Development of

Track Buckling Risk Analysis

Methodology

Allan M. Zarembski, Ph.D., P.E., President ZETA-TECH Associates, Inc.
Gregory T. Grissom, MCE, Project Engineer, ZETA-TECH Associates, Inc.
Henry M. Lees, Jr., P.E., BNSF Inc.

ABSTRACT

Track buckling continues to be a major concern for railroad engineering officers and MoW personnel. This paper presents a risk-based approach for identification of potential track buckling sites that was developed on behalf of BNSF. The approach uses site-specific risk factors, which are track and traffic parameter based to develop a site “risk” value. Based on the magnitude of this value, the potential for a track buckle occurring at the site is defined.

This paper describes the development of the approach and of the specific risk factors themselves, which were incorporated into a computer model. It also describes the calibration, validation, and application of this methodology over the entire BNSF system. Based on the results of this study, preliminary risk thresholds and associated “actions” were identified. The system-wide application on BNSF examined approximately 24,200 miles of mainline track, divided into 133,012 buckling risk analysis segments. For this system application, the model identified 30 segments (0.02% of system) as very high risk, and 961 segments (0.72% of system) as high buckling risk. All of the very high-risk segments underwent inspections by local forces, and approximately 1/3 of these identified segments were destressed shortly thereafter.
The results of the system-wide applications on BNSF have shown that the methodology can be applied on a consistent basis to identify potential buckling risk sites without placing an undue maintenance burden on MoW personnel.

Key Words: track buckling, risk of buckling, buckling potential, buckling prevention, thermal incidents

INTRODUCTION

Track buckling is a track failure mode that occurs when the increase in rail temperature above the neutral or force free temperature of the rail causes sufficient longitudinal rail forces to overcome the lateral strength of the track. The result is a large-scale lateral movement of the track structure, commonly referred to as a track buckle. Track buckling represents a major track failure mode both in the US and worldwide that can and does result in train derailments as well as significant maintenance costs [1]. As such, BNSF and other railroad systems, pay careful attention to those factors that can influence the potential for track buckling such as rail installation temperature, warm weather maintenance activities, and other actions, which can affect the rail neutral temperature or the track’s buckling resistance. However, since techniques to monitor the neutral temperature of the rail are very limited and difficult to employ, railroads generally rely on preventive measures to control buckling risk.

The approach presented here is designed to allow railways such as BNSF to determine the risk or possibility of track buckling on a site-specific basis, based on information, which is readily available to the railway in its track database. This risk information can then be used by the railroad for identification of locations, which require more intense investigation or follow up prevention action.
The analysis approach uses site-specific risk factors, which are track and traffic specific, to develop a site “risk” value. Based on the magnitude of this value, the potential for a track buckle occurring at the site is defined and the need for any follow up action identified. The methodology is designed to be applicable in large-scale applications, to identify potential buckling sites across an entire route, division or railway system.

The development of this track buckling risk analysis methodology on BNSF was a multi-phase activity. The initial phase developed the overall methodology as well as the theoretically based risk factors used in the application of the methodology to railroad sites. Phase II calibrated and validated the methodology by application to a series of sites on BNSF. Phase III included the development of the production computer model, and full system-wide application.

This paper documents the development of the analysis methodology. It describes the derivation of the approach and the associated track buckling risk factors as well as the techniques used to identify track sites where there are “high” levels of buckling risk and the associated actions to prevent track buckles. The intent of the methodology is to provide BNSF with a method of assessing potential buckling risk sites by determining site-specific risk values and compare these values with pre-set risk thresholds. Based on these risk thresholds, corresponding “actions” can be taken to reduce the risk of track buckling.

ANALYSIS APPROACH OVERVIEW

The overall analysis approach is a risk factor based approach, which is applied on a segment-by-segment basis to specific track locations. These segments are defined based on “homogenous” track and traffic characteristics and as such can be as short as an individual curve. For each such segment, a “base” risk factor is established based on the site’s temperature range and the rail’s force free or neutral temperature. Additional risk factors are then developed for the segment,
based on track, traffic, and related data, which is readily available in BNSF’s databases. These risk factors would then be added to (or subtracted from) the base risk factor to calculate a total risk value for each track segment or site being analyzed. The resulting calculated risk factor is compared against pre-defined risk thresholds for follow up action. The overall objective was to develop an easy to implement methodology for assessing potential buckling risk on a large scale basis, e.g. the entire BNSF railroad, and to identify from this a manageable number of high potential buckling risk locations for further investigation and/or action.

