State-of-the-Art Report on

Prestressed Concrete Ties for North American Railroads

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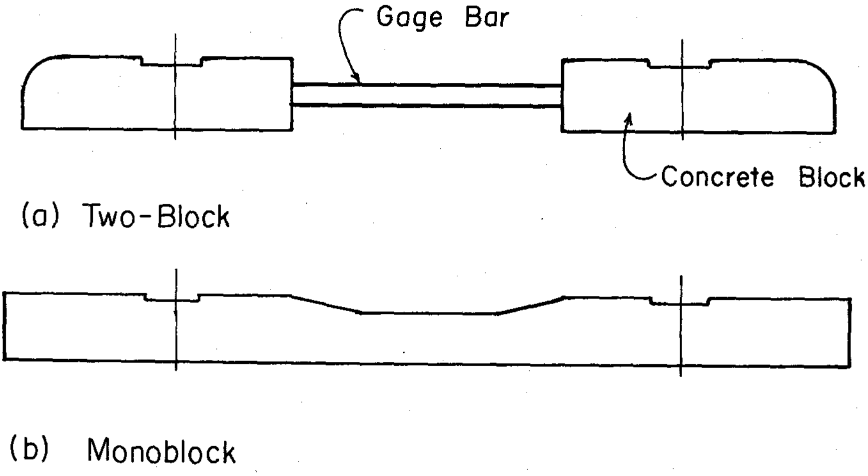


Fig. 1 Types of concrete ties.

In most countries of the world, there is a growing interest in the use of concrete ties.

The interest is justified by greater consistency in product quality that can be achieved by the use of prestressed concrete, and inherent suitability of concrete ties for use with continuously welded rails.

Experience to date indicates that use of concrete ties is desirable for reasons of economy as well as for the superior structural properties that add considerably to the overall stability and performance of the track structure.

Performance of concrete ties in track is influenced greatly by the functioning of both the rail fastening system and the ballast section. Therefore, rails, ties, fastenings, and ballast should all be considered integral parts of the track structure.

Synopsis

The extensive use of prestressed concrete ties by railroads all over the world indicates that the concrete tie has become an important constituent of the modern railway track structure. Pretensioned concrete ties account for about 80 percent of the world's annual prestressed concrete tie production.

Methods of pretensioned concrete tie fabrication, material requirements, and design considerations are presented. Requirements for rail fastening systems and ballast materials are outlined. Methods for laboratory testing of ties and fastenings, and field performance of concrete tie track in the United States are discussed. Finally, advantages of concrete ties are summarized.

The growing interest in North America in the use of concrete ties is justified by the greater consistency in product quality, suitability of concrete ties for use with continuously welded rails, expected long service life, and reduced maintenance requirements.

With more than 100 million pretensioned concrete ties already in service, experience shows that the precast prestressed tie is functional, performs well structurally, and is durable and economical.

The Concrete Tie

The first concrete ties were designed in France by Monier in 1884. In the United States, the first recorded use of concrete ties was in 1893 when 200 were installed by the Reading Company in Germantown, Pennsylvania.[1]

Since that time, several types of concrete ties have been developed and used in track systems. These types include prestressed monoblock, prestressed two-block, reinforced two-block, and longitudinal concrete ties. Fig. 1 illustrates general configurations of two-block and monoblock concrete ties.

The prestressed monoblock concrete tie is today the most widely used type. It is estimated that more than

Table 1. Recent Prestressed Concrete Tie Installation in North America.

User	Installation Year	Location	Number of Ties*	Fastening Type†	Remarks
St. Louis-San Francisco Railway (Frisco)	1967	Keysville, Mo.	40,000	T	Largest concrete tie installation at that time, excludes ties on curves that were removed
Kansas City Southern Railway Company	1967-1977	Various locations	244,332	T	Interspersed with wood ties
	1979	Various locations	8,000	T	Scheduled for installation
Atchison, Topeka and Santa Fe Railway Company	1974	Streator, Ill.	400	U	
Black Mesa & Lake Powell Railroad	1972	Page, Ariz.	130,000	T	Excludes ties on curves that were removed
Florida East Coast Railway Company	1966-1978		595,285	T	
	1979		>60,000	T	Scheduled for installation
The Alaska Railroad	1973	100 miles north of Anchorage, Ala.	200	T	Adjustable fastening system
The Chessie System	1974	Lorraine, Va.	224	U	
	1979	Sand Patch, Pa.	5,140	U	Scheduled for installation
	1979	Shelby, Ky.	10,000	U	Scheduled for installation
Norfolk & Western	1974	Kumis, Va.	802	U	
Facility for Accelerated Service Testing (U.S. Department of Transportation)	1976	Near Pueblo, Colo.	2,788	U	
		Near Pueblo, Colo.	98	T	
National Railroad Passenger Corporation (Amtrak)	1978	Northeast Corridor	109,104	U	
	1979-1981	Northeast Corridor	990,896	U	Scheduled for installation
Canadian National Railway	1965-1967	Two Locations	950	U	
	1966	Dundas Subdivision, Ont.	475	U	Post-tensioned two-block
	1972	27 miles (43 km) west of Jasper, Alta.	9,955	U	
	1974-1975	Various Locations	52,666	U	First major concrete tie installation in Canada

Table 1. (cont.). Recent Prestressed Concrete Tie Installation in North America.

User	Installation Year	Location	Number of Ties*	Fastening Type†	Remarks
Canadian National Railway	1976	Various Locations	113,717	U	
	1977	Various Locations	159,667	U	
	1978	Various Locations	291,576	U	
	1979	Various Locations	304,619	U	Scheduled for installation
	1980-1982	Various Locations	900,000	U	Scheduled for installation
Canadian Pacific Railway	1974	Beavermouth, B.C.	1,300	U	
	1979	Northern Ontario	1,000	U	Scheduled for installation

*All ties are pretensioned monoblock unless otherwise is noted.
†T and U designate threaded and threadless type fastenings, respectively.

120 million concrete ties were laid in tracks of railroads all over the world prior to 1972. Of these, more than 100 million ties were prestressed monoblock ties.[2] Pretensioned concrete ties account for more than 70 percent of this number. Also, it is estimated that of the 15 million prestressed concrete ties produced annually all over the world, 12 million are pretensioned.[2]

The first use of prestressed concrete ties on American railroads was in 1960, when 500 were installed on the Atlantic Coast Line Railroad and 600 on the Seaboard Air Line Railroad. Since that time, over 100 concrete tie track installations were built. These ranged from several ties on ballasted bridges or grade crossings to thousands of ties on mainline track.

The first major use of prestressed concrete ties in the United States was in 1966, when 74,000 were installed on the Florida East Coast Railway.[3] Recent concrete tie installations on mainline track in North America are summarized in Table 1.

Methods of Fabrication

As with other prestressed concrete products, ties may be either pretensioned or post-tensioned.

For pretensioned concrete ties, prestressing is accomplished by tensioning rods, strands, or wires prior to placing concrete in the forms. After the concrete has reached a specified strength, the prestressing force is released and transmitted to the concrete by bond.

For post-tensioned concrete ties, prestressing is accomplished by high strength rods that are appropriately coated or encased in conduits to prevent bond with the concrete. The prestressing force is applied after the concrete has reached a specified strength. This force is transmitted to the concrete by end bearing.

Pretensioned concrete ties have generally been used in North America. Therefore, only pretensioned concrete ties will be discussed in this paper.

Pretensioned concrete ties are manufactured by one of three methods. These are the long-line, stress-bench, and individual form methods.

• **Long-Line Method**—In the long-line method, several forms are set end to end on a prestressing bed. Pretensioning tendons, common to all forms, are stressed between two

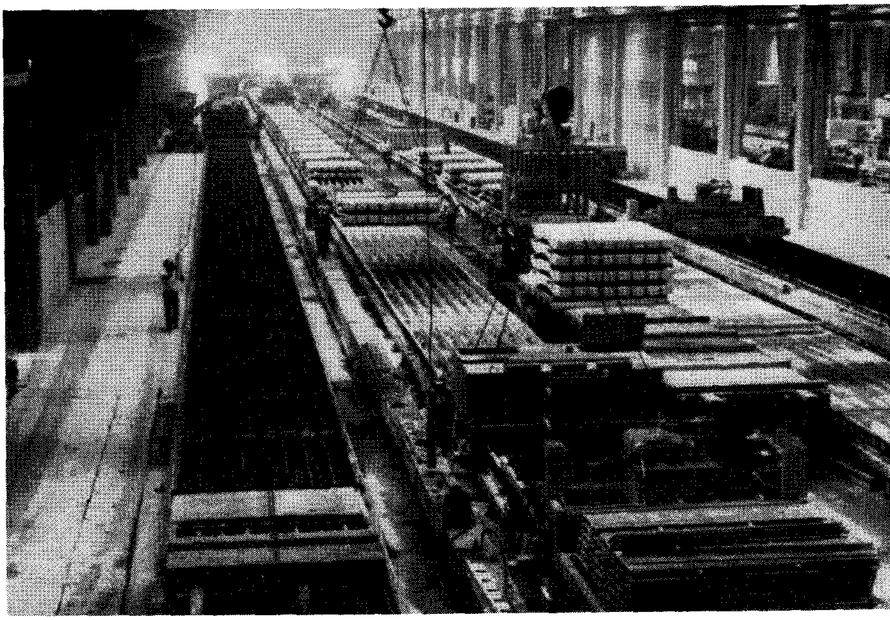


Fig. 2. Tie fabrication by the long-line method.

abutments located at the ends of the bed. After placement of fastening and other inserts, the tendons are tensioned. Then concrete is placed in the forms, vibrated, and cured.

After the concrete has reached a specified strength, the prestressing force is transferred to the ties by detensioning the tendons. In this method, the turn-around time of the forms is within a 24-hour cycle. Fig. 2 shows 600-ft (183 m) long production lines for tie fabrication by the long-line method.

Another configuration of the long-line method utilizes a fixed concreting plant. In this system, forms are placed two at a time in the middle of the prestressing bed. After the concrete is placed and vibrated, the forms are slid with their contents towards the end of the bed where the concrete is vibrated for a second time.

- **Stress-Bench Method**—The stress-bench method utilizes mobile benches made of structural steel. Each bench accommodates forms of four or five ties in the longitudinal direction. The benches are operated mechanically and can be moved in both the longitudinal and transverse directions. This permits production operations such as preparation and tensioning of tendons, placement and vibration of concrete, or curing to be performed at different working locations.

