Talking Points

- The Lateral Stability Problem Definition
  [what is track lateral stability; mechanism; problem severity]

- Track Buckling
  [fundamentals; key parameters; analysis; safety concepts]

- Track Lateral Shift
  [fundamentals; key parameters; analysis; safety concepts]

- New R&D Needs
  [what current “hot” topics]
**Track Stability:** is managing the vehicle and environmentally induced loads (L-V-P loads) to keep track geometry within “safe” limits

### 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 (small) 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 RNT (stress-free temperature)  
3) Weakened lateral resistance  
4) Train loads and dynamics  
5) Misalignments generated by track shift |
The Track Lateral Stability Mechanism

Track Shift vs. Track Buckling

**TRACK SHIFT**
- High Axle Load Problem
  - High L/V
  - Moderate L/V
  - Low L/V

**TRACK BUCKLING**
- High Thermal Load Problem
  - \( P = AE\alpha\Delta T \)

TREDA  \( \Delta T \)  \( \Delta T_{Bmax} \)  \( \Delta T_{Bmin} \)  CWR-SAFE  CWR-SAFE

US DOT/Volpe Models
### ACCIDENTS IN DESCENDING FREQUENCY BY CAUSE

**ALL US MAINLINE TRACK (2010-2013)**  
Track/ Derailment/ Main (through November, 2013)

<table>
<thead>
<tr>
<th>Accident Cause [T-Codes: 65 Total]</th>
<th>No. of Accs.</th>
<th>% Total</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>T109 Track alignment irreg. (buckled/ sunkink)</td>
<td>105</td>
<td>14.7</td>
<td>29</td>
<td>37</td>
<td>27</td>
<td>12</td>
</tr>
<tr>
<td>T110 Wide gage (defective/ missing crossties)</td>
<td>61</td>
<td>8.5</td>
<td>18</td>
<td>11</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>T207 Detail fracture - shelling/ head check</td>
<td>59</td>
<td>8.2</td>
<td>14</td>
<td>19</td>
<td>17</td>
<td>9</td>
</tr>
<tr>
<td>T220 Transverse/ compound fissure</td>
<td>55</td>
<td>7.7</td>
<td>21</td>
<td>14</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>T001 Roadbed settled or soft</td>
<td>44</td>
<td>6.1</td>
<td>16</td>
<td>12</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>T221 Vertical split head</td>
<td>42</td>
<td>5.9</td>
<td>9</td>
<td>13</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>T102 Cross level track irreg. (not at joints)</td>
<td>34</td>
<td>4.7</td>
<td>5</td>
<td>14</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>T314 Switch point worn or broken</td>
<td>27</td>
<td>3.8</td>
<td>11</td>
<td>8</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>T210 Head and web sep. (outside of bar limit)</td>
<td>23</td>
<td>3.2</td>
<td>9</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>T202 Broken base of rail</td>
<td>22</td>
<td>3.1</td>
<td>5</td>
<td>4</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>T101 Cross level of track irregular (joints)</td>
<td>21</td>
<td>2.9</td>
<td>6</td>
<td>10</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td><strong>T108 Track alignment irreg. (not buckled/ sunkink)</strong></td>
<td><strong>19</strong></td>
<td><strong>2.7</strong></td>
<td><strong>4</strong></td>
<td><strong>3</strong></td>
<td><strong>5</strong></td>
<td><strong>7</strong></td>
</tr>
<tr>
<td>T111 Wide gage (spikes/ other rail fasteners)</td>
<td>15</td>
<td>2.1</td>
<td>1</td>
<td>9</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>T299 Other rail and joint bar defects</td>
<td>15</td>
<td>2.1</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>T002 Washout/ rain/ slide/ etc. dmg - track</td>
<td>14</td>
<td>2.0</td>
<td>5</td>
<td>6</td>
<td>.</td>
<td>3</td>
</tr>
</tbody>
</table>

Track buckling caused derailments **rank #1** in BOTH the number of derailments and $$ damage/derailment **a high-priority industry goal to improve!**
The Track Buckling Problem

Problem

- Very difficult to detect
- Dynamic event; can cause derailments
- In USA: many derailments/year at high damage levels [27@ $920M/derailment]_{2012}
- Many incidents/high repair costs
- Tensile rail breaks can also contribute
KEYS TO BUCKLING PREVENTION

- Keep thermal forces within “safe” levels (manage neutral temperature)
- Ensure “good” track conditions (maintain alignment and ballast condition)
- Control train loads and dynamics (apply speed restrictions when/where required)
What is track buckling?

