Crossties for Transit Track

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ABSTRACT

The objective of the paper is to define the design requirements for rapid transit crossties as compared with crossties for railroad service. In one section the importance of the transit crosstie is identified, the significant differences between the transit and railroad versions are compared, and the materials used for transit crossties are reviewed. In the second section the application of concrete ties to transit tracks is addressed. The specific requirements of tie design parameters, the rail fastening system, and other hardware were considered. In addition, installation methods and equipment, special applications, and factors that influence first cost and life-cycle costs were identified.

Other papers in this Record have generally concentrated on crossties in railroad applications. Although railroad and transit crossties are similar in form and function, there are significant differences that are identified and discussed in the two major sections of this paper.

In the first section the importance of the transit crosstie is identified, the significant differences between the transit and railroad versions are compared, and the materials used for transit crossties are reviewed. In the second section the application of concrete ties to transit tracks is addressed. The specific requirements of tie design parameters, the rail fastening system, and other hardware are considered. In addition, installation methods and equipment, special applications, and factors that influence first costs and life-cycle costs are identified.

GENERAL CONSIDERATIONS

The functions of the crosstie in track have been defined by other papers in this Record. However, for transit application, the functions can be divided into the following categories:

1. Primary--tie the rails together to hold track gauge and distribute the various three-dimensional loads to the ballast; and
2. Secondary--provide resilience and electrical insulation, support the third rail and other electrical equipment, and support other track devices such as guardrails and restraining rails.

Significant differences between transit and railroad crossties occur in the primary function because of lighter transit loading, and in the secondary function because of additional electrical and structural requirements for transit applications.

Importance of Transit Crosstie

The procurement of crossties and rail fasteners and anchors is an important element of the installed cost of new at-grade transit track, as indicated by the data in Table 1. The total cost related to crossties exceeds 20 percent because the labor and equipment to distribute and install the crossties is included in item 4. Thus the importance of the crosstie on installed cost of track is established.

The maintenance of crossties and rail fasteners and anchors is a significant element of the annual expense to maintain at-grade track, as indicated by the data in Table 2. All tasks are performed in one pass and scheduled on an 18-month cycle. Actual working time averages 3 hr per night during system shutdown. Equipment maintenance and amortization are not included.

TABLE 1 Construction Cost per Single Track Mile

Item	Description	Cost per Mile ($000s)	Percent
1	Furnish rail	47.4	31
2	Furnish concrete crossties	30.9	20
3	Furnish and install ballast	30.5	20
4	Install track	20.1	13
5	Miscellaneous	25.0	16
Total		153.9	

Note: Data are from San Francisco Bay Area Rapid Transit (BART) average bid costs, in January 1970 dollars.

TABLE 2 Routine Maintenance Expense per Single Track Mile

Item	Task	Expense per Cycle[a] ($)	Percent
1	Line and surface	3,240	30
2	Tamp ballast	2,880	26
3	Torque and lubricate bolts	2,160	20
4	Grind rail	1,620	15
5	Materials	890	8
6	Safety	170	1
Total		10,960	

Note: Data are from BART 1983 budget planning.

[a]1983 dollars.

Transit and Railroad Crosstie Comparison

Crosstie differences can be categorized into those related to the primary function, secondary functions, maintenance, and procurement.

Primary Function

The primary function differences between transit and railroad crossties are as follows.

1. Loading conditions: The maximum wheel load for transit vehicles is less than half that of freight railroad locomotives and cars. The transit impact factor (percentage of static load) is less because of the more sophisticated vehicle suspensions and tighter maintenance tolerances for vehicle

and track. However, there are five factors that, if applied to equal wheel loads, would result in more severe conditions for transit than railroads. The first is the uniformity of transit wheel loads caused by a smaller difference between empty and loaded vehicles. The second is the more common occurrence of flat wheels and the resultant high frequency impact loads. The third is the higher speed. The fourth is the higher acceleration and braking rates and resultant longitudinal loads on the track. The fifth is the stiffer truck, which tends to increase lateral load on the railhead.

