Curve squeal modelling including transient effects and realistic curving scenarios

A. Pieringer[1], P.T. Torstensson[2], J. Theyssen[1], W. Kropp[1]

[1] Chalmers University of Technology, Applied Acoustics/CHARMEC, Sweden
[2] Swedish National Road and Transport Research Institute (VTI), Sweden

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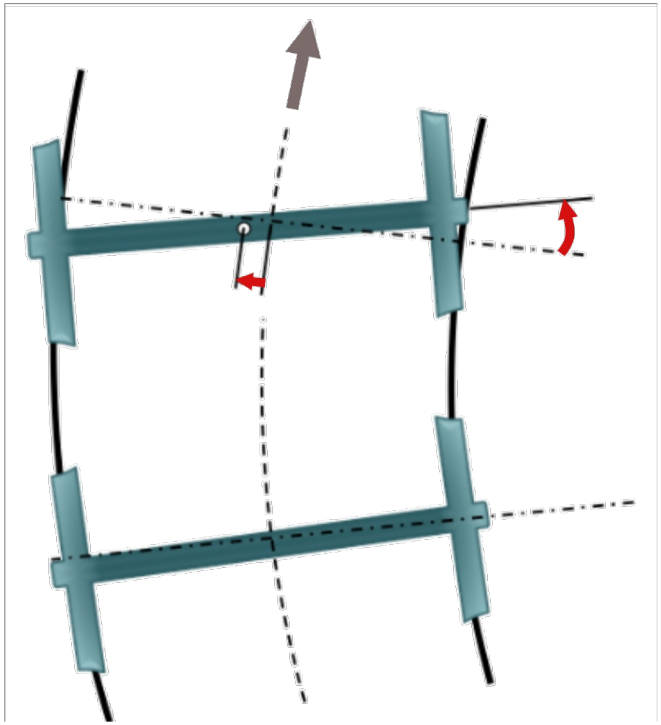
Railway curve squeal

- Highly disturbing tonal sound in tight curves
- Self-excited vibrations of the railway wheel during ‘imperfect curving’
- Threshold problem (lateral creepage, friction coefficient, contact position)



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Transient effects

- Both lateral creepage and contact position vary during curving (vehicle dynamics, rail profiles)
- Local friction conditions vary along the curve
- Squeal needs some time to build up
- Discrete defects on the rail might influence squeal build-up

→ Include transient effects in modelling

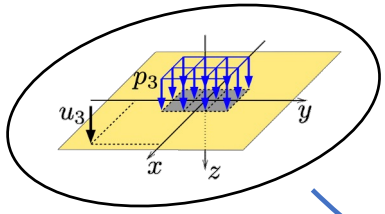
Agenda

- Model description and extension
- Model demonstration and application
  - Systematic variation of contact parameters
  - Realistic curving scenario

