

SIMULATION OF RAIL ROLL AND TRACK BUCKLING USING LS-DYNA AND ANSA

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KEYWORDS – Rail Rollover, Rail Buckling, ANSA Scripting, Automation

ABSTRACT – Rail rollover and track buckling are not well-understood phenomena that continue to cause derailments each year costing the industry millions of dollars. Cost effective maintenance and design solutions are needed but up until now, there has been no systematic way to evaluate potential solutions or to understand the influence of contributing factors in a track incident. The many influencing factors such as track condition, track curvature, rail restraint, rail wheel interaction, rail wear, thermal stress and many other factors that contribute to rail rollover and track buckling have not been systematically and parametrically studied. Limitations due to simulation software capability, the cost of model creation and available computer power have historically hindered these efforts. Today's advanced simulation software along with the dramatic decrease in the cost of computational power has made doing such a study practical. Building such detailed and extensive track models have historically been labour intensive as well as computationally expensive. This paper will discuss the complete automation of the creation of a detailed three dimensional finite element model of a section of track that includes rail curvature, spikes, tie plates, ties, wheel rail interaction and ballast stiffness. An ANSA script accomplishes a complete modular and parametric model build. The wheelsets load the rail vertically and laterally. The application of thermal stress is optional. Preliminary findings are presented.

TECHNICAL PAPER –

1. INTRODUCTION

When a train derails, determining a primary cause of the derailment is required. Secondary contributing factors and the remedial actions necessary to protect against future incidents are also desired. The physical condition of the cars, bogies (trucks), and the track are investigated along with train handling to determine the cause(s) of derailment.

There are very good and cost effective means to study the dynamic interaction of track and car. Simulation codes such as VAMPIRE® do provide indications of derailment but do not model the detailed structure of the track needed to fully describe and characterize rail buckling or rail roll and their sensitivity to many important parameters. With today's advanced simulation software and relatively inexpensive computational power a detailed three dimensional study of track geometry and condition can be performed. The influence of track curvature, rail wear, tie condition, spike condition, ground support, wheel-rail interaction with respect to rail rollover and buckling can all be evaluated. A method to perform a cost effective evaluation of the influence on derailment of detailed three dimensional track geometry is presented.

ANSA provides many tools to speed the process of model building. ANSA also provides a scripting language to automate the model creation and to exploit a template to insure each generated model is consistent. An inexperienced ANSA user or LS-DYNA analyst can use the script.

2. RAILROAD TRACK BASE MODEL

The basic components of a railroad track: the tie, tieplate, spikes and ground support are repeated over and over in a complete model. Building a finite element model of the basic sub assembly is easy. Sweeping that sub assembly and updating every set, coordinate system and constraint requires an intelligent program, a script, or both to build the complete model efficiently. Figure 1 shows the basic model.

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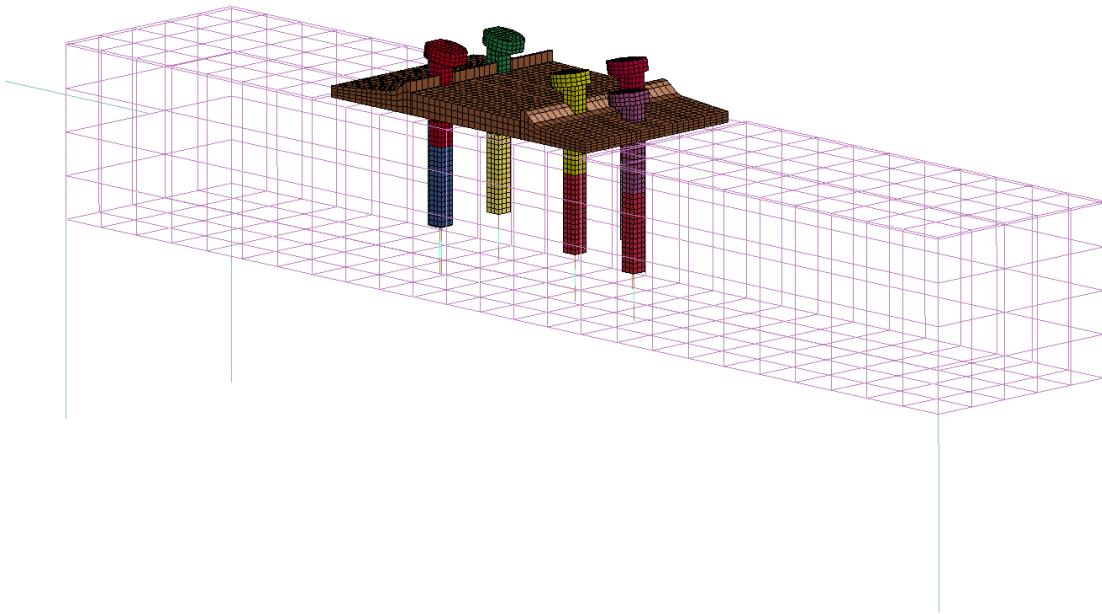


Figure . Basic Sub Assembly

In the basic model shown in Figure 1, the tie is made of a rigid material with a local coordinate system to control its motion. The bottom half of the spikes are also rigid material and are constrained to the tie via a translational joint. The springs that control the pullout behaviour of the spikes are constrained to the tie via a constraint set. As this basic model is copied and swept, each newly created sub assembly must also have these relationships updated to be specific to that assembly.

Creating relationships within LS-DYNA requires the use of individual cards or referencing cards within other cards. Manually creating all of the LS-DYNA cards using LS-PrePost took approximately one month. A faster way was needed to build tracks of various lengths, curvature, rail section, and tie age (tie plate cutting into tie) ANSA provided a solution.

A cost effective and repeatable process for any track with any geometry was the goal of the project with Beta-CAE.

3. ANSA SCRIPTING

The building of a finite element model of a section of railroad track of several car lengths is a complicated process with many hundreds of individual parts, each with its unique part attributes. However, breaking down the model into its basic components reveals its simplicity of design. In the physical world, the track is ideally an assembly of identical parts arranged according to design parameters. The ANSA script uses these parameters to build the track finite element model. ANSA Data Management (ANSA DM), serves as a repository of all the required components needed for a full assembly. Each of these components stored in the ANSA DM or library is a pre-built, self-contained and fully defined part in their original assembled location for the first sub-assembly.

