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16. Abstract

This report was prepared as part of an ongoing research effort by the Urban Mass Transportation Administration (UMTA) to develop standard concrete ties for rapid transit use. The overall objective of this contract was to fabricate and evaluate, by laboratory tests, standard ties of different designs intended for transit use. Two tie designs, a pretensioned monoblock and a post-tensioned two-block, together with preliminary specifications for tie manufacture were developed in an earlier study by the Transit Development Corporation*. To evaluate the adequacy of these tie designs and specifications, this laboratory investigation was sponsored by UMTA. Objectives of the investigation were to evaluate, by laboratory tests, the adequacy of: each of three fastening systems; each of the tie designs; and the assembled track components with ties supported on ballast and subjected to simulated rapid transit loading. Work performed to accomplish these objectives included fabrication of prestressed concrete ties and testing of ties, fastenings, and assembled track components.

This report describes laboratory methods for tie fabrication and presents results of tests on ties and fastenings. As a result of the laboratory testing program, preliminary specifications prepared under the earlier contract were modified and presented in a separate report. A related report is titled "Measurement Program for Evaluation of Concrete Ties and Fastenings in Transit Track" ~~(UMTA-MA-06-0100-79-2)~~.

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PREFACE

This report was prepared by the Construction Technology Laboratories, a division of the Portland Cement Association, under contract No. DOT-TSC-1442 managed by the Transportation Systems Center, Cambridge, Massachusetts. The contract is part of a program sponsored by the Office of Rail and Construction Technology, Office of Technology Development and Deployment, Urban Mass Transportation Administration of the U.S. Department of Transportation to develop standard concrete ties for rapid transit use.

The overall objective of this contract is to fabricate and evaluate, by laboratory tests, standard ties of different designs intended for transit use. Two tie designs, a pretensioned monoblock and a post-tensioned two-block, together with preliminary specifications for tie manufacture were developed under an earlier contract study from the Transit Development Corporation.

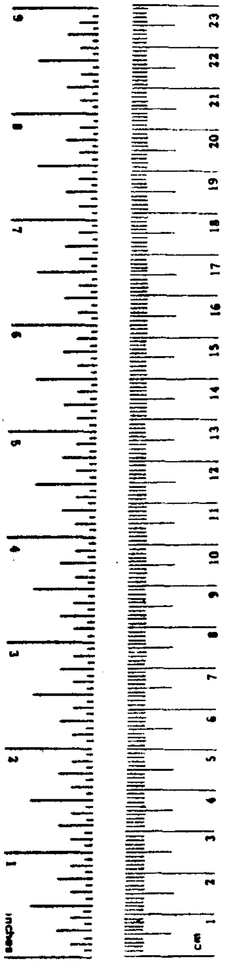
This report describes laboratory methods for tie fabrication and presents results of tests on ties and fastenings. As a result of the laboratory testing program, the preliminary specifications were modified and presented in a separate report.

Mr. P. Witkiewicz and Mr. G. Saulnier of the Transportation Systems Center were the technical monitor and alternate technical monitor, respectively, for the work reported herein. Their cooperation and suggestions are gratefully acknowledged. Mr. F. J. Cihak of the American Public Transit Association and representatives of several transit properties also deserve recognition for their assistance and suggestions.

METRIC CONVERSION FACTORS

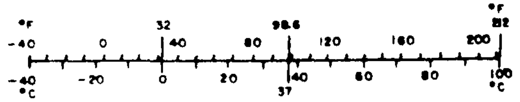
Approximate Conversions to Metric Measures

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	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square 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)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



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	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		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 feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

Work on the development of standard concrete ties for transit use started under an earlier contract with the Transit Development Corporation. Because monoblock and two-block ties were in use on transit track, designs and preliminary specifications for tie manufacture were prepared for ties of the two types. The ties, a pretensioned monoblock and a post-tensioned two-block, were designed for use in ballasted track sections under conventional operating conditions. Track and vehicle parameters normally encountered in service were established with the consensus of several participating transit properties(1). These parameters as well as tie flexural performance requirements are listed in Appendix A.

To evaluate adequacy of tie designs and specifications, a laboratory investigation was sponsored by the Urban Mass Transportation Administration of the U.S. Department of Transportation. Objectives of the investigation were:

1. To evaluate, by laboratory tests, the adequacy of each of the tie designs,
2. To evaluate, by laboratory tests, the adequacy of each of three fastening systems, and
3. To evaluate, by laboratory tests, assembled track components with ties supported on ballast and subjected to simulated rapid transit loading.

Work performed to accomplish these objectives included fabrication of prestressed concrete ties and testing of ties, fastenings, and assembled track components.

This report describes methods for tie fabrication and presents test results.

2. FABRICATION OF PRESTRESSED CONCRETE TIES

In this phase of the project, ten pretensioned monoblock concrete ties and nine post-tensioned two-block concrete ties were fabricated. Ties were constructed in accordance with designs and specifications prepared in an earlier work.(1) Each tie was cast with inserts to accommodate one of three different fastening systems, designated types A, B, and C. Tie details are shown in Appendix B. Fastening system details are shown in Appendix C.

Several ties of each design were cast with inserts to accommodate each of the fastening systems. Ties included the following:

1. Four monoblock and three two-block ties each cast with inserts for fastening type A,
2. Three monoblock and three two-block ties each cast with inserts for fastening type B, and
3. Three monoblock and three two-block ties each cast with inserts for fastening type C.

Methods employed for concrete mix selection and tie fabrication are described.

2.1 SELECTION OF CONCRETE MIX DESIGN

Prior to casting ties, laboratory methods were employed to establish a concrete mix of a suitable strength. The following concrete strength values were specified:(1)

1.	Compressive strength at 28 days	7,000 psi
2.	Compressive strength at 18 to 20 hours	4,000 psi
3.	Flexural strength at 28 days	850 psi

However, according to PCI Manual for Quality Control for Plants and Production of Prestressed Concrete Products(2) and ACI 318, Building Code Requirements for Reinforced Concrete(3), average strengths used as the basis for selecting concrete proportions should exceed the specified compressive strength by at least 400 to 1,200 psi depending on the standard deviation.

The standard deviation is determined from plant records, based on at least 30 consecutive strength tests representing similar materials and conditions to those expected.

Because the factors influencing concrete quality are closely controlled in the laboratory, a standard deviation less than 300 psi can be achieved. Therefore, mix proportions were designed for the following compressive strengths:

1. 7,400 psi at 28 days, and
2. 4,400 psi at 18 to 20 hours.

Three trial mixes, designated mixes A, B, and C, were proportioned according to ACI 211.3, Recommended Practice for Selecting Proportions for No-Slump Concrete(4). Water-cement ratios were 0.39, 0.36, and 0.34 for mixes A, B, and C, respectively. Mix proportions are listed in Table 2-1.

2.1.1 Materials

Materials used for trial mixes included the following:

1. Portland Cement Type III conforming to ASTM Designation: C150, Specification for Portland Cement.
2. Partially crushed dolomotic gravel from Elgin, Illinois with a maximum size of 3/4 in.
3. Natural sand from Elgin, Illinois with a fineness modulus of 2.8.
4. A water reducing admixture conforming to ASTM Designation: C494, Specification for Chemical Admixtures for Concrete.

2.1.2 Batching and Mixing

Concrete was proportioned and mixed in 5-cu ft batches sufficient to fabricate nine 6x12-in. cylinders and three 6x6x21-in. beams. Concrete slump was measured in accordance with ASTM Designation: C143, Slump of Portland Cement Concrete. Slumps determined for the three mixes are listed in Table 2-1.

TABLE 2-1. CONCRETE MIX PROPORTIONS

Ingredient	Proportions per cu yd		
	Mix A	Mix B	Mix C
Water, lb	275	275	275
Cement, lb	705	752	799
Coarse aggregate, lb	1,797	1,797	1,797
Sand, lb	1,255	1,215	1,176
Water reducing admixture, fl oz.	28.2	30.1	32.0
Water-cement ratio	0.39	0.37	0.34
Slump, in.	1.75	1.5	1.25

2.1.3 Fabrication of Test Specimens

Nine 6x12-in. cylinders and three 6x6x21-in. beams were made from each batch in accordance with ASTM Designation: C192, Making and Curing Concrete Test Specimens in the Laboratory. All specimens were vibrated externally for 90 seconds on a vibrating table at the rate of 1,500 cycles per minute.

2.1.4 Curing

Six 6x12-in. cylinders and three 6x6x21-in. beams from each batch were steam cured. Three 6x12-in. cylinders were tested some 3 hours after steam curing or 18 to 20 hours after casting. The three remaining cylinders and three beams were additionally moist cured at 73F and 100% relative humidity in accordance with ASTM Designation: C192, Making and Curing Concrete Test Specimens in the Laboratory. These specimens were tested at 28 days. The remaining three cylinders from each batch were moist cured at 73F from the time of molding until tested at 28 days.

For steam cured specimens, a period ranging from 3 to 5 hours was allowed after concrete placement prior to temperature rise. Temperature of steam room was raised at a uniform rate to 150F over a period of 2 hours. Thereafter, temperature was controlled at 150F by an electrical thermostat. Temperature was maintained constant for 10 hours after which the steam was shut off and specimens were allowed to cool for about 3 hours prior to removal from the steam room.

2.1.5 Test Procedures

Compressive strength was determined for the 6x12-in. cylindrical specimens in accordance with ASTM Designation: C39, Compressive Strength of Cylindrical Concrete Specimens.

Flexural strength was determined for the 6x6x21-in. beams in accordance with ASTM Designation: C78, Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). During test, beams were supported over an 18-in. span.

2.1.6 Test Results and Selection of Mix Design

Compressive strength specimens were tested shortly after completion of steam curing (18 to 20 hours) and at 28 days. Flexural strength specimens were tested at 28 days.

Compressive strength for steam cured specimens at 18 to 20 hours, for steam and moist cured specimens at 28 days, and for moist cured specimens at 28 days are listed in Table 2-2. Flexural strength for steam and moist cured specimens at 28 days are listed in Table 2-3.

Data presented in Table 2-2 indicate that the 18 to 20 hour compressive strengths of all mixes exceeded the 4,400 psi required value. Also, data presented in Table 2-3 indicate that the 28 day flexural strength of all mixes exceeded the 850 psi specified value.

Also, data presented in Table 2-2 indicate that the 28 day compressive strengths of steam and moist cured specimens generally exceeded those of the moist cured specimens. Therefore, mix design was selected on the basis of moist cured strength values.

Compressive strength for moist cured specimens are presented in Figure 2-1. Interpolation of these data indicates that a concrete mix with a water-cement ratio of approximately 0.37 would produce the required 7,400 psi compressive strength. Proportions of this mix are presented in Table 2-4.

2.2 FABRICATION OF TIES

Methods used for the fabrication of pretensioned monoblock and post-tensioned two-block ties are presented.

2.2.1 Forms and Preparation for Casting

For fabrication of monoblock ties, a wooden form conforming to the tie geometrical configuration was made. Five, grade 270, 3/8-in. diameter uncoated seven-wire stress-relieved strands were accurately placed. Also, inserts for anchoring both rail fastenings and contact rail support bracket were

TABLE 2-2. COMPRESSIVE STRENGTH

Mix Designation	Specimen	Compressive Strength, psi		
		Steam Cured	Steam and Moist Cured	Moist Cured
		18-20 hrs	28 Day	28 Day
A	1	5,050	7,150	7,290
	2	4,860	7,300	7,080
	3	5,480	7,380	7,290
	Average	5,130	7,277	7,220
B	1	5,820	7,720	7,110
	2	5,930	7,750	7,550
	3	5,790	7,430	7,750
	Average	5,847	7,633	7,470
C	1	5,430	7,490	7,750
	2	6,380	8,260	7,240
	3	5,990	7,820	7,550
	Average	5,933	7,857	7,513

TABLE 2-3. FLEXURAL STRENGTH

Mix Designation	Specimen	Flexural Strength, psi
		Steam and Moist Cured
		28 Day
A	1	942
	2	875
	3	985
	Average	925
B	1	950
	2	1,040
	3	933
	Average	974
C	1	1,067
	2	1,042
	3	1,117
	Average	1,075

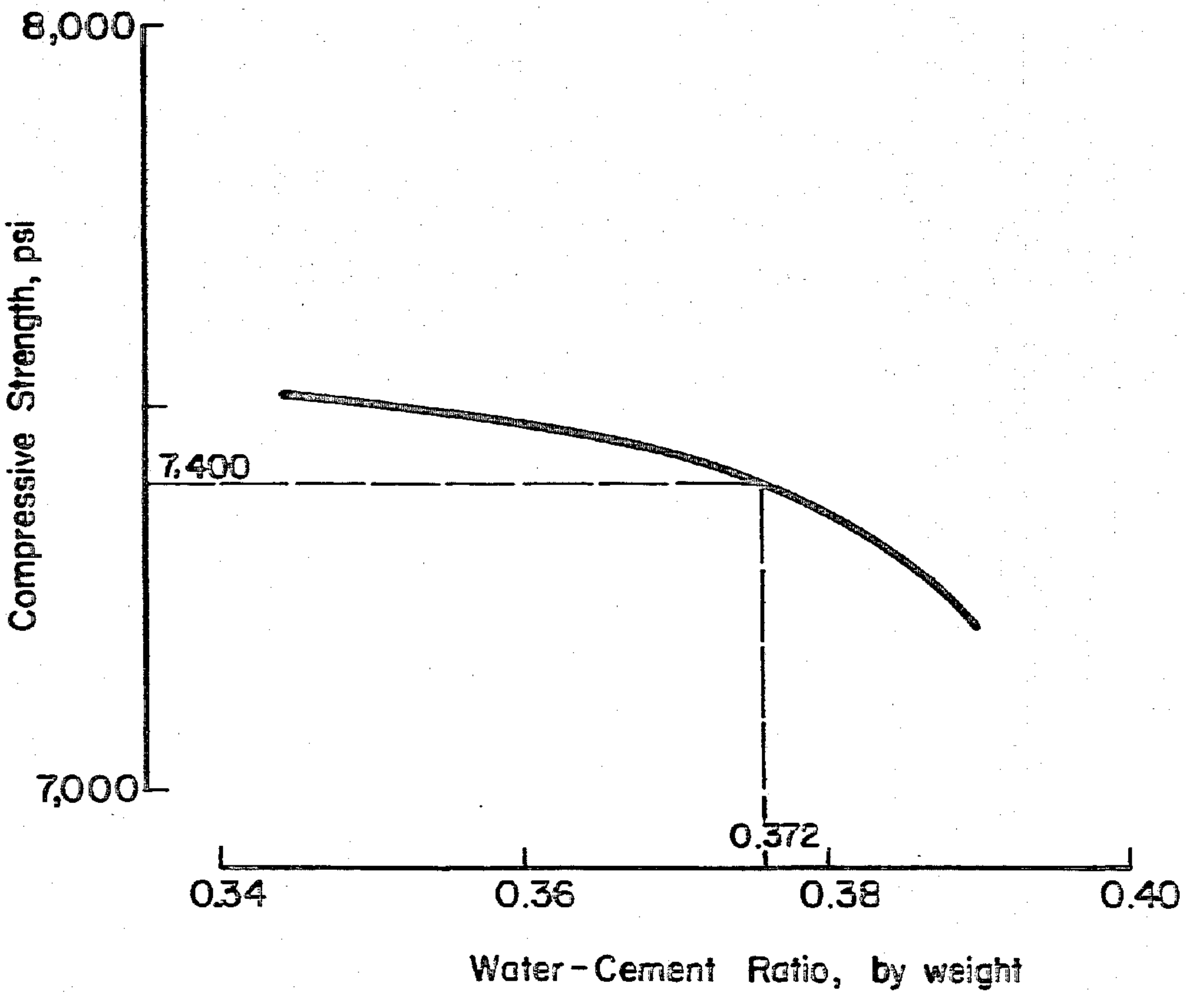


FIGURE 2-1. COMPRESSIVE STRENGTH AT 28 DAYS

TABLE 2-4. PROPORTIONS OF SELECTED CONCRETE MIX

Ingredient	Proportions per cu yd
Water, lb	275
Cement, lb	743
Coarse Aggregate, lb	1,797
Sand, lb	1,246
Water Reducing Admixture, fl.oz.	29.7

accurately placed and secured in position. Each strand was tensioned to 16,750 lb. Force in each strand was checked prior to concrete placement and was adjusted when required.

