TTCI TRANSPORTATION TECHNOLOGY CENTER, INC. TECHNOLOGY DIGEST

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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:

- Multiple tie-ballast interface parameters, including ballast density, ballast shape and gradation, ballast shoulder width, ballast crib height, and tie type, have an observable influence on the lateral tie resistance of clean ballast. Knowledge of these parameters and how they affect lateral tie resistance can inform lateral stability risk-assessments
- The test results emphasized the good practice of having both full ballast shoulders and crib heights for resisting lateral and longitudinal movements.
- The shape and gradation of the ballast particles can play an important role in resisting lateral movement by better interlocking with nearby ballast particles. The ballast shape tends to round and smooth out over time, reducing the particles' ability to interlock and resist lateral movement which may be a consideration on whether to reclaim ballast after shoulder cleaning is performed in potentially higher-risk locations.

Ballast Parameters Influencing Lateral Track Resistance

Stephen Wilk

TTCI conducted a lateral tie push test study to better identify the influence of multiple ballast parameters on lateral tie resistance. Lateral track stability in continuously welded rail (CWR) track involves ensuring the lateral resistance provided by the track structure is greater than the lateral forces induced by thermal stresses and vehicle loads. The tie-ballast interface is a key contributor to the lateral resistance of the entire track structure, but the influence of many ballast parameters on lateral track resistance is historically not well known.

This *Technology Digest* summarizes the influence of many of these ballast parameters based on the results of this lateral tie push test study conducted on the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST) in Pueblo, CO. The goal of this research was to provide a better understanding of how the tie-ballast interface affects lateral track resistance in order to aid lateral track stability risk assessments and decision-making capabilities, especially if the rail neutral temperature (RNT) and thermal stresses are not well known at a particular location.

TEST BACKGROUND

The lateral push test involved single tie push tests (STPTs) at three different tonnage intervals (0 MGT, 0.1 MGT, and 22.3 MGT) on two different track sections within Section 36 (tangent track) of the HTL. The three tonnage intervals were chosen to represent the following: 1) a post-ballast maintenance condition (0 MGT) where the ballast section provides the least amount of resistance due to ballast disruption and loosening, 2) a slow-order condition (0.1 MGT) that represents the track conditions at the release of most post-ballast maintenance slow orders, and 3) a consolidated ballast condition (22.3 MGT) that should represent a stable ballast condition.

The two track sections used for testing are a wood tie section and a concrete tie section, as shown in Figure 1. The ballast condition in both the wood and concrete tie sections was clean with minimal moisture, but the sections differed visually. Photographic analysis by the University of Illinois at Urbana-Champaign (UIUC) determined that the ballast particles in the concrete tie section had more surface texture and a higher percentage of 1.5-inch ballast particles than the smoother and similarly graded ballast particles in the wood tie section. The ballast section in the wood tie track was consistent and had a narrow shoulder region (~8 inches) while the concrete tie section had both a full shoulder region (~18 inches) and a narrow shoulder region (~8 inches) along with regions with a full- and low-ballast crib. The ballast crib height was measured at each individual tie location.

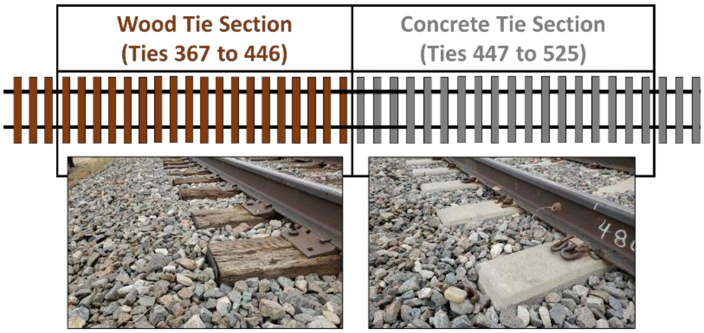


Figure 1. Diagram of test section

In addition to the STPTs that measured the lateral resistance (force) of a single tie push, elevation surveys were taken at the three tonnage intervals to calculate tamp lift height and settlement at each tie location. About 25 ties were tested at each tonnage interval in both the wood and concrete test sections, and none of the test ties were adjacent to other test ties.

GENERAL RESULTS

Figure 2 shows the tie resistance results for each tie and the median peak lateral tie resistance results of each category that was broken up by tie type/ballast condition and the various ballast sections. Figure 3 compares the results of the current study with historical tests.[1] A few observations can be made from these graphs.

