Best Practice Guidelines for CWR Neutral Temperature Management

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ABSTRACT

A key aspect of managing the stress state of the railroad involves maintaining longitudinal rail stresses to safe levels in order to reduce the risk of both buckled track and broken rail induced derailments. Thus the efficient management of longitudinal stress induced thermal forces in continuous welded rail (CWR) is an important aspect of improving network safety and capacity.

A large component of track buckling prevention deals with keeping thermal forces to safe levels. This requires the knowledge of critical buckling temperatures and forces and an ability to manage reduced rail neutral temperature (RNT) conditions which create those critical force levels. One such reduced RNT condition deals with rail break and rail defect repairs and their RNT readjustments.

The intent of this paper is to provide a new industry applicable methodology for managing rail break and defect repairs, and to offer a set of best practice guidelines for implementation. To this end the fundamentals of rail cut/break mechanics and key parameters will be reviewed, a new methodology for CWR neutral temperature readjustment will be presented, and the methodology will be formalized into industry guidelines and procedures for a more efficient management of CWR.

1.0 INTRODUCTION

An important aspect of reducing the stress state on the railroad deals with controlling the longitudinal forces to safe levels. This is important not only to reduce the number of buckled track incidents but also to reduce the number of rail defect failures. Hence the efficient management of longitudinal forces in continuous welded rail (CWR) becomes an important maintenance function of both heavy haul freight and high speed passenger operations. It is well known that CWR can experience large compressive and tensile longitudinal forces due to temperature changes. Compressive forces can induce track buckling while tensile forces can result in rail defect growth and subsequent pull-apart failures whenever these forces exceed certain limits. The force levels due to constrained thermal expansion can be calculated using the well-known formula:

\[ P = AE\alpha\Delta T \]
where \( A \) is the cross sectional area of the rail, \( E \) the modulus of elasticity, \( \alpha \) the coefficient of thermal expansion, and \( \Delta T \) is the temperature change. The temperature change, \( \Delta T \), is the difference between the instantaneous rail temperature and a reference temperature known as the neutral temperature, \( T_N \) or RNT. The \( T_N \) or RNT (sometimes also referred to as SFT for stress-free temperature) is defined as the temperature at which the net longitudinal force in the rail is zero. Therefore, the temperature change \( \Delta T \) is defined as:

\[
\Delta T = T_M - T_N
\]

where \( T_M \) is the measured (instantaneous) rail temperature. It is obvious that for buckling and pull-apart prevention, the knowledge of \( T_N \) is critical.

A build-up of thermally induced longitudinal compressive forces in the rails can result in buckling. Buckling occurs when the magnitudes of these forces exceed a critical level at which the lateral strength of the track structure is inadequate to resist the tendency to suddenly displace into a large lateral misalignment. As research has shown, buckling forces are highly track type/condition and parameter dependent, but for average or standard track conditions they can be in the range of 150-200 kips per rail corresponding to \( \Delta T \) in the range of 60-80°F. Since \( \Delta T \) is referenced to the RNT or neutral temperature, a change in the RNT changes the corresponding force level. This says that if a track buckles out at a rail temperature of 140°F when it has a RNT = 70°F, then this track buckles at the much lower rail temperature of 110°F if this RNT decreases to 40°F (which can occur when rail is cut for defect removal at temperatures less than 40°F, and it is not readjusted in time). Hence, it is obvious that for buckling prevention and for rail defect mitigation/pull-apart prevention the knowledge of RNT is critical.

If CWR were to be completely constrained, then there would be no change in its neutral temperature. Since the rails cannot be fully constrained in all directions, elongation or contraction can occur whenever the track is subjected to train and environmentally induced loads, causing RNT to change. The following rail/track kinematics influence CWR neutral temperature: rail creep, curve movement and track vertical movement/settlement.

Rail creep (longitudinal movement through the fasteners) can occur under train braking and accelerating actions as well as due to temperature gradients along the rail, and is largely anchor/fastener condition dependent. Curve movement or lateral shift can occur under repeated vehicle lateral loads and high curving forces, as well as due to thermal loads causing chording in-or-out (referred to as “rail breathing”). Track settlement can occur under repeated vertical wheel loads or high impact loads, especially on tracks with poor vertical support conditions.

It is also evident that maintenance operations which alter the longitudinal force state in the rails also influence its neutral temperature. These typically include maintenance actions such as lifting, lining, repairing defective or broken rails, installing rail in cold temperatures, and ineffective destressing.
A principal difficulty in managing the longitudinal force/neutral temperature in CWR is the fact that there is no practical measurement capability to nondestructively determine the CWR’s longitudinal force/neutral temperature. Although there are some new and emerging technologies with some good applications to RNT management, railroad maintenance personnel still rely on experience and guess work to identify conditions requiring neutral temperature readjustment. One particular concern in this regard is the management of rail defect removals and broken rail repairs which present the following difficulties:

(1) not knowing how much rail to cut out to produce the required adjustment

(2) not knowing the extent of the repair length requiring readjustment i.e. the length of rail to unfasten

(3) in the case of cold temperature “rail added” interim repairs, when to come back (i.e. at what temperature) to make the readjustment before the onset of warm temperatures renders the track buckling prone

The intent of this paper is to answer these issues by developing and providing a new industry applicable methodology for managing rail break and defect repairs, and to offer a set of best practice guidelines for implementation. To this end the fundamentals of rail cut/break mechanics and key parameters will be reviewed, a new methodology for CWR neutral temperature readjustment will be presented, and guidelines for practical applications for readjusting CWR will be offered.

