37
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W. R. PAXTON

NORTHEAST CORRIDOR IMPROVEMENT PROJECT

CONCRETE TIE COST AND PERFORMANCE FOR TRACK STRUCTURES

TASK 202

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DeLEUW, CATHER/PARSONS
1201 Connecticut Avenue, N.W.
Washington, D. C. 20036

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16. Abstract

As a result of a survey of the Northeast Corridor, it was determined that 1,100 miles of track require upgrading to meet the trip-time goals set forth in the Railroad Revitalization and Regulatory Reform Act of 1976. As a part of the determination of the best way to meet these requirements, two types of ties and three methods of reconditioning track were evaluated.

A comparative analysis was performed on the three methods of reconditioning track: component replacement of wood-tie track with traditional spike fasteners, complete rebuilding of track with preplated wood ties and elastic fasteners, and complete rebuilding of track with concrete ties and elastic fasteners. Differences in the methods were analyzed with regard to productivity rates, cost, and performance.

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PREFACE

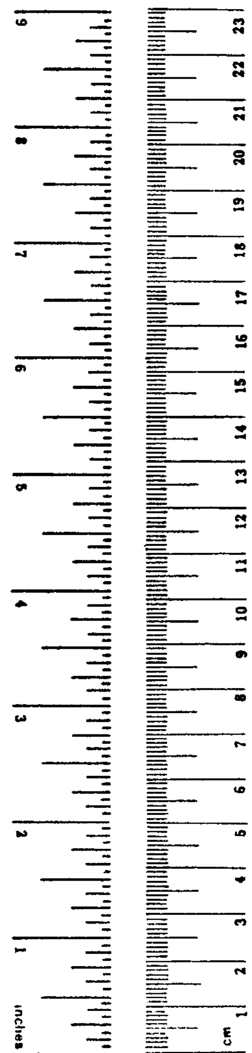
Concrete Tie Cost and Performance for Track Structures is submitted as a continuing part of the De Leuw, Cather/Parsons development of the Northeast Corridor Improvement Project under contract to the Northeast Corridor Project of the Federal Railroad Administration. This report is Contract Data Requirement List no. 37 developed under Task 202, Track Structures.

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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



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

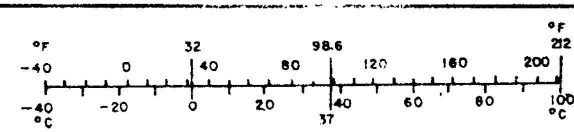


TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

Chapter 1

INTRODUCTION

As a result of a physical survey of the Northeast Corridor (NEC), 1,100 miles of track have been identified as requiring upgrading to meet the trip-time requirements specified in the Railroad Revitalization and Regulatory Reform Act of 1976. Four hundred thirty miles must be upgraded to accommodate 120-mph travel for high-speed passenger traffic and must also be capable of supporting freight traffic. Two types of ties, concrete and wood, have been evaluated, and three track reconditioning systems, listed below, have been selected for analysis based on the type of tie and method of installation in track.

- Alternative 1 - component replacement of wood-tie track using wood ties and spike fasteners
- Alternative 2 - complete rebuilding of the track using new preplated wood ties with elastic fasteners
- Alternative 3 - complete rebuilding of the track using concrete ties with elastic fasteners.

The alternatives are analyzed for a 50-year life with respect to the following engineering and economic parameters: design, performance, installation, energy consumption, and maintenance.

Alternative 1 is the traditional method in the United States, and has been in practice for over 100 years. The advantages and limitations of this method are well known.

Alternative 2 is a new method in the United States. Complete rebuilding of track is a maintenance practice employed by European and Russian Railroads for many years. Recently maintenance-of-way equipment suppliers have developed a track laying system (TLS) which is capable of removing old track from the rail to the ballast and completely replacing it with new components in a one-step operation which is faster than the traditional component-replacement method. Elastic fasteners have been selected for this alternative because they are well suited for the highly mechanized TLS operation.

Alternative 3 introduces the use of concrete-tie track with elastic fasteners installed by the TLS. Concrete ties have been the major track system selected for high-speed track by the British, French, Italian, and Japanese railroads in recent years. In the last five years concrete ties have successfully demonstrated their capability to handle the higher North American wheel loadings at demonstration sections of track on the Canadian National Railroad (CNR) at Jasper, on the Chesapeake and Ohio/Baltimore and Ohio (C&O/B&O), the Atchison, Topeka, and Sante Fe, the Norfolk and Western, the Alaskan railroads in the United States and most recently at the Transportation Test Center's Facility for Accelerated Service Testing (FAST).

Chapter 2

ENGINEERING ANALYSIS

DESIGN CRITERIA

In Task 3: Track and Structures Standards Development, a comparative design analysis was performed on concrete-tie track and wood-tie track using speeds, axle loadings, and tonnages anticipated for the NEC. The parameters analyzed were:

- Track modulus (vertical stiffness)
- Rail seat loading
- Track lateral stiffness
- Longitudinal restraint
- Rail bending stress
- Ballast depth
- Damage from derailment.

The comparative engineering analysis determined that:

- Concrete ties should be placed at 24-inch spacing and wood ties at 19½-inch spacing.
- Concrete-tie track will provide better vertical, lateral, and longitudinal track stiffness than will conventional wood-tie track.
- Rail seat loadings will not be critical for either track system.
- Because of the more stable track system, the chances of a derailment will be less on concrete-tie track, but concrete ties may experience more damage in a derailment than wood ties.[1]

PERFORMANCE

In recent months, much information has been made available on the comparative performance of concrete- and wood-tie track structures. Much of this data has been collected from preliminary observations of the Facility for Accelerated Service Testing (FAST)[2] at the Department of Transportation (DOT) Transportation Test Center. This data has supported previous observations from test sections on the Chessie, the Norfolk and Western, the Atchison, Topeka, and Sante Fe, the Black Mesa and Lake Powell, and the Florida East Coast (FEC) railroads in the United States; the CNR at Jasper, Canada, as reported in Task 22: Program Plan for Track Development and Demonstration[3]; the ORE Velim test track in Europe; and data from Russian experience.[4]

Track Settlement

Track settlement data provides a measure of the stability of track under repeated train loads. Settlement is defined as the change in elevation of the track from the as-built position as measured from a fixed benchmark. Settlement trends provide an overall measure of the effectiveness of a track system in distributing wheel-rail loads to the roadbed without putting excessive stress on the track structure foundation.

When concrete-tie track and wood-tie track were placed on newly constructed roadbed at FAST, the concrete-tie track settled faster during application of the first 20 million gross tons (MGT), but the settlement rates during application of the next 20 MGT were approximately the same. When built on an existing roadbed, concrete-tie track settled less than did wood-tie track. These results are verified by initial experience of the Velim test track as reported by ORE and not contradicted by preliminary experience in the United States from the C&O/B&O concrete-tie test track at Noble, Illinois.

More significant than the mean settlement is differential settlement (cross level or twist), which results in track roughness. Track roughness affects ride quality and uniformity in track surface. In initial measurements of track settlement, concrete-tie track settled more uniformly than did wood-tie track. The average deviation of track settlement for concrete-tie track was 12 percent lower than that for wood-tie track after 35 MGT at the Velim test track. The Commonwealth Railway in Australia confirms the improvement to ride quality with their observations that travel on concrete-tie track is "...infinitely more comfortable and less tiring than timber sleepered track."[5]

Track Geometry Deterioration

The rate of track geometry deterioration reflects the ability of the track to perform its function. As track degrades, the dynamic loads imposed on the track structure increase significantly, further increasing the rate of deterioriation of the track. The increased dynamic loads can cause breakdown in all areas of the track structure, thereby increasing the maintenance requirements of the track, and thus the cost of maintaining the track. But the track structure is not the only item affected by deterioration of the track. Track deterioration causes poor ride quality and increased wear of vehicles, thus increasing vehicle maintenance costs.

Currently, the FAST track geometry deterioration measurements are not conclusive. However, it has been observed on five-degree curves at FAST that gauge variation on concrete-tie track is less than that on comparable wood-tie sections. This trend is consistent with inspection reports from other concrete-tie installations.

Track degradation measured by a track geometry car for the Cologne-Wiesbaden Line indicated that concrete-tie track has a more gradual rate of deterioration of track alignment than does wood-tie track for equivalent maintenance cycles. Data on track geometry behavior on the FEC confirms the European trends. Data on irregularities of cross level and alignment indicate a smaller variation over a period of time for concrete-tie track than for wood-tie track. The CNR, British Railway, Swedish State Railway, Indian Railway, and Japanese National Railway all state that concrete-tie track is more stable than wood-tie track due to the greater tie weight.[6]

Reduced track degradation results in reduced maintenance costs. Experience of the CNR and the Australian Commonwealth Railway confirms this, and the British Railway reports that the estimated maintenance costs of concrete-tie track may be as low as 50 percent of the maintenance costs for wood-tie track.

