

## **CN 60E CONCRETE TIE DEVELOPMENT**

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## **ABSTRACT**

CN recently redesigned its standard prestressed concrete monoblock crosstie. This paper presents the key differences in the prior designs versus the new CN 60E design and the testing, installation, and performance benefits of the CN 60E.

The new CN 60E is an 8'6" tie fully compliant with AREMA Committee 30 structural requirements and incorporates a custom designed twin stem Pandrol e-clip ductile iron shoulder. To combat railseat abrasion, the tie is cast with an integral steel railseat plate. The fastening system was tested to 10 million cycles with a load distribution of 35,000 lbf vertical and 18,200 lbf lateral (L/V ratio=0.52). Testing has shown reduced loose component (insulators, pads, and clips) wear rates. The CN 60E tie utilizes a Pandrol e2009I clip, Pandrol SAFELOK poly pad, and Pandrol HD6 composite insulators for the rail fastening system. Installation of the new 8'6" ties is performed using custom modified, hi-rail capable backhoes out in front of a TR-10 tie production gang.

## **INTRODUCTION**

It is important to know some CN concrete tie history before going into the details of the CN 60E tie design. Although there was some concrete tie testing on the CN in the 1920's, it was small in scope. Small numbers of conventionally reinforced ties with wood pads, conventional clips and hold down bolts were installed in 1922, 1924, and 1928. All of these tests showed unsatisfactory performance due to lack of resiliency in the fastening system, which caused subsequent bolt anchorage degradation in the ties. During the depression and war years further testing of concrete ties came to a halt. It was not until October 1961 that testing resumed when

CN installed 800 “A.R.E.A. Mark 1” prestressed monoblock concrete test ties in track on the Drummondville Subdivision. These ties were removed ten years later, due to fastener loosening and tie cracking. During that period, in October 1965, 453 ties provided by Dow-Mac were installed on the Napadogan Subdivision. These ties were designed in accordance with British Rail design F23. These 453 ties were removed from track thirty-five years later due to railseat abrasion. It was this British Rail F23 design which formed the basis for the first CN standard for prestressed monoblock concrete ties—the CN60A.

In 1972 Rudi Rotter, then CN System Engineer of Production, was put in charge of finding ways to efficiently install concrete ties. Thus, the “Jasper Test Track” was born and 10,000 Costain Concrete CC241 (designed to BR F23) were installed from MP 22.9 to MP 26.9 on the Albreda Subdivision. Approximately 6500 of these original 10,000 non air-entrained ties remain in track today (see figure 1). CN began installing concrete ties in a large scale production mode in 1974, continuing through the late 1980’s. Within this period, CN installed nearly 4 million concrete ties.

## **TIE DESIGN**

Over the years, CN has installed a total of four different concrete tie designs, as follows: CN 60A, CN 60B, CN 60C, and CN 60D. The CN 60A, B, and C designs were all designed for use anywhere in mainline track, while the CN 60D was a lighter, less costly tie developed strictly for use in tangent track. The CN 60B and 60C designs provide greater center negative bending strength over the CN60A design.

By far, the CN 60B and CN 60C designs were the most widely installed. Figure 2 shows a comparison between the different designs, including the CN 60E.

Out of all Class 1 railroads, CN has the longest experience with concrete tie performance in track. To varying degrees, the ties installed in the past have exhibited performance degradation due to railseat abrasion, shoulder breakage due to fatigue, and loss of clip toe load due to shoulder wear at the heel. In order to develop the CN 60E tie design, all three of these key concerns had to be addressed.

### **Key Design Concerns**

Railseat abrasion is a gradual wearing away of the concrete paste and aggregate from the concrete beneath the tie pad (see figure 3). Railseat abrasion occurs due to the presence of water, high tonnage, steep grades, and predominantly in curves greater than two degrees. CN has many such curves throughout the lines that traverse the rugged Canadian Rockies. Since railseat abrasion was first discovered in the late 1980's, CN has been aggressively repairing ties in curves to restore their original railseat geometry to ensure proper longitudinal rail restraint, cant, and gauge. Some curves have undergone more than one repair cycle, with some curves currently undergoing their 3<sup>rd</sup> rail seat repair.

The problem of fatigue failure of the cast-in ductile iron shoulder in curves poses significant derailment risk (see figure 4). Shoulder breakage occurs at a depth of approximately two inches below the top of the tie. Laboratory testing indicates that

the cause of this failure is low cycle fatigue due to the shoulder geometry and shoulder material properties.

Lastly, there has been some loss of toe load due to the heel of the shoulder wearing from repeated clip removals and insertions necessary for rail, pad, and/or insulator replacements (see figure 5).

