5/22/91	74	3:25	2030	106.3	93.5				902	103.4	86.5	1431	106.3	86.9				
5/22/91	76	4:25	1979	102.4	92.7				854	101.3	87.2	1368	104.5	88.9				
7/16/91	64	8:10	1571	75.9	90.7				482	73.1	81.4	926	75.1	86.0				
7/16/91	75	9:06																
7/16/91	79	10:00	1950	99.3	91.3				823	99.0	86.8	1367	102.0	86.4				
7/16/91	84	11:30	1990	101.0	90.6				868	96.8	81.9	1433	105.0	85.5				
7/16/91	83	12:30	2079	105.7	90.0				940	104.3	85.1	1493	107.3	84.2				
7/16/91	85	2:00	2100	110.9	93.9				989	110.9	88.7	1551	113.5	86.9				
7/16/91	87	3:00	2226	118.2	93.6				1043	116.6	91.2	1608	118.1	88.1				
7/17/91	70	8:00	1764	84.6	87.8				580	83.0	85.4	1098	80.9	81.5				
7/17/91	75	9:00	1861	92.6	90.0				703	88.6	83.6	1230	91.5	84.2				
7/17/91	78	10:00	1938	98.1	90.8				786	92.1	82.1	1324	98.1	85.1				
7/17/91	84	11:00	2013	102.2	90.4				860	96.9	82.5	1390	102.2	85.3				
7/17/91	88	12:00	2130	108.4	89.6				981	107.2	85.5	1510	110.3	86.1				
7/17/91	92	1:00	2238	115.2	89.9				1086	113.8	85.8	1614	116.3	85.9				
7/17/91	89	2:00	2309	118.3	88.7				1150	118.7	86.8	1677	120.5	86.3				
7/17/91	87	3:30	2284	117.3	89.2				1145	118.3	86.7	1685	120.5	85.8				
7/17/91	86	4:20	2084	107.8	91.8				961	109.8	89.3	1534	110.5	84.9				
7/18/91	76	8:10	1730	86.7	91.9				589	83.3	85.2	1134	83.8	82.2				
7/18/91	80	9:30	1866	95.4	92.5				739	94.1	86.9	1292	94.9	83.8				
7/18/91	84	10:35	1916	99.6	93.7				774	98.6	89.3	1316	100.2	87.7				
7/18/91	87	11:41	1987	104.0	93.8				832	102.8	90.1	1368	104.0	88.4				
7/18/91	89	12:35	2035	106.6	93.5				880	104.1	88.5	1419	106.4	87.7				
7/18/91	88	1:30	1966	99.1	90.1				766	98.9	90.1	1305	99.8	88.0				
8/13/91	72	9:00	1670	85.4	94.2				521	83.6	89.5	1084	82.1	83.5				
8/13/91	81	10:00	1827	98.8	98.2				715	95.4	89.7	1325	96.5	83.5				
8/13/91	82	12:00	1948	105.1	97.2				842	103.5	90.2	1446	104.3	84.0				
8/13/91	69	2:30	1478	73.9	94.3				330	72.6	90.0	910	72.6	84.5				
8/15/91	70	8:40	1659	88.9	98.4				565	88.3	91.6	1172	88.3	84.5				
8/15/91	80	10:00	1808	98.1	98.6				740	97.9	90.7	1366	100.9	85.4				
8/15/91	86	11:00	1879	101.2	97.5				815	103.5	91.8	1445	106.2	85.9				
8/15/91	85	12:00	1940	105.3	97.9				859	106.5	92.1	1480	108.5	86.1				
8/15/91	90	1:00	2000	108.4	97.4				920	109.7	91.7	1544	111.3	85.1				
8/15/91	85	2:10	1991	108.3	97.8				914	107.2	89.5	1508	108.7	84.7				
8/15/91	84	3:00	1940	102.2	94.8				853	105.9	91.9	1468	106.6	85.0				

RAIL STRAIN DATA FROM SANTE FE, NM															
SECTION 1															
Date	Amb Temp	Time	1		2		3		4		Comments				
			Strain	Temp	Strain	Temp	Strain	Temp	Strain	Temp					
2/14/90	37		-85	38.5	77.8	373	32.5	68.4	557	32.1	66.8	-351	32.5	74.5	
2/15/90	20		-172	34.1	78.6	373	35.4	71.3	569	33.6	67.6	-344	35.1	76.7	
4/02/90	56		382	68.4	79.6	917	69.1	72.3	1087	70.0	72.9	235	71.8	78.6	
4/02/90		4:00	189	67.6	90.4	862	68.1	74.6	1033	68.5	74.6	165	67.3	78.3	
4/03/90	45	9:00	63	49.1	79.5	632	49.7	70.0	835	50.4	68.4	-36	51.5	74.6	
4/03/90			617	80.0	77.1	1072	80.2	74.1	1220	78.4	73.3	348	78.1	78.1	
4/03/90		4:15	607	79.8	77.5	1094	83.2	75.7	1239	81.0	74.8	394	80.5	77.7	After Tamping
4/04/90		8:15	240	57.0	76.8	714	57.5	72.9	888	56.2	71.0	24	57.6	77.1	Before Low Rail Cut
4/04/90			569	80.9		970	82.6		1135	83.5		348	84.8		Zero, after Cut
4/05/90		11:30	569	63.1	63.1	1418	79.7	52.8	1563	78.9	53.2	460	66.0	59.3	After Welding
5/04/90	48	11:30	350	57.7	70.9	948	58.3	59.6	1132	57.8	58.0	123	59.9	73.4	Jon's Data
5/04/90	55	3:00	442	66.1	73.7	1043	66.7	62.3	1209	66.1	61.7	206	66.8	75.3	Jon's Data
6/26/90	95	10:25	835	115.2	99.2	1499	119.0	87.2	1654	120.0	88.8	821	119.8	91.4	
6/26/90	92	5:35	645	105.7	101.1	1296	106.5	86.9	1463	106.4	86.7	627	109.7	92.9	
6/27/90	60	5:40am	-67	59.2	97.4	553	58.5	83.6	770	58.1	80.0	-140	58.3	87.6	Begin Full Day Test
6/27/90	65	6:40	15	63.5	96.8	646	64.8	84.3	862	64.7	81.1	-35	65.5	88.5	
6/27/90	68	7:18	300	80.3	96.5	940	79.9	81.7	1135	80.0	80.0	228	79.3	86.5	
6/27/90	84	8:25	520	91.5	94.4	1180	94.4	81.8	1359	95.6	82.1	479	97.1	89.2	
6/27/90	89	9:29	740	107.5	97.2	1400	109.8	84.0	1561	110.4	84.8				Train Prevented #4
6/27/90	92	10:45	811	117.1	102.6	1450	120.2	91.4	1603	120.2	92.1	767	122.4	97.2	
6/27/90	95	12:00	830	118.1	102.4	1614	122.0	83.3	1614	122.0	93.2	779	122.2	96.3	
6/27/90	98	1:00	888	120.6	101.4	1652	125.2	84.2	1652	125.2	94.1	815	124.8	96.7	
6/27/90	105	2:00	981	129.6	104.8	1593	126.1	88.7	1730	128.9	93.1	889	128.7	96.2	
6/27/90	95	2:57	866	120.1	102.3	1447	118.3	89.6	1585	117.6	90.6	710	116.9	95.1	End Full Day Test
7/23/90	66	9:20am	356	83.5	96.3	1007	83.7	81.5	1192	85.4	82.0	329	87.2	88.3	
7/23/90	82.8	12:08	620	101.3	98.2	1241	102.9	86.6	1400	103.2	87.3	558	103.7	91.1	12:02; Eastbound Train
7/24/90	73	9:00	311	79.8	95.3	982	82.8	82.1	1172	83.4	81.2				
7/24/90	81	10:00	497	92.6	96.9	1149	93.6	82.8	1320	93.9	82.8				
7/24/90	78	11:00	522	95.4	98.2	1182	96.7	84.0	1353	97.7	84.6				
7/24/90	83	12:00	618	101.2	98.3	1270	101.0	83.0	1431	100.7	82.9				
7/24/90	82	1:00	677	103.5	97.0	1317	103.4	82.5	1465	105.1	85.3				
7/25/90	73	8:00am	273	79.0	96.8	918	80.6	83.7	1102	81.3	83.3				
1/29/91	35	8:35am	-138	34.1	76.6	591	35.7	58.5	773	36.3	58.1	-89	37.8	64.1	
1/29/91	30	10:05	-93	37.8	77.6	586	36.8	59.9	760	37.5	60.0	-112	38.3	65.9	
1/29/91	38	1:00	115	52.5	79.8	780	49.8	61.2	938	49.0	60.8	71	48.1	64.7	
1/30/91	38	8:25	-276	30.6	81.4	453	34.1	65.2	643	33.9	63.5	-202	36.2	69.3	
1/30/91	39	9:30	-86	40.9	80.3	665	46.4	64.7	842	45.2	62.8	32	48.1	67.1	
1/30/91	40	10:32	94	50.9	79.4	820	53.3	62.3	980	53.4	62.7	175	56.0	66.4	
1/30/91	45	11:35	267	61.2	79.3	950	60.1	61.3	1095	61.6	64.0	269	62.2	66.9	
1/30/91	49	12:35	401	71.1	81.2	1058	68.4	63.1	1196	68.4	64.7	346	67.2	67.3	
1/30/91	55	2:10	541	83.0	84.7	1191	78.2	64.9	1323	78.2	66.9	468	76.9	69.7	
1/30/91	49	4:00	517	78.6	81.7	1152	73.3	62.4	1287	73.2	64.1	407	71.6	68.1	
4/03/91	60	9:00	508	79.5	83.2	1211	81.7	67.2	1345	80.2	67.6	541	84.0	72.4	
4/03/91	73	10:15	663	85.9	80.3	1364	87.6	63.9	1487	88.4	67.2	703	92.9	71.6	
4/03/91	72	11:00	736	91.6	81.6	1425	92.6	65.3	1545	94.3	69.7	739	93.3	69.8	
4/03/91	73	12:00	806	98.5	84.3	1495	97.1	65.5	1609	97.9	69.4	808	99.5	71.9	
4/03/91	77	12:45	823	101.4	86.1	1487	99.6	68.5	1605	99.5	71.3	794	100.3	73.5	
4/03/91	69	2:00	793	98.2	84.7	1454	95.8	66.7	1571	97.1	70.9	757	98.4	73.8	
4/03/91	69	3:00	668	91.7	85.8	1330	84.3	62.7	1462	90.7	71.0	649	91.7	73.6	
4/04/91	51	8:20	390	73.2	84.0	1096	75.9	68.3	1249	76.2	69.3	410	77.1	73.4	
4/04/91	63	10:00	599	82.9	81.1	1282	85.0	66.3	1416	86.1	69.2	608	87.7	72.1	
4/04/91	64	11:00	676	87.7	81.3	1354	87.1	64.0	1491	88.4	67.0	665	91.0	71.9	
4/04/91	69	10:00	747	92.6	81.9	1421	92.7	65.6	1543	92.1	67.6	712	95.0	73.1	
4/04/91	73	1:00	833	99.1	83.2	1490	98.2	67.0	1607	99.4	71.0	772	99.4	73.9	
4/04/91	75	2:00	897	105.3	85.6	1556	103.6	68.4	1662	104.3	72.6	837	104.5	75.1	
4/04/91	72	3:00	908	104.9	84.5	1580	105.5	68.8	1703	105.2	71.1	861	107.0	76.2	
4/04/91	72	4:00	897	104.5	84.8	1556	104.5	69.3	1684	104.6	71.6	847	104.9	74.9	
5/21/91	59	9:00	152	56.6	81.7	811	56.4	66.0	1008	56.5	64.1	74	56.0	72.5	

RAIL STRAIN DATA FROM SANTE FE, NM															
SECTION 1															
Low Rail															
Date	Amb	Time	1			2			3			4			Comments
	Temp		Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	
5/21/91	61	11:15	172	57.3	81.2	819	57.1	66.2	1018	57.4	64.4	58	57.5	74.9	
5/22/91	56	8:15	403	72.5	82.5	1069	73.4	67.5	1243	75.3	68.8	345	73.9	74.1	
5/22/91	64	10:00	663	89.4	83.8	1394	89.7	64.2	1506	92.4	70.1	655	92.1	73.7	
5/22/91	70	11:05	783	96.0	83.1	1489	98.2	67.0	1637	100.2	70.0	747	100.7	76.7	
5/22/91	74	12:45	843	100.6	84.1	1514	100.7	68.0	1669	96.0	63.9	809	104.0	76.3	
5/22/91	75	2:00	869	103.1	85.1	1542	102.7	68.3	1691	104.7	71.3	831	106.5	77.5	
5/22/91	74	3:25	924	105.2	83.9	1597	106.5	68.8	1737	107.1	70.9	876	109.8	78.1	
5/22/91	76	4:25	893	104.2	84.7	1568	104.9	69.0	1702	106.5	72.4	842	109.3	79.6	
7/16/91	64	8:10	333	76.2	90.4	952	78.1	79.2				286	76.6	80.3	
7/16/91	75	9:06													
7/16/91	79	10:00	704	102.0	93.9	1303	104.2	84.2				645	104.8	87.0	
7/16/91	84	11:30	624	102.5	99.2	1214	106.1	91.4				598	106.8	91.8	
7/16/91	83	12:30	681	106.7	100.0	1267	107.7	89.9				634	108.6	91.4	
7/16/91	85	2:00	674	111.1	104.8	1251	112.1	95.2				611	113.3	97.5	
7/16/91	87	3:00	743	117.3	106.8	1289	117.6	98.4				642	119.0	101.3	
7/17/91	70	8:00	529	84.6	87.0	1145	87.6	77.1				460	84.4	77.7	
7/17/91	75	9:00	641	93.0	88.7	1245	94.7	78.2				577	94.9	81.1	
7/17/91	78	10:00	658	99.4	94.1	1239	101.0	84.8				583	100.8	86.7	
7/17/91	84	11:00	683	103.4	96.5	1262	100.9	83.4				619	104.2	87.9	
7/17/91	88	12:00	735	108.9	98.9	1293	109.6	90.2				669	111.3	92.0	
7/17/91	92	1:00	772	115.9	103.7	1331	116.9	95.2				708	117.6	96.0	
7/17/91	89	2:00	816	118.9	104.1	1364	119.7	96.0				759	121.0	96.3	
7/17/91	87	3:30	795	118.3	104.7	1356	120.3	97.1				760	121.9	97.1	
7/17/91	86	4:20	604	108.3	106.2	1179	110.9	98.3				595	113.3	98.5	
7/18/91	76	8:10	477	85.3	90.8	1100	85.9	78.1				461	87.2	80.4	
7/18/91	80	9:30	605	96.8	94.6	1215	96.3	81.6				580	98.3	84.4	
7/18/91	84	10:35	536	100.3	102.3	1135	101.6	91.7				478	102.8	95.0	
7/18/91	87	11:41	581	104.5	103.8	1182	103.8	91.1				509	104.7	95.0	
7/18/91	89	12:35	612	107.2	104.6	1210	106.0	91.6				539	106.0	94.5	
7/18/91	88	1:30	499	99.6	103.8	1088	99.0	91.9				426	100.1	95.4	
8/13/91	72	9:00	496	85.9	90.3	1100	85.9	78.1				696	83.8	62.9	
8/13/91	81	10:00	513	99.2	102.6	1093	99.3	91.9				680	100.6	80.6	
8/13/91	82	12:00	593	104.5	103.1	1154	103.8	92.7				720	106.0	83.6	
8/13/91	69	2:30	252	71.4	90.5	845	70.8	78.3				432	72.7	67.7	
8/15/91	70	8:40	475	88.5	94.1	1132	90.1	80.4				815	91.3	63.2	
8/15/91	80	10:00	589	99.1	97.9	1177	101.0	88.6				805	103.4	75.9	
8/15/91	86	11:00	626	102.5	99.1	1194	103.8	90.3				855	106.5	76.0	
8/15/91	85	12:00	640	105.6	101.3	1191	105.8	92.5				876	107.4	75.7	
8/15/91	90	1:00	663	108.9	103.3	1198	108.8	95.1				949	110.6	74.5	
8/15/91	85	2:10	654	110.4	105.3	1184	108.3	95.4				910	109.7	75.9	
8/15/91	84	3:00	549	104.7	105.9	1074	104.7	98.5				809	106.9	79.2	