An ANSA script duplicates this sub-assembly and thus assembles the complete model based on user specified track parameters. The ANSA script, written in the BETA Scripting Language is analogous to C-language with ANSA specific functions. A front-end GUI, shown in Figure 2, controls the script and provides a user friendly interface for defining all of the parameters necessary for the script. The front-end GUI₇ was also developed within the ANSA environment (Figure 2). The script has the capability to read, write and auto load parameters from a previous session.

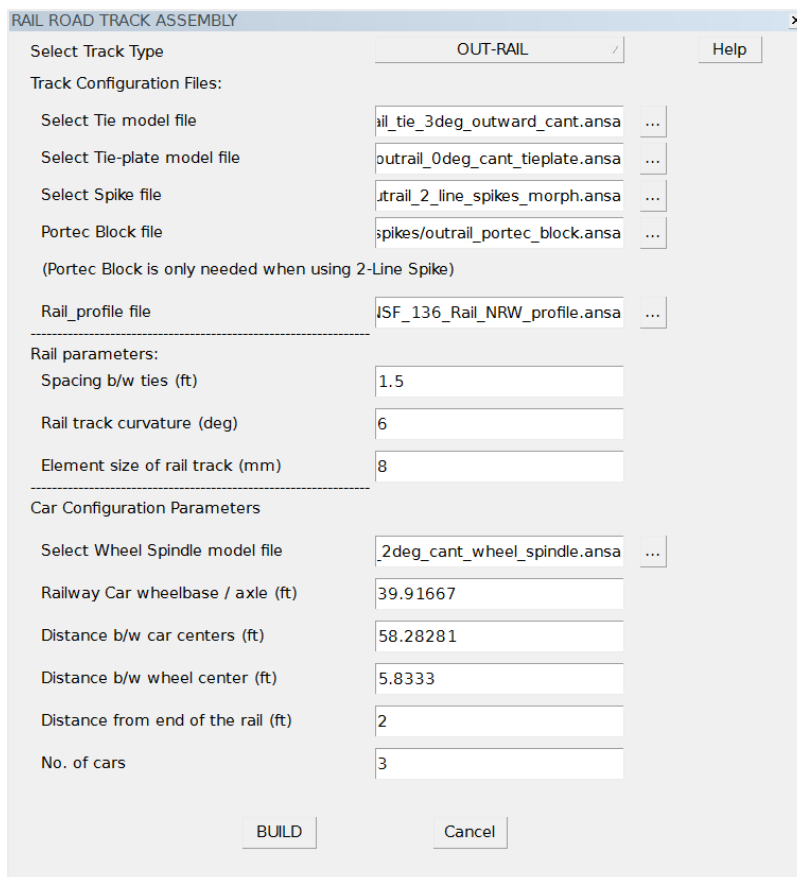


Figure . Rail Road Track Assembly GUI

In the American railway industry, railroad track curvature is defined by the degree of curvature. This is a practical way to incorporate track turns in railroad construction using surveying equipment. A 100ft engineer's tape (also commonly used is the 62 foot chord) is used to measure the chord of the circumference of a track turn. The reason for the choice of the chord rather than the actual length of circumference is that the chord can be measured easily and directly simply by stretching the tape between its ends. Stations of 100 foot lengths are used to lay out a railway. This continues through curves, so that the total length is

always the sum of lengths of a series of straight lines. The difference between this length and the actual length following the curves, is inconsequential, while the use of the polygonal length simplifies the calculations and measurements greatly.

The script replicates the same methodology in building the FE model of the track with the user input for degree of curvature through the GUI. A curve begins at the P.C., or point of curvature, and extends to the P.T., or point of tangency. See figure 3 for important quantities in a circular curve.

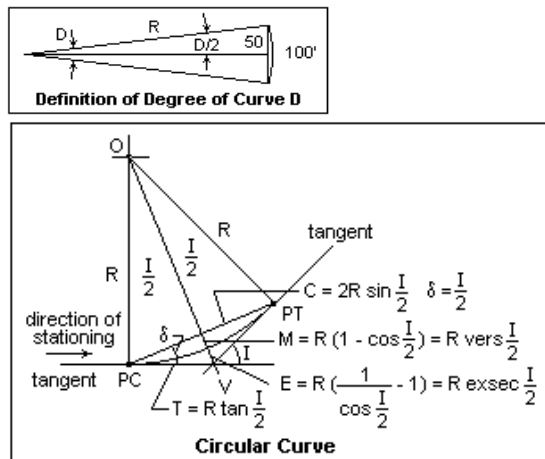


Figure . Track Curvature

The user has the option to build either Out-Rail or In-Rail (Figure 4) with the same set of basic components. The script also updates the orientation of the parts to match the cant of the tie plate. The library contains several rail cross-sections.-