Rail Wear

The CNR has experienced a four-year rail life with concrete ties compared to a two-year rail life with wood ties on track with heavy curves (of six to eight degrees). While FAST data on rail wear is not conclusive, current data is not inconsistent with reports of the CNR.

Track Resiliency

Track resiliency indicates the structural characteristics of a track system. Response of a track system to wheel loads can be determined by measuring track deflection under vertical and lateral loads, and from these measurements the vertical and lateral track modulus (pounds per inch per inch) can be determined using the theory of a beam supported on a continuously elastic foundation.

Increasing the track modulus will lower the rail deflection, track deflection, and rail stress and will have a much greater impact on limiting track deflection than will increasing rail size; but the reduction in rail stress due to an increase in modulus will not be significant after a modulus of 3,000 is obtained. Track geometry retention is directly related to track modulus, and increasing the track modulus will reduce the rate of track degradation.

At FAST, concrete-tie track exhibited substantially higher vertical track moduli (4,048 to 7,590 at zero MGT to 8,890 at 58 MGT) than did wood-tie track (2,052 to 3,192).

In measurements of lateral load applications at FAST, concrete-tie track with a 12-inch ballast shoulder exhibited much smaller and more uniform lateral deflections than did wood-tie track with an 18-inch ballast shoulder. This situation is due to the increased rigidity of concrete-tie track with elastic fastenings and the increased weight of the track system.

Service Performance

Historically, service performance of concrete ties in the United States has been poor. Since 1893, when 200 concrete ties were installed on the Reading Railroad, over 150 types of conventionally reinforced concrete ties were designed and patented in this country. Most of these ties failed due to improper design or inadequate rail fastening systems. In 1957 the Association of American Railroads (AAR) designed and manufactured a series of prestressed monoblock ties for insertion in track at 30-inch centers. Many of the ties in this program were installed in track on the Atlantic Coast Line, the CNR, and the FEC. They were designed with concrete shoulders to provide lateral restraint to a threaded-type rigid rail clip. The major problems with the AAR ties were flexural and torsional cracking in the center portion of the tie and flexural cracking beneath the rails. The experience of the FEC typifies the failure problems associated with the AAR tie.[7]

The FEC has the most miles of concrete-tie track in the United States.[8] By the end of 1976, 181.1 miles of concrete-tie track had been installed with an additional 31.1 miles scheduled for installation in 1977. The FEC began its program in 1964 with the old MR-2 monoblock tie. The MR-2 tie was designed with a V bottom to reduce the tendency to center bind. Early in the program, the ties experienced center cracking and rail-seat cracking which was attributed to deteriorating limestone ballast which cemented and destroyed drainage. In the first attempt to correct the problem, steel stirrups were added in the rail seat areas, the prestress of the tendons was increased, and tie spacing was reduced from 30 inches on center to 24 inches. Cracking problems continued to plague the FEC, so the limestone ballast was replaced with granite ballast and a flat surface was restored at the bottom of the ties. As a result, the FEC has high-quality track with concrete ties.

In order to advance the design of concrete ties, a special committee on concrete ties was formed by the American Railway Engineering Association (AREA) to develop performance specifications for all types of concrete ties which could be used by the railroad industry with reasonable assurance of reliable performance in mainline tracks. The committee, in conjunction with the American Concrete Institute Committee 545 on Concrete Railroad Ties, developed the AREA <u>Preliminary Specifications for Concrete Ties (and Fastenings)</u> in AREA Bulletin 634. This preliminary specification became the basis for the continued development and use of concrete ties in the United States.

Four major test sections of concrete-tie track designed in accordance with the specifications for concrete ties in AREA Bulletin 644 have been installed under various operating conditions on the Alaskan, the Chessie, the Santa Fe, and the Norfolk and Western railroads. These test sections have been in mainline service under severe climatic and operating conditions such as frost heave and sharp curvature since 1973-74. The ties in all sections have performed well.[9]

All concrete ties which had met the recommended requirements of the AREA are currently participating in an accelerated service program at FAST. These ties are performing well under very severe conditions, e.g., poor ballast gradation and configuration, two-percent grade, and five-degree curvature.

The performance of these concrete ties was evaluated at FAST by determining the flexural strength of the tie under load, tie degradation, and tie movement. It was determined that the flexural strength of concrete ties, designed in accordance with the current bending moment requirements recommended by AREA, is much higher than the moments measured in track under load. This data is confirmed by measurements taken on concrete-tie track on the FEC.

A visual inspection for tie degradation of 450 ties at FAST indicated good performance by concrete ties. All cracks observed were surface cracks as opposed to structural cracks except in two ties, which were removed from track for further examination.

Tie movement is a major cause of degradation for the track structure. During a visual inspection at FAST after 61 MGT, only 3.5 percent of the concrete ties showed signs of movement. The ties that moved did so on the five-degree curve, where most ballast cribs were observed to be half empty and rail was severely corrugated.

Rail Retention

Results of the FAST and other tests indicate better gauge retention on sharp curves with concrete-tie track than with wood-tie track. Measurements of creep and longitudinal rail movement indicate better performance by concrete ties than by wood ties.

Fastener System Performance on Concrete Ties

The method of fastening rail to concrete ties is a critical area in evaluating advantages and disadvantages of this tie system. Unfortunately, limited research has been done to develop fastening systems. Several types of fasteners, including bolted rigid and elastic spring clips and tie pads, are currently available. Also, insulator pieces have been built into some assemblies to remedy electrical conductivity problems. However, very little effort has been expended in the United States to match all three of these components into a complete system.

Most rail clips used on concrete ties in this country in the 1960s were the bolted rigid type. With the exception of the experience on the FEC, the performance of bolted clips has been poor. Even the FEC had early problems with the threaded insert pulling out, but this problem was corrected by increasing the length of the insert. The primary problems of the fastening assembly have been with insert pullouts and spalling of concrete rail-seat shoulders adjacent to the heel of the rail fastening clips.

Similar problems occurred in 1975 on the Black Mesa and Lake Powell Railroad shortly after its construction. Concrete shoulders spalled because of improper alignment between tie, rail clip, and rail. The improper alignment was due to a combination of poor installation practices and either inadequate tolerances of the rail clip and the concrete shoulder or inadequate quality control on the tolerances. Threaded inserts anchoring the rail clips to the tie pulled out from high dynamic-impact forces generated by train operations. These failures may have been caused by the use of too soft a pad in conjunction with rigid clips. When a tie pad is deflected under load, the rail clip loses its preload and comes loose. When the dynamic load on the tie pad is released, the rail springs back to its original position, jarring the rail clip and anchorage assembly. This situation can also cause bolt fatigue and failure.

Both of these design or construction errors, rail clip misalignment and improper tie pad, created mechanisms that caused certain failure modes. Further, each mechanism aggravates the other and compounds the failures. For example, a correctly aligned and fitted fastening clip, concrete shoulder, and rail can easily become misaligned during repeated vertical rail motion resulting from a soft pad. The Black Mesa and Lake Powell Railroad has minimized its problems by using a high-strength bolted connection and a stiffer tie pad that is compatible with the rigid clip, and by installing clips which properly fit the concrete shoulder.

The best method to date for minimizing the problems described is through the use of proven elastic rail clips mounted in a steel shoulder which is embedded in the concrete tie. This system is completed with a durable tie pad between the rail and tie. No threaded elements are required, nor are concrete shoulders. Proper gauge, lateral restraint, and alignment of the rail clip are maintained by the shoulder insert being firmly embedded into the concrete tie. It is this type of fastening system that has been successfully demonstrated in the United States at Lorraine, VA, on the Chessie; at Streater, IL, on the Santa Fe; and at Kumis, VA, on the N&W, and is currently being demonstrated at FAST. The first major elastic fastening system in North America at Jasper, Canada, on the CNR, has performed very well.

The most persistent problem with the elastic-clip fastening system are insulators breaking or working out from under the clip, and tie pad creep out from under the rail. These problems continue to a minor extent in the preliminary observations at FAST. Consideration is being given to replacing the presently used insulators with the glass-filled nylon insulators reportedly successful in South Africa. These insulators are durable and stable and provide the electrical isolation desired. (It should be noted that insulator failure had not developed into a major problem in the current demonstration sections of concrete-tie track.)