2.0 FUNDAMENTALS OF RAIL BREAK MECHANICS AND RNT READJUSTMENT

2.1 Rail Break Mechanics Fundamentals

In order to better appreciate the basic aspects of RNT management, it is important understand the rail cut/break longitudinal force behavior and the influencing parameters. To this end, Figure 2.1 shows a typical rail force/neutral temperature profile of a rail cut or broken at a rail temperature of 40°F which results in a rail gap of 3 inches. The pre break/cut RNT (blue dashed line) is 100°F, the orange solid line is the resulting RNT profile according to theory and tests [1, 2], and the black dashed line is the linear approximation to enable a “close enough” engineering estimate of the rail cut/break “influence zone” i.e. the length of rail experiencing the force/RNT change due to the cut/break. This influence zone length is referred to as 2LD where LD is on one side of the cut/break being 635 feet in this case.
Figure 2.1-Example of RNT Response to a Cold Weather Rail Break for a Timber Tie Track with Anchors on Every Other Tie (EOTA)

Note that the “close enough” assumption (linear theory) is justified based on comparison studies with the more complex non-linear theory [3] which shows that the asymptotic “tail end” of the influence zone adds only 15-20% to $L_D$ which is within an RNT error of 5-10%.

As shown in Figure 2.1, the pre-cut/break RNT of 100°F is reduced to the rail break/cut temperature of 40°F at the cut/break i.e. the RNT at the cut/break is the same as the rail break/cut temperature. Away from the cut/break the RNT increases and reaches the pre-cut/break value in a length $L_D$. It has been shown through analysis and tests [1, 2, 3] that the influence zone, $L_D$, and the resulting gap size depend predominantly on $\Delta T$ (i.e. the difference between the pre-break/cut RNT and break/cut temperature), the rail/track longitudinal resistance, $f_o$, and to a smaller extent the rail size. The longitudinal resistance is a complex non-linear parameter as illustrated in Figure 2.2 having a linear (small deflection) part given by the slope $k_f$ and constant part denoted by $f_o$. Track longitudinal resistance has two components: (1) tie moving through the ballast, and (2) the rail moving through fasteners/anchors. The lower of the two determines the actual value. As such, a “weak” longitudinal resistance can result when ballast is weak and fasteners are strong allowing the rail/ties moving through the ballast, or when ballast is strong but fasteners are weak allowing the rail to move through the fasteners.
Figure 2.2-Track Longitudinal Resistance

Based on tests [2], typical values for $f_o$ in lbs/in are given in Table 2.1, where EOTA refers to every tie anchored, ETA to every tie anchored, and CTEF to concrete tie elastic fasteners. There are special cases of “extra-strong” values for $f_o$ such as for frozen ballast conditions with strong fasteners. For such cases, the “average” values are multiplied by a 1.5 factor. Other cases include higher degree curves where there is extra friction resistance produced by the rail base/tie-plate binding. For such cases the 1.5 factor is also recommended.

Table 2.1 - Longitudinal Resistances for Different Fastener Conditions

<table>
<thead>
<tr>
<th>Fastener Condition</th>
<th>$f_o$ (lbs/in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOTA$_{weak}$</td>
<td>15</td>
</tr>
<tr>
<td>EOTA$_{avg}$</td>
<td>20</td>
</tr>
<tr>
<td>EOTA$_{str}$</td>
<td>25</td>
</tr>
<tr>
<td>CTEF$_{weak}$</td>
<td>25</td>
</tr>
<tr>
<td>CTEF$_{avg}$</td>
<td>30</td>
</tr>
<tr>
<td>CTEF$_{str}$</td>
<td>35</td>
</tr>
</tbody>
</table>

Note: ETA=CTEF; for some extra strong conditions multiply “avg” by 1.5

The relationship between the temperature difference ($\Delta T$) and longitudinal resistance, and their influence on $L_D$ is shown in Figure 2.3 for a 136# rail. The dashed line indicates the conditions depicted in Figure 2.1, and the yellow box insert shows the influence of rail size.
Figure 2.3- Influence Zone ($L_D$) as a Function of Force in the Rail ($\Delta T$) and Rail/Track Longitudinal Resistance

Research has shown [1] that in addition to the relationships between $L_D$, $\Delta T$ and $f_o$, there are relationships between these parameters and the gap size as indicated in Figure 2.4. The data portrayed in the figure is important because they can be used to provide an estimate of the rail’s RNT before the cut/break, which in turn enables the determination of the influence zone $L_D$ in conjunction with Figure 2.3.

Figure 2.4- Gap Size as a Function of $\Delta T$ and Longitudinal Resistance
To afford easy field application of the results of Figures 2.3 and 2.4, and to account for the many parametric aspect of rail size, longitudinal resistance, $\Delta T$ and gap sizes, the methodology has been automated into a user-friendly software program called CWR-Adjust which is described in [12] and is available in [13].

