Modern Track Ballast Management

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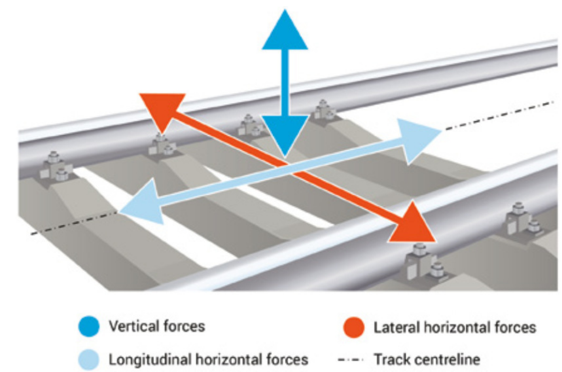
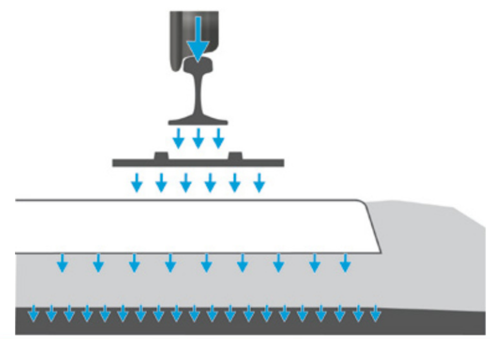
Functions and defects of our ballast bed

THE BEHAVIOUR OF RAILWAY BALLAST TRACK

Functions of the ballast bed

- Resisting Forces Applied to the Track
  - ballast resists vertical, lateral and longitudinal forces applied to the sleeper in order to retain the track in its required position
- Elasticity
  - ballast provides the elasticity of the track and reduces pressures from the sleeper-bearing area to acceptable stress levels for the underlying formation

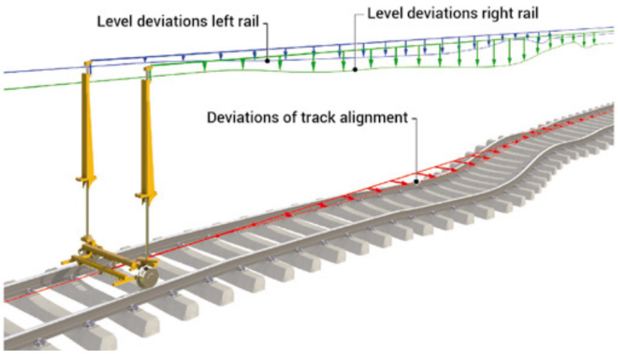




Source: Nemetz, W., Hansmann, F.: Keeping track of track geometry

Functions of the ballast bed

- Drainage
  - provides large voids; allow effective drainage
- Allows Correction of Track Geometry
  - allows correction of the vertical and horizontal alignment defects of the track (track geometry) through a process of lifting, levelling, aligning and tamping



Source: Nemetz, W., Hansmann, F.: Keeping track of track geometry

Why do those things happen?


Source: Zaayman, L.: The Basic Principles of Mechanised Track Maintenance, p.46

Why do those things happen?


Source: Zaayman, L.: The basic principles of mechanized track maintenance, p.84

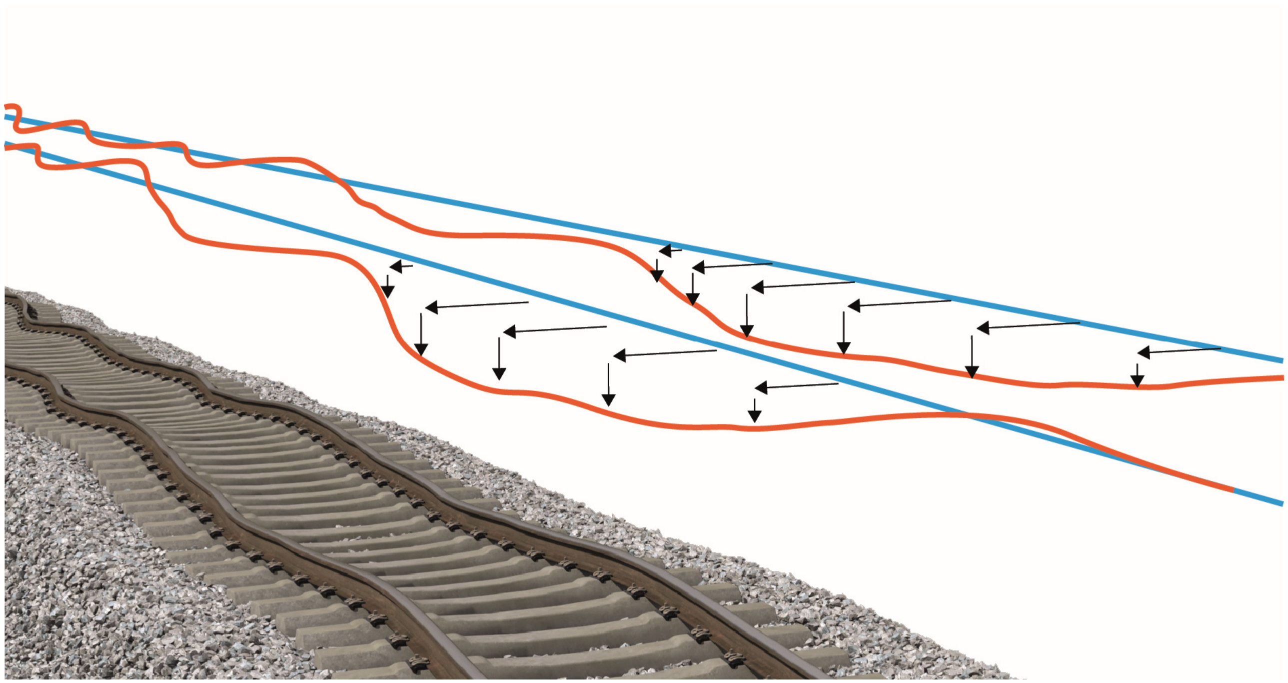
- **Track buckling** due to not enough lateral resistance of track bed
- **Temperature Kick-Out** due to compressive forces in the Rail (CWR temperature was lower)

Why do those things happen?


Source: Zaayman, L.: Optimization of mechanized maintenance management, p.48

- Formation failure visible as **white spots**

Plastic deformations of trackbed lead to misalignment



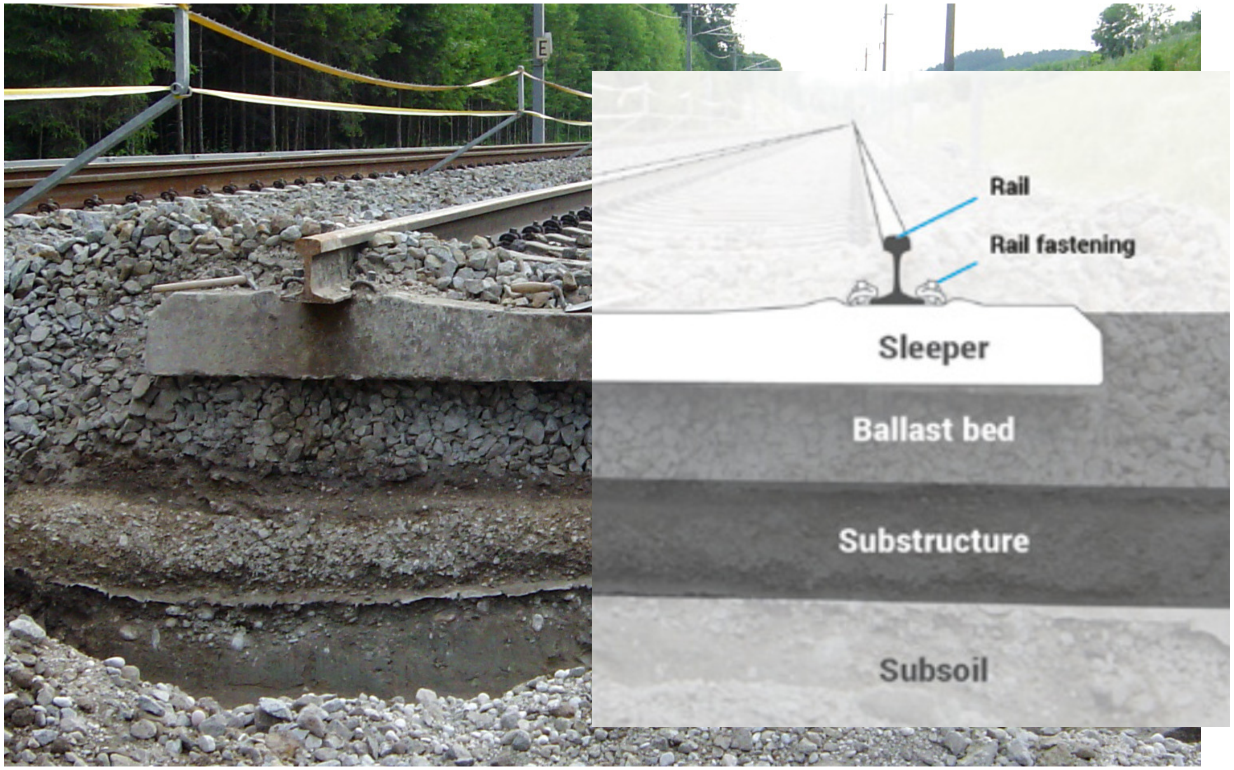
- Crosslevel deviations
- Vertical profile deviations
- Horizontal alignment deviations

Source: Nemetz, W., Hansmann, F.: Keeping track of track geometry, p.62

Ballast Bed Material

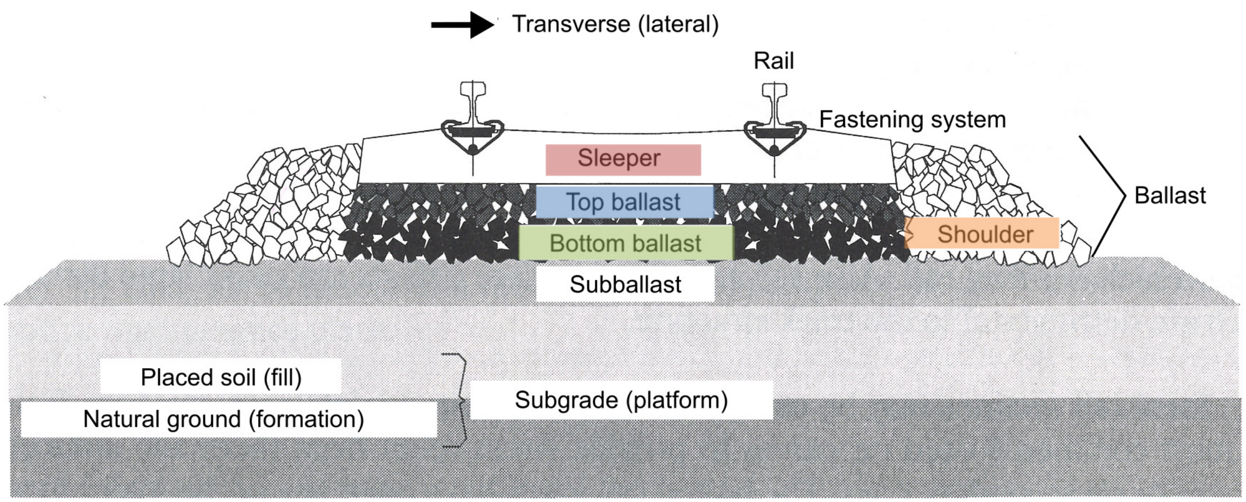
- A good ballast stone should have as many sides as possible.
- Ballast stones can interlock and remain stable
- Particle angularity increases the shear strength of the ballast bed.
- **Round stones** cannot interlock
- Rounded ballast decreases shear strength
- **Flaky stones** have too large a surface which reduces the void spaces.