First, all four categories show an increase in lateral resistance with tonnage. The slow order tonnage adds about 10 to 20 percent resistance (0.1 to 0.35 kips) and the consolidation situation (22.3 MGT) is about 70 to 90 percent greater than the post-ballast maintenance (0 MGT) condition. This agrees with all the previous research and is the basis for slow order tonnage.[1,2]

Second, the wood tie section shows lower than anticipated lateral tie resistance values. This can be observed in Figure 3a and b where the red-outlined results are from the current study. The lower resistance values in the wood tie section are attributed to the combined factors of a narrow shoulder, smoother ballast surface, and worn wood tie sides that did not allow for much ballast indentation. The influence of ballast angularity in resisting the tie push is emphasized in Figure 4 by the redrawing of the region of ballast engagement (yellow shaded region) that resisted the tie push in the wood and concrete tie sections. These regions were easily observed during the test and could be identified by a clear "bulb" of uplifted ballast.

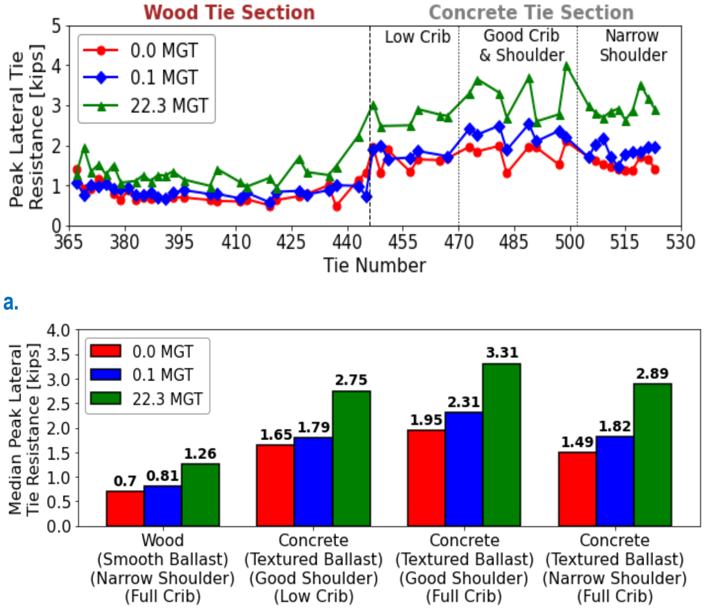


Figure 2. Peak lateral resistance values at each tie (a) and median values from four track categories (b)

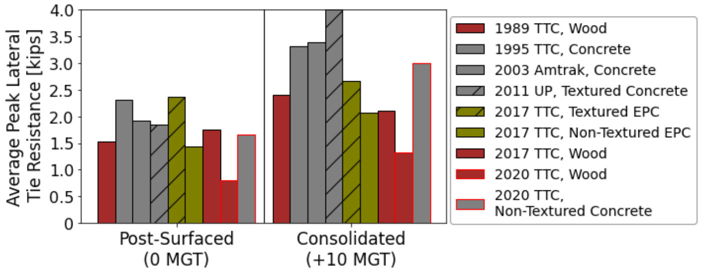
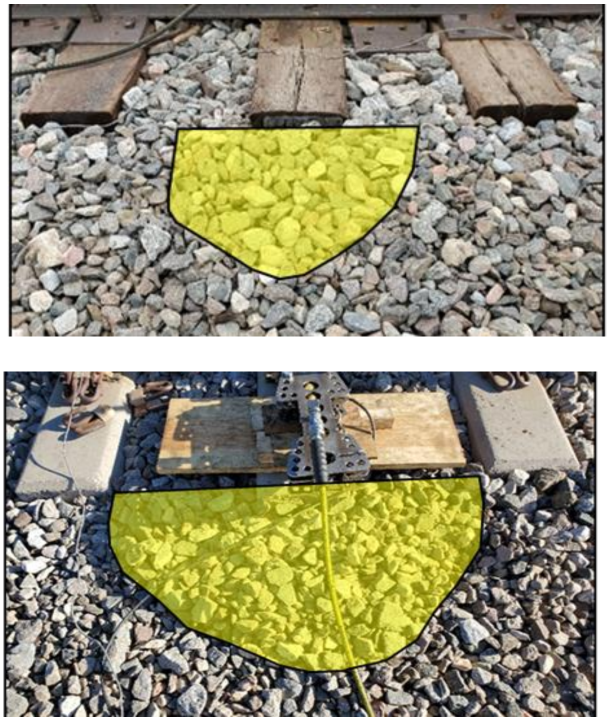


