Optimized Readjustment Length Requirements for Improved CWR Neutral Temperature Management

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ABSTRACT

Research activity currently sponsored by the Association of American Railroads and carried out by Transportation Technology Center, Inc. (TTCI) in conjunction with Kandrew, Inc. Consulting Services has focused on improving the performance of continuous welded rail (CWR) track through enhanced rail neutral temperature (RNT) maintenance practices. One issue being investigated is the process of restoring RNT that has been lowered when the rail is cut or broken at temperatures below the rail’s existing RNT. Readjustment of the RNT is accomplished by restoring the tension that was lost when the rail broke or was cut. This loss of tension is evident by the rail gap that is created at the break/cut location and it influences the rail over some distance each side of the gap. Ideally, the rail in this influence zone will be unfastened and the RNT brought back to a desired condition during the readjustment process. However, influence zone lengths can be long, requiring substantial time and resources for unfastening and RNT readjustment.

This paper presents an approach where RNT readjustment lengths can be reduced without compromising the safety of CWR track. This optimized readjustment length is based on allowing a pocket of decreased RNT to remain in the influence zone that is compensated for by overstressing at the location where the rail broke or was cut. It is expected that this uneven readjusted RNT profile will be equalized by subsequent train traffic.
1 INTRODUCTION

It is recognized that effective management of longitudinal thermal forces in CWR is essential for safe and efficient railroad operations. Thermal forces are generated when the thermal expansion and contraction of the rail is constrained by rail anchors and fasteners and the ballast section and is calculated as Equation 1:

\[ P = AE\alpha \Delta T \]  

where \( P \) = rail thermal force (pound), \( A \) = rail cross sectional area (inch\(^2\)), \( E \) = rail steel modulus of elasticity (psi), \( \alpha \) = rail steel thermal expansion coefficient, and \( \Delta T = (T_M - T_N) \), where \( T_M \) is the existing rail temperature (°F) and \( T_N \) is RNT (°F).

It is evident from Equation 1 that the force magnitude is determined by the rail area (i.e., 115 RE rail section produces about 20 percent less force/°F than the 141 RE rail section) and, more importantly, by the \( \Delta T \). Because the \( \Delta T \) is a function of the neutral temperature, the RNT condition becomes the most important parameter to consider in terms of controlling thermal forces.

Rail temperatures above the RNT produce compressive forces and temperatures below produce tensile forces. Compression in the rails can cause the track to buckle when the force levels exceed the track’s lateral strength. Analytical and experimental investigations indicate buckling forces are typically in the range of 150,000 to 200,000 pound/rail which corresponds to a \( \Delta T \) of 60 to 80 °F. Tensile forces have been shown to accelerate rail defect growth, cause rail and welds to fracture and rail joints to pull apart.

To minimize the development of damaging force levels, track maintenance policies require that CWR be installed and maintained within a specified RNT range. Currently, most North American railroads specify a rail laying temperature, or target RNT, that is about 75 to 85 percent of the anticipated maximum temperature. The target RNT is intentionally biased toward the maximum rail temperature to limit compressive forces and the associated buckling potential at the expense of much higher tensile forces.

Because the rail is never absolutely constrained and some elongation and contraction can occur due to train and environmentally induced loads, the RNT commonly varies from its as-installed condition. Rail creep, curve movement and, to a lesser extent, vertical track settlement, all can have some influence on the RNT and its variability. Rail creep (longitudinal rail movement), which can substantially change the RNT, takes place when longitudinal rail forces exceed the longitudinal restraint and can occur under train braking and acceleration, from temperature gradients along the rail or from insufficient rail anchoring/loss of rail fastener toe loads. Curve movement, or lateral shift, can occur under repeated vehicle curving forces in conjunction with thermal rail forces or from track maintenance.

Rail maintenance, specifically the repair of defective or broken rails, can also have a significant influence on the RNT. Of all the potential influences on RNT behavior, a rail
that is broken or cut during cold weather has the greatest likelihood of reducing the RNT to values that are unacceptably low. Under these circumstances, the readjustment and restoration of the RNT to the target value either during or after the rail repair procedure becomes necessary before the onset of warm weather.

The intent of this paper is to present a science-based approach to defining and optimizing RNT readjustment lengths based on a safe minimum required RNT criteria. The optimized readjustment lengths are expected to provide an economically feasible maintenance procedure while maintaining track buckling safety.

