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The use of under sleeper pads to improve the performance of ballasted railway track at switches and crossings: A case study

Louis Le Pen, Taufan Abadi, Andrew Hudson
Antonis Zervos & William Powrie

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Presentation overview

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- Under sleeper Pads – manufacturers data and laboratory tests
- Geophone measurements from a study site in the UK
- Importance of track support conditions – some simple insights from a beam on elastic foundation model

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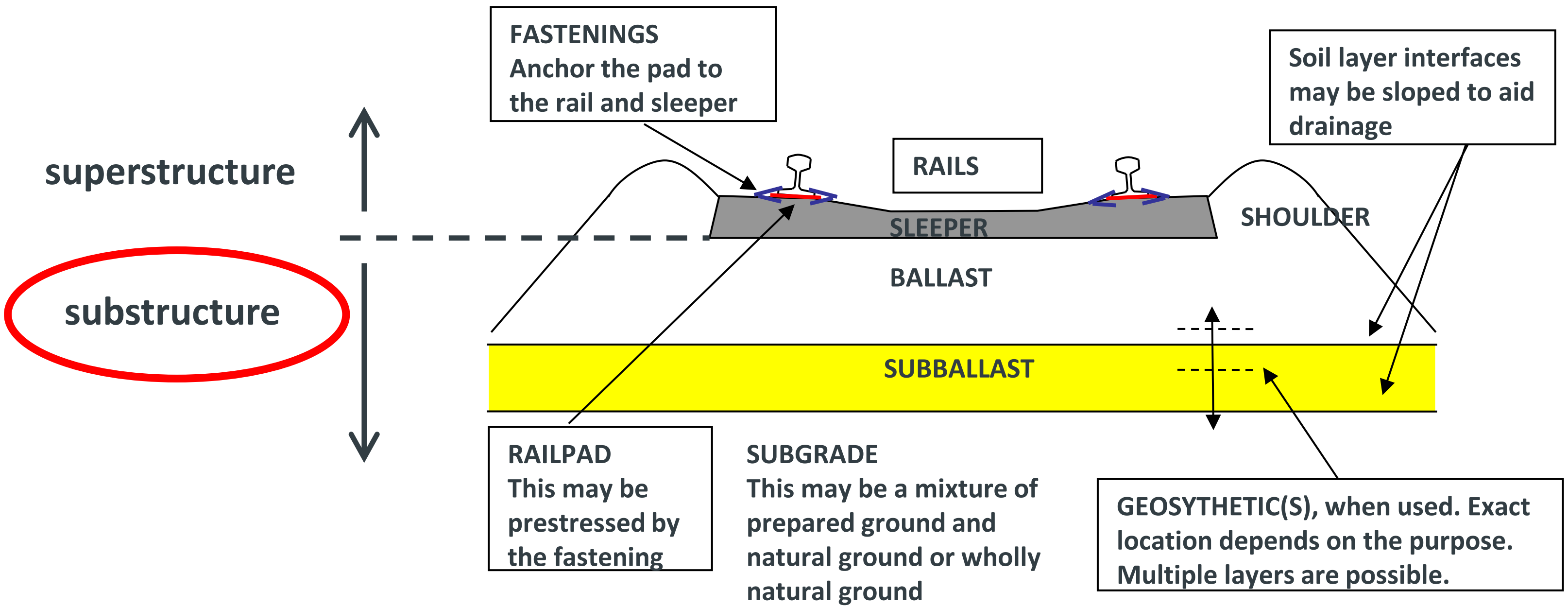
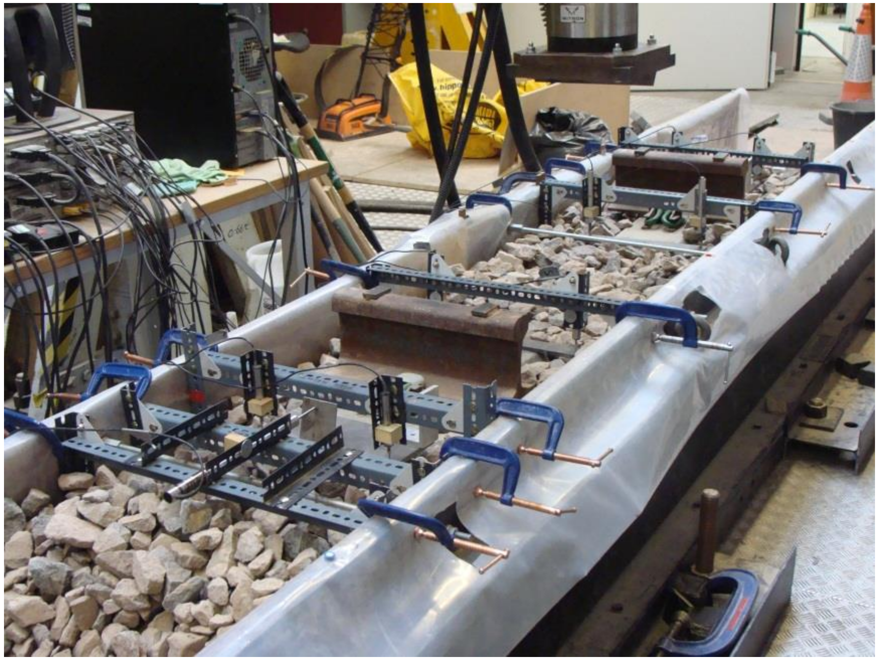
Background: track structure



Full scale laboratory tests



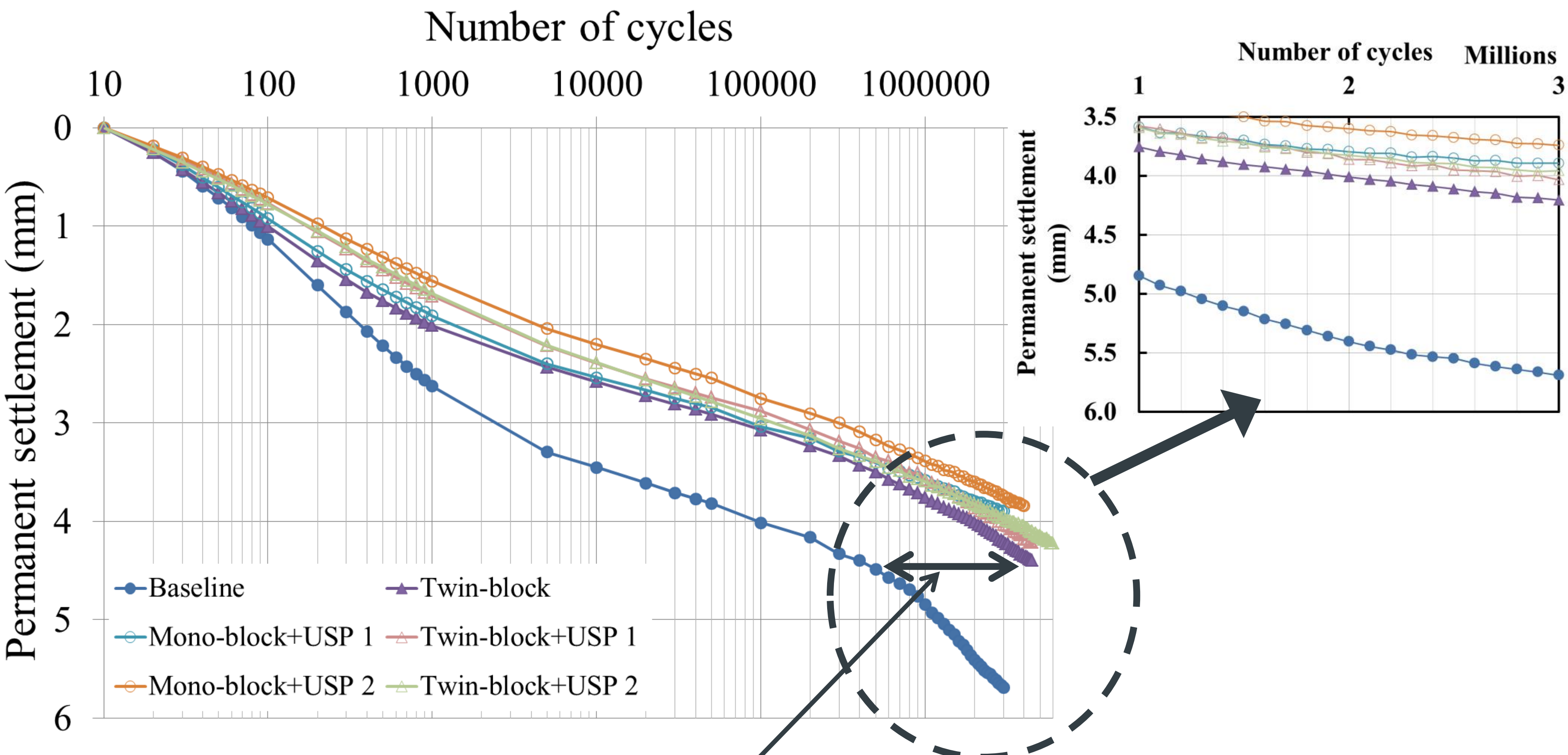
General test conditions:
3 million equivalent 20 tonne axle passes at 3Hz. The ballast was placed to 300 mm depth and typical size ballast shoulders and crib ballast were placed.
Mono-block sleepers, 3 tests were carried out on NR ballast grading covering: 1 baseline and 2 tests with two different types of under sleeper pad (hard, soft)
Twin-block sleepers, 3 tests were carried out on NR grading covering: 1 baseline 1 test with a hard under sleeper pad and 1 test with a soft under sleeper pad

USPs tested in the laboratory and installed on site

	Type of USPs in the LAB tests (made by Tiflex)		Types of USP used in SITE trial (made by Getsner)	
	USP1 - Hard	USP2 - Soft	Hard	Medium
Technical ID	FC500	FC208GF	SLB2210G	SLB 1510 G
Thickness	**4 mm**	**9 mm**	**10 mm**	**10 mm**
Weight	6 kg/m²	5.6 kg/m²	4.2 kg/m²	4.2 kg/m²
Stiffness (C_{Stat})	**0.228-0.311 N/mm³**	**0.079-0.105 N/mm³**	**0.22 N/mm³**	**0.15 N/mm³**
Core material	Trackelast FC500	Bonded cork	polyurethane	polyurethane