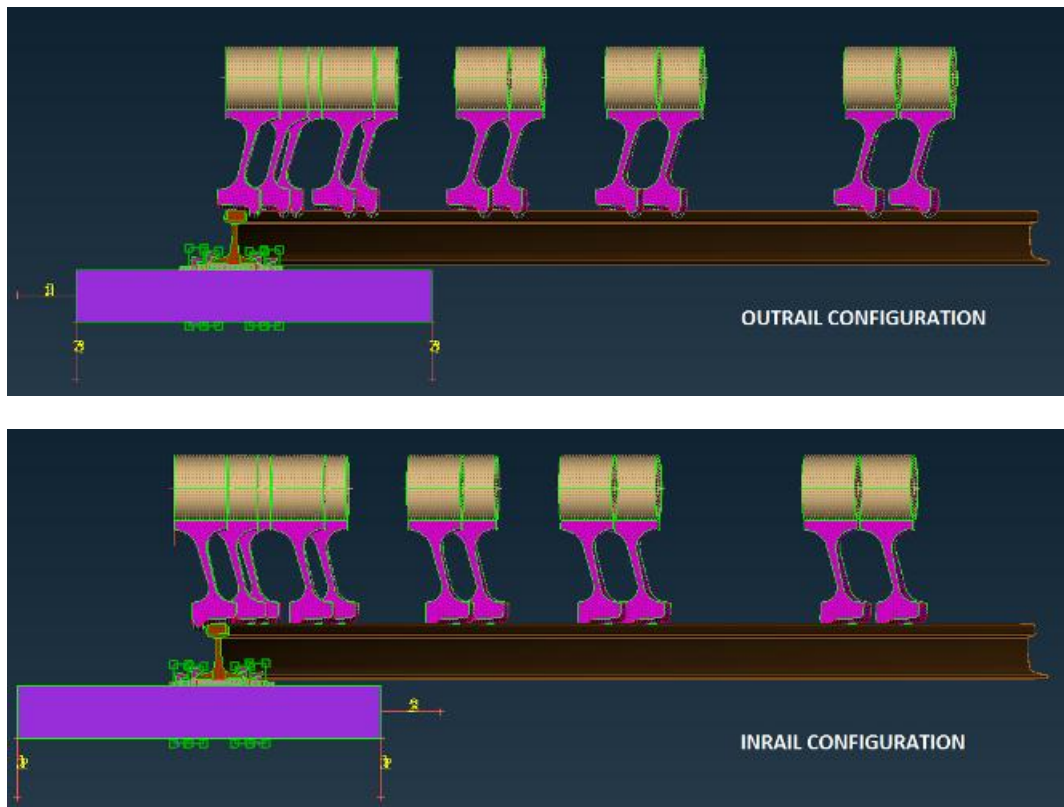


Figure . Rail Configurations

The various spike configurations are pre-built as individual components. Provision is made to change the height of the spikes to simulate spike pull-out phenomenon using ANSA Morphing (Figure 5).

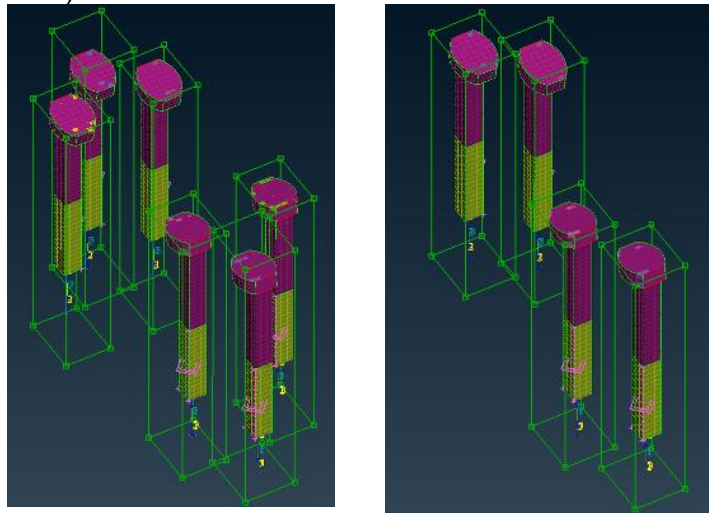


Figure. Spike Configurations

The user has options to vary various track dimensions and car configurations, as shown in the figures below (Figure 6).

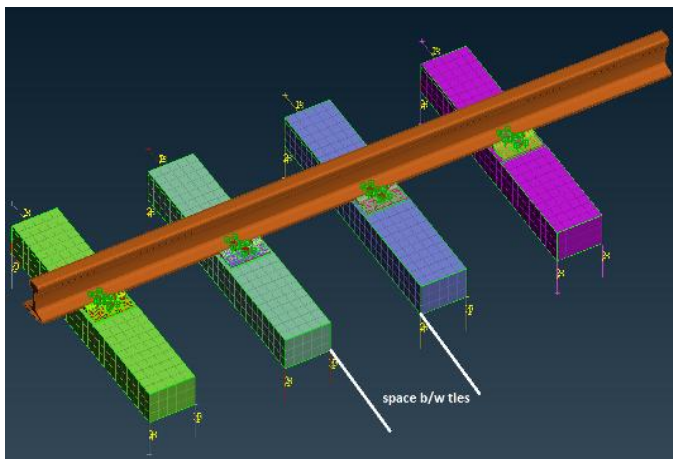


Figure . Track Build Parameters

The position of the wheel wedges are according to dimensional distances that take into account the curvature of the track specified. The wheel wedges apply lateral and vertical loads to the rail (Figure 7). The script also creates LS-DYNA specific contacts, materials, local coordinates for each sub assembly or the whole model as the case may be.

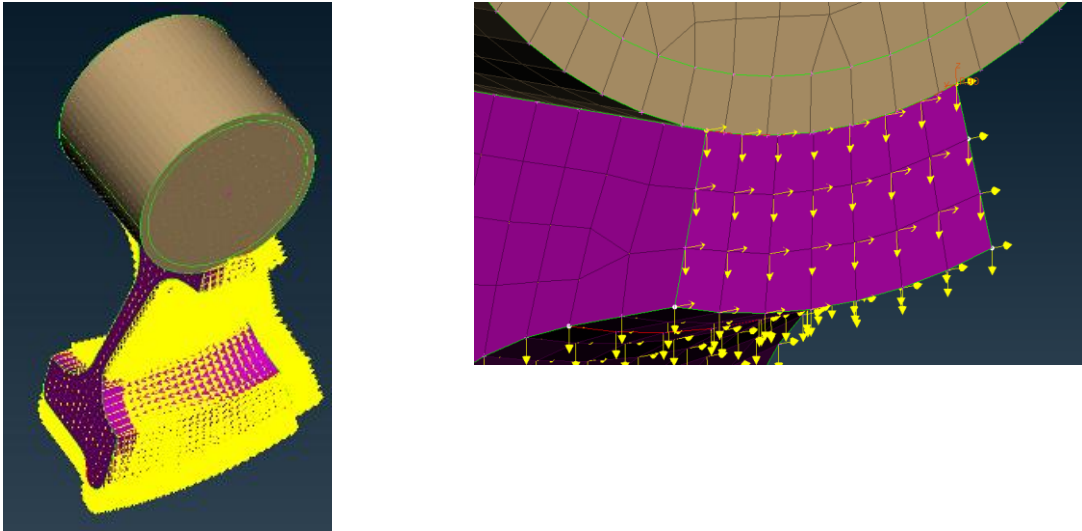


Figure . Wheel Wedge Loads

4. RAILROAD TRACK ASSEMBLY

The base model can take on many different configurations. The track spans several rail car lengths to analyze the track response to multiple wheel loads. Figure 8 shows a worn track configuration. This configuration consists of a wood tie cut with differential plate cutting which cants the rail outward, along with a worn rail profile. Spikes are set to allow free vertical movement of the tie plate. An additional component, a Portec block, is also added. Springs are used to model the ballast response. Using MRail patented technology, track modulus is measured to determine the ballast vertical stiffness.

