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# **Causes and Preventative Methods for Rail Seat Abrasion in North America's Railroads**

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## **ABSTRACT**

This paper focuses primarily on the mechanics of rail seat abrasion with an emphasis on cold regions due to the severity of the issues in those climates. The investigation includes a synthesis of the best practices used to mitigate this type of failure. Also included is an exploration of alternative materials with good abrasion resistance for use in the rail seat region. The objective of this research is to evaluate materials and/or methods to eliminate the problem of railseat abrasion.

## **INTRODUCTION**

Following the increased use of concrete crossties during the 1980's in North America, railroads began to notice a reoccurring problem. The concrete and specifically the cement paste of the tie beneath the rail degraded at an accelerated rate compared to the rest of the tie. This degradation results in an uneven aggregate bearing area in most cases, which left untreated causes rail instability and derailments. The phrase rail seat abrasion was coined and has since been used to describe the problem (Reinschmidt 1991).

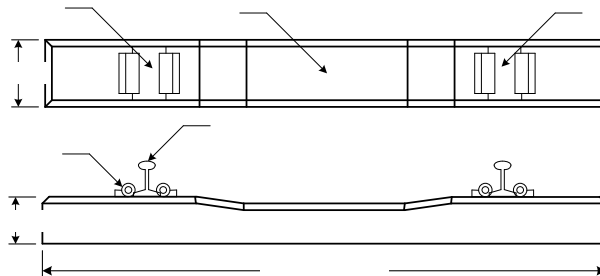
To identify the cause of this deterioration, railroads and tie manufacturers initiated testing and monitoring practices of the affected ties. Theories on causes of failure include: freeze-thaw action, since most affected ties are located in moist northern climates, hydraulic pressure in the air void system of the paste caused by rail loading, fastener failure causing excessive rail movement and abrasion due to the intrusion of rail grit. In addition, railseat abrasion has been found almost exclusively on heavy haul mainlines and sections of track located on curves. Testing has revealed that all theories contribute to railseat abrasion, but that the primary cause of the deterioration is hydraulic pressures inside the air voids of the cement paste; the result is an explosion of the cement paste at the microscopic level. To combat rail seat abrasion, tie and fastener manufacturers have devised methods of prevention:

- epoxy spread over the railseat region of the tie (Peters 2007)
- cast-in-place steel plates covering railseat (Peters 2003)

While these methods have been effective in delaying rail seat abrasion, they have not eliminated the problem completely. Over time the epoxy wears down allowing abrasion to occur and steel plates add to the production cost of the tie. Therefore, other methods of prevention are required to ultimately solve the rail seat abrasion issue. Current research is investigating the concrete in the railseat region and evaluating methods for increasing abrasion resistance and also the application of materials with increased resistance which may be incorporated into the tie at the interface (Hanna 1986).

## PROBLEM EXPLANATION & HISTORY

Prior to 1972, it is estimated that 120 million concrete ties were in service around the world (Hanna 1979). The reason for the introduction of concrete railroad ties is their 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 began being utilized on large scale projects in the United States. The primary reason for the avoidance of this new technology was that the designs originally adopted from Europe were simply not sized for the larger loads within the North American mainline 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 heavy haul railroad system (Hanna 1979). The shape and typical dimensions of a typical North American concrete tie is illustrated in Figure 1.



**Figure 1. Typical concrete tie shape and dimensions**

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 tie's design. During the initial years of concrete tie usage in North America, failures were often a result of inadequate development of prestressing steel and insufficient flexural capacity. Over the last several decades tie failures due to flexure and development have nearly been eliminated. Research to improve performance and durability in terms of railseat abrasion have been the primary field of interest (Hanna 1979).

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 (Figure 2). 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. Regions with extreme freeze-thaw cycles often experience rail seat abrasion at an accelerated rate due to increased concrete deterioration below the tie pad (Peters 2003).



**Figure 2. Rail seat abrasion due to water intrusion (Peters 2003)**

Today it is estimated that approximately 2 million concrete ties are installed in North American track systems annually. Expectations are that this quantity will increase in the future as adequately sized timber for wooden ties becomes scarce and concrete becomes the more economical option for tie material (Wanek-Libman 2008).

Even with the use of concrete ties on the rise, the issue of rail seat abrasion is still the leading cause of premature tie failure and track maintenance. Railseat abrasion was first observed during the mid 1980's by Canadian National (CN). Ties were experiencing accelerated wear in the railseat region characterized by a degradation of the cement paste material. Soon after CN's discovery, documented cases were found by almost all major railroads in North America including Burlington Northern Santa Fe (BNSF) and Union Pacific (UP) (Reinschmidt 1991).

