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REPORT NO. FRA/TTC-80/02 PB

CONCRETE AND WOOD TIE TRACK PERFORMANCE THROUGH 150 MILLION GROSS TONS

FAST Facility for Accelerated Service Testing

TRANSPORTATION TEST CENTER
PUEBLO, COLORADO 81001

MARCH 1980

INTERIM REPORT

PREPARED FOR
THE FAST PROGRAM

AN INTERNATIONAL GOVERNMENT - INDUSTRY RESEARCH PROGRAM

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Washington, D.C. 20590

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NOTICE

NOTICE

Moody

Southern Railway System

Engineering Department
P. O. Box 1808
Washington, D. C. 20013

March 23, 1979

W. W. SIMPSON
Vice President

23-6-3

920 15TH STREET, N.W.
TEL.: (202) 628-4460

Mr. R. M. McCafferty
TTC, Technical Documentation Control
U.S. Department of Transportation
Federal Railroad Administration
Washington, DC 20590

Dear Mr. McCafferty:

Please refer to your letter of March 1, 1979, your file RTC-30, concerning a report entitled "Concrete and Wood Tie Track Performance".

I gave you my comments on March 16, but now attach some additional comments which are the result of our Laboratory personnel analysis of the report.

This is for your information.

With respect to the statements made in this report, we are not in full agreement in the following areas and suggest consideration be given to changing these statements:

Page 9 - 150 million gross tons was obtained in November 1977. This dates the report. If it is possible to include more recent test data, the report would be of greater value.

Agree
+ Review

Page 10 - We question why the maintenance man-hours to restore the concrete crosstie track after buckling are removed from the maintenance requirement comparison between wood and concrete ties. We suggest this be included. *Removed because train ops caused buckling*

Page 10 - We find it difficult to understand how track geometry degradation was the same for concrete and wood ties when constant problems with alignment and surface occurred in Section 17. The comparison of track geometry does not reflect this, and we believe it should. *but it does in 57*

Page 11 - Rail wear - we do not believe an accurate comparison can be made when different rail metallurgy and rail lubrication was used in the wood and concrete tie sections. *OTHER FACTORS*

With regard to rail creep, no mention is made that rail creep was stablized after anchors were applied. Our observations showed that the Pandrol clips were not holding the rail in the concrete crosstie section.

Page 13 - The report indicates that there was no evidence the concrete ties caused tie and rail movement, ballast flow, or ballast crushing. However, these problems did not occur, or they were of less severity, in the wood tie sections. This is not explained, and we believe this difference should be pointed out. The fact that these problems did occur on the concrete tie section and did not occur to the same magnitude on the wood ties makes us suspicious that the concrete ties contributed to the problem.

Page 21 - The statement that buckled track was the result of poor ballast in the concrete tie section, and that related maintenance costs should be subtracted from the concrete tie maintenance costs is an assumption that has not been proven.

Page 28 - Rail wear - we believe this comparison of rail wear is innapropriate to the concrete tie test since there were too many uncontrolled variables.

Rail wear is being handled by rail experiment in a more controlled test.

Page 46 - Tie performance - the report states that concrete ties have cracked under service loads, but there have been no failures. This seems somewhat inconsistent as the ties are not designed to crack.

Page 57 - Reference is made to metallurgical evaluation of failed Pandrol fasteners. To our knowledge, these evaluations were done by the manufacturer; if this is correct, we would suggest an independent examination. The issue here that needs to be resolved is why the original Pandrols first came loose, and the replacement Pandrols broke.

We recognize the difficulties in obtaining factual and accurate data in a test where the authors are far removed from the test site and the test period is 1-1/2 years old. In general, we find the report unbiased and satisfactory. Battelle's handling of the test data is an improvement over previous reviews by groups or individuals with a special interest in concrete crossties.

Very truly yours,

W. W. Simpson

Southern Railway System

Engineering Department
P. O. Box 1808
Washington, D. C. 20013

March 16, 1979

W. W. SIMPSON
Vice President

23-6-3

920 15TH STREET, N.W.
TEL.: (202) 628-4460

Mr. R. M. McCafferty
TTC, Technical Documentation Control
U.S. Department of Transportation
Federal Railroad Administration
Washington, DC 20590

Dear Mike:

Please refer to your letter of March 1, 1979, your file RTC-30, concerning a report entitled, "Concrete and Wood Tie Track Performance."

Consideration should be given to deleting the following statements:

Page 13: "The ballast flow has apparently been caused by the use of marginal quality ballast."

To my knowledge, "marginal quality" has never been defined.

Page 58: "The size and shape of the ballast which determine how well the ballast interlocks and consolidates."

This statement has no real meaning and infers that optimum size and shape is known.

Page 58-60: "The granite ballast conforms to AREA gradation No. 5. While there are no specific restrictions on the use of Grade 5 ballast, its application in a combined curve and grade on new embankment under an experimental track section can be questioned."

I do not think that such a statement has been sufficiently validated.

Delete 5.3.3 Summary of Ballast Performance.

This could be politically sensitive in that it tends to absolve concrete ties and suggest that "marginal" granite ballast is responsible and that granite might not be a good ballast.

Very truly yours,

KISH
MOODY
SL43

Technical Report Documentation Page

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FRA/TTC-80/02		

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7. Author(s): Francis E. Dean and Robert H. Prause	
9. Performing Organization Name and Address: *Battelle-Columbus Laboratories 505 King Avenue Columbus, Ohio 43201	10. Work Unit No. (TRAIS) 11. Contract or Grant No.: DOT-TSC-1044
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15. Supplementary Notes

*Under Contract to: U.S. Department of Transportation, Transportation Systems Center, Kendall Square, Cambridge, MA 02142

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16. Abstract

This report has been prepared as part of the Improved Track Structures Research Program sponsored by the Office of Rail Safety Research of the Federal Railroad Administration. The report presents an evaluation of concrete and wood tie track performance from test data taken at the Facility for Accelerated Service Testing (FAST). The evaluation examines track performance on two levels:

a. The system performance level, in which maintenance burdens, geometric stability, track stiffness and railwear are compared for similar sections of concrete- and wood-tie track, and

b. The concrete tie component performance level, in which particular types and combinations of ties, pads, fasteners, and ballast are examined for their resistance to wear and failure.

The primary purpose of this effort is to contribute to the establishment of the technical and economic feasibility of concrete cross ties in U.S. mainline service. The report neither proves nor disproves this feasibility, but a number of important problems in the design and application of concrete ties are identified.

When using the information in this report to evaluate potential revenue service applications, the FAST test environment should be taken into consideration.

17. Key Words	18. Distribution Statement
Concrete Cross Ties, Track Performance, Track Components, Track Testing, Track Loading, and Accelerated Service Tests	Document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	71	

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	sq inches	6.5	sq centimeters	cm^2
ft^2	sq feet	0.09	sq meters	m^2
yd^2	sq yards	0.8	sq meters	m^2
mi^2	sq miles	2.6	sq kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
^oF	Fahrenheit	5/9 (after subtracting 32)	Celsius	^oC

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	sq centimeters	0.16	sq inches	in^2
m^2	sq meters	1.2	sq yards	yd^2
km^2	sq kilometers	0.4	sq miles	mi^2
ha	hectares (10,000 m)	2.5	acres	a
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic	ft
m^3	cubic meters	1.3	cubic	yd
		TEMPERATURE (exact)		
^oC	Celsius	9/5 (then add 32)	Fahrenheit	^oF

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PREFACE

This report was prepared by Battelle-Columbus Laboratories (BCL) under Contract No. DOT-TSC-1044 as part of the Improved Track Structures Research Program (ITSRP) managed by the Department of Transportation, Transportation Systems Center (TSC). This program is sponsored by the Office of Rail Safety Research, Improved Track Structures Research Division, of the Federal Railroad Administration (FRA), Washington, D.C.

This report, which is the sixth and final report for this contract, gives an evaluation of concrete and wood tie track performance using data collected from the Facility for Accelerated Service Testing (FAST) Track at the Transportation Test Center (TTC) in Pueblo, Colorado. The first interim report (FRA/ORD-77/03) was a planning document for a project to measure a track service load environment. The second interim report (FRA/ORD-77/71) covered the review, selection, and development of track analysis models for predicting track response and included a statistical description of concrete tie track loads from measurements made on the Florida East Coast Railway. The third interim report (FRA/ORD-77/75) was a parametric analysis of track response which included the effect of variations in the principal track design variables of tie size, tie spacing, and ballast depth. The fourth interim report (FRA/ORD-78/02) was an economic analysis of concrete and wood tie track to determine the justifiable cost of concrete ties as a function of track and traffic conditions. The fifth interim report (FRA/ORD-78/37) gave an assessment of current design/performance specifications for tie/fastener systems based on the performance history of concrete-tie track in the U.S.

Andrew Kish of the Transportation Systems Center was the technical monitor for this contract, and he was also the Experiment Manager for the concrete tie/fastener experiment program at FAST. His cooperation and assistance are gratefully acknowlegded. Howard Moody of the FRA also contributed much helpful information about the FAST Track and the FAST measurement program. Preliminary data reductions were performed by the data processing and analysis staffs of the TTC and the Association of American Railroads (AAR).

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1.0 INTRODUCTION

This report presents a performance evaluation of selected concrete and wood tie track sections over the first 150 million gross tons (MGT) of test train operations at the Facility for Accelerated Service Testing (FAST). The evaluation examines track performance on two levels:

a. The system performance level, in which maintenance burdens, geometric stability, track stiffness, and rail wear are presented for similar sections of concrete and wood tie track, and

b. The concrete tie component performance level, in which particular types and combinations of ties, pads, fasteners, and ballast are examined for their resistance to wear and failure.

This effort is expected to contribute to the following objectives:

a. The improvement of design specifications and guidelines for concrete tie track and track components, and

b. The establishment of the technical and economic feasibility for concrete tie track in U.S. mainline service.

This work is also intended to contribute to the development of data reduction procedures and measurement plans for the continuing FAST Track performance evaluation program.

This report is a continuation of the study[1-1] which evaluated FAST Track performance through the first 50 MGT of operation. Groundwork for the present study was laid by an analysis plan[1-2] and by a request for data reduction[1-3] which was submitted to the Association of American Railroads (AAR) Technical Center and to the Transportation Test Center (TTC).

1.1 FAST BACKGROUND

The Facility for Accelerated Service Testing consists of a 4.8-mi loop of track, an 80-car test train, and support facilities located at the DOT Transportation Test Center near Pueblo, Colorado. This facility was created

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[1-1] Kish, A., et al., "Track Structures Performance--Comparative Analysis of Specific System and Component Performance," Report No. FRA/ORD/77/29, June 1977, PB #275177.

[1-2] Dean, F.E., and Prause, R.H., "Plan for the Reduction, Analysis and Interpretation of Track Performance Data from the Facility for Accelerated Service Testing," report by Battelle-Columbus Laboratories to Transportation Systems Center, Task 9.1 of Contract DOT-TSC-1044, December 15, 1977.

[1-3] Kish, A. and Dean, F.E., "Data Analysis Requirements for FAST Track Performance Evaluation," prepared by Battelle-Columbus Laboratories and distributed under cover letter from Transportation Systems Center, Task 9.2 of Contract DOT-TSC-1044, December 8, 1977.

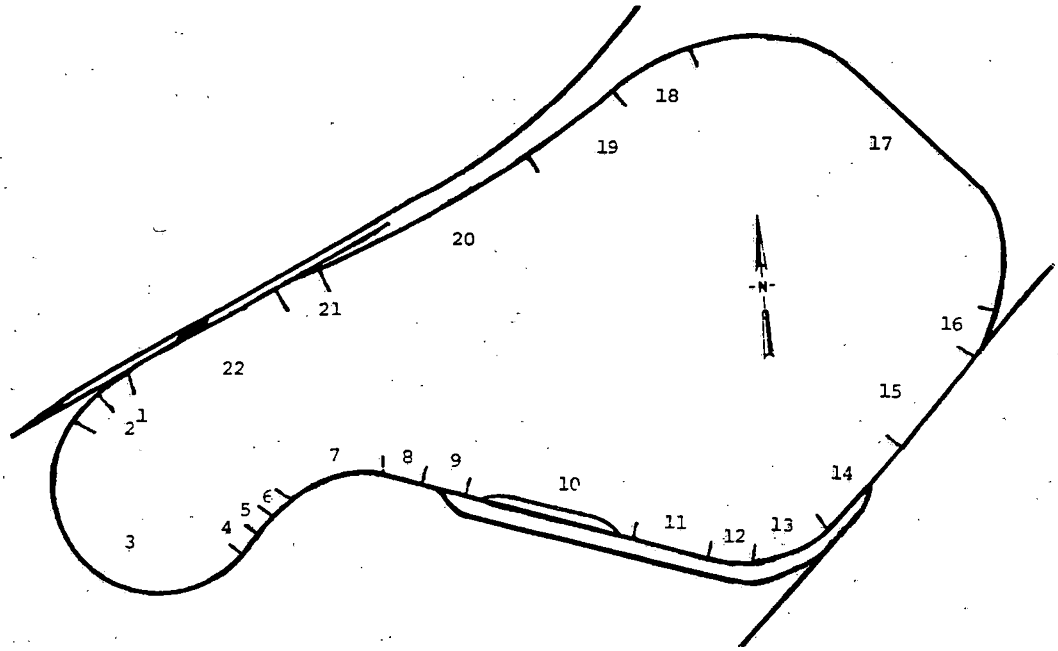
by the joint efforts of the Federal Railroad Administration (FRA), the Association of American Railroads, the Transportation Development Agency (TDA) of Canada, and by the railroads and Railway Progress Institute (RPI).

The purpose of FAST is to provide a facility where simulated service testing of both track and vehicles can be accomplished at rates of service much higher than those produced by normal revenue traffic. Between September 1976 and December 1977, the test train subjected the track to over 150 MGT of traffic. This is a rate approximately seven times higher than average revenue service.

The test train fleet consists of over 80 cars and locomotives. Regular maintenance is performed and measurements are taken on four cars each day, so that normally about 75 cars and four locomotives were in the consist during the reported test period. The test train accumulates 100 to 125 laps of the track each night, five nights per week, at speeds up to 45 mi/h.

As shown in figure 1-1 the FAST Track is divided into sections which provide many variations in track construction. The variations include wood and concrete ties, bolted joint and continuously welded rail, rail of different cross sections and metallurgies, several types of ballast, and both tangent and curved track.

Numerous measurements of track and vehicle characteristics have been made at planned intervals since the start of operations. Track performance data were collected at tonnage intervals ranging from 1 to 50 MGT. Additional track performance measurements were required before and after many maintenance procedures. The data are stored in digital tape form both at the TTC and at the AAR Technical Center in Chicago. A group of experiment managers from the FRA, the Transportation Systems Center (TSC), and the AAR has been responsible for experiment design and data analysis.



Legend:

Test Section	Description/Test Variable
01	Existing No. 20 Turnout
02	Rubber Pads/Wood Ties
03	Rail Metallurgy, Tie Plate Cant, Ballast Shoulder Width, and Spiking Pattern
04	Spiral, Standard Track
05	Bonded Joints
06	Steel Ties (Removed at 28 MGT)
07	Fasteners/Wood Ties (Changed at 135 MGT)
08	Spiral, Standard Track
09	Dowel Laminated, Reconstituted Ties
10	Elastic Spikes, Spring Frogs
11	Joints, Frogs, and Guard Rails
12	Spiral, Standard Track
13	Rail Metallurgy, Spike Hole Filler
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
22	Spiking Patterns, Rail Anchors

FIGURE 1-1. SECTIONS OF THE FAST TRACK (0-150 MGT).

2.0 TEST SEGMENTS AND PERFORMANCE MEASURES

The test segments utilized in this evaluation consist of track sections, subsections, and combinations of subsections from the FAST loop. All segments had 136 lb/yd rail and, with one exception, the rail was continuously welded. Test segments were defined separately for the comparative evaluation of track system performance and for the evaluation of concrete tie component performance.

The system performance of concrete and wood tie track was examined using the test segments shown in figure 2-1. There are three segments from the concrete tie Section 17: a 5^o curve with 2% grade, a 3^o curve, and a tangent section. The wood tie segments have a 5^o curve and tangent contours without appreciable grade. Section 15 is a tangent wood tie section having the only jointed rail examined. Performance data used in the track system evaluation are also shown in figure 2-1. Table 2-1 lists the properties of the test sections.

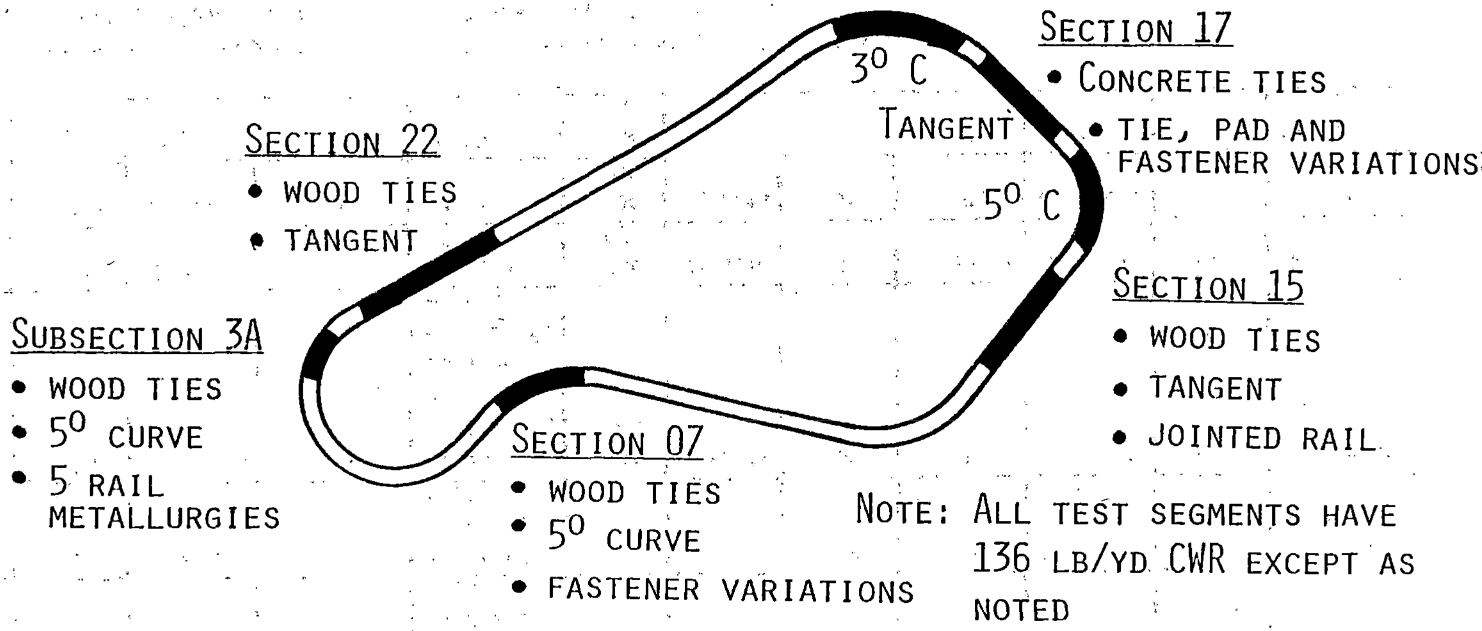
The performance of concrete tie components was studied in the subsections of FAST Section 17, which contained 6 types of ties, 11 types of pads, and 4 types of fasteners. As shown in figure 2-2, the subsections span the entire range of track contour in this section, beginning in the 5^o curve with 2% grade and continuing through the tangent to the 3^o curve. Also shown in figure 2-2 are the performance data used for the concrete tie component evaluation. Table 2-2 provides a breakdown of subsections according to types of ties, pads, and fasteners, all of which are identified by assigned code numbers for this report.

Preliminary reductions of the data in formats prescribed by Kish and Dean[1-3], were prepared by the data processing and analysis staffs of the AAR Technical Center and the TTC. Additional information was obtained from the performance evaluation conducted after 50 MGT[1-1] and from a report of ballast quality by the University of Illinois[2-1].

[1-3] Ibid.

[1-1] Ibid.

[2-1] Thompson, M.R., "FAST Ballast and Subgrade Materials Evaluation--Ballast and Foundation Materials Research Program," Report No. FRA/ORD-77/32, December 1977, PB #281167.



