Rail corrugation types in transit systems: Impact of TOR friction modifiers on mitigating growth rate

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Overview

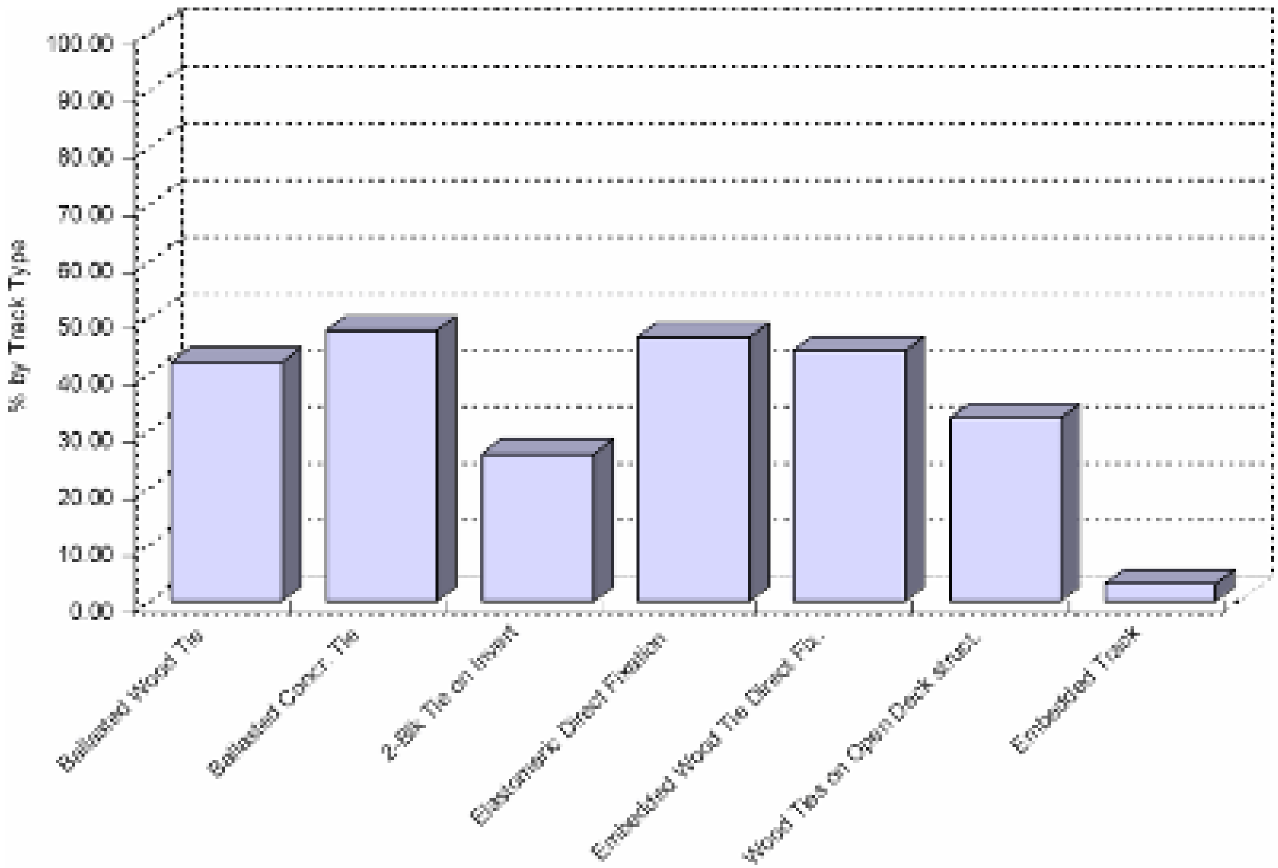
- Corrugation: types, formation mechanisms, characterization and measurement
- TOR Friction Control – Friction modifiers and lubricants
- Case Studies: Effects of Friction Modifiers on corrugation growth rate
- Effect of FM on existing corrugations – noise and vibration
- Summary, Conclusions and future directions

Widely prevalent on transit systems, great variety, can occur on all types of track




Corrugation impacts

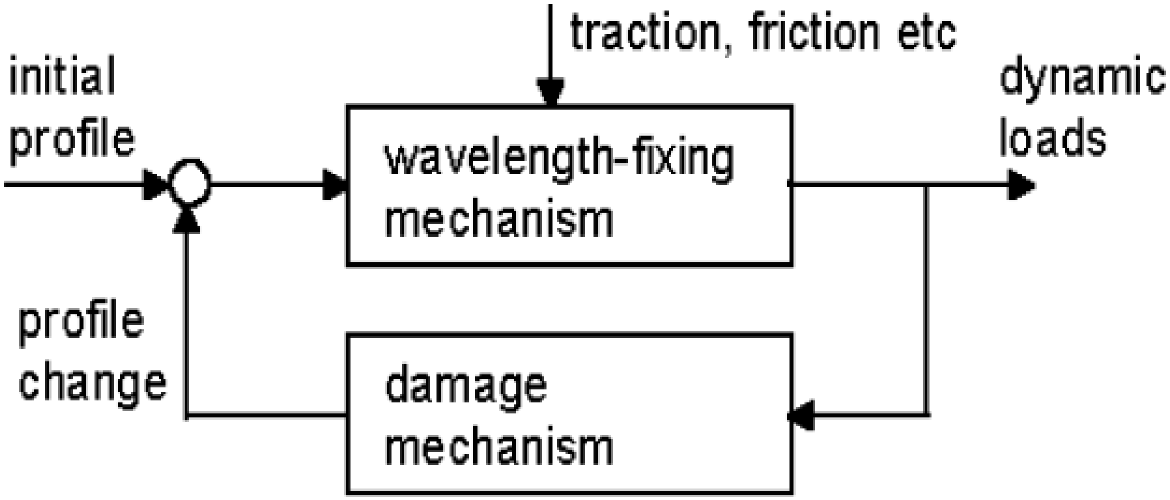
- Noise and vibration
- Potential track and vehicle damage
- Reduced rail life
- Costs to control:
  - 2007 estimate for Europe $MM90 annually
  - Grinding
  - Premature rail replacement
  - Track and vehicle damage



Source: http://www.corrugation.eu/research/

Basic Corrugation Mechanism

(Kalousek and Grassie)



Damage mechanism is almost always WEAR

Wear = tangential force x slip

$$\lambda = \frac{v}{f}$$

Train Speed

Corrugation wavelength

Corrugation frequency

Identifying corrugation frequency is a useful tool for identifying the underlying mechanism

Wavelength fixing mechanisms

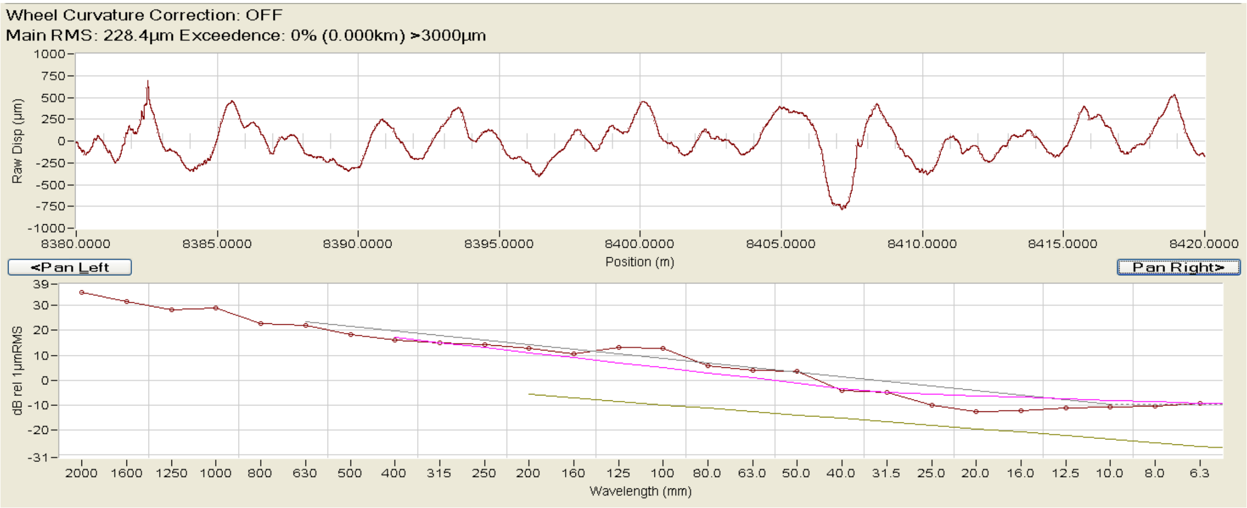
(Dr. S. Grassie, Proc. IMechE Vol. 223 Part F: J. Rail and Rapid Transit)

Type	Wavelength-fixing mechanism	Where?	Typical frequency (Hz)	treatments	
				Demonstrably successful	**Should be successful**
pinned-pinned resonance	pinned-pinned resonance	Straight track, high rail of curves	400-1200	Hard rails, control friction	Increase pinned-pinned frequency so that corrugation would be <20mm wavelength
Rutting	2^{nd} torsional resonance of driven axles	Low rail of curves	250-400	Friction modifier, hard rails, reduce cant excess, asymmetric profiling in curves	reduce applied traction in curving, improve curving behaviour of vehicles dynamic vibration absorber
Heavy haul	P2 resonance	Straight track or curves	50-100	Hard rails	Reduce cant excess when corrugation is on low rail
Light rail	P2 resonance	Straight track or curves	50-100	increase rail strength and EI	Reduce unsprung mass
Other P2 resonance	P2 resonance	Straight track or high rail in curves	50-100	Hard rails, highly resilient trackforms	Reduce unsprung mass
Trackform-specific	Trackform specific	Straight track or curves	-	Hard rails, friction control	Avoid “peaky” resonances, improved steering

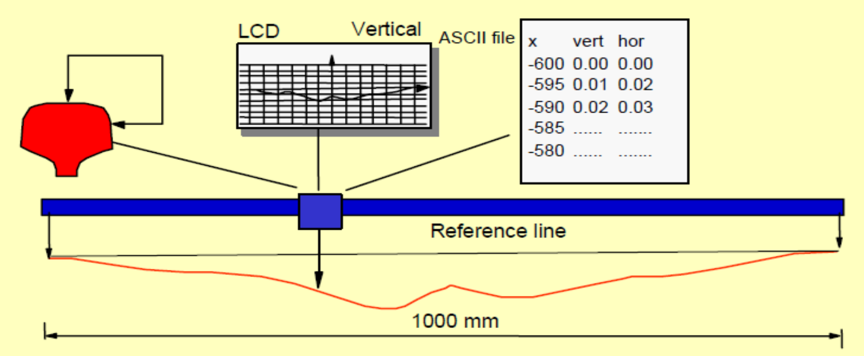
Pinned – pinned Resonance	P2 resonance	Rutting
Rail oscillation pinned by ties (nodes)	Second oscillation of unsprung mass of vehicle. (Vehicle "bouncing" on track)	Roll–slip oscillation associated with differential tangential force between low and high rail wheels
Wavelength influenced by tie spacing and rail stiffness		Wavelength fixing mechanism is the second torsional resonance of the wheelset.
Leads to variation in vertical load of wheels on rail. At unloading point of cycle, wheel / rail slip leads to wear.	Leads to periodic variation of vertical load and similarly periodic variation of wear through slip.	