A view of the steel frame used for strand tensioning is shown in Figure 2-2. A view of the form with the prestressing strands and fastening inserts in place is shown in Figure 2-3.

For fabrication of two-block ties, a wooden form conforming to the tie geometrical configuration was made. A 7/8-in. diameter plastic tubing was properly positioned in the center of a 2-1/2-in. diameter, 28-in. long steel pipe. Also, steel reinforcement extending from the pipe into the tie blocks was accurately placed and secured in position. The pipe was then filled with grout while it was being held in a vertical position. Prior to concrete placement, the pipe was properly positioned between tie blocks. A 3/4-in. diameter prestressing rod was then inserted in the center of the pipe. Also, inserts for anchoring both rail fastenings and the contact rail support bracket were accurately placed and secured in position.

A view of the form with the prestressing rod and fastening inserts in place is shown in Figure 2-4.

2.2.2 Mixing, Placing, and Curing of Concrete

Concrete was proportioned and mixed in 5.5 cu ft batches sufficient to fabricate a monoblock tie and four 6x12-in. cylinders, and 4.0 cu ft batches sufficient to fabricate a two-block tie. Concrete mix proportions selected on the basis of trial mixes, listed in Table 2-4, were used. Concrete was placed in forms and test specimen molds with the aid of an internal vibrator.

All ties and test specimens were steam cured. A period ranging from 3 to 5 hours was allowed after concrete placement prior to temperature rise. Temperature of the steam room was raised at a uniform rate to 150F over a period of 2 hours. Temperature was then maintained constant at 150F for 10 hours after which steam was shut off.

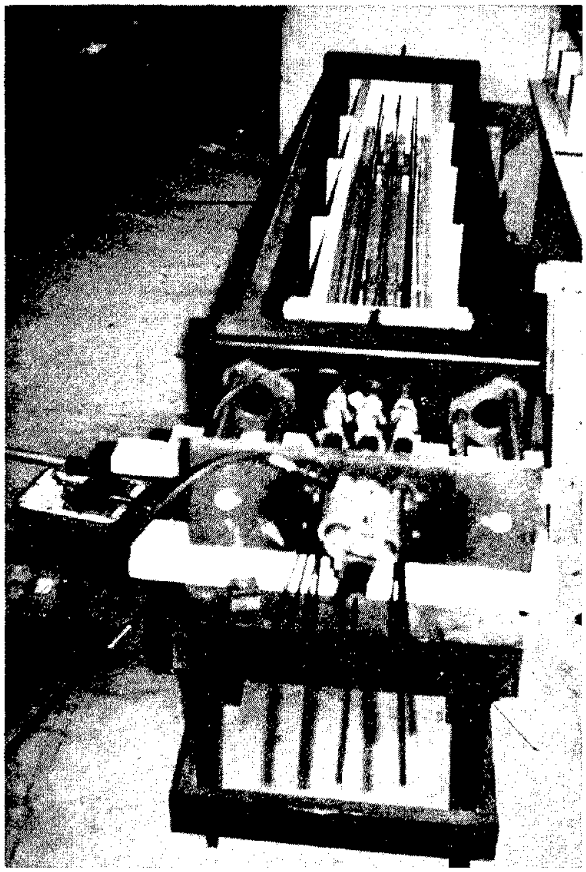


FIGURE 2-2. STRAND TENSIONING FRAME

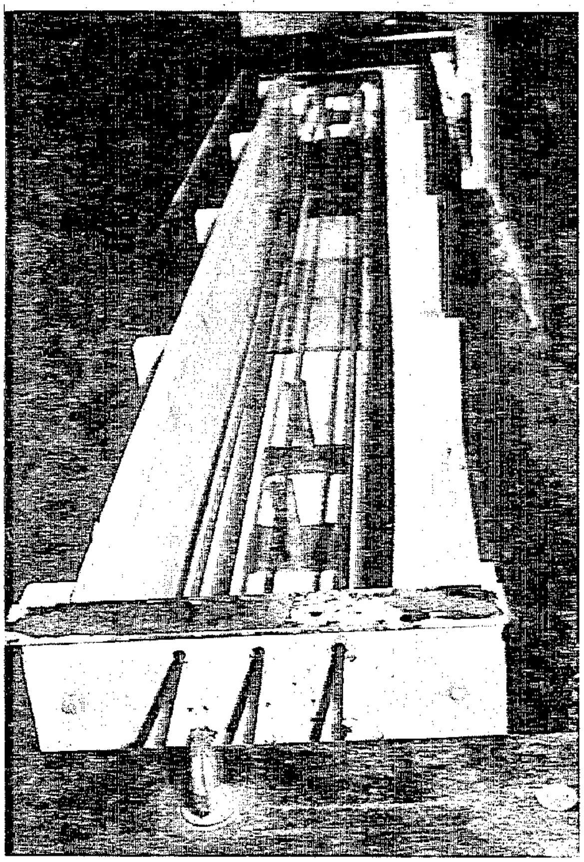


FIGURE 2-3. MONOBLOCK TIE FORM

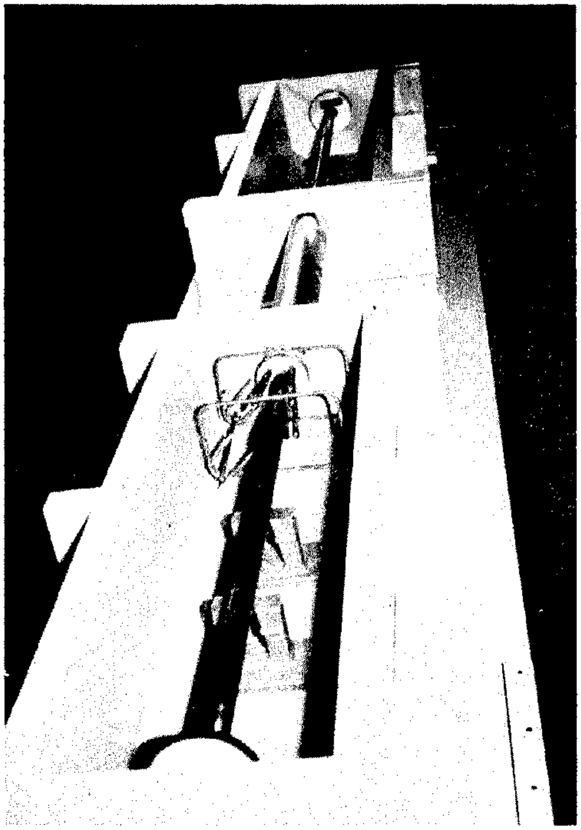


FIGURE 2-4. TWO-BLOCK TIE FORM

Following steam curing, ties and test specimens were allowed to cool for about 3 hours. One 6x12-in. cylinder from each batch was tested to check concrete strength. Thereafter, prestressing force was transferred to the monoblock ties and both the monoblock and two-block ties were removed from forms. The three remaining cylinders from each batch and the ties were stored in a moist room for 6 days and then in a 50% humidity room until tested.

Two-block ties were post-tensioned immediately following the moist curing period. Force applied to the prestressing rod was 39,000 lb.

Compressive strength specimens were tested shortly after steam curing (18 to 20 hours) and at 14 days. Test results are listed in Table 2-5. These data indicate that average compressive strengths were 5,376 and 7,459 psi at transfer and 14 days, respectively.

Views of pretensioned monoblock and post-tensioned two-block ties are shown in Figures 2-5 and 2-6, respectively. Average weights of monoblock and two-block ties were 615 and 500 lb, respectively.

TABLE 2-5. AVERAGE COMPRESSIVE STRENGTH

Batch No.	Compressive Strength, psi	
	At 18-20 hrs	At 14 days
1	5,380	7,577
2	5,050	7,473
3	5,650	7,940
4	5,170	7,137
5	5,320	7,333
6	5,520	7,580
7	5,470	7,517
8	5,020	7,107
9	5,710	7,487
10	5,470	7,387
Average	5,376	7,459

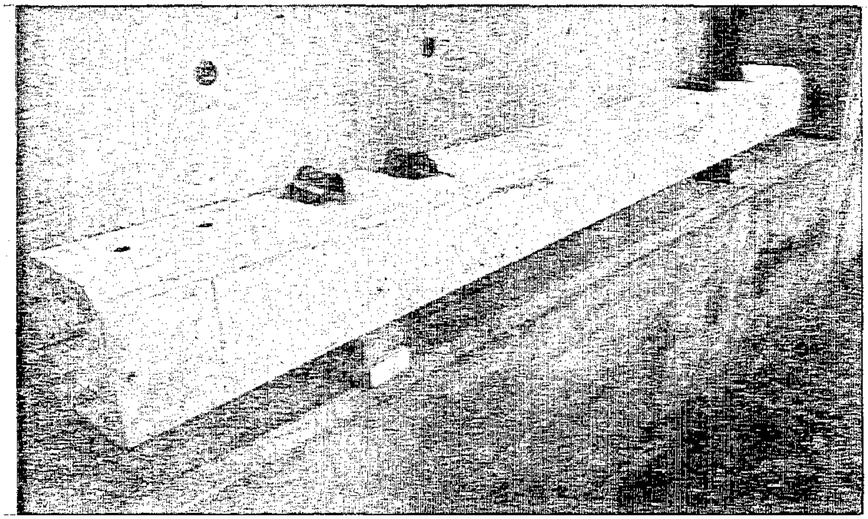


FIGURE 2-5. PRETENSIONED MONOBLOCK TIE

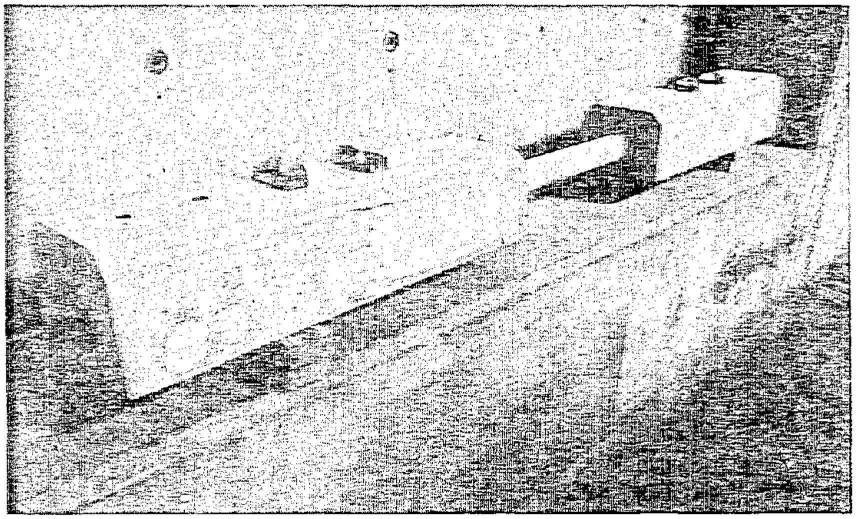


FIGURE 2-6. POST-TENSIONED TWO-BLOCK TIE

3. TESTING OF TIES

Ties of the two designs were tested under static and dynamic loads. Tests included the following:

1. Rail seat vertical load test,
2. Tie center vertical load test,
3. Bond development, tendon anchorage, and ultimate load test,
4. Rail seat repeated load test, and
5. Contact rail support bracket insert test.

Tests were conducted on five monoblock and seven two-block ties cast with inserts for the different fastening types. Tests performed on each tie are listed in Table 3-1. Test procedures were similar to those generally specified by railroads and transit properties. Test loads were determined from flexural performance requirements established in previous work. Test procedures and results are presented.

3.1 MONOBLOCK TIE TEST PROCEDURES

Procedures for tests conducted on monoblock ties are described.

3.1.1 Rail Seat Vertical Load Test

Tie was supported and loaded as shown in Figure 3-1. Load was applied at a uniform rate and in such a manner to avoid shock up to 18,000 lb during a 3-min. period. Then, force was increased in increments of 1,000 lb. After each increment, tie was inspected to determine if cracking had occurred. A 5-power illuminated magnifying glass was used to locate cracks. Load was increased until cracking was detected and cracking load was recorded.

3.1.2 Tie Center Vertical Load Test

Tie was supported and loaded as shown in Figure 3-2. Load was applied at a uniform rate and in such a manner to avoid

TABLE 3-1. SUMMARY OF TIE TESTS

	Tie Type	Monoblock					Two-Block						
	Fastening Type	A		B		C	A		B			C	
	Tie Number	1	2	1	2	1	1	2	1	2	3	1	2
Type of Test	Rail Seat Vertical Load, Seat A	X		X	X	X	X	X	X	X		X	X
	Rail Seat Vertical Load, Seat B	X	X	X	X	X	X	X	X	X	X	X	X
	Bond Development, Tendon Anchorage and Ultimate Load, Seat B	X		X		X	X		X			X	
	Tie Center Vertical Load	X		X		X	X		X			X	
	Rail Seat Repeated Load, Seat A		X								X		
	Contact Rail Support Bracket Insert				X								X