Ballast track cross section



Source: Hansmann F., Nemetz W., Spoors R.: Keeping Track of Track Geometry (2021), p.39; Foto: Wels-Passau Track (2005)

Ballast cross section



Source: Barbir, O.; adapted from *Selig and Waters*

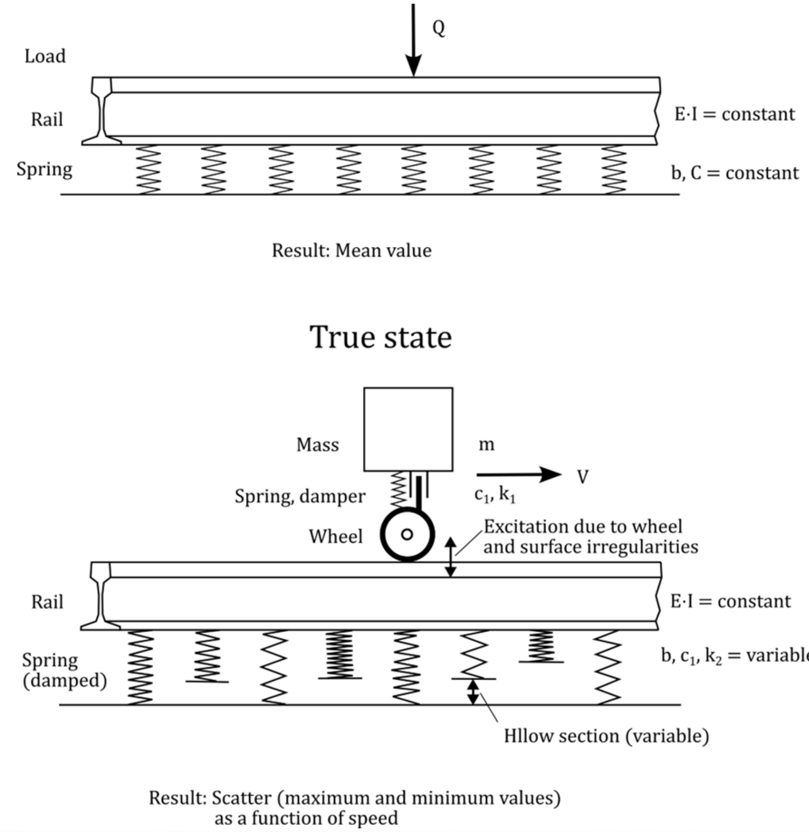
- **Bottom ballast** - lower portion of supporting ballast layer not disturbed by tamping,
- **Top ballast** - upper portion of the supporting ballast exposed to tamping,
- **Shoulder ballast** - ballast zone between the end of the sleeper and the top of the subballast layer,
- **Crib / Sleeper bay ballast** - ballast zones between the sleepers.

Understanding vertical track displacement behaviour

THE ZIMMERMANN/WINKLER THEORY

How much deflection does occur?

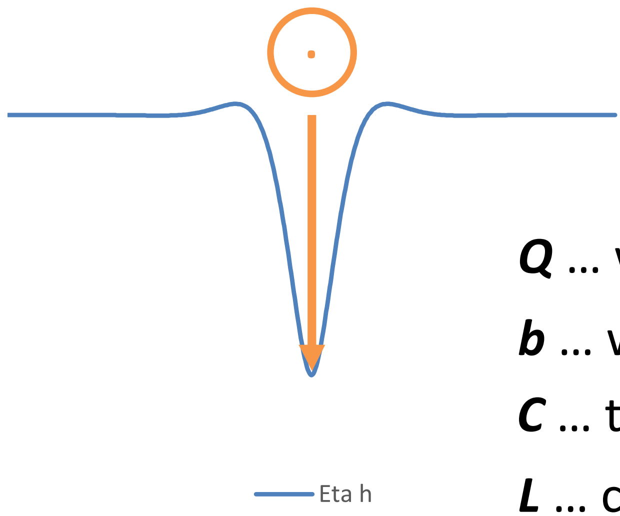
- The theory of Zimmermann/Winkler allows to calculate the deflection/rise of the rail under a wheel



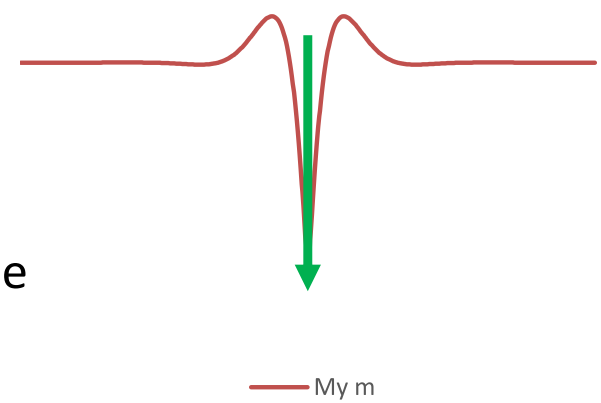
Source: reproduced from Fastenrath, F.: „Die Eisenbahnschiene“ (1977)

Deflection y_0 and bending moment M_0 due to single load below a wheel

$$y_0 = \frac{Q}{2 \cdot b \cdot C \cdot L} \cdot 1$$



$$M_0 = \frac{Q \cdot L}{4} \cdot 1$$

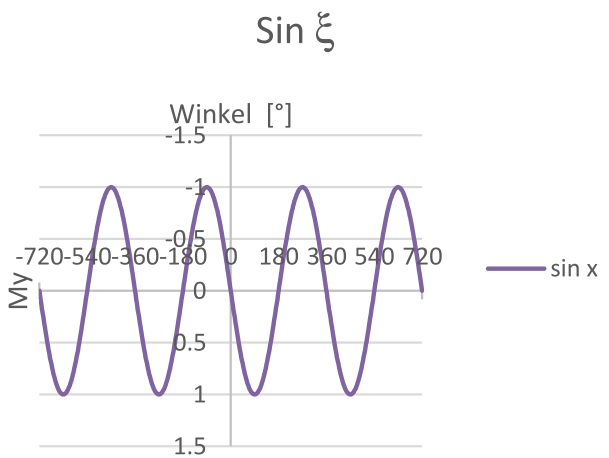


Q … wheel load

b … width of converted long tie

C … track modulus

L … characteristic tie length



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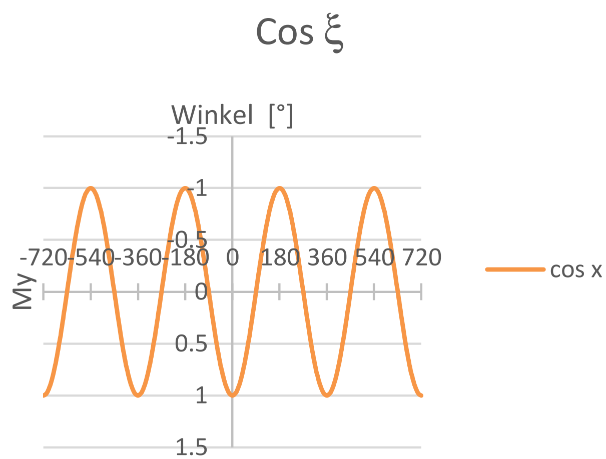

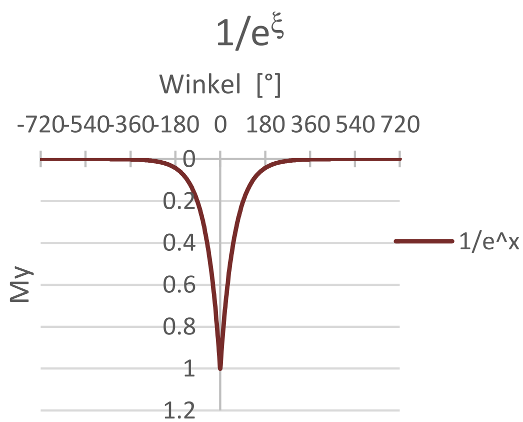

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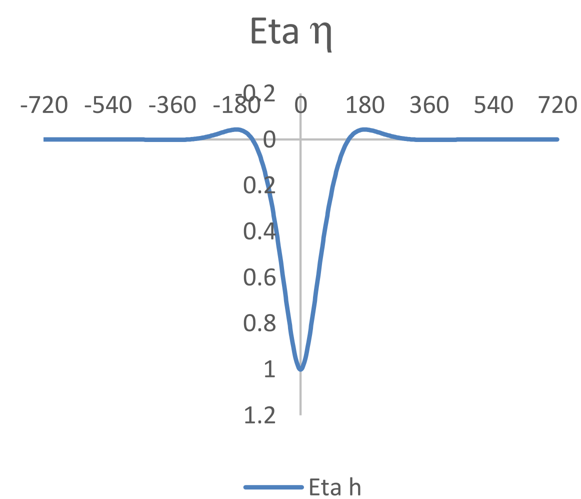
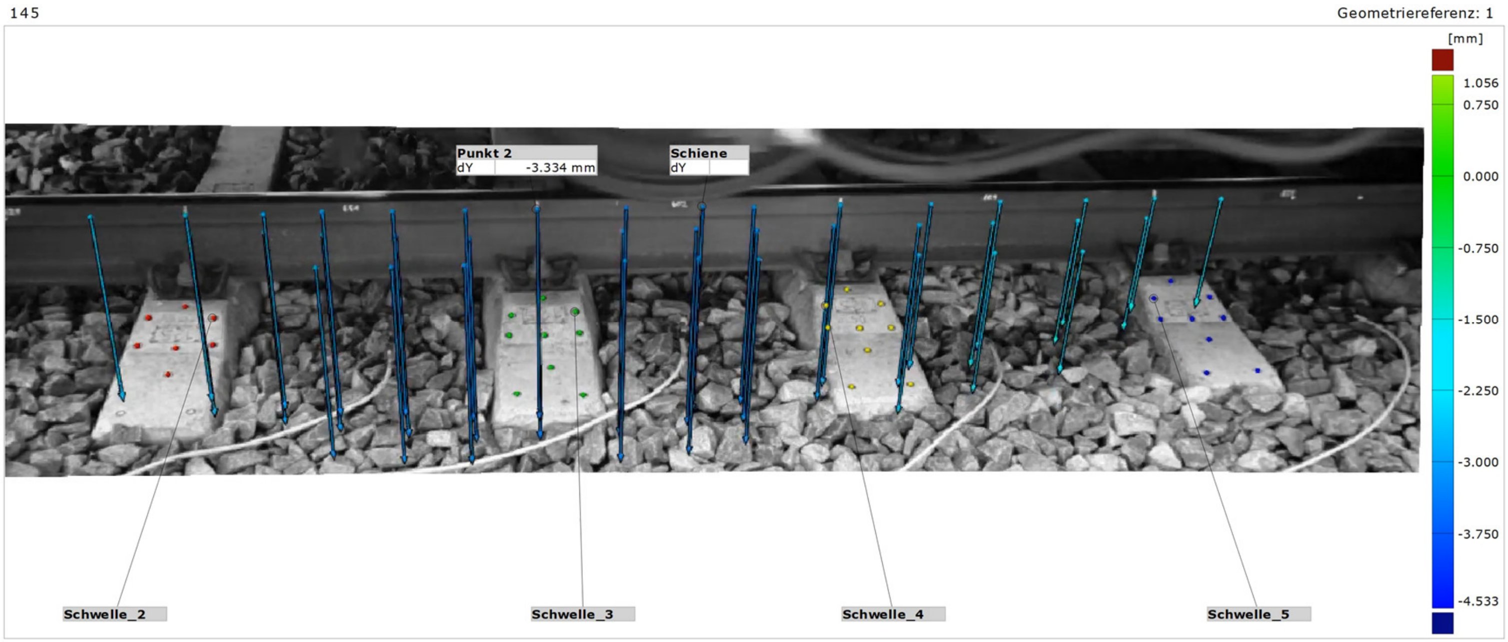


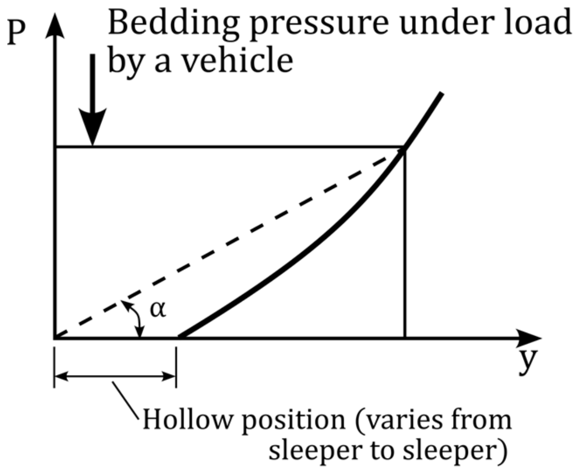
$$y_0 = \frac{Q}{2 \cdot b \cdot C \cdot L} \cdot \eta \qquad \eta = \frac{\sin \xi + \cos \xi}{e^{\xi}} \qquad \xi = \frac{x}{L}$$

How does it look in real life?



