THE EFFECT OF SERVICE LOADING ON THE BENDING STRENGTH OF CONCRETE TIES

FAST Facility for Accelerated Service Testing

TRANSPORTATION TEST CENTER
PUEBLO, COLORADO 81001

INTERIM REPORT
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16. Abstract

Concrete tie bending strength tests were conducted by Battelle-Columbus Laboratories at Columbus, Ohio, as part of the Tie and Fastener Verification Studies contract (DOT-FRA-1652) sponsored by the FRA Office of Rail Safety Research. The object of the testing was to determine the effects of service loading on the strength of concrete ties and to formulate assumptions about the economy of their use compared to wood ties. Of interest, also, is the comparison of concrete ties meeting the 1973 AREA structural requirements to earlier design types and to the manufacturers' test results. Used and unused ties from the same production runs were provided by the Transportation Test Center, Pueblo, Colorado, from a rebuilt section of the FAST track. Tabulations of tie strength for each group are presented, methods of testing are described, and the significance of the findings is discussed.

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PREFACE

The tests of concrete tie bending strength described in this report were conducted under a contract entitled "Tie and Fastener Verification Studies" (Contract No. DOT-FRA-1652) which was sponsored by the Office of Rail Safety Research of the Federal Railroad Administration (FRA). The Contracting Officer's Technical Representative was Mr. Howard Moody. Concrete ties in new and used condition were supplied by the Facility for Accelerated Service Testing (FAST) and were selected according to Battelle specifications by Mr. John Weber, consultant to the Association of American Railroads. Collection and shipment were performed by personnel of the FAST organization at the Transportation Test Center. The tests were carried out in the Battelle Fatigue Laboratory by Mr. Kenneth Schueller.

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ACRONYMS

AREA	American Railway Engineering Association
FAST	Facility for Accelerated Service Testing
MGT	million gross tons

ABBREVIATIONS AND METRIC CONVERSIONS

", in	inch	= 25.4 mm
μ in	microinch	
MGT	million gross tons	= 0.907 MGMg
kip	kilopounds	= 453.597 kg
lb	pound	= 0.454 kg
V	Volt	
°	degree	
%	percent	

EXECUTIVE SUMMARY

Bending strength tests were conducted on prestressed concrete railway ties from the track at the Facility for Accelerated Service Testing (FAST). Some of the ties had experienced 425 million gross tons (MGT) of service loading while others, of the same types and manufactured in the same production runs, were unused. Bending moments at which the ties experienced first cracks, structural cracks, tendon slippage and ultimate loads were recorded for tests at rail seats and tie centers.

Results are compared with specifications of the American Railway Engineering Association (AREA) and with available data from manufacturer's tests. There were no indications of loss of bending strength except for tests representing a small number of one type of tie where top center flexural cracks had developed early in the service period. The center bending strength of these cracked ties averaged 20% below unused ties of the same type. However, there was no parallel loss of ultimate bending strength. The tests demonstrate that the FAST ties, which were designed to the latest (1973) AREA strength specifications, represent significant improvements in structural effectiveness in comparison to many earlier tie designs.

INTRODUCTION

One of the principal concerns in the development of prestressed concrete railroad ties is the rate at which the bending strength of the ties may deteriorate in service. Strength retention is critically important to the economic feasibility of concrete tie track, which competes in life cycle cost with wood tie track only when it is assumed that the average life of concrete ties is considerably greater than the life of wood ties.[1] Many early designs of concrete ties for U.S. service have experienced premature structural failures. Bending strength specifications of the American Railway Engineering Association (AREA) have been increased several times in response to the early failures.[2]

An opportunity to test used FAST ties arose when operations were suspended in July 1979 to permit the rebuild of several track sections (see Appendix B for FAST background). Nine hundred concrete ties produced by two manufacturers (identified as Type A and Type B) were removed from the 5° curve and 2% grade of Section 17. The ties had experienced 425 MGT of service loading under the FAST consist, which was predominantly composed of cars and locomotives with average axle loads of about 33 tons. These ties were designed to the latest and most demanding AREA bending strength specifications, which were published in 1973.

An inspection of the ties removed from service[3] revealed that all ties had experienced tamper damage (chipping along the lower edges of the tie) and that several patterns of minor hairline cracks had developed. Among these were:

a. Cracks originating on the top surface at fastener shoulders and propagating toward the ends of the ties on many of the Type A ties.

b. Transverse, top center flexural cracks which had appeared early in the FAST operations program on a small number of Type B ties.

The ties had developed none of the rail seat flexural cracks which have led to premature failure of many earlier tie designs.

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1 White, D.W., Arnlund, R.C., and Prause, R.H., Economics of Concrete- and Wood-Tie Track Structures, Report No. FRA/ORD-78/2, prepared for U.S. Department of Transportation, Federal Railroad Administration, by Bechtel, Inc., and Battelle-Columbus Laboratories, August 1978.

2 Prause, R.H., Kennedy, J.C., and Arnlund, R.C., An Evaluation of Performance Requirements for Cross Ties and Fasteners, Report No. FRA/ORD-78/37, prepared for U.S. Department of Transportion, Federal Railroad Administration, by Battelle-Columbus Laboratories, December 1978.

3 Dean, F.E., Concrete and Wood Tie Performance, 425 MGT, Report No. FRA/TTC-81/06, prepared for U.S. Department of Transportation, Transportation Systems Center, by Battelle-Columbus Laboratories, October, 1981.

To test minimum samples of rail seats and tie centers of each tie type in new and used condition, and to test used ties with and without the cracking patterns identified above, a total of 15 ties of each type, 6 new and 9 used, were requested.

