INNOTRACK
Innovative Track Systems

Corrugation, squats, insulated joints – maintenance limits

Anders Ekberg
Chalmers

Sixth Framework Programme

Background

Details on the presented work is available in INNOTRACK deliverables:

- **D4.2.3** – Improved model for loading and subsequent deterioration of insulated joints
- **D4.2.4** – Improved model for loading and subsequent deterioration due to squats and corrugation

Main results and recommendations for implementation compiled in:

- **D4.2.6** – Recommendation of, and scientific basis for minimum action rules and maintenance limits

Corrugation

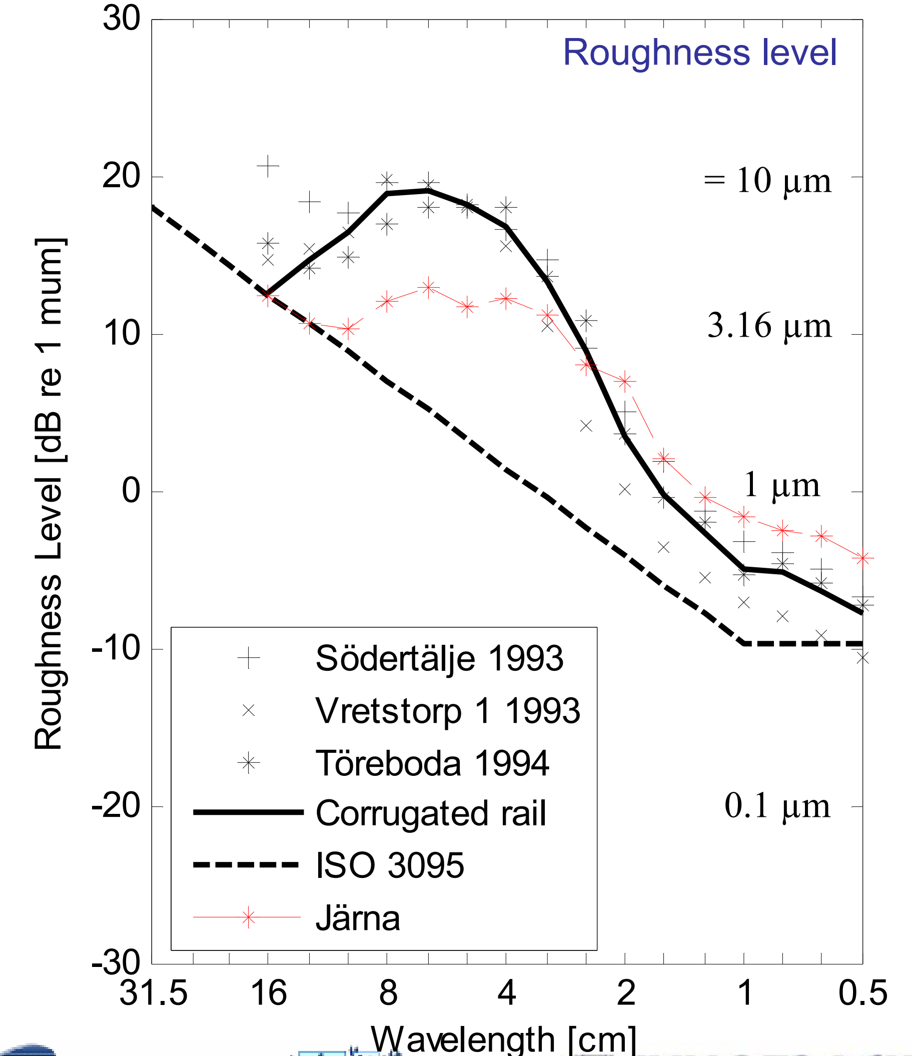
- Small amplitude undulations (roughness, waviness)
- Broad spectrum of wavelengths gives a broadband relative displacement excitation
- Inducing high-frequency wheel–rail contact forces, vibrations and rolling noise
- In severe cases, may cause further degradation of wheels and rails in the form of deep shelling or sub-surface initiated rolling contact fatigue

Rail corrugation and roughness level

- Three test sites with severe rail corrugation on the line Stockholm – Gothenburg
- Roughness level spectra from Corrugation Analysis Trolley measurements
- Roughness level evaluated in 1/3 octave bands and averaged

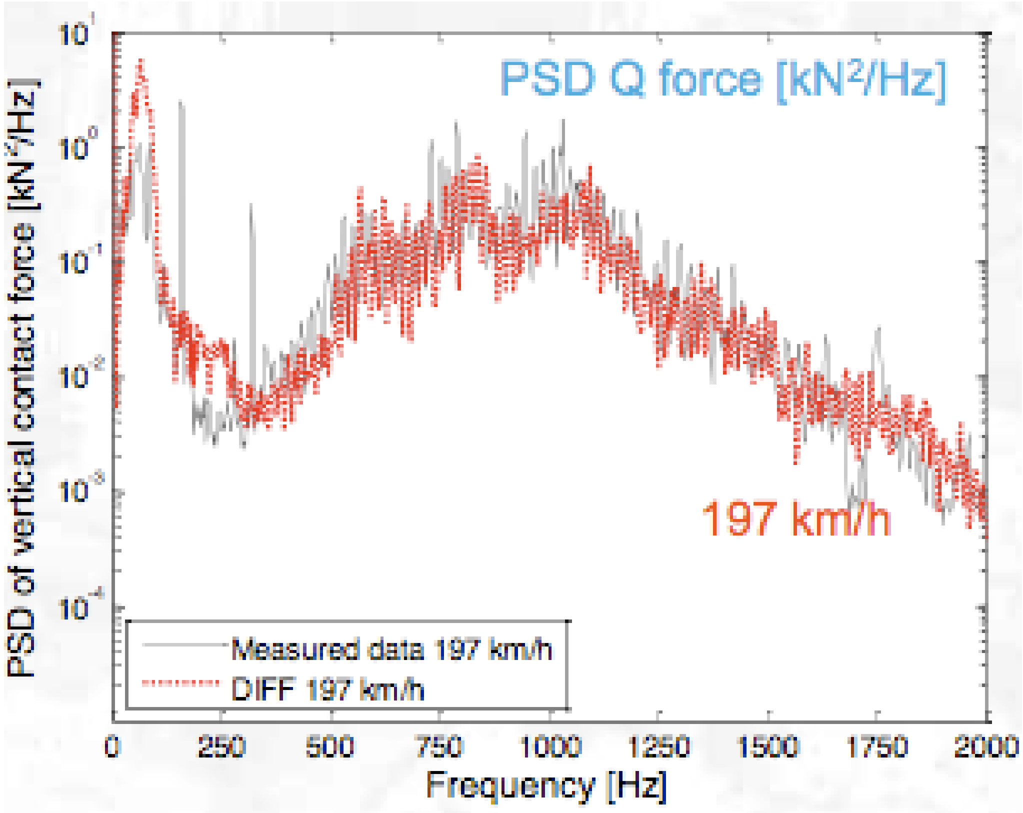
$$L_{\mathrm{r,3-8cm}} = 20\log_{10}\left(\frac{\tilde{r}_{\mathrm{mean,3-8cm}}}{r_{\mathrm{ref}}}\right)$$

