RAILWAY SUBSTRUCTURE EVALUATION USING FWD

Simona Fontul

LNEC - Laboratório Nacional de Engenharia Civil, Lisbon, Portugal
Railway substructure evaluation using FWD – main issues

- MEASUREMENT SYSTEM - STUDIES PERFORMED ON AN EXISTING RAILWAY LINE
- CLIMATIC INFLUENCE - TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE
- LOAD INFLUENCE - TESTS PERFORMED ON PHYSICAL MODEL – GRANULAR VS BITUMINOUS
- INTERPRETATION - BACK-CALCULATION OF GRANULAR MATERIAL LAYERS
- CONCLUSIONS
MEASUREMENT SYSTEM
STUDIES PERFORMED ON AN EXISTING RAILWAY LINE

• FWD UPGRADE TO RAILWAYS
• LOAD PLATE ADAPTED TO MEASURE ON BALLAST
STUDIES PERFORMED ON A OLD RAILWAY LINE

• The experimental studies presented in this work aimed to **construct and evaluate** four solutions for structural reinforcement of old railway tracks, **maintaining the ballast layer as structural layer.**

• Ballasted track section
  ▪ 36 m long, (4 experimental sections)
  ▪ Iberian gauge (1.668 m)
  ▪ bi-block sleepers
  ▪ limestone ballast.
Before reinforcement

- FWD upgrading for railways tests
Load tests – PLT and FWD before reinforcement

FWD
0.40 m diameter plate/ 500 kPa

Plate load tests (PLT)
0.45m diameter plate / 200 kPa

PLT & FWD results
Deformation moduli (E)

\[ E = 0.75 \cdot d \frac{P}{\delta} \]

- 60 - 80 MPa existing
- 120 MPa design
GPR results on experimental sections

Section 1
CBGM/0.10m
FB/0.20-0.25m
SG

Section 2
UGM/0.20m
UGM+B/0.10m
FB/0.23-0.25m
SG

Section 3
UGM+B/0.10m
FB/0.23-0.25m
SG

Section 4
FB/0.23-0.25m
SG
Load tests on experimental sections

LFWD on the subgrade
- 0.30 m diameter plate
- 200 kPa
- E ~ 70-80 MPa.

FWD on the top of the reinforcement
- 0.30 m diameter plate
- 400 kPa
- 2 FWD test series
  - August
  - September
FWD results on experimental sections

<table>
<thead>
<tr>
<th>Position related to initial point of test zone (m)</th>
<th>E (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>200 MPa</td>
</tr>
<tr>
<td>9</td>
<td>130 MPa</td>
</tr>
<tr>
<td>18</td>
<td>80 MPa</td>
</tr>
<tr>
<td>27</td>
<td>200 MPa</td>
</tr>
<tr>
<td>36</td>
<td>130 MPa</td>
</tr>
<tr>
<td>200 MPa</td>
<td>15% - 20% lower</td>
</tr>
<tr>
<td>130 MPa</td>
<td>15% lower</td>
</tr>
<tr>
<td>80 MPa</td>
<td>30% lower</td>
</tr>
</tbody>
</table>

August and September

Railway substructure evaluation using FWD
Simona Fontul
FWD results on experimental sections

Railway substructure evaluation using FWD
Simona Fontul
Backcalculation of FWD results

Deformation moduli obtained $E$ (MPa)

<table>
<thead>
<tr>
<th>Material</th>
<th>FWD-August $E$ (MPa)</th>
<th>FWD-September $E$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement bound granular material (CBGM)</td>
<td>600</td>
<td>500</td>
</tr>
<tr>
<td>Unbound granular material (UGM)</td>
<td>150</td>
<td>120</td>
</tr>
<tr>
<td>UGM mixed with ballast (UGM+B)</td>
<td>180</td>
<td>160</td>
</tr>
<tr>
<td>Fouled Ballast (FB)</td>
<td>180</td>
<td>160</td>
</tr>
<tr>
<td>Subgrade (SG)</td>
<td>80</td>
<td>60</td>
</tr>
</tbody>
</table>

- UGM and fouled ballast modulus are adequate and similar to resilient modulus obtained in triaxial tests.
- Subgrade soil modulus is similar to the LFWD results.
- Cement bound granular material modulus is low probably due to the difficulty of adequately mix the materials on site.
- Decrease in the modulus values after rainfall: subgrade soils, UGM.
Backcalculation of FWD results

DIFFICULTIES IN BACKCALCULATION
CLIMATIC INFLUENCE

TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

• E MODULI INCREASE DURING DRY WEATHER SIGNIFICANTLY

• MEASUREMENT PROBLEMS - DEFLECTION MEASUREMENT

• MEASUREMENT PROBLEMS - INCREASE NUMBER OF DROPS UNTIL DEFLECTIONS STABILISE

• DIFFICULIES IN BACKCALCULATION
CLIMATIC INFLUENCE
TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

Falling Weight Deflectometer (FWD) tests were undertaken during the construction of a 29 km new railway line, at the top of the substructure and in different months November, December, January and March (June)

