On the Fundamentals of Track Lateral Resistance

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ABSTRACT

A key aspect of track lateral stability assurance is the provision of adequate lateral resistance to the rail-tie structure by the ballast. When lateral resistance is reduced, such as when ballast is worked, the track cannot only lose alignment and surface, but can become buckling prone in the presence of high thermal forces. Current methods to restore ballast strength after track work is through mechanical compaction through dynamic track stabilization (DTS) or through traffic (train load/tonnage) induced consolidation. Research has confirmed the effectiveness of DTS, however, due to the complex nature of ballast compaction mechanics under train loads, a reliable quantification of the effectiveness of train/tonnage based consolidation is still missing.

This paper presents a review of the fundamentals of track lateral resistance, its measurement and its key influencing parameters, provides a test/data summary of US measurements to date, present analysis results on influence on track stability, and offers insights on research needs for further research studies for track lateral resistance improvements.

Key Words: track lateral resistance, ballast maintenance, track buckling, track shift, lateral resistance measurement, STPT, track stabilization

Word Count: 4253

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1.0 INTRODUCTION

Track resistance is one of the most important parameters influencing track performance and safety. Through its three in-plane components of lateral, longitudinal, and torsional, and one out-of-plane of vertical, it influences most track lateral stability aspects including geometry retention and buckling prevention. The three in-plane components are schematically shown in Figure 1 with their typical “spring” analogy representations.

![Figure 1- Track Lateral Resistance Spring Analogy](image)

Longitudinal resistance provided to the rail/tie structure by fasteners and anchors is important to prevent rail running (and thus limit rail neutral temperature variation), and to limit tensile break gap sizes in the event of rail breaks. Torsional resistance provided by the spiked tie plates, anchors and fasteners against rail rotation (in-plane-bending) also offers “rigidity” to the track structure, especially against buckling.

Lateral resistance is the reaction offered by the ballast against lateral movement, often referred to as the “lateral strength”. It is a tie-ballast interaction parameter which is influenced by several factors such as ballast section, condition, consolidation, maintenance, tie type and condition, and train loads. As such, track lateral resistance becomes a fundamental but highly variable parameter in track lateral stability assurance, and is the focus of this paper.
The paper will present a review of the fundamentals of track lateral resistance, its measurement and parametric influences, provide a test/data summary of US measurements to date, present analysis results on influences on track stability, and offer insights on research needs for further quantification studies for track stability safety and maintenance improvements.

2.0 LATERAL RESISTANCE FUNDAMENTALS

2.1 Basic Response Characteristics

As indicated in Figure 1, lateral resistance can be envisioned as a “spring” load-deflection response characteristic representing tie-ballast interaction. As over 30 years research and tests have confirmed, it is a load versus deflection non-linear “spring” response as illustrated in Figure 2, including a simplified analytic representation.

![Figure 2 - Lateral Resistance Load Deflection Characteristics](image)

Key features include an initial linear stiffness, a peak (break-away) value, and a decreasing (drooping) portion to a constant “limit” value. Representations of typical “strong”, “average”, “weak” behaviors for concrete ties are also shown. Key parameters/conditions influencing the behavior include: tie type, weight, shape and spacing; ballast type/condition (fouled, wet, frozen,
etc.), shoulder width, crib content; maintenance, degree of consolidation, and train loads. Typical values and ranges are shown in Figure 3.

![Figure 3 - Typical Peak Lateral Resistance Values](image)

Lateral resistance has three contributing components of bottom friction ($F_b$), side friction ($F_s$), and end or shoulder restraint ($F_e$), and their approximate contributions are as indicated in Figure 4. As research has shown, the bottom friction component is most influenced by tie type and weight, the side friction by crib content, and the end restraint by ballast shoulder geometry. Consolidation and compaction influence all of the three components to different degrees.

