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Survey and modeling of wheel-rail creep forces

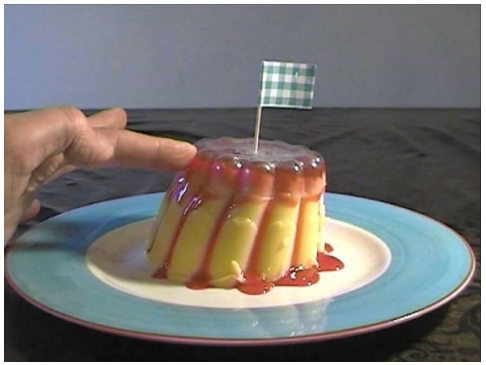
This work was supported by the FRA under contract DFTR 5317 C00012

Edwin Vollebregt & Niels van der Wekken
ICRI WebEx, July 28, 2020.

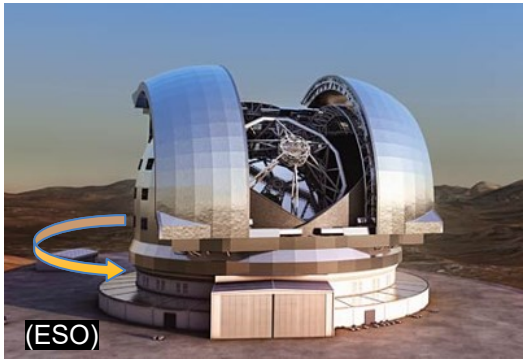
Vtech CMCC

Providing research, custom & standard software.

Supporting design, optimization & troubleshooting.



Enjoying the study of contact mechanics.



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Importance of wheel-rail contact forces

Curving behavior

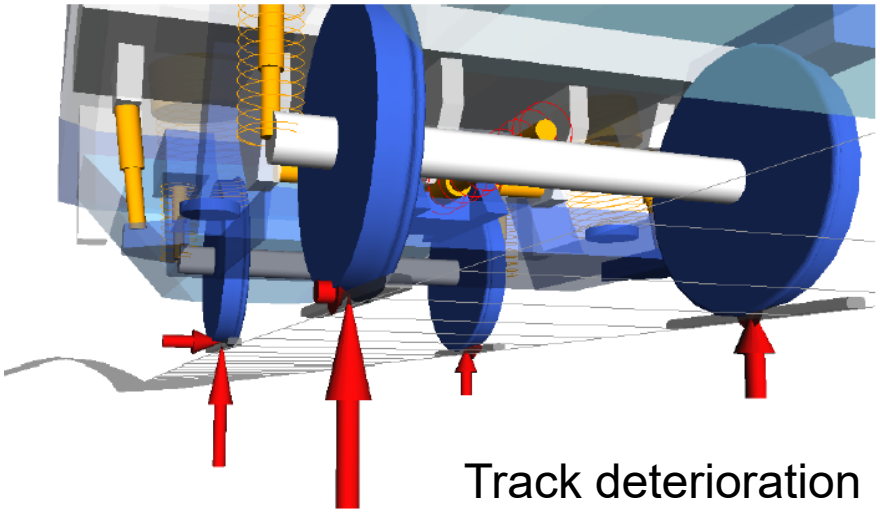
Flange climb

Rail rollover

Hunting motion

Dynamic amplification

Ride quality



Track-shifting forces

Switches and crossings

Wheel flats

Traction and braking

Track friendliness

Track deterioration

Crack initiation

Low adhesion

Wear

RCF

Crack growth

Squeal noise

Corrugation

(picture: Ch. Weidemann)

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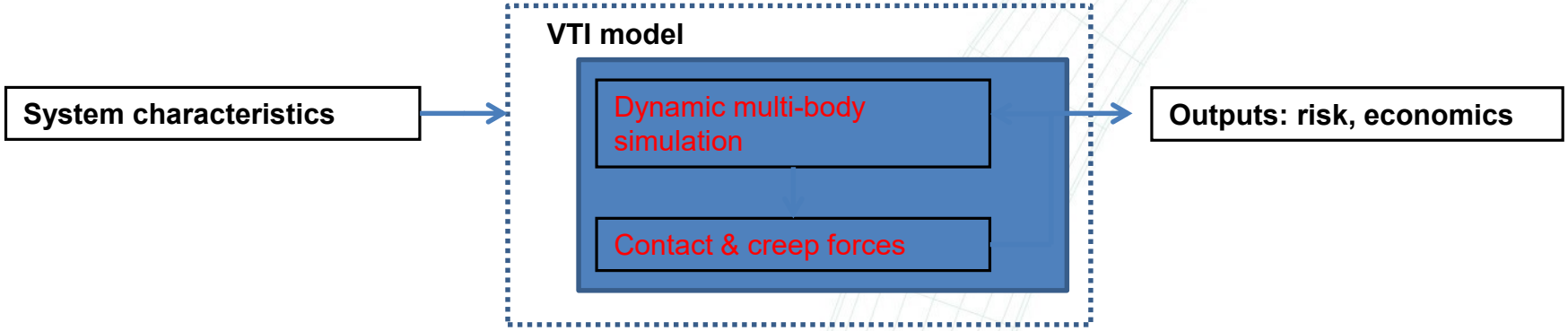
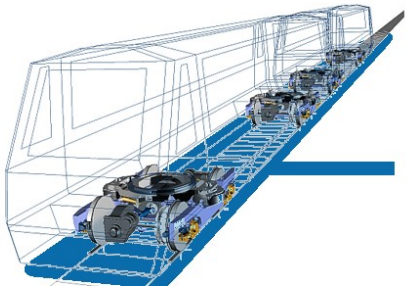
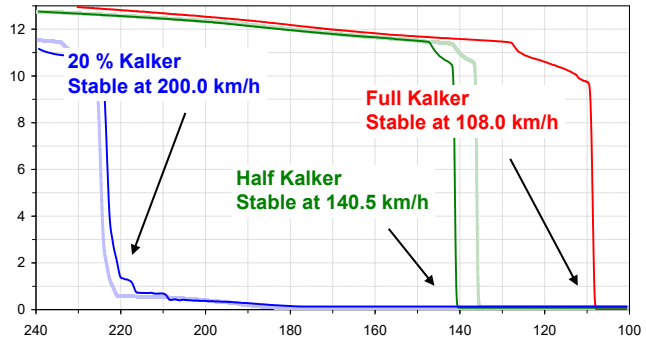
Simulation of vehicle-track interaction





(Simpack)



(Klauser)

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Extended simulation approach

