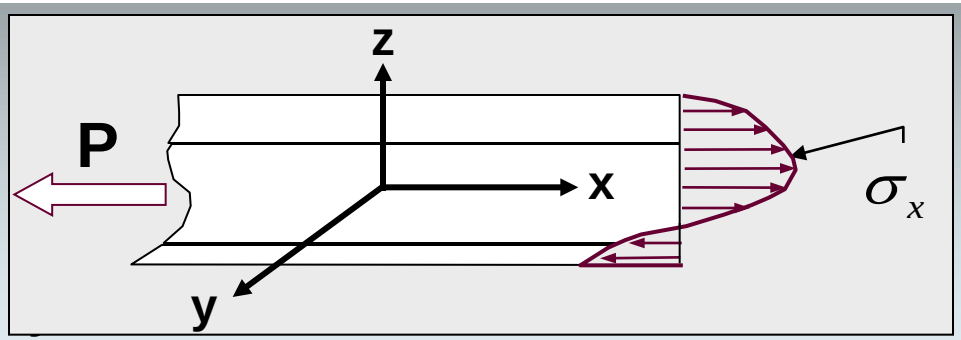
Fundamentals of Rail Stress Management



Dr. Andrew Kish
President - Kandrew Inc. Consulting
Peabody, MA, USA

Talking Points

- What is the rail stress/neutral temperature (RNT) problem?
- What impacts on track buckling and rail breaks?
- Why are rail break/defect repairs key to rail stress management?
- How to more correctly manage rail break/defect repairs?
- What new challenges/topics?

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Problem Definition

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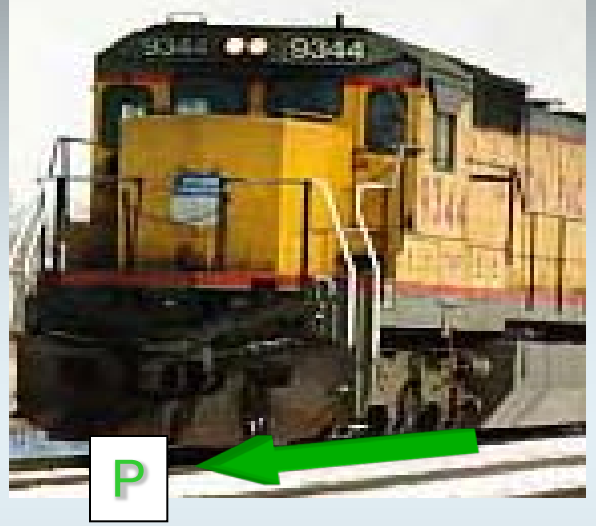
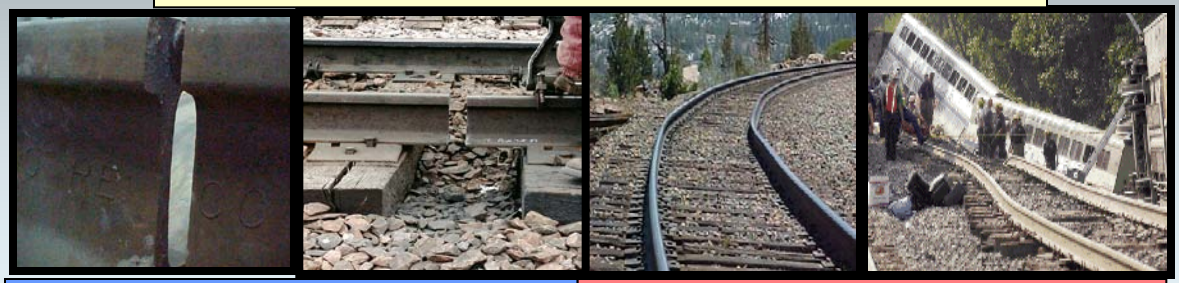
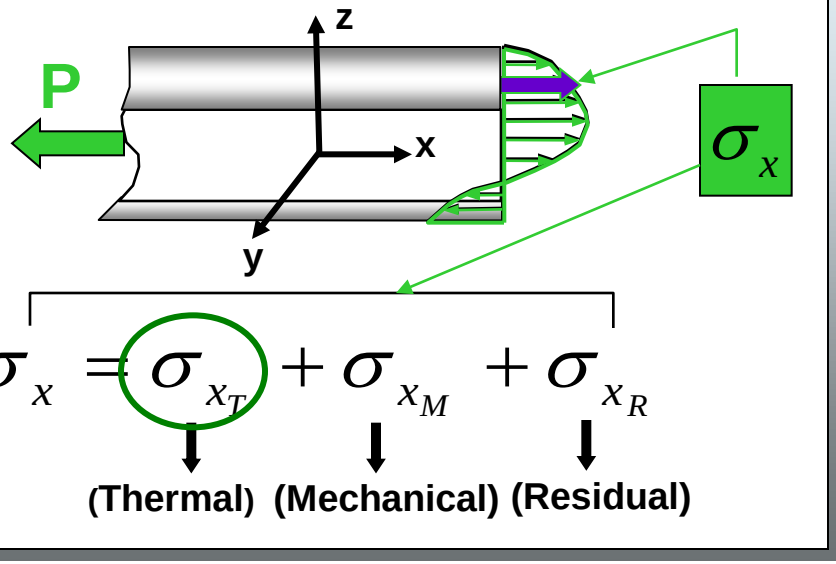
Managing the Stress State on the Railroad



P → **The Thermal Force Problem** ← P



High Tensile Forces | **High Compressive Forces**



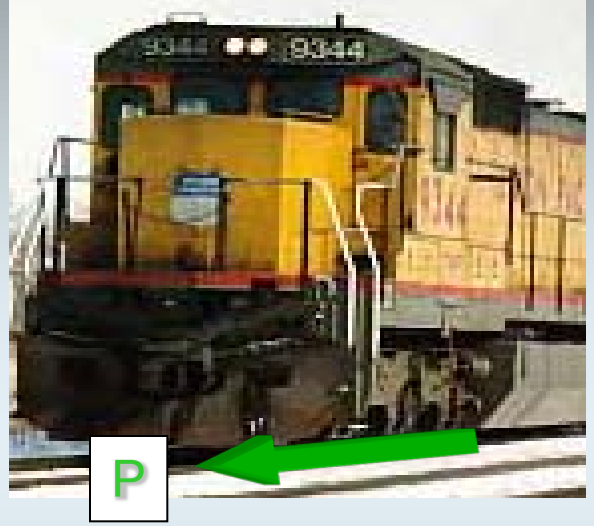
How to keep the longitudinal forces within "safe" limits?

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

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

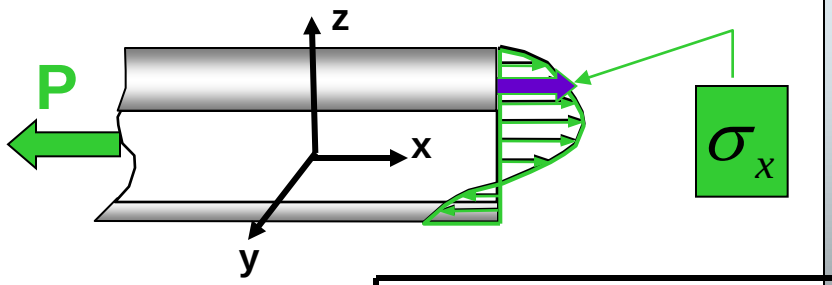
Problem Definition

Managing the Stress State on the Railroad



Due to Traction and Braking

- Important when close to track's buckling temperature
- Important in causing RNT changes (areas of heavy train action, bottom of grades)



Do NOT Contribute to P

- Important for RNT measurement when measurement concept is "stress" based
- Important in fracture mechanics

$$\sigma_x = \sigma_{x_T} + \sigma_{x_M} + \sigma_{x_R}$$

(Thermal) (Mechanical) (Residual)

What Is the Track Buckling Problem?

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What is the Track Buckling Problem?