The above problems notwithstanding, CN has recognized substantial economic and performance benefit from the concrete ties in track and decided it was necessary to develop an improved standard tie design for use as either replacement on abrasion-prone curves and also as the standard for any future new or out-of-face construction.

### **Options Considered to Address Key Concerns**

To address railseat abrasion, the following options were considered:

- a) Steel fiber reinforced grout applied at the railseats during manufacture,
- b) Post installed (bonded to concrete with epoxy) steel wear plates of varying abrasion resistance,
- c) Cast-in-place steel wear plates of varying abrasion resistance, and
- d) Current class 1 railroad approved 3-part abrasion resistant pad assembly consisting of a 1mm foam gasket, 1.4mm martensitic steel wear plate, and 6.0mm polyurethane pad.

To address shoulder breakage and heel wear, the following options were considered:

- a) Various material types and grades as follows:
  - i. Austempered Ductile Iron (65-45-12)
  - ii. Ductile Iron ASTM A536 60-40-12, 80-55-06, 100-70-03, and 120-80-10
  - iii. Cast Steel ASTM A27, 60-30 and 70-36
  - iv. Cast Steel ASTM A148, 80-40
  - v. Cast Steel AISI 8620-8635, 90-60
  - vi. Ductile Iron ASTM A536 65-45-12 (existing shoulder material)
- b) Various shoulder geometry considerations as follows:
  - i. Single stem anchorage
  - ii. Twin stem anchorage
  - iii. Under heel support

### **Chosen Design**

To improve railseat abrasion resistance, a cast-in-place ASTM A36 ¼" thick Nelson™ studded steel plate was chosen over the other three considered options because of ease of manufacture, economics, epoxy debonding in field tests, and 3-part pad assembly abrasion plate wear that occurs in track due to relative movement.

To reduce the loss of toe load due to shoulder heel wear from repeated clip application and removals, a tougher shoulder material, Ductile Iron ASTM A536 80-55-06 was chosen. To aid in shoulder material selection, CN commissioned Bodycote Materials Testing Canada Inc. to undertake tensile, impact, Brinell hardness, and fatigue testing for the material types under consideration. The results of these

tests were compared against published data and the existing ASTM A536 65-45-12 shoulder material. The shoulder material chosen was based upon increased toughness, strength, wear resistance, and value. The 80-55-06 provides 15 to 30% improved hardness over the existing 65-45-12 grade. Other grades of ductile iron, cast steel, and austempered ductile iron were not chosen due to economics and availability.

To solve the shoulder stem breakage due to fatigue, the shoulder shape and material type were changed. The existing single stem design was changed to a twin stem design, making this shoulder the first twin stem e-clip shoulder for concrete ties. The twin stem design reduces shoulder stresses by better distributing the lateral, vertical, and rotational loads into tie versus what can occur with the single stem design. Fatigue strength was also improved between 25 and 30% over existing by choosing the 80-55-06 ductile iron as the material type.

Since the shoulder geometry was being redesigned and therefore new patterns required, additional features were added to further improve performance. These included adding a clip anti-backout feature and skirts to reduce grout leakage and secure the cast-in-place steel plate during manufacture (see figure 6). In addition, an anti-rotational fin and more area under the heel was added to better distribute rotational and overturning moments into the concrete tie.

Since new tie designs were being considered, CN and CXT reviewed current concrete tie designs in use by other heavy haul Class 1 Railroads. Most of the railroads using concrete ties have migrated to 8'6" long ties to reduce ballast pressures by approximately 10% versus 8'3" long ties. Current use also indicated prevalent use of a multiplicity of indents along the sides of tie to improve lateral resistance in track. As such, an 8'6" tie with multiple side indents was selected, with structural performance also increased from existing to meet current AREMA Chapter 30 requirements (see figure 7 for structural comparison).

The chosen fastening system for the CN 60E tie is comprised of a Pandrol SAFELOK 37693 5mm pad, Pandrol HD6 composite insulators, Pandrol e2009L clips, and the Pandrol 10326 shoulder.

## **DESIGN VALIDATION**

Three key design validation activities occurred for the final CN 60E tie design. These activities were clip toe load confirmation, assembly and track gauge confirmation, and fastener assembly testing.

Pandrol Canada and CXT Incorporated jointly validated the toe loads provided with the improved twin stem shoulder using both the older style PR 631 clip and the proposed e2009L clip (see figure 8). This testing showed that the CN 60E tie provides the anticipated toe loads with either clip type, which allows for flexibility in the field.



CN and CXT Incorporated jointly validated the assembly and track gauge by assembling a 12 foot track panel mock-up at CXT's plant in Spokane, Washington. The mock-up showed that the assembly and gauge were also as anticipated.