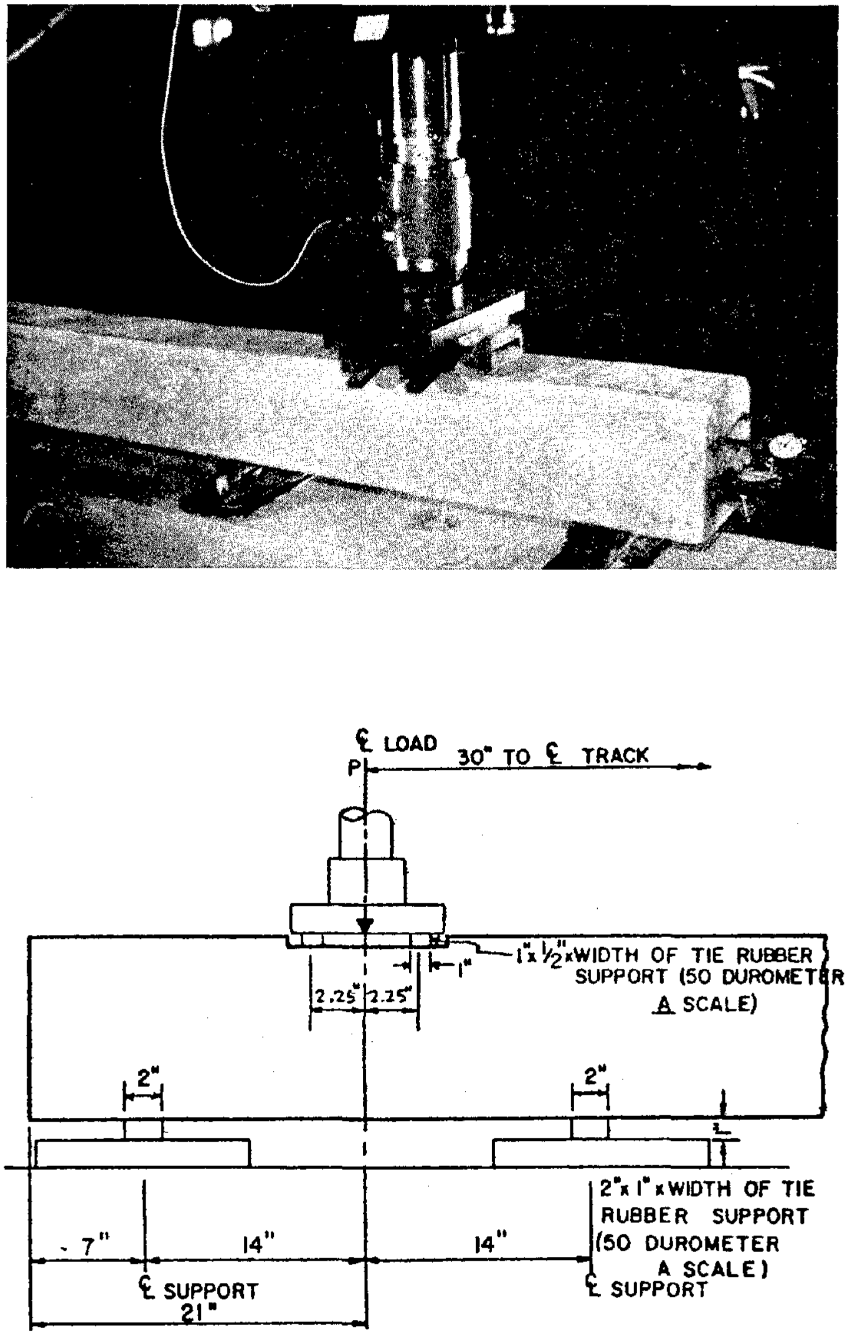


FIGURE 3-1. MONOBLOCK TIE RAIL SEAT VERTICAL LOAD TEST

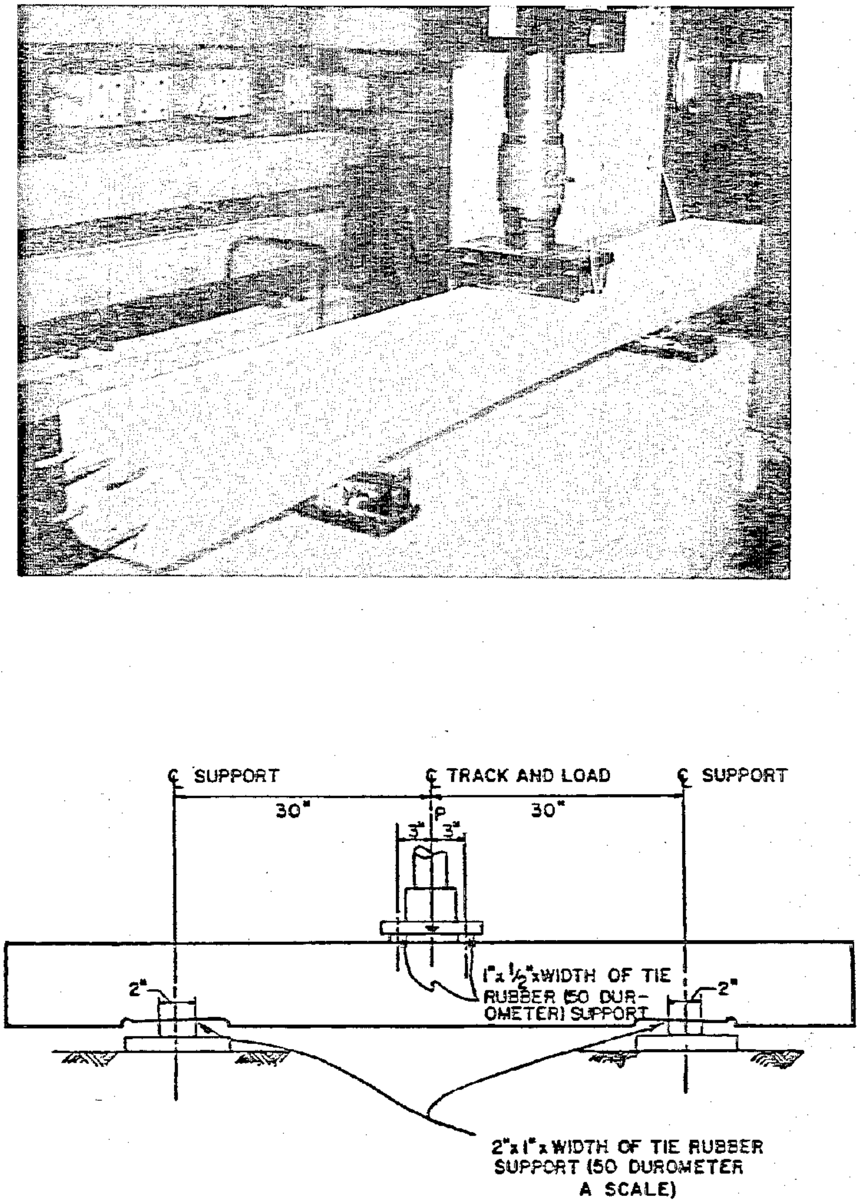


FIGURE 3-2. MONOBLOCK TIE CENTER VERTICAL LOAD TEST

shock up to 6,000 lb during a 2-min. period. Then, force was increased increments of 500 lb. After each increment, tie was inspected to determine if cracking had occurred. A 5-power illuminated magnifying glass was used to locate cracks. Load was increased until cracking was detected and cracking load was recorded.

3.1.3 Bond Development and Ultimate Load Test

Tie was supported and loaded as shown in Figure 3-1. Extensometers, reading to the nearest 0.001 in., were attached to the tie end to measure strand slippage. Load was applied in the manner described for rail seat vertical load test until initial cracking was detected. Load was then increased at a rate of approximately 5 kips per minute until ultimate load was recorded. The load at which 0.001-in. strand slippage occurred was recorded.

3.1.4 Rail Seat Repeated Load Test

Tie was supported and loaded as shown in Figure 3-1, except that the rubber supports were replaced by 1/4-in. thick plywood strips. Tie was subjected to 3 million load cycles. Each cycle varied uniformly from 2.5 kips to 19.5 kips. Frequency of repeated loading was 480 cycles per minute. After completion of 3 million load cycles, a static load of 19.5 kips was applied and held for approximately 5 minutes. During this time, an inspection was made to determine if cracking had occurred. A 5-power illuminated magnifying glass was used to locate cracks.

3.1.5 Contact Rail Support Bracket Insert Test

An axial load of 6 kips was applied to each insert separately as shown in Figure 3-3. Load was held for 3 minutes. During this time, an inspection was made to determine if inserts had moved or concrete had cracked.

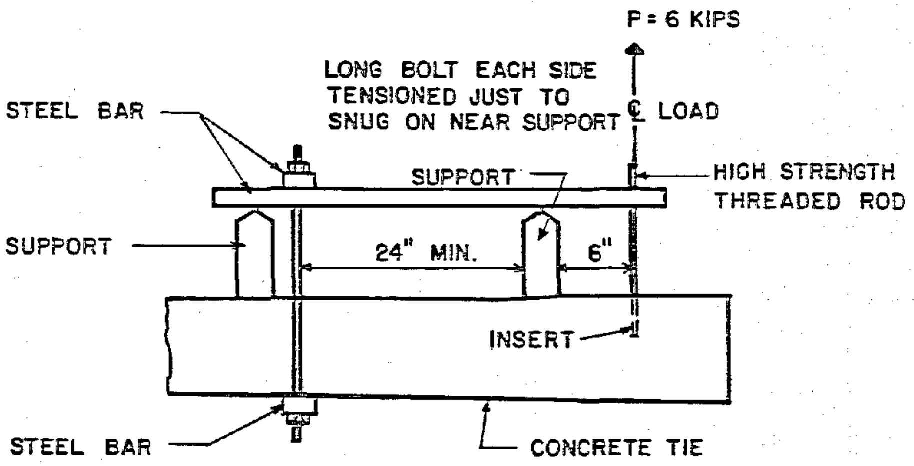


FIGURE 3-3. CONTACT RAIL SUPPORT BRACKET INSERT TEST

3.2 MONOBLOCK TIE TEST RESULTS

As shown in Table 3-1, the following tests were conducted on monoblock ties:

1. Rail seat vertical load test on both rail seats of four ties and one rail seat of a fifth tie.
2. Bond development and ultimate load test on one rail seat of each of three ties.
3. Tie center vertical load test on three ties.
4. Rail seat repeated load test on one rail seat.
5. Contact rail support bracket insert test on inserts of one tie.

Test results for rail seat vertical load, bond development and ultimate load, and tie center vertical load tests are summarized in Table 3-2.

Data presented in Table 3-2 and inspections made during the tests indicate the following:

1. Average cracking load for rail seats was 30.9 to 31.9 kips.
2. Average cracking load for tie center was 11.7 to 12.2 kips.
3. Average load at 0.001-in. strand slippage was 68.0 kips.
4. Average ultimate load for rail seats was 68.0 kips.
5. No cracks had occurred during the rail seat repeated load test.
6. The concrete did not crack and the inserts did not move during contact rail support bracket insert tests.

As indicated, average cracking load for the rail seats exceeded 30.9 kips. This load corresponds to a bending moment of 181 in.-kip. This moment exceeds the 154 in.-kip requirement shown in Appendix A. Therefore, tie strength at rail seats is adequate.

Also, average cracking load for tie centers exceeded 11.7 kips. This load corresponds to a bending moment of 158 in.-kip. This moment exceeds the 131 in.-kip requirement shown in Appendix A. Therefore, tie strength at center is adequate.

TABLE 3-2. MONOBLOCK TIE TEST RESULTS

Fastening Type	Tie Number	Initial Cracking Load, kip			Ultimate Load, kip*
		Rail Seat A	Rail Seat B	Tie Center	Rail Seat B
A	1	29-30	28-29	12.5-13.0	65.4
	2	-	36-37	-	-
B	1	34-35	28-29	11.5-12.0	66.4
	2	33-34	34-35	-	-
C	1	28-29	28-29	11.0-11.5	72.3

*Same load for 0.001-in. strand slippage

3.3 TWO-BLOCK TIE TEST PROCEDURES

Procedures for tests conducted on two-block ties are described.

3.3.1 Rail Seat Vertical Load Test

Tie was supported and loaded as shown in Figure 3-4. Load was applied at a uniform rate and in such a manner to avoid shock up to 20 kips during a 3-min. period. Then, force was increased in increments of 1 kip. After each increment; tie was inspected to determine if cracking had occurred. A 5-power illuminated magnifying glass was used to locate cracks. Load was increased until cracking was detected and cracking load was recorded.

3.3.2 Tie Center Vertical Load Test

Tie was supported and loaded as shown in Figure 3-5. Load was applied at a uniform rate and in such a manner to avoid shock up to 3.2 kips during a 2-min. period. This load was held for approximately 3 minutes. During this time, an inspection was made to determine if cracking had occurred on the gage faces of the blocks. A 5-power illuminated magnifying glass was used to locate cracks. Also, deflection at tie center was measured and recorded.

3.3.3 Tendon Anchorage and Ultimate Load Test

Tie was supported and loaded as shown in Figure 3-4. Load was applied in the manner described for rail seat vertical load test until initial cracking was detected. Load was then increased as a rate of approximately 5 kips per minute until a load of 42 kips was reached. This load was held for 5 minutes. The ability of the tie to support the load during this period was evaluated. Load was then increased until ultimate load was recorded.

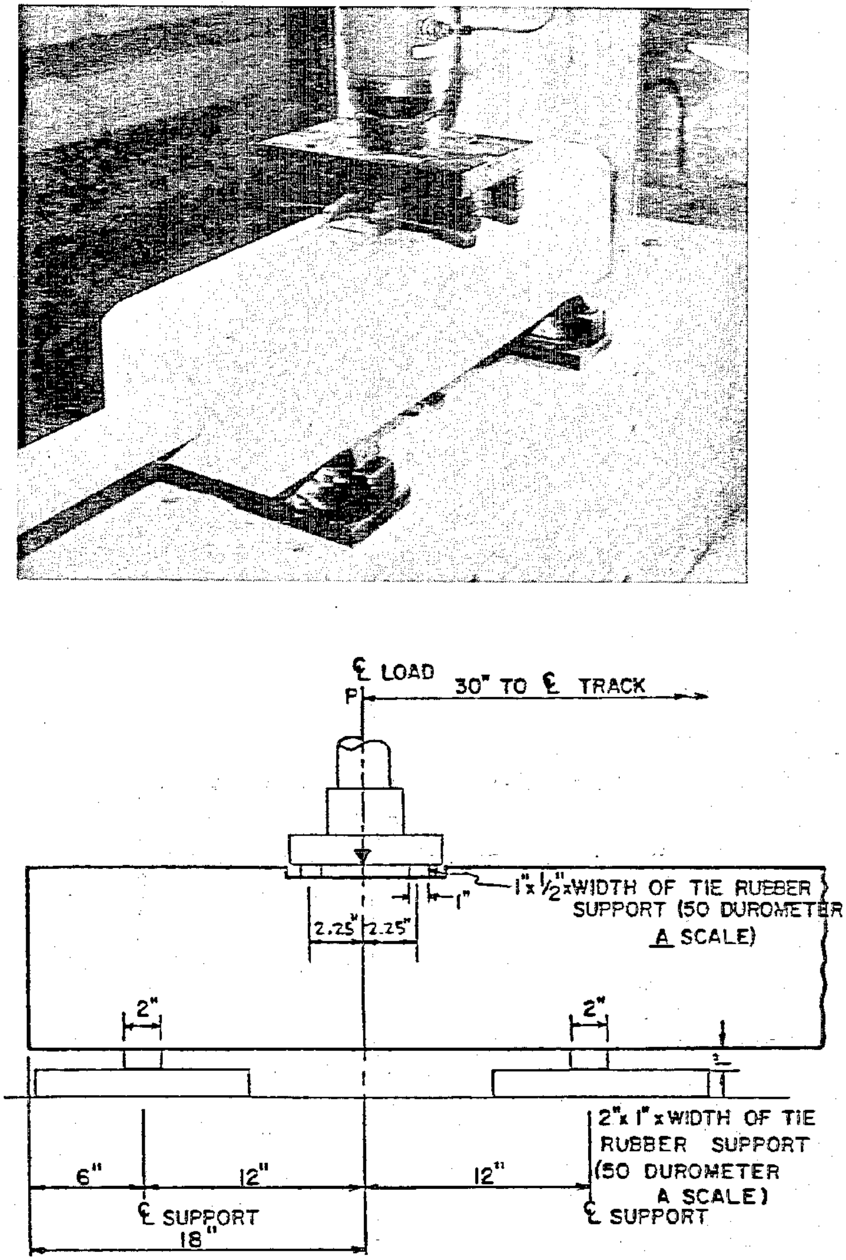


FIGURE 3-4. TWO-BLOCK TIE RAIL SEAT VERTICAL LOAD TEST

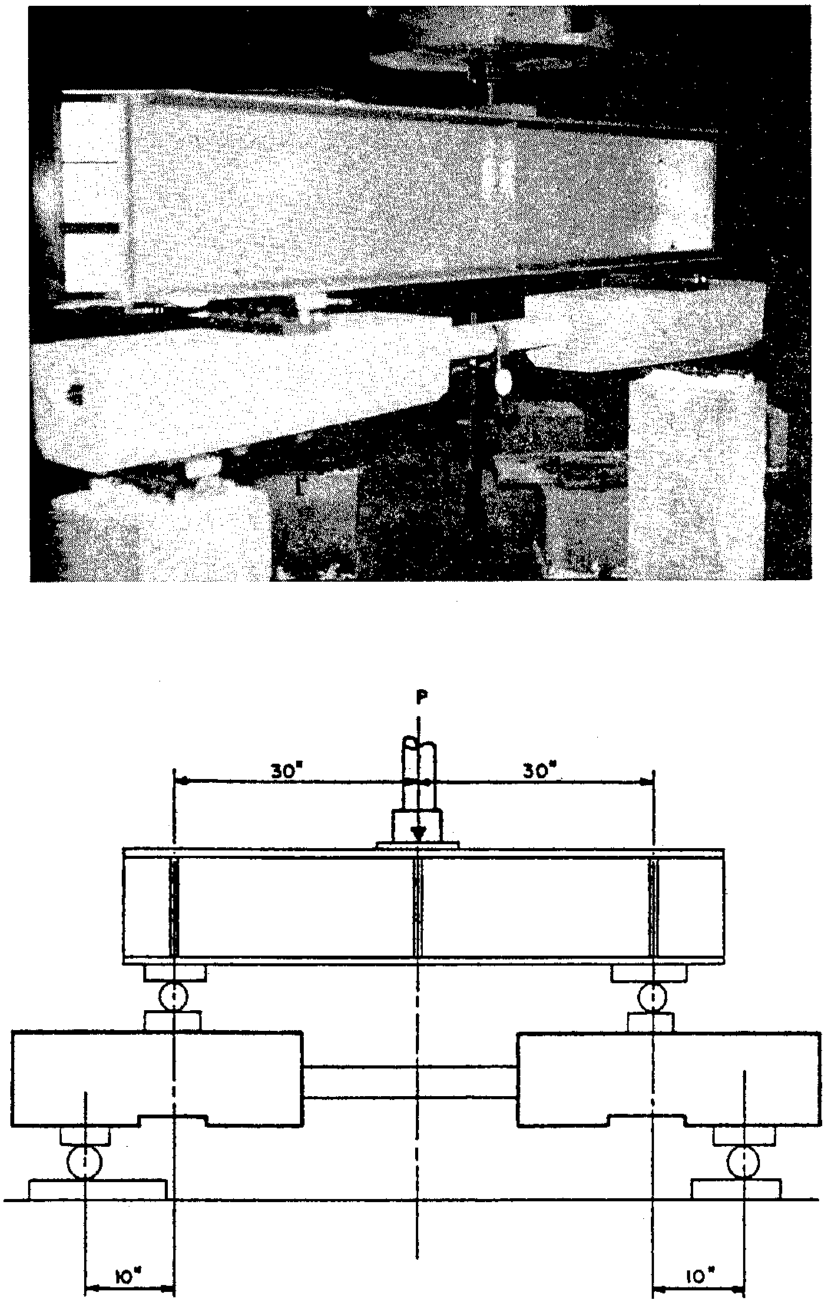


FIGURE 3-5. TWO-BLOCK TIE CENTER VERTICAL LOAD TEST

3.3.4 Rail Seat Repeated Load Test

Tie was supported and loaded as shown in Figure 3-4, except that the rubber supports were replaced by 1/4-in. thick plywood strips. Tie was subjected to 3 million load cycles. Each cycle varied uniformly from 2.5 kips to 20.0 kips. Frequency of repeated loading was 480 cycles per minute. After completion of 3 million load cycles, a static load of 20.0 kips was applied and held for approximately 5 minutes. During this time, an inspection was made to determine if cracking had occurred. A 5-power illuminated magnifying glass was used to locate cracks.