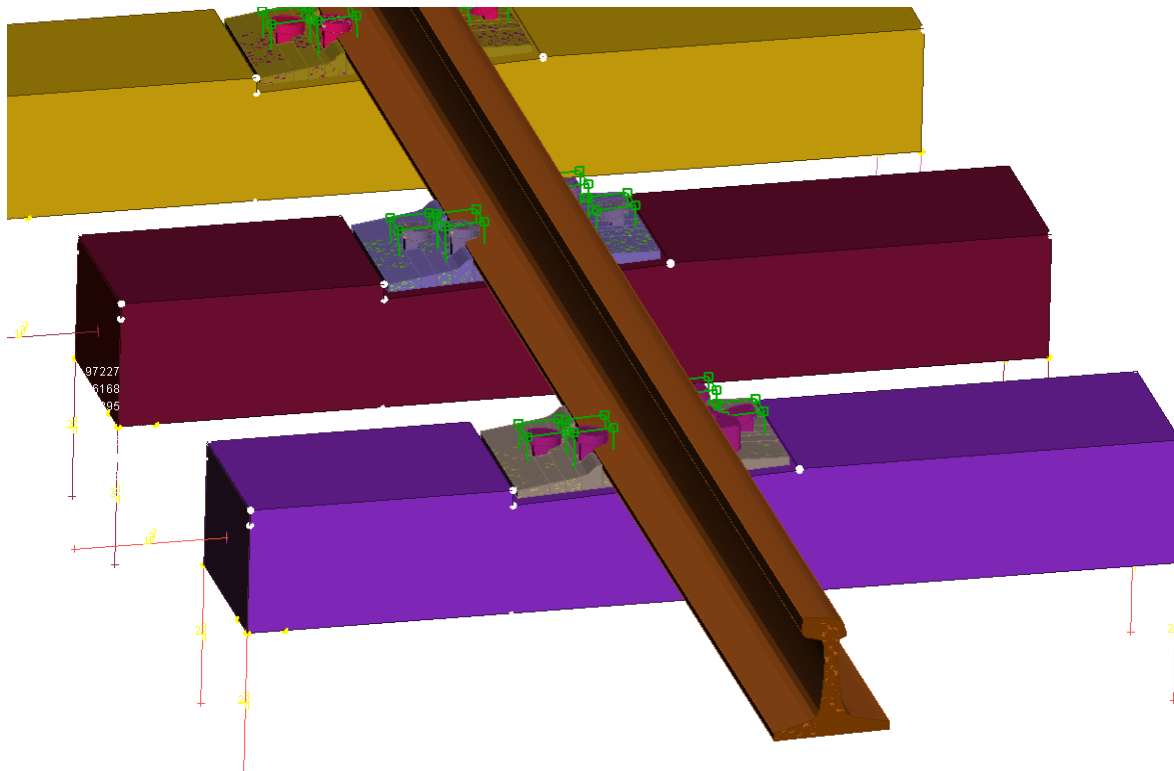


Figure . Worn Track Configuration

The model shown in Figure 8 is an outside rail. The inside rail is also created by the script and the complete track can be created by combing the two models. All of the

interconnections that have to be updated and edited for each tie sub assembly and the positioning in 3 dimensional spaces are accomplished by the ANSA script.

5. DISCUSSION

A post derailment investigation provides information on the mechanical condition of the cars, track measurements and train handling. From this data, a kinematic program such as VAMPIRE® analyzes the vehicle dynamics to provide indications of the primary and secondary causes for the derailment. A program such as VAMPIRE® is an excellent tool but does not model the track in enough detail to investigate actual track conditions. Factors like spike pullout resistance and how it would influence the rolling of the rail or neutral temperature, rail outward cant, and tie plate slippage as a function of wheel vertical and lateral load are not included.

The output from a VAMPIRE® kinematic study provides vertical and lateral loads imparted to the rail from a rail vehicle. These loads are the input into the LS-DYNA model. The LS-DYNA model studies the sensitivity of track condition on the derailment. Figure 9 shows one of several wheel wedges that load the rail. The vertical load is applied and then the lateral load is applied. A rapid application of these forces approximates the movement of a train onto a section of track. A forward velocity is also possible.