RAIL STRAIN DATA FROM SANTE FE, NM															
SECTION 2															
Date	Amb	Time	1	Neut	2	Neut	3	Neut	4	Neut					
	Temp		Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Comments
2/14/90	37		249	40.7	83.5	356	39.5	83.6	-94	39.0	81.3	2	39.6	81.2	
2/15/90	20		215	31.6	76.4	344	31.7	76.5	-116	35.7	79.3	-22	35.7	78.8	
4/02/90	56		888	75.4	79.8	1004	74.9	80.0	535	75.8	80.3	605	75.2	80.6	
4/02/90		4:00	750	70.0	82.7	857	72.1	86.0	397	72.0	84.8	513	73.9	84.8	
4/03/90	45	9:00	462	46.5	76.5	595	45.6	75.3	116	45.8	75.5	182	44.5	75.3	
4/03/90			845	66.3	73.3	961	67.2	74.9	477	67.4	75.4	525	64.1	74.3	
4/03/90		8.0	784	75.2	85.8	917	76.0	86.3	448	76.3	86.0	535	75.8	85.4	Before Low Rail Cut
4/03/90		1:47	961	84.0		1089	86.7		610	86.6		695	87.8		Zero, after Cut
4/05/90		11:56	1043	79.7	74.8	1191	76.5	70.4	721	71.5	64.8	796	74.3	68.2	After Welding
5/04/90	48	11:30	807	65.0	74.3	931	64.0	73.5	490	64.0	71.2	565	65.0	72.8	Jon's Data
5/04/90	55	3:00	891	69.2	73.4	972	69.0	76.0	551	69.0	72.5	646	71.2	74.1	Jon's Data
6/26/90	95	10:25	1444	113.5	84.5	1509	114.0	88.8	1012	113.9	89.7	986	113.6	96.1	
6/26/90	92	5:35	1400	113.5	87.1	1424	113.6	93.5	918	113.0	94.5	865	108.1	97.9	
6/27/90	60	5:40am	489	58.8	87.2	562	58.2	89.9	72	58.3	90.6	73	58.0	95.4	Begin Full Day Test
6/27/90	65	6:40	512	60.5	87.5	597	61.1	90.7							Train Prevented #3&4
6/27/90	68	7:18	772	73.2	84.6	804	75.5	92.6	311	72.1	90.1	306	75.1	98.5	
6/27/90	84	8:25	961	84.2	84.2	1011	84.7	89.4	517	84.1	89.7	554	85.8	94.3	
6/27/90	89	9:29													Temp Probe Failed
6/27/90	92	10:45	1140	113.8	103.0	1474	111.8	88.7	967	111.7	90.2	944	111.5	96.5	Temp Probe Repaired
6/27/90	95	12:00	1607	124.1	85.3	1649	122.6	88.9	1138	122.9	91.2	1105	120.3	95.7	
6/27/90	98	1:00	1680	131.0	87.8	1723	127.3	89.2	1208	126.7	90.8	1187	126.2	96.6	
6/27/90	105	2:00	1753	135.2	87.6	1807	134.4	91.3	1291	133.6	92.7	1267	131.3	96.9	
6/27/90	95	2:57	1526	120.5	86.5	1547	118.2	90.7	1026	117.3	92.3	959	111.8	95.9	End Full Day Test
7/23/90	66	9:20am	832	76.7	84.5	876	75.5	88.3	345	75.8	91.7	400	76.0	93.7	
7/23/90	82.8	12:08	1129	104.8	94.7	1191	104.7	98.6	655	101.3	98.6	715	101.1	99.9	12.02; Eastbound Trai
7/24/90	73	9:00am	747	75.6	88.5	804	74.3	91.4	278	74.2	94.2	297	75.1	99.0	
7/24/90	81	10:00	920	88.4	90.9	894	88.1	99.8	449	87.3	97.0	524	87.8	98.1	
7/24/90	78	11:00	1060	99.0	93.1	1129	99.2	96.8	593	100.2	101.2	678	99.1	100.1	
7/24/90	83	12:00	1171	105.7	93.1	1238	106.1	97.1	701	107.2	101.7	778	106.8	101.8	
7/24/90	82	1:00	1227	109.3	93.3	1294	110.5	98.2	751	108.9	100.4	829	108.9	100.8	
7/25/90	73	8:00am	558	68.1	92.3	652	68.0	94.3	133	68.4	97.1	251	70.0	96.7	
1/29/91	35	8:35	192	36.1	82.3	347	34.4	79.0	-221	33.1	83.0	-118	30.3	79.2	
1/29/91	30	10:05	229	40.7	84.7	372	39.5	82.6	-183	39.3	87.0	16	39.3	80.1	
1/29/91	38	1:00	464	52.6	82.5	619	51.4	79.6	60	51.1	84.2	215	51.2	80.0	
1/30/91	38	8:25	4	31.7	89.2	166	29.0	84.5	-402	28.3	89.1	-223	24.8	80.0	
1/30/91	39	9:30	344	52.1	89.2	483	47.9	84.3	-78	47.4	88.7	84	44.0	80.7	
1/30/91	40	10:32	634	69.1	88.8	759	65.5	85.3	200	64.4	89.0	363	62.4	82.4	
1/30/91	45	11:35	782	76.1	86.9	916	77.5	87.9	358	77.1	92.2	530	74.9	84.8	
1/30/91	49	12:35	836	82.6	90.1	979	83.1	89.7	428	83.7	94.6	617	82.6	87.3	
1/30/91	55	2:10	920	84.1	86.6	1082	87.2	87.6	525	88.9	94.0	683	84.7	85.4	
1/30/91	49	4:00	716	69.1	83.8	909	70.8	81.6	366	70.4	85.1	534	74.2	83.9	
4/03/91	60	9:00	702	71.3	86.9	972	66.9	73.9	217	66.2	89.8	380	63.5	82.4	
4/03/91	73	10:15	997	92.2	90.0	1079	86.9	87.5	502	85.9	92.4	676	84.2	85.3	
4/03/91	72	11:00	1115	99.6	90.3	1205	96.3	89.3	641	95.9	94.0	808	93.3	86.5	
4/03/91	73	12:00	1190	102.6	88.8	1295	101.1	88.7	728	101.3	94.2	906	98.1	85.4	
4/03/91	77	12:45	1111	102.6	93.6	1225	100.2	92.0	669	99.2	95.7	859	96.7	86.8	
4/03/91	69	2:00	1137	101.5	90.9	1262	101.4	91.0	711	101.4	95.3	905	99.8	87.2	
4/03/91	69	3:00	1068	92.8	86.4	1184	93.7	88.0	629	92.8	91.7	794	92.5	86.6	
4/04/91	51	8:20am	632	62.9	82.7	733	59.6	81.0	164	57.5	84.3	312	66.3	89.3	
4/04/91	63	10:00	943	83.7	84.8	1037	81.5	84.6	468	80.9	89.4	623	78.6	82.9	
4/04/91	64	11:00	1083	93.1	85.8	1184	92.0	86.3	617	91.9	91.5	777	91.2	86.3	
4/04/91	69	12:00	1174	97.7	84.9	1272	96.8	85.8	704	96.9	91.3	866	96.7	86.4	
4/04/91	73	1:00	1224	103.0	87.2	1325	101.1	86.9	764	101.6	92.3	932	100.3	86.1	
4/04/91	75	2:00	1202	99.2	84.7	1314	100.1	86.6	755	101.3	92.6	934	100.2	85.8	
4/04/91	72	3:00	1158	97.2	85.4	1272	97.5	86.5	712	97.3	91.2	874	97.3	86.5	
4/04/91	72	4:00	1097	94.0	85.8	1202	94.3	87.5	644	93.8	91.8	805	93.1	86.5	
5/21/91	59	9:00	528	57.0	83.0				102	56.8	87.3				
5/21/91	61	11:15	548	57.9	82.7				124	58.1	87.3				
5/22/91	56	8:15	514	56.4	83.3				62	54.5	87.4				

RAIL STRAIN DATA FROM SANTE FE, NM															
SECTION 2															
High Rail															
Date	Amb	Time	1			2			3			4			Comments
	Temp		Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	
5/22/91	64	10:00	816	76.4	85.1				343	73.6	89.6				
5/22/91	70	11:05	1039	90.3	85.6				579	87.4	89.3				
5/22/91	74	12:45	1244	102.0	85.0				745	100.5	92.4				
5/22/91	75	2:00	1277	109.2	90.2				779	108.0	97.8				
5/22/91	74	3:25	1363	111.1	86.9				857	109.7	94.9				
5/22/91	76	4:25	1281	106.8	87.6				772	105.5	95.8				
7/16/91	64	8:10	620	64.5	85.0				148	64.2	92.0				
7/16/91	75	9:06	832	77.0	84.8				317	75.6	93.2				
7/16/91	79	10:00	1032	89.7	85.4				503	88.3	94.7				
7/16/91	84	11:30	1256	107.0	89.3				706	102.8	97.0				
7/16/91	83	12:30	1368	113.4	88.9				817	109.7	97.3				
7/16/91	85	2:00	1347	114.6	91.4				804	112.8	101.1				
7/16/91	87	3:00	1427	118.4	90.4				880	116.6	100.4				
7/17/91	70	8:00	705	70.1	85.5				225	69.0	92.1				
7/17/91	75	9:00	888	81.3	85.7				386	78.2	91.7				
7/17/91	78	10:00	1063	91.8	85.7				555	90.2	93.5				
7/17/91	84	11:00	1202	101.9	87.4				689	100.3	95.6				
7/17/91	88	12:00	1355	112.9	89.2				832	110.8	97.5				
7/17/91	92	1:00	1471	120.4	89.8				929	117.7	98.5				
7/17/91	89	2:00	1534	125.4	91.0				983	120.6	98.2				
7/17/91	87	3:30	1547	125.6	90.4				1006	122.1	98.3				
7/17/91	86	4:20	1336	115.4	92.9				790	112.4	101.6				
7/18/91	76	8:10	741	73.2	86.4				245	71.4	93.3				
7/18/91	80	9:30	965	88.3	88.1				453	85.3	94.7				
7/18/91	84	10:35	1136	99.1	88.6				630	97.9	96.7				
7/18/91	87	11:41	1260	107.3	89.3				754	103.9	95.2				
7/18/91	89	12:35	1377	114.2	89.2				881	113.4	97.1				
7/18/91	88	1:30	1240	106.2	89.4				751	106.5	98.0				
8/13/91	72	9:00	718	72.8	87.4				262	71.1	92.0				
8/13/91	81	10:00	960	91.2	91.3				472	89.6	97.9				
8/13/91	82	12:00	1167	149.2	136.8				699	102.6	97.3				
8/13/91	69	2:30	765	73.5	85.3				322	76.7	94.0				
8/15/91	70	8:40	683	74.5	91.2				190	70.1	95.3				
8/15/91	80	10:00	973	91.7	91.0				485	88.9	96.4				
8/15/91	86	11:00	1141	102.8	92.0				651	100.1	97.6				
8/15/91	85	12:00	1230	109.3	93.1				742	107.4	99.5				
8/15/91	90	1:00	1346	115.3	92.2				867	114.9	99.5				
8/15/91	85	2:10	1164	109.8	97.6				685	109.5	105.0				
8/15/91	84	3:00	1274	108.5	89.7				790	109.2	98.4				

RAIL STRAIN DATA FROM SANTE FE, NM																													
SECTION 2																													
Date	Amb	Time	1	Neut		2	Low Rail		3	Neut		4	Neut		Comments														
				Temp	Temp		Temp	Temp		Temp	Temp		Temp	Temp															
	Temp		Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp															
2/14/90	37		85	37.4	86.7	472	37.2	86.5	68	36.7	85.4	-179	36.7	86.6															
2/15/90	20		290	31.4	68.4	440	36.9	88.1	39	39.2	89.6	-186	31.3	81.6															
4/02/90	56		743	76.7	86.4	1118	76.9	87.4	699	76.7	87.5	465	76.7	87.9															
4/02/90		4:00	627	70.2	86.9	1014	69.9	86.6	598	70.4	87.2	387	71.3	87.2															
4/03/90	45	9:00	281	47.1	84.6	658	45.0	83.1	244	45.5	83.6	15	44.8	83.0															
4/03/90			656	68.7	83.7	1024	69.6	85.7	607	66.7	83.0	363	65.8	83.1															
4/03/90		11:37	658	76.3	91.1	1094	78.9	90.8	663	78.3	91.2	443	77.3	89.8	Before Low Rail Cut														
4/03/90		2:48	905	85.2		1292	88.1		878	86.0		651	91.4		Zero, after Cut														
4/05/90		11:56	912	82.7	82.3	1212	79.4	78.5	782	73.7	79.5	617	81.5	83.5	After Welding														
5/04/90	48	11:30	638	65.0	81.0	951	65.0	85.5	559	65.0	84.2	366	65.0	82.1	Jon's Data														
5/04/90	55	3:00	747	68.6	78.1	1020	71.0	87.3	640	71.0	85.3	480	71.8	82.1	Jon's Data														
6/26/90	95	10:25	1302	113.1	89.2	1612	110.8	91.6	1195	112.7	93.6	915	112.3	96.4															
6/26/90	92	5:35	1248	113.6	93.0	1552	110.4	94.8	1111	110.5	96.5	827	108.2	97.6															
6/27/90	60	5:40am	391	58.5	89.4	747	58.2	91.0	314	58.1	92.0	55	58.2	94.0	Begin Full Day Test														
6/27/90	65	6:40	415	60.5	89.9	781	61.7	92.4							Train Prevented #3&4														
6/27/90	68	7:18	594	70.7	89.4	950	69.4	90.0	521	68.6	90.1	243	67.6	92.1															
6/27/90	84	8:25	824	84.2	89.1	1163	82.8	90.6	741	83.1	91.3	484	84.0	94.0															
6/27/90	89	9:29													Temp Probe Failed														
6/27/90	92	10:45	1302	113.0	89.1	1602	111.6	93.0	1168	111.8	94.4	885	110.7	96.6	Temp Probe Repaired														
6/27/90	95	12:00	1455	124.4	91.3	1762	123.2	95.0	1330	121.9	94.7	1038	119.4	96.1															
6/27/90	98	1:00	1516	129.3	92.6	1829	125.9	93.6	1390	125.7	94.9	1114	125.0	97.2															
6/27/90	105	2:00	1583	132.4	91.7	1906	132.8	95.9	1473	132.0	96.2	1192	129.5	97.0															
6/27/90	95	2:57	1360	118.4	91.1	1651	116.8	95.2	1202	116.8	97.3	905	112.9	97.6	End Full Day Test														
7/23/90	66	9:20am	704	77.4	89.5	1062	75.4	89.2	620	76.3	91.8	360	76.0	93.5															
7/23/90	82.8	12:08	1119	105.8	92.9	1474	104.1	93.2	1020	102.3	93.8	734	99.6	94.6	12.02; Eastbound Trail														
7/24/90	73	9:00am	697	76.6	89.1	1059	74.5	88.5	618	74.1	89.7	362	74.1	91.5															
7/24/90	81	10:00	890	88.4	89.3	1259	86.8	88.8	812	86.9	90.9	540	86.9	93.6															
7/24/90	78	11:00	1047	99.1	90.6	1430	99.4	91.1	981	97.9	91.7	712	98.0	94.3															
7/24/90	83	12:00	1161	105.2	89.8	1536	106.8	92.1	1090	107.6	94.9	816	107.9	98.0															
7/24/90	82	1:00	1186	109.9	93.0	1578	109.9	92.7	1135	109.4	94.0	863	107.1	94.4															
7/25/90	73	8:00am	563	68.5	89.1	936	68.0	89.4	499	68.4	91.2	255	69.6	93.4															
1/29/91	35	8:35	76	37.6	87.4	490	34.9	83.1	69	33.3	81.9	-172	31.3	80.8															
1/29/91	30	10:05	236	41.1	81.3	642	40.2	79.3	223	40.3	79.7	8	40.3	78.9															
1/29/91	38	1:00	393	52.9	83.7	814	52.2	80.9	393	52.3	81.4	172	53.3	82.1															
1/30/91	38	8:25	22	32.1	85.2	489	29.3	77.6	47	28.7	78.6	-210	25.2	76.9															
1/30/91	39	9:30	362	54.1	86.7	792	49.1	79.1	363	48.3	79.2	103	46.4	79.3															
1/30/91	40	10:32	622	70.4	87.4	1044	65.3	80.2	605	65.6	82.0	348	64.1	82.3															
1/30/91	45	11:35	814	80.1	85.6	1234	78.6	82.1	810	77.7	81.8	558	76.4	82.0															
1/30/91	49	12:35	900	83.1	83.4	1330	85.3	83.0	901	85.4	84.0	667	83.9	82.9															
1/30/91	55	2:10	861	85.3	87.9	1302	88.7	88.1	875	90.3	90.5	674	90.1	88.7															
1/30/91	49	4:00	620	69.1	86.2	1058	71.6	85.7	645	71.0	85.0	470	74.9	85.8															
4/03/91	60	9:00	695	72.5	85.1	1085	68.6	81.0	640	67.9	82.2	378	63.3	79.7															
4/03/91	73	10:15	972	90.8	86.8	1389	89.4	83.6	946	86.3	82.2	701	85.2	82.2															
4/03/91	72	11:00	1135	100.1	86.3	1520	98.1	84.4	1081	94.5	82.3	836	92.6	81.5															
4/03/91	73	12:00	1209	103.7	85.4	1597	100.7	82.4	1158	97.8	81.0	922	98.7	82.4															
4/03/91	77	12:45	1135	103.0	89.2	1524	97.4	83.5	1088	97.5	84.9	868	94.5	81.5															
4/03/91	69	2:00	1148	101.2	86.6	1580	101.3	84.0	1143	100.3	84.4	931	96.7	79.9															
4/03/91	69	3:00	1012	92.2	85.8	1429	92.9	84.7	1004	92.1	84.5	792	90.9	82.4															
4/04/91	51	8:20am	591	65.8	84.7	972	60.6	79.8	533	58.2	78.9	291	57.3	78.9															
4/04/91	63	10:00	934	85.9	84.2	1322	83.3	81.5	882	80.0	79.8	632	78.8	79.9															
4/04/91	64	11:00	1082	95.1	84.5	1470	93.2	82.5	1034	90.9	81.5	795	92.0	83.3															
4/04/91	69	12:00	1169	100.3	84.4	1554	97.5	81.8	1116	96.4	82.1	879	95.1	81.4															
4/04/91	73	1:00	1210	102.9	84.6	1607	101.3	82.4	1175	97.3	79.5	946	96.4	78.7															
4/04/91	75	2:00	1117	99.2	86.5	1582	98.1	80.7	1151	99.3	82.9	935	96.0	78.9															
4/04/91	72	3:00	1102	97.1	85.3	1519	96.2	82.6	1093	96.5	83.6	883	94.1	80.2															
4/04/91	72	4:00	1036	93.4	85.5	1452	92.6	83.0	1081	92.6	80.4	803	92.0	82.9															
5/21/91	59	9:00	486	57.0	82.2	885	57.1	81.6	473	56.8	81.1	252	56.8	80.8															
5/21/91	61	11:15	516	57.7	81.1	914	58.0	80.7	496	57.8	80.8	275	57.8	80.4															