SYSTEM PERFORMANCE MEASUREMENTS

- MAINTENANCE
- TRACK GEOMETRY
- TRACK STIFFNESS
- RAIL WEAR

COMPONENT PERFORMANCE MEASUREMENTS

- TIE FLAWS
- TIE BENDING MOMENT
- FASTENER FAILURE AND FALL-OUT
- PAD REPLACEMENT, HARDNESS, THICKNESS
- TIE MOVEMENT, REPOSITIONING
- 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 CWR	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

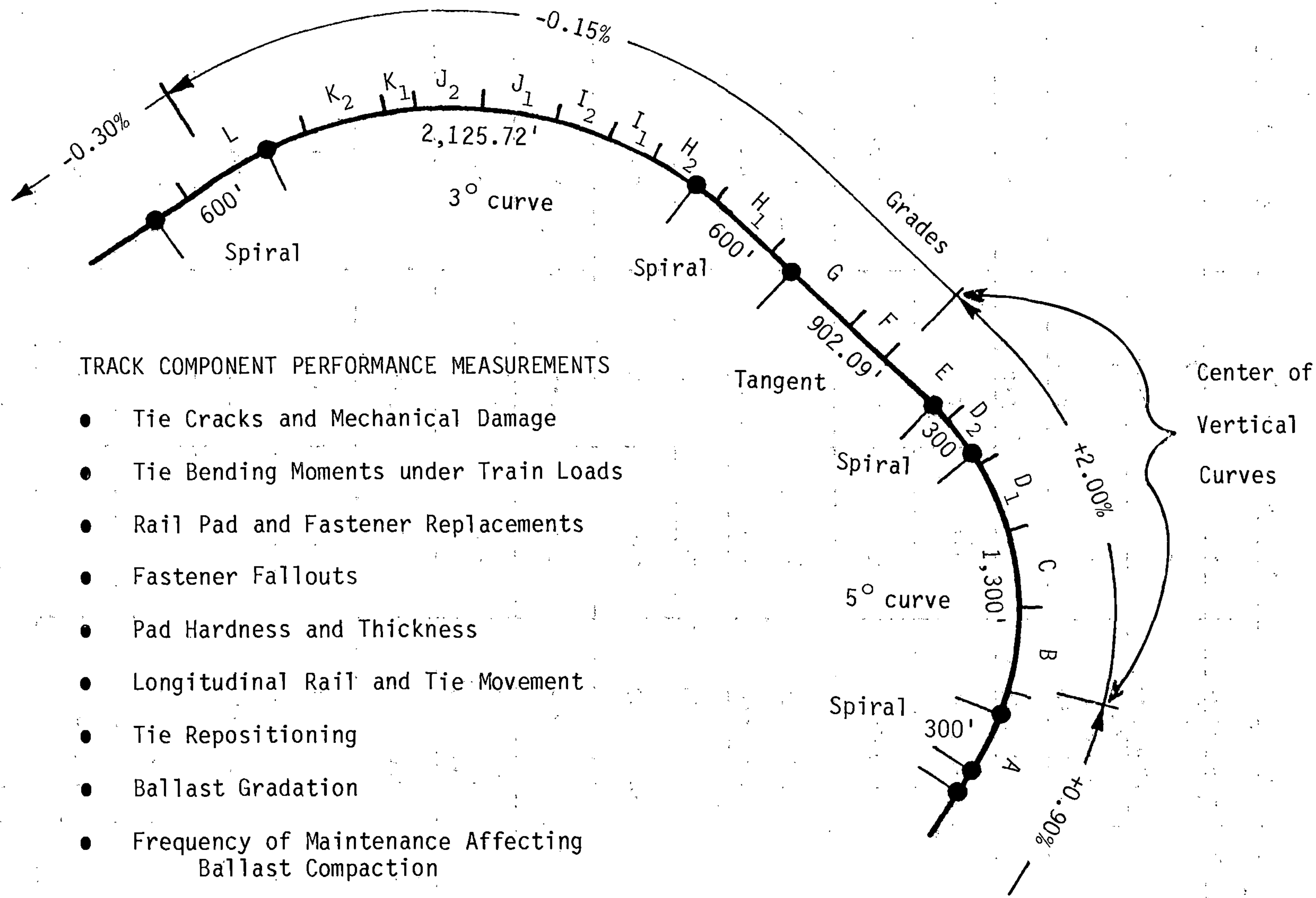


FIGURE 2-2. LAYOUT OF CONCRETE TIE SECTION 17.

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

Sub-section	Tie No.	Tie Type	Pad Type	Fastener Type
	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_1	2656-2955	T-6	P-8	F-1**
L_2	2956-3079	Wood		

*Same as F-1 but without insulator
**Fastener slightly different from other F-1 fasteners

3.0 SUMMARY OF RESULTS AND CONCLUSIONS

This evaluation of FAST track performance through 150 MGT is not conclusive on the relative economic merits of concrete and wood tie track construction. However, the results to date have identified several specific design and maintenance areas which require additional research and experimentation to evaluate the significance of the performance observed through 150 MGT, and to determine the long term effects. The FAST program has identified a number of specific design and maintenance problems in a very short time compared to normal in-service evaluations. These problems are defined in this report and in other concurrent investigations. It is expected that this information may contribute to a significant reduction in the time required to implement improvements, and that the solution of such problems will constitute a major step toward a conclusive evaluation of the technical and economic feasibility of concrete tie track for U.S. mainline service. It is also expected that this report will contribute to the continuing improvement of track performance experiments and methods of evaluation both at FAST and at other concrete tie test sites installed on revenue service track.

Those general areas of concrete tie track construction which have been identified for additional development include:

a. Criteria for the specification of ballast quality, ballast consolidation, and/or speed restrictions to assure running safety after ballast maintenance,

b. The effects of various maintenance procedures on ballast compaction,

c. The prevention of damage to ties and fastener shoulders during normal track maintenance operations, and

d. Improvements to selected rail fasteners to increase fatigue life and reduce rail creep and tie movements.

The following sections present details of major results of the evaluation of track system performance and track component performance.

This report is the second in a planned series on track performance at FAST. A third report will cover the period from 150 to 450 MGT, when the track will be shut down for the major rebuild of Sections 03, 17, and 22. A fourth report will cover the first 200 MGT after the rebuild.

3.1 TRACK SYSTEM PERFORMANCE

3.1.1 Important Events - Concrete Tie Track

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

a. Frequent tamping to correct ballast flow and geometry degradation in the period from 48 to 102 MGT,

b. Track restoration (including the addition of a berm) after a lateral buckle at 61 MGT,

c. Rail transposition at 84 MGT,

d. Replacement of large numbers of rail fastener clips because of fatigue failures and fallouts, generally after 100 MGT (40 MGT service), and

e. Rail grinding to correct corrugations.

3.1.2 Important Events - Wood Tie Track

The 5° curve of wood tie track in Sections 03 and 07 required the following major items of maintenance:

a. Frequent regaging due to high rate of rail head wear (Section 07) (this high wear rate may have been due to inadequate rail lubrication),

b. Rail transposition at 32 MGT (Section 07) and spot replacements (Sections 03 and 07),

c. Rail grinding to correct corrugations,

d. New low rail at 83 MGT, both rails at 135 MGT (Section 07),

e. Complete rail replacement at 135 MGT (Section 03), and

f. Early regaging of Section 07 is, in part, a result of to the initial installation of much of the section with wide gage up to 1/2".

3.1.3 Maintenance Man-Hours

When the immediate requirements of track restoration after the lateral track instability at 61 MGT were removed from the concrete tie track totals, the maintenance man-hours required by concrete tie track on curve and grade were equivalent to those required by the curved level section of wood tie track. However, for the very limited samples of data available for tangent track segments, concrete tie track required more maintenance than wood tie track. This was caused at least partially by a spillover of maintenance activity from the concrete tie curved section to the tangent section. It should also be noted that one tangent wood tie section was part of an older track loop, while the concrete tie track was constructed on new embankment.

3.1.4 Track Geometry

In terms of crosslevel, alinement, and profile, track geometry was approximately equivalent for comparable sections of concrete and wood tie track. One exception was the very high rate of gage widening in the wood tie Section 07 caused by rail wear and failure of some types of fasteners. The initial wide gage and inadequate rail lubrication were contributing factors to the gage widening problem. Frequent regaging and rail transposition eventually resulted in the spike-killing of the ties.

3.1.5. Track Stiffness

Both the small deflection lateral stiffness and the maximum attainable lateral resistance loads were consistently higher for concrete tie track than for wood tie track.

3.1.6 Rail Wear

Substantial differences in rail lubrication around the FAST Track and variations of tonnage make it difficult to compare rail wear data for concrete and wood tie track. This must be considered when evaluating rail wear. For example, between 0 and 135 MGT, the rail in the 5° curve of the Section 07 wood tie track experienced approximately 80% greater cumulative wear than in the 5° curve and 2% grade portion of the Section 17 concrete tie track.

From 0 to 60 MGT, rail head wear in the 5° curve of Section 17 concrete tie track was about equal to the wear on the standard metallurgy rail in the curve of subsection 3A wood tie track. Improvements in rail lubrication produced substantial reductions in rail wear in subsection 3A after 50-60 MGT. Average wear of the rail with improved metallurgy in subsection 3A was less than half that of the standard metallurgy rail.

Extensive rail corrugations developed in the 5° curves of both concrete tie track (Section 17) and wood tie track (Section 03). Grinding effectively removed all but the deepest corrugations, but recorrugation began almost immediately after grinding.

3.1.7 Rail Creep/Tie Movement

Rail creep in the 5° curve, 2% grade of concrete tie Section 17 began at about 20 MGT and increased rapidly up to a maximum of 4.5" immediately after the lateral track buckle at 61 MGT. The track then stabilized, so that when the creep markings were "rezeroed" with the rail transposition at 84 MGT, no significant rail creep was found from that time to the end of the evaluation at 150 MGT (tie movement may have been controlled by anchors). Creep in the latter period did not exceed 0.6".

3.2 CONCRETE TIE TRACK COMPONENT PERFORMANCE

3.2.1 Tie Replacement

A total of four ties damaged during track maintenance were replaced during the first 150 MGT. None of the 2,885 concrete ties has been replaced because of failure from train loads.

3.2.2 Tie Cracks

In concrete tie subsection 17A, one segment of 141 ties included 32 (23%) with center cracks. In three other subsections, rail seat cracking was reported for 30-50% of very limited samples. In one of these subsections the ties were precracked, having been originally installed in the Kansas Test Track, but only a few of the cracks were considered to be structural and none has resulted in tie failure. All other rail seat cracks were hair line cracks visible only on the tie face.

3.2.3 Tie Damage

Mechanical damage (chipping of concrete) has been found in four subsections. It was done during maintenance involving the ballast tamper and replacement of fasteners.

3.2.4 Tie Strength

Tie bending moments measured under train action at the tie center and at the rail seat remained well below the limits of the American Railway Engineering Association (AREA) design specifications.

3.2.5 Rail Fastener Failures

Extensive fatigue fractures of type F-1 elastic rail clips began to develop in one region of the 5^o curve of Section 17 at about 100 MGT. These fasteners were all new, installed after the track buckled at 61 MGT. The fractures were concentrated over the region of the 5^o curve where the type P-2 pads, one of the softest tie pads, were installed. Other fasteners, which were installed at 61 MGT in the 5^o curve with different pads, had much lower failures rates.

3.2.6 Rail Fastener Fallouts

Numerous fallouts of type F-1 elastic rail clips also occurred in the 5^o curve, the highest rate occurring where clips were installed without insulators and with type P-2 (soft) pads. The next highest fallout rate occurred where clips were installed with insulators and type P-2 pads.

3.2.7 Tie Pad Failures

Replacement of worn pads was concentrated in the type P-2 pad region on the 5^o curve. The dominant failure mode was concentrated wear (abrasion, fraying) over a 1"- 2" diameter area in the center of the pad.

3.2.8 Pad Hardness

The 11 types of tie pads were arranged into three groups according to hardness. The P-2 pad, which is connected with high rates of fastener fracture and fall-out, is one of the softest pads.

3.2.9 Tie and Rail Movement

Significant tie and rail longitudinal movement occurred near the start of the 5° curve, 2% grade of Section 17. These data show the need for good ballast compaction and fastener longitudinal restraint in severe track contours. Tie skewing occurred in both types of track; however, the concrete ties experienced greater movement.

3.2.10 Ballast Flow

In Section 17, the problem of ballast flow from the shoulders and tie cribs in the 5° curve, 2% grade created a major part of the maintenance requirements for concrete tie track. There is no conclusive evidence on the exact cause of excessive ballast flow because no other area of the FAST Track had the same geometry and operating conditions. There are indications that excessive ballast flow initiated in regions of welds and rail corrugations. Many observers believe the ballast flow resulted from the small average size of ballast particles and their lack of angularity and did not result from any feature peculiar to the concrete tie track.

3.2.11 Ballast Crushing

Ballast crushing, surrounding ties and under rail seats, was particularly noticeable in the vicinity of rail corrugations in both wood and concrete tie track. Based on visual observation, it was determined that the degree of crushing was greater in concrete tie track. Ballast crushing comparisons are entirely subjective since different types of ballast were used in Section 03 and Section 17, slag and granite, respectively.

4.0 SYSTEM PERFORMANCE OF CONCRETE AND WOOD TIE TRACK

4.1 INTRODUCTION

The following measures were used to compare the system performance of concrete and wood tie track:

a. Maintenance burdens,

b. Rates of track geometry degradation,

c. Track stiffness under applied lateral load,

d. Rail wear, and

e. Rail creep.

4.2 MAINTENANCE BURDENS

4.2.1 Important Maintenance Events

The history of the FAST concrete tie track is dominated by several notable events which took place in the 5° curve, 2% grade of Section 17 (table 4-1). The 5° curves of wood tie Sections 03 and 07 also required several major items of maintenance (table 4-2).

4.2.2 Total Maintenance Man-Hours

In figure 4-1, the total maintenance man-hours, normalized to a uniform track length of 1,000 ft, are compared for 5° curve segments of concrete and wood tie track. For both sections, the initial period before rail transposition at 83 MGT required far more maintenance than the period from 83 to 135 MGT. For the concrete tie sections, maintenance required to restore the track after the lateral buckle at 61 MGT represented a large single input. When this is removed, maintenance required for the two track systems is nearly equal.

Figure 4-2 compares man-hours per 1,000 ft of track for the tangent segment of concrete tie track with two wood tie tangent segments, one with bolted joint rail (BJR) and the other with continuous welded rail (CWR). When the requirement for switch maintenance in the BJR wood tie Section 15 is removed, the results showed that the tangent concrete tie track segment required about five times the maintenance of CWR wood tie track and about twice the maintenance of the BJR wood tie section. It should be noted, however, that the CWR wood tie Section 22 was part of an existing track before its incorporation into FAST. Thus, the initial consolidation and a number of the early problems caused by new ballast and subgrade may have been avoided.

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

MGT	Description
48-61	Ballast flow from tie cribs and off the embankment shoulder necessitated frequent ballast maintenance (reshaping, surface/lining/tamping, out-of-face tamping, and spot tamping).
54	Beginning of unusual longitudinal tie movement and rail creep which increased sharply up to 61 MGT.
61	Lateral buckle of the track at three locations (one S-curve, two half waves).
61	New type F-1 rail fastener clips were installed.
70	Rail grinding to eliminate corrugations.
83	Transposition of rail due to excessive head wear-replacement of insulators.
100	Beginning of unusual numbers of elastic clip fastener fractures, all installed at 61 MGT.
148	Second rail grinding to remove corrugations.

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

MGT	DESCRIPTION
	Section 07
21-32	Frequent spot regaging caused by high rate of rail head wear.
32	Rail transposition.
52-80	Spot replacements of rail.
78	Rail grinding.
83	Replacement of low rail with rail from Bypass Track.
135	New rail installed (140 lb/yd).
	Section 03*
30-80	Frequent joint welding and grinding, made necessary by the failure of many field welds, and standard rail replacements
81-84	Rail grinding to remove corrugations
135	Replacement of all rail-rail metallurgy test lengths redesigned into longer sections.

* Because of rail metallurgy test segments and variations in rail cant in Section 03, only the standard rail in a subsection was used for the rail wear comparisons of concrete and wood tie track performance.

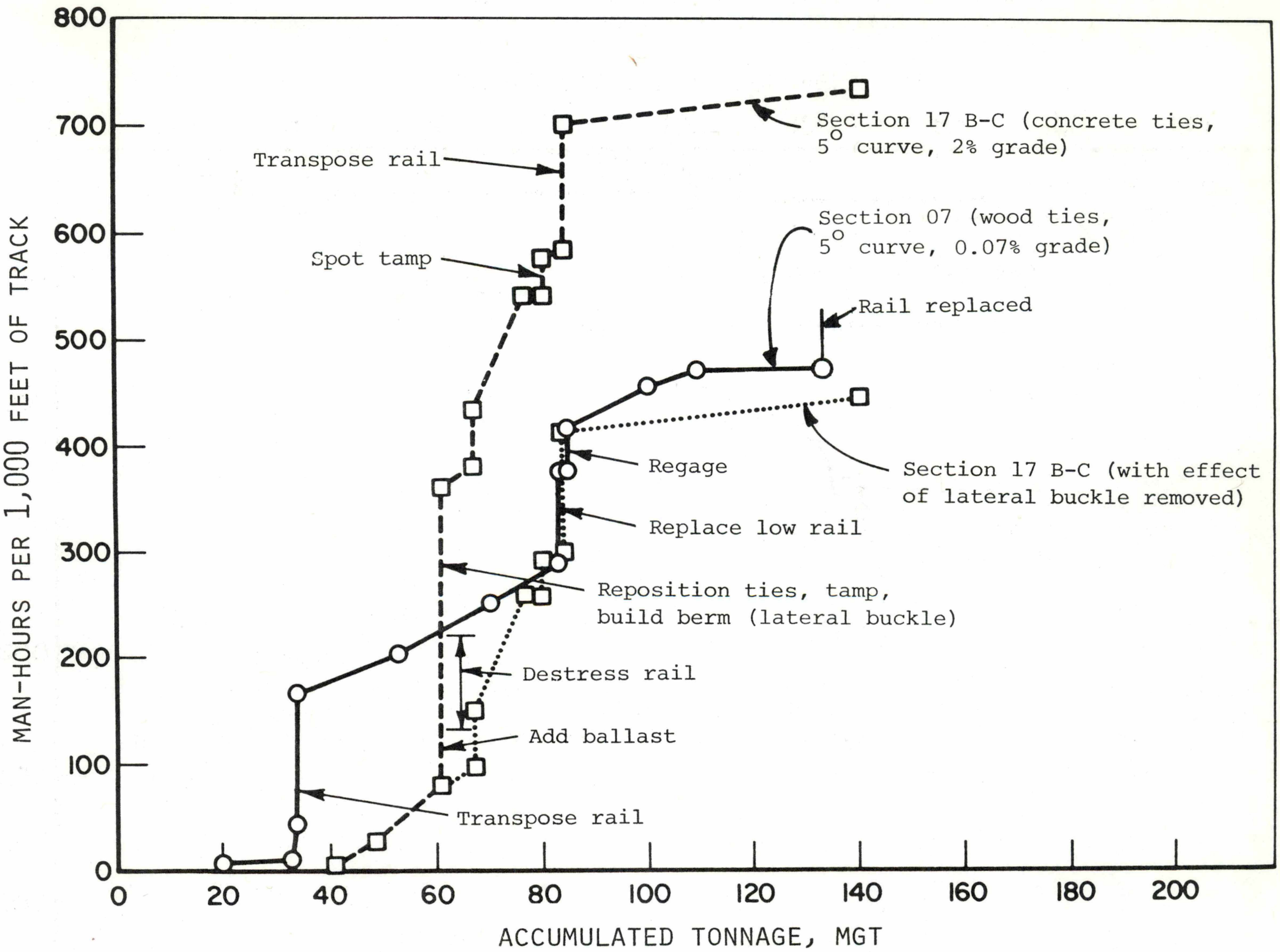


FIGURE 4-1. MAINTENANCE MAN-HOURS PER 1,000 FEET OF TRACK ON 5° CURVES OF CONCRETE AND WOOD TIE TRACK.

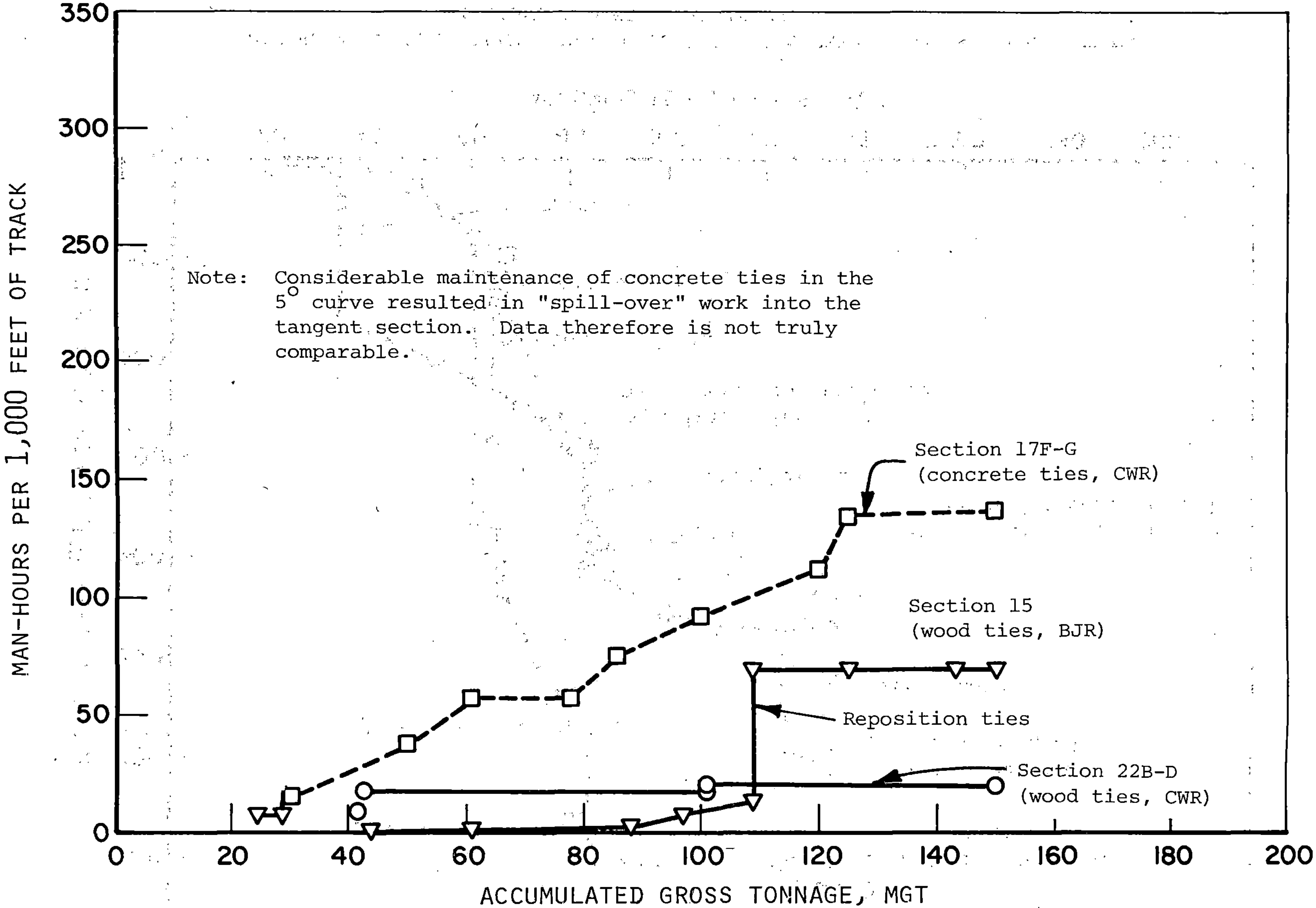


FIGURE 4-2. MAINTENANCE MAN-HOURS PER 1,000 FEET OF TRACK ON TANGENT SECTIONS OF CONCRETE AND WOOD TIE TRACK.

