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Fastening Systems

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

Destruction of rail seat

Corrugation

Stiff pad deterioration

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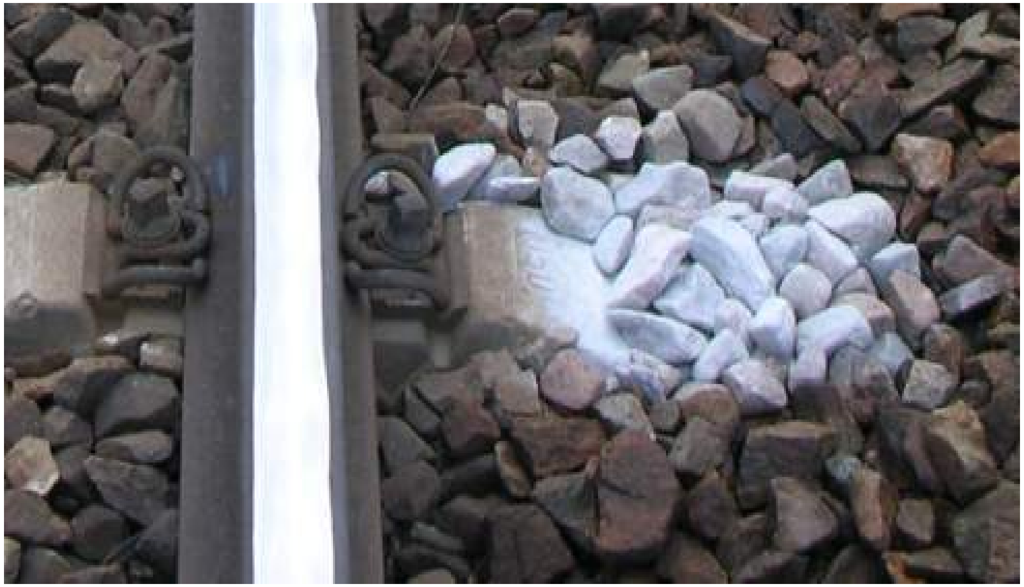
Consequence: destruction of the substructure (e.g. ballast – white spots)

- 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



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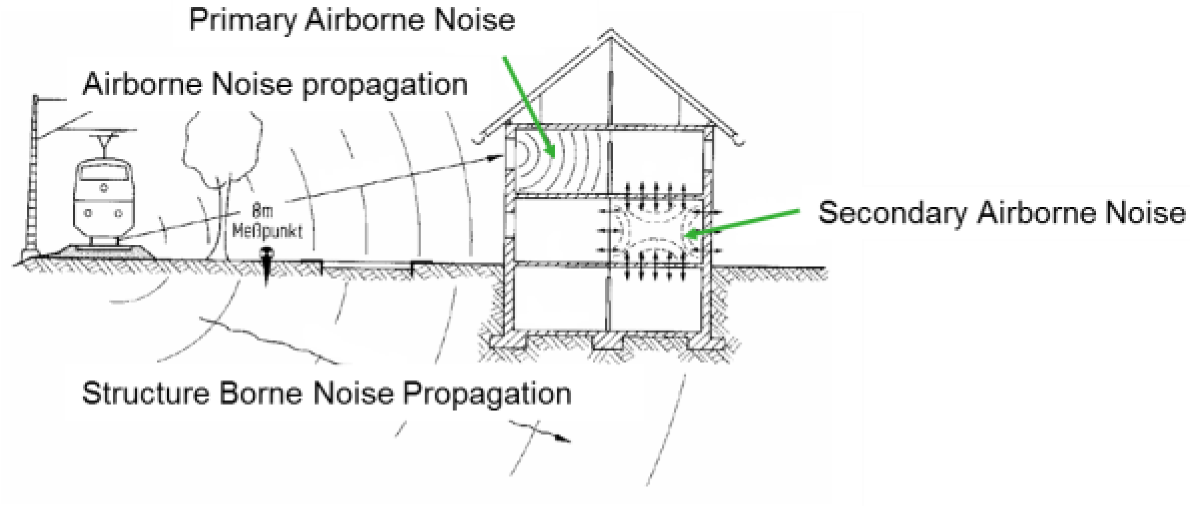
Noise and vibration – classic scheme

- 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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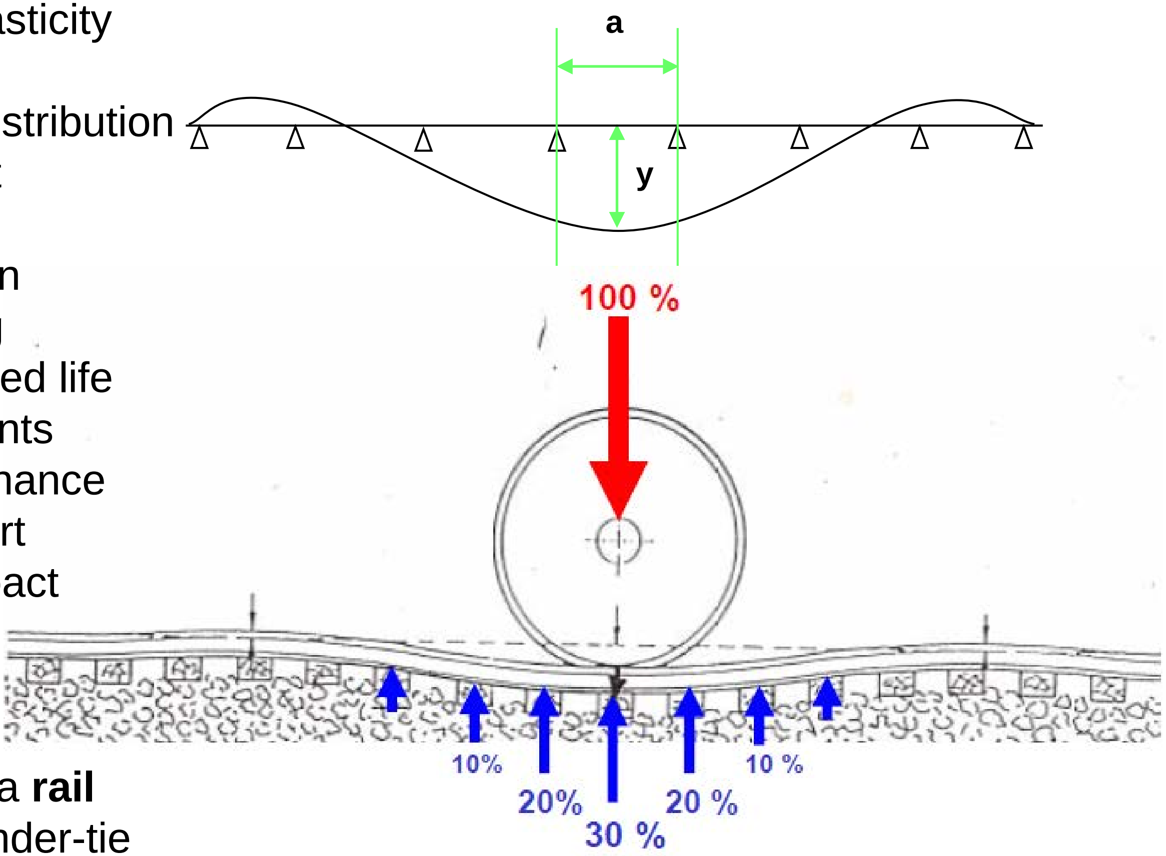
Elasticity helps to distribute the wheel load

- 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’