Track buckling theory has shown that the potential for track buckling is directly related to the increase in rail temperature above the neutral or force free temperature of the rail. This increase in temperature results in compressive forces being generated in continuously welded rails, which are restrained, from expansion or movement in the longitudinal (axial) direction. When this compressive force exceeds the track structure’s buckling strength then track buckling occurs. This behavior is defined in the following equation:

$$N_t = EA \alpha \Delta T$$  \hspace{1cm} (1)

Where

- $N_t$ is the axial compression force in the rail
- $\Delta T$ is the temperature increase above the neutral (force free) temperature
- $E$ is Young’s Modulus of rail steel
- $A$ is the cross-sectional area of both rails
- $\alpha$ is the coefficient of linear thermal expansion for steel

Noting this relationship between the increase in temperature and the longitudinal rail force, it was determined that a set of buckling risk values corresponding to an “equivalent” temperature increase be developed. This buckling risk was to consist of:

- Base risk which was the actual $\Delta T$ value for a given site
Supplemental risk factors which are non-temperature related factors that effect the strength or neutral temperature of the track but are defined in terms of “equivalent” increase or decrease in temperature above the base value.

By thus adding together the base risk with the supplemental risk factors, an “equivalent” temperature increase is developed which in turn is directly related to the risk of the track segment buckling. The higher this risk value the greater the potential for track buckling at that site being analyzed.

**Base Risk**

As noted above, the base risk factor is defined as the difference between the maximum rail temperature and the rail neutral temperature at the site being analyzed.

The maximum rail temperature experienced at a given location is specific to its geographic region. For this reason, the US National Oceanic and Atmospheric Administration (NOAA) and National Climatic Data Center (NCDC) climate records were used to calculate the maximum ambient temperature experienced in the region under consideration. To obtain the maximum rail temperature, this maximum ambient temperature was increased by 30°F While rail temperatures have been seen to increase up to 40°F above the ambient temperature, investigations at BNSF buckle sites has shown that 25°F to 30°F is more appropriate.

The NCDC database has between 20 and 90 years of temperature data depending on the geographic location. In order to define a consistent and representative time frame, 5-year, 10-year, 20-year, 30-year, and 100-year maximum temperatures were analyzed. Based on this analysis, the 10-year maximum ambient temperature, which was determined to represent 99.95% reliability (based on 182 warm days/year), was selected.
The other parameter used in the base risk calculation is the neutral temperature of the rail. However, while the actual neutral temperature of the rail would be the best value to use here, it is generally not available, unless taken by field measurements through cutting the rail and measuring its expansion or using either a VERSE measurement system. If the actual neutral temperature is not available it is then necessary to use the best available information on the rail temperature, which is usually the installation or readjustment temperature of the rail. Again, if accurate records exist as to the local rail laying (or recent readjustment) temperature this value should be used. However, in situations when neither the actual neutral temperature nor the local rail laying temperature is available, which is most often the case, the BNSF target neutral temperature (TNT), shown in Figure 1 [2], is then used. In general, the accuracy of the model is greatly improved when the rail neutral temperature or the exact temperature at which the rail was laid initially is known.

The base risk value is then calculated by taking the difference between maximum rail temperature \( T_{\text{max}} \) and the rail neutral or installation temperature \( T_0 \). For a territory with a maximum ambient temperature of 105°F and a target neutral temperature of 95°F, the base risk is:

\[
\begin{align*}
\text{Max Rail Temperature} &= 105^\circ F + 30^\circ F = 135^\circ F \\
\text{Base Risk} &= 135^\circ F - 95^\circ F = 40^\circ F
\end{align*}
\]

These values represent the initial site risk value, which is then adjusted based on the supplemental risk factors.

**Development of Supplemental Risk Factors**

The second part of the risk analysis methodology involves the use of supplemental risk factors to reflect conditions, which affect either the buckling resistance strength of the track or the neutral temperature of the track. These supplemental risk factors are not temperature related but rather
are traffic and/or track condition related. As such, they can act to reduce (or increase) the strength of the track by weakening (or strengthening) the track from the basic track structure, e.g. inadequate or missing ballast shoulders. Alternately they can affect the neutral temperature of the track, such as by causing longitudinal movement of the rail with corresponding changes in rail neutral temperature, e.g. heavy braking on a severe grade.

The values of the supplemental factors are defined in terms of “equivalent” increase or decrease in temperature above the base value, so as to allow them to be added to or subtracted from the base risk value. This allows for an easy to apply and understand mathematical approach, in which the calculation of overall risk involves adding and subtracting from the base risk value those parameters that increase and decrease the potential for track buckling.