![Figure 4 - Lateral Resistance Components](image)

2.2 Lateral Resistance Measurement

Over the years several measurement techniques have been developed, including:

- single tie push test (STPT)
• discrete cut panel pull test
• continuous track panel pull test (TLPT)
• continuous dynamic measurement (Plasser-DGS)
• analytic empirical model

The most advantageous and frequently used technique is the STPT which mobilizes a single tie in the ballast and measures the force versus displacement behavior as shown in Figure 1. This provides the non-linear “spring” type characteristic required in track stability analyses. Figure 5 shows the STPT device developed by the Volpe Center in the US, and for detailed descriptions refer to [1, 2].

The discrete cut panel pull test requires cutting rails and is highly destructive, while the TLPT measures an entire continuous panel’s load-deflection response which includes the rail flexural rigidity, the rail thermal force, and the non-uniform resistance offered by several ties. Thus from TLPT data the single tie resistance is not calculable. The recently developed continuous measurement technique through Plasser’s Dynamic Track Stabilizer (DTS, DGS) is an indirect measurement relating the DTS energy output to the “frictional power” to move ballast in the track grid. For a more detailed description on this measurement and tests refer to [3, 4]. The analytic empirical model is lateral resistance estimator based on empirical equations developed through over 500 STPT measurements in the US which evaluated the influences of shoulder width, crib content, and consolidation levels on lateral resistance for both wood and concrete ties in granite ballast. The model is available in the CWR-INDY module of the CWR-SAFE program which is discussed in 4.2.
2.3 Concept of “Dynamic” Lateral Resistance and Tie/Ballast Friction Coefficient

Train loads and dynamics play a key role in track lateral stability behavior due to their impact on lateral resistance. Dynamic lateral resistance refers to the increase/decrease in resistance due to train loads as illustrated in Figure 6.

The impact of dynamic uplift is that a percentage of the tie bottom component can be lost, whereas under load the resistance is increased. This increase has been shown to be related to a tie-ballast friction coefficient parameter, $\mu$, as indicated in Figure 7, and as discussed in [5, 6]. Based on resistance measurements on vertically loaded ties, this parameter has been shown to
be vertical load and tie type/condition dependent. The parameter $\mu$ plays an important role in both buckling and track shift analyses as discussed later.

\[ F_{dy} = F_{st} + \mu R_v \]

Friction coefficient, $\mu$, is a tie bottom roughness index

Another aspect of dynamic lateral resistance is the influence of train induced vibration. Although the effect is difficult to measure and quantify, tests by British Rail under the ERRI/D202 work indicated a 25-50% reduction in lateral resistance depending on the acceleration and vibration frequency levels [7]. Such reductions are currently not included in track stability analyses, and further quantification would be most useful for US heavy tonnage tracks/equipment.

### 3.0 LATERAL RESISTANCE AND BALLAST CONSOLIDATION

When lateral resistance is reduced, such as when ballast is worked, the track can not only lose alignment and surface, but can become buckling prone in the presence of high thermal forces. Current methods to restore ballast strength after track work are through dynamic track stabilization (DTS), or through traffic (train-load) induced consolidation. Research has shown both methods to be effective to various degrees, however due to the complex nature of ballast...
compaction mechanics under train loads and to its many influencing components, a reliable quantification of MGT effectiveness is still missing. Such information is a prerequisite for the effective placement and removal of slow orders. Key points addressing ballast lateral resistance restoration include:

- Surfacing and tamping can reduce track lateral resistance (TLR) by 40-70%. The actual amount depends on ballast type, ballast section/condition, wood vs. concrete ties, tie design and condition, etc, i.e. on the initial conditions before surfacing. It also depends on the nature of the ballast disturbance/work. As an example in the case of surfacing, the amount of lift is considered to have a large influence. Therefore the key issues are: (1) how much is the reduced resistance from which resistance restoration is required, (2) how fast can it be regenerated to “safe” levels, and (3) what are the safe levels?

- DTS has been shown to regenerate 30-50% of resistance (from the reduced value) based on European data. Limited US data is in the similar range, as discussed in 3.2.

- DTS tonnage equivalent (European tests – UIC Leaflet #720) is on the order of 0.1 MGT (million gross tons) of traffic. However this equivalence has not been conclusively demonstrated for US tracks/conditions as indicated in 3.2.

