Prestressed Concrete Ties in North America

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ABSTRACT

Approximately two million concrete railroad ties are installed annually in North America. The introduction of concrete railroad ties increased durability and capacity when compared to the typical wooden tie, which has historically been the standard in the railroad industry. It was not until the early 1970s that concrete ties were utilized on large scale projects in North America. The primary reason for the initial avoidance of this new technology was that the designs originally adopted from Europe were simply not sized for the larger loads of the North American track system. Following the involvement of the Portland Cement Association (PCA) during the early 1970s, standards and designs were created for new concrete ties suited for use on North America’s transit and heavy haul railroad systems.

Unlike wooden ties, concrete ties require considerable amounts of engineering and a relatively complicated fabrication process. The reason for this is the prestressing steel integrated into the design of the tie. Currently research to improve performance and durability is the field of interest.

This paper focuses primarily on the state-of-art of concrete ties including design considerations, failure mechanisms, durability, fabrication, economics and industry utilization with an emphasis on cold regions applications as it pertains to the proposed Alaska Canada Rail Link. The investigation includes a synthesis of the best practices used worldwide related to concrete ties with the objective of enhancing the application of concrete ties in North America.
INTRODUCTION

Today the use of concrete ties is on the rise in North America as they become an economically competitive alternative to the historical industry standard wood ties, while providing performance which exceeds its competition in terms of durability and capacity. Issues of adequacy in regards to flexural capacity and concrete durability were experienced during the early years of concrete ties in North America. However, with the aid of the Portland Cement Association (PCA) suitable designs capable of withstanding the tremendous loads of North American railroads were developed during the 1970’s [1]. Since that time concrete ties have developed into an adaptable tie alternative with applications in both transit and heavy haul rail lines. The generic shape and dimensions of a typical North American concrete tie is illustrated in Figure 1. As energy costs continue to increase and transportation on the North American continent evolves, railroads will see a swell in demand therefore increasing the concrete tie demand.

To achieve the performance exhibited by concrete ties considerable amounts of engineering have been employed with respect to materials and design. The interaction between the concrete and prestressing provides the necessary strength to resist the cyclic loading of the trains while concrete provides the protection and rigidity to hold the system together. Initially, this relationship was not well refined and failures were often the result of inadequate development of prestressing steel and insufficient flexural capacity. However, over the last several decades tie failures due to flexure and inadequate development have been nearly eliminated [2]. Currently the focus of the rail industry is to improve tie durability and service life. Additionally, the application of concrete ties in unique environments such as permafrost is of interest.
RESEARCH SIGNIFICANCE

This work focuses on the application and potential challenges of using prestressed concrete ties for the Alaska Canada Rail Link (ACRL) expansion project. The proposed 1300 mile expansion of heavy haul mainline track will link the mineral deposits of interior portions of Alaska, the Yukon Territory and British Columbia with ports on the Pacific Rim. A secondary goal of the project is to connect the Alaska Railroad to the continuous forty eight states [3]. A map showing the proposed working alignment is shown in Figure 2.

A major obstacle for this project is the presence of permafrost and potential for heavy frost heave that exists on large sections of the proposed track. This frost heave could be detrimental to the track structure, especially the concrete ties. As a result, the evaluation of the designs and fastening systems is necessary to determine the feasibility of construction and the expected service life of a critical component of this track expansion. A thorough investigation is expected to highlight other critical considerations related to concrete ties in prolonged freeze-thaw cycle environments.

TIES IN PERMAFROST REGIONS

Permafrost is the term given to soil that is frozen for a period of time greater than two years. Approximately 20 percent of the Earth’s land mass is covered by permafrost [4]. Undisturbed permafrost is rather stable, but when structures or foundations are built upon it, freeze-thaw cycles and uneven settling can begin causing frost up-heave in the soil. Railroads and other structures built on permafrost are often plagued with up-heave as a result of the freeze-thaw cycles of the permafrost [5]. Such a lesson was learned by the builders of the Copper River Northwestern Railroad in south-central Alaska; uneven settling and frost up-heave on the
magnitude of feet lead a section of track to be called the “roller coaster railroad,” which ultimately lead to the abandonment of the track.