2 METHODOLOGY FOR CWR RNT READJUSTMENT

The basic objective of RNT readjustment is to restore the rail tension that was lost when the rail broke or was cut. Tension is induced by elongating the rail mechanically or thermally and welding/anchoring it in place at the adjusted position. Ideally, the rail should be free of longitudinal resistance (unfastened or de-anchored) as it is being tensioned. Test results indicate that failure to de-anchor an adequate rail length can produce a readjusted RNT profile that is uneven and lower than desired. A methodology based on earlier analytical studies and testing has been developed to provide maintenance personnel with a best practical estimate of the required RNT parameter and the length of rail to be adjusted, both of which are generally unknown.\textsuperscript{2,3,4}

The first step in defining RNT adjustment guidelines and optimal de-anchoring distances is to understand how the RNT responds to a rail break, i.e., the rail break RNT influence zone. When a rail breaks or is cut at a temperature below its neutral temperature, the release of tension produces a gap and the existing (pre-break) RNT drops to the rail ambient temperature at the point of separation. This differential between pre and post cut RNT diminishes with distance away from the gap due to the incremental restraint provided by the rail anchors/clips and the ballast section. Accordingly, at some distance from the break/cut, the restraining force exceeds the pre-break tensile force and change to the existing RNT is nonexistent. This distance on each side of the gap over which the release of tension affects the RNT is referred to as the influence zone ($L_D$) and is a function of the $\Delta T$ and the longitudinal resistance.

Figure 1 shows an example of this RNT response, where pre and post-rail break RNT profiles for a concrete tie track with average longitudinal resistance, 100 °F pre break RNT, and the rail break at 40 °F giving a $\Delta T$ of 60 °F are plotted against distance from the break.
In Figure 1, the RNT changes at a linear rate for a distance of about 350 feet beyond the break and then asymptotically approaches zero-change. Extending the linear portion of the curve and ignoring the tail end simplifies the analysis and provides sufficient accuracy; therefore, the linear approximation of the LD is used in this study. It is also important to keep in mind that the tension force P is being generated by ΔT, therefore, both variables can be considered to be synonymous.

As previously stated, the influence zone length is a function of the ΔT and the longitudinal resistance, as Figure 2 shows. Figure 2 also indicates that influence zones can be long and de-anchoring the entire length may be difficult in terms of resource and track time availability. For example, in the case of wood ties with every other tie box anchored, the influence zone produced by a ΔT of 60 °F is about 650 feet on each side of the rail break/cut, for a total length of 1,300 feet. For this reason a techno-economic compromise is desirable in terms of reducing the de-anchored portion of the influence zone to an optimal length that does not compromise buckling safety by inadequate RNT reset value.

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**Figure 1. Parameters Governing the RNT Influence Zone**

**Figure 2. Influence Zone versus Longitudinal Resistance and ΔT**
3  OPTIMIZATION OF RNT READJUSTMENT LENGTHS

Figure 3 shows the basic effect on the adjusted RNT if the de-anchoring distance is less than the total influence zone length. Here, using the same conditions that are depicted in Figure 1 (concrete tie track, 100 °F pre break RNT, and rail break at 40 °F giving a ΔT of 60 °F), but only showing one side of the total influence zone; adjusted RNT values from de-anchor lengths each side of the break of 225, 300, and 425 feet are given.

As indicated in Figure 3, de-anchoring 300 feet each side of the rail break will produce an RNT near the end of the de-anchoring of about 80 °F. Figure 4 shows the generalized effect on the RNT profile from Figure 1 of closing the gap with heat or applied tension from a rail tensor and partially de-anchoring the influence zone length. The adjusted RNT profile that is conceptualized in Figure 4 has been measured in tests at the Transportation Technology Center, (TTC), Pueblo, Colorado, and elsewhere.5
The test data indicates that when de-anchored distances are less than the influence zone length and the rail is readjusted using a rail tensor, the applied tension needed to close the gap tends to overstress the de-anchored free rail and under-stress the anchored rail leaving a pocket of reduced RNT near the end of the anchored zone that is roughly equivalent to the RNT at that distance from the rail break. The reduced RNT pocket will be most pronounced and abrupt if heat is used to induce tension in the free rail only. The reduction will be less abrupt and severe if tension is induced mechanically with a tensor or if the anchored rail is heated in addition to the free rail. In this case, tension is also induced in the anchored rail, as permitted by the longitudinal resistance, and contributes to the total rail movement and increase of RNT. The permissibility of the reduced RNT is the basis for the determination of an optimal de-anchoring distance.

### 3.1 Overstressing to Compensate for RNT Reduction

From Figures 3 and 4, it is apparent that the lowest RNT produced by the readjustment process is determined from the length of rail that is de-anchored. Therefore, an optimal de-anchored length can be based on the concept of a minimum allowable RNT that does not compromise track stability retention. Minimum RNT is dictated by the buckling strength of the track, which depends primarily on the track type, condition, and maximum anticipated rail temperature. One potential approach toward minimizing the de-anchoring requirement without leaving an unacceptable RNT condition is to take advantage of the overstressing tendency of the unanchored shown Figure 4. Figure 5 illustrates that with this approach, the uneven adjusted RNT profile is equalized with traffic.
This traffic equalization process has been measured during tests at TTC and in revenue service. Figure 6 shows a good example of the traffic equalization effect where RNT being monitored in revenue service on the Union Pacific South Morrill subdivision quantified the RNT effects of a broken rail, the uneven profile following the readjustment, and the equalization after 37 million gross tons of traffic. The data in Figure 6 was collected on concrete tie track that carries predominately single direction 36-ton axle load coal traffic. It is not clear at this point how consistent traffic equalization might be under all track conditions and will be the subject of further investigation.
3.2 Safety Aspects of Reduced De-anchoring