The solution to the tie-pad problem is a bit more complicated. Much effort has been expended to find more durable materials for tie pads. Nylon, polyurethane, corded rubber, and high-density polyethylene have performed very well, but the problem with creeping pads continues. Much work needs to be performed in this area, perhaps reverting to the Sonneville system of matching the spring rates of the pad and the clip so that constant pressure is exerted on the pad, prohibiting it from creeping out from under the rail.[10]

Fastener System Performance on Wood Ties

Plate cutting measurements were taken at FAST to compare conventional wood-tie plate/cut-spike rail fastenings with tie plates using elastic rail fastenings.

The plate cutting measurements were taken from FAST at 33 MGT and compared to a zero baseline for conventional versus elastic fastenings. Because of the low tonnage, the measured plate cutting was negligible on the low rail and of small magnitude on the high rail. The significant factor, however, was that all plate cutting occurred in conventional tie plate and fastening, with no plate cutting in elastic fastenings.

INSTALLATION TECHNIQUES

Two methods for upgrading tracks have been presented for analysis: one is the traditional method of component replacement, currently used by U.S. railroads (Alternative 1, Chapter 1); the other is the practice developed in Europe and Russia of total track renewal (Alternatives 2 and 3, Chapter 1).

In component replacement, a track component remains in track as long as it is capable of performing its function satisfactorily. The use of this method accepts the fact that the life of an individual component will be reduced at a different rate than will the life of other components. This is due to the fact that when a new component was installed, it had to do more than was intended to compensate for the deteriorated condition of the track components which remain in the track. Component replacement relies heavily on regular visual inspections of the track to locate defective components for replacement. A wide variety of maintenance equipment on a labor-intensive basis is then employed on cyclic schedules to perform out-of-phase rehabilitation of track. This selective renewal of defective components, especially of ties, is followed by a surfacing gang to bring the track into required geometric tolerances. Rail renewal normally occurs independently of tie renewal and surfacing.

Component replacement is the method with which railroad maintenance personnel in the United States are more familiar. Additionally, maintenance equipment for this method is well standardized and is available from several American manufacturers.

The component-replacement method adopted for the installation of wood ties cannot be considered for the placement of concrete ties. Experience has shown that concrete ties do not perform satisfactorily when randomly interspersed in wood-tie track. Concrete ties settle more slowly and therefore take a disproportionate share of the dynamic load, resulting in an unstable track structure. The greater weight of concrete ties is also an impediment for their installation by conventional maintenance equipment. Most equipment would have to be modified to be capable of handling the heavier concrete ties.

In the total renewal method, an integrated TLS is utilized. The method was developed to maximize the amount of maintenance performed in a limited period of track access. The method employs the philosophy of cyclical total track renewal; complete units of track components are renewed at one time, at regular intervals, based on the removal of track components before excessive failure and maintenance costs occur.

The ultimate example of this philosophy is practiced in Russia, where the entire track structure is replaced after a predetermined amount of tonnage has been hauled over the line. The primary parameter for determining rail renewal cycles is by defect analysis, with rail wear a secondary parameter. The primary practice in the United States is to replace rail on the basis of wear, with defect rate a secondary parameter. The Russian philosophy is that the number of defects per gross ton increases as tonnage increases. Therefore, they establish predetermined levels of tonnage for total track renewal to maintain a stable, safe track structure.[11]

The TLS system is designed to remove all the old ties, fastenings, and rail simultaneously. During this operation, the TLS places new ties (concrete or preplated wood) at designated spacing, aligns the track, and replaces or restores jointed or continuous welded rail and fastenings. All of the activities described for the TLS are performed by one set of machinery.

MAINTENANCE

Requirements Assumed for Each System

To establish maintenance requirements for each of the track renewal systems being evaluated, the following general program elements are reviewed:

- Track inspection
- Spot surface
- Ballast life
- Tie and surface renewal
- Surface and line
- Renewal of rail and other track material
- Rail surface grinding
- Undercutting and surfacing.

To determine productivity, wear-out rates, and associated costs of all the work elements listed above, experience and judgment were used to develop qualitative decisions on the level of designated maintenance programs required on dedicated passenger high-speed tangent track.

Determination of Maintenance Level

The maintenance effort required for each track system will vary with the passenger-train speed to be accommodated, the weight of cars, and the level of joint usage of the track structure by passenger and freight equipment. An increase in train speed and axle loading will result in an increase in the maintenance effort required to maintain track within the tolerances demanded for passenger comfort and safe operation. Similarly, an increase in freight usage will result in an increase in the required maintenance effort.

The maintenance effort required for each usage was analyzed. It was readily apparent that many cost combinations are possible as a result of the many characteristics and levels of service encountered. The attempt to recognize, in detail, too many service levels, would render the analysis quite unwieldy. On this premise, maintenance levels were reconciled to their basic stratified form with which axle load, speed, and tonnage parameters had been developed. Inputs to this process were based on:

- Direct experience with maintenance of the New York-to-Washington portion of the Corridor during the initial years of the Metroliner Demonstration Project
- Measurement and maintenance operation evaluation of the NEC test track between "County" and "Trenton", which historically has had a level of joint usage between 15 to 20 MGT per year
- Evaluation of Japanese National Railway maintenance requirements and procedures for 132-mph exclusive passenger operation with 25 to 30 MGT per year per track.

The related level of service was assumed to be as follows: 120-mph maximum speed for passenger trains, joint usage with road and local freight, and total tonnage of 15 to 30 MGT annually.

Inspection

Corridor track was assumed to require three types of inspection to detect defective components and deteriorating alignment: visual inspection by walking, ultrasonic rail testing, and measurement of track geometry.

Visual Inspection. Eight to ten miles of double track per man per day is the maximum rate of visual inspection by walking. Frequent inspections by supervisory personnel riding passenger equipment would also be required. Ride quality would be spot checked with portable accelerometers. For all alternatives analyzed, it was assumed that visual inspection would be performed twice weekly with at least one day between inspections.

Ultrasonic Rail Testing. Annual testing for internal rail defects is prescribed in Federal Railroad Administration (FRA) track safety regulations. An ultrasonic inspection car can test up to 120 miles of track in eight hours, depending on track availability.

For all alternatives analyzed, it was assumed that ultrasonic rail testing would take place three times per year. This increase over present FRA rules was deemed necessary to ensure safe operations on high-speed tracks where joint usage would occur.

Measurement of Track Geometry. The accurate measurement of track geometry is essential to efficient programming of track maintenance to keep high-speed track at required tolerances. The frequency of such recording would vary with the speed and traffic. For each of the track systems being analyzed, the frequency of recordings was assumed to take place on a two-week cycle for upgraded NEC designated passenger tracks.

Spot Surfacing

Spot surfacing was assumed necessary for all track systems on a three-month cycle to maintain the high quality of track required for NEC operations. The track will require a periodic major surface and line operation which would be substituted in the spot-surfacing schedule.

Additional Ballast

Additional ballast will be required after the renewal of ties and undercutting. It was assumed that two inches should then be added for all track systems.

Tie and Surface Renewal

Tie renewal is a major maintenance item, second only to rail renewal, and is required to maintain the proper gauge and riding quality. It results in some disturbance to line and surface under even the best conditions. To minimize this disturbance, the tie cycle should be as long as possible without permitting bad ties to affect safety or ride quality.

Wood Ties

Wood-tie life has been reported to range from 15 to 35 years depending on the type of wood, tie treatment, maintenance, climate, track configuration, and traffic.[12] A comparison between actual tie life and annual gross tons for main, side, and yard tracks on the NEC indicates that a traditional tie life of

24 years would be reasonable for wood ties placed by traditional methods (Alternative 1).[13] Based on a 24-year life for hardwood ties in high-speed track, a six-year cycle would be required, or 812 ties per mile per cycle after initial upgrading. A mechanized dual-tie gang can renew this number of ties on one pass and not violate established rules of safe practice for this work. Such a tie gang should average slightly less than one mile of track per day under Corridor conditions. The subsequent surfacing and lining operation can easily keep pace with the tie operation.

All spikes would be renewed when ties are replaced. Plates and anchors would be renewed only where broken or missing items are found.

Wood ties installed by the TLS (Alternative 2) were assumed to have a life of 25 years. The increase in tie life of one year was attributed to the uniform placement and support of ties by the TLS machine and the accurate positioning of gauge from the preplating operation.

Spot replacement of defective wood ties installed by the TLS was assumed to begin 12 years after initial installation and continue on a four-year cycle. To minimize the potential number of defective ties which would affect the safety of operations, it was assumed that 20 percent of all defective ties would be replaced. These tie renewals would be done by hand due to the low number of ties per mile expected to be replaced.