While rail seat abrasion can be identified on nearly any track, the most severe cases are restricted to regions with significant moisture in the form of rain or poor track drainage and temperature fluctuations producing freeze-thaw cycles (Peters 2003). Track sections exposed to regular high tonnage service and those located on curves also appear to have accelerated abrasion rates. The result is a decrease in tie service life from an estimated 25-30 years to 10 or less depending on the location and conditions.

Maintenance and replacement practices to deal with degraded ties have been instituted by railroads including the placement of epoxy on the abraded surface to return it to its original level (Peters 2007). However, this process is labor intensive and time consuming, also requiring track closure. Even though this maintenance is an inconvenience, in most cases it is essential to keeping a track safe. Rail seat abrasion if left untreated is capable of eliminating a tie's ability to maintain track gage and rail stability inevitably leading to derailments.

## **CHARACTERISTICS & CAUSES OF RAILSEAT ABRASION**

To understand the causes of rail seat abrasion it is essential to determine the common characteristics such as: climate, track conditions, loading and materials which are present during failure. The following sections describe the characteristics which appear to be common among cases of rail seat abrasion in North America.

## **Environmental Conditions**

### *Climatic Characteristics*

While occurrences of rail seat abrasion have been documented in nearly every region of North America, the most severe cases tend to originate in regions where water is available and in contact with the rail seat region of the tie. This moisture collects through precipitation or poor drainage due to dirty ballast. The key is that water must be present long enough to intrude into the interface between rail and tie. Therefore, it is no surprise that the Northern United States and Canada, which have temperate climates and moderate precipitation, contain the highest concentrations of ties affected by rail seat abrasion (Bakharev and Struble 1997). Drainage of water away from the tie's surface is controlled by the ballast. Sufficient drainage is critical for regions that experience freeze-thaw cycles. For this reason ballast is often replaced or cleaned when adequate drainage is no longer achieved (Weber 1979).

### *Freeze-Thaw Action*

Concurrent with the availability of water, geographical regions with high concentrations of railseat abrasion failures typically have fluctuating temperatures, allowing for freeze-thaw cycles. Like any other concrete product, railroad ties can be affected by changes in temperature and moisture; freeze-thaw cycles in particular cause accelerated deterioration of the concrete. Experimental results have shown that the freezing and expansion of pore water in the air void structure of the cement paste leads to micro-cracking and the degradation of the overall concrete structure (Stark 1989; Bakharev and Struble 1997). This becomes particularly important in concrete ties where flexural cracking combined with freeze-thaw cycles result in premature tie failure. Water is responsible for rail seat abrasion via hydraulic pressures, but when frozen the volume increase within cracks propagates additional cracking. Concrete ties like any other concrete member will be stressed during the freeze-thaw action, but the extent of how the freeze-thaw process affects rail seat abrasion is yet to be determined.

The duration of the freezing period and the frequency of freeze-thaw cycles affect the rate at which degradation occurs. Long freezing periods (greater than 7 days) allow water to migrate towards and combine to form larger ice structures, generating large internal pressure with the paste. However, long freezing periods often correlate with fewer freeze-thaw cycles over the life of a tie. During the thaw phase of the cycle, water migrates further into the tie through cracks created during the previous freezing period. This allows degradation to occur at greater depths from the concrete surface (Stark 1989).

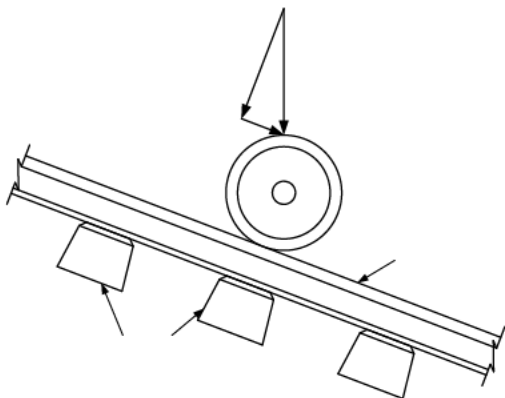
Regions that experience these freezing periods represent a large percentage of North America including the Midwest which experiences a large number of freeze-thaw cycles and much of Canada and Alaska where air and ground temperatures can remain below freezing for months or years at a time. Effects of the freeze period duration, such as a permafrost region, where soil is frozen for a minimum of two years at a time, remains uncertain.