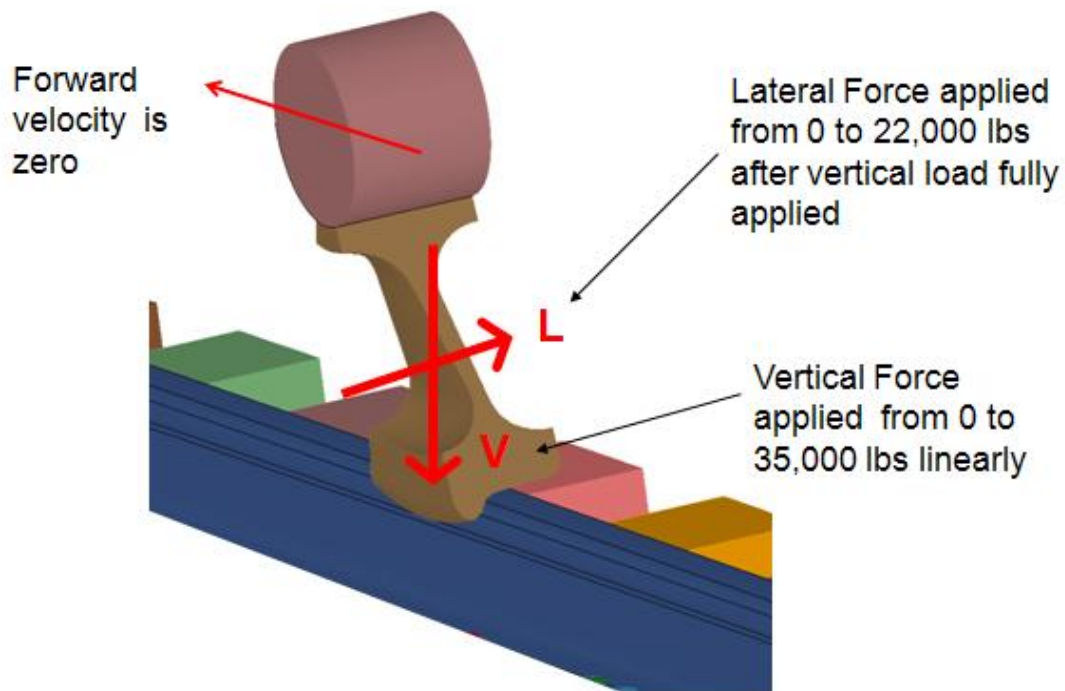


Figure . Wheel loading

A spike resistance study shows one application of this new tool. The track is of nominal geometry with new rail and wheel, three line spikes and four total spikes per tie plate. Spike pullout resistance forces of 50, 500, 1000, 2000 lbs (222 N, 2224 N, 4448 N, 8896 N) per spike were compared. Figure 10 shows the applied vertical and lateral forces. Eight wheels apply the load.

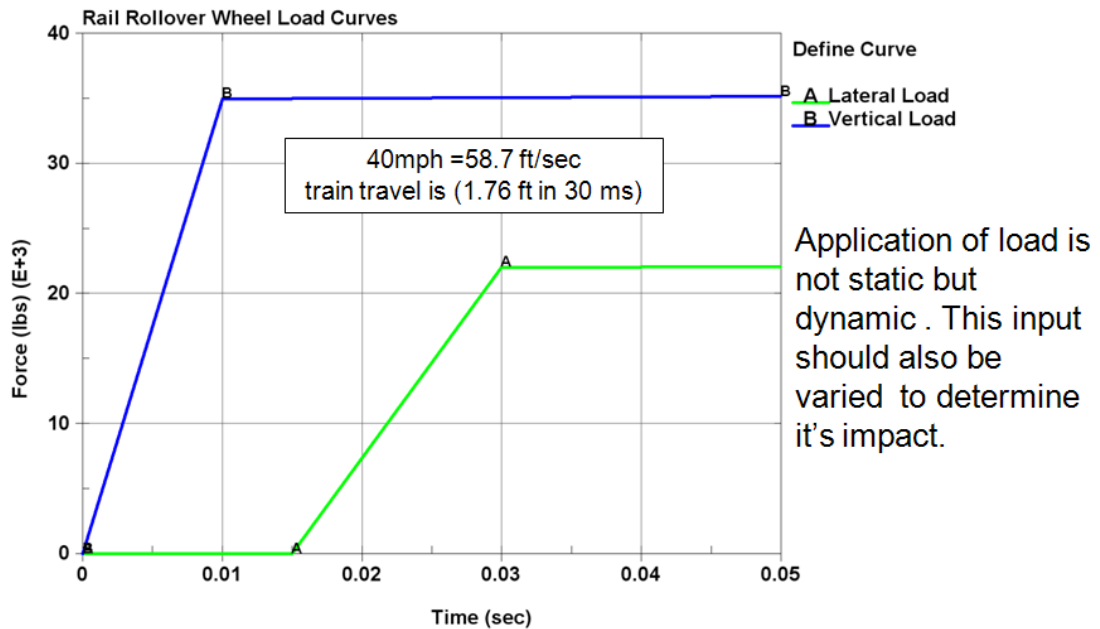
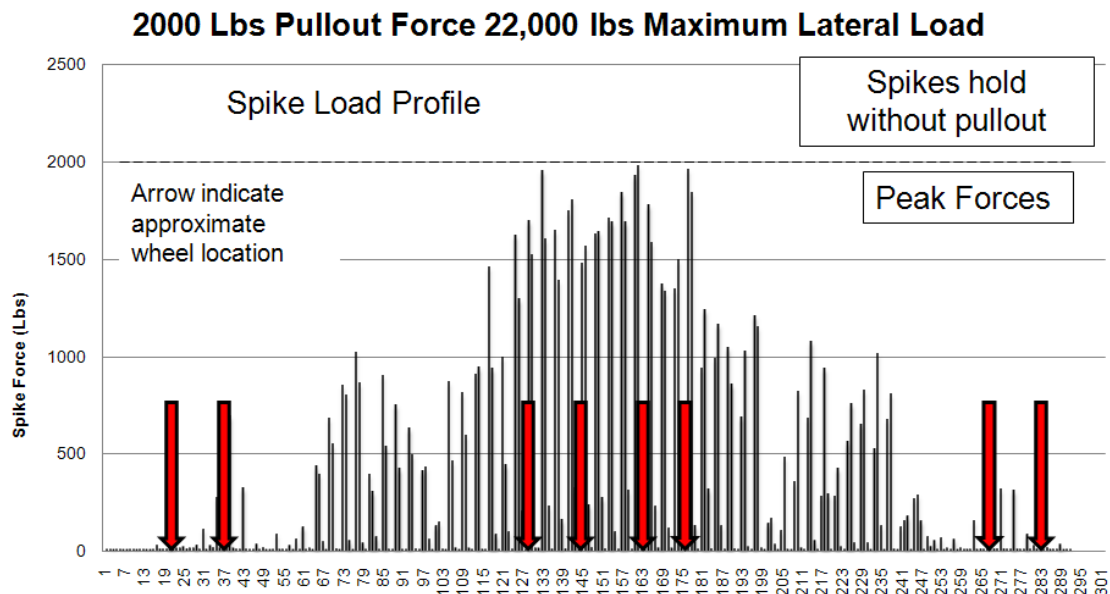


Figure . Rail Loading

An expected result is that the rail acts to redistribute the wheel loads along a length of track. The greater the pullout resistance of each spike the less redistribution of load is needed and the less the rail rolls. Figures 11-14 shows the influence of spike resistance to the distribution of loading on the spikes.