The concrete tie tangent segment received considerable ballast maintenance (shoulder reshaping, surface/line/tamping, and tamping only), which was mainly spillover of maintenance from work begun in the 5° curve. Other major items included the retightening of bolted fasteners and one rail plug was required at a defective weld.

4.2.3 Frequency of Specific Maintenance Operations

Table 4-3 lists the frequency of the operations required in several test segments for a number of specific maintenance actions. Maintenance frequency is expressed as the sum of the lengths of track worked in the segment divided by the total length of the segment. The table is compiled in this manner because it provides a direct comparison of maintenance activity required for analysis of the economic impact of maintenance. Arnlund, et al.,[4-1] provides an example of such an analysis.

Table 4-3 shows the heavy demand of the concrete tie 5° curve for surface, line, and tamping operations and for ballast shoulder reshaping performed over a total of 12 times the section length. The largest maintenance requirement of the wood tie, 5° curve was for regaging. This was performed over a total of 1.7 times the section length and required about half of the total maintenance man-hours.

4.2.4 Maintenance Summary

Problems created by ballast movement in the 5° curve and 2% grade between 40 and 83 MGT comprised about 80% of the total maintenance demand for the concrete tie 5° curve. The size, shape, and type of ballast may have contributed to the lack of normal consolidation in service under concrete ties.

When the immediate requirements of track restoration after the lateral buckle at 61 MGT are removed, the maintenance man-hours required by the concrete tie track on curve and grade were equivalent to those required by the curved wood tie track on level grade and equal curvature.

This comparison is significant because instability in the concrete tie curve is believed to have been caused by the poor ballast performance, derived in part from lack of ballast in both the crib and shoulder.

The small samples available for comparing tangent track systems show that more maintenance man-hours were devoted to concrete tie tangent track than to comparable wood tie track. However, this finding was biased by spillover of activity from the adjacent 5° curve and therefore, is not a true comparison.

[4-1] Arnlund, R.C., White, D.W., and Prause, R.H., "Economics of Concrete- and Wood-Tie Track Structures," Report No. FRA/ORD/78/2, August 1978, PB #291613.

TABLE 4-3. FREQUENCY OF SPECIFIC MAINTENANCE OPERATIONS THROUGH 150 MGT (CUMULATIVE LENGTH WORKED/TEST SEGMENT LENGTH).

Operation	Concrete Ties: 5° Curve Section 17	Concrete Ties: 3° Curve Section 17	Concrete Ties: Tangent* Section 17	Wood Ties: 5° Curve Section 7	Wood Ties: Tangent Section 22
1. Surface, Line, and Tamp					
a. Complete S/L/T	3.2	1.7	1.0	1.0	0
b. Out-of-face Tamping Only	5.8	0.8	3.0	0	1.0
c. Out-of-face Lining Only	2.5	0	0	2.0	0
d. Spot Tamping	6.7	0.2	0.2	0.4	0.25
2. Regaging	0	0	0	1.7	0
3. Tie Repositioning	0.67	0.10	0.107	0	0
4. Ballast Work					
a. Add Ballast	4.5	3.0	2.8	0.11	0
b. Reshape Shoulder	12.0	6.3	5.7	2.0	1.0
5. Rail Work					
a. Replacement					
Inside	0	0.013	0	2.013	0.016
Outside	0.017	0.018	0	1.041	0.019
b. Transpose Rail	1.0	1.0	0.14	1.5	0
c. Grind Rail	1.5	1.0	0	1.0	0

* Considerable tamping and lining work was the result of spillover from the work in the 5° curve.

4.3 TRACK GEOMETRY

4.3.1 Degradation

Errors in gage, alinement, crosslevel, and profile have been monitored at frequent intervals by a total of three different track geometry cars. Data produced by the first two cars were not fully compatible with those produced by the current FAST track geometry car, which was introduced at about 30 MGT. Shakedown problems with this car prevented its becoming fully able to obtain reliable data until about 58 MGT. From that point on, comparisons between somewhat similar sections of concrete and wood tie track are available. They are shown in figure 4-3 for curved track and in figure 4-4 for tangent track.

The data consist of the amplitudes of track geometry errors which were exceeded by 5% of the measurements and are plotted vs. MGT. In Figure 4-3 it can be seen that the retention of track geometry is approximately equivalent between concrete and wood tie track on the 5^{o} curve, with the exception of rapid growth in gage widening on wood tie track prior to an initial rail transposition at 32 MGT (not shown) and continuing to the low rail change at 83 MGT. The tangent track performance data shown in figure 4-4 contain no major differences between concrete and wood tie segments, and the geometry appears to be quite stable up to 150 MGT of service.

For reference, figures 4-3 and 4-4 also show FRA Track Safety Standard limits for Class 4 through Class 6 track and the "maintenance demand" limits designated FAST 03 and FAST 05 by the FAST Track Specification.[4-2] These limits are summarized as follows:

Allowable Track Geometry Error (Inches)

		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
Alinement	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

The FAST Track Specification requires spot maintenance in a given section if the track geometry measurements exceed FAST 03. Out-of-face maintenance is planned if a given percent of the measurments exceed FAST 05. The value of "x %" for each section is to be assigned.

4-2 McIntosh, G.P., et al., "FAST Track Specification, Volume II - Track," Report No. 7134 of the U.S. Department of Transportation, Facility for Accelerated Service Testing, June 8, 1977.

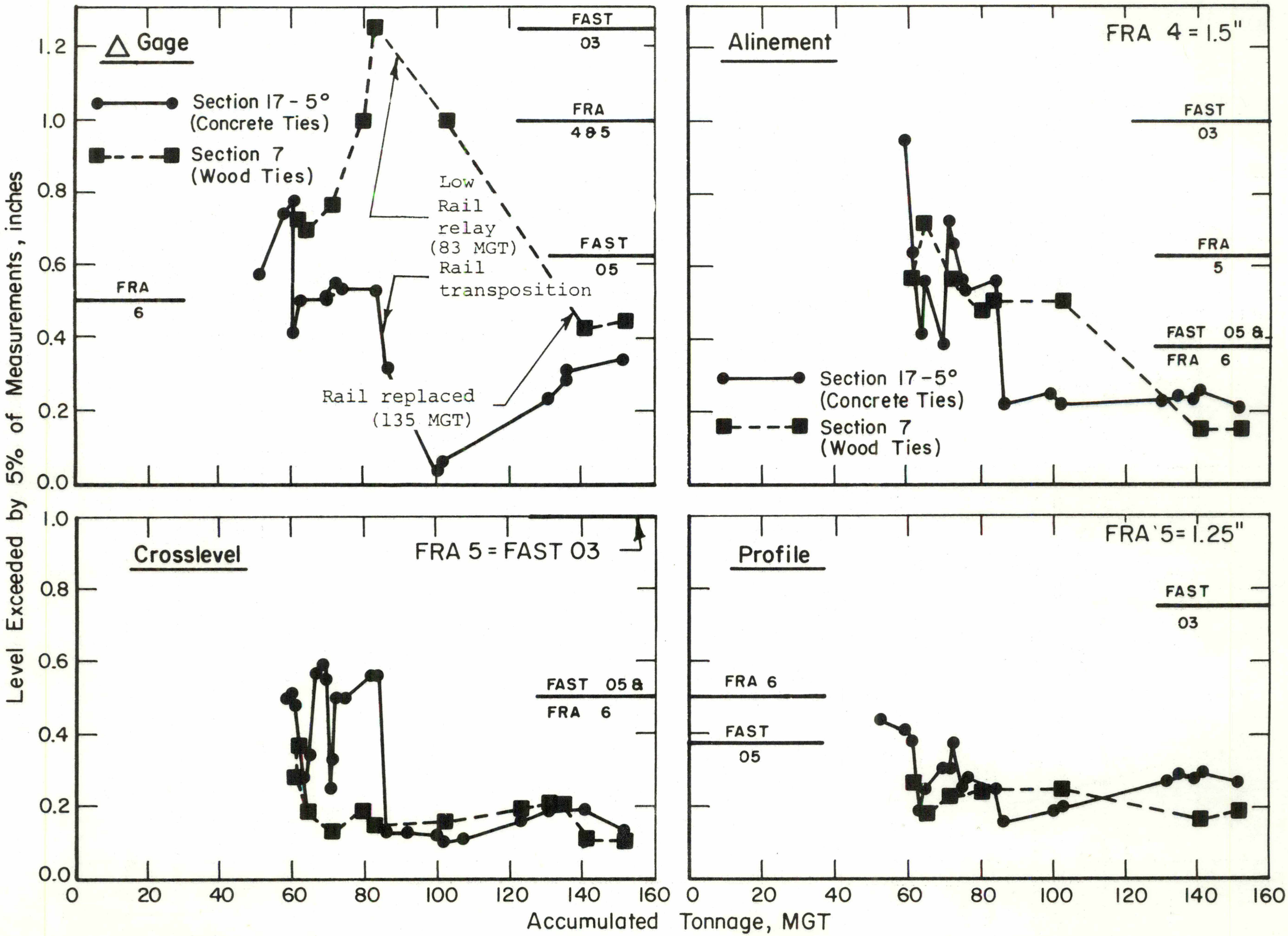


FIGURE 4-3. TRACK GEOMETRY ERRORS vs MGT ON 5° CURVES OF CONCRETE AND WOOD TIE TRACK.

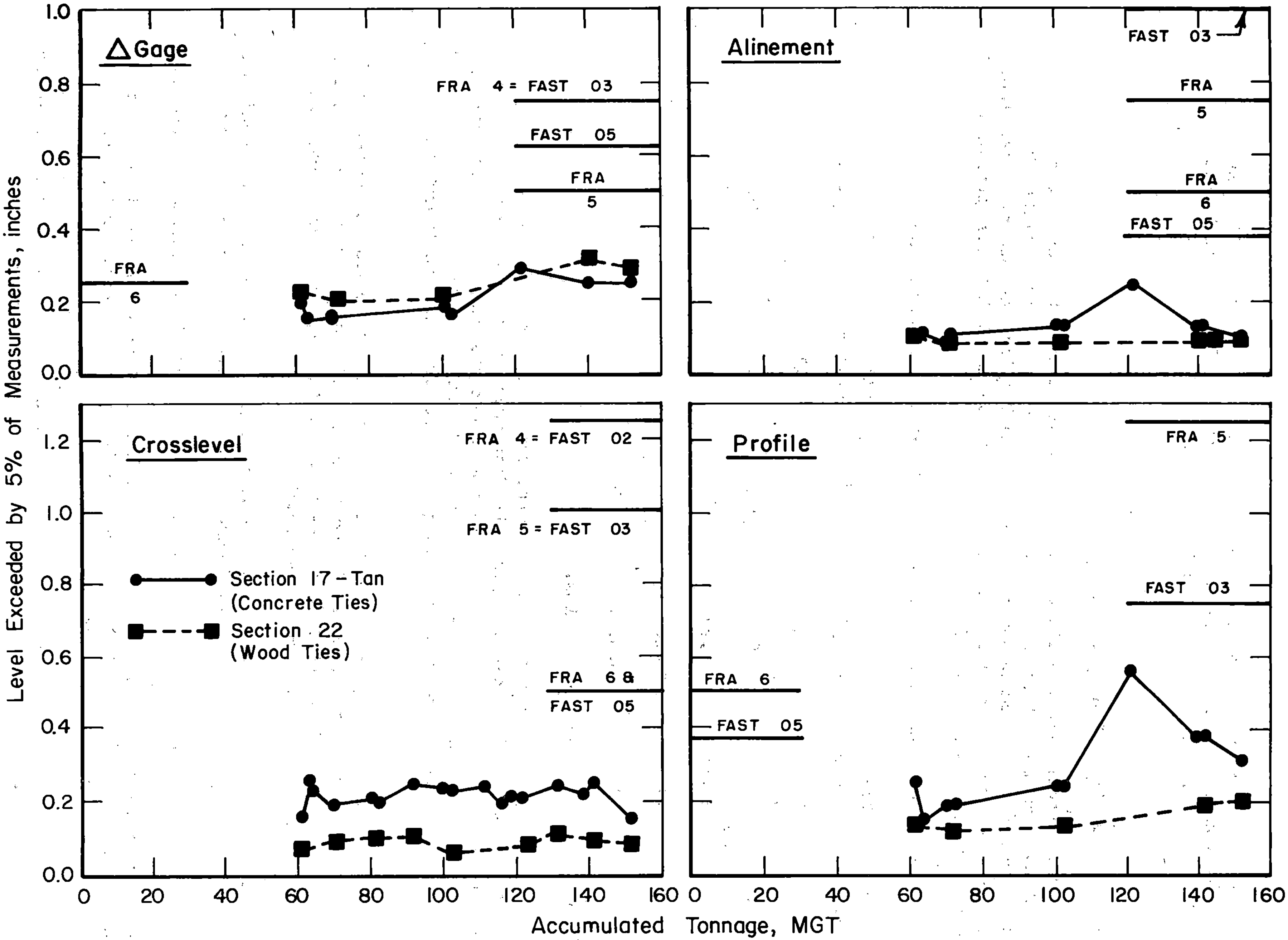


FIGURE 4-4. TRACK GEOMETRY ERRORS ON TANGENT SECTIONS OF CONCRETE AND WOOD TIE TRACK.

In summary, track geometry retention of the concrete and wood tie track was approximately equal through 150 MGT except for the high rate of gage widening in the wood tie, Section 07 track.

4.4 TRACK LATERAL RESISTANCE

The lateral track stiffness test setup is illustrated in figure 4-5. The load was applied through a yoke to one rail at two points 60" apart. Displacement gages measured tie and rail deflection, as shown. Load application was continued until a rail deflection of 0.25" was obtained. No vertical loads were applied.

Tests were run on track with the following characteristics:

Tie Type	Tie Spacing	Contour	Rail	Ballast Shoulder	Test Segment
Concrete	24"	Tangent	CWR	12"	17-E
Concrete*	24"	5° Curve	CWR	12"	17-D
Wood	19.5"	Tangent	BJR	6"	15-A
Wood	19.5"	Tangent	BJR	18"	15-B
Wood	19.5"	Tangent	CWR	12"	$17\text{-}L_2$

* One-time-only test--see below.

To compare performance in the different test segments vs. MGT, the load developed at 0.2" of centerpoint rail displacement is shown for each test in figure 4-6. A general increase in load at about the same rate occurs for both concrete and wood tie track up to about 100 MGT. Approximately 50% higher lateral resistance loads were developed on the concrete tie track than on the wood tie track.

Also shown on figure 4-6 are the results of two tests conducted on the same day at the same site in the concrete tie 5° curve. These were special tests conducted after the lateral track buckle that occurred at 61 MGT and are the only tests conducted on curved track.

Envelopes of applied load vs. deflection representing all tests conducted from 0 to 150 MGT are shown in figure 4-7 for concrete and wood tie track.

The two envelopes shown in figure 4-7 differ in these important respects:

a. Concrete tie track shows higher initial stiffness than wood tie track as evidenced by higher initial breakout loads (loads at zero displacement) and higher slips in the small deflection range, and

b. Concrete tie track shows consistently higher maximum lateral resistance loads than wood tie track.

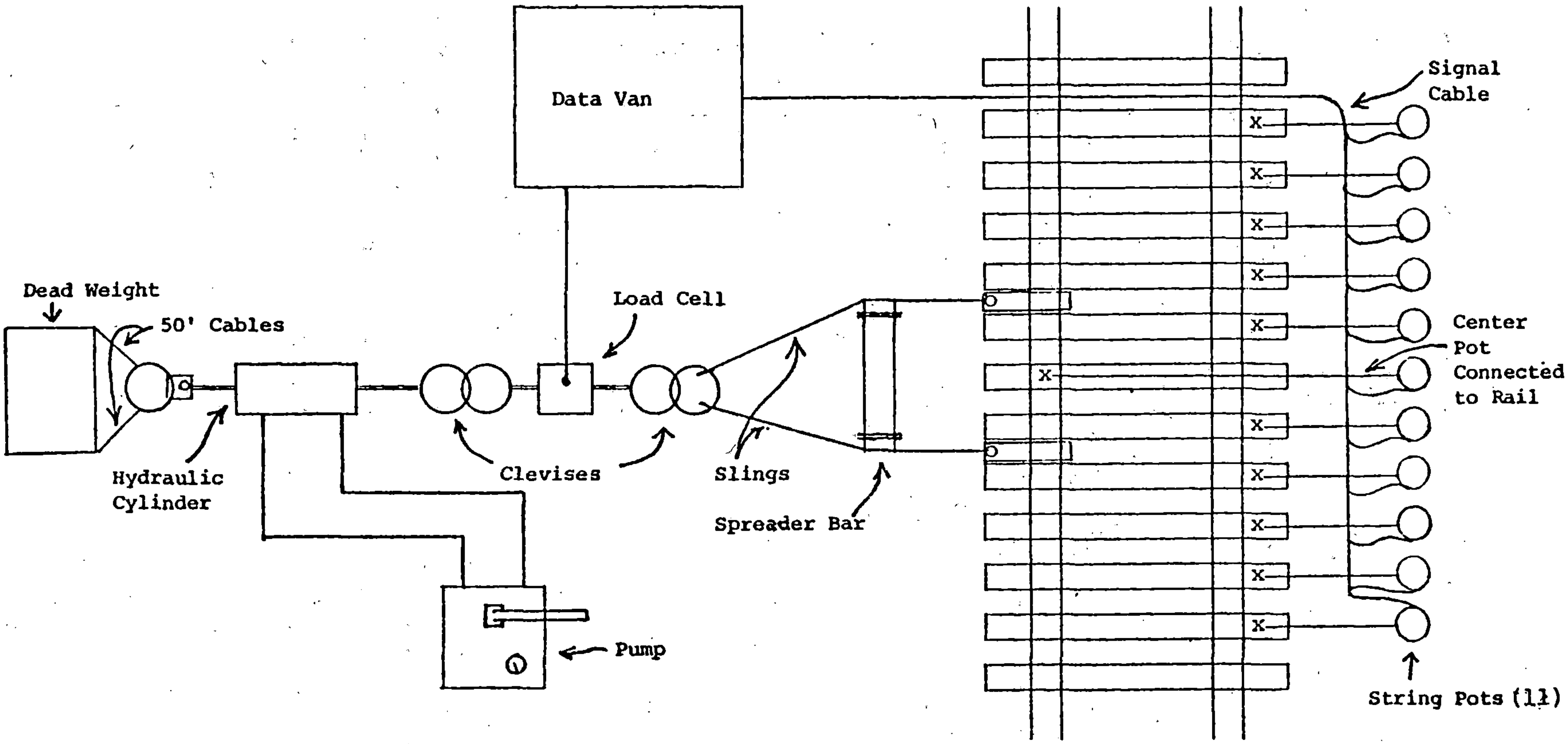


FIGURE 4-5. EQUIPMENT FOR LATERAL TRACK STIFFNESS TEST.