All lock spikes would be renewed when the ties are replaced. Plates and clips would be renewed only where broken or missing items are found.

Concrete Ties

OPTIMISTIC!

LIGHTER AXLE LOADS

Concrete ties (Alternative 3) were estimated to have a service life of 50 years. This is supported by the fact that British Railways, the Swedish State Railway, the Australian Commonwealth Railway, and the German Federal Railway, all assume 50 years for concrete-tie life in their economic studies based on their long experience with concrete-tie track. The Russians assume a 40-year life for concrete ties in their economic evaluations, while the Chessie has assumed the service life of concrete ties to be 45 years.[14] If they are properly installed and surfaced regularly, and if other track material is replaced as required, renewals would be required only to replace the few that exhibit obvious defects which potentially affect safety or ride quality.

Spot replacement of defective ties was assumed to begin 24 years after initial installation with the TLS, and to be repeated 36 and 44 years after installation. To minimize potentially dangerous tie conditions, it was assumed that ten percent of all defective ties would be replaced for these renewal years. These tie renewals would be done by hand due to the low number of ties per mile expected to be replaced.

Insulators, clips, and tie pads would be renewed only where broken or missing items are found.

The TLS machine is scheduled to renew all concrete ties and other track material every 50 years.

Track Surface and Line

The surface and line of high-speed track are the items most critical to ride quality. Out-of-phase surfacing and lining are performed following rail renewal and tie renewal and as often as conditions dictate between these cycles. On well established wood-tie track, such as on the NEC, this procedure would be required every year. On concrete-tie track, surfacing and lining were assumed necessary on a two-year cycle because of the more stable track support. Each time the track is surfaced and lined, it was assumed that one inch of ballast would be added and 0.32 percent of all anchors or clips replaced.

Renewal of Rail and Other Track Material

The assumed life of 140# RE continuous welded rail (CWR) for NEC service conditions is approximately 25 years on wood-tie track.[15] Service histories on the Corridor confirm these assumptions. In demonstration sections of concrete-tie track at the Transportation Test Center, on the Chessie System, and on the CNR, rail wear was observed to occur at a slower rate than that normally found on wood-tie track. To account for decrease in rail wear in the economic analysis, a rail life of 35 years was assumed for concrete-tie track based on these observations.

For all the track systems analyzed, all other track material was assumed to be renewed along with the rail. Tamping and lining must follow rail renewal to ensure full support of the rail at each tie to prevent permanent damage to the new rail. A standard rail gang working one rail at a time should lay eight 1,440-foot strings of rail per day on the Corridor.

Rail Surface Grinding

New welded rail should be surface ground three months to one year after it is installed. This operation is required to provide a smooth running surface for the high-speed vehicle, reducing the noise generated by the wheel-to-rail relationship and the dynamic impact to the track structures. Two passes with a grinding train, removing 0.001 to 0.002 inch per pass from the surface of the rail would eliminate minor rolling imperfections in the rail and improve the contour of the weld areas.

Similar grinding was assumed to occur on a four-year cycle throughout the life of the rail for all track systems to remove corrugations and other minor surface damage caused by the action of wheels passing over the rail.

Surface Undercutting

The track was assumed to require periodic ballast cleaning of impermeable fines, mud, and other material which accelerate track degradation. For the NEC, ballast cleaning was assumed necessary on a 12-year cycle for wood-tie track installed by traditional methods and on an alternate 12- and 13-year cycle for wood- or concrete-tie systems installed by the TLS. Ballast would be cleaned by a high-speed undercutter which would pull the ballast out from under the track, clean it, and replace it. Along with the undercutting operation would be a ballast train to distribute ballast where needed and a surfacing gang to bring the track back to proper line and surface after ballast cleaning.

ENERGY CONSUMPTION

Based on information provided by the Portland Cement Association, National Forest Products Association, and U.S. Forest Products Laboratory, the Transportation Systems Center (TSC) prepared a study comparing the energy consumption in manufacturing concrete and wood ties.[16] The energy-consumption figures from that report for both types of tie systems are presented below:

- Concrete ties - 3.17×10^9 btu per mile using Portland Cement Association data; 9.95×10^9 btu per mile using National Forest Products Association data

- Wood ties (based on equivalent 50-year life) - 6.10×10^9 btu per mile using U.S. Forest Products Laboratory data; 7.34×10^9 btu per mile using National Forest Products Association data.

In reviewing the TSC report, Bechtel Corporation found a discrepancy in the amount of steel required for wood ties.[17] The TSC study was based on ten pounds per tie, whereas this should have been 57 pounds per tie. The energy consumed in manufacturing wood ties with the added steel is 9.04 x10^9 btu per mile for wood ties, or nearly equal to the highest energy figures for concrete ties.[18] The energy requirements to produce creosote and to treat wood ties are not supported in the report, nor does the report include energy-consumption data on transportation of ties, laying of tracks, track maintenance, or fuel savings in train operation.

Operating on concrete-tie track provides an energy-conservation advantage when compared with wood-tie track as reported by the Australian and British railroads.[19] The Commonwealth Railway of Australia reports that fuel costs are lower on concrete-tie track due to the smoother riding track which reduces train rolling resistance. British Railways reports a fuel savings of up to four percent in train operation on concrete-tie tracks.

Chapter 3

ECONOMIC ANALYSIS

TRACK STRUCTURE AND INSTALLATION SYSTEMS SELECTED FOR COMPARISON

The three alternatives mentioned in Chapter 1 were analyzed for cost comparisons. Wood ties were evaluated for both component replacement and complete renewal.

In the component-replacement method a 40-percent replacement of treated wood ties on 19½-inch spacing using conventional other track material of two tie plates per tie, three spikes per plate, and one rail anchor per rail per tie were assumed.

With the complete track-renewal method requiring total replacement of wood ties, an alternate method for fastening the rail to the ties was adopted. Because of the necessity for total preplating prior to installation, alternatives to the cut spike/rail anchor system can be considered. Although more costly, the elastic fastener described below demonstrates superior performance when applied to wood ties. Under these conditions it is assumed that the track would consist of wood ties on 19½-inch spacing with each tie predrilled and preplated with two tie plates fastened by four lock spikes per plate. Therefore, instead of anchoring the rail to the tie plate with cut spikes, four elastic clip fastenings per tie are used. This eliminates the requirement for rail anchors. For both renewal methods, the wood ties were assumed to comply with AREA grade requirements for treated hardwood ties, seven inches by nine inches by eight feet, six inches.

Concrete-tie track was used in the complete track-renewal concept. The concrete ties selected were eight feet, six inches long, conforming to the requirements of the new AREA-recommended performance specifications, with each tie fitted with two bearing pads, four insulator clips, and four elastic rail clips. The tie spacing assumed in the analysis was 24 inches.

For all the alternatives described above, it was assumed that each track system used 140# RE CWR. Each method of renewing track assumes that the track is being placed on an existing track system and that the rail is being renewed along with the ties.

PRODUCTIVITY RATES

The rate of track replacement renewed by the component-renewal method is based on the average mile of track requiring 1,200 (40 percent) new ties. Also required with the normal tie-renewal gang, surfacing gang, and ballast cleaner is an independent rail-renewal gang. For this analysis, it was assumed that the component-renewal method will renew track (rail and ties) at the rate of one-half mile per day. The production rate for the total track renewal by the TLS is assumed to be one mile per day.

COSTS

Development of Maintenance Costs

The maintenance frequencies derived earlier in this report for each work item for wood-tie track component renewal, wood-tie track total renewal, and concrete-tie track total renewal are summarized in Table 1.

In addition to the major cycle items, such as tie renewal and surfacing, certain other costs were recognized as occurring within the maintenance-of-way area. As they cannot be projected to sufficient accuracy, they were identified only. From the life-cycle cost aspect, they were not considered significantly different in magnitude for any system under consideration. Some typical items were:

- Special track inspection for debris or obstruction on track, ties on fire (wood-tie track), reported rough spots, and damage from heavy rain
- Repair of wheel burns by welding
- Repair or replacement of insulated joints
- Replacement of broken or defective rail

Table 1

INTERVALS BETWEEN MAINTENANCE OPERATIONS
(Years)

Operation	Alternative 1 Wood-Tie Track Component Renewal (24-year tie life)	Alternative 2 Wood-Tie Track Total Renewal (25-year tie life)	Alternative 3 Concrete-Tie Track Total Renewal (50-year tie life)
Inspection			
Visual	1/104	1/104	1/104
Ultrasonic	1/3	1/3	1/3
Measurement	1/26	1/26	1/26
Spot surface	1/4	1/4	1/4
Ballast addition	6	12-13	12-13
Tie renewal (years between renewal)	6	4*	12-8**
Surface and line	1	1	2
Rail renewal	25	25	35
Undercutting and surfacing (years between operation)	12	12-13	12-13
Rail surface grinding	4	4	4

*Beginning at year 12
**Beginning at year 24

- Repair of damage due to derailment, accident, or dragging equipment
- Cleanup of spilled lading
- Repair of damage due to vandalism
- Vegetation control
- Fence maintenance
- Drainage and ditch maintenance
- Snow removal.