The actual risk factors and their preliminary values were derived from a series of theoretical and practical sources that included:

- The VNTSC CWR SAFE Model [3,4]
- Buckling Theory of Dr. A. D. Kerr [5,6,7]
- Longitudinal Creep Theory [8]
- “Expert” Evaluation

The risk factors themselves were based on those engineering parameters, to include track, traffic and operational parameters that the different theories showed to affect the potential for track buckling. Wherever possible, the different theoretical approaches noted above were applied to each parameter (though not all theories included all of the buckling parameters) and the effect of the parameter’s variations was calculated in terms of the effect on the buckling risk (as an equivalent change in temperature, in degrees F). The different theoretical (and practical) sensitivities were compared and combined into a single composite risk value for each parameter.
A partial listing of these risk factors includes the following:

- Curvature
- Track Grade
- Train Braking/Acceleration
- Tonnage
- Presence of “Hard Spot’ in Track
- Track Characteristics
  - Rail size
  - Tie type
  - Fastener type
  - Anchoring
  - Tie spacing (in.)
  - Ballast type /condition
  - Track consolidation (MGT)
  - Shoulder width (in.)
  - Ballast crib condition
  - Track Class
    - Recent Maintenance Activity
    - Track /Rail Movement
- History of Track Buckles
- Time Since Last Adjustment
- Rail Repair
  - Cold weather plug
The development of these factors, based on the different theoretical approaches is presented in the following sections.

**CWR Safe**

CWR SAFE is the track buckling analysis software package developed by the US Department Of Transportation’s Volpe National Transportation Systems Center (VNTSC) in Cambridge, MA and its contractor Foster-Miller, Inc [3, 4].

CWR SAFE is in fact composed of three models: CWR-BUCKLE, CWR-INDUSTRY and RISKGEN. While all three models are based on the theoretical studies performed by VNTSC, FRA and its contractors, CWR-INDUSTRY, also referred to as CWR-INDY, is the model that is most directly geared to analysis of industry track, where the general track and traffic parameters are available to users [4]. The other models require more detailed testing and/or numerical representation of track conditions, which is generally not available in the railroad environment and as such not as readily applicable.

CWR-INDY calculates a $T_{all}$ value which is defined to be the safe allowable temperature increase above the rail neutral temperature for which buckling will not occur. This $T_{all}$ value is calculated as a function of key track and traffic input parameters to include many of the risk factors noted above. Thus, for a given set of these input parameters, CWR SAFE: INDY calculates the allowable safe temperature increase above the neutral temperature, $T_{all}$.

Using the VNTSC CWR SAFE INDY model, sensitivity studies were conducted for each of the available buckling parameters, holding all other track factors constant. Using this analysis approach, the value of the risk factor is set to be the difference in $T_{all}$ value between the “base
case” track conditions and the variable under investigation. Since the risk factors were defined in terms of “equivalent” temperature changes, for every 1°F decrease in the allowable safe temperature increase given by CWR SAFE, there is a corresponding 1°F increase in buckling risk, and thus an increased risk factor of 1.0.

In this manner, one set of buckling risk factors was obtained for those parameters that are included in the CWR-INDUSTRY model. Note, not all of the relevant parameters are included in CWR-INDY. For example parameters related to grade, train braking/acceleration, longitudinal movement, etc. are not included in the model and as such had to be developed using another analysis methodology.

**KERR Buckling Theory**

A parallel analysis for the determination of the supplemental risk factors was performed using the track buckling theory developed by Kerr et al [5,6,7] which defined the fundamental nature of the track buckling behavior for tangent and curved track. This theory focused on the calculation of an allowable “safe temperature increase” above rail neutral temperature, $T_L$, as a function of key track parameters such as curvature, lateral and longitudinal track resistance, rail section size, etc.

In a manner analogous to that described above, but using the Kerr theory safe temperature increase above rail neutral temperature, $T_L$, the value of those risk factors addressed by the Kerr theory were determined, again defined in terms of “equivalent” temperature changes.

Thus, using the Kerr theory, a second set of buckling risk factors was obtained. Again it should be noted that not all of the relevant parameters were available.
Longitudinal Rail Creep Theory

The two theoretical analyses discussed above did not incorporate any longitudinal creep effects, such as commonly experienced on severe grades or under train braking/accelerating conditions. Since these factors have been found, in practice to contribute significantly to the change in rail neutral temperature, over time, it was determined that they must be included in this analysis methodology. Therefore, the longitudinal creep theory, as defined by Johnson-Albrext-Kerr [8] was introduced. The objective was to quantify the effect of such key longitudinal movement related parameters, such as grade and braking, on the longitudinal strength of the track structure. This mechanical creep behavior is independent of the rail temperature effects already included in the VNTSC and Kerr buckling theories, and is related to the rail movement due to train action (braking and/or acceleration) [8].