All spikes across entire rail length

Figure . 2000 lb spike pullout resistance

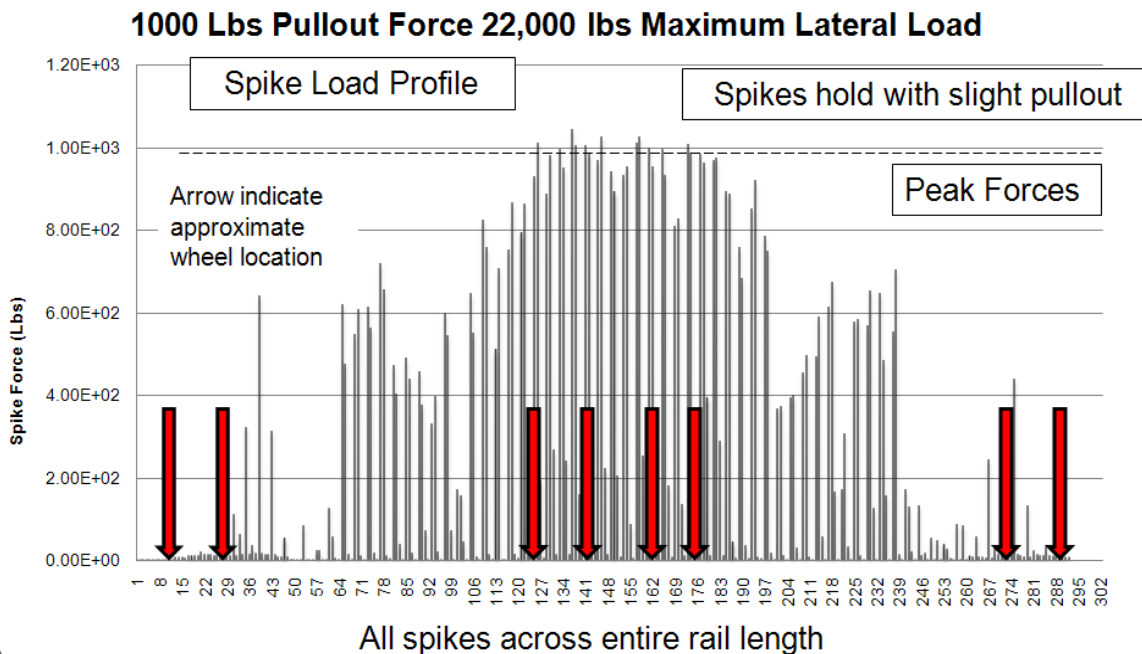


Figure . 1000 lb spike pullout resistance

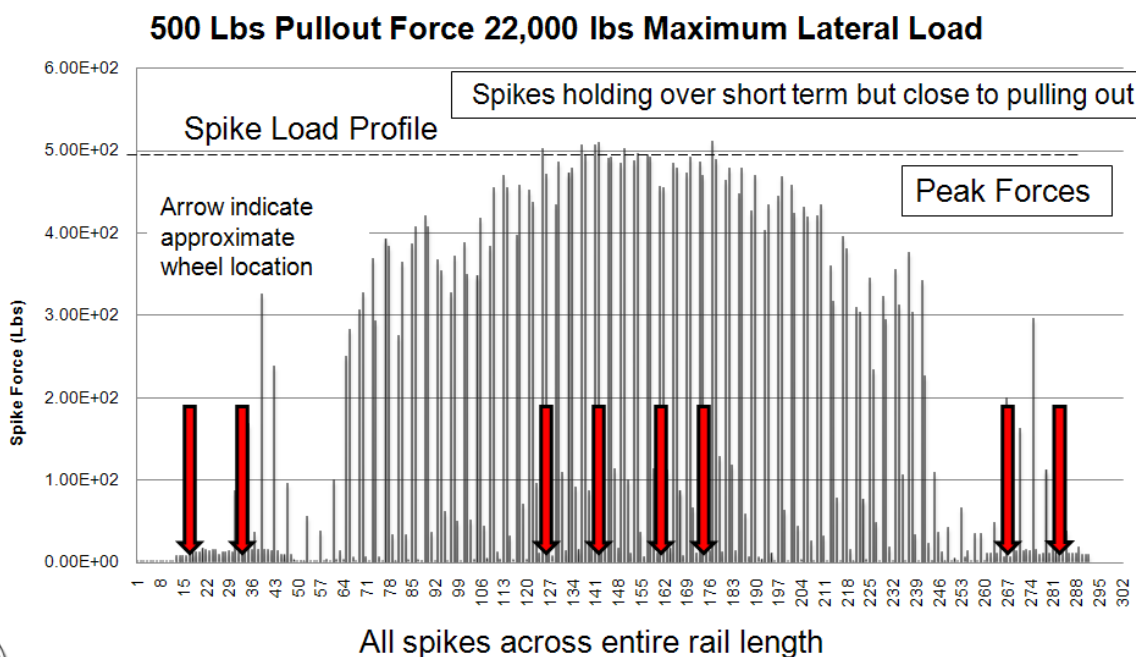


Figure . 500 lb spike pullout resistance

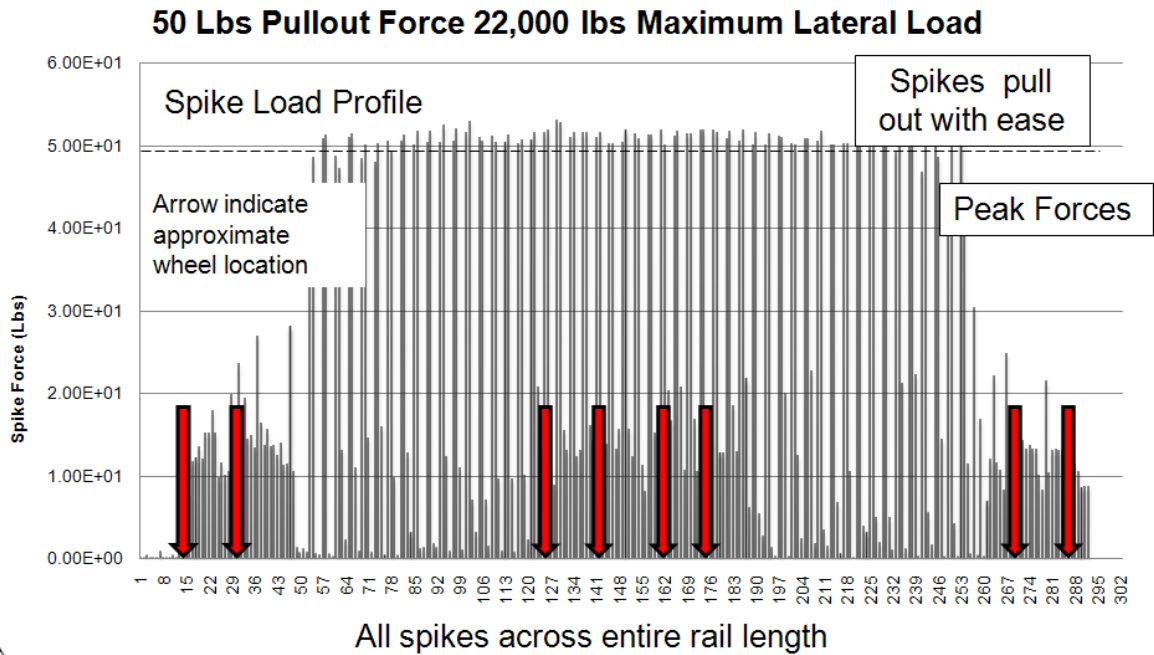


Figure . 50 lb spike pullout resistance