$$[\mathrm{dB}, r_{\mathrm{ref}} = 1\mu\mathrm{m}]$$



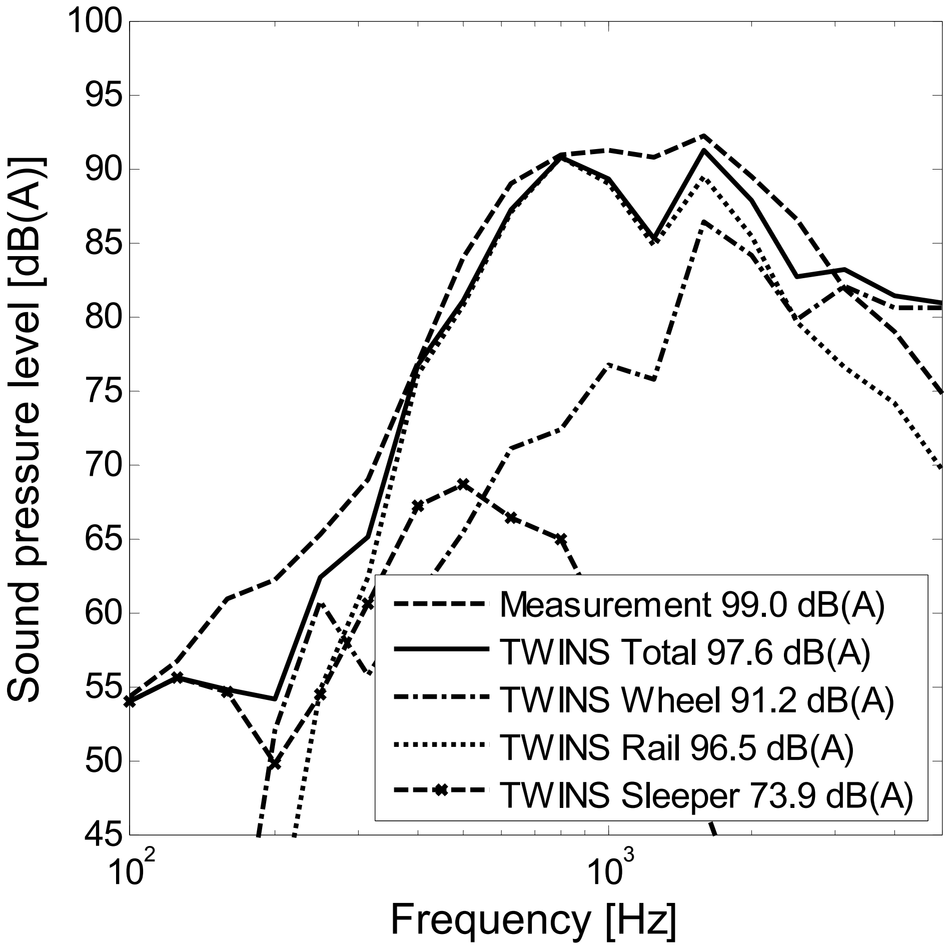
Validation of numerical simulations of contact force

- Power Spectral Density of measured and calculated vertical contact forces
- Simulation along 100 sleeper bays with irregularity containing wavelengths in interval 2-250 cm
- Good agreement for most frequencies



Validation of TWINS

- Measured and calculated sound pressure level at 7.5 m from track centre
- Freight traffic at 100 km/h
- Low rail roughness, moderately exceeding ISO 3095 spectrum
- Good agreement for most frequencies up to 5 kHz



Subsurface initiated RCF

- RCF is predicted if FI_{sub} exceeds the material's fatigue limit in shear (reduced due to occurrence of material defects)
- A reasonable reduced magnitude is 220 MPa

Deep shelling due to high vertical contact forces in combination with material defects

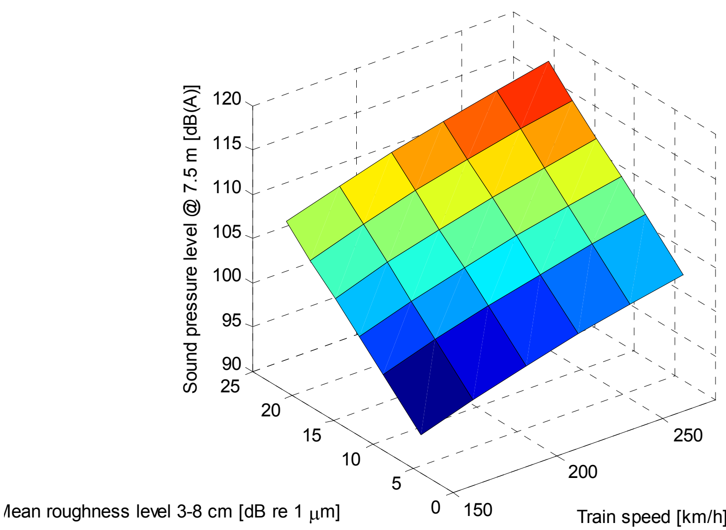
$$FI_{\mathrm{sub}} = \frac{F}{4\pi ab}(1+\mu^2) + a_{\mathrm{DV}}\,\sigma_{\mathrm{h,res}}$$

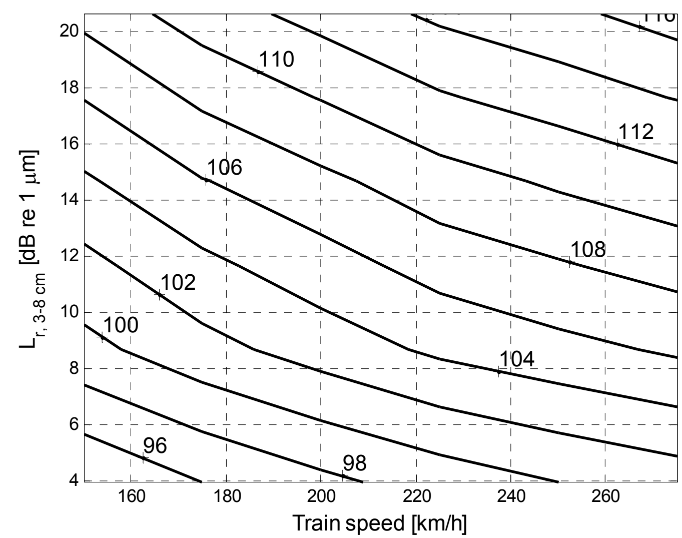
Sixth Framework Programme
INNOTRACK
Innovative Track Systems

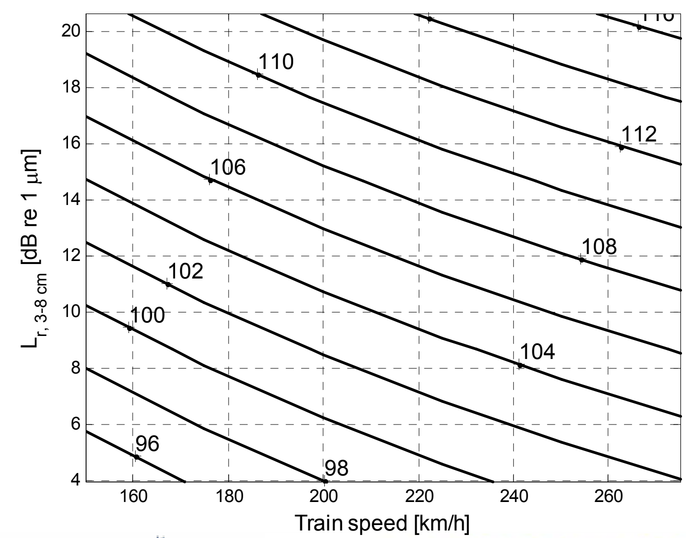
Example –
SPL from passenger vehicle

- Parametric study of influence of rail roughness spectrum on rolling noise
- Passenger vehicle, SPL @ 7.5 m
- Response surface model based on least square fitting

$$L_{\mathrm{p}}^{7.5\mathrm{m}} = 94.4 + 28.6 \log_{10}\left(\frac{v}{200}\right) + 0.9 L_{\mathrm{r},3-8\mathrm{cm}}$$