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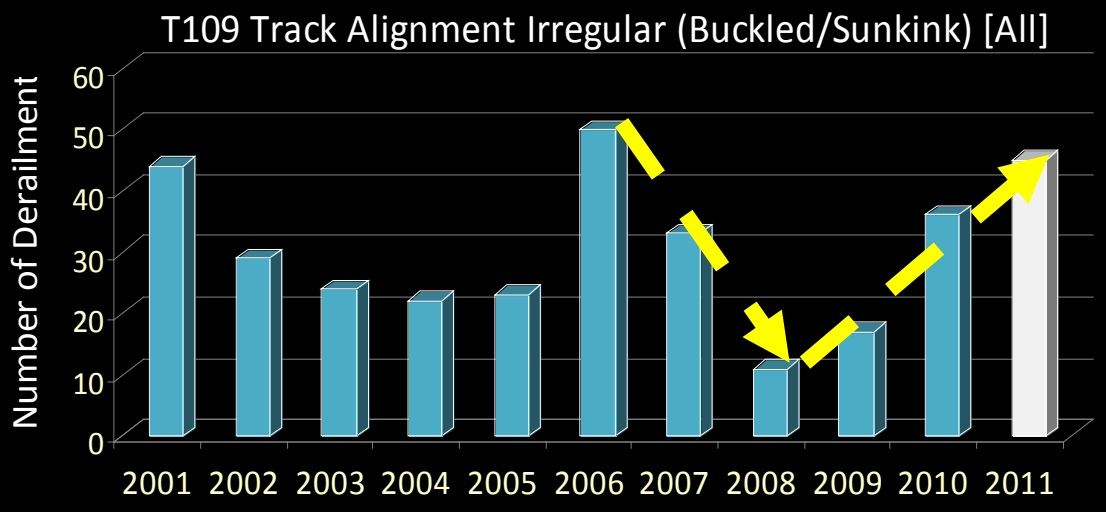


***2011*: 45 @ $19M** - #1 in BOTH number of derailments and $$$ damage; mainline: 37 @18.7M = $505K/derailment *(NOT including injuries/fatalities, evacuations, emergency response; legal fees, etc.)*

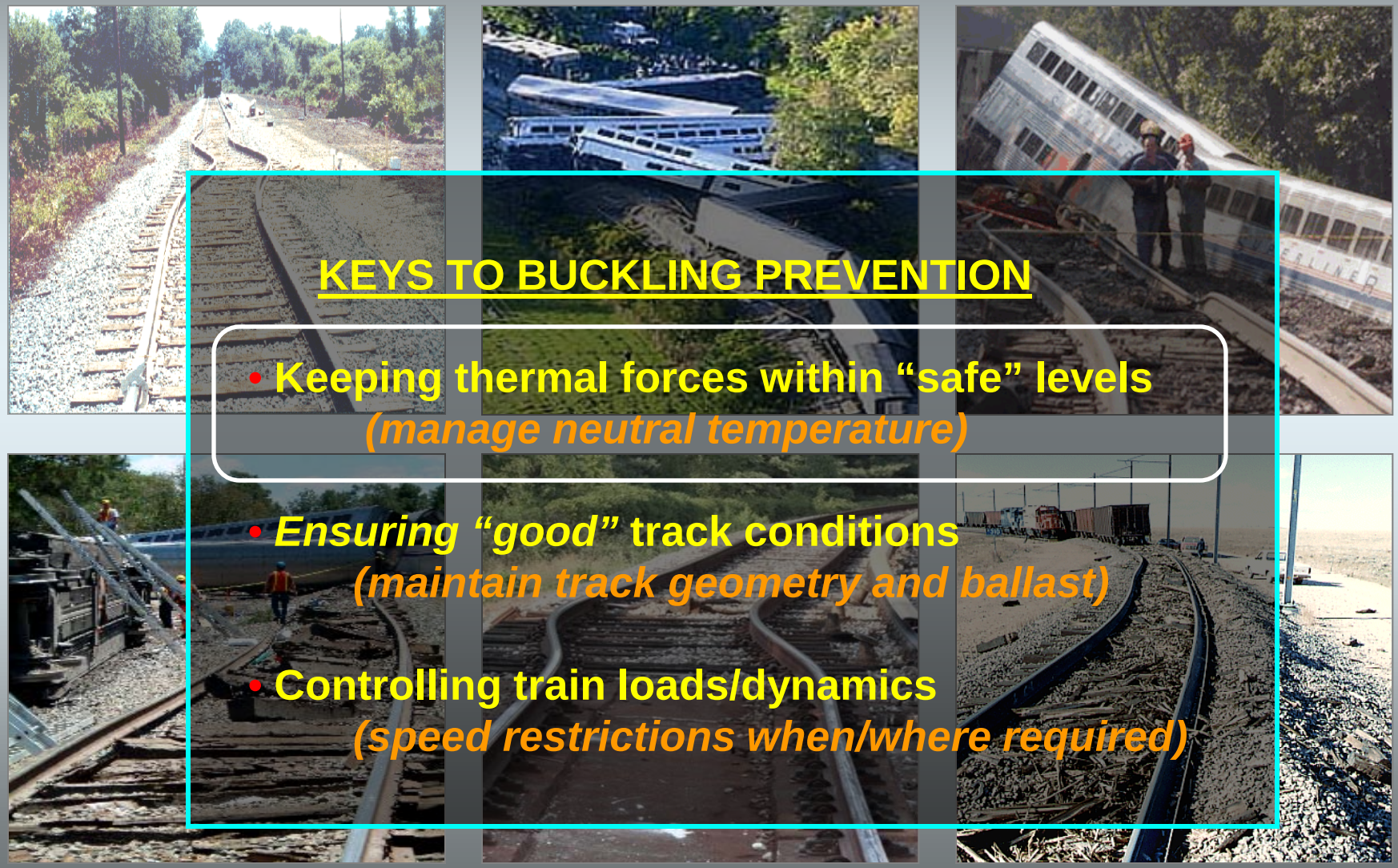
2012 (mainline) - 27 @ $900 K/derailment: ➡ **32%** of TOTAL track caused derailment damage

Principal Cause

AAR/TTCI Study: in over 70% of buckled track derailments Neutral Temperature (RNT) was a major contributing factor

***BOTTOM LINE:* need to manage RNT more effectively to reduce the number of track buckling caused accidents**

How to Prevent?



KEYS TO BUCKLING PREVENTION

- **Keeping thermal forces within "safe" levels**
  (manage neutral temperature)
- ***Ensuring "good"* track conditions**
  (maintain track geometry and ballast)
- **Controlling train loads/dynamics**
  (speed restrictions when/where required)

The RNT Problem

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:

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

$2600_{136\#}$

T_N	Rail Temp (T_R)	Force/Rail, P (US-136# Rail)	RESULT
90°F(32°C)	130°F(54°C)	104,000 lbs (463kN)	NO BUCKLE
50°F(10°C)	130°F(54°C)	208,000 lbs (925kN)	BUCKLE

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

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The RNT Problem

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Longitudinal Force ⇄ Neutral Temperature

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

T_N: Variable

Rail Kinematics

Rail/tie movement longitudinally, curve shifting laterally, and vertical settlement