RESULTS OF BENDING STRENGTH TESTS

Twenty-eight FAST ties of two manufacturers' types were subjected to tests of higher positive rail seat bending strength or negative tie center bending strength, using the standard AREA test arrangements defined in chapter 10 of the AREA manual.[4] The test procedure is described in appendix A. Most of the ties had been removed from the track after 425 MGT of service, but small samples of previously unused ties from the production runs used to construct the track were also tested to measure the extent of any change in bending strength. The service ties of each type included samples with and without a minor cracking pattern. Tables 1 and 2 summarize the tie conditions and the bending moments at which each of the following events occurred:

a. First appearance of a crack,

b. Crack propagation to the nearest level of prestress tendons,

c. Prestress tendon slippage (on rail seat tests only), and

d. Ultimate load.

The tables also list the AREA bending strength specifications for qualification tests of ties spaced in the track at 24" or 30". While the FAST ties were spaced at 24", the design goal for most ties produced after 1973, when the current requirements were specified, is to satisfy the spacing requirement of 30".

The test results, when compared to the AREA requirements and to available manufacturer's test data, are significant in several respects:

a. For all tests, the bending moments at structural cracking (first propagation of a crack to the level of a prestress tendon) exceeded AREA specifications for ties installed on 30" centers.

b. There was only one consistent trend in loss of bending strength at structural cracking, when new ties were compared against used ties both with and without cracks. This occurred in tie center tests of the Type B ties, where a 20% reduction can be seen between the new ties and those with the top center cracks. With the very small samples used to make this comparison, the test results indicate a difference in mean bending strengths at the significance level of 0.05, which is usually termed "probably significant." However, all bending moments remained well above the AREA requirements, and there was no parallel reduction in ultimate loads.

c. The Battelle tests produced bending strength data consistently above comparable results from manufacturer's tests of unused ties of various ages, as shown in table 3. In some cases the manufacturer's tests were not carried to ultimate load because of inadequate loading capacity. In such

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4 Manual for Railway Engineering, American Railway Engineering Association, 1978.

TABLE 1. SUMMARY OF TEST RESULTS FOR TYPE A TIES.

Tie Condition Before Tests	Tie No.	Rail Seat	AREA Requirement For Structural Crack (in-kips)	Bending Moment (in-kip) at: Initial Crack	Structural Crack	Tendon Slip	Ultimate Load
(a) Positive Rail Seat Bending Moment Tests							
New Ties	RT-2	A	300 (30-inch spacing)	326	384	646	646
		B		390	453	610	610
	RT-3	A	250 (24-inch spacing)	359	391	608	609
		B		388	417	650	650
	MEAN			366	411	629	629
Used Ties Without Top Surface End Cracks	0389	A		342	371	592	609
		B		359	405	696	696
	0653	A		384	417	650	650
		B		384	425	655	655
	0795	A		371	400	597	601
		B		396	417	650	651
	MEAN			373	406	640	644
Used Ties With Top Surface End Cracks	0774	A		442	442	667	667
		B		417	438	717	717
	0805	A		376	421	630	630
		B		409	425	684	684
	0844	A		300	318	500	530
		B		Precrack*	342	512	601
	MEAN			389	398	618	638
(b) Negative Tie Center Bending Moment Tests							
New Ties	RT-1		200 (all tie spacings)	331	331	- -	541
	RT-4			304	326	- -	526
	RT-5			308	336	- -	548
	MEAN			314	331	- -	538
Used Ties - Random Condition (No Center Cracks)	0333			298	336	- -	517
	0698			311	336	- -	541
	0905			326	345	- -	541
	MEAN			312	339	- -	533

* Indicates growth of an existing crack.

TABLE 2. SUMMARY OF TEST RESULTS FOR TYPE B TIES.

Tie Condition Before Tests	Tie No.	Rail Seat	AREA Requirement For Structural Crack (in-kips)	Bending Moment (in-kip) at: Initial Crack	Structural Crack	Tendon Slip	Ultimate Load
(a) Positive Rail Seat Bending Moment Tests							
New Ties	CC1	A	300 (30-inch spacing)	363	414	784	784
		B		400	425	780	780
	CC2	A	250 (24-inch spacing)	380	409	700	747
		B		400	434	755	784
	MEAN			386	421	755	774
Used Ties, Random Selection (no rail seat cracks)	0092	A		318	385	650	692
		B		384	429	696	696
	0248	A		434	475	743	747
		B		376	413	713	717
	0501	A		363	384	700	700
		B		384	400	708	708
	MEAN			377	414	701	710
(b) Negative Tie Center Bending Moment Tests							
New Ties	CC3		200 (all tie spacings)	313	345	- -	504
	CC4			304	385	- -	547
	CC5						
	MEAN			309	365	- -	526
Used Ties Without Top Center Flexural Cracks	0088			318	336	- -	550
	0244			304	325	- -	550
	0581			251	280	- -	512
	MEAN			291	314	- -	537
Used Ties With Top Center Flexural Cracks	0232			Precracked	287	- -	532
	0252			Precracked	284	- -	534
	0292			Precracked	298	- -	519
	MEAN				291	- -	528

TABLE 3. SUMMARY OF DIFFERENCES BETWEEN BATTELLE AND TIE MANUFACTURERS' TEST RESULTS.