- **Individual Form Method**—The prestressing tendons are tensioned against the forms in the individual form method. Therefore, forms must be strong to resist the pretensioning forces. As with other methods, the prestressing force is transferred to the tie after the concrete has reached a specified strength.

Each fabrication method has inherent advantages and disadvantages. For example, the long-line method requires a large number of forms and consequently large capital investment.

The individual form and stress-bench methods achieve high form utilization with relatively less capital. However, fewer man-hours are required to produce a concrete tie by the long-line method than by the other methods. In addition, it is generally agreed that the long-line method provides better uniformity in tie quality. The long-line method is used in most tie plants in North America.

Materials

Concrete and prestressing tendons are the principal materials in concrete ties.

Concrete—Use of high strength concrete is necessary for the production of prestressed concrete ties for the following reasons:

1. High compressive strength at an early age permits transfer of the prestressing force to the concrete early and results in better form utilization.
2. Prestress losses are reduced.
3. High flexural strength improves resistance to cracking under service loads.

In the United States, a minimum compressive strength of 7000 psi (48.3 MPa) at 28 days has been generally specified.[4,5,6,7] In Canada, however, a minimum compressive strength of 6000 psi (41.4 MPa) at 28 days has been used. A minimum compressive strength of 4000 psi (27.6 MPa) at transfer has been considered satisfactory.[6] Also, a minimum 28-day flexural strength of 750 psi (5.2 MPa) has been proposed.[6,7]

To obtain these strength levels and improve freeze-thaw durability, the following guidelines have been used:

1. Maximum size of coarse aggregate should not exceed ¾ in. (19 mm).
2. Cement content should not be less than 650 lb/cu yd (386 kg/m^3).
3. Water-cement ratio should be kept at a minimum, not to exceed 0.40 by weight. This is accomplished by the use of water-reducing admixtures.
4. Curing should be accomplished by low-pressure steam, radiant heat and moisture, or similar means to accelerate strength gain.
5. Proper consolidation of the concrete should be accomplished by vibration.
6. Air-entraining admixtures should be used to improve freeze-thaw durability, where environmental and other factors make it necessary.

Prestressing Tendons—High strength prestressing tendons are generally used in pretensioned concrete ties. Tendons should be selected to insure adequate bond with the concrete, to reduce bond transfer length and thus produce maximum prestress at the rail seat region, and also to reduce prestress losses. To accomplish these goals, the following guidelines have been used:

1. Tendons should be stress-relieved wires or strands with a strength of 225 ksi (1552 MPa) or more.
2. The nominal diameter of the tendon should not exceed ⅜ in. (9.5 mm).
3. Tendons should consist of indented wires or indented wire strands. Fig. 3 shows three types of indented tendons: 0.2-in. (5-mm) diameter wires, ¼-in. (6.4-mm) diameter 3-wire strands and ⅜-in. (9.5-mm) diameter 7-wire strands.

Production Operations and Control

When producing pretensioned concrete ties by the long-line method, the following operations are generally performed in sequence:

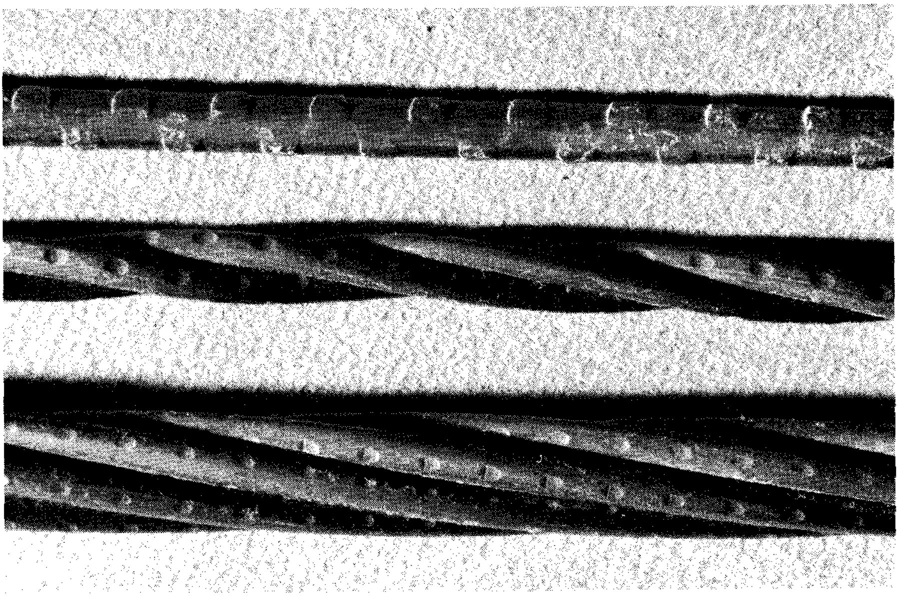


Fig. 3. Indented tendons for pretensioned concrete ties.

1. Cleaning and oiling of forms.
2. Positioning of fastening and other inserts.
3. Placement and tensioning of pretensioning tendons.
4. Placement and consolidation of concrete.
5. Surface screeding, if required.
6. Curing.
7. Tests to verify compressive strength.
8. Transfer of prestress by detensioning.
9. Separating of ties by sawing concrete and tendons, or tendons only if end gates are used between forms.
10. Lifting of ties from forms and storing of ties. Forms can be used again for Step 1.
11. Tie inspection and daily quality control testing.

Although the process for fabricating concrete ties is straight forward, adequate quality control should be maintained during each stage of manufacture to insure consistency in quality and performance. A proper quality assurance program generally addresses the following material properties, production operations, and tolerances:

1. Quality of concrete materials including aggregates, cement, water, and admixtures.
2. Quality of concrete including strength, durability, and workability.
3. Quality of prestressing tendons including strength and physical properties.
4. Form dimensions and location of fastening inserts.
5. Location of prestressing tendons.
6. Concrete proportioning and weigh-batching.
7. Mixing, placing, consolidation, and curing of concrete.
8. Application of prestressing force.
9. Detensioning of prestressing tendons.
10. Handling and storing of ties.

Design Considerations

The design of concrete ties is a complex problem because of variable loading conditions. However, design bending moments can be easily determined if loads imposed on the rail seats and ballast support reactions are known.

Rail seat loads depend on rolling stock characteristics, operating conditions, and track structure details. Ballast support reactions depend on tie configurations and spacing, ballast characteristics, and maintenance standards.

Based on extensive field measurements, simplified loading and support conditions have been developed by European railroads as a basis for tie design.[8] These conditions represent the variation in support conditions during tie life.

Rail Seat Load—Static and dynamic loads are transmitted to the tie at the rail seats. Static rail seat loads are determined from track analysis methods. Dynamic loads are accounted for by using an impact factor.

Extensive measurements by European railroads[9] have shown that dynamic stresses in railroad track depend on the condition of track and rolling stock, and speed of operation. A dynamic impact model has been developed to account for these factors.

For analysis of concrete ties, European railroads have used impact factors that reflect the most severe track conditions. A similar approach is used in the American Railway Engineering Association's Manual for Railway Engineering.[4]

Based on track analysis methods, the rail seat load, R, is given by the following equation:[10]

$$R = \frac{Pa}{2} \sqrt[4]{\frac{k}{4EI}} (1 + \alpha)$$

where

P = static wheel load

a = tie spacing, generally ranges from 20 to 27 in. (508 to 686 mm)

k = track modulus which is the load per unit length of the rail necessary to produce a rail deflection equal to unity, generally ranges from 4,000 to 20,000 lb/in./in. (28 to 138 kN/m/mm)

E = modulus of elasticity of rail steel

I = moment of inertia of rail cross section

α = impact factor, generally ranges from 0.5 to 1.5

The American Railway Engineering Association's Manual for Railway Engineering[11] recommends Cooper E72 loading with a 36,000-lb (160 kN) wheel load for the design of concrete structures on mainline track.

This load may be reduced for design of structures on branch lines and other locations where the loading is limited to the use of light equipment or cars only. However, for concrete ties, the American Railway Engineering Association's Manual for Railway Engineering[4] assumes a 41,000-lb (182 kN) wheel load to derive concrete tie performance requirements.

Ballast Support Reaction—Normally, ballast under a tie is tamped at each side under the rail with little tamping at midlength. As a result, the tie initially lacks support in its central portion as shown in Fig. 4a. However, as a result of repeated traffic loads, the tie support conditions change causing some pressure in the middle portion as shown in Fig. 4b or even along the total length of the tie as shown in Fig. 4c.

The ratio of pressure intensity at the tie center to that under the rail seats may be referred to as the center binding coefficient. This coefficient is