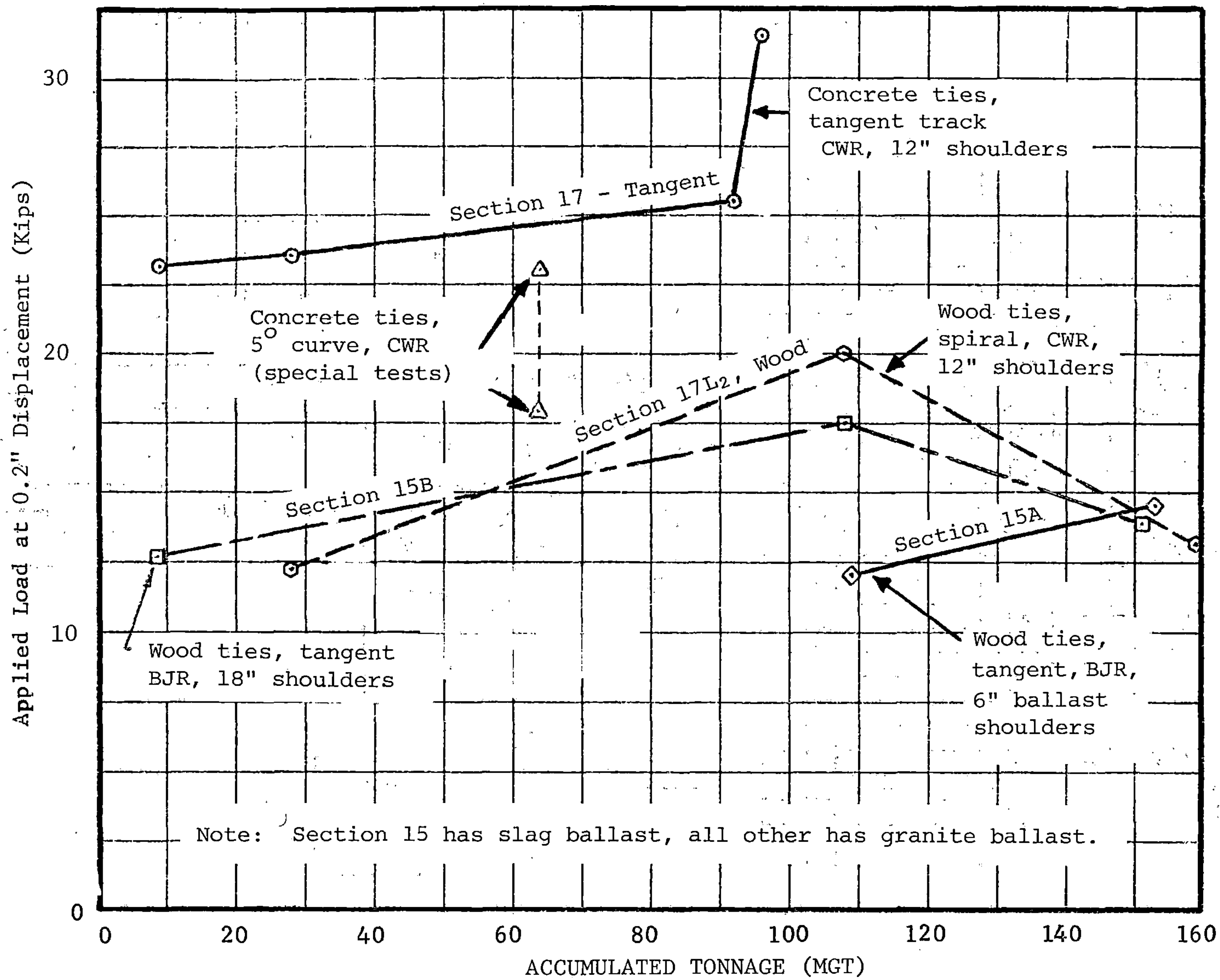


FIGURE 4-6. APPLIED LATERAL LOAD AT 0.2" DISPLACEMENT FROM HORIZONTAL TRACK STIFFNESS TESTS FOR SECTIONS OF CONCRETE AND WOOD TIE TRACK.

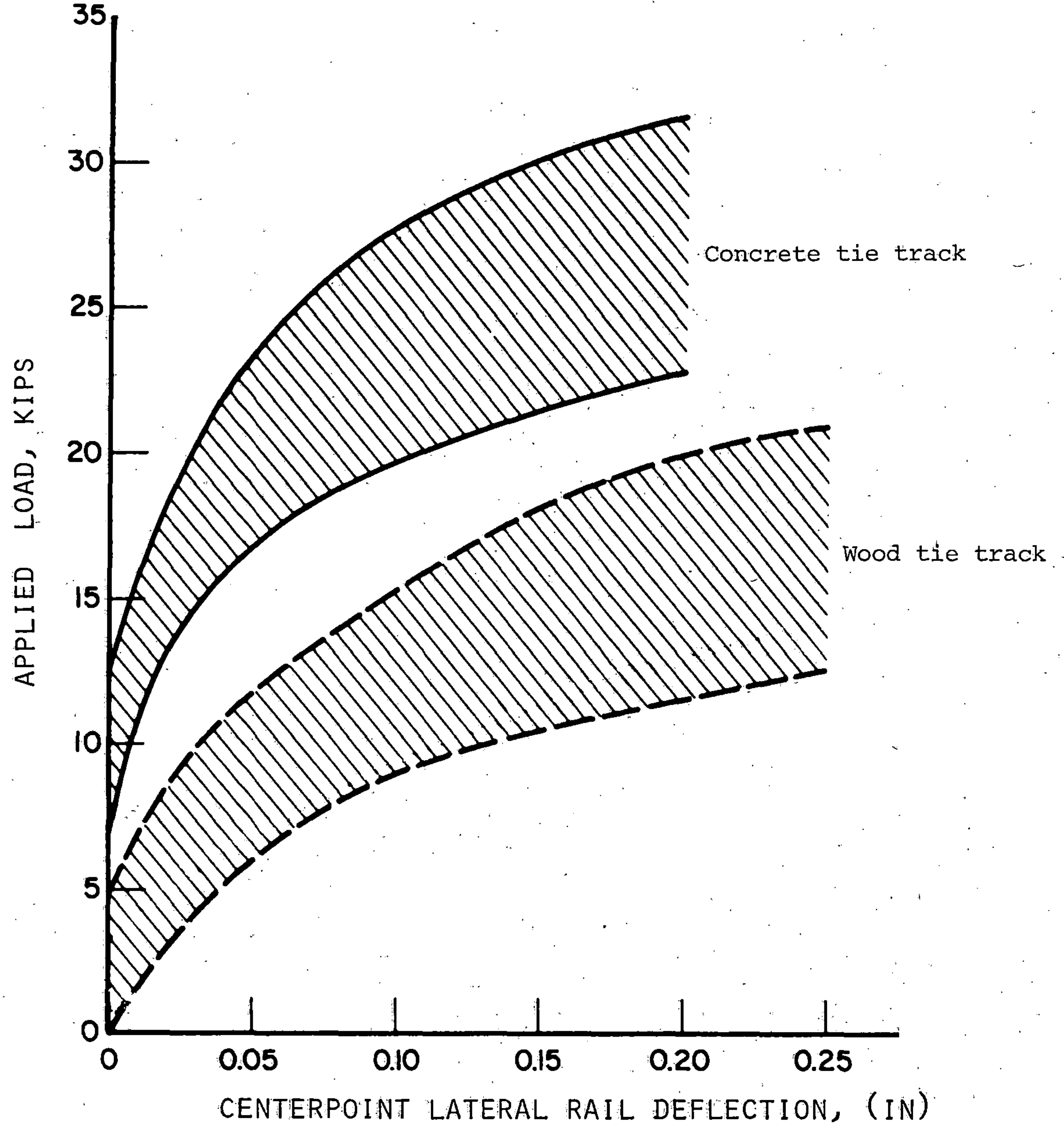


FIGURE 4-7. ENVELOPES AND CURVES OF CENTERPOINT LATERAL RAIL DEFLECTION vs. APPLIED LATERAL LOAD FOR SECTIONS OF CONCRETE AND WOOD TIE TRACK, 0-150 MGT.

4.5 RAIL WEAR

4.5.1 Rail Head Area Loss

Differences in rail lubrication around the FAST Track and variations with respect to tonnage and rail wear data for concrete and wood tie track make it difficult to compare. This must be considered when evaluating the following results.

Figure 4-8 summarizes the results of measurements taken with a rail head profilometer in the 5^{o} curves of concrete tie Section 17 and wood tie Sections 07 and 03A. Curves show the maximum, minimum, and average values found at a given MGT in each test section. Between 0 and 135 MGT, each subsection of Section 03 contained rails with five different metallurgies, each in a 78-ft segment. In figure 4-8, the standard metallurgy segment is plotted separately from improved metallurgies--these included chrome molybdenum, fully heat-treated, high silicon, and head hardened rails.

Sharp breaks in the area loss plots occur for each test section. Two are caused by rail transposition, but one break at 100 MGT in Section 07 cannot be explained by maintenance activity. There is a sharp knee in the envelope for standard metallurgy in subsection 03A. This was probably caused by the addition of effective rail lubrication between 40 and 50 MGT. Lubrication substantially reduced the wear rate.

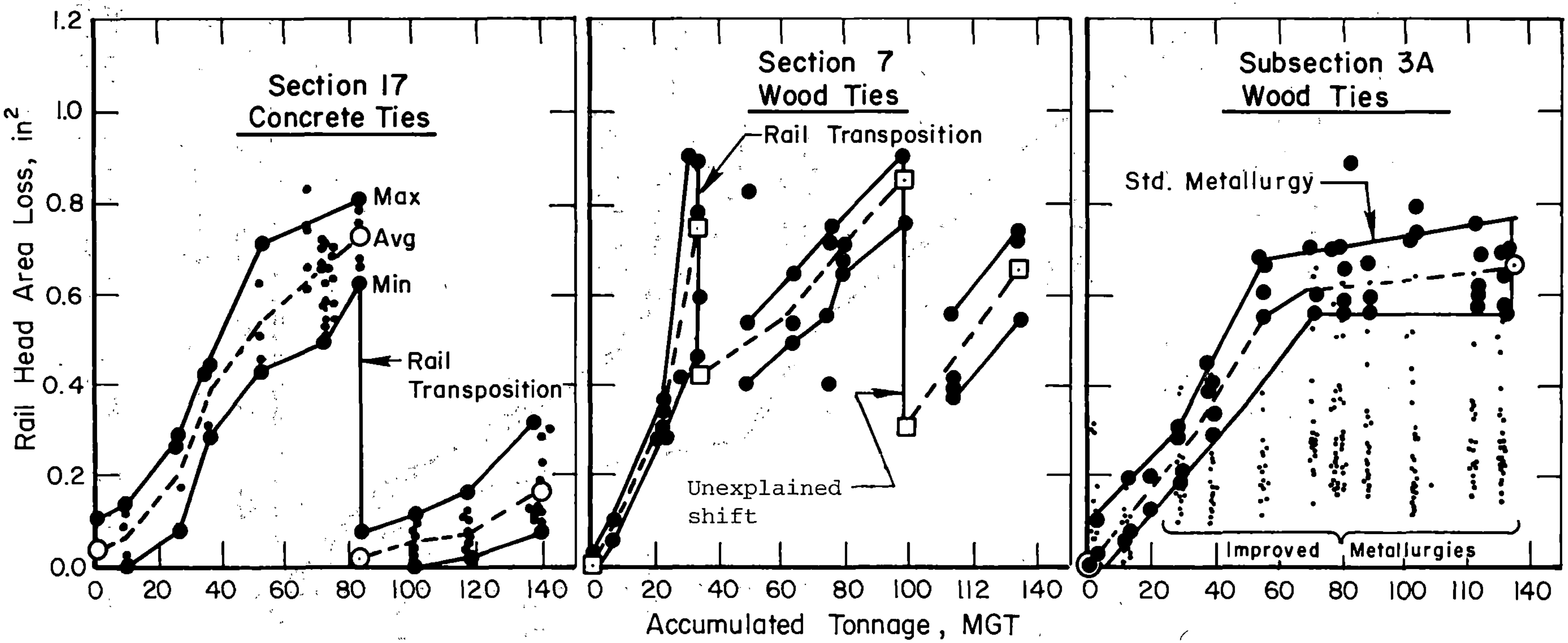
Cumulative average rail head area loss is plotted vs. MGT in figure 4-9. The curves were constructed by eliminating maintenance-related discontinuities in figure 4-8. Through 135 MGT, the rail in the wood tie Section 07 experienced approximately 80% greater wear than the rail in the concrete tie Section 17. Wear of standard rail in the wood tie subsection 03A was equivalent to that in Section 17 up to 50-60 MGT, when rail lubrication produced a significant reduction in wear rate.

In figure 4-10, average rates of wear from the FAST test segments are compared with those of five-unit train operations in Australia, Canada, Brazil, and the U.S.[4-3] Wear rate is expressed as area loss per 100 MGT. By far the greatest wear rate occurred in Section 07 to 32 MGT, at which time the rail was transposed. All sections experienced much more wear during the early phase of operations than in later periods. Initial FAST operations with all new rail and new wheel profiles probably produced atypical wheel/rail contact geometry that caused unusually high wear rates when combined with little or no rail lubrication.

4.5.2 Rail Corrugations

Figure 4-11 summarizes rail corrugation measurements taken in the 5^{o} curves of the concrete tie Section 17 and the wood tie Section 03.

[4-3] Mair, R.I., and Murphey, R.S., "Rail Wear and Corrugation Studies," American Railway Engineering Association, Bulletin 660, November-December 1976.



Note: FAST track lubrication varied with location and tonnage.

FIGURE 4-8. COMPARISON OF RAIL WEAR ON HIGH RAIL OF 5° CURVES IN SEVERAL SECTIONS OF CONCRETE AND WOOD TIE TRACK.

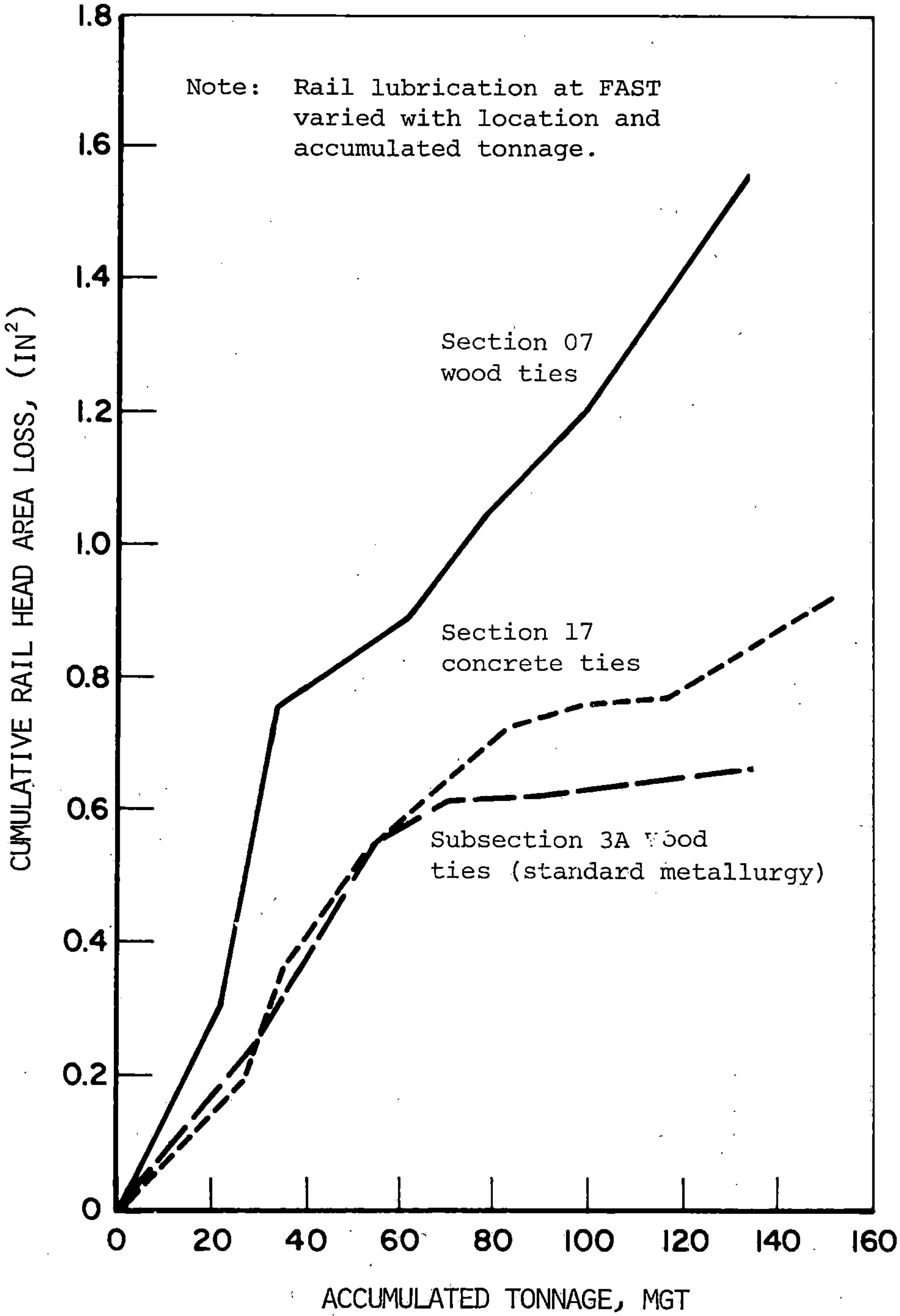


FIGURE 4-9. CUMULATIVE AVERAGE RAIL WEAR ON THE HIGH RAIL IN 5° CURVES OF CONCRETE AND WOOD TIE TRACK.

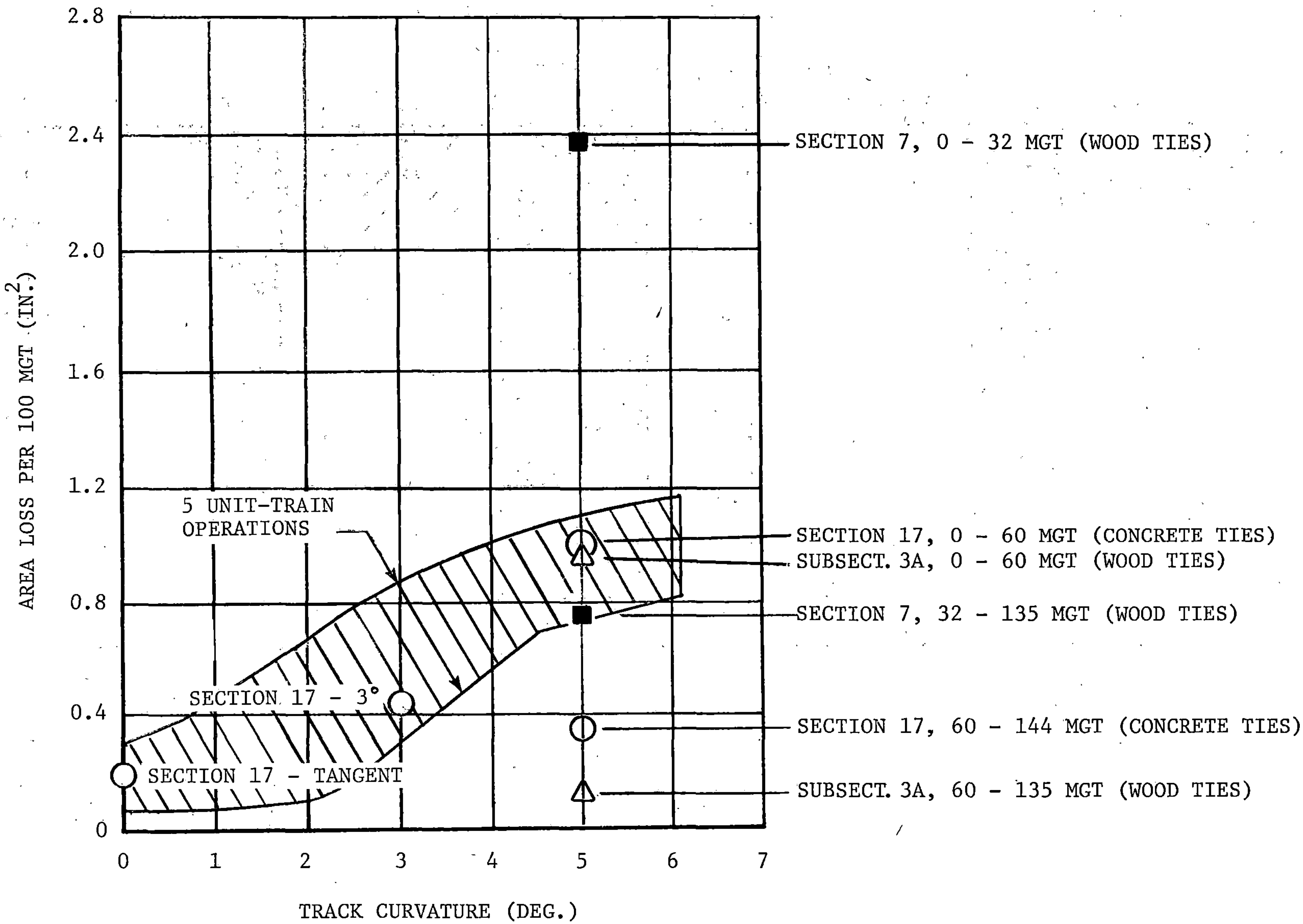


FIGURE 4-10. RAIL HEAD AREA LOSS PER 100 MGT VS. CURVATURE FOR SEVERAL SEGMENTS OF CONCRETE AND WOOD TIE TRACK.