	Bending Moment (in-kips) for: Battelle Tests**	Bending Moment (in-kips) for: Manufacturers' Tests	Percent Difference
RAIL SEAT TESTS	(Mean values)	(Age of Test Ties) (Mean values unless indicated by # for single test)	
Type A Ties			
Initial Crack	366	338 (3 - 7 days)	8
		277 (4.5 months)	28
		314 (3.3 years)	15
Structural Crack	411	323 (3.3 years)	24
Ultimate Load	629	>536* (3 - 7 days)	<16
		>526* (4.5 months)	<18
		>559* (3.3 years, no test failures)	<12
Type B Ties			
Initial Crack	386	344# (<6 months)	12
Structural Crack	421	373# (<6 months)	12
Ultimate Load	774	646# (<6 months)	18
TIE CENTER TESTS			
Type A Ties			
Initial Crack	314		
		277# (1 - 3 weeks)	13
		312# (18 months)	0.6
Ultimate Load	538		
		500# (1 - 3 weeks)	7
		569# (18 months)	-6
Type B Ties			
Initial Crack	309	270# (<6 months)	13
Structural Crack	365	297# (<6 months)	21

* >Indicates that some test ties did not fail at maximum applied load.

** Age of all Battelle test ties was approximately 3.6 years.

cases only an upper bound to the percent difference between test results could be obtained. While all tests were conducted in accordance with the nominal procedures specified in reference 4, the possibility of systematic differences in test procedure exists.

CONCLUSIONS

a. The tests of FAST ties were designed to determine the possible effects on tie strength of the service history, particularly of the minor cracking patterns. Very little effect of service loading was found. Transverse, top center flexural cracks on one type of tie were found to have reduced average tie center bending strength by 20%, but strength levels remained well above the maximum requirements of the latest AREA specifications.

b. The preceding results are significant because the FAST ties had experienced 425 MGT of service under severe loading conditions (5^{o} curve, 2% grade, average axle loads of about 33 tons). Also, tamper bars had defaced the bases of all the ties early in the program due to use of improper length tamping bars and cylinder opening for concrete ties. Although several minor cracking patterns developed, there were no flexural rail seat cracks of the type that have led to premature failures of several earlier concrete tie designs. It is assumed that the ties could have sustained at least several hundred MGT of additional service, and possibly would have sustained the equivalent of an average 50-year life (1,000 MGT at 20 MGT/year) under the FAST loading environment.

c. It should be recognized that the development of flexural cracks and an associated loss of bending strength do not necessarily indicate that the tie will prematurely fail in service. A service failure is defined as loss of the ability to sustain bending loads, or deterioration to the extent that too-frequent maintenance is required to keep the track alined, the ties spaced, or the fasteners maintained. The most extensive test of cracked ties is in progress at FAST, where 100 previously cracked ties from the Kansas Test Track (RT-7 ties) were installed on tangent track and have provided satisfactory service for over 450 MGT. It is possible that colder and wetter climates or less stable subgrades would cause more rapid deterioration from repeated freeze-thaw cycles, rusting of the prestress tendons or less uniform support conditions. However, this example shows that in environments comparable to that at FAST, concrete ties can function satisfactorily long after structural cracks have developed.

APPENDIX A

TEST PROCEDURE

The ties were positioned in a servo-controlled, 500-kip load machine as shown in figure A-1. The loading arrangements conform to those prescribed in figures I and II of the AREA Manual for Railway Engineering, chapter 10. Load was applied by lifting a strongback beam which supported the tie. For rail seat tests, the opposite end of the tie was supported by a sling which became slack as the beam was lifted.

The upper reaction load P was monitored through a load cell whose output was continuously recorded on the Y-axis of the X-Y plot. The X-axis of the plot consisted of the "bending deflection" of the tie between its support points, as illustrated on the typical plot of figure A-2. Dial indicators were attached to the end of the tie (figure A-3) during the rail seat tests to detect tendon slippage. When slippage occurred separately from ultimate load, it was normally accompanied by a dip in the load-deflection curve, and it occurred with an easily detectable magnitude of at least several thousandths of an inch.

Cracking events were detected with the aid of lines drawn on each tie face to indicate the levels of prestress tendons. Mirrors were placed under the tie at the load centerline as an additional aid to detection. Alcohol was applied to the tie face as soon as a crack was detected, to aid in following crack propagation. Applied loads at various cracking events were recorded by releasing a hand-held control switch that caused a small perturbation in the X-Y plot.

The relationships between applied load P and bending moment M, consistent with the dimensions shown in figure A-1, are:

a. Rail Seat Tests

$M = 6.04\ P$, and

b. Tie Center Tests

$M = 13.5\ P$.

Photos of typical tie failure modes are shown in figures A-4 through A-7.

After completion of the tests, an error was discovered in the load calibration conducted before the start of testing. The machine was recalibrated using a proving ring calibrated at the National Bureau of Standards. The load-voltage relationships for the load cell range of 200 kips (used exclusively during the tests) is shown in table A-1. From the calibration, the load-voltage relationship which existed during the tests was established by the ratio of the shunt resistance offset voltages which were measured during testing and during the proving ring calibration.