The frequency and cost of each item relates to various factors, such as tie material (wood or concrete), track usage, and geographical location. Some of these items could occur on any NEC track, while others are predominantly associated with freight operations. These costs were assumed to be reasonably constant for all types of track structures.

Finally, to complete any total system maintenance cost, the costs of supervision, engineering, and support staff, with appropriate overheads, were considered. Again, these were assumed to be relatively constant to the work items included and were not specifically designated in this analysis.

Computation of Material Costs

To develop these costs, it was first necessary to determine costs for each component of each track system (Table 2). The cost of concrete ties was projected from recent informal inquiries of the industry based on a minimum order of one million ties from a new plant to be located and built near the NEC for FOB delivery at NEC sidings. All other costs were derived from industry inquiries and were based on first-quarter 1977 prices. Other component costs common to all systems are shown on Table 3.

Computation of Initial Investment: Year 0 Costs

For each of the three types of track structure, initial construction data is developed for Year 0 costs. This data basically consists of the per-mile cost of labor, materials,

Table 2

TRACK COMPONENT COSTS

Wood Ties and Conventional OTM*	Cost per Tie
Wood tie (AREA No. 4 7"x9"x8'6") 1 @ $16.80	$16.80
Tie plate (AREA Plan No. 13) 2 @ $3.67	7.34
Cut spikes 6 @ $0.24	1.44
Rail anchors 2 @ $0.72	1.44
Total Cost per Tie	$27.02
Wood Ties, Elastic Fastening	
Wood tie 1 @ $17.22	$17.22
Special plates 2 @ $5.34	10.68
Lock spikes 8 @ $0.18	1.44
Elastic clips 4 @ $1.52	6.08
Total Cost per Tie	$35.42

*other track materials

Table 2 (continued)

Concrete Ties, Elastic Fastening

Concrete tie (AREA Performance Specification for monoblock, 8'6" in length) includes shoulders for elastic clips 1 @ $31.50	$31.50
Insulator assembly (nylon) 4 @ $0.45	1.80
Tie pads (polyethylene) 2 @ $0.50	1.00
Elastic clip 4 @ $1.52	6.08
Total cost per tie	$40.38

Table 3

OTHER COMPONENT COSTS

Component	Cost
Rail	$341.25 per net ton
Freight cost on rail, tie plates, and spikes	18.48 per gross ton
Ballast	2.75 per net ton
Freight on ballast	1.00 per net ton
Freight on wood ties	2.16 each
Freight on concrete ties	0.00 each FOB NEC

FUDGE

and equipment for installing the proposed track structure as detailed in Tables 4, 5, and 6. All costs are based on 1977 constant dollars.

Maintenance Costs

Tables 7, 8, and 9 summarize the costs per mile for each of the maintenance cycles considered for each track system considered. These costs are not discounted, but are present-day construction costs as inserted into the computer program at the frequencies described for each maintenance program.

Residual Values

In addressing each type of track structure and each configuration within the track structure, an offset to cost was considered at the time of rail replacement and at the end of the hypothetical system life. This offset to cost was labeled residual value. Each track configuration might have a scrap or reuse value associated with the rail, the ties, and other track material, e.g., plates, anchors, and spikes.

Computation of Life-Cycle Costs

Life-cycle costs encompass the initial material costs, initial installation costs, annual maintenance costs, and residual value of the track structure components for the projected life of the particular track system analyzed. In performing this analysis, the concept of present value of cash flow was employed. The Office of Management and Budget specifies the use of a ten-percent discount factor in present value calculations for all but a limited number of public investments.[20] This rate is intended to represent the opportunity cost of capital in the private sector of the U.S. economy, i.e., the returns that are foregone by investing in federal projects rather than private projects. The rate is not intended to incorporate considerations of uncertainty or inflation, but only the time value of money to the federal government.

A system life of 50 years was designated for the baseline cases. A 50-year life cycle was selected as baseline case because:

- The expected life of an improved rail right-of-way and track system capable of supporting subsequent vehicle sophistication should exceed 50 years

Table 4

ALTERNATIVE 1

YEAR 0 COSTS FOR WOOD-TIE TRACK WITH TRADITIONAL OTM* INSTALLED BY COMPONENT RENEWAL

Item	Labor	Material	Equipment	Subtotal	Total
Distributing tie	.59	2.16	.29	3.04	
Installing tie and surfacing	10.13	18.26	2.88	31.27	
Tie clean up	.60	.90	1.52	3.02	
Subtotal for each tie	11.32	21.32	4.69	37.33	
Total for 1,218 Ties**	13,788	25,968	5,712	45,468	45,468
Distributing CWR	612	4,082	1,116		5,810
Distributing OTM	1,406	1,880	634		3,920
Installing rail (includes rail cleanup and OTM)	21,380	122,618	9,080		153,078
Undercutting and surfacing with machine costs	4,859	425	6,574		11,858
Distributing bal-last	340	1,901	342		2,583
Inspection	287		51		338
Spot surfacing	151		92		243
Salvaging rail and OTM	—	(28,223)	—	—	(28,223)
Total Year 0 costs	42,823	128,651	23,601		195,075

*Other track materials.

**One mile tangent track; 1,218 ties of 3,250 removed.

Table 5

ALTERNATIVE 2

YEAR 0 COSTS FOR WOOD-TIE TRACK WITH ELASTIC FASTENING INSTALLED BY TOTAL RENEWAL

Item	Labor	Material	Equipment	Total
Distributing CWR	$ 612	$ 4,082	$ 1,329	$6,023
Preplating ties	838		271	1,109
Removing OTM	971		72	1,043
TLS including OTM cleanup	4,347	213,234	6,970	224,551
Tie sorting plant	1,126	1,211	404	2,741
Rail cleanup	1,074		1,469	2,543
Undercutting and surfacing with machine costs	3,764		6,144	9,908
Distributing ballast	340	1,901	342	2,583
Inspection	287		51	338
Spot surfacing	151		92	243
Salvaging rail and OTM		(28,223)		(28,223)
Salvaging ties	———	(10,968)	———	(10,968)
Total Year 0 Cost	$13,510	$181,237	$17,144	$211,891

Table 6

ALTERNATIVE 3

YEAR 0 COSTS FOR CONCRETE-TIE TRACK WITH ELASTIC FASTENING INSTALLED BY TOTAL RENEWAL

Item	Labor	Material	Equipment	Total
Distributing CWR	$ 612	$ 4,082	$ 1,329	$6,023
Removing OTM	971		72	1,043
TLS (rail and ties including OTM cleanup)	5,660	196,583	7,397	209,640
Tie sorting plant	1,126	1,211	404	2,741
Rail cleanup	1,074		1,469	2,543
Undercutting and surfacing with machine costs	5,356		10,642	15,998
Distributing ballast	340	1,901	342	2,583
Inspection	287		51	338
Spot surfacing	151		92	243
Salvaging rail and OTM		(28,223)		(28,223)
Salvaging ties		(10,968)		(10,968)
Total Year 0 Costs	$15,577	$164,586	$21,778	$201,941

Table 7

ALTERNATIVE 1

MAINTENANCE COSTS FOR WOOD-TIE TRACK WITH TRADITIONAL OTM INSTALLED BY COMPONENT RENEWAL

Item	Frequency	Unit Cost	Total
Inspection	Walk - twice weekly Geometry - two-week cycles Rail - three times yearly	$ 574 91 15	680
Spot surface	Three times yearly	243	729
Adding ballast	500 tons after renew ties and undercut	2,583	2,583
Renew ties and surface	812 every 6 years start Year 6	37.33/tie	30,312
Surfacing and lining, adding one inch of ballast	Yearly except at time of renew ties and undercut Includes replacing .32 percent anchors 250 tons of ballast	2,070 1,292	3,362
Renew rail and all OTM	Every 25 years	162,334	162,334
Surface grind rail	Every 4 years starting year after renew rail	488	488
Undercut and surface with air dump	Every 12 years	10,260	10,260

Table 7 (continued)