Spike resistance directly influences rail roll. Figure 15 shows the measurement of rail roll used in this study.

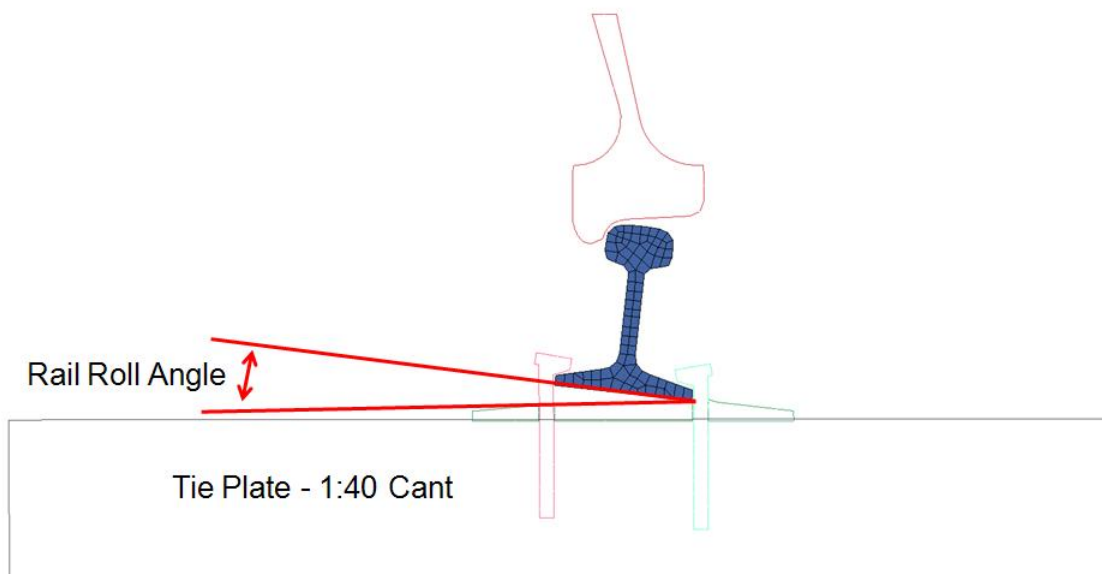


Figure . Rail roll angle

Figure 16 shows the roll angles for the four cases. For 22,000 lbs of lateral and 35,000 lbs of vertical load the 500 lbs per spike resistance verges on rail roll. Figure 17 shows how incremental increases of lateral load results in rail roll at 25,000lbs.