RAIL STRAIN DATA FROM SANTE FE, NM															
SECTION 2															
Date	Amb	Time	Low Rail												Comments
			1	Neut	2	Neut	3	Neut	4	Neut					
Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	
5/22/91	56	8:15	515	55.8	79.2	905	54.6	77.9	487	53.8	77.3	214	55.1	81.4	
5/22/91	64	10:00	863	76.3	78.8	1240	74.2	77.3	801	73.0	77.6	503	73.1	82.0	
5/22/91	70	11:05	1085	91.5	80.7	1440	89.2	80.3	999	86.6	79.3	742	85.5	80.0	
5/22/91	74	12:45	1252	102.5	81.6	1618	101.6	82.0	1191	99.8	81.0	936	97.2	80.1	
5/22/91	75	2:00	1266	109.1	87.4	1650	108.2	86.7	1235	106.8	85.3	991	103.9	83.5	
5/22/91	74	3:25	1280	110.2	87.7	1651	111.1	89.5	1227	109.1	88.1	987	106.3	86.1	
5/22/91	76	4:25	1182	106.2	89.6	1553	104.7	89.0	1125	103.6	88.8	882	99.3	85.4	
7/16/91	64	8:10	570	64.7	84.8	1008	64.0	81.1	604	64.1	80.6	379	64.6	80.9	
7/16/91	75	9:06	792	76.8	83.6	1210	75.7	80.6	799	75.5	80.2	559	77.7	83.2	
7/16/91	79	10:00	988	89.7	84.7	1404	88.8	82.1	985	86.9	80.5	734	87.2	82.2	
7/16/91	84	11:30	1196	106.5	89.0	1612	104.4	85.2	1185	102.4	84.0	909	98.3	82.8	
7/16/91	83	12:30	1300	113.0	89.3	1725	112.2	86.2	1297	107.6	82.4	1020	105.1	82.9	
7/16/91	85	2:00	1255	114.8	93.8	1706	114.4	89.5	1275	111.6	87.7	1020	107.3	85.1	
7/16/91	87	3:00	1282	117.1	94.4	1730	116.6	90.3	1306	114.6	88.9	1055	110.1	85.8	
7/17/91	70	8:00	659	70.1	84.9	1086	68.6	81.0	673	68.7	81.0	457	69.6	81.3	
7/17/91	75	9:00	851	80.8	84.0	1265	78.1	79.7	850	78.1	79.8	618	79.0	81.0	
7/17/91	78	10:00	1020	91.8	84.9	1454	90.3	80.6	1037	90.1	80.5	791	89.6	81.2	
7/17/91	84	11:00	1140	102.0	87.9	1589	101.3	83.5	1166	100.2	82.9	918	100.1	84.1	
7/17/91	88	12:00	1287	112.8	89.8	1740	112.6	85.7	1318	112.1	85.7	1064	108.1	83.3	
7/17/91	92	1:00	1393	120.4	91.1	1825	118.3	86.3	1395	116.3	85.2	1134	112.2	83.2	
7/17/91	89	2:00	1446	124.1	91.6	1876	121.6	86.5	1444	120.1	86.1	1193	115.8	83.2	
7/17/91	87	3:30	1450	123.9	91.1	1889	121.6	85.7	1464	120.5	85.3	1200	115.4	82.4	
7/17/91	86	4:20	1217	113.8	95.1	1665	111.9	89.5	1235	111.6	90.1	989	106.0	85.7	
7/18/91	76	8:10	703	73.7	85.8	1124	72.2	82.3	705	72.2	82.6	479	72.7	83.0	
7/18/91	80	9:30	949	88.1	85.5	1354	85.6	81.9	929	84.8	81.7	683	84.9	83.0	
7/18/91	84	10:35	1026	99.3	92.0	1495	98.5	86.3	1072	97.4	85.7	833	96.1	85.2	
7/18/91	87	11:41	1146	108.0	93.5	1616	106.1	86.6	1194	105.1	86.1	952	104.0	85.9	
7/18/91	89	12:35	1261	114.5	93.1	1741	113.5	86.5	1319	113.2	86.7	1077	112.2	86.6	
7/18/91	88	1:30	1115	105.5	92.9	1606	104.2	85.3	1190	105.4	86.7	959	104.8	86.3	
8/13/91	72	9:00	618	72.7	89.9	1130	71.5	81.2	714	71.3	81.2	477	70.8	81.3	
8/13/91	81	10:00	844	89.8	93.5	1370	89.1	84.4	948	86.7	82.5	697	88.5	85.7	
8/13/91	82	12:00	1069	105.1	95.2	1591	103.1	85.1	1181	103.7	85.5	936	103.2	86.1	
8/13/91	69	2:30	600	72.3	90.6	1180	76.3	83.0	760	76.8	83.9	536	77.3	84.2	
8/15/91	70	8:40	557	74.1	95.0	1078	70.5	83.4	655	70.6	84.0	413	70.2	84.5	
8/15/91	80	10:00	861	92.4	95.0	1375	89.6	84.6	954	87.9	83.3	694	87.2	84.6	
8/15/91	86	11:00	1020	103.8	96.9	1545	102.0	86.8	1122	99.7	85.0	862	98.3	85.6	
8/15/91	85	12:00	1099	110.1	98.4	1640	108.3	87.4	1229	106.2	85.1	967	106.2	87.2	
8/15/91	90	1:00	1205	114.9	96.9	1759	115.3	87.2	1342	114.7	86.8	1090	114.3	87.9	
8/15/91	85	2:10	1052	110.3	101.5	1606	109.1	90.2	1180	110.0	91.9	937	109.2	92.0	
8/15/91	84	3:00	1071	108.6	98.6	1636	109.7	89.0	1224	108.5	87.7	986	108.5	88.4	

RAIL STRAIN DATA FROM SANTE FE, NM																		
SECTION 3																		
Date	Amb	Time	1		Neut		2		Neut		3		Neut		4		Neut	Comments
Temp			Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	
2/14/90	37		593	34.2	79.6	467	34.6	79.3	0	35.1	76.0	416	43.3	81.0				
2/15/90	20		581	31.1	77.2	443	31.6	77.7	-31	32.0	74.7	237	31.8	80.3				
4/02/90	56		1215	73.7	81.7	1096	73.0	79.9	566	71.8	78.7	874	75.1	85.3				
4/02/90		4:00	1133	66.0	78.9	987	68.3	81.7	465	67.3	80.2	779	68.0	83.9				
4/03/90	45	9:00	849	48.2	78.2	733	48.4	77.1	235	48.6	75.3	501	48.0	80.6				
4/03/90			1261	77.0	82.2	1133	75.5	80.1	598	75.3	80.2	934	75.5	82.1				
7/23/90	66	9:20am	1189	81.6	91.2	1130	81.0	85.8	617	81.5	85.3	922	81.0	88.3				
7/23/90		10:42				1285	92.4	87.9	763	91.6	86.6							Before Rail Cut
7/23/90		11:19	1348	101.3		1210	100.9		680	100.3		1044	99.4					Zero
7/23/90		12:08	1303	102.7	105.4	1216	104.6	104.2	691	107.5	106.8	1061	105.2	104.2				12:02;Eastbound Train
7/24/90	73	9:00am	1099	80.9	95.9	949	79.1	94.8	472	81.9	94.4	741	79.4	97.6				Rail Not Welded
7/24/90	81	10:00	1190	89.1	98.6	1118	88.2	93.7	590	91.2	96.6	884	88.5	98.1				
7/24/90	78	11:00	1268	95.1	99.9	1220	96.2	95.6	695	99.0	98.1	1016	96.5	98.2				
7/24/90	83	12:00	1548	100.5	88.5	1299	100.9	95.6	763	101.8	96.8	1105	102.9	99.2				
7/24/90	82	1:00	1406	101.9	98.4	1348	104.4	96.1	804	106.4	98.9	1154	105.7	99.1				
7/25/90	73	8:00am	967	76.4	99.3	851	73.5	95.1	346	75.1	95.2	609	73.6	99.7				
7/25/90		11:15	1322	102.3	103.9	1200	111.1	111.7	661	107.0	108.1	1010	101.6	103.6				Pre-weld
7/25/90		12:14	1347	101.8	101.9	1205	115.5	115.8	672	108.6	109.1	1026	103.8	104.9				Right after Weld
7/25/90	89	3:26	1418	105.4	101.2	1320	112.7	106.1	777	111.8	106.0	1132	108.7	103.4				3 hrs. after Welding
7/25/90	85	4:01	1414	109.1	105.1	1305	111.5	105.8	765	112.0	106.9	1118	107.7	103.3				
1/29/91	35	8:35	429	38.8	94.0	255	39.9	97.3	-219	40.1	94.1	43	37.1	97.3				
1/29/91	30	10:05	432	39.5	94.5	246	39.3	97.2	-223	40.2	94.5	28	39.0	100.1				
1/29/91	38	1:00	558	46.5	94.0	383	47.2	96.9	-89	48.6	94.8	214	48.5	98.4				
1/30/91	38	8:25	315	35.5	97.6	120	35.6	101.1	-341	35.2	96.6	-133	34.5	105.2				
1/30/91	39	9:30	594	50.8	96.1	419	55.0	102.5	-55	53.2	97.4	212	51.6	101.6				
1/30/91	40	10:32	785	62.6	96.4	629	63.7	98.6	153	65.1	96.8	470	64.3	98.8				
1/30/91	45	11:35	879	67.2	95.4	734	69.3	97.9	245	73.0	99.1	604	73.2	99.6				
1/30/91	49	12:35	896	67.7	94.9	748	70.3	98.1	257	72.5	97.9	641	74.1	98.3				
1/30/91	55	2:10	934	69.7	94.6	765	68.1	94.8	273	71.0	95.5	620	71.3	96.8				
1/30/91	49	4:00	815	62.7	94.7	628	61.1	96.1	145	62.2	94.4	422	60.2	97.6				
4/03/91	60	9:00	1091	79.1	94.5	891	78.8	98.0	383	75.6	93.4	667	74.2	96.9				
4/03/91	73	10:15	1308	90.9	93.3	1134	92.7	97.3	606	91.6	96.0	933	92.9	99.6				
4/03/91	72	11:00	1363	93.8	92.9	1206	93.5	93.7	677	95.6	95.8	1028	98.2	99.2				
4/03/91	73	12:00	1417	96.7	92.6	1252	97.8	95.3	716	98.3	96.1	1071	99.1	97.5				
4/03/91	77	12:45	1393	96.8	94.1	1205	96.7	97.0	670	97.6	98.2	989	97.7	101.0				
4/03/91	69	2:00	1366	96.3	95.2	1188	96.1	97.4	659	98.0	99.3	997	96.8	99.6				
4/03/91	69	3:00	1251	89.4	95.2	1094	89.3	96.3	572	90.7	97.2	918	90.5	98.1				
4/04/91	51	8:20am	965	71.8	94.8	773	71.7	98.0	277	70.9	95.1	569	70.1	98.6				
4/04/91	63	10:00	1218	85.6	93.4	1046	86.1	96.0	529	86.4	95.5	856	84.1	95.4				
4/04/91	64	11:00	1299	90.3	93.2	1138	92.5	96.8	612	90.6	94.7	966	92.7	97.4				
4/04/91	69	12:00	1356	91.0	90.5	1203	94.1	94.5	672	94.6	95.1	1040	96.9	97.1				
4/04/91	73	1:00	1398	96.4	93.4	1236	97.0	95.4	699	97.1	96.0	1063	96.9	95.8				
4/04/91	75	2:00	1403	96.2	92.9	1231	96.3	95.0	689	97.6	97.1	1027	96.0	97.0				
4/04/91	72	3:00	1433	99.5	94.4	1238	98.4	96.7	706	98.8	97.2	1026	95.8	96.9				
4/04/91	72	4:00	1405	97.4	94.0	1189	97.3	98.6	688	98.1	97.6	997	95.0	97.8				
5/21/91	59	9:00	707	56.6	95.1	536	56.2	96.7	54	56.7	94.3	366	56.7	97.4				
5/21/91	61	11:15	722	57.3	94.9	560	57.3	96.4	65	57.7	94.7	394	57.5	96.6				
5/22/91	56	8:15	874	68.2	96.7	660	65.6	98.7	100	65.8	100.7	363	61.7	102.6				
5/22/91	64	10:00	1197	85.1	94.2	1001	82.4	95.0	381	82.5	100.5	689	81.8	103.1				
5/22/91	70	11:05	1387	96.5	94.2	1180	95.8	97.6	594	100.9	106.1	901	93.4	102.0				
5/22/91	74	12:45	1469	100.6	93.3	1310	101.6	95.6	772	99.7	94.2	1081	100.8	98.6				
5/22/91	75	2:00	1519	104.7	94.4	1358	106.5	97.6	818	106.7	98.4	1144	106.5	100.5				
5/22/91	74	3:25	1594	109.1	94.3	1447	109.8	95.6	894	111.2	98.3	1229	110.6	99.5				
5/22/91	76	4:25	1570	106.8	93.5	1413	108.4	96.2	866	107.4	96.2	1197	106.8	97.6				
7/16/91	64	8:10	920	70.3	96.0	736	70.0	98.5	222	69.4	96.9	486	66.9	100.4				
7/16/91	75	9:06	1207	86.0	94.5	1029	85.2	96.1	508	85.8	96.1	767	82.9	99.5				
7/16/91	79	10:00	1406	99.1	95.6	1248	97.6	95.3	708	97.9	96.2	993	96.2	99.3				
7/16/91	84	11:30	1597	110.8	95.8	1448	109.2	94.9	883	109.4	97.2	1200	105.9	96.5				
7/16/91	83	12:30	1647	109.9	91.9	1516	112.2	93.8	944	111.8	95.9	1295	111.2	96.1				

RAIL STRAIN DATA FROM SANTE FE, NM																		
SECTION 3																		
High Rail																		
Date	Amb	Time	1		Neut		2		Neut		3		Neut		4		Neut	Comments
	Temp		Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	
7/16/91	85	2:00	1655	113.1	94.7	1510	113.4	95.4	935	114.2	98.9	1278	114.4	100.3				
7/16/91	87	3:00	1732	117.2	94.1	1589	117.9	95.1	999	118.5	99.3	1347	115.9	97.7				
7/17/91	70	8:00	1078	80.9	97.1	898	78.0	96.8	383	75.6	93.4	623	74.3	99.6				
7/17/91	75	9:00	1233	89.1	96.0	1068	88.0	96.5	544	87.2	95.4	803	86.5	101.0				
7/17/91	78	10:00	1365	97.2	96.2	1209	96.0	96.1	680	95.4	95.4	969	94.9	99.4				
7/17/91	84	11:00	1456	102.2	95.7	1310	101.5	95.5	770	101.1	95.7	1079	101.2	99.1				
7/17/91	88	12:00	1587	110.2	95.8	1454	110.3	95.6	889	110.4	97.8	1227	110.2	99.2				
7/17/91	92	1:00	1729	117.8	94.9	1589	117.2	94.4	1008	118.2	98.5	1351	117.2	98.8				
7/17/91	89	2:00	1792	120.1	93.4	1657	120.6	93.7	1074	121.7	98.0	1424	120.9	98.1				
7/17/91	87	3:30	1817	120.9	92.7	1688	121.1	92.4	1103	122.7	97.3	1452	123.2	98.7				
7/17/91	86	4:20	1652	113.2	94.9	1505	113.5	95.8	933	116.3	101.1	1262	116.3	103.2				
7/18/91	76	8:10	1100	81.6	96.5	914	80.2	98.0	397	79.7	96.7	643	77.4	101.5				
7/18/91	80	9:30	1304	94.3	96.9	1126	93.1	98.1	596	93.1	98.1	873	92.1	102.4				
7/18/91	84	10:35	1397	98.6	95.7	1248	99.2	96.9	701	98.4	97.1	1013	98.2	100.1				
7/18/91	87	11:41	1451	102.5	96.3	1315	103.3	97.0	758	103.6	98.9	1092	103.5	100.6				
7/18/91	89	12:35	1506	105.0	95.5	1381	106.1	95.8	821	106.9	98.4	1181	107.4	99.2				
7/18/91	88	1:30	1383	98.9	96.8	1254	99.7	97.1	705	100.4	98.9	1042	100.2	100.3				
8/13/91	72	9:00	1074	81.1	97.6	900	80.0	98.6	362	78.9	98.0	638	77.9	102.3				
8/13/91	81	10:00	1308	96.8	99.2	1129	93.2	98.1	598	94.9	99.8	883	94.6	104.3				
8/13/91	82	12:00	1465	105.2	98.2	1274	104.5	100.7	710	104.4	102.6	1049	104.4	104.1				
8/13/91	69	2:30	948	72.7	96.7	792	71.2	96.3	271	73.3	97.9	582	73.4	101.2				
8/15/91	70	8:40	1149	85.0	97.0	938	83.2	99.5	399	85.0	101.9	668	79.4	102.0				
8/15/91	80	10:00	1386	98.9	96.6	1202	99.2	99.7	644	99.2	101.4	944	95.3	101.3				
8/15/91	86	11:00	1478	104.5	96.7	1305	105.2	99.5	740	105.2	101.6	1072	103.2	101.5				
8/15/91	85	12:00	1508	106.3	96.7	1343	106.9	98.9	775	107.7	102.0	1121	105.7	101.1				
8/15/91	90	1:00	1576	109.9	96.2	1124	110.4	115.6	852	111.4	101.1	1225	110.2	99.3				
8/15/91	85	2:10	1478	106.2	98.4	1296	104.2	99.0	719	105.8	103.5	1049	104.5	104.2				
8/15/91	84	3:00	1508	106.1	96.5	1360	106.1	97.1	791	106.5	99.8	1153	106.2	99.6				