2.2 Cold Temperature Readjustment Issues: Restressing

As indicated earlier, rail breaks and cuts for defect removal in cold temperatures result in large changes in the rail’s RNT profile which require readjusting to the desired target values. Current practices tend to favor quick in-situ readjustments with minimal rail unfastening resulting in readjustment issues as summarized in the Figure 2.5 below:

<table>
<thead>
<tr>
<th>Current Readjustment Practice Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>METHOD 1:</strong> When rail is added as an interim (plug) repair for broken/cut rail, remove the added rail later at a warmer temperature with unfastening 195 ft both sides of the cut – AREMA recommendation/Chapter 5</td>
</tr>
<tr>
<td><strong>ISSUES:</strong> Removing the added rail is often NOT enough, nor is the 195 ft unfastening length; also the “warm” temperature to return to readjust is not defined.</td>
</tr>
<tr>
<td><strong>METHOD 2:</strong> When the rail break/cut gap is small, close the gap by pulling or heating the rail without any anchor/fastener removal.</td>
</tr>
<tr>
<td><strong>ISSUES:</strong> RNT may be restored to nominal pre-break value, but NOT necessarily to the desired target level.</td>
</tr>
</tbody>
</table>

**Figure 2.5 - Current RNT Readjustment Issues**

The illustrative example in Figure 2.6 explains the issues/problems referred to in Figure 2.5. Consider 3 rail defect cut-outs (or breaks) all occurring at the same rail temperature of $10^\circ F$ in identical rail/track conditions (CTEF refers to concrete tie elastic fastenings), but with different resulting gap size/rail added scenarios as indicated.
Figure 2.6- Examples of Three Rail Gap Scenarios for Readjustment

Figure 2.6 shows the post break RNTs profiles on one side of the break/cut in blue, the pre-break RNTs (purple), and territory’s target laying temperature (green). The influence zones on one side of the cut are 680 ft, 425 ft and 370 ft respectively, and adding rail as shown locks in the reduced RNT profile. It is this reduced profile that needs to be adjusted to target RNT.

It is evident from the figure that when returning later for the readjustment and removing just the rail added will only restore RNTs to the pre-break values. This may be adequate for Case 1, but not so for Cases 2 and 3. Additionally, in view of the influence zone lengths, unfastening only the AREMA recommended 195 ft on either side of the break/cut is too short and will produce large pockets of reduced RNTs. It is further evident that Method 2 of pulling the gaps together in Cases 2 and 3 would only restore RNT to the pre-break/cut values of 70°F and 50°F respectively, hence:

- Removing rail added typically restores RNT only to the prebreak/cut values
- Unfastening rail length much shorter than the influence zones is not adequate in most cases.

Therefore for efficient RNT readjustments following cold temperature rail break/defect removals it is important to know the rail break/cut temperatures, gap sizes/rail added, the break/cut influence zones, the prebreak/cut RNTs, the target RNTs, and the rail temperatures when the readjustments are made. All these form the key components of the new methodology for RNT readjustments.

3.0 NEW RNT READJUSTMENT METHODOLOGY

A methodology for improved CWR longitudinal force management through more correct and efficient neutral temperature readjustment practices is based on the parameters
discussed in 2.0 above and the science behind them. The methodology provides a technique to determine the RNT before the cut/break and the required length of rail to be adjusted. These two are critical for a “correct” RNT readjustment since they determine the third key parameter, the amount of rail to cut out. Thus the methodology enhances current maintenance practices by providing a tool to more efficiently and correctly manage the rail’s RNT restoration process, thereby more effectively managing the longitudinal stress state of the railroad.

3.1 - Methodology Overview

For a particular anchor/fastener condition, the reduced RNT profile to be readjusted is determined from the rail cut/break or rail-added temperature and by the measured gap size resulting from the cut/break. The RNT before the cut/break is determined from the ΔT and the rail cut/break temperature along Figure 2.4. The RNT readjustments are to be performed at rail temperatures as close to the territory’s laying temperatures as possible, but not exceeding the “safe” limits provided by the railroad’s CWR policies. The territory’s target RNT value and the rail cut/break temperature are used to determine the temperature differential being adjusted. The unfastening length is determined from curves similar to Figure 2.3, but can be reduced by an optimization strategy as described in the next section. The required amount of rail cut-out for the temperature differential and unfastened length is prescribed in charts and tables or by automated software output as described in 4.0. For more details on the methodology refer to [4,5].

3.2 - Fastener Removal Length Reduction through “Extra Rail Cut-Out” for Compensation

The influence zone length (2L_D) over which the RNT is affected when a rail is cut or broken is determined by the longitudinal force in the rail and the longitudinal resistance provided by the anchor/fasteners and the ballast. As Figure 2.3 indicates, L_D’s can be longer than 1000 feet each side of the break/cut. However, unfastening long lengths of rail require track time and resources which prompted investigations into the viability of shorter repair lengths and their impacts on the RNT restoration [6, 7], keeping in mind the concern that unfastening too short a rail segment leaves “pockets” of reduced RNT. An example of such reduced RNT pocket is illustrated in Figure 3.2 (a) for a concrete tie track with136# rail, a break at 40°F, a pre break RNT of 100°F producing an L_D= 430 ft. (i.e. 860 ft total). As the figure indicates, unfastening ½ L_D i.e. 215 ft (430 ft total) and cutting out rail based on this length results in a profile as shown by the orange curve with a pocket of reduced RNT approximately 30°F below the intended target of 100°F.

A trade off between unfastening the full 2L_D versus some “reduced” amount to minimize railroad resources and track time can be made however by allowing some “admissible pocket” of reduced RNT. The magnitude of these “pockets” are functions of the pre-break RNT, rail break/cut temperature and the unfastening length, hence the determination of an “admissible pocket” but still within some safe range requires parametric trade-off studies. Based on such studies [6] the “best practice” recommended unfastening lengths can be based on ½L_D, however in combination with localized
overstressing i.e. cutting rail out based on the original full length $L_D$’s. Hence the unfastening length can be based on one half if the influence zone, while the amount of rail removal can be based on the full influence zone as illustrated in Figure 3.1.