To prove the chosen CN 60E fastener design, Bodycote was again commissioned to provide testing. Since the tie shape and structural design were already proven for other Class I Railroads, the testing regime was setup solely to qualify the chosen shoulder material, shoulder geometry, cast-in-place studded steel railseat, pads, clips, and insulators. This test subjected the complete assembly to a load distribution of 35,000 lbf vertical and 18,200 lbf lateral ( $L/V$  ratio=0.52) per railseat at a rate of 2.5 cycles per second. Throughout the test, traction sand and water were applied continuously to both railseats to simulate in-track abrasion conditions (see figure 9).

The test ran for 10 million cycles with no shoulder loosening and no railseat abrasion on the cast-in-place steel plate (see figures 10A through 10D). Similar tests run on other accepted North American concrete tie designs generally show detrimental railseat abrasion and/or shoulder loosening within 2.5 million cycles.

An unexpected benefit discovered as a result of this testing was improved component wear life. The condition after 3 million cycles was found to be representative of the condition typically observed after only 1 million cycles. This threefold improvement in component life is most likely due to the complete assembly being held tightly together in

a near new condition due to lack of railseat degradation and lack of shoulder movement.

## **INSTALLATION**

The vast majority of CN's concrete ties were installed using the Canron-Tamper P-811 in the 1980's. The recent need for replacement ties does not justify the use of the P-811 due to the quantities involved and the available track time. Therefore an innovative method was developed using conventional wood tie gang equipment to replace the existing concrete ties.

The concrete tie replacement concept is to replace the ties in an out of face operation. In preparation for the installation, the new concrete ties are laid out ahead of time (usually several weeks in advance) on the opposite side of the track from where the existing ties will be removed. A rubber tired backhoe with hi-rail attachments and a special designed claw bucket was used to replace every sixth tie with a new 60E concrete tie, being careful not to lift the track (see figures 11 and 12). This is usually performed a few days ahead of the main tie gang arriving.

When the tie gang arrives at the location, the clips and insulators are removed. The five consecutive old ties are then removed so as to place them on opposite side of the track from the new ties, leaving every recently installed sixth tie to hold gauge. This is accomplished using a TR-10 tie remover/insertter. Tie cranes then pick up the old ties and stack them on tie carts, to be unloaded at a nearby convenient location.

Other tie cranes transfer the new ties to the other side of the track in preparation for installation. A following TR-10 installs the new concrete ties (see figure 13). A rail lifter then lifts the rail so that the rail seats can be cleaned of ballast by compressed air and the pads installed (see figure 14). A production tamper then tamps the ties so they are snug to the rail (see figure 15). The insulators and clips are then installed (see figure 16). The track is then tamped, regulated and stabilized (see figure 17).

This work is accomplished with a gang of 28 people, consisting of 2 supervisors, 12 laborers, 13 machine operators and 1 mechanic. The gang can install an average of 230 ties in a 3 hour work block. Table 1 indicates the work equipment assigned to this gang.

## **SUMMARY AND CONCLUSIONS**

CN has recognized economic and performance benefit by using concrete ties with resilient fasteners. This performance is only expected to improve with the CN 60E tie design with an anticipated fourfold or better increase in tie railseat abrasion wear life and threefold or better increase in insulator and pad life.

The laboratory testing performed during development of the CN 60E tie is very encouraging and CN believes they are headed in the right direction regarding improved resistance to railseat abrasion by using the cast-in steel plate. The modified shoulder design with higher grade ductile iron also appears to address the issues of fatigue breakage and loss of toe load due to shoulder heel wear.

CN is currently on year two of a five year replacement program of 75,000 ties. Tie performance is monitored regularly and further enhancements will be introduced as appropriate.

## **ACKNOWLEDGEMENTS**

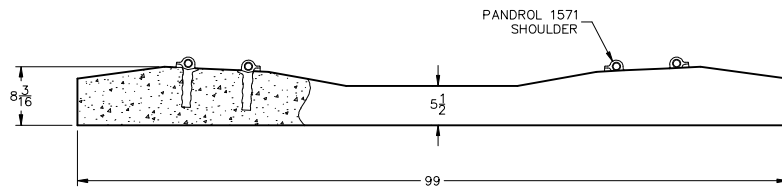
The authors wish to acknowledge Art Worth, former CN Engineer of Standards, and John White, former President and CEO of CXT Incorporated, for their assistance regarding CN concrete tie history. The authors would also like to acknowledge Bodycote Materials Testing Canada Inc., Pandrol Canada, and Pandrol UK for their assistance during the CN 60E tie development.