2. Track alignment and tolerances: Transit criteria allow sharper curves and steeper grades than feasible with railroad, as the data in Table 3 indicate. In general, transit follows railroad practice for maximum superelevation and unbalance. Therefore, the lateral acceleration acting on transit and railroad vehicles is similar. Transit track maintenance tolerances are generally set in accordance with passenger comfort and therefore are tighter than freight railroads.

3. Track configuration: Typical transit design practice uses the freight railroad ballast section, as recommended by the American Railway Engineering Association (AREA). This includes 12 in. under the crosstie and 9 to 12 in. of shoulder width. Transit crosstie spacing is increased based on the maximum allowable pressure on the ballast and subgrade, as recommended by AREA or as required by local conditions.

TABLE 3 Transit and Railroad Alignment Comparison

Requirement	Unit	Transit	Railroad
Maximum horizontal curve radius	Feet	500	1,146
	Degree	11-28	5
Maximum vertical curve rate			
Sag	Feet per station	1.17	0.05
Summit	Feet per station	0.58	0.10
Maximum grades	Percent	4	2

Note: Data are typical for new construction of main tracks for heavy rail transit and freight railroads.

Secondary Functions

The secondary function differences between transit and railroad crossties include the following.

1. Electrical insulation: A resistance or impedance of 20,000 ohms between running rails is a common requirement for transit and railroad crossties to be installed in tracks with automatic signals. However, transit crossties and rail fasteners and anchors to be installed on direct current (dc) traction systems must provide higher resistance to minimize electrical leakage and the resultant electrolytic corrosion of adjacent pipelines and structures. Resistance values of up to 1,000,000 ohms between each rail seat and ground have been specified for transit crossties.

2. Electrical equipment: Transit crossties must support and restrain an electrified third rail. Loads transmitted to the crossties include gravity, wind, thermal expansion, and electromagnetic attraction. In addition, other electrical equipment (such as impedance bonds, trip stops, and signal loops) may be mounted on the crosstie.

3. Guardrails: The urban setting of transit systems requires more guardrails to protect adjacent bridge piers and other structures near the track.

4. Restraining rails: The sharper curves of transit tracks require more restraining rails to help guide and restrain the wheels.

Maintenance

The maintenance differences between transit and railroad crossties are a matter of degree. In general, the maintenance of transit tracks is more difficult than railroad tracks because of the following factors.

1. Limited access: Workers, equipment, and materials must move on the tracks to the work site. All work must be done within the right-of-way or structural limits.

2. Limited time: Train frequency, which is usually in minutes, requires either late night work or complex operating and work procedures under traffic.

These factors tend to stimulate interest among transit engineers in crosstie and fastener designs that allow for quick change-out of worn components.

Procurement

The procurement differences between transit and railroad crossties include the following.

1. Capital financing: Transit projects are funded with public money and controlled by government regulations that cover competitive bidding, bonding, minority participation, minimum wages, and so forth. Railroad projects are privately funded subject to accounting practices and income tax regulations.

2. Procurement quantities: Transit projects require smaller quantities of crossties than railroad projects.

Transit Crosstie Materials

Transit crossties, like their railroad counterpart, are fabricated from a full range of materials, including timber, steel, and concrete. Historically, timber crossties and standard railroad fasteners and anchors were selected by most transit properties because of availability and lowest first cost. Even today, the majority of transit crossties are of this type.

Timber crossties are cut, seasoned, and pressure treated in accordance with specifications, such as those by the American Wood Preservers Association. Wood is selected by the locale; however, oaks and mixed hardwoods are the most common. The widespread use of timber has not hampered the development of new technology. Laminated and remanufactured timber ties have been tested, and new resilient rail fasteners are in service to reduce maintenance expenses and improve performance.

Steel crossties are used where transit tracks are set in pavement. There are two types: the tie bar bolted through the rail webs, and the flat type clipped to the rail bases. Both types hold track gauge and anchor the track in the pavement.