Variable

Rail Maintenance

Installation, realignment, broken/defective rail repair, incorrect destressing

The RNT Problem

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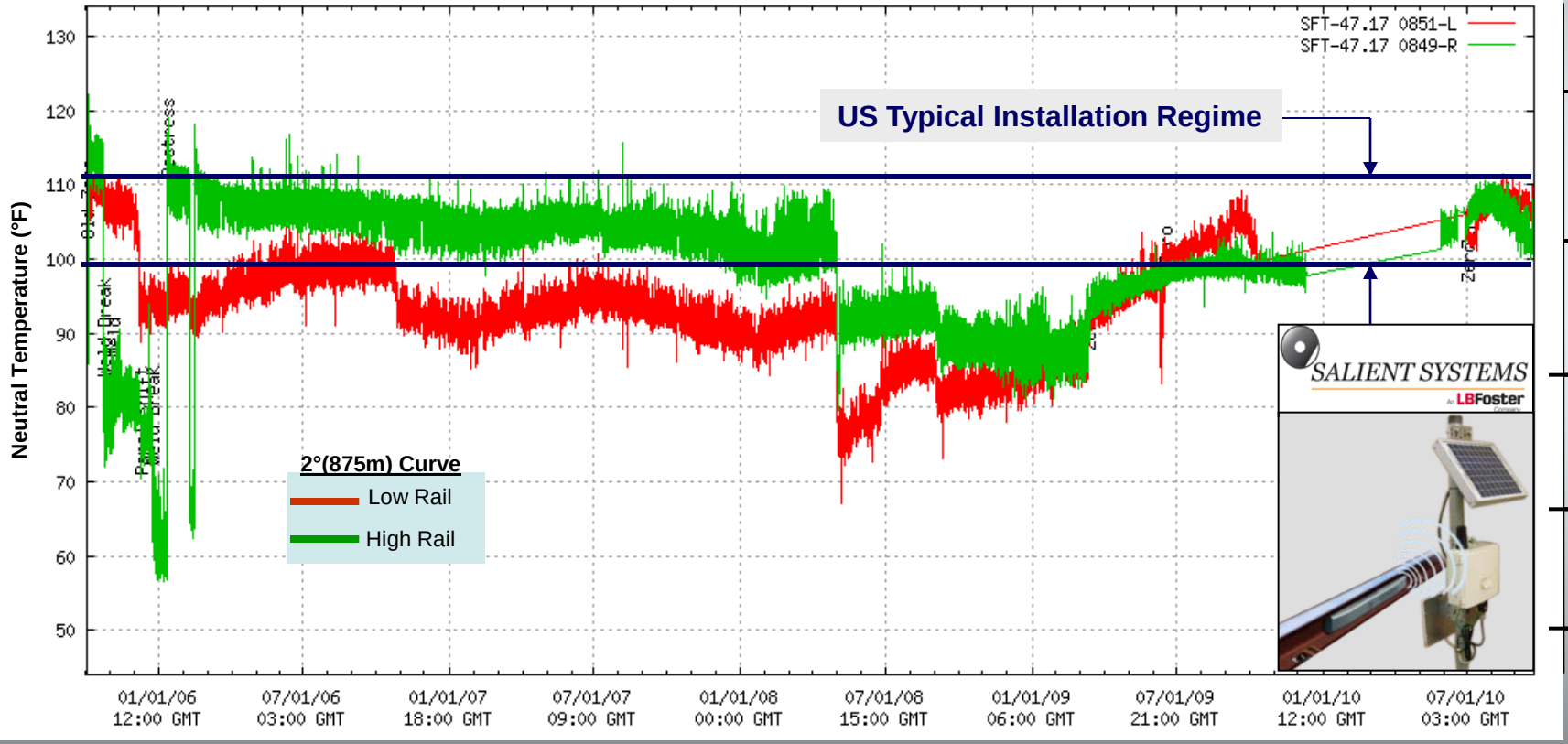
5 Years of RNT Data on a High Tonnage US Railroad



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The RNT Problem

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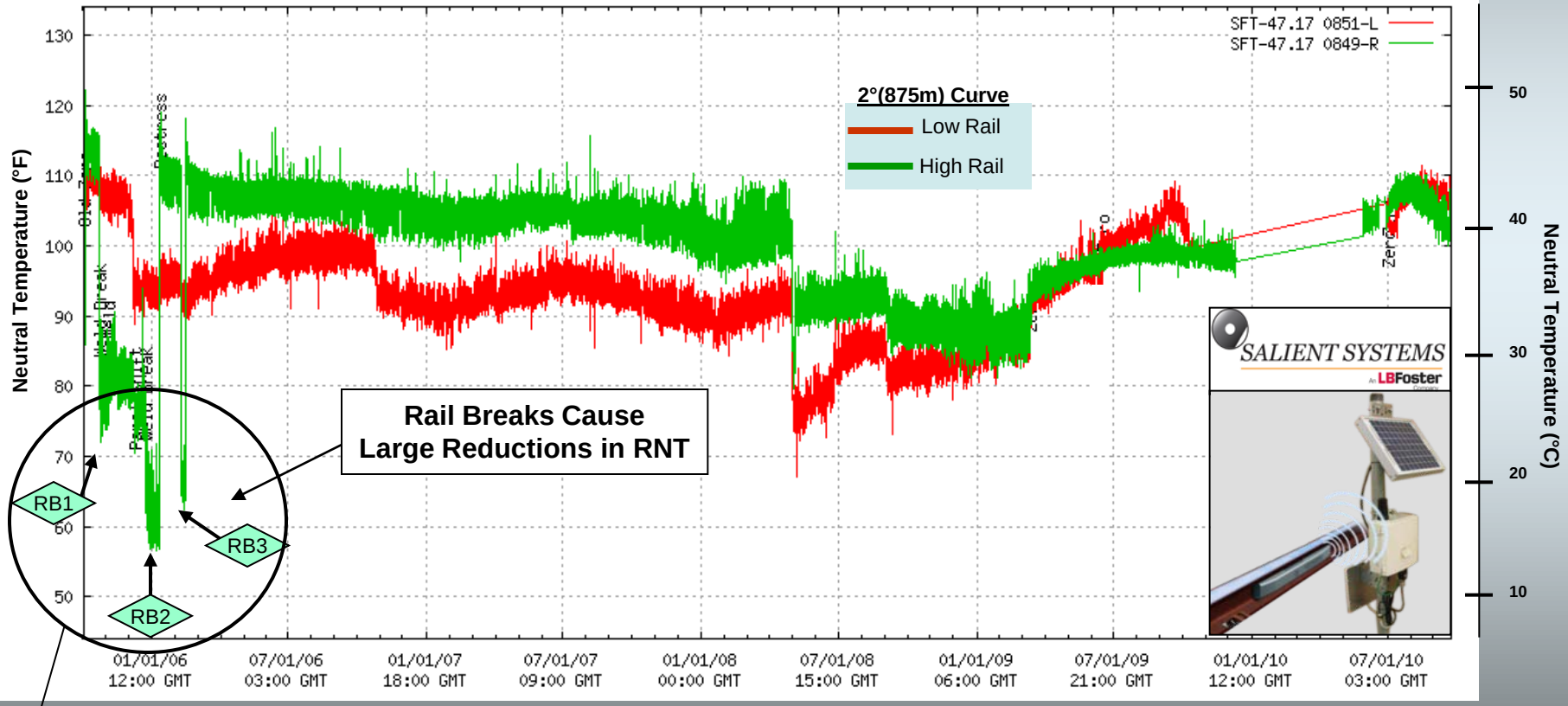
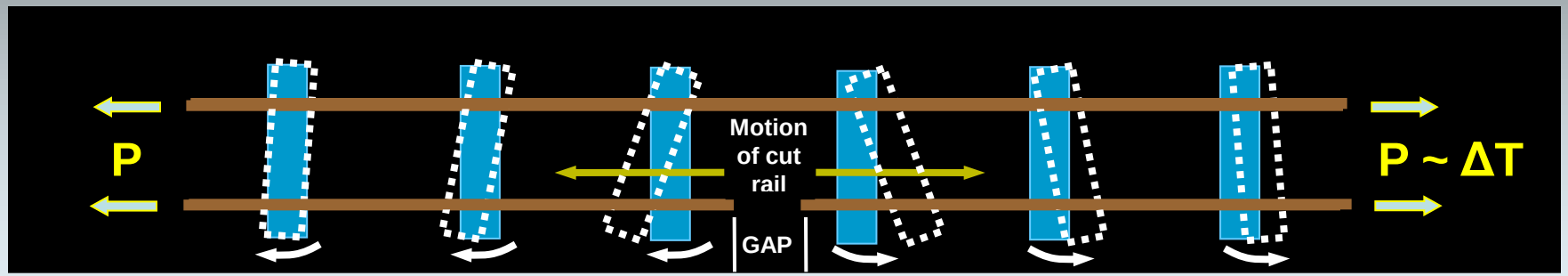


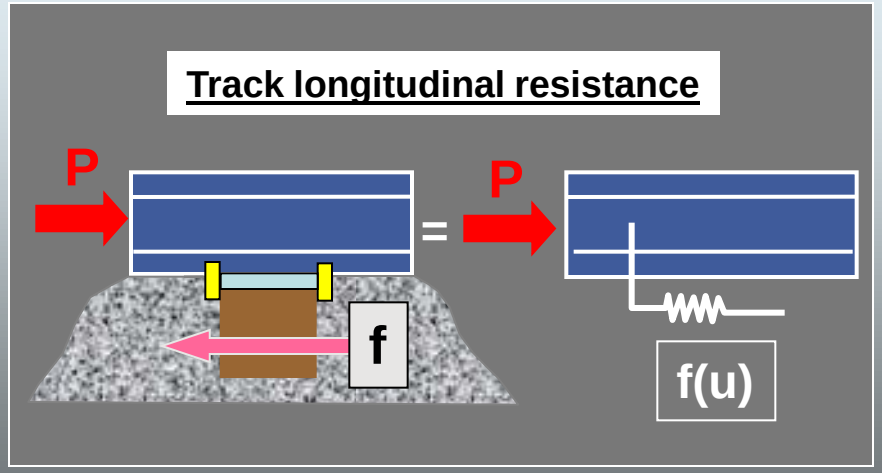
If NOT readjusted prior to onset of warm temperatures, the track can become buckling prone!

