Trackbed Evaluation and Design Using FWD Deflections as Performance Indicators

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• Trackbed evaluation using the Falling Weight Deflectometer
• Analytical design and performance calibration
• Case studies
UK ballasted trackbed design

- Based on past performance
- Subgrade strength/stiffness
- Design speed
- Granular materials thickness
- Typically top 300mm is ballast
Influence of Trackbed Stiffness on Track Quality

- Trackbed condition and ride quality deteriorate with time and loading
- Good track geometry requires stiff uniform formation
- Most tracks in UK 150 years old (trackbed not suitable for high speed)
- Trackbed stiffness is historically difficult to determine
- Sampling and testing subgrade is not commercially viable, theoretically based design unsuitable for existing railway
- Can use Plate Bearing Tests (PBT’s) - expensive and time consuming
- Elastic Modulus is dependent on rate of loading - PBT’s apply static loading
- Falling Weight Defectomoter can be used to measure stiffness and critical velocity
Trackbed evaluation using the Falling Weight Deflectometer
Falling Weight Deflectometer

- Measures deflections under dynamic load – developed for pavement analytical evaluation
- Determined layer stiffnesses to estimate residual life
FWD loading plate and geophone

- Sensor
- Studs to specific drop height (4 no)
- Weather resistant cable connection box
- 4.3m

- 12V DC powered hydraulic unit
- Loading plate (450mm diameter)
- Front support wheel
- Electric cable
- Raise/lower bar
- Pavement surface

- Rubber pads (2 No each side) (for damping of falling weight)

- Falling weight (in pairs)
- Rear wheel
- Loading plate (300mm diameter)

- Return spring
- Deflection Transducer
- Tip

- Electric wire
- Hand brake lever

- Spare wheel
- Back-up batteries (in pair)
FWD Adapted for Railways
Relationship Between Stiffness and Track Quality

New High Speed Line
SD 0.7mm

UK Main Line
Good TQ
SD 1.5mm

UK Main Line
Poor TQ
SD 2.5mm

Secondary Line
Very Poor TQ
SD >5.0mm

FWD Deflections – mm Normalised to 12.5T Sleeper Load

KEY
- Sleeper
- Formation
- Subgrade
Simplified Trackbed Model
Motorway Underbridge

KEY
- Sleeper
- Formation
- Subgrade

FWD Deflections – mm Normalised to 12.5T Sleeper Load

Distance - m
Reinforced Trackbed

![Diagram showing FWD deflections for different sections of a trackbed, normalized to 12.5T sleeper load. The diagram includes a key indicating the different sections: sleeper, formation, and subgrade. The horizontal axis represents distance in meters, ranging from 0 to 200, and the vertical axis represents FWD deflections normalized to 12.5T sleeper load, ranging from 0.00 to 3.00.]
Deflections as performance indicators

- Technique well established in UK and Ireland (more than 100 miles since 1998)
- FWD deflections can be used as performance indicators
  - Sleeper deflection d0 – Overall trackbed condition
  - Defection at 300mm – ballast condition
  - Deflection at 2m – subgrade

- FWD deflections can be analysed to determine layer stiffness (material condition), requires layer thicknesses
Automatic Ballast Sampling
Automatic Ballast Sampling:
through core holes to determine unbound materials and subgrade
Analytical design and performance calibration
Analytical trackbed design

- Model the trackbed as a multilayered elastic system
- Specify trackbed layer and subgrade stiffnesses
- Calculate deflections under FWD loading applied on one sleeper
- Calculate maximum stress in subgrade under actual axle loading applied on multiple sleepers
- Compare calculated deflection with the design values based on the desire Track Quality (e.g. <1mm for UK Mainline Good TQ)
- Compare the subgrade shear stress to the allowable material strength (e.g. limit the stress to 50% of the material strength)
- Compare results with current standards/reference structure
Theoretical model – multi-layered elastic model