The concept of using concrete ties in permafrost regions is not new, however information regarding proper track structure and the effects of the heavy frost heave on concrete ties over long periods of time is unknown. Several test tracks using concrete ties were built by the Federal Railroad Administration (FRA) during the fall of 1973 along the Alaska Railroad. The performance of the concrete ties was satisfactory in terms of failure rates and track geometry performance, but little information about the ties was documented because the objective of the test tracks was to study the effects of heavy frost heave on track structure and geometry [6]. Since this study, no new evaluations of the performance of concrete ties on permafrost have been performed.

The use of concrete ties in permafrost regions outside of North America has been documented in areas of Northern Scandinavia on the Malmbanan and Ofoten railways, Eastern Russia on the Trans-Siberian Railway and recently Tibet during the construction of the Qinghai-Tibet railway [7]. On these railways, concrete ties have shown to provide superior track rigidity and be capable of withstanding the extreme climatic conditions.

MATERIALS

Typical to any prestressed concrete member are early high strength concrete and high tensile strength steel [8]. In addition to the concrete and prestressing steel, tie fasteners and pads are integral to the concrete tie. However, it should be noted that the application of these connection devices is dictated by the railroad operators and their design is outside of the scope of the tie

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manufacturer responsibilities. This presents a unique challenge because a component failure is often considered a tie failure.

Concrete

The use of high strength concrete is necessary in the production of concrete ties due to the use of prestressing. It is generally suggested that a minimum compressive strength of 7,000 psi at 28 days be used [9]. Reasons for high early strength concrete are the following:

- To efficiently produce concrete ties or any prestressed member for that matter the prestressing force must be transferred to the tie at an early age. A compressive strength of 4,500 psi is typically considered satisfactory for prestressing load transfer.
- High early strength concrete allows beds to be turned over more rapidly due to shorter release times.

Other considerations related to concrete mixture include admixtures. In order to achieve early high strength concrete, manufacturers commonly include accelerator and water reducer admixtures. Accelerators increase the rate of cement hydration while water reducers allow for workability of the concrete at low water-cement ratios [10]. For areas of permafrost or severe freeze-thaw cycles, air-entraining mixtures should be used. This relates to the fact that concrete with entrained air is more durable with respect to freeze-thaw cycles.

Prestressing Tendons

Along with concrete, prestressing tendons give ties the tensile resistance required to support the flexural forces imparted by the trains. During the initial days of concrete tie fabrication, when the concrete is only at a fraction of its design strength, the most difficult issues to satisfy are prestressing bond and allowable stresses of the concrete in tension [1, 11]. However, bond and

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stress issues during the fabrication process have been solved by using smaller tendon diameters and larger numbers of tendons set in a uniform pattern to avoid tension stresses at prestressing transfer [12].

Prestressing may consist of either the typical 7-wire strand found in most prestressed concrete fabrication or steel wire (Figure 3). Dimensions of 7-wire strand vary with the most common among North American manufacturers being 3/8 in. diameter. Size of wire used over the years has varied from 0.19 in. to 0.21 in. (4.80 mm to 5.32 mm). Due to manufacturers achieving better bond between concrete and prestressing, the strand diameter has increased while maintaining the same development length and therefore length of tie. This has also decreased the number of wires required per tie, with the larger wires providing increased tensile resistance. Unlike conventional reinforced concrete, high strength steel is required to resist the applied prestressing forces. An ultimate strength of 260 ksi is common for wire whereas 7-wire strand typically has an ultimate strength of 270.

The choice to use either 7-wire strand or individual wire is up to manufactures and is dictated by design and material efficiency. However, wire prestressing offers several advantages over conventional twisted multi-wire strand. Using wire provides the ability to change the quantity of steel within the tie by smaller increments compared to 7-wire strands. Therefore, the ties can be more efficiently designed to parameters dictated by predicted service loads, decreasing excess material, in turn decreasing the cost of the tie [11]. Similarly, wire requires a shorter length for development, resulting in a shorter tie to achieve the appropriate flexural strength.
Attachment Components

Tie Pads

Tie pads are installed between the rail and concrete ties to minimize water intrusion and tie abrasion of the rail seat area. Pads also reduce impact and vibration effects on the track structure leading to quieter operation [9]. Tie pads come in a variety of materials and configurations. Steel and polymers are the most common materials used in tie pads. A common pad configuration will include a polymer top pad, a steel plate for added rigidity, and a rubber gasket between the steel plate and concrete tie to decrease sound, vibrations and water intrusion. Pads can also be made solely of steel or polymeric materials [9].