3.3.5 Contact Rail Support Bracket Insert Test

Test was conducted in the same manner used for testing contact rail support bracket inserts of monoblock ties.

3.4 TWO-BLOCK TIE TEST RESULTS

As shown in Table 3-1, the following tests were conducted on two-block ties:

1. Rail seat vertical load test on both rail seats of four ties and one rail seat of a fifth tie.
2. Tendon anchorage and ultimate load test on one rail seat of each of three ties.
3. Tie center vertical load test on three ties.
4. Rail seat repeated load test on one rail seat.
5. Contact rail support bracket insert test on inserts of one tie.

Test results for rail seat vertical load, tendon anchorage and ultimate load, and tie center vertical load tests are summarized in Table 3-3.

Data presented in Table 3-3 and inspections made during the tests indicate the following:

1. Average cracking load for rail seats was 29.2 to 30.2 kips.
2. Average ultimate load for rail seats was 55.4 kips.

TABLE 3-3. TWO-BLOCK TIE TEST RESULTS

Fastening Type	Tie Number	Initial Cracking Load, kip		Tie Center Deflection, in.	Ultimate Load, kip
		Rail Seat A	Rail Seat B		Rail Seat B
A	1	29-30	27-28	0.103	57.0
	2	30-31	28-29	-	-
B	1	30-31	29-30	0.098	53.2
	2	27-28	28-29	-	-
	3	-	32-33	-	-
C	1	28-29	27-28	0.098	56.0
	2	32-33	32-33	-	-

3. Average tie center deflection for tie center vertical load tests was 0.10 in.
4. Ties were able to support a 42-kip load during the tendon anchorage and ultimate load tests for 5 minutes.
5. No cracks had occurred during the rail seat repeated load test.
6. Neither the concrete had cracking nor the inserts had moved during the contact rail support bracket insert tests.

As indicated, average cracking load for the rail seats exceeded 29.2 kips. This load corresponds to a bending moment of 142 in.-kip. This moment exceeds the 137 in.-kip requirement shown in Appendix A. Therefore, tie strength at rail seats is adequate.

4. TESTING OF FASTENINGS

Three fastening types designated A, B, and C were tested under static and dynamic loads. Views of the fastening systems are shown in Figures 4-1, 4-2, and 4-3. As these figures indicate, each of fastening Types A and B used insulators placed between clips and rail. However, insulation for fastening Type C was provided by coating on inserts. The following tests were conducted in sequence on each of the three fastening types:

1. Fastening insert test on rail seat A,
2. Fastening uplift test on rail seat A,
3. Electrical resistance and impedance test,
4. Fastening repeated load test on rail seat B,
5. Fastening longitudinal restraint test on rail seat B, and
6. Fastening lateral restraint test on rail seat B.

A different monoblock tie, with rail seats designated A and B, was used for testing each fastening type. Test procedures were similar to those generally specified by railroads and transit properties. Test loads were selected to represent transit loading conditions. Test procedures and results are presented.

4.1 TEST PROCEDURES

Procedures for tests conducted on the fastening systems are described.

4.1.1 Rail Fastening Insert Test

An axial load of 8 kips was applied to each insert separately as shown in Figure 4-4. Load was held for 3 minutes. During this time, an inspection was made to determine if inserts had moved or concrete had cracked.

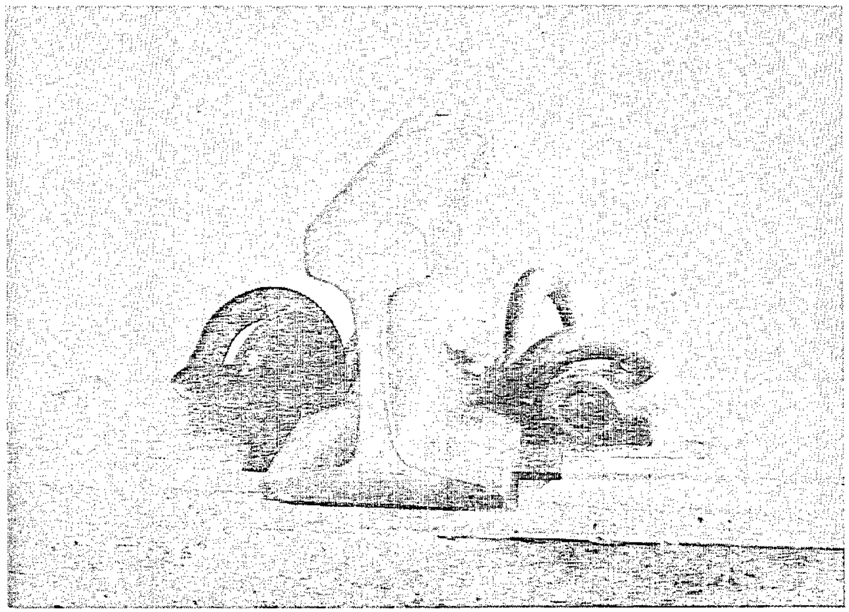


FIGURE 4-1. RAIL FASTENING TYPE A

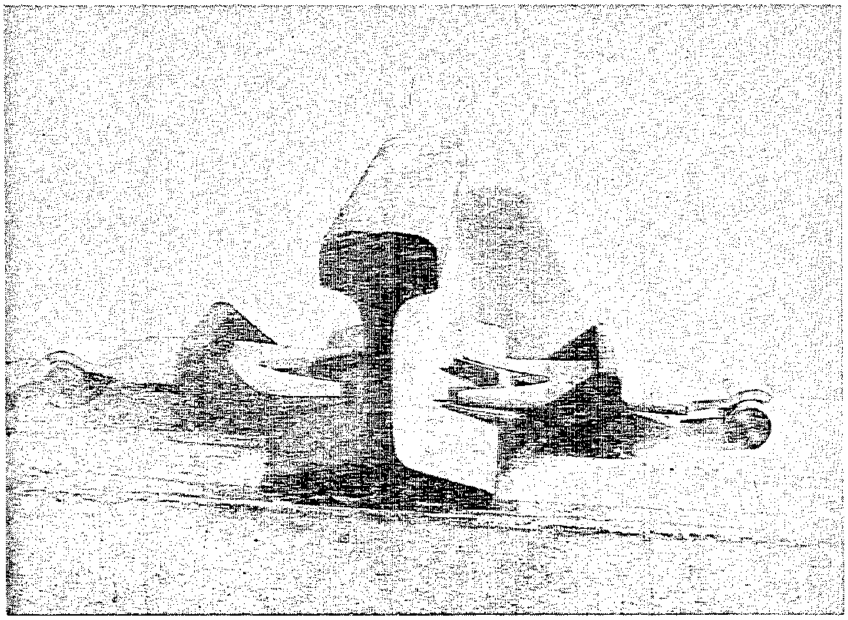


FIGURE 4-2. RAIL FASTENING TYPE B

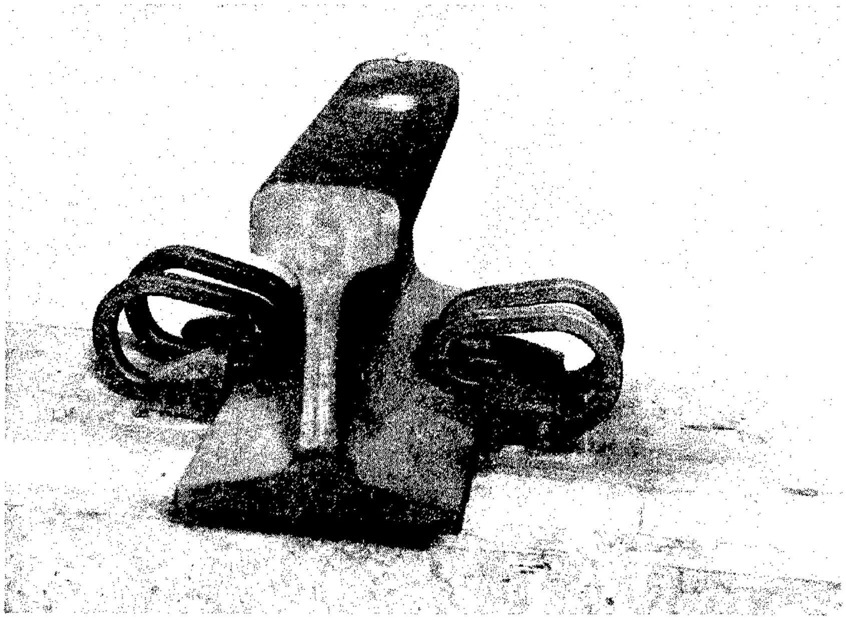


FIGURE 4-3. RAIL FASTENING TYPE C

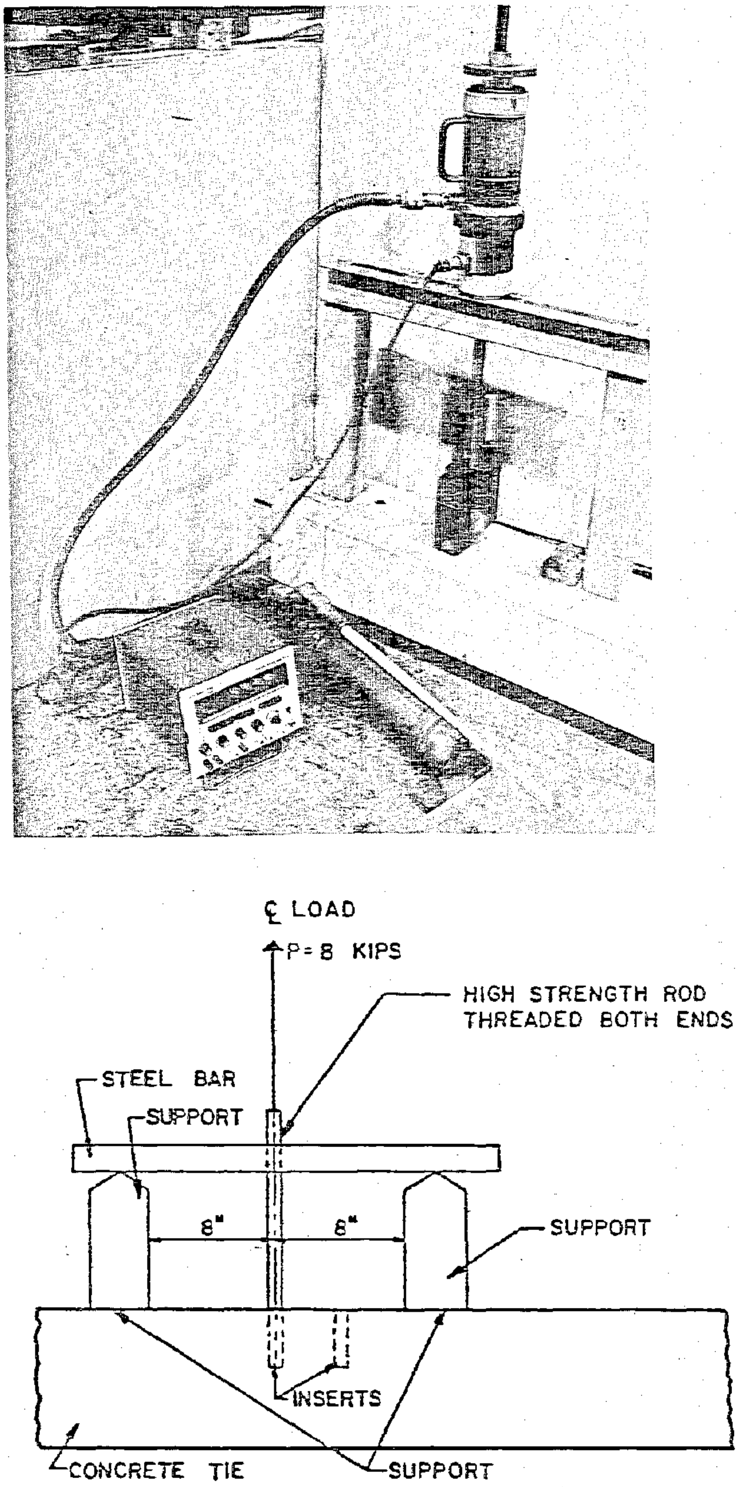


FIGURE 4-4. RAIL FASTENING INSERT TEST

4.1.2 Rail Fastening Uplift Test

An 18-in. section of 115 RE rail was secured to one rail seat using a complete rail fastening system including pads, clips, and associated hardware. In accordance with the loading diagram in Figure 4-5, an incremental load was applied to the rail. The load P at which separation of the rail from pad or pad from rail seat (whichever occurred first) was recorded. The load was then completely released, and a load of 1.5P was applied. A visual inspection was made to determine if inserts had pulled out or loosened in the concrete, any fastening component had fractured, or rail had been released.

4.1.3 Electrical Resistance and Impedance Test

Concrete test tie was assembled with insulating components, rail clips, and two short pieces of 115 RE rail. The complete assembly was immersed in water for about 16 hours. Within 1 hr. after removal from water, an a-c 10-volt 60-Hertz potential was applied across the two rails for a period of 15 minutes. The current flow in amperes was read using an a-c ammeter and the impedance was determined by dividing the voltage by the current flow in amperes.