System characteristics

VTI model

Dynamic multi-body simulation

Contact & creep forces

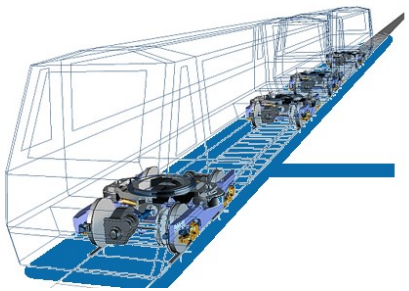
Damage model

Detailed contact stresses

Wear & RCF

Profile grinding

Outputs: risk, economics



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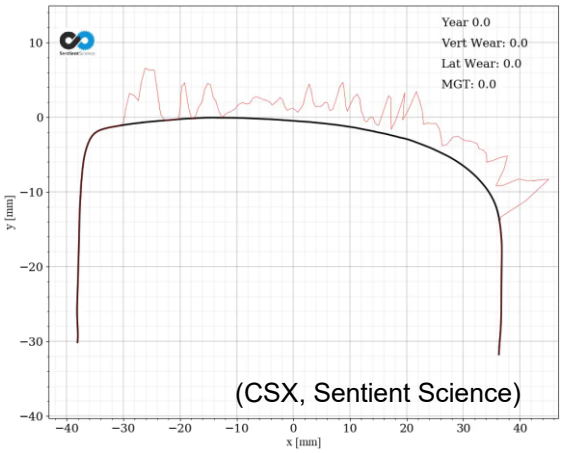

(CSX, Sentient Science)

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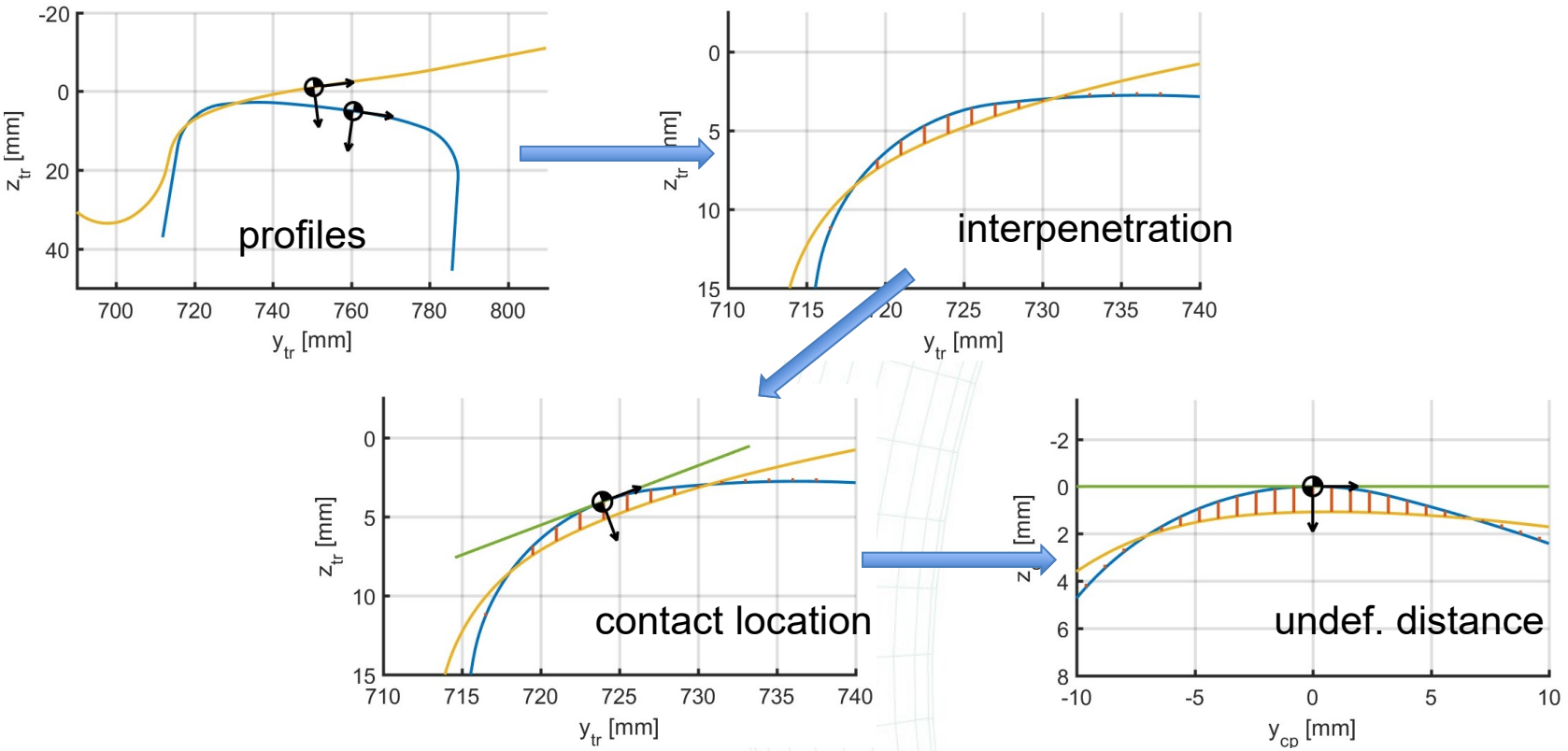
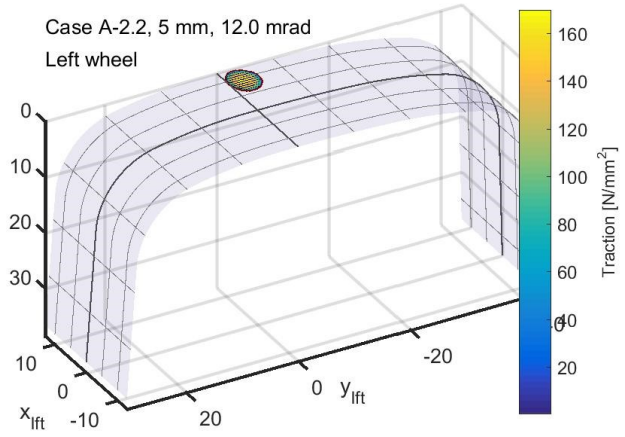
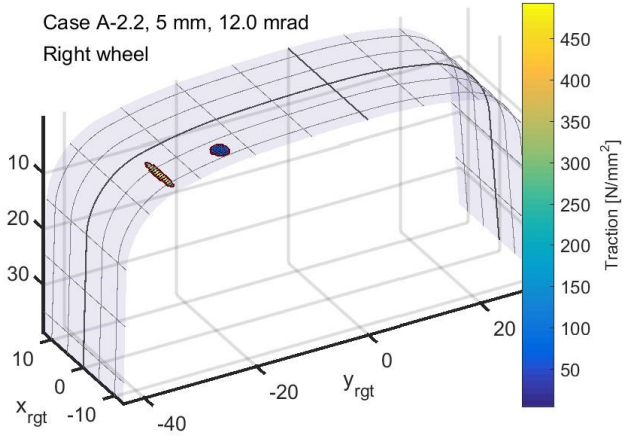
Automated contact detection