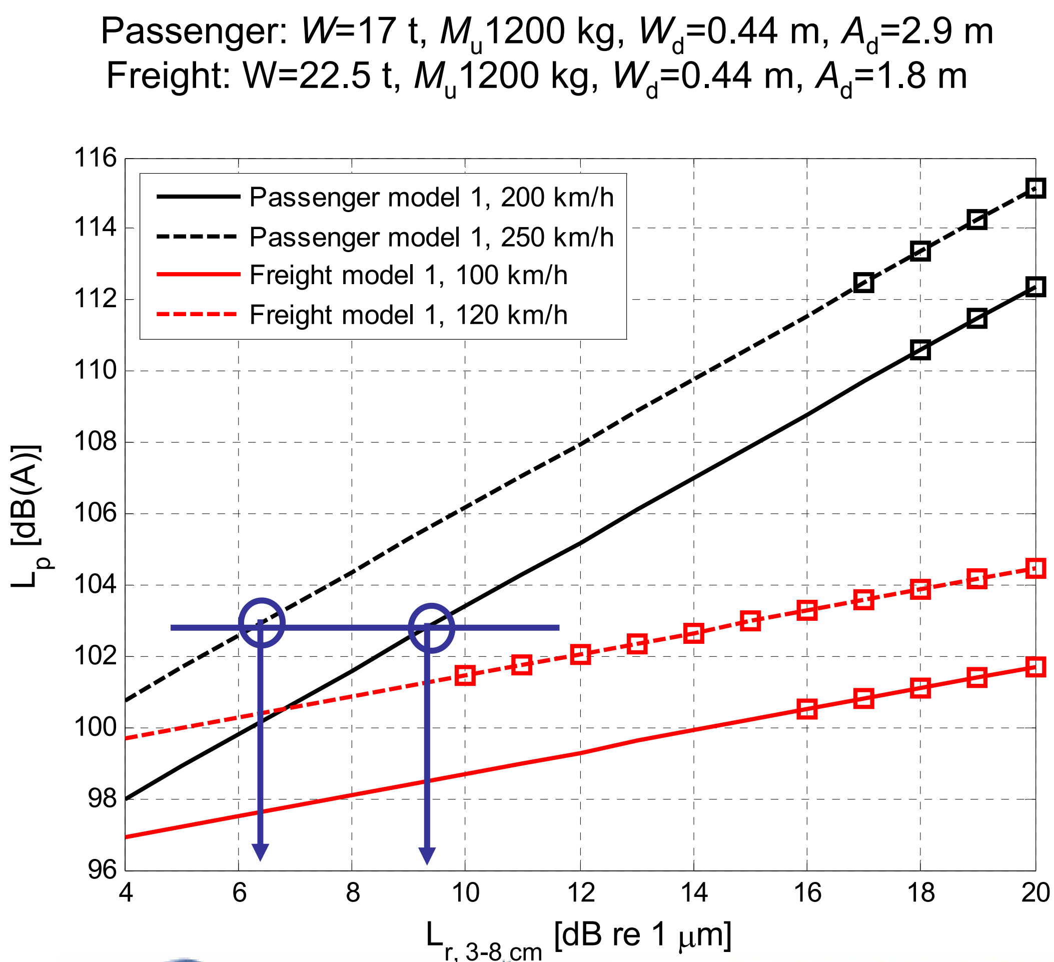


Sixth Framework Programme

INNOTRACK
Innovative Track Systems

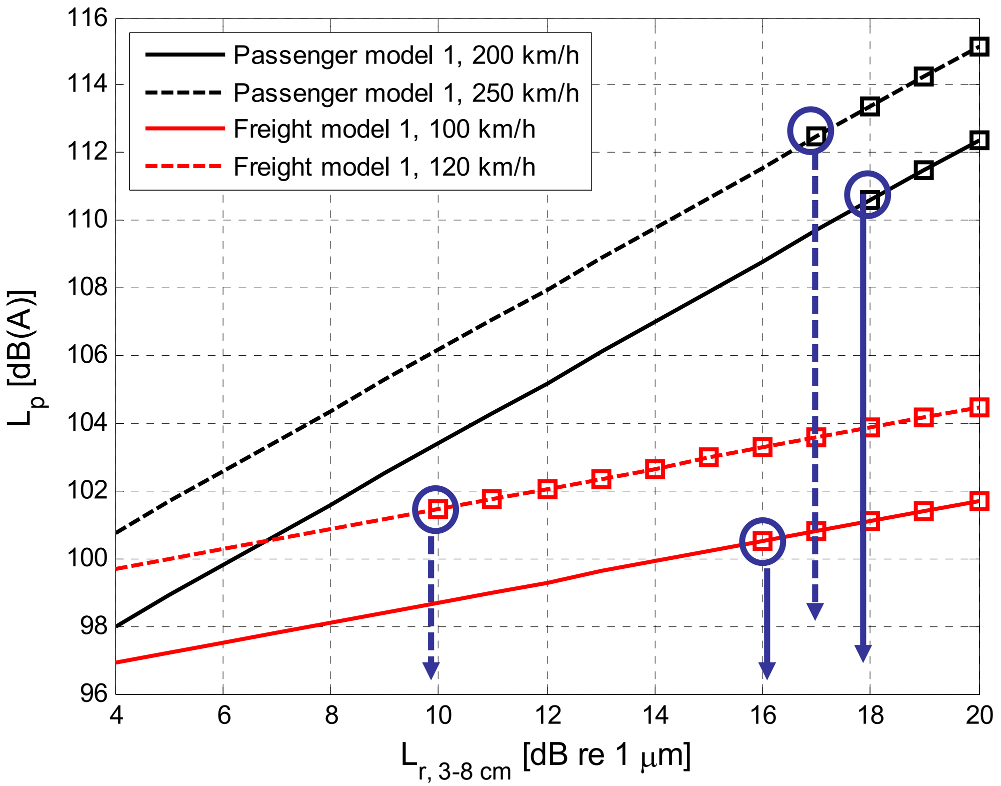
Establishing acceptance limits for corrugation

- For this example case the maximum rolling noise is generated by passenger traffic
- Assuming max allowed SPL at 7.5 as 103 dB(A), Lr,3-8cm < 10 dB can be accepted for 200 km/h
- For 250 km/h, Lr,3-8cm < 7 dB is needed

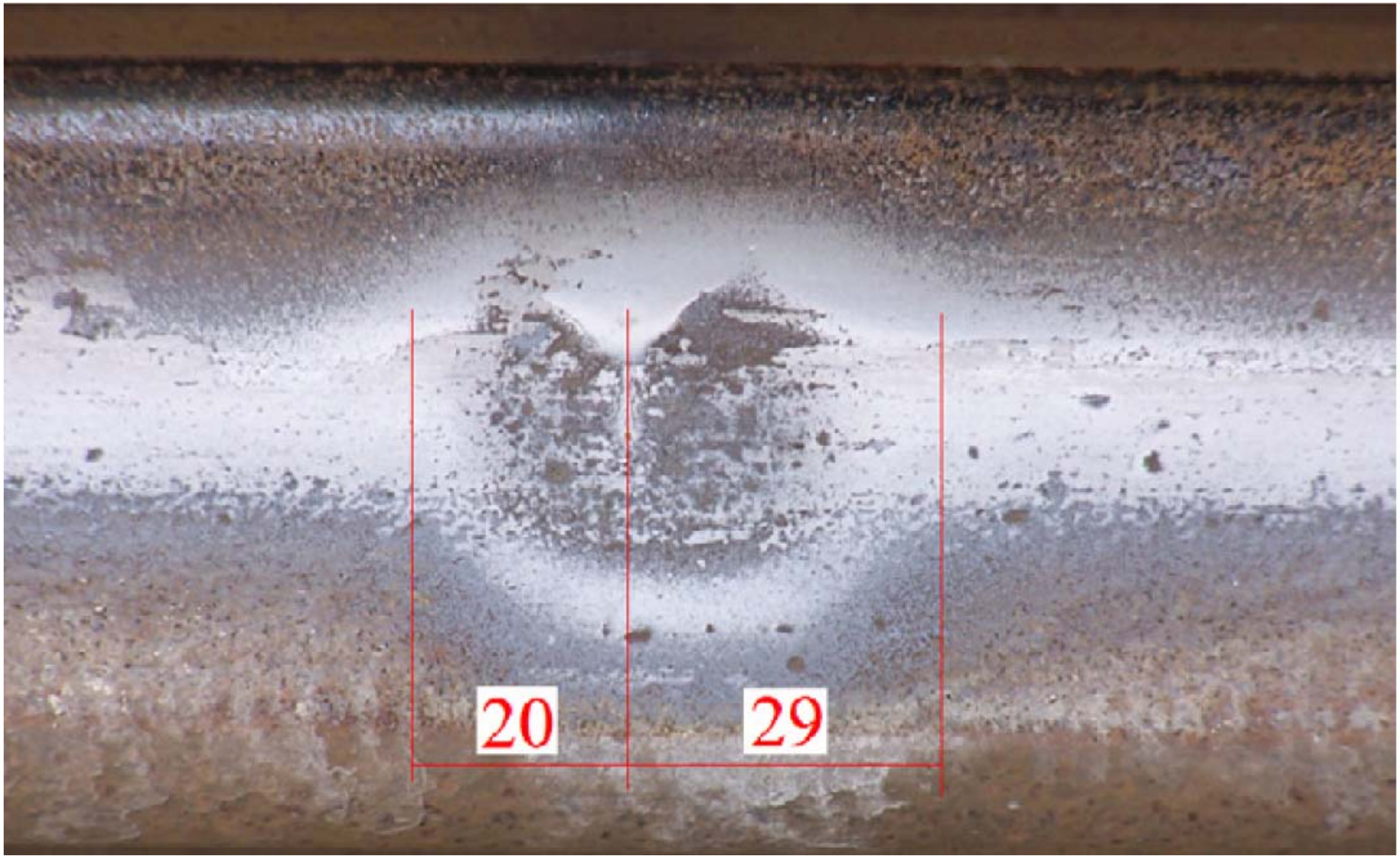


Establishing acceptance limits for corrugation

- To avoid subsurface initiated RCF for the reference case (200/100 km/h), rails need to be maintained such that $L_{r,3\text{-}8cm}$ < 16 dB
- To avoid subsurface initiated RCF with increased train speeds (250/120 km/h), rails need to be maintained such that $L_{r,3\text{-}8cm}$ < 10 dB