3.1 Ballast Consolidation Mechanism

For DTS the basic mechanism for resistance restoration is a “reintensification of the tie-bottom contact”. The DTS horizontal vibratory input under a specified vertical load causes a dynamic re-arrangement of the ballast particles and an increases tie-bottom contact area [3]. Such tie-bottom contact restoration effectively increases the tie/ballast friction coefficient represented in Figure 7, as well as assures the 35-40% tie bottom resistance contribution as referred to in Figure 4.
Train traffic induced (MGT) consolidation is however a different mechanism altogether. The wheel induced dynamic uplift versus downward pressure coupled with vertical vibration input presents a different compaction mechanics mode, and remains a minimally researched topic to date. Hence the questions to resolve include: (1) how traffic tonnage consolidates (by what mechanism), and (2) how effectively (at what tonnage rate)?

3.2 US Data on Maintenance, DTS and MGT Influences on Lateral Resistance

Over the past 30 years the US railroads, the US DOT’s Volpe Center, and the Association of American Railroads have conducted numerous STPT tests to evaluate lateral resistance behavior. Aside from the fundamental mechanistic aspects, a large focus was placed on evaluating the influences of maintenance and subsequent restoration of lateral resistance through DTS and tonnage. The following is a brief synopsis of some applicable results:

1. **Chessie and Amtrak Tests** – concrete ties (1985, Sluz, [8])
   a. Chessie: 9% recovery after 0.076MGT
   b. Amtrak: 11% recovery after 0.073MGT

2. **AAR/TTC Tests** – wood ties (1990 – Trevizo, [9])
   a. Tangent: 17% recovery after 0.1MGT; 32% after 1MGT
   b. 5° Curve: 9% recovery after 0.1MGT; 21% after 1MGT

   a. Wood - tangent: 26% recovery after 0.1MGT
   b. Concrete – 5° Curve: 52 % reduction due to tamping
   c. Concrete – 5° Curve: 22% recovery after 0.1MGT
   
   a. Concrete (new-scalloped) -17% recovery after 0.35MGT
   
   b. DTS increase - 33%

   
   a. 43% reduction due to surfacing with ½ inch lift
   
   b. DTS increase: 31%

   
   a. 39-70% reduction due to tamping/surfacing
   
   b. 0.1MGT had negligible influence on wood after tamping; 0.2MGT was 28%
   
   c. DTS increase on concrete: 22%
   
   d. After DTS, traffic decreased lateral resistance initially, then it increased
   
   e. Heavy rain/wet ballast: 20% decrease in lateral resistance on wood

Some key features of items 3 and 5 are illustrated in Figures 8 and 9. As the above summary indicates there is a large variability on traffic/MGT influence on track lateral resistance recovery after maintenance, and it appears that a larger than 0.1 MGTs may be required for a DTS equivalent of 30-50% lateral resistance restoration. Thus while the DTS benefits are relatively reliable and consistent, there are several traffic/tonnage based consolidation issues/questions not resolved to date. These include: (1) is there a train speed influence on consolidation, (2) is there an axle load influence, (3) is there a curvature influence, (4) is there a track material influence i.e. ballast type, tie type, etc., and (5) is there an “initial condition” influence i.e. for example a skin lift might produce a 30% decrease in resistance, whereas a major surfacing might be a 60% reduction, both requiring different recovery rates. Tests are needed to better evaluate and quantify these parameters/conditions. The key railroad impact issue is that there is an urgent need for such data to manage speed restrictions after maintenance quickly an effectively without compromising safety.
Figure 8 – Concrete Tie MGT Consolidation Tests at FAST (Ref. 10)

Figure 9 – Concrete Tie Track Stabilization Tests on Amtrak/New Carrollton (Ref. 12)

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4.0 LATERAL RESISTANCE INFLUENCE ON TRACK STABILITY

Track lateral stability assurance requires effective lateral strength management. The track stability mechanism features are outlined in Table 1, where track lateral resistance is a contributor to all three events of the lateral stability mechanism.