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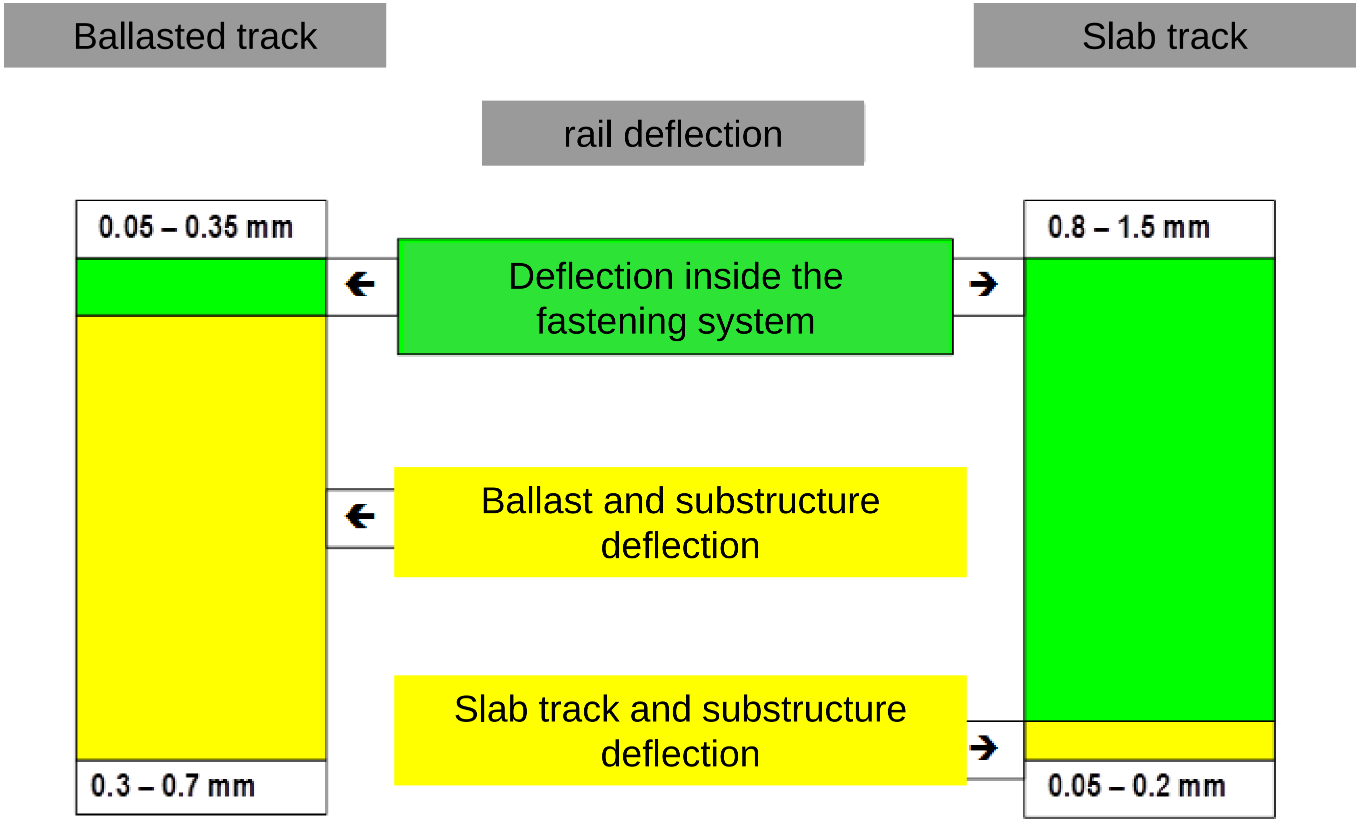
Comparison of ballasted and slab track (example)



Ballasted track

Slab track

rail deflection

0.05 – 0.35 mm

0.8 – 1.5 mm

Deflection inside the fastening system

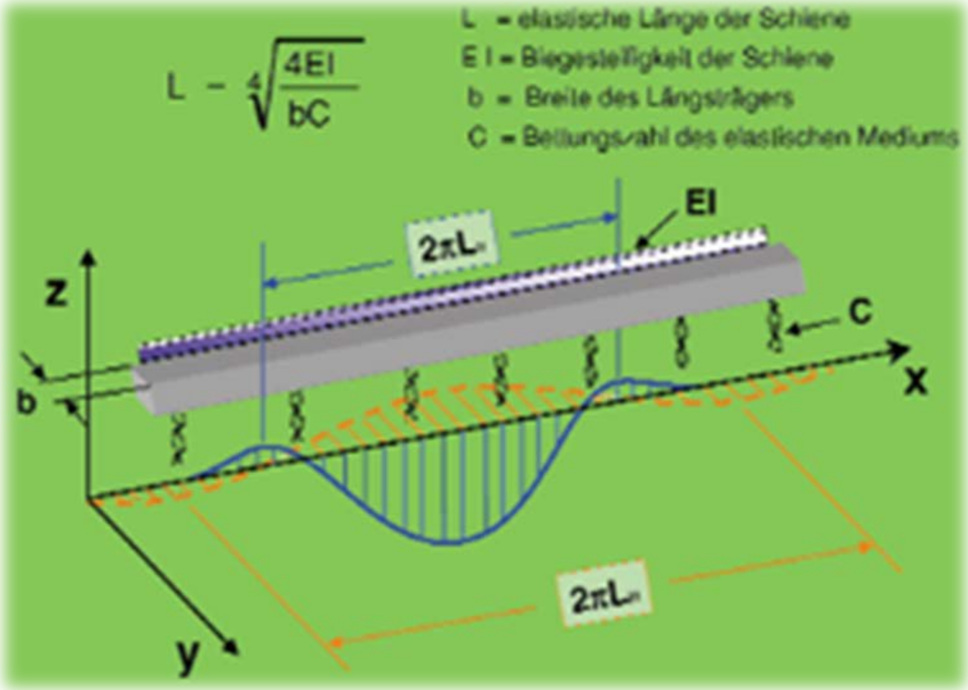
Ballast and substructure deflection

Slab track and substructure deflection

0.3 – 0.7 mm

0.05 – 0.2 mm

Zimmermann calculation and multi-body simulation (MBS)



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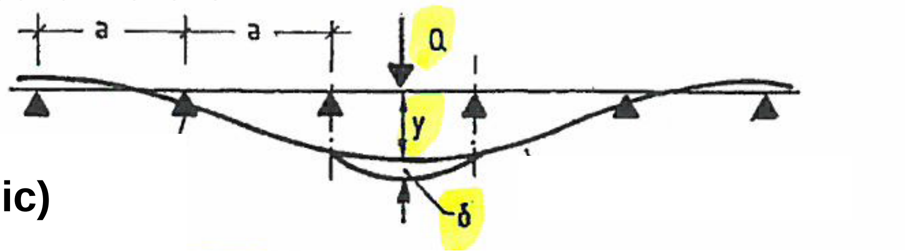
Zimmermann calculation – Important parameters



