Effects of Maintenance Operations on Track Buckling Potential

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Summary: This paper presents the results of buckling analyses based on data from recent tests determining the influence of track maintenance and consolidation on track lateral resistance. The buckling analyses were performed using the USDOT/Volpe "CWR-SAFE" model to determine the critical temperatures and probability of buckling risk envelopes for several track conditions and parameters. The results of the analyses are presented in buckling advisory tables indicating track buckling potential at elevated temperatures for pre-maintenance, post-maintenance, and post-stabilization lateral resistance conditions for various alignment defects, neutral temperatures, and track curvatures.

Index Terms: track buckling, lateral resistance, track stabilization, concrete tie lateral resistance testing

INTRODUCTION

Continuous welded rail (CWR) is replacing jointed track for the advantages of better economics of maintenance and enhanced ride comfort. A well-known risk with CWR, however, is its potential for buckling due to high thermally induced compressive loads, with possible train derailment consequences. CWR is typically installed in the range of 90° to 110°F, but this initial stress-free (sometimes referred to as neutral) temperature can subsequently come down to 50° to 70°F due to a variety of causes including rail/track movement and rail cutting/repair. On a hot summer day, the rail temperature can reach values in the range of 140° to 160°F, depending on the geographic location. The resulting compressive loads, coupled with weakened track conditions can result in track buckling. The weakened track conditions typically are due to track lateral alignment deviations, and to a reduced track lateral resistance. Hence the three key parameters influencing track buckling are the rail force (or neutral temperature variation), alignment defects, and the track lateral resistance. In this paper the effects of these parameters on track buckling will be addressed with an emphasis on the influence of track lateral resistance as it varies with maintenance.

Railroad maintenance practices that help mitigate the development of buckling prone conditions include CWR installation, welding, and repair practices that help maintain a high rail neutral temperature (the temperature at which the net longitudinal force in the rail is zero). Railroads also typically employ track stabilization following ballast disturbance such as surfacing, realignment, or ballast renewal to help restore lost lateral resistance. Figure 1 illustrates typical lateral resistance values after surfacing and after stabilization referenced to an initial consolidated condition. The lateral resistance is given in terms of the load required to move a tie laterally in the ballast to a peak load value.

Track maintenance involving the ballast (such as surfacing, lining, tie renewal, etc.,) can typically result in 40 to 60% loss of lateral resistance (Δ_1 in Figure 1) leaving the track in a potentially buckling prone condition at high rail temperatures. It is expected that track consolidation either via traffic or dynamic stabilization will restore up to 60 – 80% of the original resistance (as shown by Δ_2), which is considered by most railway properties to provide adequate restraint against track buckling under most conditions (exceptions being improperly destressed track with poor lateral alignment). An important aspect for buckling safety is the *absolute value* of the resistance after consolidation since (together with other key track parameters) it determines the track's buckling strength in terms of the temperature at which buckling takes place referred to as the critical buckling temperature. The determination of Δ_2 and its impact on the track's buckling potential thus becomes a key aspect of CWR safety and performance evaluation.

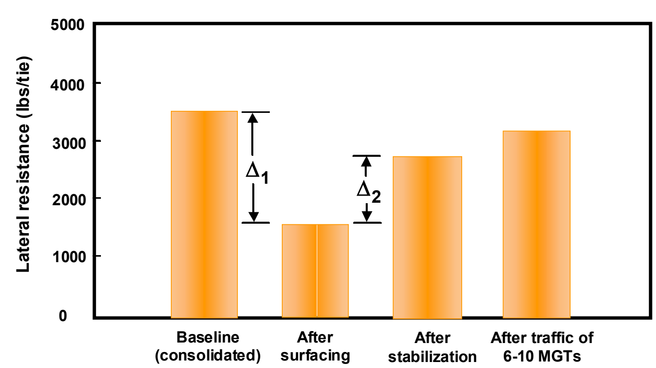

Figure 1 - Typical lateral resistances after surfacing and consolidation

The principal focus of the analysis reported herein is the determination of the critical buckling temperatures based on the measured values of the surfaced and consolidated resistances obtained through dynamic track stabilization, or with the application of a specified traffic tonnage. Lateral resistance tests were conducted on a concrete tie track segment on the Northeast Corridor (NEC) in New Carrollton, MD in August of 2001. Lateral track resistance was measured using the Single Tie Push Test (STPT) technique, which moves the tie laterally in the ballast through an applied lateral load, and records the applied load versus tie deflection. The key test conditions/parameters included were: lateral resistance measurements before maintenance, after surfacing, and after dynamic stabilization at different speeds. For the details of the test conduct, measurements, and results refer to [1].