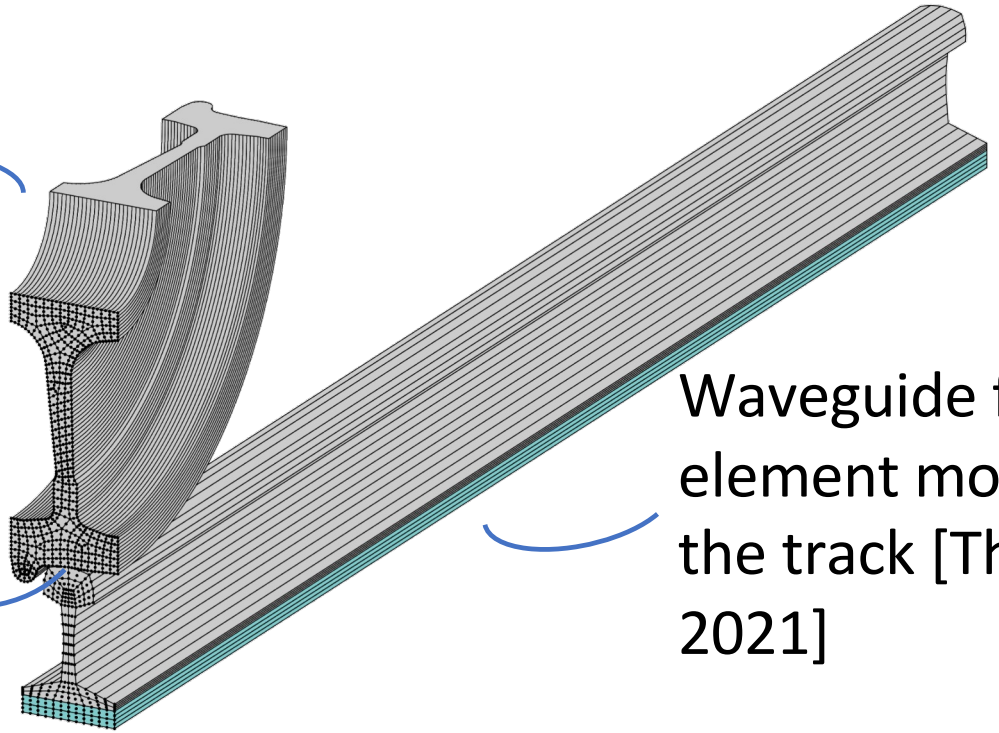
Curve squeal model WERAN

High-frequency wheel/rail interaction in the time domain

Flexible wheel model (FE)



Variational method by Kalker [Kalker, 1990] constant friction



Waveguide finite element model of the track [Theyssen, 2021]

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Curve squeal model WERAN
Model characteristics

- Representation of wheel and track dynamics by pre-calculated **impulse response functions** (Green's functions)
- **Convolution** of the Green's functions with the contact forces to obtain wheel and rail displacements
- **Coupling between vertical and lateral** wheel/rail **dynamics** included; longitudinal dynamics neglected
- **Non-linear, transient rolling contact**
- Wheel rotation and discrete rail supports can be included, but are neglected here

Model extension

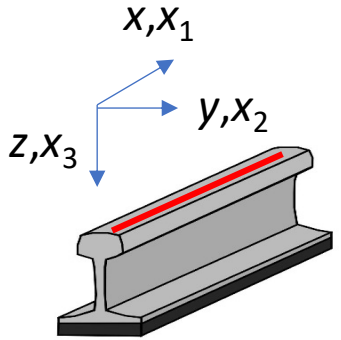
Inclusion of the lateral motion of the contact point

Modification of the Green's functions (example rail):

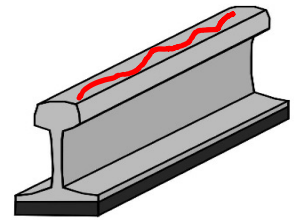
$$\begin{cases} x(t) = vt \\ \xi_j^{\mathrm{R}}\left(x(t)\right) = \displaystyle\int_0^t \sum_{i=2}^{3} F_i\left(x(\tau)\right) \cdot g_{ij}^{\mathrm{R}}\left(x(\tau), x(t)\right) \mathrm{d}\tau\,, \quad j = 2,3\,. \end{cases}$$

position of contact point

rail displacement — contact force — Green's function



$$\begin{cases} \mathbf{x}^{\mathrm{R}}(t) = \left[x(t), y^{\mathrm{R}}(t)\right]^{\mathrm{T}} = \left[vt, y^{\mathrm{R}}(t)\right]^{\mathrm{T}}\,. \\ \xi_j^{\mathrm{R}}\left(\mathbf{x}^{\mathrm{R}}(t)\right) = \displaystyle\int_0^t \sum_{i=2}^{3} F_i\left(\mathbf{x}^{\mathrm{R}}(\tau)\right) \cdot g_{ij}^{\mathrm{R}}\left(\mathbf{x}^{\mathrm{R}}(\tau), \mathbf{x}^{\mathrm{R}}(t)\right) \mathrm{d}\tau\,, \quad j = 2,3\,. \end{cases}$$



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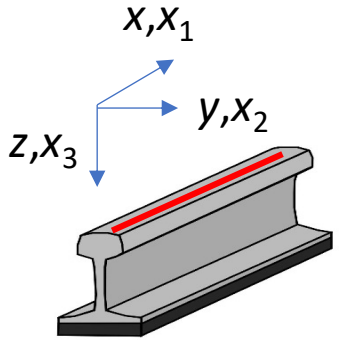

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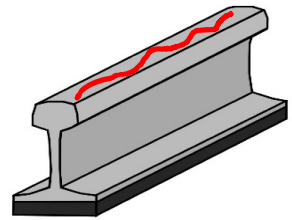