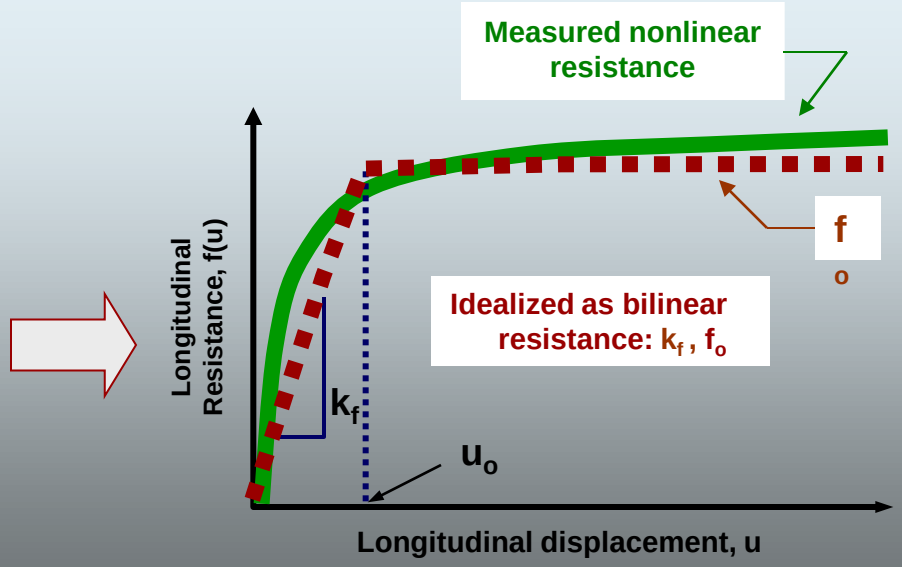
Rail Break Mechanics

Cold Temperature Rail Defect/Break Repair/RNT Readjustment Issues



- ΔT, longitudinal resistance, and rail size





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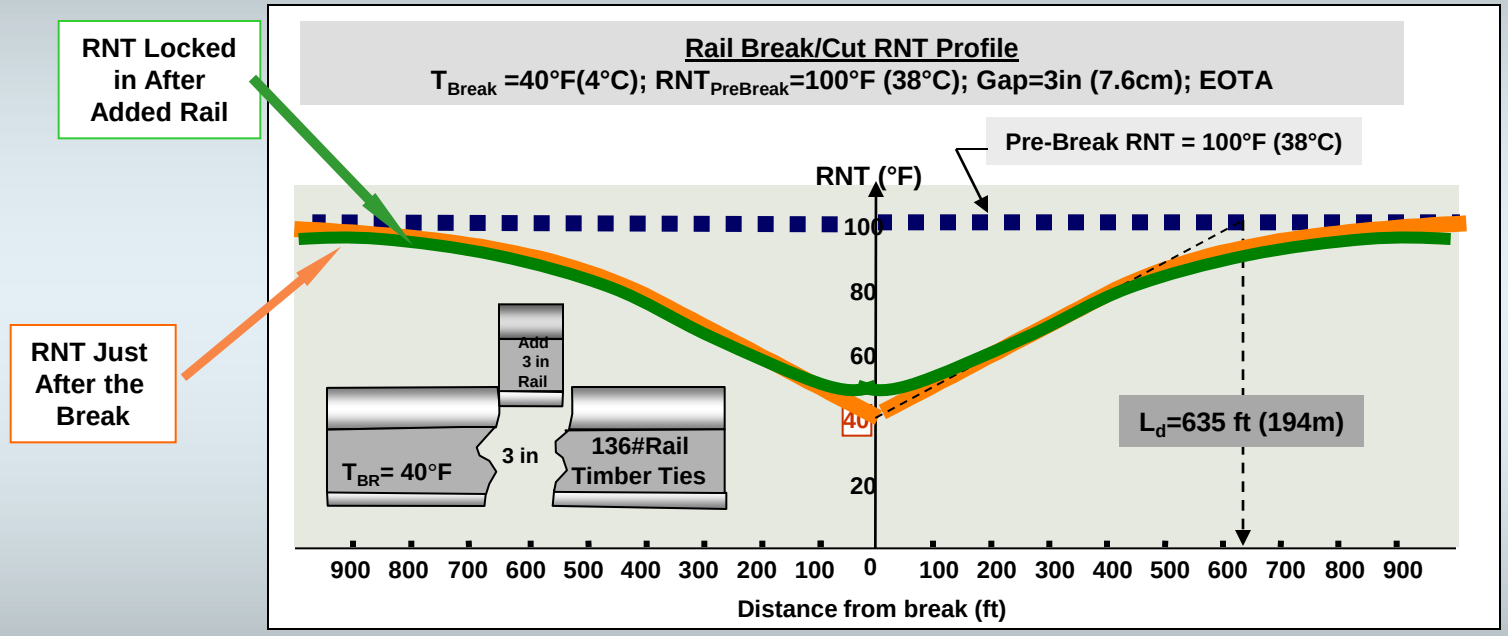

Key RNT Readjustment Issues:

(1) when to come back to readjust

(2) how to readjust (how much rail to cut out and what length to unfasten)

RNT Readjustment Difficulties

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Why Are Some Current Readjustment Methods Ineffective?

METHOD 1: When rail is added as an interim (plug) repair for broken/cut rail, remove the added rail later at a *warmer* temperature with unfastening 195 ft both sides of the cut – AREMA Recommendation/Chapter 5

Issues: removing the added rail often is not enough, and nor is the 195' unfastening length; also the *"warm"* temperature to readjust is not known?

Rail break INFLUENCE ZONES are much longer than 195 ft !!

METHOD 2: When the rail break/cut gap is *small*, close the gap by pulling or heating the rail without any anchor/fastener removal

Issues: RNT may be restored to nominal pre-break value but NOT necessarily to the desired target level

