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
Presentation overview

• 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
Background: track structure

- **Ballast**
  - This may be a mixture of prepared ground and natural ground or wholly natural ground.

- **Subgrade**
  - This may be a mixture of prepared ground and natural ground or wholly natural ground.

- **Geosynthetic(s)**, when used. Exact location depends on the purpose. Multiple layers are possible.

- **Sleepers**

- **Shoulder**

- **Rails**

- **Railpad**
  - This may be prestressed by the fastening.

- **Fastenings**
  - Anchor the pad to the rail and sleeper.

- **Soil layer interfaces** may be sloped to aid drainage.

- **Superstructure**

- **Substructure**

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Background: track structure

- **Track structure** includes the superstructure and substructure.

- **Superstructure** includes elements above the ground, such as rails, sleepers, and ballast.

- **Substructure** includes elements below the ground, such as subballast, subgrade, and ballast.

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Background: track structure

- **Anchor the pad to the rail and sleeper** for stability.

- **Prestressed by the fastening** to ensure longevity and safety.

- **Soil layer interfaces** may be sloped to aid drainage, improving the overall efficiency of the track system.

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Background: track structure

- **Network Rail**

- **EPSRC**

- **Track 21**

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Background: track structure

- **Train in the background**

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Background: track structure

- **Train in the background**

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Background: track structure

- **Train in the background**

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Background: track structure

- **Train in the background**
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**

<table>
<thead>
<tr>
<th>Type of USPs in the LAB tests (made by Tiflex)</th>
<th>Types of USP used in SITE trial (made by Getsner)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USP1 - Hard</td>
<td>Hard</td>
</tr>
<tr>
<td>USP2 - Soft</td>
<td>Medium</td>
</tr>
<tr>
<td>Technical ID</td>
<td>SLB2210G</td>
</tr>
<tr>
<td>Thickness</td>
<td>SLB 1510 G</td>
</tr>
<tr>
<td>4 mm</td>
<td>10 mm</td>
</tr>
<tr>
<td>9 mm</td>
<td>10 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>Weight</td>
</tr>
<tr>
<td>Stiffness (C\text{\textsubscript{stat}})</td>
<td>Stiffness</td>
</tr>
<tr>
<td>0.228-0.311 N/mm\textsuperscript{3}</td>
<td>0.079-0.105 N/mm\textsuperscript{3}</td>
</tr>
<tr>
<td>6 kg/m\textsuperscript{2}</td>
<td>4.2 kg/m\textsuperscript{2}</td>
</tr>
<tr>
<td>Core material</td>
<td>Core material</td>
</tr>
<tr>
<td>Trackelast FC500</td>
<td>polyurethane</td>
</tr>
<tr>
<td>Bonded cork</td>
<td>polyurethane</td>
</tr>
</tbody>
</table>

- $C_{\text{stat}}$ 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
Results: Stiffness

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

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

Where

\[ K = \frac{\text{railseat load}}{\text{deflection}} \]

**Figure 2 – Required Thickness of Trackbed Layers**

- \( K = 100 \text{kN/mm/SL} \)
- \( K = 60 \text{kN/mm/SL} \)
- \( K = 30 \text{kN/mm/SL} \)

**Required Thickness of Trackbed Layers** (metres below base of sleeper)

**Undrained Subgrade Modulus (E) MN/m²**

Figures in brackets give approximate \( C_u \) values (kN/m²)
Sleeper/ballast contact analysis

Pressure sensitive paper shows contact history at selected locations below sleeper
Results: Mono-block SLEEPER/BALLAST interface with USPs

- Baseline test
- Hard USP
- Soft USP
Results: Twin-block SLEEPER/BALLAST interface with USPs
Pressure paper analysis, area and number of contacts for 10 MPa to 50MPa paper

<table>
<thead>
<tr>
<th>Sleeper type</th>
<th>Average (%) contacts per sleeper (mono-block = 0.71 m², twin-block = 0.50 m²)</th>
<th>Average contacts per sleeper (mono= 0.71 m², twin = 0.50 m²)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>MONO-BLOCK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.18</td>
<td>147</td>
<td>Baseline</td>
</tr>
<tr>
<td></td>
<td>1.64</td>
<td>314</td>
<td>Hard USP</td>
</tr>
<tr>
<td></td>
<td>1.05</td>
<td>447</td>
<td>Soft USP</td>
</tr>
<tr>
<td>TWIN-BLOCK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.53</td>
<td>243</td>
<td>Baseline</td>
</tr>
<tr>
<td></td>
<td>2.91</td>
<td>268</td>
<td>Hard USP</td>
</tr>
<tr>
<td></td>
<td>4.75</td>
<td>329</td>
<td>Soft USP</td>
</tr>
</tbody>
</table>
Potential sleeper/ballast contacts