It has been observed that when a train moves at a constant speed, the rails have a tendency to permanently displace in the direction of the moving train. This effect is magnified in a train-braking situation (and even further so in a train-braking situation on a grade). When the rails are prevented from moving axially at a specific location (i.e. turnout, grade crossing, or open deck bridge), rail creep may cause the accumulation of compression forces at these locations, and a corresponding change in rail neutral temperature, which can contribute to track buckling.

For the steady state situation, with no train acceleration or braking, the rail creep due to the deflection wave in front of the train can be calculated using the Johnson-Albrext-Kerr creep model [8]. This model allows for the analysis of a rail section with one fixed end with varying grade. By superimposing the forces generated by train braking, which induce an additional creep
element, it is possible to quantify the magnitude of the rail creep, and the associated level of buckling risk, once again defined in terms of “equivalent” temperature changes.

**Engineering Judgment**

Finally, in parallel to the three analysis approaches defined above, engineering judgment by experienced personnel knowledgeable in track buckling behavior and practice was also used to define the risk factor values. These were performed through a set of engineering judgment assessments conducted on each individual buckling parameter. Again the concept was to attempt to hold all other parameters constant and to use engineering judgment to define the magnitude of the risk factor value. These assessments were performed by ZETA-TECH and BNSF personnel with knowledge and experience in track buckling behavior with the intent that this “practical” experience approach would provide balance to the theoretical approaches outlined above.

**Developed Risk Factors (Modification to Base Risk)**

As noted above, all four of the approaches were run in parallel and then compared in order to develop the preliminary risk factor values to be used in the analysis.

A sample set of these risk factor values, which are to be added to (or subtracted from) the base risk for a given segment, are illustrated in Table 1. Appendix A provides a full listing of the parameters that make up the full buckling risk analysis approach. As noted above, the risk factors include parameters associated with the track structure and traffic, as well as maintenance,
history, and track geometry data. These factors have undergone modifications through the different applications and through review by BNSF personnel.

As noted previously, these risk factors are added to (or subtracted from) the Base Risk, which is defined as:

**Base Risk** = Maximum Rail Temperature – Neutral Temperature +30°F

Where

- Maximum Rail Temperature is 10-year maximum
- Neutral Temperature is one of the following:
  - Actual Neutral (Force-Free Temperature)
  - Actual Installation Temperature TNT (BNSF Target Neutral Temperature)

**Sample Application**

To illustrate the application of the buckling risk factor methodology, consider a track segment consisting of concrete tie track (with SafeLock fasteners) on a 6-degree curve with 141 RE rail. The track is classified as FRA Class 4 and the segment contains a 1-inch misalignment defect. There was rail added during a winter repair, and there is no record of a destress within the last five years. The maximum ambient temperature for this territory is 105°F. The BNSF TNT for this territory is 95°F.

Based on the TNT and maximum ambient temperature, the “base risk” for this track segment is calculated as follows:

\[
\begin{align*}
\text{Max Rail Temperature} &= 105^\circ F + 30^\circ F = 135^\circ F \\
\text{Base Risk} &= 135^\circ F - 95^\circ F = 40^\circ F
\end{align*}
\] (3)

Applying the risk factors associated with the track segment results in the following changes to the base risk:
\[ \text{Base Risk Factor} = 40 \]
\[ \text{Concrete Tie Factor} = -8 \]
\[ \text{Curvature Factor} = +9 \]
\[ \text{Rail Factor} = +1 \]
\[ \text{Misalignment Factor} = +3 \]
\[ \text{Cold Weather Plug Factor} = +15 \]
\[ \text{Last Destress} > 5 \text{ years} = +5 \]

RISK FACTOR = 65

Note: the other factors presented in Appendix A were not applied since they were not relevant to or present in this segment. The final risk factor of 65 is obtained for this track segment. This is its overall risk of buckling.

Initial Applications on BNSF

After the development of the analysis approach, this methodology was applied to 40 miles of BNSF track, divided into four ten-mile segments as follows:

(1) Orin Subdivision MP 55-65
(2) Galveston Subdivision MP 205-215
(3) Hi-Line Subdivision MP 965-975
(4) Needles Subdivision MP 690-700

Analysis segments were developed based on homogeneous track characteristics and ranged in size from 0.2 to 0.3 miles in length. A total of 180 segments were obtained for the 40 miles analyzed. Temperature data was collected from the nearest US Government recording site for each subdivision, with the 10-year maximum ambient temperature used in the analysis. Table 2 presents a summary of the calculated risk factors for all 180 segments in the four subdivisions.
As can be seen from Table 2, three segments had risk values above 70, with the Galveston subdivision producing the site with the largest risk factor (71) at MP 206.2 to 206.6. This site contained the following characteristics:

- 2.03° curve
- 1.22% grade
- Wood Ties
- Signal and Turnout (Heavy Braking)
- Class 4 track with major cross-level defect

The local roadmaster confirmed that this was a problem site.