4.1.4 Fastening Repeated Load Test

An 18-in. section of 115 RE rail from which loose mill scale had been removed by wiping with a cloth was secured to the rail seat using a complete rail fastening assembly. In accordance with the loading diagram in Figure 4-6, alternating downward and upward loads were applied at an angle of 20 degrees to the vertical axis of the rail. A double-acting hydraulic ram was used to apply both the upward and downward loads at a rate of 240 cycles per minute for 5 million cycles. Each load cycle consisted of both a downward and upward load. During test, rail was free to rotate under the applied loads. The downward load was 17 kips. The magnitude of the upward load was 0.6P where P is the load that caused minute separation of the rail

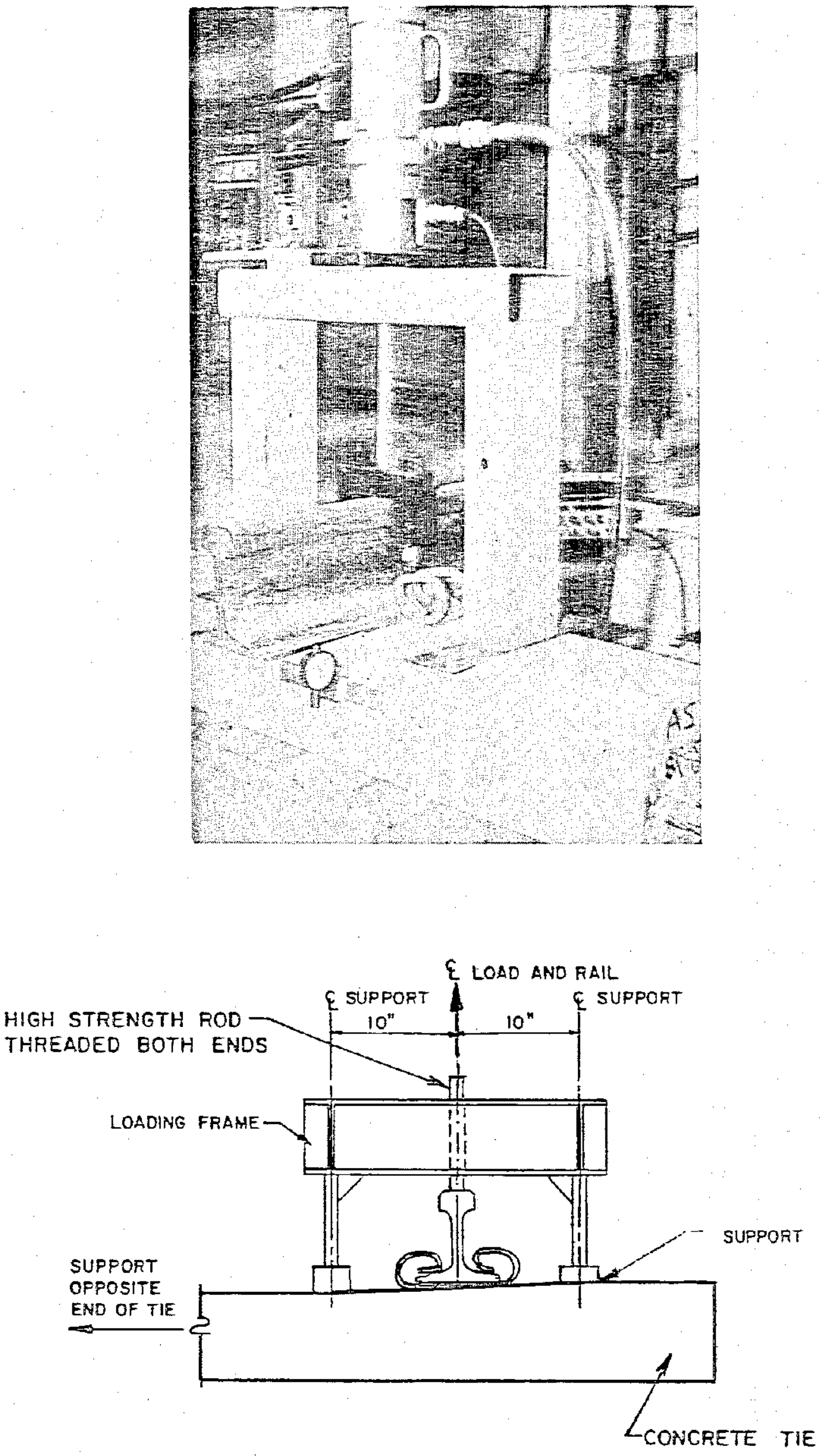


FIGURE 4-5. RAIL FASTENING UPLIFT TEST

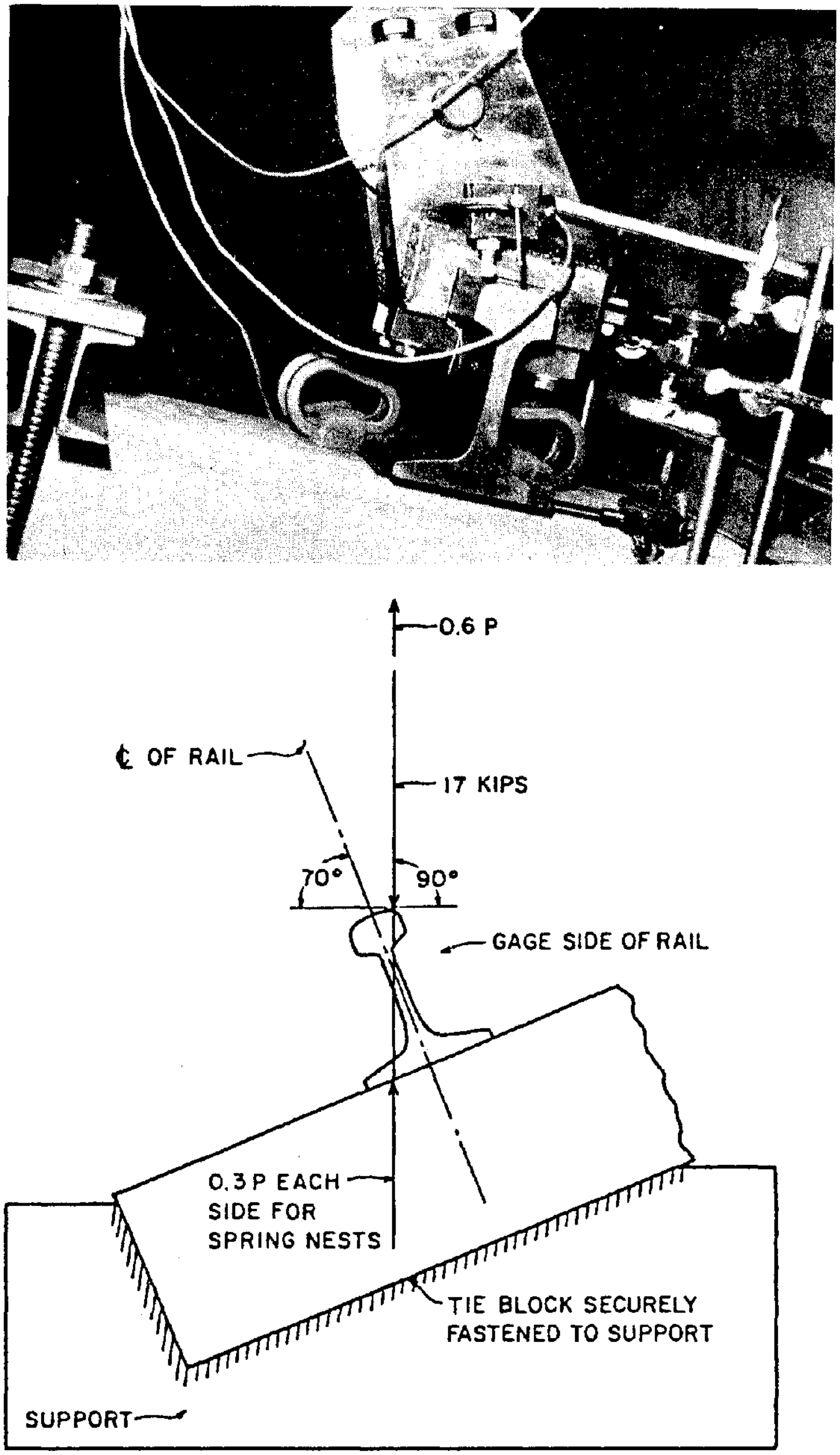


FIGURE 4-6. RAIL FASTENING REPEATED LOAD TEST

from the rail seat pad or the pad from the rail seat, whichever occurred first, as determined from the fastening uplift test.

During test, measurements were made of lateral rail movement and rail head rotation. Following completion of 5 million load cycles, a visual inspection was made to determine if any fastening component had fractured.

4.1.5 Rail Fastening Longitudinal Restraint Test

After completion of the rail fastening repeated load test and without disturbing the rail fastening assembly in any manner, the tie and fastening were subjected to a longitudinal restraint test. A longitudinal load was applied as indicated in Figure 4-7, in increments of 400 pounds. Readings were taken of longitudinal rail displacement after each increment. Rail displacement was the average movement of two dial indicators reading to 0.001 in. One dial indicator was placed on each side of the rail with dial indicator plungers parallel to the longitudinal axis of the rail. Load was increased incrementally until a load of 2.4 kips was reached or rail slipped, whichever occurred first. The 2.4-kip load, if reached, was held for 15 minutes. Rail movement was recorded every 3 minutes.

4.1.6 Rail Fastening Lateral Restraint Test

An 18-in. section of 115 RE rail was secured to the tie in a manner appropriate to the fastening being used. The entire assembly was supported and loaded as indicated in Figure 4-8. The loading head was fixed against translation and rotation. The wood block was 10-in.x10-in.x3/4-in. thick, 5 ply exterior grade plywood.

A preload of 10 kips was applied to seat the rail in the fastening. Upon release of the preload, a zero reading was taken on the dial indicators that measure rail translation. Load was applied at a rate of approximately 3 kips per minute until a load of 19 kips was reached. Rail base translation was recorded.

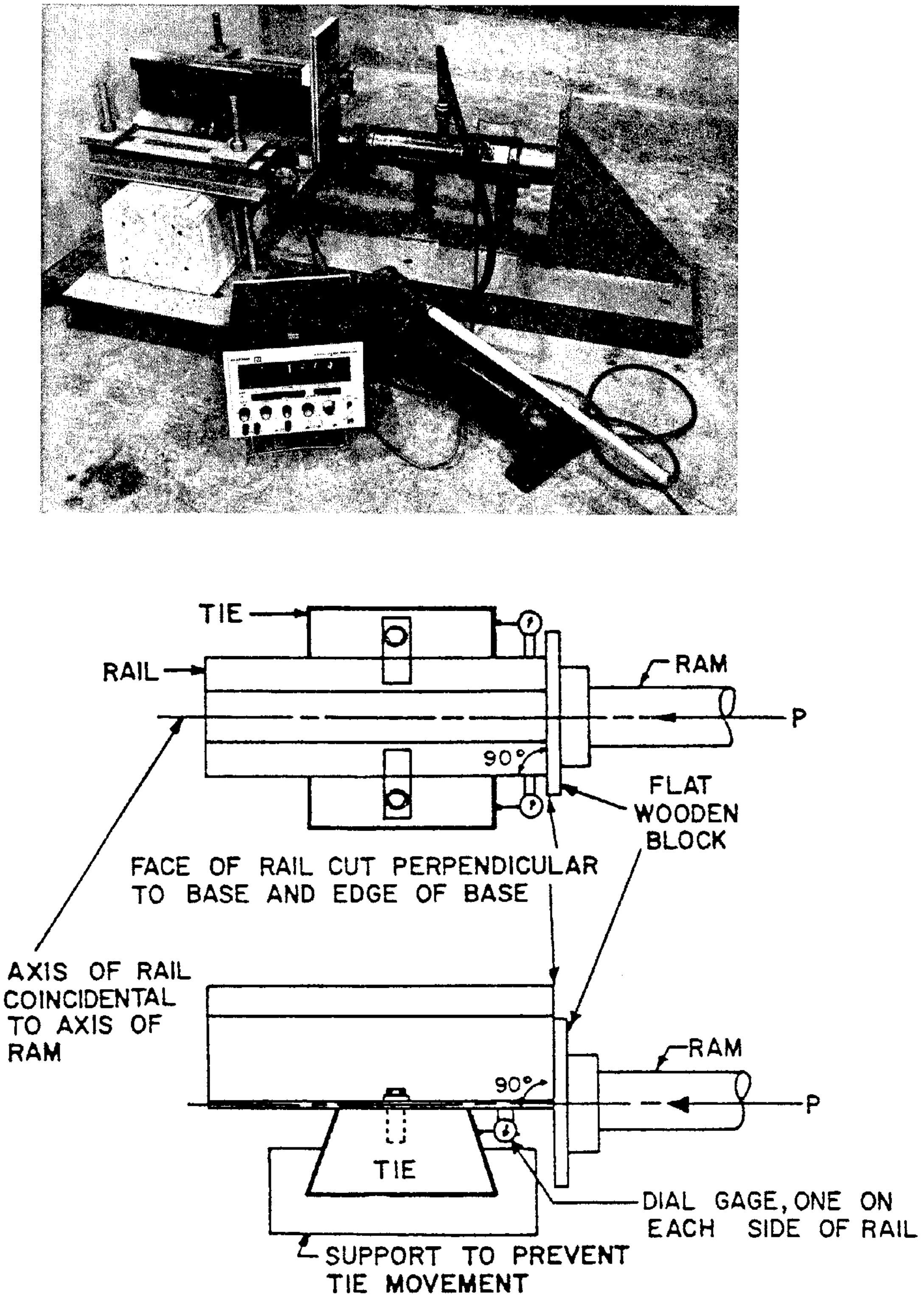
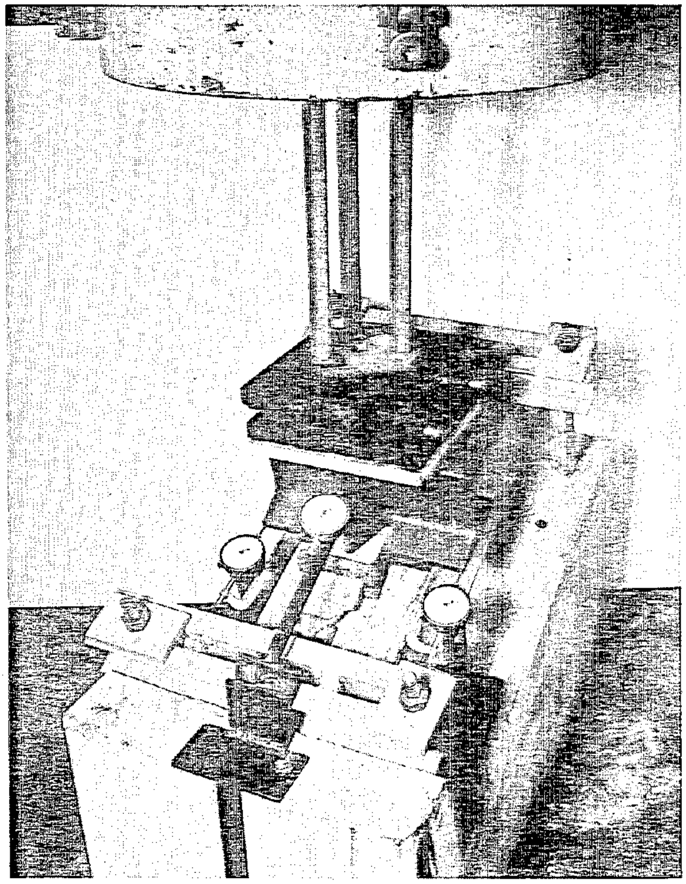


FIGURE 4-7. RAIL FASTENING LONGITUDINAL RESTRAINT TEST



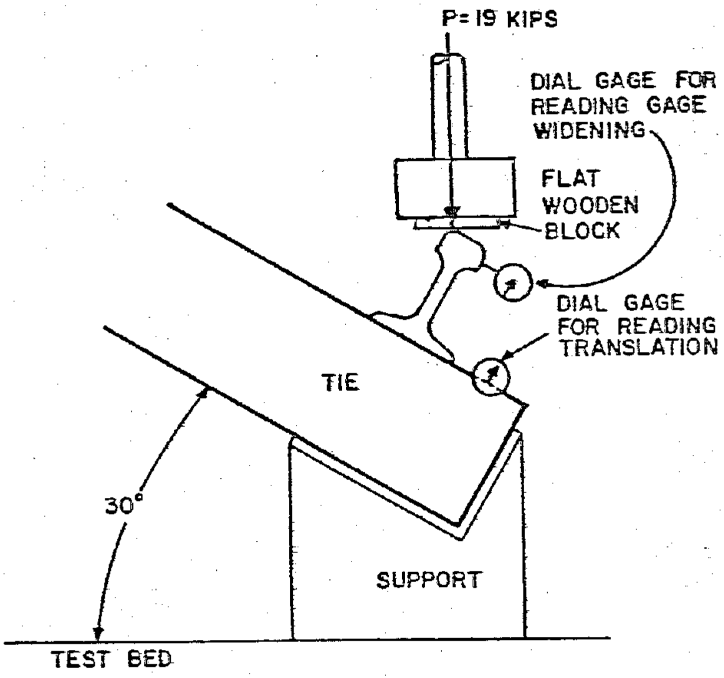


FIGURE 4-8. RAIL FASTENING LATERAL RESTRAINT TEST

With all load removed from the rail, a roller nest was placed between the fixed loading head and the wood block on the rail head. The roller nest did not offer resistance to lateral movement of the rail head. After taking zero readings on the dial indicators that measure gage widening and rail translation, a load of 10 kips was applied at a rate of approximately 3 kips per minute. Gage widening and rail translation were recorded and rail rotation was calculated.

4.2 TEST RESULTS

Data and observations obtained from tests on the three fastening types are summarized.

4.2.1 Fastening Insert Tests

Inspection of the ties and inserts during insert tests on the three fastening types revealed no insert movement or concrete cracking.

4.2.2 Fastening Uplift Tests

Recorded loads at which separation of the rails from rail seat pads occurred were 3,500, 3,700 and 4,500 lb for fastening types A, B, and C, respectively. Load versus movement data obtained for the three fastening types are shown in Figure 4-9.

