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# Improving Lateral Track Buckling Safety Margins

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## Summary

A computational finite element model has been developed by the Association of American Railroads' (AAR) Affiliated Laboratory at Texas A&M University (TAMU) for the purpose of enhancing the ability to predict and prevent the onset of lateral track buckling in railway structures.

Attempts to model this phenomenon date back almost a century.[1] The current state of practice on track maintenance uses a previously developed model,[2-4] together with information about the state of the track (such as rail neutral temperature) to assess the likelihood of lateral buckling in the rails.[5,6] Because some of the track information required to use this model is not well known, the previous model did not always provide a precise prediction. The current research attempts to account for some track information that was heretofore difficult to measure, but may now be measurable with such state-of-the-art devices as machine vision, thereby leading to improved accuracy in predicting the onset of track buckling.

The intent of the newly deployed computational model is to provide a more consistent margin of safety. The computational robustness contained within the model allows greater emphasis to be placed on predicting resistance of the track structure to lateral buckling as a function of: (1) nonlinear crosstie-ballast friction, (2) track residual displacements, and (3) longitudinal and rotational resistance due to rail fasteners and anchors. The results of this research indicate that it may be possible in the future to monitor these track properties as functions of track tonnage in order to better plan track maintenance and/or replacement.

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## INTRODUCTION

A computational algorithm has been developed for the purpose of possibly improving current practices for avoiding track buckling. This newly developed algorithm has the capability of predicting the effects of nonlinear and tonnage dependent crosstie-ballast friction, as well as track connection methodology, on track buckling.

When railways were first introduced in the early nineteenth century it was commonplace to connect discontinuous rails with a bolted joint. However, the discontinuity at the rail ends resulted both in reduced ride quality and rapid degradation of the rail head at the joints. As a result, rail butt welding (originally developed in Germany in the late nineteenth century) eventually overtook bolted joints, with the first butt welding rails deployed within the United States in 1930. Once these "continuous" rails became commonplace, it became apparent that a different problem emerged – track buckling. And for a time track buckling was a common cause of derailments across the United States. However, beginning with research by Stephen Timoshenko in the 1920s,[1] considerable effort has been expended in avoiding this problem within the rail industry. Most notably, the theoretical work of Arnold Kerr[2,3] has helped to mitigate track buckling considerably in recent times. Using the model developed by Kerr, Andrew Kish, and coworkers at the U.S. DOT Volpe Laboratory have developed guidelines that have substantially reduced derailments due to lateral buckling of rails.[5,6] Their approach uses an approximate analytic solution obtained by Grissom and Kerr[4] in which certain simplifications were made in the model in order to obtain an analytic solution. However, recent improvements in computer capacities have made it possible to obtain more accurate computational solutions using Kerr's model that account for the effects of: (1) nonlinear ballast-crosstie friction, (2) residual lateral track deformations, and (3) the effects of various rail-to-tie fastening systems and anchors.

Accordingly, the author was engaged by TTCI to encode Kerr's previously developed theoretical model for predicting track buckling (using the finite element method) to construct an algorithm that is both robust in the sense that it accounts for the above physical effects, and simple enough to be deployed via an app on a hand-held device. The resulting tool is intended to be usable by engineers in the field to make on-the-spot assessments regarding when and where intervention is required to avoid track buckling, the intention being to provide a consistent margin of safety.

### Track Buckling Model

The track buckling model developed by Kerr proceeds from a free body diagram of a single rail (Figure 1), as shown in Figure 2.