This paper describes the analysis performed with the measured data using the Volpe Center CWR-SAFE model to determine critical buckling temperatures and temperature regimes in which the buckling probability is no longer minimal. In addition to the measured values of track lateral resistance, other key parameters of rail neutral temperature, lateral alignment defect condition and track curvature are also included in the analysis.

TRACK LATERAL STABILITY FUNDAMENTALS

Track lateral stability failure is generally characterized by two failure modes: track shift and track buckling. Track shift typically deals with the creation and growth of lateral alignment defects due to high net-axle lateral loads and is not covered in this paper, but is described in [2]. Track buckling is a suddenly occurring large deflection (snap-through) type instability phenomenon. The main factors influencing track buckling are the rail longitudinal force (largely influenced by the rail's neutral temperature), track lateral resistance (especially as influenced by maintenance activities such as surfacing, realignment and tie renewal), and the track's lateral alignment condition. For a detailed description of track buckling, its mechanics, parametric behavior, and relevant safety concepts and criteria, refer to [3]. Recent advances in the theoretical aspects of track buckling include risk based (probabilistic) predictions which employ the use of the *statistical distributions* of the three governing parameters of lateral resistance, rail neutral temperature and alignment defects to evaluate the probability of buckling. These probabilities then can be used to develop risk-based strategies, including slow orders, to mitigate track buckling potential [4]. A comprehensive modeling capability for track buckling evaluation is available in a program called CWR-SAFE [5], which is currently being updated for a final version release.

CWR-SAFE AND ITS APPLICATION

The safety implications of the lateral resistance data obtained at this recent joint Amtrak/FRA test on the NEC were evaluated using the Volpe buckling safety analysis software CWR-SAFE to determine the track's buckling potential. The software, through three separate analysis modules, performs both deterministic and probabilistic buckling analyses. These consist of determining the *"allowable temperature increase"* for buckling prevention, performing safety analysis to determine the buckling safety margin, and evaluating the probability of buckling as a function of the rail's temperature. Embedded in the software is a track quality based safety criterion which enables the determination of the *"allowable temperature increase"* or the safe temperatures for buckling prevention based on the minimum point or T_{bmin} on the stability curve as schematically indicated on Figure 2 below and described in [3].

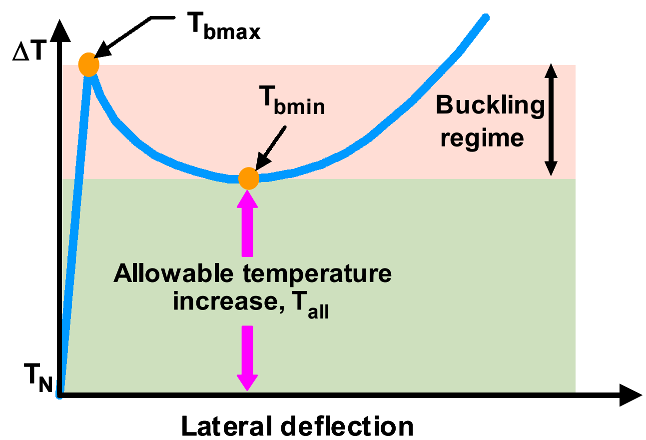

Figure 2 – Buckling stability curve and safe temperature concept illustration

For the buckling safety assessment performed for this study, the probabilistic module of CWR-SAFE was utilized to determine "critical temperatures" and "probability of buckling versus rail temperature" risk envelopes as schematically illustrated in Figure 3.