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2. CN Service Test No. SL-7 MR (Monoblock) and RS (Two Block) Concrete Ties.
3. CN Service Test No. AR-67 Dow-Mac Concrete Ties.
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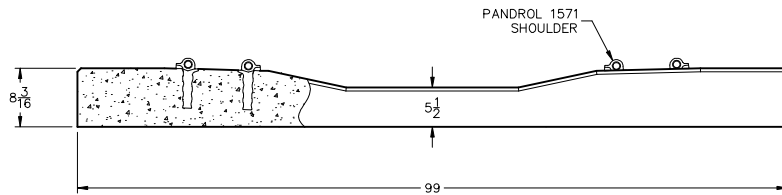


Figure 1 – Original 1972 CC241 (BR F23) Tie in Jasper Test Track



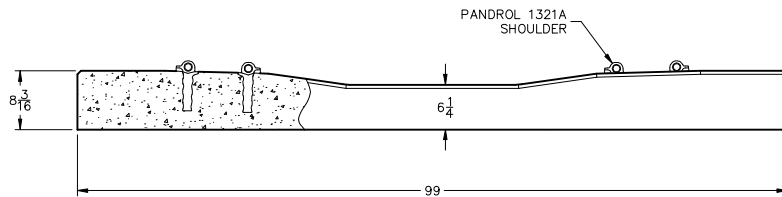
**BR F23/CC 241**

JASPER TEST TRACK TIE  
1972



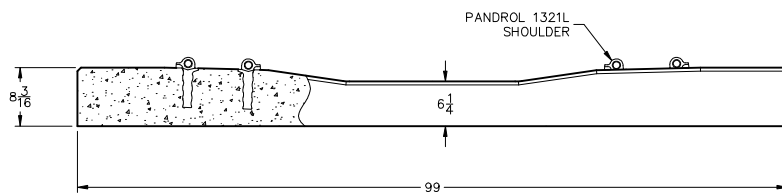
**CN 60A**

CN ADOPTED  
JUNE 1973



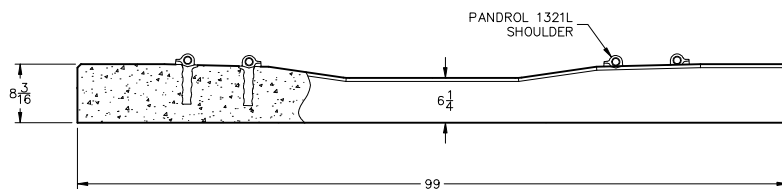
**CN 60B**

CN ADOPTED  
FEBRUARY 1982



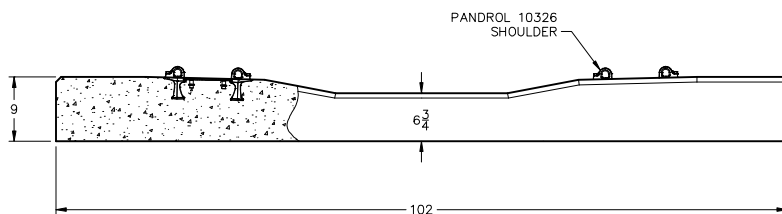
**CN 60C**

CN ADOPTED  
OCTOBER 1987



**CN 60D**

CN ADOPTED  
JANUARY 1989