Influence Zone Lengths

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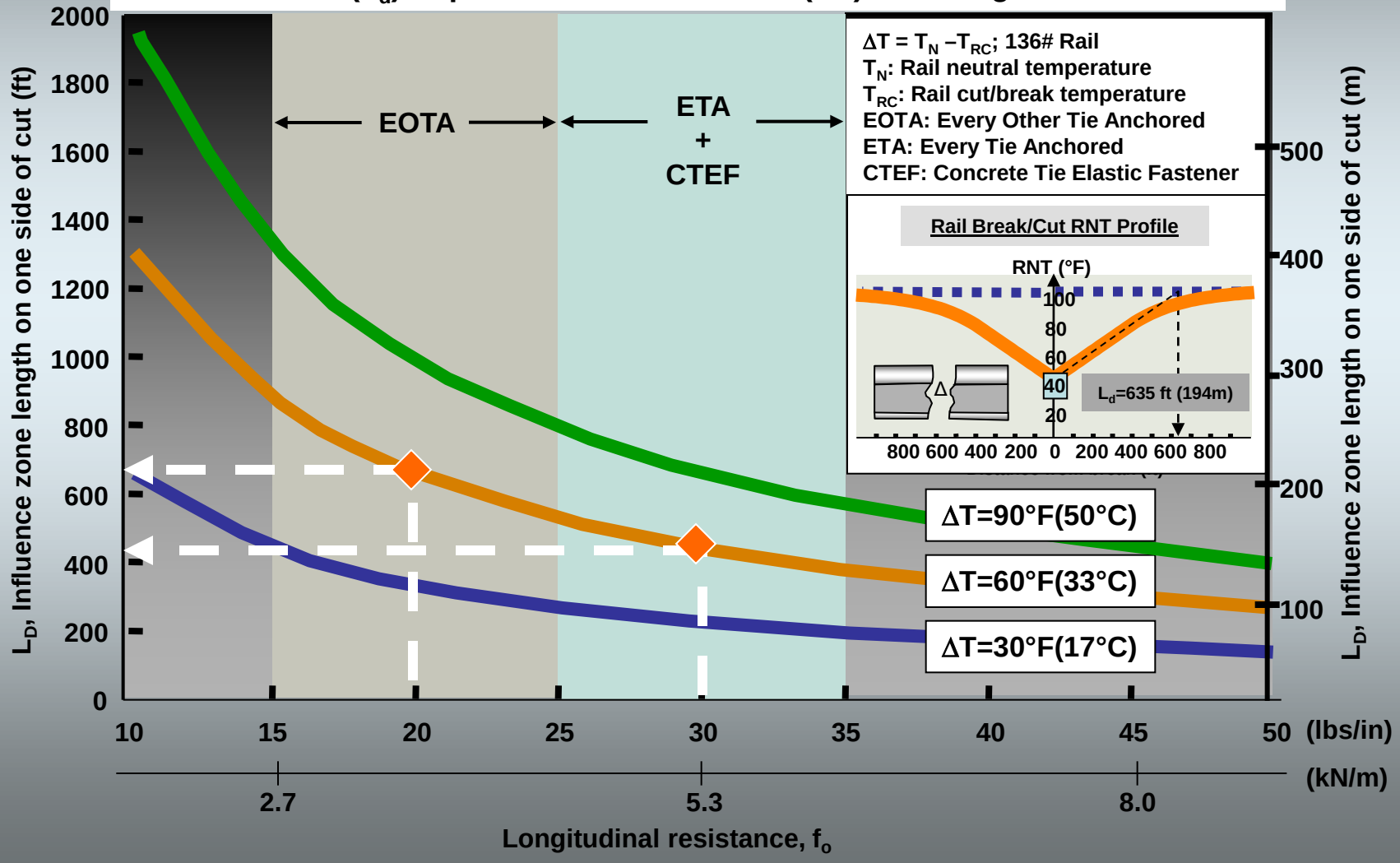
How Long Are the Influence Zones?

Influence Zone (L_d) Depends on Thermal Load (ΔT) and Longitudinal Restraint!



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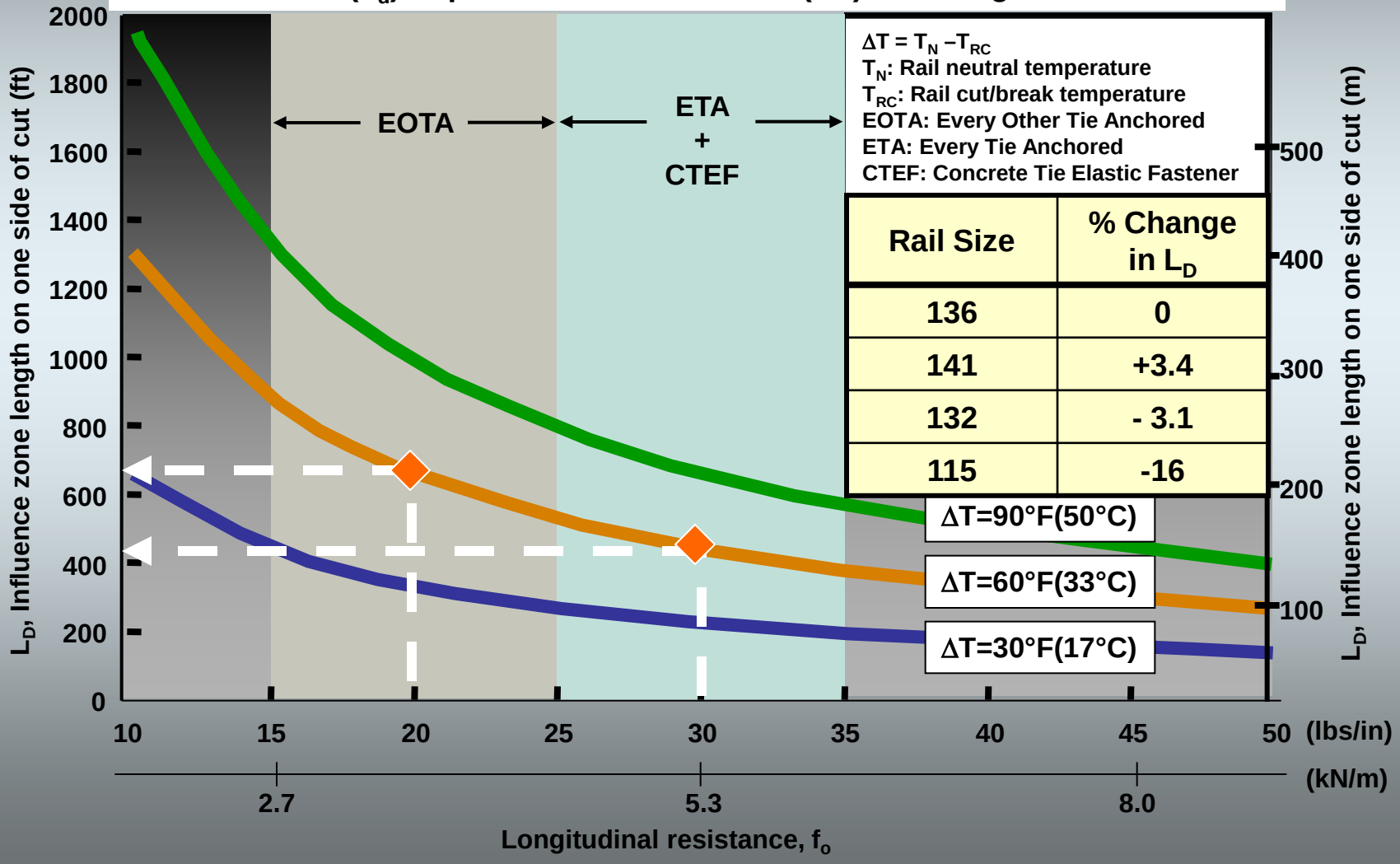

Rail Size	% Change in L_D
136	0
141	+3.4
132	- 3.1
115	-16

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Gap Size as a Measure of RNT