Fasteners

In addition to the primary tie components of concrete and steel, fasteners are essential to attach the steel rail to the tie and protect the tie from rail movement. The fastener type used is dictated by the railroad operator and the tie application. Most fasteners are composed of two or three parts; the ductile iron shoulder, spring clip, and insulator. The ductile iron shoulder is cast into the tie during tie fabrication and varies in terms of size and embedment depth depending on the fastening system used and tie application (Figure 4).

Fasteners are divided into two categories; captive and non-captive. The difference is in how and when fastener parts are attached to the tie. Non-captive fasteners include those where only the ductile iron shoulder is attached to the tie prior to shipping and tie installation (Figure 5). Captive systems have all parts, shoulder, spring clip and insulator, installed prior to shipment and installation (Figure 6). Captive systems are at risk of damage to the fastener during transportation
and installation, whereas non-captive systems require additional labor and time for component installation once the tie is placed within the track.

FAILURE MECHANISMS

The three primary failure mechanisms of concrete ties observed by the rail industry today are rail seat abrasion, flexural cracking from center binding and rail fastener failure [13, 14]. Of these three, rail seat abrasion is the most common and difficult to prevent. Failures may be related to concrete tie materials, design or a combination of the two. Installation and maintenance practices also contribute to a tie’s resistance to these failure mechanisms. A discussion of the three primary failure mechanisms is presented in the following sections.

Rail Seat Abrasion

The most common failure mode in the modern prestressed concrete railroad tie is rail seat abrasion. Rail seat abrasion is the gradual wearing away of the cement paste from the concrete, resulting in an uneven aggregate bearing surface beneath the tie pad [14]. Figure 7 illustrates the abraded surface of a degraded rail set. Factors contributing to rail seat abrasion include: the presence of water, high tonnage (static wheel loads larger than 25,000 lbs), steep track grades, and especially track curves greater than two degrees [1]. Regions with freeze-thaw cycles often experience rail seat abrasion at an accelerated rate due to increased cement paste deterioration below the tie pad.

To prevent rail seat abrasion and prolong tie life, concrete tie manufactures have investigated methods to protect concrete in the rail seat region. Research has focused on the application of abrasion resistant materials applied in the form of pads, adhesive polymers (epoxy and...
polyurethane) or cast-in-place plates in the rail seat region. Some industry techniques used to mitigate rail seat abrasion to date include:

- Epoxy or polyurethane applied to rail seat shortly after casting [15],
- Cast-in-place steel plates [16],
- 3-part abrasion resistant pad assembly [16].

Of these options, epoxy or polyurethane has shown promising short term results and appears to have gained acceptance among manufacturers and railroads. However, epoxy and polyurethane do wear down over time allowing rail seat abrasion to take place. For rail seat abrasion repair operations, the application of epoxy is common, but requires specific temperature and humidity control and also results in costly track closures [15]. Testing of cast-in-place steel plates has shown no rail seat abrasion at 4 times the number of cycles required to cause failure of currently used tie designs. However, issues with water intrusion below the plate and the additional cost of materials and fabrication have limited the use of the cast-in-place steel plate method[16]. 3-part abrasion resistant pad assemblies remain the industry standard due to lower initial cost and ease of replacement [17].

Additional solutions that been explored by tie manufactures and railroad operators with mixed results include:

- Steel fiber reinforced grout applied to the railseat region during manufacturing,
- Steel plates bonded to the tie using epoxy after casting [18],
- Metallic aggregate in the rail seat region [19],
- Variations to concrete mix in terms of strength and porosity to increase abrasion resistance.
To date, numerous methods have proven to delay the onset of rail seat abrasion, but issues of cost and repeatability on a high production basis remain a concern. To replace current rail seat abrasion prevention techniques such as epoxy and the 3-part pad assembly, new methods must outperform conventional methods in cost, ease of fabrication, and most importantly, abrasion resistance.