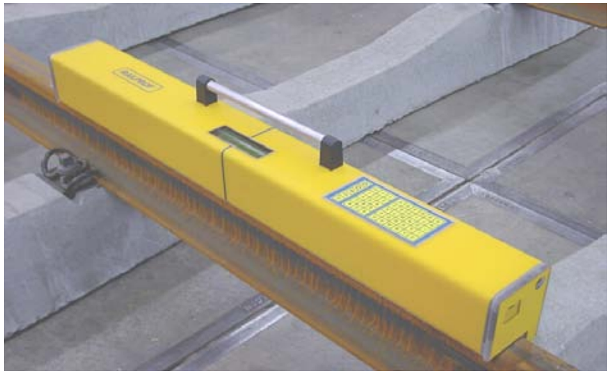
Corrugation Measurements: Corrugation Analysis Trolley (CAT)

- Accelerometer measures corrugations along the rail
- Counter determines the position of the trolley by emitting pulses at regular intervals
- Multiple post-processing analysis options

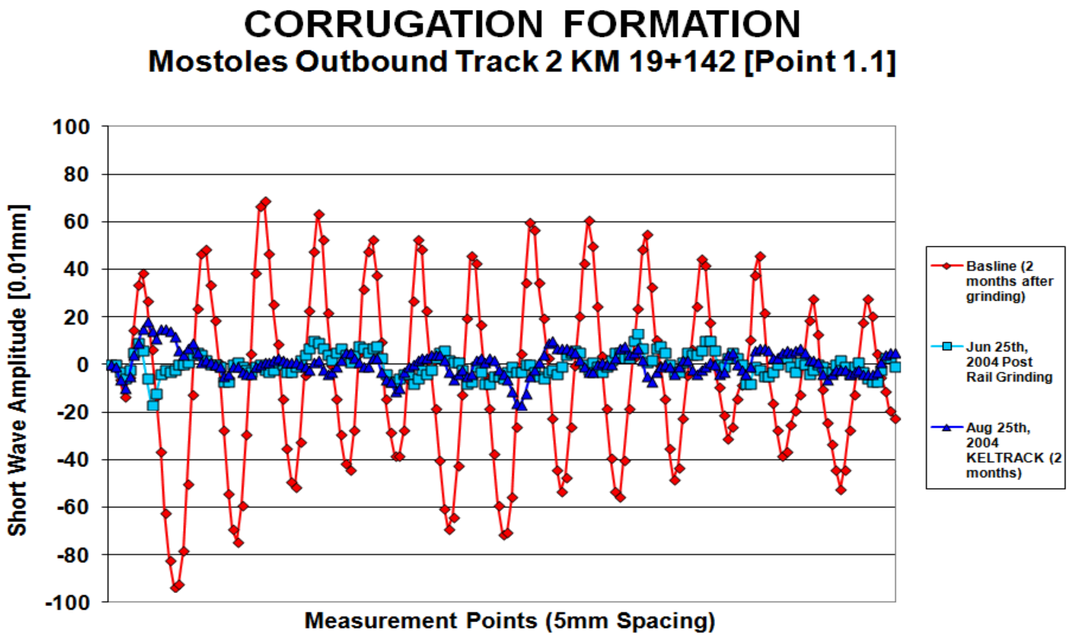


Corrugation Measurement: Esveld Railprof





- Stationary device
- Two non-contact sensors driven by stepper motor, measure every 5 mm



Grinding and corrugation

- A basic treatment for removing corrugations
- Where damage mechanism is wear, grinding is not prevention – corrugations will return
- Residual corrugations often remain
  - Require grinding to meet rail roughness standards (e.g. EN 13231-3)
- Reduce discrete irregularities (e.g. at welds) that trigger corrugation initiation
- Restoring transverse profile to improve steering should slow “rutting” corrugation

Designing a Corrugation Trial

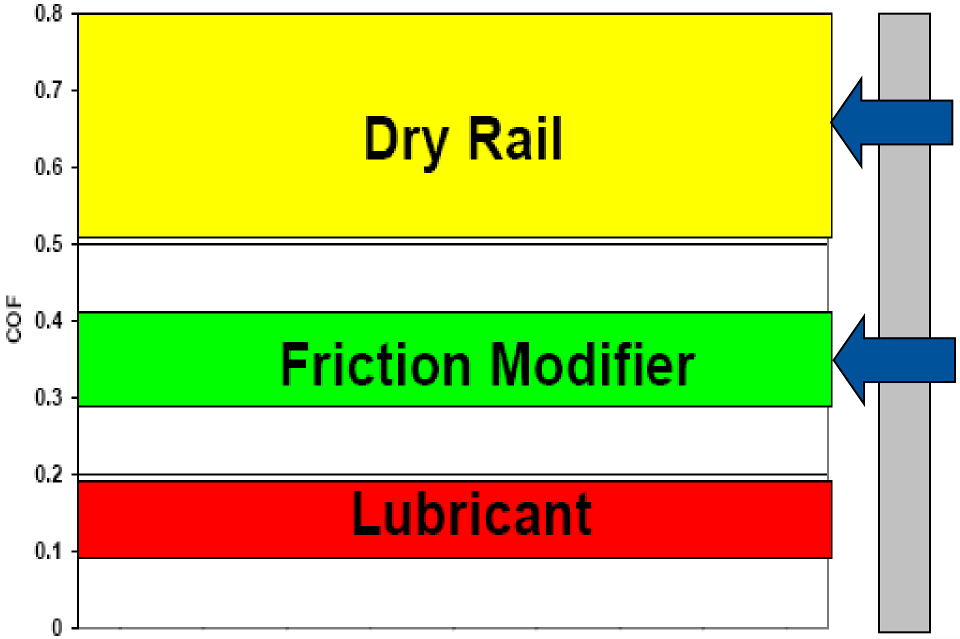
- Select site → Corrugation must be a clear problem
- Grind or replace rail → Ensure all corrugation is removed
- Measure baseline corrugation growth rate → Ensure sufficient time for significant corrugation growth
- Grind or replace rail → Ensure all corrugation is removed
- Implement test technology
- Measure corrugation growth rate → Compare corrugation growth rates

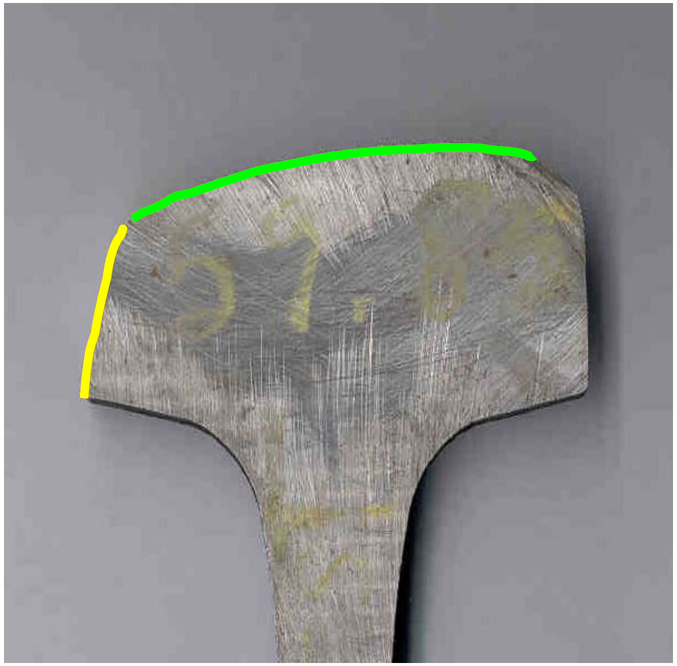
TOR Friction Modifiers and corrugation growth control