Automated contact analysis

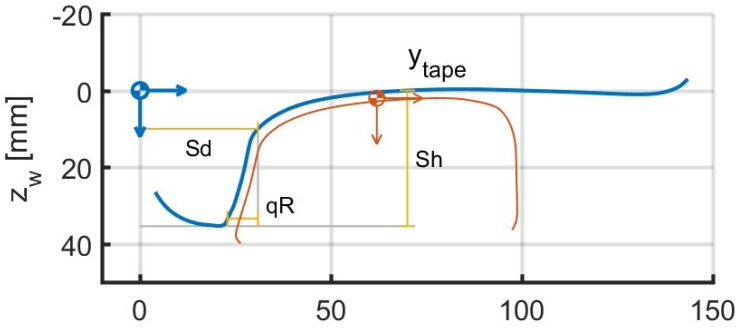
3D contact search, including the yaw angle

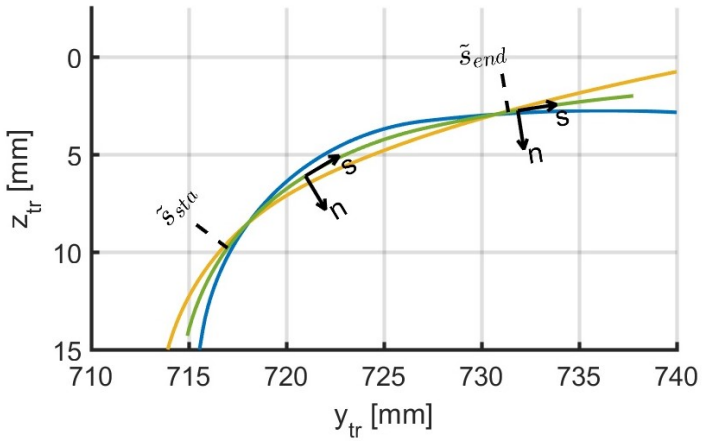


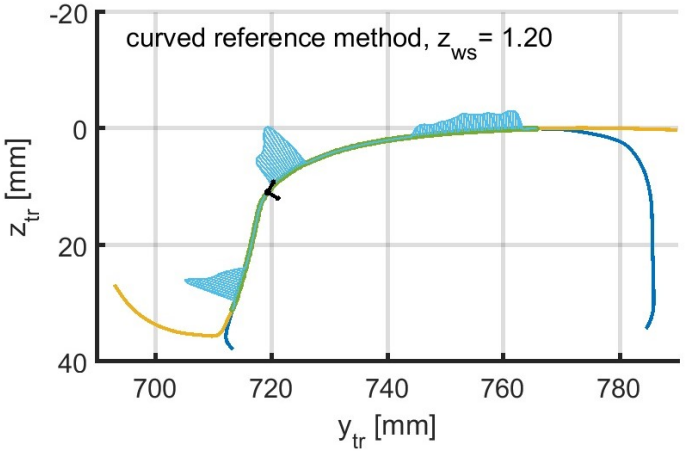


Conformal contact analysis

Automatic construction of curved reference surface







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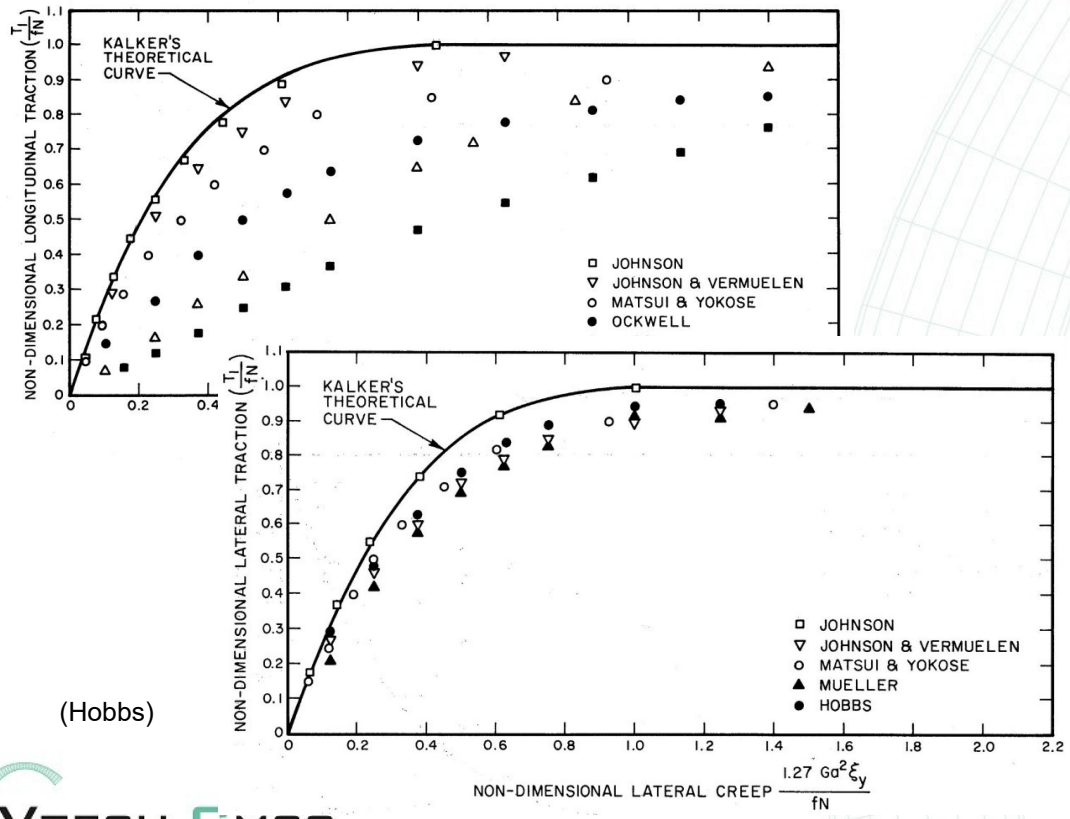
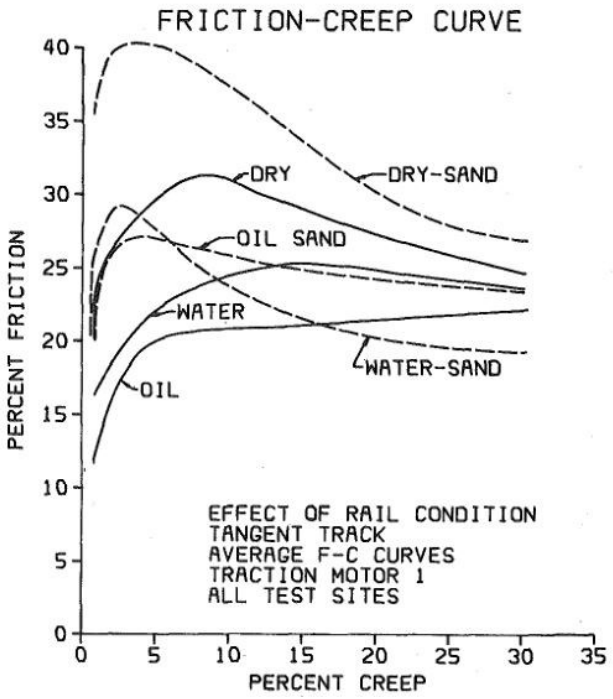
Behavior of railway creep forces