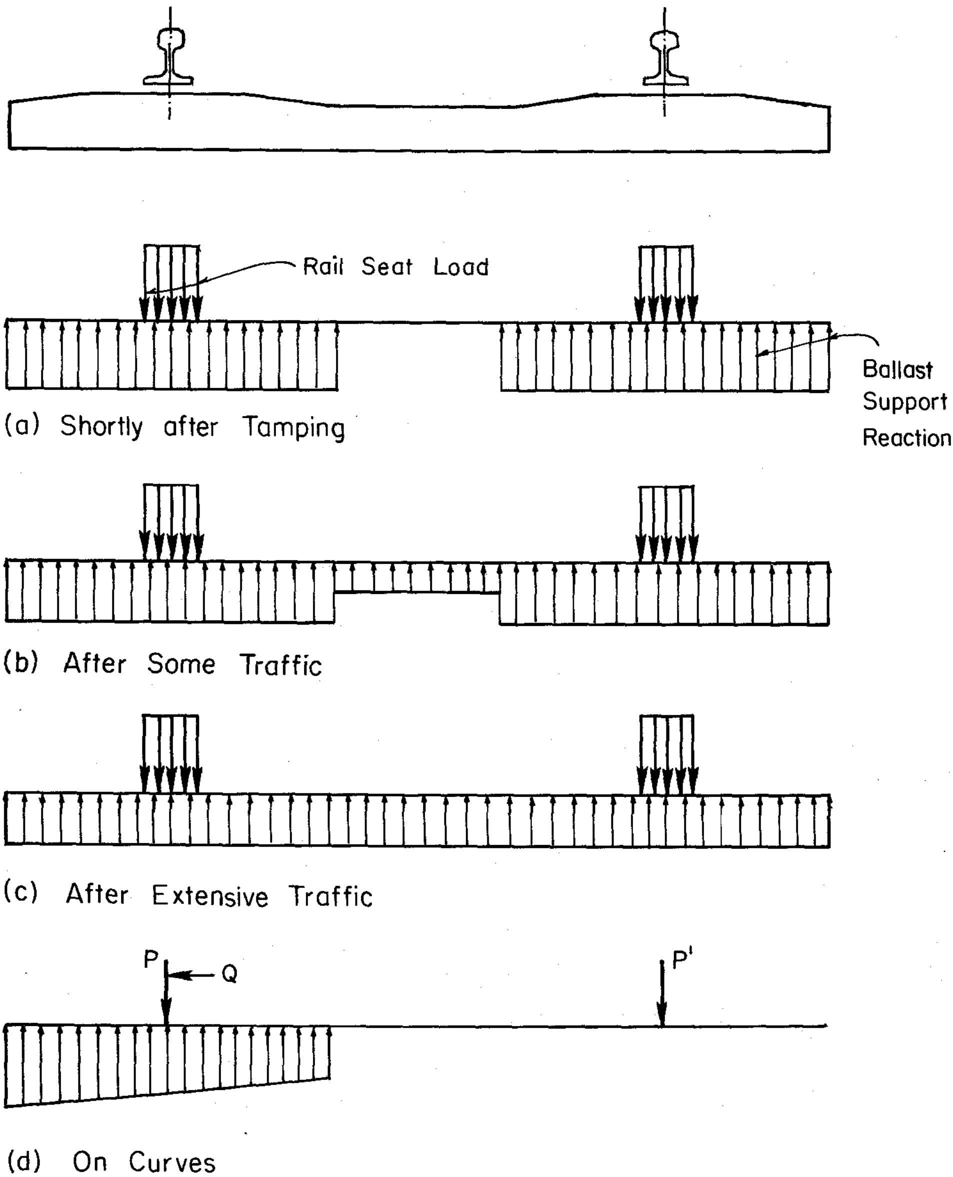


Fig. 4. Tie support reactions for various loading conditions.

large in areas where insufficient track maintenance is performed or where frost-heaving occurs. However, the center bound condition can be greatly reduced or even eliminated if proper maintenance is performed. Therefore, several railroads have considered a center-bound coefficient of 0.5 or less adequate for concrete tie design.[8]

To account for the most severe track conditions, the tie bending moment at the rail seats is calculated for a center-binding coefficient of zero while the bending moment at tie center is calculated for a center-binding coefficient of 0.5. In calculating tie bending moments, consideration should be given to load distribution through rail base and rail pad.

On curves, vertical and lateral forces are transmitted to the tie at the rail seats. Where lateral forces occur, the magnitude of vertical force is increased on the outer rail and reduced on the inner rail. Under this condition, tie support is similar to that shown in Fig. 4d.

Because of normally reduced speeds on curves, dynamic effects on curved track may be less than those for tangent track. As a result, bending moments for ties on curved tracks could be lower than for those on tangent track. Loading conditions used by some railroads[12] for concrete tie design confirm this assumption.

Selection of Tie Dimensions and Prestressing Tendons—In selecting tie dimensions, consideration should be given to proper selection of tie length and width. Tie length should be sufficient to assure development of the prestressing force by bond within the distance between the rail seat and tie end. Also, the tie bottom width should be sufficient to produce a ballast pressure within permissible limits.

It should be recognized that under critical loading conditions, tensile stresses occur on the bottom surface at rail seats and on the top surface at the tie center. Therefore, a shallower section at the tie center than that at rail seats permits locating the prestressing force towards the tensile surface at both locations and thus reduces tensile stresses in the concrete.

Also, consideration should be given to the proper selection of diameter and surface treatment of prestressing tendons. Tendons should provide short transfer lengths to insure adequate resistance to bond failure and slip. This can be accomplished by roughening tendons without reducing the strength below that needed and by using small diameter tendons.[13,14,15]

It should be recognized that tie strength depends on dimensions as well as on magnitude and location of prestressing force. Therefore, a trade-off is required to obtain optimum dimensions, and amount and location of tendons. Fig. 5 illustrates a general configuration and ranges of dimensions for prestressed concrete ties.*

Material Properties—Use of high strength concrete and tendons is required for production of prestressed concrete ties. Thus, prestress losses are reduced and resistance to cracking under service loads is increased.

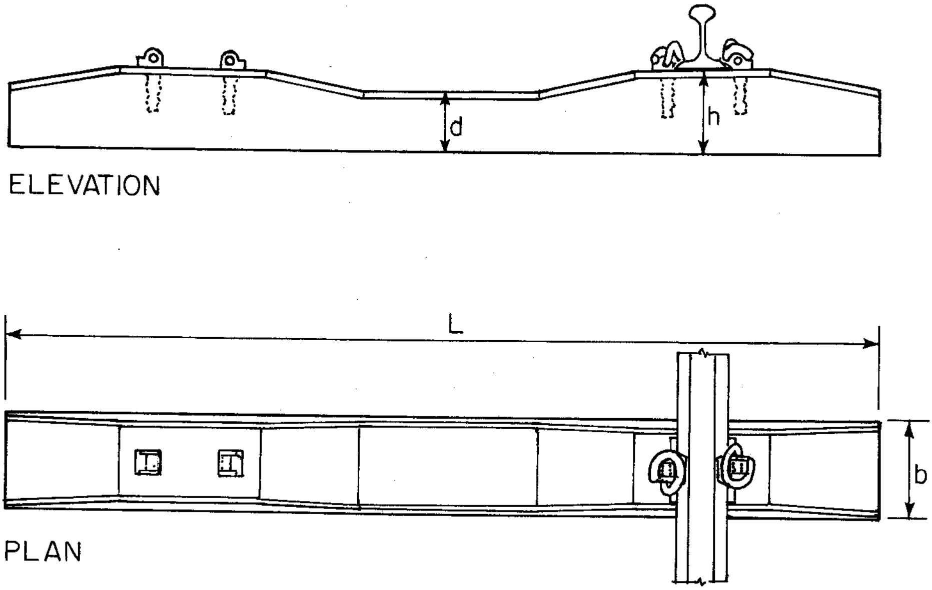
No nationally acceptable standard or recommended practice has yet been developed for material properties. However, material properties specified in the American Railway Engineering Association's Manual for Railway Engineering[4] have been adopted for recent concrete tie procurements.[5]

These recommendations cover compressive strength requirements for concrete, but do not address the flexural strength of the concrete or tendon strength. Table 2 lists these compressive strength values. In addition, concrete flexural strength and tendon tensile strength values generally used for prestressed concrete tie production are listed in Table 2.

Design Criteria—In developing tie designs, permissible stresses specified in applicable codes and standards should not be exceeded. This generally requires an evaluation of concrete stresses for two conditions:

1. Immediately after prestress transfer, and

*In Canada, ties with dimensions smaller than those shown in Fig. 5 have been used.



L 8'-3" to 9'-0" (2.515 to 2.743 m)

b 10½ to 12" (267 to 305 mm)

h 9 to 10" (229 to 254 mm)

d 6 to 7½" (152 to 191 mm)

Prestressing force
110 to 150 kips (489 to 667 kN)

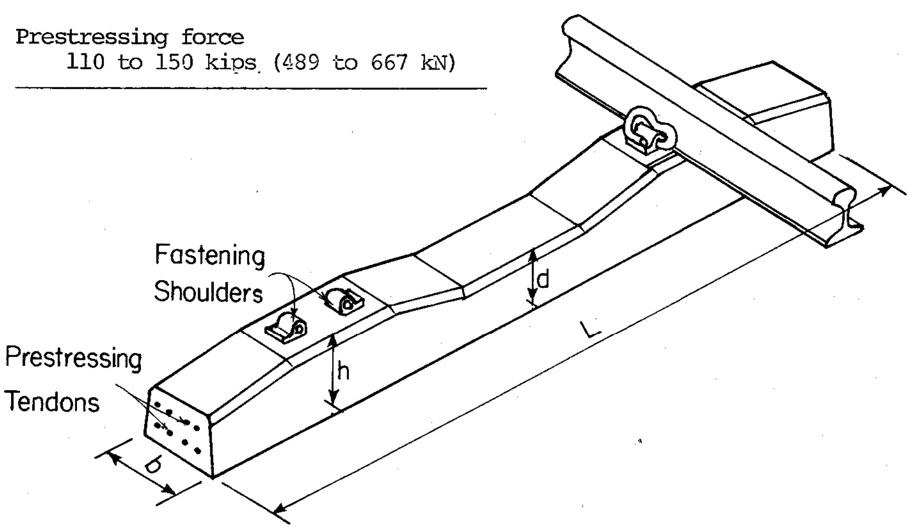


Fig. 5. Tie configuration and typical dimensions.

Table 2. Material Properties.

Concrete	Properties
Coarse aggregate	¾ in. (19 mm) maximum size
Cement content	650 lb/cu yd (386 kg/m^3) minimum
Water-cement ratio	0.40 by weight maximum
Air entrainment	Where environmental factors make its use necessary
Compressive strength at 28 days[4-7]	7000 psi (48.3 MPa) minimum
Compressive strength at transfer[6]	4000 psi (27.6 MPa) minimum
Flexural strength at 28 days[6,7]	750 psi (5.2 MPa) minimum
Tendons	
Tensile strength	225 ksi (1552 MPa) minimum
Nominal diameter	⅜ in. (9.5 mm) maximum

2. At service loads.

In estimating concrete stresses immediately after transfer, consideration is given to short-term prestress losses caused by elastic shortening and other factors.

In calculating concrete stresses at service loads, instantaneous and time-dependent prestress losses are considered. These include losses caused by the following factors:

1. Slip at anchorages.
2. Elastic shortening.
3. Creep of concrete.
4. Shrinkage of concrete.
5. Relaxation of steel.

In addition, steel stresses immediately after transfer should not exceed those specified in applicable codes and standards.

Because a concrete tie is subjected to tens of millions of load repetitions during its service life, development of cracks in the tie should be minimized.[12,16] Thus, occurrences of bond failure and tendon fatigue will be reduced[17] and long life can be achieved under fatigue loads.