As stated above, the fundamental issue surrounding reduced de-anchoring lengths is the minimum RNT required to maintain track buckling safety. The track’s buckling strength can be defined as the temperature increase above neutral that is required to cause buckling and is highly dependent on the condition of the track and track components. Figure 7 illustrates buckling strengths that have been cast into a summary distribution, where buckling strengths vary from about 60 ºF for tracks with weak lateral resistance to 130 ºF for tracks that are very strong laterally. The minimum RNT will be based on the low buckling strength of 60 ºF above the RNT and will be determined simply as the maximum anticipated rail temperature for the territory minus 60 ºF. For example, if the maximum anticipated rail temperature is 140 ºF, the minimum allowable RNT would be 80 ºF. The optimized de-anchoring length would then be distance from the rail break/cut that is equivalent to an 80 ºF RNT based on the track longitudinal resistance characteristics and the target RNT.
Figure 7. Buckling Strength Distribution Schematic

Table 1 provides de-anchor distances based on the full influence zone and the reduced zone corresponding to an 80 °F minimum for wood and concrete tie track having average longitudinal resistance values and a target RNT of 100 °F. The 80 °F reduced de-anchor distance would be coupled with 20 °F overstressing of the de-anchored rail with the expectation that traffic equalization will provide a reasonably uniform RNT condition close to 100 °F.

Table 1. Full and Reduced De-anchoring Lengths for Wood and Concrete Tie Track

<table>
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<tr>
<th>T_{cut/break} (°F)</th>
<th>80 °F RNT L_d (feet)</th>
<th>Full L_d (feet)</th>
<th>80°F RNT L_d (feet)</th>
<th>Full L_d (feet)</th>
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<tbody>
<tr>
<td>60</td>
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<td>740</td>
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</tr>
<tr>
<td>-20</td>
<td>725</td>
<td>880</td>
<td>1,085</td>
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The optimized de-anchoring length approach presented here is expected to offer railroads additional flexibility and accuracy when readjusting CWR neutral temperatures. Additional testing at TTC and on revenue service tracks is expected to further evaluate and quantify the benefits of reduced readjustment lengths.

3.3 Automated Procedure CWR-DESTRESS Under Development
It is recognized that automation of the process just described will greatly enhance its value and usefulness for track maintenance personnel. Therefore, TTCI is working on a Visual Basic program that will operate from an Excel spreadsheet that provides critical data for RNT readjustment such as influence zone length, de-anchoring length, existing RNT condition and final gap size based on inputs that include rail break temperature, gap size, target RNT, and track characteristics.

4 CONCLUSIONS

1. Maintaining a high and stable neutral temperature is a key part of track buckling prevention and efficient CWR performance. Due to the highly variable nature of RNT and its inability of being easily measured, maintenance personnel often lack information for correct readjustment of the RNT. Therefore, a new methodology has been developed to more effectively readjust the RNT condition following a rail break defect removal.

2. The new methodology proposes to determine the RNT condition being adjusted from graphs or tables generated from empirical data on rail break/cut movement versus rail longitudinal force (or temperature difference). Similarly, the length of rail required adjusting is determined from test and analysis data on rail break/cut influence zone lengths versus rail/track longitudinal resistance and longitudinal force.

3. The new methodology offers immediate economic advantages for repairing and readjusting broken rails. Specifically, it affords a quick temporary rail break repair to facilitate resumption of traffic, and provides an easy science-based procedure to perform the permanent weld repair and RNT readjustment at a later time.

4. One key aspect of the new methodology is prescription of a required length of rail to de-anchor. Since these lengths can be in excess of 1,000 feet on either side of the break/cut, their repair may require time and resources not readily available, suggesting an investigation on the feasibility of employing shorter repair lengths and their impact on CWR track stability. Such investigation has resulted in an optimized length approach based on overstressing the rail at the break to compensate for a pocket of reduced RNT at the ends of the de-anchored rail. However, this reduced RNT must be within a minimum acceptable RNT limit that is based on buckling safety considerations. The minimum RNT is based on weak buckling strength considerations and on the territory’s expected maximum rail temperature. It is expected that additional testing will further fine tune this reduced length approach in line with specific industry requirements to produce improved maintenance practices for more effective RNT maintenance.
5 ACKNOWLEDGEMENTS

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6 REFERENCES