Source: Pittrich, M. (M.Sc.); Prüfamt für Verkehrswegebau, TU Munich School of Engineering and Design: „Application of innovative camera systems for measurements on track infrastructure"; ÖVG Track Conference, Salzburg Austria (05/2022)

The track (foundation) modulus C



Source: reproduced from Fastenrath, F.: „Die Eisenbahnschiene“ (1977)

$$\boldsymbol{C} = \tan \boldsymbol{a} = \frac{p}{y} = \frac{\frac{N}{mm^2}}{mm} = \frac{\frac{lbs}{inch^2}}{inch} = \frac{\boldsymbol{lbs}}{\boldsymbol{inch^3}}$$

p = pressure between tie and ballast bed [N/mm² ≈ lbs/inch²]
y = displacement of the rail due to elasticity of trackbed [inch]

- The unit of the track modulus is [N/m³ ≈ lbs/inch³]
- The track modulus is a systems parameter

The track foundation modulus C

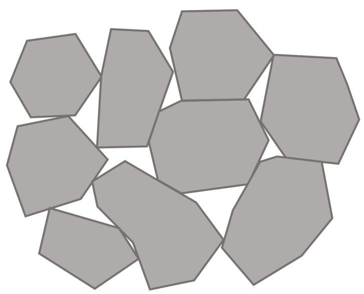
Quality of trackbed and subsoil	Track foundation modulus C	
	N/cm³	lbs/inch³
Very bad (clay)	**< 50**	< ~184
Bad (silt)	**>50**	> ~184
Good (sandy gravel)	**>100**	> ~370
Very good (gravel)	**>150**	> ~553
Concrete slab (bridge, tunnel, slabtrack)	**>300**	> ~1105

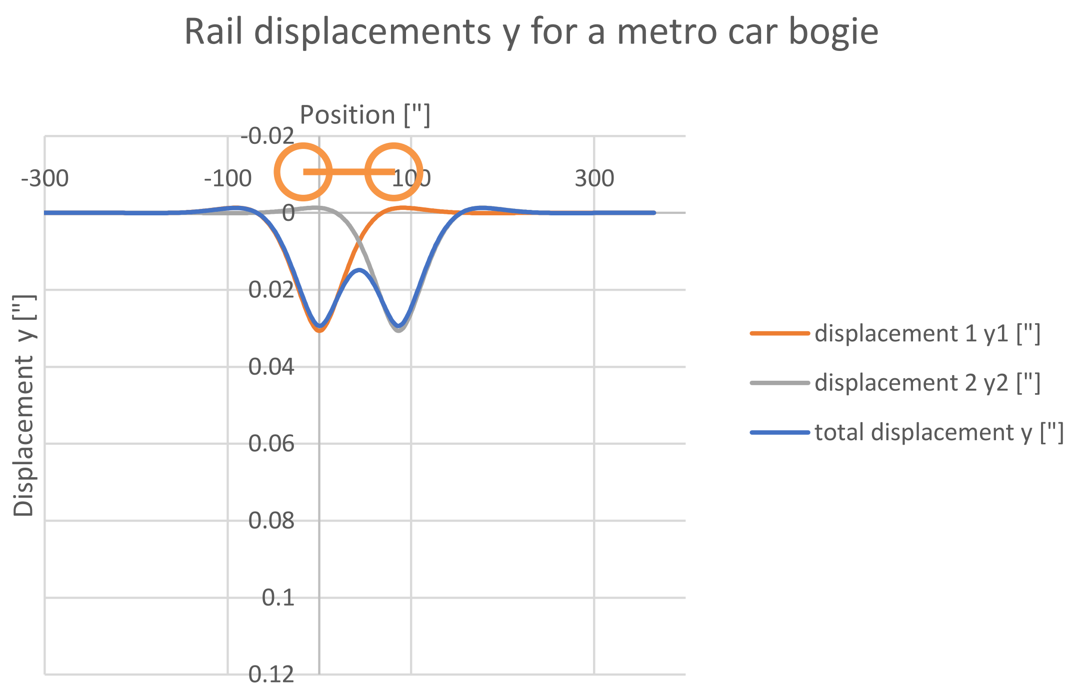
Source: reproduced from Göbel C., Lieberenz K.: Handbuch Erdbauwerke der Bahnen

Rail displacements due to stiffness change

Metro car bogie
Wheel load 12,900 pounds

Track modulus **100 N/cm³ = ~ 370 lbs/inch³**



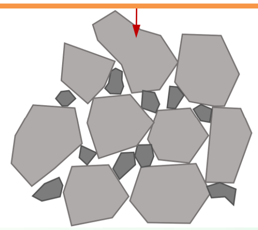


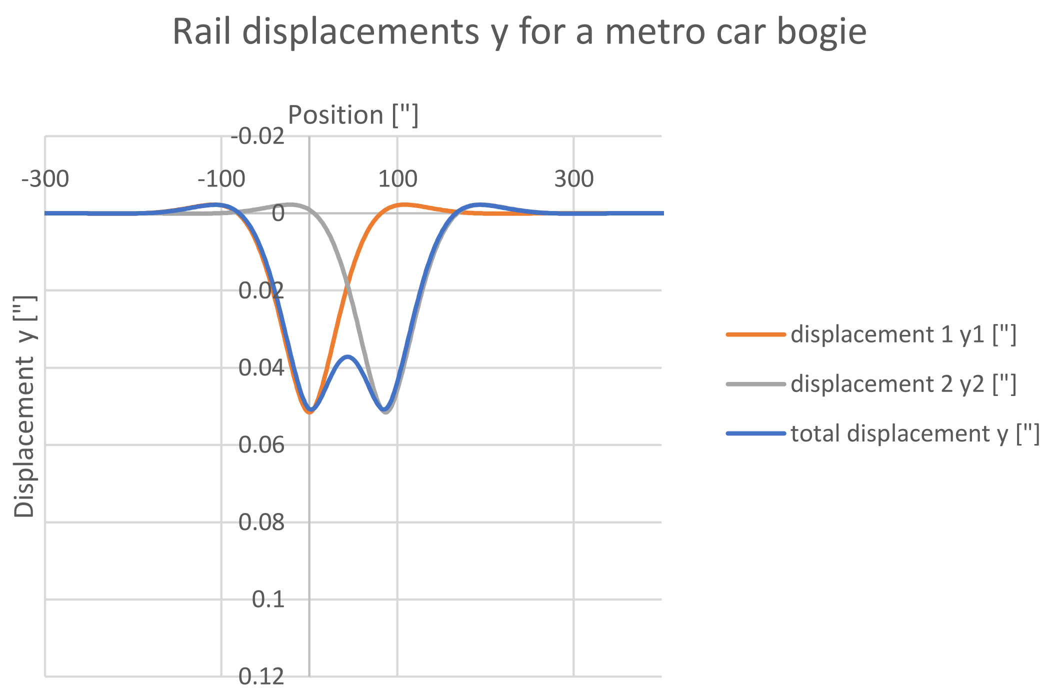
Rail displacements due to stiffness change

Metro car bogie
Wheel load 12,900 pounds

Track modulus **50 N/cm³ = ~ 184 lbs/inch³**

A weaker bedding modulus changes rail displacements



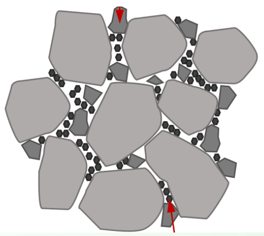


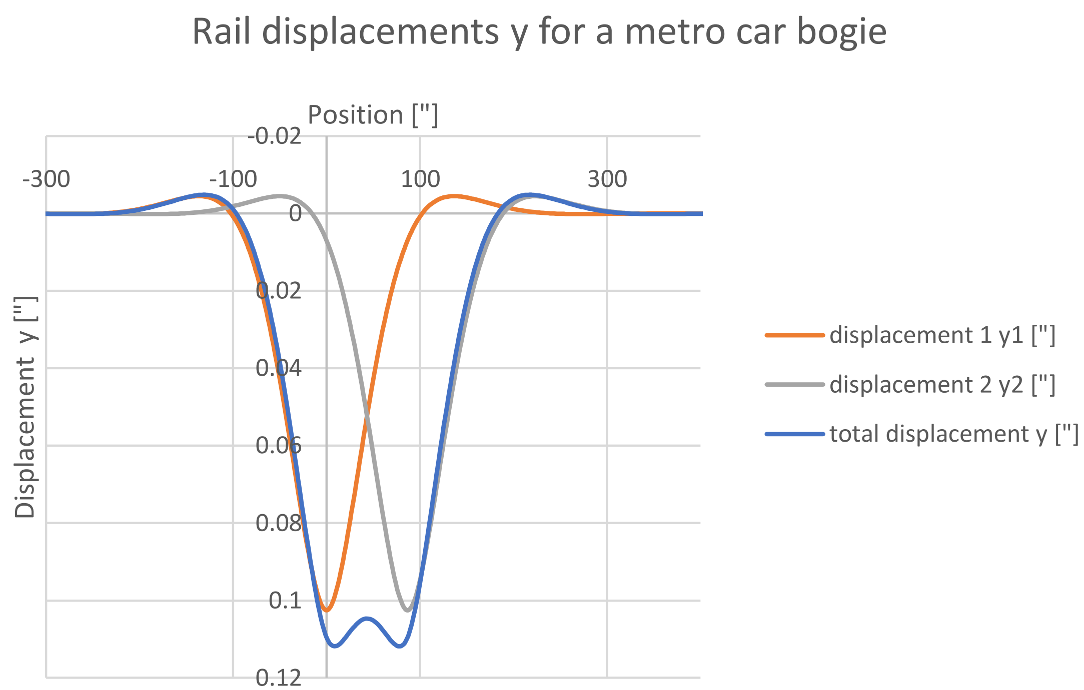
Rail displacements due to stiffness change

Metro car bogie
Wheel load 12,900 pounds

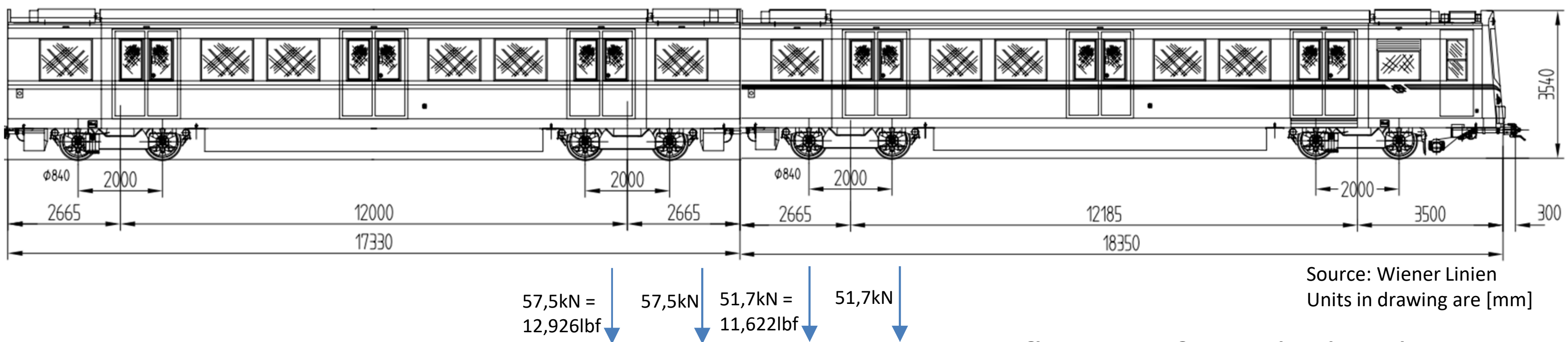
Track modulus **20 N/cm³ = ~ 74 lbs/inch³**