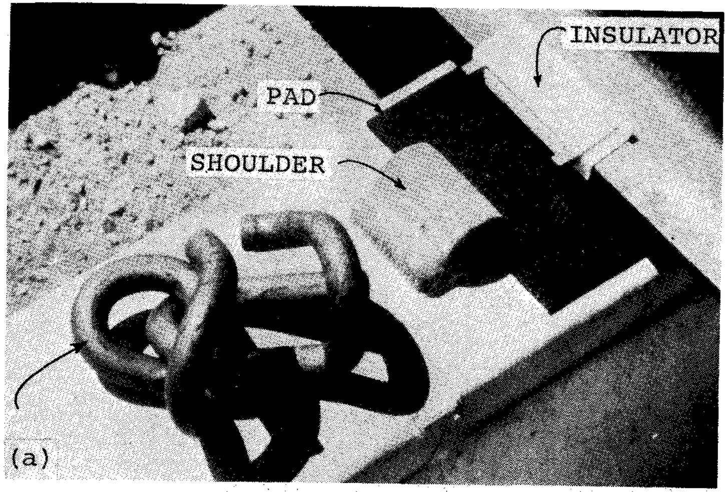
Therefore, a tie design based on the prevention of cracks under normal service conditions after consideration of concrete fatigue[18] is required for good performance and long life.

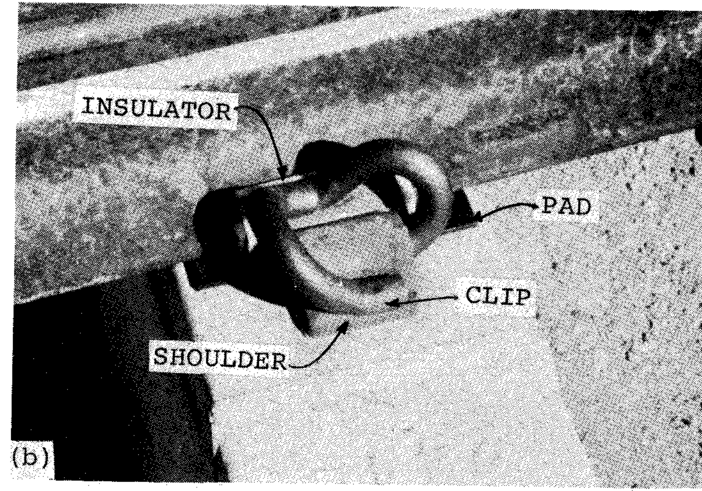
The American Railway Engineering Association's Manual for Railway Engineering states this requirement as follows:[4]

> In order to give satisfactory service a prestressed monoblock concrete tie should be capable of withstanding without cracking the maximum loads likely to be found in service.

Rail Fastening Systems

In concrete tie track, the rail fastening system has four primary functions. It maintains gage and alignment, restrains longitudinal rail movements, provides resilience, and assures electrical insulation. To provide these functions during their service life, rail fastenings should be capable of withstanding repeated traffic





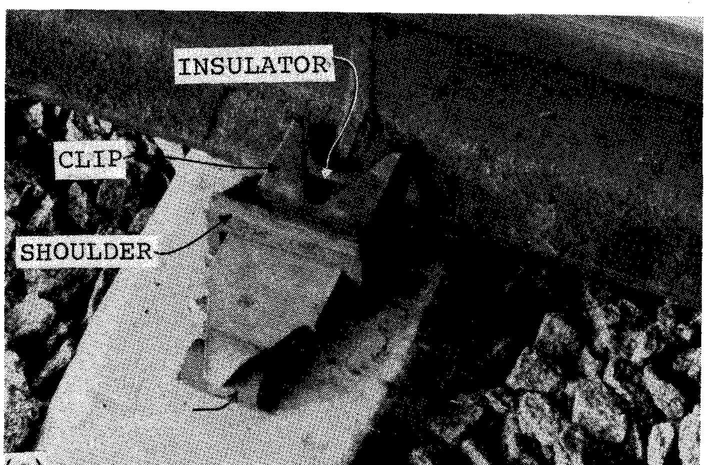
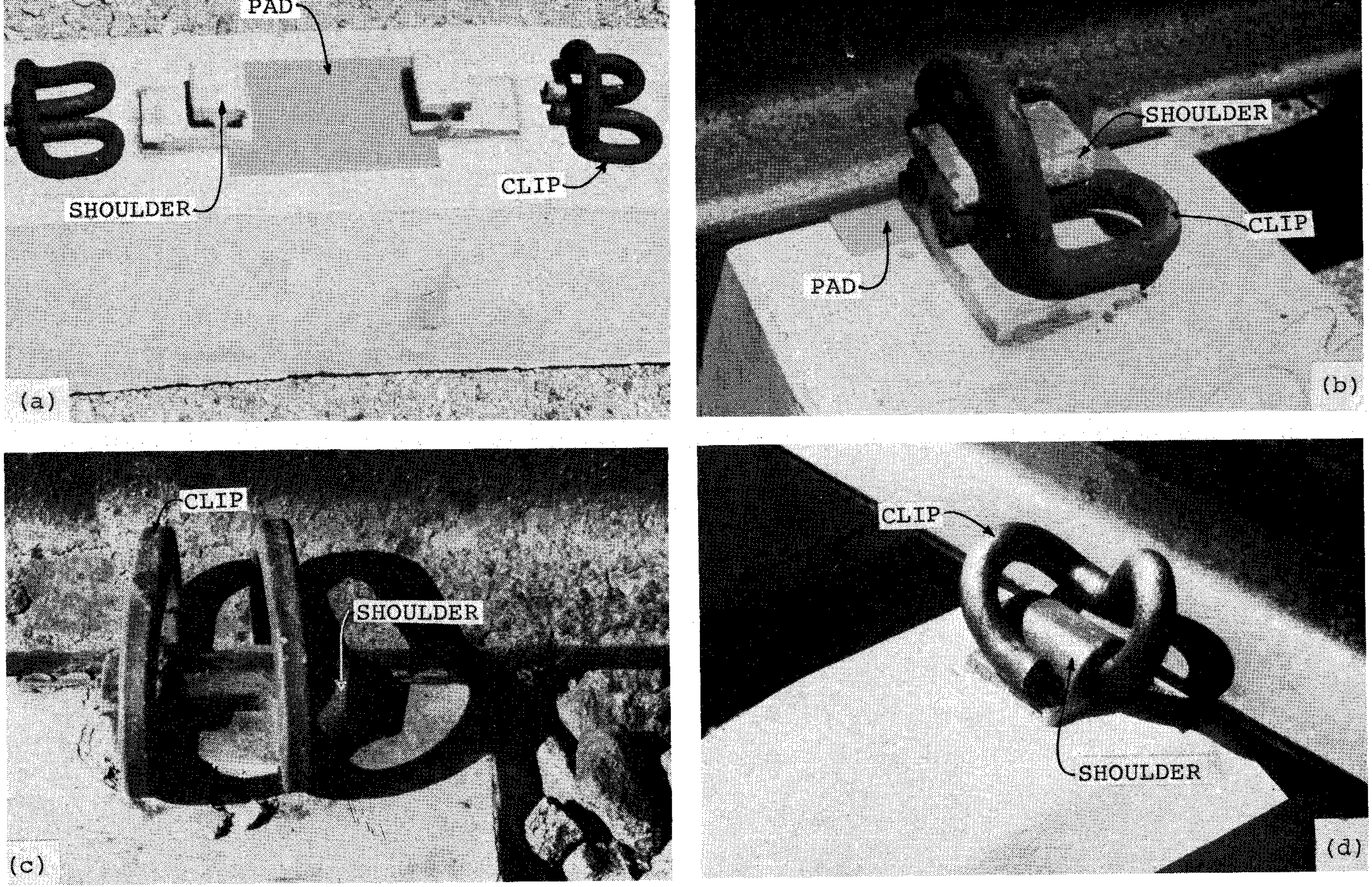


Fig. 6 a through c (above and left). Threadless flexible type fasteners with insulators.

Fig. 7 a through d (below). Threadless flexible type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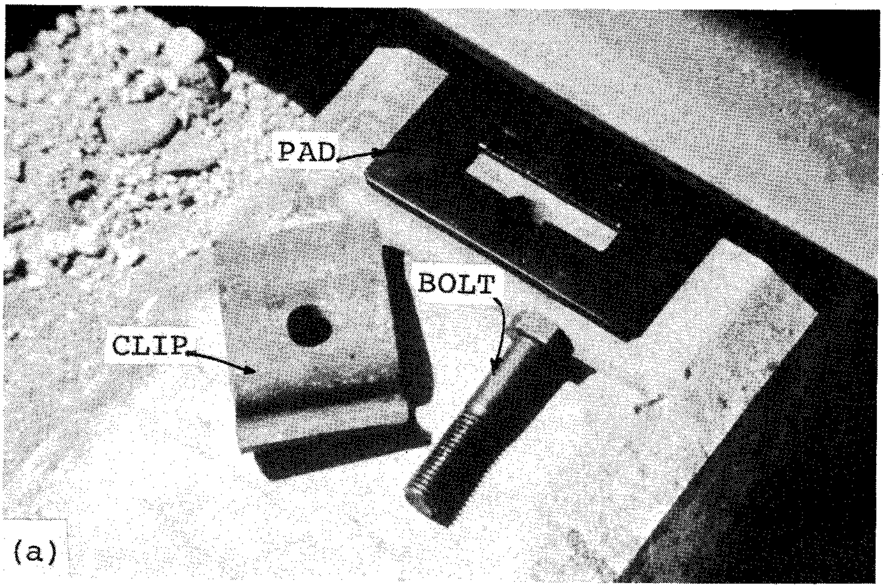

Fig. 8 a and b (above and below). Fastener with bolts and spring clips.

loads and environmental effects without deterioration or damage.

Concrete ties often use threadless flexible-type fasteners. This fastener type consists of four components:

1. Two inserts or fastening shoulders cast into the tie during manufacture. These inserts provide means for anchoring the clips to the tie.
2. A tie pad placed under the rail to provide resilience and insulation.
3. Two spring clips placed between the inserts and the rail to restrain rail movements.
4. Two insulators placed between each clip and the rail to provide electrical insulation.

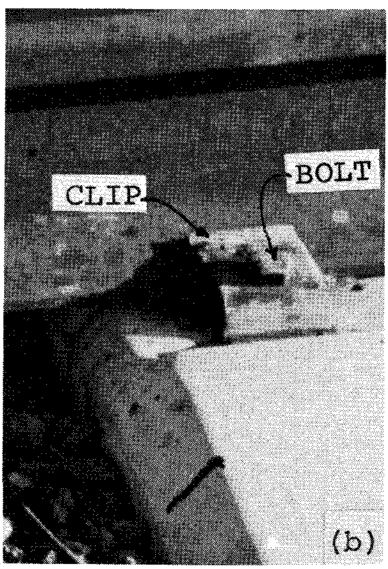

Fig. 6a shows the different components of one type of threadless fastening. Fig. 6b shows the assembled fastener. Fig. 6c shows a second type of threadless fasteners.