RAIL STRAIN DATA FROM SANTE FE, NM															
SECTION 3															
Date	Amb	Time	1	Neut	2	Neut	3	Neut	4	Neut					
Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Temp	Comments	
2/14/90	37				898	34.7	75.6	-312	34.8	74.6	-162	35.6	75.7		
2/15/90	20				915	36.4	78.3	-322	34.7	75.1	-196	36.6	78.8		
4/02/90	56				254	74.8	77.0	298	75.3	78.5	450	76.7	80.1		
4/02/90		4:00			387	66.7	76.9	172	67.7	78.5	327	68.9	79.7		
4/03/90	45	9:00			610	51.2	74.8	-44	51.2	74.9	102	49.7	74.0		
4/03/90					240	76.4	77.8	319	76.1	78.0	467	79.8	82.1		
7/23/90	66	9:20am	-407	84.1	87.3	250	82.5	84.5	318	81.8	83.8	434	81.4	85.7	
7/23/90		9:55			221	86.3	86.5	346	86.3	86.6				Before Rail Cut	
7/23/90		10:10			213	88.3	88.1	350	87.0	87.1				After Cut, Anchors on	
7/23/90		10:22	-354	92.4		217	88.4		351	87.5		506	89.6	Zero	
7/23/90	82.8	12:08	-133	104.4	91.1	-30	107.1	92.3	574	106.4	93.0	746	106.8	92.4	2:02; Eastbound Train
7/24/90	73	9:00	-328	80.6	79.0	124	82.7	77.1	438	81.4	76.2	516	80.8	80.2	
7/24/90	81	10:00	-236	91.7	84.6	82	92.9	84.8	470	92.2	85.0	586	89.8	85.0	
7/24/90	78	11:00	-182	97.9	87.6	35	99.9	89.0	519	100.3	90.2	658	99.1	90.0	
7/24/90	83	12:00	-134	103.5	90.3	-10	103.3	89.7	556	103.4	91.1	703	104.9	93.1	
7/24/90	82	1:00	-113	104.1	89.6	-25	105.7	91.2	572	107.5	94.2	760	107.5	92.2	
7/25/90	73	8:00am	-410	76.7	80.1	208	75.3	74.8	352	75.5	75.4	411	73.5	79.2	Rail Bolt-joined
7/25/90		10:20	-289	96.9	93.0	197	100.2	99.0	354	99.1	98.9	543	97.7	95.5	1" of Rail Cut Out
7/25/90		11:22	-221	102.4	94.4	140	111.0	106.4	400	105.3	102.4	626	104.2	97.0	Right after Weld
7/25/90		12:14	-210	102.8	94.1	150	120.1	116.1	391	109.8	107.4	657	106.4	97.3	Grinding on Low Rail
7/25/90	89	3:26	-137	108.8	95.8	21	111.4	99.6	527	110.5	99.9	720	110.5	97.6	4 hrs. after Welding
7/25/90	85	4:01	-133	109.3	96.0	22	110.6	98.9	515	110.8	100.9	701	109.5	97.8	
1/29/91	35	8:35	-927	41.8	76.2	870	42.2	81.4	-251	43.0	79.2	-125	40.9	78.8	
1/29/91	30	10:05	-927	39.5	73.9	886	40.9	81.1	-255	41.3	77.7	-100	40.9	77.3	
1/29/91	38	1:00	-814	46.4	74.0	743	48.5	80.1	-108	49.2	76.8	37	48.9	77.1	
1/30/91	38	8:25	-1041	39.1	80.4	979	40.1	85.9	-342	39.1	80.7	-208	36.0	78.9	
1/30/91	39	9:30	-739	57.0	80.1	658	56.6	83.1	-32	57.3	80.3	105	56.5	80.6	
1/30/91	40	10:32	-547	66.9	78.5	459	71.0	85.5	167	70.7	81.8	323	70.3	81.3	
1/30/91	45	11:35	-470	71.3	78.3	352	76.1	84.2	268	77.5	82.5	436	77.9	82.1	
1/30/91	49	12:35	-476	69.8	77.1	346	76.0	83.8	286	77.5	81.4	458	78.4	81.3	
1/30/91	55	2:10	-424	71.8	76.0	340	71.6	79.0	276	72.3	76.8	431	73.5	78.0	
1/30/91	49	4:00	-544	64.9	76.3	480	63.7	79.5	117	63.4	77.5	241	61.5	77.4	
4/03/91	60	9:00	-296	84.0	80.5	249	84.4	86.3	337	82.0	82.8	470	78.8	81.0	
4/03/91	73	10:15	-95	96.2	80.6	31	99.0	87.8	557	97.6	85.2	716	95.6	83.0	
4/03/91	72	11:00	-63	95.8	78.3	-30	98.3	83.5	619	98.1	82.0	798	98.7	81.2	
4/03/91	73	12:00	-45	97.5	78.9	-44	100.5	84.8	634	99.9	82.9	820	101.3	82.4	
4/03/91	77	12:45	-87	97.6	81.6	17	96.5	84.5	565	99.6	86.7	732	98.1	84.5	
4/03/91	69	2:00	-112	96.1	81.6	26	98.2	86.7	569	98.9	85.8	733	98.1	84.5	
4/03/91	69	3:00	-206	91.1	82.2	131	92.5	87.3	454	91.3	85.1	618	91.6	84.9	
4/04/91	51	8:20am	-451	76.6	82.4	395	75.7	86.4	192	76.1	85.7	325	72.4	83.3	
4/04/91	63	10:00	-206	89.0	80.1	138	90.4	85.7	448	90.3	84.5	595	88.3	83.0	
4/04/91	64	11:00	-140	93.4	80.5	60	96.5	87.1	529	95.5	84.8	691	94.3	83.2	
4/04/91	69	12:00	-102	95.2	80.1	46	97.0	86.7	579	97.3	83.6	758	98.9	83.8	
4/04/91	73	1:00	-84	97.8	81.6	9	98.9	86.4	577	98.9	85.3	752	98.3	83.5	
4/04/91	75	2:00	-96	94.5	79.0	37	95.4	84.6	549	97.5	85.6	712	96.5	84.1	
4/04/91	72	3:00	-57	98.5	80.7	30	98.1	86.9	561	98.5	85.9	708	96.2	84.1	
4/04/91	72	4:00	-84	96.2	80.0	33	97.4	86.3	545	96.8	85.1	687	94.7	83.8	
5/21/91	59	9:00	-706	56.3	77.5	643	56.4	82.0	-16	56.9	79.0	147	56.6	78.2	
5/21/91	61	11:15	-688	57.4	77.5	615	57.7	81.6	2	57.7	78.7	156	57.9	78.9	
5/22/91	56	8:15	-539	70.6	81.7	507	69.2	86.6	109	66.5	81.0	237	65.9	82.1	
5/22/91	64	10:00	-206	89.1	80.2	165	89.3	86.2	459	86.9	80.4	588	84.4	79.5	
5/22/91	70	11:05	-28	101.2	81.6	-3	101.3	88.1	680	95.0	75.2	771	97.5	81.6	
5/22/91	74	12:45	24	101.5	78.8	-73	105.0	87.6	671	104.1	84.9	853	104.2	83.3	
5/22/91	75	2:00	51	107.0	82.7	-111	108.7	89.0	707	109.3	87.9	886	106.5	83.7	
5/22/91	74	3:25	136	111.3	81.9	-197	113.1	88.2	789	112.1	85.8	938	111.3	85.3	
5/22/91	76	4:25	118	109.9	81.5	-161	110.9	88.2	754	109.6	85.4	889	109.3	86.3	
7/16/91	64	8:10	-338	72.7	71.7	189	70.9	69.2	452	70.2	64.1	558	67.5	64.4	
7/16/91	75	9:06	-163	88.9	77.4	104	88.3	81.5	519	85.7	75.6	669	82.5	72.7	
7/16/91	79	10:00	-102	99.1	84.0	61	103.0	93.6	542	99.5	88.0	696	96.0	84.6	

RAIL STRAIN DATA FROM SANTE FE, NM																
SECTION 3																
															Low Rail	
Date	Amb	Time	1			2			3			4			Neut	Comments
	Temp		Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp		
7/16/91	84	11:30	35	114.6	91.2		111.5	98.5	648	109.8	92.0	815	107.5	88.9		
7/16/91	83	12:30	66	109.4	84.2	-101	113.7	94.6	697	112.6	91.8	884	112.2	89.5		
7/16/91	85	2:00	50	114.2	89.9	-142	115.5	93.9	758	116.8	92.3	927	115.9	90.6		
7/16/91	87	3:00	99	118.0	90.8	-165	118.6	95.6	783	117.8	91.8	958	116.5	89.3		
7/17/91	70	8:00	-207	81.1	72.3	97	80.1	72.9	534	78.2	67.2	662	75.8	66.4		
7/17/91	75	9:00	-139	91.4	78.5	89	89.2	81.5	538	89.4	78.2	709	87.5	75.3		
7/17/91	78	10:00	-120	99.2	85.1	62	99.8	90.5	555	97.8	85.5	730	97.3	83.8		
7/17/91	84	11:00	-67	104.7	87.5	44	104.6	94.2	567	103.1	90.1	769	104.2	88.4		
7/17/91	88	12:00	30	112.1	89.0	-47	114.4	98.5	656	113.2	94.9	851	112.4	91.7		
7/17/91	92	1:00	112	118.2	90.2	-120	119.5	99.2	736	119.1	96.0	936	118.7	92.9		
7/17/91	89	2:00	166	121.4	90.2	-177	122.2	98.5	794	122.7	96.1	993	122.3	93.0		
7/17/91	87	3:30	179	122.6	90.6	-192	121.6	97.0	809	123.3	95.8	1004	122.4	92.5		
7/17/91	86	4:20	42	115.1	91.3	-118	116.0	95.9	748	116.8	92.9	913	117.2	92.7		
7/18/91	76	8:10	-175	82.9	72.1	104	82.4	75.6	514	81.1	71.3	674	78.8	68.7		
7/18/91	80	9:30	-139	96.4	83.5	85	97.1	89.2	530	94.0	83.2	683	94.0	83.4		
7/18/91	84	10:35	-147	101.9	89.5	54	104.0	94.2	563	102.7	90.0	726	102.0	88.8		
7/18/91	87	11:41	-100	103.6	88.3	5	107.2	94.5	616	106.2	90.3	795	106.8	89.4		
7/18/91	89	12:35	-75	107.1	90.3	-34	108.4	93.3	657	110.1	91.7	854	110.4	89.5		
7/18/91	88	1:30	-193	99.2	89.5	93	101.6	94.1	537	102.4	91.2	716	102.8	90.2		
8/13/91	72	9:00	-232	81.7	74.4	132	80.0	74.9	495	79.3	70.6	647	78.7	70.2		
8/13/91	81	10:00	-199	99.4	90.1	138	97.9	93.2	495	97.2	88.5	662	91.2	81.8		
8/13/91	82	12:00	-73	106.5	89.6	8	106.6	94.0	605	106.1	90.8	766	105.8	90.2		
8/13/91	69	2:30	-362	70.3	70.8	270	70.2	73.4	390	70.9	68.6	501	71.4	71.7		
8/15/91	70	8:40	-200	86.5	77.2	144	86.2	81.8	484	84.6	76.6	653	82.8	74.0		
8/15/91	80	10:00	-140	102.5	89.6	96	102.8	95.5	510	100.0	90.4	683	99.0	88.4		
8/15/91	86	11:00	-80	106.1	89.6	43	108.2	97.7	564	106.9	94.1	729	106.0	92.6		
8/15/91	85	12:00	-63	107.4	89.9	13	108.6	96.3	593	108.6	94.1	769	107.5	91.7		
8/15/91	90	1:00	-23	109.5	89.6	-40	112.0	96.6	650	112.5	94.5	842	111.8	91.6		
8/15/91	85	2:10	-77	105.1	88.5	-7	106.9	93.4	612	104.3	88.6	780	106.4	89.9		
8/15/91	84	3:00	-89	105.8	89.9	-10	107.4	93.8	623	107.5	91.2	806	106.9	88.9		

RAIL STRAIN DATA FROM BLUEFIELD, WV															
SECTION 1															
High Rail															
Date	Amb	Time	1	Neut	2	Neut	3	Neut	4	Neut	Comments				
	Temp		Strain	Temp	Strain	Temp	Strain	Temp	Strain	Temp	Strain	Temp	Temp	Temp	Temp
3/06/90		4:30	182	82.1	75.9	922	89.2	74.8	390	91.3	78.9	1021	104.2	80.6	Old Ind. Box (x2.42)
3/07/90		9:40	-198	52.4	69.0	513	51.6	61.8	5	52.0	62.7	378	50.4	65.5	Old Ind. Box (x2.42)
3/07/90		12:15	51	68.8	70.5	830	70.8	61.9	252	70.6	66.5	627	69.2	69.3	Old Ind. Box (x2.42)
4/23/90	60	9:20	32	66.6	69.4	675	64.5	64.9	216	63.7	61.7	607	60.9	62.2	
4/23/90	79	11:30	402	93.6	74.2	1045	85.3	63.5	560	87.3	64.6	982	89.0	67.8	After One Pass of Liner
4/23/90	88	12:36	380	105.4	87.3	957	100.1	83.6	689	103.4	73.0				After Line, Tamp, Bal. Reg
4/23/90	85	4:21	416	105.4	85.1	1058	105.6	83.0	567	106.6	83.5	974	106.4	85.7	
4/24/90	56	8:48	-281	56.8	78.4	375	55.4	73.8	-118	55.9	74.0	312	57.0	76.1	
4/24/90	75	10:05				604	71.9	76.6	103	70.8	75.6				Pre LR Cut, Anch Part Out
4/24/90	76	10:29				716	79.1		211	78.2					After LR Cut
4/24/90	80	10:44	79	86.0		682	82.4		183	83.0		629	81.1		After HR Cut
4/24/90	90	2:20	399	119.9	100.7	1026	119.5	98.8	519	123.6	103.4	861	121.4	107.5	After Welding, Anchors On
4/25/90	64	9:30	-481	68.4	102.1	129	65.4	98.6	-355	65.1	97.4	5	64.2	101.7	
4/25/90	85	11:30	-23	96.8	102.9	657	97.5	99.0	169	99.2	100.0	575	97.6	100.8	
6/06/90	74	10:10	-302	77.5	100.4	274	72.8	97.3	-211	69.5	93.2	167	69.1	96.9	Rec. by J. Pietrak (TSC)
6/06/90	84	11:40	62	101.1	102.1	687	98.6	98.3	212	98.5	96.8	645	92.6	91.6	Rec. by J. Pietrak (TSC)
6/06/90	92	2:25	349	121.0	104.8	959	119.5	102.9	479	120.6	102.8	890	121.5	105.8	Rec. by J. Pietrak (TSC)
6/06/90	89	3:30	446	123.1	101.0	1046	122.3	100.4	571	124.1	100.8	964.0	125.6	105.5	Rec. by J. Pietrak (TSC)
6/06/90	90	4:45	323	119.8	105.1	937	119.9	104.6	453	120.8	104.6	866.0	122.4	108.2	Rec. by J. Pietrak (TSC)
7/03/90	65	9:30	-298	75.8	98.5	205	68.2	96.9	-270	64.7	91.9	104.0	63.9	95.5	Rec. by D. Cregger (NS)
7/03/90	82	11:15	-10	92.1	97.4	530	89.4	98.5	60	87.6	95.0	180.0	81.5	108.5	Rec. by D. Cregger (NS)
7/03/90	90	12:55	284	115.5	103.2	894	115.6	102.9	418	117.5	103.4	778.0	115.8	106.8	Rec. by D. Cregger (NS)
7/30/90		9:44am	-216	78.7	96.4	332	76.2	97.2	-196	76.2	99.0	292.0	76.3	96.6	
7/30/90	87	11:41	80	98.1	98.0	616	94.5	98.5			11.0	572.0	87.2	90.6	
7/30/90	96	12:15	290	112.7	100.0	842	108.7	99.1	398	109.6	96.7	796.0	104.7	94.7	
7/30/90	89		394	120.0	101.1	970	117.8	100.5	520	116.0	95.7	948.0	115.7	96.5	
7/31/90	72	8:05am	-241	77.9	97.1	341	78.5	99.0	-92	79.4	95.9	334.0	79.6	97.3	
7/31/90	92	1:41	316	113.3	99.1	889	113.0	100.6	448	113.8	97.9	866.0	112.6	98.4	
2/04/91	70	1:50	208	98.6	90.8	739	92.5	89.1	288	95.2	88.9	794.0	102.9	93.0	
2/04/91	65	4:05	185	92.2	85.8	707	97.2	95.7	282	97.8	91.9	745.0	92.8	85.8	
2/05/91	45	8:20	-482	44.6	78.3	47	44.6	82.8	-376	44.9	78.5	125.0	45.9	76.2	
2/05/91	54	10:00	-284	56.1	77.9	246	54.2	80.4	-178	58.7	80.4	175.0	54.8	82.1	
2/05/91	58	11:35	-20	62.1	68.0	460	61.2	74.5	19	63.9	73.8	454.0	63.5	74.0	
2/05/91	65	12:55	40	74.5	76.8	551	75.1	83.0	121	77.9	81.6	587.0	76.7	79.2	
2/05/91	69	2:30	81	78.4	78.3	596	79.1	84.3	164	80.0	81.1	630.0	80.5	80.4	

