NOISE & VIBRATION MITIGATION IN RAILWAY TRACK

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Noise:
- Rolling;
- Engines;
- Curves;
- Braking;
- Aerodynamics.

Vibration:
- Rayleigh waves (at surface);
- Compression waves (tunnels);
- Shear waves (tunnels).
CLASSIFICATION NOISE ANNOYANCE

$V_{rms} [m/s]$ vs $f [Hz]$

- Vibrations likely to be annoying
- Structure borne noise likely to be annoying

Audibility limit
SQUEALING NOISE

Mitigating measures:

- Lubrication;
- Asymmetric rail grinding, shift of contact point wheel rail.
 CONTRIBUTION OF NOISE SOURCES

- Sleeper
- Wagon
- Rail
- Wheel

Lp [dB]

f [Hz]

10 dB

Total

dB(A)
METHODS OF NOISE REDUCTION

- **Track Design**
  - Component selection (pads/sleepers)
  - Embedded rail/special slabtracks
  - Damping

- **Barriers**
  - Up to 10dB but affected by layout of tracks/buildings
  - Expensive & visual impact
  - Low barriers & shrouds: not interoperable

- **Acoustic grinding**
  - Effective for corrugation
  - Not so effective for tracks in good condition

- **Absorptive Layers**
  - Low results on the rail
  - Higher results on slab track - absorbs wheel noise

- **Vehicle Design**
  - Wheel diameter
  - Wheel damping
ENERGY DISTRIBUTED IN STRESS WAVES:

- Rayleigh 67 %
- Shear 26 %
- Compression 7 %
VIBRATION PROPAGATION AT GRADE

Vibrations due to trains on track in the open. Annoying vibrations mainly at frequencies less than 10 Hz.

emission primarily via Rayleigh waves
VIBRATION PROPAGATION BY UNDERGROUND

Vibrations due to trains in tunnels. Annoying mainly due to radiated noise at frequencies above 30 Hz.

- P-wave
- S-wave
- Direction of particle motion
- Direction of wave propagation
- Soil
- Tracks
- Vibrations
- Rooms on higher floors
- Cellar
- Noise emitted by walls

Emission primarily via P and S waves of vibrations at frequencies between 30 - 150 Hz.
The human body is susceptible to the following frequencies:

- **0.1 - 0.2 Hz**: resonance of the organ of balance, resulting in phenomena characteristic of seasickness;
- **4 - 8 Hz**: resonance of the contents of abdomen and thorax;
- **30 - 80 Hz**: resonance of eyes in the eye sockets, resulting in loss of focus;

*The audibility limit lies at a frequency of approximately 20 Hz.*
\[
EP = \frac{0.18 f}{\sqrt{1 + \left(\frac{f}{5.6}\right)^2}} v_{\text{rms}}(f)
\]

\[
v_{\text{peak}} = \sqrt{2} v_{\text{rms}}
\]

\[
a = 2\pi f v = (2\pi f)^2 d
\]
# Classification of Vibration Levels

<table>
<thead>
<tr>
<th>EP value</th>
<th>$L_{EP}$ [dB] $v_0 = 5 \times 10^{-8}$ m/s</th>
<th>$L_{EP}$ [dB] $v_0 = 10^{-8}$ m/s</th>
<th>$L_{EP}$ [dB] $v_0 = 10^{-9}$ m/s</th>
<th>Classification of perceptibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.1</td>
<td>&lt; 66</td>
<td>&lt; 80</td>
<td>&lt; 100</td>
<td>not noticeable</td>
</tr>
<tr>
<td>0.10-0.25</td>
<td>66-74</td>
<td>80-88</td>
<td>100-108</td>
<td>very weak</td>
</tr>
<tr>
<td>0.25-0.63</td>
<td>74-82</td>
<td>88-96</td>
<td>108-116</td>
<td>weak</td>
</tr>
<tr>
<td>0.63-1.60</td>
<td>82-90</td>
<td>96-104</td>
<td>116-124</td>
<td>good</td>
</tr>
<tr>
<td>1.60-4.00</td>
<td>90-98</td>
<td>104-112</td>
<td>124-132</td>
<td>strong</td>
</tr>
<tr>
<td>&gt; 4.00</td>
<td>&gt; 98</td>
<td>&gt; 112</td>
<td>&gt; 132</td>
<td>very strong</td>
</tr>
</tbody>
</table>