- **C_{stat} values give comparative indication of stiffness and performance in track but the stiffness values do not allow direct calculation of in service performance (**DIN 45673)

Results: Permanent settlement on mono-block and twin-block sleeper tests



Possible reduction in maintenance related to settlement

Results: Resilient deflection

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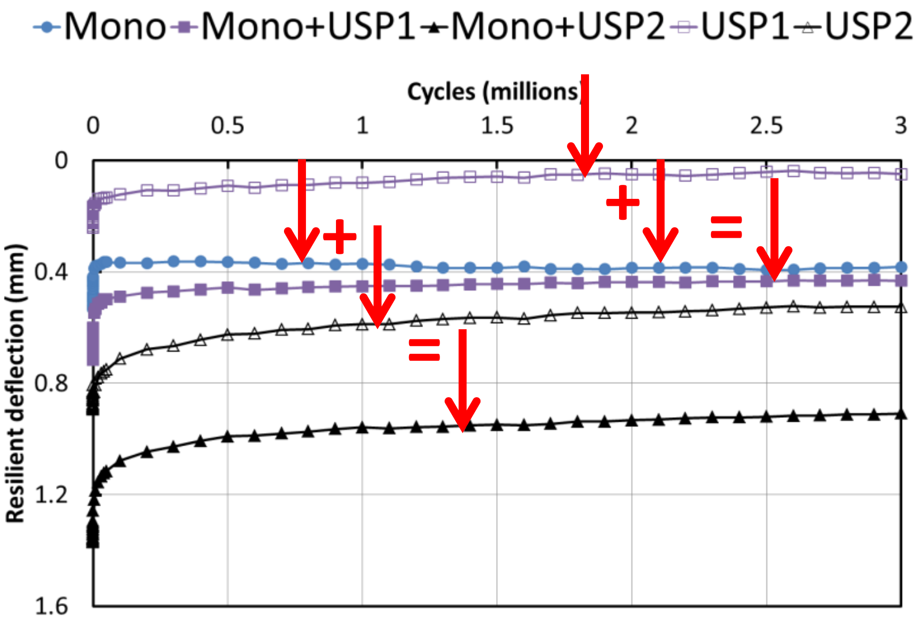

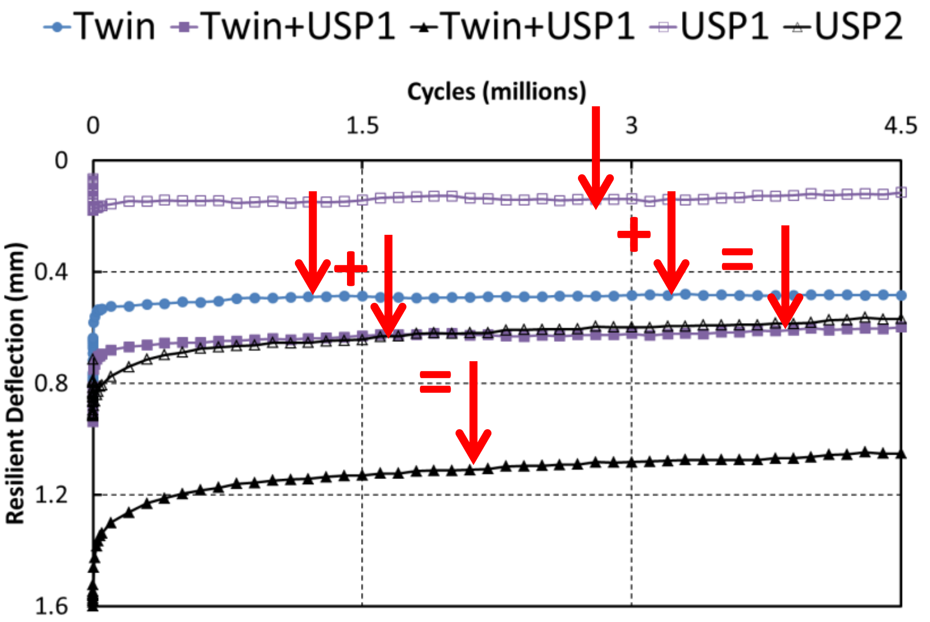

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Results: Stiffness

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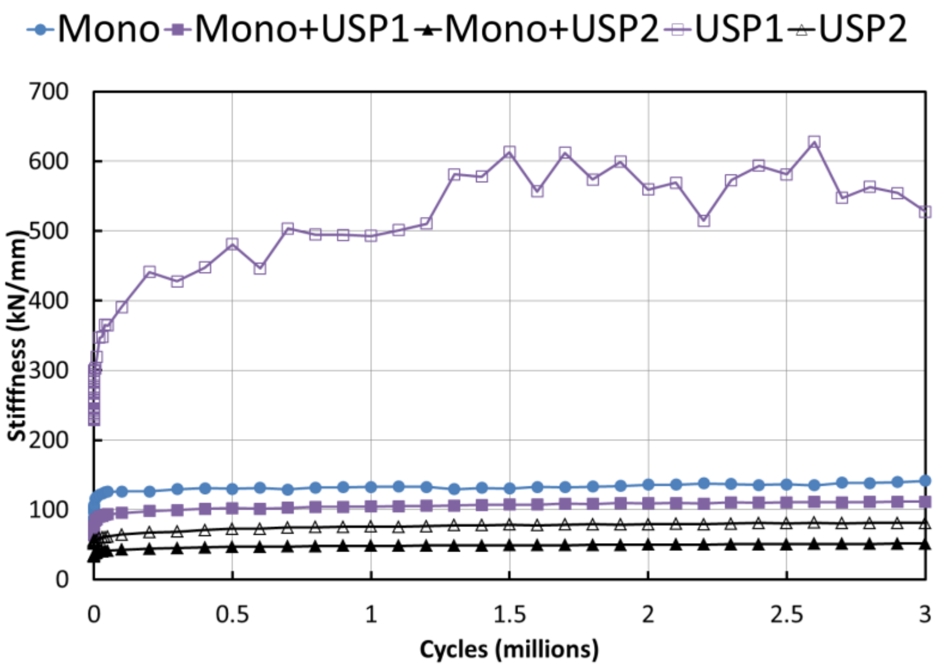

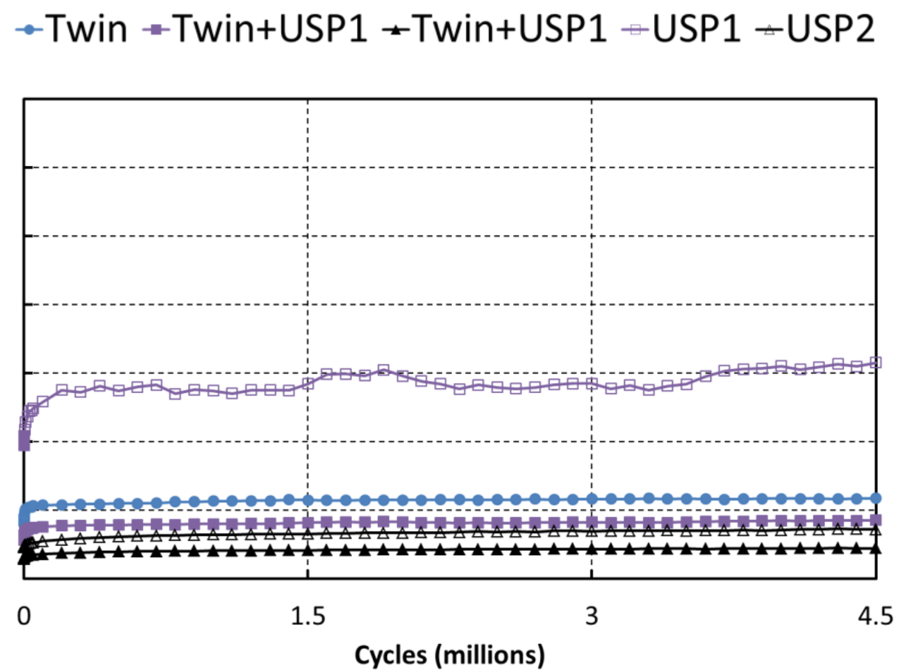

- Stiffness worked out as equivalent spring stiffness per railseat load
- Spring stiffness of USPs worked out as: $1/k_{usp} = 1/k_{sleeper\ +USP} - 1/k_{twin\ block}$

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Track stiffness: design method

Design methods are usually empirically based. Network Rail currently provide a chart:

Ref:	**NR/SP/TRK/9039**
Issue:	01
Date:	December 2005

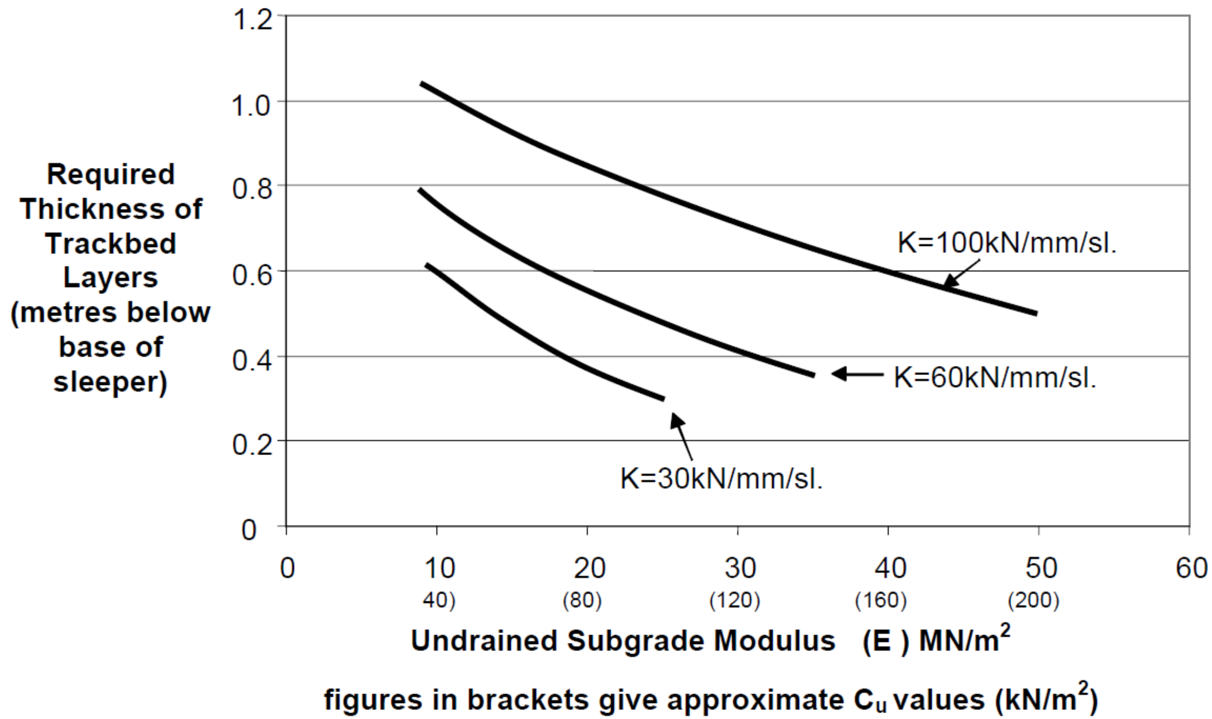

Figure 2 – Required Thickness of Trackbed Layers

Where
K= [railseat load]/
[deflection]

