CONCRETE AND WOOD TIE PERFORMANCE THROUGH 425 MGT

FAST Facility for Accelerated Service Testing

TRANSPORTATION TEST CENTER
PUEBLO, COLORADO 81001

PREPARED FOR
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16. Abstract

This study is the third in a series which has reviewed the performance of concrete and wood tie track at the Facility for Accelerated Service Testing (FAST). It presents an evaluation of both types of track through 425 million gross tons (MGT) of service in the FAST Track at the Transportation Test Center (TTC), Pueblo, Colorado. The discussion covers two general interests:

a. Comparative performance of concrete and wood tie track, including maintenance requirements, geometric stability, track stiffness, and rail wear.

b. Specific performance of concrete ties, components and ballast at FAST and in revenue service, examined for resistance to wear and failure.

The purpose of this study is to present interim data related to the technical and economic feasibility of concrete tie use in U.S. mainline service. The critical issue of concrete tie life is addressed only indirectly; Therefore, performance assumptions necessary to justify the installation of concrete ties are neither verified nor refuted. Problems in design and application identified in earlier reports are discussed, and some trends are discernable in light of the accumulated data.

17. Key Words Ballast Clip fall-out Clip load Concrete ties Insulator Lateral restraint Pad hardness Rail fasteners Tie bending moment Tie pad Wood ties	18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161

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PREFACE

This study is the third in a series which has reviewed the performance of concrete and wood tie track at the Facility for Accelerated Service Testing (FAST). Each study covers a different interval of FAST train operations, measured in terms of accumulated tonnage in MGT (million gross tons). The first report was completed after 50 MGT (FRA/ORD-77/29), the second after 150 MGT (FRA/TTC-80/02), and this third report after 425 MGT. A final report will cover the completion of current train operations at about 800 MGT.

Battelle-Columbus Laboratories conducted this evaluation for the Office of Rail Safety Research of the Federal Railroad Administration (FRA) under Contract No. DOT-FR-9162. Other tasks of the contract require support of FAST studies of track safety, instrumentation and tests of concrete ties, evaluation of a FAST steel tie experiment, and a study of improved performance requirements for concrete and wood tie fasteners.

Mr. Howard Moody of the FRA was the Contracting Officer's Technical Representative (COTR) and is also the experiment manager for the general tie and fastener experiment program at FAST. Dr. Andrew Kish of the Transportation Systems Center was the original COTR and a principal author of the statement of work. Mr. John Weber provided inspections of ties and pads and compiled records of fastener problems. Data analysis for the track performance evaluation was performed by the FAST organization at the Transportation Test Center. The contributions of these people are greatly appreciated.

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ACRONYMS

AAR	Association of American Railroads
AREA	American Railway Engineering Association
CN	Canadian National Railway
CO	clamp-on
COTR	Contracting Officer's Technical Representative
CWR	continously welded rail
FAST	Facility for Accelerated Service Testing
FEC	Florida East Coast Railway
FRA	Federal Railroad Administration
HH	head hardened rail
HiSi	high silicon rail
IF	inside-rail, field position
IG	inside-rail, gage position
MGT	million gross tons
NEC	Northeast Corridor
OF	outside-rail, field position
OG	outside-rail, gage position
Std	standard carbon rail
TTC	Transportation Test Center

ABBREVIATIONS AND METRIC CONVERSIONS

°	degree	
', ft	foot	= 0.305 m
Hz	hertz	
", in	inch	= 2.54 cm
kip	kilopound	= 453.59 kg
MGT	million gross tons	= 0.907 MGMg
mi	mile	= 1.609 km
mi/h	miles per hour	
%	percent	
lb	pound	= 0.454 kg

EXECUTIVE SUMMARY

Concrete and wood tie track sections at the Facility for Accelerated Service Testing (FAST) have been evaluated using data collected from September 1976 to July 1979, during which 425 million gross tons (MGT) of service load were accumulated by the FAST test train. As part of the FAST effort to identify structural characteristics that improve track performance, the study evaluates selected track segments and components in terms of maintenance demands, geometric stability, strength, resistance to dislocation, damage, and wear of components. Qualified comparisons are drawn between concrete and wood tie track segments of the same curvature, although the segments differ in track grade, ballast quality, and train handling conditions. The differences between FAST and recent major installations in revenue service are also discussed.

The most significant results of the performance review are:

- The 5° curve and 2% grade of concrete tie track in Section 17 required high rates of surface and line maintenance, tie repositioning, and replacement of fastener clips due to clip fall-out and fracture. Rail anchors were installed at the bottom of the grade to alleviate the tie movement problem. Much of this maintenance can be attributed to two factors: (1) the combination of a 5° curve with a 2% grade, and (2) the fine particle size and physical characteristics of the ballast in the concrete tie section.

- The 5° curves of wood tie track (Sections 03 and 07) required high rates of maintenance to maintain gage and to repair defects in rails and rail welds. Complete tie replacement was specified for experiment purposes in Section 07. However, the wood ties were adversely affected by the failure of some of the special wood tie fasteners in Section 07, by the failures of field welds joining rail metallurgy strings in Section 03, and by rail replacements.

- Until the rebuild at 425 MGT, total rail replacement requirements in the 5° curves, expressed as multiples of section length, were:

Section	Tie Type	Rail Replacement
17	Concrete	1.35
07	Wood	1.5
03	Wood	2.3

It is believed by some observers that rail wear was unusually sensitive to the state of lubrication at FAST. Much of the rail replacement in the wood tie sections was caused by rail defects created by plastic flow and bad welds, rather than by gage face wear. Much of the replacement in Section 03 was due to the need to redesign the rail metallurgy test strings, and initiate the second rail metallurgy experiment.

- The concrete ties developed no rail seat flexural cracks during the 425 MGT service period. This type of crack has often caused failure of earlier designs. Laboratory bending strength tests conducted on used ties from the 5° curve and on unused ties from the same production runs showed that the ties have retained their original bending strength.

- Although the FAST test train produces high average loads, the lack of wheel flats eliminates the low-probability, high-impact loads found in all U.S. revenue service track. Measurements in revenue service test segments have shown that the highest levels of tie bending moment are produced by either track anomalies or wheel flats.

The major conclusions of the study are:

- The results at FAST through the first 425 MGT neither verify nor refute the performance assumptions that are necessary to justify the installation of concrete ties in U.S. revenue service track.

- The lack of directly comparable test segments of concrete and wood tie track at FAST has prevented direct comparisons of the performance of concrete and wood tie track. This comparison will be achieved by the planned "Phase IIb" test segments in track Section 03, which are scheduled for installation in the summer of 1981.

- The critical issue of concrete tie life cannot be addressed adequately at FAST until dynamic loads equivalent to those produced by wheel flats in revenue service are reproduced in FAST operations.

1.0 INTRODUCTION

A major purpose of the Facility for Accelerated Service Testing (FAST) is to provide a test track where potential improvements to the economics and safety of North American railway track can be evaluated under accelerated conditions which simulate revenue service.[1] For readers not familiar with FAST, appendix A presents a brief description of the physical facilities and the track and vehicle experiment programs. A wide variety of vehicle and track performance experiments have been carried out since FAST began operations in September 1976. One of the principal experiments has involved the continuous measurement of a number of performance indicators for a variety of prestressed concrete ties and fastener components located on a 6000-foot section of the FAST track loop. This report reviews the results of this experiment from the beginning of operations until July 1979, when the test track had accumulated 425 million gross tons (MGT) of service loading. Operations were suspended at that time to permit rebuild of several track sections and the installation of some new experiments. For the purposes of establishing an approximate "baseline" performance, several sections of wood tie track are also included in the evaluation. The review ends with a discussion of the major differences between the FAST concrete tie test environment and that found in recent revenue service installations.

This report represents a continuation of earlier studies[1] [2] which evaluated concrete and wood tie track performance through 50 and 150 MGT, respectively. A final evaluation will be prepared at the end of operations with 100-ton cars, at about 800 MGT. The latter two studies have been guided by an analysis plan and request for data reductions[3] which was submitted to the FAST data analysis group at the Transportation Test Center (TTC). Much of the data reduction was done by this group at TTC.

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[1] Kish, A., et. al., "Track Structures Performance--Comparative Analysis of Specific Systems and Component Performance", Report No. FRA/ORD/77/29, June 1977.

[2] Dean, F.E., and Prause, R.H., Concrete and Wood Tie Track Performance through 150 Million Gross Tons, Report No. FRA/TTC-80/02, prepared by Battelle-Columbus Laboratories for U.S. Department of Transportation, Transportation Systems Center, Contract DOT-TSC-1044, December 1978.

[3] Dean, F.E. and Ahlbeck, D.R., "Data Request and Plan for Evaluation of Track Performance at the Facility for Accelerated Service Testing, 150-650 MGT", prepared by Battelle-Columbus Laboratories for U.S. Department of Transportation, Transportation Systems Center, Contract No. DOT-TSC-1652, May 1979.

2.0 TEST SEGMENTS AND PERFORMANCE MEASUREMENTS

The major sections of this report present performance evaluations of: (a) concrete and wood tie track systems, and (b) concrete tie and fastener components. The segments of concrete and wood tie track selected for evaluation are shown in Figure 2-1, and additional physical characteristics of the segments are summarized in Table 2-1.

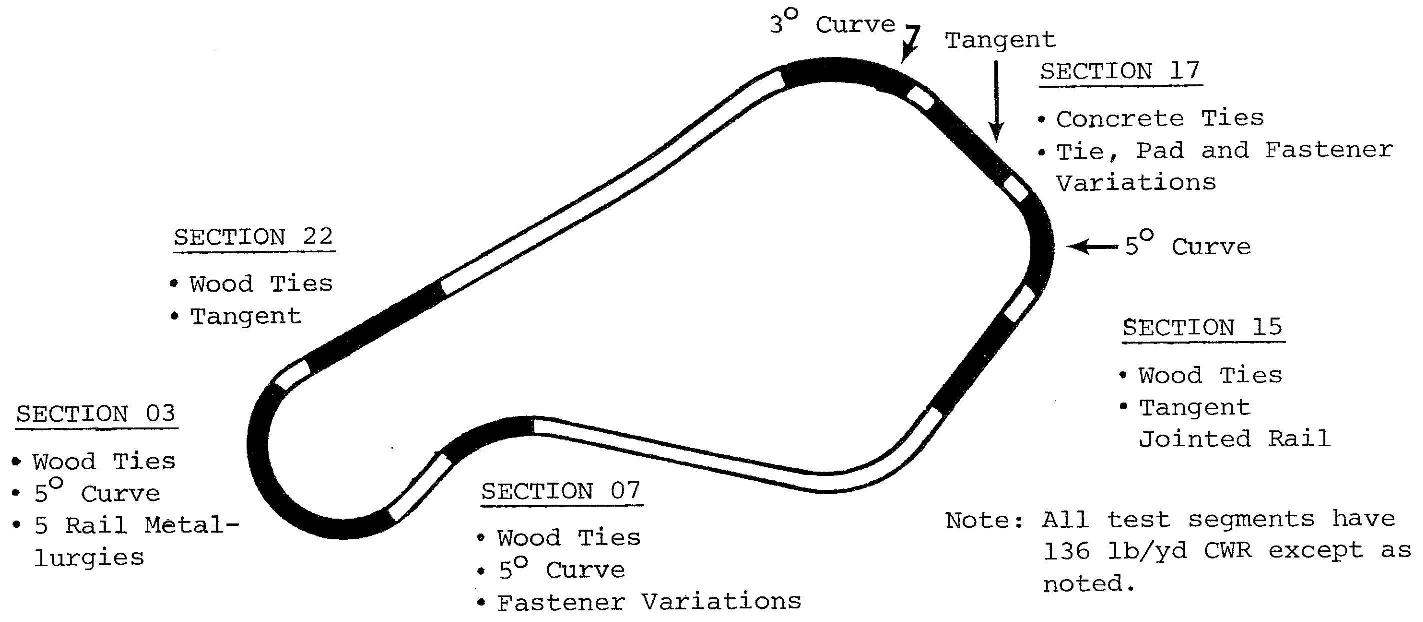
For the period of this study, which is prior to the rebuild at 425 MGT, Section 17 contained all of the concrete ties installed in the FAST track. This section, 6,128' in length, contained 2,886 concrete ties with a wood tie transition at each end. Track contours consisted of a 5° curve with 2% grade and 4" superelevation, a 3° curve with 2" superelevation, a mid-section tangent, and connecting spirals. The section is illustrated in Figure 2-2.

Track Sections 03 and 07 are wood tie segments built on 5° curves with 4" superelevation. While Section 07 has no significant grade, Section 03 has a grade of -0.9% (for counterclockwise travel around the track loop) which extends over about half the section. During the first 425 MGT, Section 03 was dedicated to the study of the relative wear characteristics of different rail metallurgies, and many difficulties in maintenance of welded joints in the first 135 MGT resulted from this experiment. Section 07 was dedicated to the study of wood tie fasteners. An extraordinary rate of rail wear in this section was attributed to lubricator problems early in the program. Where performance data were affected by the presence of other experiments or operations problems, they have been excluded from this evaluation.

The performance histories of concrete and wood tie track systems are compared on the basis of maintenance records, rates of track geometry degradation and horizontal track stiffness. The stiffness measurements on wood tie track were taken in transition spiral subsection 17-L_W and in the bolted-joint, tangent, wood tie Section 15, which was also used to compare the effect on lateral stiffness of variations in ballast shoulder width. Wheel/rail load measurements taken in Sections 07 and 17 define the general loading environment of the track in relation to those of several typical revenue service tracks in the U.S.

The seventeen subsections of Section 17 were constructed with six different types of concrete ties, eight types of pads and four types of rail fasteners. Table 2-2 identifies the locations of ties, pads and fasteners by manufacturers' code numbers. The characteristics of many of these components are discussed in Section 5 of this report.

Component performance is examined in terms of the rates of clip fall-out and of the required replacements of pads, clips and insulators due to damage or fracture. Pad hardness is presented in comparison to the hardnesses of identical pads kept in a storage area, and is displayed in a manner to permit comparisons of hardness against the rates of clip fall-out and fracture. The results of an inspection of concrete ties, conducted after their removal from the track at 425 MGT, are summarized. Concrete tie bending moments are



SYSTEM PERFORMANCE MEASUREMENTS

- Maintenance
- Track Geometry
- Track Stiffness

COMPONENT PERFORMANCE MEASUREMENTS

- Tie Flaws
- Tie Bending Moment
- Fastener Failure and Fall-out
- Pad replacement, Hardness
- Tie Movement, Positioning
- Ballast Gradation

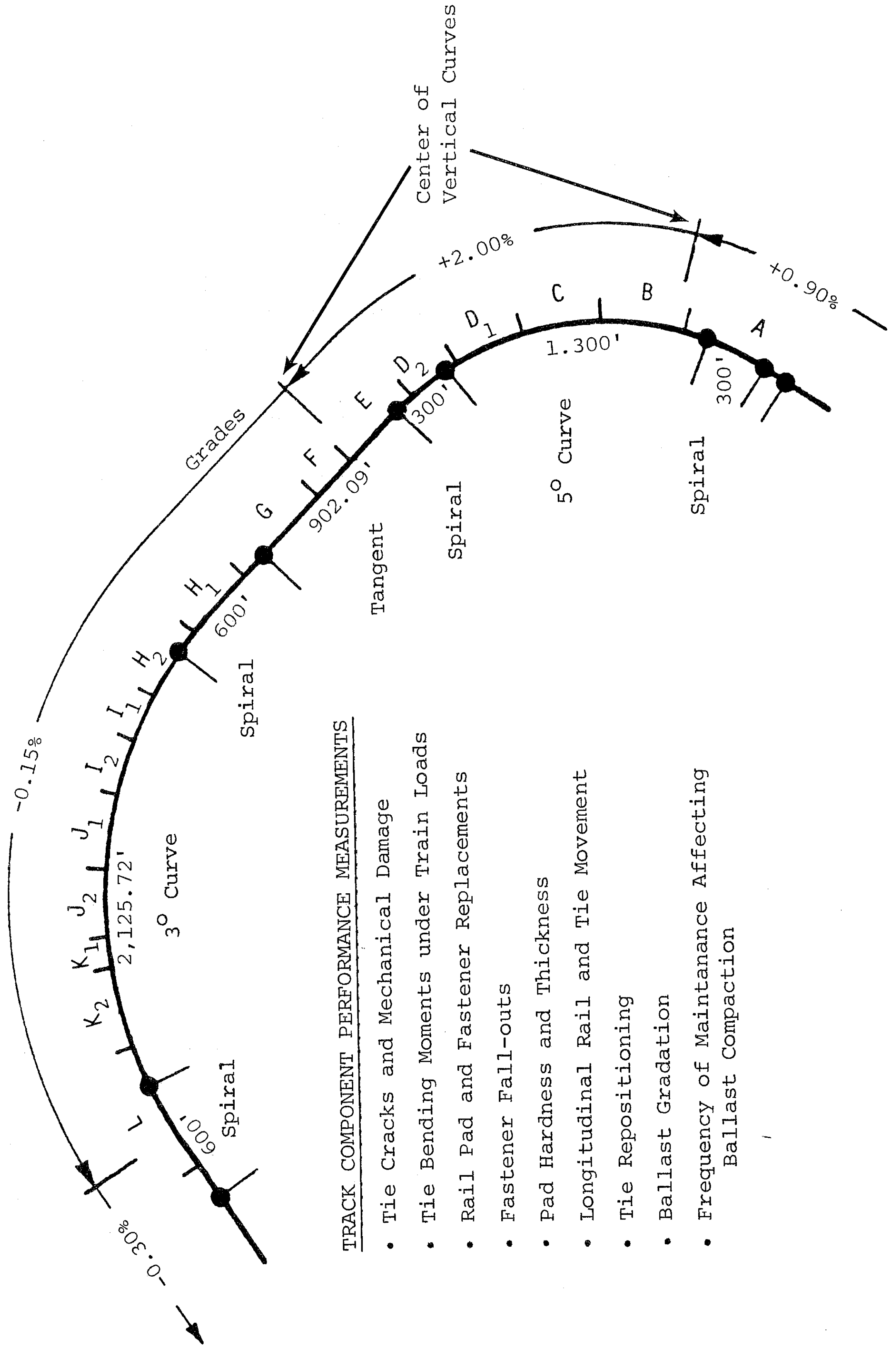
FIGURE 2-1. PRIMARY TEST SEGMENTS FOR TRACK PERFORMANCE EVALUATION.

TABLE 2-1. PROPERTIES OF TEST SEGMENTS FOR COMPARATIVE EVALUATION OF CONCRETE AND WOOD TIE TRACK.

Sub-sections	Length (ft)	Contour	Super-elevation (Curves)	Grade % Counter-clockwise	Rail Type lb/yd	Ballast Type	Ballast Depth	Ballast Shoulder	Tie Type	Tie Spacing (in)	Construction History
3A	374	5° Curve	4"	500' Vertical Curve (VC) Between -0.34 and -0.90	136 CWR	Slag	15"	18"	Wood	19.5	Existing Embankment
7A-E	1,000	5° Curve	4"	+0.07	136* CWR	Slag	15"	12"	Wood	19.5	Existing Roadbed Some New Ballast at 135 MGT
15A	550	Tangent	-	1500' VC Between 0.00 and 0.90	136 BJR	Slag	15"	6"	Wood	19.5	Existing Track
15B	550	Tangent	-	1500' VC 0.00 and 0.90	136 BJR	Slag	15"	18"	Wood	19.5	Existing Track
17B-C	648	5° Curve	4"	+2.00 1/2 (1,000' VC Between +2.00 and -0.15	136	Granite	15"	12"	Concrete	24.0	New Track
17F-G	702	Tangent	-	(-0.15)**	136 CWR	Granite	15"	12"	Concrete	24.0	New Track
$17I_1$-K_2	1,726	3° Curve	2"	-0.15	136 CWR	Granite	15"	12"	Concrete	24.0	New Track
22B-D	906	Tangent	-	-0.05	136 CWR	Slag	15"	12"	Wood	19.5	Existing Track

NOTE: CWR = Continuous Welded Rail
BJR = Bolted Jointed Rail

*At 135 MGT replaced with 140 lb/yd rail
**See figure 2-2 for details



TRACK COMPONENT PERFORMANCE MEASUREMENTS

- Tie Cracks and Mechanical Damage
- Tie Bending Moments under Train Loads
- Rail Pad and Fastener Replacements
- Fastener Fall-outs
- Pad Hardness and Thickness
- Longitudinal Rail and Tie Movement
- Tie Repositioning
- Ballast Gradation
- Frequency of Maintanance Affecting Ballast Compaction

FIGURE 2-2. LAYOUT OF CONCRETE TIE SECTION 17.