Friction Control Materials

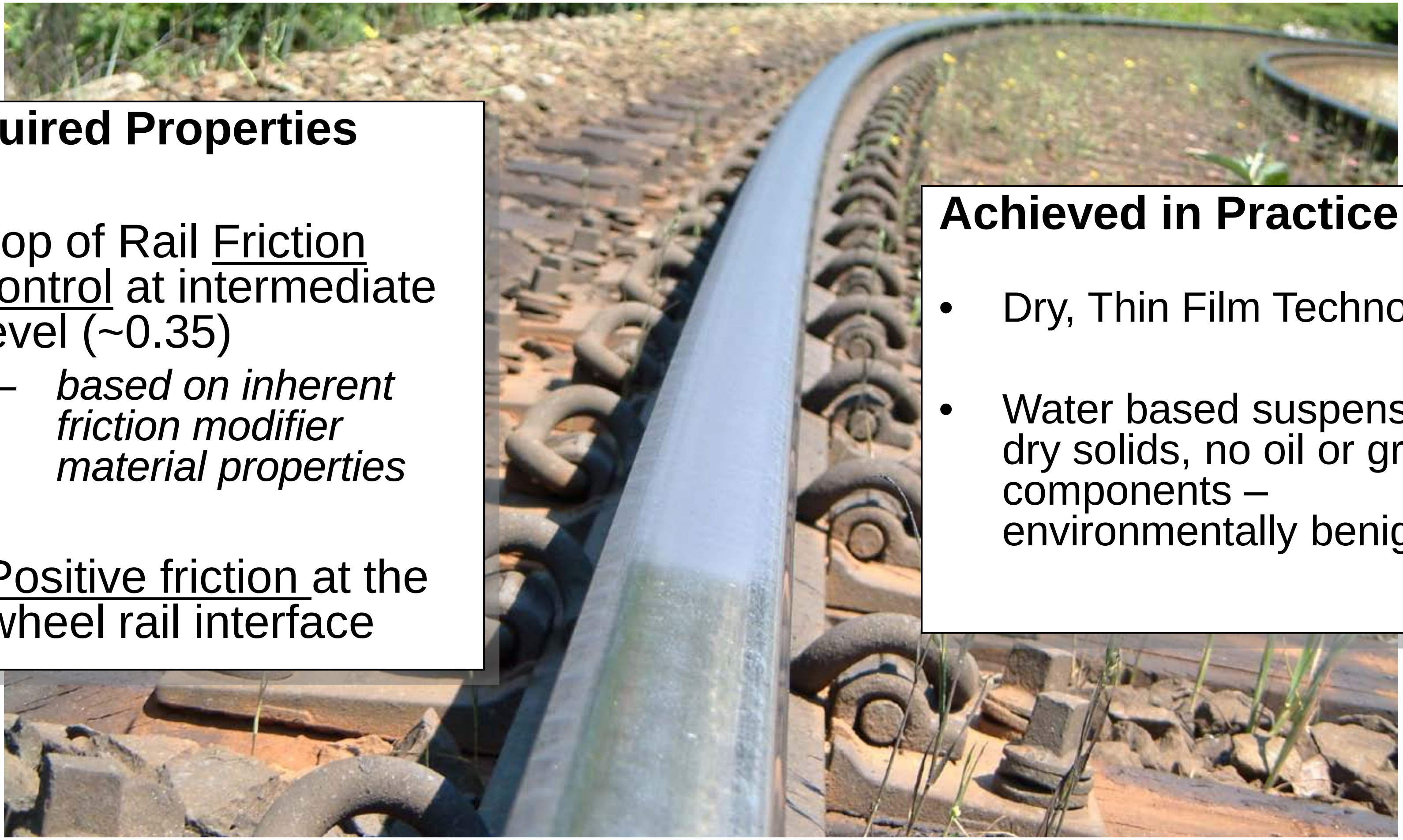
(AREMA Manual for Railway Engineering
Section 4.7 - Recommended Practices for Rail/Wheel Friction Control)

- ***Applying the proper materials to the proper surface***





Top of Rail Friction Modifier



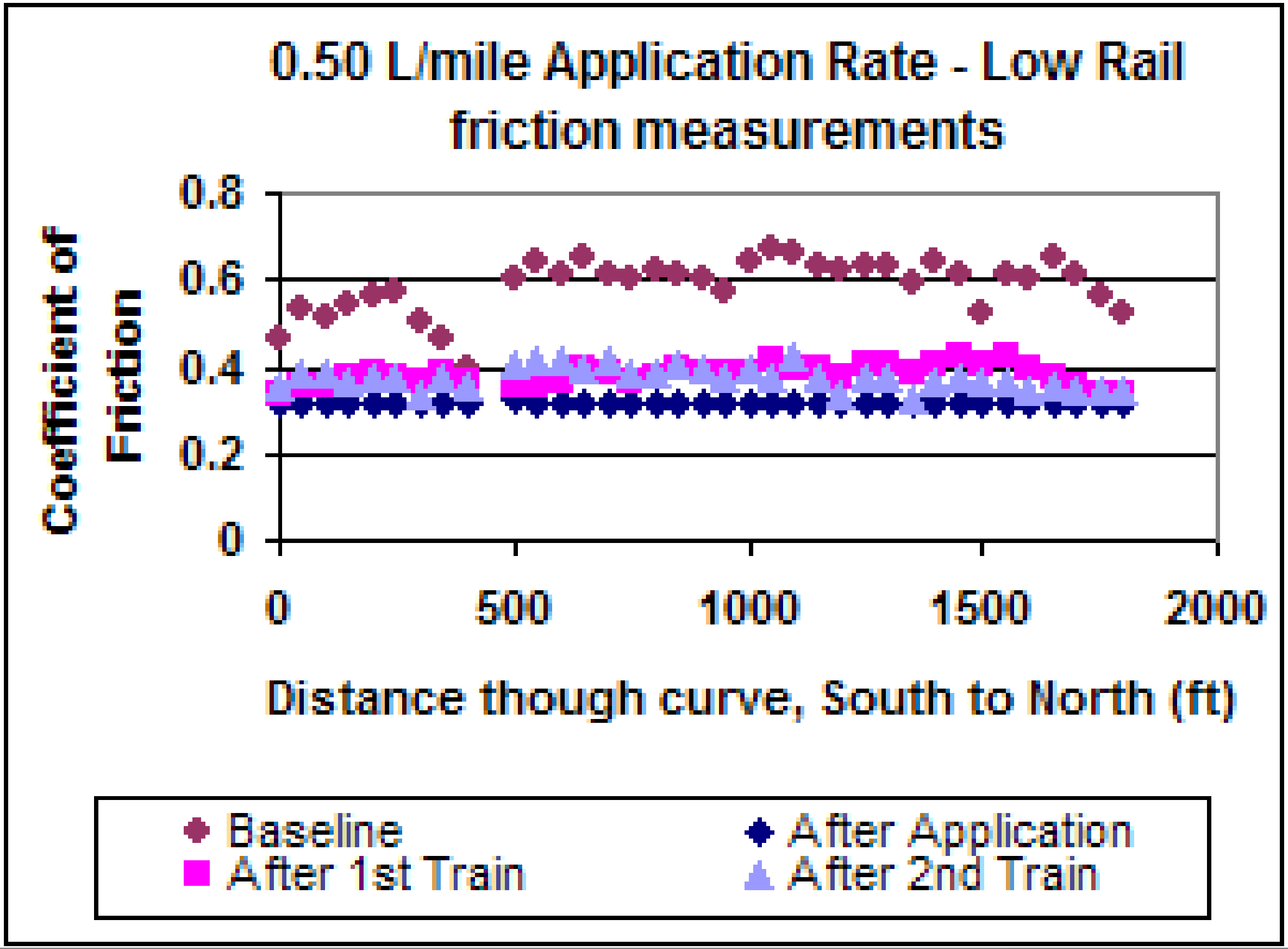
Required Properties

- Top of Rail Friction control at intermediate level (~0.35)
  - *based on inherent friction modifier material properties*
- Positive friction at the wheel rail interface

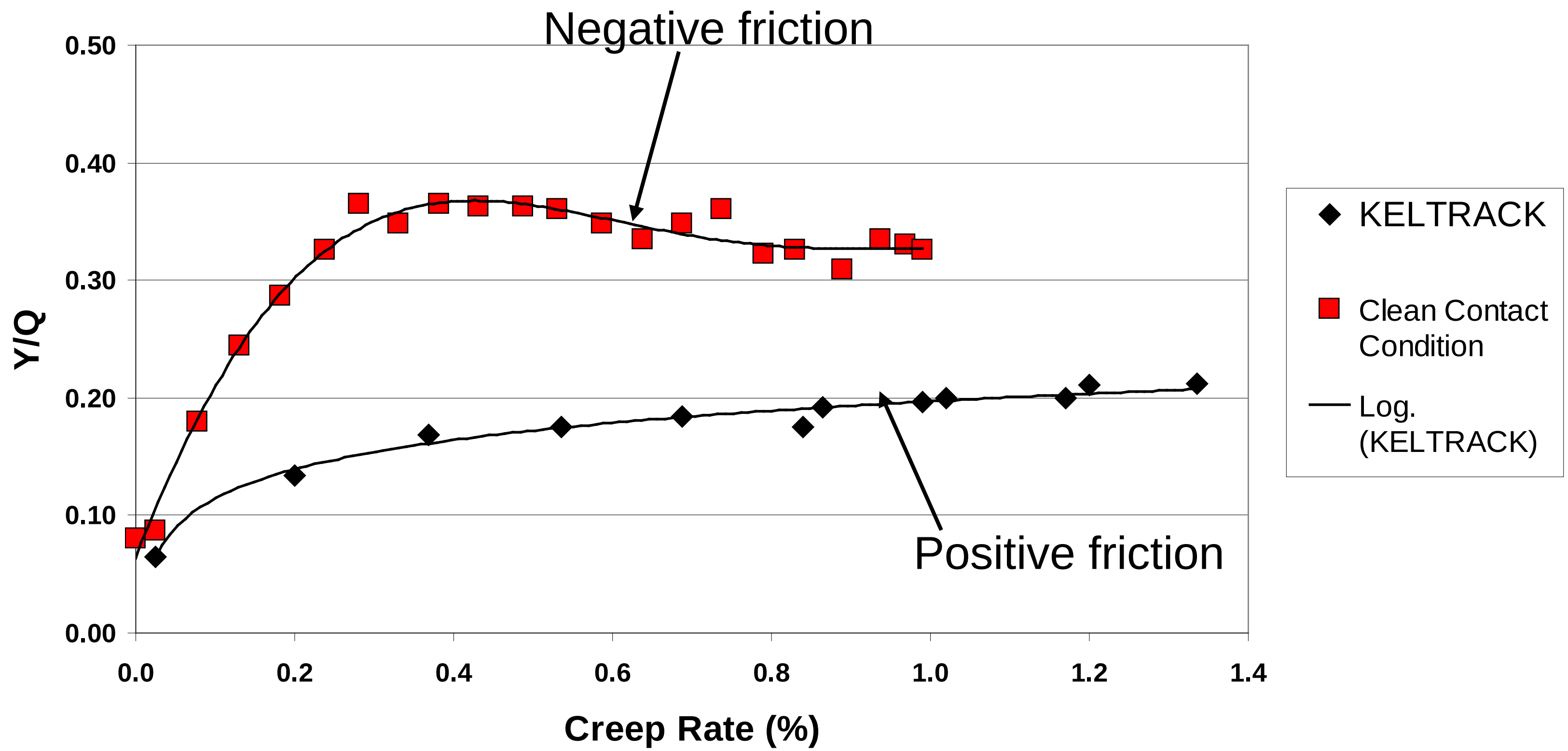
Achieved in Practice via:

- Dry, Thin Film Technology
- Water based suspension of dry solids, no oil or grease components – environmentally benign