- 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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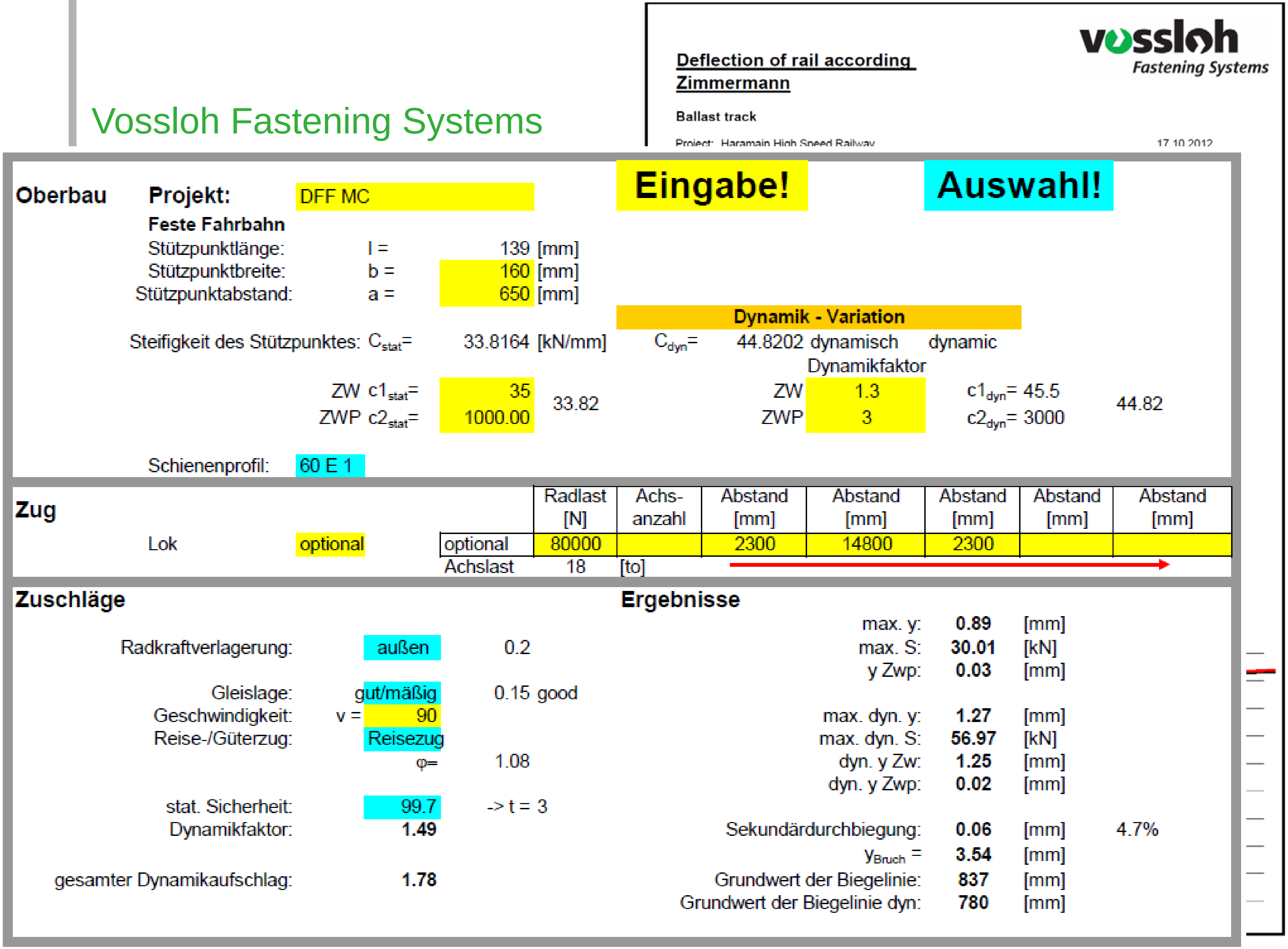

Deflection of rail according Zimmermann

Ballast track

Project: Haramain High Speed Railway 17.10.2012

Oberbau **Projekt:** DFF MC

Eingabe! **Auswahl!**

Feste Fahrbahn

Stützpunktlänge: l = 139 [mm]
Stützpunktbreite: b = 160 [mm]
Stützpunktabstand: a = 650 [mm]

Dynamik - Variation

Steifigkeit des Stützpunktes: C_{stat}= 33.8164 [kN/mm] C_{dyn}= 44.8202 dynamisch dynamic

Dynamikfaktor

ZW $c1_{stat}$=	35	33.82	ZW	1.3	$c1_{dyn}$= 45.5	44.82
ZWP $c2_{stat}$=	1000.00		ZWP	3	$c2_{dyn}$= 3000	

Schienenprofil: 60 E 1

Zug

			Radlast [N]	Achs-anzahl	Abstand [mm]	Abstand [mm]	Abstand [mm]	Abstand [mm]	Abstand [mm]
Lok	optional	optional	80000		2300	14800	2300		
		Achslast	18	[to]					

Zuschläge

Radkraftverlagerung:	außen	0.2
Gleislage:	gut/mäßig	0.15 good
Geschwindigkeit:	v = 90	
Reise-/Güterzug:	Reisezug	
	φ=	1.08
stat. Sicherheit:	99.7	-> t = 3
Dynamikfaktor:	**1.49**	
gesamter Dynamikaufschlag:	**1.78**	

Ergebnisse

max. y:	**0.89**	[mm]	
max. S:	**30.01**	[kN]	
y Zwp:	**0.03**	[mm]	
max. dyn. y:	**1.27**	[mm]	
max. dyn. S:	**56.97**	[kN]	
dyn. y Zw:	**1.25**	[mm]	
dyn. y Zwp:	**0.02**	[mm]	
Sekundärdurchbiegung:	**0.06**	[mm]	4.7%
y_{Bruch} =	**3.54**	[mm]	
Grundwert der Biegelinie:	**837**	[mm]	
Grundwert der Biegelinie dyn:	**780**	[mm]	

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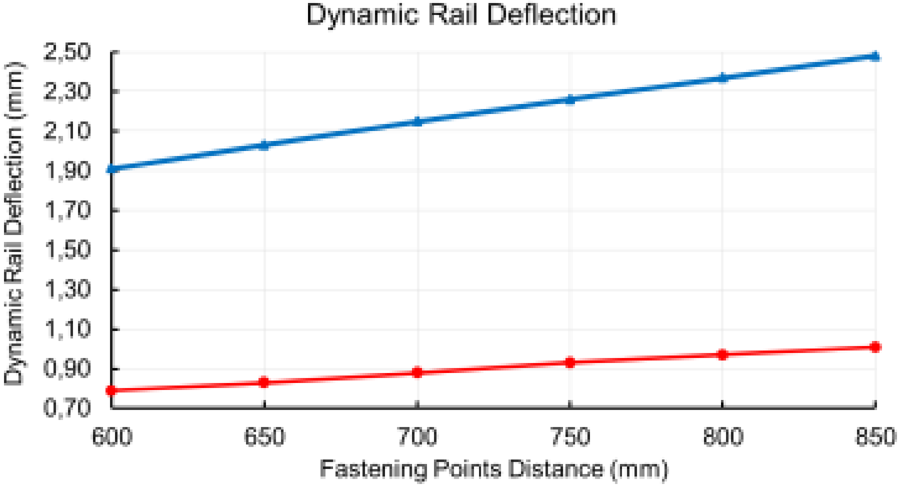
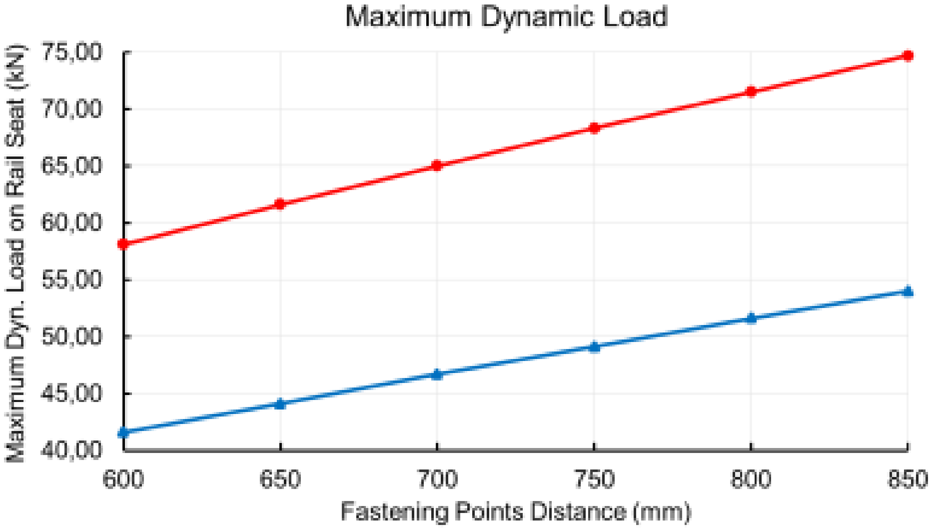
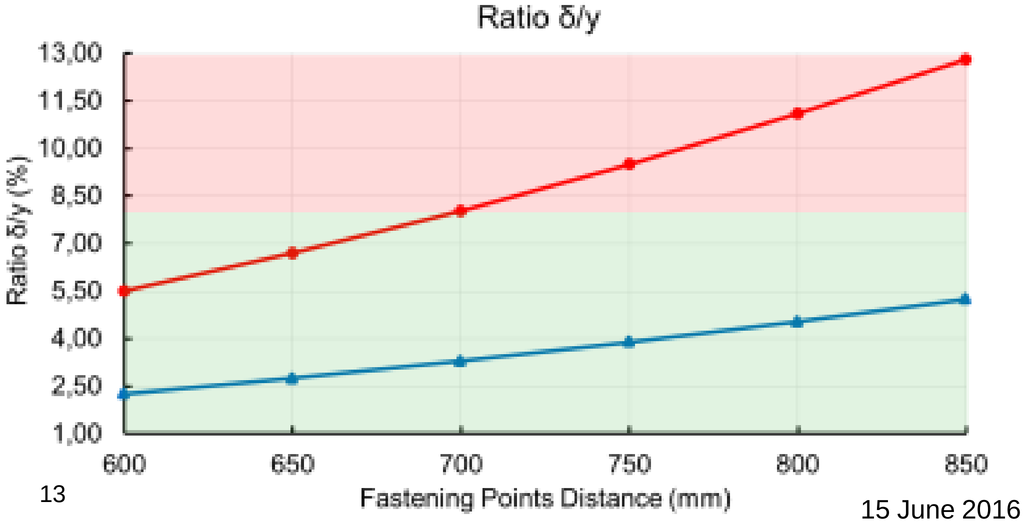
Example – slab track (15-tonne axle load)