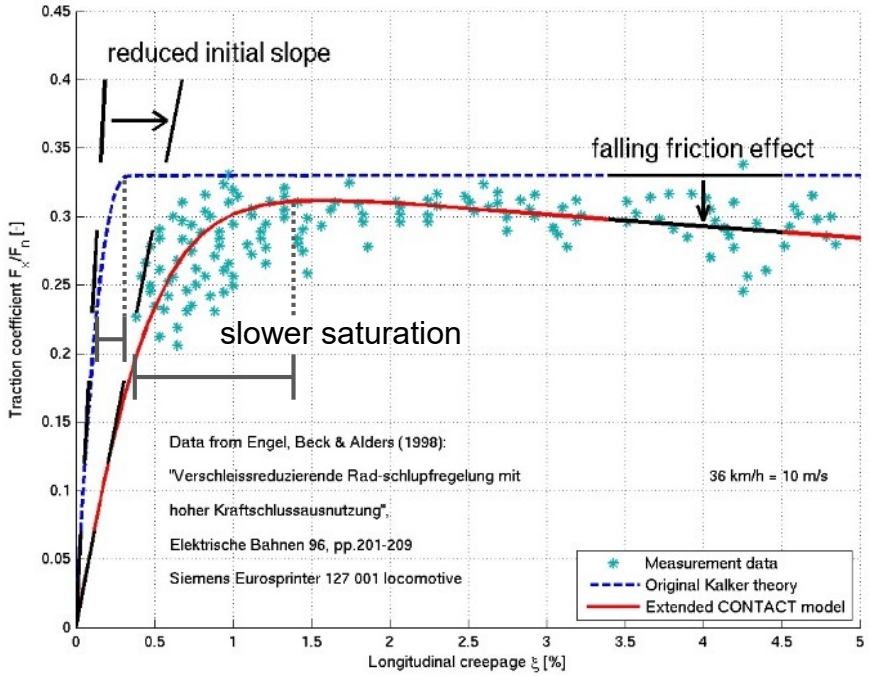
(Hobbs)

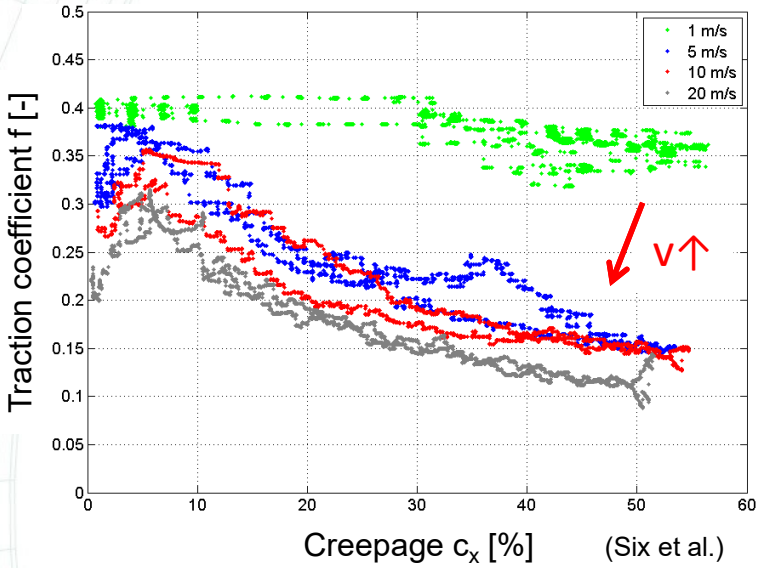


(Logston & Itami)

Behavior of railway creep forces

Deviations from Kalker's original theories

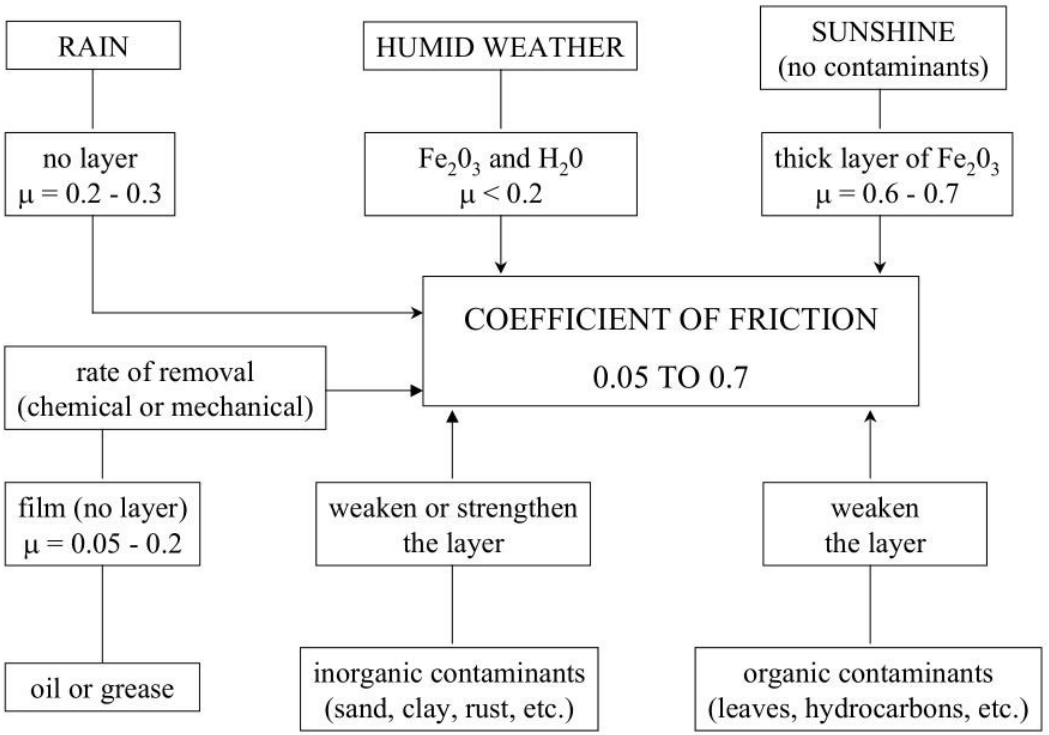




Factors affecting friction

Effects of:

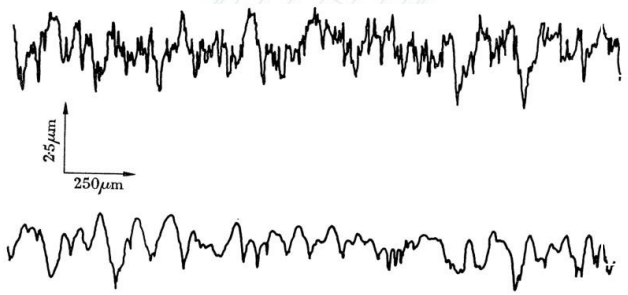
- fluids,
- third body layers,
- temperature,
- roughness …



(Kalousek)

Effects of surface roughness

- Contact happens at tips of asperities
- Actual contact may be $1 - 30\%$ of nominal contact area
- Asperities may deform plastically.