Following this initial application, the methodology was applied to BNSF’s database of thermal incident (track buckle) sites for the period 1996 to 2002. From this database, 54 sites were identified with sufficient information to allow for application of the buckling risk methodology. This application also served as a calibration step, since all 54 of the sites represented acknowledged incidents of track buckling or related thermal incidents and so this application saw much higher risk values than the previous study. Table 3 presents a summary of the calculated risk values for the 54 sites. As can be seen in Table 3, nearly half of the segments had risk factors greater than or equal to 70, which was the risk threshold identified in the initial 40 mile application. Furthermore, six segments had risk values greater than or equal to 90, with a maximum risk factor of 97, and another 8 segments had risk values of between 80 and 89. Of these high-risk segments, four had a track buckle prior to the incident studied and ten segments had disturbed track with less than 1 MGT of traffic consolidation.

After calibration of the risk factors using these two initial applications, the updated methodology was applied to an additional 130 miles of BNSF track divided between four BNSF
selected subdivisions. The purpose of this application was to demonstrate a larger-scale application of the risk methodology to correlate any identified high-risk sites with the assessments of local roadmasters. This application of the buckling risk methodology was applied to the following line segments:

(1) Montana Division, Milk River Subdivision, MP 316 to 346, (Saco, MT to Malta, MT): 30 miles

(2) Powder River Division, Twin Peaks Subdivision, MP 265 to 290, (Branson, CO to Des Moines, NM): 25 miles

(3) Springfield Division, Birmingham Subdivision MP 660 to 710, (Glen Allen, AL to Dora, AL): 50 miles

(4) Southern California Division, Cajon Subdivision, MP 55 to 80, (Summit, CA to San Bernardino, CA): 25 miles

It was noted by BNSF that since 1996, these subdivisions had 24 thermal incidents representing track buckling derailments, track buckles, reported tight rail, or reported thermal misalignment.

Data was collected for these 130 miles of track from BNSF data sources to include track charts, BNSF data bases such as its Roadway Information System (RIS database), DARS, and PARS (Planning and Activity Reporting System) systems, service/detector car defects, and track geometry data files. In order to simplify segmentation for these 130 miles, a uniform 0.2 miles (1056 foot) segmentation was applied which generated a total of 650 analysis segments. Table 4 presents a summary of the resulting track buckling index values for these sites.

As can be seen from this Table, one site had a buckling risk index value of 80 or greater and another three had index values of between 70 and 79, for a total of four sites with index values greater than 70, the previously defined threshold. Following this analysis, the BNSF
Roadmaster’s responsible for maintaining the highest risk segments were contacted and their experience correlated with the analysis results. In general, this application produced reasonable correlation with the local roadmaster’s assessment of risk with

- 1/1 sites greater than 80
- 2/4 sites greater than 70

correlating with the local Roadmaster’s assessment of buckling risk at these sites. Following this application, the risk factors were finalized together with the risk thresholds.

**Suggested Risk Thresholds and Associated Actions**

Noting the results of the analyses of the 170 miles of BNSF track and the 54 recorded buckling incidents, the following buckling risk thresholds were identified:

- Very High Buckling Risk: $\geq 80$
- High Buckling Risk $\geq 70$

As noted previously, as the site risk index value increases so does the possibility of a track buckle.

After discussions with BNSF personnel, a series of “actions” were defined as a function of these buckling risk thresholds and are presented in Table 5.

As can be seen from this Table, the scope of the actions increase as the index increases, with the initial threshold level set to provide better information and to increase inspections, while the higher level actions are intended to directly reduce the possibility of a track buckle:

**Development Of Track Buckling Model And BNSF System-Wide Application**

The final phase of this activity addressed the development of a fully automated buckling risk analysis model and full BNSF system-wide application. As such, this phase consisted of the following tasks:
- Development of automated segmentation and risk assessment computer model
- Full system data collection
- Full system-wide application
- Generation of high-risk segment report

In this full system application, 24,200 track miles were analyzed across the BNSF system.

**Buckling Risk Model and Data Requirements**

Using the approach and methodologies defined above, a fully computerized buckling risk analysis model was developed. This model utilizes track, traffic, and environmental data from several sources within various BNSF and external databases. The general data requirements include the following information: (1) Subdivision boundaries, (2) Rail (welded/jointed and rail section), (3) Ties (tie material and fastener), (4) Grades, (5) Curves, (6) Road crossing locations, (7) Line speeds and speed changes, (8) Tonnage, (9) Bridge locations and type, (10) Turnout and signal locations, (11) Gang and track work records, (12) Track Geometry Data, (13) Previous thermal incident records, (14) Rail adjustment reports, and (15) NOAA maximum ambient temperature data.

