

# Concrete Tie Track System

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## ABSTRACT

In this paper the concrete tie track system is reviewed, with emphasis on the interrelationship of mechanical equipment with management of the track system. The research described in this paper is directed to the use of the concrete tie track system on North American freight railroads, with comments on the environment that justify its use. The concrete tie is reviewed relative to specifications, design parameters, production, quality control of materials and finished product, and procurement methods. Design considerations of the fastening system are discussed together with requirements for rail and ballast. Comments are also made with reference to mechanical equipment design. Field performance of the concrete tie track system is reviewed with comments on track and train dynamics; fuel savings; maintenance; electrical properties; rail life, renewal, and corrugation; tie cracking; and damage. A brief overview of three concrete tie installation methods is given together with comments on future developments of the system. Also, reference is made to international publications and research reports.

During the past 10 years in North America there has been much research activity into track and train dynamics, with particular reference to the performance of concrete tie track systems compared with the time-tested wood tie track assembly. In addition, four major North American railroads have made significant investments in concrete tie track systems: Florida East Coast (FEC) Railway, National Railroad Passenger Corporation (Amtrak), Canadian National (CN) Rail, and Kansas City Southern (KCS).

In this paper the results of some research projects and real-life railroading are discussed, together with an overview of manufacture and specification of the components, outline of three installation methods, the environment and benefits of concrete tie systems, and future developments.

In this paper it is assumed that use is made of monoblock pretensioned (or posttensioned) prestressed concrete ties with an elastic fastening system. Comments are mainly directed toward concrete tie track for use on North American freight railroads, although some of the comments apply equally to high-speed passenger lines.

## HISTORY

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

Prestressed concrete ties were first used on British Rail during World War II because of the acute shortage of lumber. Bull head rail was used on chairs anchored to the tie by screw spikes in

hardwood plugs. British Rail started their major concrete tie installation program (2) with the advent of flat bottom continuously welded rail (CWR) in the United Kingdom in the early 1950s.

The first use of prestressed concrete ties in the United States was in 1960 when 500 ties were installed on the Atlantic Coast Line Railroad and 600 ties were installed on the Seaboard Air Line Railroad, followed by 600,000 ties on the combined Seaboard Coastline Railroad.

In 1961 CN Rail started their extensive track test program in Canada, having put a few normally reinforced-concrete ties into track in the early 1920s. Subsequently, there have been more than 100 different concrete tie test installations throughout North America, including the test installation at the Facility for Accelerated Service Testing (FAST) in Colorado.

The first continuous North American installation started in 1966 on the FEC Railway, on which more than 900,000 concrete ties have now been installed. More recently, Amtrak has installed 1.1 million ties on the Northeast Corridor, and CN Rail has installed more than 2.3 million ties on their heavily trafficked and curved main line.

## COMPONENTS OF CONCRETE TIE TRACK

### The System

The concrete tie track system consists of subgrade, ballast, concrete ties, fastener system, and rail. The composite of these discrete items comprise today's concrete tie track. However, the interactions of vehicle and track are key to the performance of both. Therefore, the axle load, speed, curvature, gradient, train handling techniques, rail lubrication, design, and maintenance of mechanical equipment should all be considered when reviewing a track system.

### Ballast

Ballast for concrete ties should have the following qualities (3). Ballast should be

1. Hard enough to resist breakdown by abrasion;
2. Tough enough to resist breakdown by fracturing under the impact of traffic loads, with high wear and abrasive durability;
3. Dense enough, with good particle shape, to resist shear forces and to thus anchor the ties in the ballast;
4. Large, well-graded, and clean enough to provide free draining; and
5. Inert with resistance to temperature changes, chemical attack, freezing, or thawing.

Generally, granites, traprocks, or quartzites satisfy these requirements. Specifications for ballast for concrete tie track appear in Chapter 10 of the American Railway Engineering Association (AREA) manual (4). However, gradations No. 3, 4, and 24 of Chapter 1 of the AREA manual have performed well with concrete ties (3).

The tests found most effective in ballast selec-

tion are the Los Angeles Abrasion and the Thin Section Analysis tests. Other tests, as specified by AREA, are helpful but are secondary to the tests just mentioned and to in-track testing. Once a source is selected, then production-control tests would of course be necessary (5).