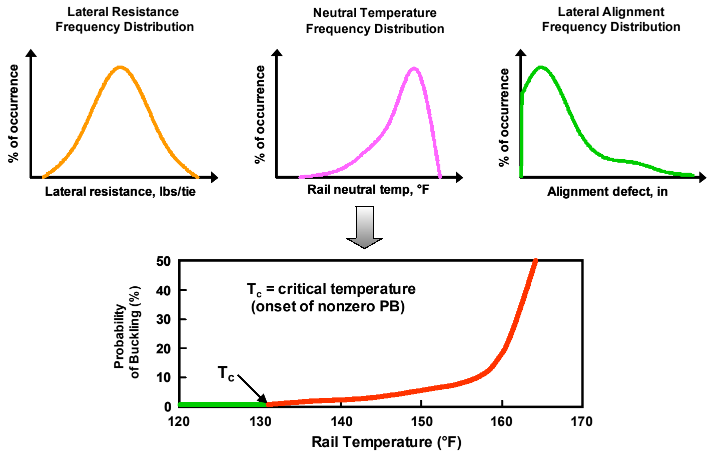

Figure 3 – CWR-SAFE risk analysis illustration

As indicated in the upper part of Figure 3, the three driving parameters for this model are the variable (statistical) distributions of the lateral resistance, rail neutral temperature, and lateral alignment parameters over the line segment being analyzed. For the analysis of a typical line segment, an adequate number of measurements are required for each of the three parameters to adequately describe the variations, and hence to construct the required input distributions. These statistical input parameters allow for the probabilistic description of buckling potential in terms of probability of buckling versus rail temperature as indicated in the lower part of the figure. Other site-specific parameters such as rail size, track curvature, fastener resistance, vehicle type, etc., are prescribed by single valued inputs to the model. Computationally, for all combinations of the frequency distributions and a rail temperature, the model determines if a buckle occurs or not, and thus creates a probability of buckling percentage. The critical temperature, T_c on Figure 3, is defined as that temperature beyond which a finite probability of buckling exists (i.e. no buckling occurs below T_c, hence this temperature is construed to be a "safe" value). For numerical computational purposes, T_c is determined as the 10^{-6} probability value. Beyond this temperature the buckling probability increases initially at a slow rate with the rail's temperature, and subsequently at a fast rate (beyond the "knee" in the curve). It can be shown that the T_c value depends on the "weak" ends of the input distributions, while the slope and shape of the buckling probability curve depends on the "content" i.e. the spread of the three distributions.

ANALYSIS AND SAFETY IMPLICATIONS

For the lateral resistance distribution, the actual measured data over the New Carrollton test line in accordance with the statistics of Figure 4 were used. It should be noted that the post-maintenance condition reflects a routine Amtrak surfacing operation (up to 10mm lift), the dynamic track stabilization (DTS) operation reflects stabilization performed using the Plasser-Theurer Dynamic Track Stabilizer operating at speeds of 0.7, 1.5, and 2.0 mph, and the post-traffic condition represents 12 passes over the surfaced track segment with an Amtrak AEM7 locomotive and 3 MARC passenger cars (approximately 3360 tons) at speeds up to 20mph. For this study, for the Post – DTS condition, the three DTS speed results were lumped together since there was no appreciable speed effect measured [1].

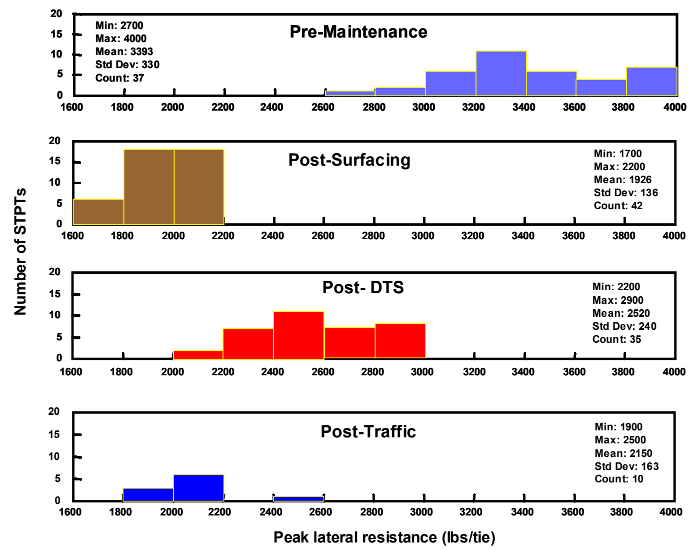

Figure 4 – New Carrollton STPT Data statistics

For the rail's neutral temperature (RNT) condition two *assumed* distributions were used as shown in Figure 5 below,