Track buckling is the sudden formation of large lateral misalignments caused by:

- High compressive forces
- Weakened track conditions
- Vehicle loads

High compressive forces:
- Temperature induced thermal loads
- Low or “decreased” neutral temperature

Weakened track conditions:
- Reduced track resistance
- Alignment defects

Vehicle loads:
- Dynamic uplift
- High axle L/V’s
- Braking/traction loads
Buckling Mechanics

Column Analogy for Buckling

Railroad track

Ballast resistance

Initial alignment defect, $\delta_0$

Temperature increase above neutral

Deflection, $w$

Deflection

Safe temperature increase

Buckling regime

Temperature increase above neutral

Deflection

Safe temperature increase

Buckling regime

Initial alignment defect, $\delta_0$

Ballast resistance

Deflection, $w$

Deflection
Critical Parameters Influencing Track Buckling

- Track resistance
- Alignment defects/curvature
- Train loads/dynamics
- Rail neutral temperature
Track Resistance Components

- Lateral resistance (ballast - lateral)
- Longitudinal resistance (fasteners/ballast - longitudinal)
- Torsional resistance (fasteners - in plane bending)

*Lateral Resistance*: reaction offered by the ballast to the rail/tie structure against lateral movement.
How to Measure Lateral Resistance?

Measurement Methods

• single tie push test (STPT)\checkmark
• discrete cut panel pull test
• track lateral 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 level.
What is an STPT Signature?

- **Peak Resistance**
- **Limit Resistance**
- **Elastic Limit**
- **Initial Stiffness**

**Applied Load (lbs)** vs **Displacement (inches)**

**Typical concrete tie peak values (static)**

<table>
<thead>
<tr>
<th>lbs/tie</th>
<th>kN/tie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak</td>
<td>1800</td>
</tr>
<tr>
<td>Marginal*</td>
<td>2000</td>
</tr>
<tr>
<td>Average</td>
<td>2200</td>
</tr>
<tr>
<td>Strong</td>
<td>2400</td>
</tr>
</tbody>
</table>

*Typical consolidation range

**Note:** for wood ties subtract 500 lbs/tie (2.2 kN/tie)
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)

Dynamic Uplift

Increased Resistance

Reduced Resistance

Can result up to 40% loss of lateral resistance

% Contribution Rule of Thumb

Friction (Tie side ballast in crib)

- 25%
- 35%
- 40%

Friction (Tie bottom ballast)

Key Points:

- Track stability analyses require both loaded and unloaded resistances
- Do not neglect the importance of the 25% shoulder width contribution, especially in curves
Curves “breathe” (move in-and-out) under temperature changes. This results in neutral temperature (RNT) change.

As curves pull in ballast at tie ends get voided thereby reducing lateral resistance. Also there can be line defects formed due to non-uniform curve movement.

Take-away: maintain good ballast shoulders on both low and high sides of curves to enhance curve stability!
Friction coefficient, $\mu$, is a tie bottom roughness index.

$$F_{\text{dyn}} = F_{\text{stat}} + \mu R_V$$

What is the increased resistance due to vertical load?

- Friction coefficient $\mu$ is a key parameter in stability analyses.
Factors Influencing Lateral Resistance

- Tie type, weight, shape and spacing; ballast type and condition (fouled, frozen, etc.); shoulder width, crib content; maintenance and consolidation, and vehicle loads.

Ballast maintenance (surfacing, tamping, lining) can reduce TLR by 40 - 60%; requires consolidation either by dynamic track stabilization (DTS) or traffic tonnage.

DTS can increase the reduced TLR by 30 - 60%; traffic consolidation may require over 0.1 MGTs (million gross tons) of traffic at reduced speeds to produce at least a 30-40% DTS equivalent.

