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Influence of Tie, Fastener, and Ballast Parameters on Track Lateral Stability

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The research described was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

Key Findings:

- Key parameters influencing track lateral behavior during analysis include:
  - Tie type, weight, dimensions and spacing.
  - Ballast type/condition (degraded, wet, frozen, etc.), shoulder width, crib content, maintenance, degree of consolidation.
  - Train loads.
- Increased ballast shoulder width and height and ballast compaction are the most commonly employed and most effective techniques for improving track lateral strength. Increasing tie-to-ballast coefficient of friction (COF) can increase lateral resistance up to 40 percent.
- Increased tie plate size and use of elastic fasteners can effectively improve rail roll resistance.
- Small variations in the tie height or width do not significantly increase lateral resistance of the tie-in ballast.

Transportation Technology Center, Inc. (TTCI) is investigating the extent to which high longitudinal in-train forces may develop lateral wheel/rail forces large enough to result in track panel shift and/or rail rollover. This complex problem requires an understanding of the factors that influence in-train forces and wheel-rail forces, as well as the factors that affect track stability and rail roll phenomena.

TTCI is conducting parallel studies of loads (in-train forces and wheel-rail forces) and resistance (track lateral resistance and rail roll). This *Technology Digest* focuses on the fundamentals of track lateral resistance. Track properties selected from a literature review were examined using newly developed three-dimensional (3D) finite element models (FEM). Results of the parametric study are presented.

BACKGROUND

Track resistance is one of the most important parameters influencing track performance and safety. Geometry retention and buckling prevention are primarily provided by lateral, longitudinal, and torsional resistance of the track structure. Fasteners and anchors prevent rail running and limit gap sizes in the event of rail breaks while providing longitudinal resistance. Torsional resistance created by the tie plates, anchors, and fasteners working together against rail roll also offers rigidity to the track structure; especially against buckling. Federal Railroad Administratin (FRA) safety data statistics from four track geometry-caused derailment types (T108, T109, T110, and T111) show that the number of occurrences in the last 10 years is decreasing (see Figure 1).

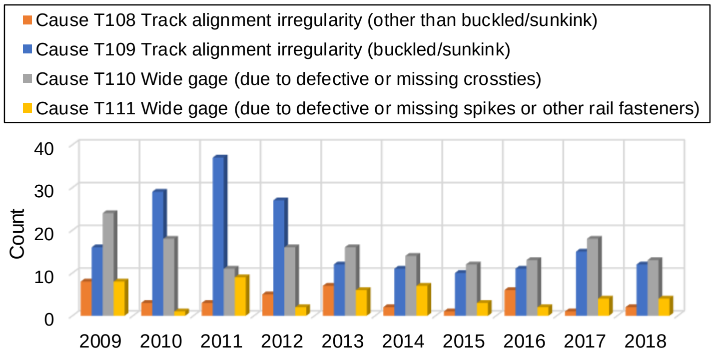

Figure 1. Historical FRA safety data for track geometry-caused derailment types

EFFECT OF HIGH NET AXLE FORCES

The evaluation of the influence of vehicle-induced forces on the lateral stability of CWR tracks has been a major research concern for several decades. The track lateral strength required to handle these loads is key for track alignment retention.[1]

The net lateral-to-vertical (L/V) wheel load ratio is a common metric used to assess demand placed on track by trains.[2] In combination with thermal loads, high wheel L/V ratios could contribute to a sudden track shift or buckle. Other effects of high net axle lateral forces can lead to wheel climb or other failures such as rail rollover and gage widening (Figure 2).

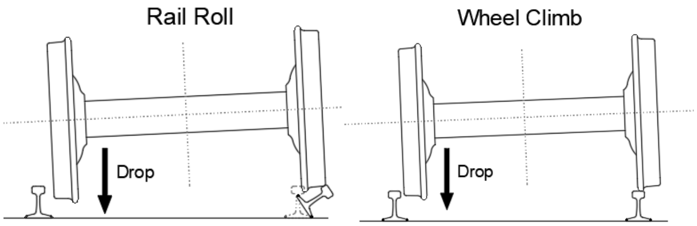

Figure 2. Derailment failure: rail rollover and wheel climb

Wheel-rail forces associated with steering generally create very little net lateral force and do not contribute to panel shift. These forces tend to be associated with wheel climb and rail rollover. Gross lateral forces, from the carbody level, tend to produce net lateral forces and could result in panel shift.