A new ballast performance-oriented test (3) is being developed. Impact testing by dropping a predetermined weight from a specific height onto a graded and confined ballast sample is the essence of this new test. The test appraises the impact degradation of the ballast particles through several test cycles. The objective is to simulate in the laboratory the track impact loadings and to compare field degradation with laboratory degradation to classify ballast.

A minimum of 12 in. of ballast is required between the bottom of the tie and the subballast to ensure even distribution of loads into the subballast. Base width of ties varies between 10 and 12 in. to keep ballast pressures low.

Tamping of concrete tie track is concentrated around the rail seat area to ensure that little reaction occurs at the tie center; that is, it is important to avoid center-bound track with concrete ties. Surfacing cycles must be planned to avoid this condition.

#### The Tie

##### Specifications

The standard specification for main-line concrete ties (including fastening systems and ballast) is given in Chapter 10 of the AREA manual (4). This manual sets down design considerations, performance requirements, and test procedures to both prove the design and to check the quality of production. Based on this specification and on the experience gained from AREA tests, certain railroads have developed their own specifications, for example, CN Rail, Canadian Pacific (CP) Rail, Amtrak, and FEC Railway. Likewise, most transit authorities have developed their own specifications, but with widely diverging requirements for bending moment capacity.

##### Tie Design Parameters

Concrete railroad ties in North America are now designed for static wheel loads of up to 40,000 lb, plus an impact factor that accounts for vehicle dynamics, wheel flats, track irregularities, and track stiffness. Tie bending moment requirements to satisfy these criteria are set out in the AREA manual (4). These requirements are dependent on axle load and tie spacing. Currently, ties are 8 ft, 3 in. to 8 ft, 6 in. long, weigh 630 to 800 lb, and are normally spaced at 24-in. centers and with a rail seat positive flexural capacity of 300 kip.in.; such ties perform well.

The objective of the specification is to produce a concrete tie that will not structurally crack during its service life of 45 to 50 years and to produce a fastening system that will maintain both lateral and longitudinal track restraint over millions of cycles. The static test load is approximately twice the expected load a tie will meet in service. Service loads can exceed the design load if

1. Rail is allowed to corrugate and remedial action is not taken;
2. The support conditions are unsatisfactory;
3. The number and size of wheel flats becomes excessive, particularly at high speeds;
4. Jointed track is used; and

5. Locomotives with axle-hung motors are used at high speeds.

These problems all result in higher-than-anticipated impact loads being transmitted into the tie, and the tie may become cracked. This situation should be avoided. Thicker pads used between rail and tie (to attenuate the impact loads) or an improved ballast may alleviate, but not cure, these problems.

##### Production of Concrete Ties

A full-sized tie plant requires efficient material handling processes, and it is therefore beneficial to establish a manufacturing facility completely dedicated to the production of concrete ties year round, on line, and close to the major area of tie requirement. In North America the use of long line processes and multicavity forms (with the ties cast upside down) has become standard. Some plants still use individual self-stressing forms, or posttension ties after the concrete has hardened, but these methods are generally limited to low-volume production and locations where labor costs are low.

Ties can be made in existing precast and prestressed concrete plants for small batches (up to 50,000), but for large quantities of 300,000 to 400,000 ties per year, the custom-designed and dedicated plant with good material handling systems has advantages, despite its initially higher capital cost.

##### Quality Requirements for Raw Materials

Concrete quality is key to the system, with emphasis placed on concrete durability and resistance to abrasion. Frost attack and alkali-aggregate reaction can cause premature concrete failure, and standard tests should be completed before production of ties commences to ensure compatibility of cement and aggregate. In frost zones, air entrainment is essential.

To obtain satisfactory bond between the concrete and the prestressing tendons and to minimize the bond transfer length, small diameter indented tendons are preferred. The standard tendons for pretensioned ties in North America are 0.2-in.-diameter indented high-tensile wires or 0.375-in. indented 7 wire strands. It is important to note that too deep an indent will cause an excessively short bond transfer length, which causes the tie to fracture at the ends, whereas too shallow an indent may result in tendon slippage and loss of structural integrity in the rail seat.

If iron shoulders are cast into the tie to provide positive gauge control, the dimensional accuracy of the shoulder is important, with key dimensions being checked to within  $\pm 0.020$  in. Sample shoulders should also be sectioned to ensure the absence of voids or internal flaws. The shoulders must be free of any oil or grease, loose rust, or scale to ensure good bond in the concrete.