This overstressing concept is further illustrated in Figure 3.1 (b), whereas Figure 3.1 (c) indicates the anticipated “RNT smoothening” or equalization with traffic, which has been observed by tests [6].

![Figure 3.1 – Reduced Unfastening Length and Localized “Overstressing” Influence on RNT](image)

It should be noted that the optimization strategy also calls for a “refinement” for those cases where the pre break/cut RNTs are low such as in Cases 2 and 3 in Figure 2.6. For such cases the $\frac{1}{2}L_D$ reductions are based on an extrapolated $L_D^*$ referenced to the pre
break/cut RNTs as illustrated in Figure 3.2 where the unfastening length is \( L_U = \frac{1}{2}L_D^* \) on either side of the break/cut.

![Figure 3.2 – Reduced Unfastening Length for Low Pre-break/Cut RNTs](image)

### 3.3 – Refinements to Methodology: Additional Rail Cut-Out Due to End Movement Effects

When the rail break or defect removal interim repair’s readjustments are made at warm temperatures, they’re typically made by the use of either normal ambient heating conditions, by rail heating via rail heaters, or by hydraulic pullers to produce the final weld gap conditions. As been shown in [1], such methods of final gap setting can result in extra rail being “pulled-in” from the unfastened end thereby influencing the “correct” amount of steel removal. Such end movements depend on the actual tensioning method. For example, if the rail is stretched with a tensor or by ambient (solar) heating, the ends of the unfastened rail can move inward. The amount of this inward movement depends on the longitudinal resistance at the ends of the unfastened section and the pulling force or the temperature differential. This end movement has to be included as part of the gap setting i.e. in the total amount of rail removal. Without this correction, errors on the order of 30-40% could result in resetting to the target RNT as shown in [1]. The new methodology makes the appropriate corrections for these end movement influences in line with approach presented in [1]. Depending on the actual conditions, such additional rail removals can typically be in the 1-2 inch range.

### 3.4 – Methodology Illustration

In line with the discussions above, the following is an illustration of the methodology application. The example is Case 2 of Figure 2.6 where a rail defect cut-out was made at 10°F in a 136# rail on concrete ties with “average” elastic fasteners resulting in a 2” gap. With the assumption that the interim repair was through a plug insertion adding the 2” of rail and that the territory’s preferred laying temperature is 100°F, Figures 3.3 and 3.4 summarize the methodology’s application.
Figure 3.3 – Methodology’s Illustrative Example

Figure 3.3 indicates that the 2" gap, the rail cut temperature of 10°F, the 136# rail size, and the concrete tie elastic fastener condition (CTEF avg) determines the post cut RNT profile, the influence zone L_D=425 ft, and the pre cut RNT=70°F as shown in the right hand side of the figure. Using the extended 2L_D* as per Figure 3.2 and the RNT target of 100° F (giving a temperature difference of 90°F to adjust), the methodology computes the total rail cut-out of 6 inches. The physical interpretation of the 6" cut-out is provided in Figure 3.4, where RC refers to rail cut amounts.

Figure 3.4 – Illustrative Example’s Physical Interpretation

For easy interpretation it is useful to think of the total readjustment in this case to consist of two steps or 2 cuts denoted by RC1 and RC2 where RC1 brings the RNT back to the pre-cut value i.e. to 70°F, and RC2 to bring the 70°F value up to the desired target of
100°F. Thus RC₁ requires 2", while RC₃ requires another 2". The end movement contributes 1/2" from each end for a total of 1". The remaining 1" is for the weld allowance. The unfastening length for this case is 330 ft on either side of the cut, as illustrated in Figure 3.2.

3.6 – Buckling Prevention Criterion to Determine “Return” Temperatures for Readjustment

An important aspect of applying the methodology is performing the RNT readjustments before the onset of “warm” temperatures in order to reduce the risk of track buckling. In line with track buckling fundamentals [8, 9], the “allowable” temperature increase values for buckling prevention are strongly track type/condition dependent. When these conditions are categorized as “weak”, “average” and “strong”, and choosing the “weak” condition as a conservative estimate for all tracks, the return temperatures can be evaluated in accordance with the 70:70 rule [11] resulting in Figure 3.5.

<table>
<thead>
<tr>
<th>Rail Break/Cut Temperature (°F)</th>
<th>Return Rail Temperature at Which to Readjust (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>135</td>
</tr>
<tr>
<td>50</td>
<td>130</td>
</tr>
<tr>
<td>40</td>
<td>125</td>
</tr>
<tr>
<td>30</td>
<td>120</td>
</tr>
<tr>
<td>20</td>
<td>115</td>
</tr>
<tr>
<td>10</td>
<td>110</td>
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<td>0</td>
<td>105</td>
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<tr>
<td>-10</td>
<td>100</td>
</tr>
<tr>
<td>-20</td>
<td>95</td>
</tr>
<tr>
<td>-30</td>
<td>90</td>
</tr>
<tr>
<td>-40</td>
<td>85</td>
</tr>
</tbody>
</table>

Note: the 70:70 rule assumes Buckling Strength = 70°F and other rail's RNT=70°F

Figure 3.5 – Return Temperature Criterion Based on Buckling Prevention Guidelines

3.7 – Methodology Application Issues and “Prudency” Rules

In principle the methodology is relatively straightforward, but in practice it can encounter some in-field application issues requiring some “prudency” decisions. These are summarized below:

1. When measuring the rail break/cut gap, be sure to measure gap within ±1/16 inches

2. At time of rail cut/break, be sure to record location, gap size, rail size, rail temperature, curvature, and anchor/fastener type and ballast condition
3. If unable to determine “weak”, “average” or “strong” condition for anchor/fastener strength, use the conservative “WEAK” designation

4. Be sure to record the interim repair procedure, including “rail added” temperature and gap size change if any

5. Based on measured rail temperature, determine and record the return temperature for RNT readjustment (in line with railroad policies such as Figure 3.5).