Squats



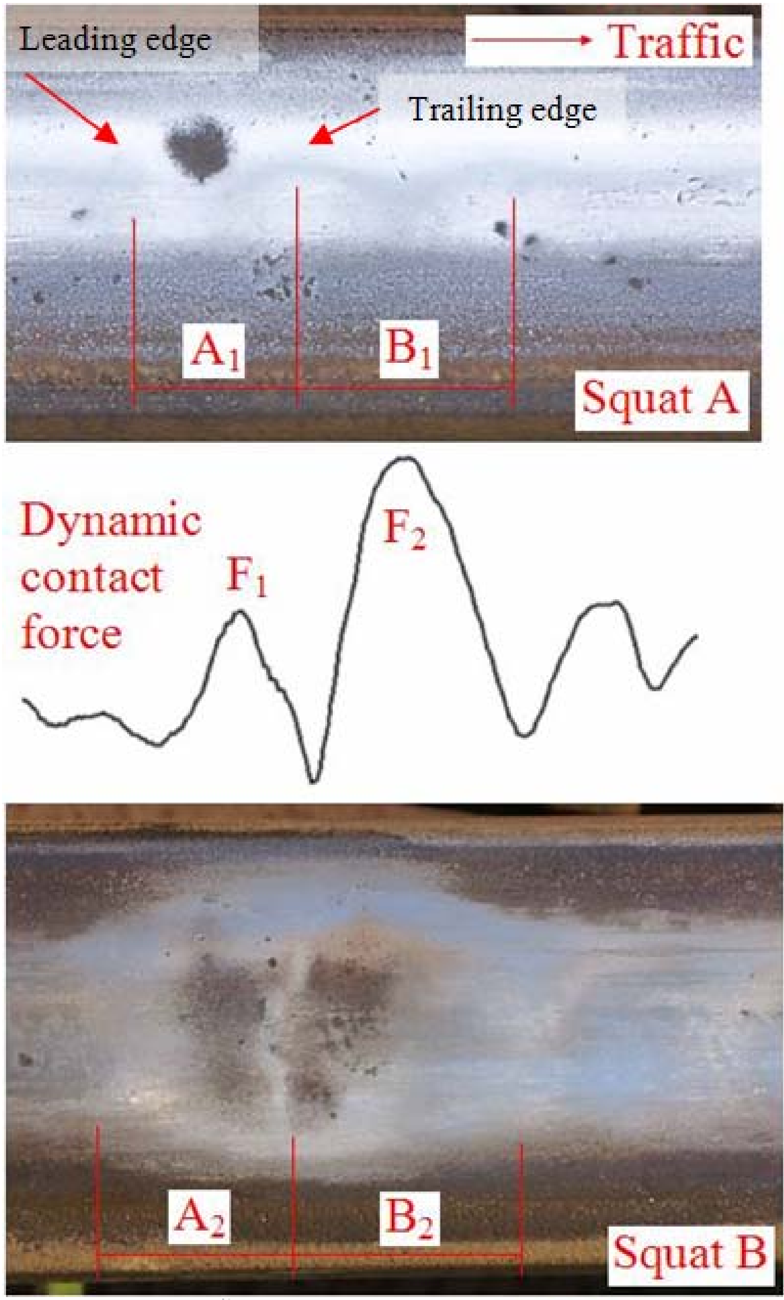
Major work items

- Characteristics of light/initiating squats?
- An initiation spot can basically be any rail top defects which causes ratcheting due to high frequency dynamic wheel-rail interaction (impact)
  - Indentation
  - Corrugation
  - Wheel burns

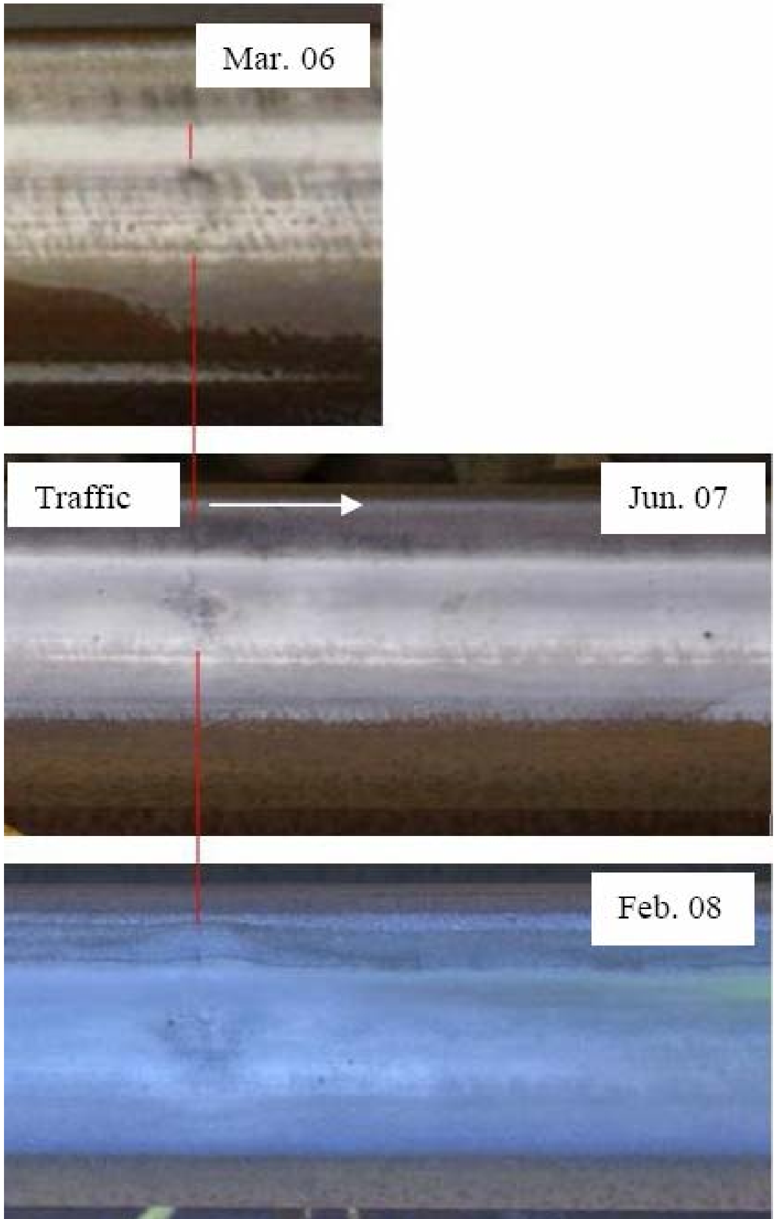
    etc
- How do light squats grow into matured?
- Is there a critical size?

