Fastening System Stiffness Measurement and Influence on Railway Track
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Outline

► Stiffness influence of the rail pad / fastening system to the track
  – Consequences of improper elasticity
  – Load distribution concepts
  – Zimmermann calculation and multi-body simulation

► EN / AREMA load categories and track types

► Relationship between load secants and elasticity

► Fastening system design methods to modify elasticity, load distribution, and deflections

► Conclusion
Improper elasticity in a rail support and its consequence
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Possible consequences of improper elasticity

- Head checks
- Corrugation
- Stiff pad deterioration
- Destruction of rail seat
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Consequence: destruction of the substructure (e.g. ballast – white spots)

► Inadequate elasticity within the track may lead to overloaded components within the track structure
► Stiff rail pads may cause high tie acceleration, resulting in deterioration of ballast and other portions of track structure
Noise and vibration – classic scheme

- **Primary airborne noise**
  - Emitted directly by the source
  - Inside or beside the vehicle
  - Inside buildings, passing through doors and windows

- **Secondary airborne noise**
  - Caused by vibrations of walls, floors, and ceilings
  - Relevant for subways, railways with noise barriers, and rooms not facing railroad tracks
  - Dominating at lower frequency range (20 – 200 Hz)
Load distribution
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Elasticity helps to distribute the wheel load

► Benefits of introducing elasticity into the track structure
  ► Pressure and load distribution
  ► Reduction of wear at wheel/rail interface
  ► Optimal rail deflection
  ► Reduction of bearing pressure and improved life cycle of all components
  ► Reduction of maintenance
  ► Improved ride comfort
  ► Increased shock/impact resistance

► Elasticity can be added via rail pads, base plate pads, under-tie pads (UTP or USP), under-ballast mats (UBM), or ‘floating slab’
Comparison of ballasted and slab track (example)
Zimmermann calculation and multi-body simulation (MBS)
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Zimmermann calculation – Important parameters

- **Inputs**
  - Fastening (tie) spacing
  - Pad stiffness (static and dynamic)
  - Rail profile
  - Speed
  - Axle load
  - Axle spacing
  - Track condition (including track modulus)

- **Outputs**
  - Rail deflection
  - Rail seat load
  - Pad deflection
  - Secondary deflection
  - Ballast pressure

Undesirable deflections can result in rail defects, breaks, component wear and deterioration, excessive noise and vibration, and high train resistance.

Q = wheel load
y = rail deflection with continuous support
δ = secondary deflection of the rail between two supports
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**Zeit Unterlagen**

**Oberbau Projekt:** DFF MC

**Feste Fahrbahn**
- Stützpunktlänge: $l = 139$ [mm]
- Stützpunktbreite: $b = 160$ [mm]
- Stützpunktabstand: $a = 650$ [mm]

Steifigkeit des Stützpunktes: $C_{stat} = 33.8164$ [kN/mm]

**Dynamik - Variation**
- $C_{dyn} = 44.8202$ dynamisch
- $C_{dyn} = 44.82$ dyn.

Dynamikfaktor
- $c_1 = 35$
- $c_2 = 1000.00$
- $c_1 = 1.3$
- $c_2 = 3$
- $c_1 = 45.5$
- $c_2 = 3000$

**Schienenprofil:** 60 E 1

**Zug**

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**Zuschläge**

<table>
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<tr>
<th>Zuschläge</th>
<th>Ergebnisse</th>
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<tbody>
<tr>
<td>Radkraftverlagerung:</td>
<td>max. $y$: 0.89 [mm]</td>
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<td>Gleislage:</td>
<td>max. $S$: 30.01 [kN]</td>
</tr>
<tr>
<td>gut/mäßig</td>
<td>$y$ Zwp: 0.03 [mm]</td>
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<td>Geschwindigkeit:</td>
<td>max. dyn. $y$: 1.27 [mm]</td>
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<tr>
<td>$v = 90$</td>
<td>max. dyn. $S$: 56.97 [kN]</td>
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<tr>
<td>Reise-/Güterzug</td>
<td>dyn. $y$ Zwp: 1.25 [mm]</td>
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<tr>
<td>$\varphi = 1.08$</td>
<td>dyn. $y$ Zwp: 0.02 [mm]</td>
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**stat. Sicherheit**: 99.7, -> $t = 3$

**Dynamikfaktor**: 1.49

**gesamter Dynamikaufschlag**: 1.78

**Sekundärdurchbiegung**: 0.06 [mm] 4.7%

**Grundwert der Biegelinie**: 837 [mm]

**Grundwert der Biegelinie dyn**: 780 [mm]
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Example – slab track (15-tonne axle load)