(a) Surface ground only

(b) Ground and lightly polished

(c) Ground and lightly abraded

(Greenwood & Williamson)

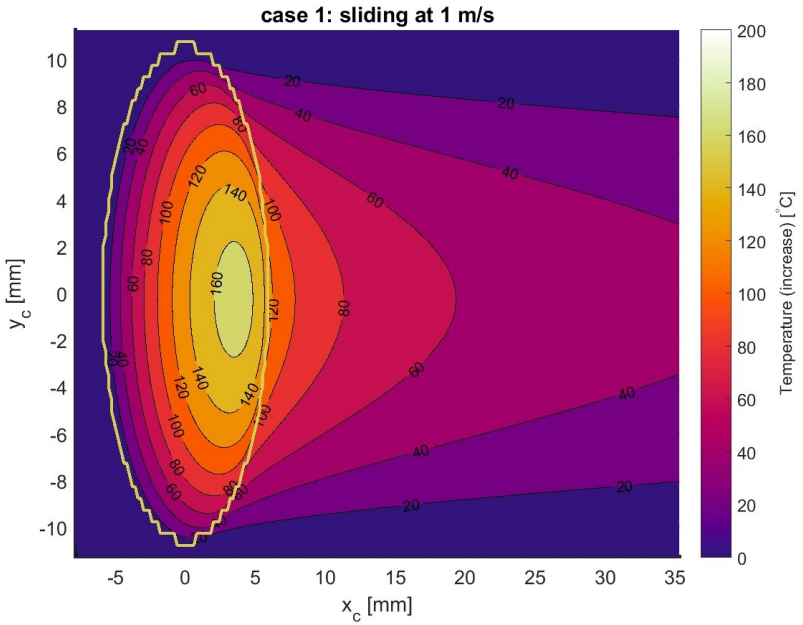
- In case of lubrication, there's a strong effect of surface roughness on macroscopic friction
- For dry contacts, roughness has little or no influence on the (maximum) level of friction.
- The initial slope seems not to be affected by surface roughness.

Effects of surface temperature

- Sliding generates considerable heat input.
- Diffusion is slow compared to the time in contact.

- High temperatures may be produced in a layer near the surface.

- Load + creepage + speed.
- Good models available in the literature.
- Implemented in CONTACT for non-Hertzian + steady rolling.

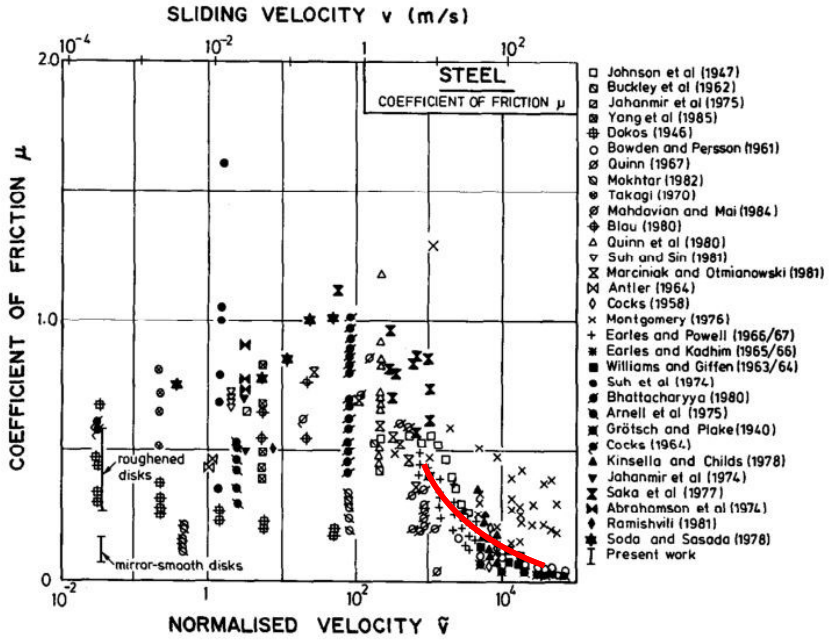


Effects of surface temperature

- Oxidation changes with surface temperature.
- Melting occurs.

- High temperature is one cause of falling friction.
- Mainly on full scale locomotives.

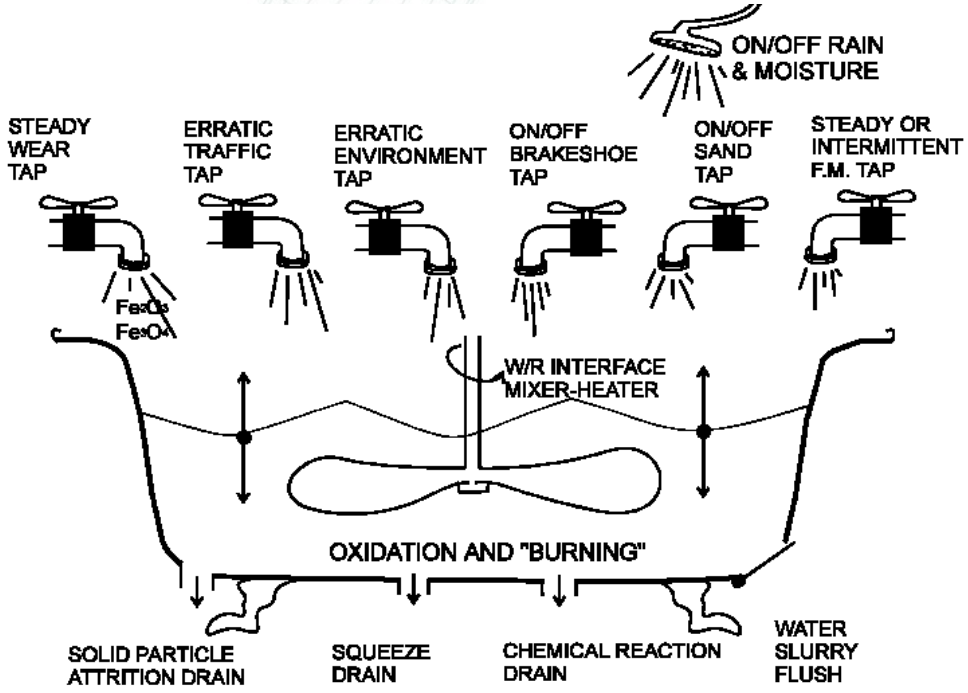
- Implemented in CONTACT using a piece-wise linear dependence.



