U.S. Department of Transportation
Federal Railroad Administration

RESEARCH RESULTS
FRA OFFICE OF RESEARCH, DEVELOPMENT & TECHNOLOGY

RR 22-22 | **July** 2022

LONGITUDINAL RESISTANCE MODELING FOR FROZEN BALLAST

SUMMARY

On behalf of the Federal Railroad Administration (FRA), Transportation Technology Center, Inc. (TTCI) developed a "proof-of-concept" finite element (FE) longitudinal resistance model to simulate a rail break based on historical data. Longitudinal track resistance (f_o) is an important parameter for rail break repairs to re-establish the rail neutral temperature (RNT) [1]. If an incorrect f_o is used, the resulting RNT could be too high, which increases the risk of additional rail breaks. Conversely, if it is too low, this increases the risk of the track buckling. This project was undertaken to better define f_o on frozen ballast due to the lack of sufficient data for this condition. Researchers developed an FE model to support much-needed field testing in the future. Research was conducted between Fall 2021 and Spring 2022.

The FE model differs from the historical closed-form longitudinal resistance calculation [1] in that it is mechanistically based; it directly simulates the longitudinal force-displacement response and can represent the longitudinal resistance at both the rail-to-tie and tie-to-ballast interfaces. To match historical datasets, the model required an assumed tri-linear force-displacement curve at the rail-to-tie and tie-to-ballast interface. This resulted in the model's sensitivity to changes in the force-displacement curve.

Before the FE model can be considered validated, it requires additional laboratory or field data that directly characterizes the rail-to-tie and tie-to-ballast force-displacement curves. However, if realistic force-displacement curves can be used, this model has the potential to provide f_o values for a wider range of track conditions than has currently been tested in the field. These untested conditions can include, but are not limited to, frozen ballast.

BACKGROUND

Rail breaks are a common issue in continuously welded rail (CWR). As such, a thorough understanding of the longitudinal track resistance is needed to re-establish the pre-break RNT.

During a rail break, the rail at the break location typically moves from a tensile state to a zero-stress state. This causes the rail on either side of the break to release tension and pull away, producing a gap at the break location (Figure 1). The gap size will depend on the RNT, the ambient rail temperature at the break, and the longitudinal track resistance. For the latter, higher track resistance produces smaller gap sizes. This process also changes the rail stress for hundreds of feet in both directions from the break location (affected region, L_d).

Figure 1. Rail Gap After a Rail Break Test

Rail break repairs require de-anchoring the affected region, pulling the rail enough to re-establish the desired RNT, and then welding and re-anchoring the affected region (L_d). If performed correctly, the post-break RNT should equal the pre-break RNT [2,3], assuming the pre-break was at the desired RNT.

The calculated pre-break RNT, the distance of the affected region, and the rail-pulling force required to re-establish RNT are dependent on the f_o from anchors, fastening systems, and the tie-to-ballast interface. This parameter, which is in pounds per inch, has been calculated from previous field tests [1] and assumes uniform track resistance along the track.

The f_o parameter is powerful and useful in practical applications but is based on a limited number of field tests and track conditions. Three general track conditions are typically used: (1) wood ties with every other tie anchored (EOTA), (2) wood ties with every tie anchored (ETA), and (3) concrete ties with elastic fasteners.

Additional field tests are necessary to address the limited f_o values in untested track conditions, such as frozen ballast; f_o values in frozen ballast are unknown and are often simply estimated as twice the unfrozen condition. If this estimation is not accurate, it could lead to an improper re-establishment of RNT.

OBJECTIVES

The research objective was to develop a mechanics-based numerical model capable of (1) isolating the rail-to-tie and tie-to-ballast resistance interfaces and (2) being used alongside physical testing. The primary motivation for the model development was identifying an appropriate f_o parameter for frozen ballast conditions.

METHODS

As a supplement to difficult-to-run field tests, an FE model was developed in the commercially available LS-DYNA software package to simulate the rail-break process. The FE model allows for the simulation of separate rail-to-tie and tie-to-ballast force-displacement (P-u) curves and can have non-uniform values along the track. This flexibility is useful for simulating a wider range of anchoring and ballast conditions (e.g., frozen ballast). It is also useful for understanding how f_o may vary for a particular track condition, based on its natural variations of anchoring/ballast conditions.

Figure 2 shows a conceptual diagram of the FE model. The only model inputs are the change in temperature (i.e., pre-break RNT to ambient temperature), and the rail-to-tie and tie-to-ballast P-u curves. The boundary condition at the rail break becomes a zero-force condition, and the opposite end 600 feet away remains a fixed boundary condition. Two springs in series are used to represent the rail-to-tie and tie-to-ballast interfaces.