**Segmentation Process** A key initial step in the analysis is the segmentation of the track into uniform homogeneous segments, for which a buckling risk index is calculated. To obtain these homogeneous analysis segments, subdivisions are segmented based on curves/tangent, rail section, bolted or welded rail, tie/fastener type, and grade changes. Optimally buckling risk segments are in the range of 0.1 to 0.2 miles, and any segments generated larger than 0.25 miles are reduced accordingly. The model’s segmentation routine was run on the entire BNSF system (24,200 track miles), and generated 133,012 segments, with an average segment length of 0.18 miles.
For each of these segments, the following post segmentation data is collected from the indicated BNSF and external databases and assigned to the segment:

- % Grade and Grade Reversals
- Freight Speed and Speed Changes
- Grade Crossing locations
  - Includes county and state, used to obtain maximum ambient temperature from NOAA data
- Bridges, Turnouts, and Signal locations
- DARS (Large Production Type Work)
  - Ballast Work: Cleaning, Surfacing, Undercutting
  - Last Rail Production Gang
  - Last Tie Production Gang
- PARS (Planning and Activity Reporting System)
  - Rail Destress or Rail Adjustments
  - Field Welds, Rail Repairs, Rail Installations at Division Levels (noting cold weather work)
  - Ballast Work: Cleaning, Surfacing, Undercutting
- Rail Adjustment Reports (includes amount of rail added or removed)
- Latest Thermal Incident Reports
  - Derailments, Buckles, Thermal Misalignments, Tight Rail
- Annual Tonnage
- Track Geometry
  - Maximum surface defect
  - Maximum alignment defect
• Maximum Ambient Temperature (NOAA)
• BNSF TNT (Target Neutral Temperature)

After the entire system is segmented, the risk factors shown in Appendix A are applied and the buckling risk index value calculated for each individual segment. Segments exceeding the “very high risk” threshold of 80 were immediately given to BNSF engineering department for investigation.

BNSF System Results and Actions  In anticipation of the 2004 hot weather season, the buckling risk model was run for the entire BNSF system in February 2004. The risk analysis performed on the 24,200 miles of mainline track (133,012 buckling risk segments) identified 30 segments (0.02% of system) considered very high risk with index values greater than 80 and an additional 961 segments (0.72% of system) considered high buckling risk with index values of between 70 and 79. The 30 very high-risk segments were given directly to the BNSF engineering department and underwent immediate inspection by local forces. As a result of these follow up inspections, 10 of the 30 segments were destressed (in March-April 2004). In mid-May a new data upload was conducted which included an improved rail adjustment report outlining specific amounts of rail added in all winter work as well as all recent rail removals (destressing). The buckling risk analysis was then re-run to ensure that all previously identified “very high risk” sites were now below the threshold of 80. Through field verification of the segment specific data, and subsequent BNSF remedial actions, all 30 segments were brought below the very high-risk threshold. Thus the model showed the ability to identify locations with high buckling potential and allowed for preventative measures before the onset of hot weather.
SUMMARY

The methodology presented in this paper uses a defined set of track buckling risk factors to calculate track-buckling risk on a site-specific basis. These risk values are then compared to predefined risk thresholds to determine which are real buckling risks and what action should be taken.

In a phased application of this methodology to selected BNSF track sites, representing a total of approximately 170 track miles, plus an additional 54 specific buckling incident sites, the buckling risk analysis methodology was calibrated and validated to BNSF conditions and practices. The resulting analytical approach was able to successfully identify sites with high potential buckling risk, as verified by the local roadmasters or by actual buckling incidents as reported by BNSF. It also generated a “reasonable” number of high-risk segments and thus showed that it would not generate an excessive maintenance burden on local track forces. As a result, it was determined that there was reasonable correlation between the calculated high buckling risk values and actual experience or field observation.

Based on these results, preliminary buckling risk thresholds were identified as follows:

- Very High Buckling Risk: $\geq 80$
- High Buckling Risk $\geq 70$

A full system application on 24,200 miles of BNSF track, with 133,000 buckling risk segments, was performed using the ZETA-TECH buckling risk computer model. The results of identified 30 segments (0.02% of system) as very high risk and an additional 961 segments (0.72% of system) as high buckling risk. Follow up investigation of the 30 very high-risk segments by the BNSF engineering department resulted in the destressing of 10 of the segments.
Thus the results of this study show that this methodology can be applied on a consistent basis to identify potential buckling risk sites without placing an undue maintenance burden on MoW personnel. The computerization of the methodology allows for ease of application and permits frequent data uploads and calculation of up-to-date buckling risk indices.