TABLE 2-2. LAYOUT OF TIES, PADS, AND FASTENERS IN CONCRETE TIE SECTION 17.

Subsection	Tie Number	Tie Type	Pad Type	Fastener Type
A_w	0001-0069	Wood		
A	0070-0229	T-1	P-1A	F-1
	0230-0329		P-1B	
B	0330-0425	T-2	P-1B	F-1
	0426-0488		P-1A	
C	0489-0650	T-1	P-2***	F-1
D_1	0651-0808	T-2	P-2***	F-1
D_2	0809-0909	T-2	P-2***	F-2*
E	0910-1107	T-1	P-3	F-1
F	1108-1206	T-3	P-4	F-3
G	1207-1458	T-4	P-2	F-1
H_1	1459-1633	T-5	P-5	F-4
H_2	1634-1804	T-5	P-5	F-1
I_1	1805-1872	T-4	P-1C	F-1
	1873-1927		P-1D	
I_2	1928-2054	T-4	P-6	F-1
J_1	2055-2251	T-1	P-6	F-1
J_2	2252-2411	T-1	P-7	F-1
K_1	2412-2478	T-2	P-7	F-1
K_2	2479-2655	T-2	P-2	F-1
L	2656-2955	T-6	P-8	F-1**
L_w	2956-3079	Wood		

* Same as F-1 but without insulator
** Fastener slightly different from other F-1 fasteners
*** Most pads were changed to Type P-5 at 235 MGT

presented and compared to the strength requirements of the American Railway Engineering Association (AREA).

Characteristics of the various FAST ballasts are also discussed. Many observers have pointed out that certain physical characteristics of the concrete tie ballast (rounded edges, elongated shape, lack of large particles) may have contributed to a lack of interlocking and thus to some of the performance problems encountered in the 5° curve and 2% grade.

3.0 MAINTENANCE HISTORY

Maintenance on both concrete and wood tie track was performed as scheduled or required. Significant track maintenance events are described here briefly as a prelude to later discussion of each component.

CONCRETE TIE TRACK

Most of the maintenance for the concrete tie track of Section 17 was performed in the 5° curve and 2% grade. The major work items were:

- Frequent surfacing and lining began at 48 MGT and culminated in a lateral track buckle in three locations at 61 MGT. The track was rebuilt at 61 MGT, a preventive berm was constructed, and all fastener clips were replaced because of damage from a ballast regulator.

- Rail was ground to eliminate corrugations (73-75 MGT) and transposed (83 MGT).

- A rapid increase in the number of clip fall-outs and fractures began at 100 MGT, mostly at the inner rail, gage side (IG) position.

- Rails were ground a second time (148 MGT), rail anchors were installed at the bottom of the grade (175-179 MGT), and 1,200 ft of high rail was replaced to correct a shelling condition (179-210 MGT).

- A partial rebuild at 235 MGT included replacement of most clips, pads and insulators and replacement of standard rail with high silicon (HiSi) rail on the inside and head hardened (HH) rail on the outside.

- Very high rates of clip fall-outs occurred shortly after the rebuild. Clips were driven by an additional 1/4". Clip fall-outs and fractures continued through the remainder of the test period, to 425 MGT.

WOOD TIE TRACK

- Section 07. Most problems in this section were caused by gage widening, rail wear and failures of special wood tie fastener components. The rail was transposed and regaged at 32 MGT. The low rail was replaced and regaged at 83 MGT due to plastic flow, and both rails were replaced at 135 MGT with 140-pound, fully heat-treated rail. Screw spikes originally installed at 135 MGT and rearranged at 270 MGT began to fail rapidly between 270 and 276 MGT, when they were replaced. Between 250 and 358 MGT, significant numbers of tie plates and screw spikes (used with elastic clips) fractured. At 358 MGT, all ties were replaced to permit installation of new wood tie fastener test segments.

- Section 03. Excessive rail wear caused by inadequate lubrication was corrected at about 40 MGT. Frequent joint welding and grinding was required by the failure of many field welds between 30 and 80 MGT.

At 135 MGT, all rail was replaced with new rail metallurgy test strings in longer lengths. Spot tie replacements totalling 12 percent were required between 266 and 303 MGT. Most of these were required by damage from an earlier derailment. At 385 MGT, 15 percent of the rail was replaced due to shelling, head splitting, and cracked field welds.

4.0 PERFORMANCE OF CONCRETE AND WOOD TIE TRACK SYSTEMS

INTRODUCTION

The available indicators of track system performance at FAST include the maintenance records, track geometry data, limited measurements of track strength, and the observations of those who have worked with the track since the beginning of operations. These sources have been used to compile performance summaries for selected segments of concrete and wood tie track. While the summaries illustrate the major problems that have occurred in the track structures to date, they should not, in most cases, be used to compare the effectiveness of the different track systems because the segments have too many dissimilarities in track support, grade and operating conditions.

MAINTENANCE REQUIREMENTS

Major Requirements of Concrete and Wood Tie Track

Summaries of major events requiring maintenance in the 5° curves of concrete and wood tie track are provided in Tables 4-1 and 4-2. Both types of track required significant maintenance in the following areas:

- Fasteners. Concrete tie fasteners required high rates of component replacements due to clip fall-out and fracture and damage to pads and insulators. Wood tie track required regaging, some gage bar installation, spot replacements of spike-killed ties, and replacements of nonconventional fastener components (clips, tie plates used with clips, screw spikes). Tie repositioning and spot tamping were frequently required on both types of track to correct tie skewing. Prevention of skew is a fastener/anchor function.

- Rail. Transposition, grinding to correct corrugations, and rail replacements were required on both types of track. The wood tie Section 03 required frequent weld repairs and spot rail replacements due to the unsatisfactory rail welds produced by the different rail metallurgy test segments. Extremely high rail wear occurred early in the program in wood tie Section 07. This was attributed to a lack of adequate lubrication. The rapid development of corrugations in Section 03 was partially caused by poor welds.

- Surface and alignment. This was especially evident in the 5° curve and 2% grade of the concrete tie Section 17. Many observers believe the problems were aggravated by the use of a finer graded ballast material in Section 17 than in most other track sections and by the grade (2%) in this section.

Frequencies of Specific Maintenance Operations

Table 4-3 summarizes the cumulative amounts of specific maintenance operations required in several sections of concrete and wood tie track over the

TABLE 4-1. SUMMARY OF IMPORTANT MAINTENANCE EVENTS IN THE 5° CURVE OF CONCRETE TIE SECTION 17.

MGT	Description
0-61	No major fastening problems. Severe corrugations developed. Ballast flow from the tie cribs and off the embankment shoulder necessitated frequent surfacing and lining maintenance, beginning at 48 MGT. An unusual increase in longitudinal tie movement and rail creep began at 54 MGT, culminating in a lateral track buckle in three locations at 61 MGT. Buckle was attributed to ballast condition, rail corrugation and train braking action at an elevated rail temperature.
61	Track was rebuilt to remove buckles, and a berm was constructed as a preventive measure. Because many of the Type F-1 clips were damaged by the ballast regulator, all clips in the 5° curve were replaced by new clips from England.
73-75	Rail was ground to eliminate corrugations.
83	Rail was transposed. Type F-1 clips were color coded to assure replacement at original locations.
100	Rapid increase in numbers of clip fall-outs and fractures began, mostly in subsections C, D_1 and D_2 where Type P-2 corded rubber pads were located. Most of these events occurred at the inside gage (IG) location.
148	Rails were ground to remove corrugations (second grinding).
175-179	Rail anchors were installed on every tie in subsection A and on every other tie in subsection B, to reduce tie skewing.
179-210	1,200 ft of high rail in the 5° curve was replaced with high-silicon rail to correct shelling condition.
235	The 5° curve was partially rebuilt. Rail and fastener component replacements included: ● 94 percent of the Type F-1 clips, which were replaced with new clips manufactured in Canada. Old clips were retained in two 25-tie segments of subsection D_1. ● 88 percent of the Type P-2 corded rubber pads, which were replaced with Type P-5 polyurethane pads. Old pads were retained in two 25-tie segments of subsection D_1.

TABLE 4-1. SUMMARY OF IMPORTANT MAINTENANCE EVENTS IN THE 5° CURVE OF CONCRETE TIE SECTION 17 (CONTINUED).

MGT	Description
	● 100 percent of the external insulators (does not include subsection D_2). ● Both rails, were replaced with HiSi type on the inside rail and HH type on the outside rail. Rail anchors were removed, ties were repositioned, and anchors were replaced in subsections A and B.
235 +	High rates of clip fall-outs, almost exclusively at the IG position, occurred in the first few days after installation. All clips were driven by an additional 1/4" according to the manufacturer's recommendations.
260-425	High rates of clip fall-outs and fractures continued, mostly in subsections C, D_1, and D_2, with much lower rates in subsections A and B. Most of these events occurred at the IG position.

TABLE 4-2. SUMMARY OF IMPORTANT MAINTENANCE EVENTS IN 5° CURVES OF WOOD TIE TRACK (SECTIONS 03 AND 07).

MGT	Description
	Section 07
21-32	Frequent spot regaging was caused by high rate of rail wear.
32	Rail was transposed.
52-85	Rail was replaced in spots (5.9 percent of inside rail, 1.3 percent of outside rail).
82	10 gage bars were applied in a region overlapping two fastener test segments: (1) elastic clip fasteners with lock spikes, (2) cut spikes (line) and screw spikes (holddown).
83	Low rail was replaced with rail from the bypass track.
135	New, 140 lb, fully heat-treated rail replaced the standard 136 lb rail. Wood tie fastener test segments were rearranged using mostly old components but some introduced for the first time.
240-358	Significant numbers of fractures occurred in tie plates used with elastic clip fasteners.
270-275	Rapid growth in fracture of screw spikes installed at 135 MGT resulted in termination of the test.
281	10 gage bars were applied in a test segment of elastic clips and screw spikes.
358	All ties were replaced to permit installation of new wood tie fastener test segments.
	Section 03
30-80	Frequent joint welding and grinding was necessitated by failure of many field welds, and replacements of standard rail were required in high wear locations due to underlubrication.
81-84	Rail was ground to remove corrugations.
135	All rail was replaced with new rail metallurgy test strings in longer lengths.
266-393	Spot tie replacements totalled 12 percent.
385	15 percent of rail was replaced due to shelling, head defects and field weld problems.

TABLE 4-3. FREQUENCY OF SPECIFIC MAINTENANCE OPERATIONS.

(Cumulative Length Worked/Test Segment Length)
(Rebuild at 425 MGT is not included.)

	5° Curved Track			3° Curve	Tangent Track		
					(1)	(2)	(3)
	Concrete Ties	Wood Ties			Concrete Ties	Wood Ties	
	Section 17	Section 03	Section 07	Section 17		Section 15	Section 22
1. Surface, Line & Tamp							
a. Complete S/L/T	3.2	2.7	1.0	1.9	2.0	0	0
b. Out-of-face Tamping	7.4	5.2	0	1.9	4.0	3.1	.9
c. Out-of-face Lining	1.9	.2	2.0	0	.1	0	0
d. Spot Lining or Tamping	6.1	1.6	.5	.6	1.7	.4	.1
2. Regaging	0	.4	2.6	0	0	.05	0
3. Tie Work							
a. Tie Replacements	.00	.20	1.03	.00	.02	.01	.01
b. Tie Repositioning	1.6	1.05	0	.3	.3	.3	0
4. Ballast Work							
a. Add Ballast	5.4	3.5	1.5	3.1	4.8	1.1	.7
b. Reshape Shoulder	12.8	8.2	3.6	7.3	7.1	0	1.0
5. Rail Work							
a. Spot Replacements							
- Inside Rail	.00	.33	.06	.01	.05	.03	0
- Outside Rail	.69	.67	.01	.02	.03	0	.01
b. General Replacements							
- Inside Rail	1.0	1.8	2.0	.52	.11	0	0
- Outside Rail	1.0	1.8	1.0	.88	.12	0	0
c. Transpose Rail	1.0	0	1.0	.5	.1	0	0
d. Grind Rail	1.5	1.4	1.0	1.0	0	0	0

NOTES: (1) Maintenance of the tangent portion of Section 17 includes some spillover from work in the adjacent 5° curve.
(2) Section 15 has bolted joints. All other segments have welded joints.
(3) Data for Section 22 excludes maintenance of grade crossing and switch. The segment examined is from Ties 100 to 1,100.

entire measurement period of 425 MGT. For each activity, the cumulative track length worked has been divided by test segment length to provide a common index for work intensity. The table shows that:

- Very high levels of surface, line and tamping maintenance, as well as the associated addition and regulation of ballast, were required in the 5° curve of Section 17. Lesser but significant amounts of the same work were required in the wood tie Section 03, while very little work of this type was required in wood tie Section 07. There are several possible reasons for these differences:
  - The quality of the ballast, which had a distinctly finer gradation and poorer physical characteristics (angularity, sphericity) in Section 17 than in the other test segments.
  - The lower longitudinal restraint produced by the elastic clip fasteners in Section 17 as compared to the rail anchors of Sections 13 and 17. Most of the work in Section 17 was performed before the installation of rail anchors.
  - The track grade: 2% in Section 17, 0.9% over the north half of Section 03, and essentially zero in Section 07.
- Significant numbers of tie replacements were required in the curves using wood ties, while very few were required in the concrete tie track. Twenty percent of the wood ties in Section 03 were replaced on a spot basis. Many of these had been battered by train loads at faulty welds connecting metallurgy strings, and others were damaged by a derailment. Section 07 required a complete tie replacement at 358 MGT plus three percent spot replacements for experiment integrity. Problems with the nonconventional wood tie fasteners in this section (broken screw spikes, broken tie plates for elastic fasteners) contributed to some of the tie failures.

Concrete tie replacement rates were negligible throughout Section 17. Two ties were replaced in the 5° curve, 4 in the subsection of previously used ties from the Kansas Test Track, and 5 in the 3° curve or its spirals. All replacements were required by damage inflicted during installation or maintenance, rather than by train loads.

- Tie repositioning was a frequent spot maintenance activity in the curves of Sections 17 and 03, but not in the curve of Section 07. Frequency of repositioning was in direct proportion to track grade.
- Spot replacements of concrete ties (2 in the 5° curve, 4 in the subsection of previously used ties from the Kansas Test Track, 5 in the 3° curve) were required by damage done during maintenance rather than by train loads.
- Rail replacements in the 5° curves (average of inside and outside rails) totalled 1.35 times the section length in Section 17, 2.3 times in Section 03 and 1.5 times in Section 07. The high rate of rail replacement in Section 03 was partially caused by the difficulties in welding the joints between strings of different metallurgies. It has been observed that rail wear at FAST is highly sensitive to the state of lubrication. The differences in track grade may have affected the results. For these reasons, the data cannot be used as an indicator of the relative effects of concrete and wood tie track. Future experiments will place concrete and wood ties in the same 5° curve to permit such comparisons on similar grade, ballast support, and state of lubrication.

TRACK GEOMETRY

A track geometry car traverses the FAST track after each night of train operations and after each day of maintenance which affected geometry. Early problems were encountered with two measurement cars. However, a fully operational measurement system has been available since 80 MGT, at which point the records summarized in Figures 4-1 and 4-2 begin. The figures show the levels of gage, alignment, profile and crosslevel which were exceeded by 5 percent of the measurements taken in selected sections of concrete and wood tie track on 5° curves and tangents.

The figures also show the FRA Track Safety Standards measurement limits for Classes 4 through 6 track and the FAST "maintenance demand" limits, FAST 03 and FAST 05. These limits are summarized as follows:

Allowable Track Geometry Error

(in)

	FRA 4	FRA 5	FRA 6	FAST 03	FAST 05
Gage					
Curve	1	1	0.5	1.25	0.625
Tangent	0.75	0.5	0.375	0.75	0.625
Alignment					
Curve	1.5	0.625	0.375	1	0.375
Tangent	1.5	0.75	0.5	1	0.375
Crosslevel	1.25	1	0.5	1	0.5
Profile	2	1.25	0.5	0.75	0.375

Figures 4-1 and 4-2 show that with respect to alignment, crosslevel and profile, the track is maintained within the limits for FRA Class 6 track, although the 45 mi/h maximum track speed would require maintenance only to Class 4 levels. Only the gage variation on curved track displays any progression toward limits requiring maintenance. On wood tie track, this gage widening results from spike yielding in the ties and from rail wear. Gage widening on concrete ties results almost entirely from rail wear, but some compression of the insulator lip between the rail base and the fastener shoulder is also possible.

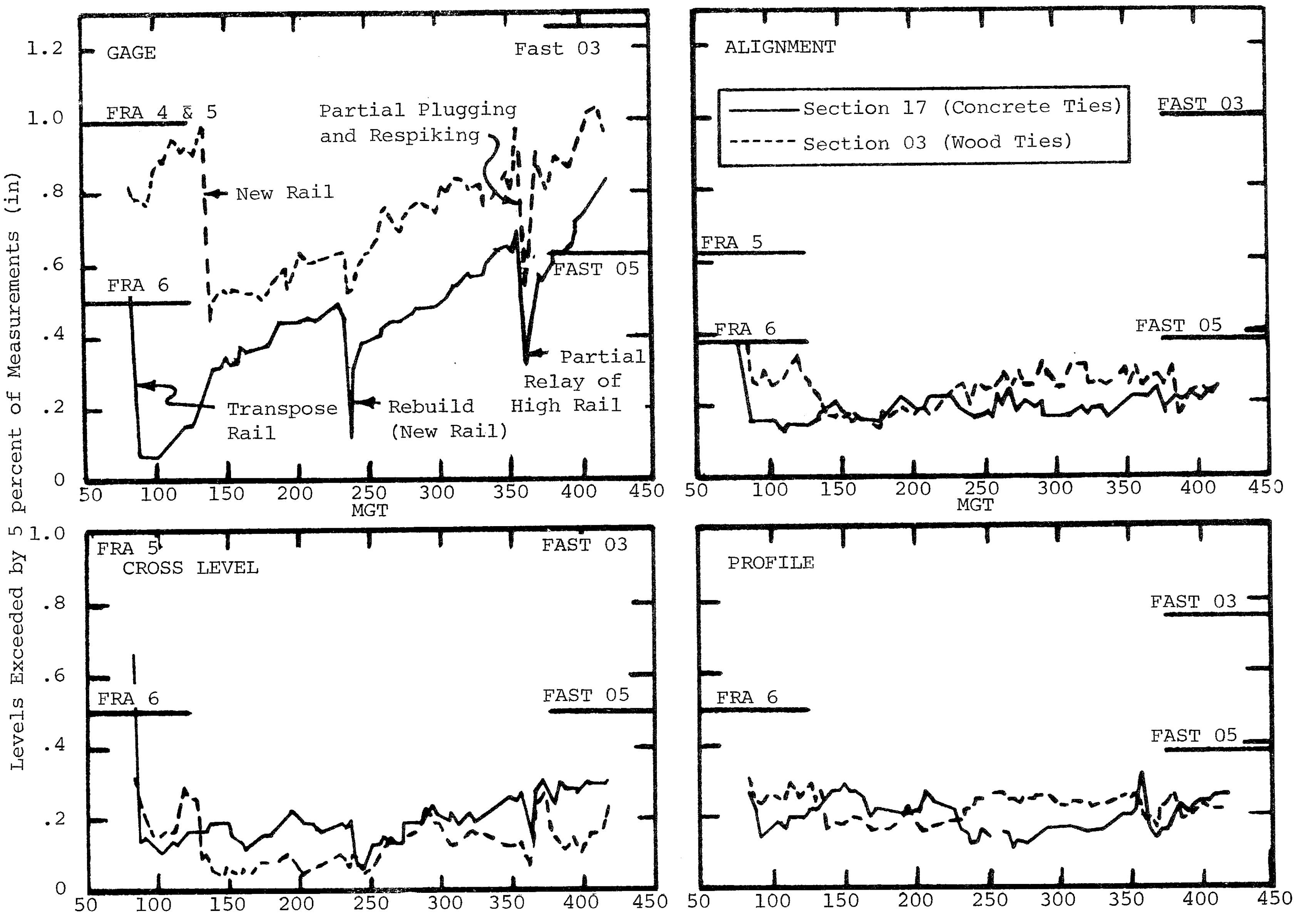


FIGURE 4-1. TRACK GEOMETRY MEASUREMENTS VS MGT ON 5° CURVES OF CONCRETE AND WOOD TIE TRACK.