Table 1 – Track Lateral Stability Mechanism

<table>
<thead>
<tr>
<th>Stage</th>
<th>Event</th>
<th>Major causal factors</th>
</tr>
</thead>
</table>
| 1     | Formation of initial track misalignments  | 1) High L/V’s  
       |                                             | 2) Reduced local lateral resistance  
       |                                             | 3) Initial imperfections (welds), construction anomalies, and install errors          |
| 2     | Growth of misalignments (Track Shift)     | 1) Increase in L/V, and high longitudinal forces  
       |                                             | 2) Reduced lateral resistance at line defects  
       |                                             | 3) Track “dynamic uplift”  
       |                                             | 4) Many cycles of L/V’s                                                                  |
| 3     | Buckling                                  | 1) High longitudinal force  
       |                                             | 2) Reduced $T_N$ (stress-free temperature)  
       |                                             | 3) Weakened lateral resistance  
       |                                             | 4) Train loads and dynamics  
       |                                             | 5) Misalignments generated by track shift                                                  |

The mechanistic difference between track shift and track buckling is in the principal load mechanism producing the event, namely the many cycles of L/V’s for track shift versus the high longitudinal forces for track buckling. Also, track buckling typically requires the presence in initial line defects which are usually generated by track shift. Both track shift and track buckling events are highly impacted by lateral resistance, but in different aspects as discussed below.
4.1 Lateral Resistance Influence on Track Shift and Lateral Alignment Retention

Track lateral shift is the formation and growth of lateral track misalignments due to high lateral to vertical load ratios (net axle L/V’s or NAL’s) coupled with longitudinal forces. Usually many axle passes and high L/V’s are required to produce a misalignment. Typical description of track shift is in terms of cumulative lateral deflections versus the number of axle passes is shown in Figure 10 together with the influencing parameters, including the lateral resistance components.

The lateral resistance function and its idealization for track shift analyses have to account for both the loaded and unloaded resistance, hence the importance of the tie/ballast friction coefficient parameter. Figure 11 depicts the lateral resistance elements for track shift. As research has shown, the key lateral resistance parameters for the determination of cumulative deflection due to net axle L/Vs are the slopes defining the elastic and the peak limits as indicated by $F_e$, $w_e$, $F_p$ and $w_p$ on Figure 11. The lateral resistance elastic limit ($F_e$ and $w_e$) is most important in track shift response because it governs the ballast load-unload hysteresis characteristics, hence the residual deflections. The analysis to predict track lateral shift response is by the US DOT/Volpe model called TRED (short for Track Residual Deflection Analysis). For a detailed description of

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TREDA, its validation, parametric studies, and for its applications to determine maximum allowable L/Vs to prevent excessive residual lateral displacements refer to [5, 6, 15, 16].

An example on the influence of lateral resistance elastic limit on track lateral deflection response is illustrated in Figure 12. The response is highly elastic limit dependent, and the figure shows that for the parameters chosen to represent a “weak” resistance, 2° curve, concrete tie track under summer conditions, an L/V=0.5 (vertical axle load of 55kips and a lateral axle load of 27.5 kips) is not permissible due incurring progressive lateral deflections.
4.2 Lateral Resistance Influence on Track Buckling

It is well established that track lateral resistance plays a key role in track buckling. Many buckling derailments are attributable all or in part to weakened ballast condition, hence to a reduced lateral resistance. In order to better portray the impact of lateral resistance on track buckling, it is important to provide a brief synopsis of track buckling fundamentals.

4.2.1 The Buckling Mechanism

Track bucking is best described through a stability diagram that portrays all the positions of equilibrium as illustrated in Figure 13 in terms of temperature increase above neutral (T_N) versus lateral displacement.
The two equilibrium positions of interest are the peak and minimum points on the curve denoted by $T_{b\text{max}}$ and $T_{b\text{min}}$ which define the “buckling regime” in which buckling takes place. $T_{b\text{min}}$ is referred to as the “safe allowable temperature increase” in accordance with structural stability criterion. Current track buckling safety criterion is in fact based on $T_{b\text{min}}$ plus a safety factor [17]. As expected, $T_{b\text{max}}, T_{b\text{min}}$ and the buckling regime are highly track parameter dependent, where one key parameter is lateral resistance.