RAIL STRAIN DATA FROM BLUEFIELD, WV															
SECTION 1															
Date	Amb	Time	1			2			3			4			Comments
	Temp		Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	
3/06/90		4:30	-397	80.4	76.8	499	89.7	82.8	1079	90.3	74.8	525	103.8	84.6	Old Ind. Box (x2.42)
3/07/90		9:40	-777	50.6	69.8	63	50.7	70.1	627	49.7	61.4	-184	47.8	71.2	Old Ind. Box (x2.42)
3/07/90		12:15	-496	69.7	72.0	358	69.3	70.9	929	71.2	64.7	148	68.4	71.9	Old Ind. Box (x2.42)
4/23/90	60	9:20	-229	66.6	52.9	260	64.0	71.5	797	63.8	65.2	43	61.2	71.0	
4/23/90	79	11:30	-160	93.2	75.4	614	86.3	72.5	1130	87.3	68.7	430	89.0	75.5	After One Pass of Liner
4/23/90	88	12:36	-110	108.0	87.1	533	100.3	91.4	1035	103.3	90.4	260	99.8	96.6	After Line, Tamp, Bal. Reg
4/23/90	85	4:21	-216	105.7	91.2	607	105.8	92.5	1053	107.7	93.8	420	109.1	96.2	
4/24/90	56	8:48	-832	58.7	81.2	-51	57.2	83.4	452	57.4	79.6	-275	57.0	85.9	
4/24/90	75	10:05				214	71.9	82.2	673	71.6	80.5				Pre LR Cut, Anch Part Out
4/24/90	76	10:29	-492	76.4		381	76.9		842	75.7		150	76.2		After LR Cut
4/24/90	80	10:44	-457	86.8		385	82.5		821	86.0		206	80.6		After HR Cut
4/24/90	90	2:20	-163	119.6	101.9	687	119.7	101.6	1120	119.6	101.6	485	120.0	103.2	After Welding, Anchors On
4/25/90	64	9:30	-885	69.3	95.0	-80	66.8	94.7	424	65.9	89.8	-322	63.8	95.5	
4/25/90	85	11:30	-472	96.5	97.4	405	96.3	95.1	840	98.5	97.4	218	97.2	96.5	
6/06/90	74	10:10	-682	76.3	89.8	135	72.8	87.8	306	70.5	101.4	-95	69.8	87.9	Rec. by J. Pietrak (TSC)
6/06/90	84	11:40	-372	99.8	94.7	489	96.5	90.3	470	96.5	117.6	288	91.4	86.5	Rec. by J. Pietrak (TSC)
6/06/90	92	2:25	-62	120.2	96.5	808	119.0	93.6	1281	120.1	92.5	609	119.9	95.7	Rec. by J. Pietrak (TSC)
6/06/90	89	3:30	-40	123.3	98.2	831	123.6	96.8	1325	123.5	93.2	652	124.2	97.4	Rec. by J. Pietrak (TSC)
6/06/90	90	4:45	-73	112.3	89.2	798	122.7	97.9	1300	120.2	91.4	597	121.6	98.1	Rec. by J. Pietrak (TSC)
7/03/90	65	9:30	-682	77.0	90.5	76	67.8	86.4	777	64.2	66.8	-155	64.0	85.7	Rec. by D. Cregger (NS)
7/03/90	82	11:15	-435	91.5	90.2	398	88.9	88.1	966	87.5	78.8	438	79.7	65.8	Rec. by D. Cregger (NS)
7/03/90	90	12:55	-170	114.5	97.3	712	114.6	94.9	1294	114.8	86.4	510	111.7	93.4	Rec. by D. Cregger (NS)
7/30/90		9:44am	-772	80.6	99.5	32	75.3	96.5	604	74.9	87.9	-132	74.7	95.0	
7/30/90	87	11:14	-492	98.5	100.6	320	95.1	99.0				146	89.9	93.5	
7/30/90	96	12:15	-288	113.8	103.6	538	110.7	101.5	1056	109.5	95.4	364	105.2	95.7	
7/30/90	90	1:15	-234	116.3	102.9	608	114.0	100.6	1126	114.6	96.3	448	112.1	97.6	
7/30/90	89		-196	119.5	103.8	654	118.5	102.3	1174	118.3	97.1	502	117.9	100.1	
7/31/90	72	8:05am	-857	76.1	100.1	0	76.8	99.9	540	76.4	93.3	-124	76.2	96.0	
7/31/90	92	1:41	-296	114.0	104.3	564	113.3	102.5	1086	114.1	98.2	403	112.8	101.0	
2/04/91	70	1:50				849	87.8	59.9	1389	93.5	59.4	679	93.3	64.9	
2/04/91	65	4:05				831	95.7	68.9	1380	94.9	61.3	643	91.8	65.5	
2/05/91	45	8:20				191	43.8	55.5	726	43.8	49.5	21	43.7	54.8	
2/05/91	54	10:00				350	54.6	56.7	900	54.6	49.9	320	58.7	51.8	
2/05/91	58	11:35				416	60.0	58.1	952	59.7	51.8	245	61.4	59.1	
2/05/91	65	12:55				539	70.5	61.2	1089	70.7	54.6	355	70.2	61.2	
2/05/91	69	2:30				632	77.1	62.3	1185	76.4	54.5	454	76.3	61.4	

RAIL STRAIN DATA FROM BLUEFIELD, WV															
NEW SECTION 2 (Middle Section)				High Rail											
Date	Amb	Time	1	Neut	2	Neut	3	Neut	4	Neut					
	Temp		Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Comments
3/06/90		2:50	428	99.3	71.0	404	92.2	61.3	1089	98.4	43.2	828	104.0		Old Ind. Box (x2.42)
3/07/90		9:30	-213	48.5	58.7	-206	47.5	53.3	503	48.8	28.8	182	48.0		Old Ind. Box (x2.42)
3/07/90		11:50	-10	66.1	64.1	0	66.2	59.6	695	65.4	33.9	375	66.6		Old Ind. Box (x2.42)
4/23/90	69	10:05	2	65.3	62.6	2	66.4	59.7	242	65.5	61.2				
4/23/90	85	12:58	562	104.4	68.0	409	105.4	74.2	741	105.1	70.8				
4/23/90	86	2:46	480	111.6	80.2	504	110.4	73.5	604	112.3	86.3				After STPT's
4/23/90	85	4:39	472	113.0	82.1	406	104.4	73.4	591	102.9	77.7				
4/24/90	56	8:30	-251	57.2	69.7	-207	56.8	62.6	136	58.4	60.5				
4/24/90	88	12:45	307	104.5	83.5	362	105.0	76.6	502	104.8	84.9				Pre LR Cut
4/24/90	87	1:15	377	109.4	84.2	419	109.0	77.2	573	109.8	85.6				After LR Cut
4/24/90	87	1:35	-43	114.3		-110	113.7		171	112.8					After HR Cut
4/24/90	85	4:25	-63	121.7	122.9	-61	104.1	101.2	207	110.8	108.6				After Weld, 2 & 3 Shaded
4/25/90	64	9:20	-678	64.0	102.2	-655	65.0	97.8	-153	65.3	84.8				
4/25/90	84	11:30	146	98.4	87.0	-125	101.6	102.5	210	102.2	99.9				
6/06/90	74	10:10	-402	66.9	88.5	-360	68.2	83.2							Rec. by J. Pietrak (TSC)
6/06/90	84	11:40	-15	96.7	95.0	18	102.0	94.3							Rec. by J. Pietrak (TSC)
6/06/90	92	2:25	205	119.9	105.0	230	122.4	102.0							Rec. by J. Pietrak (TSC)
6/06/90	89	3:30	253	126.1	108.3	261	127.7	105.4							Rec. by J. Pietrak (TSC)
6/06/90	90	5:07	179	123.4	110.1	211	121.5	102.2							Rec. by J. Pietrak (TSC)
7/03/90	65	9:30	-468	62.8	88.3	-480	61.7	83.9							Rec. by D. Cregger (NS)
7/03/90	90	12:55	80	116.4	109.0										Rec. by D. Cregger (NS)
7/30/90		9:44	-310	75.5	91.5	-325	76.1	89.0							
7/30/90	87	11:14	-74	86.5	88.4	-104	94.8	94.4							
7/30/90	96	12:15	76	103.3	96.1	2	102.7	96.0							
7/30/90	90	1:15	168	111.0	98.3	118	113.3	99.6							
7/30/90	89		216	116.8	101.2	161	117.9	101.6							
7/31/90	72	8:05am	-327	80.5	97.6	-359	79.6	94.6							
7/31/90	92	1:41	162	112.8	100.5	131	113.9	99.4							
2/04/91	70	1:50				136	97.8	83.0							
2/04/91	65	4:05				64	89.7	79.2							
2/05/91	45	8:20				-480	44.0	66.2							
2/05/91	54	10:00				-342	54.6	68.5							
2/05/91	58	11:35				-330	62.0	75.2							
2/05/91	65	12:55				-115	76.9	77.2							
2/05/91	69	2:30				-63	80.7	77.9							

RAIL STRAIN DATA FROM BLUEFIELD, WV															
NEW SECTION 2 (Middle Section)															
Low Rail															
Date	Amb	Time	1	Neut	2	Neut	3	Neut	4	Neut					Comments
	Temp		Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	
3/06/90		2:50	411	96.0	74.9	443	90.2	69.6	956	97.5	76.4	278	102.0	78.4	Old Ind. Box (x2.42)
3/07/90		9:30	-244	45.6	63.9	-232	46.1	66.1	336	45.7	61.9	-387	45.0	61.3	Old Ind. Box (x2.42)
3/07/90		11:50	39	64.5	65.8	56	64.2	66.9	615	64.1	63.5	-123	65.5	66.0	Old Ind. Box (x2.42)
4/23/90	69	10:05	63	67.8	67.6	117	68.8	67.8							
4/23/90	85	12:58	557	102.7	72.8	494	104.4	80.7							
4/23/90	86	2:46	523	109.3	81.5	792	109.0	67.4				372	109.8	80.5	After STPT's
4/23/90	85	4:39	502	111.3	84.7	560	104.8	77.2	1043	100.0	73.7	368	108.0	79.0	
4/24/90	56	8:30	-199	57.7	73.3	-125	56.4	69.9	421	58.0	69.1	-283	56.6	66.7	
4/24/90	88	12:45	431	103.0	80.7	542	103.3	76.7	1026	103.2	77.9	349	99.0	71.1	Pre LR Cut, New Plug #4
4/24/90	87	1:15	60	107.5		100	107.8		605	106.8		-115	105.7		After LR Cut
4/24/90	85	4:25	109	117.3	114.4	145	105.7	103.0	640	108.4	106.3	-78	115.3	113.1	After Weld, 2 & 3 Shaded
4/25/90	64	9:20	-570	63.7	101.6	-537	64.0	102.3	-14	64.7	101.9	-662	66.3	99.2	
4/25/90	84	11:30	-34	97.8	103.4	26	99.5	103.9	443	93.8	103.5	-147	100.3	102.2	
6/06/90	74	10:10	-82	69.9	78.4	35	72.6	76.5	594	77.7	78.4	-71	69.4	66.8	Rec. by J. Pietrak (TSC)
6/06/90	84	11:40	227	98.4	88.4	318	100.6	87.5	854	102.2	87.2	136	96.8	81.7	Rec. by J. Pietrak (TSC)
6/06/90	92	2:25	428	119.0	96.9	528	119.6	93.9	1017	120.1	95.3	318	117.7	91.7	Rec. by J. Pietrak (TSC)
6/06/90	89	3:30	473	125.1	100.3	581	125.8	96.9	1065	124.4	96.8	383	125.3	95.4	Rec. by J. Pietrak (TSC)
6/06/90	90	5:07	379	121.5	102.3	481	110.4	87.5	956	110.7	89.6	271	108.7	85.5	Rec. by J. Pietrak (TSC)
7/03/90	65	9:30	-190	62.7	77.7	-108	62.2	74.7	442	61.9	71.7	-250	61.4	69.5	Rec. by D. Cregger (NS)
7/03/90	90	12:55	356	116.9	99.1	476	115.4	92.8				310	114.7	89.2	Rec. by D. Cregger (NS)
7/30/90		9:44am	-5	74.0	77.9	140	75.2	72.8	890	75.2	58.1	-22	75.1	69.5	Bolted Joint
7/30/90	87	11:14	190	89.7	81.9	274	95.4	84.9	1026	96.8	71.5	50	83.3	73.4	Bolted Joint
7/31/90	72	8:24am	25	76.1	78.2	103	76.2	76.0				-111	76.9	76.7	Bolted Joint
2/04/91	70	1:50	582	90.6	59.2							297	98.3	73.5	
2/04/91	65	4:05	551	90.8	61.3							290	94.1	69.8	
2/05/91	45	8:20	-77	43.3	51.5							-343	43.7	57.4	
2/05/91	54	10:00	73	53.1	52.3							-190	54.2	58.7	
2/05/91	58	11:35	153	60.5	54.9							-102	62.2	61.4	
2/05/91	65	12:55	265	71.8	59.5							18	72.6	64.6	
2/05/91	69	2:30	372	76.7	58.0							119	78.4	64.3	
4/01/91	60	3:45	127									-140			Rail Replaced
4/01/91		4:00	129									-141			

RAIL STRAIN DATA FROM BLUEFIELD, WV															
NEW SECTION 3 (End Section)															
High Rail															
Date	Amb	Time	Strain	1	Neut	Strain	2	Neut	Strain	3	Neut	Strain	4	Neut	Comments
	Temp			Temp	Temp		Temp	Temp		Temp	Temp		Temp	Temp	
3/05/90		12:30	0	84.7		31	78.5	68.2	995	79.1	56.5	281	78.1	52.3	(x2.42), #1 Taken @ 1:30
3/06/90		11:00	-327	66.8		29	65.2	55.0	733	67.3	60.4	-29	60.8	53.6	Old Ind. Box (x2.42)
3/06/90		2:30	167	97.5		511	98.8	59.6	1227	96.1	59.6	477	97.7	60.1	Old Ind. Box (x2.42)
3/07/90		9:00	-368	44.9		-121	45.5	44.3	568	45.2	48.3	-206	45.6	49.0	Old Ind. Box (x2.42)
3/07/90		11:30	-322	67.8		58	66.2	54.2	772	68.0	58.8	34	68.4	57.4	Old Ind. Box (x2.42)
4/25/90	80	10:30				157	92.3	74.4	910	95.8	78.3	247	98.3	74.5	Wired Direct to Ind. Box
4/25/90	88	1:24	470	110.5	82.3	409	111.7	78.6	1160	111.8	79.3	533	113.0	72.0	Wired Direct to Ind. Box
6/06/90	74	10:10	152	90.3	81.2	42	96.1	85.1	775	84.7	75.3	81	92.3	78.5	Rec. by J. Pietrak (TSC)
6/06/90	84	11:40	434	108.7	82.6	341	110.1	81.1	1088	109.4	81.2	431	111.8	76.9	Rec. by J. Pietrak (TSC)
7/30/90		9:44am	98	78.0	72.1	-52	85.7	80.4	685	78.1	74.1	-42	83.4	77.0	Bolted Joint
7/30/90	87	11:14	242	101.2	86.7	-12	99.7	91.9	636	95.8	94.8	-28	102.4	95.1	Bolted Joint
7/31/90	72	8:40	0	80.1		-141	81.8		619	80.9		-149	81.2		Zero, Joint Unbolted
2/04/91	70	1:50	570	92.3	58.0	455	93.3	57.5	1115	90.6	60.8	351	89.8	59.8	
2/04/91	65	4:05	467	86.1	58.0	352	85.8	56.2	1008	84.6	61.2	287	85.0	58.8	
2/05/91	45	8:20	-81	43.4	48.3	-185	43.7	46.3	494	43.6	51.1	-280	44.1	52.0	
2/05/91	65	12:55	283	76.7	59.7	172	77.8	59.0	833	72.1	59.2	104	77.6	62.4	
2/05/91	69	2:30	367	80.0	57.9	266	82.1	57.6	929	79.7	61.1	205	81.0	59.7	
4/01/91	60	3:45	77												Rail Replaced
4/01/91	60	4:00	76												

RAIL STRAIN DATA FROM BLUEFIELD, WV															
NEW SECTION 3 (End Section)															
Date	Amb	Time	1	Neut	2	Neut	3	Neut	4	Neut					
	Temp		Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Strain	Temp	Temp	Comments
3/05/90		12:30	15	84.0	73.3	-19	76.3		511	77.5	58.1	1808	75.1	63.0	(x2.42), #1 Taken @ 1:30
3/06/90		11:00	-85	66.1	61.4	-324	66.0		353	67.0	57.1	1607	59.6	59.5	Old Ind. Box (x2.42)
3/06/90		2:30	261	96.5	71.0	-5	94.0		673	94.2	65.1	1965	92.0	70.4	Old Ind. Box (x2.42)
3/07/90		9:00	-477	45.2	64.1	-610	44.1		82	43.6	50.0	1297	43.8	62.4	Old Ind. Box (x2.42)
3/07/90		11:30	-133	64.6	62.8	-353	66.4		332	67.9	59.2	1638	68.1	66.2	Old Ind. Box (x2.42)
4/25/90	80	10:30	-32	92.4	84.5				442	94.2	78.9	1850	97.2	82.5	Wired Direct to Ind. Box
4/25/90	88	1:24	218	109.9	87.0				679	110.6	81.1	2138	112.0	80.0	Wired Direct to Ind. Box
6/06/90	74	10:10	48	90.4	77.7				462	90.6	74.1			96.5	Rec. by J. Pietrak (TSC)
6/06/90	84	11:40	214	106.1	83.4				674	109.8	80.6	2136	110.4	78.5	Rec. by J. Pietrak (TSC)
7/30/90		9:44am	-74	83.0	77.7				329	78.2	69.7	1742	84.9	76.7	
7/30/90	84	10:44	-163	95.2					188	83.5		1606	95.3		After Cut, Anchors Off
7/30/90	87	11:14	-88	103.3	98.8				272	97.3	92.3	1736	105.7	97.9	Bolted Joint
2/04/91	70	1:50	241	86.4	62.1				440	86.4	71.3	1854	84.3	69.4	
2/04/91	65	4:05	203	84.9	62.9				393	81.1	68.8	1807	81.7	69.6	
2/05/91	45	8:20	-334	42.9	53.2				-81	43.0	59.2	1283	42.7	62.1	
2/05/91	65	12:55	14	70.7	60.1				234	74.6	71.8	1661	71.3	68.0	
2/05/91	69	2:30	109	77.1	60.8				317	77.7	69.9	1750	77.8	69.1	
4/01/91	60	3:45										1503			Rail Replaced
4/01/91	60	4:00										1502			