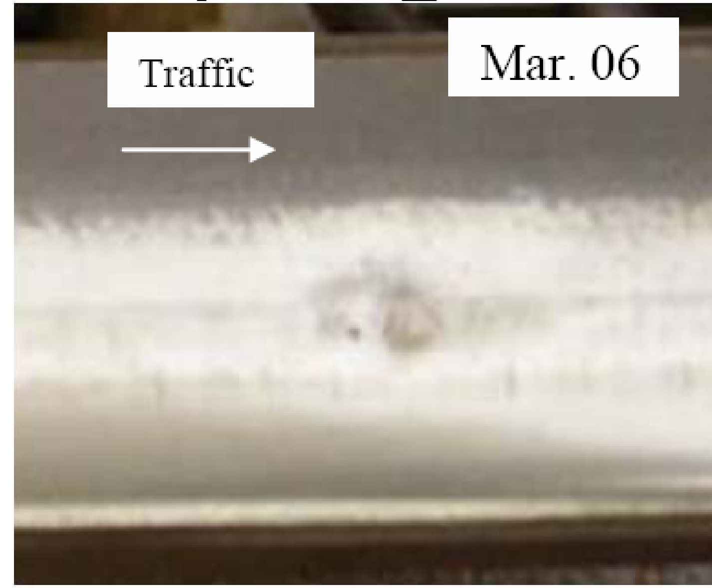
Growth process

- Wave length
- 2 lungs develop from the initial surface indentation
- There is a widening running band
- A W-shape is created in the longitudinal profile



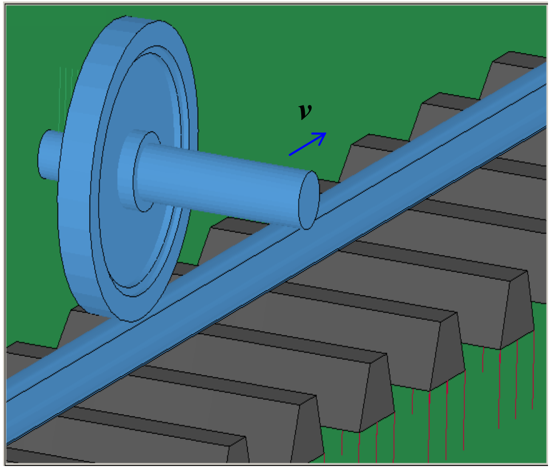
Field observations of squat growth

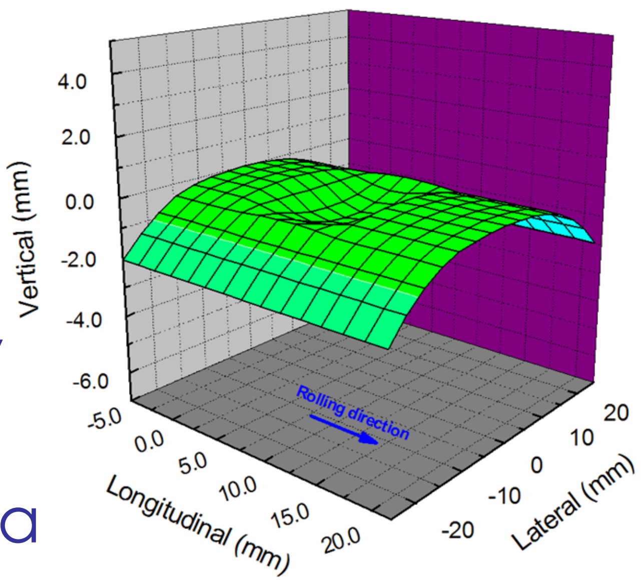




Major work items

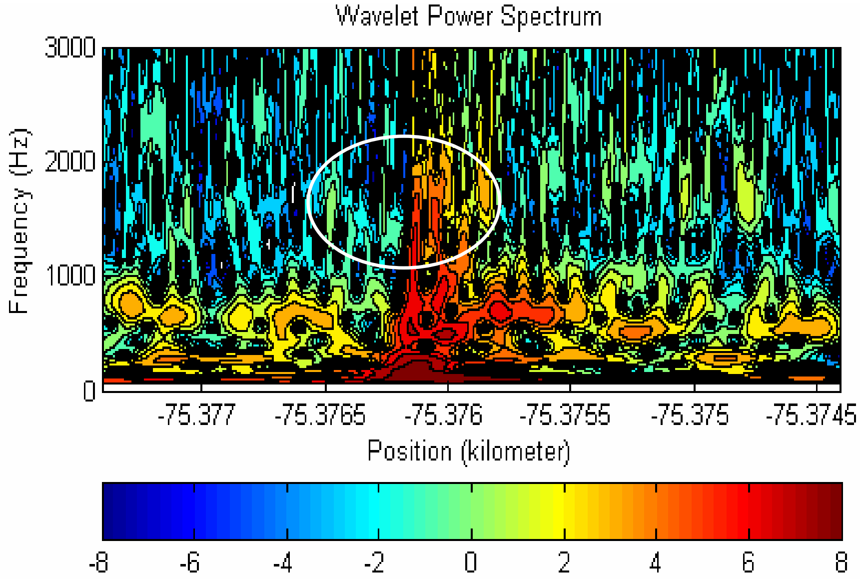
- Numerical simulations of squat
  - 3D frictional rolling contact
  - High frequency vehicle-track interaction
  - Validated towards CONTACT + Hertz solution
  - By monitoring + measurement e.g. of axle box acceleration
- Correlation to Corrugation
  - 33% of all squats are caused by corrugation
  - 41% of all squats are related to a wave pattern on the rail head





Detection of squats

- Detection of squats by instrumented wheels or axle boxes from wavelength/frequency characteristics

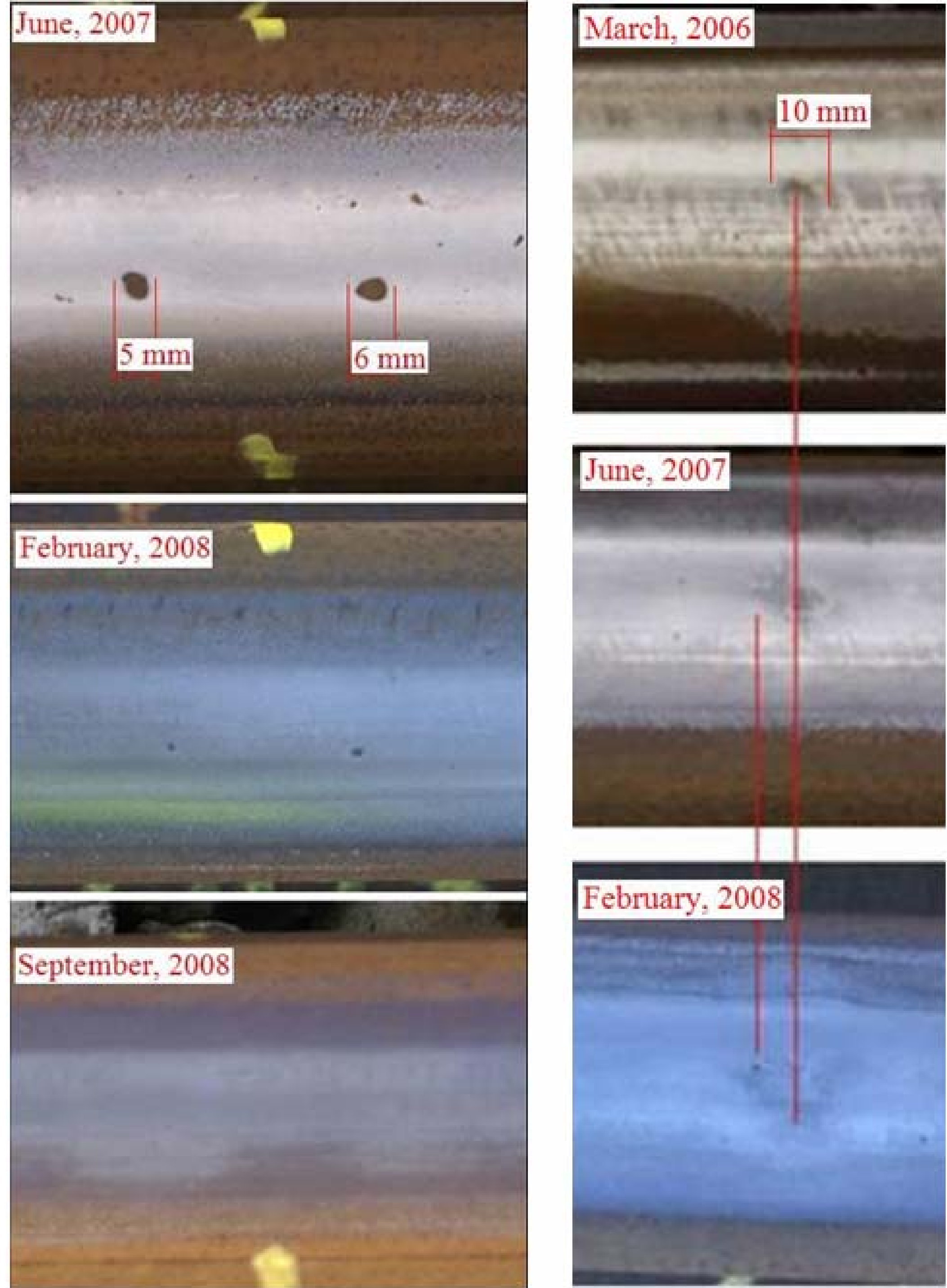


Sixth Framework Programme

INNOTRACK Innovative Track Systems

Critical size

- Which surface defects will propagate and form squats?
- On the Dutch tracks studied: Roughly 7 mm