17 kN/mm system stiffness
30 kN/mm system stiffness
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Modeling of track superstructure

Ballasted Track

Structural Analysis

Track Model

Rail, tie, ballast, subgrade
► MBS: rigid bodies
► FEM: with material properties

Rail (elastic) pad, USP, UBM
► MBS and FEM: elastic elements
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Vehicle-track interaction – multi-body simulation

Track with intermediate stiffness
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Vehicle on elastic track

European E-locomotive with axle load of 21.5 t

Graph showing elastic rail deflection over time for track sections with low and high stiffness.
EN / AREMA load categories and track types
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EN / AREMA load categories and track types

- EN 13481 (Performance requirements for fastening systems) defines five testing categories based on track/operating characteristics
  - Category A – Light rail
  - Category B – Heavy rail (metro lines)
  - Category C – Conventional rail
  - Category D – High speed rail
  - Category E – Heavy haul

- Qualification testing procedures and requirements vary based on track category

- AREMA Chapter 30 (Ties) doesn’t maintain track categories; loads, angles, and testing procedures generally represent heavy haul conditions
Relationship between load secants and elasticity
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Typical load-deflection diagram

- **Progressive characteristic**: e.g. rubbers and elastomers
- **Linear characteristic**: e.g. spring Fe 28
- **Regressive characteristic**: e.g. archery bow
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Elastomer load-deflection diagram

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<th>Force (kN)</th>
<th>Deflection (mm)</th>
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<tr>
<td>10 kN ≈ 2.25 kips</td>
<td>2.5 mm ≈ 0.1 in</td>
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10 kN ≈ 2.25 kips  2.5 mm ≈ 0.1 in  15 June 2016
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Elastomer load-deflection diagram

Traffic load

Fastening system toe load

- Secant 20 – 95 kN
- spring curve Zw
- relief curve
- load curve

10 kN ≈ 2.25 kips
2.5 mm ≈ 0.1 in

Deflection (mm)

15 June 2016
Elastomer load-deflection diagram

- Secant 20 – 95 kN
- Spring curve Zw

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Importance of the measuring secant

- Static vertical stiffness, according to EN 13146-9
  - 18-68 kN secant: high speed (Category D)
  - 20-95 kN secant: heavy haul (Category E)
- With some materials, same rail pad can record two different nominal stiffnesses (e.g. difference of around 23%)

10 kN ≈ 2.25 kips  2.5 mm ≈ 0.1 in
Fastening system design methods to modify elasticity, load distribution, and deflection
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Modifying elasticity via different rail pad materials

► Heavy haul freight or industrial lines ($c_{stat} > 200$ kN/mm (1.1 million lb/in))
  ► EVA
  ► HDPE
  ► TPU (current standard for North American Class I railroads)

► Conventional, high-speed, and transit ($8 < c_{stat} < 200$ kN/mm)
  ► TPU
  ► TPE
  ► PU
  ► NR/BR
  ► EPDM
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Microcellular EPDM

- Very high resilience (with no border flow or plastic deformation)
- Excellent noise and vibration damping
- Minimal elasticity changes in the working temperature range (-50°C to +100°C (-58°F to 212°F))
- Aging-, weather-, ozone-, and UV-resistant
- Very low water absorption (closed cell)
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Modifying elasticity via different geometries

► Utilization of different geometries in rail pads affects stiffness, load distribution, and rail deflections
  ► Studs, dimples, or grooves can provide stiffness variation while maintaining particular material and thickness
  ► Large variations in stiffness can be achieved with modification of thickness and bearing area
► Rail pads with reinforced (thicker) edges improves load distribution and decreases rail tilting, resulting in decreased clamp dynamic loading, decreased component wear, and decreased dynamic gauge widening
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Improving load distribution – utilizing a load distribution plate and large elastic pad

Static Load:
41.9 kN (9.4 kip)

Load assumption for high speed traffic, per Zimmermann

Static Load:
39.5 kN (8.9 kip)

Static load rail pad pressure:
1.884 N/mm² (273 psi)

Static load elastic base plate pressure:
0.974 N/mm² (141 psi)
(52% of rail pad pressure)
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Conclusion

► Elasticity exists in the track within many components and can be modeled to achieve proper understanding

► Careful selection of proper fastening system elasticity has effect on many track characteristics and components

► Method of measuring stiffness is critical for understanding nominal values

► Design of fastening system can have significant effect on elasticity, load distribution, and track deflections
  
  – Utilization of proper materials, geometry, and additional components will allow for improved performance and increased life cycles
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Questions

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