Sleeper/ballast contact analysis

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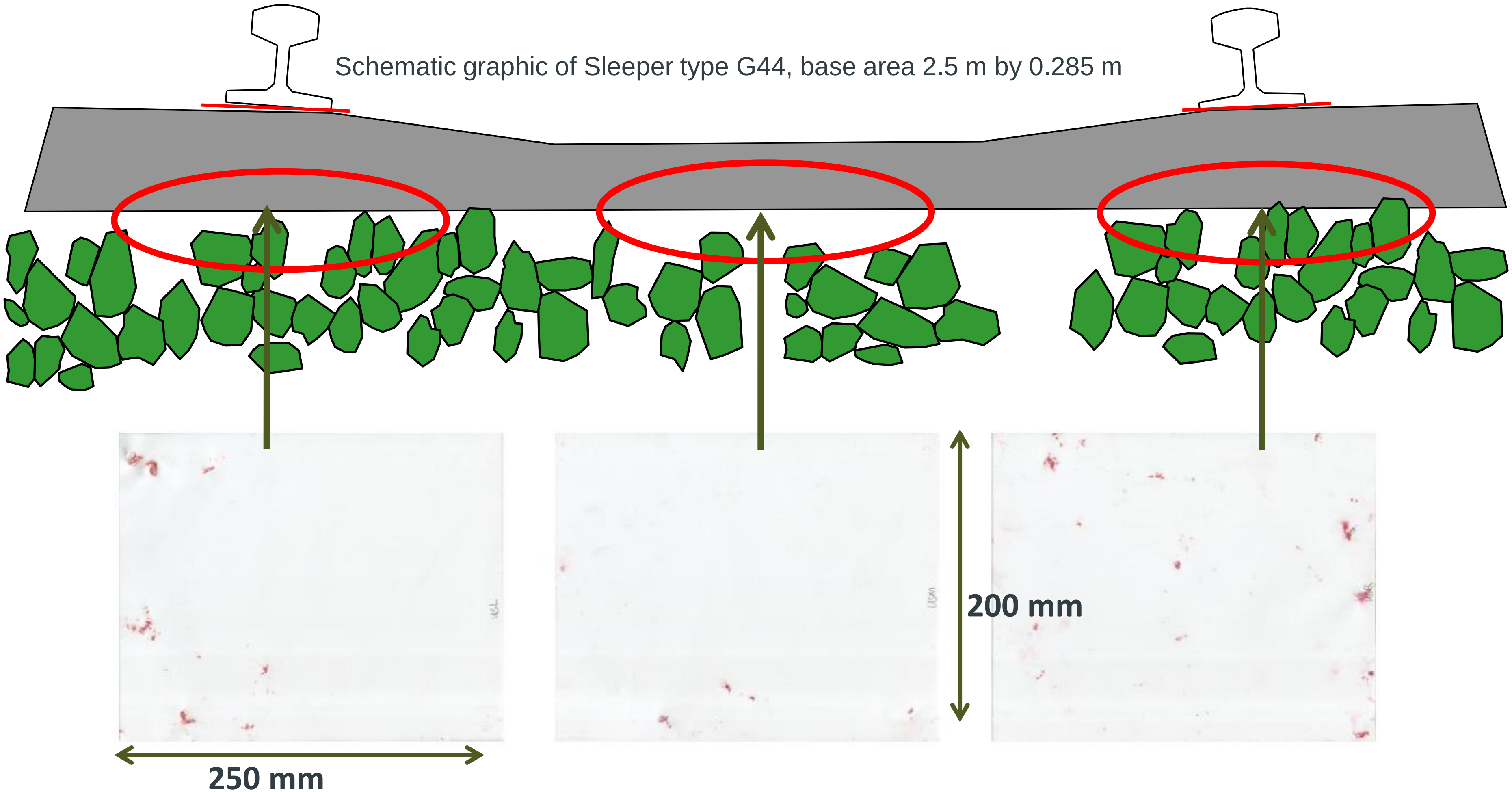

Pressure sensitive paper shows contact history at selected locations below sleeper

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Results: Mono-block SLEEPER/BALLAST interface with USPs

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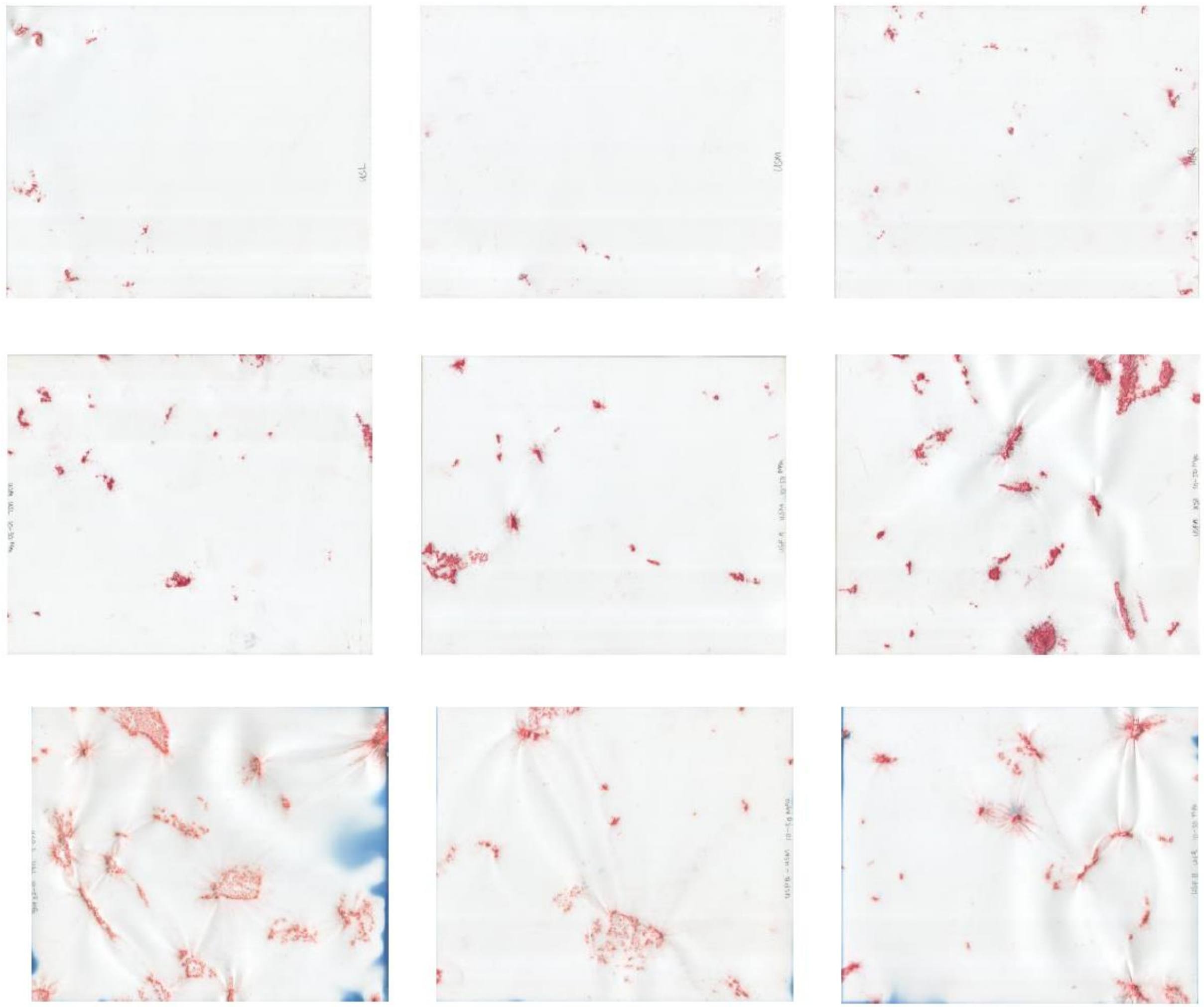
Mono-block



Baseline test

Hard USP

Soft USP

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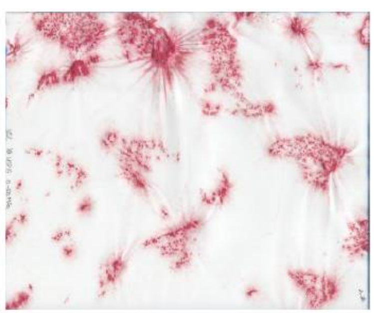
Results: Twin-block SLEEPER/BALLAST interface with USPs

TWIN-BLOCK


Baseline


Hard USP




Soft USP

Pressure paper analysis, area and number of contacts for 10 MPa to 50MPa paper

Sleeper type	Average (%) contacts per sleeper (mono-block = 0.71 m^2, twin-block = 0.50 m^2)	Average contacts per sleeper (mono-= 0.71 m^2, twin = 0.50 m^2)	Notes
MONO-BLOCK	0.18	147	Baseline
	1.64	314	Hard USP
	1.05	447	Soft USP
TWIN-BLOCK	0.53	243	Baseline
	2.91	268	Hard USP
	4.75	329	Soft USP