Friction control in test curve with KELTRACK FM

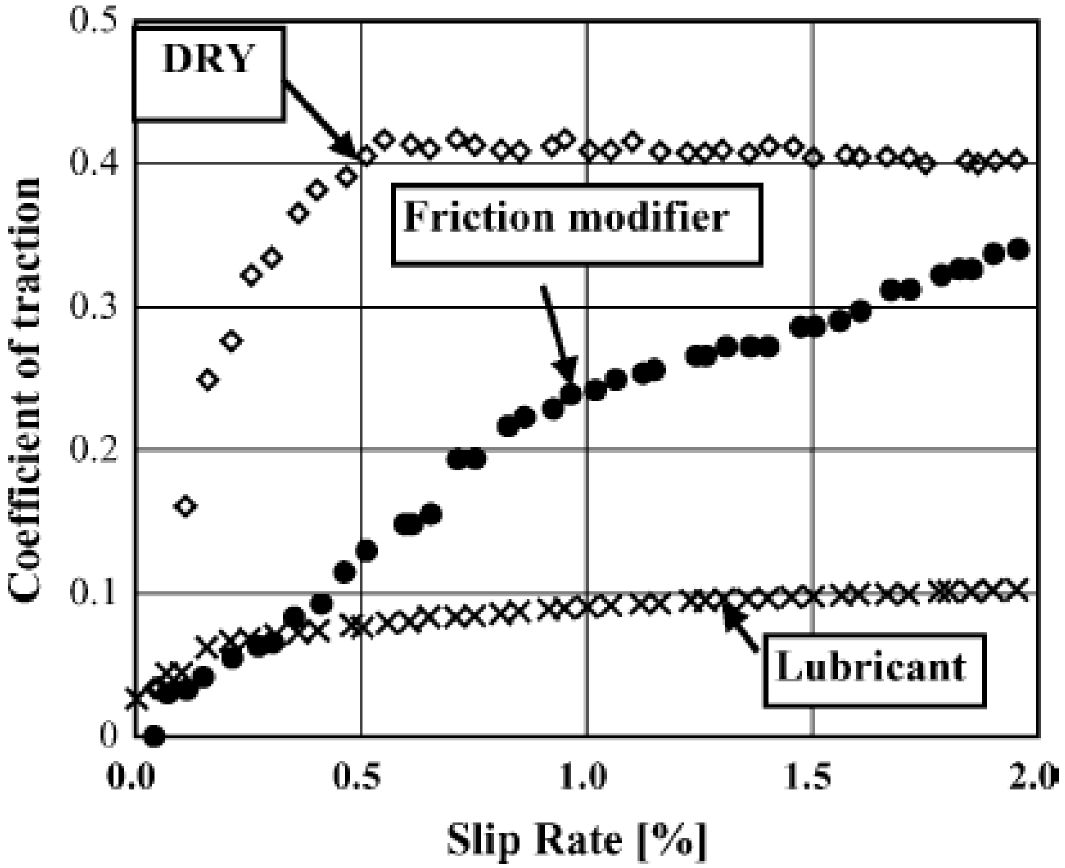


"Positive" Friction:
Lateral creep force characteristics*



* Replotted from: "Matsumoto a, Sato Y, Ono H, Wang Y, Yamamoto Y, Tanimoto M & Oka Y, Creep force characteristics between rail and wheel on scaled model, *Wear,* Vol 253, Issues 1-2, July 2002, pp 199-203

Traction-creepage curves for KELTRACK and lubricants*



* Reproduced from Suda et al. *Wear* 258 (2005) 1109–1114

Influence of friction modifier on corrugation: theory

- Reduced absolute friction levels on the rail head (<u>without compromising traction / braking</u>) expected to reduce *wear component* of corrugation mechanism

- Positive friction characteristics of interfacial layer
  Reduction of roll-slip oscillations associated with wavelength fixing / initiation component of rutting corrugation mechanism

Case Studies

- A: Metro
- B: Commuter rail system
- C: Japanese metro (LIM)
- D: Commuter rail
- E: Commuter rail

Protector IV Wayside Applicator

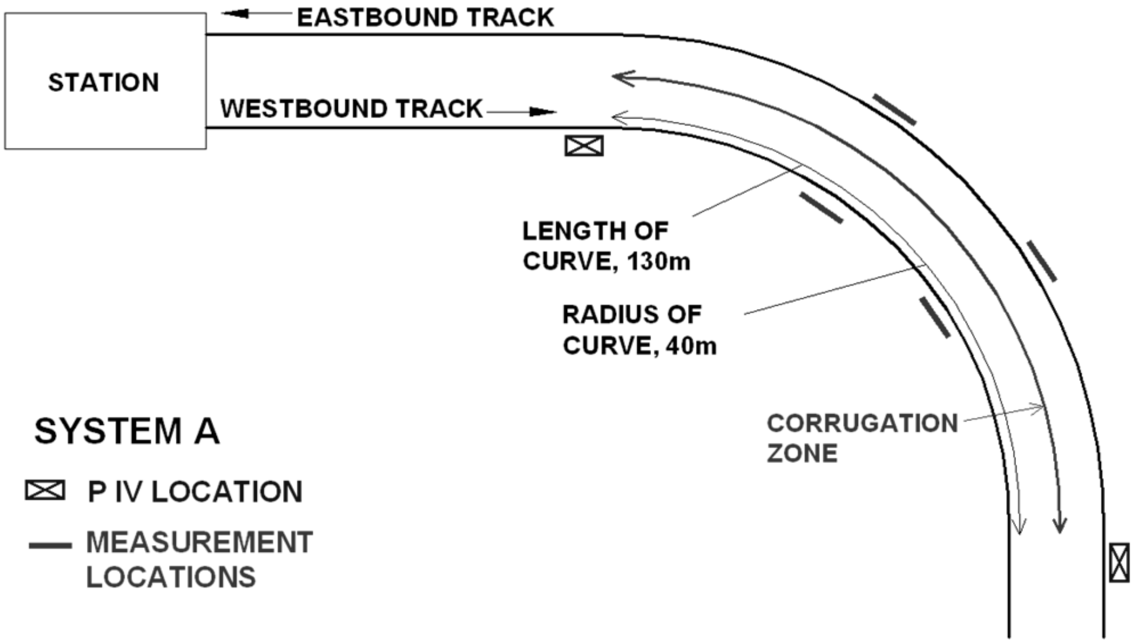
Standard Transit unit

Wall Mounted Unit

In Ground Tank

Top of Rail Applicator Bar (one or two per rail)

Site A characteristics



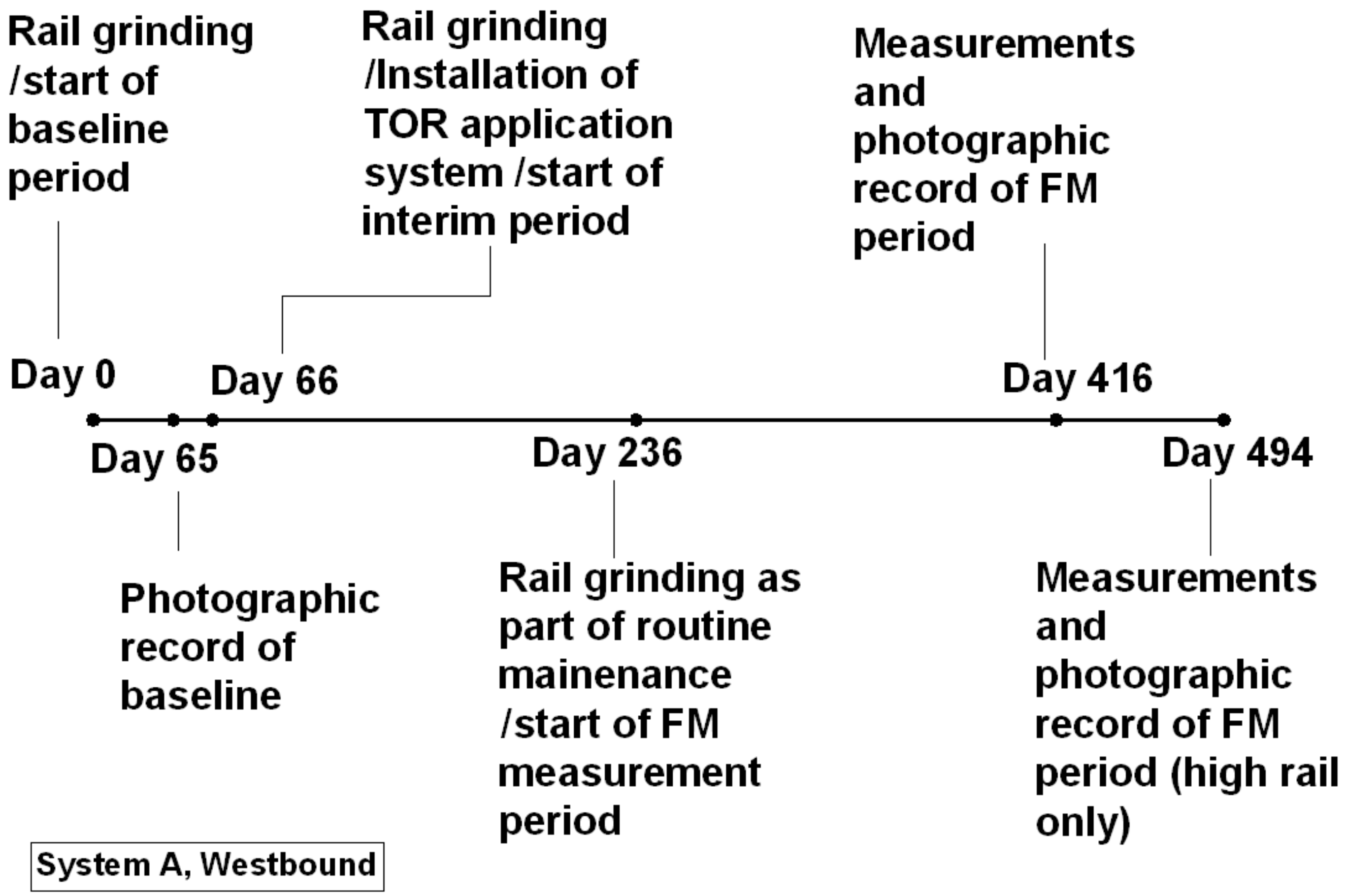
- European Metro
- Concrete slab
- Concrete sleepers
- 260 BHN rail

Low rail corrugations, Site A Westbound, 65 days after grinding, no FM

Corrugation Wavelength: 60-70 mm

Corrugation Amplitude: 0.21 mm

Site A: trial sequence



Site A Westbound (traction), low rail condition after 180 days FM application.