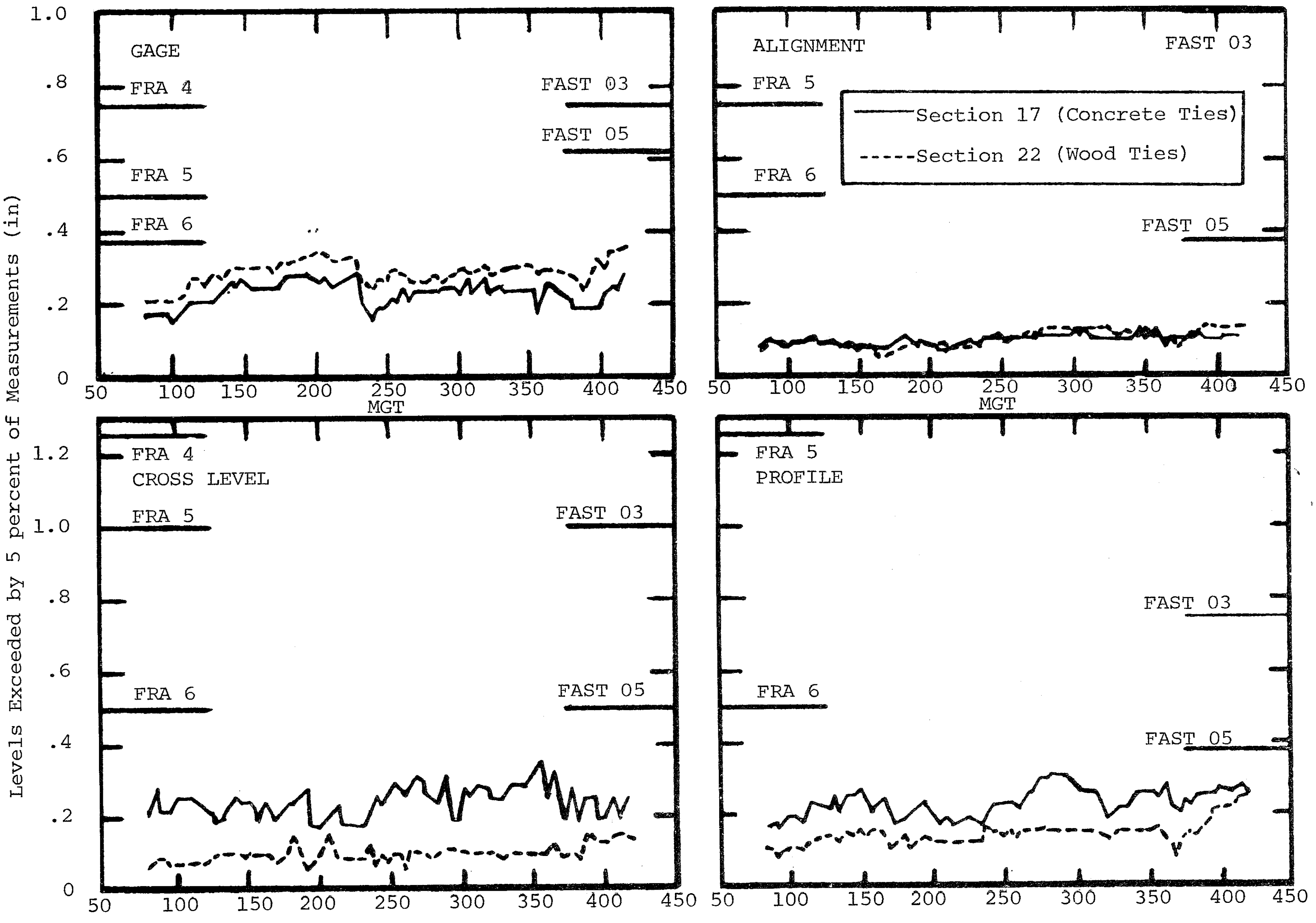


FIGURE 4-2. TRACK GEOMETRY MEASUREMENTS VS MGT ON TANGENT SECTIONS OF CONCRETE AND WOOD TIE TRACK.

In the upper left-hand plot of Figure 4-1, it can be seen that:

- The gage variation at 5% exceedance level on concrete tie track approached zero after the transposition at 83 MGT. One observer offered the following explanation. The narrow gage was due to a field side flow lip on a former low rail. Transposition placed the lip on the gage side of the high rail. The higher than normal wear rate after the transposition was caused by wearing away of this lip. Most of the wear occurred at an elevation on the rail head higher than the nominal gage measurement height of 5/8" below the crown.
- Deep spikes in the concrete tie curve at 235 MGT and in both curves at 358 MGT are probably the result of a rapid "settling in" of the rail in its seat after installation.
- The initially narrow gage of the concrete tie track at 80 MGT appears to have contributed to a very high level of gage wear between 80 and 150 MGT. An additional high rate of wear is evident after the rail was partially re-laid at 358 MGT.
- After the rebuild of the concrete tie track at 235 MGT, the rail "settled" to a wider initial gage than had occurred at the transposition of 80 MGT. Most clips and pads and all insulators were replaced during the rebuild. It is possible that the top 5 percent of the measurements in this section could have come predominately from subsection D_2 where external insulators were not used. Some wear of the fastener shoulders occurred in this subsection, and the lack of an external insulator affords less positive control of the rail position. Unfortunately, the measurement zones for track geometry did not identify data from individual subsections of Section 17.
- Cumulative gage widening between 80 and 400 MGT (sum of gage increases between rail maintenance intervals, excluding the deep spikes in the gage curves after rail renewal) was
  - .60" for the concrete tie track, and
  - .49" for the wood tie track.

It should be emphasized that no reliable conclusions can be drawn from these results. Differences in rail metallurgy and in the state of lubrication existed during the measurement period. Some observers believe that rail wear at FAST has been more sensitive to lubrication than is normally expected in revenue service. This is possibly due to the highly repetitive nature of the train loading.

LATERAL TRACK STRENGTH

Measurements of the lateral strength of unloaded track[4] were taken at infrequent intervals on tangent or spiral concrete and wood tie track. The tests were conducted by applying a lateral load through a yoke to two points on one rail. Lateral displacements were measured on the opposite rail where the rail intersected the line of action of the force, and on 5 ties either side of this line of action.

The purposes of the measurements were to determine the possible effects on both the small-displacement lateral stiffness and the ultimate yield load as determined by such track conditions as wood vs concrete ties, jointed vs welded rail, ballast shoulder width, maintenance affecting ballast compaction, season of the year, gradual deterioration caused by ballast degradation, fastener wear, etc. The regular-interval measurements on tangent track produced only one consistent trend, which is illustrated in Figure 4-3. The concrete tie track produced consistently higher results both in the initial, small displacement phase before ballast yielding and in the eventual yield load. The figure plots individual curves for the extreme cases of lateral load vs lateral displacement and draws envelopes over the rest of the data for each type of track. The overall mean of loads developed at the "large" lateral deflection of 0.2" was 62 percent higher on concrete tie track than on wood tie track (22.5 kips for concrete ties vs 13.9 kips for wood ties). At the "small" deflection of 0.05" the mean load on concrete tie track was 149 percent higher than that on wood tie track.

A pair of special tests was conducted immediately before and after tamping as part of the investigation of the lateral instability in the 5° curve of Section 17.[5] The tamping resulted in a reduction in lateral load at 0.2" deflection of 4 kips in the first case and 4.5 kips in the second case for an average reduction of 31 percent. This indicates that sun kinks or lateral instabilities are more likely to occur just after maintenance affecting ballast compaction. The sun kink at 61 MGT was preceded by an unusual amount of such maintenance.

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[4] Dean, F.E., "Evaluation of Lateral Track Strength Measurements at FAST", prepared for U.S. Department of Transportation, Transportation Systems Center, Contract No. DOT-FR-9162, July 1979.

[5] Lin, C. and Chueng, T., "Lateral Track Instability", FAST/TTC/TN 79-15, Transportation Test Center, January 1979.

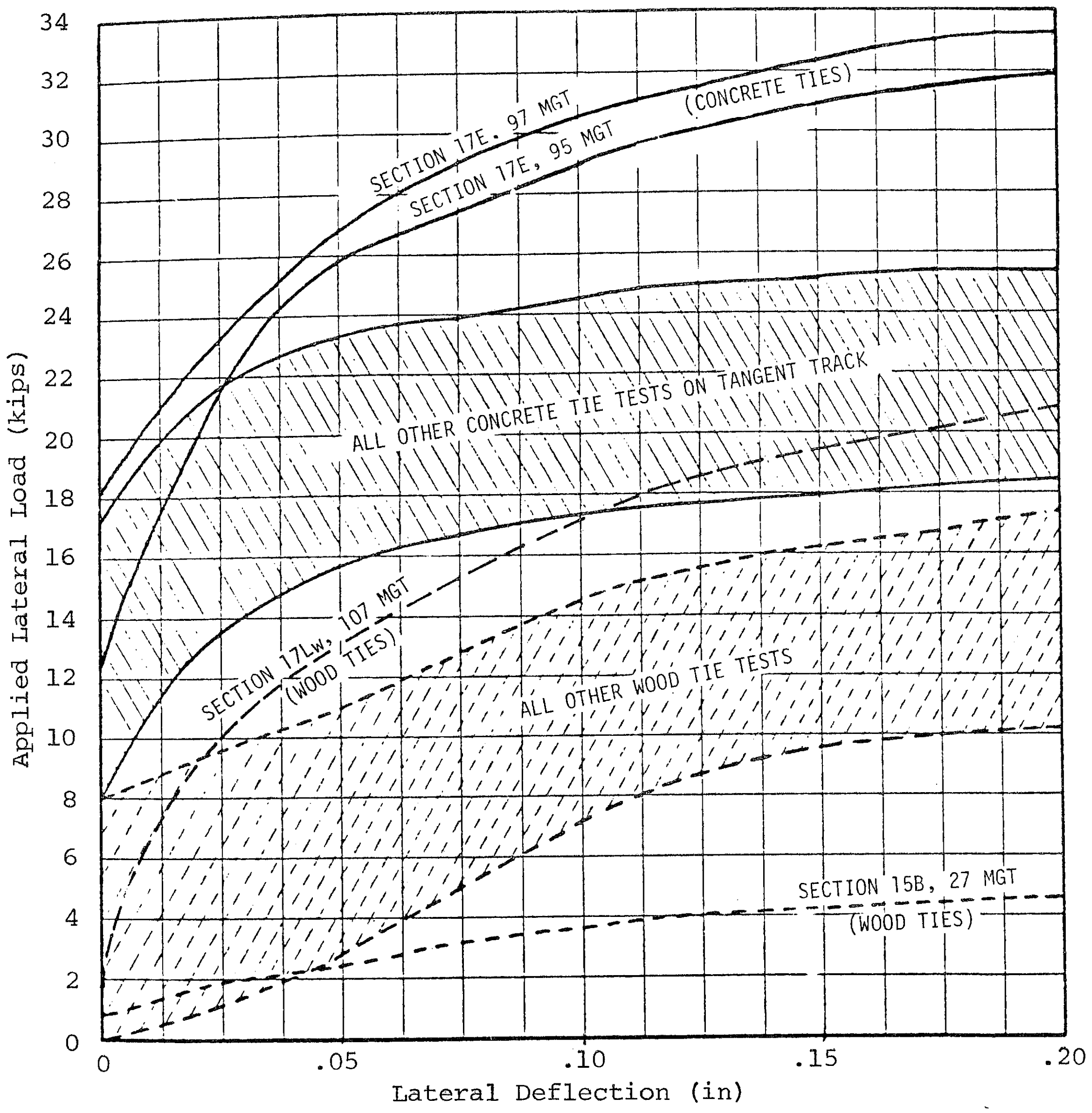


FIGURE 4-3. ENVELOPES OF APPLIED LOAD VS LATERAL DEFLECTION FOR ALL WOOD TIE AND CONCRETE TIE TESTS ON TANGENT TRACK.

5.0 CONCRETE TIE COMPONENT PERFORMANCE

INTRODUCTION

A complete concrete tie and fastener assembly includes the prestressed concrete tie structure, the fastener anchorage systems, fastener clips, tie pads, and insulation to electrically isolate the rails from the tie. The performance of concrete ties and components has been monitored through the following activities:

- Compilation of clip fall-out and failure summaries from the track walker's reports,
- Special studies to determine the cause of high rates of clip fall-outs and fractures in the 5° curve and 2% grade of Section 17,
- Compilation from maintenance records of pad replacement, insulator replacement and tie repositioning histories,
- Inspection of tie pads in the 3° curve during rail renewal at 235 MGT,
- Inspection of tie condition after their removal from the 5° curve for the 425 MGT rebuild, and
- Laboratory tests of a sample of used ties.

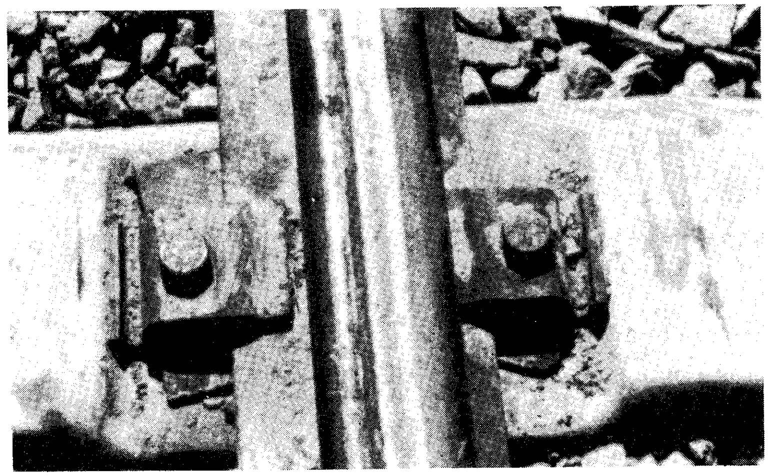
The results of each of these studies are summarized in the following sections.

CLIP PERFORMANCE

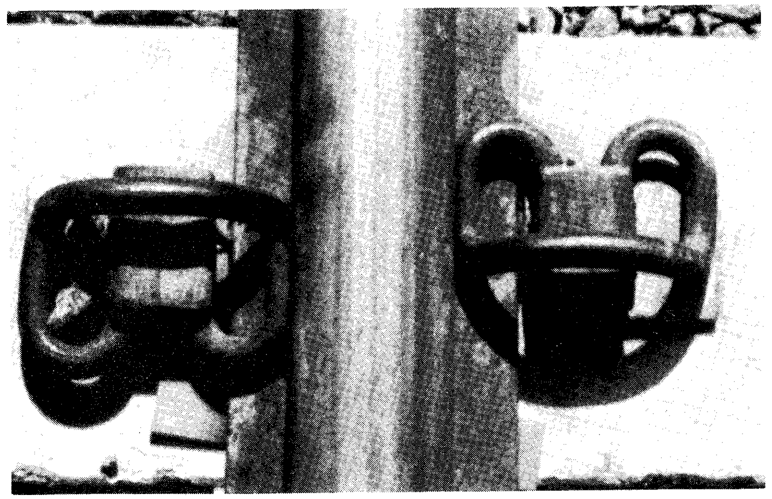
The types of concrete tie fastener assemblies installed in concrete tie Section 17 through 425 MGT are illustrated in Figure 5-1. They include:

- Type F-1, a threadless elastic clip with external shim-type insulator separating the rail base from the clip and embedded fastener shoulder. These were installed with several pad variations in all but three subsections.
- Type F-2, which used the Type F-1 clip with insulation bonded to the shoulder stem. Dimensional adjustments of the embedded shoulders were required during tie manufacture to accomodate this insulation system. These fasteners were installed in subsection D_2, where most of the clip fall-out problems occurred. This installation was not approved by the clip manufacturer.
- Type F-3, a "compression" type (rigid) clip with anchor bolt used on ties from the Kansas Test Track and installed in FAST subsection F. Fiberglass insulation was bonded to the underside of the clip.

Type F-1 threadless elastic clip with external insulator. (Type F-2 uses the same clip with insulation bonded inside shoulder.)



Type F-3 rigid clip with insulation bonded to clip.



Type F-4 threadless elastic clip with insulation bonded inside shoulder.

FIGURE 5-1. CONCRETE TIE FASTENER ASSEMBLIES USED AT FAST THROUGH 425 MGT.

- Type F-4, a threadless elastic clip which had insulation bonded inside the fastener shoulder and was installed in subsection H_1.

Clip Fall-out and Fractures

The history of clip fall-outs through 425 MGT is summarized in figure 5-2. It can be seen that by far most fall-outs occurred in subsection D_2 where no external insulator was used. This installation with its internal insulator was not approved by the manufacturer. Other subsections where high fall-out rates occurred were:

Subsection	Track Contour	Total Fall-outs (%)
A	5° curve	19
C	5° curve	55
D_1	5° curve	19
J_1	3° curve	22

One issue, which arose when the fall-out problem became evident, concerned the possible effect of pad hardness on the fall-out rate. In subsections C, D_1 and D_2 the soft Type P-2 pad was replaced with a medium hard Type P-5 pad at 235 MGT. It can be seen in Figure 5-2 that fall-outs continued at a slightly higher rate after the pad replacement. The highest fall-out rate in the 3° curve occurred with a hard type P-6 pad.

A summary of clip fractures in Section 17 over the first 425 MGT is shown in Figure 5-3. The highest rates occurred in subsections C, D_1 and D_2. These fractures were approximately equally distributed over the period before 235 MGT (soft Type P-2 pads) and after 235 MGT (medium hard Type P-5 pads). Apparently, the hardness of the pads had little, if any, effect on the rates of either fall-outs or fractures.

Rates of fall-out and fracture are plotted vs MGT, over the period of 0 to 350 MGT, in Figure 5-4. For a restricted period (141-350 MGT) the rates are presented by location on the tie. It can be seen from the figure that:

- Most clip fall-outs and fractures occurred at the inside gage (IG) location on the tie. Over all of this period of time (until a train derailment at 358 MGT) the counterclockwise travel of the train up the grade in the 5° curve resulted in a reduction of speed to about 31-32 mi/h, vs a balance speed of 34 mi/h with 4" superelevation. In addition, the draft force of the train on this grade is thought to have created a significant component of lateral load on the inside rail, directed radially inward.

- The clip fracture problem began at about 100 MGT, or about 40 MGT after the replacement of the original clips with clips from a batch made in England. (The replacement was necessitated by damage from a ballast regulator rather than by the sun kink at 61 MGT.)