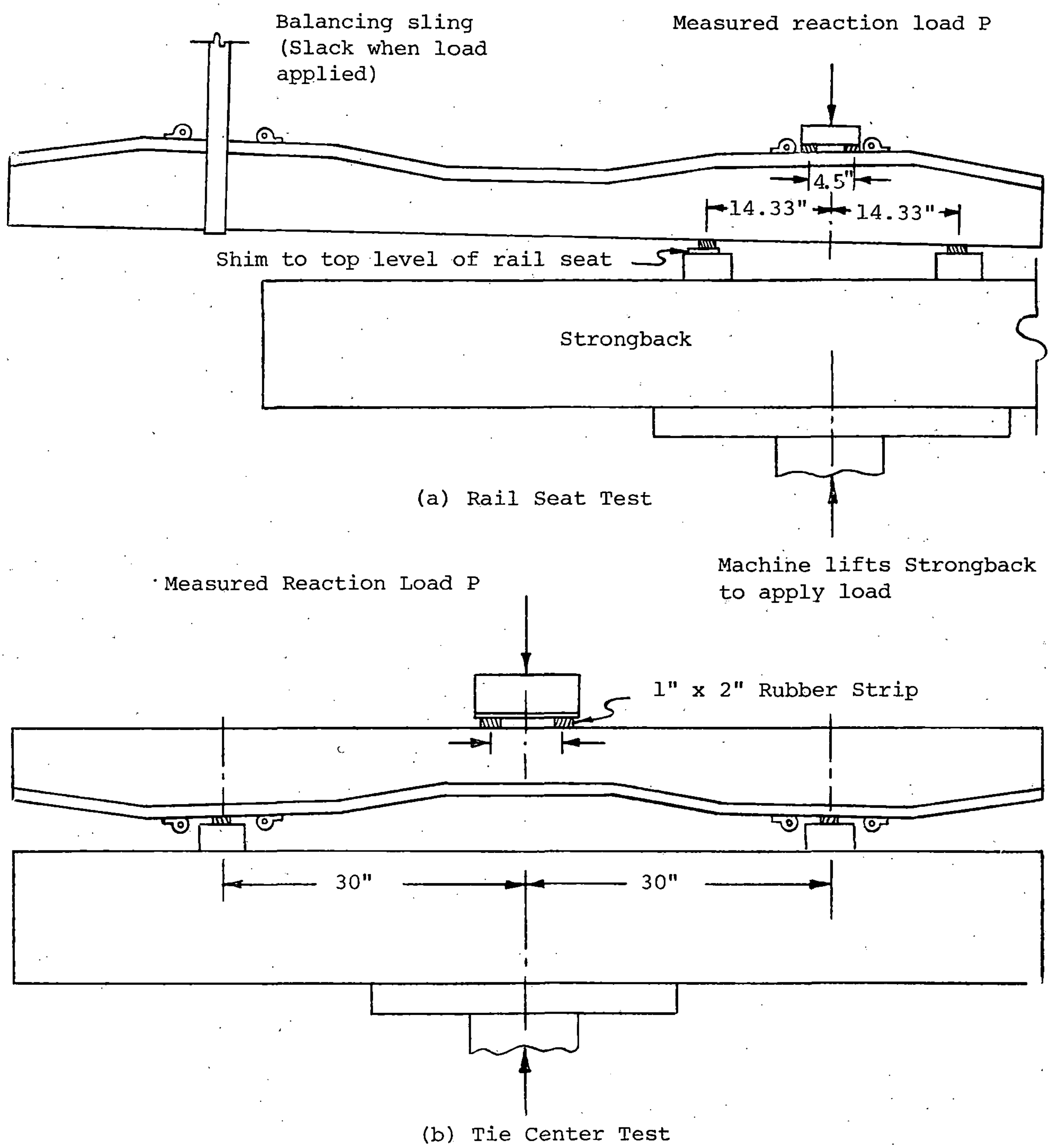


FIGURE A-1. LOADING ARRANGEMENTS FOR TESTS OF POSITIVE RAIL SEAT BENDING MOMENT AND NEGATIVE TIE CENTER BENDING MOMENT.

