Innovative Sleeper Design with Under Sleeper Pads as an Efficient Method to reduce Railway induced Vibration Propagation
Research Results of RIVAS
(Railway Induced Vibration Abatement Solutions)

05th June 2014; UIUC: Crosstie & Fastening Symposium Urbana-Champaign, Illinois

Dipl-Ing. Arnold Pieringer, RAIL.ONE GmbH
2. Initial problem and starting points for vibration issue

- Parametric excitations: sleeper pitch, axle/boogie interval, flats
- Rail-/Wheel- contact inhomogeneity's (roughness, OOR)

Unsprung / sprung mass!

Direct noise

Structure born noise = secondary noise

Ground borne vibration

Air borne noise
2. Initial problem and starting points for vibration issue

Freight trains more severe in terms of vibration emission

Source: RIVAS Del. 3.15, measurements on commercial track, non isolated track (8 m)
Dr. Heiland

presentation RAIL.ONE UIUC, Crosstie & fastening conference 2014 | Urbana, Illinois | 5th June 2014
2. Initial problem and starting points for vibration issue

Measures are alternatively! $c_{RP, \text{ballast}} = 2 \times 450 \text{ kN/mm}$

<table>
<thead>
<tr>
<th>'Spring type'</th>
<th>Area [cm²]</th>
<th>~ Costs</th>
<th>Mass [kg/tie]</th>
<th>$f_0$ [Hz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail Pad (RP)</td>
<td>2 x 15 x 20 = 600</td>
<td>84 (2xrail)</td>
<td>63.7*</td>
<td></td>
</tr>
<tr>
<td>Under Sleeper Pad (USP)</td>
<td>0.25 x 2.6 = 6500</td>
<td>434 (tie+rail)</td>
<td>51.0*</td>
<td></td>
</tr>
<tr>
<td>(11 x RP)</td>
<td>(5 x ^RP)</td>
<td>(45)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Under Ballast Mat (UBM)</td>
<td>0.61 x 5.0 = 30500</td>
<td>4 944 (59 x ^RP)</td>
<td>21.4*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(51 xRP / 4.7 x USP)</td>
<td>(12 x ^USP)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*example with sleeper pitch: 600 mm, $m_{tie} = 350$ kg
stiffness $c_{\text{ballast,RP}} = c_{\text{USP}} = c_{\text{UBM}} = 100$ kN/mm/tie, $m_{US/axle} = 1.35$ t

Angular frequency formula

$$ f_0 = \frac{1}{2 \cdot \pi} \sqrt{\frac{c}{m}} $$

$E(t)$ = energy
$m$ = mass (track, axle)
$F(t)$ = ground force
$C$ = spring stiffness
$D$ = damping
2. Initial problem and starting points for vibration issue

\[ \Delta L_e \] [dB] vs. frequency [Hz]

- Vibrations
- Secondary noise
- Air-born noise

Amplification

Reduction

\[ m_4 > m_3 > m_2 > m_1 \]
3. RIVAS – Project structure: WP 3.2 track solutions

**Installation on commercial tracks**

**Lab and 1:1 scale test**

**Prototyping**

**Simulation**

Finally carried out within RIVAS

Source: DB AG
4. Lab tests series

USP Thickness: 7 to 15 mm

Determination of static bedding modulus of USP on concrete block

Determination of high frequency bedding modulus

Fatigue tests of USP material

Bending moments and crack tests of ties (EN)

Testing of USP: DIN 45673 -6/7, of ties: EN 13230

Source: DB AG/BAM
5. Field tests – installation of 7 track sections:

Step 2 - measurements for insertion loss

7,80m = 13 sl.  
7,80m = 13 sl.  
7,80m = 13 sl.  
7,80m = 13 sl.  
7,80m = 13 sl.  
8,45m = 13 sl.

B70 G04 NE  B70 G04  B90.2 G04  B90.2 G13  BBS4 G15  BBS4 G13  BBS 3.1 V2

modulus: 0.1 N/mm²  0.1 N/mm²  0.1 N/mm²  0.06 N/mm²  0.03 N/mm²  0.06 N/mm²  0.08 N/mm²

1st measurement - all rail pads Zw 687a

2nd measurement - rail pads Zw 900b

Source: Eiffage Rail GmbH
5. Field tests – installation of 7 track sections: Track arrangement in workshop yard

Location of test track in workshop yard ➔ death end

➔ No consolidation of half year old track!