LATERAL TRACK RESISTANCE

Lateral track resistance is the reaction offered by the ballast against lateral movement often referred to as the track lateral strength. It is a tie-ballast interaction parameter influenced by several factors such as ballast section, condition, consolidation, maintenance, tie type and condition, and train loads. Track lateral resistance becomes a fundamental, but highly variable, parameter in track lateral stability.

TRACK SHIFT

A literature review was performed to gather information about the fundamentals of the track lateral stability mechanism in terms of track shift and track buckling. Kish and Mui summarized the track lateral stability mechanism in three major stages.[3]

Stage 1: "Formation of initial track misalignment" can be triggered by high L/Vs, reduced local lateral resistance, and/or initial imperfection such as a weld, construction anomaly or installation error. A combination of the high vehicle loads and thermal loads can lead to a sudden track shift (1-2 inches); particularly in curved tracks or in the presence of a misalignment.

Stage 2: "Growth of misalignment (track panel shift)" is related to an increase in L/Vs in combination with high longitudinal forces, reduced lateral resistance at line defects, and track dynamic uplift due to vertical loads (Figure 3). Many cycles of high L/Vs can produce track lateral shift. The progressive track shift is defined as the incremental change in displacement due to each vehicle with the applied lateral load.

Stage 3: "Buckling" is a result of high rail longitudinal force in combination with reduced rail neutral temperature. Buckling can be induced by weakened lateral resistance, dynamic train loads, and misalignment generated by track shift. This mode of failure can generate large levels of track movement.

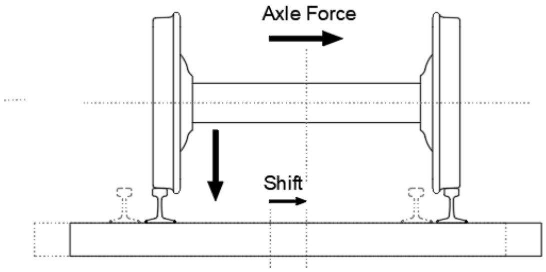

Figure 3. Track panel shift

BUCKLING

The shape of the initial misalignments (lateral alignment defects) is instrumental in determining the resulting buckling mode shape (Figure 4). Field tests and observations of actual buckles show that the buckling behavior of curved tracks can be different from that of tangent tracks.[4] Tangent track is generally a sudden explosive type of buckle that can displace to either side depending on the direction of the initial misalignments or the weaker side of lateral resistance. Track buckles with Shape III (Figure 4) on tangent track typically have the amplitude of the relatively large middle wave when compared with the two end waves.

Buckling under a vertical uplift wave should be distinguished from the potential track shift that could occur if the wheels carry high lateral loads during negotiation of curves.[4] Track buckling due to a vertical uplift wave is generally not dependent on the net axle lateral (NAL) force because the lateral deflection, if any, from the NAL load is confined to a small region under the wheel where the lateral resistance is the highest.

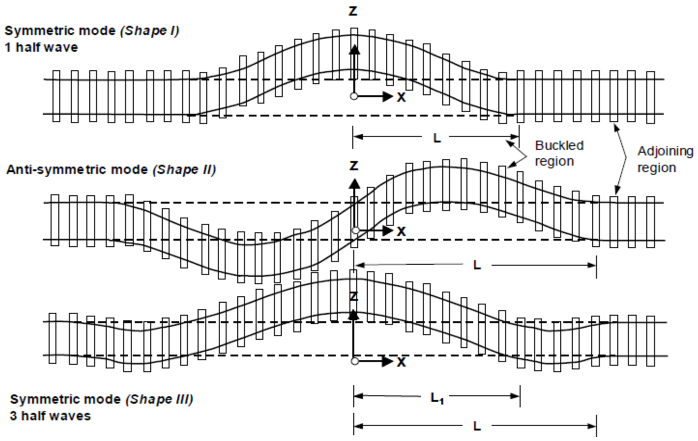

Figure 4. Buckling mode shapes[4]

A principal distinction between track shift and track buckling is that track shift safety typically requires the determination of allowable NAL loads; whereas, track buckling safety requires the determination of the allowable thermal loads.

PARAMETRIC STUDY

Key parameters/conditions influencing track lateral behavior include: tie type, weight, dimensions and spacing, ballast type/condition (e.g., degraded, wet, frozen.), and shoulder width, degree of consolidation, as well as wheel lateral and vertical loads.[5] A 3D FEM was developed to evaluate the importance of each parameter on the lateral track strength (Figure 5). The 3D FEM includes two rails, nine ties, fastening systems, and ballast.