6. Prioritize return readjustments based on rail break/cut severity as “indexed” by the coldest rail break/cut temperature.

7. Determine if “special conditions” apply i.e. cases in which the methodology is NOT directly applicable. These include location near switches, crossings, bridge approaches, etc.; locations where other rail break/defects exist in close proximity; and locations where rail break/defects exist on both rails in near proximity. For such conditions refer to Guidelines in 4.0.

8. Use railroad’s recommended practice to determine unfastening lengths and rail removal requirements in line with 4.0.

9. Be sure to record readjustment particulars, including readjustment temperatures, rail length unfastened, amount of rail removed, rail heating/stretching method, etc.

10. If a railroad is using ambient temperatures to dictate return temperatures, be sure understand the difference between rail temperature and ambient temperature (noting the accepted rule that Rail temperature = Ambient temperature + 30°F for warm sunny conditions).

Because of the methodology’s many facets including assumptions, key parameters and their influences and practical implementation issues it was deemed necessary to develop an automated procedure to enable an easy application of the methodology. The automated procedure consists of a software program called CWR-Adjust which is available to the industry as an AAR/TTCI Software [13].

4.0 BEST PRACTICE GUIDELINES FOR COLD TEMPERATURE READJUSTMENT

These guidelines address rail breaks or cuts in line with service defects removals. The rails are typically interim-repaired in cold temperatures right after a rail is cut for defect removal or after a break by a plug repair insertion requiring adding rail. Such repairs are typically accompanied by a reduced RNT profile such as exhibited in Figure 2.1 and the “interim” repair’s rail added condition locks in the reduced RNT profile which has to be readjusted to the territory’s designated rail laying temperatures.
Railroad’s CWR policies typically require that rail that has pulled apart, broken or been cut for defect removal must be readjusted to within the subdivision rail laying temperature (RLT) minus 20°F (RLT-20°) safe range in accordance with a time/temperature requirements specified by the Table in Figure 3.5. It should be noted that some railroads specify RLT-20 or RLT-10 or RLT as the readjustment targets.

The following provides the guideline on the procedures to be followed when making cold temperature rail repairs and subsequent neutral temperature (RNT) readjustments. A key proviso is that, in general, CWR cannot be adequately readjusted in cold temperatures i.e. interim repairs are needed with a requirement to return at warmer temperature conditions to readjust.

To facilitate the procedure it is required that:

1. The railroad’s have CWR policy in place which stipulates when to return to readjust RNT (such as table in Figure 3.5), and has an internal management system to record gap sizes and calculated pre-break/cut RNTs.

2. Have available the CWR-Adjust software (or equivalent graphs, charts, tables) to provide the pre-break/cut RNTs and the minimum required unfastening lengths and rail cut-outs when making the readjustments.

   Note: if CWR-Adjust or equivalent charts/tables are NOT available, refer to Scenarios 3 and 4 under Guidelines below.

3. Railroad instructions on the particular procedures to follow when making readjustment in line with the four scenarios outlined in the guidelines below:

   **GUIDELINES**: the specific readjustment requirements are based on the measured gap size, the rail temperature at the time of the break/cut, and the fastener/anchor condition in line with the following four scenarios:

   **Scenario 1 - Measured gap size indicates that the pre-break/cut RNT is in the RLT-20°F range or above**: the procedure is to cut 1" for the weld allowance, and heat or pull the rails together through the fasteners* (i.e. no unfastening is required). Make the welds, and reposition anchors/fasteners displaced due to break/cut and the rail pulling. This repair is considered readjusted and in line with the RLT-20 requirement.

   * Implicit in this is that the gap size after the 1" additional weld allowance cut is such that the rail can be pulled together with rail fasteners/anchors NOT being removed. If the rail cannot be pulled together for whatever reason, proceed to Scenario 2 below.

   **Scenario 2 - Measured gap size indicates that the pre-break/cut RNT is below RLT-20**: the procedure is to either:
(a) repair through a plug rail (adding rail) and secure by welding or a bolted joint, or:
(b) pull the rail together through the fasteners and secure by joint

Both (a) and (b) are considered **interim repairs**, therefore MUST return to readjust at warmer temperatures in line with the railroad’s readjustment table. In case (a) CWR-Adjust is directly applicable, but in case (b) CWR-Adjust provided “amount of rail cut-out” has to be decreased by the amount the rail has been pulled together. When returning at warmer temperature to readjust cut out rail and unfasten lengths specified by CWR-Adjust/charts or tables.