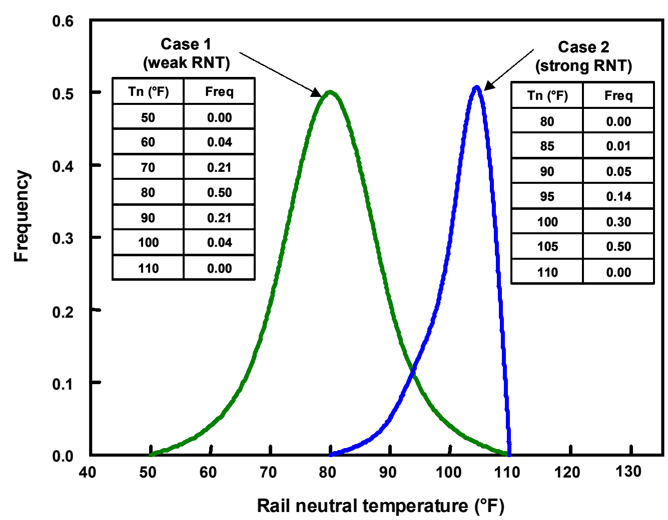

Figure 5 – Assumed rail neutral temperature (RNT) distribution for analysis

one representing a relatively low or "weak" RNT condition, while the other represents a desired high or "strong" RNT condition. As can be seen from the table part of the figure, the "weak" case depicts a track segment where the lowest RNT found was 60°F, whereas for the "strong" case the lowest RNT found was 85°F. The upper end of the curves (between 90°F and 110°F) represent typical installation temperatures, hence the "weak" case shows a large variation from initial installation conditions, while the "strong" case shows a small variation. To simulate the test section's Class 4 track alignment condition, the distribution shown in Figure 6 was used which exhibit some locations with the Class 4 alignment limit of 1.5 inches. Such alignment data can be obtained from the track geometry car surveys.

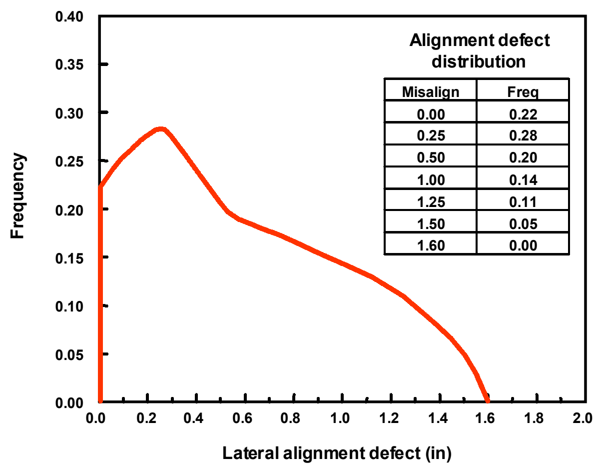

Figure 6 – Assumed Class 4 alignment defect distributions for analysis

Using these input parameters (together with the other site specific parameters) for both a tangent and a 5° curve track in CWR-SAFE, the results shown in Figures 7a and 7b are obtained. (Note the assumption that the lateral resistance test data obtained on the New Carrollton tangent track is applicable to the 5° curve case, as well. This may not be valid if a curve's superelevation has an influence on the compaction mechanics).

These figures depict the relationship between the buckling probability as a function of rail temperature and show the buckling safety implications of track maintenance as influenced by lateral resistance, rail neutral temperature condition, and track curvature. The T_c values (i.e. rail temperature above which buckling can occur) shown on Figure 7 are summarized in Table 1 below.

Table 1 – Critical temperature summary

	Critical temperature, T_C (°F)			
	Tangent		5° curve	
	Weak RNT	Strong RNT	Weak RNT	Strong RNT
Pre-maintenance	142	168	132	158
Post-surfacing	134	160	110	136
Post-DTS	138	162	120	146