DTS principle - vertical loads coupled with horizontal vibration:
- restores a large part of the ballast particle’s interlocking capability, and
- increases the tie bottom/ballast friction coefficient. Test results indicate an immediate 30-60% TLR recovery.

Tonnage principle: the application of many axle loads at slow speeds produces ballast compaction, but the mechanism and the rate are unknown.

0.1 MGT = 30 - 40% DTS increase

This equivalence has NOT been demonstrated in the US [more R&D is needed to evaluate]
Critical Parameters Influencing Track Buckling

- Track resistance
- Alignment defects/curvature
- Train loads/dynamics/uplift wave
- Rail neutral temperature
Managing the Stress State on the Railroad

\[
\sigma_x = \sigma_{xT} + \sigma_{xM} + \sigma_{xR}
\]

(Thermal) (Mechanical) (Residual)

\[
P = EA\alpha(T_R - T_N)
\]

Stress vs. Temperature vs. Force

Managing thermal forces requires managing neutral temperature (RNT, SFT, T_N)

High Tensile Forces

High Compressive Forces

The Thermal Force Problem
Managing the Stress State on the Railroad

Due to traction and braking forces
- Important when close to track’s buckling temperature
- Important in causing RNT changes (areas of heavy train action, bottom of grades)

Due to rail manufacture
- Do NOT contribute to P
- Important in RNT measurements
- Important in fracture mechanics

\[
\sigma_x = \sigma_{xT} + \sigma_{xM} + \sigma_{xR}
\]

- (Thermal)
- (Mechanical)
- (Residual)
**Definition:** Neutral temperature ($T_N$, RNT, SFT) is that rail temperature at which the net longitudinal force in the rail is zero. It is often associated with the “laying” or “fastening” temperature. It has a relationship to the force ($P$) in the rail:

$$P = EA\alpha(T_R - T_N)$$

<table>
<thead>
<tr>
<th>$T_N$</th>
<th>Rail Temp ($T_R$)</th>
<th>Force/Rail, $P$ (US-136# Rail)</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>90°F (32°C)</td>
<td>130°F (54°C)</td>
<td>104,000 lbs (463kN)</td>
<td>NO BUCKLE</td>
</tr>
<tr>
<td>50°F (10°C)</td>
<td>130°F (54°C)</td>
<td>208,000 lbs (925kN)</td>
<td>BUCKLE</td>
</tr>
</tbody>
</table>

Does neutral temperature change, why, and by how much?

Yes, because: (1) CWR is not fully constrained, and (2) stress discontinuity due to breaks/cuts
q RNT is highly variable!

5 Years of RNT Data on a Major US Railroad

Typical Installation Regime

2°(875m) Curve

Neutral Temperature (°F)

Low Rail
High Rail
RNT is highly variable!

The RNT Problem

Rail Breaks Cause Large Reductions in RNT
RNT is highly variable!

**BOTTOM LINE**: RNT is highly variable, and need to know/measure for track buckling mitigation!
The RNT Problem

Why do rail breaks and defect removals cause buckling prone conditions?

5 Years of RNT Data on a Major US Railroad

The Rail Break and Defect Removal Problem

In the US, rail flaw inspection detects over 100,000 internal defects annually requiring removal; in addition there are another 80,000 service failures.

When rail breaks or is cut for defect removal the RNT is substantially reduced - requires adjustment.

RNT readjustments after rail breaks/defect removals are difficult due to NOT knowing what reduced RNT condition is being adjusted.

If RNT is NOT readjusted prior to the onset of warm temperatures, the track can become buckling prone.