**Scenario 3 - When CWR-Adjust is NOT available (i.e. when Scenarios 1 and 2 are not employable):** procedure is to record gap size, rail temperature, and location, and perform any expedient interim repair. Then the required RNT readjustment is to be made at warmer temperatures in accordance with the following:

(a) From the railroad’s CWR Policy determine the “return temperature” for readjustment, and perform readjustment at or below this temperature.
(b) At this return temperature, apply reference marks at ± 12 inches from the joint being opened rail being cut.
(c) Apply bench marks at ± 390 feet away from joints. These benchmarks are thin paint marks on the rail base extending to the tie plate, or with concrete ties rail base extending to the tie.
(d) Open joint or cut rail as required.
(e) Cut out rail until it stops moving.
(f) After rail stopped moving, unfasten 390 feet rail in both directions.
(g) Keep cutting rail out till there is no more rail movement. Measure and record rail temperature and the amount of rail cut out from the reference mark movements.
(h) Compare the recorded rail temperature to subdivision’s RLT. The difference is the temperature differential to determine if any additional rail has to be cut out.
(i) Determine the additional rail to be removed based on the Table A below. Note: if recorded rail temperature is above the RLT no additional rail has to be removed.
(j) Measure and record the benchmark movements at the ends (difference between rail base and tie plate markings at ± 390 feet), and add the two end movements.
(k) Add the two end movements plus the weld allowance to Table 4.1 values. This is the total amount of additional rail to cut out.
(l) Cut out the additional rail as determined in (k) above.
(m) Pull or heat the unfastened rail length to close the gap to welding allowance.
(n) Reapply anchors/fasteners and make the weld.
(o) Record welding temperature, readjusted RLT, rail added previously during interim repair, bench mark movements, total rail removed [the sum of (g) and (k)], and rail length unfastened.

Note: Scenario 3 option is based on best practice engineering assumption that for all cases one unfastening length of 10 rail lengths on either side of the cut or break is adequate for readjustments. Theory and tests suggests that influence zone lengths range between 400 to 1200 feet, so the ± 390 (780 feet) is a reasonable industry accepted compromise.

Table 4.1 – Additional Rail to Remove for Readjustment (for 780 feet, Scenario 3)

<table>
<thead>
<tr>
<th>Temperature Differential (°F)</th>
<th>Additional Rail to Remove (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>¼</td>
</tr>
<tr>
<td>10</td>
<td>½</td>
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<tr>
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<td>1</td>
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<tr>
<td>20</td>
<td>1¼</td>
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<tr>
<td>25</td>
<td>1½</td>
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<tr>
<td>30</td>
<td>1¼</td>
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<tr>
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<tr>
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</tr>
<tr>
<td>65</td>
<td>4</td>
</tr>
<tr>
<td>70</td>
<td>4½</td>
</tr>
</tbody>
</table>

[Rail Removal (inches) = Total Rail Unfastened Length (inches) x Temperature Differential (°F) x 0.0000065]

**Scenario 4 - Special cases when CWR-Adjust is NOT applicable:** there are special situations in which the CWR-Adjust has theoretical limitations and do not apply. These are covered below:

1. **Defects/breaks clustered in “close” proximity to each other:** if the defects/breaks are 800 feet or more apart, apply CWR-Adjust. If the defects/breaks are closer than 800 ft, CWR-Adjust does not apply. In this case apply Scenario 3 to each location independently. (The rationale for 800 ft is based on the sum of an “average” two influence zone not (or just partially) interfering with each other, where the “average” influence zone is estimated at 400 ft on one side of the cut/break.)

2. **Defects/breaks near “fixed” structures:** if defects/breaks occur within 400 feet of a rigid structure (switches, crossings, bridges, etc.), CWR-Adjust does not apply. In such cases apply Scenario 3. When applying Scenario 3, the 390 ft of
unfastening requirement in the direction of the rigid structure can be relaxed i.e. unfasten the maximum length of rail available on that side, but retain the 390 ft on the other side. Similarly the end benchmark can be placed at the maximum rail length adjacent to rigid structure.

3. **Defects/breaks near each other on opposite rails:** if defects/breaks occur on both rails within 200 feet of each other, their readjustment is still in line with Scenarios 1 or 2 per CWR-Adjust, or Scenario 3 if applicable. However their readjustment time (temperature) must be on a priority basis because of the high buckling vulnerability due to both rails having a reduced RNT. In line with buckling probability estimates producing Figure 3.5 values, the recommended return temperature for readjustment is:

\[
T_{\text{RETURN}} = \frac{(T_{\text{RB1}} + T_{\text{RB2}})}{2} + 70^\circ F
\]

where \( T_{\text{RB1}} \) and \( T_{\text{RB2}} \) are the respective rail break/cut temperatures.

**Example:** if one rail breaks or is cut for defect removal at 10°F, and the other rail breaks or is cut at 30°F, the return is at/below a rail temperature of 90°F.

### 5.0 CONCLUSIONS

1. A major aspect of track buckling prevention deals with keeping thermal forces to safe levels. This requires an effective management of rail neutral temperatures (RNTs) which when reduced can create critical buckling force levels. One key cause of reduced RNTs is cold temperature/tensile force induced rail breaks and defect removals. Such reduce the RNT to the rail break/cut temperatures and produce long influence zones, a condition which requires readjustment to target values before the onset of warm temperatures. Till recently industry practice lacked sufficient knowledge on how and when to perform the RNT readjustment. In response to this need a methodology has been developed to more effectively restore reduced RNT condition after a cold temperature rail break or defect removal.

2. The methodology is based on rail break mechanics and tests, and incorporates industry accepted procedures. The methodology calls for measurements of the rail gap size and rail temperature following a break/cut together with an estimate of anchor/fastener condition. This information allows the pre-break/cut RNT to be estimated and is used to determine how and when the RNT is to be readjusted to target values in order to minimize track buckling potential. The mechanics of the methodology has been automated into a user-friendly software program called CWR-Adjust that provides track maintenance personnel with rail removal and de-anchoring requirements for RNT readjustments.