Reference $v_0$ not standardized

$L_{EP}$ [dB] = 20 $\log_{10}(v/v_0)$, with for instance $v_0 = 10^{-8}$ m/s

Germany

ISO
MEASURED VIBRATION NEAR UNDERGROUND

- Large wheel flats produced by skidding worn wheels
- No wheel flats: worn wheels
- No wheel flats: reprieved wheels

Acceleration level [dB] re $10^{-4} \text{ m/s}^2$

f [Hz]
EFFECT OF HIGH-SPEED MEASURED AT DB

Vertical ground vibration [dB]

$v_0 = 5 \times 10^{-8} \text{ m/s}$

- Bogie wheel-base passing frequency
- Sleeper passing frequency

ICE/V Hannover - Würzburg
measuring point 8m from track centre
track in the open
typical ground conditions

250 km/h
200 km/h
160 km/h
**VI BR AT ION TRANSFER**

\[ m\ddot{w} + c\dot{w} + kw = F(t) \]

\[ f \approx \frac{1}{2\pi} \sqrt{\frac{k}{m}} \]

\[ K = kw(f) = F(f)H(f) \]

**Transmission Ratio**

**Mitigating measures:**
- Reduce force, cq excitation: grinding, weld straightening;
- Change natural frequency relative to dominant excitation frequency: softer rail pads, resilient layers, ……

\[ f = \text{excitation (impressed) frequency [Hz]} \]

\[ f/f_n \]

\[ \zeta = 1.0 \quad \zeta = 0.5 \quad \zeta = 0.2 \quad \zeta = 0.1 \quad \zeta = 0 \]
VI BRATION TRANSFER III

Excitation spectrum

Transfer function

Response spectrum

Natural frequency structure

Dominant excitation frequency

$f_{\text{excit}} > \sqrt{2}f_{\text{natural}}$
PRACTICAL LIMITS

- Low-frequency excitations are difficult to reduce

\[ f \approx \frac{1}{2\pi} \sqrt{\frac{k}{m}} \]

- Low stiffness and large mass necessary to achieve low frequency!
- Not with sleeper and rail pad, but with elastically supported slab.
WHISPER RAIL THYSSENKRUPP

- Vertical up to 10 mm
- Lateral < 2 mm
KÖLNER EI
ELASTIC RAIL SUPPORT
SA 42 RAIL LOW NOISE

-5 dB(A) compared to ballasted track
-7 dB(A) compared to conventional slab track
60% less consumption of corkelast compared to UIC 54
EMBEDDED RAIL ON STEEL BRIDGE
SILENT BRIDGE WITH EMBEDDED RAIL
SILENT BRIDGE VERSUS CONVENTIONAL

© NS Technisch Onderzoek

Conventional bridge

Silent bridge

Leq (dB re 2e-5)

Frequency (Hz)
TRACK ON ELASTICALLY SUPPORTED SLAB

- Elastic mortar
- Concrete sleeper
- Elastomer bearing
- Pre-cast element
GERB Floating Slab Track Systems
UNDER SLEEPER PAD (USP)
UNDER SLEEPER PADS (USP)

- Increase of contact area between concrete and ballast (Riessberger):
  - 5-10% without USP
  - ~35% with USP
- Adding resilience and thus reducing dynamic forces
- Very effective in areas with high impact forces:
  - frog area of turnouts;
  - transitions near engineering structures;
- Effective solution at spots with maintenance problems due to poor subgrade;
CONCLUSIONS

- Apply mitigating measures preferably at the source:
  - smooth wheel-rail interface;
  - sufficient track resilience;
- Reduction of natural frequency:
  - low spring stiffness;
  - large mass;

\[ f \approx \frac{1}{2\pi} \sqrt{\frac{k}{m}} \]