(Lim, Ashby & Brunton)

Effects of solid third body layers

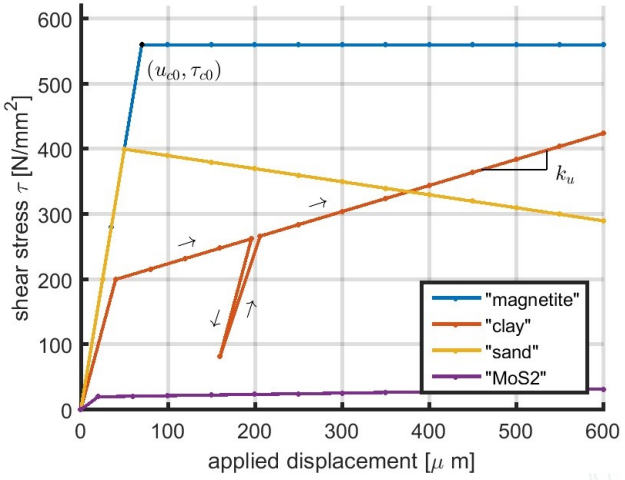
- A layer is formed of wear particles,
  - hematite Fe_2O_3
  - magnetite Fe_3O_4
- Rain, humidity,
- Contaminants,
  - dust, leaves
  - sanding
  - oil leakage, cargo spills
- Applied agents
  - grease, lubricant
  - friction modifier

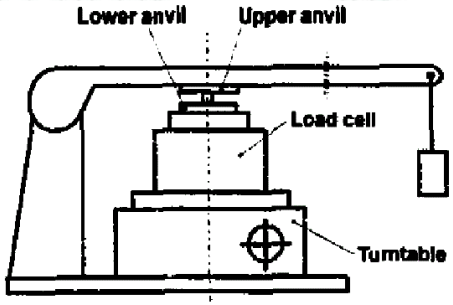


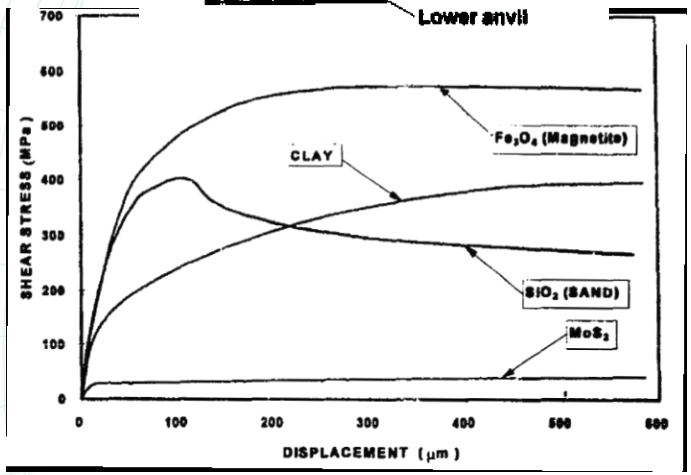
(Kalousek bathtub model)

Effects of solid third body layers

- Particles are formed, rearranged, deformed, crushed.
- The layer may be compacted first, then show work-hardening or work-softening behavior.







(Hou, Kalousek & Magel)

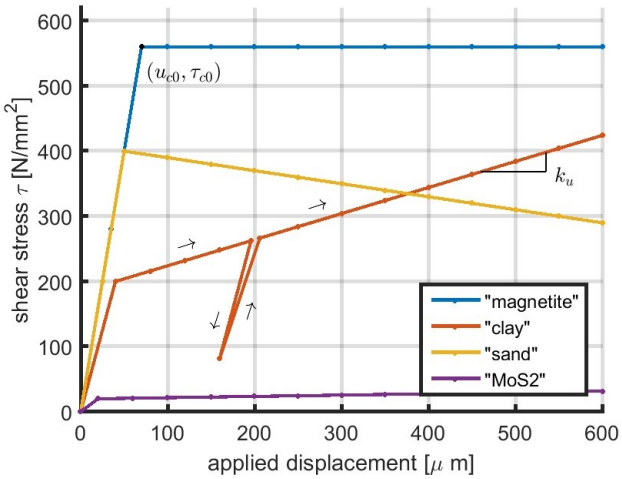
Effects of solid third body layers

A plasticity model is implemented in CONTACT.

$$\begin{cases} \|\vec{\tau}\| \le g & g = \min(\mu p_n, \tau_c) & \text{traction bound} \\ \vec{s} \parallel -\vec{\tau} & \|\vec{\tau}\| < \mu p_n \rightarrow \vec{s} = \vec{0} & \text{slip} \\ \delta\vec{u}_{pl} \parallel -\vec{\tau} & \|\vec{\tau}\| < \tau_c \rightarrow \delta\vec{u}_{pl} = \vec{0} & \text{plastic deformation} \end{cases}$$

With different work-hardening characteristics.

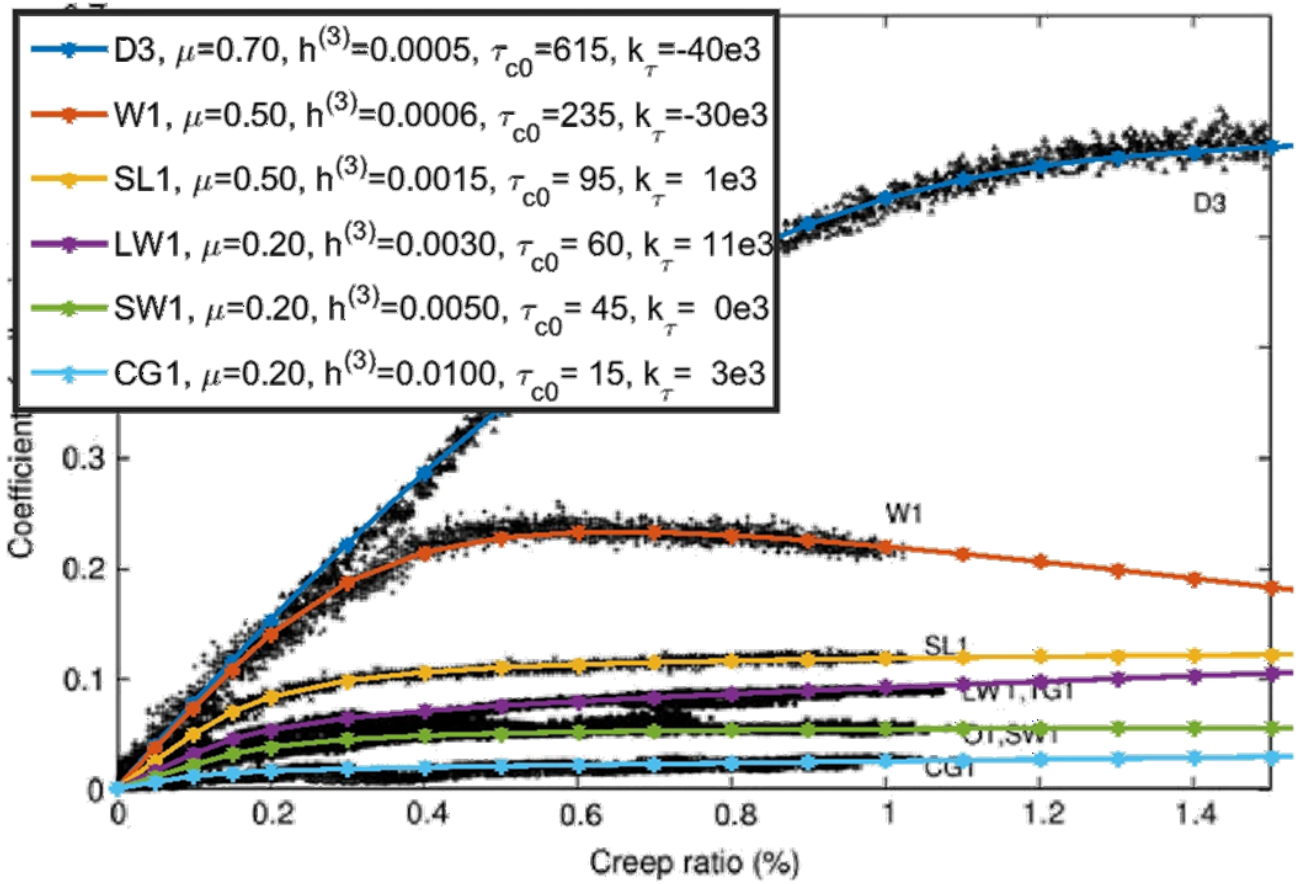
$$\begin{cases} \tau_c = \tau_{c0} + k_\tau \cdot u^*_{pl} & \text{yield stress} \\ u^*_{pl} = \int |\vec{u}_{pl}|\, dt & \text{accumulated plast. def.} \end{cases}$$