**CN 60E**

CN ADOPTED  
DECEMBER 2002

Figure 2 – CN Monoblock Concrete Tie General Comparisons





Figure 3 – Railseat Abrasion



Figure 4 – Tie with Broken Ductile Iron Shoulder





Figure 5 – Shoulder Showing Signs of Stem Fatigue, Heel Wear, and Face Wear

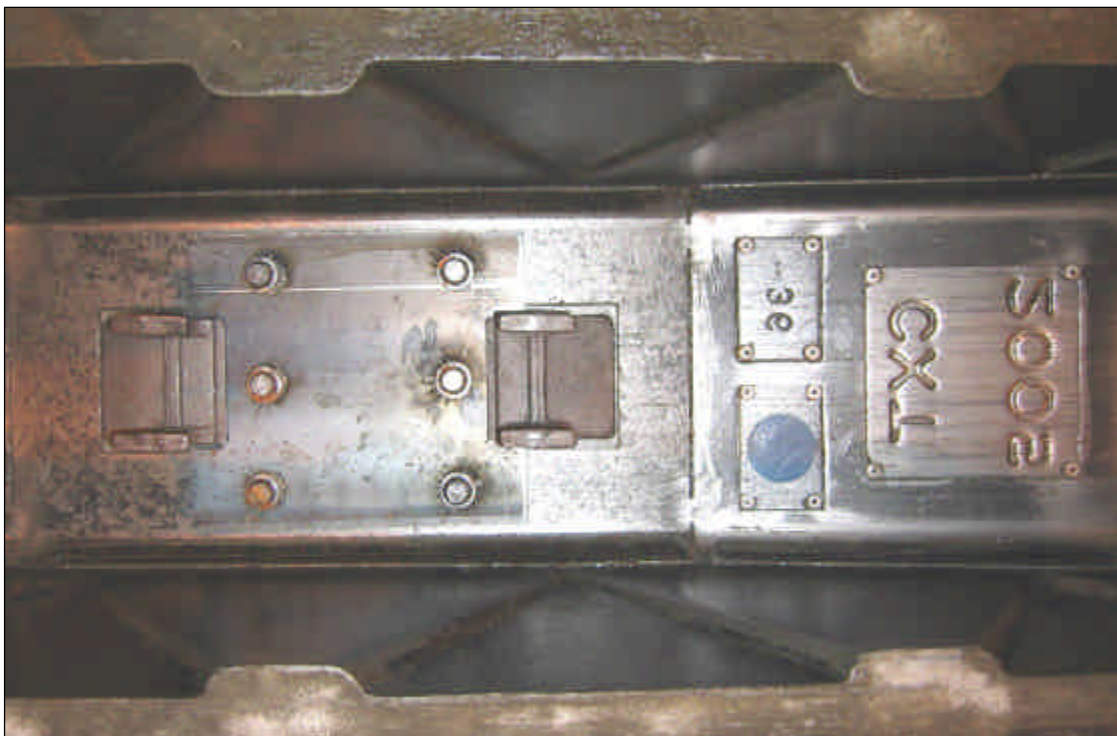


Figure 6 – Studded Steel Plate In Tie Form Prior to Casting

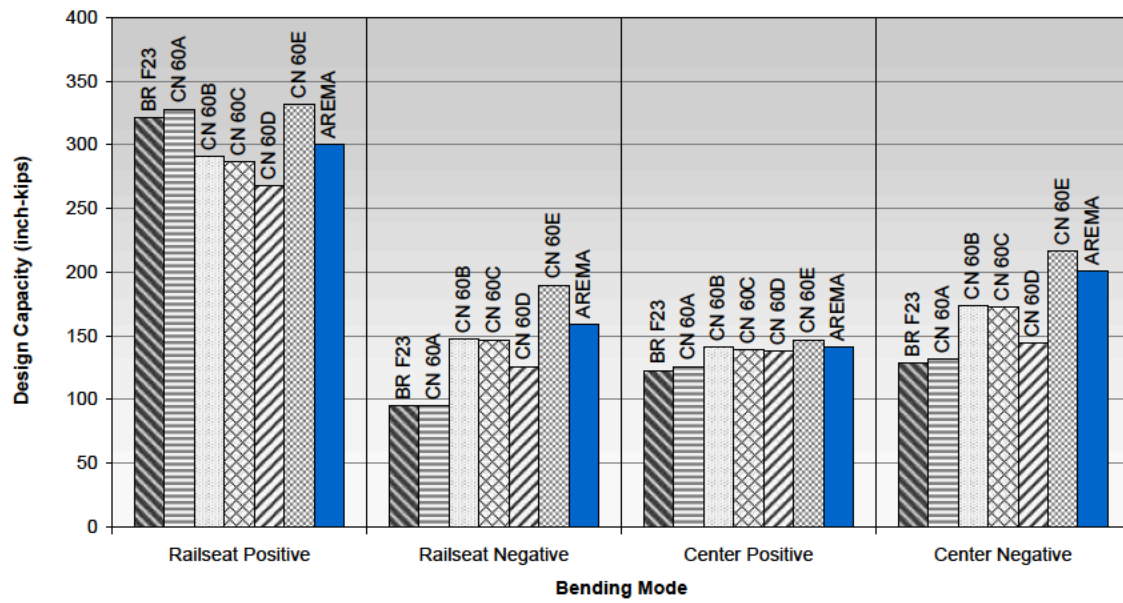


Figure 7 – CN Monoblock Concrete Tie Structural Comparisons



Figure 8 – Pandrol Toe Load Testing on CN 60E Tie



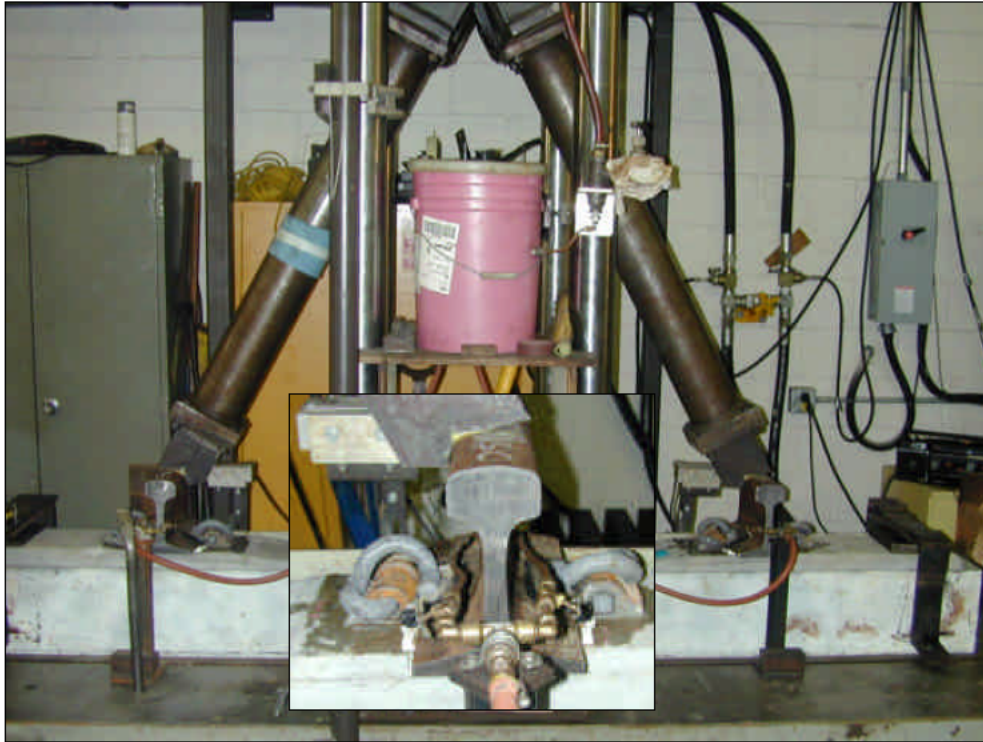


Figure 9 – Bodycote Repeated Load Test Apparatus with Sand and Water Drip, 70,000 lbs Load at 0.52 L/V. Inset Shows Railseat Configuration.