17 kN/mm system stiffness

30 kN/mm system stiffness

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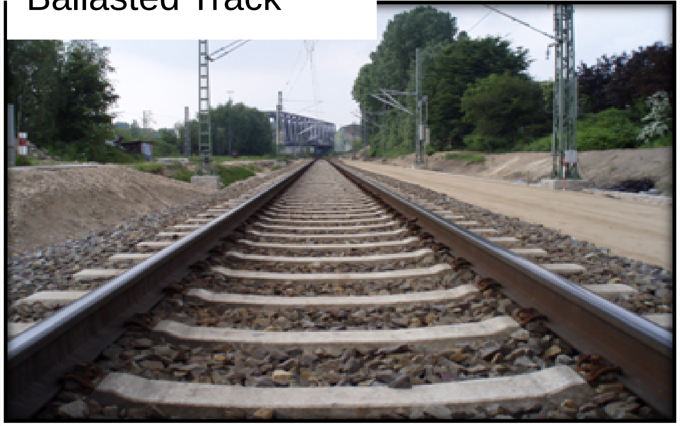
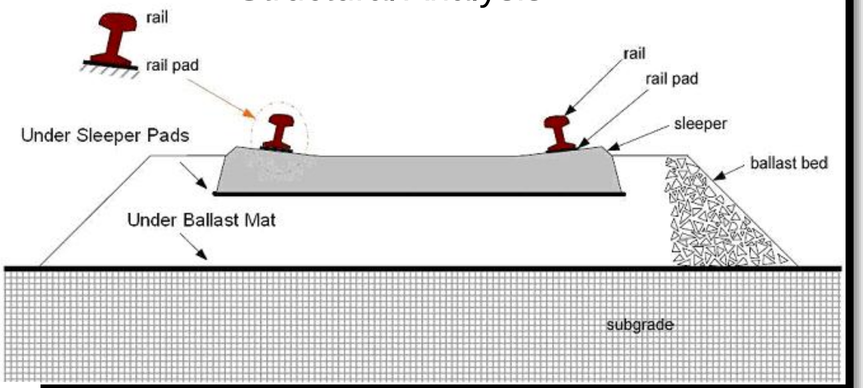
Modeling of track superstructure

Ballasted Track



Structural Analysis



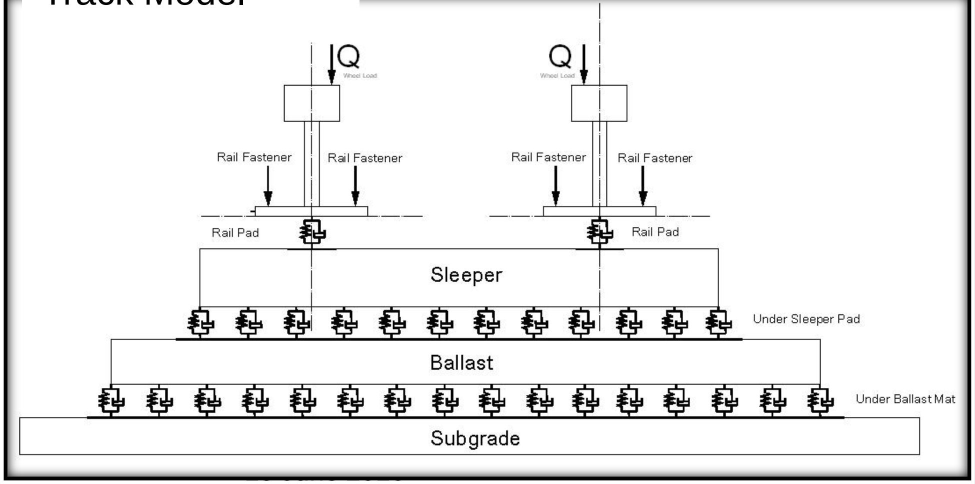
Rail, tie, ballast, subgrade

- ▶ MBS: rigid bodies
- ▶ FEM: with material properties

Rail (elastic) pad, USP, UBM

- ▶ MBS and FEM: elastic elements

Track Model



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Vehicle-track interaction – multi-body simulation