Source: Eiffage Rail GmbH
5. Field tests – installation of 7 track sections: effective static USP properties

<table>
<thead>
<tr>
<th>section</th>
<th>Tie type</th>
<th>USP type</th>
<th>Weight</th>
<th>Effect. ballast contact area</th>
<th>Calc. stat. spring stiffness/tie</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME 17</td>
<td>B70</td>
<td>G04 NE</td>
<td>300</td>
<td>5 341</td>
<td>53</td>
</tr>
<tr>
<td>ME 16</td>
<td>B70</td>
<td>G04</td>
<td>300</td>
<td>4 940</td>
<td>49</td>
</tr>
<tr>
<td>ME 15</td>
<td>B90.2</td>
<td>G04</td>
<td>605</td>
<td>6 016</td>
<td>60</td>
</tr>
<tr>
<td>ME 14</td>
<td>B90.2</td>
<td>G13</td>
<td>605</td>
<td>6 016</td>
<td>30 **</td>
</tr>
<tr>
<td>ME 13</td>
<td>BBS 4</td>
<td>G15</td>
<td>577</td>
<td>8 640</td>
<td>26 **</td>
</tr>
<tr>
<td>ME 12</td>
<td>BBS 4</td>
<td>G13</td>
<td>577</td>
<td>8 640</td>
<td>43</td>
</tr>
<tr>
<td>ME 11</td>
<td>BBS 3.1</td>
<td>V02</td>
<td>577</td>
<td>10 080</td>
<td>86 ***</td>
</tr>
</tbody>
</table>

* effective sleeper area without center area \( l = 50 \) cm, BBS 3.1 full area
** theor. stiffness per rail seat only 50%, very soft for this type! Vertical track stability !!!
*** bedding modulus on even load plates, all others on NSP, secant modulus (0.01 - 0.1 N/mm²)

Ballast Slab track (GETRAC A3.1)
5. Field tests – installation of 7 track sections: track view
5. Field tests – installation of 7 track sections: measurements

Lateral track resistance (LTR) (Single tie push test)

Deflection measurement with lever arm + 20 t axle

Drop weight

hydraulic shaker BUTTERFLY®

Source: TUM
5. Field tests – installation of 7 track sections: Two „flying“ excavators serve as a simulation for the sprung mass (dead load)

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Excavator status</th>
<th>Preload on shaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC 1</td>
<td>Most far boom/shovel position</td>
<td>2 x 16 = 32 t (72 kips)</td>
</tr>
<tr>
<td>LC 2</td>
<td>Most close boom/shovel position</td>
<td>2 x 11 = 22 t (49.5 kips)</td>
</tr>
<tr>
<td>LC 3</td>
<td>No excavator on shaker</td>
<td>2 t = (0.5 kips)</td>
</tr>
</tbody>
</table>

Source: DB AG
5. Field tests - installation of 7 test sections: maximum deflections/tie under 20 to axle

Maximium sleeper deflection

Source: TUM

Hanging ties

deflection [mm]

modulus: 0.1 N/mm² 0.1 N/mm² 0.1 N/mm² 0.06 N/mm² 0.03 N/mm² 0.06 N/mm² 0.08 N/mm²
5. Field tests - installation of 7 track sections: measured deflections/installation technology

Tamping depth 70 cm (3 cyc.)

Source: Cronau GmbH
### 5. Field tests – installation of 7 track sections:
**Lateral track resistance - LTR (non consolidated track)**

impact of soft/very soft USP on LTR of concrete ties (3 - 4 pcs/section)

<table>
<thead>
<tr>
<th>section</th>
<th>Sleeper / USP type</th>
<th>Ø Lateral track resistance (LTR) [kN/m]</th>
<th>Standard deviation [kN/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>reference</td>
<td>B70</td>
<td>8.1</td>
<td>0.4</td>
</tr>
<tr>
<td>ME 17</td>
<td>B70 G04 NE</td>
<td>11.1</td>
<td></td>
</tr>
<tr>
<td>ME 16</td>
<td>B70 G04</td>
<td>10.3</td>
<td></td>
</tr>
<tr>
<td>ME 15</td>
<td>B90.2 G04</td>
<td>17.8</td>
<td></td>
</tr>
<tr>
<td>ME 14</td>
<td>B90.2 G13</td>
<td>16.5</td>
<td>0.2</td>
</tr>
<tr>
<td>ME 13</td>
<td>BBS 4 G15</td>
<td>18.8 *</td>
<td>1.4</td>
</tr>
<tr>
<td>ME 12</td>
<td>BBS 4 G13</td>
<td>23.2 *</td>
<td>2.1</td>
</tr>
</tbody>
</table>