##### Process Control

Approximately every 25 yd<sup>3</sup> of concrete should be sampled and tested for workability and air content (where appropriate). Strength test specimens are also made from these samples for testing at transfer of prestress after curing with the ties and at 28 days after curing in a fog room.

Process checks include verifying that the wire tendon pattern is set correctly in the tie, that the wire tension measured by two independent methods is

within specification, and that the concrete temperature record indicates compliance with standard time and temperature requirements. Records of all these checks should then be maintained in such a way that they are identifiable with any particular tie.

#### Finished Product Testing

A random sample that represents approximately 2 percent of the ties is tested daily to ensure compliance with the specification being used. The primary tie acceptance test subjects the tie to a bending load at the rail seat, which checks overall performance, and in effect assures that the concrete, tendon pattern, quality, and tensioning; and other parameters are all correct. Approximately 15 percent of these test ties (i.e., 0.3 percent of total production) should then be test loaded to first visible crack. This test measures the margin above the minimum performance specified and provides an excellent guide to the quality of the finished tie. The test to first visible crack is not yet an AREA-specified test.

Randomly selected ties are also checked for dimensional accuracy. Specially designed gauges are required for these tests because the tolerances involved are small. Accuracy is essential to ensure that fastener performance in the field is as designed. Concrete strengths are recorded at transfer of prestress and at 28 days. The results are analyzed statistically to detect any adverse trends.

#### Purchasing Methods

The most efficient and therefore the most cost-effective tie plant is one that has been designed for that purpose, that is, the daily costs of production are minimized. This assumes the use of a capital-intensive plant with satisfactory material handling facilities, which would require a minimal 3-year (preferably 5-year) commitment to justify the capital expenditure. Intermittent or small batch production, although satisfactory for small quantities, can result in high operating costs and scheduling problems, and may cause multiple quality control problems for both producer and user, because all production is essentially start-up.

#### Fastening System

Vignoles, who designed the flat bottom rail in the 1830s, realized 150 years ago that railroad track could not be constructed as a rigid running surface. This was inherent in the cut spike fastening system, which does not provide vertical restraint to the rail.

The advent of concrete ties in Europe in the 1940s demonstrated that a resilient connection must be used between rails and ties to ensure that, among other things, the fastening performance is retained under traffic with varying temperature conditions (6). A similar conclusion about the need for resilience can be drawn from the work of Talbot (1918-1930) at the University of Illinois (7).

During the past 40 years, elastic fastenings for concrete ties have been developed to satisfy these requirements, and lessons have been learned from in-track experience (8). The modern concrete tie uses direct fixation (i.e., no tie plate) with a tie pad, which separates the rail from the tie and forms an important part of the total resilient assembly, besides providing part of the insulation system of the rail from the tie.

Current tie fastening systems can be divided into two categories. The first group provides for con-

tinuous adjustment during the life of the fastening and incorporates a screw thread. This type is widely used in France, West Germany, and Mexico and on the FEC railroad.

The second group requires less operator skill for installation, cannot be adjusted, but does allow easy change of wearing components. This system may be suitable for mechanized insertion and removal to simplify rail changing. This type is widely used in other Western European countries, South Africa, Australia, and North America. This group of fastenings typically consists of elastic clips, shoulders of cast iron or pressed steel cast into the ties, pads, and insulators. If the shoulder is correctly oriented when cast into the tie, the deflection of the clip when it is driven into the shoulder will provide the design toe load on the rail foot.

Concrete tie construction creates a track with much higher vertical stiffness than does wood tie construction on a similar roadbed. This must be offset by the resilience of the rail pad. The Japanese National Railway (JNR) has suggested that on high-speed tracks, vertical stiffness must be maintained below rather restrictive levels to prevent excessive ballast settlement, ballast particle degradation, growth of rail corrugations, and transmission of noise (9).

On heavy-haul railroads the elastic behavior of the pad is of less significance than for track where the speed exceeds 60 mph. Therefore, durability is the overriding requirement, and plastic materials such as ethylene-vinyl acetate (EVA) are used. Because it becomes brittle at low temperatures, high-density polyethylene (HDPE) is not suitable for use where freezing conditions occur.