A weaker bedding modulus changes rail displacements



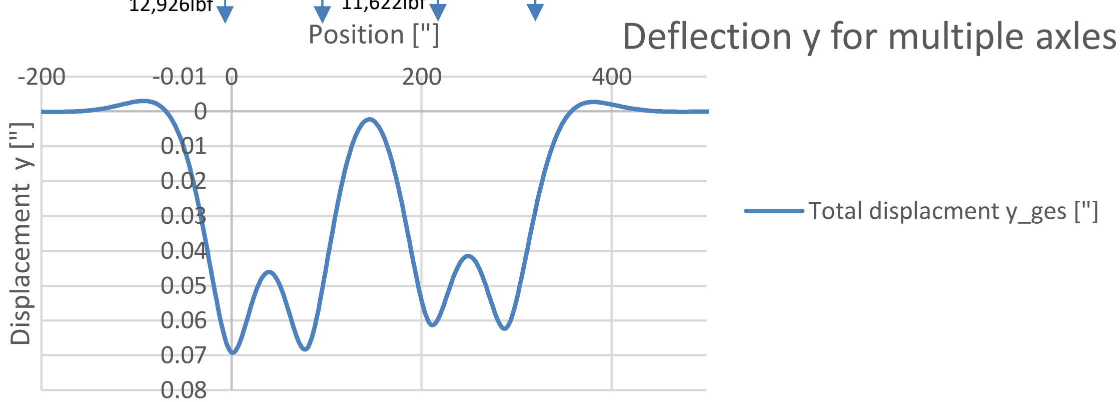


Rail Displacements for a bogie group

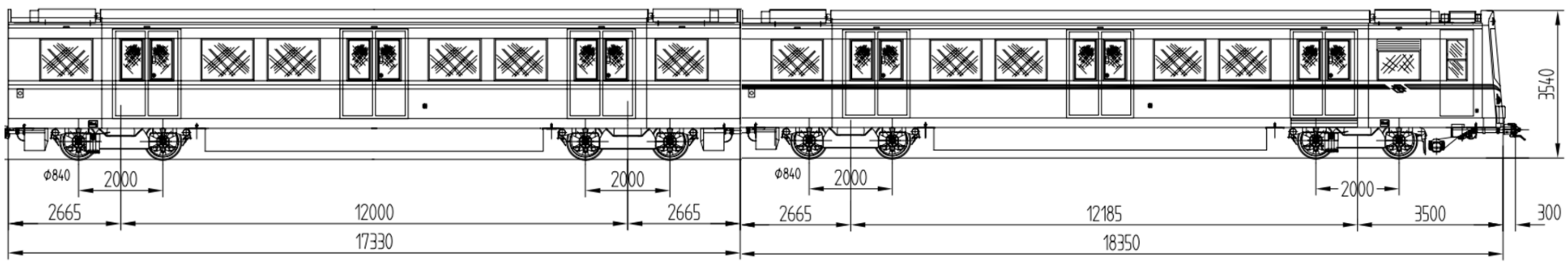


Source: Wiener Linien
Units in drawing are [mm]

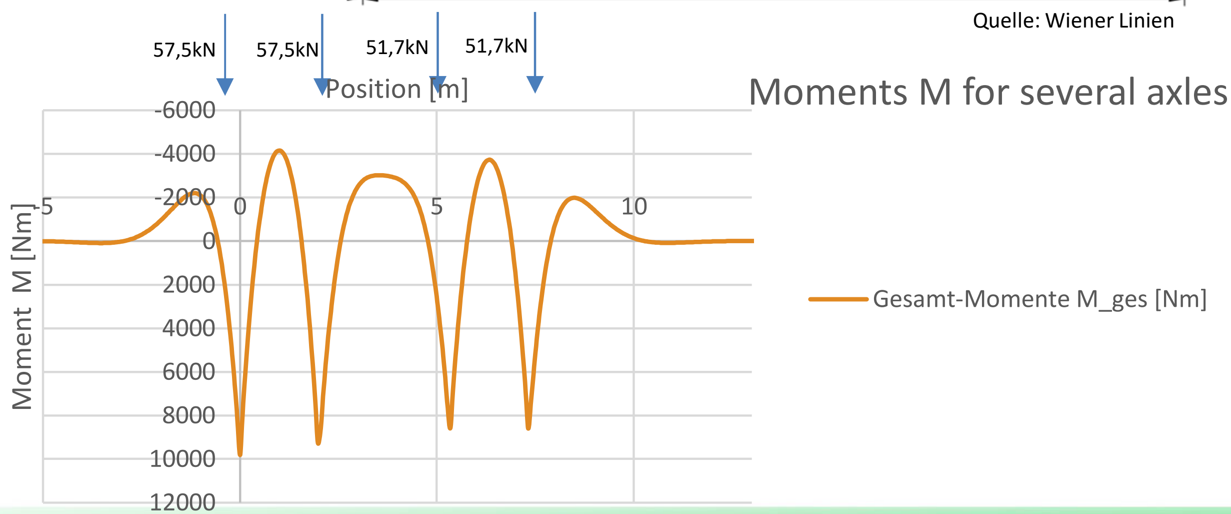
C = 100N/cm³ =
370 lbs/inch³



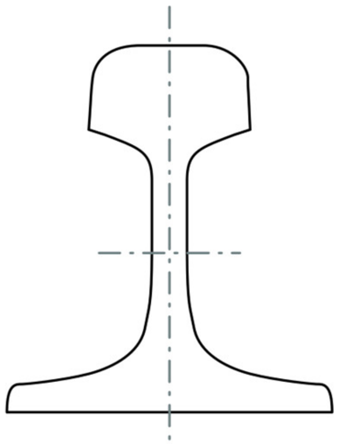
Rail bending moments from a bogie group

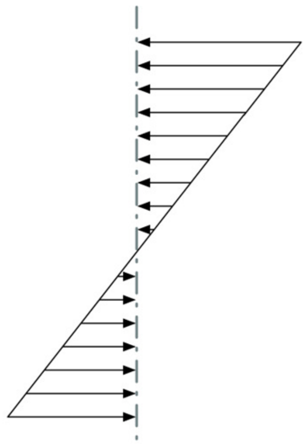


Quelle: Wiener Linien



Resulting stress effects on the rail

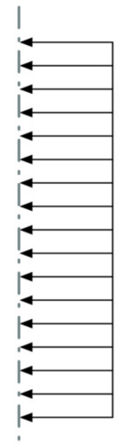




Biegespannung zufolge Q

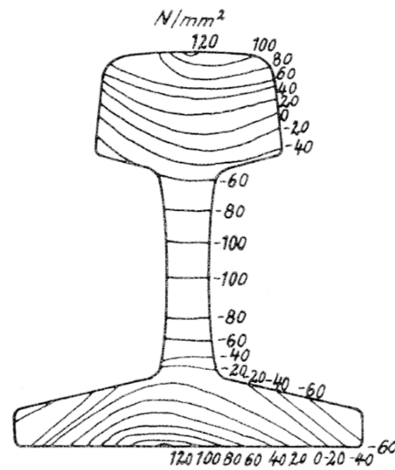
~70MPa

Kontaktspannung zufolge T_x



Temperaturspannung zufolge T_T

~120MPa



Internal stresses from rail production

up to ~250MPa

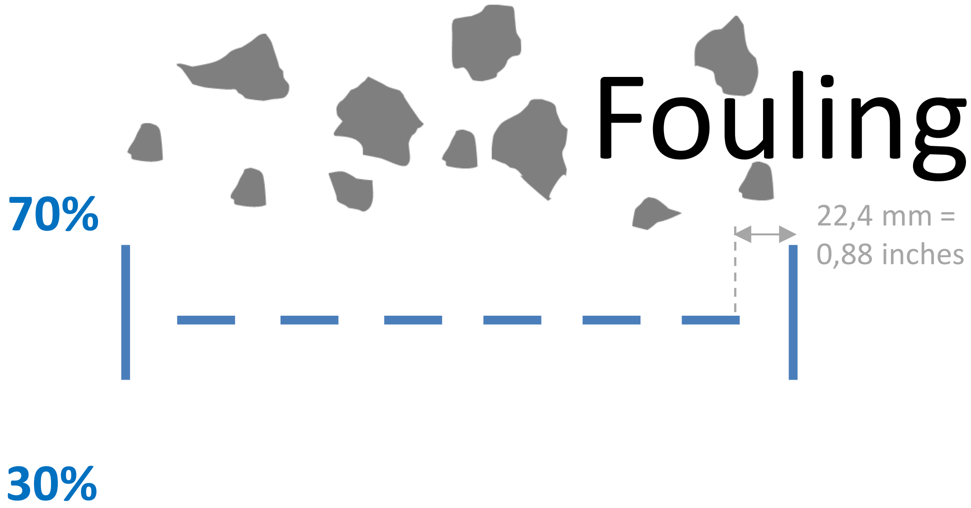
Internal stresses at rail foot max. 250MPa due to EN13674-1 vignol rail standard

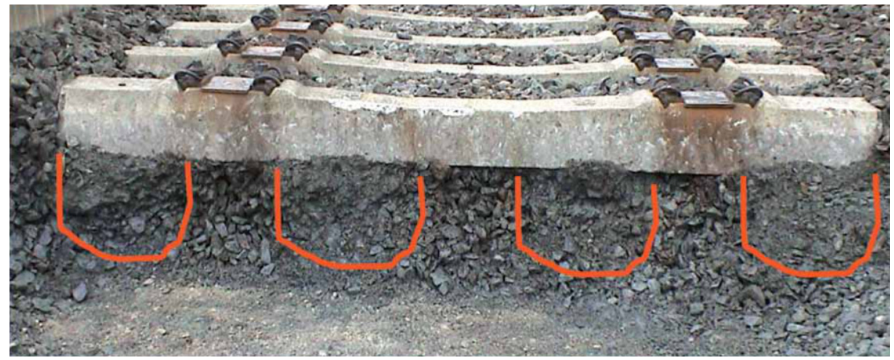
e.g. 60E1 profile at axle load 50582 lbs and -13°F

Degradation of the material

BALLAST FOULING

Fouling material



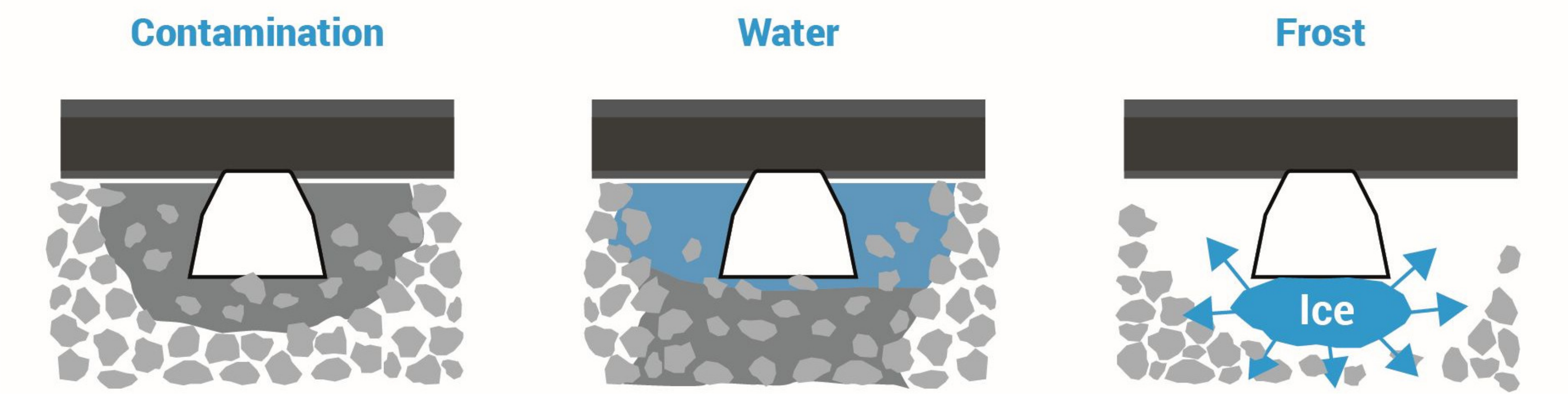


Source: Piereder, F.: Ein Leben für die Eisenbahn, p.241-242

- ERRI suggested that if >30% is passing the 0.88 inches (22.4mm) sieve, ballast cleaning should be done

(UIC Report D182/RP2 Assessment of ballast condition in the track)

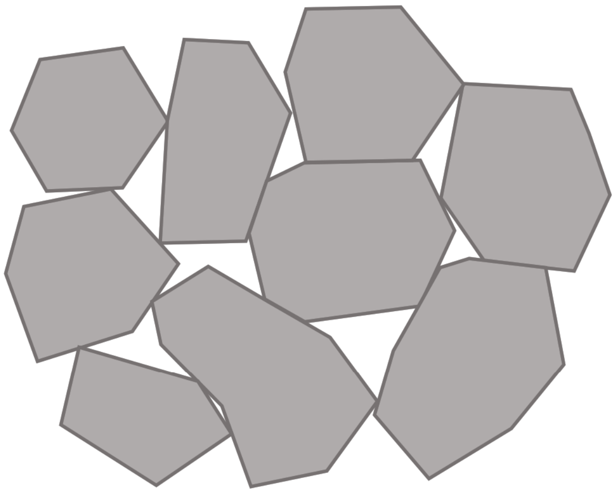
Reason for ageing of ballast



- **breakdown of ballast particles**
- **infiltration from the surface**
- **tie (sleeper) wear**
- **infiltration from the underlying gravel layer**
- **subgrade infiltration**

Source: Hansmann F., Nemetz W., Spoors R.: Keeping Track of Track Geometry (2021); p.67