4.2.2 Lateral Resistance Influence on Buckling Temperatures

Over the years numerous analytic studies have been performed on evaluating lateral resistance parametric aspects on buckling temperatures [2, 18], and here just a few salient points will be illustrated. It is most important to recognize the importance and influence of both the peak and the limit resistances which is illustrated in Figure 14 and described in [18]. Principally, the peak resistance controls $T_{b\text{max}}$, where as the limit resistance strongly influences $T_{b\text{min}}$, the safe temperature increase value. Hence since $T_{b\text{min}}$ determines buckling safety through $T_{\text{all}}$, the knowledge of the full lateral characteristic is critical.
Since in most practical applications it’s difficult to evaluate the large displacement limit resistance values, correlation statistics have been developed to afford easier analytic treatments. The resulting empirical relationships are based on the over 500 STPT measurement in the US, both at TTC/FAST and in revenue service. Additional correlations with similar results were established by British Rail (BR) and Deutsche Bahn (DB) [19]. The US measured correlation equations relating $F_P$ and $F_L$ are given from [2] as:

Wood

\[
F_L = \begin{cases} 
0.3F_P + 500 \text{ lbs} & \text{if } F_P \geq 715 \text{ lbs} \\
F_P & \text{if } F_P < 715 \text{ lbs}
\end{cases}
\]

Concrete

\[
F_L = \begin{cases} 
0.38F_P + 950 \text{ lbs} & \text{if } F_P \geq 1530 \text{ lbs} \\
F_P & \text{if } F_P < 1530 \text{ lbs}
\end{cases}
\]

Buckling analyses embodying the non-linear aspects of the lateral resistance and its tie/ballast friction coefficient based dynamic effects are available through the US DOT/Volpe Center developed CWR-SAFE model [20]. Some key lateral resistance parametric influences are illustrated below.
(a) Buckling Response Behavior for “Weak”, “Average” and “Strong” Resistance Tracks

Figure 15 shows the buckling response comparison for a 136# CWR wood tie 5 deg curve track with FRA Class 4 line defects when the lateral resistances for “weak”, “average” and “strong” conditions are as shown in the right hand side of the figure. The difference in the respective buckling regimes is evident. In fact, for the weak resistance condition there is no buckling regime indicating a highly unstable condition as evidenced by the progressive lateral displacements with temperature. Thus the inference from the figure is that for this track type/condition the “strong” resistance track buckles in between 100 – 140°F above neutral, “average” resistance between 87 and 94°F, and “weak” resistance track does not buckle in the conventional sense, but progressively shifts with temperature, indicating a highly unstable and unsafe condition.

Figure 15 – Lateral Resistance Influence on Buckling Temperatures for Weak, Average and Strong Track Conditions

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(b) Influence of Lateral Resistance on “Safe” Temperatures for Buckling Prevention

As discussed, lateral resistance is a highly variable parameter, and for concrete ties it typically falls into the four peak resistance ranges: (1) less than 1900 lbs/tie for weak, recently maintained conditions; (2) 1900 to 2500 for marginal conditions where consolidation is active; (3) 2500 to 3200 for average conditions, and (4) above 3200 for well maintained, fully consolidated tracks.

Figure 16 shows the influence of these 4 categories on “safe rail temperatures” for buckling prevention for tangent and curved tracks with FRA Class 4 line defects and with a neutral temperature of 60°F. Also shown on the figure is the measured data from the Volpe/AMTRAK tests from Figure 9.

Figure 16 – Influence of Lateral Resistance on Safe Temperature Increase

Figure 16 indicates the importance and benefit of consolidation in terms of safe rail temperatures by increasing it from a low 118°F to a more acceptable 134° for the 5 deg curve, and from 138°F to 144°F for the tangent. Note that for higher neutral temperatures, the safe temperature values increase correspondingly by the amount of the neutral temperature change.

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5.0 Conclusions and Recommendations

1. Track lateral resistance is a key parameter for lateral stability assurance. It is typically represented through “spring” type load-deflection characteristics which are non-linear and highly variable. The key descriptors are the “peak” and “limit” values which depend on: tie type, weight, shape and spacing; ballast type/condition, shoulder width, crib content; ballast maintenance, degree of consolidation, and train loads. It is measured most conveniently by a single-tie-push-test (STPT) method which mobilizes the tie in the ballast and records the load-deflection response.