**Flexural Cracking (Center Binding)**

While inadequate tie flexural capacity is predominantly an issue of the past, cases of ties cracking at the top center location due to negative moment has been reported on mainline tracks. Investigations have shown that this failure type results from ballast conditions which are beyond the scope of tie design. Over time cyclic loading applied to the track causes ties to oscillate and deform vertically within the track structure; this deformation produces pumping action which ultimately allows ballast to abrade the bottom of the tie and pulverize the ballast beneath the tie [20]. The extent of ballast deterioration is unique to concrete ties when compared to that observed with wood ties resulting from the difference in material strength and hardness. A converse scenario can occur with wood ties, where the tie is broken down by the ballast through the same action discussed above.

The pulverized ballast is routinely removed from the track and replaced with new ballast during undercutting maintenance operations. However, when undercutting and replacement is not carried out regularly, depressions in the pulverized ballast beneath the ends of the tie may develop, altering the support condition of the tie. The new support condition is a center support where ballast bearing still remains. Based on this support condition the tie cantilevers from the center over the pulverized ballast depression. When loaded, large negative moments occur at the
tie center, resulting in cracking and tie failure as the flexural capacity is exceeded. This type of failure is referred to as “center binding”. To prevent center binding regular maintenance of ballast must be performed to avoid deterioration of the material leading to unsuitable tie support conditions. The required regularity of ballast maintenance will be dictated by frequency and intensity of loading [20].

**Fastener Failure**

While many rail fastener configurations exist, a commonality between them is their shared purpose of providing a restraining spring force known as toe load to the rail. However, over time due to the effect of cyclic loading, fatigue of fastener components such as the spring clip and embedded ductile iron shoulder occurs which allows for movement of the rail, deterioration of pads, and a decrease in the fastener toe load applied to the rail [13].

In addition to a decreased toe load, polymer insulators located between the rail and spring clip are subjected to abrasion from cyclic loading. Over time this abrasion wears away insulating material, creating voids and allowing for excess movement between the rail-tie interface in the form of rail rocking side to side and slip in the longitudinal direction of the rail. This excess movement and space between the tie and rail further exacerbates the related issue of rail seat abrasion by providing an abrasive motion and allowing for the intrusion of water and abrasive agents such as rail grit or coal dust.

To prevent fastener failure or related issues such as rail seat abrasion regular maintenance of fastener components is essential. The replacement of worn insulators and other components can prevent escalation of further issues before they begin. Fortunately, for maintenance operations
component wear is typically uniform along a length of track and can be estimated based on historic performance for a given location knowing the frequency and intensity of loading. Similarly, fastener wear is relatively easy to monitor visually compared to rail seat abrasion which is typically hidden by the rail and ballast. It should also be noted that fastener fatigue requires long periods of time and is typically a secondary failure mechanism when compared to the rail seat abrasion and center binding failures.

DESIGN CONSIDERATIONS

The governing body for railroads is the American Railway Engineering and Maintenance-of-Way Association (AREMA) which is comparable to American Association of State Highway and Transportation Officials (AASHTO) for the highway system. The two are similar in that each produces recommended design practices. Within the AREMA Manual for Railway Engineering an entire chapter is dedicated to railroad ties. The largest portion of this chapter (Part 4) pertains to the design of concrete railroad ties which individual companies can use as a foundation for their own design standards.

Design aspects such as loading, material specification, testing requirements and discussion of the relationships between a tie and the surrounding track components (ballast, rail, etc…) are considered. However, to provide their customers with a reliable product, manufacturers tend to design their ties to surpass the requirements set forth by AREMA, usually with additional requirements stipulated by the railroad operators.

The first step in designing a tie begins with discussing the intended service of the tie with its consumer, the railroad operator. Conditions unique to a tie application such as: tie spacing,
loading in million gross tons annually (MGT) and operating train speed must be acquired from
the railroad operator to identify the performance requirements of the tie in service. With this
information, the tie manufacturer can then design for the various limit states including flexure
and durability.

The flexural capacity of a concrete tie is derived from material properties, tie dimensions and
number and type of prestressing wire used. Ties typically have an overall length between 8 ft and
9 ft, depth of approximately 9 in. and bottom width of 11 in. tapering to approximately 8 in. at the
top (see Figure 1). Depending on the application, industrial, transit or heavy haul, cross-section
dimensions and quantity of prestressing steel will vary, with heavier loading conditions requiring
more prestressing steel.