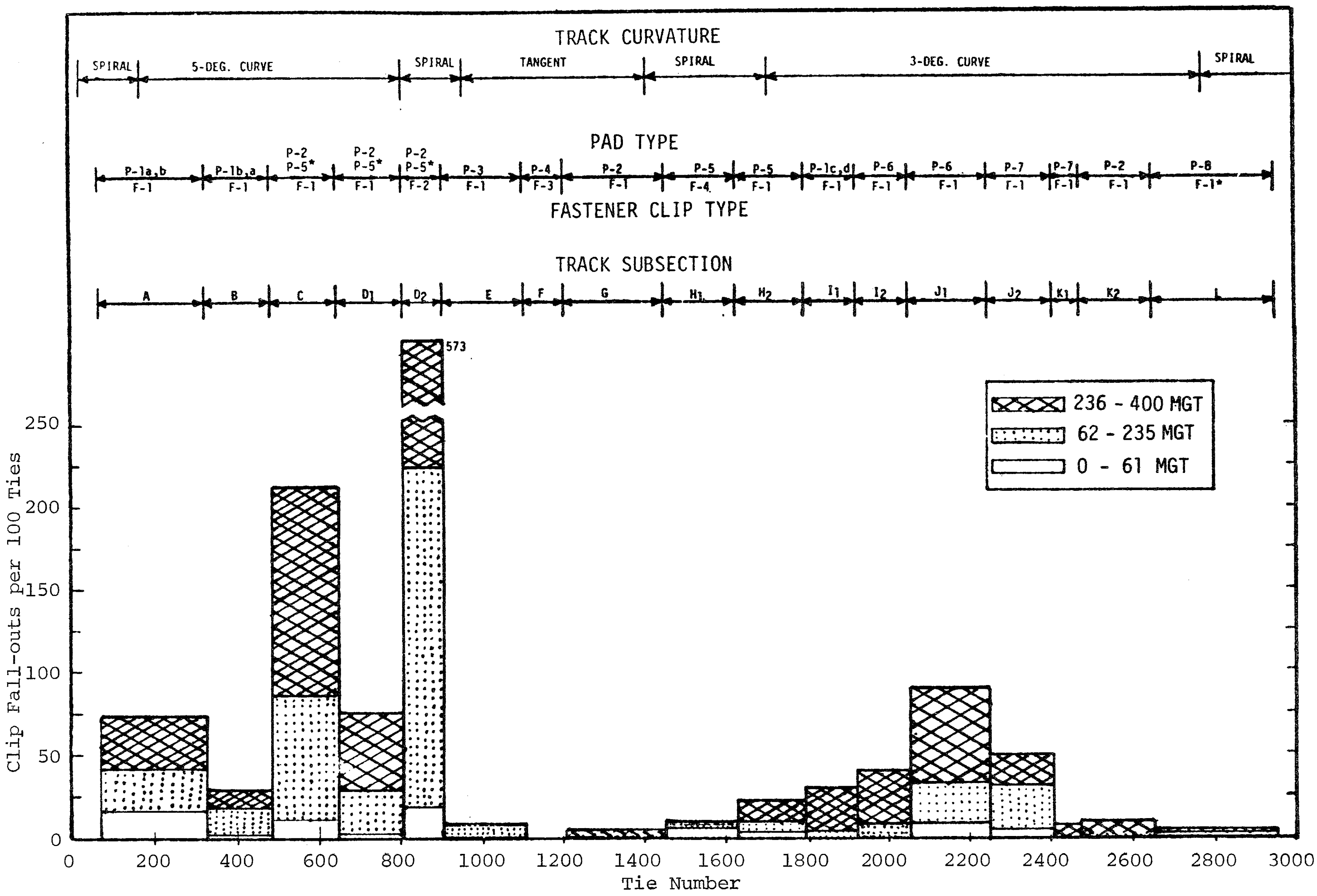


FIGURE 5-2. FASTENER CLIP FALL-OUTS IN CONCRETE TIE SECTION 17, 0-400 MGT.

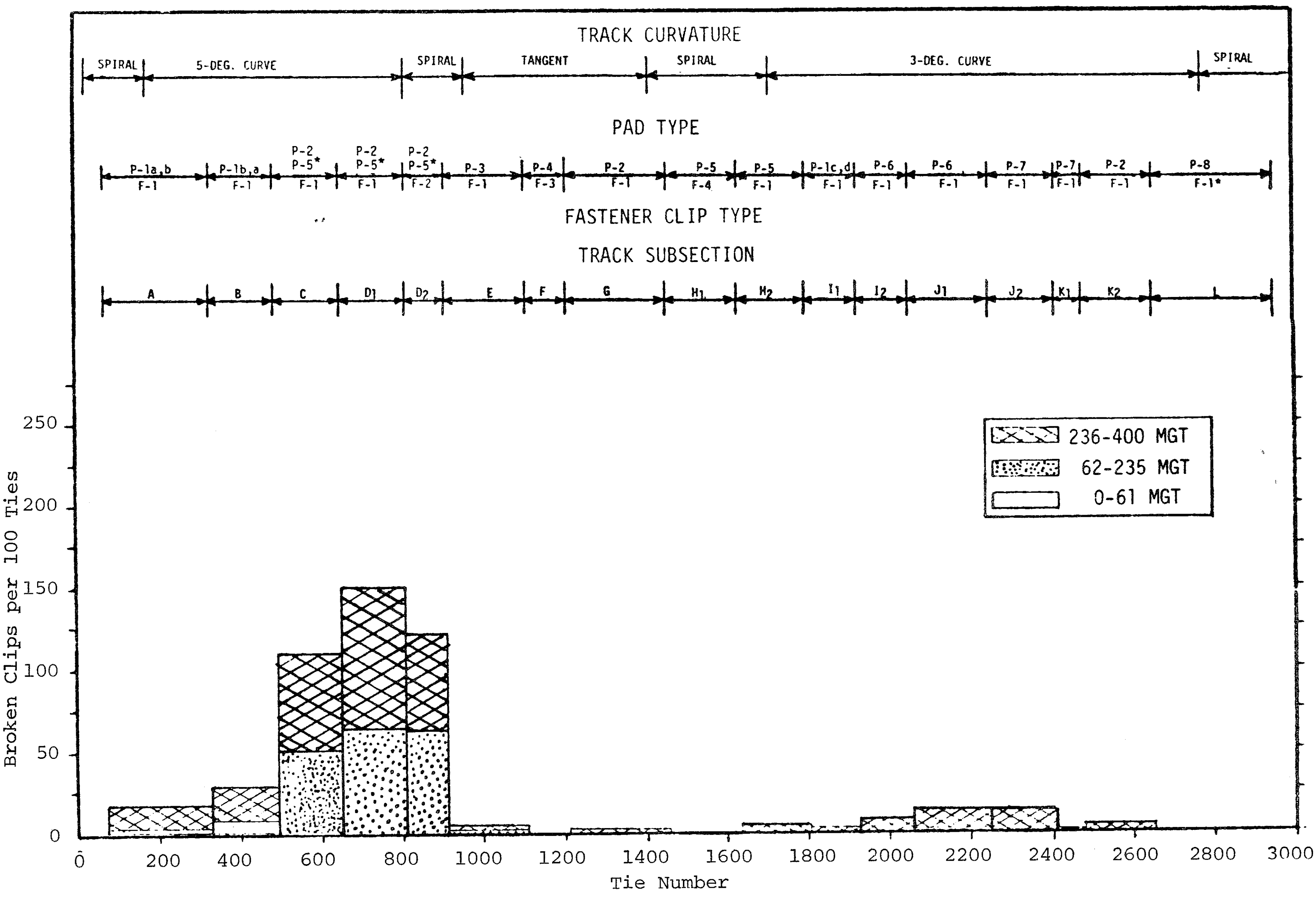
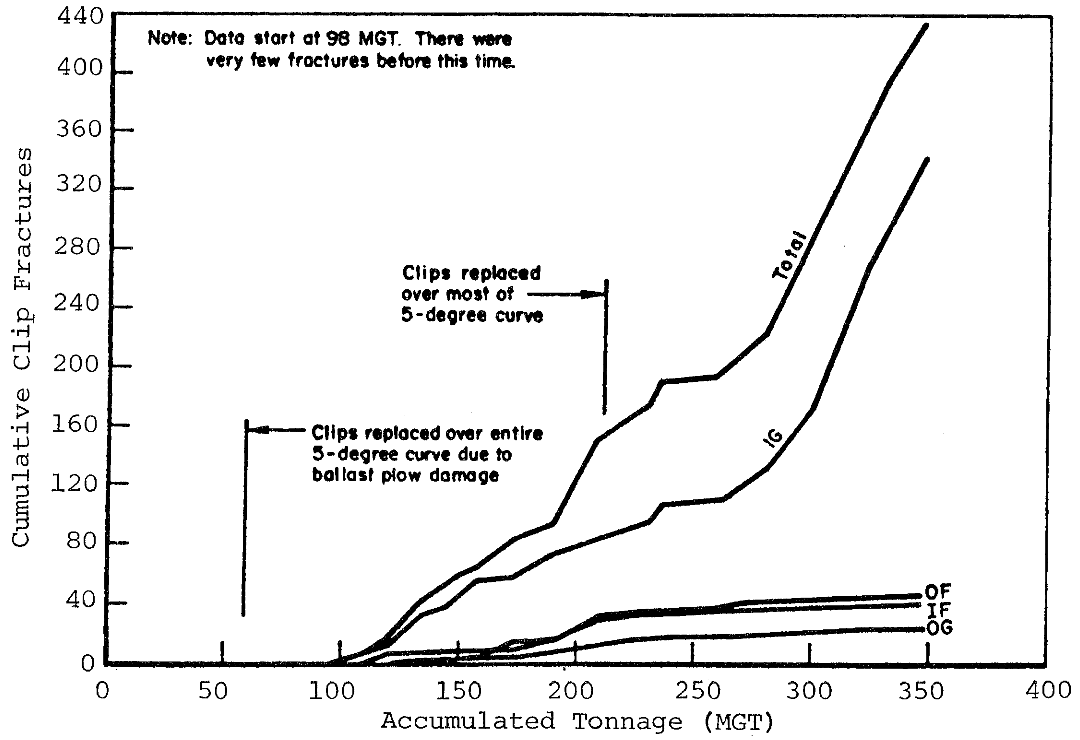
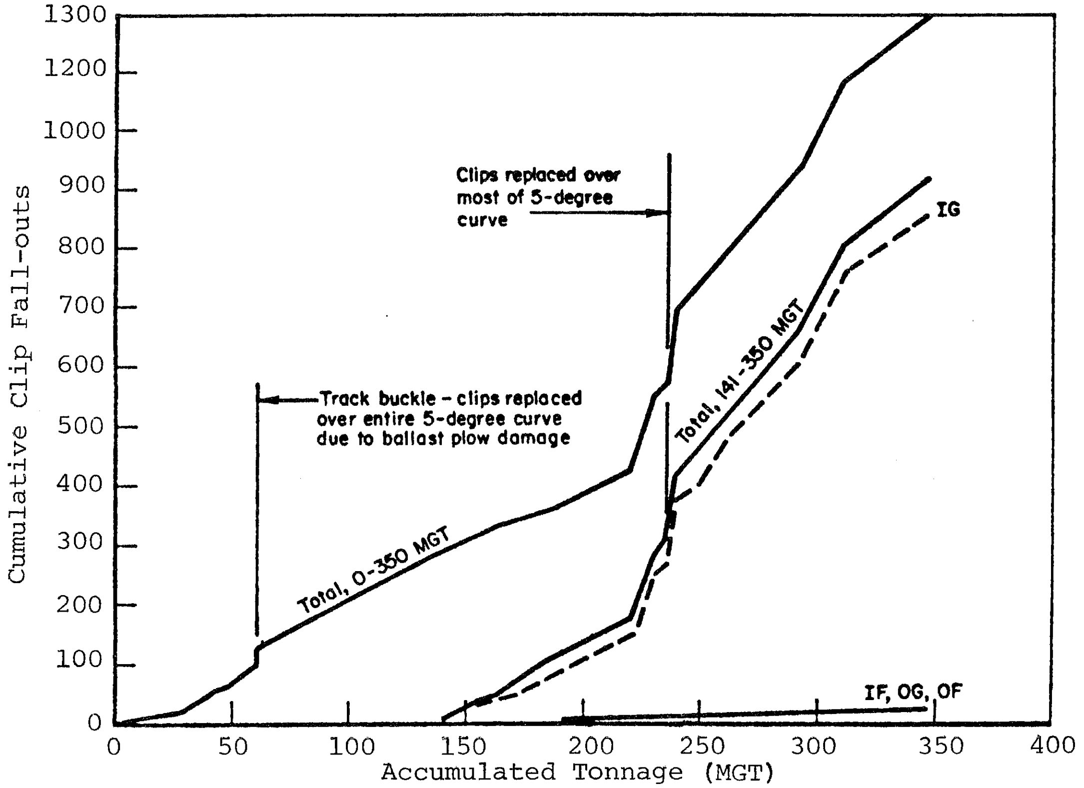


FIGURE 5-3. REPLACEMENTS OF BROKEN FASTENER CLIPS IN CONCRETE TIE SECTION 17.



Cumulative fastener fractures vs MGT for period 0-350 MGT (Subsection D_2 fractures not included).



Cumulative fastener fall-outs vs MGT for period 0-350 MGT (Subsection D_2 fall-outs not included).

FIGURE 5-4. CLIP FALL-OUTS AND FRACTURES BY LOCATION ON TIE.

- Following the second clip replacement at 235 MGT, a rapid increase in the rate of fall-outs occurred. The clips were driven into their shoulders by an additional 1/4", per recommendation of the manufacturer.

- A temporary flattening of the rate of clip fracture occurred between 235 and 260 MGT, after which the highest rates of fracture developed.

Metallurgical Study of Clip Fracture

A study[6] was conducted on a sample of FAST clips to determine the clip failure mechanism. It was determined that the fractures were caused by high-cycle fatigue. The fracture rates were possibly affected by higher surface decarburization of the English-made clips installed at 61 MGT and of the Canadian-made clips installed at 235 MGT, in comparison to the original clips.

Laboratory and Field Investigation of Clip Loads and Strains

A further investigation[7] by laboratory and field measurements was conducted to study the clip load and strain behavior. The major findings of this study were that:

- Peak strains up to 10,000 microinches/inch were measured at one point on the clip when the clip was installed on a tie. The yield point of the clip steel occurs at about 6,000 microinches/inch.

- Dynamic strains up to 20% static installation strain were measured in the field.

- Intentional overdriving of the clips to refusal produced noticeable permanent deformation and permanent strain up to 10% of static strain.

- Repeated clip installations produced permanent deformations up to .040", which can be compared to the manufacturer's nominal static deflection due to installation of 0.59 to 0.61 inches.

- The design toe load of the clips is 2,000 ±200 pounds. A sampling of toe loads measured at similar locations by the manufacturer and by the Transportation Test Center, during the shutdown at 425 MGT, produced the following results:

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[6] Buchheit, R.D. and Broek, D., "Failure Investigation of FAST Concrete-Tie Fastener Clips", prepared by Battelle-Columbus Laboratories for U.S. Department of Transportation, Transportation Systems Center, Contract No. DOT-TSC-1044, June 1978.

[7] Hadden, J., et. al., "Tests for the Structural Evaluation of F-1 Rail Fasteners in Section 17 at FAST", prepared by Battelle-Columbus Laboratories for U.S. Department of Transportation, Federal Railroad Administration, Contract No. DOT-TSC-1595, March 1980.

	Clip Toe Load	
	Manufacturer's Data	TTC Data
Sample size	12	14
Range, lb	940 - 1,725	1,010 - 1,570
Average, lb	1,581	1,378

A large range can be expected in field measurements of toe load because the values are controlled by many variables (such as clip dimensions, fastener shoulder placement, and pad performance. In addition there are apparent differences in values produced by the two toe load measurement devices. However, either set of the above measurements indicates average toe loads well below the design value of 2,000 lbs, and therefore indicate a significant reduction in longitudinal restraint.

Fastener Longitudinal Restraint

A primary function of the fastener system is to provide sufficient longitudinal restraint between the rail and the tie to inhibit tie skewing and bunching. A lower longitudinal restraint is indicated in Figure 5-5 by the frequency with which tie repositioning was required in the 5° curve with 2% grade and in the 3° curve. The restraint was lowest in subsections A and B, which were located near the bottom of the 2% grade in the 5° curve. The frequency of repositioning to correct tie skewing led to the installation of rail anchors in subsections A and B shortly before the rebuild at 235 MGT and in the 3° curve at 235 MGT. Anchors were installed on every tie in subsection A and on every other tie (normal wood tie practice) in subsections B and in the 3° curve. It can be seen in Figure 5-5 that subsection B continued to require repositioning after the 235 MGT rebuild.

No fasteners other than the Type F-1 have been tested in the the severe environments of the 5° and 3° curves at FAST. The introduction of a fastener which can provide more longitudinal restraint under the severe FAST conditions will significantly improve the economic effectiveness of concrete tie track.

PAD PERFORMANCE

A total of 8 types of pads were installed in the various subsections of concrete tie Section 17 for the first 425 MGT. Pad materials and average hardness measurements are shown in Figure 5-6. "D" scale durometer measurements (a scale normally used for hard rubber) were taken on field pads and on control pads stored off-track. It can be seen that the field pads generally lost hardness relative to the control pads. The pads can be classed generally by their initial hardness as:

- "Hard" - Types P-1, P-4, P-6, P-8
- "Medium Hard" - Type P-5
- "Soft" - Types P-2, P-3, P-7.

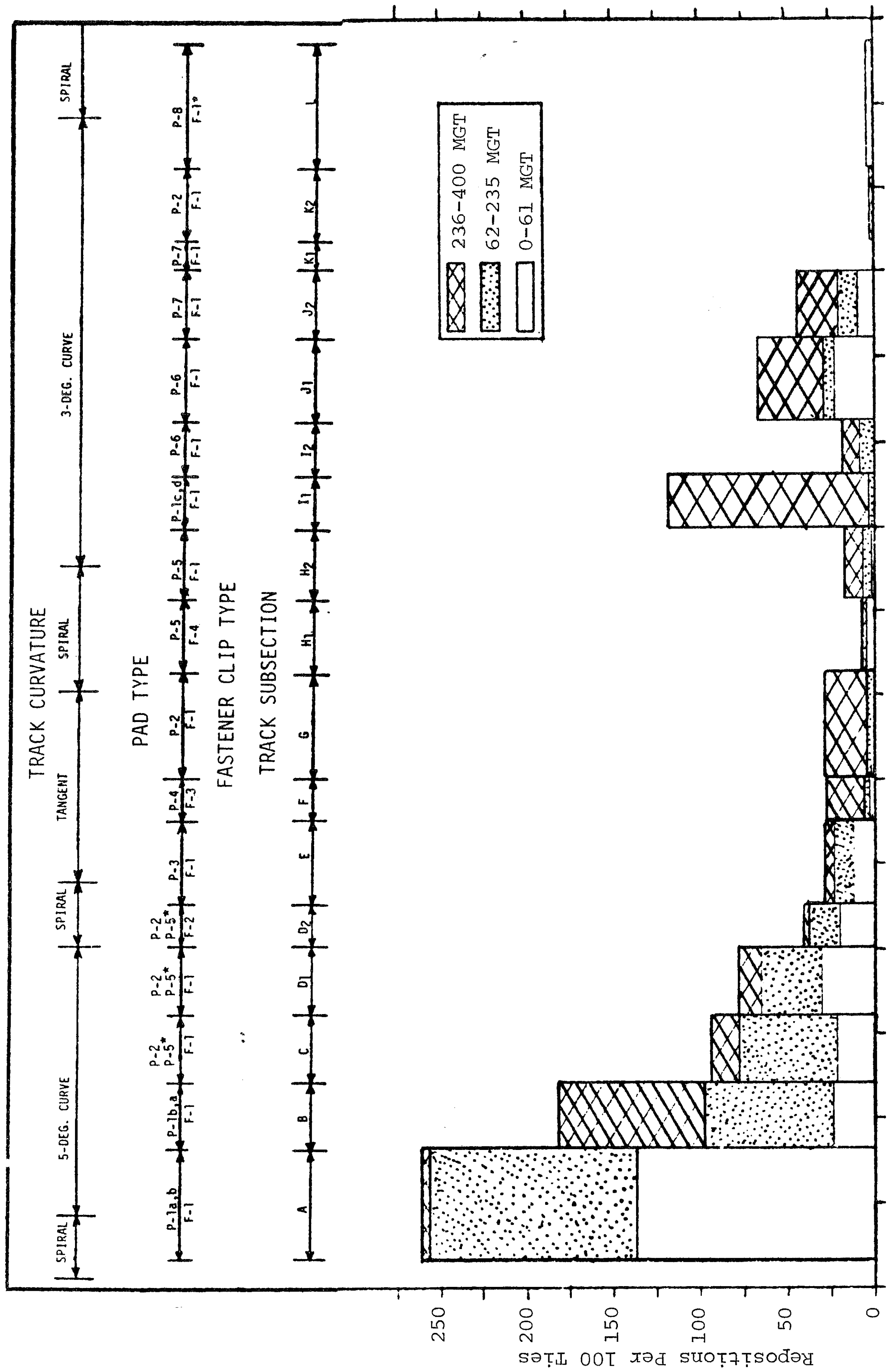
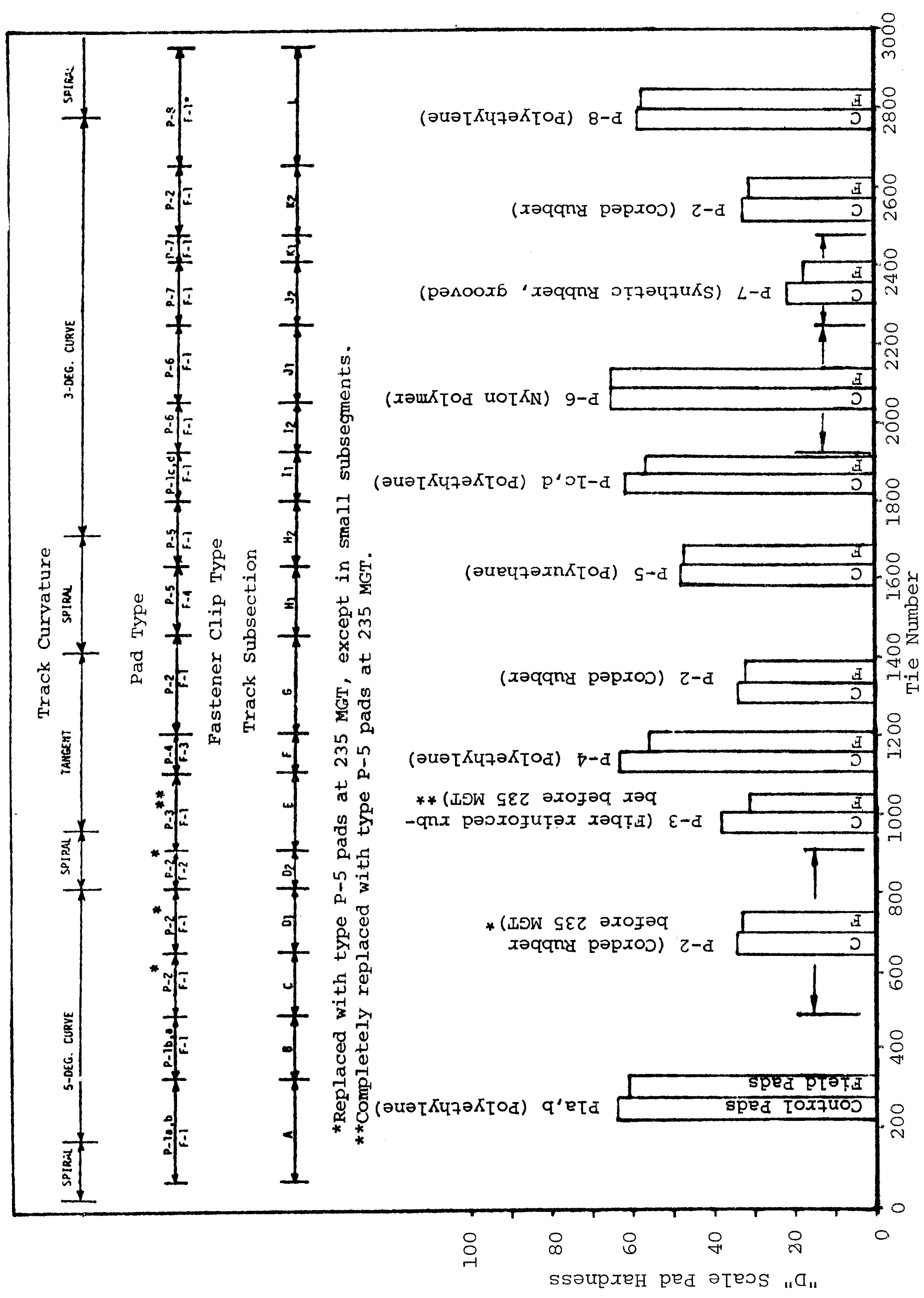