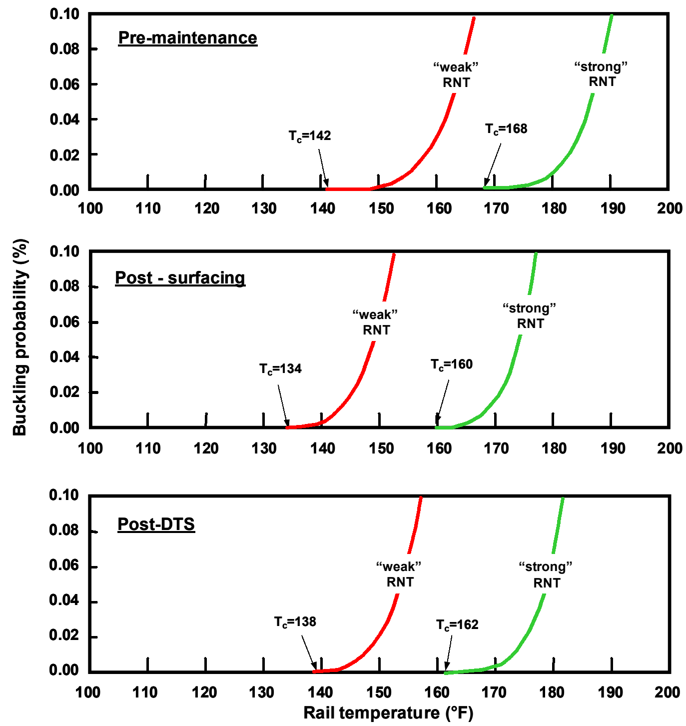

Figure 7a – Buckling probability vs. rail temperature for "weak" and "strong" neutral temperature distributions and Class 4 line defects (tangent)

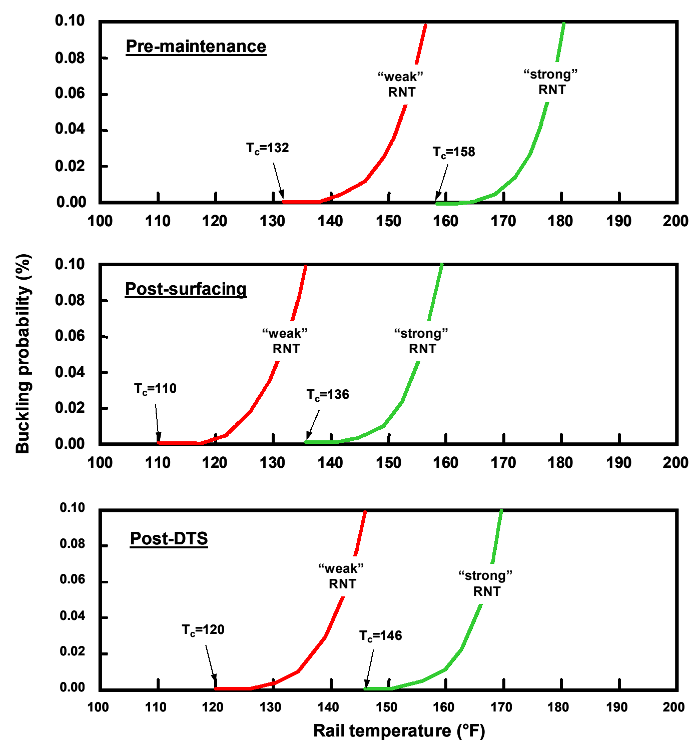

Figure 7b – Buckling probability vs. rail temperature for "weak" and "strong" neutral temperature distributions and Class 4 line defects (5° curve)

For example, for the measured lateral resistance values and assumed RNT and Class 4 line defect distributions, the critical temperatures for the tangent track are 138° and 162° F for "weak" versus "strong" RNT's respectively after stabilization. These numbers imply "*adequate*" buckling safety since summer rail temperatures usually do not exceed 138°F. (Should the rail temperatures exceed 138°F, the probability of buckling beyond this temperature will be as depicted by Figure 7a). For the 5° curve case, however, the corresponding T_c values are 120°F and 146°F, indicating a possible buckling condition for the "weak" RNT case since summer rail temperatures can reach or exceed 120°F.

Based on similar analysis performed for the case of a Class 6 line defect condition, the T_c values for the "weak" RNT case after the stabilization are 147°F and 137°F for the tangent and 5° curve respectively (as compared to the 138°F and 120°F Class 4 line defect values), showing the beneficial influence of the "better" (smaller amplitude Class 6) line defect condition. These T_c values are again high enough so that buckling should not occur since summer rail temperatures are not expected to exceed these values.