- Quality control during construction.
- Analyse and compare test results for different climatic conditions
CLIMATIC INFLUENCE

TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

- NDT tests were performed at the top of the sub-ballast layer
CLIMATIC INFLUENCE

TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

- Several load levels
  - in service traffic
  - construction traffic
- Testing campaigns in different seasons

Several other tests were performed

- PLT
- HFWD
- Portancemetre

Railway substructure evaluation using FWD
Simona Fontul
## CLIMATIC INFLUENCE

### TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

<table>
<thead>
<tr>
<th>Section</th>
<th>A1</th>
<th>A2</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-ballast (granite)</td>
<td>0.30</td>
<td>0.15</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Capping layer (limestone)</td>
<td>0.20</td>
<td>0.35</td>
<td>0.35</td>
<td>0.50</td>
<td>0.40</td>
</tr>
<tr>
<td>Subgrade</td>
<td>0.80</td>
<td>0.80</td>
<td>0.65</td>
<td>0.50</td>
<td>0.60</td>
</tr>
</tbody>
</table>
GPR MEASUREMENT

- Change in layer thickness
CLIMATIC INFLUENCE
TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE
CLIMATIC INFLUENCE
TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

Railway substructure evaluation using FWD
Simona Fontul
CLIMATIC INFLUENCE

TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

Deformation modulus values

November and December

January and March
It can be observed that the values obtained in November and December are quite similar, while in January they are **30 to 50% lower** than those obtained in November.

Then, in March, the deformation modulus values tend to increase again to values closer to the ones obtained in the first two campaigns.
CLIMATIC INFLUENCE

TESTS PERFORMED DURING CONSTRUCTION OF SUBSTRUCTURE

- Backcalculated sub-ballast elastic moduli variation with load peak
  November vs June
LOAD INFLUENCE

TESTS PERFORMED ON PHYSICAL MODEL

• E MODULI INCREASE WITH LOAD
• MEASUREMENT PROBLEMS - DEFLECTION MEASUREMENT
• MEASUREMENT PROBLEMS - INCREASE NUMBER OF DROPS UNTIL DEFLECTIONS STABILISE
• DIFFICULIES IN BACKCALCULATION
Two different substructures were reproduced in physical models, with different subballast materials:
- Traditional solution – 0.30m granite unbound granular material (UGM)
- Italian HSL solution – 0.12m bituminous material

Cells dimension: 4.0x2.0m² by 2.8m depth
Non-destructive tests

- Non-destructive tests
  - Falling Weight Deflectometer (FWD)
  - Ground Penetrating Radar (GPR)

> FWD tests location
  - six locations (A, B, C, D, E and F)
  - spaced approximately by 0.50 m

> FWD tests characteristics
  - nine transducers (D1 to D8)
  - 30 mm load plate (segmented)
  - Stress levels applied (160 to 520 kPa)
LOAD INFLUENCE

TESTS PERFORMED ON PHYSICAL MODEL

Cell 1 – 25 kN

Deflexão (µm) vs. Distância do pistão (m)

Cell 2 – 25 kN

Deflexão (µm) vs. Distância do pistão (m)

C1 - 25 kN - dist 0,90m

Deflexão (mm) vs. Distância do pistão (m)

GRANULAR

C2 - 25 kN - dist 0,90m

Deflexão (µm) vs. Distância do pistão (m)

BITUMINOUS
LOAD INFLUENCE
TESTS PERFORMED ON PHYSICAL MODEL

- $E_1$ moduli for top layer

C1 - Força 25 kN

C2 - Força 25 kN

GRANULAR

BITUMINOUS
LOAD INFLUENCE

Five levels of loading were applied:
25, 50, 75, 90 and 120 kN

E1 (MPa) - Célula 1

E1 (MPa) - Célula 2

GRANULAR

BITUMINOUS
Railway evaluation using FWD

DEBATE

- MEASUREMENT SYSTEMS ON RAILWAY LINES ??
  - TEST LOCATION
  - GEOPHONES POSITION ON SURFACE

- CLIMATIC INFLUENCE
  - THE E MODULI CAN BE SO DIFFERENT?? (5 X)
  - LIMESTONE GRANULAR E > 1000 MPa
  - HOW YOU CORRECT THE VALUES ACCORDING TO SEASON??

- LOAD INFLUENCE– GRANULAR VS BITUMINOUS
  - HOW YOU CORRECT THE VALUES ACCORDING TO SEASON??

- TESTING AND INTERPRETATION
  - TESTING PROCEDURE, NUMBER OF DROPS, NUMBER OF TESTS, GEOPHONES POSITION ON SURFACE
  - BACK-CALCULATION OF GRANULAR MATERIAL LAYERS.
Thank you for your attention!

simona@lnec.pt