Typical Stiffness (Young Modulus) $E$ - MPa

 normally assume Poisson’s Ratio to be 0.4-0.5

<table>
<thead>
<tr>
<th>Material</th>
<th>Stiffness (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballast</td>
<td>100 – 200</td>
</tr>
<tr>
<td>Blanket</td>
<td>100 - 300</td>
</tr>
<tr>
<td>Subgrade Peat</td>
<td>10</td>
</tr>
<tr>
<td>Clay</td>
<td>30</td>
</tr>
<tr>
<td>Chalk</td>
<td>&gt;200</td>
</tr>
</tbody>
</table>

Additional materials such as geoweb, stabilised and asphalt can be considered to improve track stiffness over poor subgrade.
Analytical trackbed design based on UK chart to develop tailored solutions

- Maximum Axle Load = x tonne
- Wheel Spacing = y mm
- Sleeper Spacing = z mm
- Sleeper Size = u mm * w mm
- Train Speed = v mph
Analysis - Conventional:

- high shear strain in ballast
- high shear strain in subgrade

Shear strain

700µstrain
Analysis - Asphalt Underlay:

- reduced shear strain in ballast
- low shear strain in subgrade
- design issue is cracking of asphalt
Analysis - Asphalt Trackbed:

- very low strain in subgrade
- design issue is deformation in asphalt

Granular material cover – for noise reduction

10T sleeper load

3000MPa
1500MPa
50MPa

Shear strain

700μstrain
Case Studies
Case study 1

- Poor track quality due to poor subgarde and drainage
- Level constraints
- Alternative strengthening designs using stabilised clay and asphalt materials
- Design checked analytically to match the reference structure
Track and loading information

- Maximum Axle Load = 21.6 tonne
- Wheel Spacing = 1950mm
- Sleeper Spacing = 600mm
- Sleeper Size = 2500mm*200mm
- Train Speed > 100 mph

- **Assumptions:** Dynamic Factor = 50%
Track and loading information

Axle Load = 32.4 tonne (including 50% Dynamic Factor)

Wheel Spacing = 1950mm

- 25% of the load = 8.1 tonne
- 50% of the load = 16.2 tonne
- 25% of the load = 8.1 tonne
- 25% of the load = 8.1 tonne
- 50% of the load = 16.2 tonne
- 25% of the load = 8.1 tonne

Wheel Spacing = 1950mm

Vector Image
Trackbed Designs

• Multilayer Linear Elastic System Analysis using the following stiffnesses:
  • Ballast Stiffness = 120 MPa
  • Granular Material Stiffness = 100 MPa
  • Asphalctic Layer Stiffness = 3000 MPa
  • Stabilised Clay = 120 MPa
  • Subgrade = 30 - 50 MPa

• Design considers surface deflection and subgrade shear stress
Alternative Designs

Reference Structure
- Remove 700-1000mm of existing material
- Place 800mm Ballast

Option 1
- Remove 400-700mm of existing material
- Stabilise 300mm Clay
- Place 500mm Ballast

Option 2
- Remove 300-600mm of existing material
- Stabilise 300mm Clay
- Place 100mm Asphaltic material
- Place 300mm Ballast
Case study 2

- Trackbed improvement is required
- Two sections were considered (worst and best cases, with soft clay and sand and gravel formations respectively)
- Two treatment options were considered (raising the track by 500mm and using a Geoweb)
- Deflections under FWD loading controlled to match the reference structure
- Subgarde shear stress limited to 50% of material strength
Geoweb and Geogrids
## Trackbed construction options