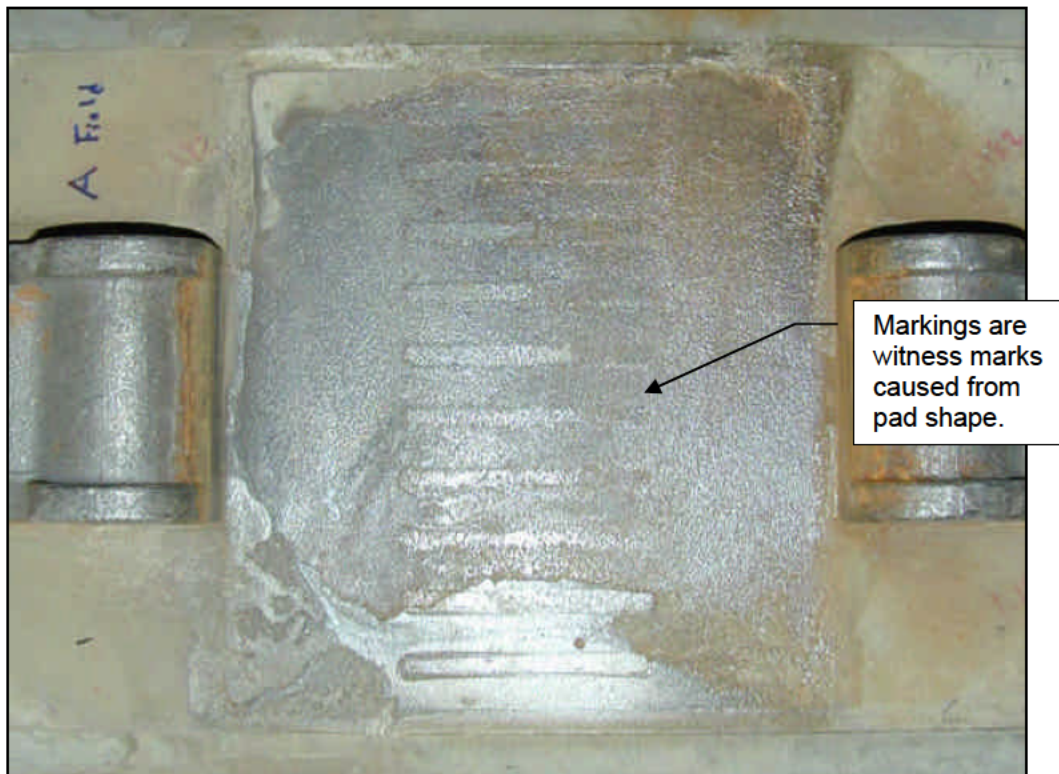


Figure 10A – Railseat A After 3.8 Million Cycles

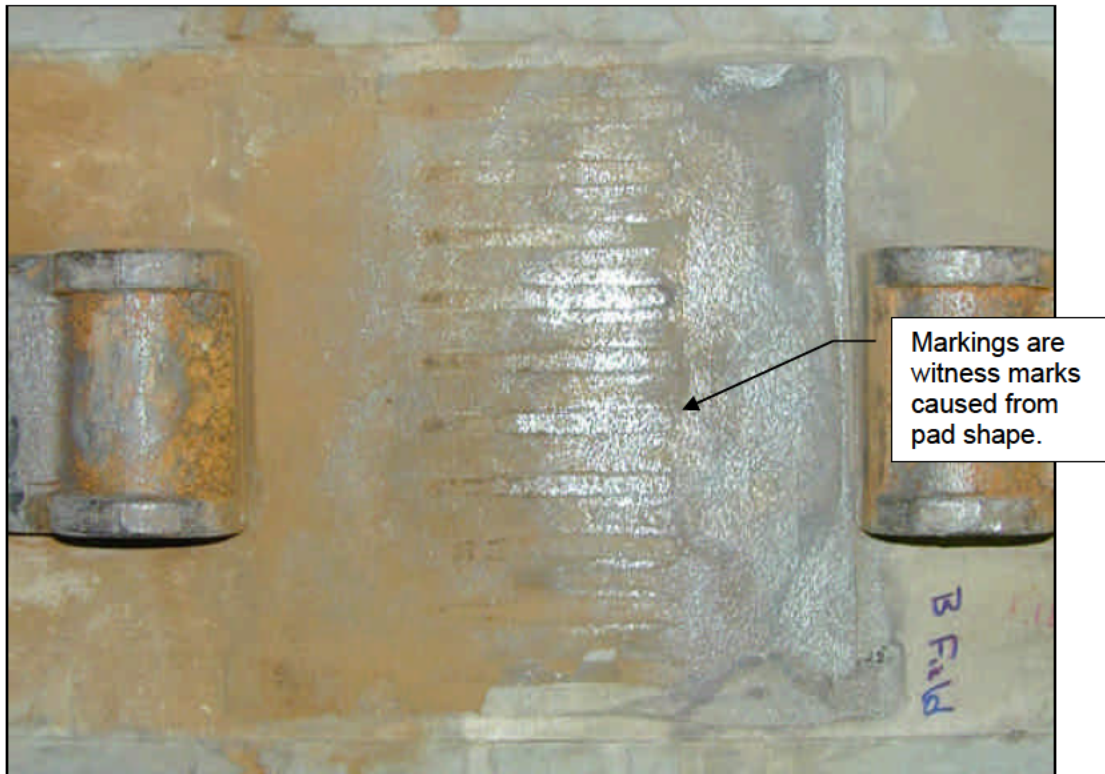


Figure 10B – Railseat B After 3.8 Million Cycles

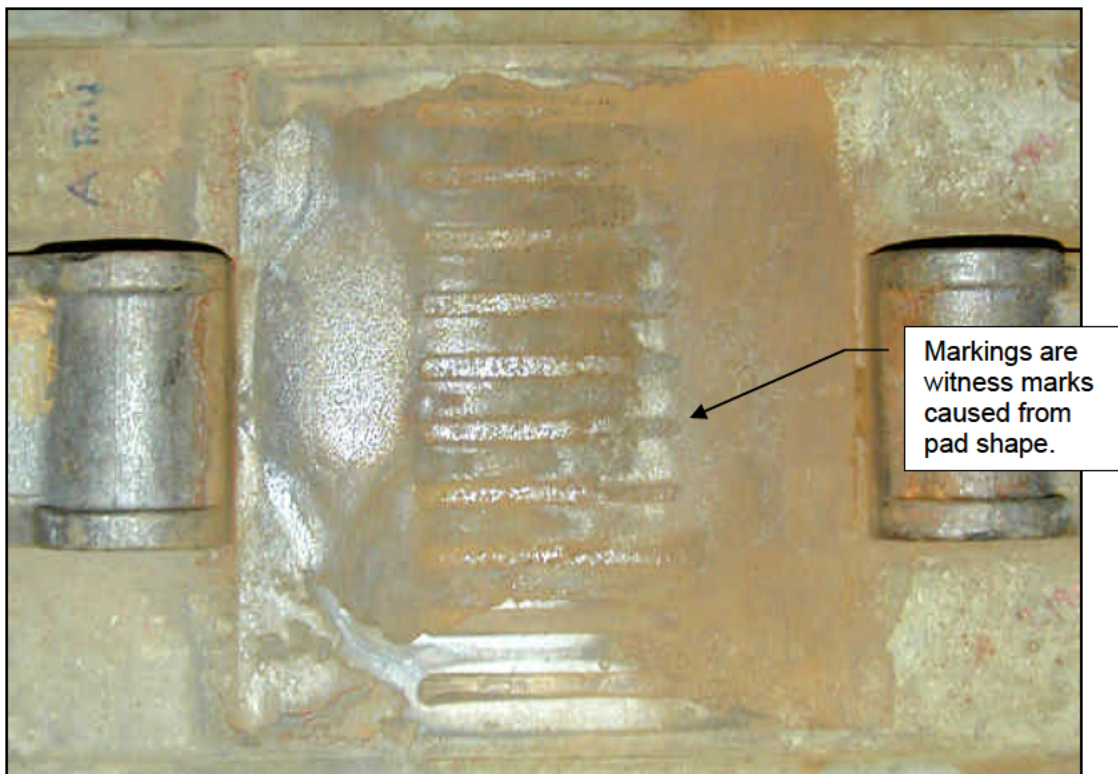


Figure 10C – Railseat A After 10 Million Cycles



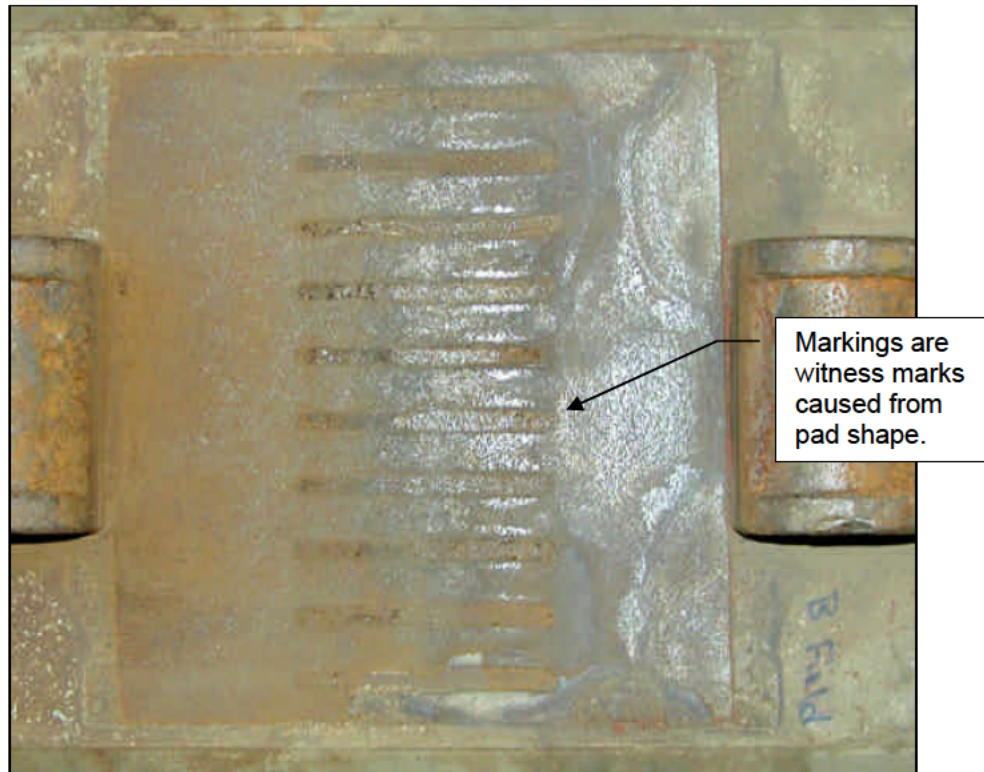


Figure 10D – Railseat B After 10 Million Cycles



Figure 11 – Hi Rail Backhoe Replacing Every 6<sup>th</sup> Tie in Front of Main Gang



Figure 12 – Track After 1:6 Replacement by Backhoe



Figure 13 – TR-10 Tie Insertion





Figure 14 – Pad Installation



Figure 15 – First Pass Tamp to Nip Ties





Figure 16 – Clip Installation



Figure 17 – Track Clipped and Ready for Ballast and Final Tamping



<b>Work Equipment Machinery</b>	<b>Number of Machines</b>
Ballast Regulator	1
Mark IV Tamper	1
Production Tamper	1
Rubber Tired Back Hoe	1
Stabilizer	1
Tie Cranes	3
TR-10 Tie Inserters/Removers	2
Rail Lifter	1
Pandrol Clip Applicator	1
Motorized Push Cart	1

**Table 1 – Work Equipment Used for Out-of Face Concrete Tie Installation**