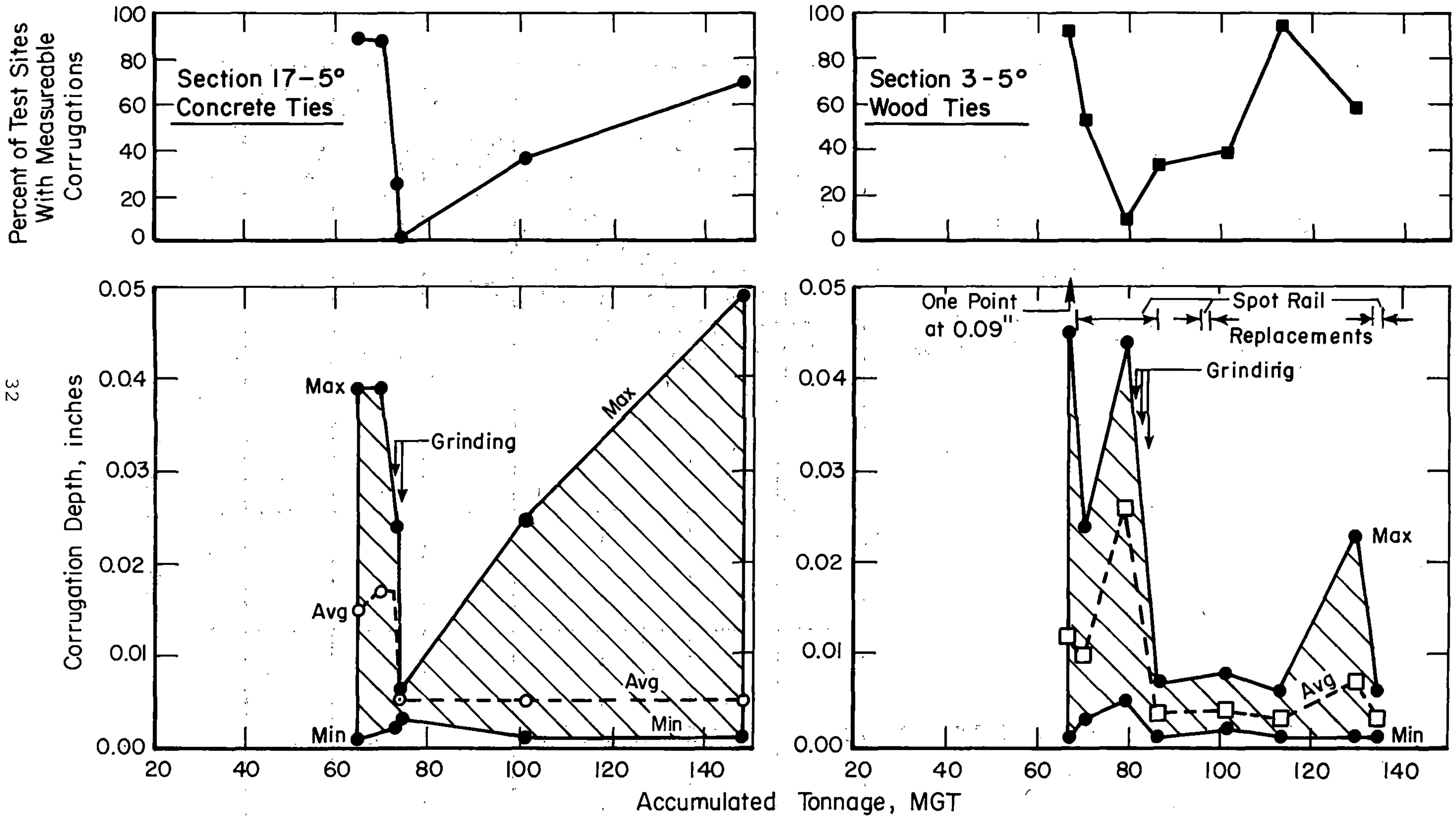


FIGURE 4-11. GROWTH OF RAIL CORRUGATIONS IN 5° CURVES OF CONCRETE AND WOOD TIE TRACK.

Corrugation measurements in Section 03 include data for several different rail metallurgies.

Corrugation measurements were begun at 25 sites in each section, but the number of measurement sites was expanded as additional corrugations developed. Therefore, the number of sites in each section was defined as the maximum or final number (49 in Section 03, and 53 in Section 17, 5° curve).

The top plot for each section in figure 4-11 contains the percentage of total measurement sites where measurable corrugations were found each time measurements were made. The data show that grinding effectively removed corrugations although they quickly redeveloped.

4.5.3 Summary on Rail Wear

Rail head area loss measurements were compared for the high rail of three 5° curves. Between 0 and 135 MGT, rail in the wood tie Section 07 experienced approximately 80% greater wear rate than rail in the concrete tie Section 17. Substantial differences in rail lubrication between various sections of the loop trackage may account for part of this difference.

Wear for Section 17 and the standard metallurgy segment of subsection 03A were equivalent up to 60 MGT. After this point, rail lubrication produced substantial wear reduction with slightly less wear in subsection 03A.

Average wear of rail with improved metallurgy in subsection 03A was less than half that of standard metallurgy.

Extensive corrugations developed in the 5° curves of Sections 03 and 17. Grinding effectively removed all but the deepest corrugations, but recorrugation began almost immediately after grinding. No conclusions can be drawn about the effect of tie type or spacing on the rate of corrugation growth.

Rail wear in curves was shown to be extremely sensitive to inadequate rail lubrication. Because of this dominant effect, no conclusion can be drawn about the relative effects of concrete and wood tie construction on the rate of rail wear.

4.6 RAIL CREEP

Rail creep is a measure of relative longitudinal displacements between the rail and selected ties. Creep is caused by thermal expansion or contraction of the rails, train braking, and acceleration loads. On curves and grades, the problem can be aggravated by ballast flow. Creep data are included to demonstrate the extent of problems which occurred in the 5° curve and 2% grade of Section 17 between 20 and 80 MGT.

Figures 4-12 and 4-13 summarize creep measurements vs. MGT for curved and tangent sections of concrete and wood tie track. In the wood tie Section 07, only those segments with standard cut spikes or lock spikes were considered. In Section 17 the data used for this comparison covered only subsections 17C and 17D, which were near the top of the 2% grade in the 5° curve. Thus the measurements did not include a zone in subsection 17A where a significant problem in tie movement developed.

The creep data show that:

a. Creep in subsections 17C and 17D was substantial between 20 and 80 MGT, a period that also included frequent repetitions of maintenance affecting ballast compaction (as will be shown later),

b. Section 17 creep reached a peak during the track buckle at 61 MGT,

c. Substantial stabilization took place in Section 17 during a period of about 20 MGT after the track buckle,

d. In Section 17 the creep markings were "rezeroed" following the rail transposition at 84 MGT; no significant rail creep was found from then to 150 MGT, and

e. Rail creep was not substantial in either the tangent section of concrete tie track or the tangent or curved sections of wood tie track.

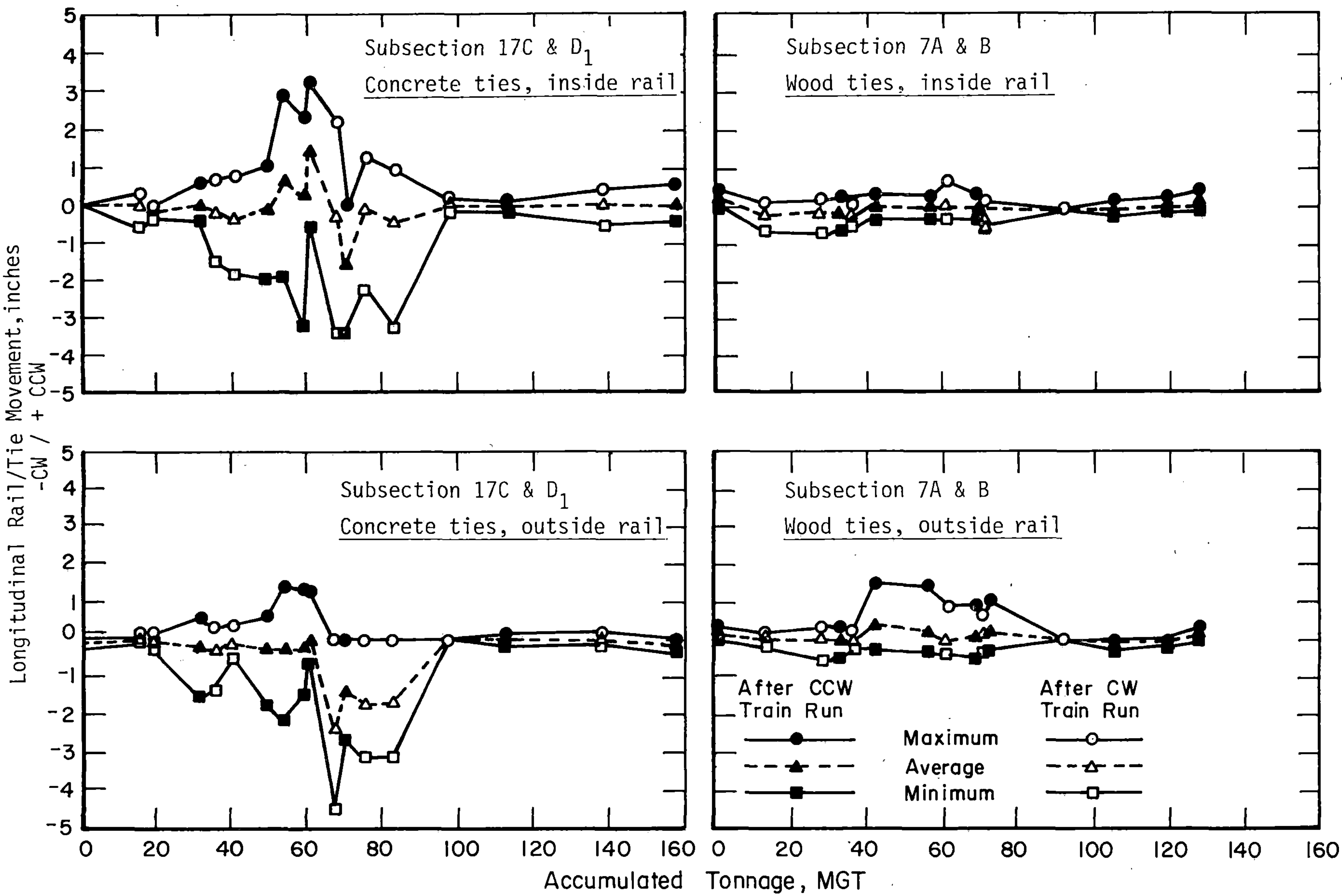


FIGURE 4-12. RAIL CREEP ON 5° CURVE SEGMENTS OF CONCRETE AND WOOD TIE TRACK.

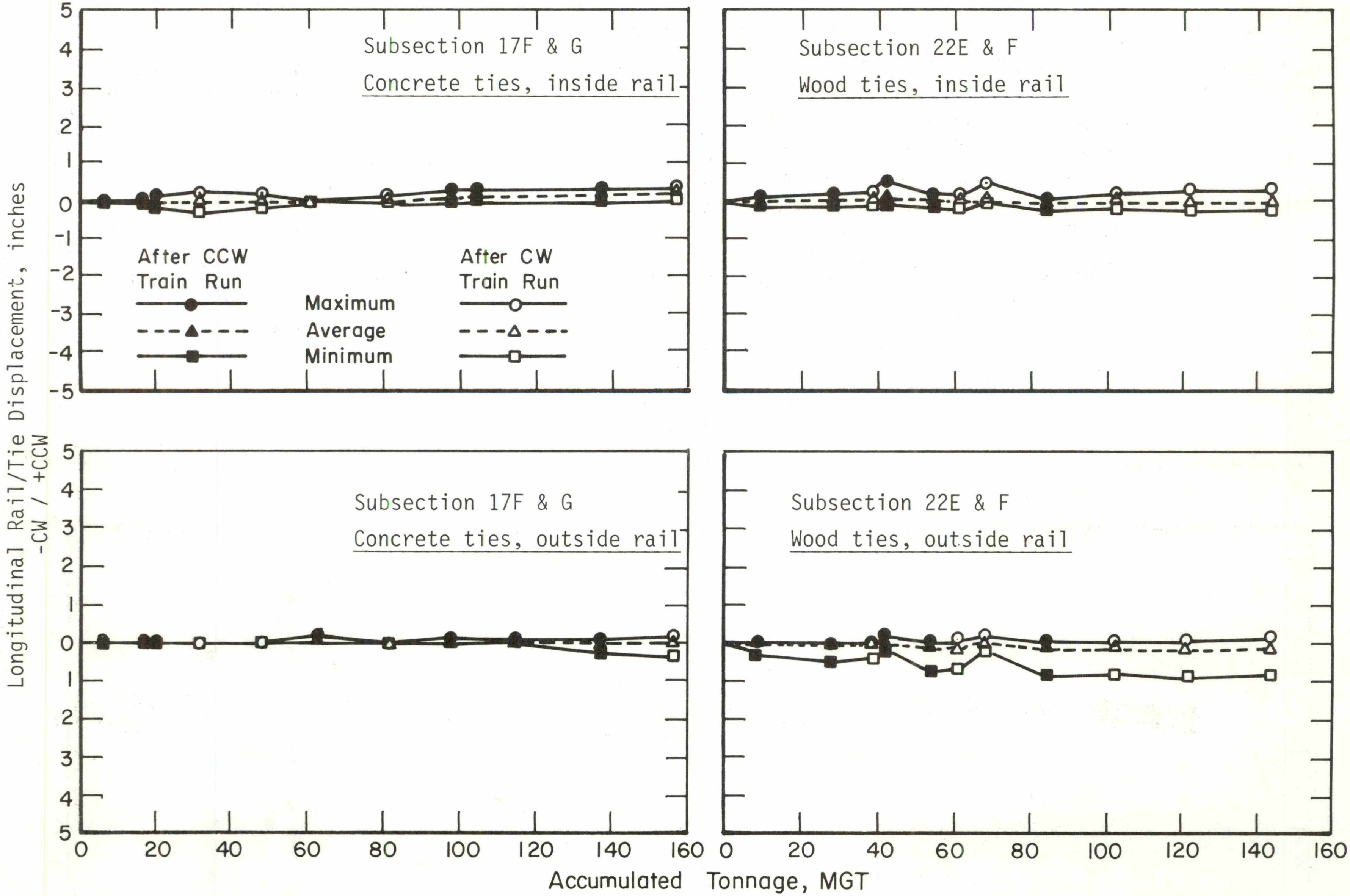


FIGURE 4-13. RAIL CREEP ON TANGENT SEGMENTS OF CONCRETE AND WOOD TIE TRACK.

5.0 CONCRETE TIE COMPONENT PERFORMANCE

Concrete tie component performance has been evaluated from several FAST measurements which include the following:

a. Ties--replacements, surface damage, and strength under load,

b. Fasteners--rates of fracture and fallout, tie movement, and rail creep,

c. Pads--replacements and hardness,

d. Insulators--movement (not covered in report), and

e. Ballast--gradation and migration of fines.

Several significant problems identified were: mechanical damage to ties, fastener fracture and fallout, the effect of soft pads on fastener fracture rate, maintenance demands of tie movement, and ballast deterioration. Correction or substantial reduction of these problems could constitute a significant advance in establishing technical and economic feasibility of concrete tie track for mainline service.

5.1 TIE PERFORMANCE

5.1.1 Tie Replacements

A total of four out of the 2,885 concrete ties were replaced during the first 150 MGT; they were:

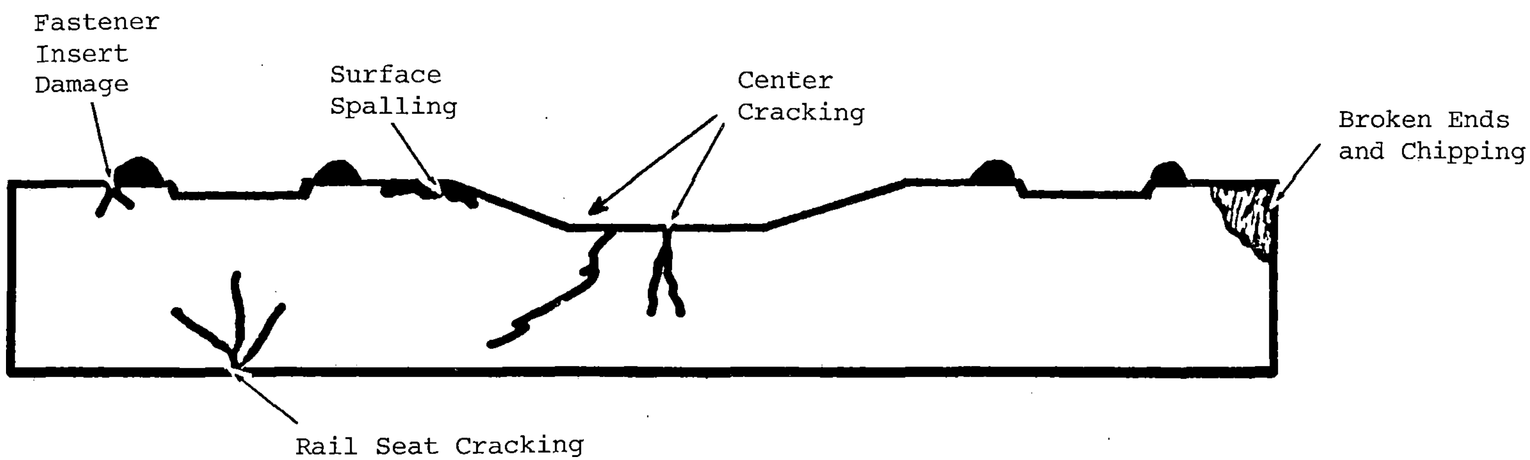
a. Two type T-3 ties originally used on the Kansas Test Track and subsequently installed in the tangent subsection 17F at FAST. Replacement was required when the F-3 threaded fastener bolts broke off during removal of pads for pad hardness measurements, and

b. Two type T-1 ties installed new in the 3° curve; these ties were damaged by blows on or near the fastener shoulder during replacement of fasteners that had fallen out.

It is significant to note that no failures have been caused by train loads. However, the possibility of tie failure because of damage inflicted during maintenance, e.g., overdriving clips, striking shoulder inserts, or gouging the sides of the tie with the tamper feet, represents potential hazards to the economical use of concrete ties.

5.1.2 Tie Flaws

Figure 5-1 illustrates the types of tie flaws which were included in regular inspections of limited numbers of ties in 12 concrete tie subsections. Several problems which were encountered in the inspections include:



Note: Not To Scale

FIGURE 5-1. TIE DEGRADATION AND FAILURE MODES.

a. They were performed on a fixed sample of the ties; thus any flaws which developed on ties not included in the sample were not recorded unless tie replacement was required,

b. Lubrication oil from the train and from rail lubricators obscured the tie tops, and

c. Some inconsistencies have appeared in the data, e.g., fewer flaws were reported at higher values of MGT.

Data from the 150 MGT inspection of specific ties are summarized in table 5-1. Significant findings from this inspection are:

a. No tie center cracking was found on this inspection, or on any previous inspection (see below for further information),

b. Considerable tie rail-seat cracking was found at:

- Subsection 17F (8 out of 14 T-3 ties used previously on the Kansas Test Track),
- Subsection 17G (3 out of 10 T-4 ties),
- Subsection $17H_1$ (3 out of 6 T-5 ties), and
- Subsection $17H_2$ (3 out of 6 T-5 ties).

Among this group the only cases of flexural cracking of this type which could lead to failure were found in Section 17F (the KTT ties). All other rail seat cracks were hair line cracks seen only on the tie face.

c. Considerable mechanical damage from maintenance operations has been encountered in these areas:

- Subsections $17H_1$ and $17H_2$ (7 out of 50 T-5 ties),
- Subsection $17I_2$ (4 out of 50 T-4 ties), and
- Subsection 17L (8 out of 50 T-6 ties).

In addition, a concentration of center cracks was observed at the entrance to the 5^o curve, 2% grade in subsection 17A. A special one-time inspection, conducted at about 97 MGT, produced these results:

a. Between ties 0160-0300, 32 out of 141 (23%) of type T-1 had visible cracks in the top surface of the center. These were caused by the negative bending moment, which indicates possible center binding, and

b. A total of five isolated center cracks were found in the rest of the 5^o curve; these occurred in type T-1 and T-2 ties. All cracked ties continued to perform with little evidence of progressing to the level of a structural crack.

TABLE 5-1. TIE FLAW INSPECTIONS OF CONCRETE TIE TOP AND FACE SURFACES AT 150 MGT.

CONCRETE TIE FACE INSPECTION			CONCRETE TIE TOP INSPECTION			
Type Subsection	Center Cracking	Rail Seat Cracking	Type Subsection	Surface Spalling	Insert Damage	Mechanical Damage
C	0/6*	0/6	C	46/50	0/50	0/50
D_1	0/6	0/6	D_1	25/25	0/25	0/25
D_2	0/6	0/6	D_2	24/25	0/25	0/25
E	0/6	0/6	E	45/50	0/50	0/50
F**	0/14	8/14	G	50/50	0/50	0/50
G	0/10	3/10	H_1	25/25	0/25	2/25
H_1***	0/6	3/6	H_2	25/25	0/25	5/25
H_2***	0/10	3/6	I_2	48/50	0/50	4/50
I_2***	0/10	1/10	J_2	25/25	0/25	0/25
J_2	0/6	0/6	K_1	19/25	0/25	0/25
K_1	0/6	0/6	L	50/50	0/50	8/50
L_1	0/10	0/10				
TOTAL	0/96	18/92	TOTAL	382/400	0/400	19/400

* Number of ties with flaw/Number of ties inspected

** Ties previously in revenue service - most believed to have had small cracks prior to testing at FAST.

*** Hair line cracks--no tie failures have resulted.

5.1.3 Tie Strength Under Load

Figure 5-2 shows a comparison of the cumulative probability density of vertical wheel/rail loads for four mainline U.S. track segments and measurements taken on three occasions on FAST concrete tie tangent track. The FAST test train with fully loaded cars has an average wheel load almost twice that found in normal freight service, where many cars are empty or lightly loaded. Except for high transient loads found in revenue service, caused by wheel flats and battered rail joints, the FAST loading environment is a conservative estimate of revenue service loading.