Figure 3. Comparison of current study (red outline) with historical results[1]

As can be seen in Figure 4, the ballast region resisting the tie push in the wood tie region (Figure 4a) is about two half-cribs while the region resisting the tie push in the concrete tie section (Figure 4b) is about two full cribs. The reason for this difference can be attributed to the interlocking ability of the ballast. The ballast particles in the wood tie section had a tendency to slide off each other during the push while the ballast particles in the concrete tie section had a tendency to interlock, creating a larger region of engaged ballast. The greater interlocking ability of ballast in the concrete section is likely attributed to a higher surface texture and the percentage of 1.5-inch ballast particles in the concrete tie section. While heavier tie types (e.g., concrete ties) are anticipated to have higher resistance values, the influence of tie type and ballast condition cannot be differentiated in this study. However, both characteristics are believed to have a contributing influence.


a.

b.

Figure 4. Ballast resistance regions in the wood tie/smoother ballast region (a) and concrete tie/textured ballast region (b)

Third, the varying ballast section in the concrete tie region produced a wider range of lateral resistance values. The track with a full shoulder and a full crib (Column group 3 in Figure 2b) had the largest lateral tie resistance. Both the low crib (~2 inches below tie top) in Column group 2 and the narrow shoulder (~8 inches) in Column group 4 showed lateral resistance values about 0.3 to 0.5 kips lower than the full ballast section (Column 3). Also, a reduction of 2 inches of crib height appears roughly equivalent to the reduction of 10 inches of ballast shoulder. This reduction is simply due to the reduced amount of ballast available to resist the tie push.

TIE PUSH PARAMETER INFLUENCE

The influential parameters affecting lateral tie resistance are categorized into four groups and described as follows:

- *Ballast particle characteristics:* Ballast particle characteristics (angularity, smoothness, gradation) can vary based on the rock type, how the rock is crushed in the quarry, and degradation. As ballast experiences tonnage, the particle corners will abrade and break off, creating a rounder and smoother ballast particle. This parameter may be relevant in decisions of whether to use new or reclaimed ballast.
- *Tie type:* Heavier concrete ties should offer greater resistance than lighter wood ties. The interface (textured, worn, under-tie pads) can have an influence as well, but this hasn't been quantified in this study.
- *Density/tonnage:* Ballast density is lowest immediately after ballast maintenance, and the ballast will densify with accumulating tonnage. This ballast densification is relevant to the slow order tonnage (~0.1 MGT) that is usually accumulated to stabilize the section after ballast maintenance. Dynamic track stabilizers may serve a similar purpose to slow order tonnage.[1]
- *Ballast shoulder and crib height:* The ballast section relates to the amount of ballast in the track. The amount of ballast in the track may be relevant in situations where the crib is low or where it is difficult to hold a ballast shoulder.

Figure 5 presents the estimated influence of each relevant ballast parameter based on the results of this study (purple) and previous studies (yellow).

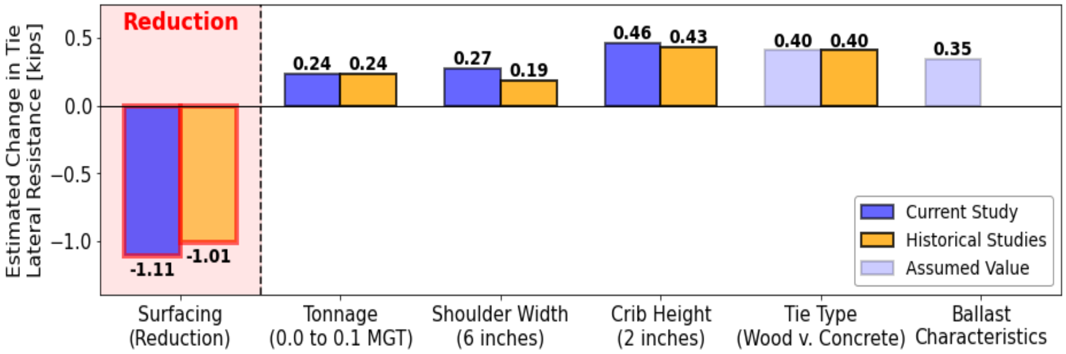


Figure 5. Estimated influence of various ballast parameters on lateral resistance

Since the tie type and ballast particle characteristics cannot be separated in this study, the influence of tie type from previous studies is assumed for demonstration purposes. A few observations can be made:

- The measured reduction in lateral tie resistance from surfacing clearly has the greatest influence. Note that this value may be significantly greater in certain circumstances.[1]
- The other relevant parameters have a comparable order of magnitude influences. There will be variation with each of these values because of the interaction with other parameters, but this should give a general understanding that multiple parameters have generally similar influences as each other.