Rail Movement		Section 1						Santa Fe											
Date	Amb Temp	Time	HR	W1 LR	W1 W	dW	HR	Wc LR	Wc W	dW	HR	W LR	W W	dW	HR	W4 LR	W4 W	dW	Comments
2/14/90	37	9:00	0.00	0.00	92.5	-1.0	0.00	0.00	89.5	-0.5	0.00	0.00	88.5	-1.4	0.00	0.00	88.5	-1.4	
4/02/90			-3.06	-2.75	91.5	-0.9	0.19	-0.94	89.0	-0.5	-1.31	-1.94	87.1	-1.5			87.0	-1.5	Before High Rail Cut
4/03/90		9:45			91.6	-0.9	-1.88		89.0	-0.3	-2.00		87.0	-1.5			87.0	-1.5	After High Rail Cut
4/04/90		9:30	1.63		91.6	-1.0	-1.75		89.3	-0.4	-2.06		87.0	-1.6			87.0	-1.6	
4/04/90		10:30	1.06		91.5	-3.0			89.1	-1.4			86.9	-1.6			87.0	-1.5	
6/27/90	60	5:40am			89.5	-3.2			88.1	-1.7			86.9	-1.6			86.9	-1.6	
6/27/90	65	6:40			89.3	-3.5			87.8	-1.4			87.1	-1.4			87.1	-1.4	
6/27/90	68	7:12			89.0	-3.2			88.1	-1.9			86.9	-1.6			86.9	-1.6	
6/27/90	84	8:25			89.3	-3.5			87.6	-1.2			87.1	-1.4			87.1	-1.4	
6/27/90	89	9:29			89.0	-3.5			88.3	-1.4			86.4	-2.1			86.4	-2.1	
6/27/90	92	10:33			89.0	-3.7			88.1	-1.4			87.1	-1.4			87.1	-1.4	
6/27/90	95	12:00			88.8	-3.5			88.1	-1.4			86.9	-1.6			86.9	-1.6	
6/27/90	98	1:00			89.0	-3.5			87.6	-1.9			86.4	-2.1			86.4	-2.1	
6/27/90	105	2:00			89.0	-3.0			88.5	-1.0			87.3	-1.3			87.3	-1.3	
6/27/90	95	2:55			89.0	-3.0			88.4	-1.1			87.0	-1.5			87.0	-1.5	
7/24/90		9:45			89.5	-3.1			88.4	-0.8			87.3	-1.3			87.3	-1.3	
7/24/90		11:10			89.4	-3.0			88.8	-1.0			87.5	-1.0			87.5	-1.0	
7/24/90		12:12			89.5	-2.8			88.5	-1.0			87.3	-1.2			87.3	-1.2	
7/24/90		1:09			89.5	-1.7			88.5	-1.0			87.3	-1.2			87.3	-1.2	
7/25/90		8:00am			89.8	-1.7			92.1	2.6			87.5	-1.0			87.5	-1.0	
1/29/91	32	9:40			90.8	-1.7			92.5	3.0			87.3	-1.2			87.3	-1.2	New Measurement Devic
1/29/91	38	1:40			90.8	-1.5			92.5	2.8			87.3	-1.2			87.3	-1.2	
1/30/91	39	9:00			91.0	-1.9			92.3	2.9			87.8	-0.7			87.8	-0.7	
1/30/91	52	1:00			90.6	-1.7			92.4	2.6			87.3	-1.2			87.3	-1.2	
1/30/91	52	3:05			90.8	-1.5			92.1	2.6			87.5	-1.0			87.5	-1.0	
4/03/91	89	9:50am			91.0	-1.5			92.6	3.1			87.5	-1.0			87.5	-1.0	
4/03/91	73	12:25			91.0	-1.6			92.6	3.1			87.3	-1.2			87.3	-1.2	
4/03/91	69	3:30			90.9	-1.7			92.6	3.0			87.3	-1.2			87.3	-1.2	
4/04/91	51	8:45am			90.8	-1.7			92.5	3.0			87.3	-1.2			87.3	-1.2	
4/04/91	74	1:25			90.8	-1.7			92.5	3.0			87.3	-1.2			87.3	-1.2	
5/22/91		9:55			90.5	-2.0			92.4	2.9			87.6	-0.9			87.6	-0.9	
5/22/91		12:00			90.8	-1.7			92.5	3.0			87.5	-1.0			87.5	-1.0	
5/22/91		3:50			90.5	-2.0			92.3	2.8			87.3	-1.2			87.3	-1.2	
7/16/91		10:40			90.8	-1.7			92.5	3.0			87.6	-0.9			87.6	-0.9	
7/16/91		1:00			90.8	-1.7			92.6	3.1			87.8	-0.7			87.8	-0.7	
7/17/91		9:30			90.9	-1.6			92.5	3.0			87.8	-0.7			87.8	-0.7	
7/17/91		12:30			90.5	-2.0			92.5	3.0			87.5	-1.0			87.5	-1.0	
8/15/91		9:15			90.5	-2.0			92.5	3.0			87.5	-1.0			87.5	-1.0	
8/15/91		1:30			90.6	-1.9			92.5	3.0			87.8	-0.7			87.8	-0.7	

Date	Amb Temp	Time	Section 2				Santa Fe				Wc LR	Wc LR	W	dW	HR	W4 LR	W4 LR	W	dW	Comments
			HR	LR	W1 LR	W1 LR	W	dW	HR	LR										
2/14/90	37	9:10	0.00	0.00	69.5	0.3	0.00	0.00	86.6	0.00	86.6	0.00	0.00	0.00	0.00	0.00	74.0	0.3		
4/02/90			0.63	0.31	69.8	0.3	-2.44	-1.84	86.3	-1.84	86.3	-1.84	-0.81	-0.47	-0.47	-0.47	74.3	0.3		
4/03/90		9:45			70.0	0.5			86.3		86.3						74.3	0.3		
4/03/90		1:00	1.63	0.81			-2.03	-1.63		-1.63		-1.38	-0.78	-0.78	-0.78	-0.78			Before High Rail Cut	
4/03/90		1:30	1.34	0.75			-2.25	-1.66		-1.66		-1.66	-0.94	-0.94	-0.94	-0.94			After High Rail Cut	
4/03/90		2:34	1.31	0.75			-2.34	-1.66		-1.66		-1.72	-0.91	-0.91	-0.91	-0.91			Before Low Rail Cut	
4/03/90		2:48	1.31	0.75			-2.31	-1.69		-1.69		-1.75	-0.91	-0.91	-0.91	-0.91			After Low Rail Cut	
6/27/90		5:40am			69.4	-0.1			85.9		85.9		-0.7				74.2	0.2		
6/27/90		6:40			69.8	0.3											74.4	0.4		
6/27/90		7:12			69.6	0.1			86.4		86.4		-0.2				74.4	0.4		
6/27/90		8:25			70.1	0.6			85.9		85.9		-0.7				74.4	0.4		
6/27/90		9:29																		
6/27/90		10:33			69.6	0.1			86.4		86.4		-0.2				74.4	0.4		
6/27/90		12:00			70.1	0.6			86.4		86.4		-0.2				74.4	0.4		
6/27/90		1:00			70.6	1.1			86.4		86.4		-0.2				74.4	0.4		
6/27/90		2:00			70.1	0.6			86.6		86.6		0.0				74.4	0.4		
6/27/90		2:55			69.8	0.3			86.4		86.4		-0.2				74.4	0.4		
7/24/90	81.3	9:45			69.3	-0.3			86.4		86.4		-0.2				74.4	0.4		
7/24/90	78	11:10			69.9	0.4			86.3		86.3		-0.3				74.4	0.4		
7/24/90	83	12:12			69.8	0.3			86.4		86.4		-0.2				74.3	0.3		
7/25/90	73	8:00am			69.8	0.3			86.5		86.5		-0.1				74.8	0.8		
1/29/91	32	9:40am			69.3	-0.2			86.0		86.0		-0.6				74.1	0.1		
1/29/91	38	1:40			69.3	-0.2			86.0		86.0		-0.6				74.4	0.4		
1/30/91	39	9:00am			69.3	-0.2			86.0		86.0		-0.6				74.5	0.5		
1/30/91	52	1:00			69.6	0.1			86.3		86.3		-0.3				74.8	0.8		
1/30/91	52	3:05			69.7	0.2			86.1		86.1		-0.5				74.9	0.9		
4/03/91	64.9	9:45am			69.8	0.3			86.4		86.4		-0.2				74.3	0.3		
4/03/91	73.3	12:25			69.8	0.3			86.4		86.4		-0.2				74.5	0.5		
4/03/91		3:30			69.8	0.3			86.3		86.3		-0.3				74.8	0.8		
4/04/91		8:45am			69.8	0.3			86.2		86.2		-0.4				74.8	0.8		
4/04/91		1:25			69.8	0.3			86.3		86.3		-0.3				74.8	0.8		
5/22/91		9:55			69.8	0.3			86.0		86.0		-0.6				74.5	0.5		
5/22/91		12:00			70.0	0.5			86.3		86.3		-0.3				74.8	0.8		
5/22/91		3:50			70.2	0.7			86.8		86.8		0.2				74.8	0.8		
7/16/91		10:40			70.0	0.5			86.3		86.3		-0.3				74.8	0.8		
7/16/91		1:00			70.0	0.5			86.4		86.4		-0.2				74.8	0.8		
7/17/91		9:30			70.0	0.5			86.1		86.1		-0.5				74.6	0.6		
7/17/91		12:30			69.9	0.4			86.5		86.5		-0.1				74.8	0.8		
8/15/91		9:15			69.9	0.4			86.4		86.4		-0.2				74.8	0.8		
8/15/91		1:30			69.9	0.4			86.6		86.6		0.0				74.6	0.6		

Section 3		Sante Fe		W1		Wc		W4		Comments	
Date	Amb Temp	Time	W	dW	W	dW	W	dW	W	dW	
2/14/90	38	9:20	103.5	0.0	125.0	0.0	96.0	0.0			
4/02/90			103.8	0.3	126.3	1.3	96.3	0.3			
4/03/90		9:45	103.5	0.0	124.8	-0.3	96.4	0.4			
7/24/90	81	9:45	103.8	0.3	125.3	0.3	96.5	0.5			
7/24/90	78	11:10	103.8	0.3	125.3	0.3	96.5	0.5			
7/24/90	83	12:12	103.8	0.3	125.3	0.3	96.5	0.5			
7/25/90	73	8:00am	103.8	0.3	125.5	0.5	96.8	0.8			
1/29/91	32	9:40	103.3	-0.2	124.8	-0.2	96.1	0.1			New Measurement Device
1/29/91	38	1:40	103.1	-0.4	125.1	0.1	96.4	0.4			
1/30/91	39	9:00	103.3	-0.2	125.0	0.0	96.1	0.1			
1/30/91	52	1:00	103.4	-0.1	125.4	0.4	95.9	-0.1			
1/30/91	52	3:05	103.4	-0.1	125.9	0.9	96.5	0.5			
4/03/91	89	9:50	103.8	0.3	125.3	0.3	96.1	0.1			
4/03/91	73	12:25	103.8	0.3	125.4	0.4	96.3	0.3			
4/03/91	69	3:30	103.8	0.3	125.5	0.5	96.3	0.3			
4/04/91	51	8:45	103.5	0.0	125.5	0.5	96.4	0.4			
4/04/91	74	1:25	103.4	-0.1	125.6	0.6	96.4	0.4			
5/22/92		9:55	103.2	-0.3	125.0	0.0	95.9	-0.1			
5/22/92		12:00	103.3	-0.2	125.2	0.2	96.0	0.0			
5/22/92		3:50	103.4	-0.1	125.3	0.3	96.4	0.4			
7/16/91		10:40	103.5	0.0	125.3	0.3	96.4	0.4			
7/16/91		1:00	103.5	0.0	125.3	0.3	96.4	0.4			
7/17/91		9:30	103.8	0.3	125.4	0.4	96.4	0.4			
7/17/91			103.6	0.1	125.2	0.2	96.4	0.4			
8/15/91		9:15	103.6	0.1	125.2	0.2	96.3	0.3			
8/15/91		1:30	103.8	0.3	125.4	0.4	96.4	0.4			

Rail Movement			Bluefield, WV							
TS1	Date	Amb Temp	Time	W1	dW	Wc	dW	W4	dW	Comments
	3/05/90		4:45	62.3		62.0		62.3		Reference Values
	3/06/90		4:00	61.2	-1.0	60.1	-1.9	60.1	-2.2	
	3/07/90		10:15	61.1	-1.2	60.1	-2.0	60.0	-2.3	
	4/23/90	79	11:40	61.0	-1.3	59.6	-2.4	60.5	-1.8	
	4/23/90	85	12:30							After Lining and Tamping
	4/23/90	85	12:30			60.3				Ref Peg Wc Moved
	4/23/90	88	12:40			61.9		62.3	0.0	Wc Peg Moved Again
	4/23/90	85	4:23	62.3	0.0	60.1		62.8	0.5	
	4/24/90	58	9:00	62.0	-0.3	59.3		62.0	-0.3	
	4/24/90	65	9:15			59.1				New Wc Ref Point
	4/24/90	80	10:50			59.1	0.0			After Both Rails Cut
	4/24/90	90	2:20	62.0	-0.3	59.5	0.4	62.1	-0.1	After Welding, Anchors On
	4/25/90	68	9:45	61.8	-0.5	59.0	-0.1	61.6	-0.6	Wc Peg Questionable
	6/06/90	72	9:30	61.5	-0.8	58.5	-0.6	61.5	-0.8	Rec. by J. Pietrak (TSC)
	6/06/90	92	2:45	62.0	-0.3	57.8	-1.4	61.8	-0.5	Rec. by J. Pietrak (TSC)
	6/06/90	89	3:40	62.0	-0.3	57.9	-1.3	62.0	-0.3	Rec. by J. Pietrak (TSC)
	6/06/90	90	4:30	62.0	-0.3	57.9	-1.3	61.8	-0.5	Rec. by J. Pietrak (TSC)
	7/30/90	96	12:15	62.0	-0.3	59.0	-0.1	62.5	0.3	Wc Reference Peg Bent
	2/04/91	67	3:00	61.6	-0.6	58.0	-1.1	62.5	0.3	New Measurement Device
	2/05/91	48	9:00	61.4	-0.9	58.3	-0.8	62.9	0.6	
	2/05/91	66	1:20	62.0	-0.3	59.0	-0.1	62.9	0.6	

Rail Movement			Bluefield, WV								
NEW TS2	Amb	Time	W	dW	W	dW	W	dW	W	dW	Comments
Date	Temp										
3/05/90		4:45	52.3		60.5		65.0		65.0		Reference Values
3/06/90		3:45	51.4	-0.9	59.5	-1.0	64.3	-0.7	64.3	-0.7	
3/07/90		10:30	51.2	-1.1	59.3	-1.2	63.9	-1.1	63.9	-1.1	
4/23/90	79	11:06			59.3	-1.3					During STPT's
4/23/90	86	3:49	50.6	-1.6	59.8	-0.8	64.4	-0.6	64.4	-0.6	After STPT's
4/23/90	85	4:42	50.6	-1.6	60.0	-0.5	64.5	-0.5	64.5	-0.5	
4/24/90	56	8:30	50.0	-2.3	59.6	-0.9	64.3	-0.8	64.3	-0.8	
4/24/90	88	12:50					64.3	-0.8	64.3	-0.8	New Top Points, Pre-Cuts
4/24/90	87	1:35									After Cuts
4/24/90	85	4:25	49.4	-2.9	59.5	-1.0	64.5	-0.5	64.5	-0.5	After Weld, Anchors On
4/25/90	67	9:45	49.9	-2.4	59.4	-1.1	64.0	-1.0	64.0	-1.0	
6/06/90	72	9:15	49.8	-2.5	59.3	-1.3	64.0	-1.0	64.0	-1.0	Rec. by J. Pietrak (TSC)
6/06/90	92	2:45	50.1	-2.1	59.5	-1.0	64.3	-0.8	64.3	-0.8	Rec. by J. Pietrak (TSC)
6/06/90	89	3:40	50.0	-2.3	59.5	-1.0	64.3	-0.8	64.3	-0.8	Rec. by J. Pietrak (TSC)
6/06/90	90	4:30	50.0	-2.3	59.5	-1.0	64.5	-0.5	64.5	-0.5	Rec. by J. Pietrak (TSC)
7/30/90	96	12:15	51.0	-1.3	59.5	-1.0	64.3	-0.8	64.3	-0.8	
7/31/90	92	1:41	51.0	-1.3	59.1	-1.4	64.0	-1.0	64.0	-1.0	Wc reference pin bent
7/31/90	67	3:00	50.8	-1.5	59.3	-1.2	64.1	-0.9	64.1	-0.9	New Measurement Device
2/05/91	48	9:00	50.9	-1.4	59.0	-1.5	63.8	-1.2	63.8	-1.2	
2/05/91	66	1:20	51.0	-1.3	59.4	-1.1	63.9	-1.1	63.9	-1.1	

NEW SECTION 3		(End Section)							
Date	Amb Temp	Time	W	dW	W	dW	W	dW	Comments
3/05/90		4:45	64.8		65.8		89.3		Reference Values
3/06/90		9:30	63.5	-1.3	64.3	-1.5	89.3	0.0	
3/06/90		3:15	63.6	-1.2	64.7	-1.1	89.6	0.4	
3/07/90		10:45	63.5	-1.3	64.3	-1.5	88.4	-0.8	
4/25/90	80	10:30	63.4	-1.4	64.6	-1.1	88.5	-0.8	
4/25/90	87	2:38	63.5	-1.3	64.9	-0.9	88.6	-0.6	
6/06/90	72	9:30	63.4	-1.4	64.5	-1.3	88.4	-0.8	
6/06/90	92	2:45	63.8	-1.0	64.8	-1.0	88.5	-0.8	
6/06/90	89	3:40	63.8	-1.0	64.8	-1.0	88.5	-0.8	
6/06/90	90	4:30	63.8	-1.0	64.8	-1.0	88.8	-0.5	
7/31/90	92	1:41	63.5	-1.3	64.8	-1.0	87.8	-1.5	
2/04/91	67	3:00	63.3	-1.5	65.1	-0.7	88.4	-0.8	New Measurement Device
2/05/91	48	9:00	63.6	-1.2	64.9	-0.8	88.1	-1.2	
2/05/91	66	1:20	63.8	-1.0	65.1	-0.7	87.9	-1.3	



APPENDIX B
Example STPT Plots



Allen De-graph, Incorporated
 2 Hook Road
 Saco, New Hampshire 03079
FOSTER MILLER INC 1005907

PRINTED
 IN
 U.S.A.