Concrete crossties are designed and fabricated in accordance with the performance requirements of each transit property. A number of new transit projects, and extensions to existing systems, have selected concrete crossties during the past 2 decades. These decisions to use concrete were based on an analysis of total purchase cost plus annual expenses, and clearly set a new trend for transit crossties. The trend toward concrete is covered in the next section.

CONCRETE TIES FOR TRANSIT TRACKS

The first major installation of prestressed concrete

ties in a U.S. transit track was made by the San Francisco BART system in the late 1960s (Figure 1). Since then, concrete ties have been installed in nine transit properties in the United States and Canada, with two more in the planning or early construction stage. In the following commentary an outline of the requirements for concrete transit ties is given, which covers such items as specifications, testing, rail fastening systems, installation, and costs.

FIGURE 1 Prestressed concrete ties on BART.

Technical

Specifications

Transit agencies that use concrete ties have usually produced their own specifications that reflect the service loading conditions for the particular property. As a general rule, the specifications are of the performance type, which lists parameters for tie spacing, dimensions, rail size, gauge, maximum ballast pressure, and design bending moments. Relevant standard specifications for the materials used in the production of the concrete ties and the fastening system are given. In each case a qualification test procedure is required, and during production a quality control program that includes material and product testing on a daily basis is also required.

In an effort to standardize transit concrete tie design and rail fastening requirements and therefore reduce costs, the Transit Development Corporation entered a contract in 1975 with Construction Technology Laboratories (CTL), a division of the Portland Cement Association in Skokie, Illinois. Two standard tie designs resulted--a pretensioned monoblock and a posttensioned two-block tie--and preliminary specifications were developed.

This earlier work was extended by CTL under a contract with UMTA. Management of the program was provided by the Transportation Systems Center, U.S. Department of Transportation. To standardize the loading parameters, CTL conducted a survey of U.S. and Canadian vehicle weights and operating conditions. The resulting designs satisfy the loading requirements. Under the program the two types of standard transit concrete ties were produced; they were then subjected to laboratory tests, and revised specifications were published for the materials, manufacture, and handling of the two standard designs.

The specifications do not prohibit other concrete tie designs, and therefore can be used as a guide for those agencies contemplating the use of concrete ties in their track structure. Some typical design values from transit agencies that have used or intend to use concrete ties are given in Table 4.

Testing

Concrete tie testing falls into two categories:

TABLE 4 Comparison of Tie Design Parameters

Transit Agency	Maximum Axle Load (lb 000s)	Rail Weight (lb/yd)	Nominal Gauge	Tie Spacing (in.)	Tie Length	Design Bending Moment (kips/in.) Railseat Positive	Railseat Negative	Tie Center Positive	Tie Center Negative
Atlanta: Metropolitan Atlanta Rapid Transit Authority (MARTA)									
Monoblock	30	115 RE	4 ft, 8.5 in.	30	8 ft, 6 in.	132	–	–	148
Two-block					7 ft, 4.75 in.				
Boston: Massachusetts Bay Transportation Authority (MBTA)									
Monoblock	30	115 RE	4 ft, 8.5 in.	30	8 ft	130	80	100	150
Two-block					7 ft, 4.75 in.				
Baltimore: Mass Transit Administration of Maryland (MTA)									
Monoblock	30	115 RE	4 ft, 8.5 in.	30	8 ft, 6 in.	141	99	81	115
Two-block					7 ft, 4.75 in.				
Calgary Transit–monoblock	21	100 AR-A	4 ft, 8.5 in.	26	8 ft, 3 in.	239	127	–	200
Chicago: Chicago Transit Authority (CTA)–two-block	26.5	115 RE	4 ft, 8.5 in.	30	7 ft, 4.75 in.				
Miami: Metropolitan Dade County Transportation Administration (MDCTA)–monoblock	30	115 RE	4 ft, 8.5 in.	30	8 ft, 6 in.	153	70	70	149
Philadelphia: Southeastern Pennsylvania Transportation Authority (SEPTA)–two-block, commuter	30	132 RE	4 ft, 8.5 in.	24	7 ft, 4.75 in.				
San Francisco: Bay Area Rapid Transit (BART)–monoblock	30	119 CF&I	5 ft, 6 in.	30	9 ft	82	–	–	113
Toronto: Toronto Transit Commission (TTC)									
Monoblock	25	115 RE	4 ft, 10.875 in.	24-30	8 ft, 6 in.	300	115	–	200
Two-block	15		4 ft, 8.5 in.	30		273	141	–	158
Vancouver–monoblock	15	115 RE	4 ft, 8.5 in.	30	8 ft, 3 in.	302	93	–	117
Transportation Systems Center (TSC)									
Monoblock	30	Any	4 ft, 8.5 in.	30	8 ft, 6 in.	153	–	–	128
Two-block					8 ft	137	–	–	–