Potential sleeper/ballast contacts

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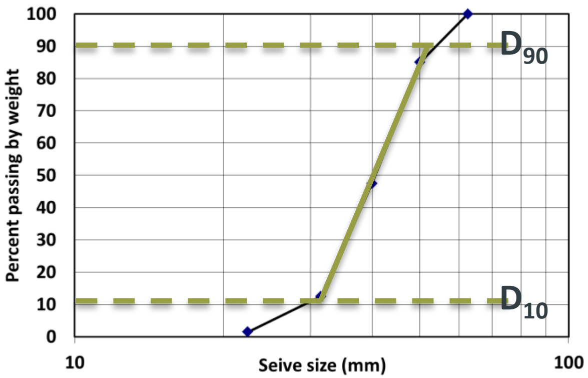
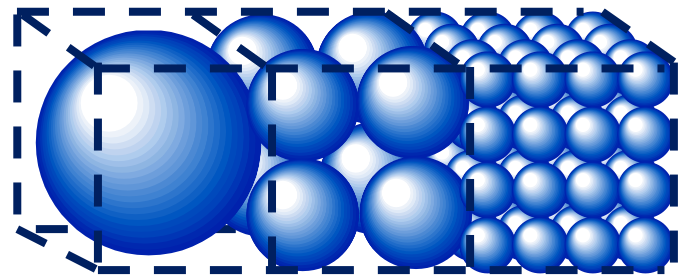
Approximated Particle Size Distribution:



Visual idealisation (square packing):



Simplified equation:

$$\text{Number of contacts} = \left(\frac{N.\,A_{\text{sleeper}}}{D_A^2}\right).\left(\frac{\sqrt[\frac{2}{3}]{\frac{1}{D_A^3}} + \sqrt[\frac{2}{3}]{\frac{1}{D_B^3}} + \cdots \sqrt[\frac{2}{3}]{\frac{1}{D_N^3}}}{\sqrt[\frac{2}{3}]{\frac{1}{D_A^3}}\,:}\right)$$

Results evaluated as a contact efficiency:

Sleeper type	Test	Measured contacts	Potential contacts calculated for 5 steps	Contact Efficiency (%)
Mono- block	Baseline	147	513	28.0%
	+ USP 1	314	513	61.2%
	+ USP 2	447	513	**87.1%**
Duo Block	Baseline	243	357	68.1%
	+ USP 1	268	357	75.1%
	+ USP 2	329	357	**92.2%**

Abadi, T. C., Le Pen, L. M., Zervos, A. & Powrie, W. (Submitted Spring 2014). Measuring the Contact Area and Pressure Between the Ballast and the Sleeper. *The International Journal of Railway Technology.* Saxe-Coburg Publications

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A trial site in the UK

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The study area – track layout

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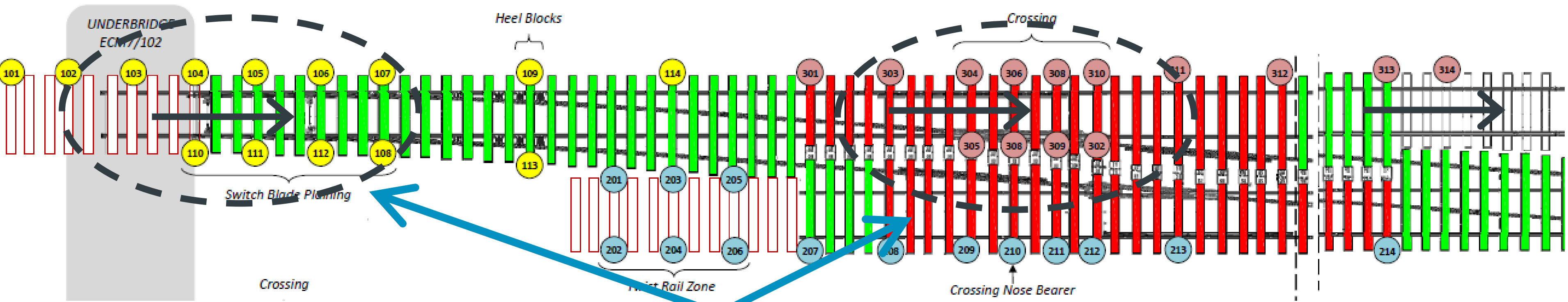
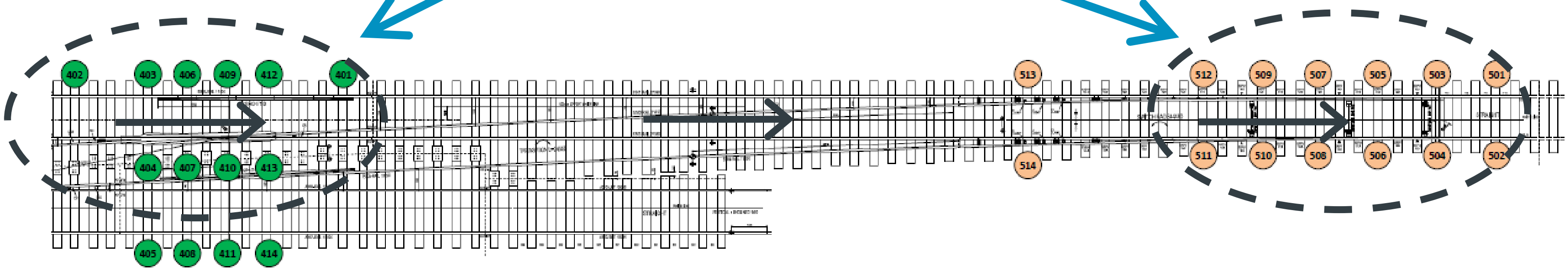
USP trial sites, USPs placed at first two locations:
(1) facing switch blades (2) facing crossing



USP trial sites, no USPs at second two control locations:
(3) trailing crossing (4) trailing switch blades

CONTROL



Notes:
Green = hard USP type
Red = soft USP type
Trains can cross the track but none do so in this study

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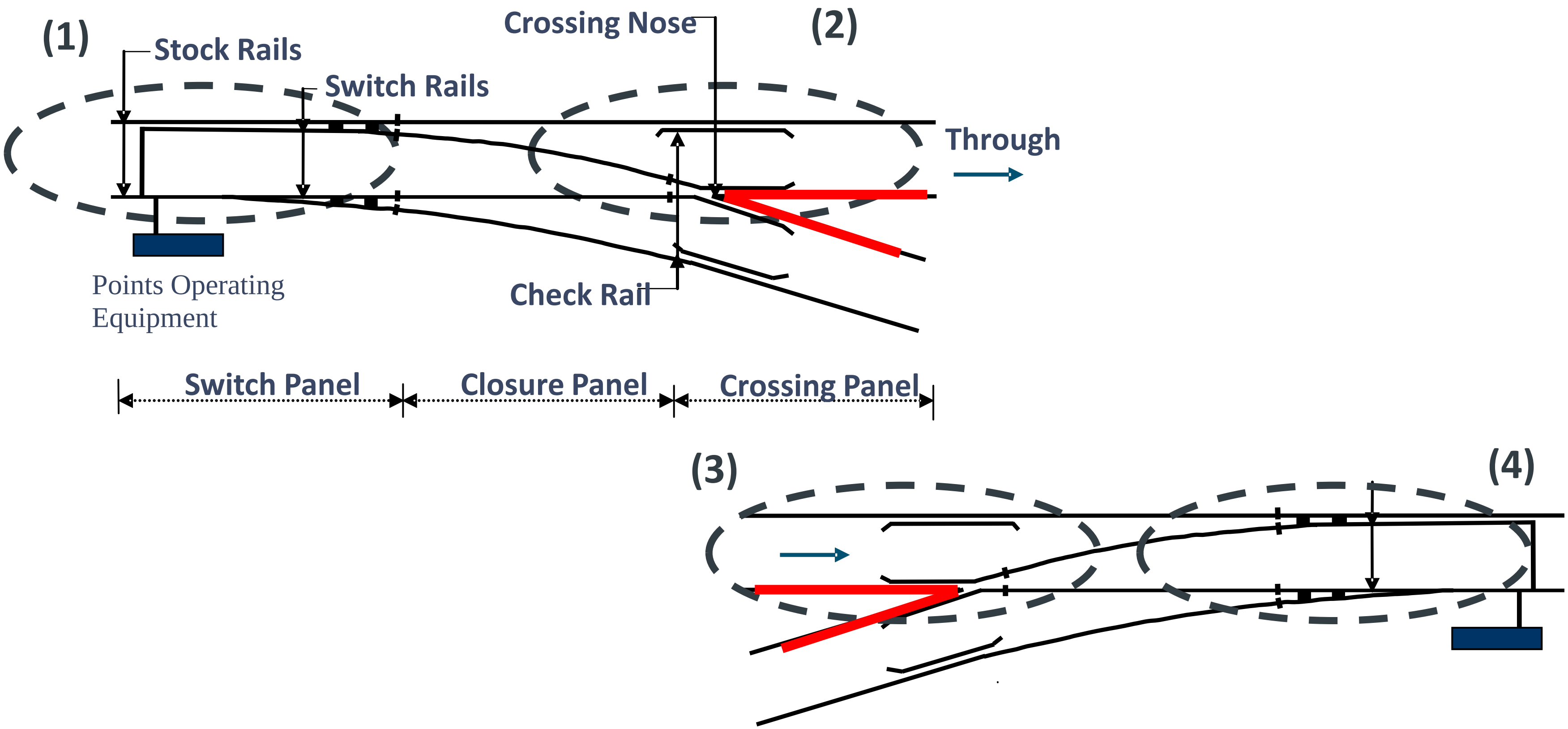
The study area – schematic of track



- **Complex track geometry leads to larger dynamic variation in load and a faster rate of track geometry degradation**