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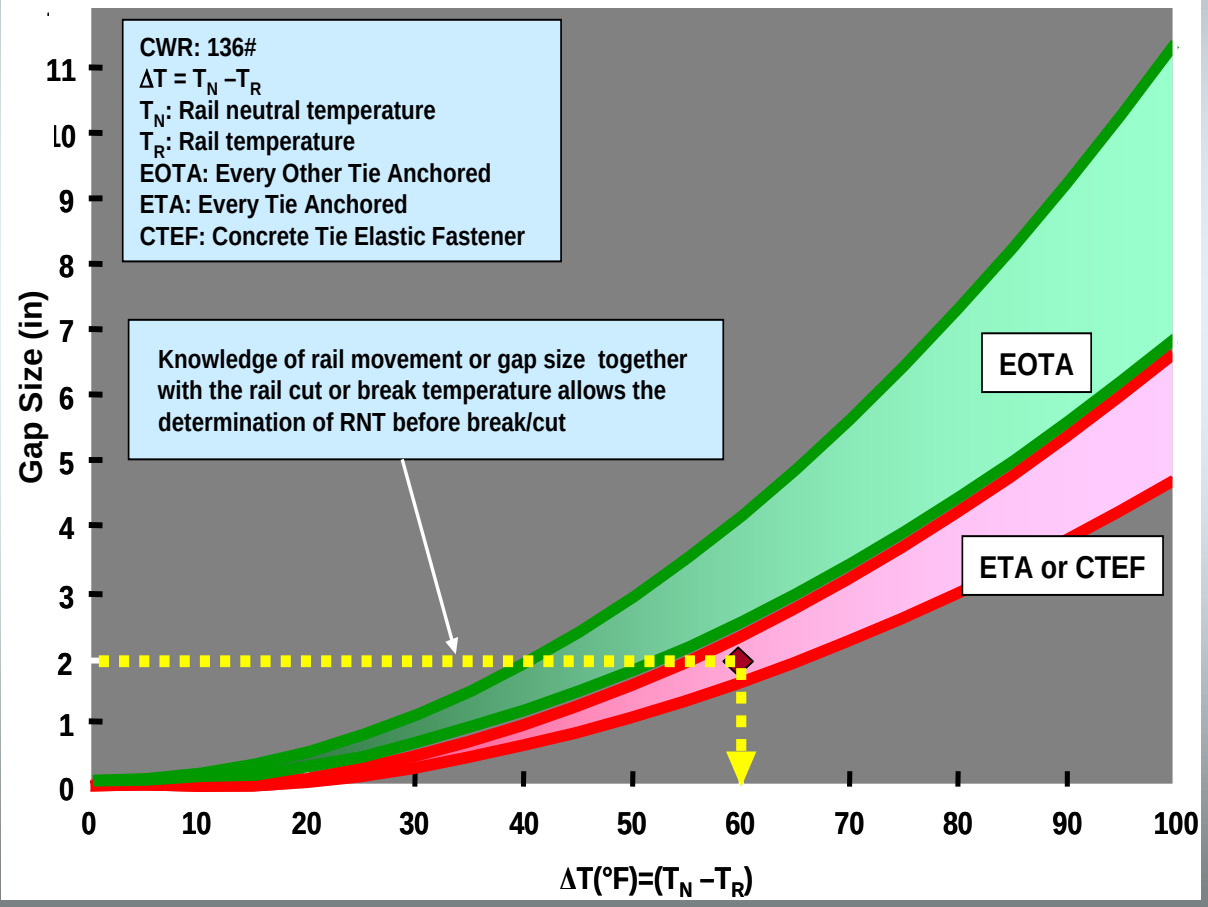
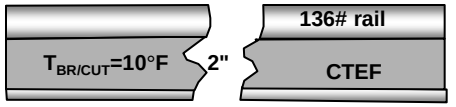
What Do Gap Sizes Depend On?

Thermal Load (ΔT) and Longitudinal Restraint Influence on Break/Cut Gap Sizes



Key Rail Break Mechanics Parameters



Gap size

Break/cut temp

Rail size

Fastener type/condition

Break/cut influence zone

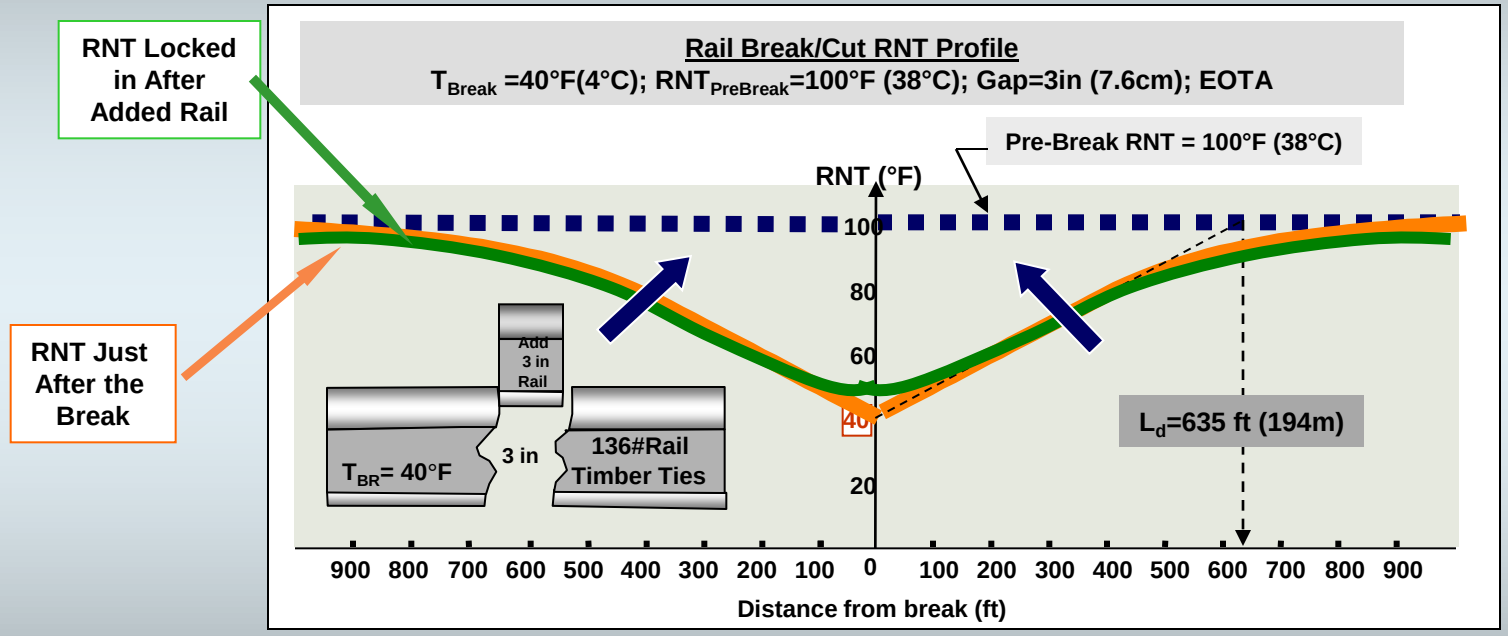
Pre-Break/cut RNT

How much rail to cut out
and
what length rail to unfasten
for a
target RNT

❑ **Importance of Gap Size:** It helps determining the pre-break/cut RNT!

Rail Break Mechanics

How to Readjust: When and What Procedure?



Key RNT Readjustment Issues:

(1) when to come back to readjust

(2) how to readjust (how much rail to cut out and what length to unfasten)

RNT Readjustment Issues

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Key RNT Readjustment Issues

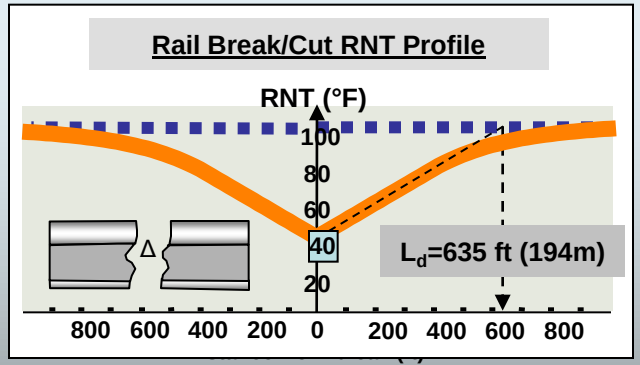
When to come back and readjust?

(at temps before track becomes bucking prone)

How to readjust i.e. how much rail to cut out and what length to unfasten)?

(have to know the reduced RNT profile)

Rail Break/Cut Temperature (°F)	Rail Temperature (°F) at Which to Readjust or Apply Slow Orders
60	135
50	130
40	125
30	120
20	115
10	110
0	105
-10	100
-20	95
-30	90
-40	85



CWR-Adjust Software for Readjusting RNT (Developed by TTCI)

- program based on rail break mechanics, theory, field tests, and practical experience

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Automated Software for Readjusting RNT Developed by TTCI

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TTCI Software: "CWR-Adjust"

Input Parameters

- Rail size
- Anchor/fastener type/condition
- Rail cut/break temperature
- Measured rail gap
- Designated/target RNT

Software algorithm

Output

- Pre cut/break RNT*
- Rail length to unfasten/deanchor
- Amount of rail to cut out

Railroads Customize for Internal Use

- CWR-Adjust coupled with RR's Maintenance Management System
- Customized Slide Rule type "Pull-Cards"
- Tables in RR's CWR Policy Document to Determine $RNT_{PREBREAK}$

* Required by RR's CWR Policy

Automated Software for Readjusting RNT Developed by TTCI

How to Chose Anchor/Fastener Condition? ["Weak", "Average", and "Strong"]

Input Parameters

- Rail size
- Anchor/fastener (type/condition)
- Rail cut/break temp
- Measured rail gap
- Designated/target RNT

Weak: missing anchors and the majority are not tight against the ties; evidence of rail slipping through the anchors/clips; crib ballast more than 2 inches below top of ties; poor tie condition; more than half of the insulators are cracked, broken or not seated in the shoulder; ties pads are slipping or deteriorated; evidence of rail seat abrasion.