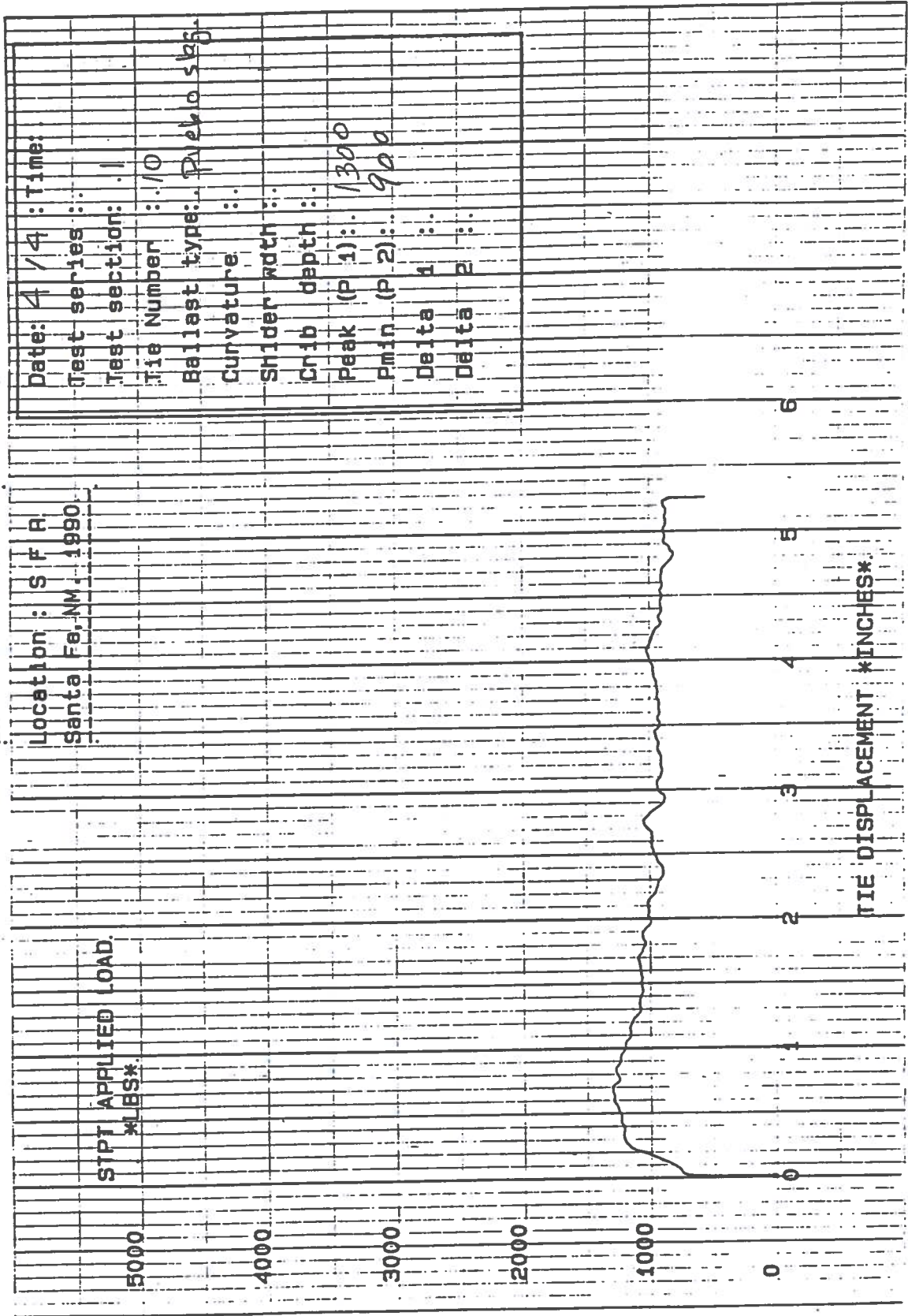
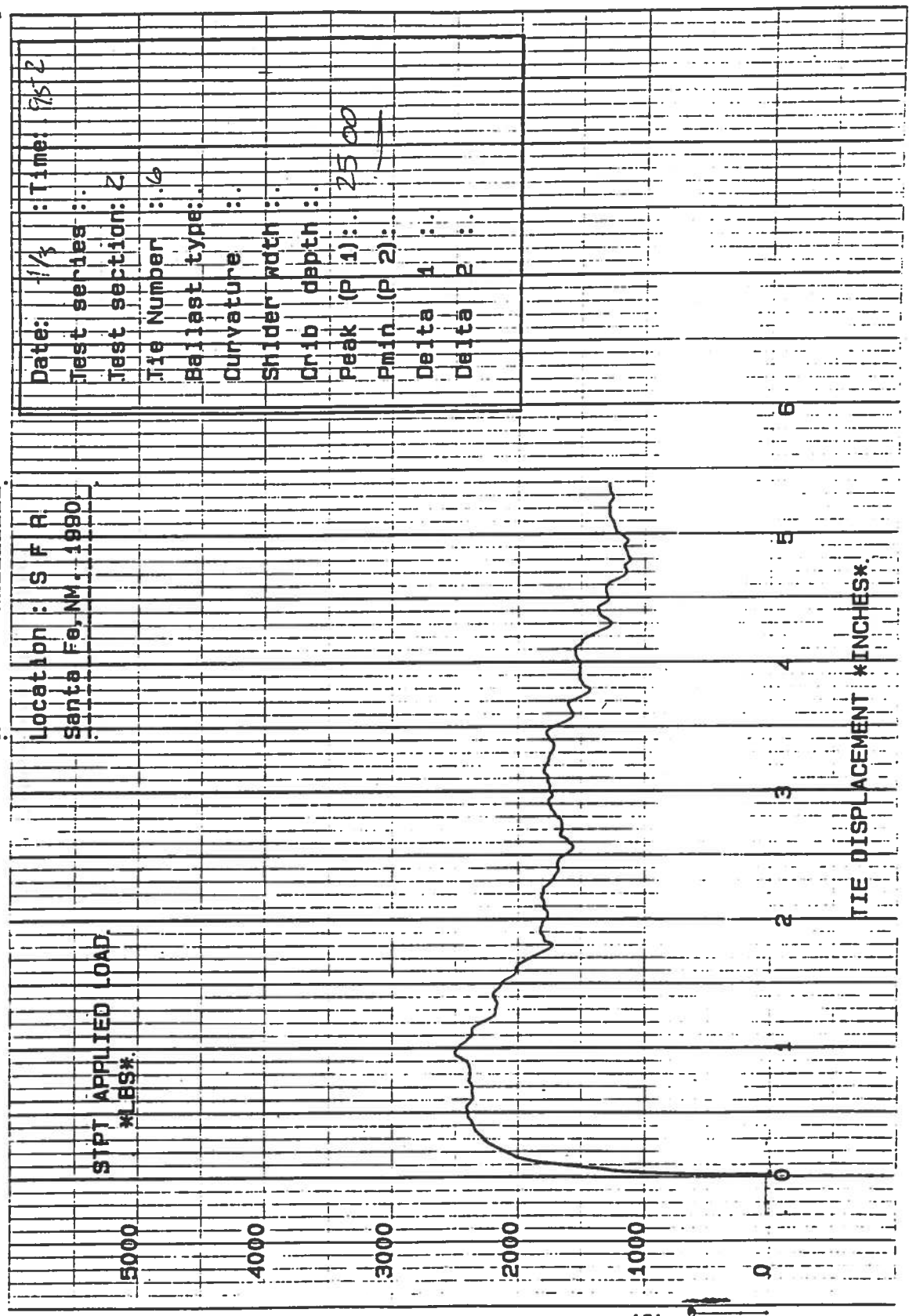


Figure B-1. Typical Low Resistance STPT



Allen-Diagraph, Incorporated
 2 Industrial Way
 Salem, New Hampshire 03079
FOSTER MILLER INC 0059007

11-19-80
 LIMITED
 IN
 U.S.A.



Date:	1/3	Time:	9:52
Test series:			
Test section:	Z		
Tie Number:	6		
Ballast type:			
Curvature:			
Slider width:			
Crib depth:			
Peak (P 1):	2500		
Pmin (P 2):			
Delta 1:			
Delta 2:			

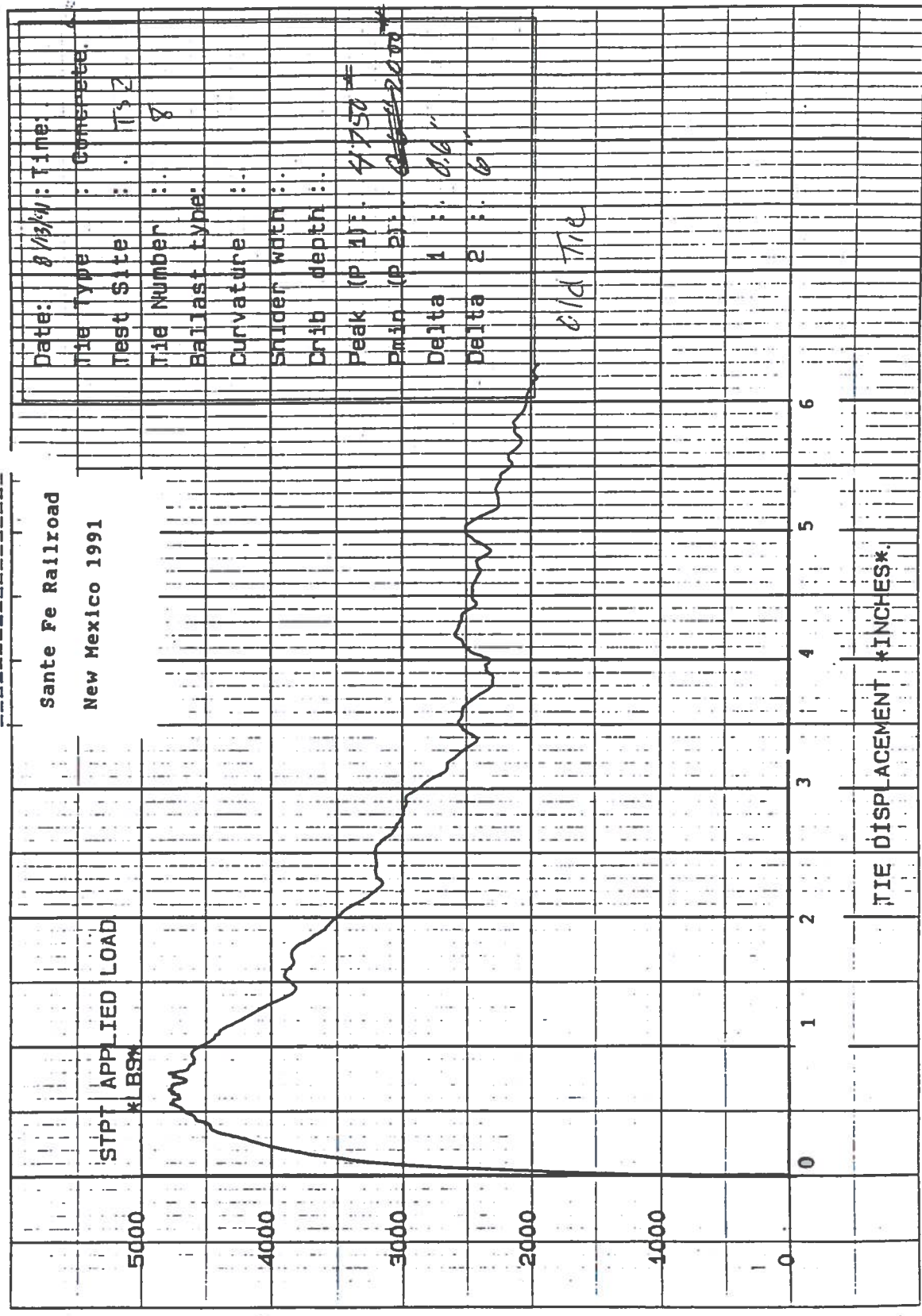
Location: S F R.
 Santa Fe, NM, 1990

Figure B-2. Typical Average Resistance STPT

11 Ties 2 → 1

FOSIER MILLER INC.

Sante Fe Railroad
New Mexico 1991



Date:	8/15/91	Time:	Concrete
Tie Type:		Test Site:	Ts 2
Tie Number:	8		
Ballast type:			
Curvature:			
Slider width:			
Crib depth:			
Peak (P 1):	4750		
Peak (P 2):	4750		
Delta 1:	0.6		
Delta 2:	0.6		