On higher speed tracks (60 mph and greater), profiled neoprene or styrene-butadiene rubber (SBR) pads are most widely used. Recent research (10,11) has indicated that a pad thicker than the normal 0.2 in. will provide better attenuation of the impact loads induced by railhead and wheel defects. In France, 0.35-in. pads are in use on high-speed lines.

However, many soft pads are less durable than harder alternatives. In most cases the soft and sometimes thicker pad permits greater deflection of the elastic rail clips. This places the clips in a more severe fatigue environment and may reduce the long-term toe load, which in turn reduces the longitudinal resistance of the fastener system. This conflict between requirements for low stiffness versus durability and longitudinal restraint is one of the principal challenges facing the fastener supplier.

Insulators that separate the rail from contact with the shoulder are required where track circuits are used because concrete does not provide sufficient electrical resistance (12,13). The insulator is also a sacrificial component to protect the gauge-retaining shoulders from attrition by the rail foot. For this reason shoulders coated with an insulating material, instead of using sacrificial insulators, are not recommended.

In one fastening that incorporates a concrete shoulder to retain gauge, the insulator is incorporated in the tie pad and provides a much larger surface area for lateral restraint than in other designs; therefore, the concrete rail seat shoulder is protected. Other designs that incorporate concrete shoulders have generally not performed well in curved track.

Tests for fastening systems are included in the AREA manual (4). Laboratory testing is used for comparative analysis of new designs and for detailed analysis of specific performance requirements, such as pad spring rates, but there is still no better way of testing than in track.

## Rail

Although it is customary in North America to use wider tie spacing (24-in. centers) with concrete ties compared with wood ties (19.5 to 20.5 in.), the rail section is unchanged. Until recently, rail of 132 lb/yd was fairly standard on heavy-haul railroads, irrespective of the type of tie. Recently there has been a trend in Canada and elsewhere to use heavier sections, such as 136 or 140 lb/yd, as these have a higher proportion of steel in the head. All these sections have the same 6-in. rail base and can be used interchangeably with the same ties and fastenings.

Factors that affect rail life are complicated (14,15), but may be summarized as follows: wear; crushing; corrugations; mechanical damage, including fatigue; and manufacturing or welding defects. Railhead wear is decreased significantly by elastic fastenings with satisfactory lateral and longitudinal restraint, and further significant reductions are achieved by the use of heavier concrete tie track, alloy rail, and lubricators (16). Rail life is also extended by the use of high-silicon or chrome alloy steel and by heat treatment, either alone or in combination. Jointed rail is not recommended for use with concrete ties. There is evidence that close matching of railhead and wheel profiles can reduce railhead stresses (16,17) and prolong service life. Lubrication is widely used to reduce friction and wear on curves; and relatively sophisticated devices have been developed to ensure that the lubricant is directed to where it is effective (18).

## Mechanical Equipment Design

The reader may wonder why mechanical equipment is included under the section on Components of Concrete Tie Track. The railway track and vehicle combination comprises heavy rigid wheels running on heavy rails (19). Imperfection in either will give rise to dynamic effects that increase with speed. The trend for higher speeds and greater axle loads will probably continue. Therefore, forces and stresses in the track structure will likely increase.

Consequently, there has to be increasing cooperation between the engineering and mechanical departments (20). Not only must track have a high standard of alignment and level and also be well maintained, but mechanical equipment must be maintained to a high level, particularly high-speed or heavy-axle-load equipment, or both.

Improvements in vehicle design that would result in longer track life include

1. Reduction in unsprung mass by using frame-hung instead of axle-hung motors, particularly at high speeds;
2. Greater use of self-steering trucks to reduce curving forces, particularly in unit trains;
3. Reduction in wheel defects, which are damaging to all track components; this effect is similar to low rail welds or joints (11); and
4. Use of larger diameter wheels to reduce stresses at rail and wheel interface.

## INSTALLATION

### Track Laying System

Amtrak and CN Rail have selected the Canron P811 series of track laying trains to install their concrete ties. The track train consists of a self-propelled track laying machine (TLM) plus 12 to 25 special tie cars pushed ahead of the machine. The

tie cars are fitted with bridges between cars to allow 2 or 3 crablike gantries to traverse the whole length of the train to deliver concrete ties to the machine and remove the displaced wood ties.