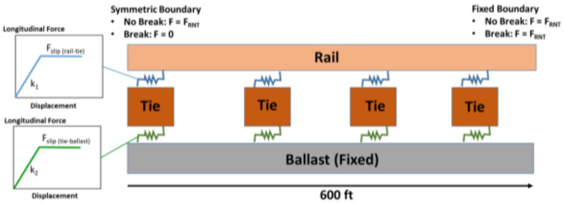


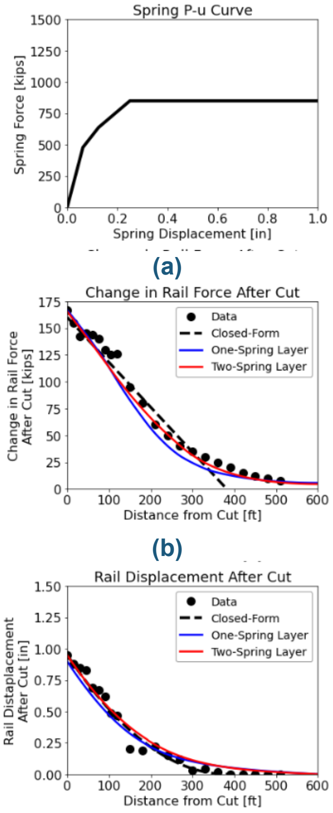
Figure 2. Diagram of Longitudinal Resistance Model

RESULTS

As a proof-of-concept, the FE model simulated a previous rail break test [1] with assumed rail-to-tie and tie-to-ballast P-u curves. These assumed P-u curves are based on engineering judgment from lateral tie push behavior [4] rather than laboratory-based P-u curves, which are necessary for calibration and will be obtained under a future effort.

Two instances are considered. The first instance uses only the rail-to-tie interface and assumes a fixed tie-to-ballast condition (i.e., one spring). The second instance uses rail-to-tie and tie-to-ballast interfaces (i.e., two springs), and the P-u curves of both interfaces are assumed to be identical.

Figure 3 shows the results of the two simulations plotted against field data and the closed-form solution. Figure 3a shows a trilinear P-u curve, Figure 3b shows the change in rail force along the track, and Figure 3c shows the rail displacement along the track. The results of both the one- and two-spring layers match well against the field data.



(a)

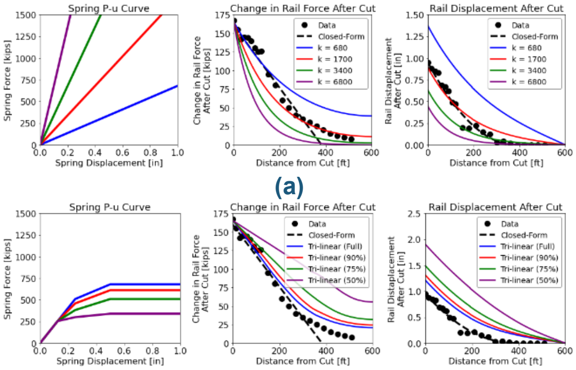
(b)

(c)

Figure 3. Results of One- and Two-Spring Layers

The similar results suggest that the rail-to-tie and tie-to-ballast interface will not resist equal amounts of force. If the P-u curves of the rail-to-tie and tie-to-ballast interface differed, a wider range of responses would be anticipated.

Researchers conducted a brief sensitivity analysis to assess how changes in the P-u curve affect the rail break response. Figure 4a changes the initial stiffness, directly affecting the region away from the cut. Low stiffness values (680 kip/in, blue) affect a large region (>600 ft) and, since displacement is proportional to the integral of rail force, this situation produces a large rail displacement. Figure 4b changes the maximum threshold of the P-u curve and affects the region near the cut where the change in rail force is the greatest. As a result, the lower threshold values (purple line) require a larger track region to resist the unconstrained rail contraction, which also produces a larger gap size at the break.



(a)

(b)

Figure 4. Results of Sensitivity Analysis with changes in (a) Initial Stiffness and (b) Threshold

CONCLUSIONS

TTCI developed a proof-of-concept FE longitudinal resistance model to simulate a rail break. The model can simulate both the rail-to-tie and tie-to-ballast interface, and initial simulations showed good agreement with field data. Laboratory or field assessed rail-to-tie and tie-to-ballast P-u curves are required before the model can be considered calibrated and used beyond matching historical field tests.

FUTURE ACTION

This model is currently being used conceptually to better interpret and measure rail break tests. Observations from recent tests in wood tie track showed the region near the cut (approximately five ties, where the first two were unfastened for the test) had little to no visual tie movement. This suggests that the rail completely slips through the fasteners and no force is distributed to the ties. After approximately five ties, tie movement is observed. This suggests that the rail-to-tie interface was still resisting movement and force was being transferred to the tie-to-ballast interface. At large distances from the cut, minimal tie movement was observed yet again, suggesting the initial stiffness of the rail-to-tie and tie-to-ballast interface was enough to prevent failure of the tie-to-ballast interface. While these observations do not provide P-u values, they can be used as a check with future laboratory tests. To further advance the work presented here, FRA plans to use this model to support future rail break tests in frozen ballast conditions. Planning is already underway to develop the necessary field testing with a Class I railroad in revenue service.

REFERENCES

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ACKNOWLEDGEMENTS

TTCI conducted this research with support from FRA and in coordination with similar Association of American Railroads Strategic Research Initiatives. TTCI team members included Steve Wilk, Wei Zhao, Chris Johnson, and Duane Otter.

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KEYWORDS

Longitudinal resistance, rail break, rail neutral temperature, frozen ballast

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