FIGURE 5-5. TIE REPOSITIONS IN CONCRETE TIE SECTION 17.



*Replaced with type P-5 pads at 235 MGT, except in small subsegments.
**Completely replaced with type P-5 pads at 235 MGT.

FIGURE 5-6. HARDNESS OF PADS IN CONCRETE TIE SECTION 17.

An inspection of pads and insulators was conducted in most subsections after rail removal in preparation for the rebuild at 235 MGT.[8] Results of the inspection and subsequent action are summarized in Table 5-1. Among pad types inspected, the largest percentages judged defective (cracked, frayed, torn) were found in the "soft" Type P-2 corded rubber pads and Type P-3 fiber-reinforced pads in the 5° curve. The failure rate of P-2 pads on the tangent section was much lower.

A summary of total pad replacements in each subsection over 425 MGT is presented in Figure 5-7. This figure verifies the previously discussed inspection, showing significant replacements only in soft pad regions. Typical wear conditions found on three types of pads at 235 MGT are illustrated in Figure 5-8.

INSULATOR PERFORMANCE

Each of the two basic types of concrete tie insulation systems (internal and external) produced a particular performance problem during the first 425 MGT. Most subsections contained the external, shim-type insulator illustrated previously in Figure 5-1(a). These displayed high rates of cracks and breaks. In many cases, the breaks would result in fall-out of the insulator. The inspection at 235 MGT[8] yielded the following defect rates for external insulators from the 5° and 3° curves:

Percent of Insulators Judged Defective at 235 MGT

	Among All Insulators In Segment	Among Insulators in Specific Tie Locations: Inner Rail Field Side	Inner Rail Gage Side	Outer Rail Field Side	Outer Rail Gage Side
5° curve	38.0	75.3	12.8	13.6	50.2
3° curve	57.8	68.6	52.0	48.3	63.2

In Figure 5-9, the distribution of insulator replacements across Section 17 shows that, with few exceptions, all replacements were made at 235 MGT. However, it can be seen that substantial replacements were required in subsection C beginning early in the program (0-61 MGT). It should also be noted that these replacements did not result from the sun kink at 61 MGT, but rather from rail movement which required frequent spot tamping and lining.

Fastener shoulder wear was found in subsections D_2 and H_1 where internal insulation was used, and was also found where external insulators were broken or missing. The wear occurred on the field side inserts where the rail base contacted the insert shoulder, as shown in Figure 5-10. Measurements made during the inspection at 235 MGT[8] showed that the wear in subsection D2

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[8] Weber, J.W., "Inspection Report of Selected Fastening System Components in Section 17 at 235.4 MGT", FAST/TTC/TN 79-07, Transportation Test Center, December 1978.

TABLE 5-1. SUMMARY OF CONCRETE TIE PAD INSPECTION AND REPLACEMENTS AT 235 MGT.

Subsection	Tie Numbers	Original Pad Type	Percent Defects	Action
A, B	0070-0488	P-1a, P-1b (Polyethylene)	1.9 (16/838)	Defective pads Replaced
C	0489-0654	P-2 (Corded Rubber)	32 (24 pads form a sample of 76 over C-D_2)	Complete Replacement with Type T-5 Pads
D_1 (1)	0655-0679			Old Nondefective Type P-2 pads reinstalled
D_1 (2)	0680-0704			Complete Replacement with Type T-5 pads
D_1 (3)	0705-0729			Old Nondefective Type P-2 pads reinstalled
D_2	0730-0808			Complete Replacement with Type T-5 pads
E (Spiral portion)	0910-0956	P-3 (Fiber Reinforced Rubber)	18 (17/94)	Complete Replacement with Type P-5 pads
G	1207-1458	P-2 (Corded Rubber)	3.2 (16/504)	Defective Pads Replaced in-kind
H_1, H_2	1459-1804	P-5 (Polyurethane)	0.3 (12/692)	Defective Pads Replaced in-kind
I_1	1805-1927	P-1c, P-1d (Polyethylene)	0.4 (1/246)	Defective Pad Replaced in-kind
I_2, J_1	1928-2257	P-6 (Nylon-Polymer)	2.3 (15/660)	Defective Pads Replaced in-kind

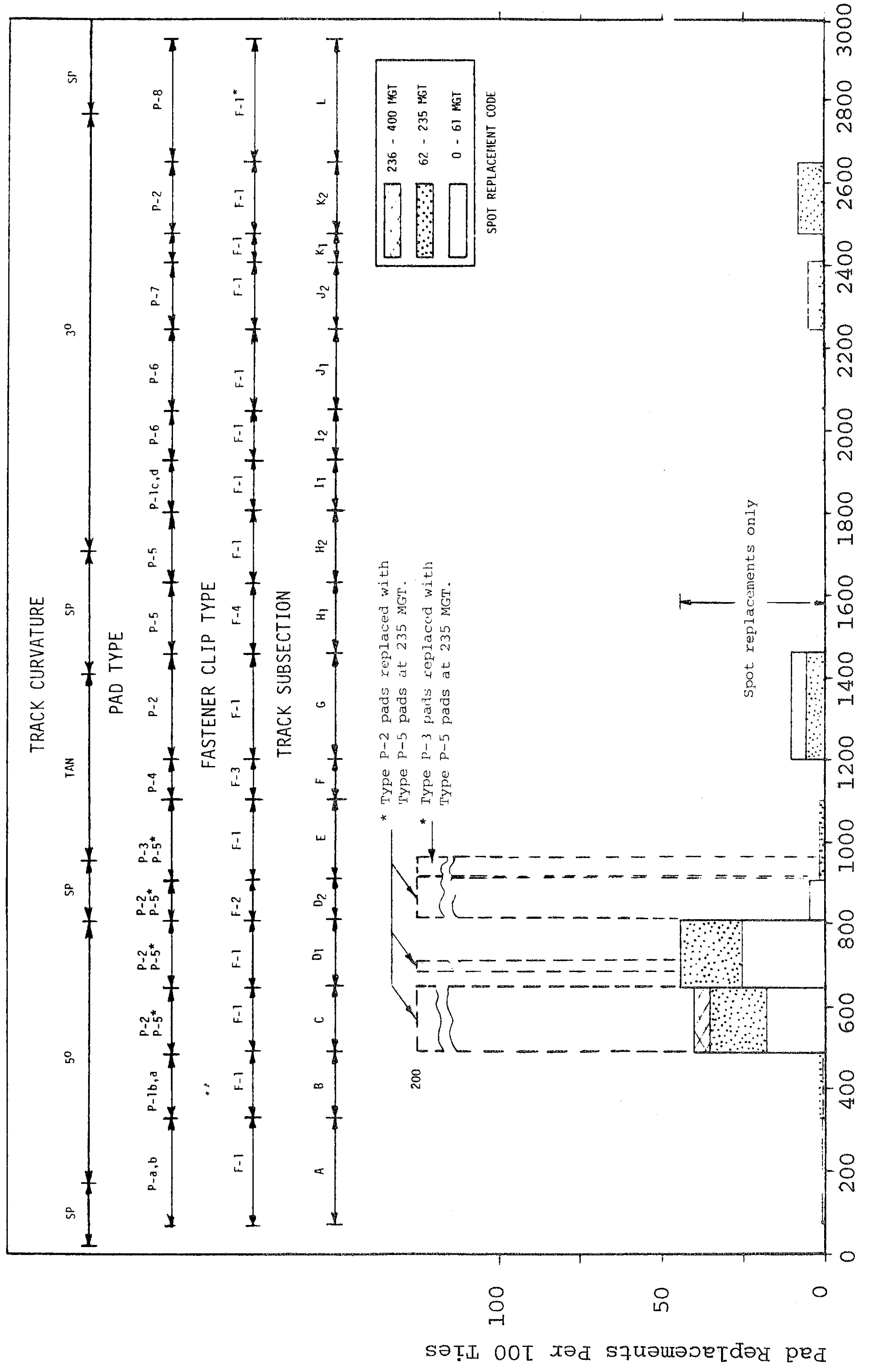
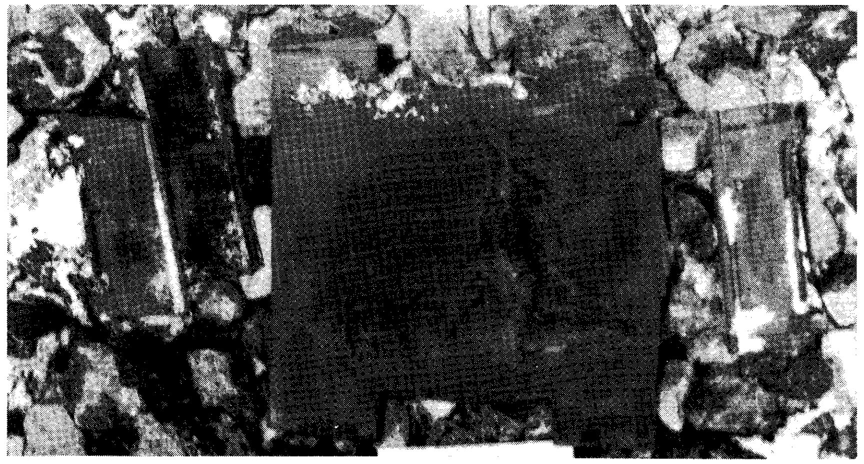
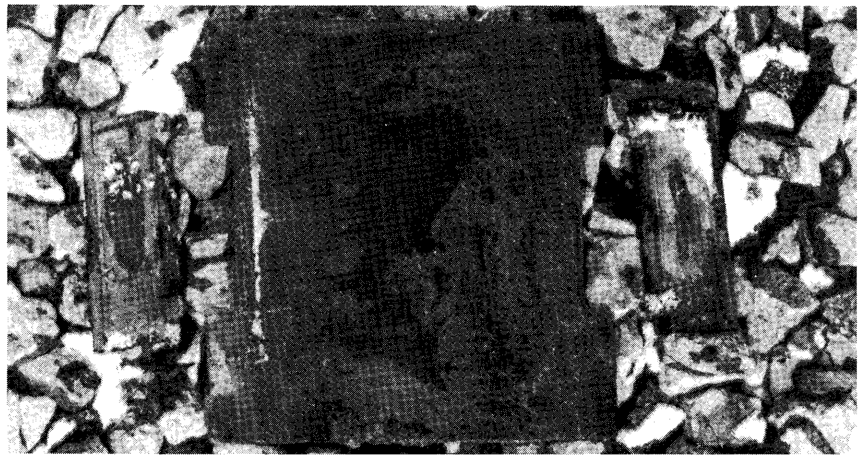


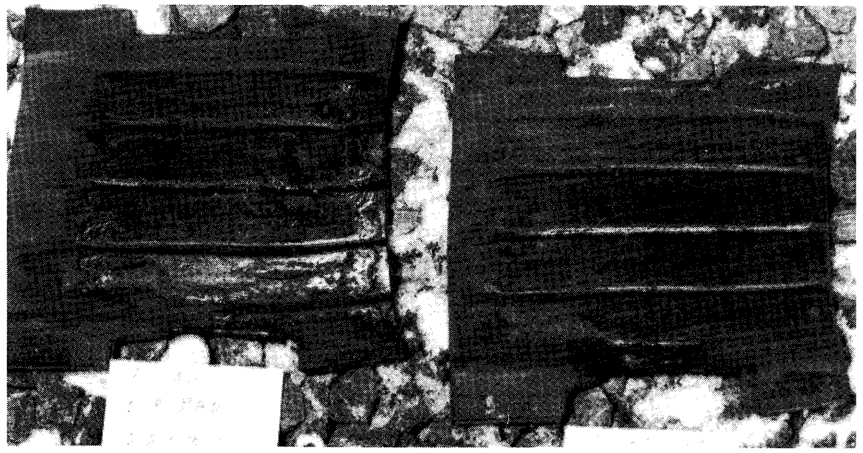
FIGURE 5-7. REPLACEMENTS OF TIE PADS IN CONCRETE TIE SECTION 17.



Type P-2
Soft corded
rubber pad



Type P-8
hard poly-
ethylene pad



Type P-7
Soft, grooved
rubber pads

FIGURE 5-8. TYPICAL CONDITION OF PADS FROM 3° CURVE OF SECTION 17, 235 MGT.

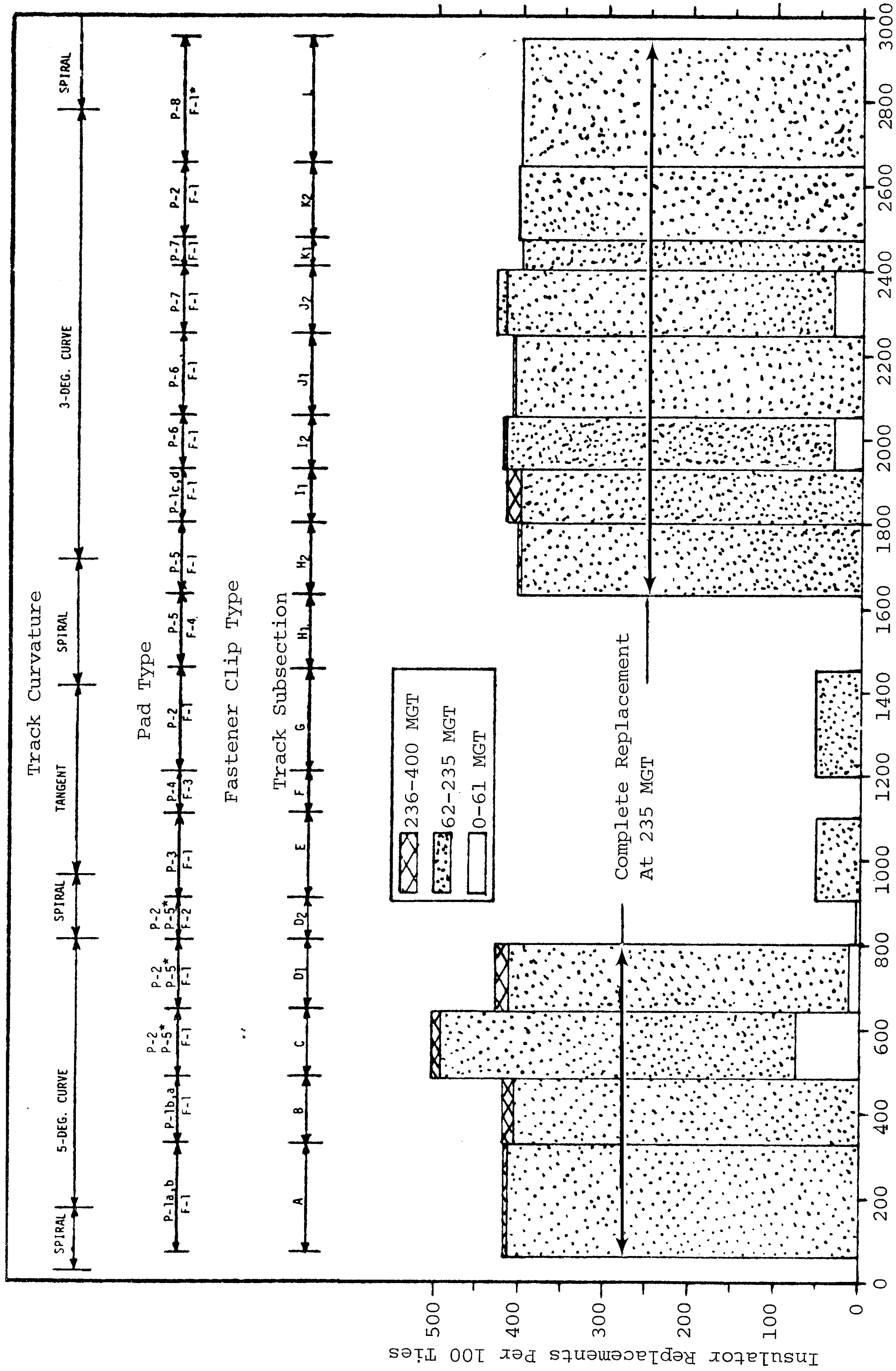


FIGURE 5-9. INSULATOR REPLACEMENTS IN CONCRETE TIE SECTION 17.

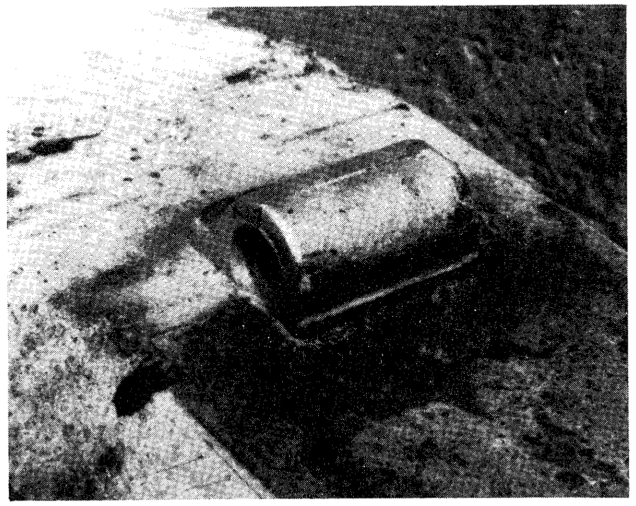


FIGURE 5-10 FASTENER SHOULDER WEAR.

frequently exceeded 1/8" and ranged up to 3/16". Wear up to 1/8" also was found in subsection H_1. This type of wear will result in gage widening and could eventually result in loss of ties, unless weld repair of the shoulders is undertaken.