Track with intermediate

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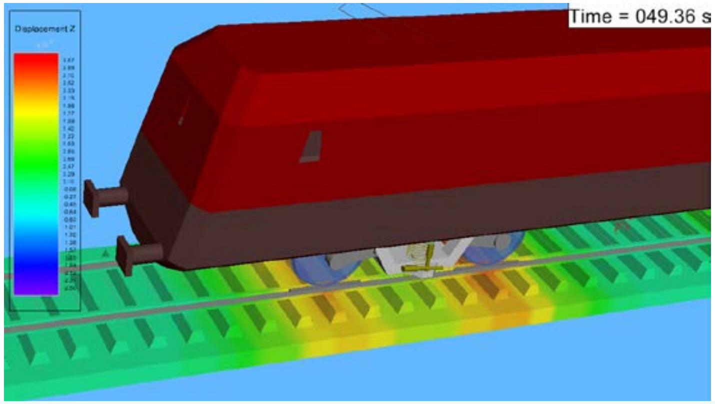
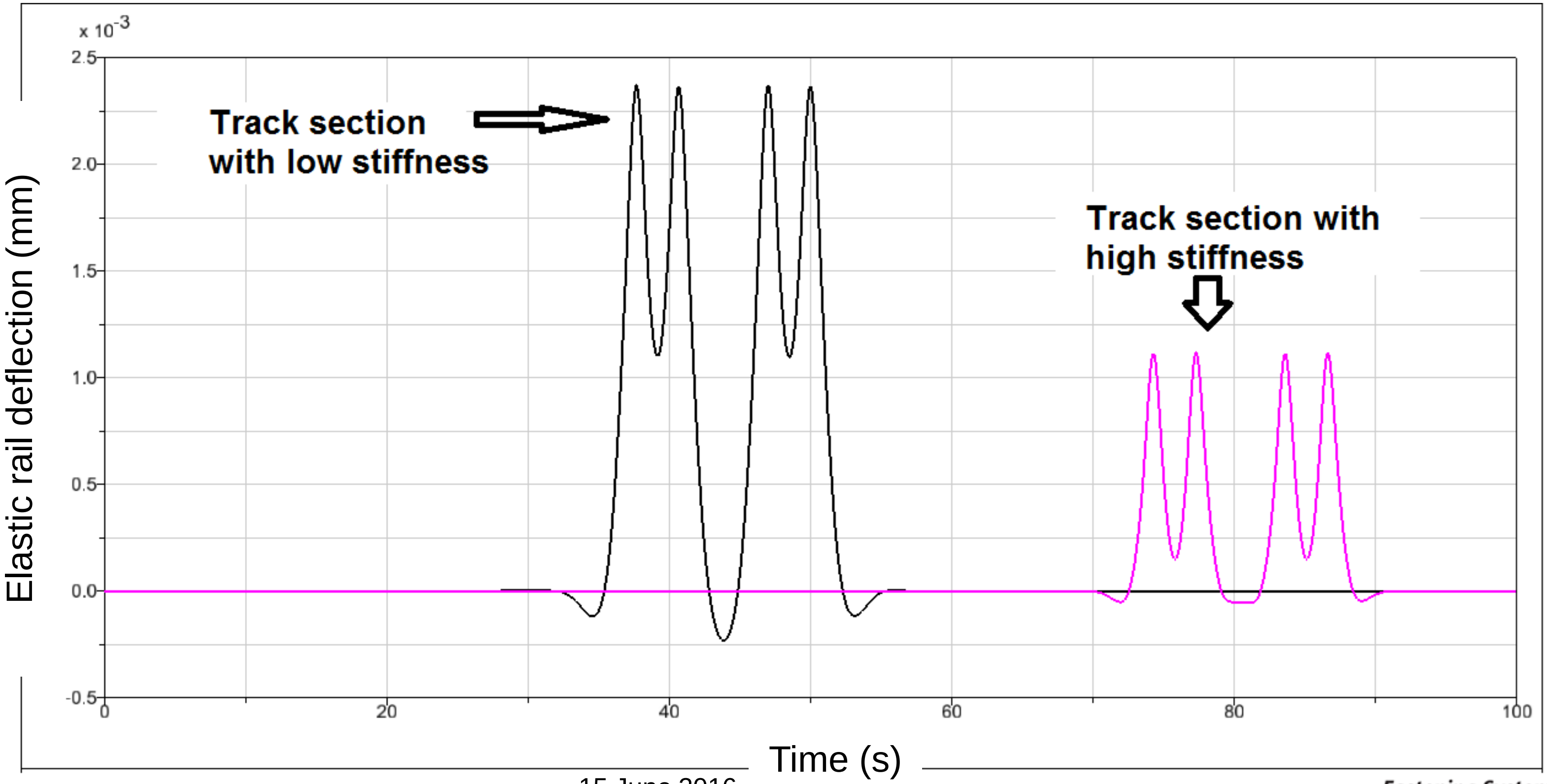
Vehicle on elastic track



European E-locomotive with axle load of 21.5 t



Track section with low stiffness

Track section with 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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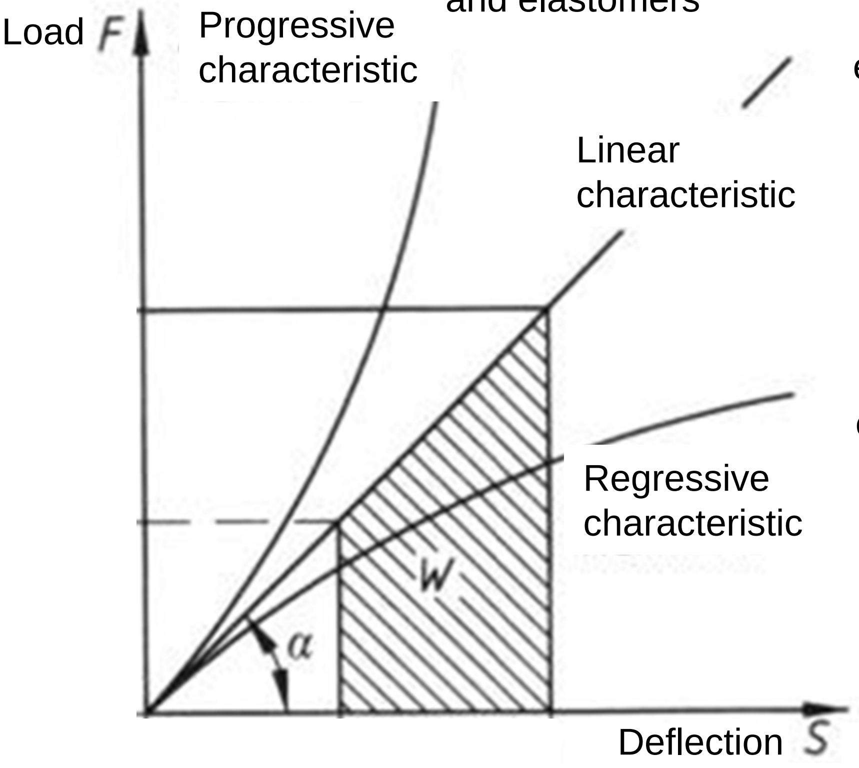
Typical load-deflection diagram