There can be 180,000 locations with RNT readjustments needs annually with potential buckling concerns!
Cold Temperature Rail Defect/Break Repair/RNT Readjustment Issues

**Key RNT Readjustment Issues:**

1. **when to come back to readjust**
   - Before rail temps exceed prescribed values

2. **how to readjust (how much rail to cut out and what length to unfasten)**
   - New TTCI software: CWR-Adjust

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**Key Points on RNT**

- RNT of both rails govern buckling potential
- Track RNT (average of two rails) acceptability "Rule of Thumb":
  - unacceptable
  - marginal
  - fair
  - good
  - 50°F
  - 70°F
  - 90°F
- 20-40°F decrease in RNT due to rail kinematics is typical; much larger RNT lowering in rail break/cut scenarios
- When rail breaks or is cut, the RNT is the same as $T_{RAIL}$
- Lowering of RNT typically occur:
  1. at breaks/cuts where rail has been added
  2. in areas of heavy train action/bottom of grades
  3. in curves after winter pull-in
  4. on approaches to "rigid" structures
  5. areas of weak anchors/fasteners (rail running) [loss of toe-load/rail-seat abraison]

**Major Impediment**

- very difficult to measure accurately, nondestructively, and continuously
RNT Measurement Concepts

Concepts Researched

- Mechanical/electrical resistance strain gage
- Rail uplift
- Rail vibration
- Vibrating wire/filament
- Ultrasonic wave
- Acoustic wave
- Electromagnetic/acoustic wave (EMAT)
- Magnetic permeability: (Barkhausen noise) (Magnetostriiction)
- X-ray diffraction
- Fiber optics
- Moiré- fringe interference

- Have accuracy issues: (sensitivity to rail microstructure, residual stresses, track parameters; hard to get RNT from stress; “zeroes” required)
- Don’t provide real-time, continuous data output
- Not nondestructive and not easily deployable
- Not cost prohibitive

Systems in Place: Salient Rail Stress Module (RSM); Rail Uplift (VERSE)
**Stress/RNT Measurement Issues**

**RNT Measurement Systems (US)**

**Salient System’s RSM**
Continuous, real-time data; has buckle hazard warning and rail break detection capability; but requires a “zero” calibration

**VERSE**
One time measurement; works in tension only; does not work in curves >3 deg; needs unfastening 100 ft of rail; may need rail profile measurement; no zero calibration
Buckling Safety Criterion

Longitudinal Load < Buckling Load

For track: \((T_R - T_N) < T_{all}\)

Typically NOT known!

Highly Variable!
- rail kinematics
- rail breaks/defect cuts

Difficult to Measure!

Most Important Rail Technology R&D Topic

Predicted by CWR-SAFE

Buckling Strength, \(T_{all}(°F)\) [above neutral]
Question: What are the “safe” temperatures to prevent track buckling?

- Track parameters and conditions
  - Rail properties
  - Curvature
  - Alignment defect
  - Track resistance
    - Lateral
    - Longitudinal
    - Torsional
  - Tie/ballast friction coeff.
  - Track modulus
  - Vehicle characteristics
  - Neutral temperature

- Analytic tools, models and tests to evaluate buckling temperatures

- Safety criterion

UIC Leaflet #720 (ERRI/D202):

- Buckling safety criteria
  - [US: $T_{Bmin}$]
  - [UIC]

Buckling Safety Criteria

- Level 1: $T_{Bmin}$
- Level 2: $T_{Bmin} + \Delta$
  
  $\Delta = 0.25(T_{Bmax} - T_{Bmin})$
Theoretical Aspects

- Classical non-linear beam theory and variational principles of minimizing the total potential energy of the track in the lateral plane

Lateral and Longitudinal Model

- Vertical track model to evaluate “dynamic resistance” aspects

Vertical Model
Theoretical Aspects

- Requires both tangent and curved track analysis and assumptions on mode shape

### Tangent and Curved Track Formulations

**Tangent Track**

**Curved Track**

\[ w(x) = \delta \left[ 1 - \frac{x^2}{L_1^2} \right] \left[ 1 + \frac{x^2}{L_2^2} \right] \]

### Buckle Mode Shape Assumptions

- **Symmetric mode (Shape I)**
  - 1 half wave

- **Anti-symmetric mode (Shape II)**
  - Buckled region
  - Adjoining region

- **Symmetric mode (Shape III)**
  - 3 half wave

Model validated by full scale dynamic buckling tests at TTC
Buckling Safety Parametric Studies