TIE PERFORMANCE

Tie Condition at 425 MGT

Figure 5-11 shows the general condition of the Type T-1 and T-2 ties after their removal from the 5° curve for the rebuild at 425 MGT. An inspection of all removed ties showed that all had been damaged at the bottom of the tie near the rail seat. The damage was caused early in the program by tamper forks designed in depth and spacing for wood ties. The tie inspection[9] further revealed that:

- Top surface cracks as shown in Figure 5-12 could be seen on many of the Type T-1 ties from a small region of the curve. These cracks were discovered very early in the operations program and were originally inspected at 100 MGT. It was noted that they had grown very little in the following 325 MGT. The original inspection identified 35 ties with cracks of this type, 32 of which were located in a zone of 141 ties in subsection 17A, which contained hard polyethylene pads. The top center cracks were

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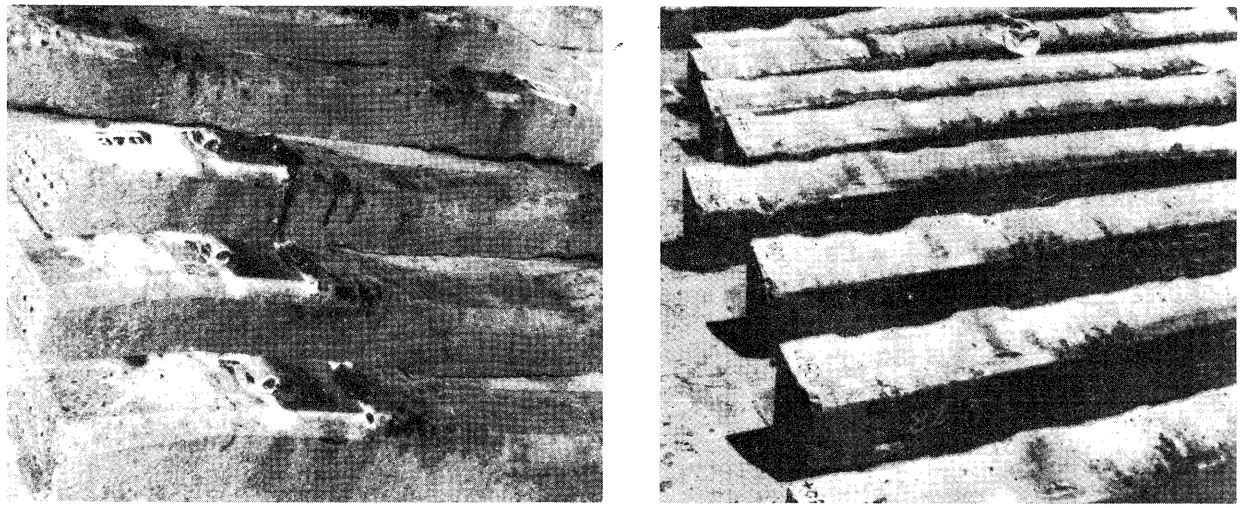
[9] Dean, F.E., "Condition of FAST Concrete Ties at 425 MGT", prepared by Battelle-Columbus Laboratories for U.S. Department of Transportation, Transportation Systems Center, Contract DOT-FR-9162, October 1979.



Type T-2 Ties

Type T-1 Ties

FIGURE 5-11 GENERAL CONDITION OF TIES REMOVED FROM SECTION 17.

FIGURE 5-12 TOP SURFACE CRACK PATTERN ON TYPE T-1 TIES.

noticed very early in the FAST operations program, and observers have reported that they grew very little after first appearing. Therefore, the cracks could have been caused by an initially poor ballast support condition.

- A top surface crack pattern occurring frequently on Type T-2 ties is shown in Figure 5-13. The cracks originate at a fastener shoulder and run either to the end of the tie or diagonally to a tie edge. All such cracks are "hairline" in nature and difficult to detect without close inspection. However, the frequency of cracked ties is extensive. In a random sample of 55 ties, 43 (78 percent) contained cracks of this type.

  An inspection of unused Type T-2 ties from the same batch as those installed in the track revealed barely perceptible hairline cracks beginning to extend from the shoulders. This indicates that crack origination occurred before installation, probably as the result of concrete shrinkage during curing.

- Longitudinally-oriented surface cracks, clustered mostly at or near rail seats were found on the faces of both Type T-1 and T-2 ties. These are surface cracks, ranging from one to seven inches in length. Figure 5-14 shows an example. Significant numbers of such cracks were found on both types of ties: 23 out of 64 Type T-1 faces inspected and 6 out of 12 Type T-2 faces inspected.

  It should be emphasized that none of these crack patterns were of the type which have most often led to failure of earlier concrete ties. The longitudinally-oriented surface cracks are rail seat flexural cracks which propagate up the face of the tie from its lower edge. None of the cracks found during the inspection appeared to be propagating toward a condition which could cause loss of bending strength. It was estimated in the inspection report[9] that the ties could have withstood at least several hundred additional MGT of FAST service loading.

Laboratory Tests of Concrete Tie Bending Strength

To determine the possible effects on tie bending strength of the previously discussed crack patterns, samples of Types T-1 and T-2 ties were subjected to bending strength tests[10] at rail seats and tie centers. These tests used the procedures recommended by the American Railway Engineering Association.[11] Test specimens of each tie type included used ties with a particular crack pattern, used ties without cracks, and previously unused ties from the same production runs. Table 5-2 summarizes the mean bending moments at which the ties experienced first cracks, structural cracks (propagation to

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[10] Dean, F.E., The Effects Of Service Loading on the Bending Strength of Concrete Ties, Report No. FRA/TTC-81/4, prepared by Battelle-Columbus Laboratories for U.S. Department of Transportation, Federal Railroad Administration, June 1980.

[11] "Manual for Railway Engineering", American Railway Engineering Association, 1978.

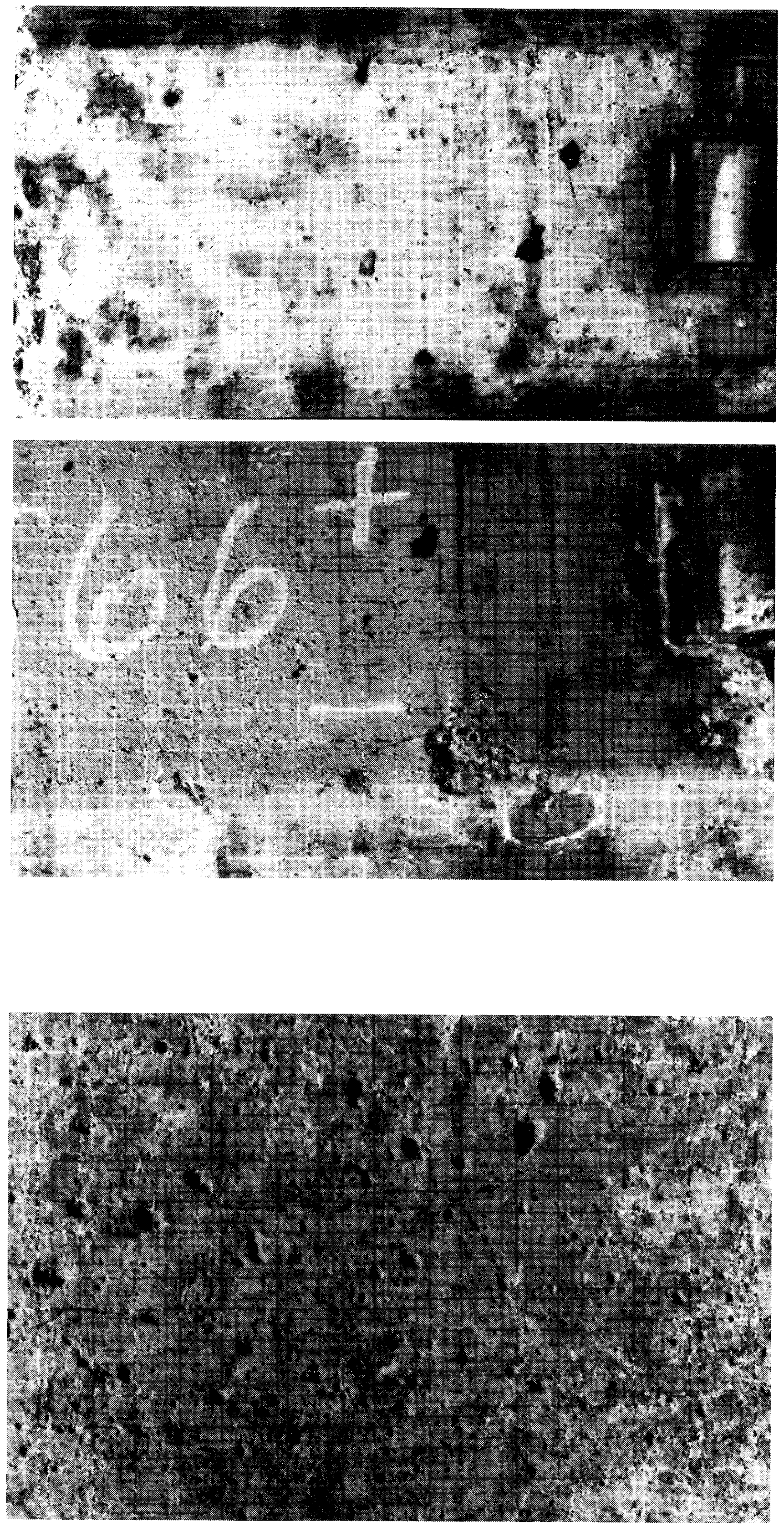

FIGURE 5-14. TYPICAL LONGITUDINAL SURFACE CRACKS ON TIE FACE.

TABLE 5-2. SUMMARY OF RESULTS FROM TIE BENDING STRENGTH TESTS.

Tie Condition Before Tests	Specification Requirement For Structural Crack (in-kip)	Mean Bending Moment at: (in-kip)			
		Initial Crack	Structural Crack-1	Tendon Slip	Ultimate Load
(a) Type T-1 Ties					
RAIL SEAT TESTS					
New Ties	300 (30-inch spacing)	386	421	755	774
Used (no rail seat cracks)	250 (24-inch spacing)	377	414	701	710
TIE CENTER TESTS					
New Ties	200 (all spacings)	309	365	--	526
Used (no top surface cracks)		291	314	--	537
Used (top surface cracks)**		Pre-cracked	291	--	526
(b) Type T-2 Ties					
RAIL SEAT TESTS					
New Ties	300 (30-inch spacing)	366	411	629	629
Used (no top surface cracks)	250 (24-inch spacing)	373	406	640	644
Used (top surface cracks)*		389	398	618	638
TIE CENTER TESTS					
New Ties	200 (all spacings)	314	331	--	538
Used (no center cracks)		312	339	--	533

*Top surface cracks on Type T-2 ties extended from fastener shoulder outward to end of tie.

**Top surface cracks on Type T-1 ties were transverse cracks extending across the center section of the tie.

a prestress tendon), tendon slippage and ultimate loads. The moments for a structural crack are compared with design values specified by the AREA manual.

In no case did the mean results (or any individual result) fall below the strength specified by AREA for the design of new ties. Loss of bending strength in used ties, as compared to the strength of new ties, occurred only in the strength at the tie centers of the Type T-1 ties. There was no comparable reduction in the ultimate strength of the ties. It can be concluded from these tests that the crack patterns found on the FAST ties at 425 MGT did not cause a degradation in the ability of the ties to perform as load-carrying structural members.

Tie Bending Strain and Loading Environment

Strain gage measurements of tie bending moment at the rail seats and tie centers were made in Section 17 over the first 235 MGT. Several ties were instrumented at each of two measurement sites, one in the 5° curve and the other on tangent track. A summary of peak bending moments from each monitored train pass is shown in Figure 5-15. Also shown are the applicable AREA requirements for bending strength which is to be sustained before structural cracking occurs in laboratory qualification tests. A structural crack is defined as one which propagates to the level of a prestress tendon.

The data in Figure 5-15 show that, with the exception of one questionable tie center measurement, no measured bending moments approached the levels to which the ties were designed. In spite of the heavy concentration of 100-ton cars, this result can be anticipated from the fact that wheel flats are not allowed to develop in the FAST test train.

The difference between the FAST bending moment spectrum and one typical of revenue service is shown in Figure 5-16*. This figure shows only the low-probability range of the cumulative distribution of bending moments for all measurements taken at FAST and for approximately 200,000 measurements at the revenue service site, a 3° curve with a high percentage of unit coal train traffic. Meaningful levels of bending moment (greater than 100 in-kips) are produced at the revenue service site by less than 0.01% of tie center measurements and less than 0.1% of rail seat measurements. While the FAST train produced these levels at a much higher frequency, its maximum values are significantly lower than those from the revenue service site.

It should be noted that only the revenue service site produced bending moments (at tie center) comparable to the AREA requirements for laboratory qualification tests. The FAST ties were designed to the 30" tie spacing

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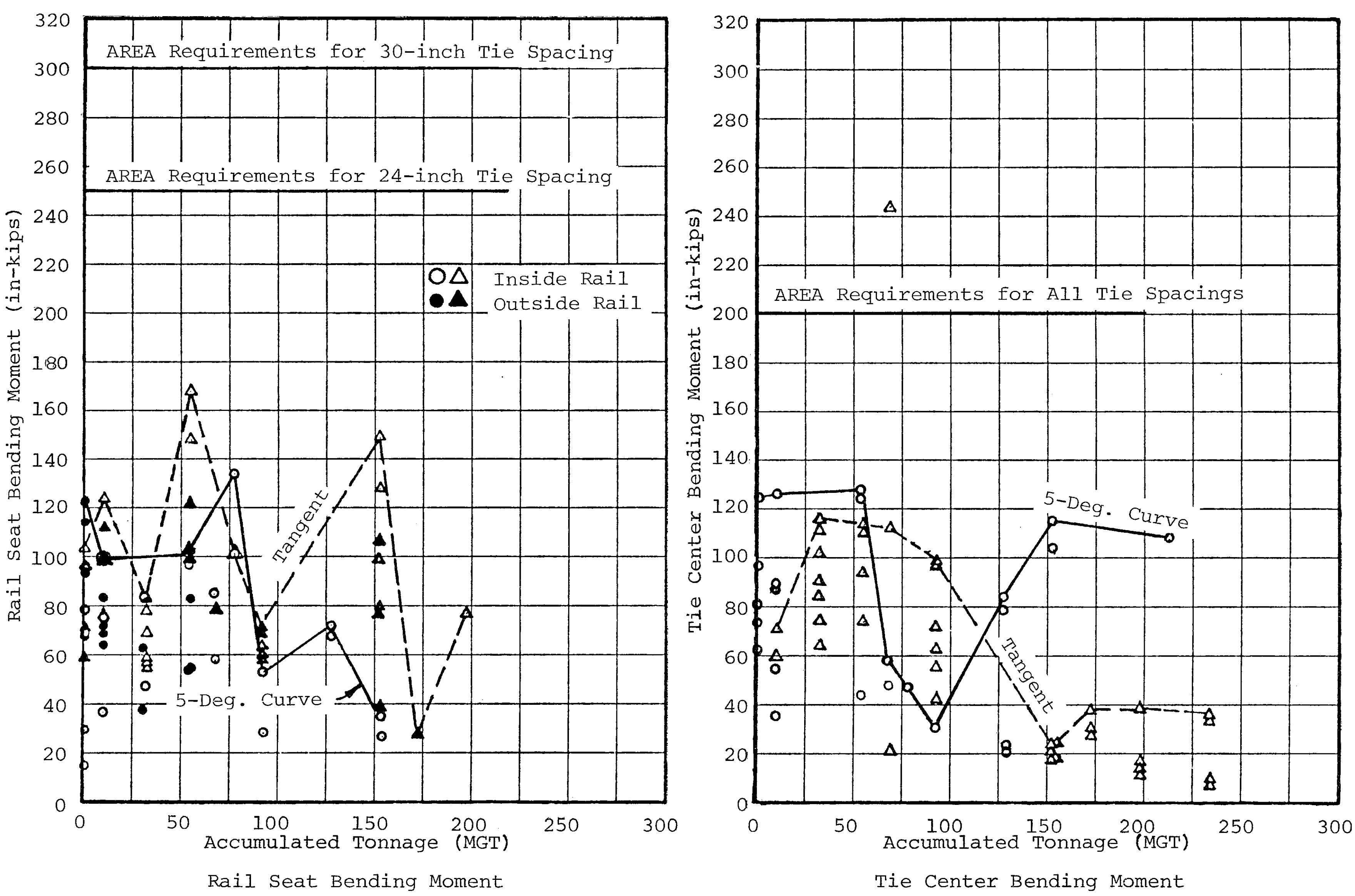
* Data in Figure 5-16 were processed with frequency bandwidth of 0-300 Hz. Recent processing of data from the Northeast Corridor track reveals high frequency spikes in the range from 300-2,000 Hz. The spikes are due to wheel flats which are present in all revenue service traffic but only rarely in the FAST train. Therefore, the differences in FAST and revenue service data shown in Figure 5-16 should be greater when the data are processed at the higher bandwidth.



Rail Seat Bending Moment

Tie Center Bending Moment

FIGURE 5-15. CONCRETE TIE BENDING MOMENT VS MGT - MAXIMUM VALUES FROM SINGLE TRAIN PASSES.

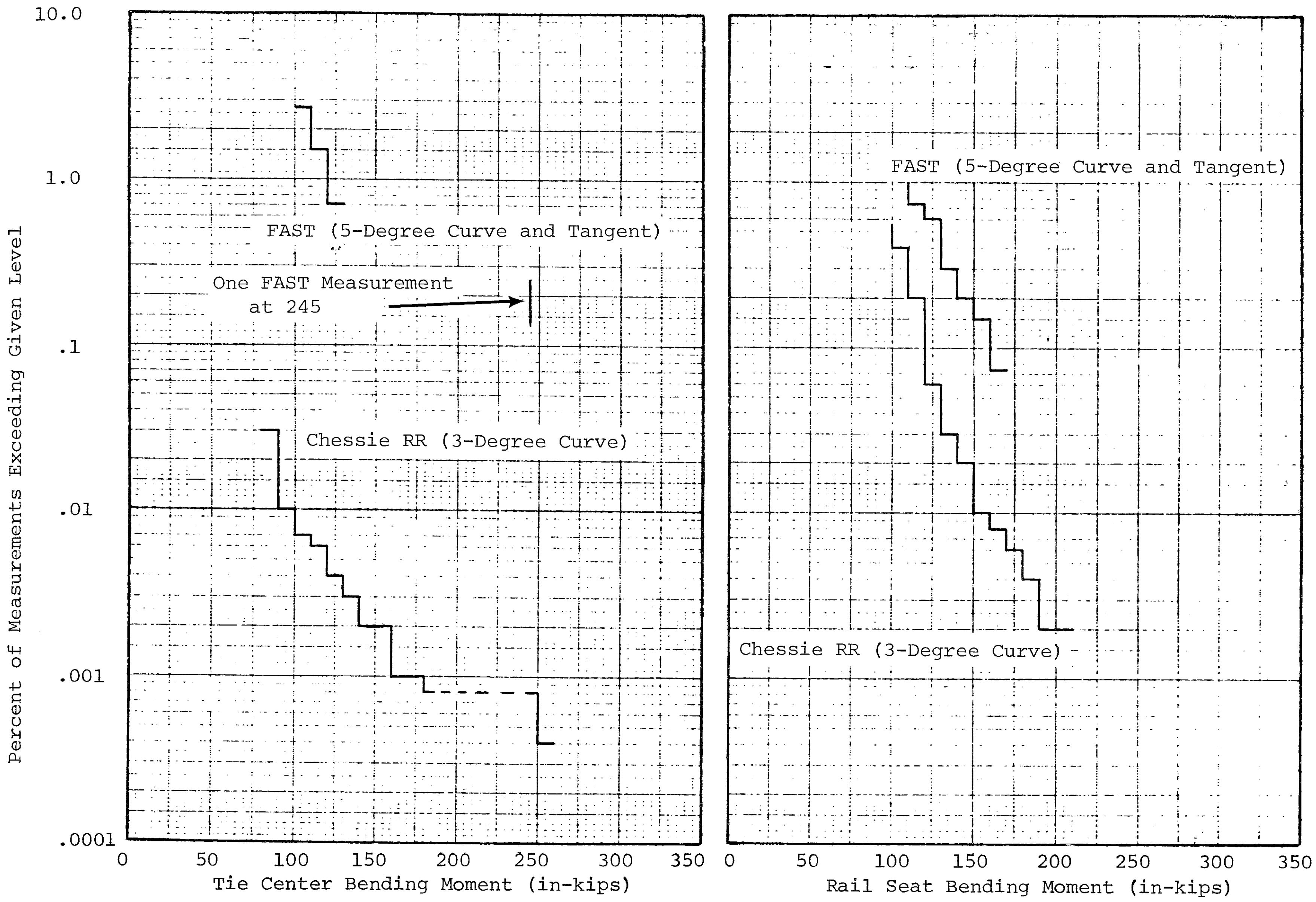


FIGURE 5-16. EXTREME VALUES OF TIE BENDING MOMENT AT FAST AND IN REVENUE SERVICE.

requirement of 300 in-kips at the rail seats, Figure 5-15, while the revenue service ties were designed to the 24" requirements (250 in-kips). The revenue service ties have developed rail seat cracks while the FAST ties have not.