Load

Progressive
characteristic

e.g. rubbers
and elastomers

Linear
characteristic

Regressive
characteristic

Deflection

e.g. spring Fe 28

e.g. archery bow

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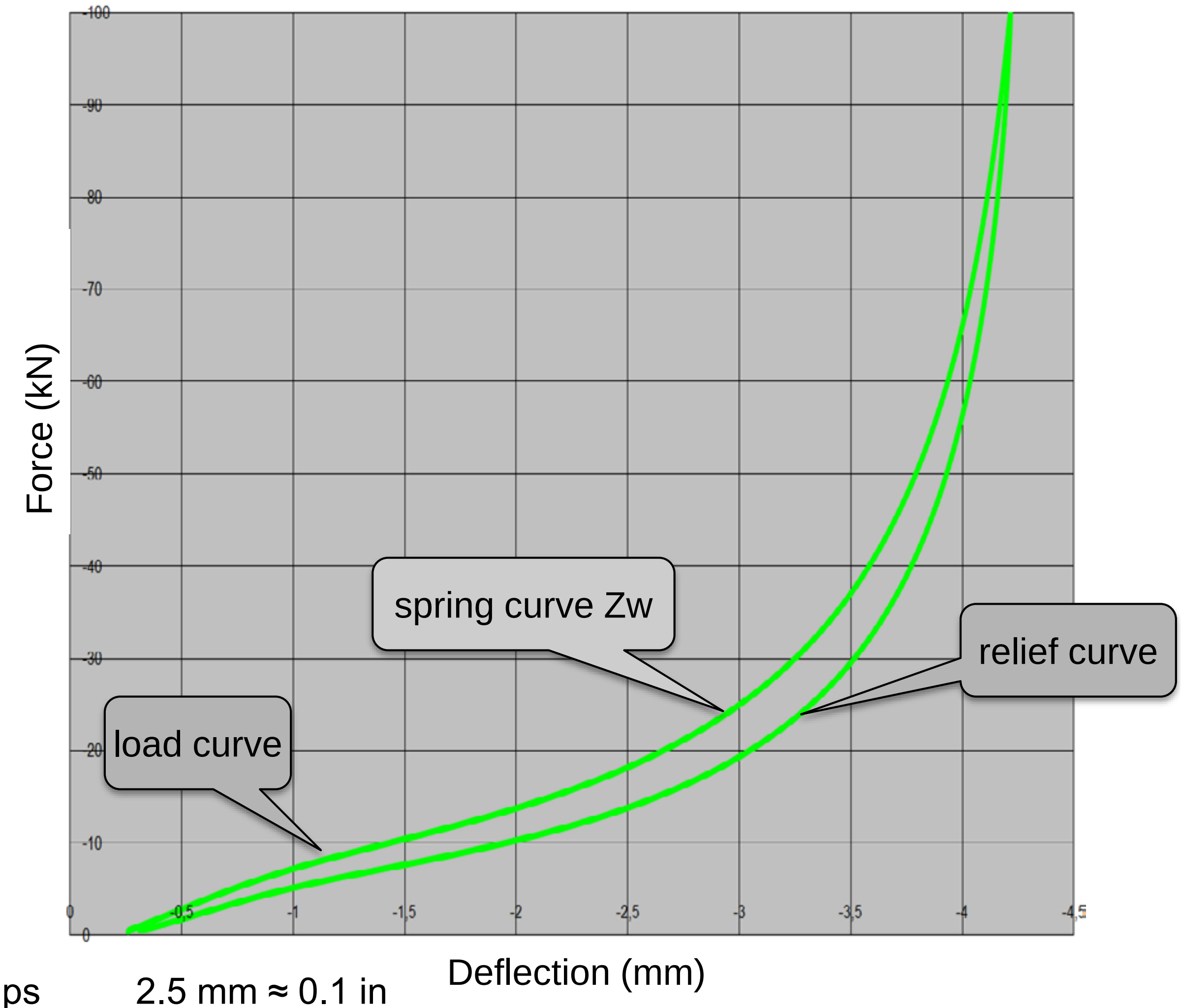
Elastomer load-deflection diagram



10 kN ≈ 2.25 kips 2.5 mm ≈ 0.1 in

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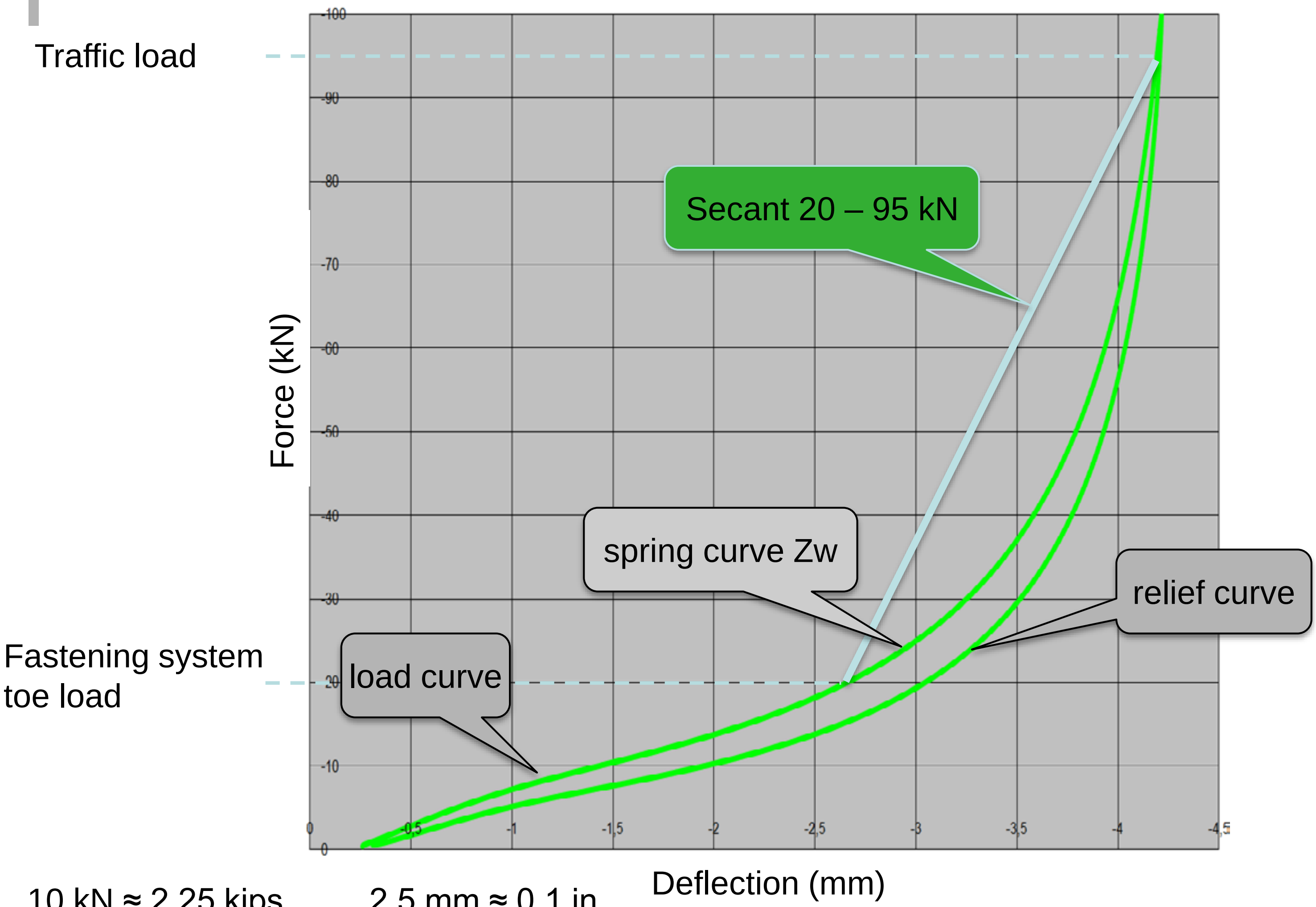
Elastomer load-deflection diagram