A summary of the bending moments produced in concrete ties at FAST is presented in figure 5-3. Values depicted in the figure were obtained from a statistical analysis of load data for single passes of the consist over the track. The plots contain envelopes of measured mean values and curves of load levels which would not be exceeded by more than 1/2% of the measurements. The latter were calculated from measured means and standard deviations under the assumption of normal load distributions.

The estimated 1/2% exceedance levels may be conservative because no directly measured bending moments exceeded these levels, except for two isolated measurements. Those are noted on the plots and are quite distinct from the rest of the data. It is possible that these measurements resulted from instrumentation problems.

The plots show that, except for the two isolated measurements, all bending moments lie well below AREA specifications[5-1] for concrete ties at 24" spacing. Since cracking has occurred (although not on strain-gaged ties), it will be important to continue monitoring the condition of the ties to ascertain whether the cracks will grow to failure.

5.1.4 Summary on Tie Performance

A total of four ties were replaced during the first 150 MGT because of mechanical damage and no ties have failed as a result of train loads. Some ties had small cracks at the following locations:

Subsection	Tie Type	Crack Type	No. Cracked/ No. Inspected	Contour
17A	T-1	Center	32/141	5° curve, 2% grade
17F	T-3	Rail Seat	8/14	Tangent (previously used ties)

[5-1] American Railway Engineering Association, Bulletin 644, Volume 75, September-October 1973, and American Railway Engineering Association, Bulletin 655, Volume 77, November-December 1975.

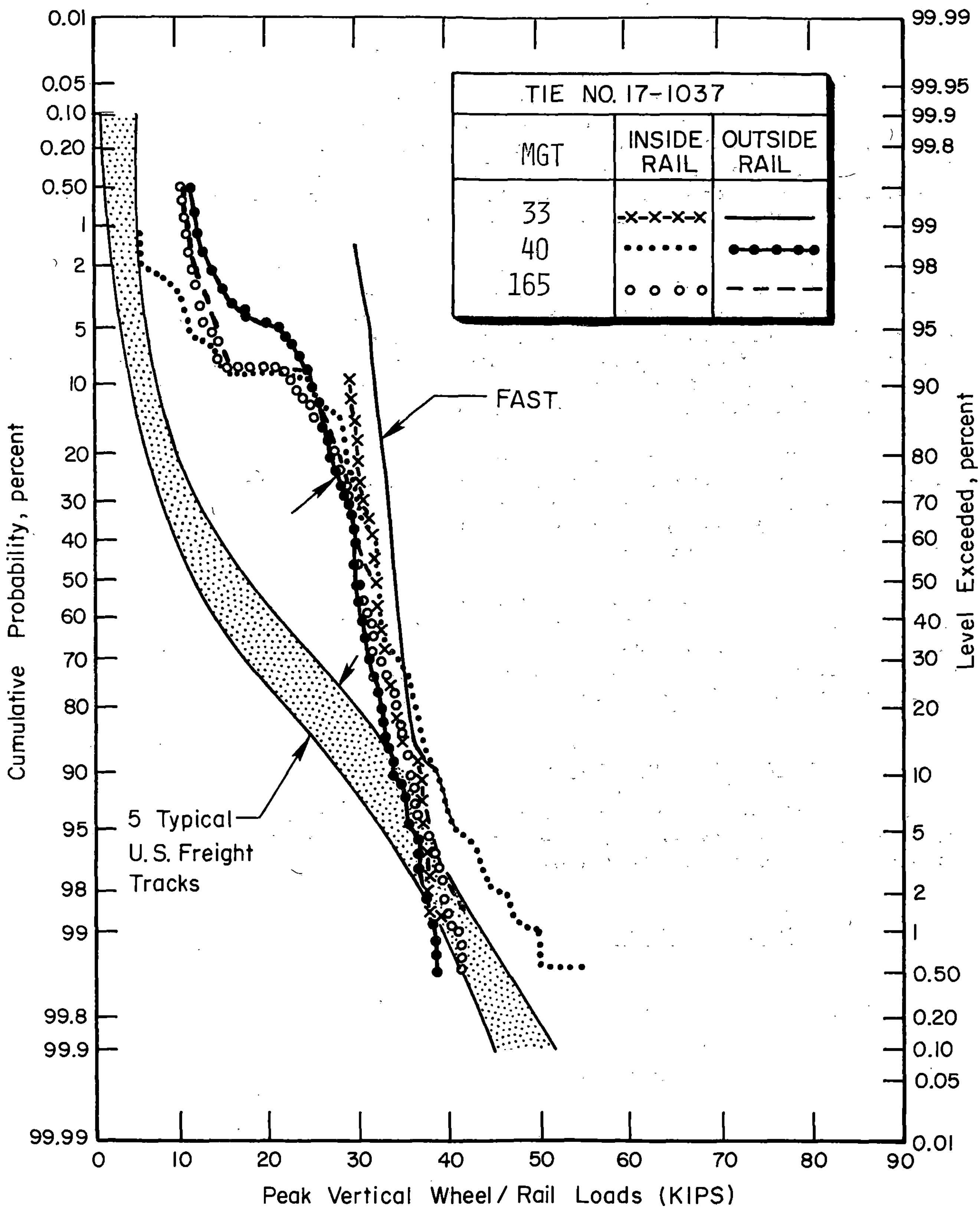


FIGURE 5-2. COMPARISON OF FAST VERTICAL LOAD DISTRIBUTION WITH THAT OF FIVE TYPICAL U.S. TRACKS.

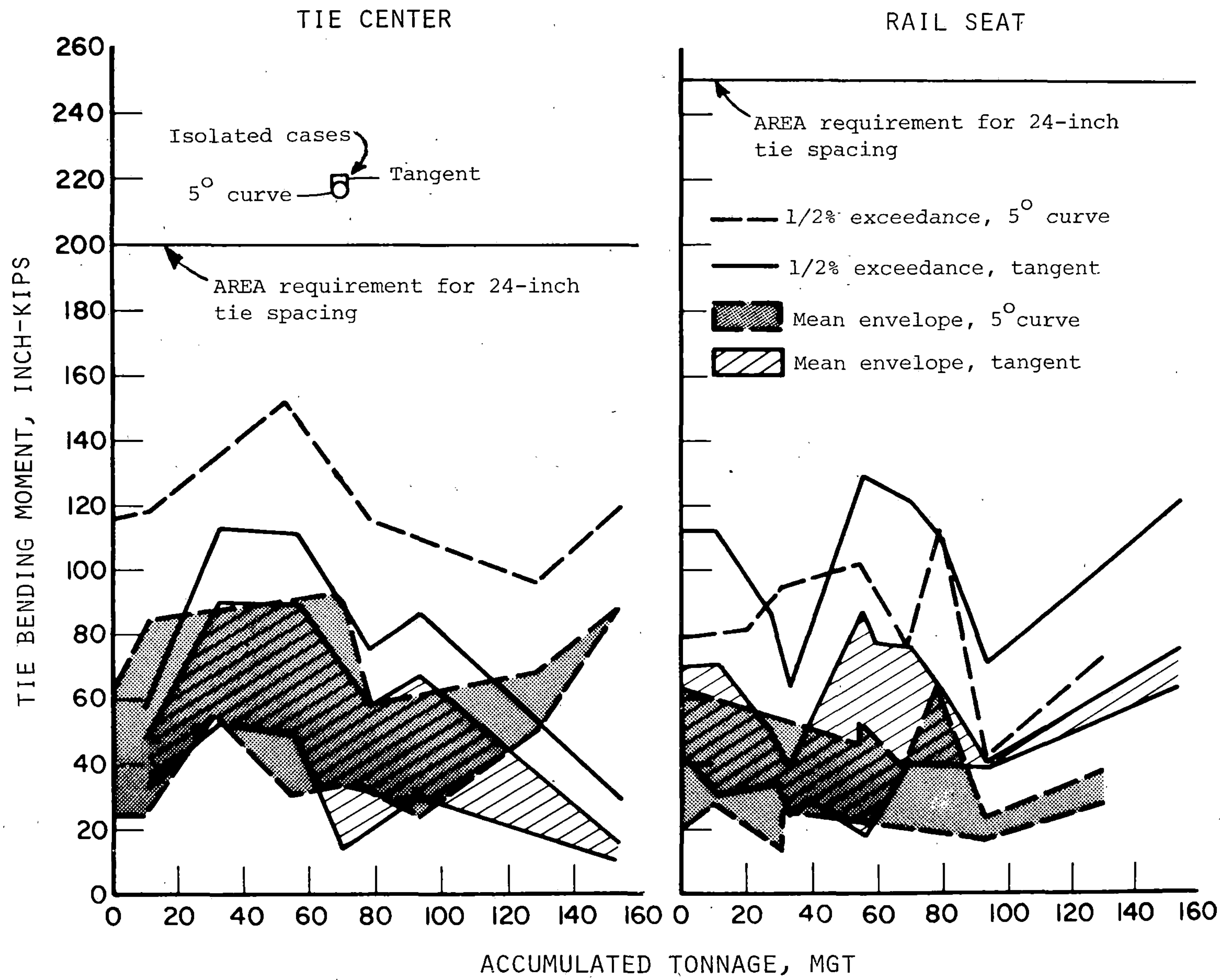


FIGURE 5-3. MEAN ENVELOPES AND 1/2% EXCEEDANCE LEVELS OF CONCRETE TIE BENDING MOMENT.

Subsection	Tie Type	Crack Type	No. Cracked/ No. Inspected	Contour
17G	T-4	Rail Seat	3/10	Tangent
17H	T-5	Rail Seat	3/6	Spiral
17H	T-5	Rail Seat	3/6	3° curve

Tie mechanical damage was found at these locations:

Subsection	Tie Type	No. Damaged/ No. Inspected	Contour
$17H_1$	T-5	2/25	Spiral
$17H_2$	T-5	5/25	3° curve
$17I_2$	T-4	4/50	3° curve
$17L_1$	T-6	8/50	3° curve

Results show that FAST bending moments remained well below AREA design requirements. In spite of this, structural cracking occurred on noninstrumented ties. Possible reasons for the cracks include:

a. Extreme loads that were not picked up by the bending moment measurements,

b. The complex state of stress in the tie was not fully represented by the measured strains, and

c. Support conditions varied, thereby producing various tie bending stresses.

The occurrence of cracks in ties which were designed not to crack is an unresolved problem; however, no degradation in function of the ties as the result of the reported cracks was observed. The development of small cracks did not constitute a structural failure in the concrete ties. Cracked ties have been known to exhibit good performance in revenue service for as long as 10-15 years. For purposes of FAST maintenance, failure has been defined as the extension of a crack to the prestress tendons. There have been no such failures as the result of service loads.

5.2 RAIL PAD AND RAIL FASTENER PERFORMANCE

5.2.1 Tie Pad and Rail Fastener Failures

As part of the track restoration at 61 MGT, all type F-1 elastic clip fasteners were replaced in the 5° curve of Section 17. Prior to that time, no fractures had been reported. At about 100 MGT, fractures began to occur in the new batch of fasteners. The spatial distribution of those failed between 100 and 220 MGT is shown in figure 5-4.

Also shown in figure 5-4 are pad replacements required between 0 and 150 MGT. Most of the pads replaced were of type P-2 and most fastener fractures occurred in the P-2 pad region of the 5° curve.

P-2 pad replacements were required because a concentrated wear pattern -- an oblong frayed area 1"-2" across--developed to a greater extent in these pads than in any others. Had they not been replaced, they would have worn completely through.

As shown in figure 5-5, about half of all clip failures occurred at the inside gage (IG) location. A possible cause of this failure pattern was the flexing of the IG clip as the rail rolled under dynamic loading.

5.2.2 Rail Fastener Clip Fallout

Extensive fallouts of types F-1 and F-2 clip fasteners occurred between 0 and 150 MGT in the 5° curve and adjacent spiral. Figure 5-6 summarizes their spatial distribution. The influence of several effects can be seen:

a. There is a definite effect from track contour. Most of the rail clip fallouts occurred in the 5° curve, 2% grade; the 3° curve produced a smaller number of fallouts and the tangent produced very few,

b. A second large group of rail clip fallouts occurred in the region of the P-2 pads, which are the most flexible pads used with the type F-1 and F-2 clips, and

c. By far the largest concentration of fallouts occurred in subsection D, which was the only location for type F-2 fasteners without insulators.

5.2.3 Tie Pad Hardness

Tie pad hardness was measured on a group of control pads in 11 subsections of Section 17 spanning the entire range of pad type and track contour; the measurements were taken with durometers of two different hardness ranges.

Figure 5-7 summarizes the hardness data. Black dots show measurements of control pads kept in the laboratory, and shaded regions show the measurement ranges for the service pads. In general, there was little variation with tonnage, but the pads can be classified into three ranges of hardness:

a. Hard pads--P-1 a through d, P-4, P-6, and P-8,

b. Medium pads--P-3 and P-5, and

c. Soft pads--P-2 and P-7.

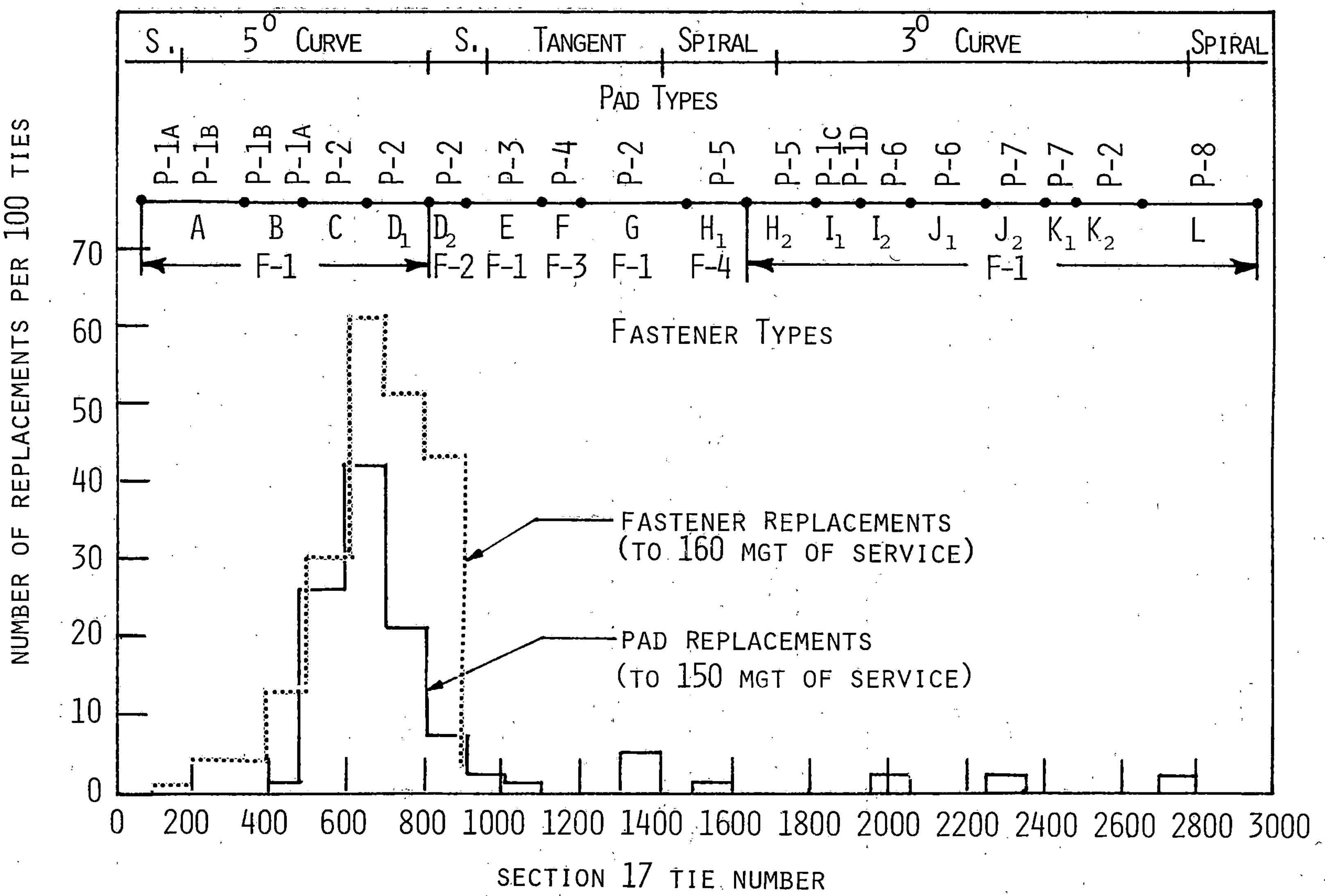


FIGURE 5-4. SUMMARY OF RAIL PAD AND FASTENER CLIP FAILURES IN SECTION 17.

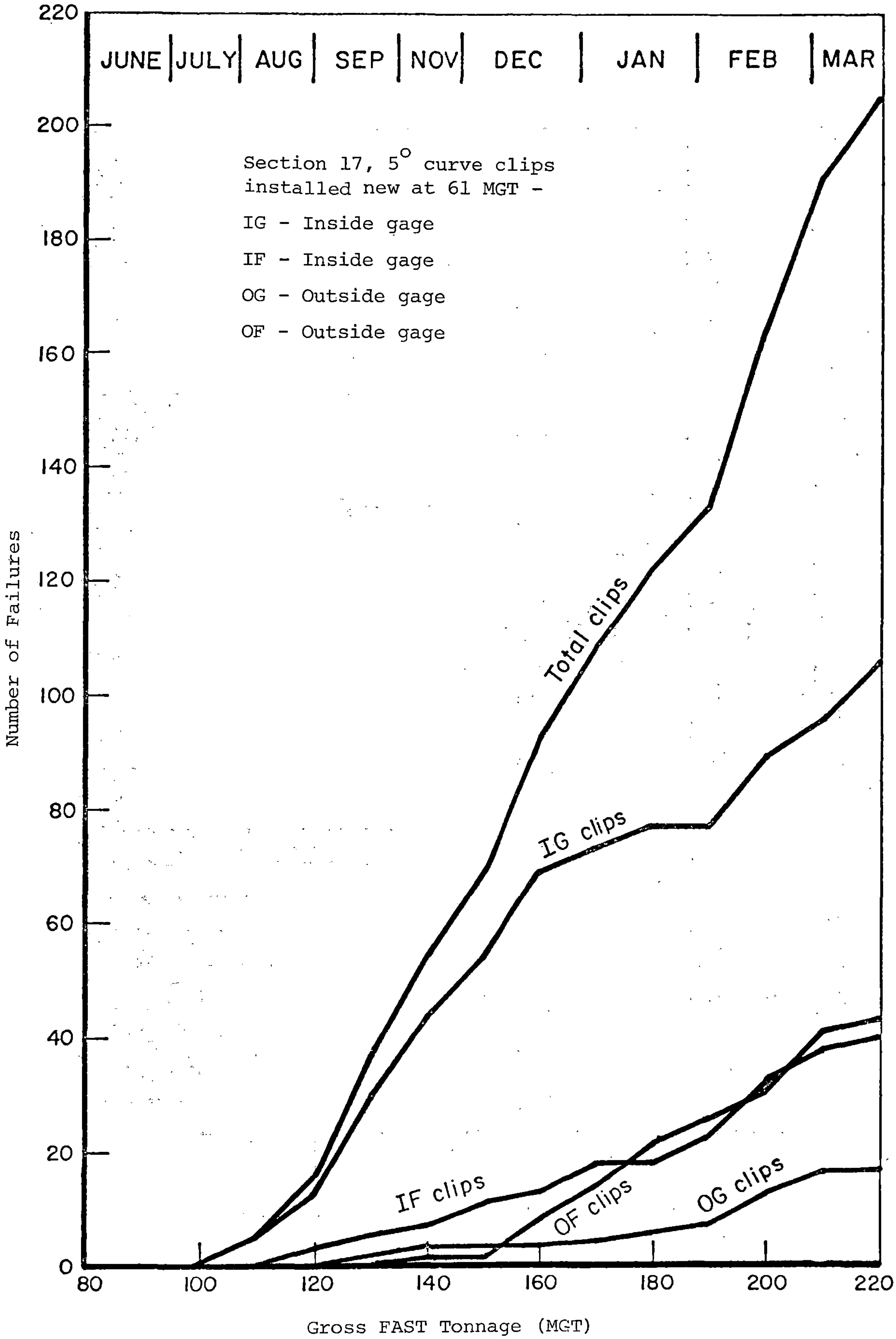


FIGURE 5-5. ELASTIC CLIP FAILURES AT EACH CLIP LOCATION VS. MGT.