3. The methodology together with CWR-Adjust has been cast into a set of best practice guidelines for industry application. The guidelines stipulate four
Scenarios of application together with step-by-step procedures covering the majority of the rail break and defect repair conditions and incorporate current best engineering principles and industry accepted maintenance techniques. Thus these guidelines provide the rail industry a best practice approach to more effectively manage CWR thermal force conditions, thereby enhancing overall system safety and network capacity.

6.0 REFERENCES


**List of Figures and Tables**

Figure 2.1 – Example of RNT Response to a Cold Weather Rail Break for a Timber Tie Track with Anchors on Every Other Tie (EOTA)

Figure 2.2 – Track Longitudinal Resistance

Figure 2.3 – Influence Zone (L_D) as a Function of Force in the Rail (ΔT) and Rail/Track Longitudinal Resistance

Figure 2.4 – Gap Size as a Function of ΔT and Longitudinal Resistance

Figure 2.5 – Current RNT Readjustment Issues

Figure 2.6 – Examples of Three Rail Gap Scenarios for Readjustment

Figure 3.1 – Reduced Unfastening Length and Localized “Overstressing” Influence on RNT

Figure 3.2 – Reduced Unfastening Length for Low Pre-break/cut RNTs

Figure 3.3 – Methodology’s Illustrative Example

Figure 3.4 – Illustrative Example’s Physical Interpretation

Figure 3.5 – Return Temperature Criterion Based on Buckling Prevention Guidelines

Table 2.1 – Longitudinal Resistances for Different Fastener Conditions

Table 4.1 – Additional Rail to Remove for Readjustment (for 780 feet, Scenario 3)
Best Practice Guidelines for CWR Neutral Temperature Management

Dr. Andrew Kish
Kandrew Inc. Consulting Services
Peabody, MA USA
Introduction

Overview
- Paper deals with the development of a methodology and “best practice guidelines” for managing CWR neutral temperature after cold temperature rail breaks and defect removals.

Key Issues Addressed
- What is a new methodology to manage cold temperature rail breaks and defect removals?
- How to translate into “best practice guidelines” for industry use?

Paper Content
- Rail stress/neutral temperature (RNT) fundamentals
- Rail break mechanics, key parameters, and readjustment issues
- New methodology for rail break/defect removal RNT readjustment
- Best practice guidelines for CWR neutral temperature management

The Rail Break Problem

Issue: Welded rail (CWR) can experience rail fractures/breaks under cold temperature induced tensile force conditions.

Problem:
- Rail break caused derailments rank #1 in ALL track failure caused derailments
- In the US there over 80,000 service failures annually, and rail flaw inspection detects over 70,000 internal defects requiring removal
- When rail breaks or is cut for defect removal the neutral temperature (RNT) is substantially reduced – requires adjustment
- RNT readjustments after rail breaks/defect removals are difficult due to NOT knowing what reduced RNT condition is being adjusted
- If RNT is NOT readjusted prior to the onset of warm temperatures, the track can become buckling prone

Take away: over 150,000 locations of reduced RNT annually if NOT readjusted!

The Track Buckling Problem

Problem
- Very difficult to detect
- Dynamic event; can cause derailments
- In USA: many derailments/year at high damage levels [45 @ $19M] 2011
- Many incidents/high repair costs
- Tensile rail breaks can also contribute

The RNT Problem

Definition: Neutral temperature (T_N, RNT, SFT) is that rail temperature at which the net longitudinal force in the rail is zero. It is often associated with the “laying” or “fastening” temperature. It has a relationship to the force (P) in the rail:

\[ P = E \alpha (T_R - T_N) \]

T_N is Highly Variable!

Bottom line: need to manage RNT more effectively to reduce the number of track buckling caused accidents
Rail Break Influence Zone Issues

Influence Zone length on one side of the break (ft)

- Influence Zone length on one side of the break (m)
- Influence Zone length on one side of the break (kN/m)

Cold Temperature Rail Defect/Break Repair/RNT Readjustment Issues

Key RNT Readjustment Issues:
1. When to come back to readjust
2. How to readjust (how much rail to cut out and what length to unfasten)

Rail Break RNT Profile

Rail breaks cause large reductions in RNT

RNTs reduce to rail break/cut temperature!

Why Are Some Current Readjustment Methods Ineffective?

**METHOD 1:** When rail is added as an interim (plug) repair for broken/cut rail, remove the added rail later at a warmer temperature with unfastening 195 ft both sides of the cut – AREMA Recommendation/Chapter 5

**Issues:**
- Removing the added rail often is not enough, and nor is the 195 ft unfastening length
- The “warm” temperature at which to readjust is not known

**METHOD 2:** When the rail break/cut gap is small, close the gap by pulling or heating the rail without any anchor/fastener removal

**Issues:**
- The RNT may be restored to nominal pre-break value but NOT necessarily to the desired target level

Rail Break RNT Readjustment Difficulties

Influence Zone length on one side of the break (ft)

Key RNT Readjustment Issues:
1. When to come back to readjust
2. How to readjust (how much rail to cut out and what length to unfasten)
Rail Break Influence Zone Issues

Influence Zone (Ld) Depends on Thermal Load (AT), Longitudinal Resistance, and Rail Size

- Rail cut/break temperature
- Rail size
- Measured rail gap
- Designated/target RNT

Knowledge of rail movement or gap size together with the rail cut or break temperature allows the determination of RNT before break/cut.

Example: if T=60°F and rail break temp = 10°F, then the prebreak RNT=70°F

Rail Break/Cut RNT Profile

L=635 ft (194m)

RNT Readjustment Issues

How to Readjust: When and What Procedure?