A large articulated beam spans between the front and rear of the TLM. The tie conveyors (new concrete and old wood), concrete tie placing, wood tie removal equipment, and the rail change-out equipment are all supported from this beam. At the front of the TLM the old rail is spread out to allow a pair of forks to dig under the wood ties and remove them. A plough immediately levels the ballast, and the concrete ties are then placed. Pads are placed on the ties by hand.

Either the old CWR or the new CWR is then threaded onto the ties, and the rear end of the TLM then runs on the new track before the rail is clipped. Clips and insulators are applied behind the TLM. Later the ballast can be undercut if required, the rail destressed, more ballast applied, and the track realigned, lifted, and tamped. The average rate of production on CN Rail is more than 3,400 ties in an 8-hr work block at an average cost of \$4.00 per tie for installation, including labor and equipment depreciation (21).

### Gantry Method

The gantry method is a medium production rate system used where the rail is jointed or with worn out CWR, which can be cut to length. Continuous welded rail is set at a constant wide gauge of 10 ft on the ballast shoulder, either on special chairs or on a ploughed level area in the shoulder ballast. Two gantries straddling the rail cars with a lifting beam between them run on the wide track and raise 39- or 78-ft panels of old ties and rails and move them to a flatcar on the old track. The gantries then pick up either 39 or 78 individual concrete ties or complete panels of ties and service rails and set them down in the gap first created by removing the old track. A Donelli-type rail positioner, running on the new track, threads the CWR onto the ties. The Donelli is followed by clip application and so forth. The rate of progress is about 1,100 ties per day (21).

### Panel Method

In specific situations, when there is double track, concrete ties and 39-ft service rails can be panelized adjacent to point of use, delivered on flatcars, and set down beside the track ready for installation or set down immediately on the prepared roadbed. Later the service rail can be replaced by CWR. This method is used with side cranes on British Rail and is also used extensively in the U.S.S.R.

## ENVIRONMENT AND BENEFITS OF CONCRETE TIE TRACK SYSTEMS

Recent developments in Canada and Australia indicate that concrete tie track will not only perform under heavy-axle loads, but it also has distinct cost benefits in curved, high-tonnage territory (21,22). The following criteria indicate where the greatest benefits have been derived from concrete tie track in Canada (21): (a) where there are at least 20 million gross tons of traffic per year, (b) where there is a high proportion of 100-ton cars in unit train configuration, (c) where there are multicurves generally greater than 2-degree curvature, and (d) where 6-axle locomotives are used, that is, in heavy-tonnage areas. This environment is typical of



other North American railroads.

What then are the advantages of concrete tie track over the traditional wood tie track? The advantages fall into four categories: tie, rail, maintenance, and fuel conservation.

Tie-related advantages of concrete tie track are as follows.

1. Durability--The concrete tie should last up to 50 years.
2. Consistent gauge holding--Because shoulders are either cast into the tie or preformed, there is a consequent reduction in dynamic wide gauge problems.
3. There is no plate cutting caused by high lateral loads, which on wood ties leads to static and dynamic wide gauge with loss of rail life.
4. Concrete has higher vertical and lateral stiffness than wood tie track because of the greater mass of concrete ties and the more determinate, yet resilient, fastening system.
5. Longitudinal restraint is built into the system continuously.
6. There is no spike kill during rail change out and transposition.
7. The quality is consistent and reproducible.
8. Fewer concrete ties per mile are needed (2,640 concrete versus 3,110 wood).

Rail-related advantages include the following:

1. Easier and quicker rail transposition, which is important in high-tonnage areas with short rail life; and
2. Increased rail life, where CN Rail studies revealed that at the Jasper concrete tie test track on 4- and 6-degree curves using HiSi 132 lb rail at an average 45 million gross tons (MGT) per annum, rail life varied between 6 and 11 years compared with 3 years previously on wood; overall, CN found a 50 percent improvement in rail life with carbon or HiSi rail on concrete (16).

The achievement of this rail life is a function of the complete track structure, not just concrete ties. Important contributions to this increased life are good rail lubrication, correctly profiled rail grinding, and consistent gauge.

Maintenance-related advantages include the following:

1. More uniform settlement than wood tie track, thus providing a smoother, safer ride and greater passenger comfort (20);
2. Extended surface and alignment cycles, which can be reduced by one full cycle in a 5-year period (21);
3. Reduced derailment frequency (21);
4. More time to run revenue trains, which is the primary objective of a railroad; and
5. Improved ride quality due to improved track geometry retention (20).