Buckling Safety Criteria Based Temperature Limits

Parameters: 5° (350m radius) curve; concrete tie track with Class 4 (25mm/10m) line defect; US-136#CWR; variable lateral resistances → CWR-SAFE

Parameter: Safe rail temperature (°F / °C)

- Strong
  - $T_N = 50°F (16°C)$
- Average
  - $T_N = 60°F (16°C)$
- Marginal
  - $T_N = 80°F (26°C)$
- Weak
  - $T_N = 100°F (38°C)$

Parameter: Lateral resistance (lbs/tie / kN/tie)

- Weak
  - 15
- Average
  - 10
- Strong
  - 5

Note: for more details, refer to Kish & Samavedam: “Track Buckling Prevention: Theory, Safety Concepts, and Applications” [DOT/FRA/ORD-13/16, March 2013]
The High Axle Load (L/V) Problem - Track Shift

**Track Shift**: incurrence of cumulative lateral residual deflections under many axle L/V passes

- Moving axle loads; dynamic (vertically loaded and unloaded) lateral resistance; thermal loads; curvature influences, and alignment defects

**Key Issue**:
- What is the permissible net axle L/V to limit lateral deflections to “allowable” values
- For a prescribed L/V, what is the minimum ballast resistance required to limit lateral deflections to “allowable” values
Elastic Limit, Peak Resistances, and Vertical Load Issues

Hysteresis loop (loading/unloading cycle) is a key part of the track shift mechanism.
Tack Shift Residual Deflection Mechanism: Moving L/V Loads

- **F_p (stat)**
- **F_p (dyn)**
- **We**
- **Lateral Deflection, W**
- **W_p**
- **Tie load**
- **Tie friction coefficient**
- **µ**
- **R_v**

**Cumulative deflection (in)**

<table>
<thead>
<tr>
<th>Number of passes</th>
<th>Cumulative deflection (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>20</td>
<td>0.05</td>
</tr>
<tr>
<td>40</td>
<td>0.10</td>
</tr>
<tr>
<td>60</td>
<td>0.15</td>
</tr>
<tr>
<td>80</td>
<td>0.20</td>
</tr>
<tr>
<td>100</td>
<td>0.25</td>
</tr>
<tr>
<td>120</td>
<td>0.30</td>
</tr>
</tbody>
</table>

**Safety limit**

- L/V = 0.45
- L/V = 0.43
- L/V = 0.41
- L/V = 0.39
- L/V = 0.37

**TREDA**

- Stable
- Unstable

**# of Passes**

- Stable
- Unstable
**Track Shift Safety Criteria**

“Lateral loads generated by high-speed vehicles operating under maximum speed, cant deficiency, thermal load, and initial line defect conditions should not produce permanent lateral track displacements exceeding X inches”

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**Level 1 Safety:**
elastic limit criteria
[zero permanent set]

**Level 2 Safety:**
allowable deflection criteria
[0.1” finite permanent set]

**US Safety Limits**

$L = 0.4V + 5$

(L,V in kips; V = axle load)
Question: what minimum track lateral resistance is required for compliance with track shift safety limits?

US Safety Limits

\[ L = 0.4V + 5 \]

(L, V in kips; V = axle load)

UIC Safety Limits

\[ H = k(0.33P + 10) \]

(H, P in kN; P = axle load; k=0.9 for HSR)
What lateral resistance is required to comply with safety limits?

**High Speed Passenger**

- **US Limits**
  \[ L = 0.4V + 5 \]
  (\(L, V\) in kips, \(V\)=axle load)

- **UIC Limits**
  \[ H = k(0.33P + 10) \]
  (\(H, P\) in kN, \(k=0.9\) for HSR)

Have \(L/V\) (\(H/P\)) criteria, but don’t have limiting ballast resistance

**High Tonnage Freight**

Don’t have either \(L/V\)’s criteria or limiting ballast resistance

Requires R&D: what ballast strength required?
**Question:** have we reached the limit of lateral ballast strength capacity?

**YES:** with reduced RNTs

**YES:** with high L/V’s

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How to Improve?