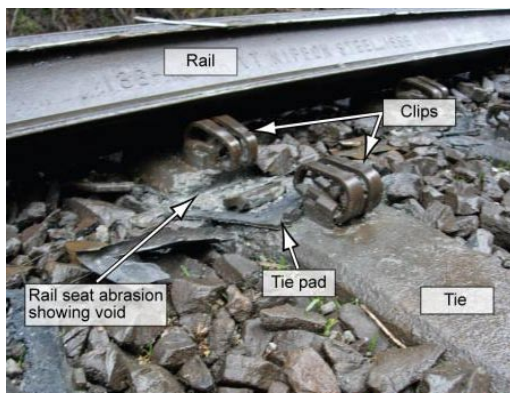
## Track Conditions

Railroad tracks while having the singular purpose of supporting trains, are dynamic and diverse in terms of their layout, construction, and operation. Track geometry, structure, and maintenance play important roles in how the loads applied by trains are transferred throughout the track from rail to sub grade. Track conditions including grades and curves have been documented as increasing the probability of railseat abrasion (Reinschmidt 1991).

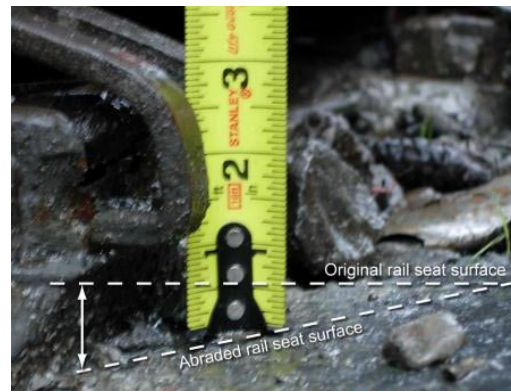
On track sections with grades greater than two percent, like those found in the mountainous region of Western North America, rail seat abrasion has been observed at an increased rate compared to flat sections exposed to the same environmental conditions (Reinschmidt 1991). A possible explanation for the difference in abrasion rates between flat and sloped track is the increased longitudinal force which occurs between the tie and rail on sloped sections. Figure 3 (a) illustrates the increased longitudinal friction force component generated on sloped track sections. The increased longitudinal friction force applied to the rail causes additional movement of the rail with respect to the tie, generating an abrasive force at the rail-tie interface. This abrasive force causes the concrete to deteriorate.

Similarly, curved track sections experience increased occurrences of rail seat abrasion. Abrasion is due to the uneven loading between the inner and outer rails and the additional lateral forces, generated as the train navigates a curve (Figure 3 (b)).





(a)



(b)

**Figure 4. (a) Rail seat abrasion on curve, which caused derailment due to widening of track gage, (b) Side view of rail seat abrasion (NTSB 2005)**

## Loading

### *Load Characteristics*

As previously highlighted, rail seat abrasion can occur in any rail application and region, however some tracks appear more prone to failure than others. A primary characteristic to this failure mechanism is the loading to which the track is subjected, with heavy haul or high tonnage tracks displaying higher rates of rail seat abrasion than low tonnage tracks typically used for transit purposes. This degradation makes tracks that cater primarily to high tonnage traffic more susceptible to failure (Kaewunruen and Remennikov 2007). In addition to the type of loading, wheel abnormalities such as flat spots have been shown to cause increased degradation to track components. Impact loading associated with wheel abnormalities can often increase the force applied to the track by 300 percent (AREMA 2003). This increased load may exceed the strength capacities of track materials, causing failure.

### *Hydraulic Pressure*

Nearly all occurrences of rail seat abrasion include the presence of water between the tie and rail. The process by which water causes the deterioration of concrete in the railseat begins when water saturates the concrete filling the air voids of the cement paste. Load is then applied to the rail, forcing additional water into the surface voids of the cement. Hydraulic pressure created within the voids due to moisture pressing against the void walls and exceeding the strength of the paste, causes cracking and deterioration of the cement structure near the surface of the rail seat region. Cyclic loading of a train exacerbates this process by causing the pressure within the void structure to vary millions of times over the life of a tie (Bakharev and Struble 1997). As cement at the surface cracks and flakes away, new voids originally covered become accessible to water intrusion. Therefore, the depth of water penetration increases over time due to the increased permeability from the continually deteriorating cement surface paste (Stark 1976).



The loading required to cause the pore water pressure to exceed the cement strength may explain why heavy haul tracks experience railseat abrasion on a greater scale than transit lines. Larger wheel loads are capable of forcing more water into the cement surface and creating higher pressures. Higher pore water pressures can also be achieved due to wheel abnormalities such as flat spots which cause larger impact loads.