2. Lateral resistance has both static and dynamic components. The dynamic characteristics depend on the loaded and unloaded (dynamic uplift) frictional interface between tie and ballast as represented by a tie/ballast friction coefficient parameter which is experimentally determined. It is this dynamic resistance value that’s required in lateral stability analyses.

3. Ballast maintenance has a large influence on reducing lateral resistance which can be on the order of 30-70%. Such reductions can cause damaging track failures through track buckling or by excessive misalignments generated by track shift. In order to mitigate such failures, lateral strength restoration is required through either mechanical (DTS) or train traffic (MGT) induced consolidation.

4. Whereas DTS has proven to be an effective and efficient means to quickly restore 30-50% of the reduced resistance, the train traffic (MGT) based consolidation may require tonnage levels well in excess of the currently accepted 0.1 MGT equivalent, as US data indicates. Since even the 0.1 MGT’s slow order traffic may be prohibitive for most railroads, more tests and analyses are required to better evaluate the tonnage consolidation aspects. Such studies need to address several ballast compaction mechanics issues, including the effects of axle loads and speeds on
consolidation, track curvature influences, track type/material/component influences, and recovery rates required for lateral stability assurance.

5. Track lateral stability assurance requires addressing the two key failure modes of track buckling and track shift. The track buckling safety limits in terms “allowable temperature increase values” above neutral are strongly lateral resistance dependent, as are the actual buckling temperatures. Hence restoration of reduced resistance due to maintenance to “safe” levels is a key part of track buckling prevention. Such lateral strength restorations through dynamic track stabilization (DTS) have proven to be quite effective, whereas the similar effects through tonnage (MGT) require more evaluation and testing.

6. Mitigation of track shift and resulting unsafe alignment defects also require high lateral resistances. The particular requirement is a high lateral resistance elastic limit, which can be achieved through a high peak resistance value. The impact of such high elastic and peak values is an allowance for higher net axle L/V’s and higher speeds.

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Paper Overview, Content, and Key Issues

Overview

Paper deals with track lateral resistance issues addressing track lateral stability management including maintenance, geometry retention and track buckling prevention.

Key Issues Addressed

What is track resistance and key influencing parameters?
What impacts on track maintenance, track buckling, and track shift?

Paper Content

• Track lateral resistance fundamentals
• Lateral resistance and ballast stabilization
• Lateral resistance influence on track stability
• Key research needs for more effective management
Talking Points

• What is track lateral resistance, key components/parameters and how to measure?

• What maintenance aspects/requirements for consolidation?

• What US data on resistance restoration after ballast work?

• What impacts on track buckling and track shift?

• What research needs?
### What is track lateral stability?

**Track Lateral Stability Mechanism**

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3) Initial imperfections (welds), construction anomalies, and install errors |
| 2     | Growth of misalignments (Track Shift)          | 1) Increase in L/V, and high longitudinal forces  
2) Reduced lateral resistance at line defects  
3) Track “dynamic uplift”  
4) Many cycles of L/V’s |
| 3     | Buckling                                        | 1) High longitudinal force  
2) Reduced $T_N$ (stress-free temperature)  
3) Weakened lateral resistance  
4) Train loads and dynamics  
5) Misalignments generated by track shift |

**Note:**
- **High Axle Load Problem**
- **High Thermal Load Problem**
- **TREDA**
- **CWR-SAFE**
**Definition:** TLR is the reaction offered by the ballast to the rail-tie structure against lateral movement.