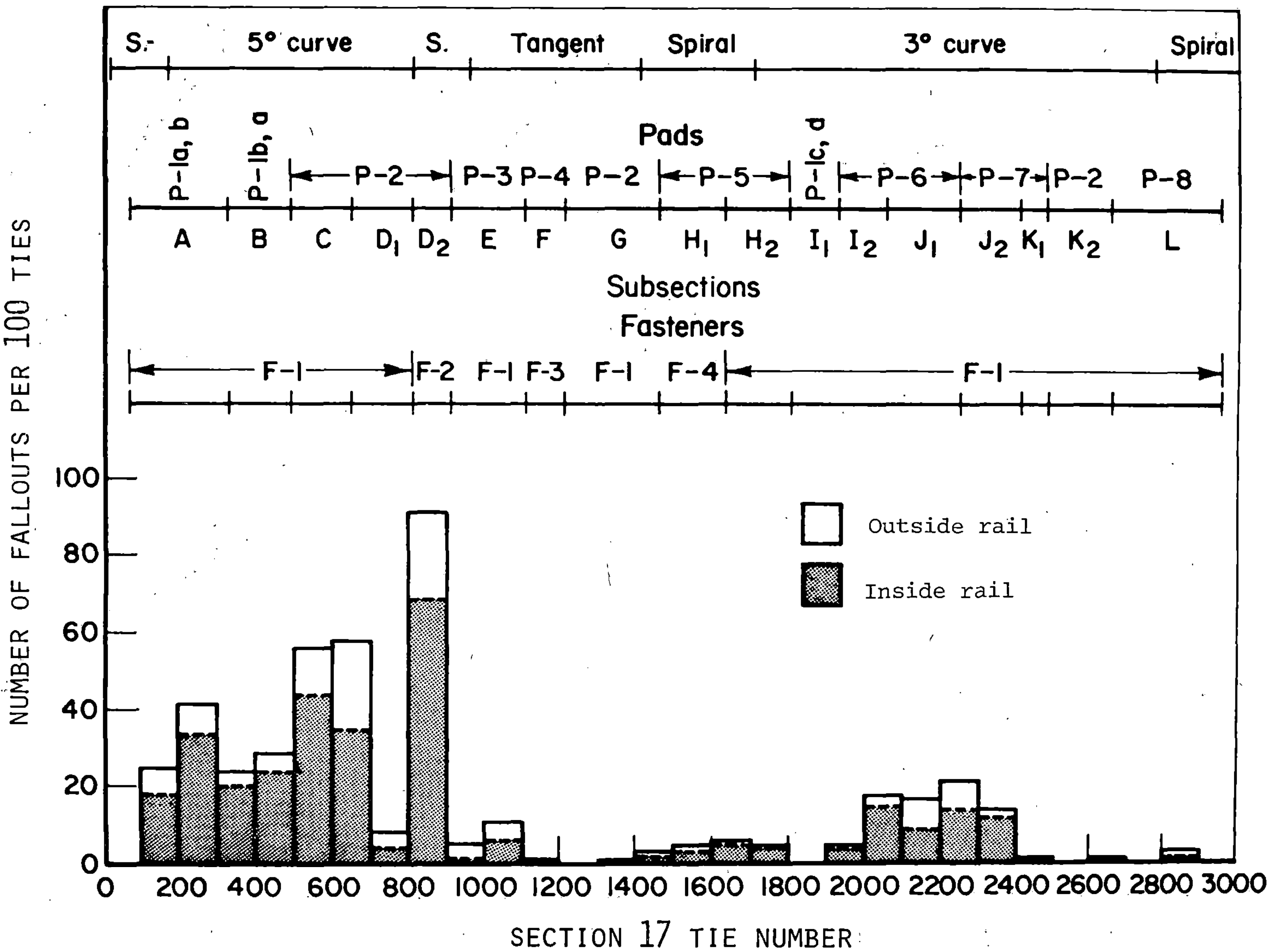


FIGURE 5-6. SUMMARY OF ELASTIC CLIP FASTENER FALLOUTS IN SECTION 17, 0-150 MGT.

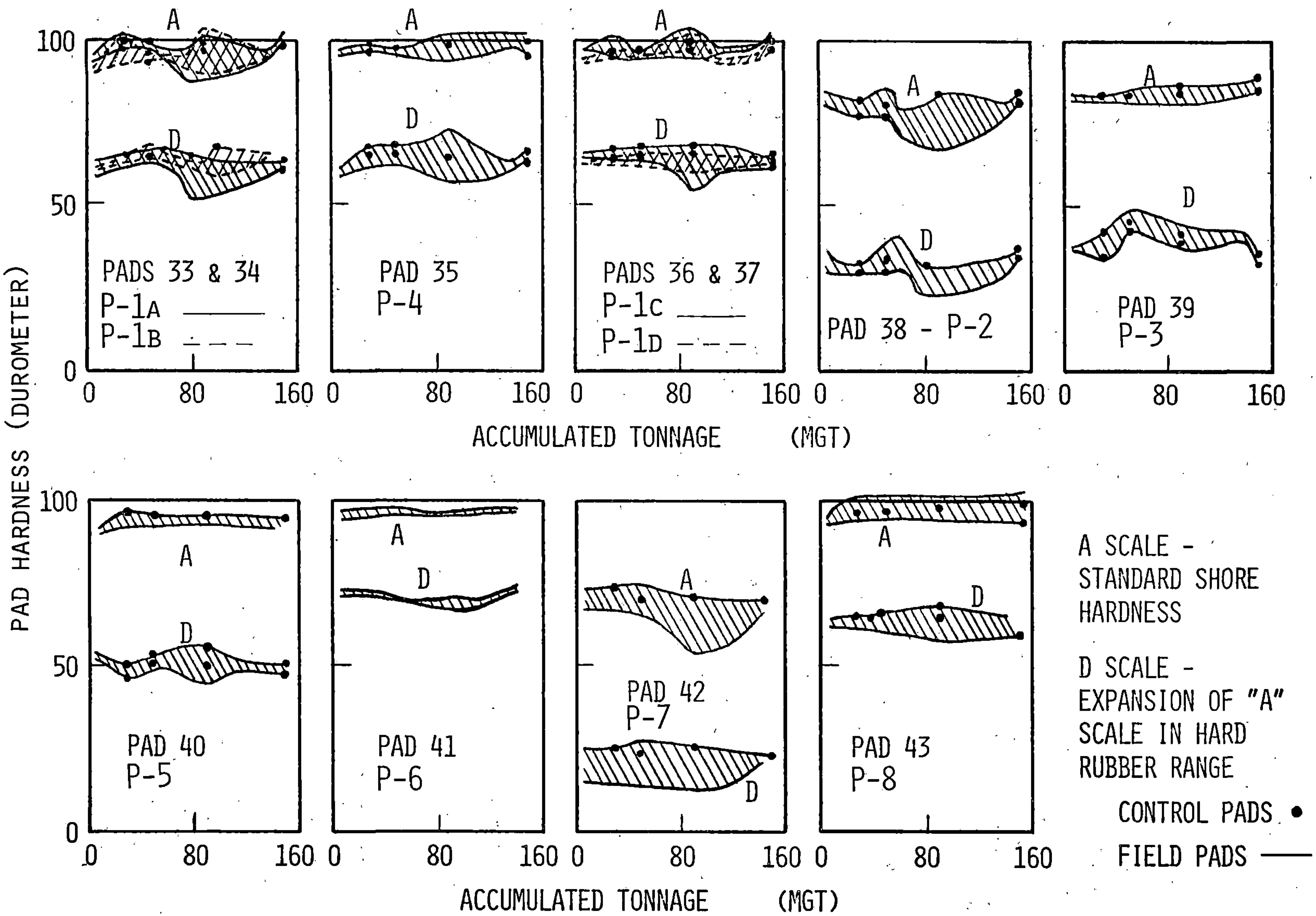


FIGURE 5-7. SUMMARY OF PAD HARDNESS MEASUREMENTS.

The softness of the P-2 pad probably contributed to the concentration of rail fastener clip failures in the 5^{o} curve.

5.2.4 Longitudinal Tie and Rail Movement

Longitudinal rail movement was measured at all survey to benchmark (STB) sites, which were located at 100-ft intervals around the track. Longitudinal tie movement was measured on the two ties nearest each STB site in the concrete tie Section 17. The positions of the ties and rail are were measured relative to a transverse reference line established from two benchmarks with a surveying instrument. Movements were calculated as changes in these positions.

As previously discussed, longitudinal tie and rail movement can be caused by thermal expansion and contraction of the rails, by train braking and acceleration, and by insufficient ballast resistance to load. When equivalent influences from these effects can be expected, the longitudinal movements provide a good comparative measure of fastener holding capacity. There are no equivalent conditions for different fastener clips in Section 17 because of variations in grade, curvature, and train handling. However, the 5^{o} curve, 2% grade of Section 17 provides a good measure of the adequacy of any installed fastener. Only type F-1 elastic clips have been used to date.

A summary of the longitudinal tie and rail movement data is shown in figure 5-8. With one exception, all subsections covered by the data have type F-1 elastic clip fasteners. Subsection F has type F-3 fasteners. Figure 5-8 shows that:

a. Rail movement was about half the magnitude of tie movement, and

b. The largest tie movement occurred near the start of the 5^{o} curve, 2% grade (ties 0200-0300) and extended for some distance.

The problem of tie movement at the start of the curve is verified by figure 5-9, which summarizes tie repositioning activity over Section 17. Tie repositioning was required when longitudinal spacing varied from the standard 24" by more than 6", or if the skew (relative longitudinal position of the two ends of the tie) exceeded 6".

In figure 5-10, average longitudinal movements of two ties at a number of measurement sites in the curve and grade are plotted versus MGT. The plot shows that rapid downhill movement of the ties began at about 54 MGT and culminated in the lateral instability at 61 MGT. This evidence of tie movement shows the need for good ballast compaction and for fasteners of sufficient holding capacity in track contours comparable to the FAST 5^{o} curve, 2% grade.

5.2.5 Summary of Tie Pad and Rail Fastener Performance

Extensive fatigue failures of type F-1 elastic clips began to develop in one region of the 5^{o} curve of Section 17 at about 100 MGT. These clips were

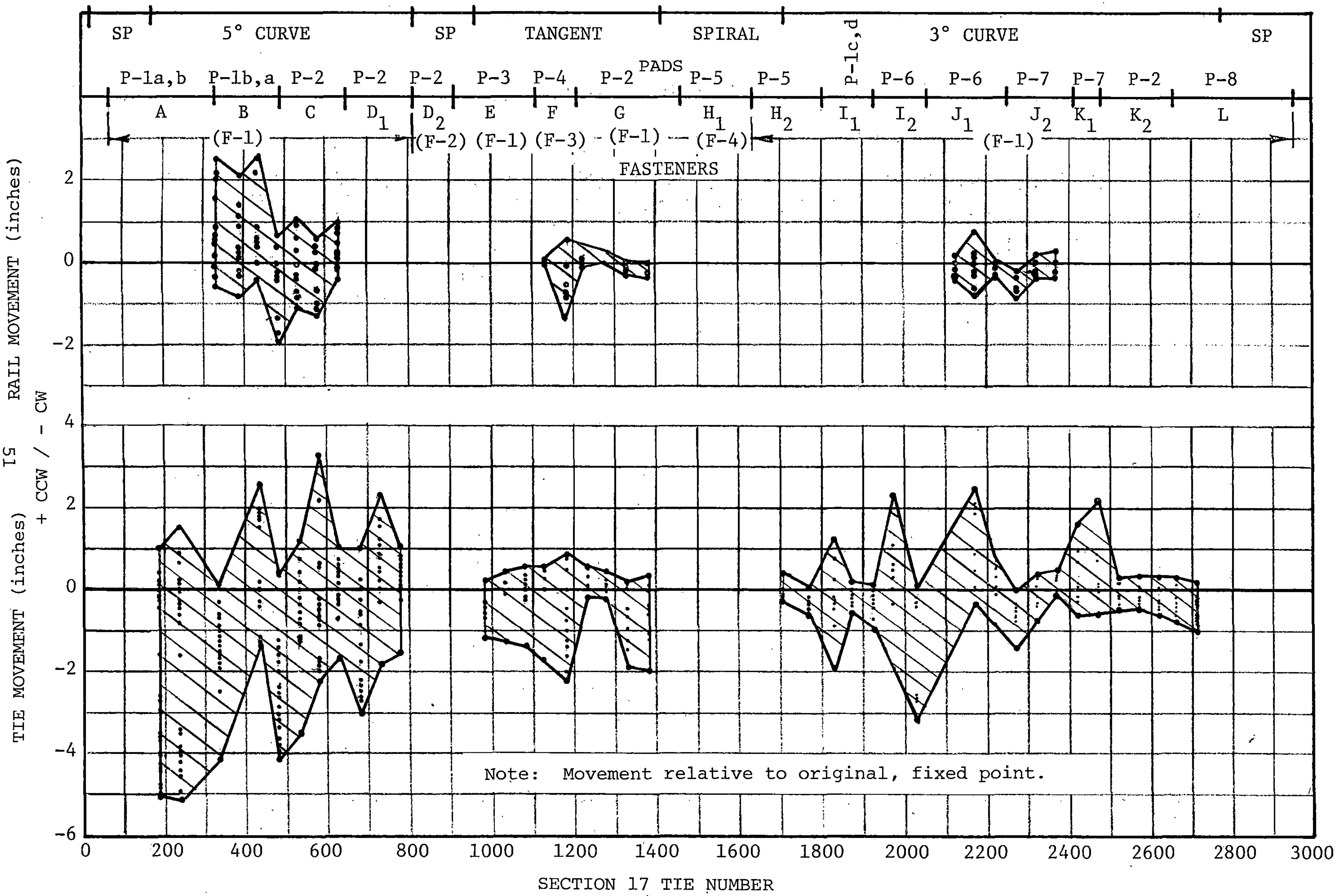


FIGURE 5-8. ENVELOPES OF LONGITUDINAL RAIL AND TIE MOVEMENT IN SECTION 17.

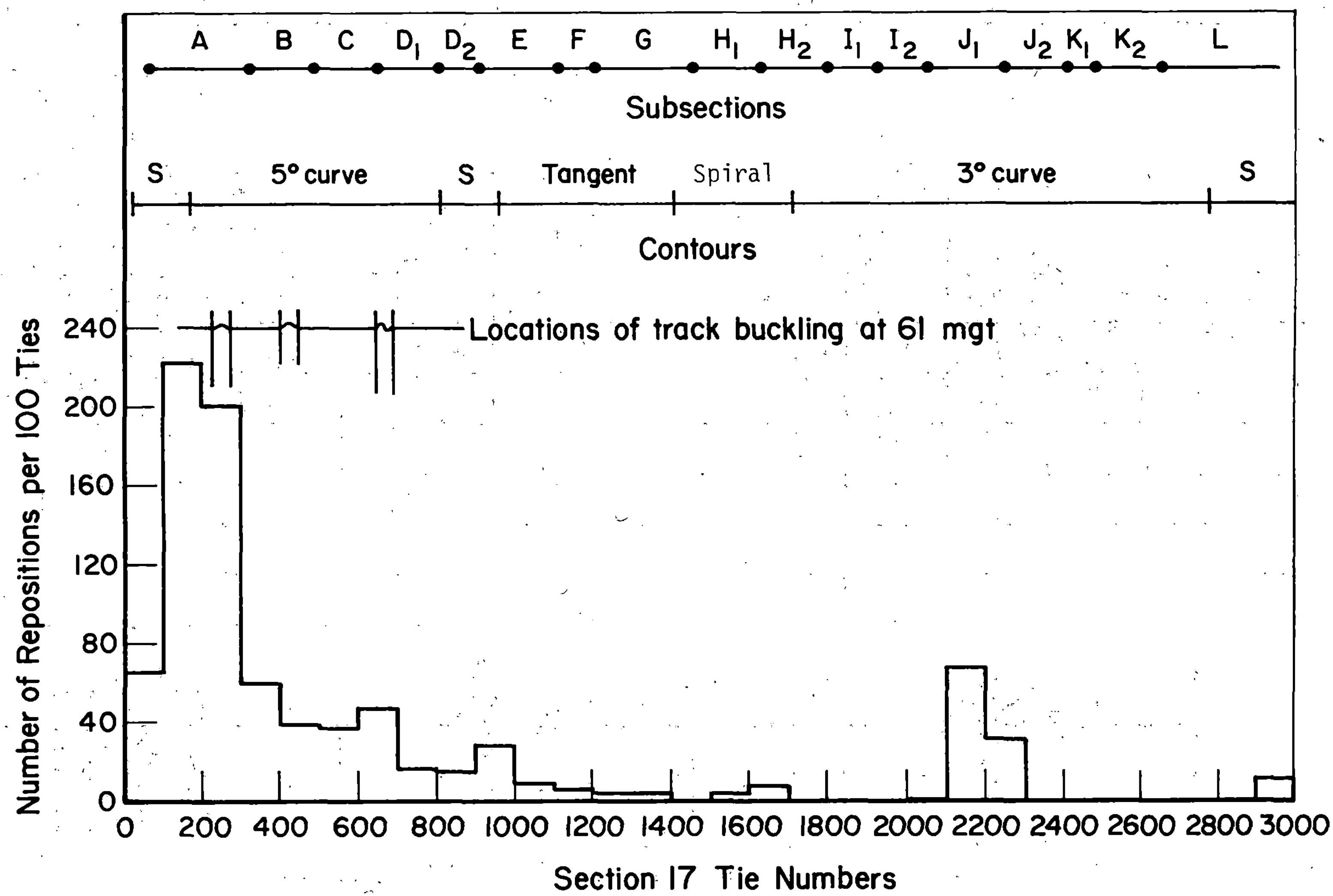


FIGURE 5-9. SUMMARY OF TIE REPOSITIONING IN SECTION 17, 0-150 MGT.

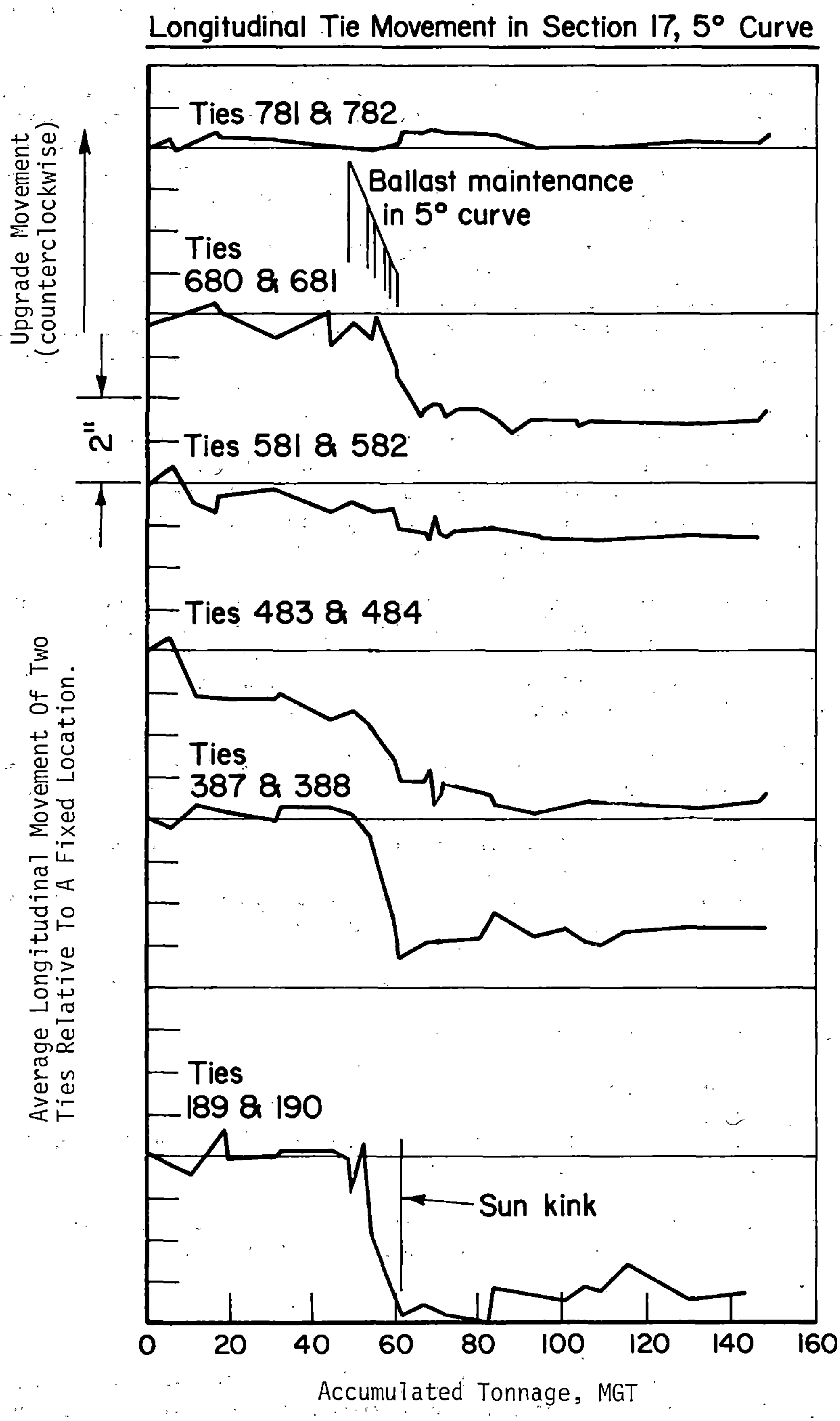


FIGURE 5-10. AVERAGE LONGITUDINAL TIE MOVEMENT VS. MGT FOR SPECIFIC SITES IN THE 5° CURVE, 2% GRADE OF SECTION 17.

all from a batch installed at 61 MGT after the lateral track buckle. No clip failures had been reported prior to 100 MGT.

A metallurgical investigation[5-2] was conducted on several failed clips and several sample clips from other batches to determine the cause of the high rate of failure in this batch. All failures were identified as bending fatigue fractures that occurred at either of the two minimum radius bends in the clips. The high rate of failure could have been caused by surface defects including decarburization, inter-granular oxide penetration, and general irregularities introduced during the manufacturing process.