Another advantage of concrete tie track systems is fuel conservation. A 1978 study conducted by the Canadian Institute of Guided Ground Transport at Queen's indicated that the increased track modulus of concrete tie track and the reduction of the procession wave in the rail ahead of each wheel set, and therefore a reduction in rolling resistance, reduced fuel consumption by a minimum of 2 to 3 percent, depending on traffic mix and tonnage (22). This reduction in rolling resistance is also being demonstrated in the Association of American Railroads' (AAR) dynamics laboratory in Chicago.

## FIELD PERFORMANCE OF SYSTEM

The primary function of a tie, whether it be of concrete, steel, or wood, is to hold the rail to gauge and to transmit train loads into the ballast and subballast. Secondary functions of a tie include prevention of lateral track displacement, prevention of longitudinal rail movement (in conjunction with the fastening system), maintenance of line and level of the rails, and provision of the designed rail cant. Therefore, the performance of any track system has to be evaluated in this context.

### Track and Train Dynamics

Theories have been developed to show the relationship between the static wheel load and the dynamic forces referred to as P1 and P2 (19,22). In this context wheel flats are considered to have a similar effect to low welds or joints, but the effect of soft spots in ballast or formation have not been analyzed. P2 force is particularly sensitive to the unsprung mass bouncing on the track. The forces experienced by the track occur over a wide range of frequencies up to 2,000 Hz. At low frequencies (10 Hz), the nature of the track is relatively unimportant, and suspension forces caused by vehicle and truck motions predominate. At medium frequencies (20 to 100 Hz), the track system and vehicle unsprung mass with its primary suspension are most important (i.e., P2 forces). At the higher frequencies (500 to 2,000 Hz), the impacts and impulsive loadings (P1 forces), dependent on track and wheelset masses and the elasticity of the wheel and rail contact zone, are the predominant factors.

When resilient pads are used, forces measured are less than the mathematical formula would indicate, particularly at speeds greater than 40 mph. Further work (23) has indicated that the longer duration of the P2 force (20 ms) allows it to be transmitted into the tie and ballast, whereas the P1 force, which has a steep rise time and short duration, mainly affects the rail.

At higher speeds there is a higher frequency tie stress component superimposed on the quasi-static response to the P2 force. This can lead to quite high tensile stresses in ties, and has led to problems of concrete ties cracking on European railroads (2) and on Amtrak and Norfolk and Western (20,24). This higher frequency response occurs at up to 1,200 Hz, and although it is attributed to wheel defects, is not yet well understood. It may have been overlooked in earlier measurements that use lower frequency filters to eliminate noise. Current research (10,20) is directed toward reducing the peak tie stresses by means of more resilient pads, but there is evidence that thicker pads may be necessary to achieve any worthwhile benefits.

### Electrical Properties

The rail to tie-ballast interface electrical resistance of concrete ties, new wood ties, and old wood ties, including fastening assemblies, has been investigated experimentally (13). Resistance values have been determined for different environmental conditions, ranging from dry and clean to saturated wet states.

Test results indicate clearly that the rail to tie-ballast interface resistance can vary a great deal, depending on environmental conditions, particularly moisture content. It may increase by one to two orders of magnitude when going from a saturated wet to a completely dry state.

The concrete tie assembly exhibits an electrical

resistance comparable to or better than wood ties, except when the ties are saturated. Other work (12) suggests that the predominant factors affecting the leakage resistance through the ties in a track circuit are (a) rail fastening system design; (b) insulation pad pattern; (c) length of conduction path from rail to tie; (d) amount of foul ballast, dust, and iron filings around fastener; and (e) separation of rail from ballast.

### Rail Corrugations

Corrugations, both short and long wave, have become more apparent during the past 12 years, where a substantial portion of traffic is carried in 263,000-lb gross weight cars, particularly in unit train configurations (16). Operating on corrugated rail requires more frequent cycles of lining and lifting, besides shortening tie life. Unless remedial measures are taken, the corrugation will grow at an accelerating rate. The immediate palliative is rail grinding; for example, at current traffic levels on the CN Rail (British Columbia South Line), rail is ground three to four times per year.