Item	Frequency	Unit Cost	Total
Residual value	Surface and line Years 6,12,18,24,30,36, 42,48	(3,362)	(3,362)
	Rail Years 25 and 50	(29,911)	(29,911)
	Residual Year 50		
	Ties-surfacing $\frac{21+15+9+3}{24}$ x	(30,312-2,070)= (56,484)	
	Rail 24/25 x 162,334 =	(155,841)	
	Undercut 9/12 x 10,260 =	(7,695)	
	Ballast 1/2 x 2,583	(1,292)	(221,312)

Table 8

ALTERNATIVE 2

MAINTENANCE COSTS FOR WOOD-TIE TRACK WITH
ELASTIC FASTENING INSTALLED BY TOTAL RENEWAL

Item	Frequency	Unit Cost Per Mile	Total Cost Per Mile
Inspection	Same as traditional method	Same	680
Spot surfacing	Same as traditional method	Same	729
Adding ballast	500 tons with undercutting	2,583	2,583
Spot ties	20 percent of defective ties		
	52 @ 12 years after TLS	58.22	3,027
	124 @ 16 years after TLS		7,219
	210 @ 20 years after TLS		12,226
Surfacing and lining adding one inch of ballast	Yearly except after undercutting includes .32 percent		
	new clips	2,138	3,430
	250 tons ballast	1,292	
Renew rail	See TLS	N/A	N/A
Undercutting and surfacing with machinery costs	After TLS	8,598	8,598
	Every 25 years starting Year 12	10,159	10,159
Rail surface grinding	Every 4 years starting Year after renew rail	488	488
TLS	Every 25 years	238,143	238,143

Table 8 (continued)

Item	Frequency	Unit Cost	Total
Residual value	Surface and line		
	Years 12,25,37,50	(3,430)	(3,430)
	Rail and ties		
	Years 25 and 50	(37,654)	(37,654)
	Residual Year 50		
	Undercut 11/12 x 8,598	(7,882)	
	TLS 24/25 x 238,143	(228,618)	
	Ballast 11/12 x 2,583	(2,368)	(238,868)

Table 9

ALTERNATIVE 3

MAINTENANCE COSTS FOR CONCRETE-TIE TRACK WITH ELASTIC FASTENING INSTALLED BY TOTAL RENEWAL

Item	Frequency	Unit Cost Per Mile	Total Cost Per Mile
Inspection	Same as traditional method	Same	680
Spot surfacing	7 times between surfacing	243 x 7/2	850
Adding ballast	500 tons with undercutter	2,583	2,583
Spot ties	10 percent defective ties		
	18 ties 24 years after TLS		1,869
	62 ties 36 years after TLS	$103.83	6,437
	100 ties 44 years after TLS		10,383
Surfacing and lining, adding one inch of ballast	Biannually except after under-cutting. Includes .32 percent clips, .46 percent pads and .95 percent insulators	2,096	
	250 tons ballast	1,292	3,388
Rail renewal	Every 35 years	140,833	140,833
Undercutting and surfacing with machine costs	Years 12,25,37 and 50	9,961	9,961
	With TLS	8,598	8,598
Rail surface grinding	Every 4 years starting year after renew rail	488	488
TLS	Tie only - Year 50	122,233	122,233

Table 9 (continued)

Item	Frequency	Unit Cost	Total
Residual value	Rail-Year 35	(24,054)	(24,054)
	TLS-Year 50		
	Clips	(860)	
	Ties	(13,150)	(14,010)
	Residual Value Year 50		
	Ballast 11/12 x 2,583	(2,368)	
	Rail 19/35 x 140,833	(76,452)	
	Grind 1/4 x 488	(122)	
	Undercut 11/2 x 9,961	(7,882)	
	9,961 - 8,598	(1,363)	
	TLS 49/50 x 122,233	(119,788)	(207,975)

- The service life of a new or rehabilitated steel or concrete bridge on which an NEC track will be placed would exceed 50 years.

A computer program was developed which accepted and arrayed the total initial construction costs and each of the categories of maintenance costs and any residual values, all identified as to years in which they occur. This program was capable of computing discount rates against all input costs and for any residual value entries. Tables 10, 11, and 12 are the computer printouts for each of the track systems.

<u>Cost Sensitivity</u>

In developing the cost analysis, several areas of sensitivity were investigated. The analyzed areas included discount rates (the discount rate varied in increments of two percent from six to 12 percent), tie life, and rail life. The analysis provided these findings:

PRETTY GOOD RETURN

- As the discount rate increases, the life-cycle cost advantage of concrete ties decreases. At a 12-percent discount rate, concrete ties no longer hold their advantage over wood ties.

- Rail life with concrete ties varied from 25 to 35 years with a negligible effect on life-cycle costs.

- Tie life of concrete ties varied from 40 to 50 years without affecting life-cycle costs by more than two percent.

The cost analysis performed in this report included the cost for renewing rail in all alternatives analyzed. Should the rail renewal operation be deleted from each alternative, it would further improve the advantage held by the component-renewal method of track upgrading in the Year 0 costs. Also, it would decrease, if not eliminate, the cost advantage held by the total-renewal method in the life-cycle costs. This results from the assumption that the TLS requires no additional equipment or labor costs to install rail, while the component-renewal method must include the costs of equipment and labor for an independent rail-renewal gang.

TABLE 10
ALTERNATIVE 1

INITIAL COST= 195075.

DISCOUNT FACTOR=.100

YR	INSPCT	SPOT-S	ADDBAL	RENTIE	SF&LNE	RERAIL	GRIND1	UCUT	RESDUE					DISCOUNTED
0														195075.
1	680	729	0	0	3362	0	488	0	0	0	0	0	0	4781.
2	680	729	0	0	3362	0	0	0	0	0	0	0	0	3943.
3	680	729	0	0	3362	0	0	0	0	0	0	0	0	3585.
4	680	729	0	0	3362	0	0	0	0	0	0	0	0	3259.
5	680	729	0	0	3362	0	488	0	0	0	0	0	0	3265.
6	680	729	2583	30312	3362	0	0	0	-3362	0	0	0	0	19364.
7	680	729	0	0	3362	0	0	0	0	0	0	0	0	2448.
8	680	729	0	0	3362	0	0	0	0	0	0	0	0	2226.
9	680	729	0	0	3362	0	488	0	0	0	0	0	0	2230.
10	680	729	0	0	3362	0	0	0	0	0	0	0	0	1939.
11	680	729	0	0	3362	0	0	0	0	0	0	0	0	1672.
12	680	729	2583	30312	3362	0	0	10260	-3362	0	0	0	0	14200.
13	680	729	0	0	3362	0	488	0	0	0	0	0	0	1523.
14	680	729	0	0	3362	0	0	0	0	0	0	0	0	1256.
15	680	729	0	0	3362	0	0	0	0	0	0	0	0	1142.
16	680	729	0	0	3362	0	0	0	0	0	0	0	0	1038.
17	680	729	0	0	3362	0	488	0	0	0	0	0	0	1040.
18	680	729	2583	30312	3362	0	0	0	-3362	0	0	0	0	6170.
19	680	729	0	0	3362	0	0	0	0	0	0	0	0	780.
20	680	729	0	0	3362	0	0	0	0	0	0	0	0	709.
21	680	729	0	0	3362	0	488	0	0	0	0	0	0	711.
22	680	729	0	0	3362	0	0	0	0	0	0	0	0	586.
23	680	729	0	0	3362	0	0	0	0	0	0	0	0	533.
24	680	729	2583	30312	3362	0	0	10260	-3362	0	0	0	0	4524.
25	680	729	0	0	3362	162334	0	0	-29911	0	0	0	0	12663.
26	680	729	0	0	3362	0	488	0	0	0	0	0	0	441.
27	680	729	0	0	3362	0	0	0	0	0	0	0	0	364.
28	680	729	0	0	3362	0	0	0	0	0	0	0	0	331.
29	680	729	0	0	3362	0	0	0	0	0	0	0	0	301.
30	680	729	2583	30312	3362	0	488	0	-3362	0	0	0	0	1994.
31	680	729	0	0	3362	0	0	0	0	0	0	0	0	249.
32	680	729	0	0	3362	0	0	0	0	0	0	0	0	226.
33	680	729	0	0	3362	0	0	0	0	0	0	0	0	205.
34	680	729	0	0	3362	0	488	0	0	0	0	0	0	206.
35	680	729	0	0	3362	0	0	0	0	0	0	0	0	170.
36	680	729	2583	30312	3362	0	0	10260	-3362	0	0	0	0	1442.
37	680	729	0	0	3362	0	0	0	0	0	0	0	0	140.
38	680	729	0	0	3362	0	488	0	0	0	0	0	0	141.
39	680	729	0	0	3362	0	0	0	0	0	0	0	0	116.
40	680	729	0	0	3362	0	0	0	0	0	0	0	0	105.
41	680	729	0	0	3362	0	0	0	0	0	0	0	0	96.
42	680	729	2583	30312	3362	0	488	0	-3362	0	0	0	0	635.
43	680	729	0	0	3362	0	0	0	0	0	0	0	0	79.
44	680	729	0	0	3362	0	0	0	0	0	0	0	0	72.
45	680	729	0	0	3362	0	0	0	0	0	0	0	0	65.
46	680	729	0	0	3362	0	488	0	0	0	0	0	0	66.
47	680	729	0	0	3362	0	0	0	0	0	0	0	0	54.
48	680	729	2583	30312	3362	0	0	10260	-3362	0	0	0	0	459.
49	680	729	0	0	3362	0	0	0	0	0	0	0	0	45.
50	680	729	0	0	3362	162334	0	0	-251223	0	0	0	0	-717.
	6742.	7228.	3313.	38882.	33334.	16366.	1374.	4749.	-9213.	0.	0.	0.	0.	297848.