When designing a tie, an evaluation of the loads being transferred and their flow through the
track structure is essential. Therefore, forces and pressures of interest include the rail seat load,
lateral load, and the ballast pressure. The required flexural capacity is a determined based on the
ballast support conditions (pressure distributions) encountered during the life of a tie and the
applied rail seat loads (Figure 8). AREMA has accounted for these various loading and support
conditions in the minimum specified positive and negative moments located at the critical
sections of the rail seat and tie center. Similarly, lateral loads are accounted for in tie and fastener
design. Fasteners are designed for the transfer of a minimum lateral load to account for those
encountered in curved sections of track, while ties must be capable of withstanding lateral loads
to maintain horizontal track geometry. A further discussion of load analysis and transfer is
presented in the following sections.
**Rail Seat Load**

As a train moves along the track, the load from an axle is distributed amongst several ties due to the rigidity of the track. A single tie typically carries between 45 to 65 percent of an axle load directly above it. Factors affecting this load distribution are the tie spacing, fastening system, rail stiffness, and ballast and sub-grade conditions with tie spacing having the largest effect. Typical track design with concrete ties utilizes tie spacing between 19 in. and 27 in. [21].

In the past, equations and variables were used to calculate the rail seat load; however, to simplify the process of calculating rail seat loads, AREMA collected the factors related to the load distribution and created a design aid relating the percentage of a wheel load transferred to a single tie as a function of tie spacing (Figure 9). For example, a tie spacing of 24 in. would correlate to approximately 50 percent of the applied axle load being carried by that particular tie. Additionally, to account for rail irregularities and dynamic wheel load effects, impact factors are applied. Typical impact factors are 200 percent of applied static wheel loads [9].

**Ballast Support Pressure**

Once wheel loads are applied to the tie they must be transferred to the ground through the ballast and sub-grade material. Ballast support is crucial to a tie’s ability to support load. Poor ballast support results in tie cracking and eventually flexural failure. Initially, the distribution of pressure from the ballast is a function of placement and gradation due to the lack of consolidation, but over time with traffic the ballast will consolidate and eventually offer a more uniform support along the length of the tie [1]. Figure 8 illustrates the different stages of ballast support. However, deterioration of the ballast, due to improper maintenance, can result in a center support condition as previously discussed.

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During service, it is essential that the ballast and sub-grade are not over stressed. In reality, pressure between the tie and ballast is not uniform across the bottom of the tie, but an approximation or average is used to limit bearing pressures and prevent excessive depression of the track. This average ballast pressure is a function of the applied axle loads, impact factors, and the bearing area of the tie per AREMA section 4.1.2.5[21].

**Lateral Loads**

Along with vertical loads applied from the wheels and ballast, ties are subjected to lateral loads especially on curved sections of track. The ability of a tie to restrict lateral movement is important for maintaining track geometry. To support these lateral loads, ties rely on bearing of their ends against ballast material, friction between tie surfaces and ballast, and gravity. A recent design innovation to increase this resistance to lateral movement has been the addition of haunches to the sides of ties, which increases friction and bearing area, whereas previous designs maintained a smooth surface.[18]. In addition to the lateral load requirement for ties, the AREMA specification requires fastener systems to have a minimum capacity of 14 kips per linear foot of track to resist lateral wheel to rail loads. This load is then used for the tie fastener anchorage design of the ductile iron shoulder embedded within the tie during casting [21].

**DURABILITY AND PERFORMANCE**

One reason railroads utilize concrete railroad ties in their tracks is their increased durability and life span when compared to timber ties. These increases result primarily from the absence of rotting and an increased resistance to climate change. Generally, a concrete tie has a lifespan longer than the typical treated timber tie with decreased maintenance requirements.
Durability

Like any other concrete product, concrete railroad ties can be affected by changes in temperature and moisture. Freeze-thaw cycles in particular may cause accelerated deterioration of the concrete if air entrainment is not used. Additionally, the durability of concrete ties is largely dependent on ballast condition, because the ballast provides both support and load transfer of wheel loads and drainage of water away from the tie’s surface. Sufficient drainage is critical for preventing rail seat abrasion and in regions that experience freeze-thaw cycles. For this reason ballast material is often replaced or cleaned when adequate drainage is no longer achieved [22].