An additional indication of the difference between the FAST loading environment and that of typical revenue service is illustrated by the cumulative vertical load distributions of Figure 5-17. Comparing the two envelopes of tangent track data, the FAST train produced higher loads 90 percent of the time, but did not achieve the extremes found in revenue service.

BALLAST PERFORMANCE

Many of the performance problems which have developed in the 5° curve and 2% grade of Section 17 have been attributed to physical characteristics of the ballast installed there. This ballast was also installed in the remainder of Section 17 (tangent and 3° curve) and in wood tie tangent Sections 18 and 20. Only in the 5° and 3° curves of the concrete tie track have problems occurred which might be attributable to ballast performance.

The following observations have been made about the ballast in Section 17. Subgrade fines intruded to the extent that there was no clear demarcation between ballast, subballast and subgrade.[12] The characteristically flattened, elongated shape and rounded edges may have prevented proper interlocking of particles. Ballast flow from the high (outside) shoulder occurred continually over the 425 MGT test period. An outside berm (high rail shoulder) was constructed at 61 MGT to retard the ballast flow.

Figure 5-18 shows the results of gradation measurements made on pre-installation samples of all FAST ballasts. The particle size range of the ballast used in Section 17 is seen to be distinctly finer than that of the other ballasts. While gradation is not directly a measure of ballast quality, it is generally believed that a broad range of particle sizes, including some in the range above 1.5", is necessary for good interlocking.

The ballast material was originally called "granite", but subsequent samples given petrographic analyses were termed hornfels, granodiorite and quartzmonzonite. The material name most often applied is hornfels, a brittle material which has a tendency to break down.

Unused samples from the 5 sources of FAST ballast were subjected to characterization tests which are summarized in Table 5-3.[13] In each of the characteristics, while in 5 of the 6 categories the hornfels was most similar to the traprock. Only the Flakiness index, which indicates a tendency to break down into elongated particles, and the particle size index (percent passing 3/8" sieve) give indications that the hornfels is inferior to other ballasts.

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[12] Sluz, A., "Section 17 Ballast Quality Tests", FAST/TTC/TN 79-10, Transportation Test Center, December 1978.

[13] Thompson, M.R., "Ballast and Subgrade Materials Evaluation", Report No. FRA/ORD-77/32, U.S. Department of Transportation, Federal Railroad Administration, December 1977.

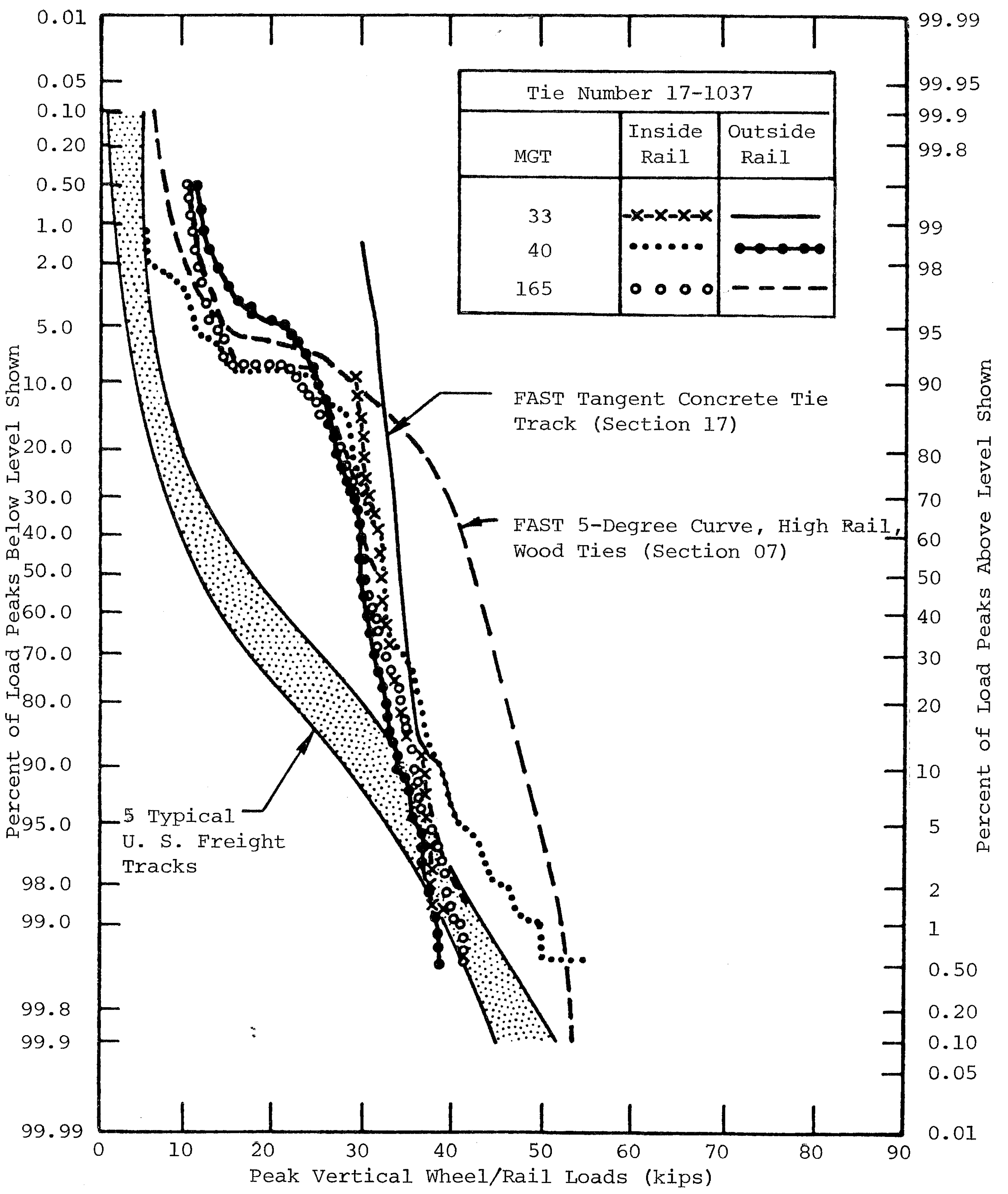

FIGURE 5-17. COMPARISON OF FAST VERTICAL LOAD DISTRIBUTION WITH THAT OF FIVE TYPICAL U.S. TRACKS.

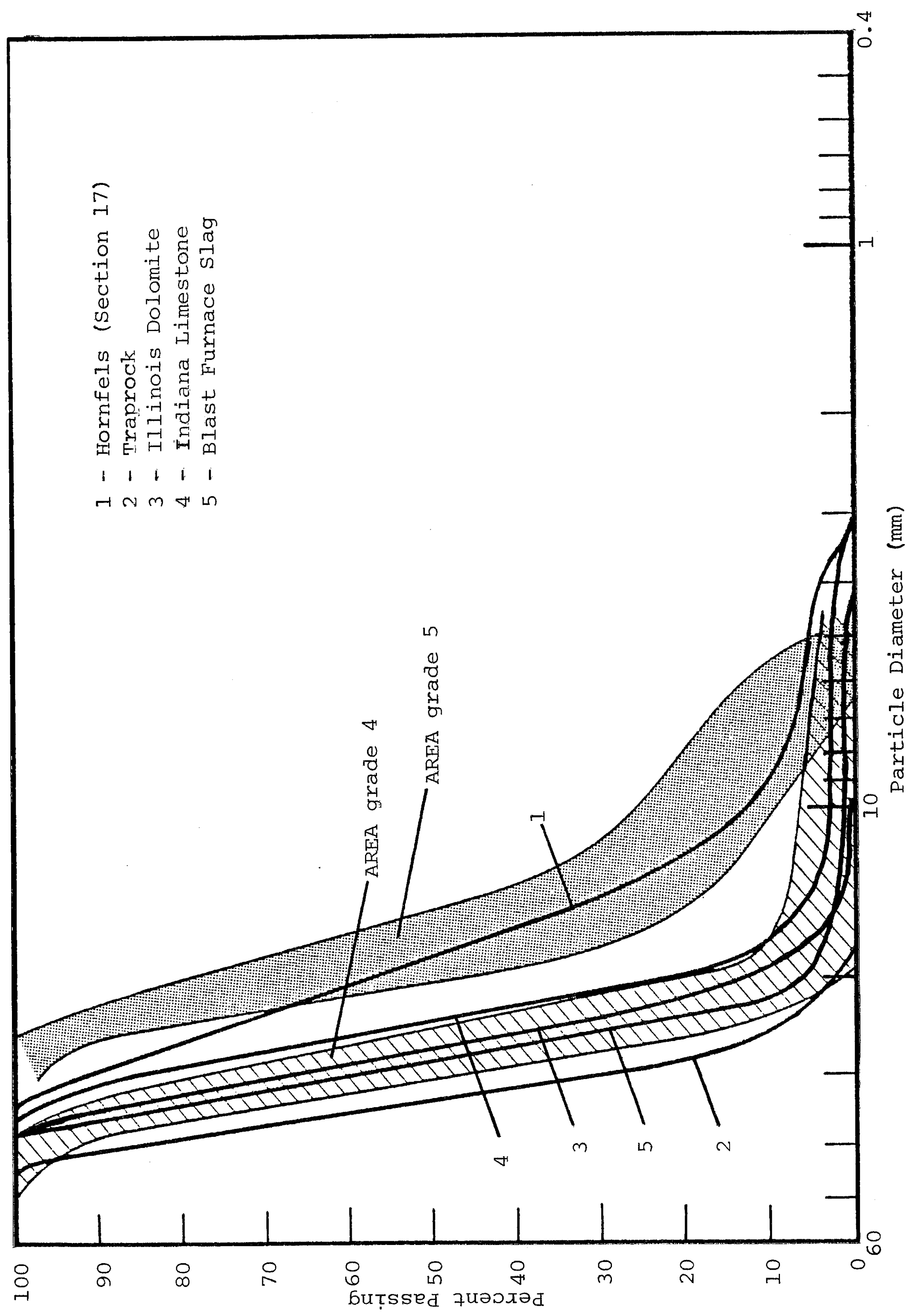

FIGURE 5-18. ORIGINAL PARTICLE SIZE DISTRIBUTION OF FAST BALLAST MATERIALS.

TABLE 5-3. FAST BALLASTS - CHARACTERIZATION TEST RESULTS.

	Wyoming Granitic Hornfels	Pennsylvania Basalt (Traprock)	Illinois Dolomite	Indiana Limestone	Blast Furnace Slag	Specification Limit (Max. value, %)
LA Abrasion* (% passing No. 12 sieve after abrasion test)	18.8	13.2	25.7	26.3	28.8	20 (CN)
Absorption Index (% water absorption)	.40	.20	1.65	1.95	1.60	.5 (CN)
Sulphate Soundess (% dissolved in sulphate solution)	.77	.55	11.9	6.3	1.6	5 (CN)
Flakiness Index (% particles less than 0.6 nominal sieve size)	20.8	22.7	9.4	10.8	5.9	--
Crushing Index (from amount of particle breakdown under pressure)	18.4	13.1	19.3	22.2	29.2	--
Particle Size (% passing 3/8" sieve)	12	0	.7	3	1.5	AREA 4: 5% AREA 5: 15%

* Los Angeles Abrasion Test

NOTES: ____ = best characteristic

____ = worst characteristic

Tests conducted with wood ties on Canadian National (CN) revenue service track from 1968 to 1971 provide additional indications of the relative importance of the material characteristic indices.[14] Averaged results from 5 of the 9 quarter-mile test segments are shown in Table 5-4. A mixture of 30% traprock and 70% hornfels produced unsatisfactory performance (fines intrusion, trouble maintaining joints) with wood ties. However, the only characteristic which might indicate poor performance of this ballast is the Flakiness Index, which was more than 50 percent higher than that of traprock alone.

Two other common indices show little correlation with performance. The LA Abrasion test is within the CN specification limit for the two unsatisfactory ballasts, but slightly above the limit for two of the satisfactory ballasts. The slag ballast had by far the finest particle size index but was rated satisfactory in performance. It should be noted, however, that none of these measurements is considered sufficient to alone determine ballast quality. In addition, the test results indicate that in some cases the satisfaction of prescribed specification limits (Los Angeles Abrasion, Particle Size) is not strictly necessary.

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[14] Dalton, C.J., "Field Durability Tests on Ballast Samples as a Guide to the Significance of the Specification Requirements", Canadian National Railways, Technical Research Center, January 1973.

TABLE 5-4. SUMMARY OF RESULTS FROM CN BALLAST TESTS IN REVENUE SERVICE WITH WOOD TIES.

	Specification Limit (Max. value, %)	30% Traprock 70% Hornfels	Medium Grained Limestone	Traprock	Slag	Igneous Intrusive Diabase
LA Abrasion* (% passing No. 12 sieve after abrasion test)	20 (CN)	12.3	25.6	12.8	24.5	18
Absorption Index (% water absorption)	.5 (CN)	.18	.28	.26	.19	1.96
Sulphate Soundness (% dissolved in sulphate solution)	5 (CN)	.75	.59	.78	.07	9.9
Flakiness Index (% particles less than 0.6 of nominal sieve size)	--	38.4	15.1	24.7	13.1	23.4
Particle Size (% passing 3/8" sieve)	AREA 4: 5% AREA 5: 15%	3.8	2.9	4.1	38.4	5.9
Observed Results (3-year test)		Unsatisfactory Fines produced muddy paste; trouble maintaining joints	satisfactory Some scaling and splitting	satisfactory Minimal particle breakdown	satisfactory No noticeable change in 3 years	unsatisfactory Serious chemical degradation, trouble maintaining joints in curve

* Los Angeles Abrasion Test

NOTES: ____ = best characteristic

____ = worst characteristic

6.0 COMPARISON OF CONCRETE TIE EXPERIENCE AT FAST AND IN REVENUE SERVICE

The ultimate objective of FAST is to act as a predictor for revenue service performance. It is therefore useful to compare the concrete tie experience at FAST with that found in some of the more recent installations in revenue service.

BACKGROUND

Since 1960, there have been more than 60 installations of concrete tie test segments in North America ranging in size from a few to 10,000 ties. In addition, major conversions of wood tie track to concrete tie track began on the Florida East Coast Railway (FEC) in 1965, on the Canadian National Railways (CN) in 1976, and on the Amtrak Northeast Corridor (NEC) in 1978.

The design of concrete tie track has experienced an evolution during this period, much of it by the process of trial and error in response to premature failures of all concrete tie track components. Early failures included:

- tie cracking at rail seats and tie centers,
- loss of clip anchorage,
- fall-out and breakage of clips,
- rapid pad deterioration, and
- insulator fall-out, breakage and loss of electrical resistance.

It was often discovered that subgrade and ballast support conditions which were adequate for wood tie track were not adequate for concrete ties. Specifications of the AREA for bending strength of ties have been increased several times as the result of the early tie failures.[15] The FEC was the first U.S. railroad to undertake a large-scale conversion to concrete tie track, and they have experienced most, if not all, of the above problems. Some problems on a more recent installation (1974) on another railroad are shown in the 1980 photos of Figure 6-1. It should be emphasized that most of the ties and fasteners in this test section are in acceptable condition for the Class 4 track where they are placed.

FAST VS REVENUE SERVICE

The FAST installation of concrete ties differs in several respects from most recent revenue service installations:

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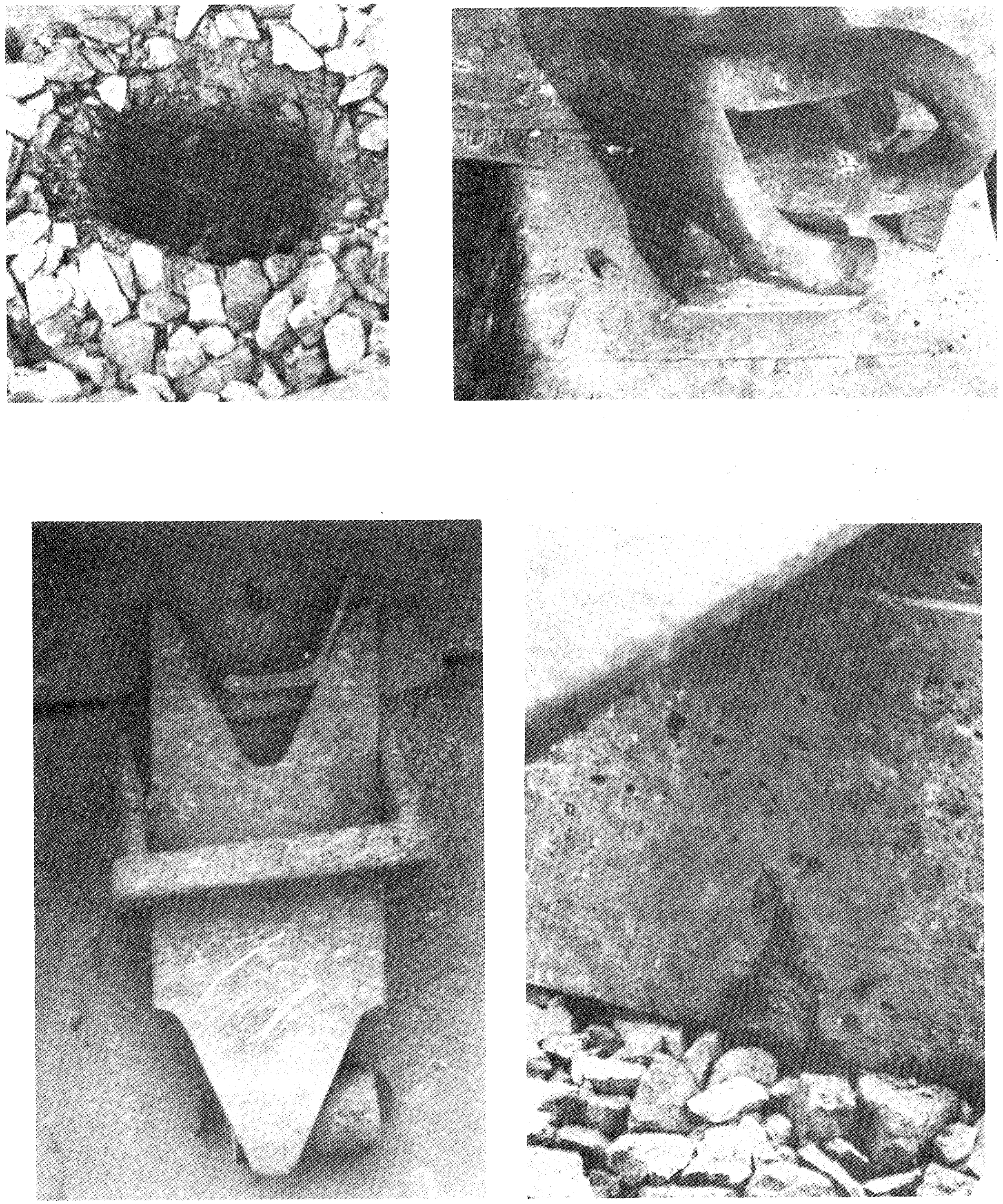
[15] Prause, R.H., et. al., "An Evaluation of Performance Requirements for Cross Ties and Fasteners", Report No. FRA/ORD-78/37, prepared by Battelle- Columbus Laboratories for the U.S. Department of Transportation, Transportation Systems Center, December 1978.