qualification and quality control production testing. Typical requirements are as follows. The objective of qualification testing is to prove new concrete tie and fastening system designs by subjecting samples to the sequence of tests outlined. For ties produced to UMTA specifications, qualification testing of the tie is not required, as this phase has already been completed by CTL. In the same manner, existing concrete ties and fastening systems could be qualified by similarity, thus eliminating the time and expense of a full qualification test program.

For concrete tie qualification testing, samples are subjected to the following tests:

1. Static flexural tests at the center of the rail seat and tie center;
2. Repeated load test at the center of the rail seat, and for some properties at the tie center (3 million cycles);
3. Pullout tests for rail fastening and contact rail inserts; and
4. Prestress tendon anchorage and ultimate tests.

For concrete tie quality control testing, the following tests are conducted during production on ties randomly selected from the production line:

1. Verification of rail seat center-to-center dimensions, and verification of rail seat configuration and fastening insert location;
2. Static flexural test at center of rail seat; and
3. Tendon anchorage and ultimate load test.

(Note that tests 1 and 2 are conducted at the rate of one tie for each 200 produced, and test 3 is conducted on one tie per 2,000 produced.)

For rail fastening systems, the following tests are conducted:

1. Uplift test,
2. Repeated load test (3 million cycles),
3. Longitudinal restraint test,
4. Lateral restraint test, and
5. Electrical resistance and impedance test.

Fastening Systems

Running Rail

The fastening systems used for securing the running rail to the concrete tie fall into two categories: bolted (e.g., BART, SEPTA) and nonbolted (e.g., MARTA, MBTA, MDCTA). There are advantages and disadvantages to both systems that may influence the choice of one or the other by the transit property. The two systems are compared as follows.

Bolted

A common rail seat is used for all ties and clips, and insulators are dimensioned to accommodate whatever rail section is chosen. An example (Figure 2) for BART is the system used for the 119-lb main-line rail and the 90-lb yard rail. Bolts, clips, and insulators may be disassembled if it is required to remove a tie from the track for any reason. This means that the tie can be pulled out with a minimum amount of jacking or disturbance to the ballast under the tie.

A disadvantage is that usually more maintenance is required to keep the bolts at specified torque, although this disadvantage is offset to a degree because the clip toe load can be kept at a specified value by the adjustability of the bolted connection. It is also somewhat more difficult to install bolted fastenings than to install the nonbolted type, as the rail must be aligned before the bolts can be properly inserted.

FIGURE 2 Bolted rail seat.

Nonbolted

Nonbolted systems use rail-locating shoulder inserts that are cast into the concrete tie during manufacture. These inserts are located in accordance with the chosen size of rail. Examples (Figures 3 and 4) are the Pandrol and DE systems. For installation, spring clips are inserted in the shoulder inserts, and electrical isolation is provided by insulators at the toe of the rail. The clips need no further adjustment. A disadvantage is that the shoulder insert location in the tie is fixed for all time, therefore limiting the rail size. This generally is of less consequence to transit lines than it is to normal railroad use, where ties may be required to accommodate 5.5- and 6-in. rail bases.