50m from FM application point

100m from FM application point

Site A, East bound (braking)

Baseline, 65 days after grinding

Low rail

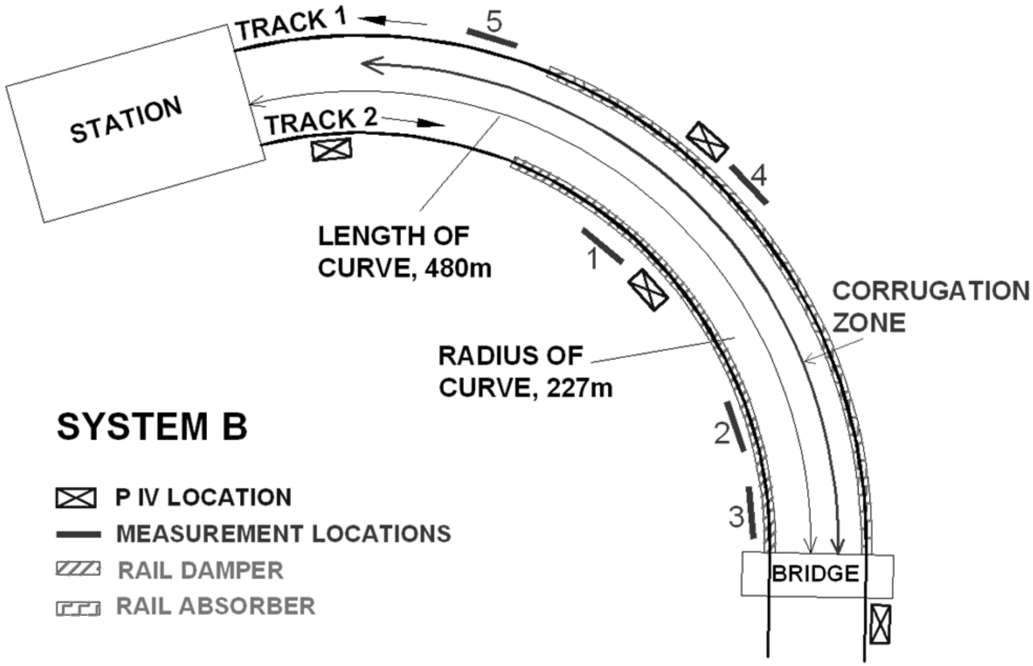
High rail

FM application, 155 days after grinding

Site B, suburban commuter rail system

Site B characteristics

- Ballast / concrete sleepers
- 260 BHN rail
- 3% gradient



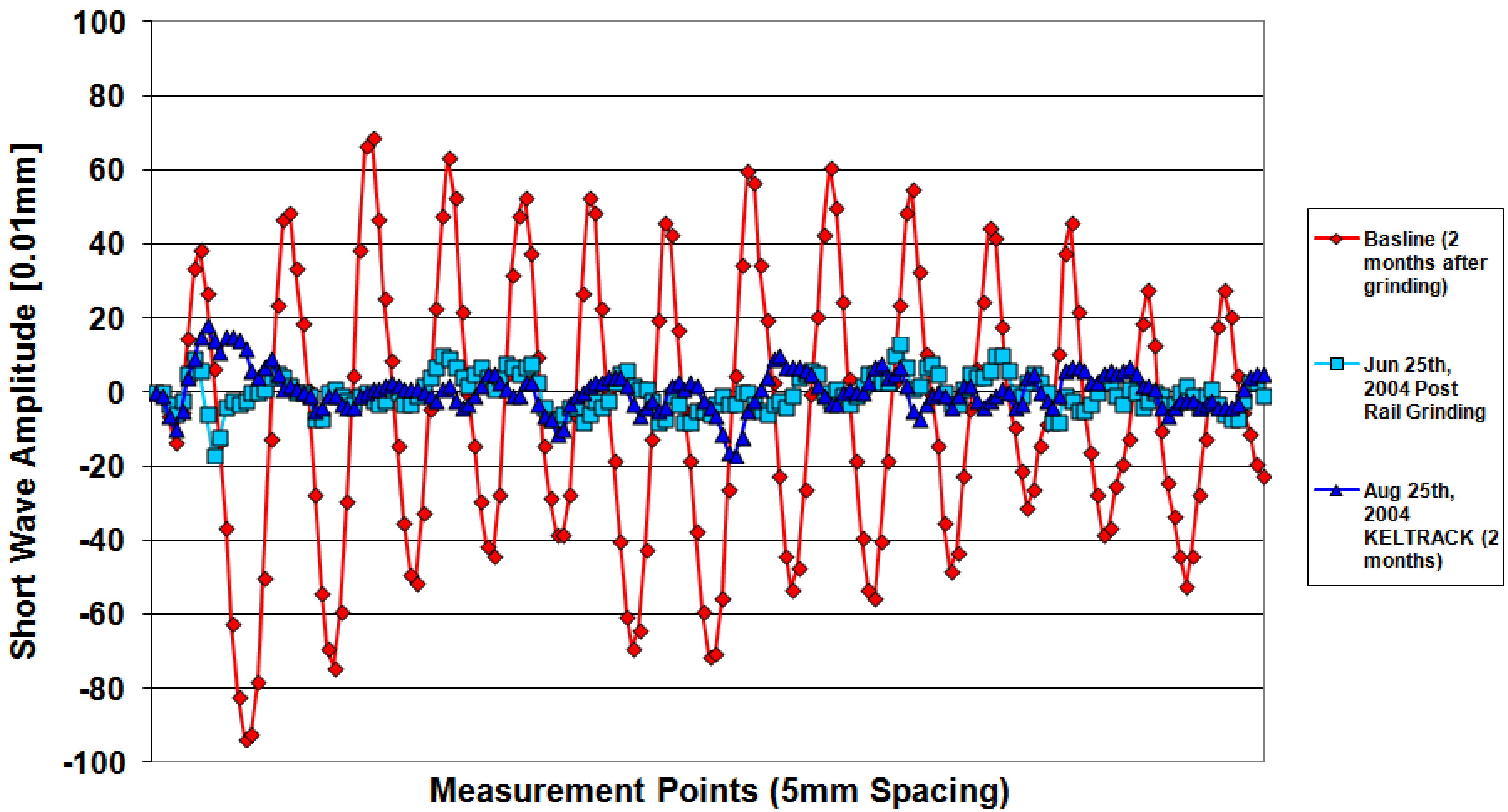
Low rail 1 month after grinding, no FM

Site B Corrugation

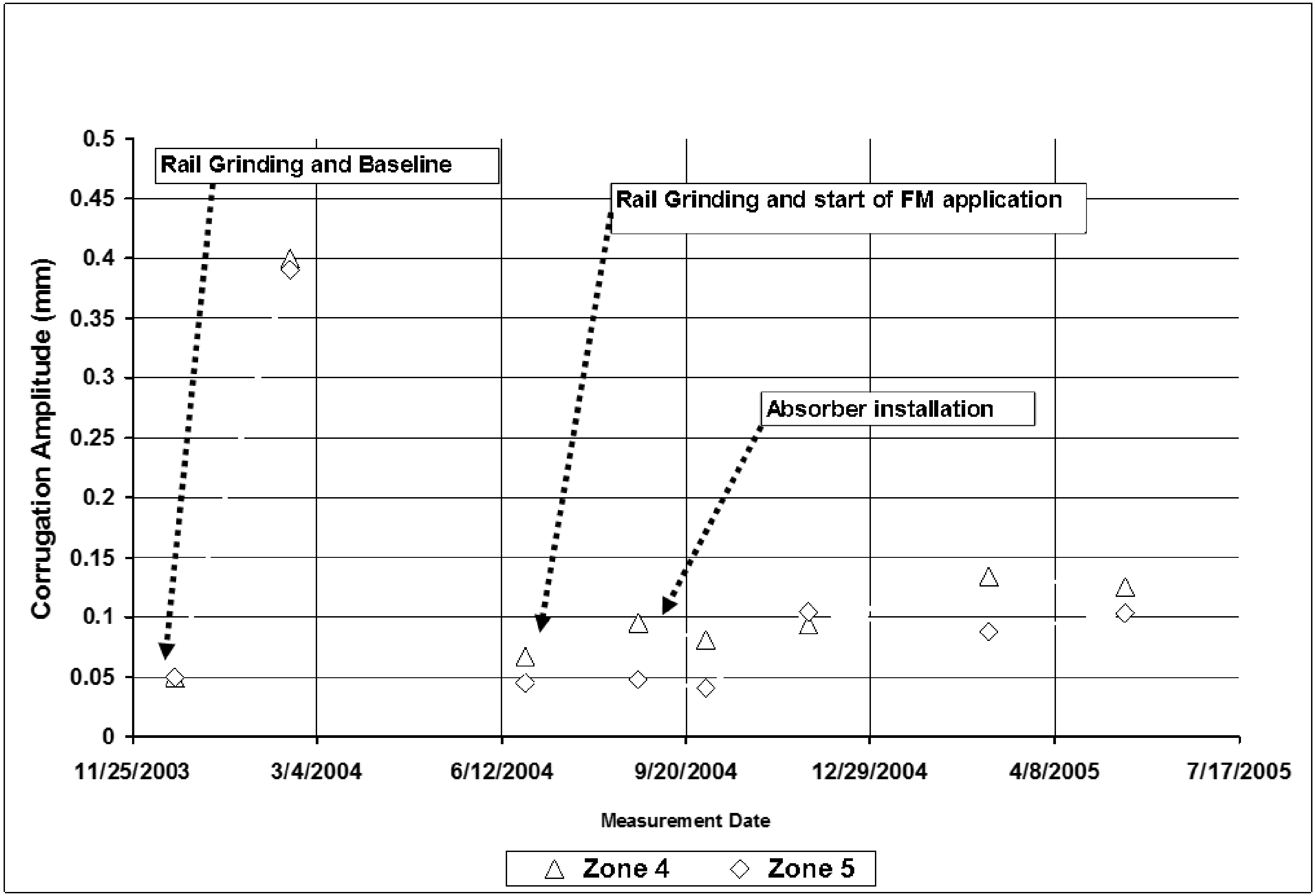
Track 2

Track 1