Other designs of threadless, elastic-type fasteners utilize a coating on the inserts to provide electrical insulation. This eliminates the need for insulators placed between the clips and the rail. The different components of one of these fastening types is

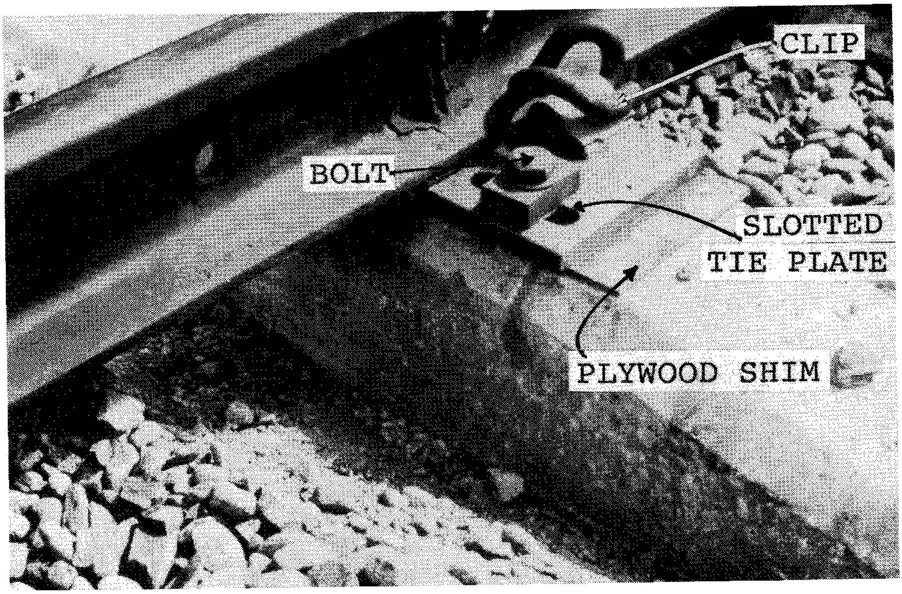

Fig. 9. Fastener with rail adjustment capabilities.

shown in Fig. 7a. The assembled fastener is shown in Fig. 7b. Two other types of threadless fasteners that rely on insert insulation rather than external insulators are shown in Figs. 7c and 7d.

Other types of fastening systems utilize spring clips fastened with bolts that screw into inserts embedded in the tie. Fig. 8a shows the components of one of these fastening types. The assembled fastening is shown in Fig. 8b.

Another fastening type capable of providing vertical and lateral rail adjustment is shown in Fig. 9. This fastening consists of a slotted tie plate with built-in shoulders for spring clips. To hold the tie plate in place, anchor bolts screw into inserts embedded in the tie. Vertical adjustment is accomplished by loosening the bolts and inserting wood shims between the tie and the tie plate. Lateral adjustment is accomplished by loosening the bolts and displacing the tie plate.

Ballast Materials

In recent years, field tests were conducted on several designs of concrete ties installed on different types of ballast materials. These tests concluded that ballast properties should be considered in the design of the track structure.[19]

Ballast must provide adequate supporting strength and resistance to vertical, lateral, and longitudinal loads imposed on track. It must also provide resilience, stability, and drainage capabilities. Therefore, ballast material must perform in track in such a manner that particle degradation, if it occurs, does not restrict drainage or induce undesirable changes in basic loading patterns of the ballast section.

There are many physical and chemical properties that determine qualities of a suitable ballast material. However, the preferred ballast material should be clean and graded crushed stone aggregate and/or pro-

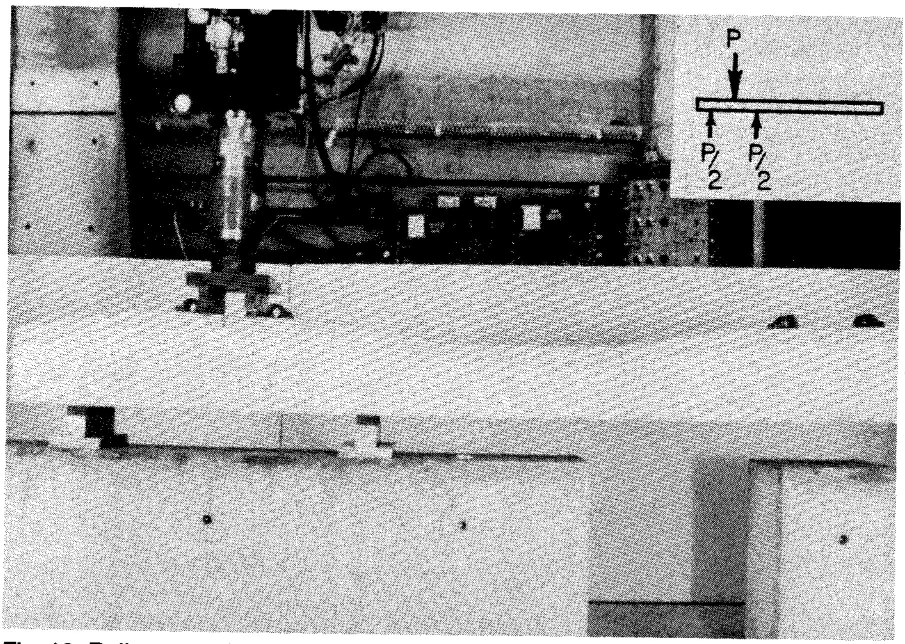

Fig. 10. Rail seat positive moment test.

cessed slag that provides the following qualities:

1. Hard, dense, angular particles with sharp corners and cubical fragments to provide good drainage and particle interlock.
2. High wear and abrasive qualities to withstand impacts of traffic loads without excessive degradation.
3. Minimum longitudinal fragments to enable better consolidation.
4. High resistance to temperature changes and chemical attack, high electrical resistance, and low absorption.
5. Free of cementing properties that will cause small particles to cement together and reduce drainage capabilities, and provide undesirable distribution of track loads.

These prime qualities of a ballast material provide the maximum stability in the ballast section and reduce permanent deformations in track structure and thus assure proper functioning and performance of concrete ties in track.

In addition to the need for a good quality ballast for concrete tie track, the subgrade should provide adequate strength and stability. Excess subgrade moisture contributes to fouling and degradation of ballast. Therefore, provisions should be made for adequate subgrade drainage. Also, stabilizing processes may be used to strengthen poor subgrades.

Laboratory Testing

To assure the ability of ties and fastenings to provide their intended functions, specifications set forth minimum performance requirements. Compliance of ties and fastenings with specification requirements is evaluated by laboratory tests. Details of selected tests are outlined.

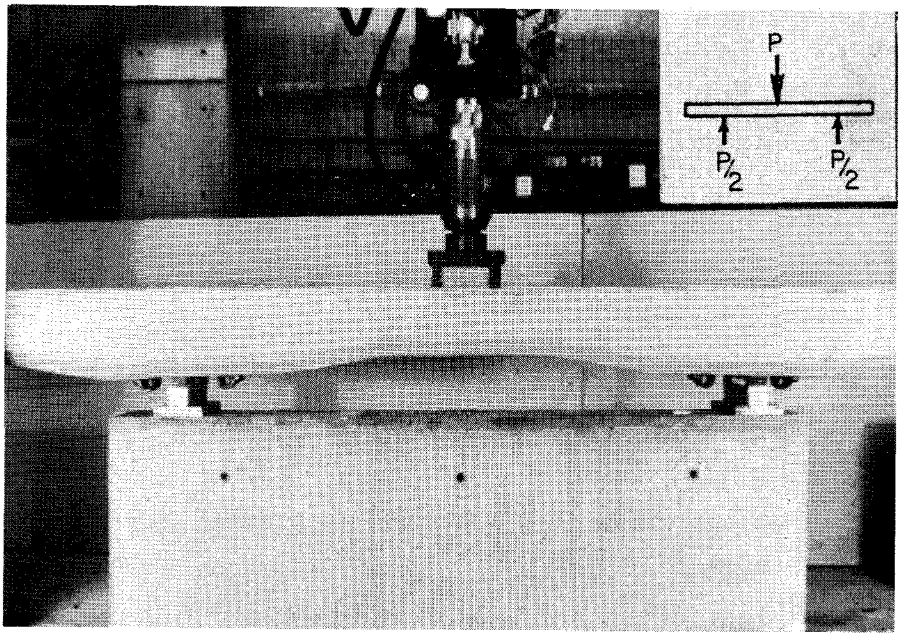

Fig. 11. Tie center negative moment test.

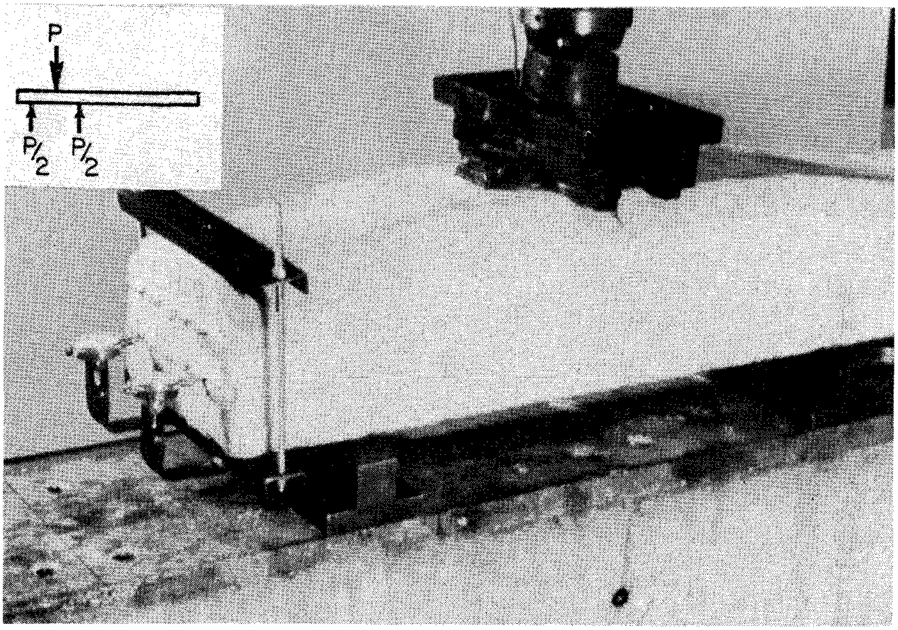

Fig. 12. Bond development test.