The sites

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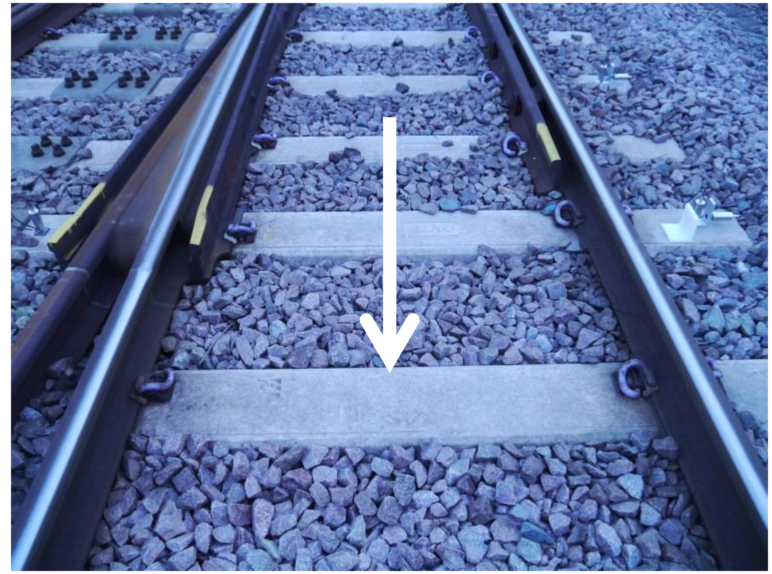
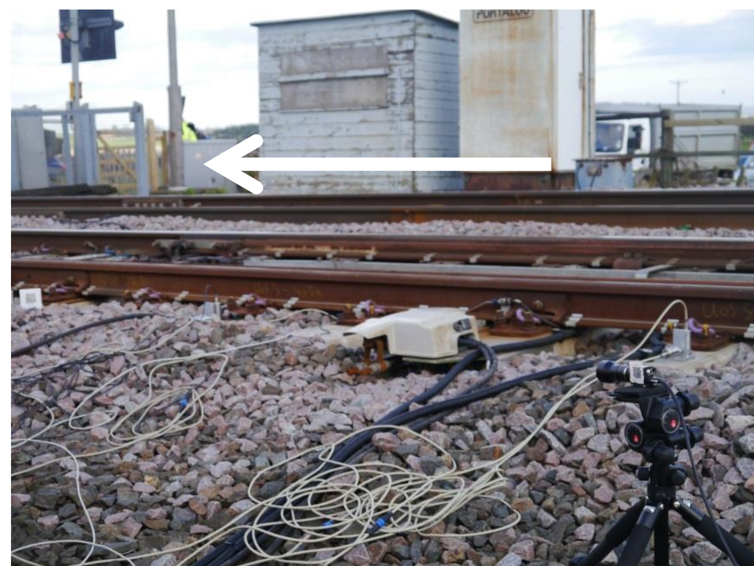
Site 1: leading switch blades

Site 2: facing crossing



Site 3: trailing crossing

Site 4: trailing switch blades



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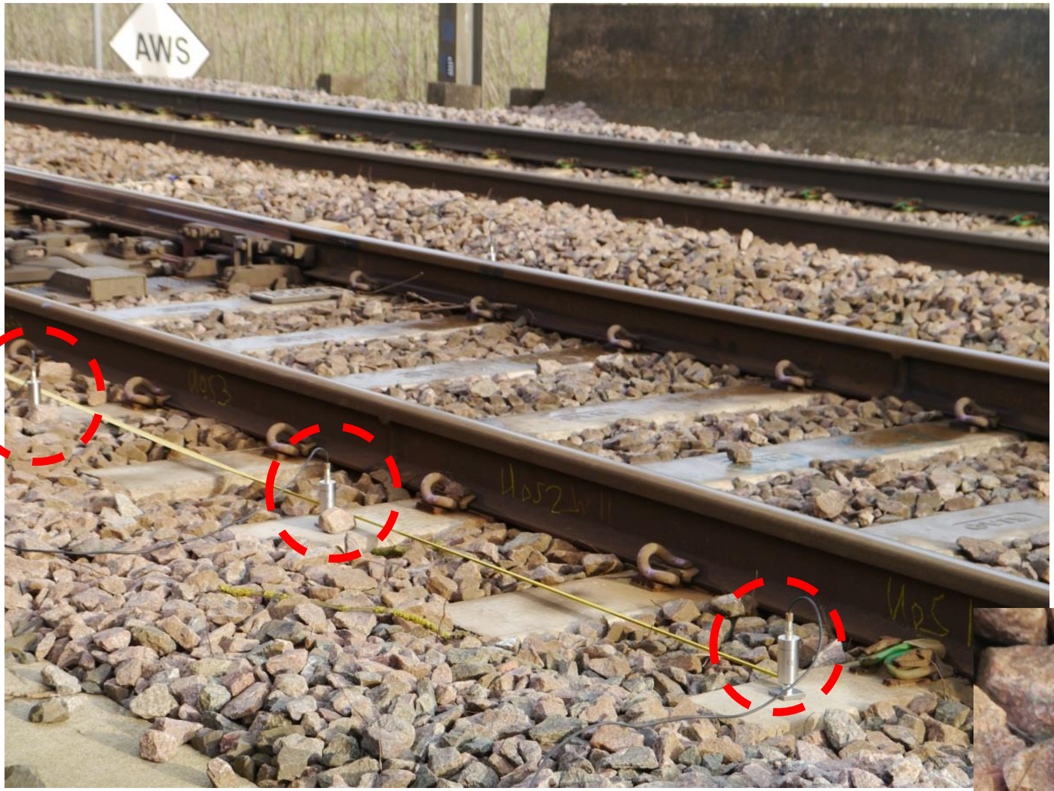
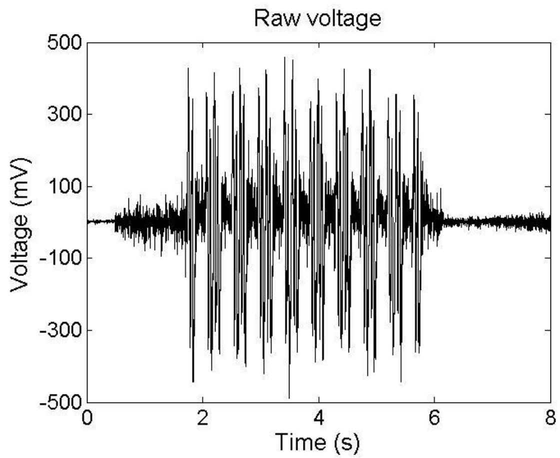
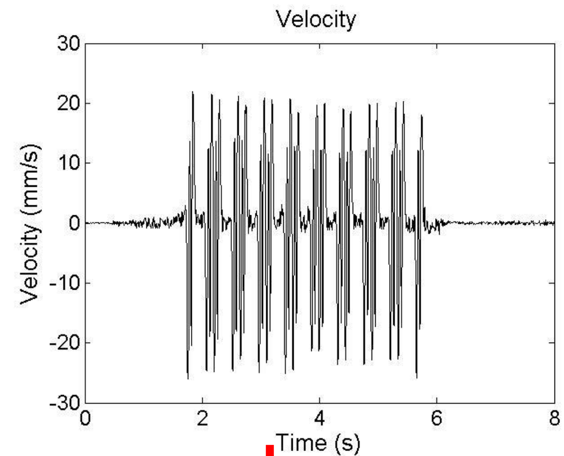
Background: Monitoring equipment



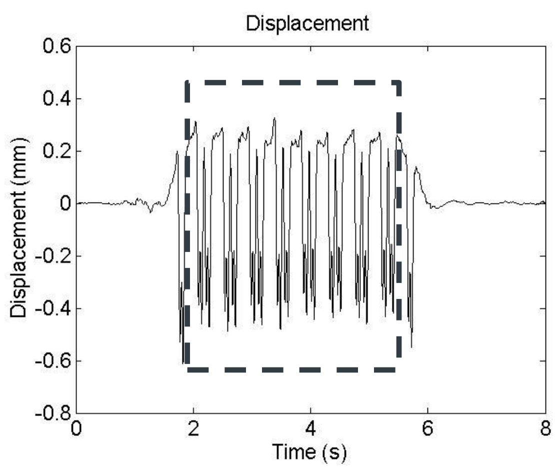
Background: How geophone data is interpreted



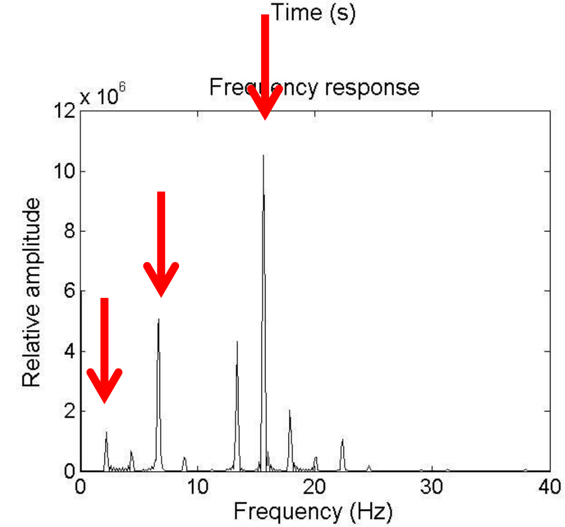
1. Geophone produces a voltage proportional to velocity of the sensor



2. Knowing the response characteristics of the geophone the velocity can be computed



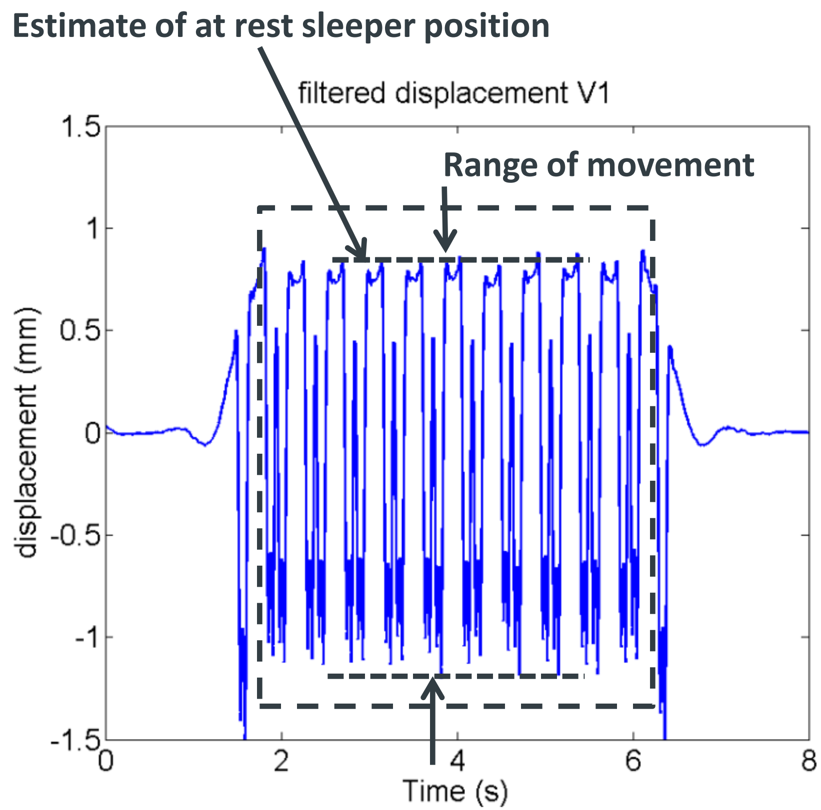
3. Integration of data leads to calculated displacement



4. Dominant axle, bogie, and car passing frequencies responsible for the major displacements are between 1 and 20 Hz usually

Example data from a 9 car train at 110 mph (~180kmph).