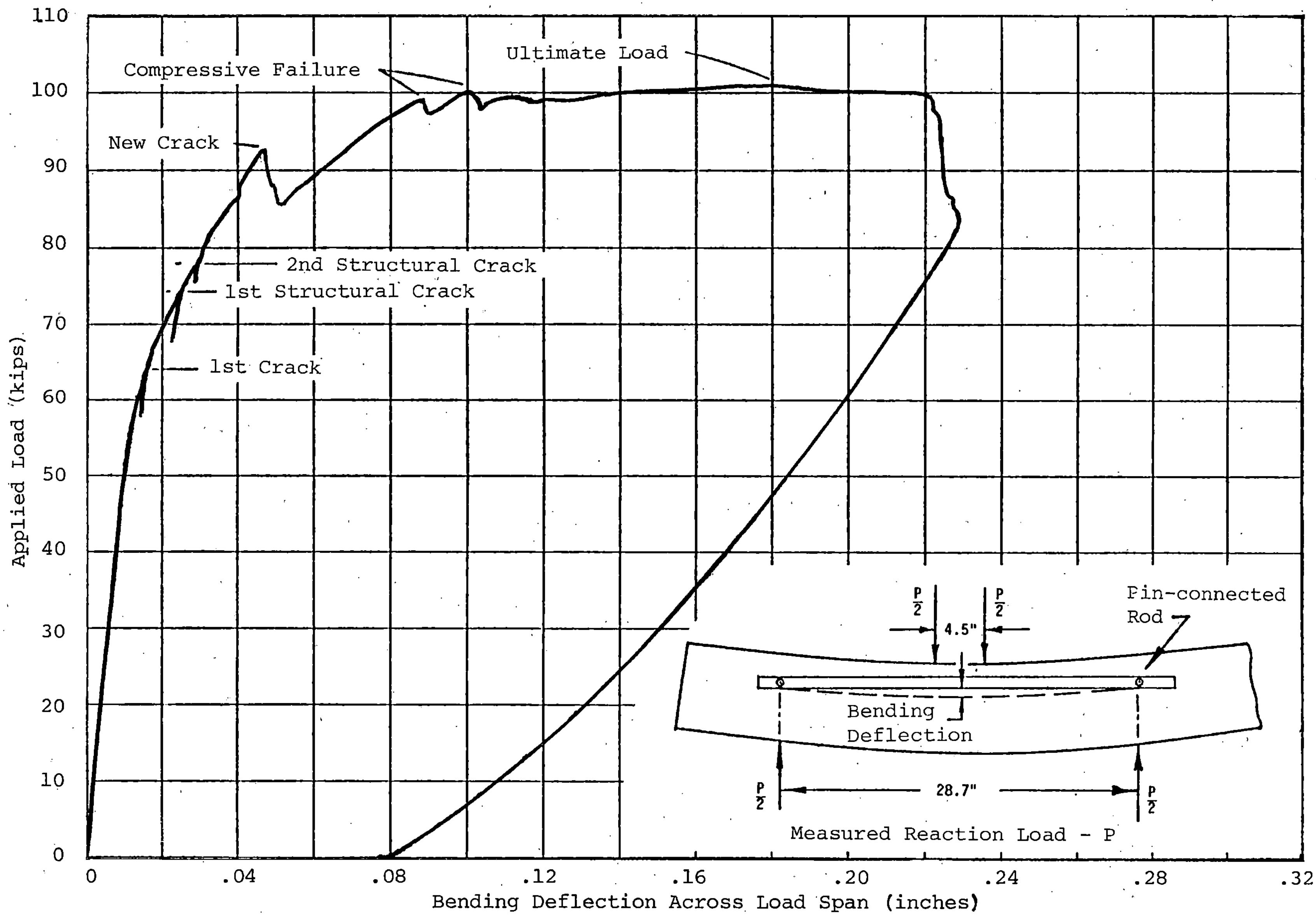
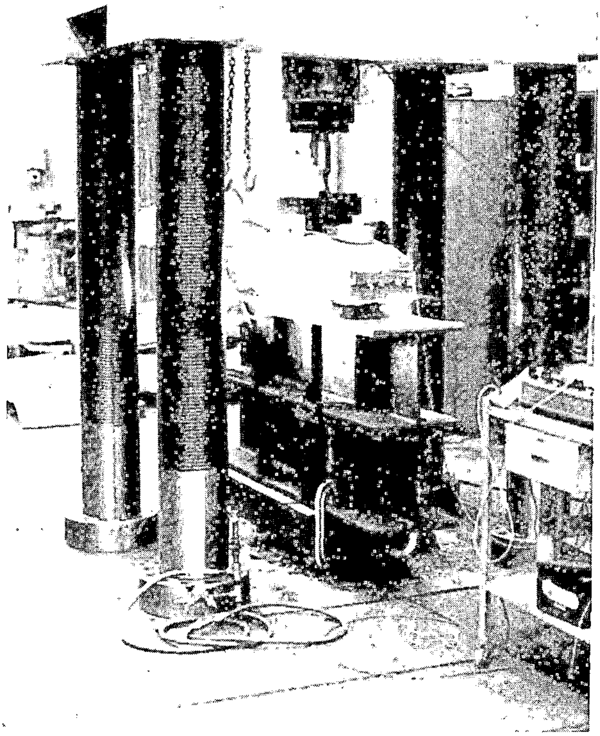
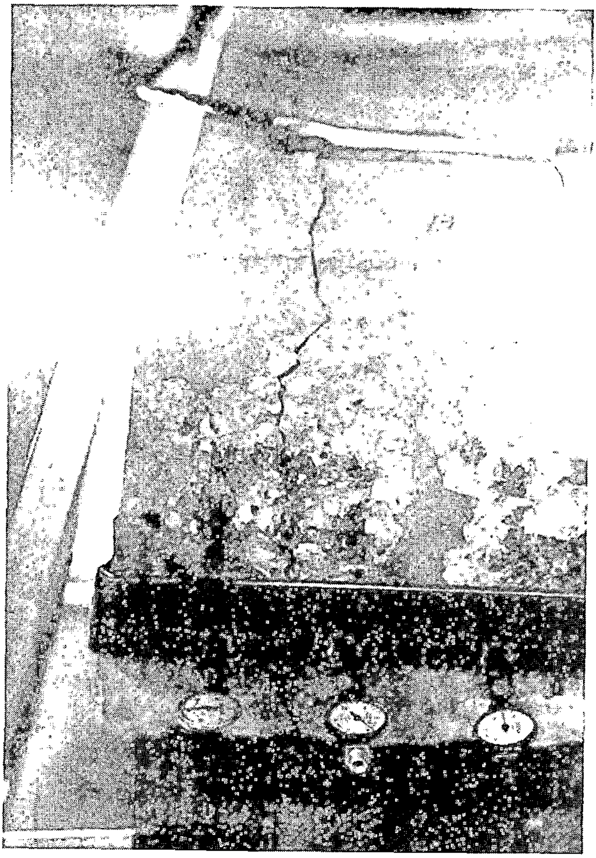


FIGURE A-2. TYPICAL LOAD-DEFLECTION PLOT, FOR RAIL SEAT TEST.