(c) Insulator Broken, Clip Displaced

(d) Rail Seat Bending Crack

(Ties installed in 1974, photos taken in 1980.)

FIGURE 6-1. TIE/FASTENER CONDITIONS FROM A REVENUE SERVICE TEST SECTION, 3° CURVE.

- Track Construction. While some concrete tie track in revenue service has been constructed on poor ballast or ballast which has become badly fouled, as in Figure 6-1(a), most of the recent installations have benefitted from the early experiences such as those on the Florida East Coast and Canadian National Railways. In most later installations the concrete ties have been installed on good quality crushed stone ballast. The FAST concrete tie track was constructed with a Grade 5 ballast which did not have optimal characteristics in angularity, sphericity and hardness, for this application.

  What was intended to be granite ballast later proved to be hornfels, based on tests conducted well after FAST was in operation.

  The combination of a 5° curve and 2% grade is unusual in track construction. While it does provide severe contour conditions for test purposes, it has made the performance data collected there unusable for more than qualitative comparisons with other track segments.

- Traffic. It has been demonstrated in measurements of wheel/rail loads and tie bending moments on revenue service test segments that most revenue freight and passenger trains contain a small but significant percentage (5 to 10 percent) of wheel flats. The worst of these flats can cause dynamic impact load factors up to three times the static wheel loads. In most cases it is only the wheel flats which produce high levels of tie bending moment, unless the tie is located near a joint or other track anomaly. While the FAST train contains a high percentage of cars and locomotives with 33-ton axle loads, it does not contain wheel flats and thus does not produce the loads which might most often produce concrete tie failure.

RECENT MAJOR CONCRETE TIE INSTALLATIONS

The recent major installations on the CN and the NEC have moved the development of concrete tie track from the experimental stage into large-scale production. These are the only current, large-scale concrete tie installations which use ties similar to those used or in use at FAST, and about which the circumstances leading to the selection of concrete ties and some early indications of performance are known. These are reviewed briefly, as follows.

Canadian National Installation.[16] The CN began the development of alternative track construction for two reasons:

- Increased axle loads and tonnage levels were causing premature failures of existing softwood ties on curved track.
- Hardwood ties were not available at economically feasible costs for their western regions.

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[16] Cann, J.L., "CN Experience with Concrete Sleepers", Railway Gazette International, February 1978, pp. 49-65.

For a test program conducted in 1972 and 1973, the following substitution was made:

Old Track	New Track
softwood	concrete ties
gravel ballast	10" new crushed stone over existing gravel
standard carbon rail (Std)	HiSi rail
jointed rail	continuously welded rail (CWR)

This replacement produced immediate improvements in retention of gage, retention of surface and alignment, and in reduction of rail wear. However, the improved retention of gage is the only characteristic directly attributable to the use of concrete ties. It is probable that the improved gage retention contributed to the reduction of rail wear and the improved retention of surface and line.

Following the test phase, the CN ordered 1.5 million concrete ties designed to CN specifications. The ties were to be installed on curves greater than 2° where annual tonnage exceeded 20 MGT and where the traffic contained high percentages of 100-ton cars and unit trains. A track laying system was acquired to permit complete track renewal on a large scale. It was concluded that this type of renewal was required for the economical conversion from wood to concrete ties.

While the CN is generally satisfied with the overall performance of the track, they are disappointed with the durability of the pads and insulators on curves, and there have been limited numbers of clip fall-outs and fractures. However, these clip problems, even on reverse curves up to 8° under heavy unit train operations, are not comparable in magnitude to those experienced on the 5° curve and 2% grade at FAST.[17]

Northeast Corridor Performance. As part of the Northeast Corridor Improvement Project, it was decided to rebuild 400 track miles with concrete ties. This decision was reached on the basis of the following assumptions:[18] [19]

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[17] Weber, J.W., "The Concrete Tie: An Update", Railway Track and Structures, prepublication draft.

[18] "Concrete Sleeper Breakthrough in the Northeast Corridor", Railway Gazette International, February 1978.

[19] White, D.W.; Arnlund, R.C.; and Prause, R.H., "Economics of Concrete- and Wood-Tie Track", Report No. FRA/ORD-78-2 prepared by Bechtel, Inc. and Battelle-Columbus Laboratories for U.S. Department of Transportation, Transportation Systems Center, August 1978.

- The wood tie industry could not supply all of the ties required within the originally planned construction period.*
- There was a need to establish production facilities and to demonstrate construction methods for alternative track construction.
- At least 400 track miles required complete renewal rather than the traditional renewal involving only partial tie replacement.
- The average life of concrete ties would be 50 years vs 25 years for wood ties.
- Certain maintenance operations would be less expensive on concrete tie track.
- The costs of fastener maintenance, other than the regaging of wood tie track, would be approximately equal for wood and concrete tie track.

This installation will be monitored closely to determine the differences in loading environment and structural performance between FAST and the NEC.

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* The wood tie industry does not agree with this assumption.

7.0 PERFORMANCE SUMMARY

This review of the wood and concrete tie track performance at FAST and the comparison of the FAST environment with revenue service has shown that:

- Performance problems occurred in the 5° curves of both the concrete and wood tie track at FAST. The most serious problems of the concrete tie track were the rates of fall-out and fracture of fastener clips and the requirement for rail anchors to control the longitudinal movement of the ties. The most serious problems of the wood tie track were the control of gage, damage to ties through yielding of inadequate fasteners, the occurrence of rail defects, and weld failures generated by the rail metallurgy test segments.

- In two important performance areas (frequency of surface, line and tamping maintenance and tie repositioning), major differences in performance between concrete and wood tie track appear to have been caused by differences in grade and ballast and by the lack of adequate longitudinal restraint of concrete tie fasteners without rail anchors.

- The current purchase cost of a fully equipped concrete tie is 25 to 30 percent higher than for a fully equipped wood tie.* Unless this ratio is significantly improved, the economic justification for the use of concrete ties in U.S. mainline track must depend upon the assumption of performance differences, such as:

  - that the average life of concrete ties will be much longer than that of wood ties,

  - that concrete tie track can significantly improve the gage widening problem in curves, and

  - that other maintenance costs of concrete tie track will be, at worst, no higher than for wood tie track.

  These performance projections have not been verified or refuted by the track performance experiments at FAST. A more meaningful comparison in the performance of wood and concrete tie track systems will be obtained by the Phase II experiment which began at 425 MGT and will run to about 800 MGT. In the latter half of this experiment, concrete and wood tie test segments will be installed on the same 5° curve (Section 03) without the effects of grade.

- Major differences between the FAST environment and those of recent major concrete tie installations in revenue service existed during the first 425 MGT. These include:

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* Note: Recent conversations with track equipment suppliers.

- the lack of wheel flats in the FAST consist
- the combination of the 5° curve and the 2% grade at FAST
- the poor quality of the ballast in the FAST concrete tie test section
- poor welding practices, causing variations in rail hardness at welds. Early corrugations resulted.

- Concerning the possible effect of ballast quality on track performance, it should be pointed out that some observers believe that the physical characteristics of the ballast in Section 17 created many of the performance problems. This ballast was replaced with AREA Grade 3 granite during the 1979 rebuild. Performance problems, such as fastener failures and tie movement, have continued. This indicates that the ballast may not be a major contributing factor to the concrete tie performance problems.
- Measurements of dynamic loads and tie strains at FAST and in revenue service show that most of the impact loading which normally occurs in revenue service does not develop at FAST. Most significant levels of tie bending moment in revenue service are produced by impact loads.
- The Phase II concrete tie experiment at FAST will eliminate most of the difficulties which have prevented meaningful performance comparisons between wood and concrete tie track. However, the critical question of concrete tie life cannot be reliably investigated at FAST until dynamic loads equivalent to those produced by wheel flats in revenue service are reproduced at FAST.

CONCRETE TIE FASTENER COMPONENTS

- Clips. The 5° and 3° curves of concrete tie Section 17 contained only one type of elastic rail fastener clip during the first 425 MGT. This clip was installed with external insulators separating the clip and the rail base (Type F-1) except in Subsection D_2 where the insulation was bonded to the fastener stem (Type F-2).

  Type F-1 fasteners required high rates of clip replacement due to fall-out and fracture in the 5° curve of Section 17. The clips were replaced almost entirely on two occasions (61 and 235 MGT), and required spot replacements due to clip fracture totalling over 15 percent of the clips in the 5° curve. Most fractures occurred at the inside gage (IG) position.

  The cumulative fall-out rate totalled over 50 percent in Subsection C where it appears to have been relatively independent of pad hardness. The soft corded rubber pads were replaced by a medium hard polyurethane pad at 235 MGT. Fall-outs continued at a slightly higher rate.

  Clip fall-outs totalled over 140 percent in subsection 17-D_2 where internal insulation was used (Type F-2 fastener, same clip as for Type F-1). This installation had not been approved by the clip manufacturer. Friction between the rail base and fastener shoulder caused shoulder wear up to about 3/16".

  The Type F-1 fastener was also installed exclusively in the 3° curve of Section 17. In this section the rates of clip reinstallation due to fall-out and replacement due to fracture were much lower than those required in the 5° curve. Most clips in the 3° curve survived the entire 425 MGT period.

  A metallurgical study of the causes of clip fracture concluded that the clips failed in high-cycle fatigue, and that fracture rates were possibly affected by surface decarburization in the replacement clips installed at 61 and 235 MGT. Decarburization in the replacement clips was higher than in the original clips.

  A laboratory and field investigation of clip load-strain behavior found that clips were locally strained from 6,000 to 10,000 microinches (past the yield point of 6,000 microinches) on installation and that dynamic strains were produced by train action up to 20% of installation strain. Field measurements of toe load produced averages from 1,400 to 1,600 lbs, vs the nominal design toe load of 2,000 lbs.

  A lack of adequate longitudinal restraint for the track on the 5° curve and 2% grade was indicated by high rates of tie repositioning in subsections 17-A and 17-B, necessitating installation of rail anchors at 179 MGT. One goal of using direct fixation clips with concrete ties is to eliminate the necessity of rail anchors.

- Pads. The 8 types of pads originally installed in Section 17 can be approximately separated into three classifications of hardness: "hard", "medium hard", and "soft". Only the "soft" Type P-2 and P-3 pads installed in the 5° curve experienced significant failure rates. About 25 percent of the Type P-2 corded rubber pads in the 5° curve were replaced (due to wear and delamination) before the rebuild at 235 MGT. Defect rates identified during an inspection at 235 MGT included:

  - 32 percent of the Type P-2 corded rubber pads, and
  - 18 percent of the Type P-3 fiber-reinforced pads.

  In the 3° curve, pad failure rates among "soft", "medium hard", and "hard" pads did not exceed 3.2 percent through 235 MGT.

  Most of the Type P-2 pads and all of the Type P-3 pads in the 5° curve were replaced at 235 MGT with Type P-5 "medium hard" polyurethane pads. Pad defect rates were reduced but a possible side effect could be seen in an increased rate of clip fall-out; and beginning about 260 MGT, a renewed and slightly higher rate of clip fracture. However, the extent to which the pad may have contributed to these failure rates cannot be separated from the possible variations among replacement clips. All clips in the 5° curve were replaced at 235 MGT.

- Insulators. External insulators (metal-plastic shim inserted between the clip and the rail base) were completely replaced in the 5° and 3° curves of Section 17 at 235 MGT. Prior to the replacement, the condition of the old insulators was inspected. Percentages judged defective (broken or cracked) were:

  - 5° curve: 38 percent defective, and
  - 3° curve: 58 percent defective.

Defective insulators on the 5° curve were concentrated on the inner rail, field side (IF) and outer rail, gage side (OG) positions. Defective insulators on the 3° curve were distributed approximately uniformly with respect to position on the tie.

TRACK GEOMETRY

Variations in gage, alinement, profile and crosslevel were plotted vs MGT for representative sections of wood and concrete tie track on tangents and 5° curves. With the exception of the gage variation on curved track, all plots were approximately equivalent for concrete and wood tie track and fell within the limits of FRA Class 6 track at the 5% exceedance level.

Gage variations in the 5° curves of wood tie Section 03 and concrete tie Section 17 were almost equivalent between 150 and 425 MGT, although the concrete ties maintained a narrower average gage. Between 80 and 150 MGT, the initially tighter setting of the concrete tie gage appears to have contributed to a very high rate of gage widening. Cumulative gage widening between 80 and 425 MGT was 0.60" for the concrete tie track and 0.49" for the wood tie track.

It should be emphasized that gage widening on concrete tie track occurs primarily by rail wear, whereas it occurs from a combination of wear and fastener yielding on wood tie track. Some of the results for the concrete tie section were probably affected by the lack of external insulators in one subsection where wear of the fastener shoulders up to 3/16" was observed.

LATERAL TRACK STRENGTH

Measurements of the lateral forces required to deflect unloaded track were consistently higher on concrete track than on wood tie track. In comparing overall mean lateral test forces at given deflections, results for the concrete tie track were higher by the following amounts:

- 149 percent at the "small" deflection of 0.05",
- 62 percent at the "large" deflection of 0.2".

CONCRETE TIE PERFORMANCE

The ties installed in the 5° curve of Section 17 were of two types (T-1 and T-2) which had been designed to satisfy the current requirements of the AREA for bending strength at rail seats and tie centers. These ties were removed at 425 MGT and placed in a storage area where they were inspected. Minor cracking patterns were found on a few ties of each type, but there were no rail seat flexural cracks. Rail seat flexural cracks have been the major cause of tie failure in other test segments in revenue service.

Top center, transverse flexural cracks on Type T-1 ties developed in a restricted area of the 5° curve. These were noticed early in the operations period and were inspected originally at 100 MGT. There was very little growth in these cracks during the following 325 MGT. Most of these cracks occurred in a short zone of 141 ties where 32 ties (23 percent) were cracked. The fact that the cracks showed very little growth after they were first observed indicates that they may have been caused by poor initial support conditions.

Laboratory bending strength tests were conducted on a selection of ties removed from the 5° curve and on unused ties from the same production runs. The purpose of these tests was to determine the effect of the cracking patterns on tie bending strength. Only for the Type T-1 ties with top center flexural cracks did the bending strength relative to a structural crack show a definite drop compared to previously unused or uncracked ties of the same type. There was no comparable reduction in ultimate strength.

The remaining important indicator of tie durability can be found in subsection F where some of the ties had been originally used in the Kansas Test Track. These ties contained flexural rail seat cracks when installed at FAST, and they have since provided over 500 MGT of service in tangent track. It should be noted that this section has firm subgrade support and that the Pueblo area has a relatively dry and mild climate in comparison to other areas of the country. It has been suggested that had the ties remained in the Kansas Test Track, with its very poor support conditions, they would have failed.

TIE BENDING STRAIN AND LOAD ENVIRONMENT

Strain gage measurements calibrated to indicate tie bending moment under train loads produced data well below the strength requirements of the AREA at both the rail seats and tie centers. A comparison of very low-probability, extreme values of bending moments measured at FAST and on a revenue service test site (3° curve) shows that peak values at FAST are lower than those in revenue service by 50 percent at tie centers and by 19 percent at rail seats. The revenue service ties cracked at rail seats while the FAST ties did not. However, the revenue service ties were designed to a less demanding strength specification than were the FAST ties.

Comparisons of vertical load spectra on tangent track at FAST and on typical revenue service tracks show that while the FAST train produces higher average loads it produces lower extreme loads. The lack of flat wheels in the FAST consist and careful maintenance of the geometry of the FAST track contribute to the latter difference.

APPENDIX A

FAST BACKGROUND

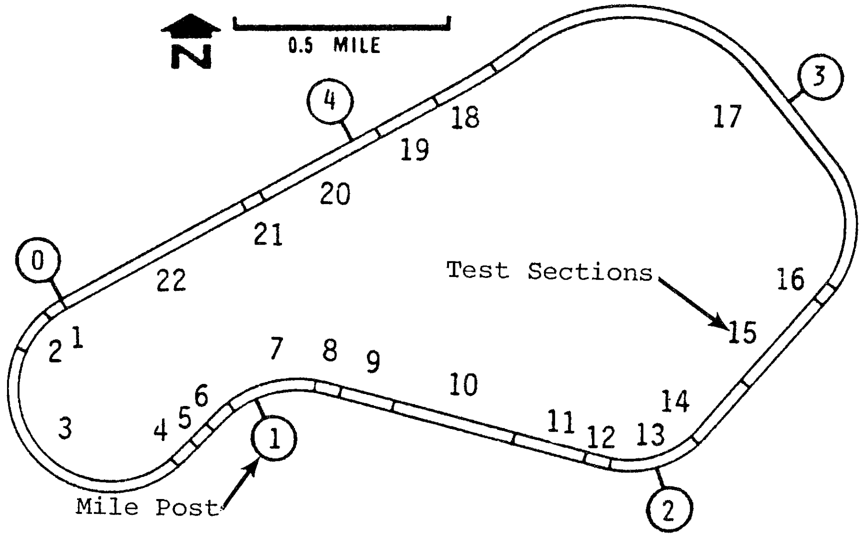
FAST has been installed and operating at the DOT Transportation Test Center since September 1976. The physical facilities include a 4.8 mi loop of track, a fleet of cars and locomotives, and a maintenance facility. The organization includes a staff of people to operate the trains, perform maintenance and inspections, carry out regular performance measurements on vehicles and track and manage the storage and retrieval of data. This facility was created as a joint effort of the Federal Railroad Administration (FRA), the Association of American Railroads (AAR), the Transportation Test Center (TTC), the Transportation Development Agency of Canada, the railroads and the Railway Progress Institute.

The purpose of FAST is to simulate the service environment of both track and vehicles at rates of tonnage accumulation much higher than those of average revenue service. The train runs five nights a week, and maintenance and performance measurements are carried out during the day. From the beginning of operations in September 1976 up to the shutdown for rebuild in July 1979, the test train accumulated approximately 425 MGT, for an annual rate of 150 MGT, over seven times that of an average mainline track (about 20 MGT per year). Future rates can be expected to increase, since several shutdowns have been required for repair of vehicles and track.

The test train fleet, which is loaned by the railroads, normally consists of 80 cars and five locomotives. Regular maintenance and measurements are performed on four cars each day, so that about 76 cars and 4 locomotives are in the consist.

A wide range of performance measurements are regularly made on both the vehicles and track. Track performance data are collected at tonnage intervals ranging from 1 to 50 MGT. Additional track performance measurements are required before and after many maintenance procedures. The data are digitized and stored on permanent files at TTC.

The FAST track is divided into 22 sections providing many combinations of track construction components, as shown in Figure A-1. Twenty of the 22 sections were initially built with wood ties. Section 06 was initially built with steel ties which were removed at 28 MGT. Section 17 is 6,100' long and contains 2,886 concrete ties installed on 24" centers, with short transitions of wood tie track at either end of the section. Much of this evaluation concerns the performance of this concrete tie section.



LEGEND:

Test Section	Description/Test Variable
1	Existing No. 20 Turnout
2	Rubber Pads (0-358 MGT) Wood and Reconstituted Ties (358 MGT - Present)
3	Rail Metallurgy (Changed at 425 MGT)
4	Spiral, Standard Track (0-358 MGT) Wood and Reconstituted Ties (358 MGT - Present)
5	Bonded Joints (Removed)
6	Steel Ties (Removed at 28 MGT)
7	Fasteners/Wood Ties (Changed at 135 MGT and 358 MGT)
8	Spiral, Standard Track
9	Dowel Laminated, Reconstituted Ties
10	Elastic Spikes, Spring Frogs (Removed)
11	Joints (Originally included Frogs and Guardrails which were removed before 200 MGT)
12	Spiral, Standard Track
13	Spike Hole Filler Test (Deleted)
14	Existing No. 20 Turnout
15	Ballast Shoulder Width
16	Glued No. 20 Turnout
17	Concrete Tie Track
18	Ballast Depth
19	Oak and Fir Ties
20	Ballast Type and Depth, Rail Anchors
21	Welded No. 20 Turnout (Straight Railed, Deleted)
22	Spiking Patterns and Rail Anchors (Test Deleted)

FIGURE A-1. SUBSECTIONS OF THE FAST TRACK LOOP.

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