The contributions of each parameter can be used conceptually to estimate track buckling risk based on the track condition of aparticular location. Figure 6 presents an example that shows that track with reduced risk has consolidated ballast, angular ballast particles, and a full shoulder and crib. Track with increased risk may show loose ballast (after maintenance), worn and rounded ballast particles, narrow shoulder, and low cribs.

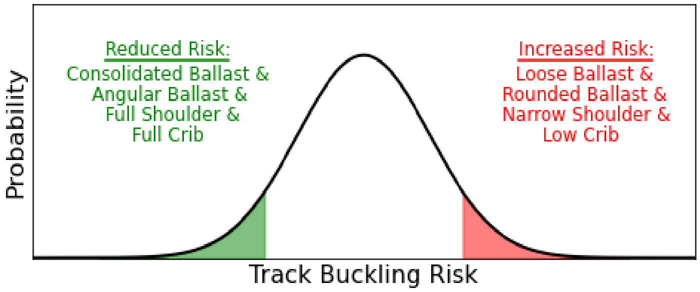


Figure 6. Conceptual track buckling risk due to ballast condition

LATERAL TIE RESISTANCE MODELING

Modeling the lateral tie resistance is outside the scope of this study but, for discussion purposes, the lateral tie resistance can roughly be projected by modeling three general contributions. First, the initial 0 MGT resistance is affected by the ballast particle characteristics, the tie type, and the ability for the tie to interlock with the ballast particles. The second and third contributions of ballast density and the amount of ballast available to resist the tie push, respectively, are just proportional changes from the initial 0 MGT conditions.

TAMP HEIGHT AND SETTLEMENT

For informational purposes, Figure 7 shows the tamp lift height (black line) and settlement (blue and green lines) and how these values varied along the track. The median tamp lift height was 0.50 inch in the wood tie section and 0.92 inch the concrete tie section. As a note, the median ballast diameter (D_{50}) is about 1.25 inches, so it is unlikely that all the ballast particles were pushed underneath the tie during tamping. The median rail settlement was 0.17 inch at 0.1 MGT and 0.4 inch at 22.3 MGT in the wood tie section and 0.21 inch at 0.1 MGT and 0.58 inch at 22.3 MGT in the concrete tie section. These values exclude Ties 409 to 481 because were these ties were considered part of transition regions and not representative of open track. This data exclusion is only relevant for TOR measurements because the rail elevation of the surrounding track affects the rail elevation, but not the STPT, at a particular location because an STPT only measures the tie-ballast interface.

It was found that ties with higher tamp lifts had a lower 0 MGT lateral resistance, likely due to a looser ballast density. Lateral tie resistance values increased with increased settlement, but the relationship was less discernable when broken up by tie section and tonnage intervals.

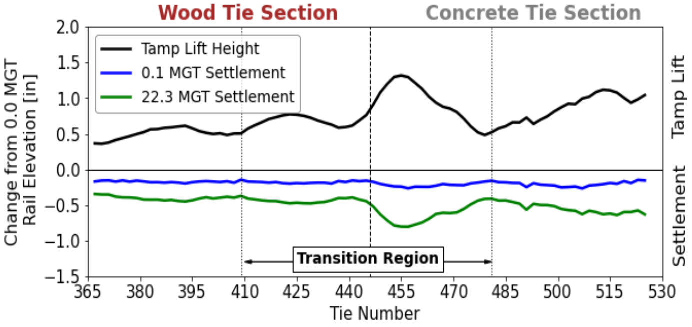


Figure 7. Tamp lift height and settlement in the test section

References

1. Wilk, S. 2017. "Literature Review of Lateral Track Resistance Testing." *Technology Digest* TD17-022. AAR/TTCI, Pueblo CO.
2. Kish, A. "Ballast and Lateral Track Stability." *AREMA Railroad Roadbed and Ballast Symposium*. Kansas City, MO. February 2020.

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