*B Hollow sleepers not taken into account

All sections with USP show higher LTR than the sections with standard sleeper (B70) without USP

B70: 8.1 kN/m

BBS 4 USP: > 18

Source: TUM
5. Field tests - installation of 7 track sections: Measurement layout of the test-rig at Herne test-site (Eiffage Rail)

- one measuring point on the unsprung mass (steel foundation of the hydraulic shaker, coupled with the rails)
- three points at 12m distance
- one point at 16m distance from the center of the track

Source: DB AG
5. Field tests - installation of 7 track sections: Relation of unsprung mass mobility at Load Case 2 (LC2) for all investigated track systems (0 m = shaker) – stationary excitation

Source: Dr. Heiland
5. Field tests - installation of 7 track sections: IL at Load Case 2 (LC2) for all investig. track systems (12 m) – stationary excitation

- Vibrations
- Secondary noise
- Abatement effect for B70/ B90.2
- Reduction
- Amplification

Soil = damping effect

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Source: Dr. Heiland
6. Field tests – reference site in commercial track: Insertion loss measurements with artificial and natural train excitation (close to Regensburg)

Source: DB AG
6. Field tests - reference site in commercial track: installation of sleepers with USP in several sections of track

The real track section ME 1 and the section ME 5 with USP G04 have identical track configuration as ´ME18´ / ME 16 at the Eiffage Rail test track

Source: Dr. Heiland
6. Field tests: reference site in commercial track - Insertion loss (IL) under artificial and natural train excitation (freight trains)

- IL with BUTTERFLY® excitation and different preload positions (8m)
- IL of train passage (freight trains) (Ø 96 km/h = 26.7 m/s) (8m)

Higher frequencies: good accordance of IL by artificial excitation / train passages!

Lower frequencies: additional mitigation effects with natural excitation compared to artificial excitation (not shown in stationary excitation + simulations)

k) Peak @20 Hz from point source excitation incorrect, better line source: dip @ 40 Hz

Source: Dr. Heiland
7. USP field tests: Conclusions

- Soft/very soft USP on ties **improves LTR**
- Artificial shaker with preload \(\Rightarrow\) good **accordance** with train pass-by: >50 Hz
- \(\Rightarrow\) **preload** (sprung mass) **necessary** in measurement + simulation for realistic results!
- USP property stiffer under preload, than nom. secant stiffness (0.01-0.1 MPa)
- Reduction of parametric excitations only with real train (5 – 20 Hz, 40 Hz)
- Wide ties + G13 USP most efficient for vibration **abatement**: IL: -15 dB (12m)
  (Specific **tamping** machine!); **abatement** B90.2 G13 tie IL: -10 dB (12m)
- BBS 3.1 V02 (slab track) \(\approx\) effective as softer G13 type on ballast: IL: -16 dB
- USP effective for abatement of secondary noise ( > 55 (35; freight) Hz)
- Soil influences the vibration level noticeable, but beneficial

Source: Dr. Heiland
8. USP Advantages over all

- **Cheap compared to other solutions**
- **Easy to install**
- **Compatible to common track installation processes**
- **Positive impact on LCC: 2 - 2.5 x tamping cycles**
- **Preservation of ballast by lowering contact pressure Sleeper/ballast**

*Source: DB AG
*Source: TU Graz/ÖBB*
Thank for all Partners and subcontractors for their contributions!

References:
All presented results are fully described in the project-deliverables. Most of them are public. Please refer to the project web-site for further information:
http://rivas-project.eu/index.php?id=9

D1.10: Description of test procedures based on laboratory tests and field tests including validation (comm. track)
D3.1: State of the art review of mitigation measures on track
D3.2: Results of the parameter studies and prioritisation for prototype construction for ballasted track
D3.3: Results of the parameter studies and prioritisation for prototype construction for slab track
D3.7: Results of laboratory tests for ballasted track mitigation measures
D3.9: Results of laboratory tests of slab track mitigation measures (not public)
D3.14: Results of field test of slab track mitigation measures (not public)
D3.15: Results of field test for ballasted track mitigation measures (not public)
ANY QUESTIONS?

CONTACT

Dipl.-Ing. Arnold Pieringer
Technique & Development
RAIL.ONE GmbH
Ingolstaedter Strasse 51
92318 Neumarkt,
Germany

Tel +49 9181 8952-274
Fax +49 9181 8952-5007
arnold.pieringer@railone.com
www.railone.com