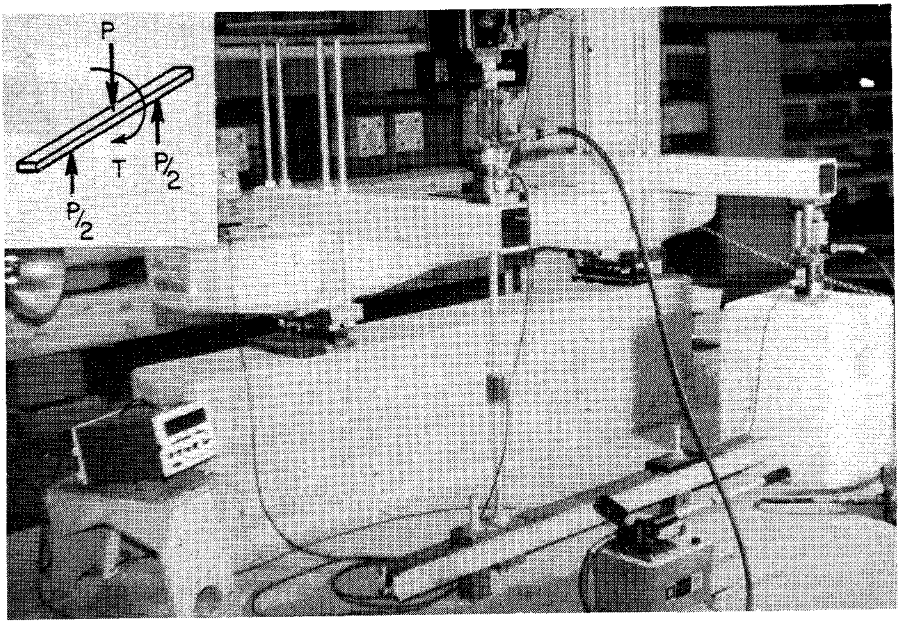

Fig. 13. Tie center moment and torsion test.

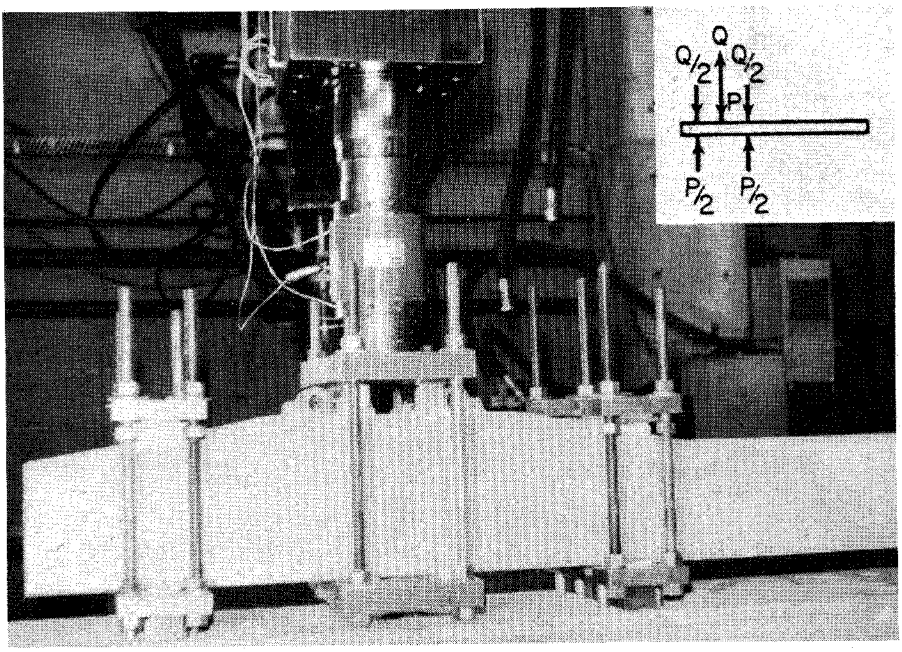

Fig. 14. Rail seat repeated load test.

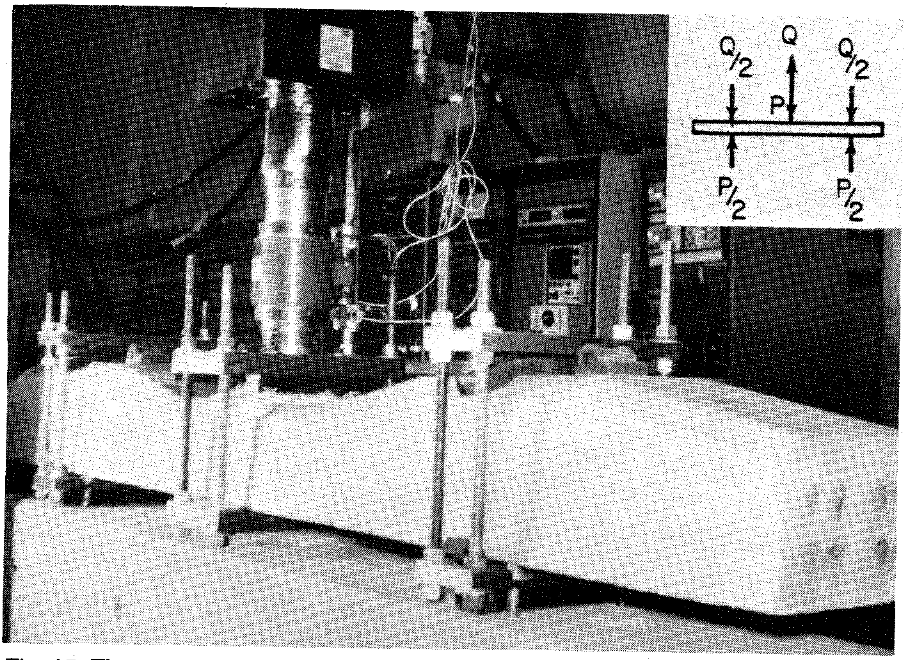

Fig. 15. Tie center repeated load test.

Tie Tests

Static and dynamic tests are generally performed to evaluate tie ability to carry specified bending moments at the cross sections directly beneath the rails and at tie center. Some specifications require that no cracking occurs during the tests, while others permit cracks of specified length. Required tie tests include the following:

1. Rail seat moment test to evaluate the ability of the tie to carry a specified bending moment at the rail seat.[4,5] Fig. 10 shows a rail seat positive moment test.
2. Tie center moment test to evaluate the ability of the tie to carry a specified bending moment at the center.[4,5] Fig. 11 shows a tie center negative moment test.
3. Bond development test, shown in Fig. 12, to evaluate the ability of the tie to withstand overloading without tendon slippage.[4,5]

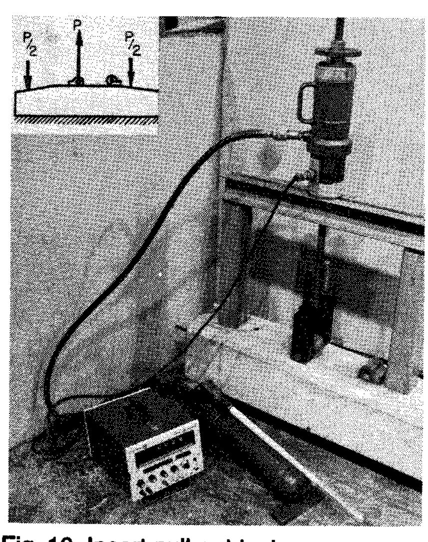

Fig. 16. Insert pull-out test.

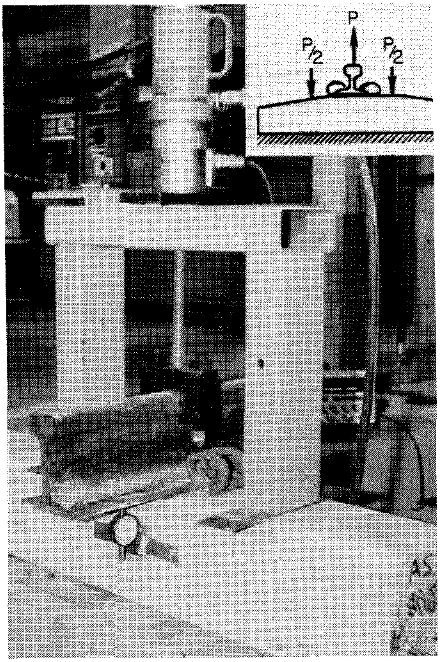

Fig. 17. Fastening uplift tets.

4. Tie center moment and torsion test, shown in Fig. 13, to evaluate the ability of the tie to carry a specified combination of bending moment and torsion at tie center.[5]
5. Repeated load tests to evaluate the ability of the tie to withstand repeated loading.[4,5] Figs. 14 and 15 show rail seat and tie center repeated load tests, respectively.

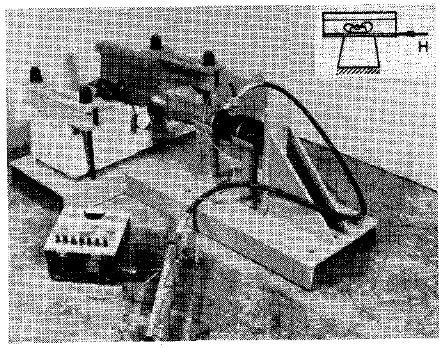

Fig. 18. Longitudinal restraint test.

Fastening Tests

Static and dynamic tests are generally performed to evaluate fastening performance under specified loads or in specified environment. Typical fastening tests include the following:

1. Insert pull-out test, shown in Fig. 16, to evaluate the ability of fastening inserts to resist pull-out forces without slippage or cracking of the surrounding concrete.[4,5]
2. Fastening uplift test, shown in Fig. 17 to evaluate the ability of the fastening system to resist uplift forces without damage of fastening components.[4,5]
3. Longitudinal restraint test, shown in Fig. 18, to evaluate the ability of the fastening system to

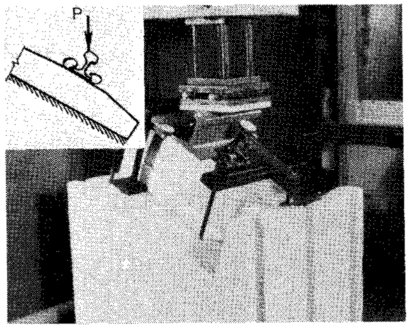

Fig. 19. Lateral restraint test.