Old Tie

Figure B-2. Typical High Resistance STPT

APPENDIX C
Site Photographs: Santa Fe, NM

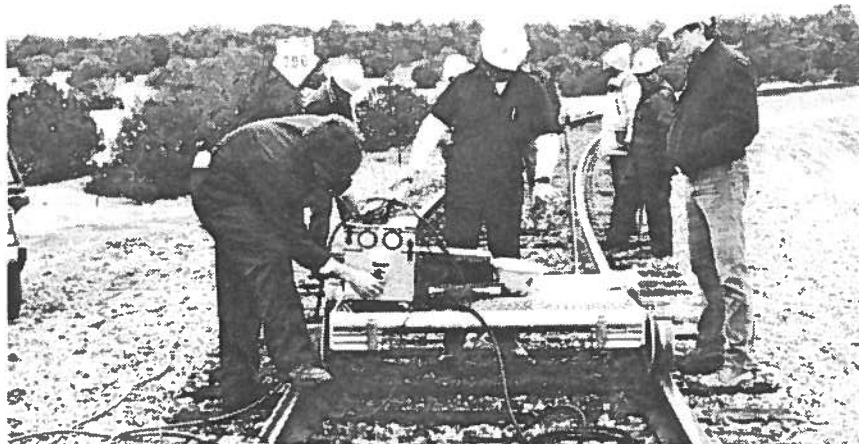


Figure C-1. STPT Operation

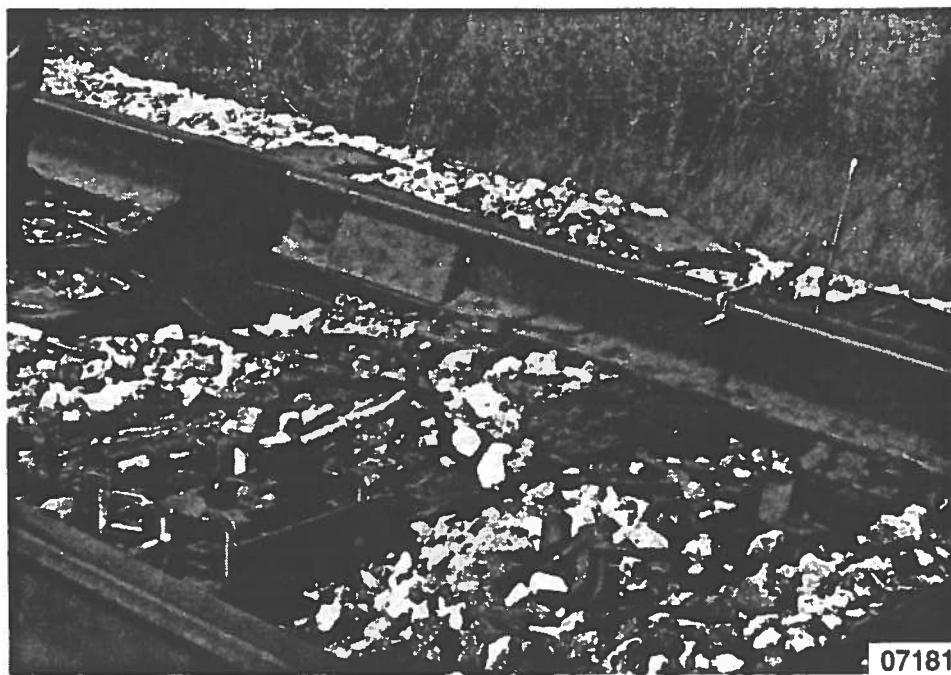


Figure C-2. STPT Device

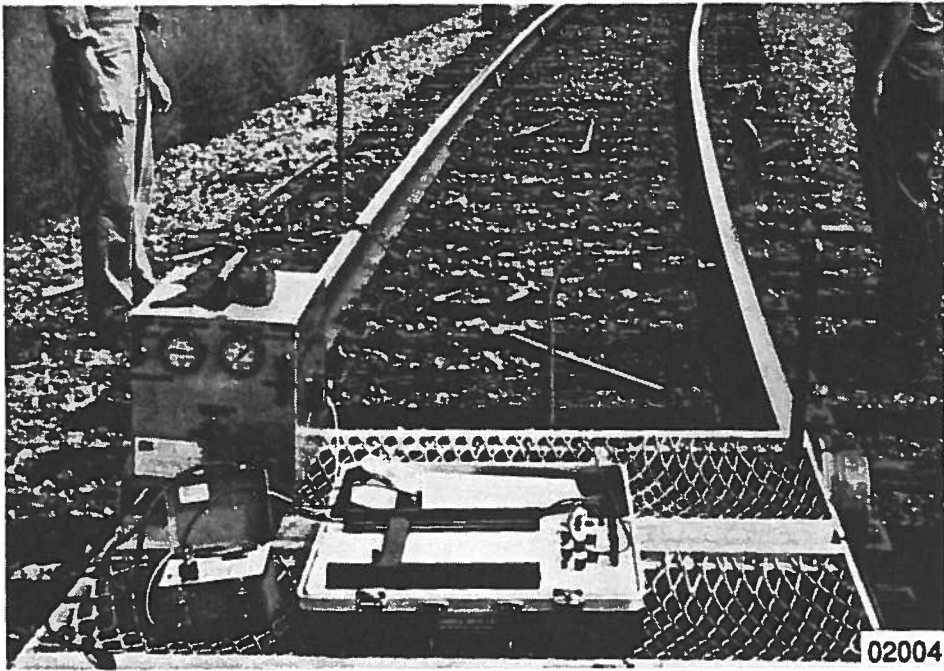


Figure C-3. STPT Data Acquisition



Figure C-4. STPT Deflection Measurement



Figure C-5. Strain Gauge Data Acquisition



Figure C-6. Tamping in TSI



Figure C-7. Cutting the Low Rail in TS3



Figure C-8. Welding the High Rail in TS1

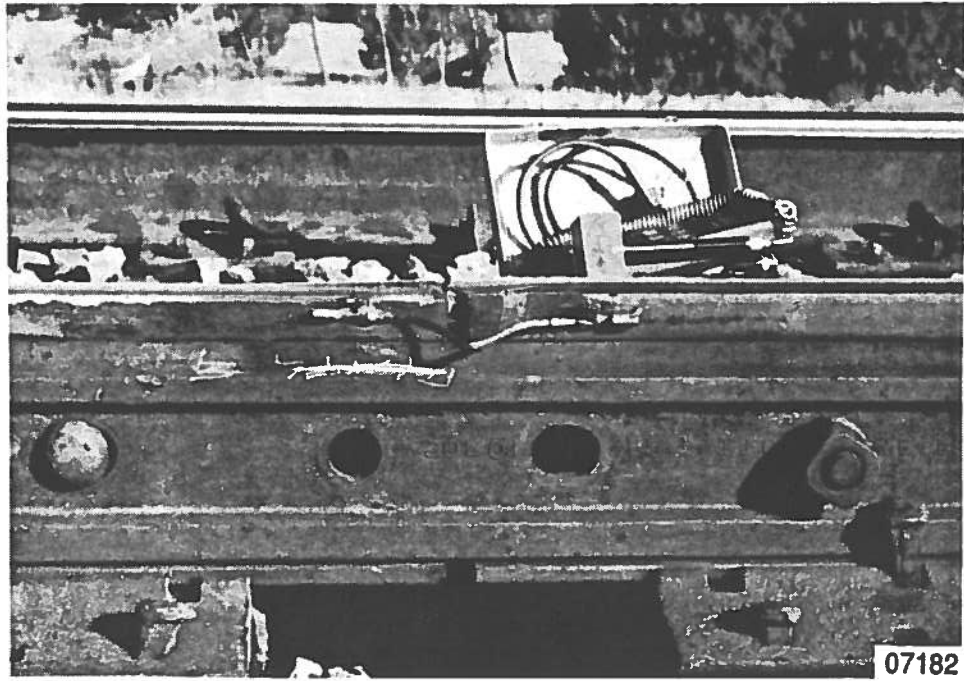


Figure C-9. Open Gap at Bolted Rail Joint

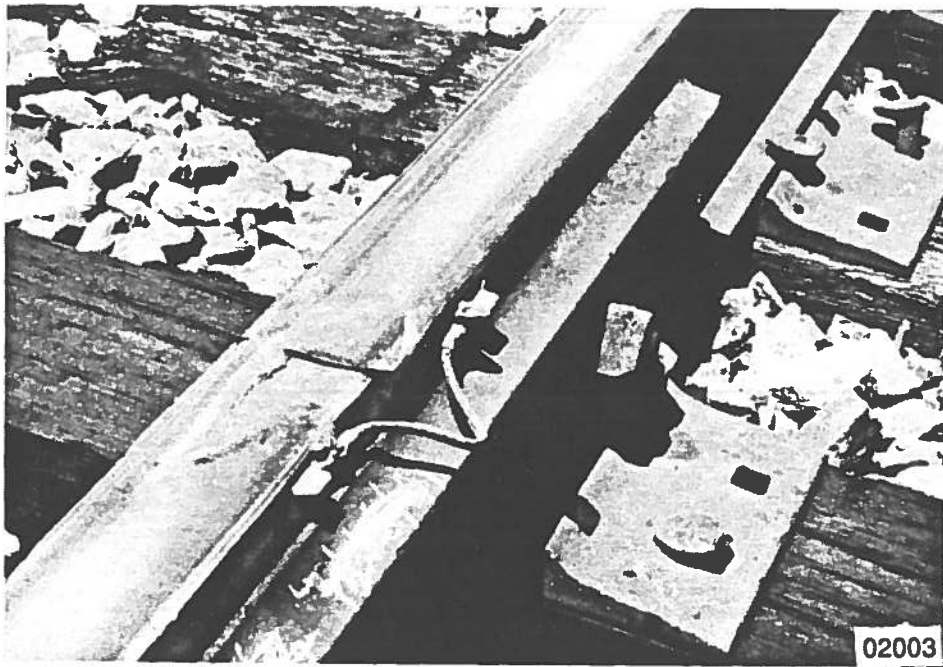


Figure C-10. Closed Gap at Bolted Rail Joint

APPENDIX D
Site Photographs: Bluefield, WV



Figure D-1. Rough Grinding of Rail for Strain Gauge Application



Figure D-2. Fine Grinding of Rail for Strain Gauge Application



Figure D-3. Welding of Strain Gauge to Rail Neutral Axis

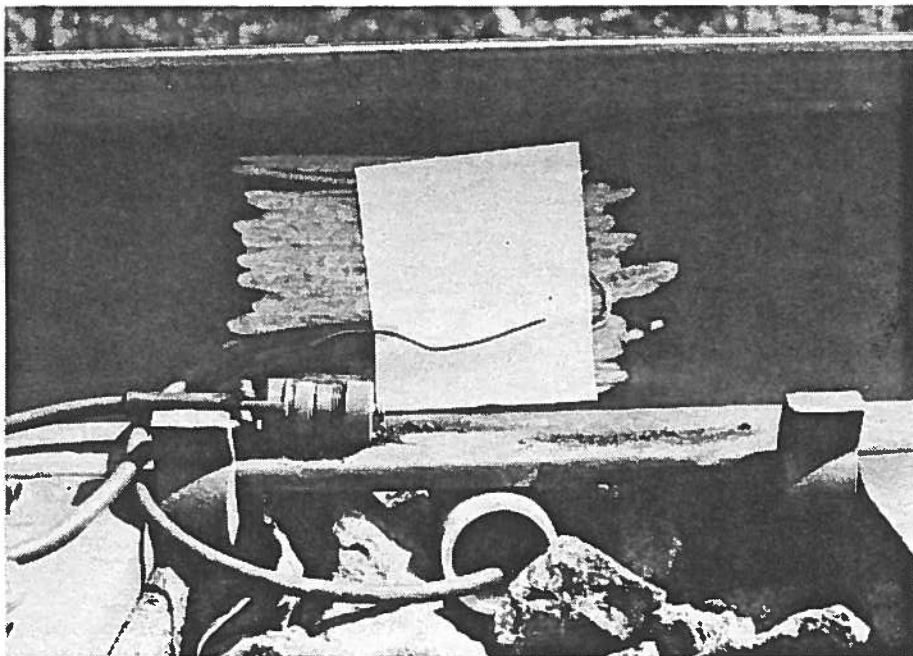


Figure D-4. Strain Gauge after Application and Weatherproofing

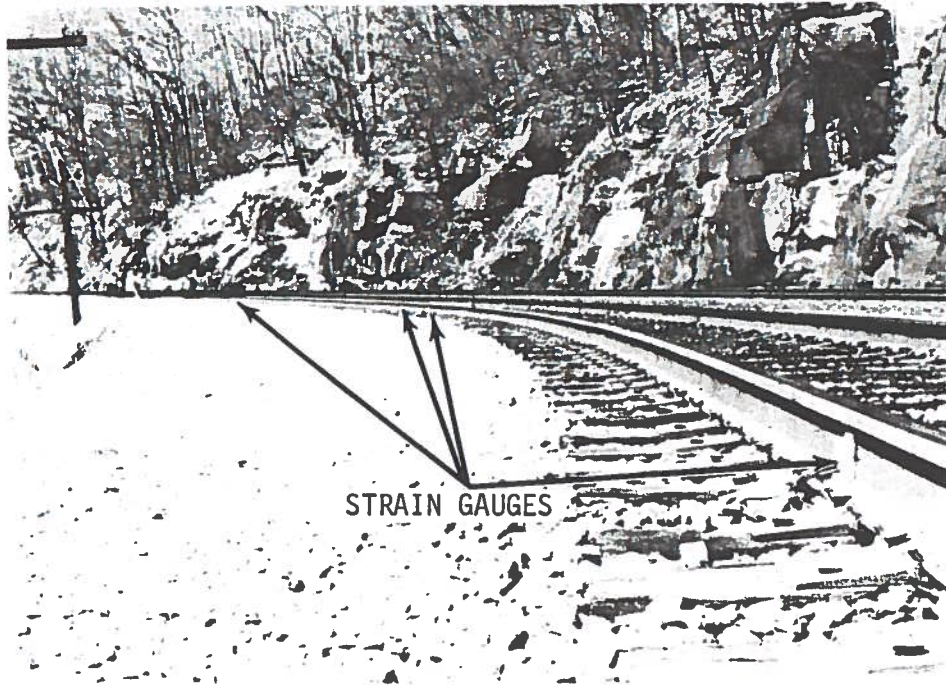


Figure D-5. Test Section 2 in Bluefield, WV

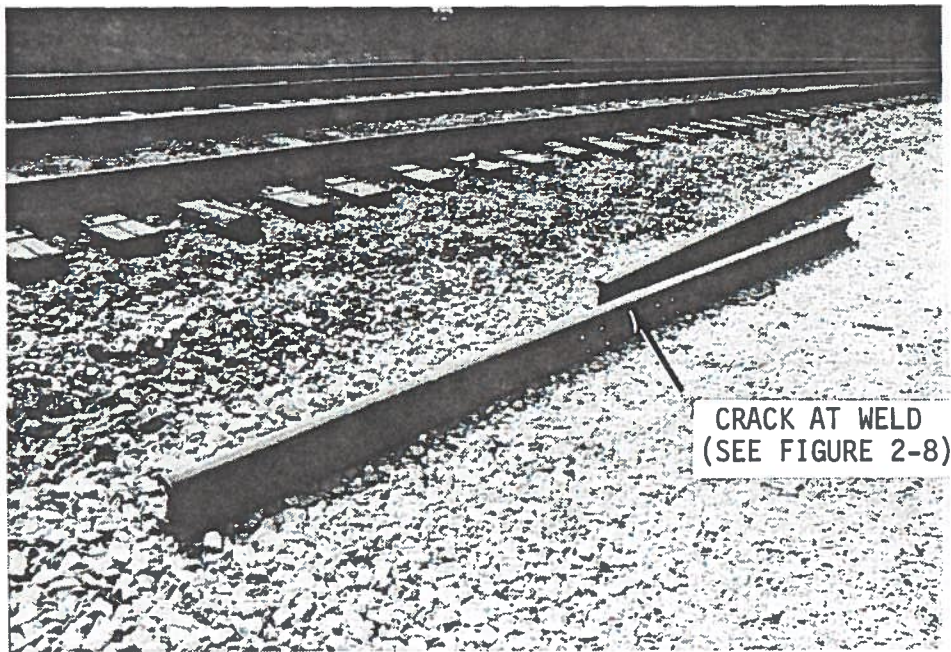


Figure D-6. Rail Sections Removed from Test Section 3

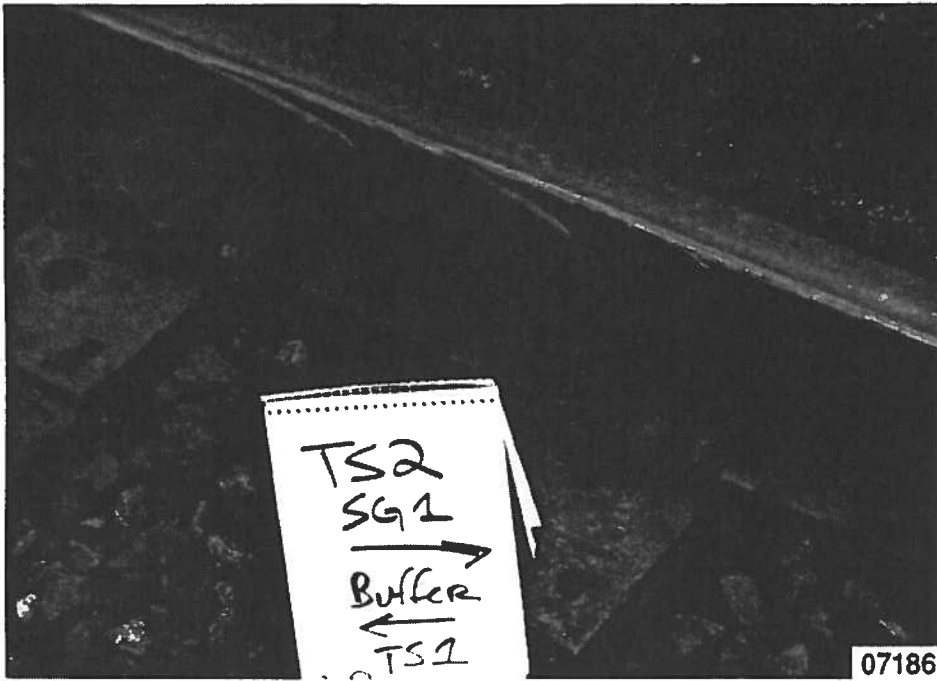


Figure D-7. Rail Wear Before Replacement

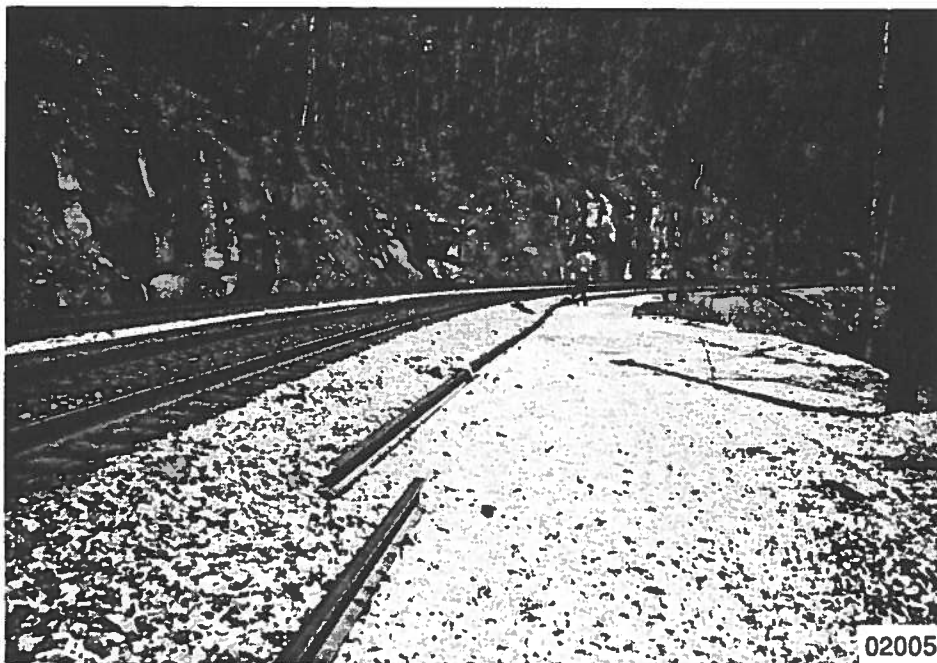


Figure D-8. Rail Sections Removed from Test Sections 1 and 2