10 kN ≈ 2.25 kips

2.5 mm ≈ 0.1 in

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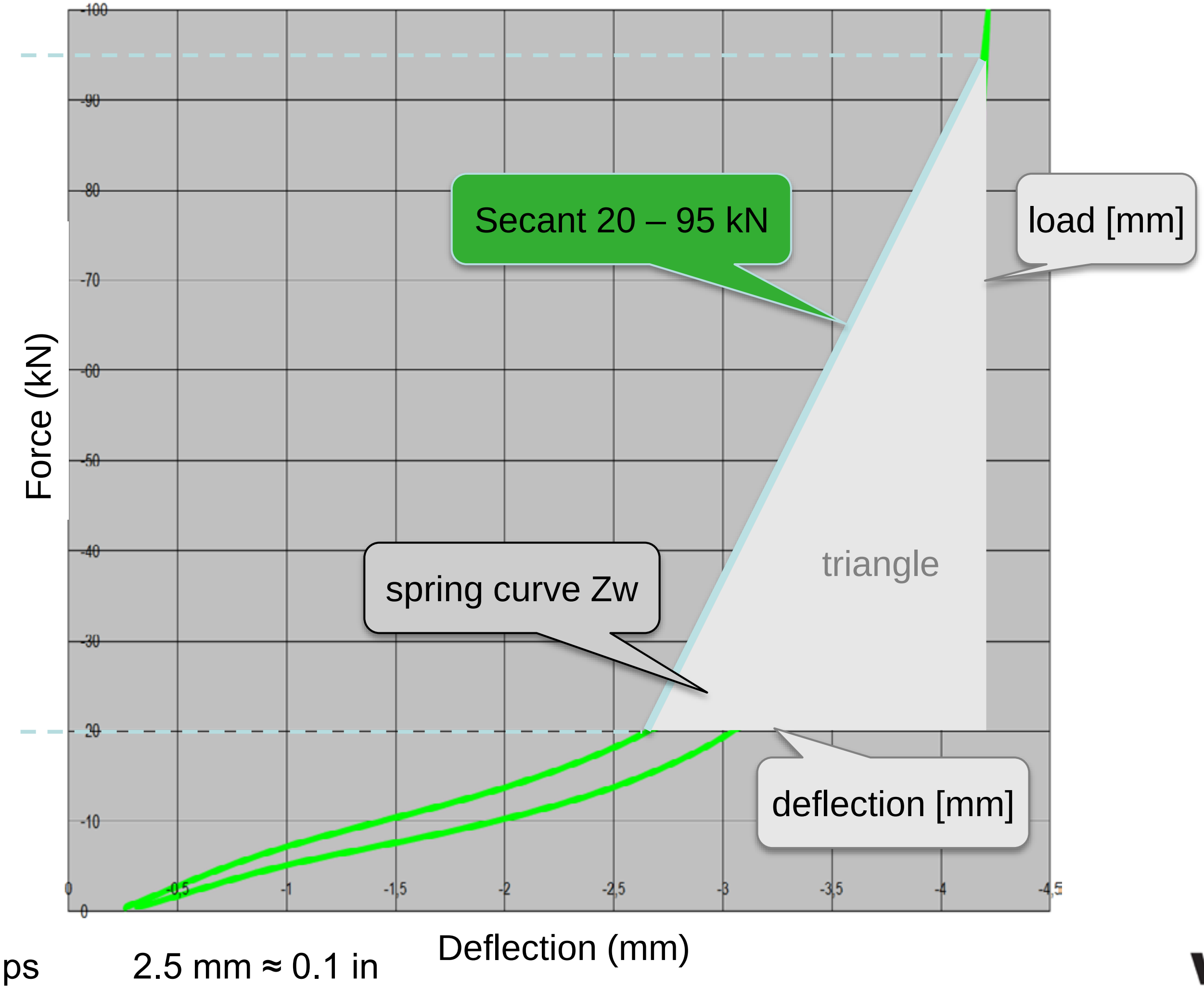
Elastomer load-deflection diagram



Secant 20 – 95 kN

load [mm]

spring curve Zw

deflection [mm]

10 kN ≈ 2.25 kips

2.5 mm ≈ 0.1 in

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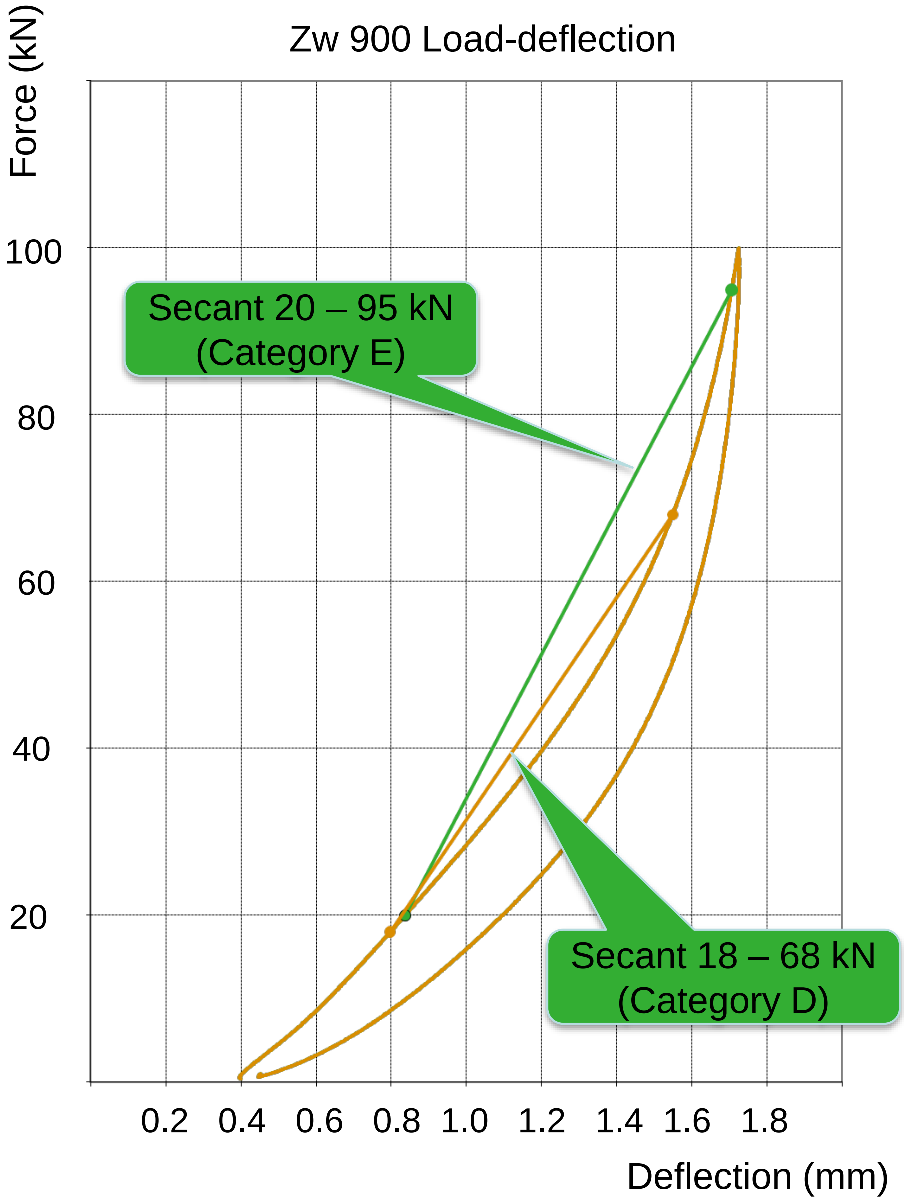
Importance of the measuring secant

- 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%)



Zw 900 Load-deflection

Secant 20 – 95 kN
(Category E)

Secant 18 – 68 kN
(Category D)

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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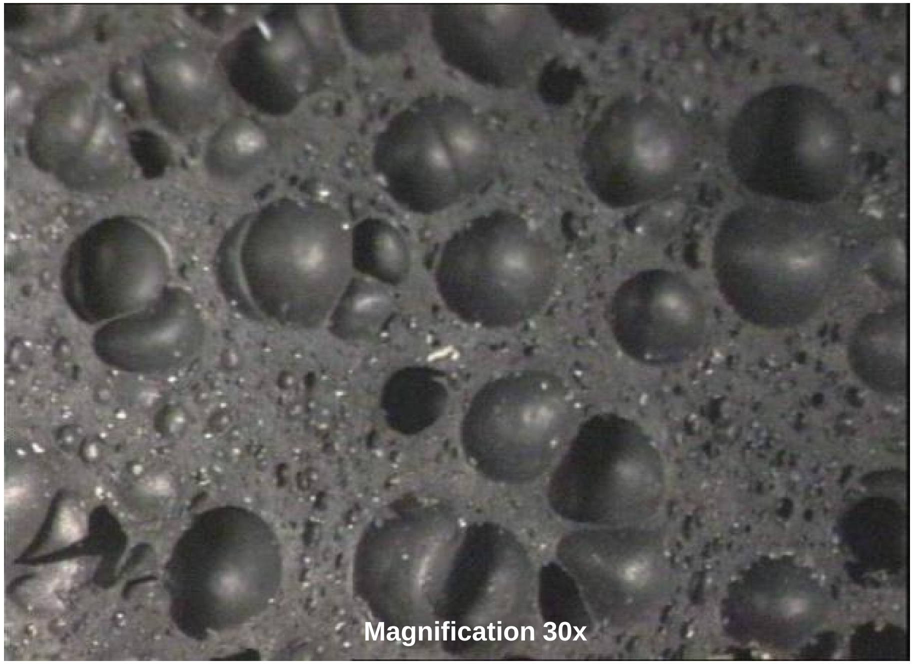
Microcellular EPDM