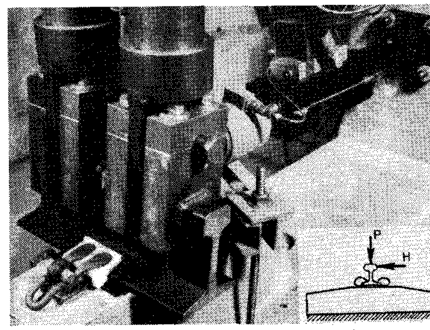

Fig. 20. Fastening repeated load test.

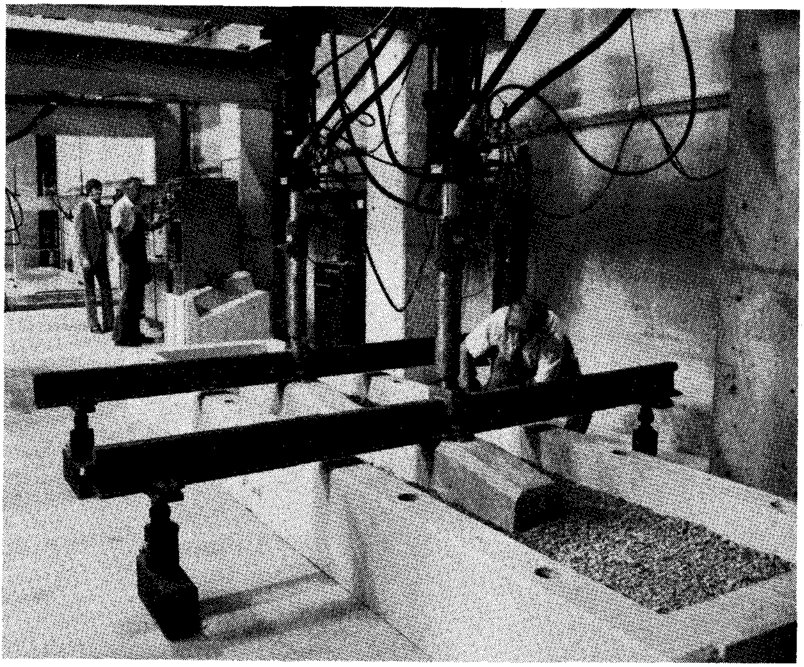

Fig. 21. Simulated track test.

restrain longitudinal rail movements.[4,5]

4. Lateral restraint test, shown in Fig. 19, to evaluate the ability of the fastening system to restrain lateral rail movement and to hold proper gage.[4]
5. Repeated load test, shown in Fig. 20, to evaluate the ability of the fastening system to resist repeated vertical and lateral loads without damage of fastening components.[4,5]
6. Electrical test to evaluate the ability of the fastening system to provide electrical insulation.[4,5]

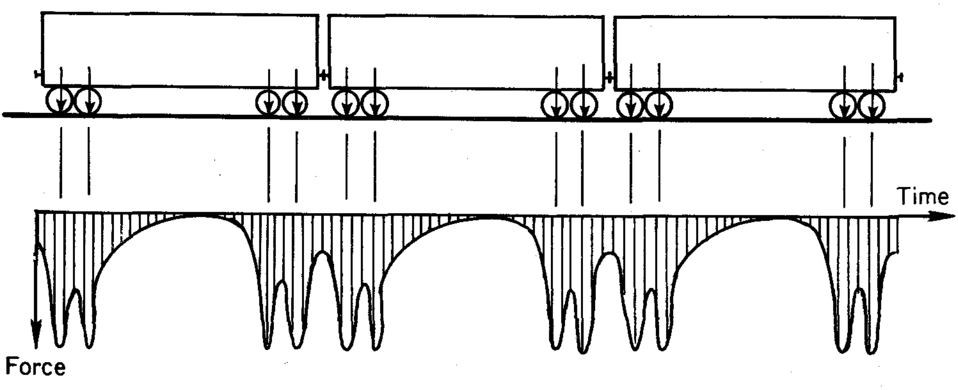

Fig. 22. Loading pattern for simulated track tests.

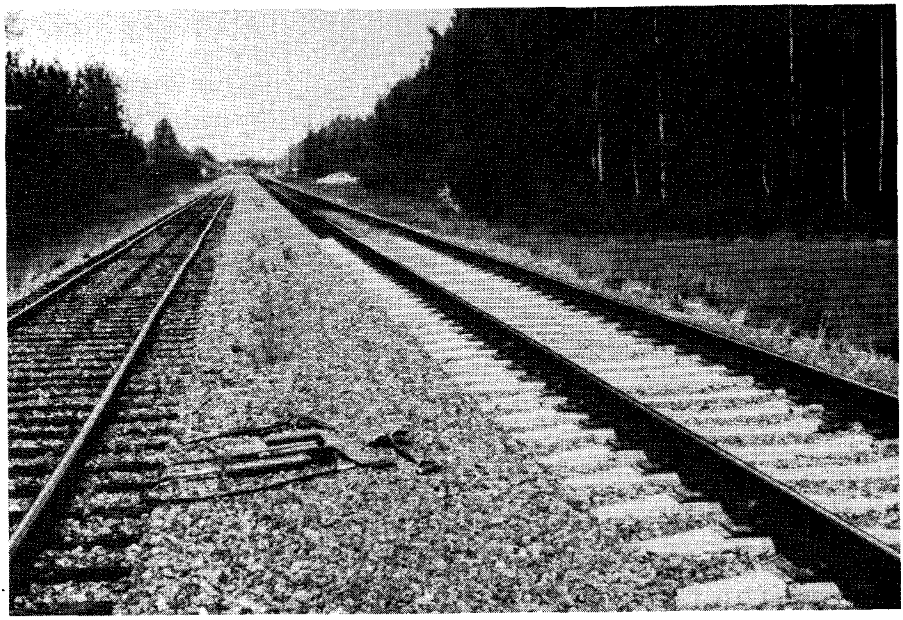

Fig. 23 Concrete tie track on the Alaska railroad.

Simulated Track Tests

Assembled track components can be evaluated by laboratory tests. In such tests, tie support condition and loading environment are simulated.

In the test of assembled track components shown in Fig. 21, two pieces of rail are attached to the tie using fastening components. The tie is supported on representative ballast and subgrade. A loading cycle, following the time versus force relationship shown in Fig. 22, is applied. This loading simulates the effects of axle and truck spacing as well as car length and speed of operation.

Depending on traffic conditions, as much as 12 million gross tons of simulated traffic can be applied in 24 hours of test. Thus, each year of service on a track with a traffic density of 30 million gross tons per year, can be simulated in only 2½ days of test.

Evaluation of track components during this accelerated test is accomplished by visual inspection in combination with monitoring strains, movements, and pressures.

Field Installations and Performance

In the last 20 years, several concrete tie test sections were built in the United States. Early installations indicated several problems primarily due to improper tie and fastening designs. However, installations built in the past decade featured improved tie and fastening designs.

These recent test sections performed satisfactorily. Ties used in recent installations were pretensioned and were manufactured by the long-line method. Some of these installations are described in References 20 and 21.

Alaska Railroad Test Section

This test section, shown in Fig. 23, was built in October 1973 on the

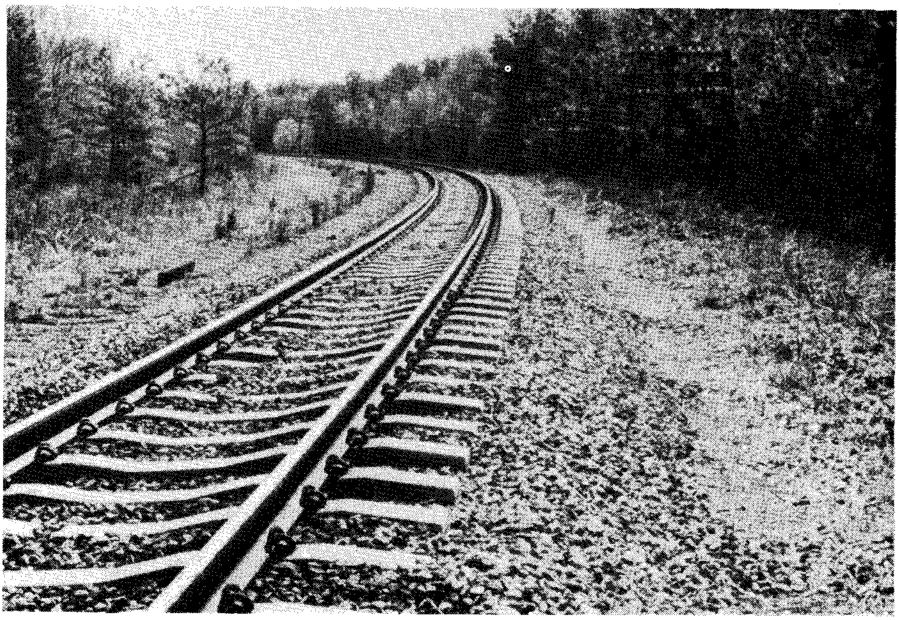

Fig. 24 Concrete tie track on the Chessie system.

Alaska Railroad some 100 miles (160 km) north of Anchorage, Alaska. Traffic on the track is only about 5 million gross tons annually. However, climatic and support conditions are extremely unfavorable. Winter temperature reaches −60 F (−51 C) and frost heave up to 6 in. (152 mm) occurs.

The 9-ft (2.74 m) long ties used on the Alaska Railroad were prestressed with eight, ⅜-in. (9.5 mm) diameter, 7-wire strands. Ties were spaced at 26 in. (660 mm) center to center and supported on crushed gravel ballast. A rail fastening system that provides vertical and lateral rail adjustments, shown in Fig. 9, was used.

Recent inspection of the test section[22] indicated that the ties have performed very well. Cracking at tie center and rail seat has not been observed. Also, the fastening system has performed very well.

Although some pad movement occurred shortly after installation, no movement was detected after field welding of rail joints. The fastening was capable of providing track adjustment needed to accommodate frost heaving during the winter months.