Inspection of fastening components during tests on the three fastening types revealed no insert loosening or component fracture.

4.2.3 Electrical Resistance and Impedance Tests

Impedances measured 15 minutes after removal of assembled concrete ties, rails, and fastenings from water were 213,000, 370,000 and 42,000 ohms for fastening types A, B, and C, respectively.

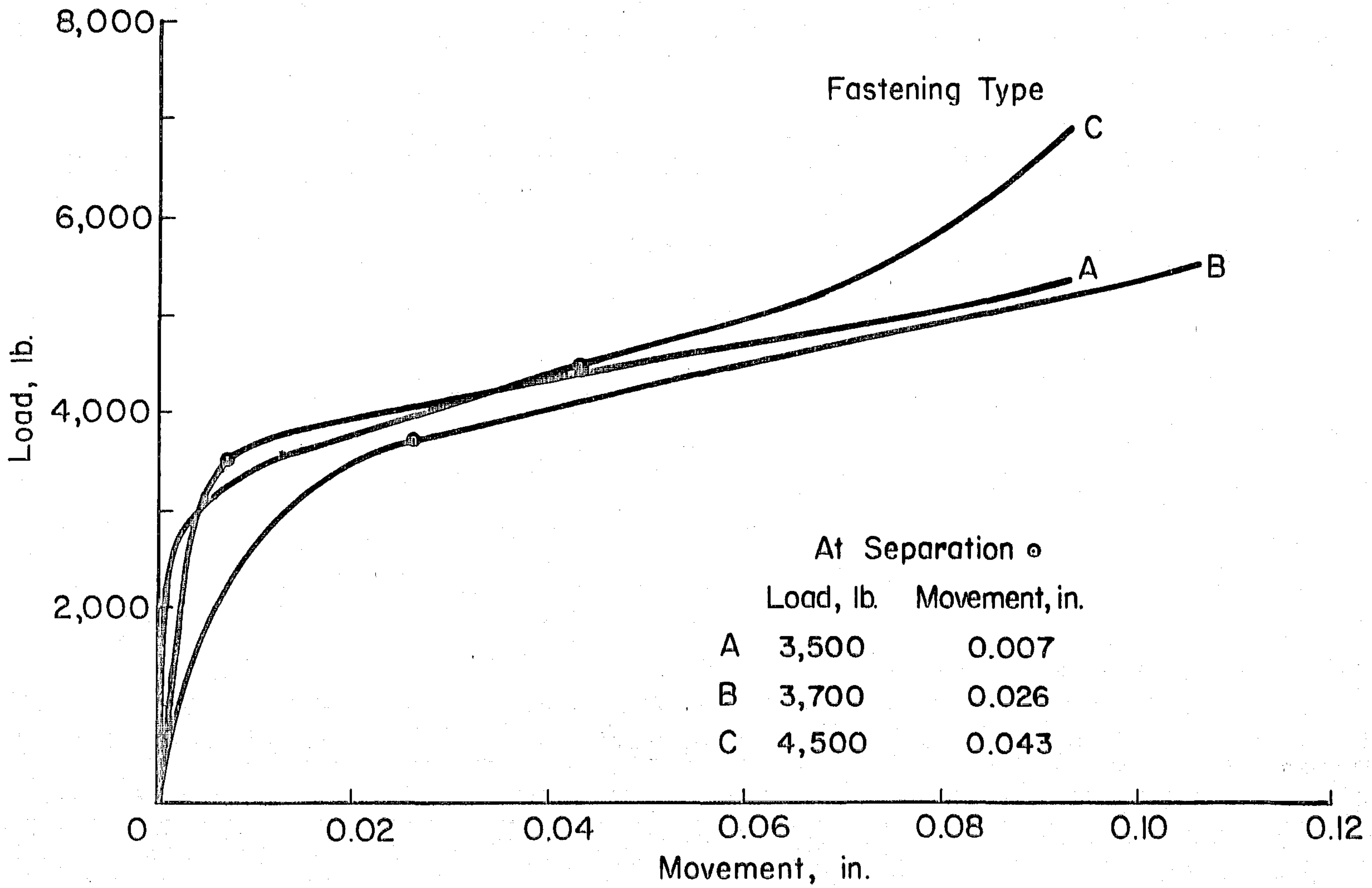


FIGURE 4-9. LOAD VERSUS MOVEMENT FOR FASTENING UPLIFT TESTS

4.2.4 Fastening Repeated Load Tests

Total gage widening that occurred during the 5 million load applications amounted to 0.020, 0.043, and 0.011 in. for fastening types A, B, and C, respectively. Total rail base translation that occurred during the tests amounted to 0.014, 0.012, and 0.009 in. for fastening types A, B, and C, respectively.

Inspection of fastening components after completion of tests on the three fastening types revealed no component fracture.

4.2.5 Fastening Longitudinal Restraint Tests

Measurements obtained during tests indicated that none of the three fastening types resisted a 2,400 lb longitudinal force without slippage. Loads at which slippage occurred were 1,600, 1,850 and 2,350 lb for fastening types A, B, and C, respectively.

4.2.6 Fastening Lateral Restraint Tests

Measurements obtained during tests indicated that rail base translations under a 19-kip load were 0.023, 0.018, and 0.056 in. for fastening types A, B, and C, respectively. Rail rotations under a 10-kip load were 0.027, 0.075, and 0.025 in. for fastening types A, B, and C, respectively.

Data and observations obtained from tests on the three fastening types indicate that, except for the longitudinal restraint resistance, the three fastening types have performed satisfactorily under test conditions.

5. TESTING OF ASSEMBLED TRACK COMPONENTS

In these tests, ties of the two designs were supported on two ballast types and subjected to repeated loads simulating train effects. A monoblock and a two-block tie were tested on trap rock ballast. Also, a monoblock and a two-block tie were tested on limestone ballast. Test procedures and results are discussed.

5.1 TEST PROCEDURES

In the tests, two short pieces of 115 RE rail were secured to the rail seats using complete fastening assemblies. The assembled track section was supported on ballast. The ballast was built with shoulders of a representative track. Ballast was compacted using a sled virbrator. However, ballast was loosened in the middle 20 in. of tie length and near tie ends to simulate compaction by tamping equipment. General views of test set-ups for monoblock and two-block tie tests are shown in Figures 5-1 and 5-2, respectively.

Two types of ballast, trap rock and limestone, with nominal size ranging from 3/4 to 1-1/2 in. were used. Ballast gradation conformed to AREA Size No. 4. In contrast to the limestone ballast used, the trap rock material lacked angular particle structure and sharp corners. Ballast was placed on a soft building board to provide the resilience supplied by a subgrade, and to allow penetration of ballast particles and interlocking. Ballast depth was approximately 12 in. A monoblock and a two-block tie were tested on trap rock ballast. Also, a monoblock and a two-block tie were tested on limestone ballast.

Repeated loads were applied to each rail seat of the tie. Loading pattern was selected to simulate a 75-ft long car with 7-ft axle spacing and 54-ft truck spacing. Each load cycle varied from a minimum of 2.0 kips to a maximum of 22.6 kips. Loading pattern is shown in Figure 5-3. Frequency of loading

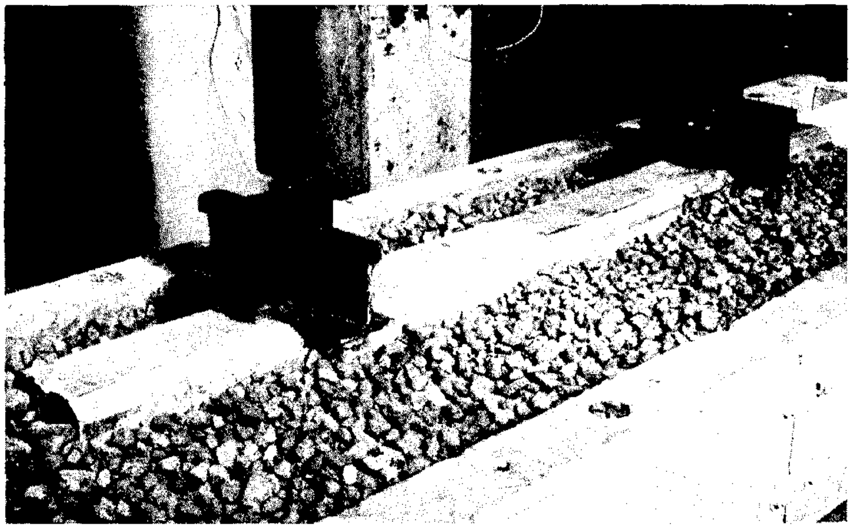


FIGURE 5-1. MONOBLOCK TIE TEST ON BALLAST

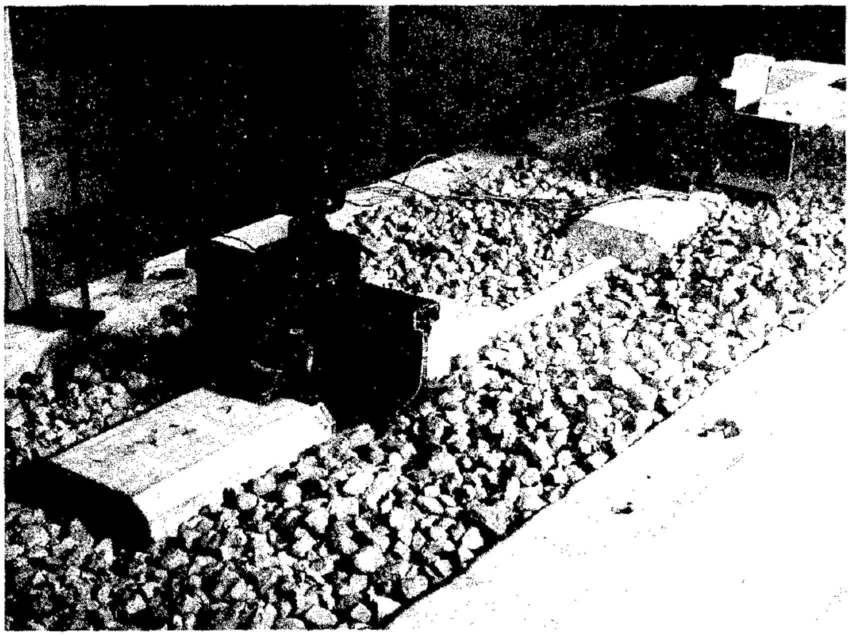


FIGURE 5-2. TWO-BLOCK TIE TEST ON BALLAST

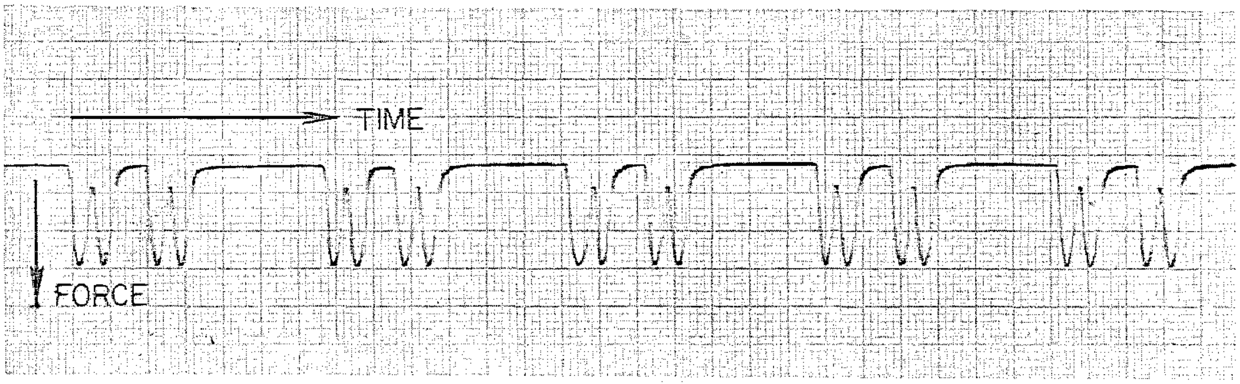


FIGURE 5-3. LOADING PATTERN FOR TIE TESTS ON BALLAST

was changed during the tests to simulate speeds ranging from 30 to 75 mph. A total of 10 million load cycles (2.5 million transit cars) were applied, in the following sequence:

a. One million load cycles simulating a 30 mph speed,
b. Two million load cycles simulating a 45 mph speed,
c. Three million load cycles simulating a 60 mph speed, and
d. Four million load cycles simulating a 75 mph speed.

Prior to tests, strain gages were cemented on tie surfaces at cross sections below rails of monoblock and two-block ties. In addition, strain gages were cemented on tie surfaces at mid-length of monoblock ties. Ties were supported and loaded in the manner described for rail seat and tie center vertical load tests, strains were recorded. Thus, relationship between tie strains and applied bending moments was determined. These measurements indicated that tensile strain at rail seat cross sections, 1 in. above bottom surface, averaged 1.2 millionths/in.-kip for both monoblock and two-block ties. Tensile strain on top surface at mid-length of monoblock ties was 2.15 millionths/in.-kip.

During the tests, periodic strain measurements were made under static loads of 22.6 kip applied to each rail seat. These strains were used to calculate applied bending moments. Upon completion of tests, ties were examined to determine cracking or damage. In addition, rail seat vertical load test was performed on each rail seat to determine cracking load and effect of repeated load test on tie strength.

For monoblock tie test on trap rock ballast, 10-ft long rails were initially used. Rail ends were supported on adjustable supports. This resulted in a lifting of the tie from ballast when load applied to the rails was reduced to zero. In addition, a 15-ft long section of 144 lb third rail was supported on an insulator chair bolted to a steel bracket. This bracket was attached to the tie using bolts screwed into contact rail inserts. Also, the third rail rested on a second insulator chair attached to an adjustable support located 10 ft from the tie. Thus, a portion of third rail was cantilevered beyond the test tie. This test arrangement resulted in excessive migration of ballast from under the tie and necessitated frequent adjustments during the test. Therefore, the test set-up was modified after 600,000 load cycles. Principal changes included use of short pieces of rail and elimination of third rail attachment to test tie. This modified test set-up was used for all other tie tests on ballast.

5.2 TEST RESULTS

Data and observations obtained from tie tests on ballast are presented.

5.2.1 Monoblock Tie Tests

Two monoblock ties were tested under simulated transit loads. In the tests, one tie was supported on trap rock ballast and the other on limestone ballast.

5.2.1.1 Test of Monoblock Tie on Trap Rock Ballast - Measurements made during the test indicated excessive changes in tie support condition due to repeated load effect. This was probably caused by lack of adequate angular particle structure and sharp corners required to provide ballast interlocking and stability. Observations made during the test indicated ballast migration from beneath tie rail seats, thus causing a center-bound condition.

Strain measurements during the test indicated that rail seat positive moment ranged from 90 to 140 in.-kip. However, tie center negative moment ranged from 35 to 105 in.-kip.

The test was terminated after 9.3 million load cycles due to equipment malfunction that resulted in an overloading and caused tie fracture at mid-length. However, inspection of tie at the rail seats revealed no cracking or damage. Minor wear was observed on the bottom surface.

After test completion, rail seat vertical load tests were performed on both rail seats. Recorded initial cracking loads of 36 and 40 kips indicate that tie strength was not affected by the repeated loads.

5.2.1.2 Test of Monoblock Tie on Limestone Ballast - Measurements made during test indicated slight changes in tie support condition due to repeated load effect. This is attributed to the angular particle structure and sharp corners that provided ballast interlocking and stability. Observations made during the test indicated no settlement or ballast migration from beneath the tie rail seats.

Strain measurements during the test indicated that rail seat positive moment ranged from 85 to 105 in.-kip. However, tie center negative moment ranged from 30 to 40 in.-kip. These bending moments, particularly at tie center, were less than those obtained for monoblock tie on trap rock ballast. The reductions were probably attributed to the better interlocking and stability of limestone ballast that reduced changes in tie support condition during test.

A total of 10 million load cycles were applied. Inspection of the tie after test completion revealed neither cracking nor significant wear on the bottom surface as shown in Figure 5-4. Also, inspection of ballast after test completion revealed no visible degradation of ballast particles as shown in Figure 5-5.

After test completion, rail seat vertical load tests were performed on both rail seats. Recorded initial cracking loads of 37 and 38 kips indicate that tie strength was not affected by the repeated loads.