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**CWR Stress Management 2014**

**Ballast Strength and Lateral Stability**

**High Tonnage Freight**
Develop “best practice” guidelines for CWR/RNT management

- ensure effective anchors/fasteners
- promote more effective CWR installs (especially in cold weather)
- limit/monitor curve movement
- conduct hot and cold weather inspections
- develop more effective rail break/defect repair RNT readjustments practices
- improve hot-weather speed restrictions

Know/measure RNT!

Promotes all aspects of stress management and CWR safety

Promote improved ballast maintenance practices for more effective lateral resistance management

Consider alternative track designs aimed at “High Lateral Strength Track”

DTS provides a quick, efficient and effective restoration of TLR

HDS-SSL Ties @ FAST

Require/conduct more R&D on improving track stability management
Key Current R&D Needs in CWR Stability

- Develop a unified theory/model for lateral stability
- What is the mechanics of ballast compaction under traffic loads?
- How to more effectively manage curve movement and stability?
- What are the limiting L/V conditions for heavy freight/long train/DPU applications i.e. what requirements on ballast strength?
- Develop an accurate RNT measurement technique
Under a set of L-V-P loads is the track within “safe” geometry limits?

Key Current R&D Needs in CWR Stability

- Develop a unified theory/model for lateral stability

Under a set of L-V-P loads is the track within “safe” geometry limits?
What is the mechanics of ballast compaction under traffic loads?

**Issue:** the currently accepted industry practice of 0.1 MGT traffic for consolidation may not be adequate? If NOT, what is??

**Need to Evaluate:**

- 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 track maintenance?
- How to manage settlement uniformity/vertical alignment quality during consolidation?
How to more effectively manage curve movement and stability under thermal and dynamic loads?

Key Current R&D Needs in CWR Stability

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

Problem

- Curve Movement/RNT Management
- Curve Stability Under Long Train/DPU Loads

Requirements

- Requires autonomous curve movement data and RNT correlation capability

Data Chart

- Degree of curvature
- Neutral temperature change (°F)
- Curve Shift vs RNT Change
- 1 Rear End DPU
- 1 Middle DPU
- 2 Head End Units

- Outward Force
- Inward Force
- Longitudinal and Thermal Load Influence

- 140 Car Train (36 ton axle loads)
Key Current R&D Needs in CWR Stability

- Develop an effective RNT measurement technique

**Technique Development Challenges**

- **Accuracy:** need to measure RNT within ±5°F (±3°C) [must resolve sensitivity issues with rail microstructure, residual stresses, and track type/condition parameters]

- Be as **non-destructive** as possible; easily **deployable**, and **durable**

- Provide "**absolute force/RNT**" (i.e. not require any "zero" reference calibration)

- Provide **continuous measurement with real time data**

- Be a **cost-effective/ROI based** technology

**Most Important R&D Topic in CWR Stress Management and Safety**
Thank You!

Questions?

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Dr. Kish received his Ph.D. from New York University in Applied Mechanics in 1974 under Prof. Arnold D. Kerr. He has been at the US DOT’s Volpe Center for over 30 years where as a senior technical expert on track structures and mechanics managed a multitude of research programs in the field of track mechanics including track stability, CWR maintenance, track buckling prevention and high speed rail safety. On the international front, from 1992-1998 he served as the US Department of Transportation’s representative to the European Rail Research Institute’s (ERRI) committee on track stability where he was instrumental in developing new CWR safety codes for the Union of International Railways (UIC).

His work has resulted in over 125 publications on CWR stability and safety and related topics and he has been a three-time recipient of the US Department of Transportation’s Superior Achievement Award. Dr. Kish also held the position of Adjunct Assistant Professor of Aerospace and Mechanical Engineering at Boston University and has also taught graduate courses in applied mechanics at Northeastern University.

Over the years, he has conducted many track buckling workshops and seminars for the industry and is a recognized international expert in the field of track stability, CWR maintenance and track buckling prevention. Dr. Kish retired from the Volpe Center in 2004 to form his consulting company Kandrew Inc. Consulting Services and remains active in providing railway technology consulting services to the research community and the railway industry.
Applicable Bibliography

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