Chessie Test Section

This test section, shown in Fig. 24, was built in March 1974 on the Chessie System near Lorraine, Virginia. Traffic on the track is about 40 million gross tons annually.

Two tie designs were used: a 9-ft (2.74 m) long tie prestressed with eight, ⅜-in. (9.5 mm) diameter, 7-wire strands and an 8½-ft (2.59 m) long tie prestressed with 26, 0.2-in. (5 mm) diameter wires. All ties were spaced at 26 in. (660 mm) center to center and supported on crushed stone ballast. Three fastening types, similar to those shown in Figs. 6b, 6c and 7d, were used.

Recent inspection of the test section[22] revealed that the ties have performed very well. Also, the fastening

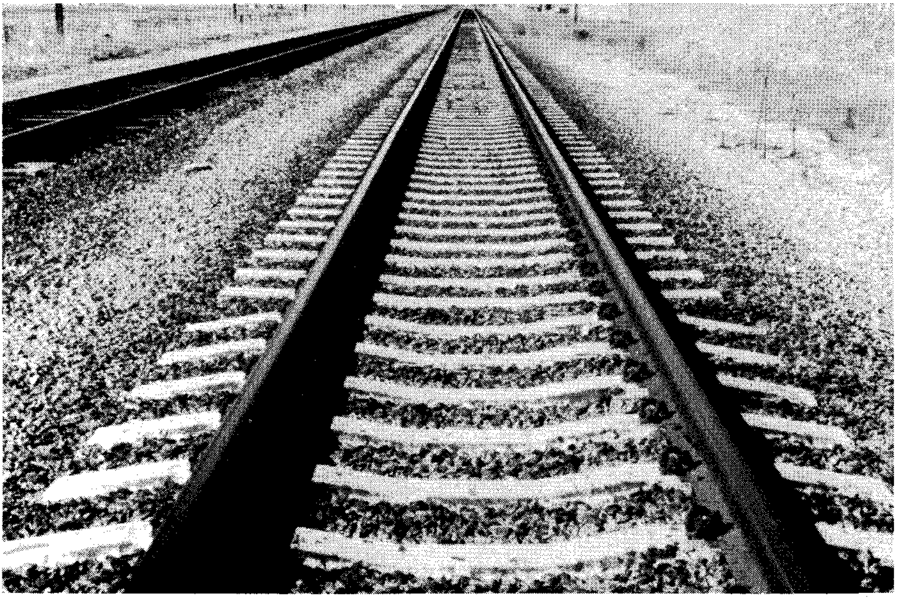

Fig. 25. Concrete tie track on the Santa Fe.

systems have performed satisfactorily except for some pad movement. The recent pad movement appears considerably less than that observed shortly after installation. Also, skewing of some fastening clips appear to be the cause of insulator breakage.

Santa Fe Test Section

A test section, shown in Fig. 25, was built in November 1974 on the Santa Fe mainline track near Streator, Illinois. Traffic on the track is about 20 million gross tons annually.

Two tie designs were used: a 9-ft (2.74 m) long tie prestressed with eight, ⅜-in. (9.5 mm) diameter, 7-wire strands and an 8½-ft (2.59 m) long tie prestressed with 28, 0.2-in. (5 mm) diameter wires. All ties were spaced at 24 in. (610 mm) center to center and supported on crushed granite ballast. Three fastening types, similar to those shown in Figs. 6b, 6c, and 7c were used.

Recent inspection of the test section[22] indicated that the ties have performed very well and no load-induced cracking has been observed. Also, all fastening types have performed satisfactorily. Pad movement and clip skewing observed shortly after installation have stabilized. No further pad movement has occurred and no extremely skewed clips or broken insulators were found.

Norfolk & Western Test Section

The test section shown in Fig. 26 was built in December 1974 on the Norfolk and Western at Kumis near Roanoke, Virginia. Traffic on the track is about 45 million gross tons annually.

Two tie designs were used: a 9-ft (2.74 m) long tie prestressed with eight, ⅜-in. (9.5 mm) diameter, 7-wire strands and an 8½-ft (2.59 m) long tie prestressed with 28, 0.2-in. (5 mm) diameter wires. Ties were spaced at 24 and 26 in. (610 and 660 mm) center to center and supported on crushed granite ballast. One fastening type, similar to that shown in Fig. 6b, was used.

Fig. 26. Concrete tie track on the Norfolk & Western.

Recent inspection of the test section[22] indicated that the ties have performed very well. Also, fastenings performed well. No appreciable pad displacement has occurred. However, some broken insulators were found.

Facility for Accelerated Service Testing

Operation on the Facility for Accelerated Service Testing (FAST) of the U.S. Department of Transportation at Pueblo, Colorado, started in September 1976 at a rate of approximately 1.0 million gross tons per day. Estimated tonnage by the end of 1978 is 350 million gross tons. The facility includes about 6000 ft (1829 m) of concrete tie track as shown in Fig. 27. Ties are located in tangent and on 3- and 5-degree curves.

Six designs of prestressed concrete ties were used: five 8½-ft (2.59 m) long and one 9-ft (2.74 m) long. All ties were spaced at 24 in. (610 mm) center to center and supported on granite ballast. Four fastening types, similar to those shown in Figs. 6b, 7b, 7d, and 8, were used.

Recent inspection of the test section[22] indicated that all ties have performed well. Also, all fastening types have performed well in both the tangent track and the 3-degree curve. However, breakage of a number of fastening clips was observed in the 5-degree curve.

Advantages of Concrete Ties

Concrete ties have been in use in Europe for over 30 years. More recently, Japan, Canada, and the United States installed concrete ties in several projects. This extensive experience has demonstrated many of the advantages of concrete ties.

These advantages have been reported in a recent study,[23] and include the following:

1. Concrete tie track provides better vertical and lateral stiffness

Fig. 27. Concrete tie track on the Facility for Accelerated Service Testing.

than wood tie track, due to the greater mass of concrete ties and the more rigid fastening system.

2. Concrete tie track settles more uniformly than wood tie track, thus providing a smoother, safer ride and greater comfort for passengers.
3. Concrete tie track maintains alignment and gage for a longer period than wood tie track.
4. Concrete ties retain gage better on curves than do wood ties with conventional fasteners.
5. The chances of a derailment are less on a concrete tie track due to the more stable track system.
6. Concrete ties have an estimated service life twice as long as that of wood ties.
7. Concrete tie track has fewer irregularities than wood tie track, thus requiring less maintenance and providing better ride stability.
8. Concrete tie track has a lower life-cycle cost than wood tie track.

It should be recognized that the greater weight of concrete ties makes it more difficult to handle during installation and replacement operations. However, with use of modern and suitable mechanical equipment, handling of concrete ties is no more difficult than wood ties.

In addition, greater weight contributes to greater track stability and increased safety. Fig. 28 shows a track renewal machine used for installing a concrete tie track on Amtrak's Northeast Corridor Improvement Program.

Generally, concrete ties are more expensive to buy than wood ties. However, because of the rigidity and larger dimensions of concrete ties they are generally placed at a larger spacing than wood ties. Furthermore,

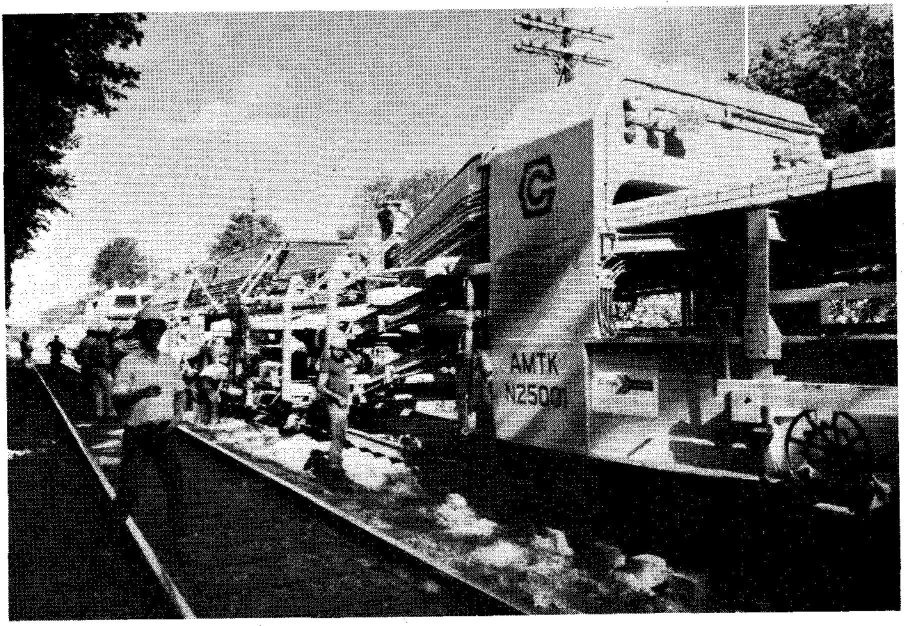

Fig. 28. Track renewal machine.

concrete ties are more effective than wood ties in limiting gage widening and alignment changes. Therefore, maintenance requirements for concrete ties are less than those for wood tie track. Because of these factors, life-cycle costs for concrete tie track are often less than for wood tie track.[23,24]

These features indicate that concrete ties are not only more economical than wood ties; they also provide superior operating characteristics. These features were important factors in the recent decisions by the Canadian National Railway to proceed with a 5-year concrete tie program involving 1.5 million ties,[25] and by the National Railroad Passenger Corporation (Amtrak) to procure 1.1 million concrete ties for the Northeast Corridor Improvement Program.[26]

* * *

Concluding Remarks

There is growing interest in the use of monoblock prestressed concrete ties. This is justified by the consistency in product quality, low annual cost, and superior performance. It is estimated that 15 million prestressed concrete ties are produced annually for railroads all over the world. Pretensioned concrete ties account for 12 million ties per year.

General methods of tie fabrication, material requirements, and design considerations are presented. Requirements for rail fastening systems and ballast materials are outlined. Methods of laboratory testing of ties and fastenings, and field installation and peformance of concrete tie track in the United States are presented. Finally, advantages of concrete ties are summarized.

Experience to date indicates that

the prestressed concrete tie has outgrown the experimental stage and become an important constituent of the modern railway track structure. This is evidenced by the extensive use of prestressed concrete ties in other countries and recent procurements by the Canadian National Railway and the National Railroad Passenger Corporation.

Basic features and design parameters of concrete ties appear to be established. However, some refinements may be desired to obtain optimum and economic track systems at specific locations.

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