LIFE CYCLE COSTS FOR WOOD–TIE TRACK WITH TRADITIONAL OTM INSTALLED BY COMPONENT RENEWAL

6742.	7228.	3313.	38882.	33334.	16366.	1374.	4749.	-9213.	0.	0.	0.	0.	297848.

LIFE CYCLE COSTS FOR WOOD–TIE TRACK WITH TRADITIONAL OTM INSTALLED BY COMPONENT RENEWAL

TABLE 10
ALTERNATIVE 1

INITIAL COST = 211891. DISCOUNT FACTOR =.100

YR	INSPCT	SPOT-S	ADDBAL	SPTIE1	SF&LNE	RERAIL	GRIND1	UCUT1	SPTIE2	TLS	SPTIE3	RESDUE	UCUT2	DISCOUNTED
0														211891.
1	680	729	0	0	3430	0	488	0	0	0	0	0	0	4843.
2	680	729	0	0	3430	0	0	0	0	0	0	0	0	3999.
3	680	729	0	0	3430	0	0	0	0	0	0	0	0	3636.
4	680	729	0	0	3430	0	0	0	0	0	0	0	0	3305.
5	680	729	0	0	3430	0	488	0	0	0	0	0	0	3308.
6	680	729	0	0	3430	0	0	0	0	0	0	0	0	2731.
7	680	729	0	0	3430	0	0	0	0	0	0	0	0	2483.
8	680	729	0	0	3430	0	0	0	0	0	0	0	0	2257.
9	680	729	0	0	3430	0	488	0	0	0	0	0	0	2259.
10	680	729	0	0	3430	0	0	0	0	0	0	0	0	1866.
11	680	729	0	0	3430	0	0	0	0	0	0	0	0	1696.
12	680	729	2583	3027	3430	0	0	10159	0	0	0	-3430	0	5473.
13	680	729	0	0	3430	0	488	0	0	0	0	0	0	1543.
14	680	729	0	0	3430	0	0	0	0	0	0	0	0	1274.
15	680	729	0	0	3430	0	0	0	0	0	0	0	0	1158.
16	680	729	0	0	3430	0	0	0	7219	0	0	0	0	2624.
17	680	729	0	0	3430	0	488	0	0	0	0	0	0	1054.
18	680	729	0	0	3430	0	0	0	0	0	0	0	0	870.
19	680	729	0	0	3430	0	0	0	0	0	0	0	0	791.
20	680	729	0	0	3430	0	0	0	0	0	12226	0	0	2537.
21	680	729	0	0	3430	0	488	0	0	0	0	0	0	720.
22	680	729	0	0	3430	0	0	0	0	0	0	0	0	594.
23	680	729	0	0	3430	0	0	0	0	0	0	0	0	540.
24	680	729	0	0	3430	0	0	0	0	0	0	0	0	491.
25	680	729	2583	0	3430	0	0	0	0	238143	0	-41084	8598	19667.
26	680	729	0	0	3430	0	488	0	0	0	0	0	0	447.
27	680	729	0	0	3430	0	0	0	0	0	0	0	0	369.
28	680	729	0	0	3430	0	0	0	0	0	0	0	0	336.
29	680	729	0	0	3430	0	0	0	0	0	0	0	0	305.
30	680	729	0	0	3430	0	488	0	0	0	0	0	0	305.
31	680	729	0	0	3430	0	0	0	0	0	0	0	0	252.
32	680	729	0	0	3430	0	0	0	0	0	0	0	0	229.
33	680	729	0	0	3430	0	0	0	0	0	0	0	0	208.
34	680	729	0	0	3430	0	488	0	0	0	0	0	0	209.
35	680	729	0	0	3430	0	0	0	0	0	0	0	0	172.
36	680	729	0	0	3430	0	0	0	0	0	0	0	0	157.
37	680	729	2583	3027	3430	0	0	10159	0	0	0	-3430	0	505.
38	680	729	0	0	3430	0	488	0	0	0	0	0	0	142.
39	680	729	0	0	3430	0	0	0	0	0	0	0	0	118.
40	680	729	0	0	3430	0	0	0	0	0	0	0	0	107.
41	680	729	0	0	3430	0	0	0	7219	0	0	0	0	242.
42	680	729	0	0	3430	0	488	0	0	0	0	0	0	97.
43	680	729	0	0	3430	0	0	0	0	0	0	0	0	80.
44	680	729	0	0	3430	0	0	0	0	0	0	0	0	73.
45	680	729	0	0	3430	0	0	0	0	0	12226	0	0	234.
46	680	729	0	0	3430	0	488	0	0	0	0	0	0	66.
47	680	729	0	0	3430	0	0	0	0	0	0	0	0	55.
48	680	729	0	0	3430	0	0	0	0	0	0	0	0	50.
49	680	729	0	0	3430	0	0	0	0	0	0	0	0	45.
50	680	729	2583	0	3430	0	0	0	0	238143	0	-279952	8598	-220.
	6742.	7228.	1159.	1054.	34008.	0.	1374.	3536.	1716.	24009.	1985.	-7371.	867.	288197.

LIFE CYCLE COSTS FOR WOOD–TIE TRACK WITH ELASTIC FASTENING INSTALLED BY TOTAL RENEWAL

TABLE 11
ALTERNATIVE 2

INITIAL COST = 201941. DISCOUNT FACTOR =.10

YR	INSPEC	SPOT-S	ADDBAL	SPTIE1	SF&LN1	RERAIL	GRIND1	UNCUT1	SF&LN2	TLS	SPTIE2	SPTIE3	RESDUE	DISCOUNTED
0														201941.
1	680	850	0	0	0	0	488	0	0	0	0	0	0	1835.
2	680	850	0	0	3388	0	0	0	0	0	0	0	0	4064.
3	680	850	0	0	0	0	0	0	0	0	0	0	0	1150.
4	680	850	0	0	3388	0	0	0	0	0	0	0	0	3359.
5	680	850	0	0	0	0	488	0	0	0	0	0	0	1253.
6	680	850	0	0	3388	0	0	0	0	0	0	0	0	2776.
7	680	850	0	0	0	0	0	0	0	0	0	0	0	785.
8	680	850	0	0	3388	0	0	0	0	0	0	0	0	2294.
9	680	850	0	0	0	0	488	0	0	0	0	0	0	856.
10	680	850	0	0	3388	0	0	0	0	0	0	0	0	1896.
11	680	850	0	0	0	0	0	0	0	0	0	0	0	536.
12	680	850	2583	0	0	0	0	9961	0	0	0	0	0	4484.
13	680	850	0	0	0	0	488	0	0	0	0	0	0	585.
14	680	850	0	0	3388	0	0	0	0	0	0	0	0	1295.
15	680	850	0	0	0	0	0	0	0	0	0	0	0	366.
16	680	850	0	0	3388	0	0	0	0	0	0	0	0	1070.
17	680	850	0	0	0	0	488	0	0	0	0	0	0	399.
18	680	850	0	0	3388	0	0	0	0	0	0	0	0	885.
19	680	850	0	0	0	0	0	0	0	0	0	0	0	250.
20	680	850	0	0	3388	0	0	0	0	0	0	0	0	731.
21	680	850	0	0	0	0	488	0	0	0	0	0	0	273.
22	680	850	0	0	3388	0	0	0	0	0	0	0	0	604.
23	680	850	0	0	0	0	0	0	0	0	0	0	0	171.
24	680	850	0	1869	3388	0	0	0	0	0	0	0	0	689.
25	680	850	2583	0	0	0	488	9961	0	0	0	0	0	1344.
26	680	850	0	0	0	0	0	0	0	0	0	0	0	128.
27	680	850	0	0	0	0	0	0	3388	0	0	0	0	375.
28	680	850	0	0	0	0	0	0	0	0	0	0	0	106.
29	680	850	0	0	0	0	488	0	3388	0	0	0	0	341.
30	680	850	0	0	0	0	0	0	0	0	0	0	0	88.
31	680	850	0	0	0	0	0	0	3388	0	0	0	0	256.
32	680	850	0	0	0	0	0	0	0	0	0	0	0	72.
33	680	850	0	0	0	0	488	0	3388	0	0	0	0	233.
34	680	850	0	0	0	0	0	0	0	0	0	0	0	60.
35	680	850	0	0	0	140833	0	0	3388	0	0	0	-24054	4331.
36	680	850	0	0	0	0	488	0	0	0	6437	0	0	274.
37	680	850	2583	0	0	0	0	9961	0	0	0	0	0	414.
38	680	850	0	0	0	0	0	0	0	0	0	0	0	41.
39	680	850	0	0	0	0	0	0	3388	0	0	0	0	120.
40	680	850	0	0	0	0	488	0	0	0	0	0	0	45.
41	680	850	0	0	0	0	0	0	3388	0	0	0	0	99.
42	680	850	0	0	0	0	0	0	0	0	0	0	0	28.
43	680	850	0	0	0	0	0	0	3388	0	0	0	0	82.
44	680	850	0	0	0	0	488	0	0	0	0	10383	0	187.
45	680	850	0	0	0	0	0	0	3388	0	0	0	0	67.
46	680	850	0	0	0	0	0	0	0	0	0	0	0	19.
47	680	850	0	0	0	0	0	0	3388	0	0	0	0	56.
48	680	850	0	0	0	0	488	0	0	0	0	0	0	21.
49	680	850	0	0	0	0	0	0	3388	0	0	0	0	46.
50	680	850	2583	0	0	0	0	9961	0	122233	0	0	-221985	-730.
	6742.	8428.	1159.	190.	13416.	5012.	1393.	4471.	1238.	1041.	208.	157.	-2747.	242649.