Measurements on SUROS twin-disk machine

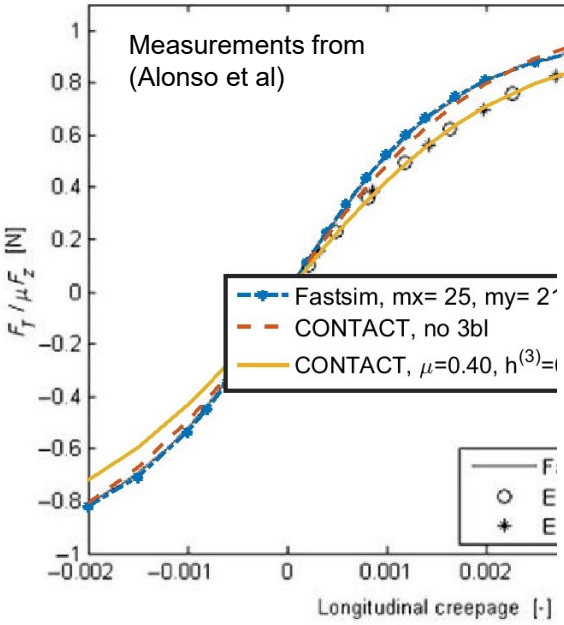
Dry
Wet
Solid Lube
Lignin + water
Soap + water
Track grease

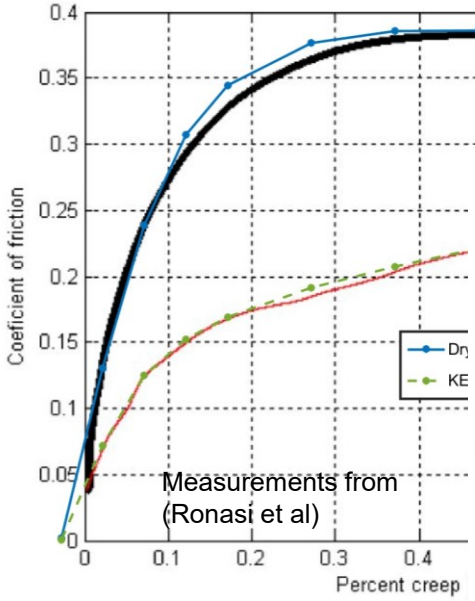
Simulations with
Extended CONTAC

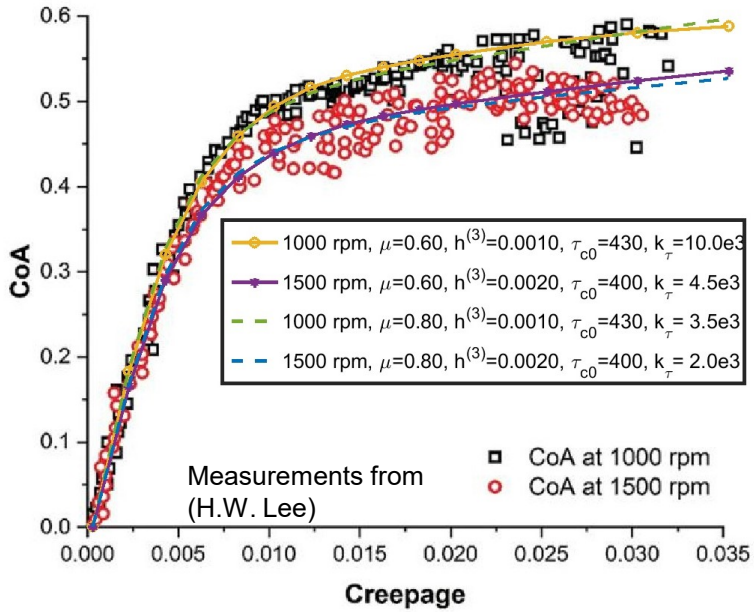


Measurements from (Fletcher & Lewis)