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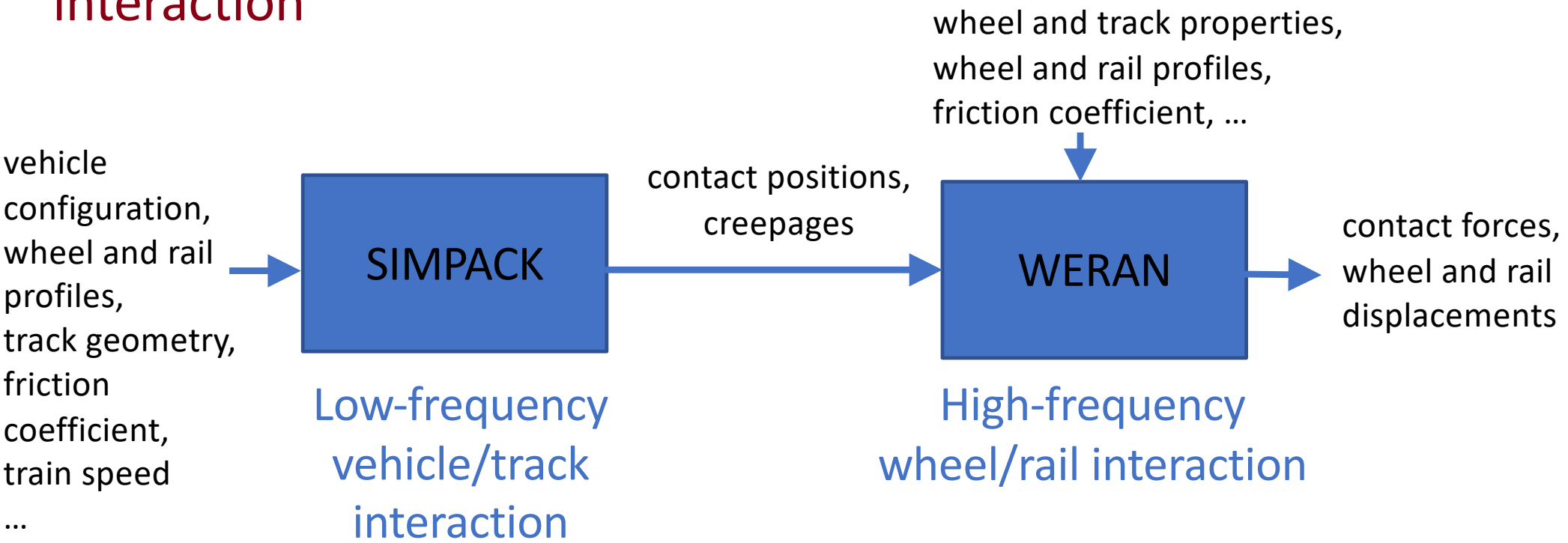
Model extension

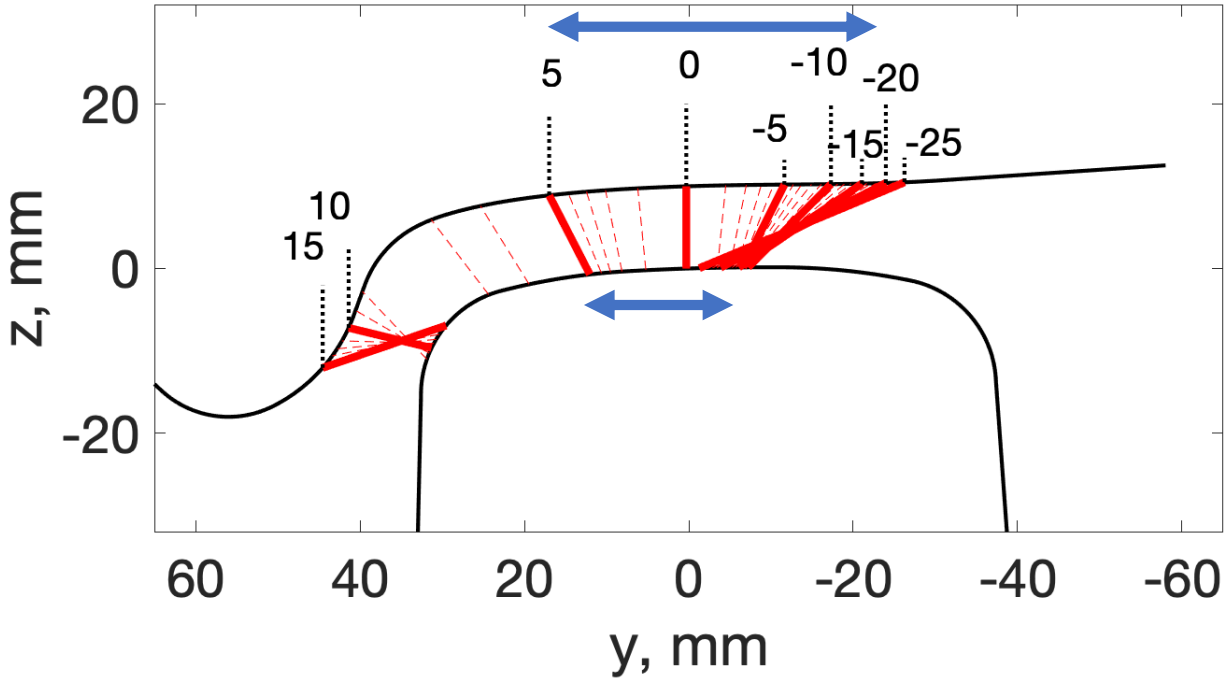
Combination with a model for low-frequency vehicle/track interaction