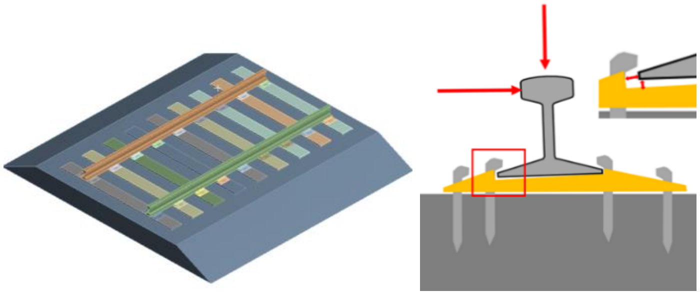

Figure 5. The 3D, FEM track model with representation of gaps in the rail-to-plate model

The components were modeled as solid 3D elements and the connection between tie and ballast were modeled as frictional contacts. The contacts between rails and tie plates (wood/EPC) or shoulders (concrete) were frictional as well, but the rail lateral movement was restricted when rails were shifted to contact tie plates or shoulders. Due to different tie conditions and typical dimension tolerances, the track system contains gaps at the rail base, tie plate, and tie. When the rail is loaded laterally, those gaps become tight first. Therefore, the following assumptions were made in the model to account for track conditions: the gaps between rail and rail plate, spike and plate, plate and tie, and tie and ballast in the model each were set to 1 mm (0.04 in.); see Figure 5. The total lateral displacement due to gaps in one direction is 4 mm (0.16 inch). The model assumption represents a worn track system. A newer track system may have smaller gaps.

The baseline model contains wood ties with cut spikes and tie modulus of 1,700 ksi. In the model 7-inch by 9-inch ties were used with a total length of 8.5 feet and tie spacing of 19.5 inches. Rail-to-tie-plate coefficient of friction (COF) was assumed 0.5 and tie-to-ballast COF was assumed 0.3. The tie plates in the model are 14 inches wide and ballast modulus is 36.2 ksi. Using the FE model, each parameter was varied to understand how it affects the lateral resistance. Table 1 describes variations of these parameters.

Table 1. Parameters used in 3D FE track model

Case	Description	Parameters
1	Increased Ballast Shoulder	Shoulder stiffness × 2
2	Increased Tie-Ballast COF	Tie-Ballast CO =0.6
3	Increased Ballast Shoulder and Tie-Ballast COF	Shoulder stiffness × 2 Tie-Ballast COF=0.6
4	Ballast with less compaction	Ballast modulus=18.1 ksi
5	Increased tie plate size (16″)	Plate width 16″
6	Increased tie plate size (18″)	Plate width 18″

The concrete tie case has a tie modulus of 5,221 ksi, elastic fasteners, elastic rail pads, a tie spacing of 24 inches, and a tie-to-ballast COF of 0.55. The engineered polymer composite (EPC) tie case has a tie modulus of 220 ksi, cut spike fasteners, 14-inch plates, and a tie spacing of 19.5 inches. Other track parameters were assumed to be the same as the baseline model with wood ties. In all cases, the L/V ratio applied is 0.5 where L=18 kips and V=36 kips. Figures 6 and 7 present the preliminary results of the study.

The results reveal that tie type and ballast properties had the most influence on lateral displacement. While the plate size and type do not affect tie lateral displacement, they do improve rail roll significantly.

The model predicts that concrete ties with elastic fasteners and highest tie modulus and tie-to-ballast COF will improve lateral strength which confirms findings from limited testing with concrete ties by TTCI in 1997.[2] The EPC ties with surface patterns similar to size of nominal ballast particle (1-2 inches) and depth of 1/8 to 1/4 inch exhibit improved track lateral resistance.[6]