Site B: Esveld Profile

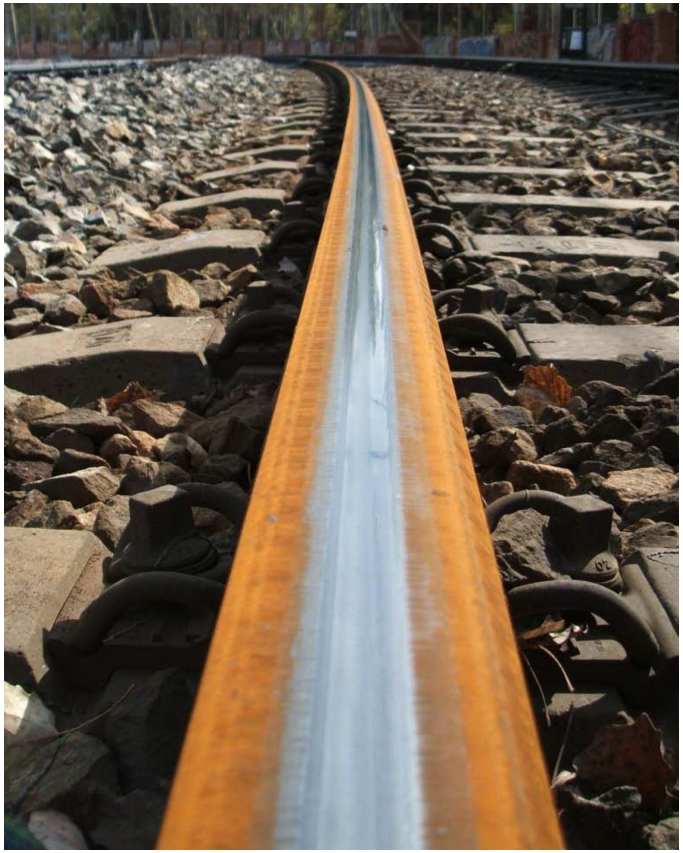


Site B, Track 1



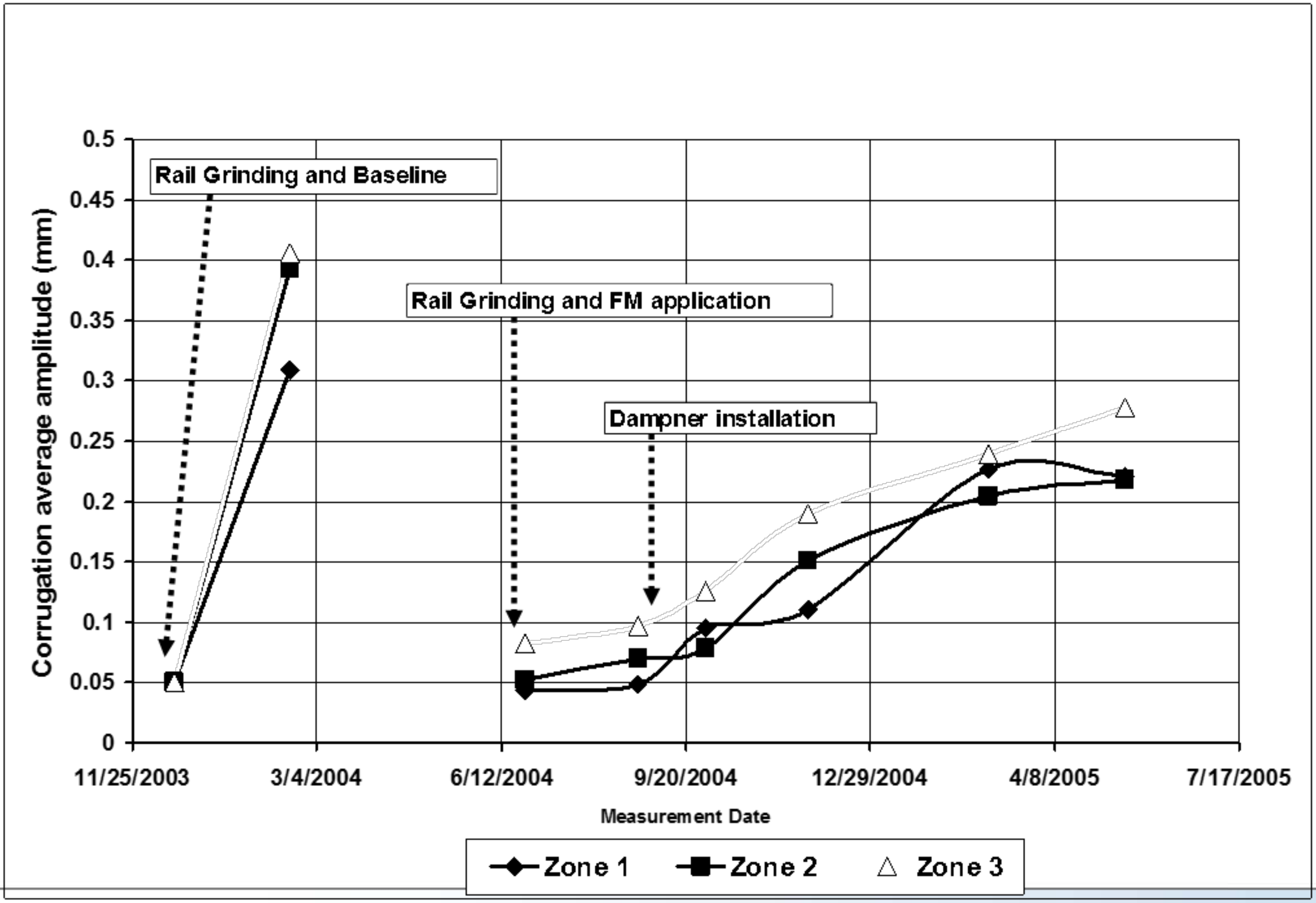
Site B, Track 1, after 280 days FM application

Zone 5



Zone 4

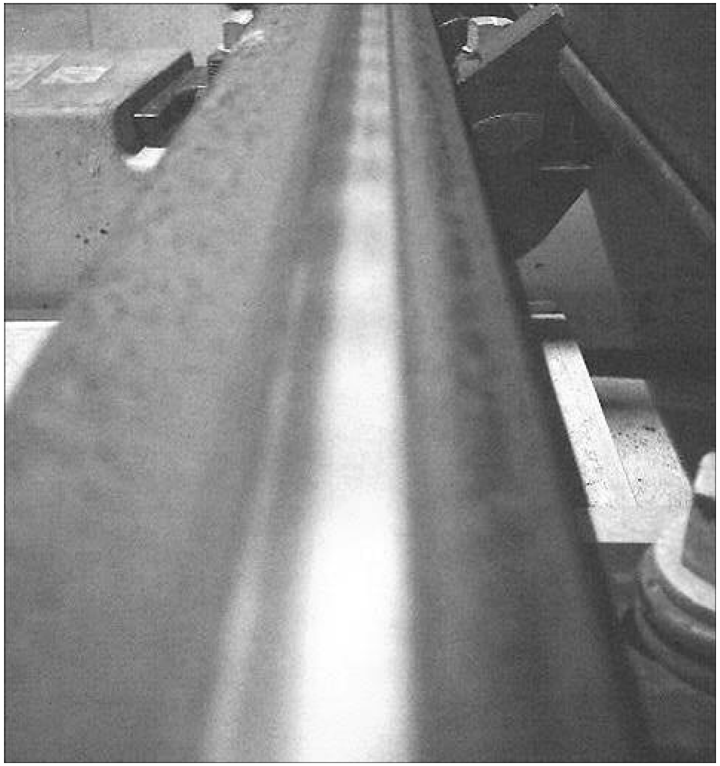
Site B, Track 2



Systems C: Japanese LIM metro system

	System C
Rail Type	**JIS50kgN DHH**
Fasteners	**Spring clip**
Construction	**Concrete slabs**
Sleeper type	**Concrete (booted)**
Sleeper spacing, mm	**625**
Curve length, m	**161**
Curve radius, m	**100**
Gradient	**0**