Phases of ballast fouling

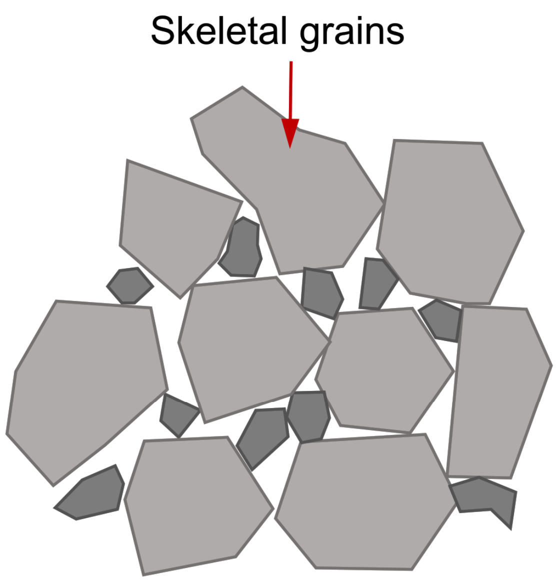


(a) Phase 1: clean ballast

- Phase 1
- clean ballast sample
- almost all grains establishing contact with each other

Source: Barbir, O.; Development of condition based tamping process in railway engineering; Ph.D. thesis, TU Wien (2022)

Phases of ballast fouling

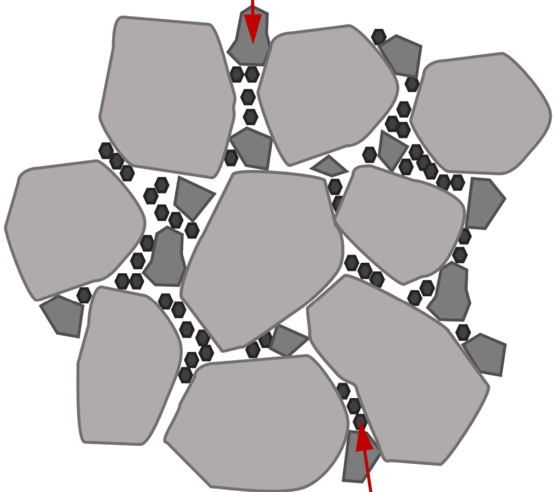


(b) Phase 2: partially fouled ballast

- Phase 2
- voids in between grains filled
- grain-to-grain contact still maintained

Source: Barbir, O.; Ph.D.thesis (2022)

Phases of ballast fouling

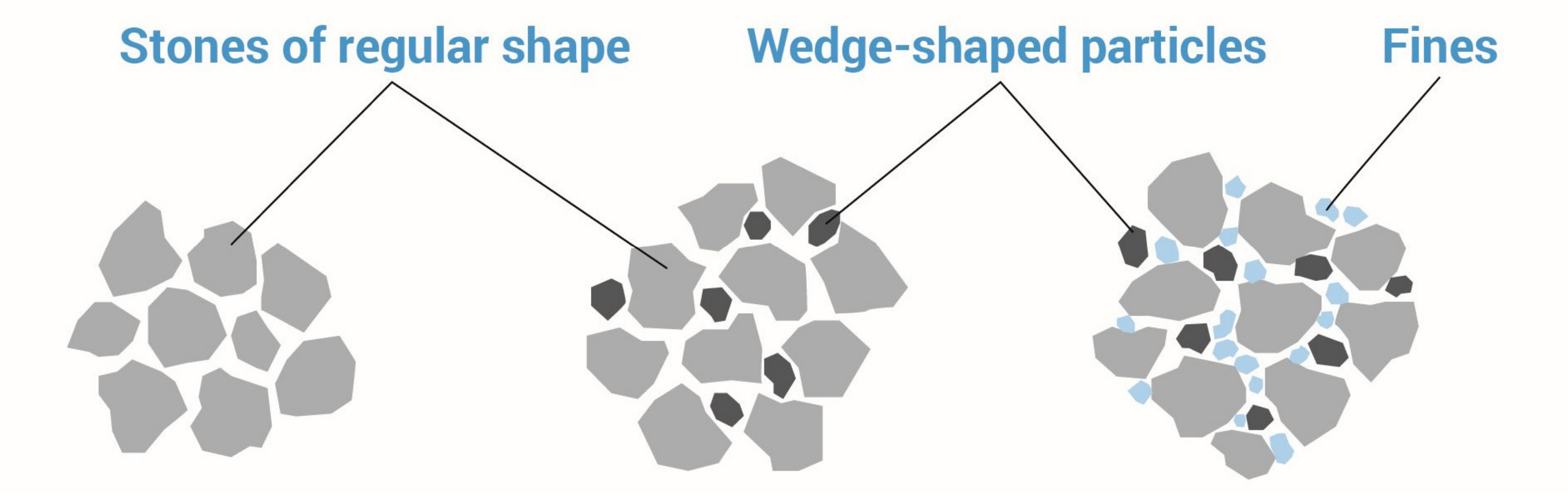


(c) Phase 3: heavily fouled ballast

- Phase 3
- excessive amount of fine particles
- **grain-to-grain contacts are mostly eliminated**
- single grain movement is constrained
- fine particles filling the voids

Source: Barbir, O.; Ph.D.thesis (2022)

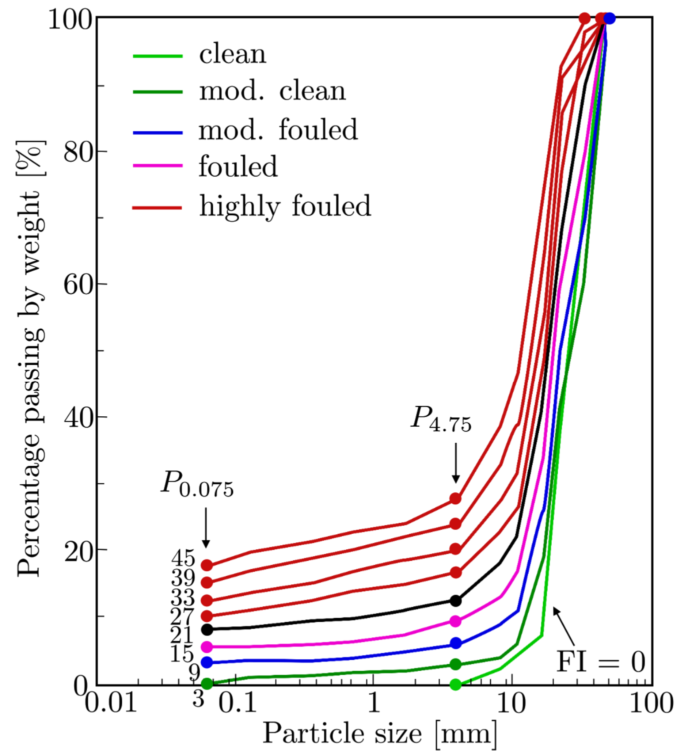
Phases of trackbed decay



Source: Hansmann F., Nemetz W., Spoors R.: Keeping Track of Track Geometry (2021); p.69

Fouling Index (FI)

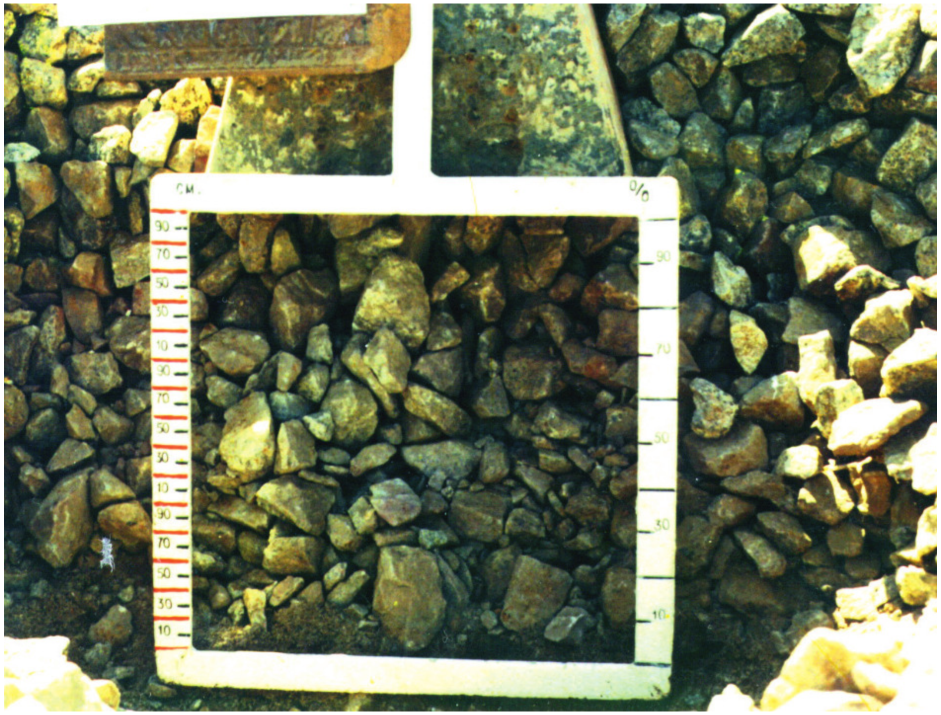
- P = percentages by mass of material passing the 0.19 inches (4.75 mm) and 0.003 inches (0.075 mm) sieve
- **FI = $P_{0.075}$ + $P_{4.75}$ (North America)**
- FI = $P_{0.075}$ + $P_{13.2}$ (Australia)



Source: Barbir, O.; adapted from *Selig and Waters*

Fouled Ballast

10 – 20% Fouling



100 – 120% Fouling

Source: Zaayman, L.: The Basic Principles of Mechanised Track Maintenance (3rd ed.) p.48

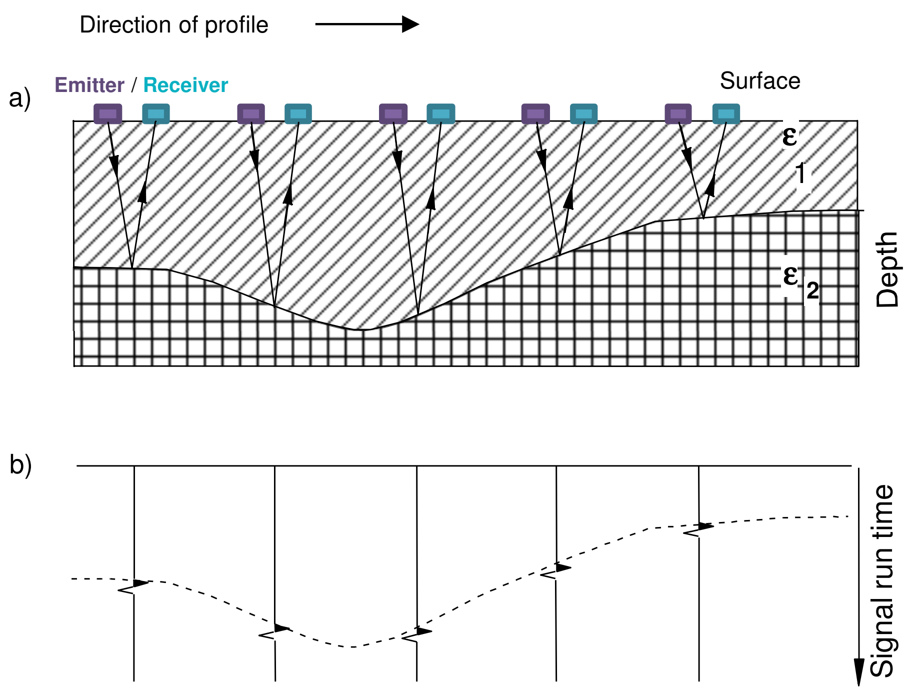
How to assess the state and schedule renewal

IN-SITU BALLAST CONDITION ASSESSMENT

- Visual inspection
- Trial pits
- Ground Penetrating Radar

Photos: Piereder F. and GroundControl

Ground Penetrating Radar



- electromagnetic pulses
- frequency range 10 MHz to 2.6 GHz
- part of signal is reflected at interfaces between layers with different different dielectric constant (ε)
- Knowing the speed of the waves in the individual layers, layer thicknesses can be calculated