**Diagram:**
- Ballast reaction (lb/tie) or (lb/in)
- Lateral spring
How to Measure?

Measurement Methods

- single tie push test (STPT) ✓
- discrete cut panel pull test
- continuous track panel pull test (TLPT)
- continuous dynamic measurement (Plasser-DTS)
- analytic empirical model (CWR-SAFE)*

* Model “trained” by over 1000 STPT measurements to provide lateral resistance based on inputs of: tie type, shoulder width, crib content, and consolidation
Typical Behavior and Values

Typical concrete tie peak values (static)

- **Weak**: 1800 lbs/tie, 7.5 kN/tie
- **Marginal**: 2000 lbs/tie, 10.0 kN/tie
- **Average**: 2200 lbs/tie, 12.5 kN/tie
- **Strong**: 2400 lbs/tie, 15.0 kN/tie

Note: for timber ties subtract 500 lbs/tie

*Typical consolidation range
Factors Influencing Lateral Resistance

- Tie type, weight, shape and spacing; ballast type and condition (fouled, frozen, etc.)
- Shoulder width, crib content
- Maintenance, degree of consolidation, and vehicle loads (dynamic uplift)

Can result up to 40% loss of lateral resistance
Friction coefficient $\mu$ is a key parameter in both track buckling and track shift analyses.
• Ballast maintenance can reduce TLR by 40 - 70%; requires consolidation either by dynamic track stabilization (DTS) or traffic. DTS can increase value by 30 – 40%; traffic consolidation may require over 0.1 MGTs (million gross tons) of traffic coupled with slow-orders.

DTS principle: a quick restoration of the tie bottom friction component of lateral resistance by applying vertical load coupled with horizontal vibration.

• Initial assumption on traffic consolidation: 0.1 MGT = 30-40% DTS

Has not been demonstrated by US experience!
### US Data on Ballast Consolidation

#### Chessie and Amtrak Tests - concrete ties (1985, Sluz, [8])
- Chessie: 9% recovery after 0.076MGT
- Amtrak: 11% recovery after 0.073MGT

#### AAR/TTC Tests - wood ties (1990 – Trevizo, [9])
- Tangent: 17% recovery after 0.1MGT; 32% after 1MGT
- 5° Curve: 9% recovery after 0.1MGT; 21% after 1MGT

- Wood - tangent: 26% recovery after 0.1MGT
- Concrete – 5° Curve: 52% reduction due to tamping
- Concrete – 5° Curve: 22% recovery after 0.1MGT

- Concrete (new-scalloped) - 17% recovery after 0.35MGT
- DTS increase - 33%

#### Volpe/Amtrak/FRA Tests - concrete (2001- Kish, et al, [12, 13])
- 43% reduction due to surfacing with ½ inch lift
- DTS increase: 31%

#### UP/Foster-Miller Tests - wood/concrete/old/new/DTS (2001-Samavedam [14])
- 39-70% reduction due to tamping/surfacing
- 0.1MGT had negligible influence on wood after tamping
- DTS increase on concrete: 22%
- After DTS, traffic decreased lateral resistance initially, then it increased
- Heavy rain/wet ballast: 20% decrease in lateral resistance on wood

---

0.1 MGT traffic does not produce the DTS equivalent, but LOWER!

More R&D and tests are required to better quantify tonnage based consolidation.
What resistance is required?

Key Notes/Questions

(1) The % recovery is important, but MORE important are the actual values i.e. where from and where to?
   (a 35% recovery from 1800 lbs/tie is different than a 35% recovery from 2300 lbs/tie)

   Need to know/measure absolute values!

(2) What is the minimum resistance required for buckling safety?

   Answer: depends on track parameters and conditions!

   • Track neutral temperature
   • Track alignment
   • Track curvature
Minimum Resistance for Buckling Safety

**Parameters:** 5° (350m radius) curve; concrete tie track with Class 4 (38mm/10m) line defect; US-136#CWR; variable lateral resistances

**Strong**

**Average**

**Marginal**

**Weak**

**T_N = 50°F**

**T_N = 60°F (16°C)**

**T_N = 70°F**

**T_N = 80°F**

**T_N = 90°F**

**T_N = 100°F (38°C)**

**Safe allowable rail temperature**

**Lateral resistance (lbs/tie)**

**Lateral resistance (kN/tie)**

**°F**

**°C**
Influence of Track Stabilization on Buckling Safety

Parameters: Tangent and 5° (350m radius) concrete tie track with Class 4 (38mm/10m) line defect; 136# CWR; $T_N=60^\circ$F (16°C); variable lateral resistances

Realized Benefit Is MORE!!