Acknowledgement

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References


2. BNSF Engineering Instructions


**Figures and Tables**

**FIGURE 1** BNSF System Target Rail Laying Temperatures

**TABLE 1** Sample Risk Factors

**TABLE 2** Summary of the Calculated Risk Factors

**TABLE 3** Summary of the Calculated Risk Values

**TABLE 4** Summary of Risk Sites

**TABLE 5** Recommended Action Items as a Function of Risk

**APPENDIX A**. Buckling Risk Factors
FIGURE 1. BNSF System Target Rail Laying Temperatures.
**TABLE 1: Sample Risk Factors**

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<td>Elastic</td>
<td>-5</td>
</tr>
<tr>
<td>Concrete</td>
<td>Pandrol</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Safelock</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Anchoring</th>
<th>Risk Factor</th>
<th>Risk Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOTA</td>
<td>Tight</td>
<td>0</td>
</tr>
<tr>
<td>Every Tie</td>
<td>Tight</td>
<td>-3</td>
</tr>
<tr>
<td>Every Tie</td>
<td>Loose</td>
<td>0</td>
</tr>
<tr>
<td>EOTA</td>
<td>Loose</td>
<td>3</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Ballast Crib</th>
<th>Risk Factor</th>
<th>Risk Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>¾</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Half</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shoulder Width (inches)</th>
<th>Risk Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>-1</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rail Maintenance Activities</th>
<th>Risk Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undisturbed Track</td>
<td>0</td>
</tr>
<tr>
<td>Disturbed-Stabilized</td>
<td>10</td>
</tr>
<tr>
<td>Disturbed &gt;5 MGT</td>
<td>5</td>
</tr>
<tr>
<td>Disturbed &gt;1 MGT</td>
<td>10</td>
</tr>
<tr>
<td>Disturbed &lt;1 MGT</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time since last rail adjustment (distressed)</th>
<th>Risk Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within last year</td>
<td>-5</td>
</tr>
<tr>
<td>1-5 years</td>
<td>0</td>
</tr>
<tr>
<td>&gt;5 years</td>
<td>5</td>
</tr>
</tbody>
</table>
### TABLE 2: Summary of the Calculated Risk Factors

<table>
<thead>
<tr>
<th>Total Segments</th>
<th>Orin</th>
<th>Galveston</th>
<th>Needles</th>
<th>Hi Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;=70</td>
<td>42</td>
<td>36</td>
<td>54</td>
<td>48</td>
</tr>
<tr>
<td>65-69</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>60-64</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>55-59</td>
<td>2</td>
<td>6</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>50-54</td>
<td>10</td>
<td>8</td>
<td>13</td>
<td>9</td>
</tr>
<tr>
<td>&lt;=49</td>
<td>9</td>
<td>9</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>12</td>
<td>11</td>
<td>0</td>
</tr>
</tbody>
</table>
### TABLE 3: Summary of the Calculated Risk Values

<table>
<thead>
<tr>
<th>Risk Factor Range</th>
<th>Number of Segments</th>
<th>%</th>
<th>Cum %</th>
</tr>
</thead>
<tbody>
<tr>
<td>95.99</td>
<td>2</td>
<td>3.7%</td>
<td>3.7%</td>
</tr>
<tr>
<td>90.94</td>
<td>4</td>
<td>7.4%</td>
<td>11.1%</td>
</tr>
<tr>
<td>85.89</td>
<td>1</td>
<td>1.9%</td>
<td>13.0%</td>
</tr>
<tr>
<td>80.84</td>
<td>7</td>
<td>13.0%</td>
<td>25.9%</td>
</tr>
<tr>
<td>75.79</td>
<td>7</td>
<td>13.0%</td>
<td>38.9%</td>
</tr>
<tr>
<td>70.74</td>
<td>4</td>
<td>7.4%</td>
<td>46.3%</td>
</tr>
<tr>
<td>65.69</td>
<td>12</td>
<td>22.2%</td>
<td>68.5%</td>
</tr>
<tr>
<td>60.64</td>
<td>8</td>
<td>14.8%</td>
<td>83.3%</td>
</tr>
<tr>
<td>55.59</td>
<td>6</td>
<td>11.1%</td>
<td>94.4%</td>
</tr>
<tr>
<td>50.54</td>
<td>3</td>
<td>5.6%</td>
<td>100.0%</td>
</tr>
<tr>
<td>&lt;=49</td>
<td>0</td>
<td>0.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Total Segments 54
### TABLE 4: Summary of Risk Sites