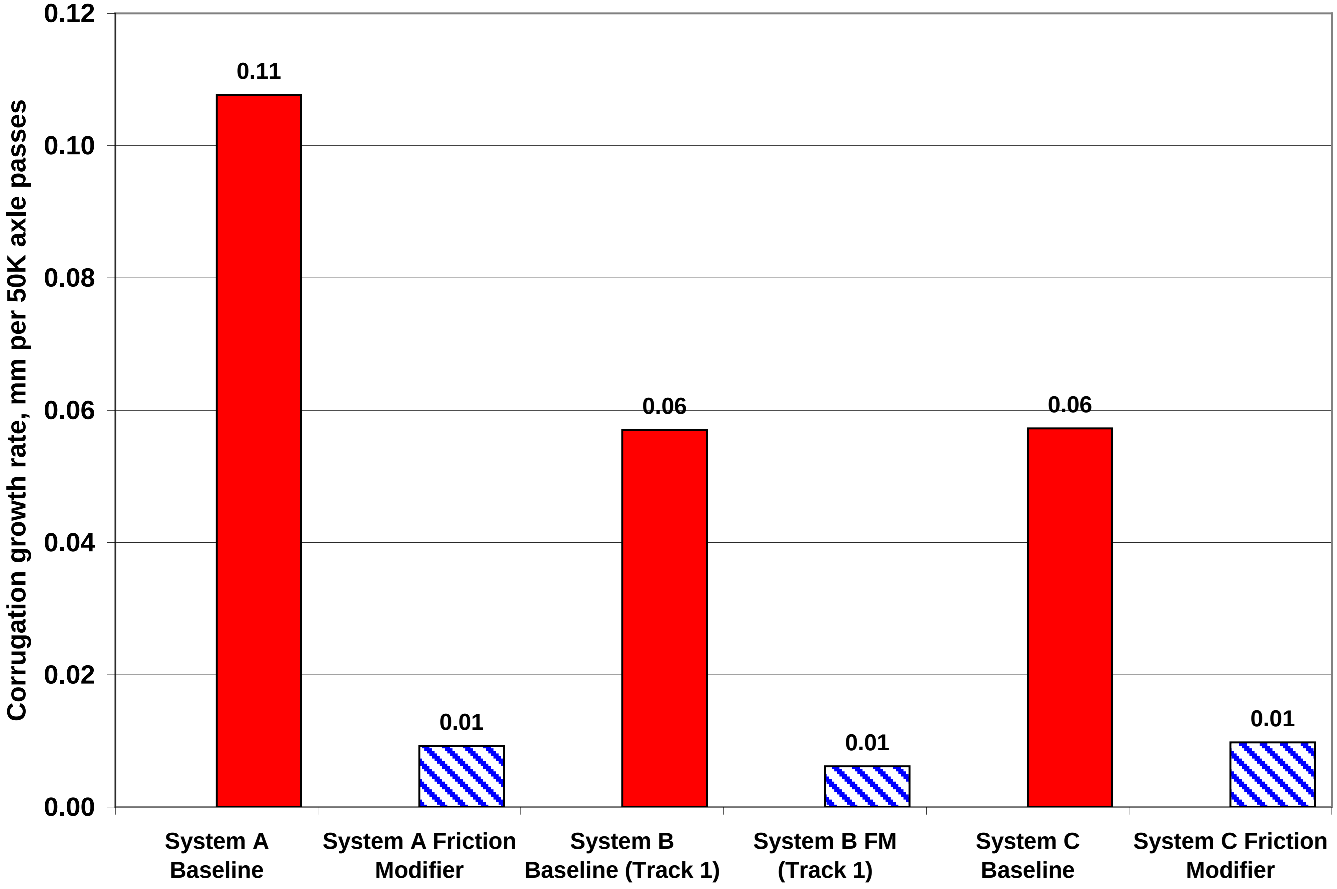
System C Observations



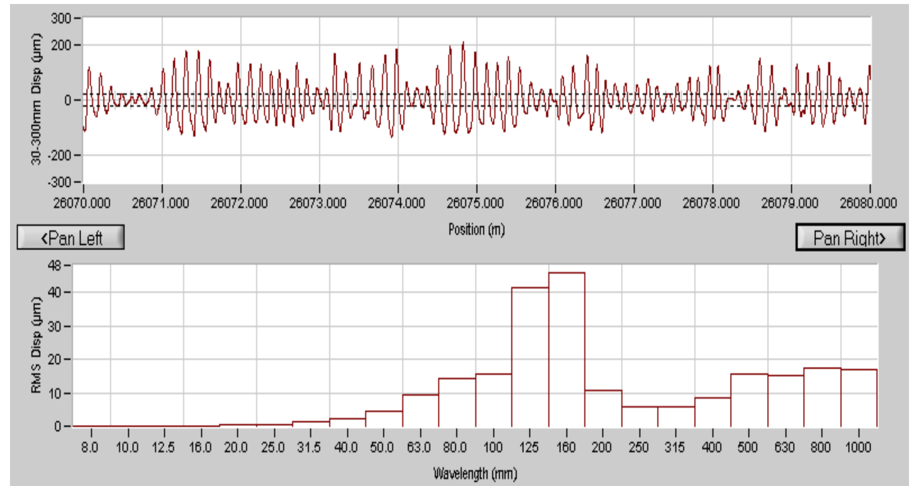
After 13 days, no FM

After 1 year, with FM

Summary of corrugation growth rates, Systems A, B and C

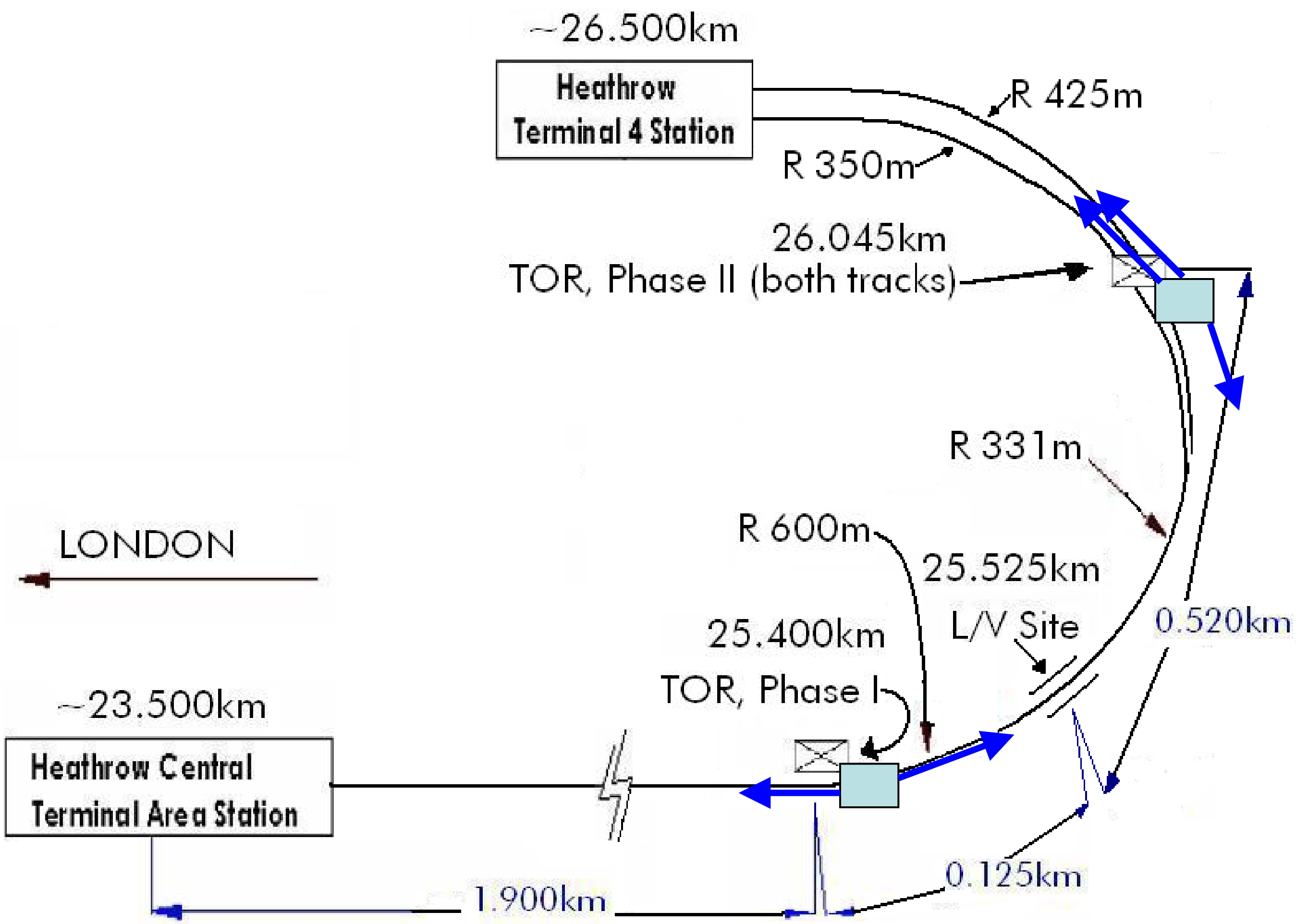


Case Study D: European commuter rail
Low Rail Corrugation

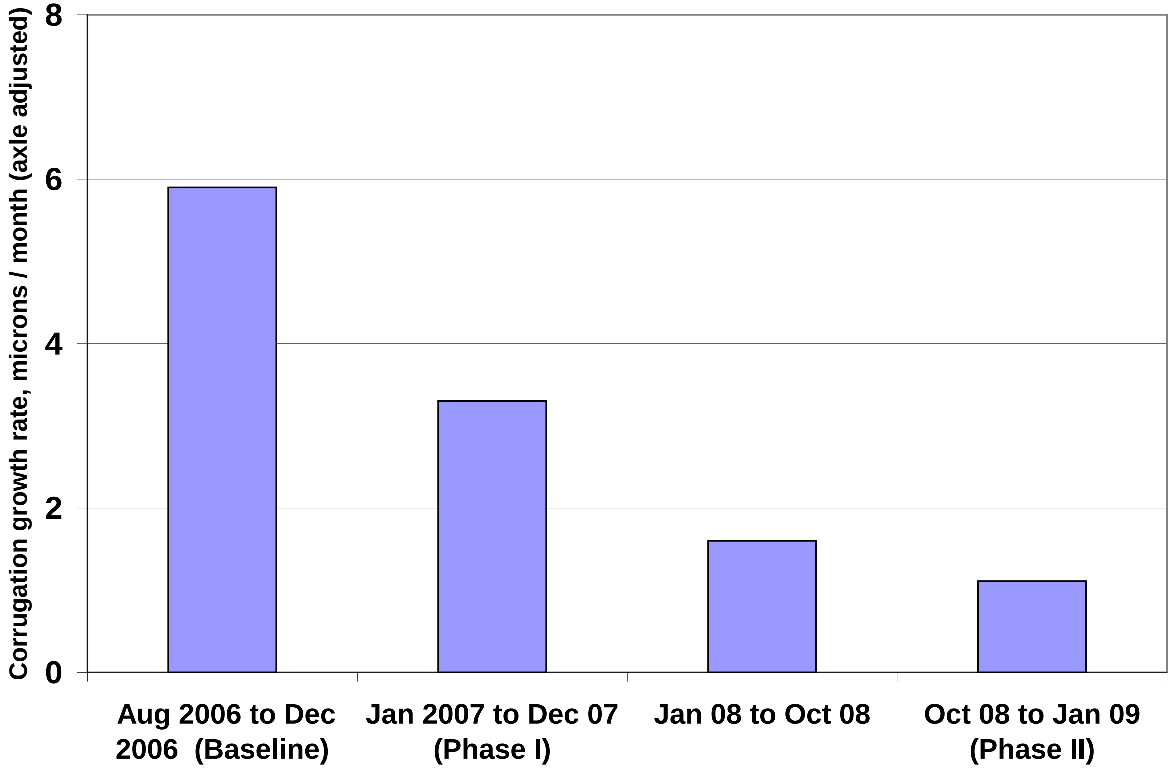


- Median wavelengths 125 to 160 mm
- Peak to valley depth up to 0.8mm
- Due to P2 resonance of the unsprung mass on the track stiffness.