Volpe/AMTRAK New Carrollton Data

$T_N=60^\circ$F(16°C) 5 deg curve

Before Surfacing

Tangent

After DTS

T $B_{min}$

(Buckle)

Lateral deflection, $\delta$

Typical Consolidation Regime

Track quality: **AVERAGE**

Track quality: **MARGINAL**

Realized Benefit Is MORE!!

Before Surfacing

New Carrollton Data

After DTS

After Surfacing
**Track Shift:** incurrence of cumulative residual deflections under many axle L/V (NAL) passes

- Moving axle loads; **vertically loaded and unloaded lateral resistance**; thermal loads; curvature and alignment defects
Tack Shift Residual Deflection Mechanism: Moving L/V Loads

- Net residual deflections are a cumulative sum of axle load passes!
Lateral Resistance Influence on Track Stability

**Track Buckling**
- Peak Resistance, $F_p$
- Limit Resistance, $F_L$
- $W_p$
- $W_L$
- $T_R$
- $T_{bmax}$
- $T_{bmin}$
- $T_{all}$
- $T_N$
- Lateral Displacement

**Track Shift**
- $W_e=0.005$ in.
- $W_e=0.03$ in.
- $W_e=0.05$ in.
- $W_e=0.015$ in.
- $2^\circ$ concrete tie; 136#;
- $\theta=50^\circ$; $V=55$ kips;
- $F_p=2000$ lbs; $F_e=1500$ lbs;
- $w_p=0.3$ in; $L/V=0.5$

**Elastic Limit Influence**
- $F_p (\text{dyn})$
- $F_p (\text{stat})$
- $F_e$
- $W_e$
- $W_p$
- $u \cdot R_v$
- Loaded tie
- Unloaded tie
- Tie ballast friction coefficient
- Tie load

**Residual deflection**
- Number of axle passes
- Residual deflection (in)
- $0$, $10$, $20$, $30$, $40$, $50$, $60$, $70$, $80$, $90$
- We=0.005 in.
- We=0.015 in.
- We=0.03 in.
- We=0.05 in.
Lateral Resistance Influence on Track Stability

Key Track Shift Issues

What is the allowable net axle \( L/V \) for high speed passenger operation?

\[ L/V = 0.4 + 5/V \]

\( L_{66} = 31.4 \text{ kips or } (L/V)_{66} = 0.48 \)

(what lateral resistance is required to meet criterion?)

What are the limiting \( L/V \) conditions for heavy freight/long train applications?

FRA Vehicle/Track Interaction Safety Limits on Track Shift

Current R&D Need

Requires industry driven R&D program to evaluate limiting conditions/factors
Conclusions

- Track lateral resistance is an important parameter for track geometry retention and track stability management.

- It is a complex parameter: highly non-linear, variable, difficult to measure, has both static and dynamic components where the tie/ballast friction coefficient plays a key role.

- Track lateral resistance is a key parameter for both track buckling and track shift evaluations, but each requires different components of the lateral resistance function.

- Ballast work (surfacing, lifting, tamping) reduces lateral resistance considerably (40-70%) requiring quick and efficient restoration. HOW TO RESTORE?

- Dynamic track stabilization (DTS) has proven to be a quick and effective means to restore lateral resistance, and typically does not require any speed restrictions.

- Based on US data, traffic (MGT) consolidation for equivalent lateral resistance recovery may require larger than the currently accepted 0.1MGTs. MORE R&D IS REQUIRED FOR EVALUATION!
Key Research Need: quantification of MGT consolidation behavior i.e. tonnage requirements for ballast resistance recovery:

- What is the mechanics of ballast compaction under traffic loads?
- What is the influence of axle loads?
- What is the influence of train speeds?
- What is the influence of track types/conditions? (concrete/wood/tangent/curved)
- What is the influence of reduced resistance on recovery? (initial conditions)

Bottom Line: is the 0.1 MGT adequate? If NOT, what is??
On the Fundamentals of Track Lateral Resistance

There's got to be a better way!

THANK YOU AND QUESTIONS?