Approximated Particle Size Distribution:

Visual idealisation (square packing):

Simplified equation:

Number of contacts = \left( \frac{N \cdot A_{\text{sleeper}}}{D_{A}^{2}} \right) \cdot \left( \frac{2}{3} \frac{1}{D_{A}^{3}} + \frac{2}{3} \frac{1}{D_{B}^{3}} + \ldots + \frac{2}{3} \frac{1}{D_{N}^{3}} \right)

Results evaluated as a contact efficiency:

<table>
<thead>
<tr>
<th>Sleeper type</th>
<th>Test</th>
<th>Measured contacts</th>
<th>Potential contacts calculated for 5 steps</th>
<th>Contact Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mono- block</td>
<td>Baseline</td>
<td>147</td>
<td>513</td>
<td>28.0%</td>
</tr>
<tr>
<td></td>
<td>+ USP 1</td>
<td>314</td>
<td>513</td>
<td>61.2%</td>
</tr>
<tr>
<td></td>
<td>+ USP 2</td>
<td>447</td>
<td>513</td>
<td>87.1%</td>
</tr>
<tr>
<td>Duo Block</td>
<td>Baseline</td>
<td>243</td>
<td>357</td>
<td>68.1%</td>
</tr>
<tr>
<td></td>
<td>+ USP 1</td>
<td>268</td>
<td>357</td>
<td>75.1%</td>
</tr>
<tr>
<td></td>
<td>+ USP 2</td>
<td>329</td>
<td>357</td>
<td>92.2%</td>
</tr>
</tbody>
</table>

A trial site in the UK
The study area – track layout

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

Notes:
Green = hard USP type
Red = soft USP type
Trains can cross the track but none do so in this study
• Complex track geometry leads to larger dynamic variation in load and a faster rate of track geometry degradation
The sites

Site 1: leading switch blades

Site 3: trailing crossing

Site 2: facing crossing

Site 4: trailing switch blades
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.
Class 221 (Super-voyager) on site 1
Site 1 – underbridge to leading switch blades

<table>
<thead>
<tr>
<th>Site 1 – underbridge to leading switch blades</th>
</tr>
</thead>
</table>

- **Direction of travel**
  - U’bridge
  - No USP
  - Switchblade
  - Hard USP

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**Wooden Gates Site 1 3/2/13**

**Class 221 super-voyager (leading axle of trailing bogie of car 3)**

<table>
<thead>
<tr>
<th>Sleeper number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection (mm)</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
</tbody>
</table>

- **Direction of travel**
  - Arrow indicates the direction of travel.
Site 2 – Crossing area, soft USPs present

Wooden Gates Site 2  3/2/13
Class 221 super-voyager (leading axle of trailing bogie of car 3)

Sleeper number

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deflection (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Cast crossing area
Site 3 - Crossing area (No USPs)

Wooden Gates Site 3  3/2/13
Class 221 super-voyager (leading axle of trailing bogie of car 3)

Sleeper number

<table>
<thead>
<tr>
<th>Sleeper number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

Deflection (mm)

Cast crossing area

Network Rail
EPSRC
TRACK 21
Site 4 – Switch area (No USPs)

[Diagram showing rail tracks with numbers (1) to (8)]

Wooden Gates Site 4 3/2/13
Class 221 super-voyager (leading axle of trailing bogie of car 3)

<table>
<thead>
<tr>
<th>Sleeper number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection (mm)</td>
<td>0.5</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
<td>2.5</td>
<td>3</td>
<td>3.5</td>
<td>4</td>
</tr>
</tbody>
</table>

Switchblade

[Photo of a railway track]
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

**Track loading: BOEF**

**Equation:**

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

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

**Definitions:**

- **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

Non –driving vehicle

Non –driving vehicle

Distance from reference axle

Q = 80 kN
E of rail taken as: 205 000 N/mm²
I of high speed rail = 30383000 mm⁴
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

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• Tom Collins (Tiflex)

• Geof Watson (University of Southampton)

• Many others
Thank you

Any questions?