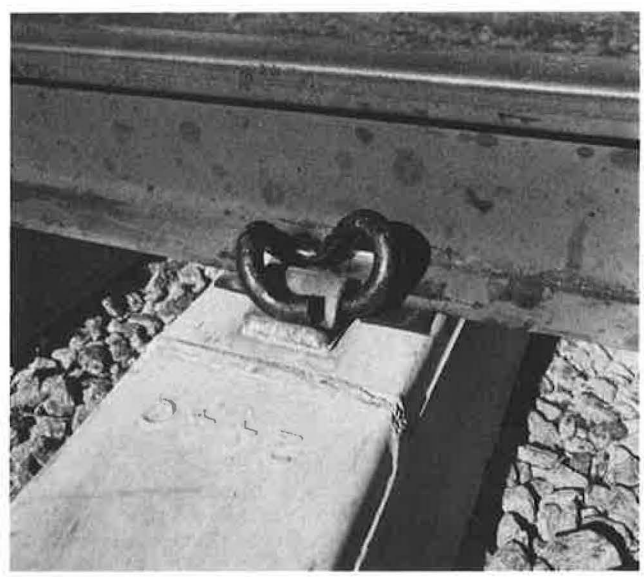

FIGURE 3 Pandrol nonbolted system.

Tie removal from the track is more difficult for nonbolted types than for bolted types, as the fixed shoulder inserts project above the rail seat sur-

FIGURE 4 DE nonbolted system.

face. Therefore, the rail must be jacked clear or the ballast removed underneath the tie to give clearance for removal. The fixed location of the shoulder inserts makes rail installation or change out easier than the bolted types, as the shoulder inserts act as guides for the rail.

Tie Pads

Elastomer or plastic tie pads are installed between the rail seat of the concrete tie and the rail. Their purpose is twofold. They are used to isolate the rail from the concrete electrically, in addition to providing a barrier against abrasion between the rail and the concrete rail seat. Recent studies on the National Railroad Passenger Corporation (Amtrak) Northeast Corridor have indicated that impact strains resulting from wheel flats and rail anomalies can be attenuated by tie pads designed for this purpose. Material selection and pad shape factors can be beneficial in reducing the effects of peak loading in the concrete tie. The use of softer pads may also help reduce noise.

Insulators

Nonconducting plastic insulators, usually molded from nylon, are used to isolate the rail from the clip and therefore provide electrical insulation between the hold-down shoulder inserts or threaded inserts and the rail.

Additional Insulation

MARTA and MDCTA specifications call for additional insulation to be provided by a 10-mil minimum thickness of nonconductive epoxy coating on the embedded surfaces of the shoulder insert that extends 0.25 in. above the surface of the concrete. Other transit agencies that use concrete ties do not require epoxy coating.

Guardrails and Restraining Rails

To date, guardrails have generally not been used with transit concrete ties. An exception is the MBTA, where a steel bracket is attached to the running rail in the crib between ties. This bracket supports the guardrail. In the future it is intended to use a double rail seat on the ties and thus eliminate this bracket and make rail removal for tamping easier. Restraining rails, also used by the MBTA, are accommodated by special ties in which the Pandrol shoulder inserts are spaced so that the running rail and restraining rail fit between them. The two rails are bolted together through the webs and spacer blocks. Hold down is provided by the spring clips.

Contact Rail Support Bracket Inserts

For contact rail support bracket inserts (Figure 5), the ties are the same length for the whole system. However, inserts are cast into one end of the tie at the time of manufacture. Although contact rail supports are usually spaced at 10-ft centers (i.e., for the normal spacing of transit concrete ties of 30-in. centers), every fourth concrete tie supports the contact rail; for flexibility during installation, each concrete tie is provided with contact rail support bracket inserts. The inserts are usually fabricated of stainless steel, although some transit properties have used plastic inserts for this purpose.

FIGURE 5 Contact rail support bracket inserts.

Installation

A typical method of installing the concrete ties is shown in Figure 6. In this case the ties are hung from a frame that is attached to a light crane. This device, used by the contractor for installing the BART concrete ties, suspends the ties so that alternate ties may be turned 180 degrees, and therefore contact rail inserts alternate on the end of every other tie to allow for the contact rail to be carried on either side of the track. This practice was discontinued in later phases of installation, as it was decided to install the contact rail on the inside ends of the ties. The frame was still used, as it provided a means of spacing the ties at the correct distance (30-in. centers).