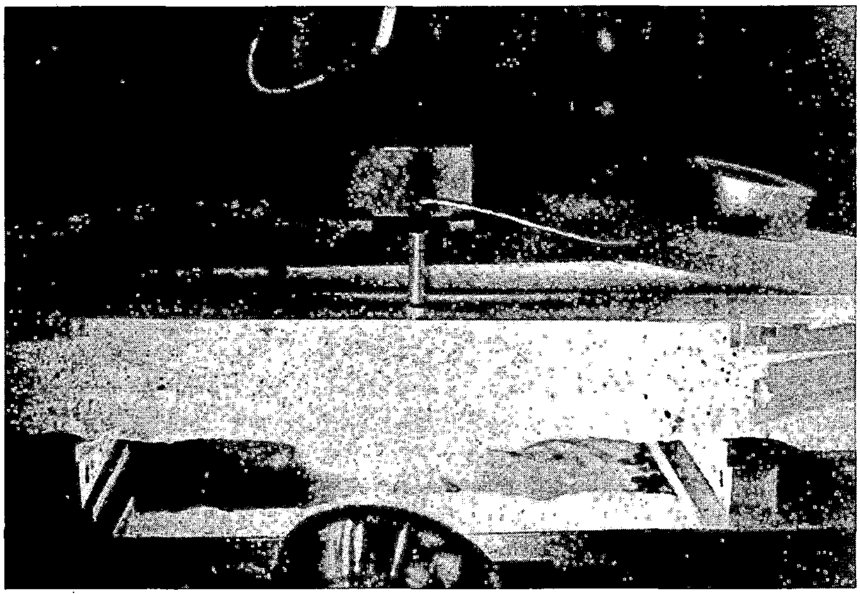
Tie in position for Rail Seat Test.

FIGURE A-3.

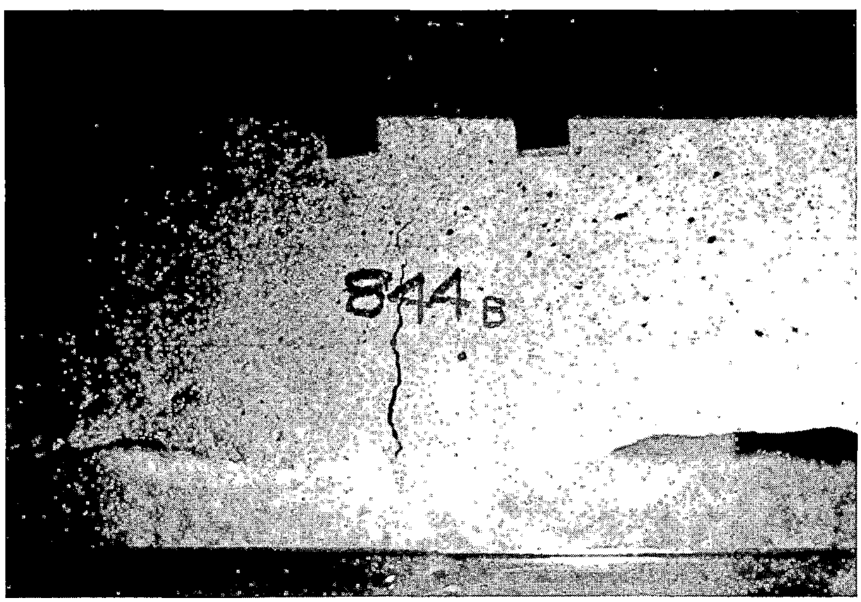


Dial indicators to detect tendon slippage.

LABORATORY SETUP.