CN Rail studies have indicated that the principal causes of corrugation on wood ties are from dynamic gauge widening caused by soft or spike-killed ties and uneven hardness of the railhead metal. The measures adopted to minimize corrugations include concrete ties because of their superior gauge-holding characteristics, the introduction of alloy steel rails (16), and correctly profiling the rail during grinding to provide correct wheel and rail contact and thus reduce curving forces and railhead stresses.

Concrete ties are sometimes blamed for increasing incidences of rail corrugations. All other things being equal, there is no evidence that there is any significant difference between wood and concrete tie track in this respect (16,25).

### Tie Cracking

The most likely locations for tie cracks are either at the top or bottom of the rail seat area or on top of the tie at the center. Rail seat positive cracks (i.e., those at the bottom of the tie) generally result from infrequent high-impact loads caused by wheel and rail defects (20), or by high-speed passenger trains with locomotives with high unsprung weight. Rail seat positive cracks are not uncommon for the reasons just outlined, but although tie life may be reduced, the tie is still capable of carrying out its primary functions, that is, it holds rail to gauge and transmits load into the ballast.

Rail seat negative cracks are more serious and less understood. Rail seat negative cracks can result in premature tie failure because of the breakup of the rail seat. Their cause is related to the dynamics of both the concrete tie system and the train. Fortunately, they are rare.

Center negative cracks in the top of the tie are caused by center binding of the track. The cure is simple: remove the cause of center binding. Horizontal splitting of ties can be caused by incorrect fastener application.

### Tie Damage

Dragging equipment or a broken axle can cause tie damage, irrespective of tie material. If the cribs are kept full, that is, up to the top of the tie, damage to the tie will be minimized. Fastenings that extend beyond the foot of the rail by more than

2 or 3 in. are more vulnerable than those that effectively shelter under the head of the rail. Although tie life may be curtailed, it is rarely necessary to change out seriously damaged ties immediately unless they cease to perform either of the primary functions, that is, holding rail to gauge or transmitting load into the ballast.

### THE FUTURE

Perhaps the greatest opportunity to the tie producer is to reduce the curing time of concrete and cast twice daily instead of only once, thereby reducing by half the size of a plant and improving return on investment.

The dynamic response of the entire track system is still not fully understood. Work should be done to optimize the mass of the system together with fastening response to impact loads. Additional work is still required to improve pad characteristics.

Concrete switch ties have been tested in Sweden, the United Kingdom, and Australia, and they will shortly be tested in Canada and in the United States. The advantages of a concrete tie switch are a constant track modulus and accurate factory-set geometry.

Finally, all new developments must be tested for durability of the system to satisfy the requirements of climate and ever-increasing loads. The problem is to debug the new system before real-life installation, knowing that real life is probably the only way to find the bugs.

### CONCLUSIONS

Four North American railroads have major portions of their main line equipped with a concrete tie track system (Amtrak, CN Rail, FEC, and KCS). Their reasons for change are diverse; however, CN Rail's traffic mix and territory for concrete ties are similar to many other North American freight railroads.

The experience of these four North American railroads cannot be ignored. All have proved that concrete ties provide a cost-effective way to create a track structure for current loads in specific applications. All four are continuing with their concrete tie programs, which would suggest their continuing satisfaction. The concrete tie track system is now a fact-of-life in North America, and it will be used in the future for specific and identifiable reasons.

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## Timber Crossties in Relation to Track Structure System Design

J. FRANK SCOTT

### ABSTRACT

The timber crosstie and cut spike rail fastening system has performed admirably for many years on North American railroads. With the introduction of six-axle locomotives, 100-ton freight cars equipped with roller bearing trucks, and concentrated unit train operations, problems with track maintenance arose on sharp curves. Simple logic dictated that the first course of action was to measure the forces that were being applied to the track structure. If the forces could not readily be alleviated through modifications in equipment or operations, then the strength of the track structure system would have to be increased to cope with the situation. In

this paper a brief review of conclusions derived from track measurements taken in the early 1970s is presented. Results from measurements taken in 1982 and laboratory fatigue tests run in early 1983 on various tie and rail fastening systems were combined with engineering judgment in an economic analysis to select an upgraded tie and rail fastening system for the sharp curves of a branch line that handles 4 to 5 million gross tons of unit train 100-ton car traffic.

The timber crosstie has been the vertebra in the backbone of the North American railroad track structure since railroading began on this continent. There were no tough decisions made in choosing the