Further measurements & simulation

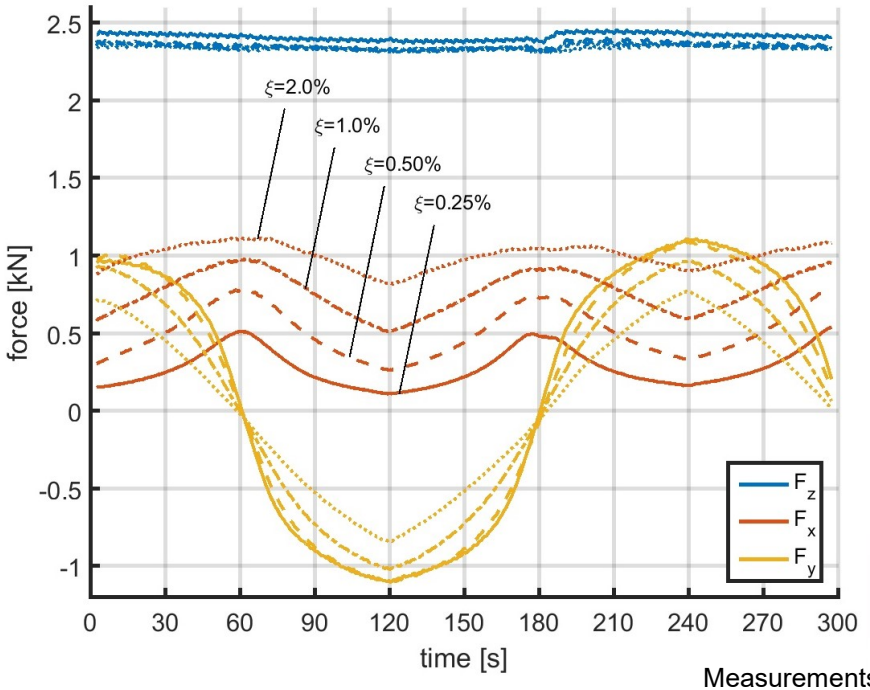


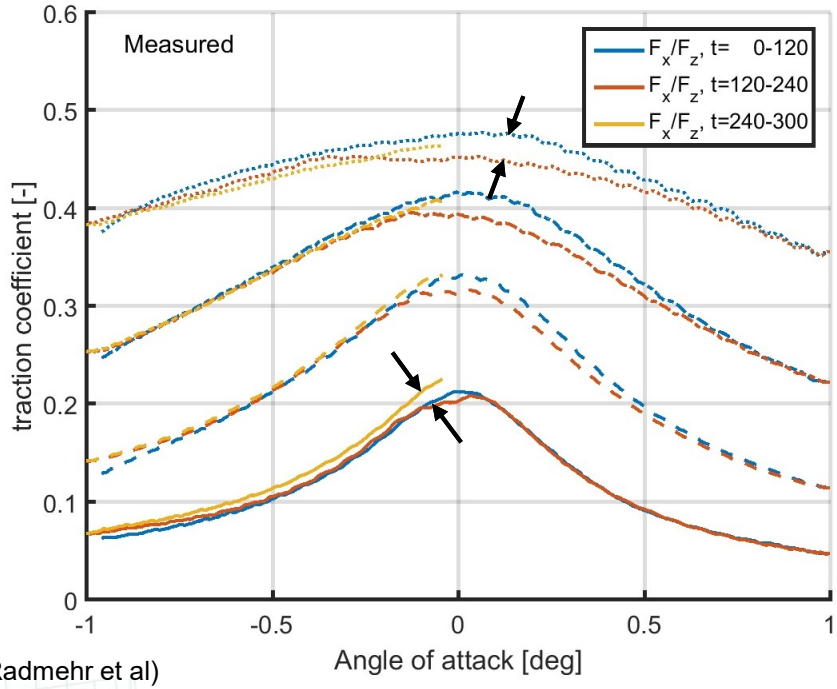




Measurements at Virginia Tech

Including angle of attack, longitudinal and lateral forces.



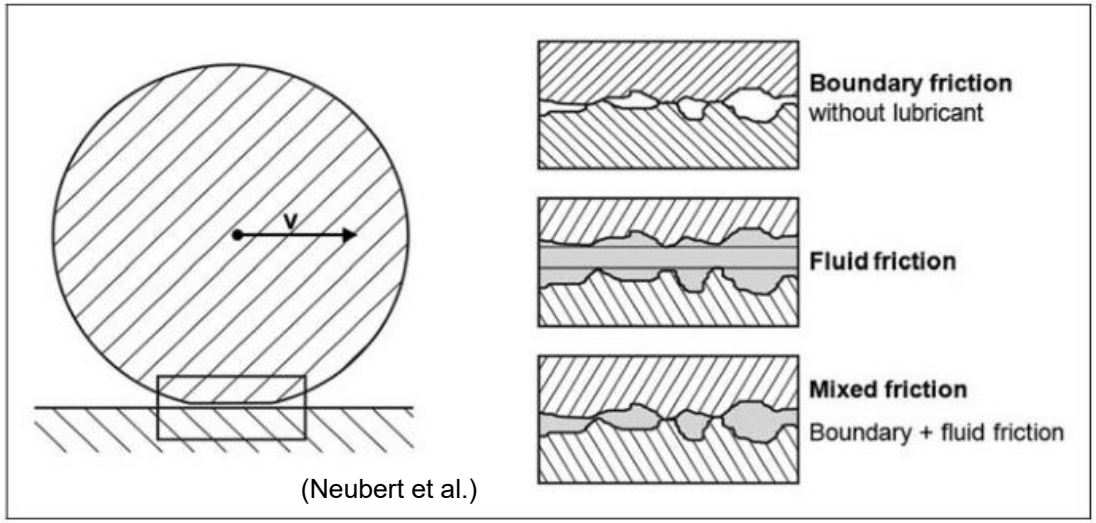


Measurements of (Radmehr et al)

Effects of fluids

Different regimes are distinguished based on the amount of fluid

- Totally clean – e.g. using plasma torch, high vacuum
- Boundary Lubrication – “one molecule”
- Mixed Lubrication – asperity contacts, load sharing
- EHL – minimum film thickness, affected by elastic deformation
- Hydrodynamic Lubrication – continuous film



(Neubert et al.)

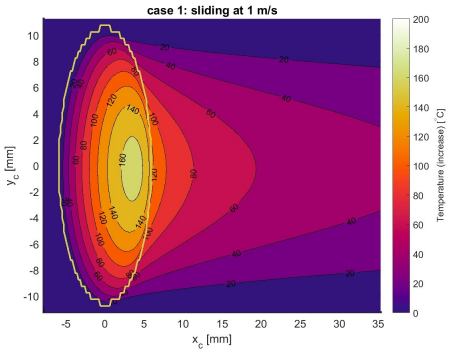
Effects of fluids

- “Clean wheels” are in the BL regime – affected by humidity, traces of oil and other contamination.
- “Wet rails” may be in ML or EHL regimes – friction reduces as speed increases.
- “Rain + 3BL” may lead to a slurry, HL regime with viscous fluid.
- “Leaves + humidity” may lead to ML with low μ at asperities.

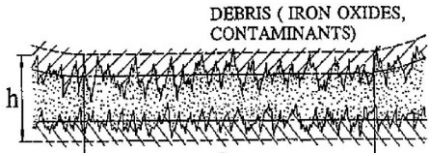

(John Kirk Photography)

Summary and conclusions

1. Frictional heating causes high surface temperatures, reducing friction, especially for locomotives at large creepage.
   – Good models available for temperature itself
   – Less so for its effect on friction



2. All kinds of solid interfacial layers occur, with different strength characteristics.
   – High pressure torsion testing: increasing / constant / decreasing
   – Viewed as compacting & rearranging, rolling, sliding & deforming
   – Modelled with plasticity with work-hardening / softening



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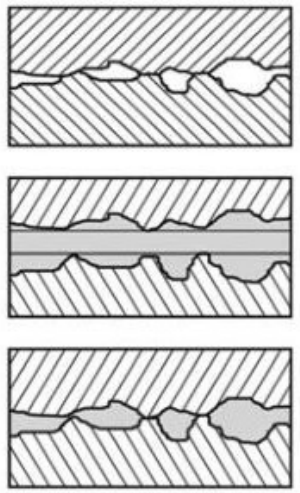
Summary and conclusions

3. Fluids occur in different lubrication regimes
   – Water + high speed: mixed → elastohydrodynamic lubrication
   – Low adhesion, cleaning: viscous paste, slurry
   – No complete model is provided in the literature



4. Surface roughness governs friction on microscopic scale.
   – Little effect on macroscopic scale in dry friction.
   – Large effects on ML & EHL lubrication regimes.

Temperature + Plasticity implemented in CONTACT.

Fluids + Roughness remain to be done.

Thank you for your attention.

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