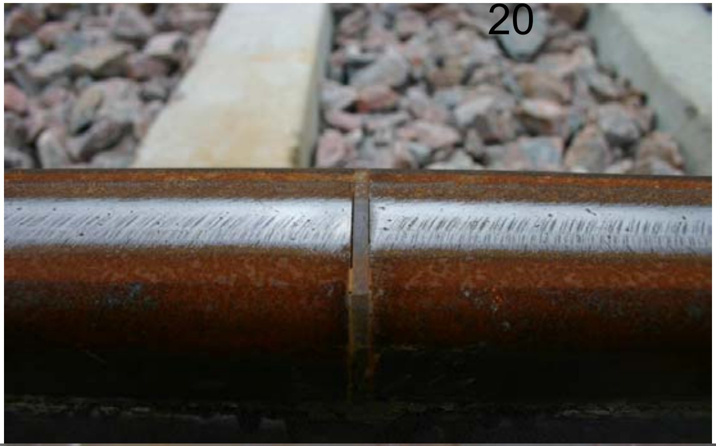
Insulating joints

Sixth Framework Programme

INNOTRACK
Innovative Track Systems

Insulating joints

- Contact load at joint negotiations
- Influence of joint gap, load magnitude *etc* on joint deterioration



2008-08-20

2009-02-20

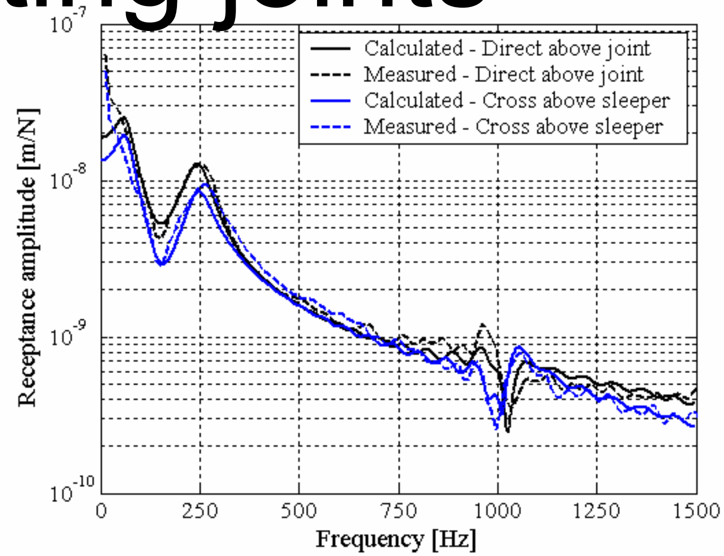
2008-06-11 (the week before the start of operational traffic, but after grinding)

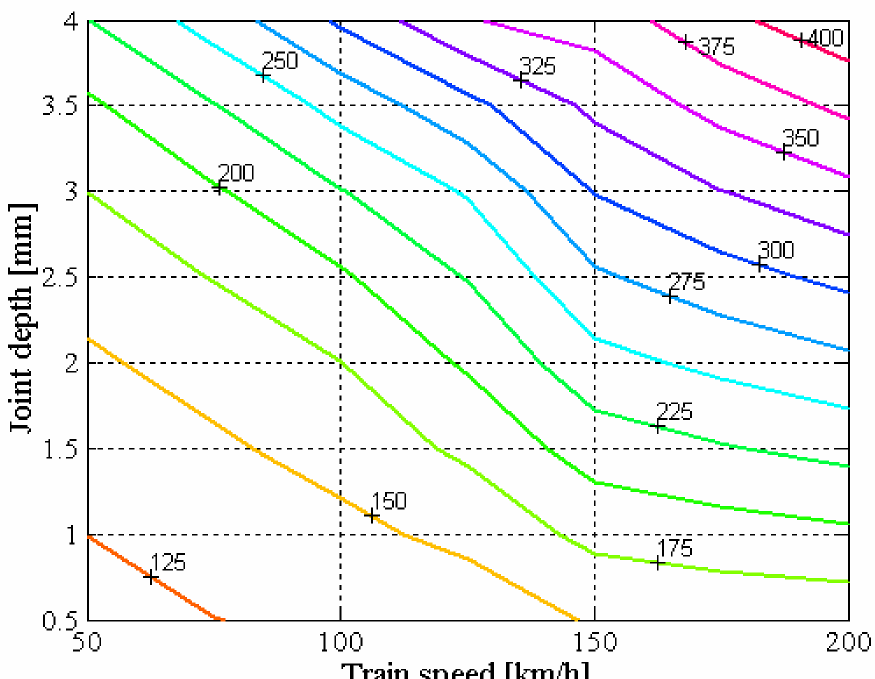
Sixth Framework Programme

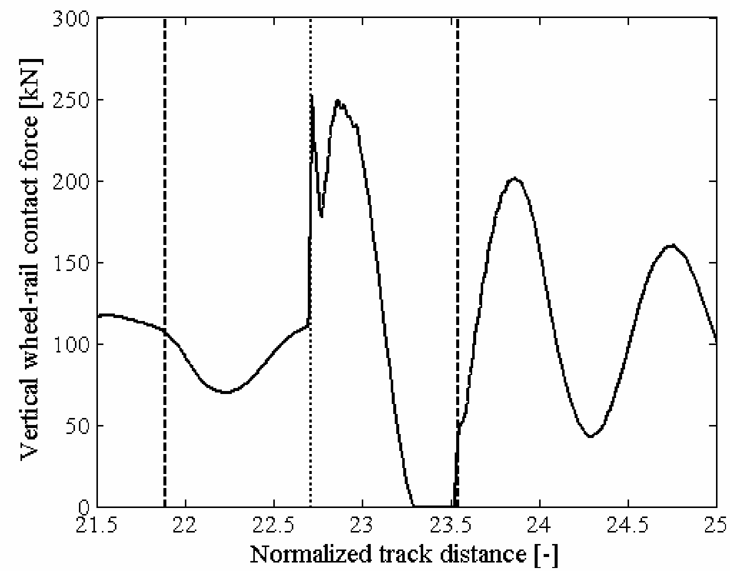
INNOTRACK Innovative Track Systems

Dipped insulating joints

- Simulation of dynamic wheel–rail interaction
- Calibration of receptance towards measurements and FE-simulations
- Accounting for track pre-loading