LIFE CYCLE COSTS FOR CONCRETE–TIE TRACK WITH ELASTIC FASTENING INSTALLED BY TOTAL RENEWAL

TABLE 12
ALTERNATIVE 3

Chapter 4

RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of this report is to examine several methods and combinations of methods and determine which should be adopted by the Northeast Corridor Improvement Project (NECIP) to upgrade track, and to recommend which tie type should be used. Two methods were studied: component replacement and complete rebuilding. For complete rebuilding, two tie types were studied, wood and concrete. From the two methods of upgrading track and the two types of ties, the three alternatives mentioned in Chapter 1 were selected for evaluation in this report.

ENGINEERING ANALYSIS

Design

The following are design factors considered in evaluation:

- Tie spacing for concrete is 24 inches; for wood ties, 19½ inches.

- Concrete-tie track provides better vertical and lateral track stiffness than does wood-tie track, due in part to the greater weight of concrete ties and the more rigid fastening system.

- The chances of a derailment is less on concrete-tie track due to the more stable track system, but concrete ties may experience more damage in a derailment. Also, the high track maintenance standards required for operation on the NEC will decrease the possibility of a derailment.

- Train operations on the NEC will consist of mixed traffic, high-tonnage freight and high-speed passenger, and will occur at frequent intervals. High track standards will be required for safe and continued train operations at designated speeds. As the frequency of train operations increases, track access for maintenance purposes will decrease. Therefore, a track structure must be selected which will be stable, degrade at a low rate and be maintainable in a cost-effective manner. Concrete-tie track provides such a structure.

Performance

The following are differences in performance between concrete and wood ties:

- Concrete-tie track settles at a faster rate than does wood-tie track on a new trackbed but at a slower rate on an existing trackbed.

- Concrete-tie track settles more uniformly than does wood-tie track, thereby providing a smoother, safer ride and greater ride comfort for high-speed passenger traffic.

- Concrete-tie track degrades more gradually than does wood-tie track, thereby maintaining alignment and gauge for a longer period. On concrete ties, rail has been observed to wear more slowly.

- Concrete-tie track exhibits much higher track modulus in the vertical and lateral planes than does wood-tie track.

- Concrete ties retain gauge better on curves than do wood ties with conventional fasteners.

- Elastic fastenings on wood ties reduce plate cutting more than do conventional fastenings.

Installation

The following installation factors were considered in evaluation:

- The traditional component-replacement method is the common method employed by most U.S. railroads.

- Maintenance equipment in this country is geared toward the component-renewal method and wood ties, and is readily available.

- Conventional maintenance equipment, while semiautomatic, requires a high level of labor support.

- The greater weight of concrete ties makes them awkward to handle with conventional maintenance equipment.

- Tighter tolerances and a more uniform, precise track structure result from total replacement by the TLS.

- The TLS has never been employed in the U.S., and maintenance forces are not familiar with its operation.

- If the TLS should incur a serious breakdown, then total track renewal would halt.

- The anticipated rate of production is higher for the TLS than for the traditional method.

- The TLS is highly mechanized, requiring minimal manual support.

- The TLS is capable of renewing rail and ties simultaneously, thus minimizing track usage and reducing cost over the component-renewal method.

- The total-renewal method will minimize the quantity of track failure due to fatigue and wear if the maintenance program presented in this report is established and maintained.

- The TLS operation with undercutting has inherent logistical problems.

Maintenance

Maintenance factors considered in the evaluation were these:

- Inspection requirements are equal for all alternatives.

- Major track surfacing is projected annually for wood-tie track and biennially for concrete-tie track.

- Tie renewal will be required more frequently for wood-tie track than for concrete-tie track.

- Wood ties have an estimated life of 24 years when conventionally installed, and 25 years when installed by TLS.

- Concrete ties have an estimated life of 50 years.

- Concrete-tie track should prove to have fewer irregularities than wood-tie track, therefore requiring less maintenance and providing more ride stability for high-speed passenger service.
- On the NEC, rail life on wood ties is estimated to be 25 years; on concrete ties, 35 years.
- After initial installation, ballast cleaning and rail grinding requirements for concrete- and wood-tie track were determined to be comparable.
- Total track renewal should minimize the operational interference due to track occupancy by maintenance forces.

Energy Consumption

Depending on the data used, there is no appreciable difference in energy consumption between the manufacture of wood ties and that of concrete ties. When considering the lower maintenance operation on concrete-tie track and the shorter life of wood ties, concrete ties show a slight advantage in energy consumption.

ECONOMIC ANALYSIS

Year 0 Costs

Concrete-tie track costs are based on new plant facilities with a minimum production capacity of one million ties for the NECIP. The three alternatives do not exhibit significant cost differences (Table 13).

Life-Cycle Costs

Concrete-tie track has a lower life-cycle cost than does wood-tie track installed by component renewal methods or by total renewal methods discounted ten percent (Table 13). Reducing concrete tie life to 40 years does not significantly affect life-cycle costs.

CONCLUSIONS AND RECOMMENDATIONS

This investigation has determined that both wood- and concrete-tie tracks are capable of supporting the high-speed passenger traffic and mixed freight traffic on the NEC in a safe and cost-effective manner. When placed in track by the

BY THE WHAT?

Table 13

COSTS PER MILE OF TRACK UPGRADING
(1977 constant dollars)

Structure Basis and Renewal Method	Year 0	50-Year Life Cycle (10-percent discount rate)
Component renewal - wood ties (Alternative 1) Wood ties with spikes (24-year average tie life, 25-year average rail life, new rail and 1,218 ties in Year 0, 812 ties every six years)	$195,075	$297,848
Total renewal - wood ties (Alternative 2) Wood ties with elastic fastener (25-year average tie life, 25-year average rail life, new rail and 3,250 ties in Year 0, and in Year 25, 52 new ties every 12 years, 124 new ties every 16 years, 210 new ties every 20 years)	$211,891	$288,197
Total renewal - concrete ties (Alternative 3) Concrete ties with elastic fastener (50-year average tie life, new rail and 2,640 ties in Year 0, 18 new ties every 24 years, 62 new ties every 36 years, 100 new ties every 44 years)	$201,941	$242,649

TLS, more miles of upgrading per dollar can be accomplished with the total-renewal program than with wood ties installed by the component-renewal method in a limited period of time. Concrete-tie track was shown to be superior to wood-tie track based on total engineering and life-cycle costs. Adequate concrete tie procurement for approximately 400 miles of track is required to ensure cost effectiveness. It is therefore recommended that concrete-tie track be installed by a TLS on the high-speed designated passenger tracks. Wood ties should be installed by traditional methods to upgrade the balance of track on the NEC.

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