It is important to note that in addition to influencing T_c, track lateral resistance also influences the buckling probability beyond T_c, i.e. the shape (slope) of risk envelopes beyond T_c (see Figure 7a for example) is important in assessing the track's buckling potential. Whereas a 10° F increase in rail temperature over a pre-maintained (high resistance) track's T_c shows a very small buckling potential increase, a 10° F increase over the surfaced (low resistance) track's T_c has a 4% buckling probability due to the curve's steeper slope. This 4% buckling probability may be prohibitive in terms of risk acceptance.

In general, the analysis results reinforced the importance of the four key track parameters influencing the track's buckling potential: track lateral resistance, rail neutral temperature, lateral alignment, and track curvature. Dynamic stabilization did restore track lateral strength to produce desired levels of buckling safety for tangent tracks with Class 4 misalignments, even when weakened neutral temperature conditions were postulated. A 5° curve track, however, is potentially vulnerable to track buckling for the same conditions.

These analysis results were used to compile the *"buckling advisory"* summary charts shown in Tables 2a and 2b below in terms of buckling potential for the several conditions and scenarios. The temperatures in parentheses represent critical temperatures (i.e. rail temperatures beyond which a finite buckling probability exists) for those conditions. All the "No" entries represent "no buckling potential" (indicating critical buckling temperatures in excess of 140°F). The "Minimal" entries denote marginal buckling potential (indicating critical temperatures between 130°F to 140°F), and the buckling prone conditions are indicated by the "Yes" entries since the critical temperatures fall into rail temperature regimes attainable during summer days. The 5° curve, Class 4, weak RNT, post-surfacing, post stabilized and post-traffic cases fall into this category. It is also instructive to note from Table 2 that for the "strong RNT" case nearly all conditions exhibit no buckling potential, with the two exceptions being cases giving a critical temperature of 136°F.

Table 2a - Buckling Advisory Based on Measured Data and Analysis for Pre and Post Surfacing Conditions

Buckling Advisory									
Buckling potential	Rail Neutral Temperature (RNT)	Pre - Maintenance				Post - Surfacing			
		Tan		5°		Tan		5°	
		Class 4	Class 6	Class 4	Class 6	Class 4	Class 6	Class 4	Class 6
	Weak *(RNT_{min} = 60°F)*	No	No	Minimal (132°F)	No	Minimal (134°F)	No	Yes (110°F)	Minimal (133°F)
	Strong *(RNT_{min} = 85°F)*	No	No	No	No	No	No	Minimal (136°F)	No

Table 2b - Buckling advisory based on measured data analysis for post DTS and post traffic conditions

Buckling Advisory									
Buckling potential	Rail Neutral Temperature (RNT)	Post - DTS				Post – Traffic (12 train passes)			
		Tan		5°		Tan		5°	
		Class 4	Class 6	Class 4	Class 6	Class 4	Class 6	Class 4	Class 6
	Weak *(RNT_{min} = 60°F)*	Minimal (138°F)	No	Yes (120°F)	Minimal (137°F)	Minimal (136°F)	No	Yes (117°F)	Minimal (136°F)
	Strong *(RNT_{min} = 85°F)*	No	No	No	No	No	No	Minimal (136°F)	No

SUMMARY AND CONCLUSIONS

Tests were conducted to evaluate the variation of concrete tie track lateral resistance during routine track surfacing maintenance on the Northeast Corridor followed by consolidation through either dynamic track stabilization or train traffic. A part of the tests results are shown in Figure 4, and a complete test description is available in [1].

The measured lateral resistance data was used with the Volpe CWR-SAFE model to evaluate the potential for track buckling. Model study results (with some assumptions on neutral temperature and lateral alignment variations) indicate that after dynamic track stabilization, tangent concrete tie track exhibits a low risk of buckling potential.

In territory with relatively high curvatures (a 5 degree curve was used in the analysis), the critical buckling temperatures are in the range of rail temperatures that could be realized on hot summer days, raising a possible track buckling concern. This concern exists for Class 4 tracks after surfacing and even after stabilization if neutral temperatures are low (such as 60°F as used in the analysis). If the neutral temperatures are high (85°F or higher), there should be no buckling concerns, nor when the track is maintained to Class 6 alignment limits. Analysis results also reinforced the importance of the four key track parameters influencing the track's buckling potential, namely, track lateral resistance, rail neutral temperature, lateral alignment defect, and track curvature. Knowledge and application of these parameters for buckling safety evaluations is paramount; the lateral resistance data generated as part of this test for this analysis is an important part of filling this knowledge gap.

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