5.2.2 Two-Block Tie Tests

Two two-block ties were tested under simulated transit loads. In the tests, one tie was supported on trap rock ballast and the other on limestone ballast.

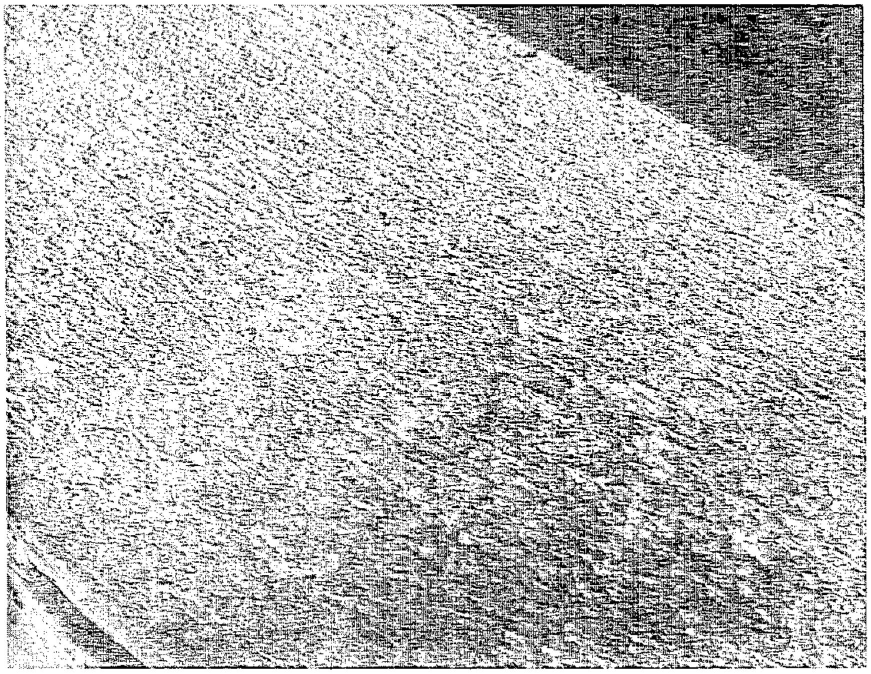


FIGURE 5-4. VIEW OF TIE BOTTOM AT A RAIL SEAT AFTER TEST COMPLETION

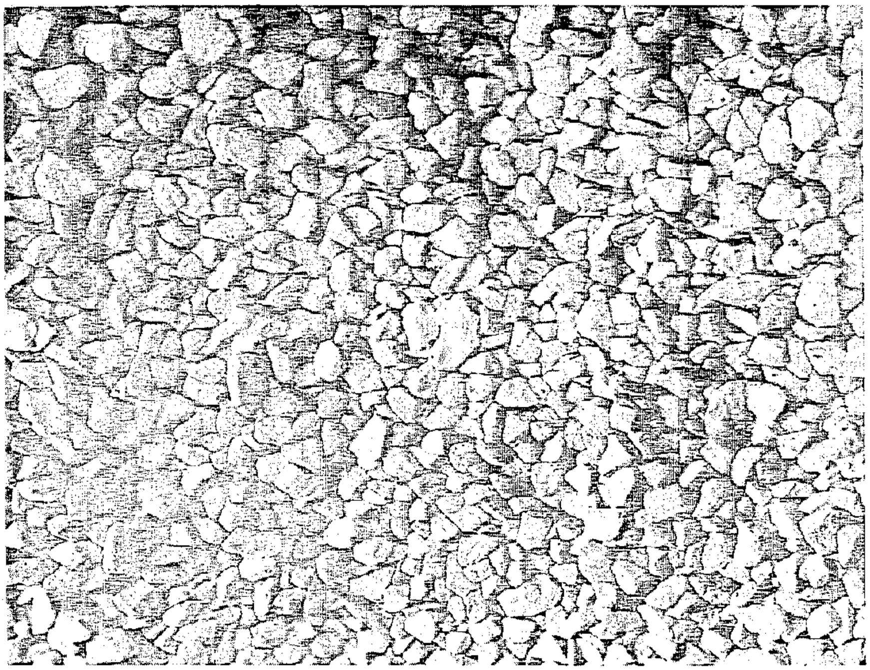


FIGURE 5-5. VIEW OF BALLAST UNDER A RAIL SEAT AFTER TEST COMPLETION

5.2.2.1 Test of Two-Block Tie on Trap Rock Ballast - Measurements and inspections made during test indicated excessive changes in tie support condition and migration of ballast from beneath the tie blocks during the test. Also, settlements of the two-blocks were generally unequal. A settlement difference in excess of 1 in. often occurred every half million load cycles. This necessitated frequent adjustment of ballast and tie and caused detrimental effects on the gage bar. These factors are generally attributed to the inadequate angular particle structure of ballast material required to provide sufficient stability and interlocking.

Strain measurements during the test indicated that rail seat positive moment ranged from 60 to 140 in.-kips.

Inspection of the tie during the test revealed a corner crack on one block after 6.5 million load cycles. A similar crack was observed on the other block after 7.5 million load cycles. These cracks are attributed to the uneven ballast settlement caused by ballast migration from beneath the tie block. These cracks did not cause loosening of the pipe or influence its ability to hold the two blocks in position.

Inspection of the tie after test completion revealed no flexural cracking in the tie blocks. However, minor wear was observed on the bottom surface.

After test completion, rail seat vertical load tests were performed on both rail seats. Recorded initial cracking loads of 32 and 33 kips indicate that tie strength was not affected by the repeated loads.

5.2.2.2 Test of Two-Block Tie on Limestone Ballast - Measurements made during test indicated slight changes in tie support condition due to repeated load effects. Observations made during the tests indicated no settlement or ballast migration from beneath the tie blocks.

Strain measurements during the test indicated that rail seat positive moment ranged from 80 to 95 in.-kips.

Inspection of the tie during and after the test revealed neither cracking nor significant wear on the bottom surface.

Also, inspection of the ballast after test completion revealed no visible degradation of ballast particles.

After test completion, rail seat vertical load tests were performed on both rail seats. Recorded initial cracking loads of 29 and 32 kips indicate that tie strength was not affected by the repeated loads.

6. SUMMARY AND CONCLUDING REMARKS

A laboratory investigation was conducted to evaluate the adequacy of two tie designs, three fastening systems, and two ballast materials for transit use. Designs included a pretensioned monoblock tie and a post-tensioned two-block tie shown in Appendix B. The fastening systems included Types A, B, and C shown in Appendix C. Ballast materials included trap rock and limestone meeting AREA size No. 4 gradation.

Ties of the two designs were fabricated and tested under static and dynamic loads. Tests included the following:

1. Rail seat vertical load test,
2. Tie center vertical load test,
3. Bond development, tendon anchorage, and ultimate load test,
4. Rail seat repeated load test, and
5. Contact rail support track insert test.

Three fastening types were tested under static and dynamic loads. Tests included the following:

1. Fastening insert test,
2. Fastening uplift test,
3. Electrical resistance and impedance test,
4. Fastening repeated load test,
5. Fastening longitudinal restraint test, and
6. Fastening lateral restraint test.

In addition, tests were conducted on assembled track sections. In the assembly test, ties of the two designs were supported on two ballast materials and subjected to repeated loads simulating train effects. A monoblock and a two-block tie were tested on trap rock ballast. Also, a monoblock and a two-block tie were tested on limestone ballast.

Results of tie tests indicated that strength of both pretensioned monoblock and post-tensioned two-block ties exceeded required values.

Results of fastening tests indicated that none of the fastening types met the requirement for longitudinal restraint test. However, the three fastening types performed satisfactorily in all other tests.

Results of tests on assembled track components indicated that strengths of both tie designs were adequate and were not influenced by repeated loads. In addition, test results indicated the importance of ballast angularity and fractured surfaces to provide interlocking and stability. Also, test results revealed no visible degradation of limestone or trap rock ballast due to repeated loads. However, minor wear of tie bottom surface occurred during tests on trap rock ballast, but no significant wear occurred during tests on limestone ballast.

7. RECOMMENDATIONS

Based on results of the laboratory investigation, the following findings and recommendations are made:

1. Ties constructed in accordance with the preliminary specifications prepared in an earlier report(1) performed satisfactorily under test conditions. However, dimensions should be modified slightly to account for manufacturing tolerances. In addition, specifications should include performance requirements for rail fastenings for securing running rails and inserts for anchoring both the rail fastenings and traction power contact rail support bracket. Revised specifications are presented in a separate report(5).
2. In general, track components used in the laboratory tests peformed satisfactorily. However, it is necessary to verify the adequacy of the design and specifications by field tests. A measurement program to obtain data on the performance of standard tie designs and associated fastenings has been prepared and presented in a separate report(6).
3. Final specifications for standard transit concrete ties and fastenings should be prepared by revising the preliminary specifications based on field test results.

APPENDIX A - TRACK AND VEHICLE PARAMETERS

In previous work(1), a survey of information pertinent to the design of standard concrete ties was made. In this survey, ten transit properties in the U.S. and Canada provided information on track and rolling stock characteristics encountered in service under normal operations. This information was reviewed and discussed with representatives from several transit properties. As a result, design parameters acceptable to the transit industry were selected.

Track and vehicle parameters established with the consensus of participating transit properties were utilized in developing designs and flexural strength requirements for standard concrete ties. Vehicle and track parameters are listed in Tables A-1 and A-2, respectively. Flexural strength requirements for both monoblock and two-block ties are listed in Table A-3.

TABLE A-1 VEHICLE PARAMETERS

Car Weight (loaded)	136,000 lb max.
Wheel Load	17,000 lb max.
Car Length	75 ft max.
Truck Spacing	54 ft max.
Axle Spacing	6 ft min.

TABLE A-2 TRACK STRUCTURE PARAMETERS

Track Gage	4' - 8-1/2"
Rail Section	115 RE, CWR
Tie Spacing	30 in. max.
Location of Contact Rail	2'-2" max. from gage line
Tie Length	
Monoblock	8'-6"
Two-Block	8'-0"

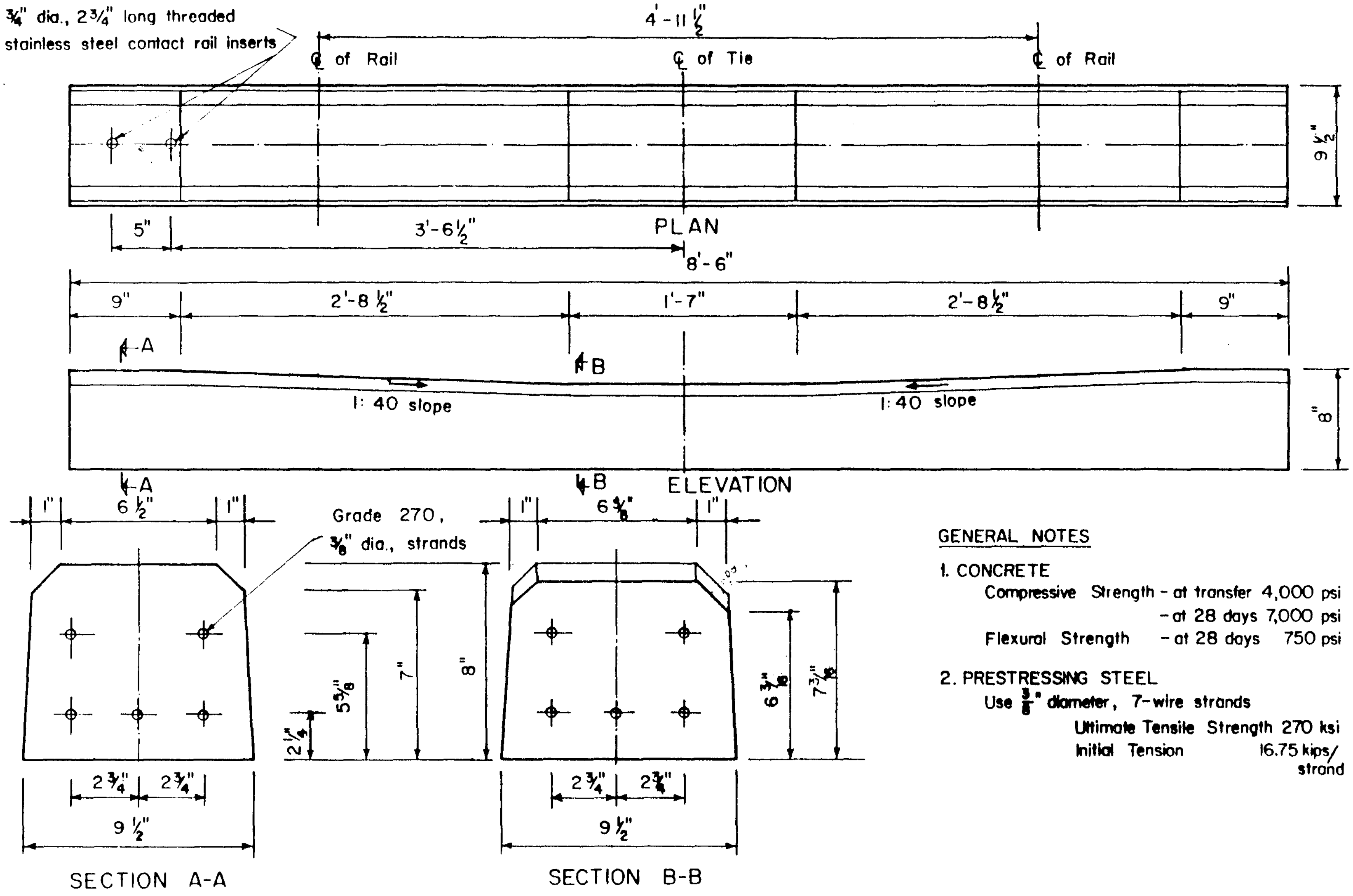
TABLE A-3 TIE FLEXURAL STRENGTH REQUIREMENTS*

Monoblock Tie	
Rail Seat Positive Moment	
Static	154 in.-kip
Dynamic	114 in.-kip
Tie Center Negative Moment	
Static	131 in.-kip
Dynamic	102 in.-kip
Two-Block Tie	
Rail Seat Positive Moment	
Static	137 in.-kip
Dynamic	96 in.-kip

*For no cracking

APPENDIX B - DETAILS OF PRESTRESSED CONCRETE TIES

Details of pretensioned monoblock and post-tensioned two-block concrete ties are shown in Figures B-1 and B-2, respectively.