## **Materials**

### *Concrete*

The primary materials in concrete ties are concrete and prestressing tendons. In addition to the concrete and prestressing tendons, ties include rail seat pads and rail fastening systems to anchor the rail to the tie (Figure 1). In the case of rail seat abrasion, the limiting materials are the concrete and rail fastening systems. These two components have the greatest variation in terms of design, and are typically the first components to fail in the track structure.

The use of early high strength concrete (compressive strength greater 6 ksi) is required in the production of concrete ties due to the use of prestressing, with general practice recommending a minimum compressive strength of 7,000 psi at 28 day (AREMA 2003). Reasons for early high strength concrete are the following:

- To efficiently produce concrete ties the prestressing stress must be transferred to the tie at an early age. A compressive strength of 4,000 psi is typically considered satisfactory for prestressing load transfer.
- High strength concrete has the effect of limiting flexural cracking under applied service loads (Hanna 1979).

Other design considerations related to concrete mixture include admixtures. For climates capable of freeze-thaw cycles, air-entraining admixtures are used by tie manufacturers to increase tie durability. Entrained air in concrete provides voids for water encapsulated by the cement paste to form ice crystals without increasing the internal pressure of the concrete causing cracking (Stark 1989).

In addition to admixtures, the aggregates used in a concrete mixture can affect the durability due to their varying levels of porosity and strength. The two most common aggregates used in concrete tie production are weaker porous sedimentary rocks such as limestone and dolomite and stronger dense igneous or metamorphic rock. The more permeable or porous a concrete is, the more susceptible to freeze-thaw degradation it is. Similarly, porous aggregates tend to deteriorate along with the cement paste in the railseat region while strong aggregates remain leaving an uneven bearing surface (Hanna 1975).

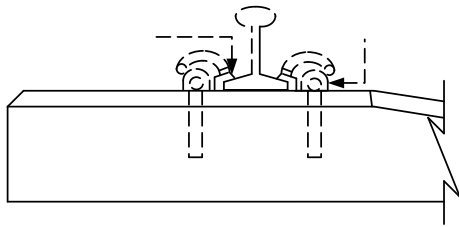
### *Fasteners Failure*

A correlation between rail fastener fatigue failure and rail seat abrasion has also been identified. Cyclic loading applied to the rail causes fatigue failure of fastener components, decreasing the restraining force applied to the rail by the fastener. Components prone to fatigue include polymer insulators and pads and steel shoulders. Figure 5 (a) illustrates a typical fastener configuration utilizing insulator pads and



steel shoulders. The increased rail movement caused by fastener deterioration has been shown to increase the rate of rail seat abrasion (Weber 1979).

Many fastener configurations exist, but a commonality is the spring force applied to the rail flange to enforce contact with the tie (Figure 5 (b)) (Hsu and Hanson 1968). Over time relaxation in the steel fastener components occurs due to fatigue loading decreasing the spring force applied. In addition, some fastening systems utilize polymer insulators which suffer from abrasion as well. Insulator material gradually deteriorates, creating voids and allowing excess rail movement. The failure of the fasteners allow for the intrusion of water and rail grit.



concrete and rail. This is achieved using polymer rail pads and epoxies. Research into new methods of prevention include:

- Steel fiber reinforced grout on railseat region (Takahashi, Sekine et al. 2008)
- Steel plates bonded to the tie using epoxy after casting
- 3-part abrasion resistant pad assembly
- Metallic aggregate in railseat region (Wu, Yan et al. 2001)

To prevent rail seat abrasion two actions must be prevented, the intrusion of water into the void structure of the cement paste beneath the rail and the abrasive action of the rail against concrete. To impede the intrusion of water, which causes hydraulic pressure failures, sealants may be used to fill the surface cracks and voids while maintaining the internal voids for freeze-thaw resistance. The abrasive movement of the rail on the concrete railseat can be transferred to an alternate interface by providing a three layer design, which allows for movement between two different surfaces rather than between the concrete tie and steel rail. Additionally, fastening systems with increased sustained rigidity will prevent movement, allowing ties to reach their intended service life.

### Industry Solutions

Methods used by railroads and component manufacturers in both design and repair to combat rail seat abrasion include a variety in techniques. However, they share a similar objective of protecting the interface between the steel rail and concrete tie. Adopted in 2002, the CN60E tie was designed during collaboration between Canadian National (CN) and largest tie manufacturer in North America, L.B. Foster CXT, for use on their mainline track. Until the introduction of the CN60E, material degradation of ties due to rail seat abrasion was the leading causes of tie failure. To remedy the issue, CN and CXT set out to develop a method of protecting the concrete in the rail seat region without increasing production and maintenance costs of tie. Several techniques were considered, however the incorporation of a cast-in steel plate in the rail seat region was selected as the best solution (Figure 6) (Peters 2003).