These fastener clip failures were concentrated over the region of the 5° curve where the soft type P-2 pad was installed. Fasteners from the same batch were installed in the 5° curve at the same time with harder pads; these had much lower failure rates.

Replacements of tie pads because of wear were concentrated in the type P-2 pad region of the 5° curve. The dominant mode of failure consisted of concentrated wear (abrasion, fraying) over a small area of the pad. Most pad replacements (65%) were made after the track buckle at 61 MGT, and the remainder were replaced between 84 and 128 MGT.

Extensive fallouts of type F-1 elastic clips occurred in the 5° curve of Section 17. Most occurred in these regions, listed in descending order:

a. Subsection 17D, where the elastic clip fasteners were installed with type P-2 pads without insulators,

b. Subsections 17C and 17D, where the fasteners were installed with type P-2 pads with insulators, and

c. Subsections 17A and 17B, the remainder of the 5° curve.

Changes in hardness showed no trend with respect to MGT. The pads could be placed into three groups ranked by hardness:

a. Hard--Types P-1, P-4, P-6, and P-8,

b. Medium--Types P-3 and P-5, and

c. Soft--Types P-2 and P-7.

The softness of the type P-2 pads probably contributed to fastener failures in the 5° curve.

A problem of excessive longitudinal tie and rail movement occurred near the start of the 5° curve and 2% grade of Section 17.

[5-2] Buchheit, R.D., and Broek, D., "Failure Investigation of FAST Concrete-Tie Fastener Clips," Report to Transportation Systems Center by Battelle-Columbus Laboratories, Contract DOT-TSC-1044, June 9, 1978.

5.3 BALLAST PERFORMANCE

The problems of ballast flow from the shoulders and tie cribs in the 5^{o} curve, 2% grade created a major part of the maintenance requirements for the Section 17 concrete tie track. The ballast flow could have been principally caused by one or more of these effects:

a. The small average size of ballast particles and the observed lack of angularity could have prevented adequate interlocking and consolidation, and

b. The type and frequency of ballast maintenance.

5.3.1 Ballast Quality

Ballast size is shown in figure 5-11, which compares particle size distributions from samples of new ballast taken from the five batches used to build the FAST Track. The granite ballast for the entire Section 17 shows a smaller mean particle size and percentage of fines than do the other samples.

The particle size distribution of the limestone, slag, and basalt (traprock) ballast falls generally in the zone which defines AREA gradation No. 4 for crushed stone and slag ballast.[5-3] The granite ballast barely conforms to AREA gradation No. 5. While there are no specific AREA restrictions on the use of Grade 5 ballast, FAST results indicate that application of this type of ballast should be closely studied before use in a combined curve and grade on new embankment under a new track section.

Figure 5-12 summarizes results from ballast gradation tests on the granite ballast in Sections 17 and 18. The figure shows the percentage of ballast finer than the 1/2" sieve dimension cited as an index of gradation. In two of the three test locations shown, significant increases in this index had taken place between 0 and 46 MGT and before any addition of new ballast. The particle size shown at zero MGT for Section 17 in the 5^{o} curve agrees well with the sample of new ballast of figure 5-11; the change in gradation between 0 and 46 MGT was sufficient to advance the percentage of particles with 1/2" or less diameter across about half of the shaded zone defining Grade 5 ballast.

Another measure of the extent of subgrade and ballast deterioration was the migration of subgrade fines into the ballast. Figure 5-13 is evidence that this migration was extensive in the concrete tie subsection 17E.

5.3.2 Maintenance Affecting Ballast Compaction

Figure 5-14 shows a summary of the maintenance affecting ballast compaction (shoulder reshaping, surfacing/lining/tamping, tamping only, and ballast addition) performed in Section 17 between 0 and 150 MGT. Such

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5-3
"Manual for Railway Engineering, Volume I," American Railway Engineering Association, March 9, 1972.

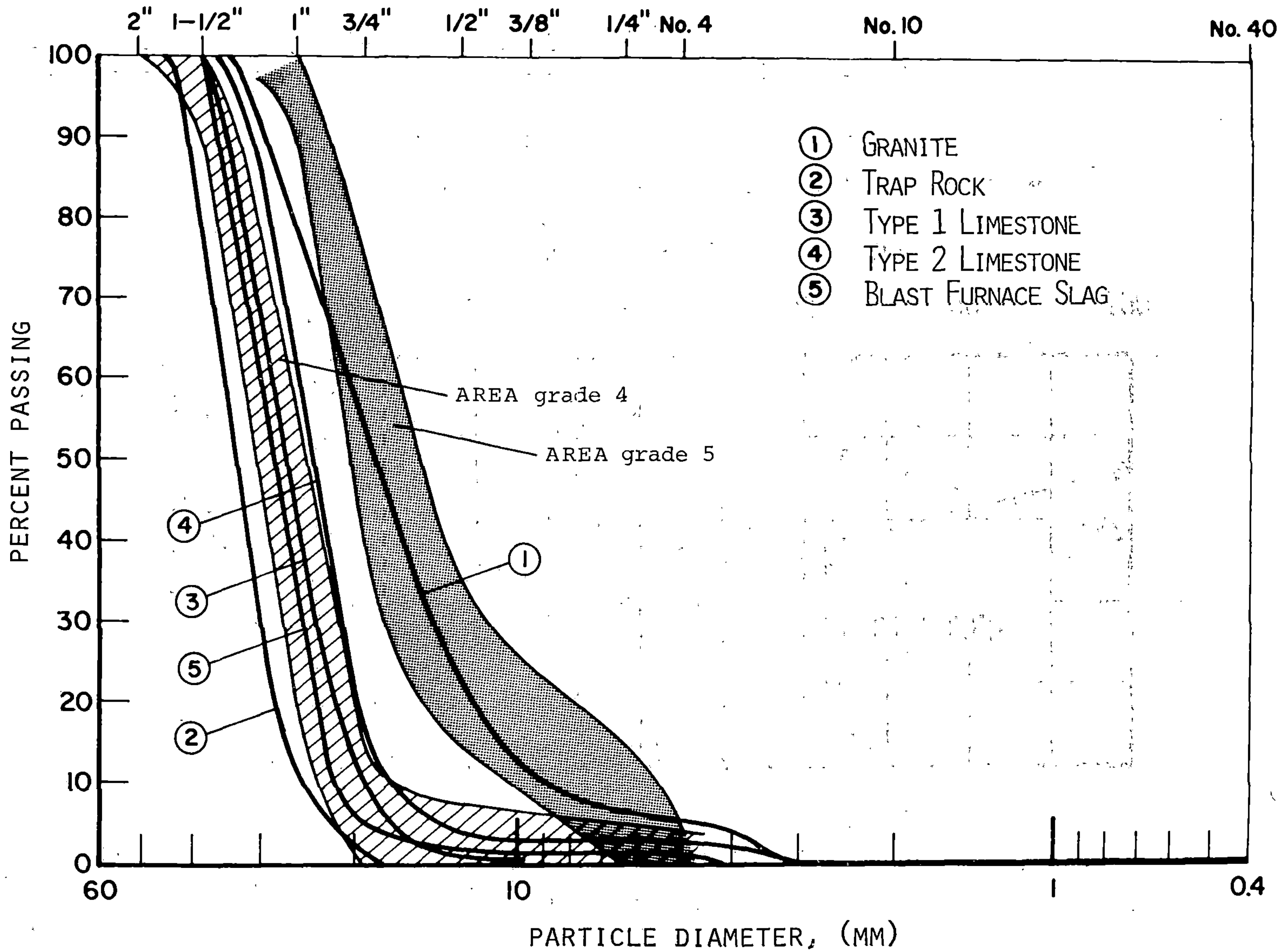

FIGURE 5-11. ORIGINAL PARTICLE SIZE DISTRIBUTION OF FAST BALLAST MATERIALS.

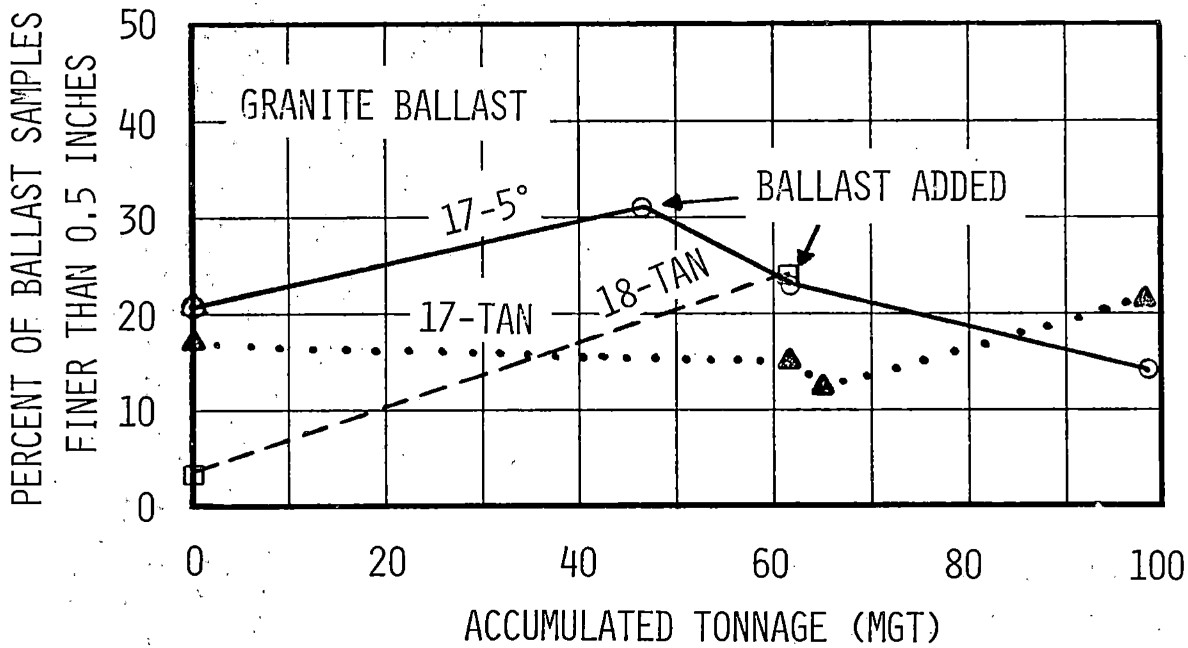

FIGURE 5-12. SUMMARY OF BALLAST GRADATION TESTS.

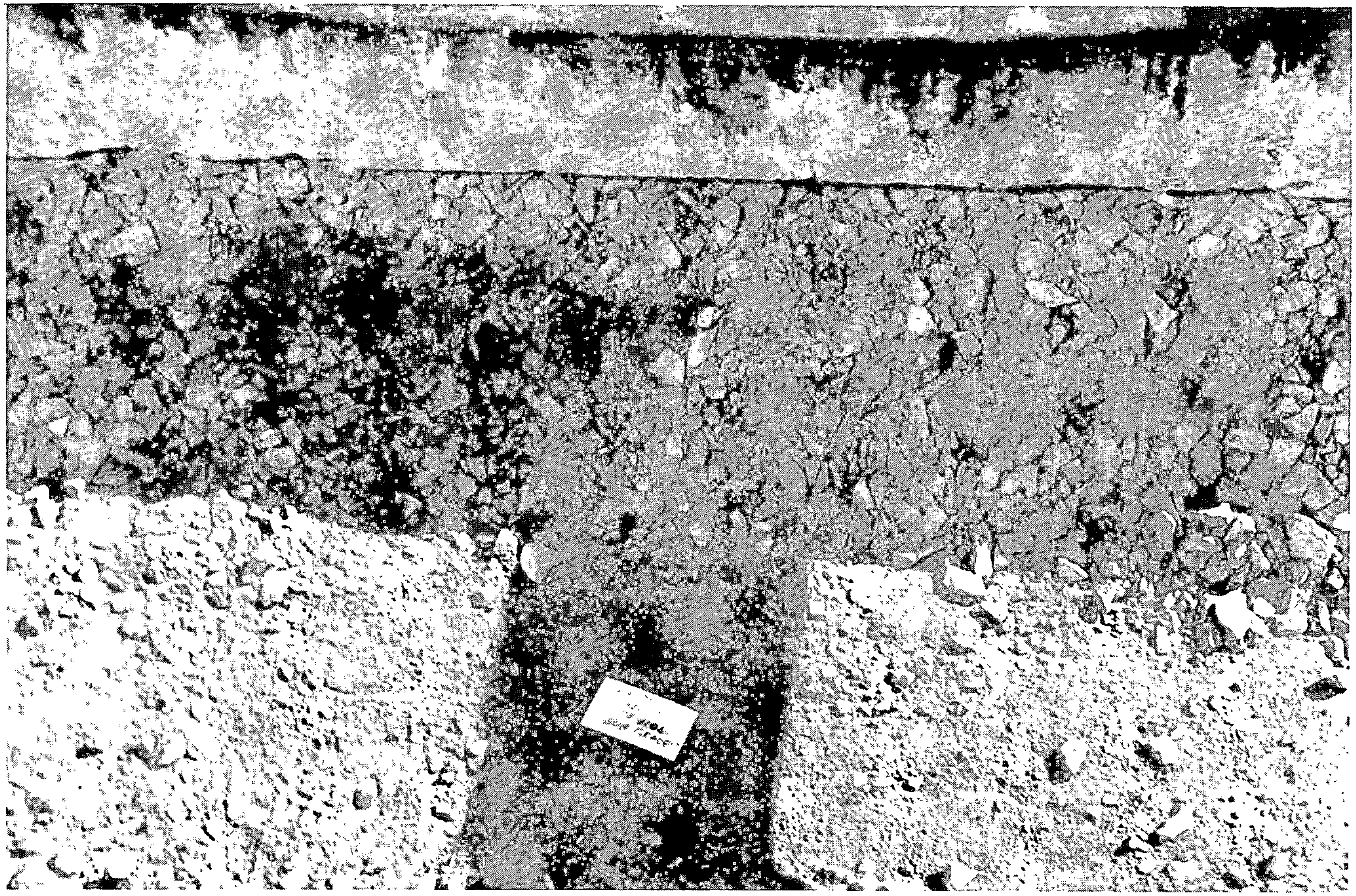

FIGURE 5-13. MIGRATION OF SUBGRADE FINES INTO BALLAST, CONCRETE TIE SUBSECTION 17E (206 MGT).

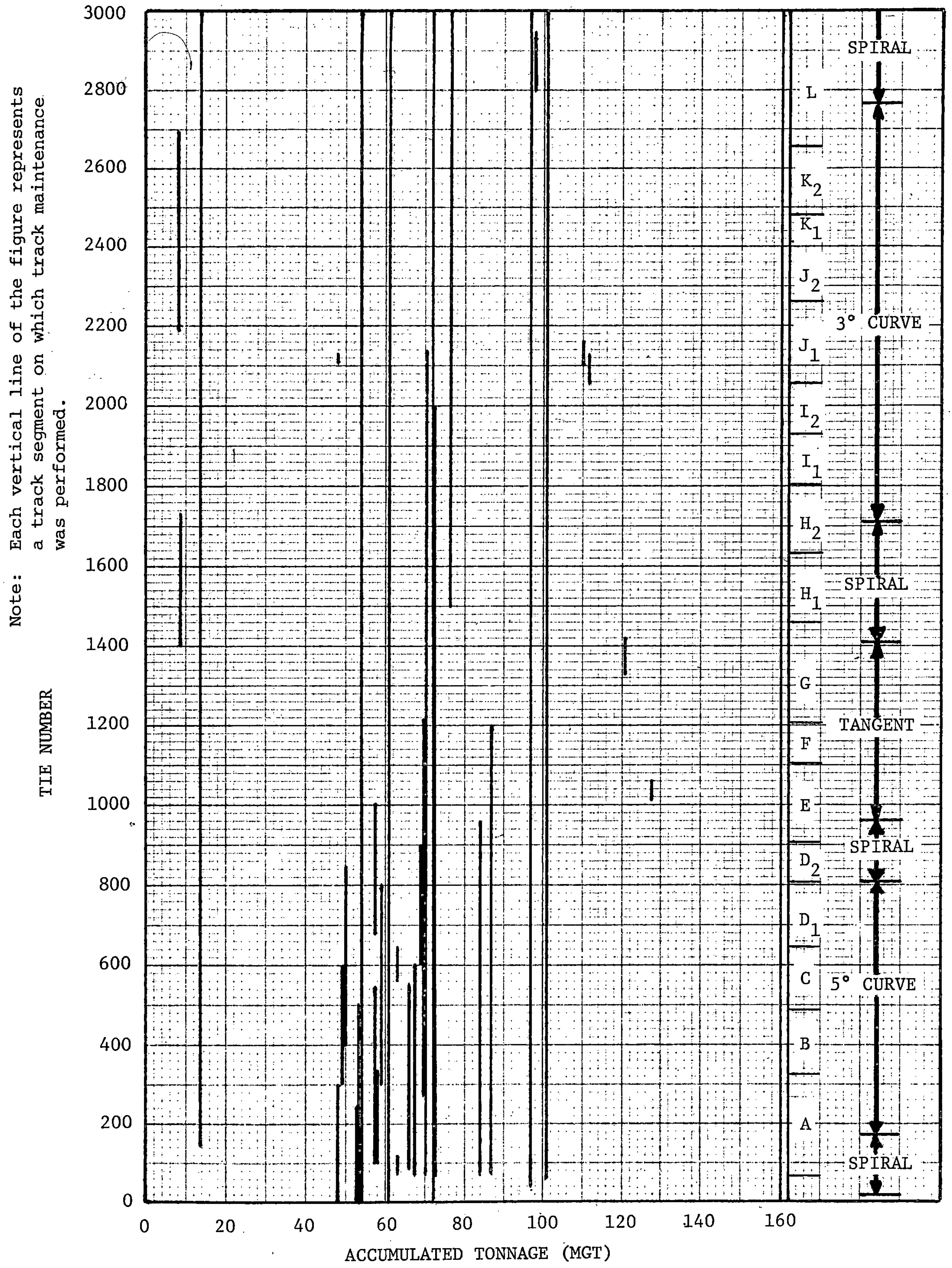

FIGURE 5-14. SUMMARY OF MAINTENANCE AFFECTING BALLAST COMPACTION IN SECTION 17 (TAMPING, SURFACE/LINE/TAMP, BALLAST ADDITION AND RESHAPING).

maintenance had a major impact on the lateral stiffness of the track.[5-4] The frequency of maintenance beginning at 48 MGT coincided with a rapid increase in tie movement seen earlier in figure 5-10. This tie movement culminated in the lateral instability incident at 61 MGT.

5.3.3 Summary of Ballast Performance

The problem of ballast flow from the shoulders and tie cribs in the 5° curve, 2% grade of Section 17 created a major part of the maintenance requirements for concrete tie track. The ballast flow may have been caused by the use of ballast which originally was small in size and experienced further deterioration from traffic and/or from extremely large amount of maintenance affecting ballast compaction. There is no evidence to support the statement that ballast flow resulted from any feature peculiar to concrete tie track. It should be noted that an analysis of the composition of ballast material in Section 17[5-5] revealed that although the material had the appearance of granite and was commonly identified as such, it contained a high percentage of hornfels, a typically hard and brittle material. This provides further evidence that the problems which have occurred in this section derived largely from the performance of the ballast.

A rebuild of the curve and grade of Section 17 is planned for the summer of 1979, when new, uniform Grade 3 granite ballast will be installed. By comparing track performance before and after this rebuild, an assessment of the effect of ballast quality on track performance in this area will be possible.

5-4 Hofmann and Pfarrer, "Influence of Various Measures on the Lateral Displacement Resistance of the Unloaded Track," Report No. DT 44/D117/D, Research and Testing Laboratory of the International Railroad Association (ORE), UTRECHT, May 1976.

5-5 Smith, R.K., "Composition Analysis Report," Department of Geosciences, University of Colorado.

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1-3 Kish, A., and Dean, F.E., "Data Analysis Requirements for FAST Track Performance Evaluation," prepared by Battelle-Columbus Laboratories and distributed under cover letter from Transportation Systems Center, Task 9.2 of Contract DOT-TSC-1044, December 8, 1977.

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4-1 Arnlund, R.C., White, D.W., and Prause, R.H., Economics of Concrete- and Wood-Tie Track Structures, Report No. FRA/ORD-78/2, August 1978, PB #291613.

4-2 McIntosh, G.P., et al., "FAST Track Specification, Volume II - Track," Report No. 7134 of the U.S. Department of Transportation, Facility for Accelerated Service Testing, June 8, 1977.

4-3 Mair, R.I., and Murphey, R.S., "Rail Wear and Corrugation Studies," American Railway Engineering Association, Bulletin 660, November-December 1976.

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5-2 Buchheit, R.D., and Broek, D., "Failure Investigation of FAST Concrete-Tie Fastener Clips," Report to Transportation Systems Center by Battelle Columbus Laboratories, Contract DOT-TSC-1044, June 9, 1978.

5-3 Manual for Railway Engineering, Volume I, American Railway Engineering Association, March 9, 1972.

5-4 Hofmann and Pfarrer, Influence of Various Measures on the Lateral Displacement Resistance of the Unloaded Track, Report No. DT 44/D117D, Research and Testing Laboratory of the International Railroad Association (ORE), UTRECHT, May 1976.

5-5 Smith, R.K., "Composition Analysis Report," Department of Geosciences, University of Colorado.

GPO 855-251

Concrete and Wood Tie Track Performance Through 150 Million Gross Tons (Interim Report), 1980
Francis E Dean, Robert H Prause