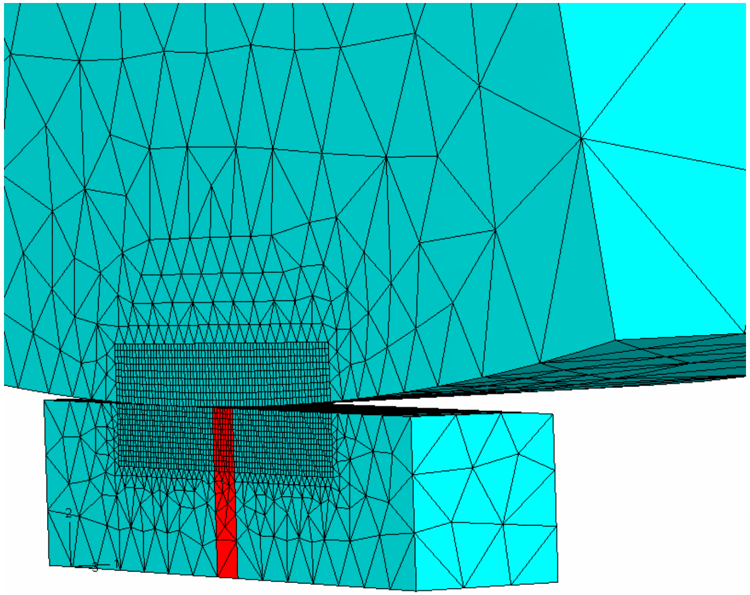


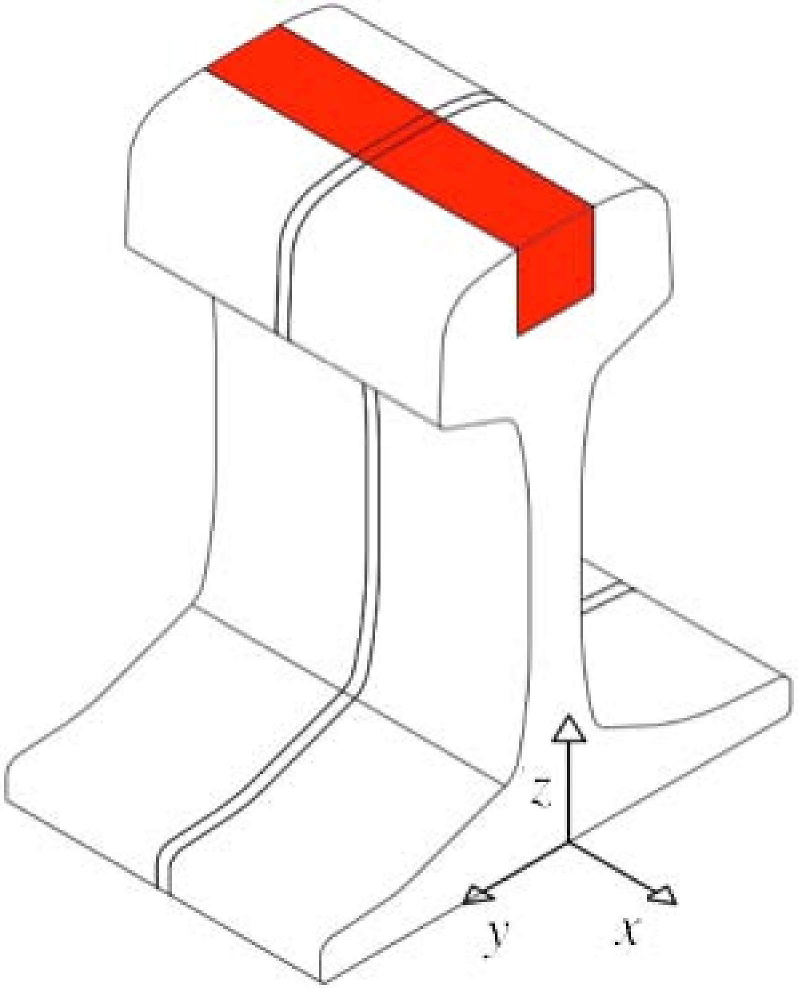
Sixth Framework Programme

INNOTRACK
Innovative Track Systems

Numerical model for analysis of plastic deformation

- Quasi-static simulation.
- Vertical load and rotational moment at the wheel center
- 4 Xeon 3GHz with 4GB memory used for every simulation.
- Calculation time between 16 hours to 5 days.



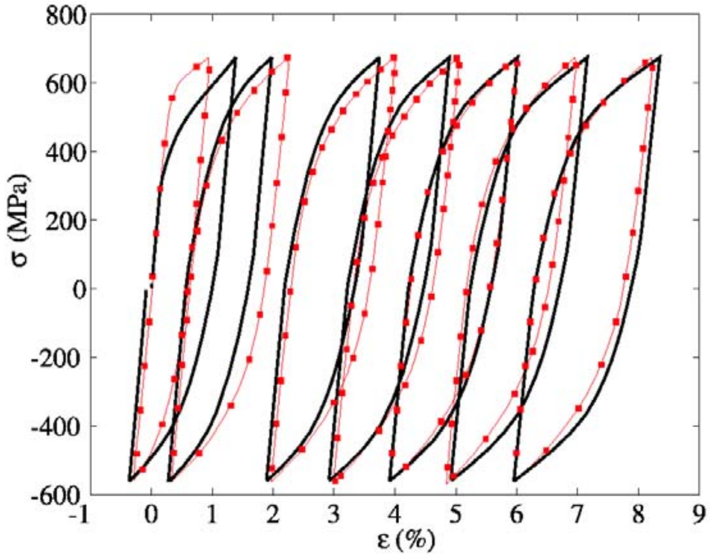


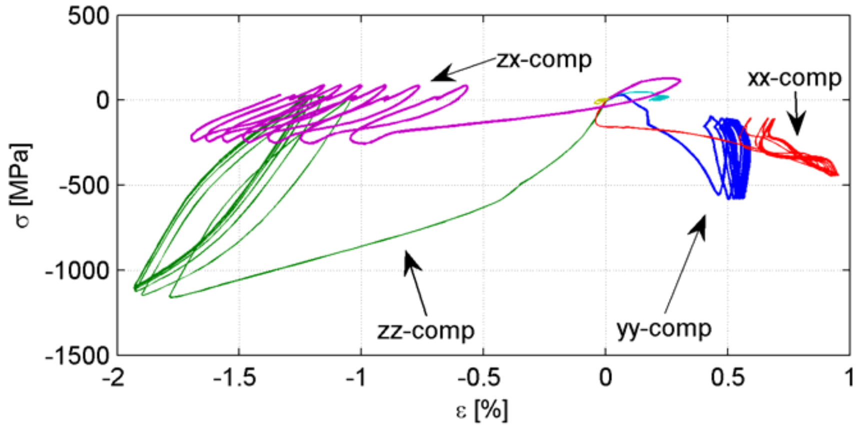
Sixth Framework Programme

INNOTRACK
Innovative Track Systems

Material model and stress–strain

- The material model needs to account for plastic deformation with non-linear hardening.
- Calibration towards tests (900A rail steel)
- The damaging stress–strain component at the joint is the shear component in the zx-direction
- This deformation corresponds to the roll-out and cracking