Another method of distributing the ties is to use a forklift truck and set the ties on the subballast at the correct spacing as the forklift moves along the track bed. Also, machines have been developed for hardware installation. A multiple-head bolting machine can be used for installing clip bolts to the specified torque. For nonbolted systems, a mechani-

FIGURE 6 Installing concrete ties.

cal clip applicator can be used to insert four spring clips simultaneously.

Special Applications

In some properties (e.g., MARTA, MTA, and SEPTA), two-block ties fitted with rubber boots have been installed in subways to attenuate noise caused by low frequency vibrations. The encasement of the rubber-booted tie in concrete can be cost-effective when compared with floating-slab, direct-fixation systems.

Lateral Resistance

The greater mass of the concrete tie together with the torsional resistance offered by the fastening systems has been shown to increase the lateral strength of a concrete tie track by approximately 15 percent over a conventional wood tie track. However, if additional ballast interlock is required, the bottom surface of the tie may be indented. In order to provide ballast interlock in a 750-ft radius curve in the BART system, special concrete ties were produced. These ties feature a waffle indent pattern of 3 x 1.5 in. in the bottom surface of the tie.

Costs

All major cities usually have existing prestress or precast plants that may be used for concrete tie production (Figure 7). Permanent plant facilities (such as concrete batching and mixing equipment, steam curing systems, casting abutments and beds, pretensioning rams and pumps, and electric, water, and compressed air supply) can be used for tie production; the only major element requiring purchase is the steel forms.

If form costs were amortized over the intended procurement, the cost per tie would be as follows, based on a production rate of 300 ties per day, with a single form cavity cost of $800 (i.e., the total cost of forms would be 300 x $800 = $240,000):

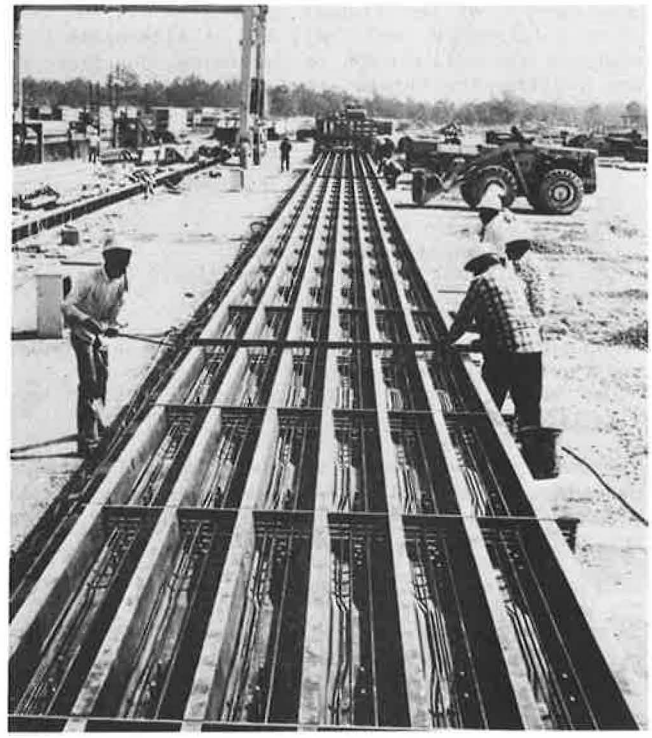

FIGURE 7 Concrete tie production.

Quantity in Procurement	Form Cost per Tie ($)
25,000	9.60
50,000	4.80
100,000	2.40
200,000	1.20
300,000	0.80

It is interesting to note that the life of the steel forms is at least 1,000 uses. Therefore, for the example quoted, 300,000 ties could be produced before replacement at a form cost of $0.80 per tie.