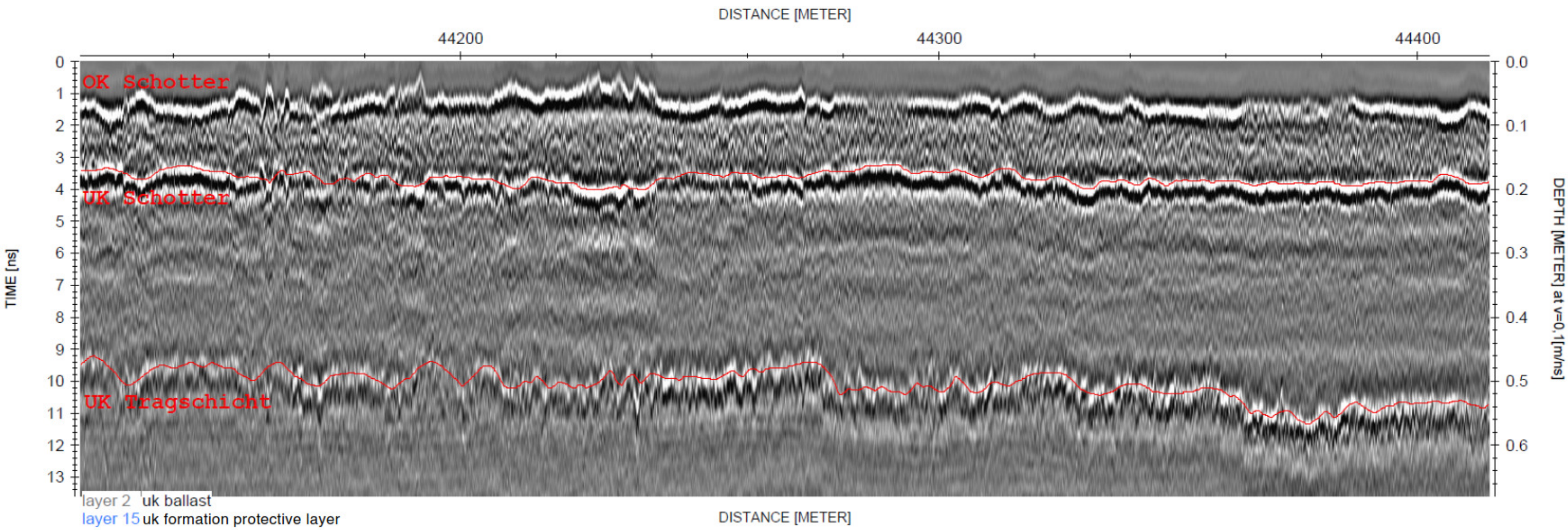
GPR used to determine BFI

Material (* by Volume)	Source	ε_r	Velocity [m/s]
Air	(Clark M. , 2001)	1,0	$3.00x10^8$
Dry Clean Ballast	(Clark M. , 2001)	**3,0**	**$1.73 x10^8$**
Wet Clean Ballast (5% water*)	(Clark M. , 2001)	3,5	$1.60 x10^8$
Dry Clean	(Sussmann, 1999)	3,6	$1.58 x10^8$
Dry Spent	(Sussmann, 1999)	3,7	$1.56 x10^8$
Moist Clean	(Sussmann, 1999)	**4,0**	**$1.50 x10^8$**
Dry Spent Ballast	(Clark M. , 2001)	4,3	$1.45 x10^8$
Moist Spent	(Sussmann, 1999)	5,1	$1.32 x10^8$
Wet Spent	(Sussmann, 1999)	7,2	$1.12 x10^8$
Wet Spent Ballast (5% water*)	(Clark M. , 2001)	7,8	$1.07 x10^8$
Saturated Clean Ballast	(Clark M. , 2001)	26,9	$0.48 x10^8$
Saturated Spent Ballast	*(Clark M. , 2001)*	***38,5***	***$0.58 x10^8$***
Water		81	$0.33 x10^8$

Source: reproduced from Clark M., Non-destructive and Geotechnical Testing of Railway Track Bed Ballast, Ph.D. thesis (2001)

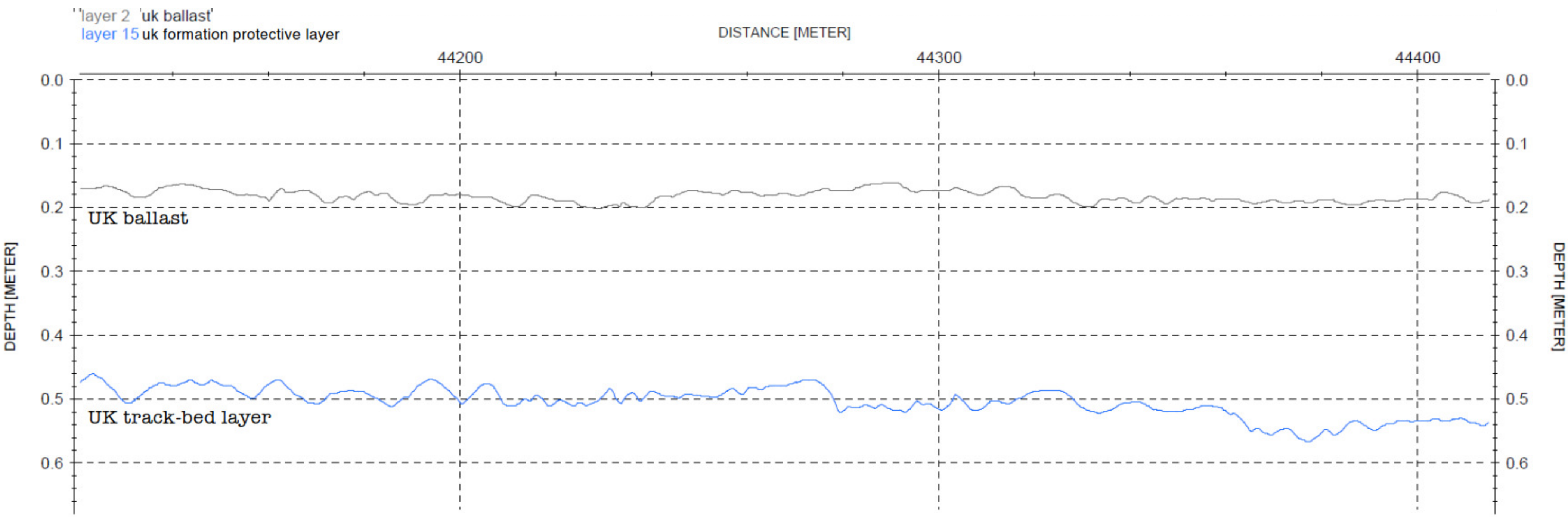
- Clean ballast → higher volume of voids →lowers the average dielectric constant → increases the transmission speed
- Moisture → increasing the average dielectric constant → reducing the transmission speed
- ***Fouled ballast*** → higher quantity of fines can hold more water → *even lower transmission speed*

GPR – distinguish layers



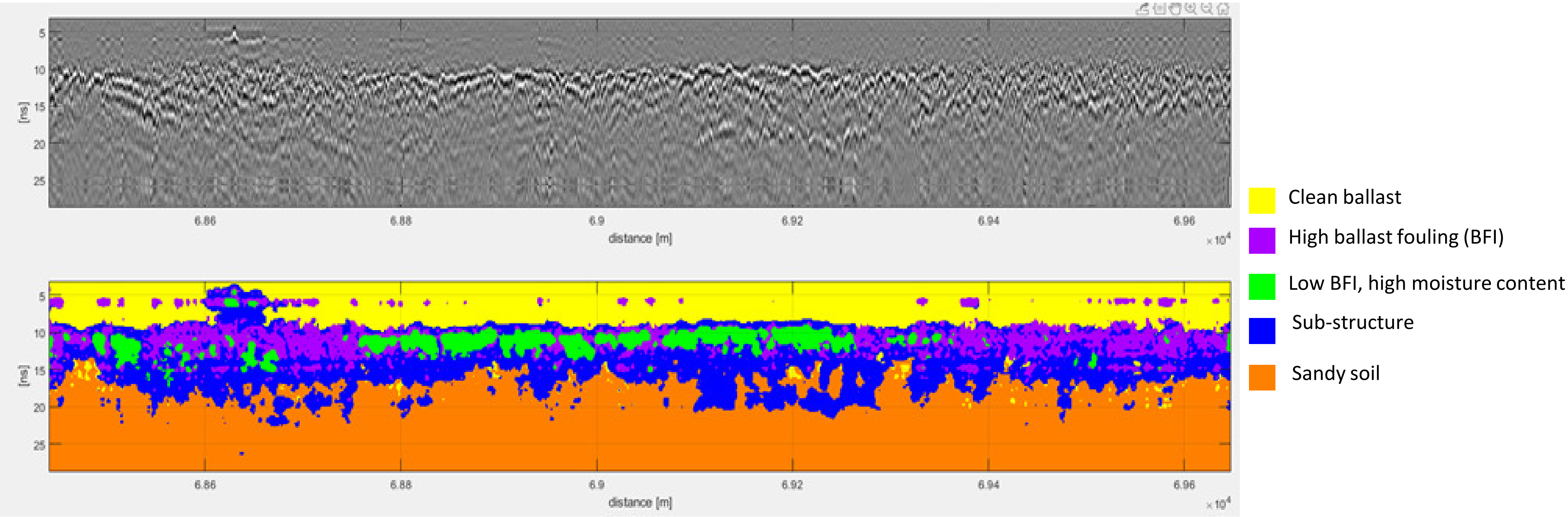
Source: GroundControl (https://saferailsystem.com/)

GPR – distinguish layers



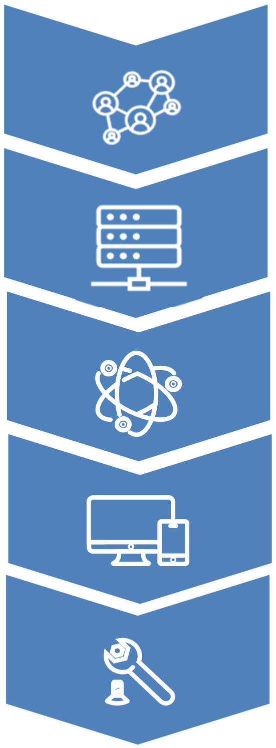
Source: GroundControl (https://saferailsystem.com/)

AI-based Fouling Index

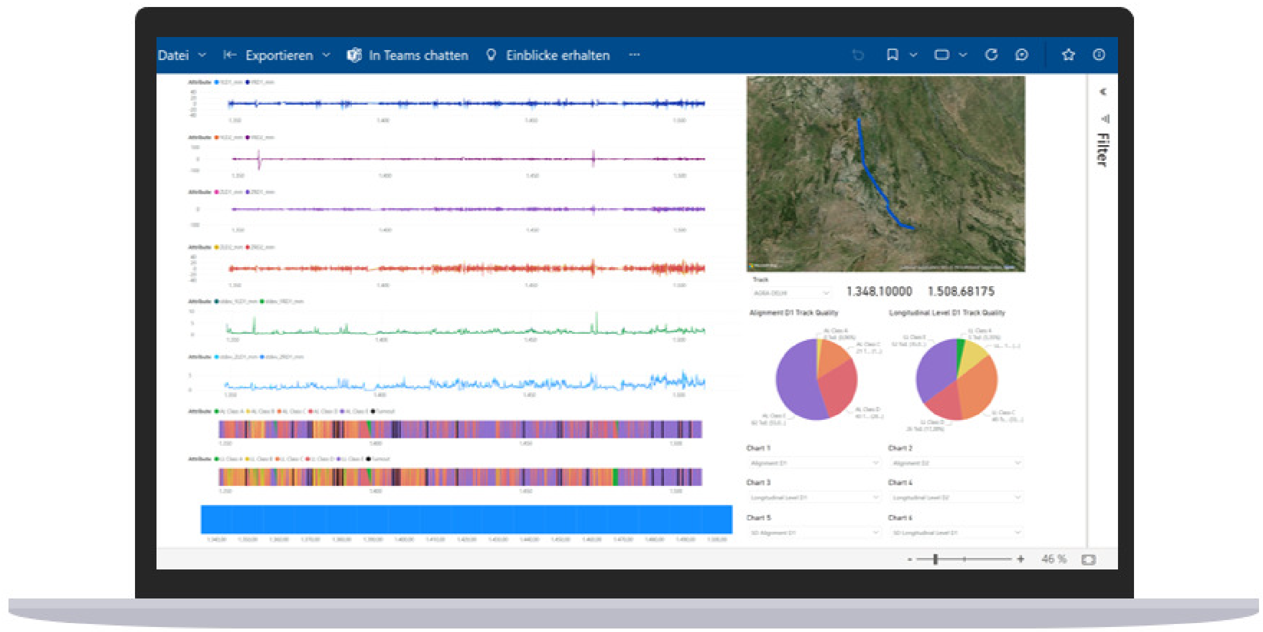


Source: GroundControl (https://saferailsystem.com/)