Corrosion

Corrosion is typically a secondary effect of thermal and flexure cracking of the tie. Within any reinforced or prestressed concrete member the formation of cracking provides a conduit for the ingress of moisture and chemicals which in turn initiate the corrosion process once they reach the internal reinforcement. To prevent corrosion, adequate concrete cover of prestressing steel must be provided in addition to proper drainage around the tie by the ballast. In general, corrosion is not often observed in service because ties are typically replaced due to another failure mechanism such as flexural failure of rail seat abrasion which tend to occur well before corrosion becomes a problem. As for corrosion of the prestressing steel during the fabrication of the tie, AREMA specifies that surface rusting may occur, however pitting may not. Under normal tie manufacturing conditions, prestressing steel is typically turned over well before any significant surface rusting occurs.
TESTING

To gauge tie performance, laboratory and service testing is performed to check that ties meet the minimum specified requirements set forth by AREMA. Testing includes both static and dynamic loadings to simulate in service conditions of the ties [1]. Flexural testing includes the rail seat moment test, center moment test, bond development test and fatigue testing. The purpose of these tests is to determine whether the tie design is adequate for the anticipated loads and load frequency [21]. Along with flexural testing, simulated track testing is also utilized to determine effects of ballast support and dynamic wheel loading during different stages of tie life [1]. Flexural strength of the ties is tested for both positive and negative bending. Dimensions and tolerance of ties are critical due to the gage of the track being permanently set during production. Testing and allowable tolerances are set by AREMA (Chapter 30: Part 4) in the following sections [21]:

- Section 4.9.1 - Design Test of Monoblock Ties
- Section 4.9.2 - Production Quality Control of Monoblock Ties

Material testing is outlined within AREMA as well. Concrete durability is tested through freeze-thaw and abrasion processes. Standards for concrete tie materials include:

FABRICATION METHODS

Concrete tie production is similar to other precast, prestressed concrete members except in terms of the repetition and quantity of concrete ties which are produced during a single casting. Depending on the fabrication method used, hundreds of ties can be cast concurrently [1]. The three methods of fabrication historically used in North America are the long-line method, stress-bench method, and the individual form method. The most common fabrication method used today is the long-line method [27]; the other two methods are less common for major manufacturing facilities and as such will not be presented.

Long-Line Method

The long-line name describes the process in which ties are produced end to end in a line, with continuous strands of prestressing steel running through them. Casting beds containing the forms are stationary and equipment moves along the length of each bed. A variation of this method in which forms are placed on train cars called lorries, which allow them to move between the different production steps is termed the Grinberg method.

The long-line fabrication process can be highly automated, but still requires a labor force with a size dependent on the number of casting beds in operation and the number of forms in each bed. Workers are typically broken down into crews performing specific tasks which includes utility, steel layout, casting, sawing, stripping, and final prep. The various stages of fabrication are illustrated in Figures 10 through 15. A turnaround time of less than 24 hours is typical for this method.
This process is efficient and has high production compared to other methods. Other advantages of the long-line method of concrete tie production include uniform tie quality and few labor hours since majority of production is mechanized. Drawbacks to the long-line method are that it requires a large capital investment for forms and space for production. Tie manufacturing facilities vary in size and capacity but the largest facility in North America is capable of producing 400,000 to 500,000 ties annually.

**INSTALLATION & MAINTENANCE**

The rate at which concrete ties are installed depends on the equipment used. Large railroads tend to use highly mechanized equipment such as the Track Renewal Train (TRT) systems which are capable of installing 8-9 miles of track in a single day, whereas smaller contractors may use either tie clamps or chain hoist systems mounted on backhoes, which can install up to 1000 and 500 ties per day, respectively.

Maintenance is the responsibility of the operating railroads and procedures vary significantly between companies. However, it is generally understood that in order for concrete ties to last, proper care must be taken to maintain the ballast and fastening systems. This is because the tie acts in conjunction with the rest of the track components, where if one component fails it tends to start a cascade of failures to the remaining components.