There are other factors that influence the cost of the tie, such as production labor efficiency (which is related to the daily production rate required to satisfy the delivery schedule), freight, and local material costs. Consideration should be given to the use of a standard transit concrete tie design, such as that proposed by TSC and UMTA, or alternatively, the use of a standard railroad concrete tie design. In both cases the use of existing forms can result in significant cost savings.

Often a standard railroad concrete tie may be modified by reducing the prestress and thus reducing the cost of prestress steel tendons. A typical railroad concrete tie weighs 750 lb, or 200 lb more than a typical transit concrete tie. This weight difference represents approximately $4 per tie for the added concrete and extra freight. This extra cost (for the railroad tie) could be offset if the ties required for the transit track were taken from a large-scale production run of railroad ties, where form and labor costs are at a minimum. Therefore, it is suggested that transit agencies contemplating the use of concrete ties should allow the option of existing, proven designs for bidding purposes, particularly when the procurement is for small quantities. In this way the most effective choice may be made.

Life-Cycle Costs

The decision to use wood or concrete ties in the

construction of new transit tracks should be made after a life-cycle cost analysis. A life-cycle cost analysis should be made to determine the present-worth difference between the wood and concrete tie track alternatives. The following elements should be considered:

1. First cost of ties and hardware;
2. Installation costs;
3. Maintenance costs;
4. Component replacement cost;
5. Escalation rates for material, labor, and equipment;
6. Discount rate;
7. Sensitivity to variations to the escalation and the discount rates; and
8. Sensitivity to variations in the assumed service life.

These factors will allow an economic evaluation to be made. Nevertheless, there are other factors that are more difficult to quantify, yet can have an important influence on the final decision:

1. Ballast quality requirements (may be lower for wood ties),
2. Energy savings related to reduced rolling resistance of concrete tie track,
3. Effects of track on vehicles,
4. Derailments,
5. Track occupancy time (favors concrete ties and positive fastening system), and
6. Environmental considerations.

As an example, an economic analysis was made by Bechtel, Inc., of timber and concrete ties for MARTA track. The present-worth method was used, and the maintenance cost items were distributed over a 75-year period, escalated by assumed inflation factors, and then discounted to present worth. The main cost items were as follows:

1. Installation;
2. Tie replacement, where service life was assumed to follow a statistical distribution with the mean values of 30 and 50 years for timber and concrete, respectively (the mean values were varied ± 5 years in a sensitivity analysis);
3. Timber ties regauged every 15 years;
4. Pad and insulators replaced for concrete ties every 25 years;
5. Rail and ballast replacement every 50 years; and
6. Line and surfacing every 5 years.

The effect of various escalation and discount rates was determined by computing 30 alternative combinations. The difference in present worth per main-line track mile between timber and concrete ties for the best estimate set of escalation and discount rates was as follows (in 1975 dollars):

1. Concrete ties higher initial cost = $15,000 per track mile;
2. Concrete tie maintenance cost present-worth savings = $33,300 per track mile; and
3. Concrete tie total present-worth savings = $18,300 per track mile.

This is equivalent to a savings of $930,000 for the total main-line track miles for the concrete alternative. An error analysis revealed as estimated error in the calculated difference of $6,000 per track mile.

The present-worth calculation is sensitive to variations in discount and escalation rates. A 2 percent variation around the best estimate set of factors indicates $134,000 at one extreme in favor of concrete and $5,000 in favor of timber ties at the other extreme. The calculations are also sensitive to changes in service life. For instance, a decrease in life for concrete ties from 50 to 45 years and an increase for timber ties from 30 to 35 years makes the difference in present worth decrease from $18,300 to $5,000. The opposite case, 50 to 55 years for concrete and 30 to 25 years for timber, increases the present worth to $35,000.

As noted previously, there are other factors that should be evaluated in the determination of the best alternative. A final choice may be made after due consideration of the economic, technical, environmental, and sociological factors.

ACKNOWLEDGMENT

Data for the section General Considerations were from research by Robert E. Clemons, and data for the section Concrete Ties for Transit Tracks were from research by Philip J. McQueen.

Publication of this paper sponsored by Committee on Track Structure System Design.