<table>
<thead>
<tr>
<th>Segments</th>
<th>Milk River</th>
<th>Twin Peaks</th>
<th>Birmingham</th>
<th>Cajon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>150</td>
<td>125</td>
<td>250</td>
<td>125</td>
</tr>
<tr>
<td>Segments 80-89</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Segments 70-79</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Segments 60-69</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Segments 50-59</td>
<td>5</td>
<td>18</td>
<td>27</td>
<td>11</td>
</tr>
<tr>
<td>Segments 40-49</td>
<td>30</td>
<td>66</td>
<td>76</td>
<td>46</td>
</tr>
<tr>
<td>Segments 30-39</td>
<td>76</td>
<td>36</td>
<td>131</td>
<td>46</td>
</tr>
<tr>
<td>Segments 20-29</td>
<td>38</td>
<td>0</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Risk</td>
<td>Action</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;70</td>
<td>Have field forces obtain up-to-date input data, and rerun the risk assessment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;70</td>
<td>Increase heat inspection frequency (rail temperature &gt; TNT)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;70</td>
<td>Avoid maintenance during hot weather (rail temperature &gt; TNT)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;80</td>
<td>Slow order the track when rail temperature &gt; TNT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;80</td>
<td>Consider risk reduction (installing additional anchors and tightening, increase ballast shoulder width, realigning track when rail temperature below TNT.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;90</td>
<td>Destress and raise neutral temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix A. Buckling Risk Factors

**Supplemental Risk Factors** (add/subtract to Base Risk)

<table>
<thead>
<tr>
<th>Shoulder Width (inches)</th>
<th>15</th>
<th>12</th>
<th>6</th>
<th>3</th>
</tr>
</thead>
</table>

**Rail Maintenance Activities**
- Undisturbed Track
- Disturbed-Stabilized
- Disturbed >5 MGT
- Disturbed >1 MGT
- Disturbed <1 MGT

**Inspection Reports**
- No Movement
- Rail Movement

**History of Buckles**
- No buckle ever
- Previous buckle but not in last 2 years
- Buckle within last 2 years

**Time since last rail adjustment (distressed)**
- Within last year
- 1-5 years
- >5 years

**Recent Rail Repairs (Thermite Welds)**
- None
- 1
- 2
- ≥3
- Cold weather plug installed (without adjustment)

**Jointed Rail**
Track Geometry
Largest Alignment Defect in Segment (inches)
0
1
2
3

Largest Surface or Cross-Level Defect in Segment (inches)
0
1
2
3

If Track Geometry Data is NOT Available use the Class of Track as an Alternative

Track Class
2
3
4
5

% Grade

Grade Limited Braking
0
1
2
3

Grade* Heavy Braking
>0
1
2
3

Heavy MGT Reduction
Light MGT Reduction

Locomotive Braking with Hard Spots (not on grade)
Heavy Braking with Hard Spot**
Limited Braking with Hard Spot**
**Grade Crossing, open deck bridge, turnout
Curvature
Degree 1 2 3 5 >=7
<table>
<thead>
<tr>
<th>Track Structure</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail Size</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>136</td>
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<tr>
<td></td>
<td>132</td>
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<tr>
<td></td>
<td>119</td>
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<tr>
<td></td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Tie Type</td>
<td></td>
</tr>
<tr>
<td>Wood</td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td></td>
</tr>
<tr>
<td>Tie Spacing</td>
<td></td>
</tr>
<tr>
<td>Wood</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>22</td>
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<tr>
<td></td>
<td>24</td>
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<tr>
<td></td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>28</td>
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<tr>
<td>Fastener Type</td>
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<tr>
<td>Wood</td>
<td>Cut Spike</td>
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<td></td>
<td>Elastic</td>
</tr>
<tr>
<td>Concrete</td>
<td>Pandrol</td>
</tr>
<tr>
<td></td>
<td>Safelock</td>
</tr>
<tr>
<td>Anchoring</td>
<td>EOTA Tight</td>
</tr>
<tr>
<td></td>
<td>Every Tie Tight</td>
</tr>
<tr>
<td></td>
<td>Every Tie Loose</td>
</tr>
<tr>
<td></td>
<td>EOTA Loose</td>
</tr>
<tr>
<td>Rail Seat Abrasion (concrete ties only)</td>
<td></td>
</tr>
<tr>
<td>Ballast</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Marginal</td>
</tr>
<tr>
<td></td>
<td>Poor</td>
</tr>
<tr>
<td>Ballast Cribs</td>
<td>Full</td>
</tr>
<tr>
<td></td>
<td>3/4</td>
</tr>
<tr>
<td></td>
<td>Half</td>
</tr>
</tbody>
</table>