Background: How geophone data is interpreted



The trace shown is of an 11 car Pendolino train.

Typical trace........

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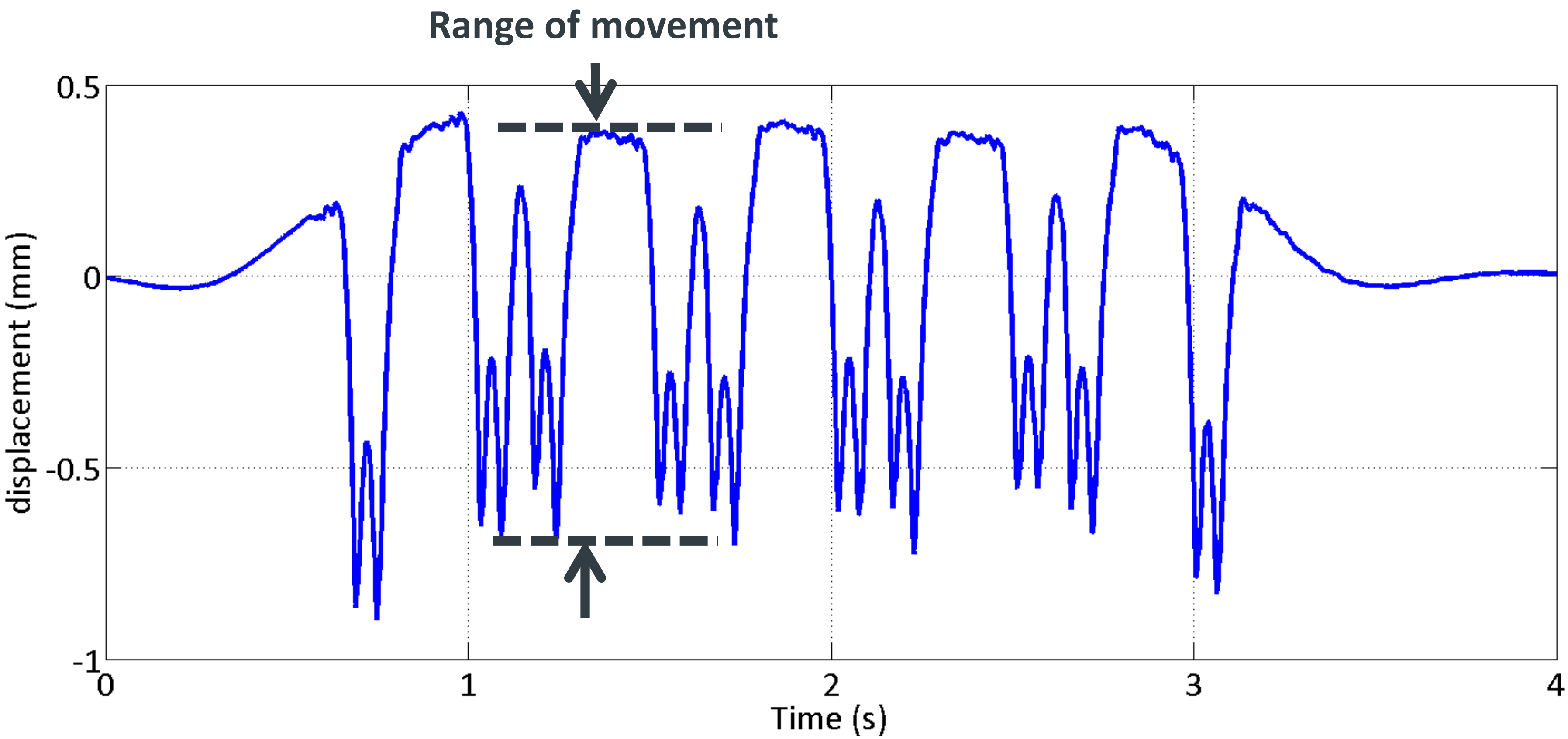

Class 221 (Super-voyager) on site 1

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Site 1 – underbridge to leading switch blades

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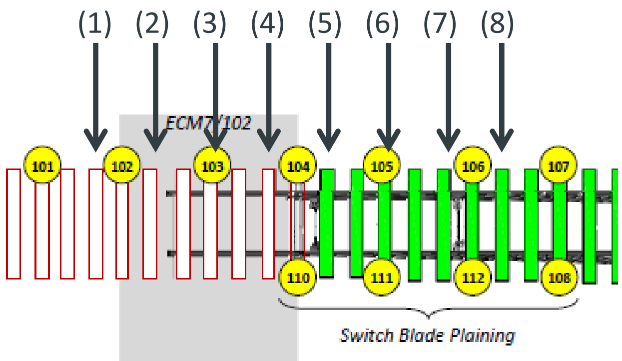