Sixth Framework Programme

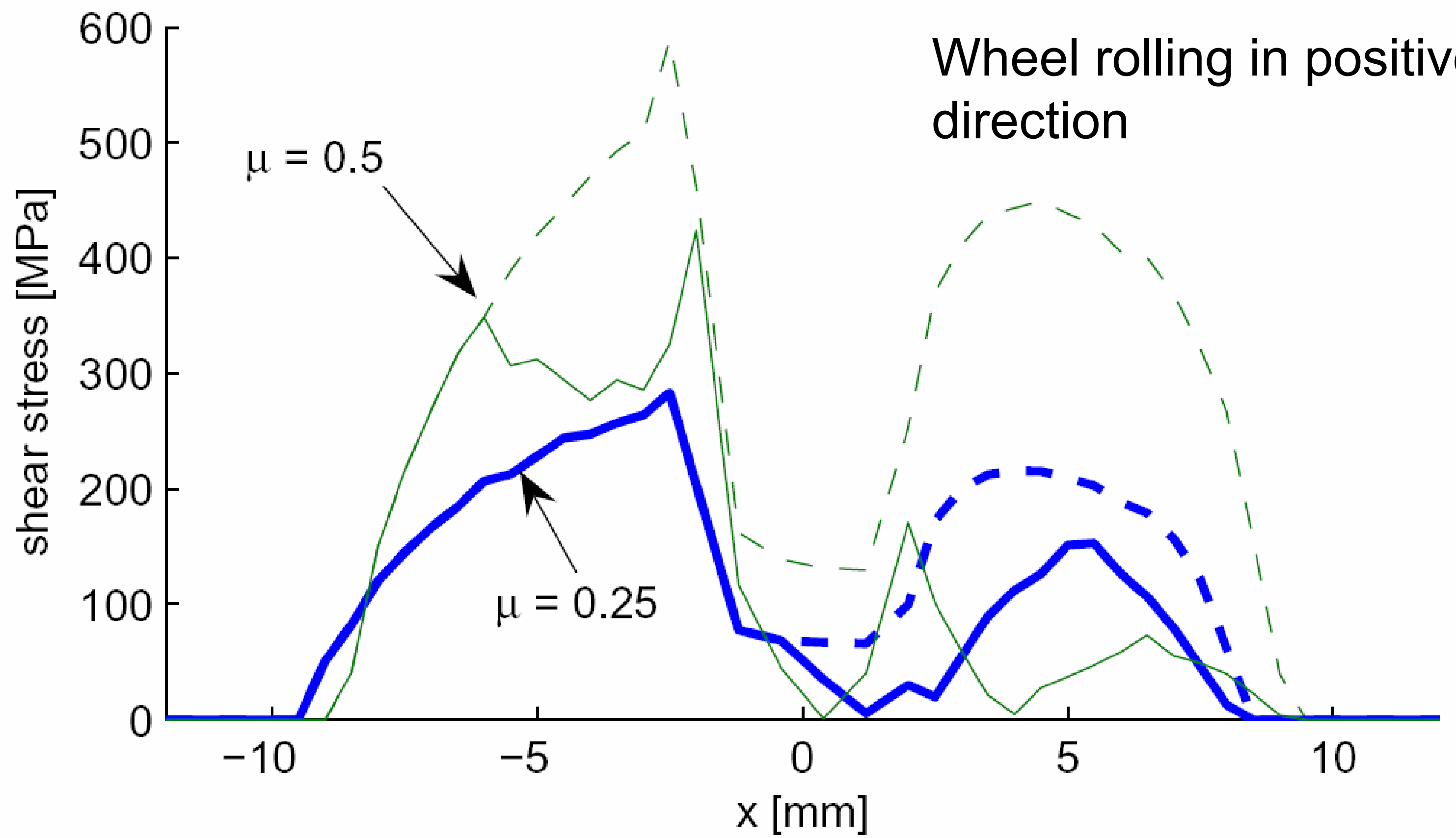
INNOTRACK
Innovative Track Systems

Contact stresses

- Peak stress at the compressed rail end

Tractive longitudinal force

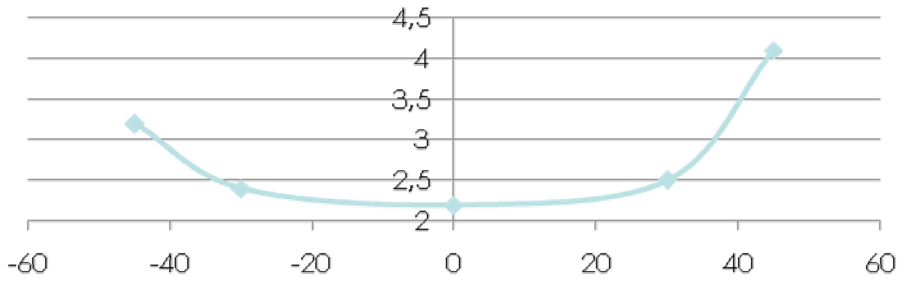
Wheel rolling in positive *x*-direction



Parametric results

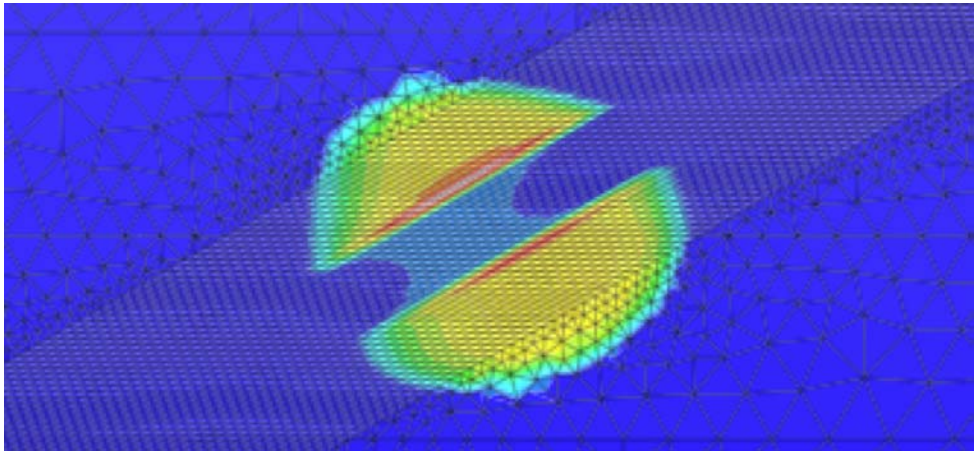
Insulating gap	4 mm	6 mm	8 mm
Vertical load 150 kN	2.47	2.67	2.84
Vertical load 200 kN	2.63	2.92	2.96

Lateral force [kN]	-45	-30	0	30	45
Plastic strain [–]	3.2	2.4	2.2	2.5	4.1



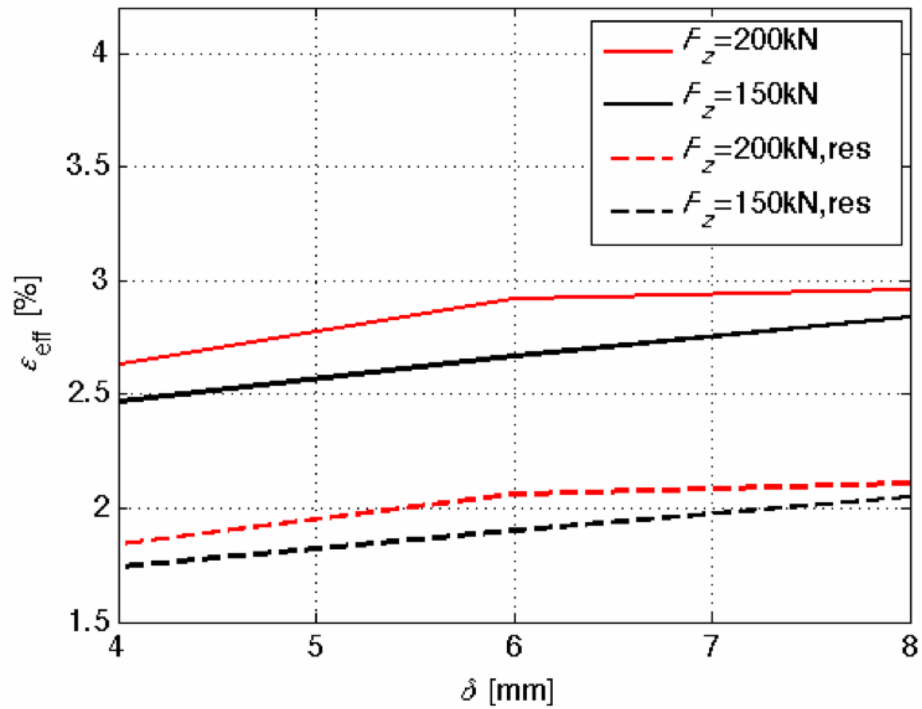
Angled joint

- Larger angle
  ➔ more yielding in the steel and larger region of the steel affected.
- Increasing angle increases surface area of insulation
  ➔ decreases the area of the steel that supports the wheel
  ➔ increased yielding
- Not beneficial for the glue.
- Decreased performance in this *quasi-static* simulation.



Recommendations / implementation

- Joint dip
  - Design graph
- Width of insulating layer
  - moderate traction (<0.2)
  - high traction and large traffic volumes
- Modified joint designs
  - No support for angled joints in this study.
- Testing
  - New joints are **always** better than old ones
  - Different failure modes (plastic roll-out vs cracking vs wear vs run-down vs ...)
  - Reliability vs total life
  - Reference joints: "same" operational conditions; "isolation" of faults



Increasing insulated gap from 4 to 6 mm
≈ Increasing load from 150 to 200 kN

RCF is a **threshold** problem:

< limit → no problem
> limit → problem

Sixth Framework Programme

INNOTRACK Innovative Track Systems

Questions?

Sixth Framework Programme

INNOTRACK
Innovative Track Systems