Case D: Trial Site

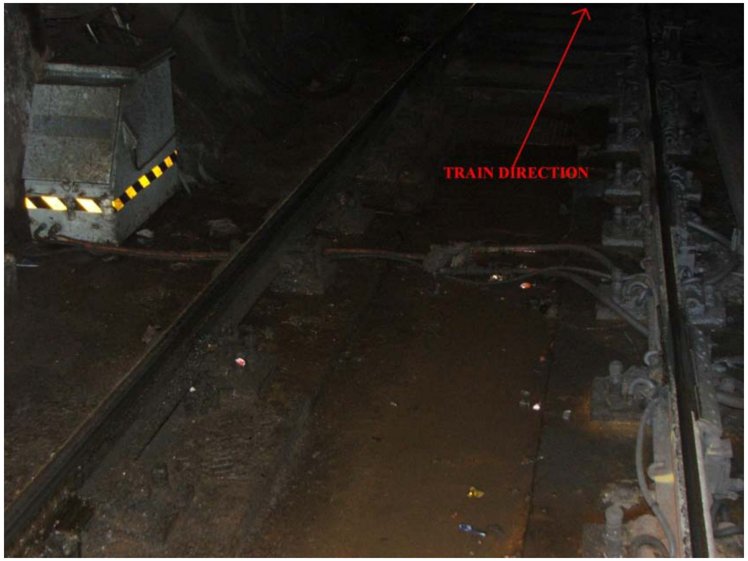


Case D: Corrugation growth rate (microns / month)



Case E: UK commuter rail

Case Study E: UK commuter rail system



Test Curve 1

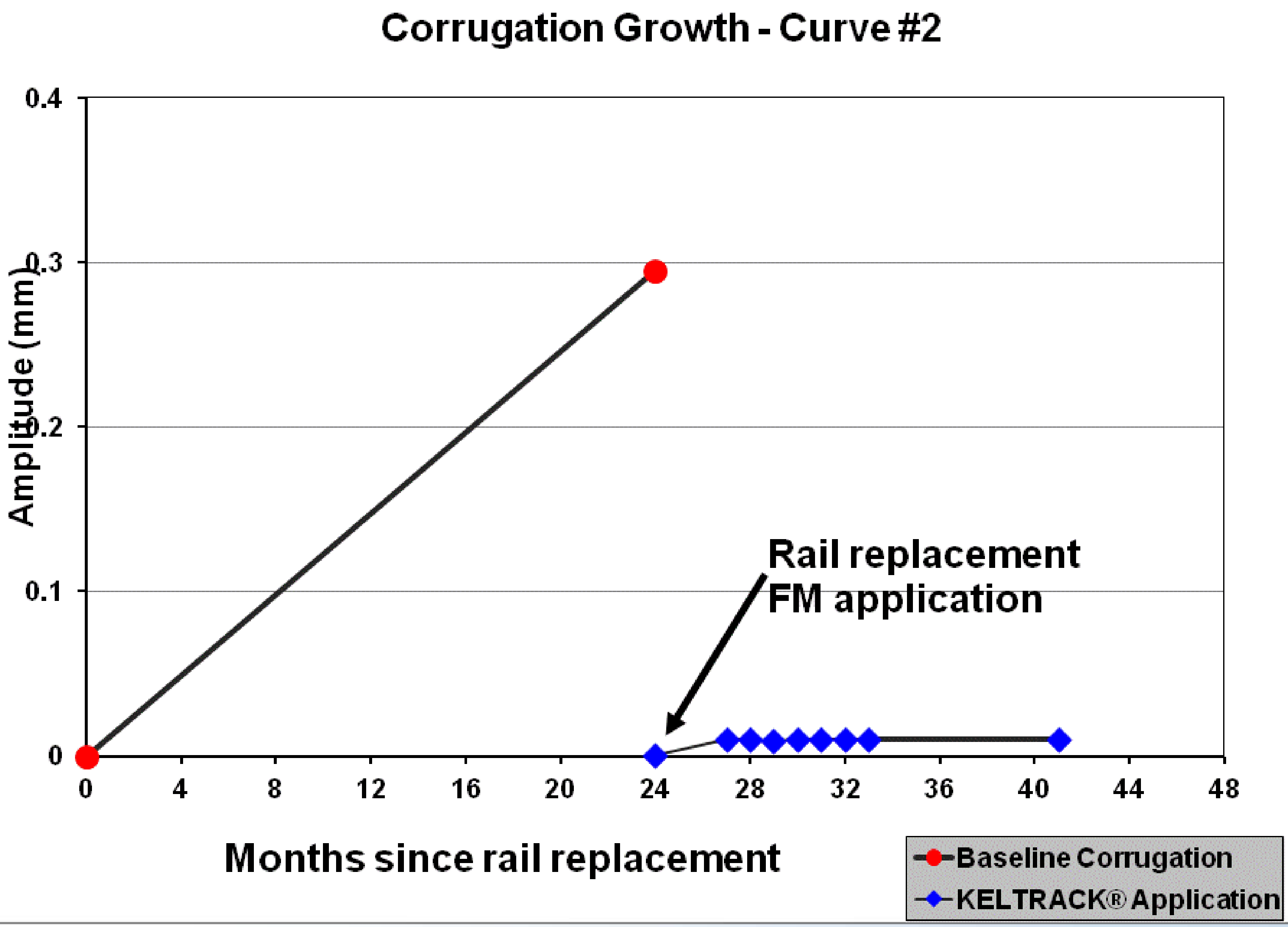
Start of curve transition 0m 880y
Top of curve 0m 957y
Radius 225 Cant 50mm
Top of curve 0m 1425y
Bottom of transition 0m 1520y

Test Curve 2

Start of curve transition 1m 311y
Top of curve 1m 339y
Radius 210 Cant 65mm
Top of curve 1m 950y
Bottom of transition 1m 978y

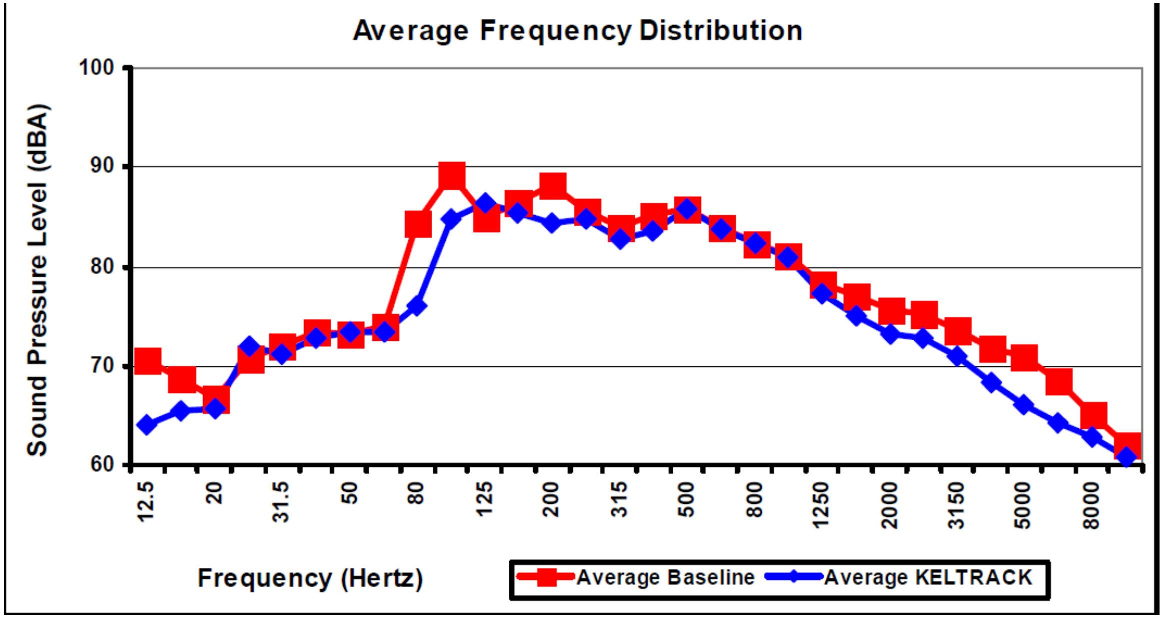
Low Rail "Rutting" Corrugation

Case E


Corrugation Growth - Curve #2
Amplitude (mm)
0.4
0.3
0.2
0.1
0
0
4
8
12
16
20
24
28
32
36
40
44
48
Rail replacement
FM application
Months since rail replacement
Baseline Corrugation
KELTRACK® Application

Effect of FM on existing corrugations – noise and vibration

Effect of FM on corrugated rail (mixed freight / passenger)



Effect of FM on corrugated rail: vibrations

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Tribology International xx (2004) 1–6

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Effect of liquid high positive friction (HPF) modifier on wheel-rail contact and rail corrugation

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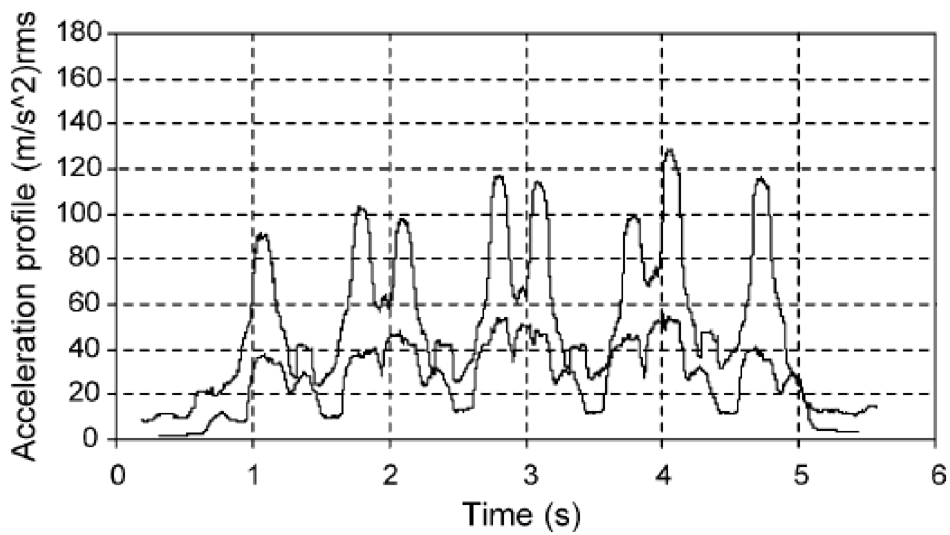

Fig. 4. Rms acceleration profile with and without HPF on the rail.

Conclusions

- Corrugations can be categorized by type
  - Identify frequency
  - Helps identify mitigation methods

- Measurement tools and standards are available to quantify impact of various mitigation technologies as well as set standards for grinding

- Wayside application of Top of Rail friction modifier shown to reduce short pitch corrugation growth rate by at least a factor of 8

- Positive friction characteristics of friction modifier is critical for maximum corrugation growth reduction in rutting corrugation
  - Can completely eliminate this type of corrugation growth