Average: majority of anchors are in place and tight against the ties; tie condition is good; no evidence of rail creep; full ballast section; most insulators are sound and seated correctly; tie pads are not worn or moving in the rail seat; no evidence of rail seat abrasion.

Strong: new construction or rail relay with new anchors or fasteners that are less than 2 years old; AND which do not exhibit the "weak" or "average" characteristics

NOTE: when in doubt, the "weak" strength assumption provides the "safest" choice!

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Illustrative Example

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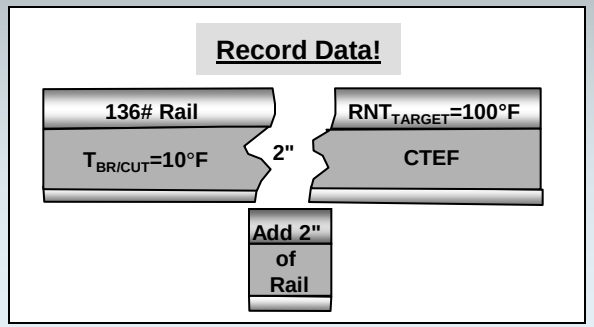
Example: a rail break occurring at a rail temperature of 10°F in a concrete tie territory resulting in a rail gap of 2" requires repair and RNT readjustment. The territory's designated laying temperature (RNT_{TARGET}) is 100°F. How to make readjustment?



- Make interim repair – requires adding 2 of rail
- Apply CWR-Adjust to determine: $RNT_{PREBREAK}$; amount of rail removal; length of rail to unfasten
- Determine when (at what temp) to return for RNT readjustment
- Return for readjustment before T_{RAIL} exceeds 110°F; and follow CWR-Adjust

Rail Break/Cut Temperature (°F)	Return Temperature (°F)
60	135
50	130
40	125
30	120
20	115
10	110
0	105
-10	100
-20	95
-30	90
-40	85

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Illustrative Example

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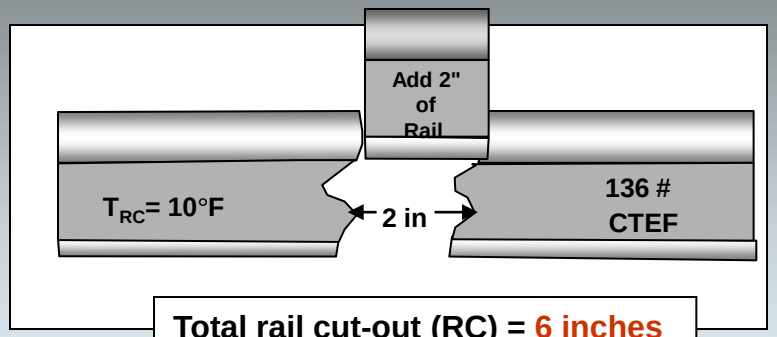
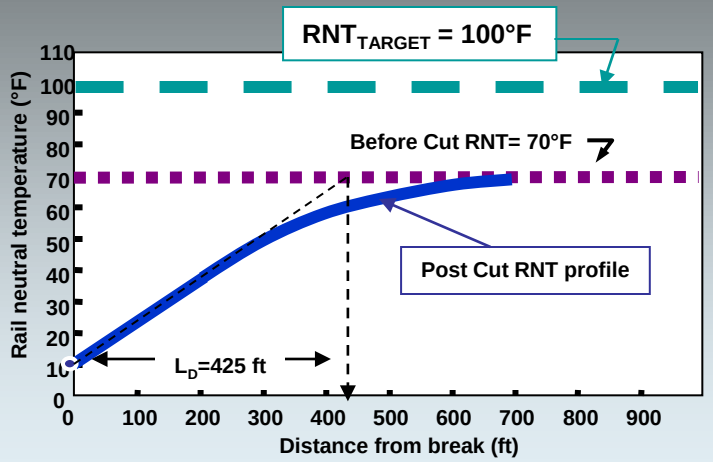
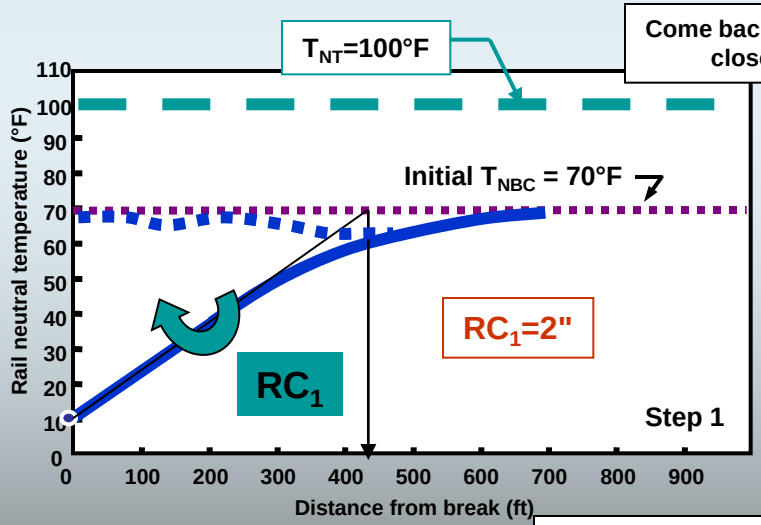


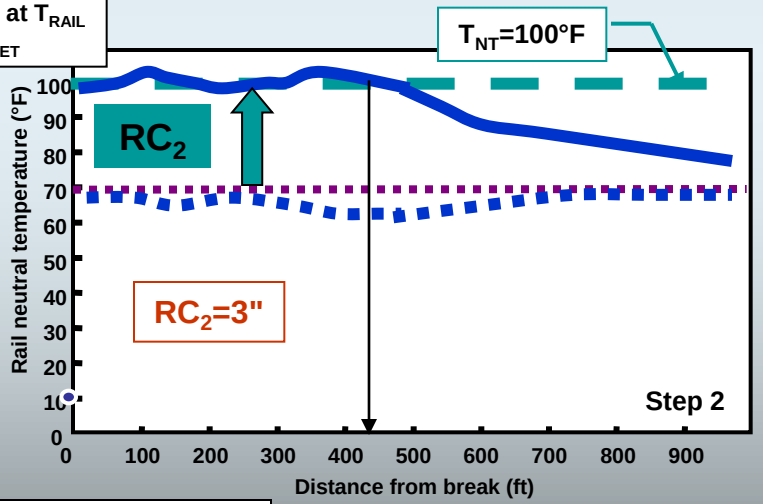
Total rail cut-out (RC) = 6 inches

METHODOLOGY





Come back to readjust at T_{RAIL} close to RNT_{TARGET}



RC = RC_1+ RC_2+ WA = 6 inches

Amount to readjust to the pre-cut/break value: 2"

Amount to readjust from the pre-cut/break value to RNT_{TARGET}: 3"

Weld Allowance: 1"

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RNT Readjustment Summary

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RNT Readjustment: Restressing versus Destressing

Rails in Tension: Rail Breaks and Defect Removals

Readjustments for "Cold" Temp Repairs

RESTRESSING

Typically Require "Interim Repairs" and Warmer Temp Returns for Readjustment

HOW?: in accordance to CWR-Adjust or as per RR's CWR Policy

Remaining Issue: how to adjust when CWR-Adjust is NOT applicable?

Rails in Compression: "Hot-Weather" Kinky/Wavy Rail

Readjustments in "Hot" Temps

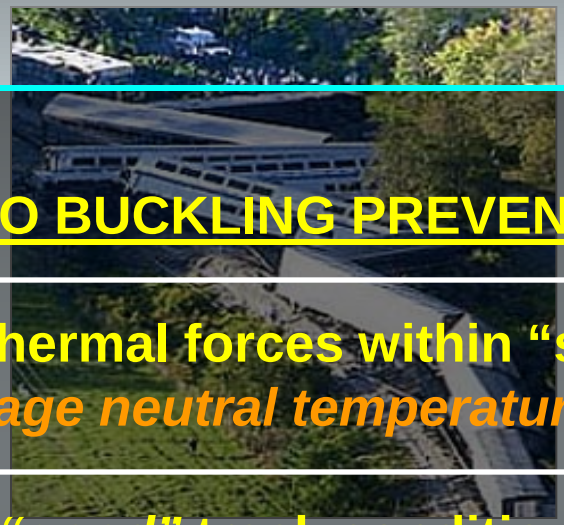
DESTRESSING

Usually Requires Immediate Action

HOW?: in accordance with RR's CWR Policy

Remaining Issue: how much rail to unfasten?