**Figure 6. Steel plate to be cast-in prior to casting (Peters 2003)**

Testing of the CN60E showed no rail seat abrasion after five times the required loading cycles to cause abrasion on other conventional North American tie designs. The steel plate design also increased track component life due to the elimination of fatigue movement of rail fasteners caused by rail seat abrasion.

Similar to steel plates, epoxy and other resins may be applied to the rail seat region filling the surface voids of the concrete and providing a wearing surface other than

the concrete itself. This technique may be used during both the production and repair of concrete ties. Epoxy is either placed on the rail seat of the tie after casting to delay the onset of rail seat abrasion or in the field to repair affected ties by returning the rail seat to its original elevation. Currently the tie manufacturer, CXT offers the option of epoxy application to the railseat to its clients such as Union Pacific (UP) and Burlington Northern Santa Fe (BNSF). UP and BNSF have outlined procedures for the repair of concrete ties using epoxy in the field to be used by their tie gangs. However, this process can be very labor intensive and requires track closures to allow for application and curing of the epoxy (Peters 2007).

While the application of these abrasion resistant materials to the rail seat has demonstrated increased tie durability, fastener manufacturers have created hardware with increased durability as well. To increase the life of their rail pads and fastener insulators manufacturers have begun to use polyurethanes with a greater ability to resist abrasion and fatigue. The improved polyurethane materials are capable of withstanding increased load cycles without wear and maintaining the connection rigidity necessary to prevent movement between the rail and tie (Kaewunruen and Remennikov 2007).

### **Experimental Solutions**

To increase concrete durability in the rail seat region, factors such as: concrete permeability, aggregate strength, water cement ratio, and curing techniques should be considered, with a goal of minimizing the effects of hydraulic pressures and freeze-thaw action the intrusion of water into the concrete. Potential solutions include increasing the abrasion resistance of the concrete in the railseat region through the means of improved mix design and materials, and the application of resistant materials to the rail seat such as cast-in polymer plates or high performance concrete during production. To do so, cracking and permeability of the concrete is restricted to a minimum because they provide channels for water to flow into the pore structure, ultimately causing degradation.

Cracking may also be managed by controlling the humidity and temperature at which concrete cures, allowing for the rate of curing and shrinkage to be monitored (David Darwin, JoAnn Browning et al. 2006). Research into the use of metallic aggregates and fiber reinforced concrete in the railseat regions has been shown to increase the compressive and tensile strengths of the concrete; however, their influence on abrasion resistance is still unknown. These alternatives represent promising solutions, but require additional testing and development (Wu, Yan et al. 2001; Takahashi, Sekine et al. 2008).

### **FUTURE WORK**

Most current concrete ties used in heavy haul applications have been designed adequately for flexure, thereby eliminating the likelihood of flexural failures prevalent in early designs, assuming proper installation and maintenance. Currently, the principal problem facing concrete ties is durability and resistance to abrasion at the interface between the rail and tie in the rail seat region. To increase the tie's resistance to railseat abrasion, research on materials and possible application

processes are a primary interest. Future efforts will continue to evaluate these issues, with the objective of finding solutions for increasing the tie life on the proposed Alaska Canada Rail Link.

Future research efforts will focus on concrete tie durability, life span and their ability to maintain track geometry. The effects of the unique climatic and geologic environment found in North America on the concrete tie should be studied to determine what aspects of the tie's design are affected.

## CONCLUSION

A primary focus of this research is to evaluate the use of concrete ties in the North American rail system, specifically northern regions where rail seat abrasion has been a major problem. Conditions and failure mechanisms associated with rail seat abrasion include:

- Hydraulic pressure caused by the saturation of surface voids in concrete and applied cyclic loading
- Freeze-thaw action, rate of deterioration dependent upon length of freeze period and number of cycles
- Intrusion of rail grit and water between tie-rail interface producing abrasive agent
- Rail fastener fatigue allowing abrasive cyclic movement of the rail with respect tie

Of the failure mechanisms discussed it appears that hydraulic pressure is the dominate process due to its immediate initiation upon installation and independence from other processes. The effect of freeze-thaw is not likely the sole cause of rail seat abrasion since the effects are seen over the entire tie, but it is a significant factor contributing to the mechanism. Similarly, the fatigue of fasteners and intrusion of rail grit further exacerbates the condition. To combat rail seat abrasion, railroads and manufacturers have worked to protect the concrete in the rail seat using abrasion resistant materials and repair procedures to extend the life the of the tie.

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