KPI dashboards for renewal plans



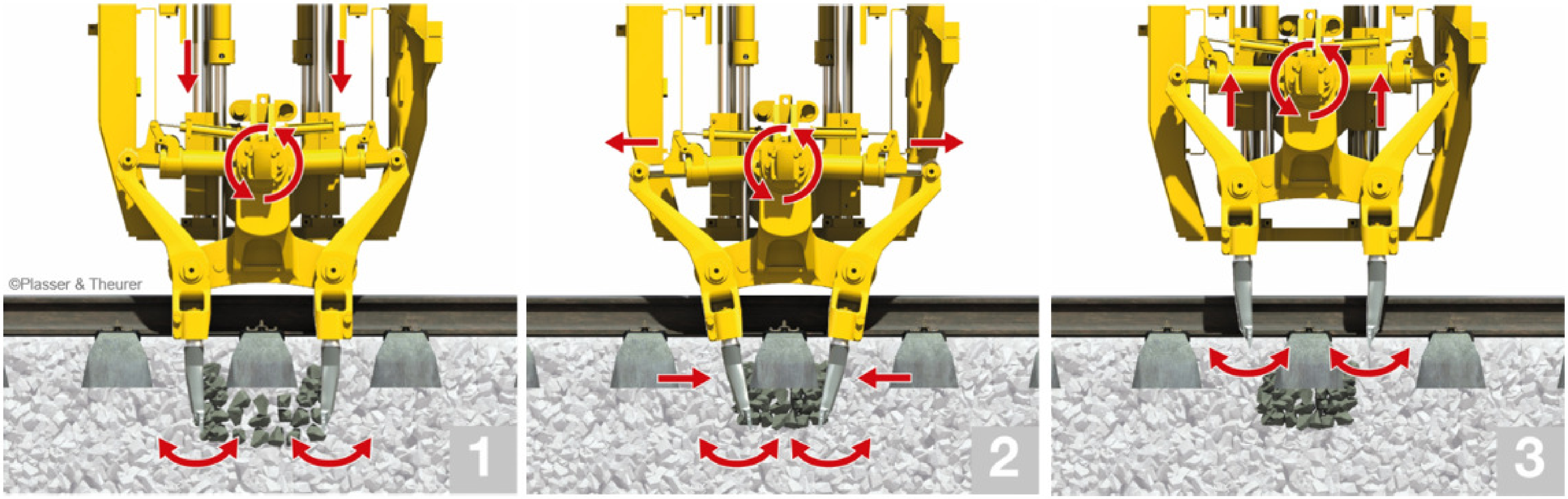
- gathering information
- managing information
- analytics
- visualization
- actions



Applied technologies and machinery

BALLAST TAMPING PRINCIPLES

Phases of the tamping process



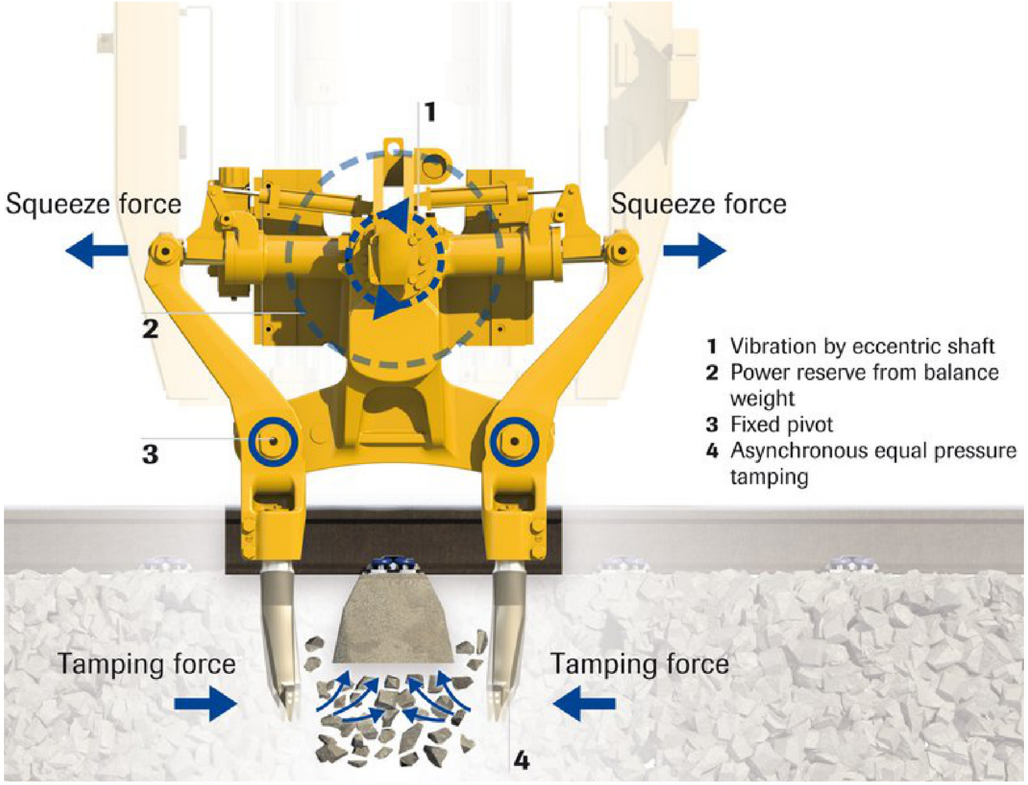
Ballast penetration | Squeezing movement | Lifting tamping unit

Source: www.plassertheurer.com

Basic tamping principles

Non synchronous tamping

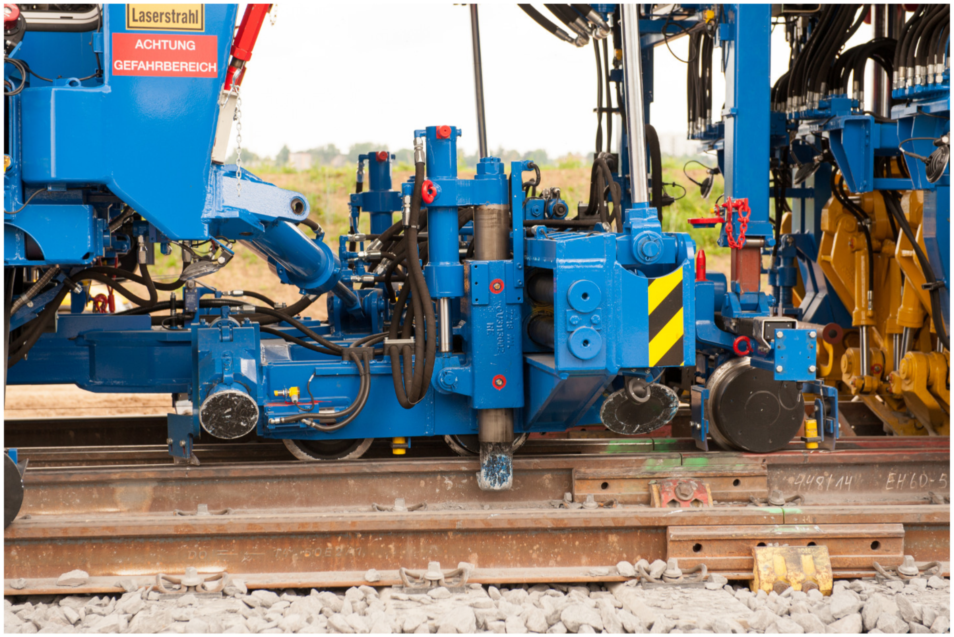
- vibrate with the ideal frequency of 35 Hz
- constant pressure (all tamping tines work with the same pressure)
- squeezing motion towards the sleeper
- amplitude 0,16 to 0,2 inches



Source: www.plassertheurer.com; Dama N.: Discrete Element Modeling of Railway Ballast for Studying Railroad Tamping Operation, MSc Thesis, Virginia Polytechnic Inst.

Lifting & levelling

(a) Roll lifting clamps and double-flange lining rollers of a plane tamping machine

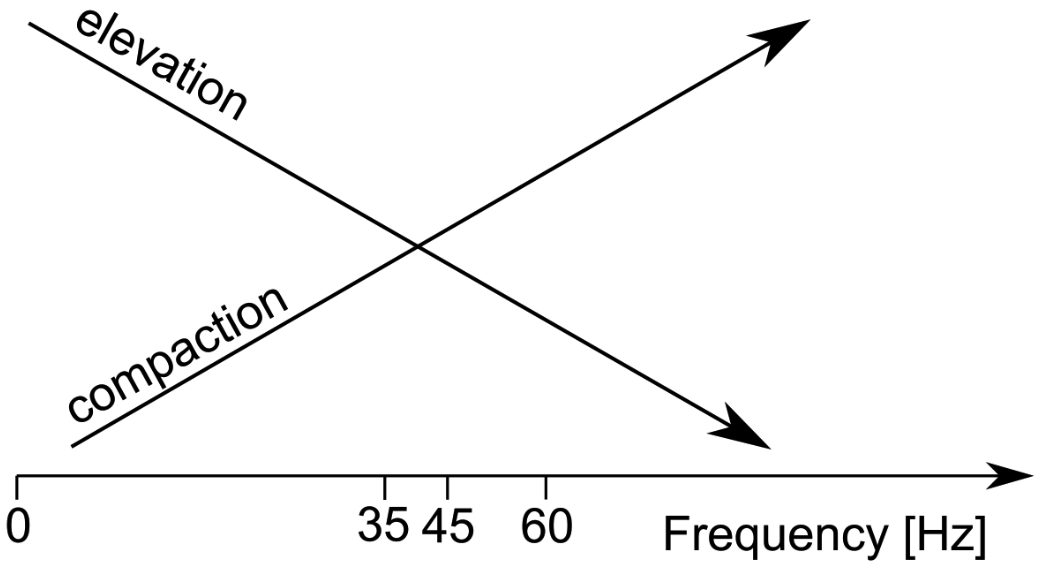


(b) Roller lifting clamps with lifting hooks and lining rollers for universal use in turnouts

Types of machinery

Source: Harsco

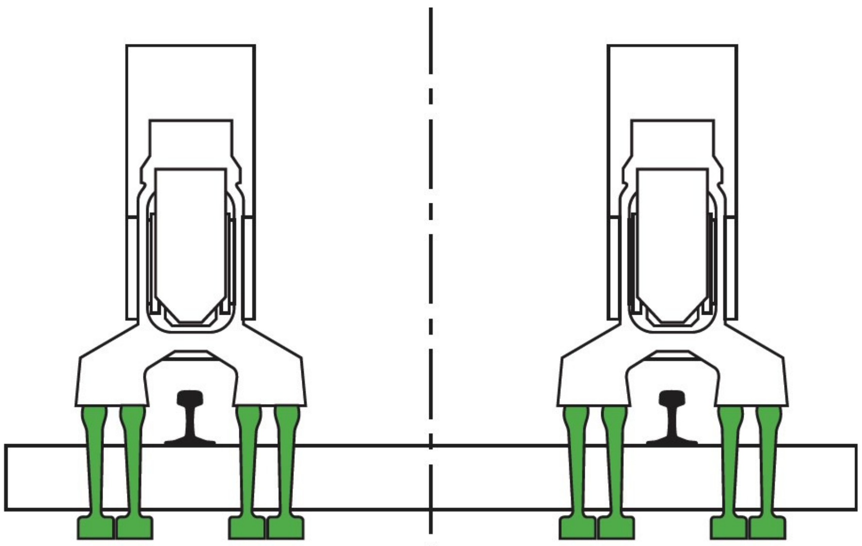
Tamping parameters



Source: reproduced from Fischer J., Ph.D. thesis TU Graz (1983)

- **Excitation frequency and amplitude**
  - 30 - 35 Hz ideal
  - Frequency levels of 40 Hz and higher trigger uncontrollable ballast movement
  - oscillation amplitude of 0,16 to 0,2 inches

Tamping parameters (2)



Source: Nemetz, W., Hansmann, F.: Keeping track of track geometry

- **Penetration depth**
  - top of tine plate ~1 inch below bottom of tie
- **Lifting values**
  - minimum lift 0,8 inches
- **Squeezing pressure, velocity and duration**