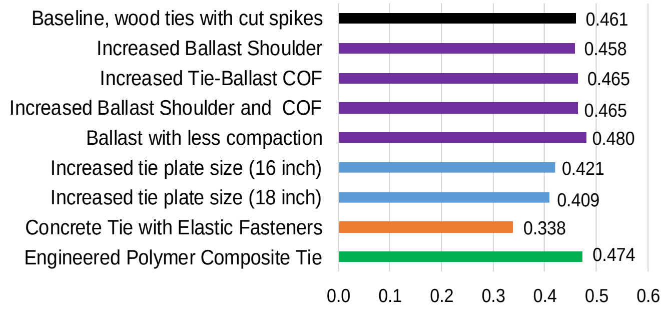

Figure 6. The rail roll (degree) for various track properties

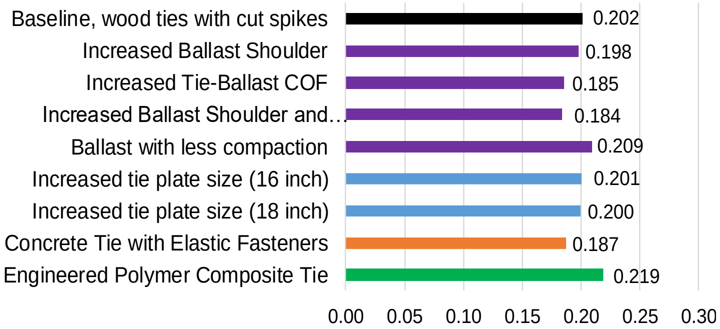

Figure 7. The lateral tie displacement (inch) for various track properties

Additional analysis shows that increasing tie height or width did not increase lateral resistance of the tie-in ballast. Modifying ballast properties provided the highest lateral track improvement. Therefore, additional analysis was carried out for tie-to-ballast COF from 0.4 to 1.0 as examined in other research by Samavedam, et al.[8] The results are presented in Figure 8 and are in agreement with the previous research findings. Increasing tie-to-ballast COF can increase lateral resistance by up to 40 percent.

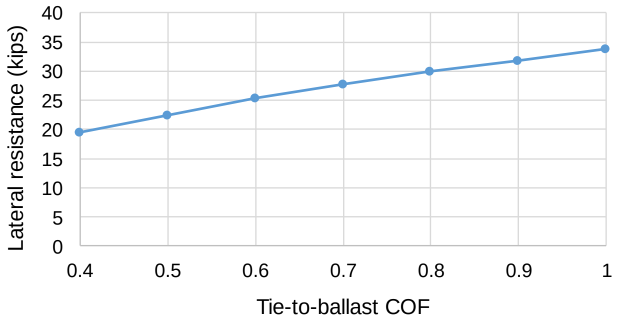

Figure 8. Effect of tie-to-ballast COF on track lateral stability

CONCLUSION

Increased ballast shoulder width and height and ballast compaction are the most commonly employed and effective techniques to improve track lateral strength. They can be applied to wood tie and concrete tie track with significant reduction of lateral displacement under loads.

Decreasing wood tie spacing from the standard 19.5-inch spacing also represents potential improvement of track lateral resistance, however, the amount of decrease may be limited by the requirements for maintaining sufficient crib spacing to allow for maintenance such as tamping, tie removals, etc.

Increasing the tie plate size and using elastic fasteners are the best factors for improving the rail-roll resistance. Additional study is recommended to investigate the effects of using elastic fasteners on wood ties.

References

1. Kish A., G. Samavedam, D. Wormley, December 1998, "Fundamentals of Track Lateral Shift for High-Speed Rail Applications," ERRI International Conference on Cost Effectiveness and Safety Aspects of Railway Track, Paris, France.
2. Li D., W. Shust, 1997, "Investigation of Lateral Track Strength and Track Panel Shift using AAR's Track Loading Vehicle," Research Report R-917, AAR/TTCI, Pueblo, CO.
3. Kish, A. and W. Mui, May 1994, "A Brief Synopsis on the Track Lateral Shift Problem," American Railway Engineering Association Bulletin 746.
4. Kish, A. and G. Samavedam, 2013, "Track Buckling Prevention: Theory, Safety Concepts, and Applications," U.S. Department of Transportation, Federal Railroad Administration, Cambridge, MA.
5. Zarembski A., 2013, "Survey of Techniques and Approaches for Increasing the Lateral Resistance of Wood Tie Track," University of Delaware. Newark, DE.
6. American Railway Engineering and Maintenance-of-Way Association, 2018, *Manual for Railway Engineering*, American Chapter 30, "Ties," Lanham, MD.
7. Samavedam G., F. Blader. and D. Thomson, February 1996, "Safety of High-Speed Ground Transportation Systems, DOT/FRA/ORD-96/03, Federal Railroad Administration, Washington, DC.

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