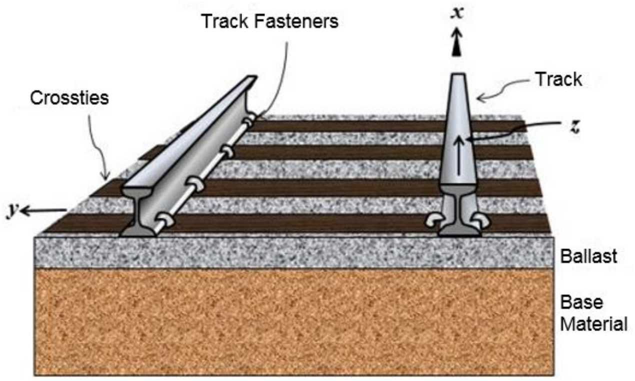

**Figure 1. Depiction of a Typical Track Structure showing Coordinate System Employed in the Model**

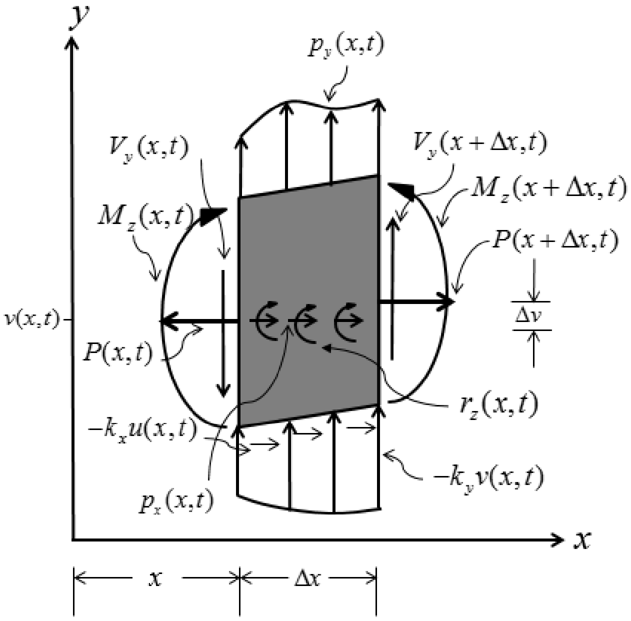

**Figure 2. Free Body Diagram of Forces and Moments Applied to a Differential Element of the Rail**

Employing Newton's laws to the free body diagram shown in Figure 2 results in a set of coupled nonlinear differential equations that can be cast into a finite element formulation describing buckling of the rail in terms of the following input quantities:[7,8]

$I_{zz}$ is twice the moment of inertia of the rail

$A$ is twice the cross-sectional area of the rail α is the coefficient of thermal expansion of the rail

$E$ is the modulus of elasticity of the rail

$k_x$ is the axial coefficient of friction due to both crosstie-ballast interfacing and rail anchoring

$k_y$ is the lateral friction due to crosstie-ballast interfacing

$r_z$ is the rotational resistance per unit length due to rail-to-tie fasteners and rail anchors.

$p_x$ is the externally applied force per unit length in the axial direction

$p_y$ is the externally applied lateral force per unit length.

In addition, $P$, $V_y$, and $M_z$ are the internal force, shear, and bending moment that result from solving the set of differential equations using the finite element algorithm. They are used to obtain the resulting axial and lateral displacement components, $u$ and v, respectively, thereby resulting in the prediction of buckling as a function of the above inputs. Although not described here, the model also accounts for track residual displacements and initial track curvature.

The resulting model has been rigorously debugged,[9] and results have been reported in the open literature.[10,11] In addition, special emphasis has been placed on the development of a phenomenological model for predicting the effects of long-term degradation of the crosstie-ballast interfacial friction due to the accumulation of track tonnage.[12] For example, Figure 3 shows a prediction of the Lateral Resistance of the track during cyclic loading compared to the results of a Single Tie Push Test.[12]

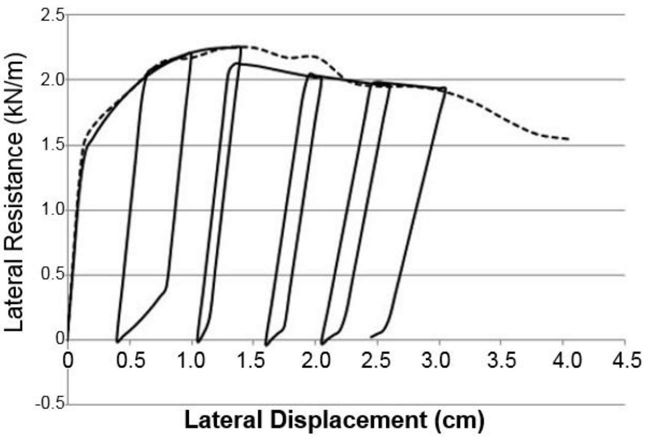

**Figure 3. Comparison of Crosstie Resistance Model to a Single Tie Push Test**

Because the model allows for nonlinear friction such as that shown in Figure 4, it is capable of making more accurate assessments than in previous analytic solutions, as shown in Figure 5, wherein it can be seen that using the initial value of the lateral crosstie-ballast friction predicts a buckling value that is too high, whereas using the final value of the lateral crosstie-ballast friction from Figure 5 results in a predicted buckling value that is too low.