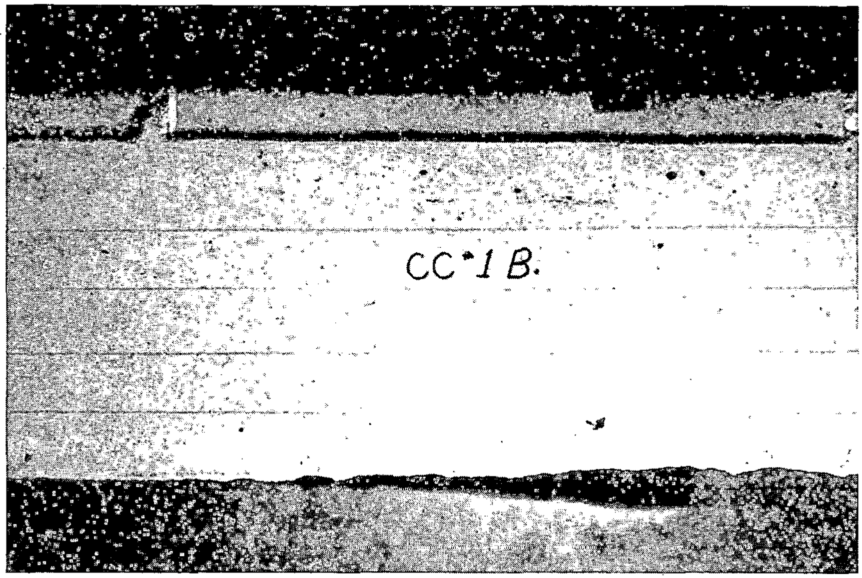


Before test

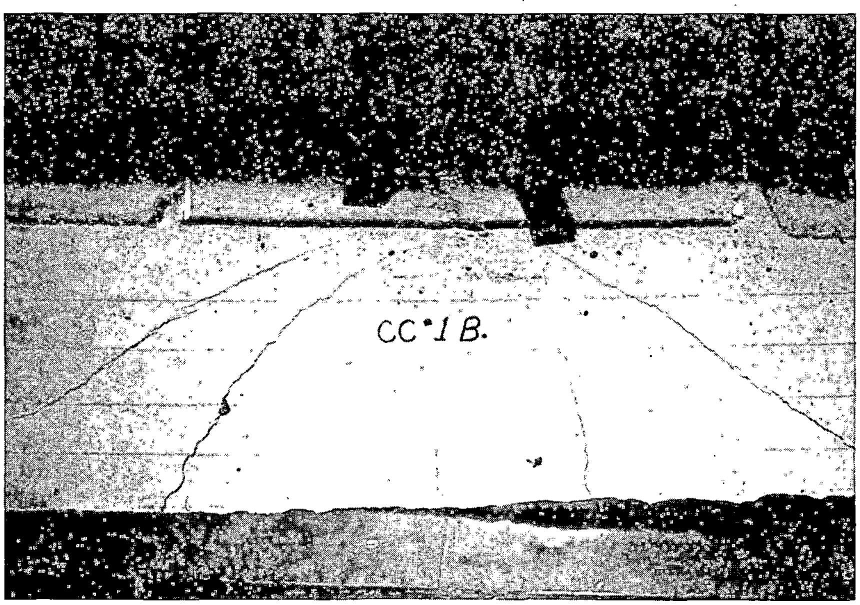


After ultimate load

FIGURE A-4. RAIL SEAT TEST OF USED TYPE A TIE.

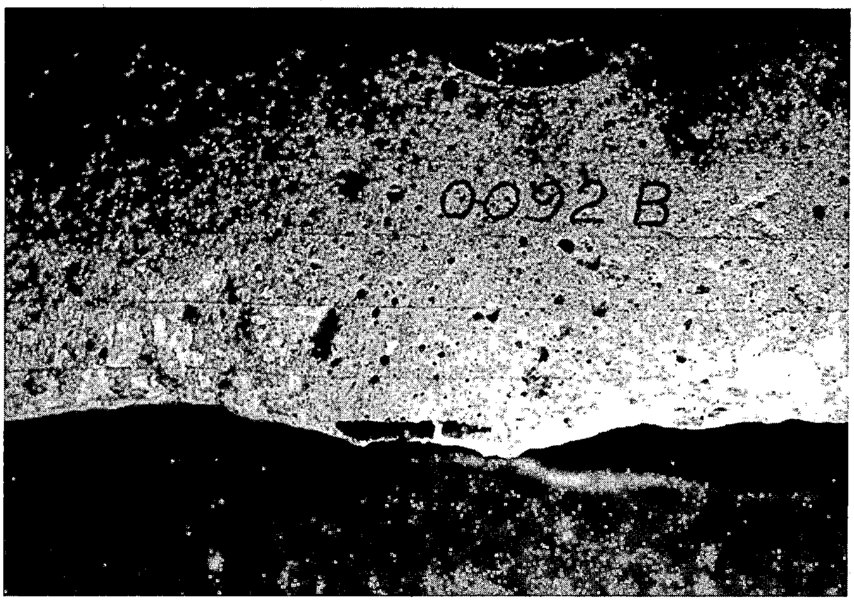


Before test

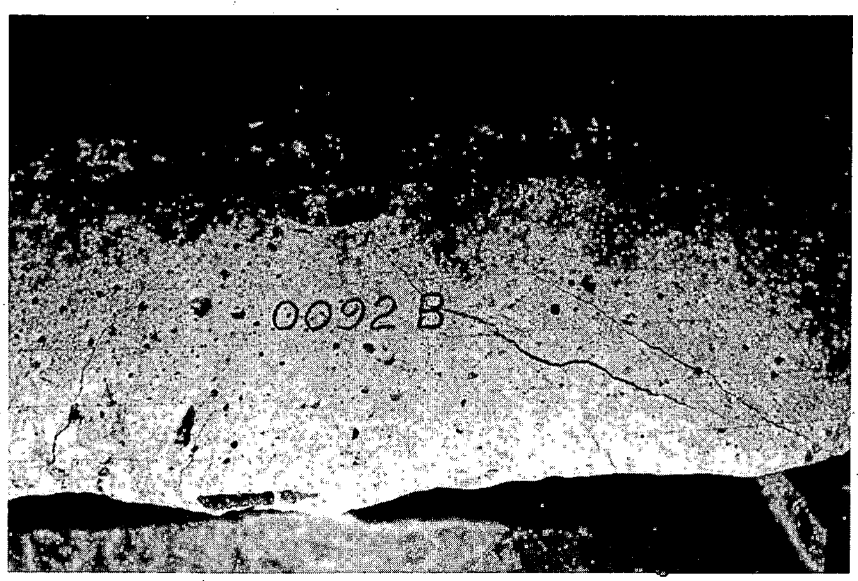


After ultimate load

FIGURE A-5. RAIL SEAT TEST OF NEW TYPE B TIE.