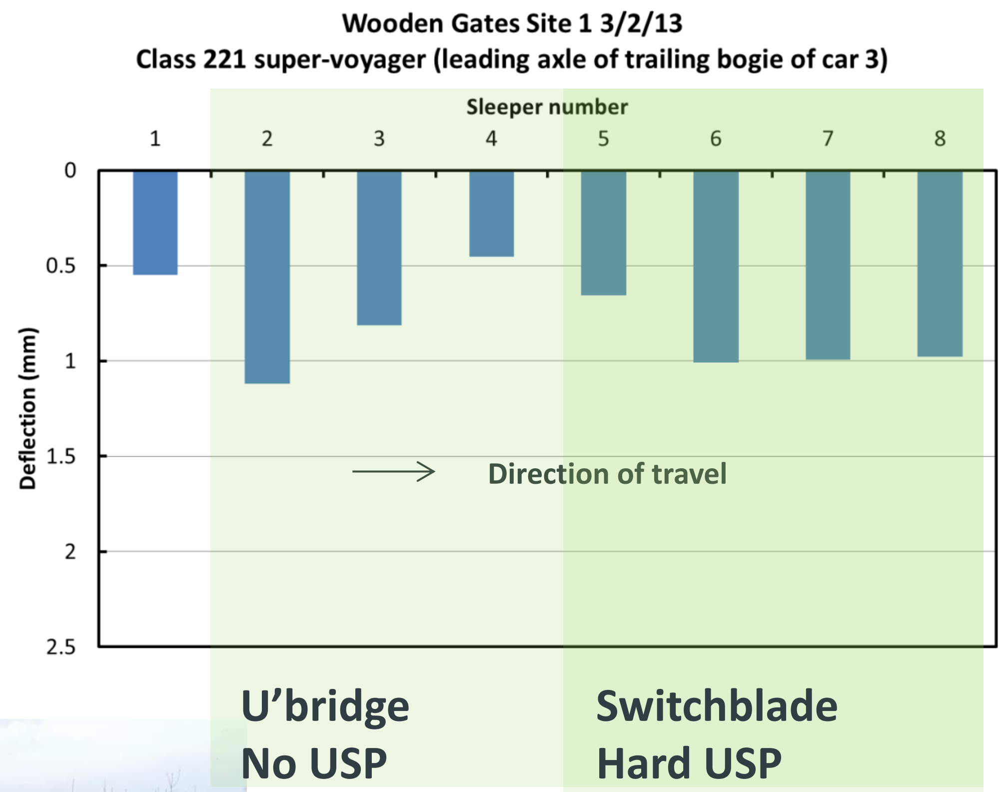

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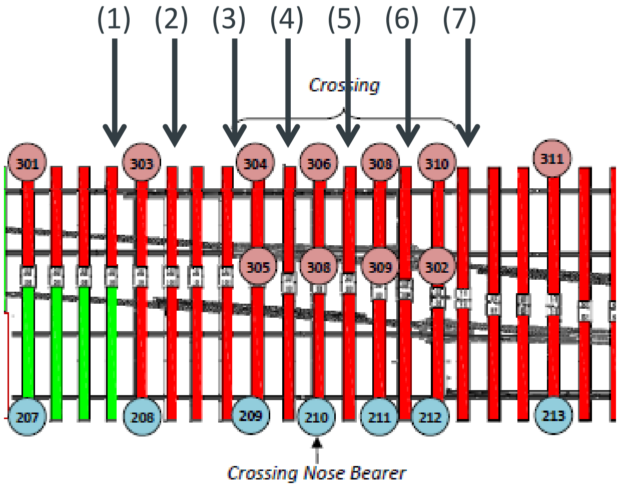
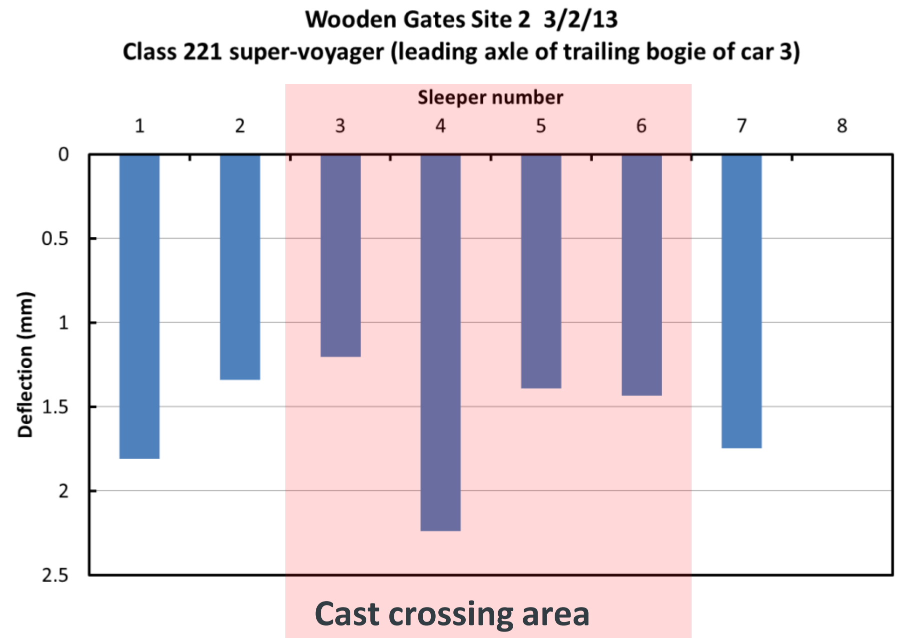
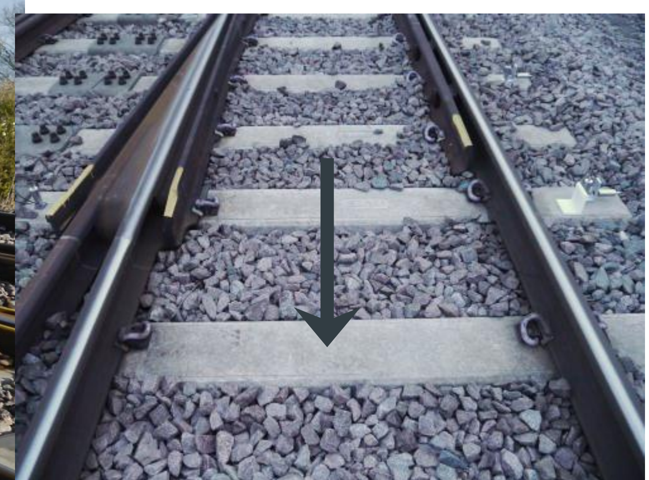
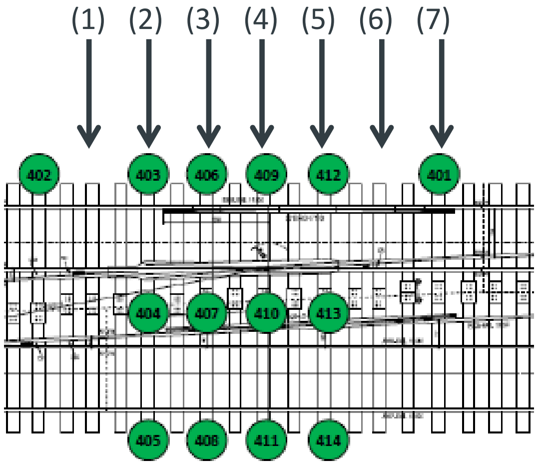
Site 2 – Crossing area, soft USPs present

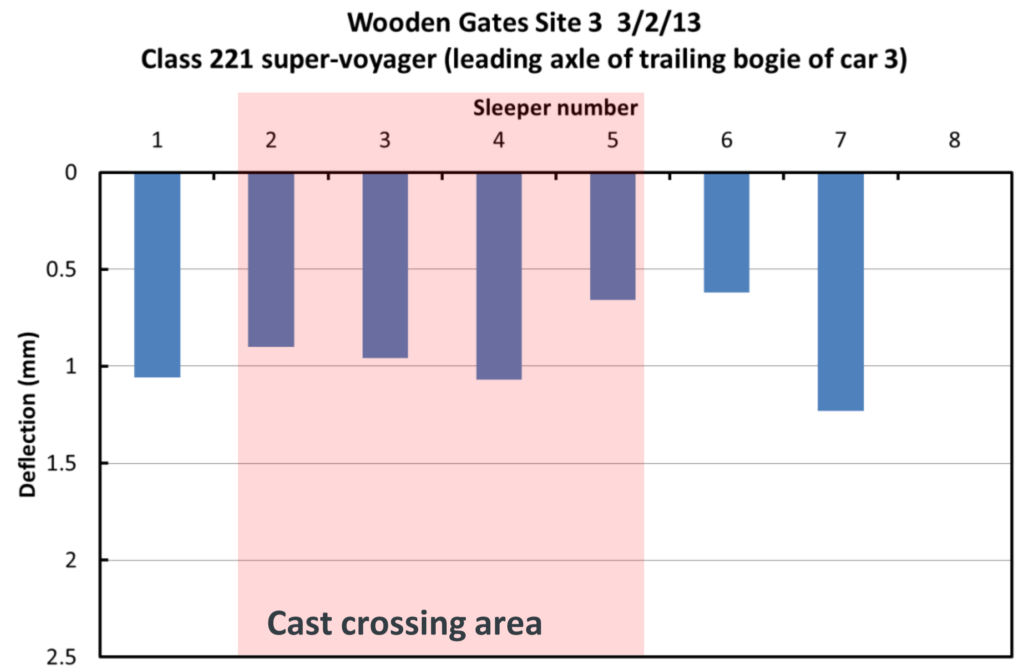




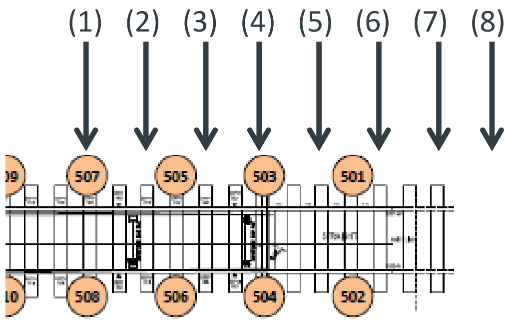


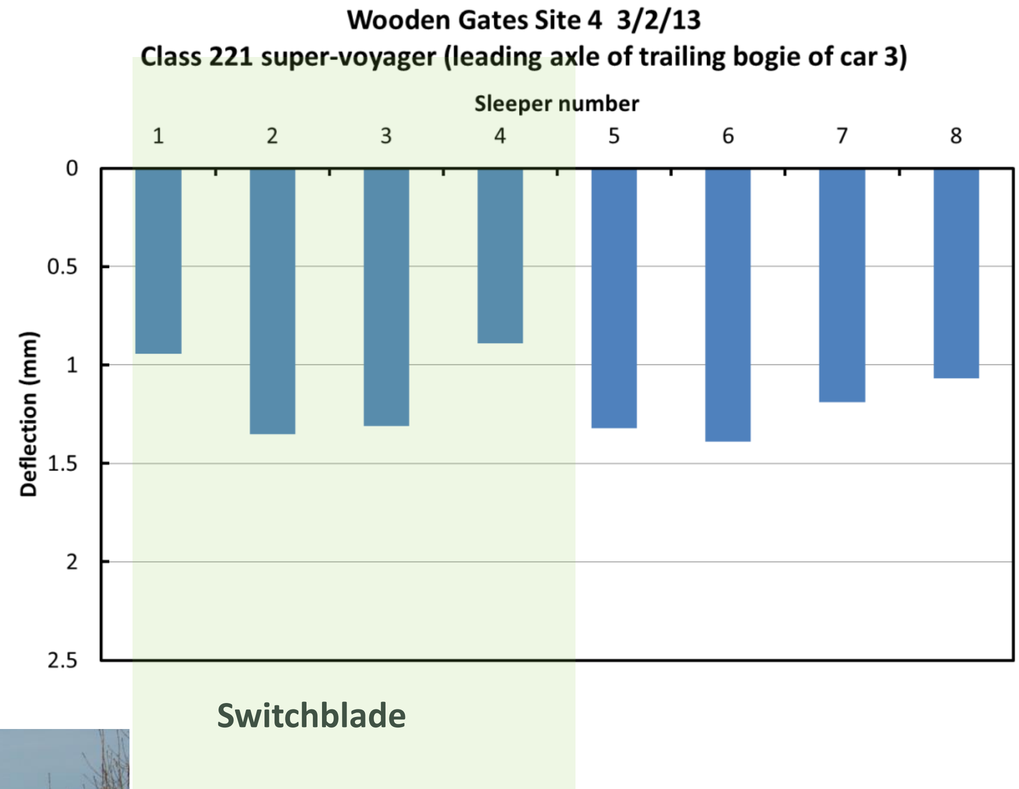
Site 3 -Crossing area (No USPs)





Site 4 – Switch area (No USPs)





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Common behaviour?

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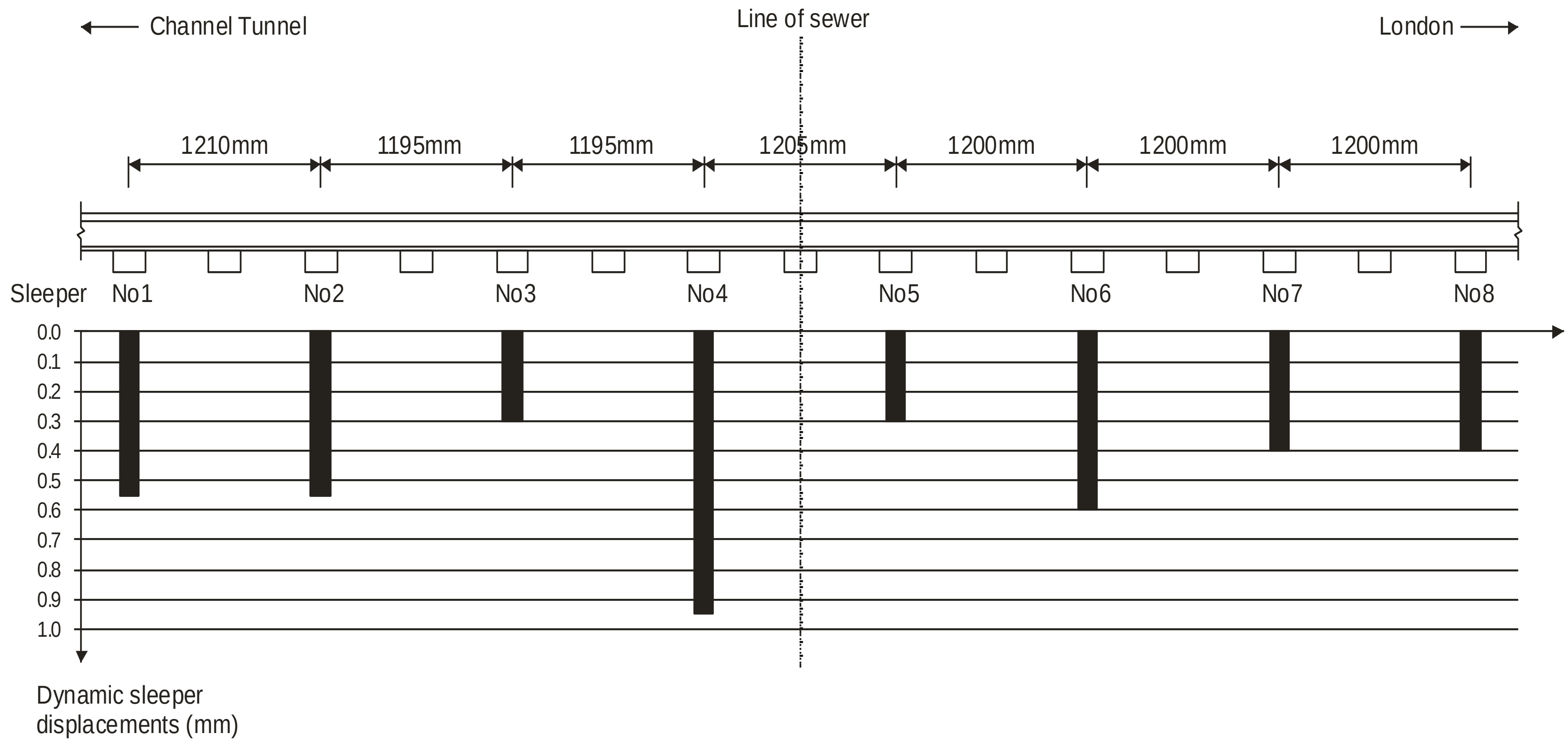