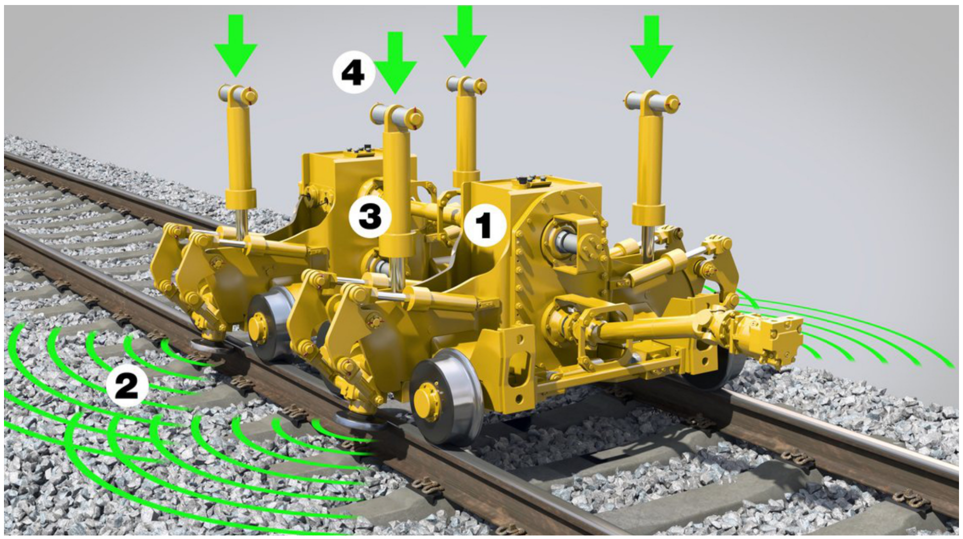
Dynamic track stabilization (DTS)

Source: www.plassertheurer.com

Source: www.harsco.com

- First machine in 1974
- inducing horizontal vibrations
- in combination with static vertical pressure

DTS – technical parameters

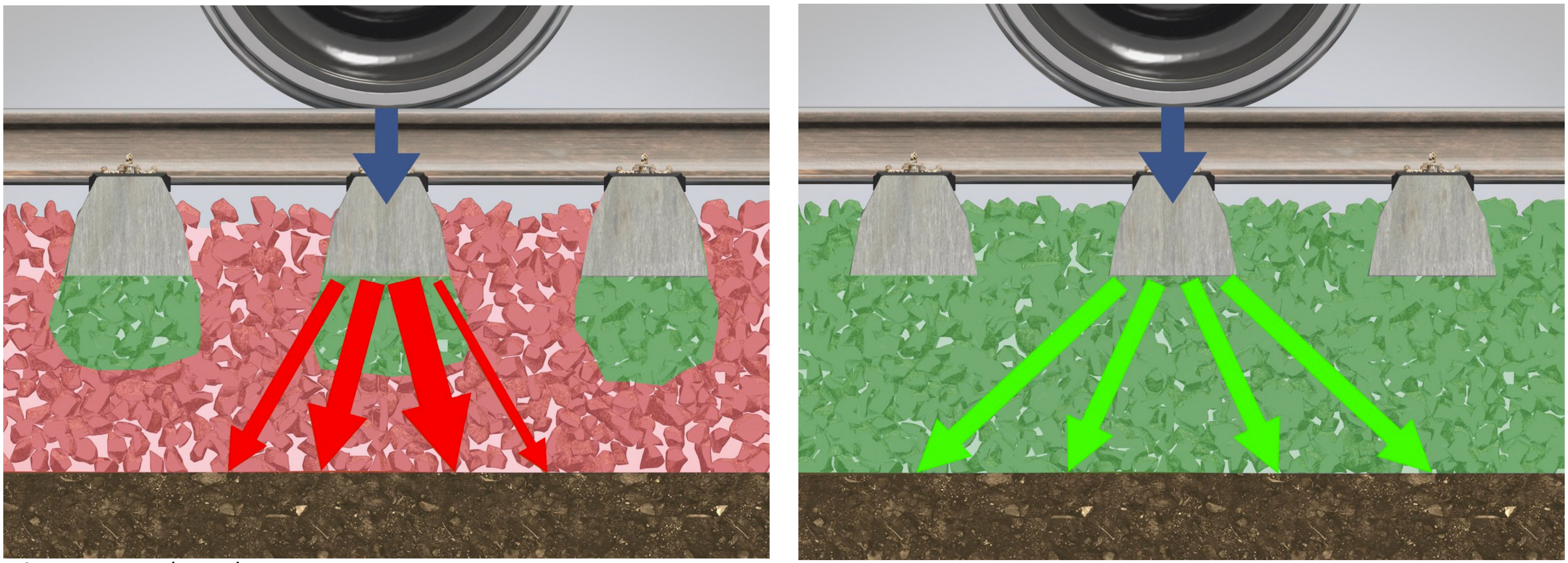


(1) variable unbalance, (2) induced horizontal vibrations, (3) hydraulic cylinder, (4) vertical load

Source: www.plassertheurer.com

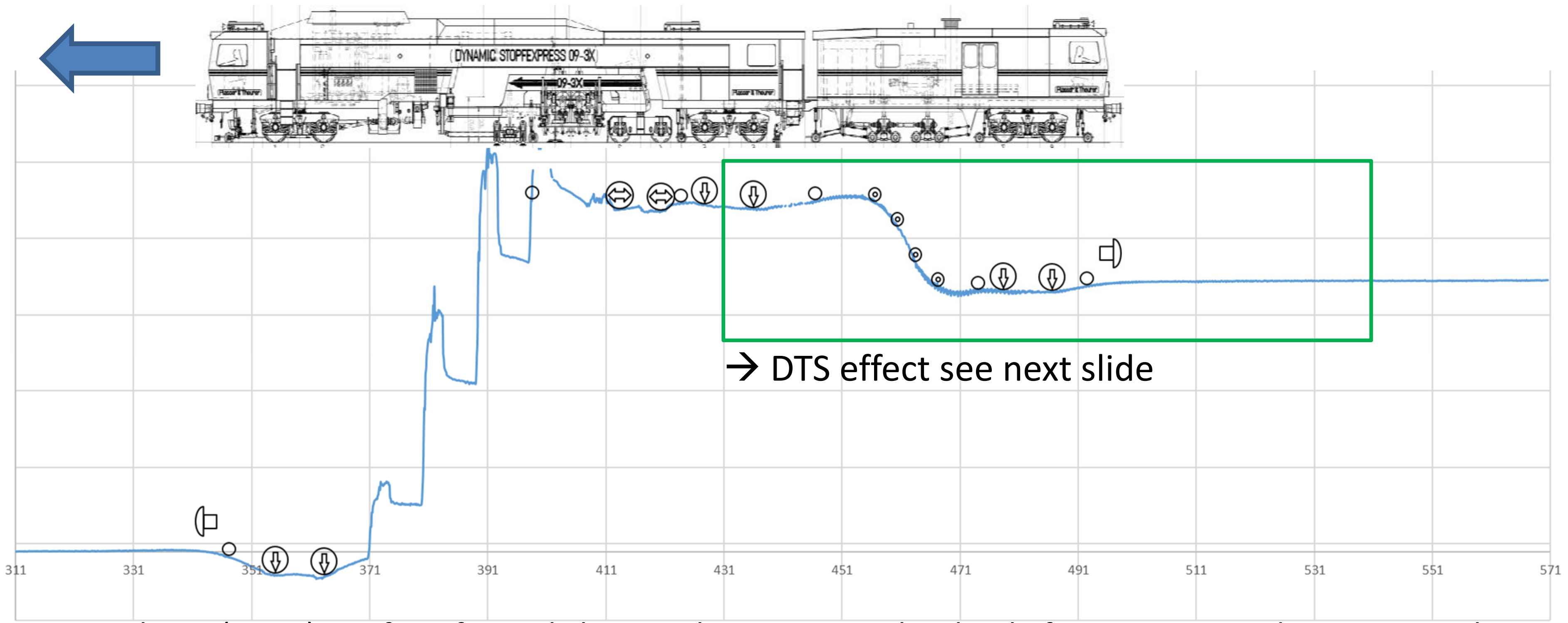
- vibration frequency (0-42 Hz)
- frequency dependent impact force F_{dyn}
- vertical load (max. 356 kN)
- working speed (approx. 0.1 mph and 1.6 mph)

Dynamic track stabilization (DTS)



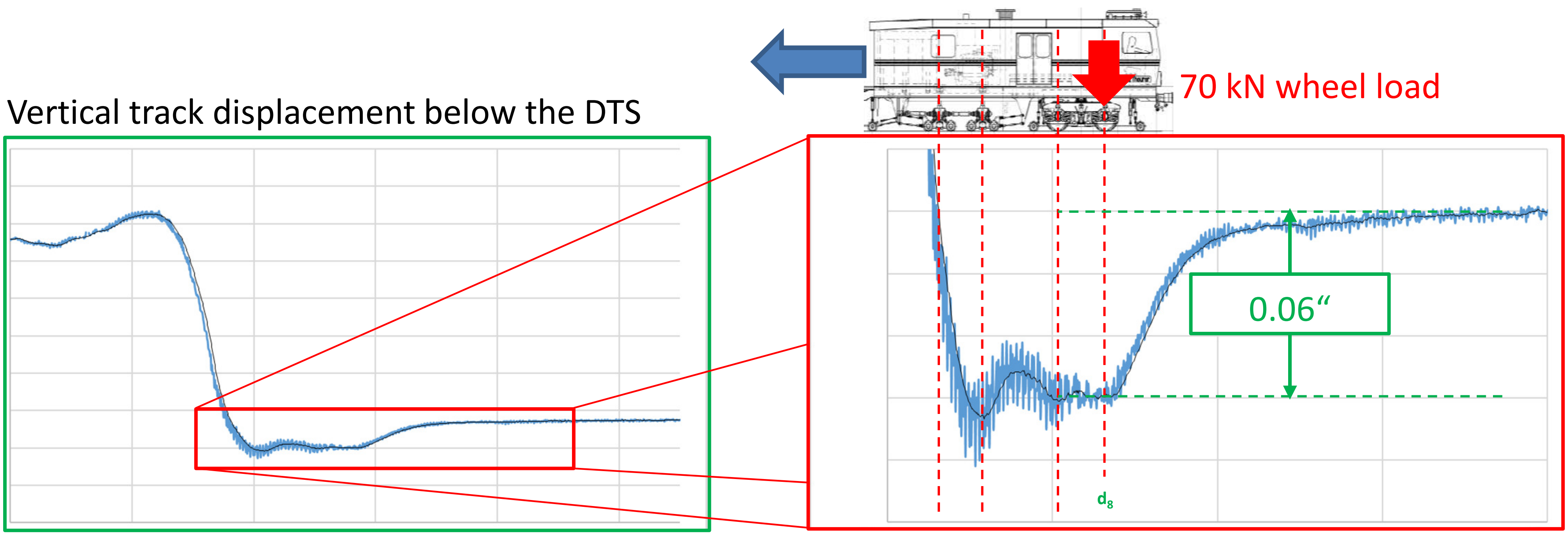
Source: www.plassertheurer.com

Lifting by tamping / compaction by DTS



Source: Pittrich, M. (M.Sc.); Prüfamt für Verkehrswegebau, TU Munich School of Engineering and Design: „Application of innovative camera systems for measurements on track infrastructure"; ÖVG Track Conference, Salzburg Austria (05/2022)

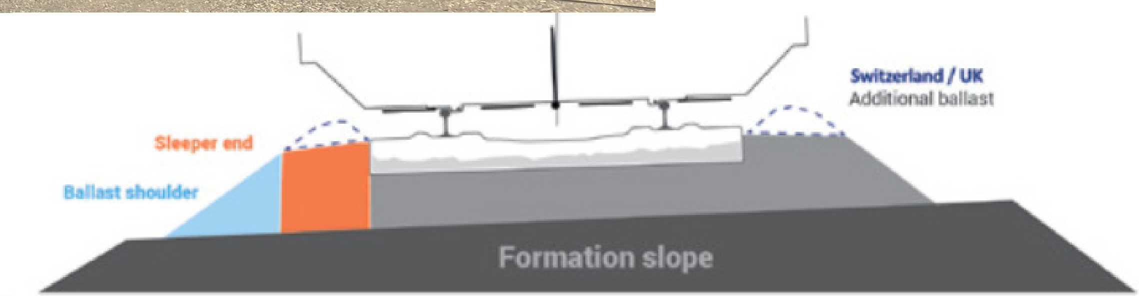
Detail on DTS behaviour



Source: Pittrich, M. (M.Sc.); Prüfamt für Verkehrswegebau, TU Munich School of Engineering and Design: „Application of innovative camera systems for measurements on track infrastructure”; ÖVG Track Conference, Salzburg Austria (05/2022)

Ballast regulators

Source: Knox Kershaw



Want to know more?