(1) When to come back to readjust
(2) How to readjust (how much rail to cut out and what length to unfasten)

Key RNT Readjustment Issues:

- Rail movement or total gap size (in)
- Rail movement or total gap size (in)
- Rail size

Rail Break/Cut RNT Profile

L=635 ft (194m)

RNT Readjustment Issues

What Do Gap Sizes Depend On?

- Rail temperature
- Rail neutral temperature
- Rail cut/break temperature

RNT (°F)

Key Rail Break Mechanics Parameters

- Breakout temp
- Rail size
- Fastener type/condition
- Pre-breakcut RNT Breakout influence zone

Example of CWR-Adjust Software: "CWR-Adjust"

Input Parameters
- Rail size
- Anchor/fastener type/condition
- Rail cut/break temperature
- Measured rail gap
- Designated/target RNT

Railroads Customize for Internal Use

- CWR-Adjust coupled with RR’s Maintenance Management System
- Customized Slide Rule type “Pull-Cards”
- Tables in RR’s CWR Policy Document to Determine RNT_{PREBREAK}

Methodology Roadmap

NEW METHODOLOGY

- Rail Break Theory
- Test Data
- Industry Guidance

How much rail to cut out and what length rail to unfasten for a target RNT

CWR-Adjust Software for Readjusting RNT

(Deprecated by TTCI)

- Program based on rail break mechanics, theory, field tests, and industry input

RNT Readjustment Issues

Rail Break Gap Size Issues

Rail Break/Gap Size Issues

- Rail movement or total gap size (in)
- Rail movement or total gap size (in)
- Rail size

What Do Gap Sizes Depend On?

- Rail temperature
- Rail neutral temperature
- Rail cut/break temperature

RNT (°F)

Key Rail Break Mechanics Parameters

- Breakout temp
- Rail size
- Fastener type/condition
- Pre-breakcut RNT Breakout influence zone

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(Deprecated by TTCI)

- Program based on rail break mechanics, theory, field tests, and industry input
Best Practice Guidelines

Guidelines on Cold Temperature Readjustment of Neutral Temperature

RR’s CWR POLICY: rail that has pulled apart, broken or been cut for defect removal must be readjusted to within the subdivision rail laying temperature (RLT) minus a safe range (usually between 0 - 20°F) within the time/temperature specified by the readjustment TABLE.

TOOLS REQUIRED:
1. TTCI’s CWR-Adjust software (or equivalent charts and tables) to provide the pre-break/cut RNTs, the unfastening lengths, and the amount of rail cut-outs.
2. The railroad’s data management system to record and store gap sizes and the calculated prebreak/cut RNTs, unfastening lengths and rail removals.
3. Procedures on how to apply - 4 APPLICATION SCENARIOS

Example: a rail break occurring at a rail temperature of 10°F in a concrete tie territory resulting in a rail gap of 2”. The territory’s designated laying temperature (RNTTARGET) is 100°F. How to make the RNT readjustment?

- Make interim plug repair – requires adding 2” of rail
- Apply CWR-Adjust to determine:
  - RNT (°F) to readjust
  - Length of rail to unfasten: 280 ft on either side of break
  - Amount of rail removal: 6” (incl. 2” added + 1” weld allowance)
- Determine when (at what temp) to return for RNT readjustment
- Return for readjustment before T_RAIL exceeds 110°F; and follow CWR-Adjust

Record Data!

Distance from break (ft)
0 100 200 300 400 500 600 700 800
RNT (°F) 85 100 110 120 130

Illustrative Example of Application

The 4 Application Scenarios

GUIDELINES: the specific readjustment requirements are based on the measured gap size, rail size, the rail temperature at the time of the break/cut, the fastener/anchor condition, and the target RNT in line with the following 4 scenarios:

Scenario 1: Measured gap size indicates the pre-break/cut RNT is in the RLT-20°F range or above
Scenario 2: Measured gap size indicates the pre-break/cut RNT is below RLT-20°F
Scenario 3: When CWR-Adjust or equivalent charts/tables are NOT available or applicable
Scenario 4: Special Cases When CWR-Adjust or charts/tables are NOT applicable:
- Defects/breaks clustered in “close” proximity to each other
- Defects/breaks near “fixed” structures
- Defects/breaks near each other on opposite rails

Innovative Aspects of Guidelines

Guidelines and CWR-Adjust: Special Features

- Reduces required unfastening lengths:
  - REDUCE L_u’s by 50%
  - Unfasten only ½ L_u, but cut more rail out to compensate by localized overstressing

- Reduces track time and resources!

- Accounts for “end-movement” effects:

Best Practice Guidelines for RNT Management

Concluding Remarks

- Managing RNT readjustments after rail breaks and defect removals is difficult, but there is a new methodology available:
  - Formalized into industry procedures as “Best Practice Guidelines for RNT Management”
  - Guidelines apply to most break/defect removal conditions as covered by 4 Readjustment Scenarios
  - Easy application facilitated by TTCI software: “CWR-Adjust”
  - Special features:
    - calculates “minimum” unfastening lengths
    - adjusts for “end movements” effects

- Anticipated benefits: improved system safety and increased network capacity

Acknowledgement: Mr. David Read (now retired) and Semih Kalay of TTCI for conducting the experimental studies and developing CWR-Adjust, to several railroads notably the Union Pacific and the BNSF for guidance and implementation, and to the US DOT’s Volpe Center for the earlier theoretical work on rail break mechanics

Questions?

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