Dynamic sleeper displacements measured using remote video monitoring, before, during and after tunnelling at Ashford during the passage of a Series 373 TGV Eurostar trainset

(Bowness, D., Lock, A. C., Powrie, W., Priest, J. A. & Richards, D. J. 2007. Monitoring the dynamic displacements of railway track. Proceedings of the Institution of Mechanical Engineers, Part F (Journal of Rail and Rapid Transit), 221, 13-22.)

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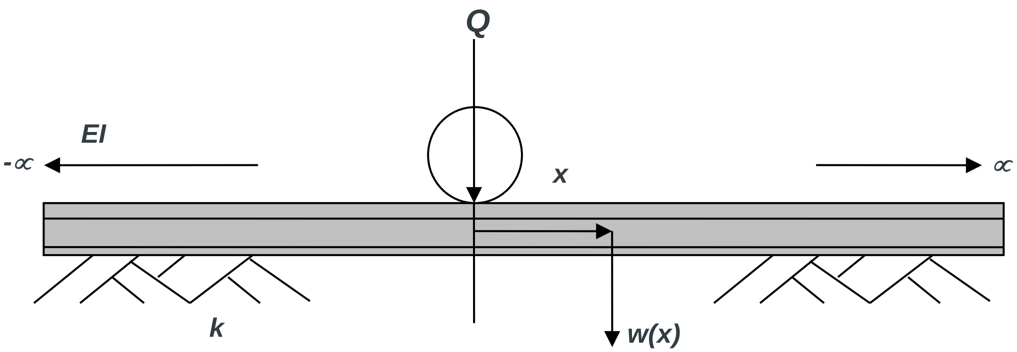
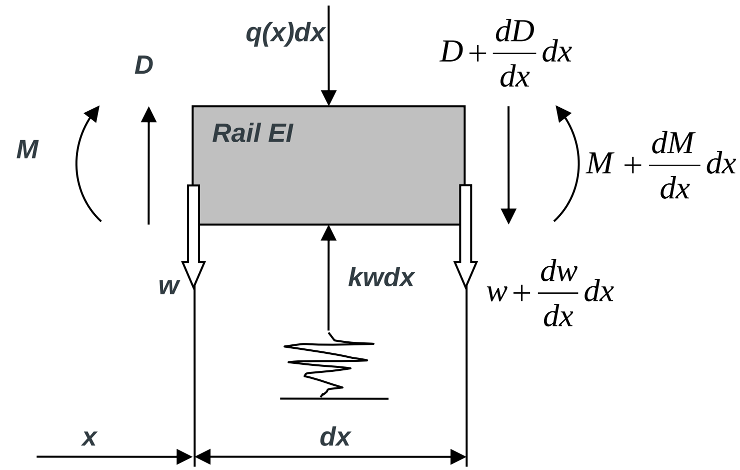
Track loading: BOEF



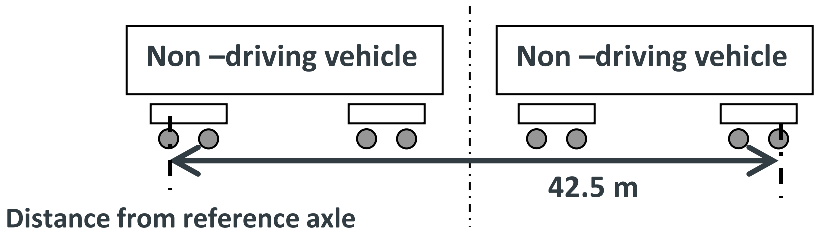


$$w(x)=\frac{Q}{2kL}e^{\frac{-x}{L}}\left[\cos\frac{x}{L}+\sin\frac{x}{L}\right] \qquad M=-EI\frac{2Q}{2kL^3}e^{\frac{-x}{L}}\left[\sin\frac{x}{L}-\cos\frac{x}{L}\right]$$

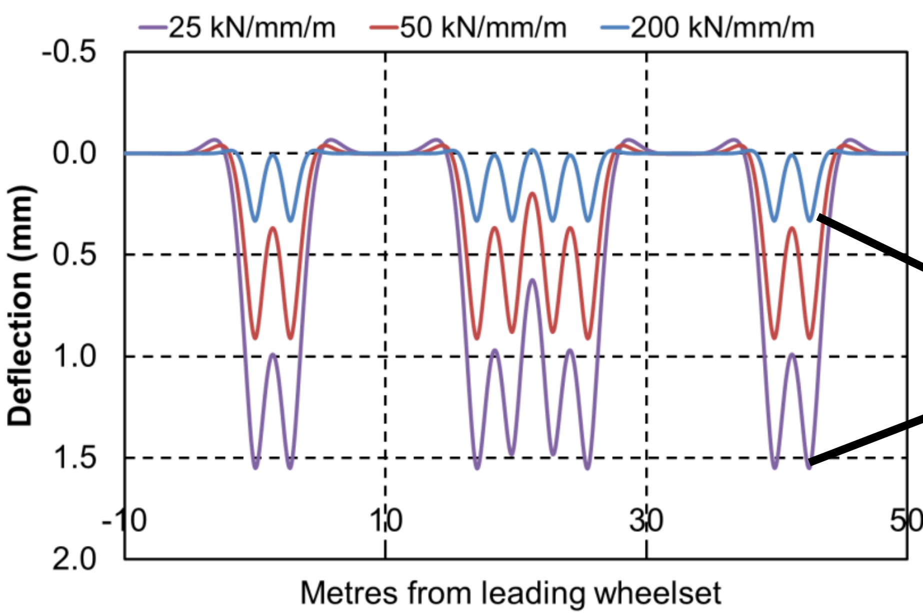
$$\frac{4EI}{L^4}=k \qquad L=\sqrt[4]{\frac{4EI}{k}}$$

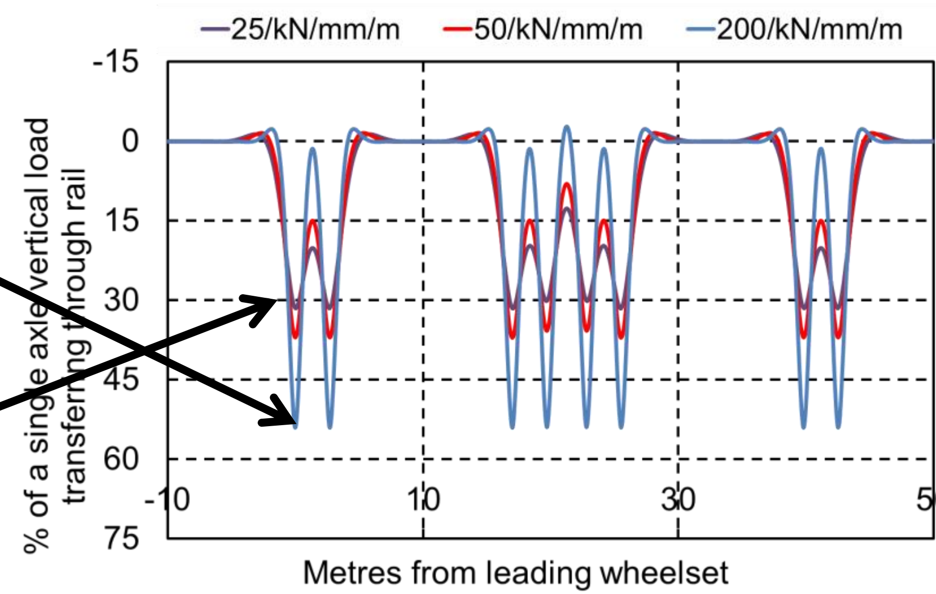
EI = Bending stiffness of the rail
k = Foundation coefficient or track modulus
w(x) = Rail vertical deflection at longitudinal distance x (which must be positive)
D = Shear force in rail
M = Moment in rail
q(x) = The variation in vertical load with longitudinal distance (x) which is replaced with Q, the wheel load in the derivation process.
L = Is termed the characteristic length and arises from the derivation process.
Q = Wheel load

Track loading: Example calculation for a passenger train using approximate data



Q = 80 kN
E of rail taken as: 205 000 N/mm^2
I of high speed rail = 30383000 mm^4





USPs: How might they bring benefit

- Increase the number and area of contacts
- Reduce the rate of plastic settlement
- Reduce the support stiffness and spread the load along a greater length of track
- Add in a consistent increment to the track deflection and reduce support stiffness variation
  - ➢ Thus dynamic load from changing support stiffness is also reduced

Acknowledgements

- Ian Coleman, Ian Bostock and Andrew Cornish (Network Rail)
- Tom Collins (Tiflex)
- Geof Watson (University of Southampton)
- Many others

Thank you

Any questions?