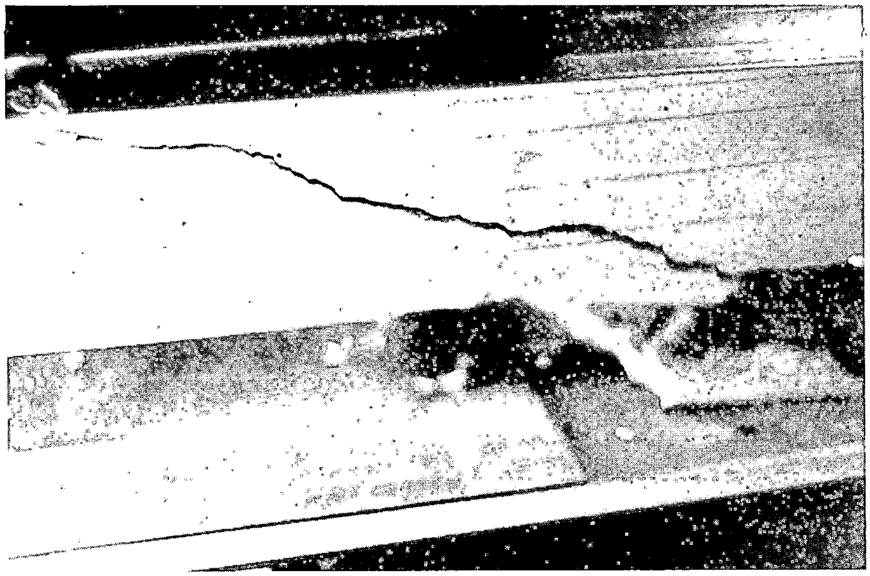


Before test



After ultimate load

FIGURE A-6. RAIL SEAT TEST OF USED TYPE B TIE.



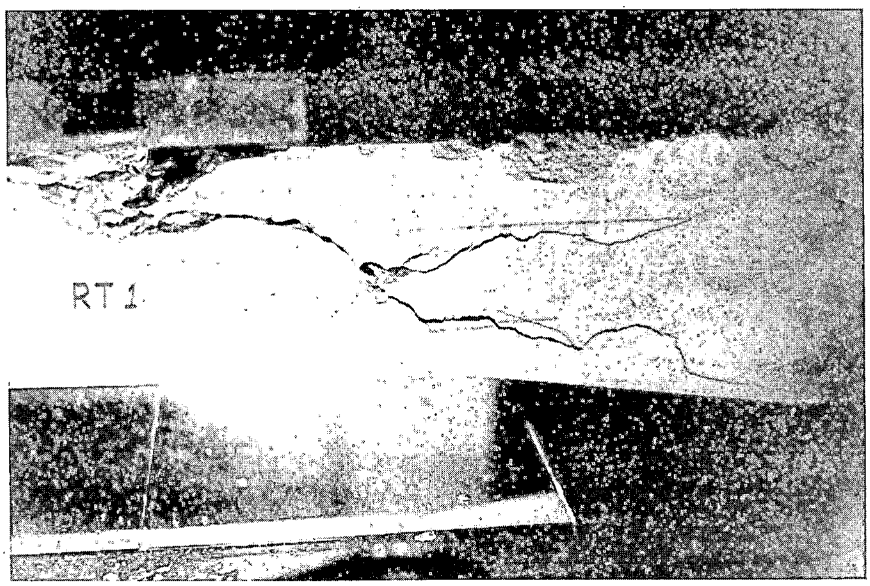


FIGURE A-7. TIE CENTER TESTS, AFTER ULTIMATE LOAD.

TABLE A-1. POST-TEST LOAD CELL CALIBRATION.

Proving Ring Load (NBS-Calibrated)		Reference Cell Strain (µin/in)	Working Cell Output Voltage (V)
Nominal Load (kips)	Corrected Load (kips)		
0	0	0	0
20	19.99	97	1.01
40	39.90	192	2.015
60	60.10	289	3.03
80	79.94	385	4.04
100	100.06	483	5.05
120	120.14	- -	- -*
140	139.87	677	7.065
160	159.88	774	8.08
180	179.84	871	9.09
200	200.08	970	10.11
160	159.88	772	8.05
120	120.14	578	6.04
80	79.94	383	4.01
40	60.10	190	1.99
20	19.99	95	.98
0	0	0	.003

* Reading missed because of hesitation in hydraulic system.

APPENDIX B

FAST BACKGROUND

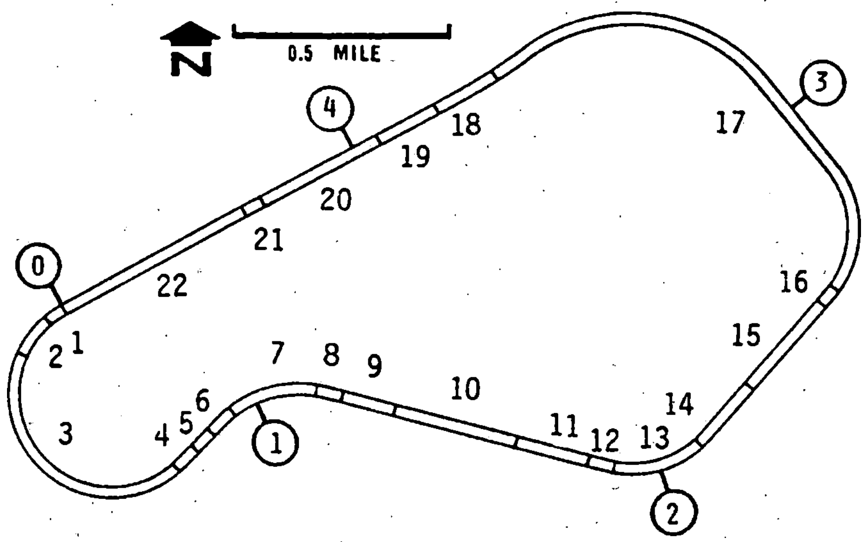
FAST has been installed and operating at the DOT Transportation Test Center since September 1976. The physical facilities include a 4.8 mi loop of track, a fleet of cars and locomotives, and a maintenance facility. The organization includes a staff of people to operate the trains, perform maintenance 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 B-1. SUBSECTIONS OF THE FAST TRACK LOOP.

GPO 833-778

The Effect of Service Loading on the Bending Strength of Concrete Ties (Interim Report),
1981
US DOT, FRA, Dr. Francis E Dean