How to Prevent?


KEYS TO BUCKLING PREVENTION

- **Keeping thermal forces within "safe" levels**
  (manage neutral temperature)
- ***Ensuring "good"* track conditions**
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- **Controlling train loads/dynamics**
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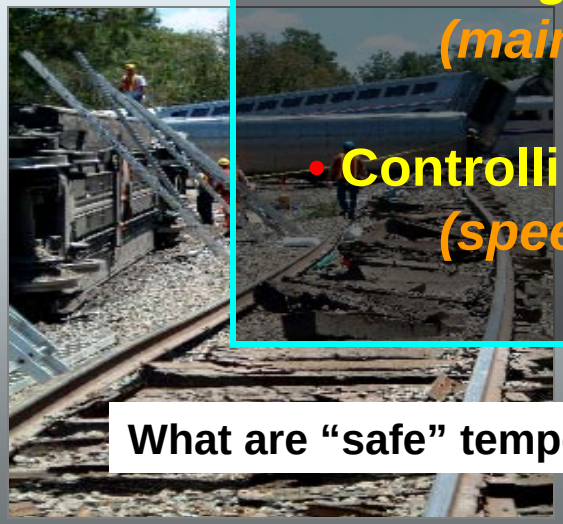
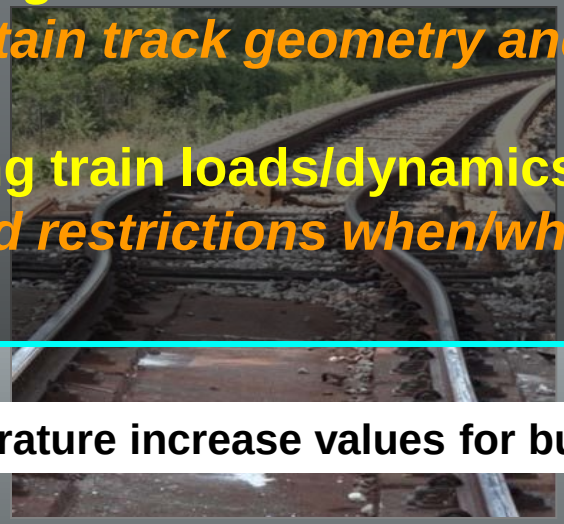




What are "safe" temperature increase values for buckling prevention?

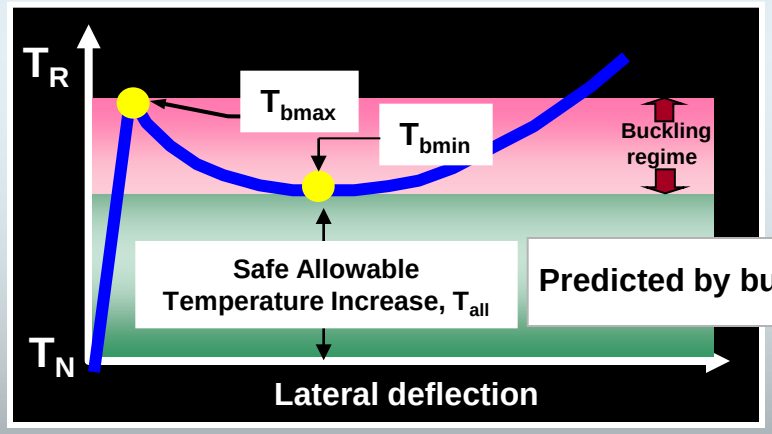
Track Buckling Prevention

What Are "Safe" Temperature Increase Values for Buckling Prevention?

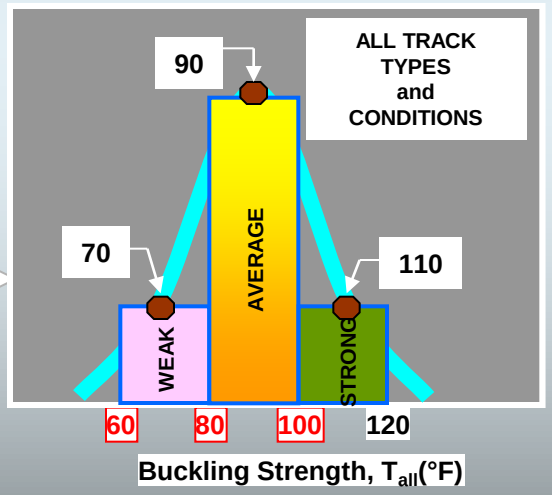
Buckling Safety Criterion

Thermal Load < Buckling Load

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



Predicted by buckling model "CWR-SAFE"



Temperature increase above NEUTRAL not to exceed:

- **60°F (WEAK TRACK)**
- **80°F (AVG. TRACK)**
- **100°F (STRONG TRACK)**

Track Buckling Prevention

What Are "Safe" Temperature Increase Values for Buckling Prevention?

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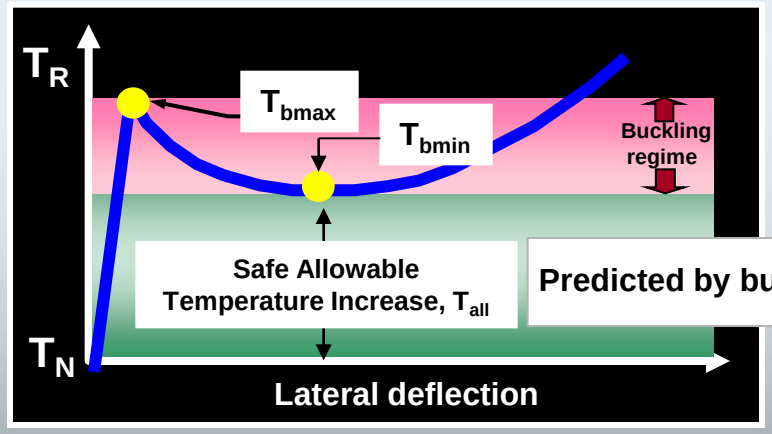

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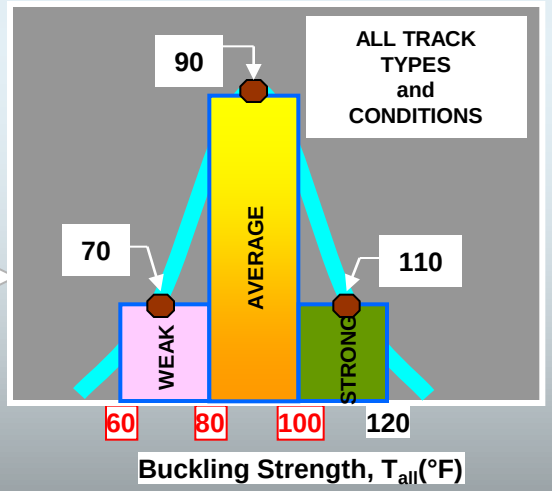

Temperature increase above NEUTRAL not to exceed:

- **60°F (WEAK TRACK)**
- **80°F (AVG. TRACK)**
- **100°F (STRONG TRACK)**

Current RNT Management Issues

Rail Stress Management Current Topics/Challenges

(1) What to do when CWR-Adjust is NOT applicable or available?

NOTE: CWR-Adjust DOES NOT apply for breaks/cuts near "fixed points"!

Apply new *"Best Practice Guidelines"*

- **Refer to 2013-Railway Interchange/AREMA Kish paper/presentation**
- **Refer to 2012 AAR/TTCI Research Report # 1003**

(2) How to detect track buckling hazards?

Log into L.B. Foster website for Webinar #1 on *"Track Buckling Hazard Detection"* presented on March 21, 2013 in conjunction with RT&S

(3) How to detect rail breaks?

Tune in on May 23, 2013 for L.B. Foster sponsored Webinar #2 on *"Rail Break Detection and Its Stress Management"* presented in conjunction with RT&S

THANK YOU, AND SAFE RAILROADING!!

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QUESTIONS?