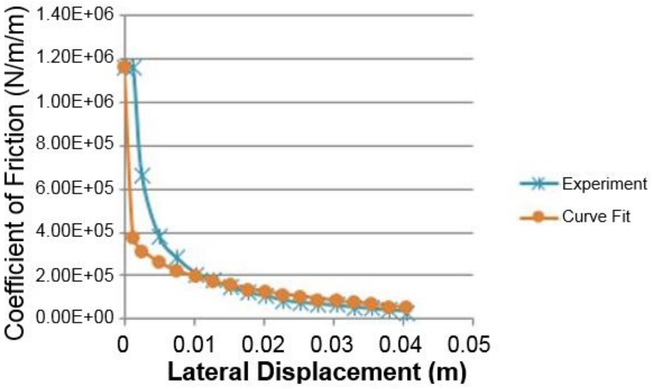

**Figure 4. Curve Fit of Crosstie-Ballast Coefficient of Lateral Friction to Actual Single Tie Push Test Data**

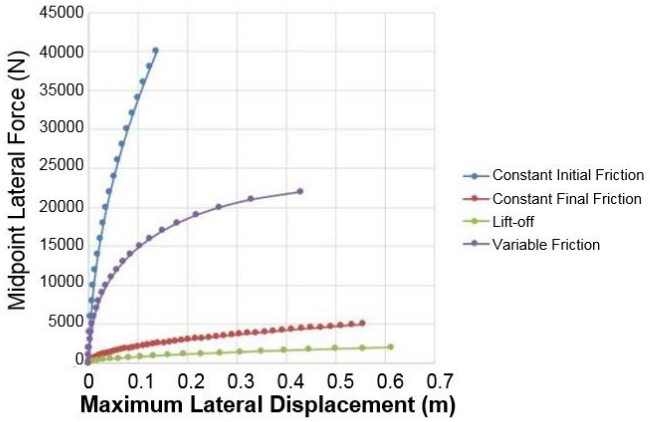

**Figure 5. Comparison of Predicted Buckling Loads Using Various Friction Coefficients Obtained from Figure 4**

As a final example, the effect of both axial and rotational spiking resistance is shown in Figure 6. It can be seen that, according to the model predictions, the form of rail-crosstie connection can have a profound effect on the resulting lateral buckling load.

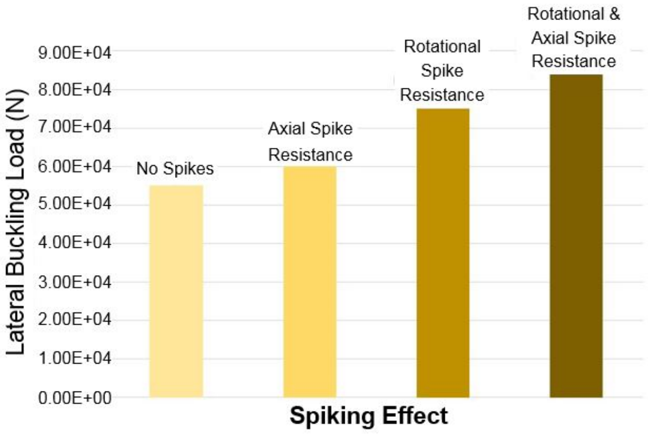

**Figure 6. Effect of Spiking Force on Predicted Lateral Buckling Load**

## CONCLUSION

A computational algorithm has been developed for the purpose of possibly improving current practices for avoiding track buckling. This newly developed algorithm has the capability of predicting the effects of nonlinear and tonnage dependent crosstie-ballast friction, as well as track connection methodology, on track buckling. However, in order for the model to be deployed within the field, it will be necessary to develop technology to accurately assess these properties in the field.

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