- 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)



Magnification 30x

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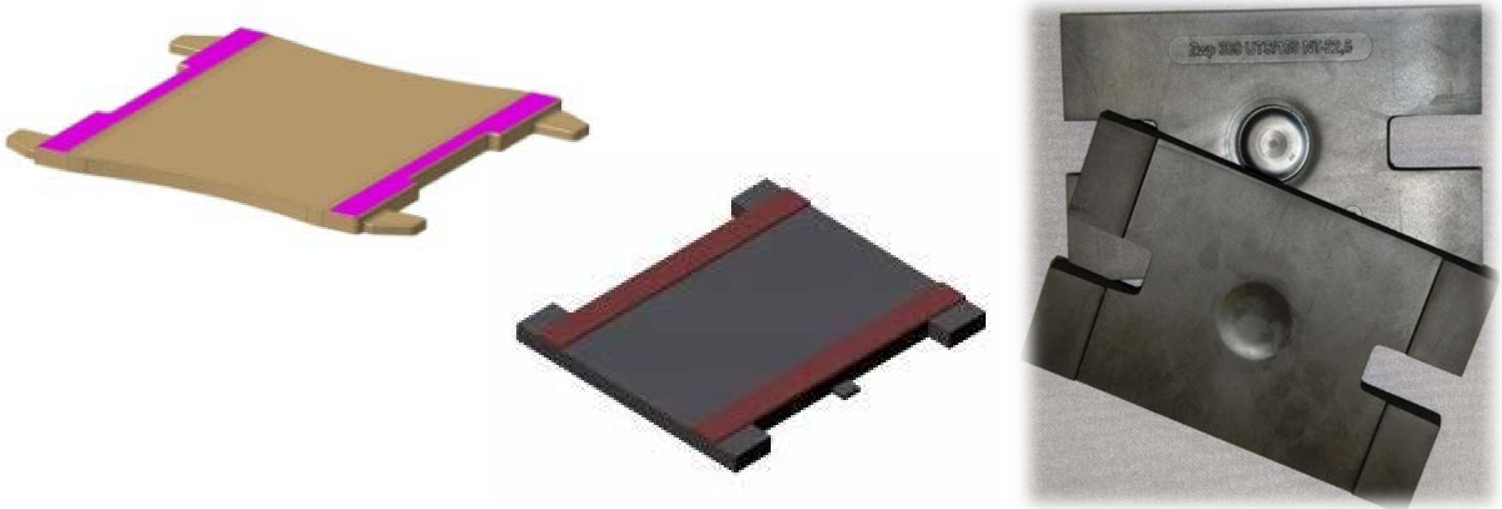
Modifying elasticity via different geometries

- 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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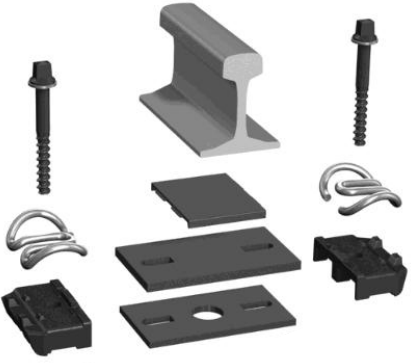
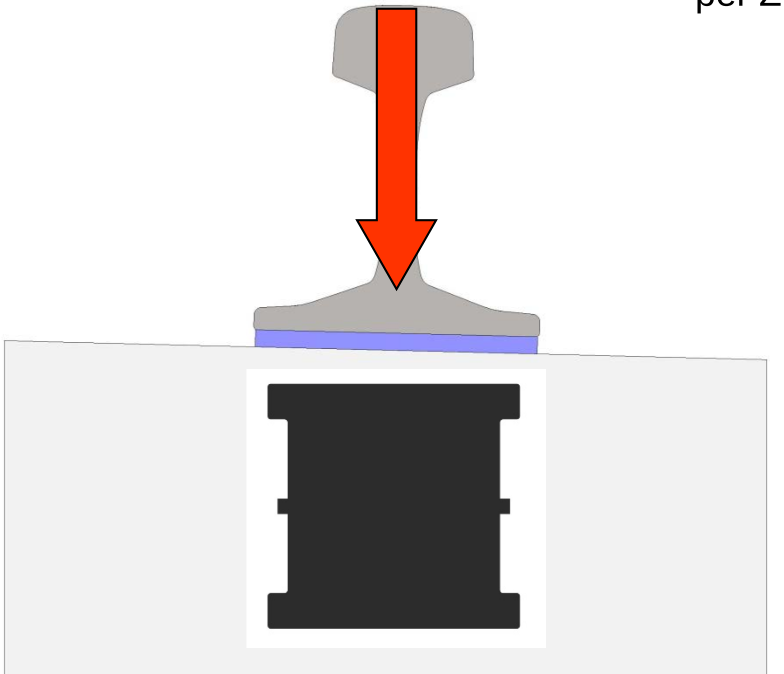
Improving load distribution – utilizing a load distribution plate and large elastic pad

Static Load:
41.9 kN (9.4 kip)

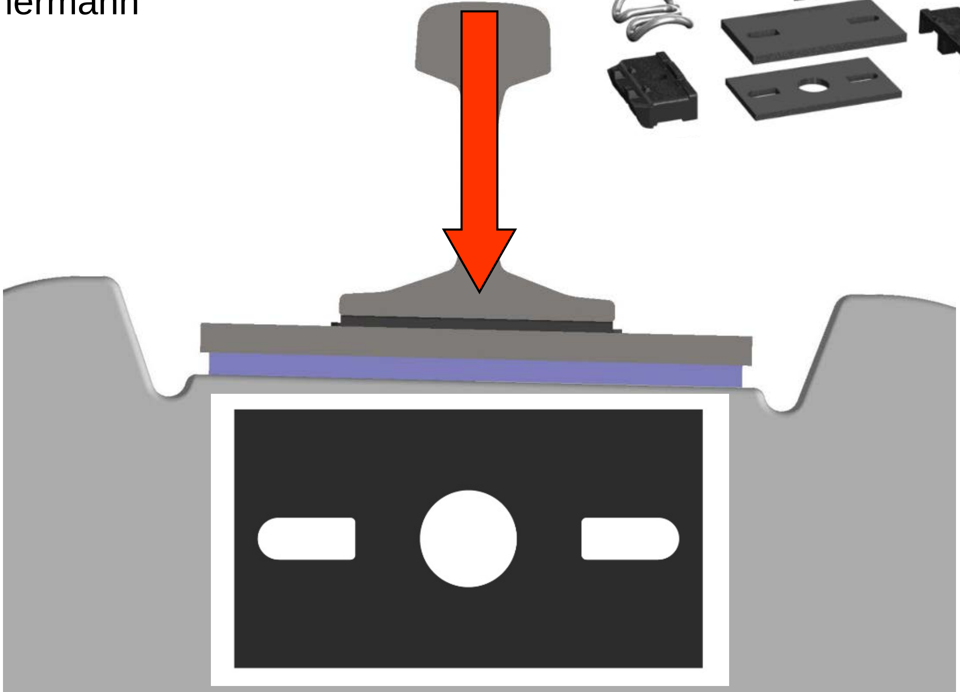
Load assumption for
high speed traffic,
per Zimmermann

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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