<table>
<thead>
<tr>
<th>Status</th>
<th>Worst Case</th>
<th>Best Case</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current Situation</strong></td>
<td>300mm Ballast</td>
<td>300mm Ballast</td>
</tr>
<tr>
<td></td>
<td>500mm Soft Clay</td>
<td>3000mm Sand and Gravel</td>
</tr>
<tr>
<td></td>
<td>3000mm+ Firn Clay</td>
<td>1000mm+ Firm Clay</td>
</tr>
<tr>
<td><strong>Design Option A</strong></td>
<td>300mm Ballast</td>
<td>300mm Ballast</td>
</tr>
<tr>
<td>(Geoweb)</td>
<td>200mm GeoWeb</td>
<td>200mm GeoWeb</td>
</tr>
<tr>
<td></td>
<td>100mm Sand</td>
<td>2800mm Sand and Gravel</td>
</tr>
<tr>
<td></td>
<td>200mm Soft Clay</td>
<td>1000mm+ Firm Clay</td>
</tr>
<tr>
<td></td>
<td>3000mm+ Firn Clay</td>
<td></td>
</tr>
<tr>
<td><strong>Design Option B</strong></td>
<td>800mm Ballast</td>
<td>800mm Ballast</td>
</tr>
<tr>
<td>(Track Lift 500mm)</td>
<td>500mm Soft Clay</td>
<td>200mm GeoWeb</td>
</tr>
<tr>
<td></td>
<td>3000mm+ Firn Clay</td>
<td>2800mm Sand and Gravel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000mm+ Firm Clay</td>
</tr>
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</table>
# Design parameters and output results

<table>
<thead>
<tr>
<th>Assumptions on foundation</th>
<th>Assumptions on material</th>
<th>Assumptions on trackbed</th>
</tr>
</thead>
<tbody>
<tr>
<td>• CBR 23-27%</td>
<td>• Ballast (old) = 80MPa</td>
<td>• Standard sleeper dimension = 0.3 x 2.6 m²</td>
</tr>
<tr>
<td>• Cu = 47 KPa</td>
<td>• Ballast (New) = 100MPa</td>
<td>• Sleeper spacing = 0.62m</td>
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<tr>
<td></td>
<td>• Soft Clay = 30MPa</td>
<td>• Single wheel load spread across 3 sleepers – 50% on centre sleeper and 25% on each adjacent sleepers</td>
</tr>
<tr>
<td></td>
<td>• Firm Clay = 50MPa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Sand and Gravel = 80MPa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Geoweb = 1000MPa*</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Problem (Cases) No.</th>
<th>Description</th>
<th>Deflection (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Current Situation – Worst Case</td>
<td>2.08</td>
</tr>
<tr>
<td>2</td>
<td>Option A – Worst Case</td>
<td>1.41</td>
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<tr>
<td>3</td>
<td>Option B – Worst Case</td>
<td>1.50</td>
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<tr>
<td>4</td>
<td>Current Situation – Best Case</td>
<td>1.32</td>
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<tr>
<td>5</td>
<td>Option A – Best Case</td>
<td>1.03</td>
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<tr>
<td>6</td>
<td>Option B – Best Case</td>
<td>1.06</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Reference Model</th>
<th>Ref. deflection (mm)</th>
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<tbody>
<tr>
<td>300mm Good Ballast 100MPa</td>
<td>1.6</td>
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<tr>
<td>200mm Old Ballast 80MPa</td>
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</tr>
<tr>
<td>Subgrade Firm Clay 50MPa</td>
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</table>

<table>
<thead>
<tr>
<th>Problem (Cases) No.</th>
<th>Description</th>
<th>Max Shear Stress (KPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Current Situation – Worst Case</td>
<td>56.7</td>
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<tr>
<td>2</td>
<td>Option A – Worst Case</td>
<td>17.3</td>
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<tr>
<td>3</td>
<td>Option B – Worst Case</td>
<td>19.4</td>
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<tr>
<td>4</td>
<td>Current Situation – Best Case</td>
<td>77.1</td>
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<td>5</td>
<td>Option A – Best Case</td>
<td>23.5</td>
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<tr>
<td>6</td>
<td>Option B – Best Case</td>
<td>13.9</td>
</tr>
</tbody>
</table>
Thank you

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