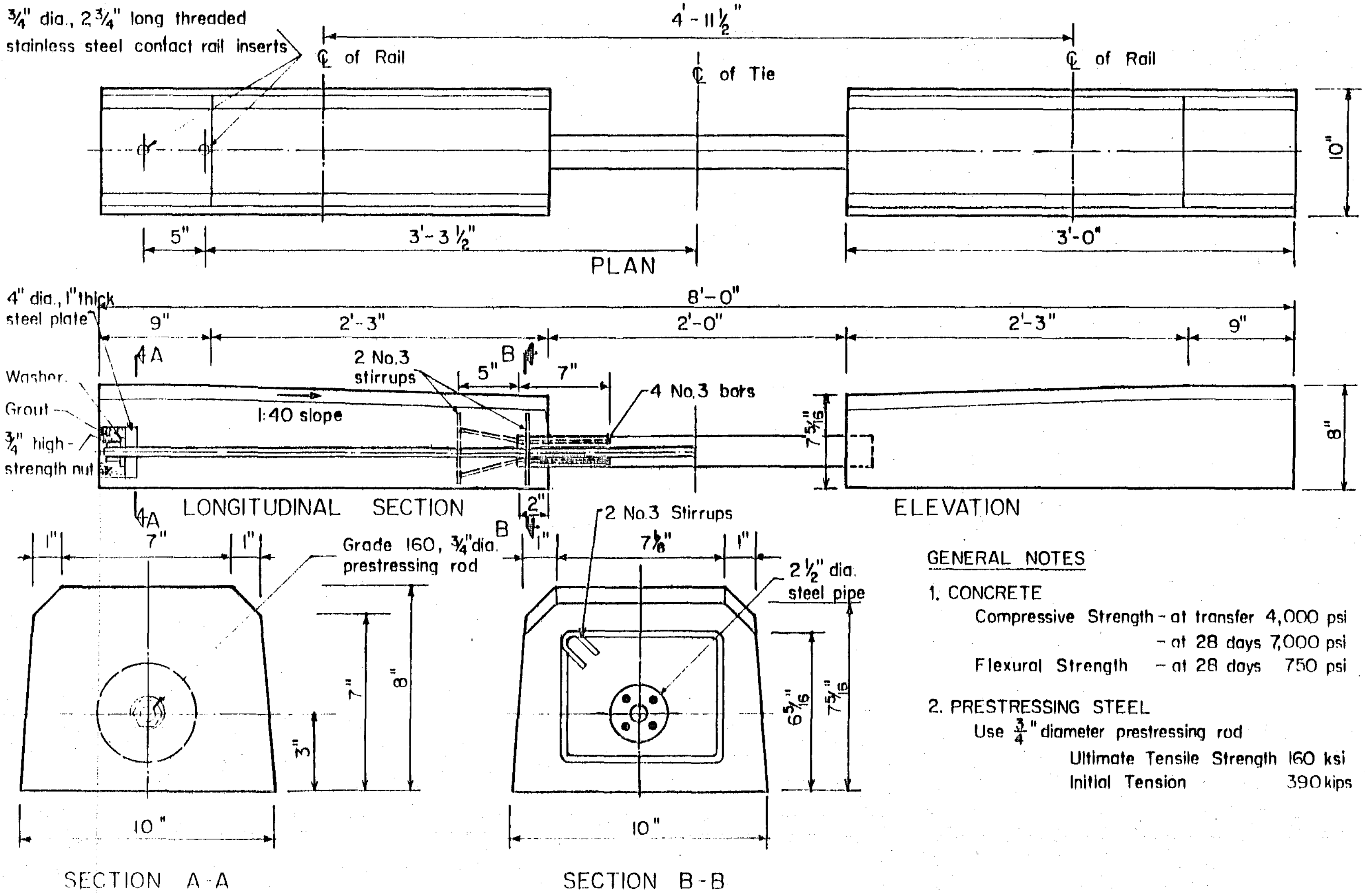


GENERAL NOTES

1. CONCRETE
   Compressive Strength - at transfer 4,000 psi
   - at 28 days 7,000 psi
   Flexural Strength - at 28 days 750 psi

2. PRESTRESSING STEEL
   Use ⅜" diameter, 7-wire strands
   Ultimate Tensile Strength 270 ksi
   Initial Tension 16.75 kips/strand

FIGURE B-1. DETAILS OF PRETENSIONED MONOBLOCK TIE



GENERAL NOTES

1. CONCRETE
   Compressive Strength - at transfer 4,000 psi
   - at 28 days 7,000 psi
   Flexural Strength - at 28 days 750 psi

2. PRESTRESSING STEEL
   Use $\frac{3}{4}$" diameter prestressing rod
   Ultimate Tensile Strength 160 ksi
   Initial Tension 390 kips

FIGURE B-2. DETAILS OF POST-TENSIONED TWO-BLOCK TIE

APPENDIX C - DETAILS OF RAIL FASTENING SYSTEMS

Details of rail fastening systems A, B, and C are shown in Figures C-1, C-2, and C-3, respectively.

Fastening Type A is known as "Pandrol Fastening" and was supplied for test purposes by Pandrol Inc. of New Jersey.

Fastening Type B is known as "CS 5 Fastening" and was supplied for test purposes by TREC Tempered Railway Equipment Company of Sheffield, England.

Fastening Type C is known as "DE Fastening" and was supplied for test purposes by Unit D.E., Inc. of Illinois.

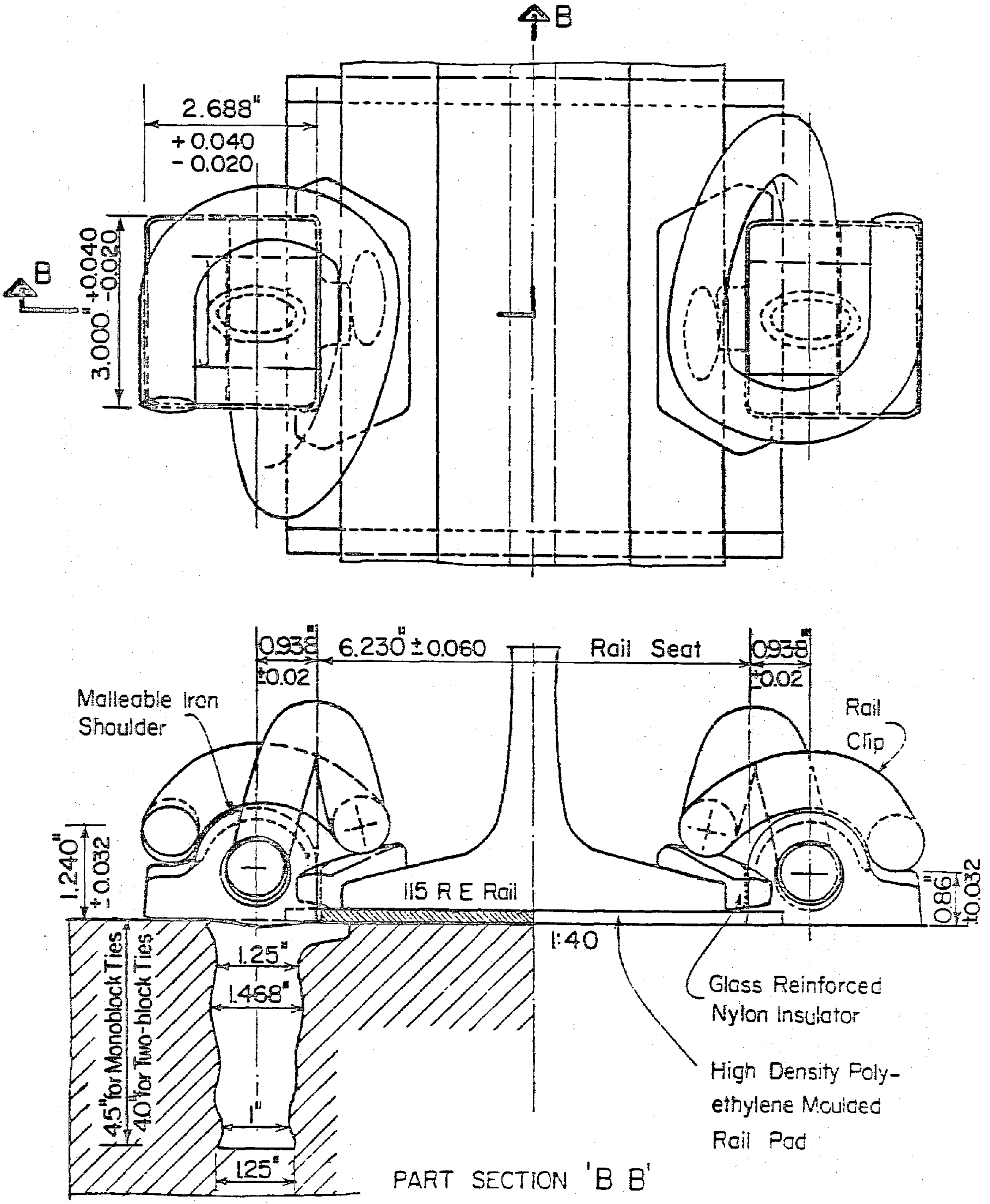
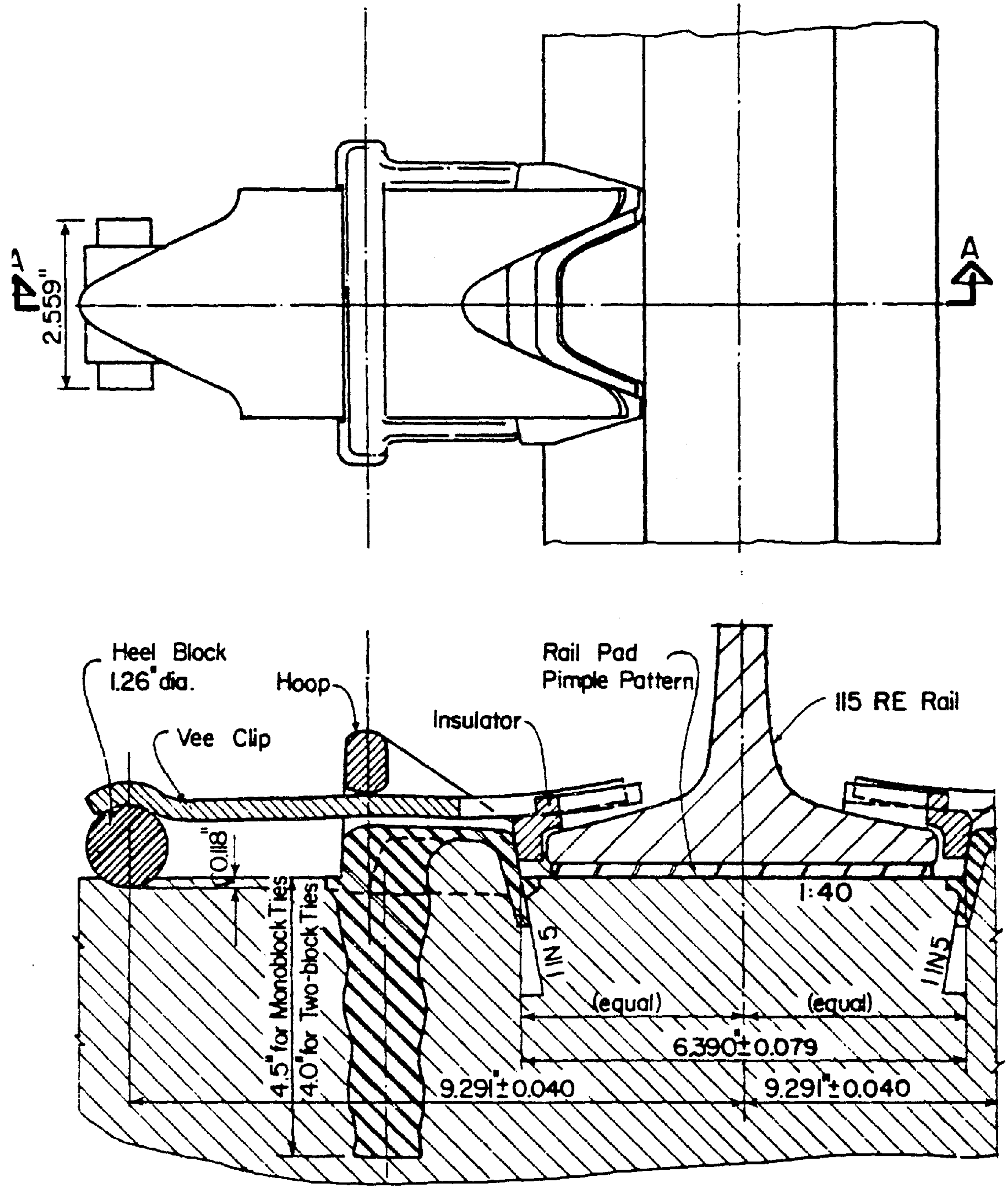


FIGURE C-1. DETAILS OF FASTENING TYPE A



SECTION 'A A'

FIGURE C-2. DETAILS OF FASTENING TYPE B

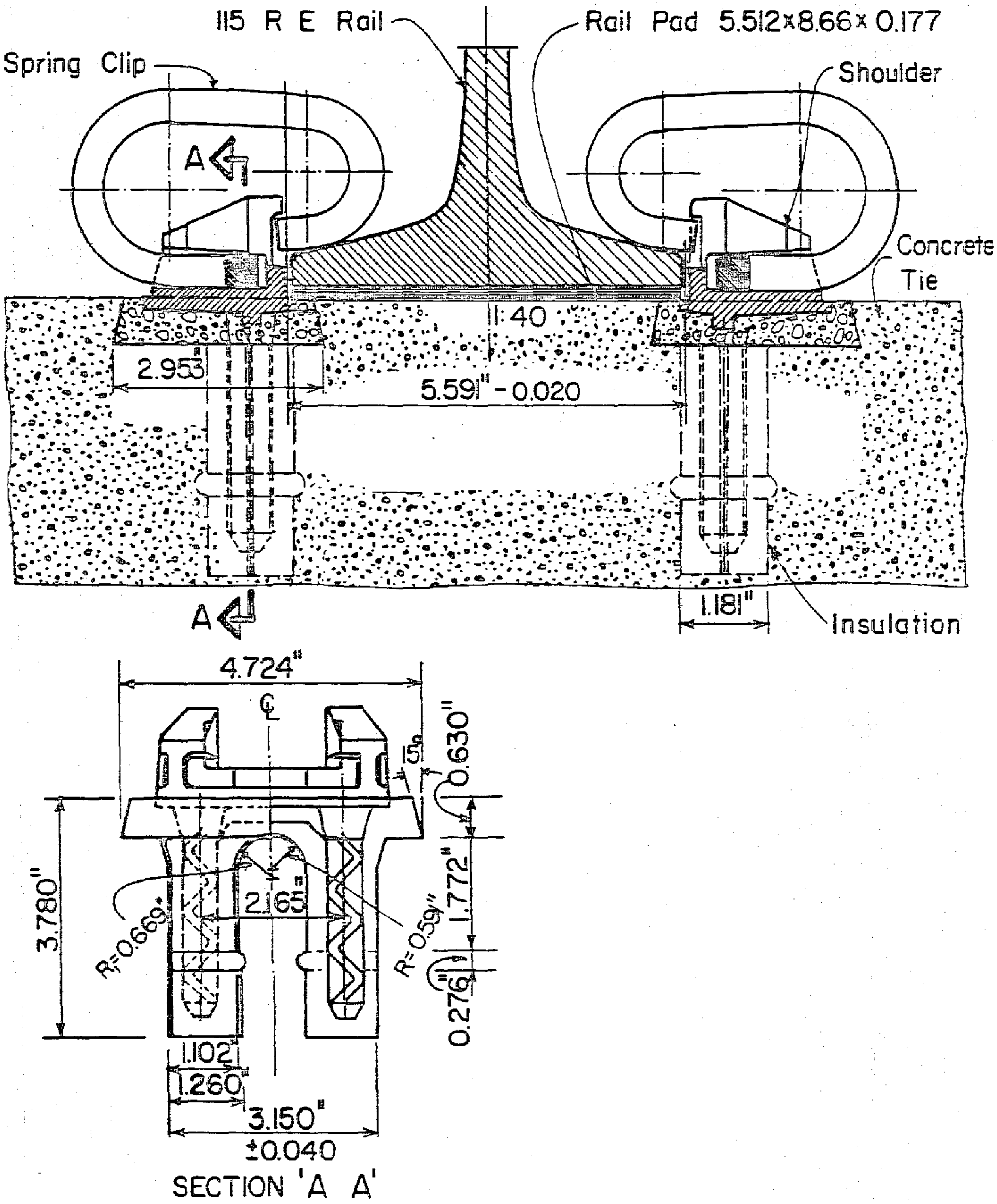


FIGURE C-3. DETAILS OF FASTENING TYPE C

APPENDIX D - REPORT OF NEW TECHNOLOGY

This report describes laboratory methods for tie fabrication and presents results of tests on ties and fastenings. A careful review of the work performed under this contract indicates that no discoveries or inventions have been made. However, the work provided useful information on the performance of ties and fastenings under test conditions. This information will be used in the development of a nationally acceptable standard or recommended practice for rapid transit concrete ties and fastenings.

REFERENCES

1. Hanna, A.N. and Weber, J.W., "Development of Standard Specifications for Concrete Ties for Rapid Transit," Report to Transit Development Corporation, Inc., October 1975, Publication #PB-247-676, National Technical Information Service, Springfield, Virginia.

2. "Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products," Publication PCI-MNL 116-70, Prestressed Concrete Institute, Chicago, Illinois.

3. "Building Code Requirements for Reinforced Concrete," ACI 318-77, American Concrete Institute, Detroit, Michigan.

4. "Recommended Practice for Selecting Proportions for No-Slump Concrete," ACI 211.3, American Concrete Institute, Detroit, Michigan.

5. Hanna, A.N., "Preliminary Specifications for Standard Concrete Ties and Fastenings for Transit Track," Report No. UMTA-MA-06-0100-79-3 prepared for U.S. Department of Transportation, March 1979.

6. Hanna, A.N., "Measurement Program for Evaluation of Concrete Ties and Fastenings in Transit Track," Report No. UMTA-MA-06-0100-79-2 prepared for U.S. Department of Transportation, March 1979.