Rail Roll Angle Comparison - Max Lateral Load 22,000 lbs

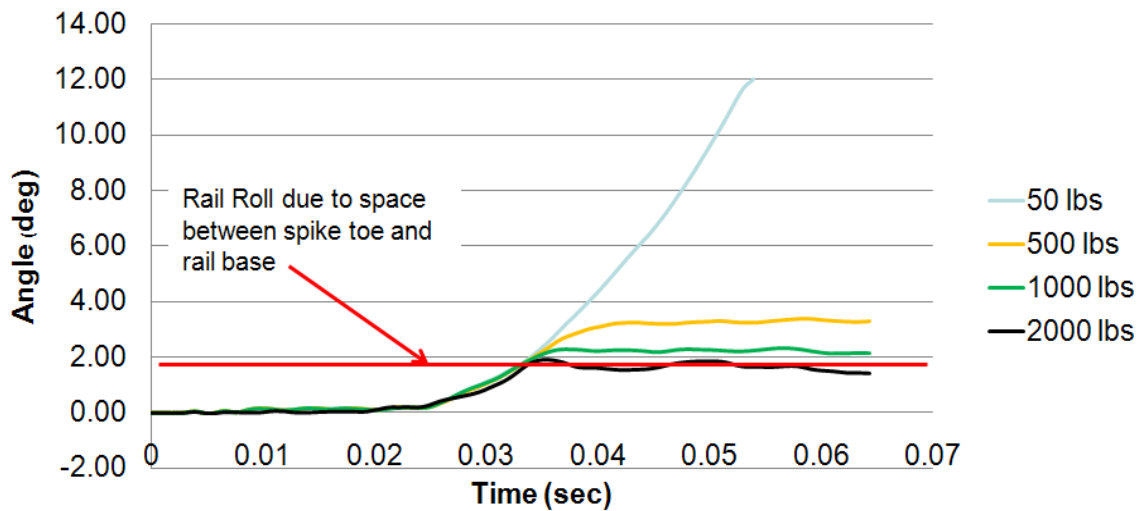


Figure . Roll angle comparison

500 Lbs Spike Pullout Force with Stepped Wheel Loading

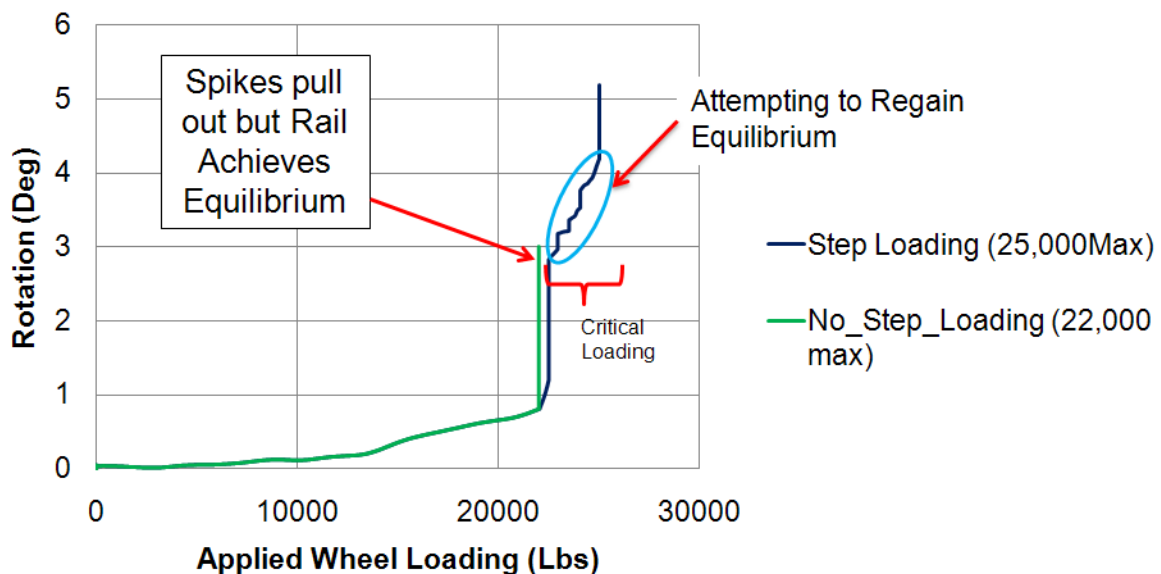


Figure . Stepped Wheel loading

TESTING AND VALIDATION

The ANSA FEA model of the track requires knowledge of the variable behaviours of track components. A test program is in progress to gather key information that will feed into the FEA model. Testing was underway at the time of publication. Sixteen channels of various strain, displacement, and temperature data are to be gathered for the calculation of model inputs.

Data acquisition is centred on a SOMAT eDAQ data acquisition system, capable of simultaneous sample rates from 0.1 Hz to 100 kHz. Force measurement is obtained through a network of strain gauges applied to both rails. Rail, fastener, bearing plate (tie plate), and track displacements are measured from a custom transducer fixture affixed to the wooden tie

(sleeper). Data acquisition (with a 30-second pre-trigger data buffer) is triggered by a bi-directional wheel counter.

Shim-mounted strain gauges are bonded to the rail web and rail base in an orientation that will produce uncoupled strains that react to vertical and lateral forces. Figure 18 shows two strain gauges during installation. Sixteen gauges are required to instrument one crib on one rail. Both rails are instrumented with strain gauges to obtain high rail and low rail responses. A calibration rig is then applied to the track, generating approximately 20 kips of lateral force and 30 kips of vertical force. Force-strain relationships for different loads are then recorded and applied to the data acquisition system. Figure 19 shows the calibration rig in use



Figure - Strain gauges bonded to rail web and rail base.



Figure - Calibration rig being used

Fixturing for track shift, rail rollover, fastener displacement, and rail to-tie movement are to be installed on the high rail of the test curve, where higher lateral loads and displacements are expected. The low rail is to be instrumented with a MicroStrain 3DM-GX1 angular displacement sensor.

The custom sensor fixture installed on the high rail of the curve consists of four string-type displacement sensors. Two sensors are affixed to the centre point of radii between the head and web and the web and base. For small displacements, under 5 degrees, the measurement has shown to be very linear in lab mock-up testing. The third displacement sensor measures bearing plate (tie plate) to tie (sleeper) lateral displacement. Finally, the fourth sensor is used to measure gross lateral displacement of the track structure, as measured from the tie to a fixed ground point. Figure 20 depicts the lab mock-up of the displacement sensors.

A fifth displacement sensor, not shown, will show the amount of fastener lift on the gauge side of the high rail. Lateral and vertical forces can be used to calculate rail moments that must be resisted by the fastener.



Figure - Displacement sensors

Six type-T thermocouples are to be applied to both rails at locations near the head of the rail on the gauge side, on the web, and on the underside of the base. The primary use of these sensors is to gather data for another project, but they shall prove useful for the validation of temperature effects in the FEA model.

The test site is a 6.5 degree main line curve. For three days of testing, it is expected that data for 50 to 60 trains will be collected. Traffic over the test location includes several types, including intermodal, coal, grain, merchandise, and passenger.

The data collected from this test setup will be used to calculate various track and fastener stiffnesses that the FEA model must make use of. Testing was underway at the time of publication.

X. CONCLUSIONS

Analysis of track geometry using the combined capabilities of VAMPIRE® and LS-DYNA is available and economically viable. The ANSA script provides the economical means to create simulation models of detailed track geometry. Post derailment and derailment prevention studies performed using these tools will increase understanding. Additionally, using M-rail technology the track modulus can be determined to provide the ballast response for the VAMPIRE® and LS-DYNA models. Thermal stresses can be included in the LS-DYNA simulation as well. Combining these tools is a viable method to more completely understand complex rail phenomena.

ACKNOWLEDGEMENTS

The authors would like to thank Glenn Bowen from the BNSF Railway TR&D Department for his support of this project from inception, and Tim Ward from the Norfolk Southern Railway Research Department for his cooperation in providing an excellent test location.

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