To increase quality control and documentation, some manufacturers have imprinted ties with information including its date and place of fabrication and tie design. Using this information an in-service tie can be identified and evaluated based on historical manufacturer records.
ECONOMIC CONSIDERATIONS

In order to analyze the cost of concrete ties in comparison with traditional wood ties, both initial production and long term maintenance costs must be considered. This cost estimate however is subject to change with respect to the price of steel, Portland Cement and timber. With rising energy costs as well as increased reservations about the harvest of dimensionally suitable timber, the future prices of both concrete and timber ties are uncertain. The following factors have been determined to have the most significant impact on the economic benefits of concrete ties:

- Annual tonnage carried on track section, as tonnage increases concrete ties benefit increases due to higher durability,
- Life of concrete ties versus wood ties,
- Savings in train fuel due to more efficient train operation on more rigid concrete tie tracks,
- Future cost of old growth timber,
- Future cost of labor to replace aging wood ties on a more regular basis than concrete ties.

Initial Production & Construction Costs

Concrete ties are an engineered product requiring specialized knowledge, equipment and a substantial capital investment in facilities to produce. In addition, more complicated and expensive fastening systems are required with concrete ties compared to the steel spike used with wood ties. With this in mind, comparing concrete and wood ties in terms of materials and manufacturing, wood ties are cheaper to produce by a small margin. However, this may change as a projected shortage of wood of sufficient size and quality may limit timber tie production. Concrete ties may experience a similar rise in price due to increasing energy costs related to
cement production and the demand for steel. It can be assumed that the price for both timber and concrete ties will rise, but the rates are subject to speculation [28].

Similar to their production, concrete and timber ties have very little in common in terms of construction and installation procedures. Crew size and equipment requirements vary depending on installation methods, but generally concrete tie construction is faster and simpler due to the track gage being set during production rather than during construction as is the case with wood ties.

**Long Term Maintenance Costs**

The main advantage of concrete ties over other tie materials is their inert nature. Concrete unlike wood and steel can neither root nor rust. Concrete ties also tend to wear uniformly over a section of track whereas the location of timber tie wear is more random. Instead of replacing individual ties over an extended period of time like timber track typically requires, concrete tie tracks are repaired in sections leading to lower overall maintenance costs [28]. The higher initial capital investment made for concrete ties is typically recouped through the tie’s extended lifespan. This is supported by the fact that there are concrete ties still in service today that were installed 35 year ago. However, concrete ties have not typically endured the originally estimated 50 year service life [20].

**CONCLUSION**

The utilization of concrete ties as an alternative to wood in North America has occurred due to the advantages they offer in terms of capacity and long-term durability. As the use of concrete ties increases in the future with projects such as the Alaska Canada Rail Link, a demand for
reliable and durable ties will grow. Currently there is still room for innovation and research related to material durability, design efficiency, and production of concrete ties. This paper has presented an overview of the North American concrete tie. As energy costs increase, the rail industry has the potential to grow into the primary means for the transportation for goods and people during the twenty first century. Should this be the case concrete ties will be in an excellent position to contribute to this expansion.

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![Figure 1: Generic concrete tie shape and dimensions](image)
Figure 2: ACRL working alignment
Figure 3: (a) 7-wire prestressing strand, diameter 0.5 in. 270 ksi (b) prestressing wire, diameter 0.21 in. 260 ksi

Figure 4: Embedded cast iron shoulder for PANDROL E-CLIP fastening system
Figure 5: Ties equipped with non-captive PANDROL E-CLIP fastening system

Figure 6: (a) Captive PANDROL SAFELOK III (b) PANDROL FASTCLIP (right) fastening systems
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Figure 13: (a) Prestressing steel is ran through steel plates that will anchor and maintain the steel layout within the tie cross section (b) Prestressing steel is attached to jacks at opposite end of casting bed from roles, each wire is loaded to 7000 lbs (pictures taken by author with permission of CXT)

Figure 14: (a) Concrete is batched in onsite plant then placed in form via hopper moved using overhead gantry crane (b) Jacks are released transferring load to concrete, saw equipment moves along casting bed cutting steel and concrete at form section joints (pictures taken by author with permission of CXT)
Figure 15: (a) De-molding apparatus travels down casting bed guiding gantry crane with tie clamp attachment over form section containing 6 ties, ties separate from forms, are rotated 180 degrees, and set on adjacent railcar right side up (b) Polyurethane is applied to railseat region using manual sprayer prior to railcars moving outside of building (pictures taken by author with permission of CXT)
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which distributes it through the tie and pulls it off the roll (pictures taken by author with permission of CXT)

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