Systematic variation of contact parameters

Sinusoidal path of the wheelset on the rail

- Pure lateral creepage 1%
- Constant friction coefficient 0.3
- Train speed 30 km/h
- Nominal wheel and rail profiles S1002/BV50



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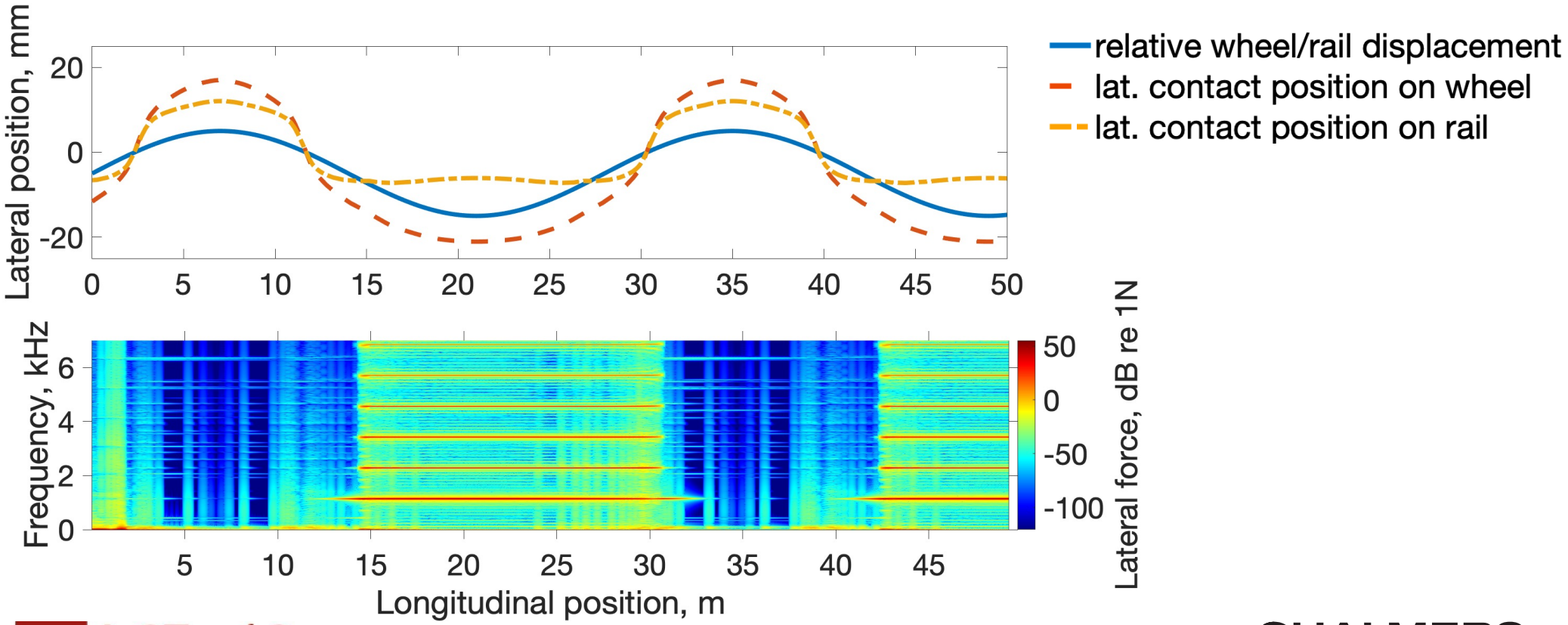

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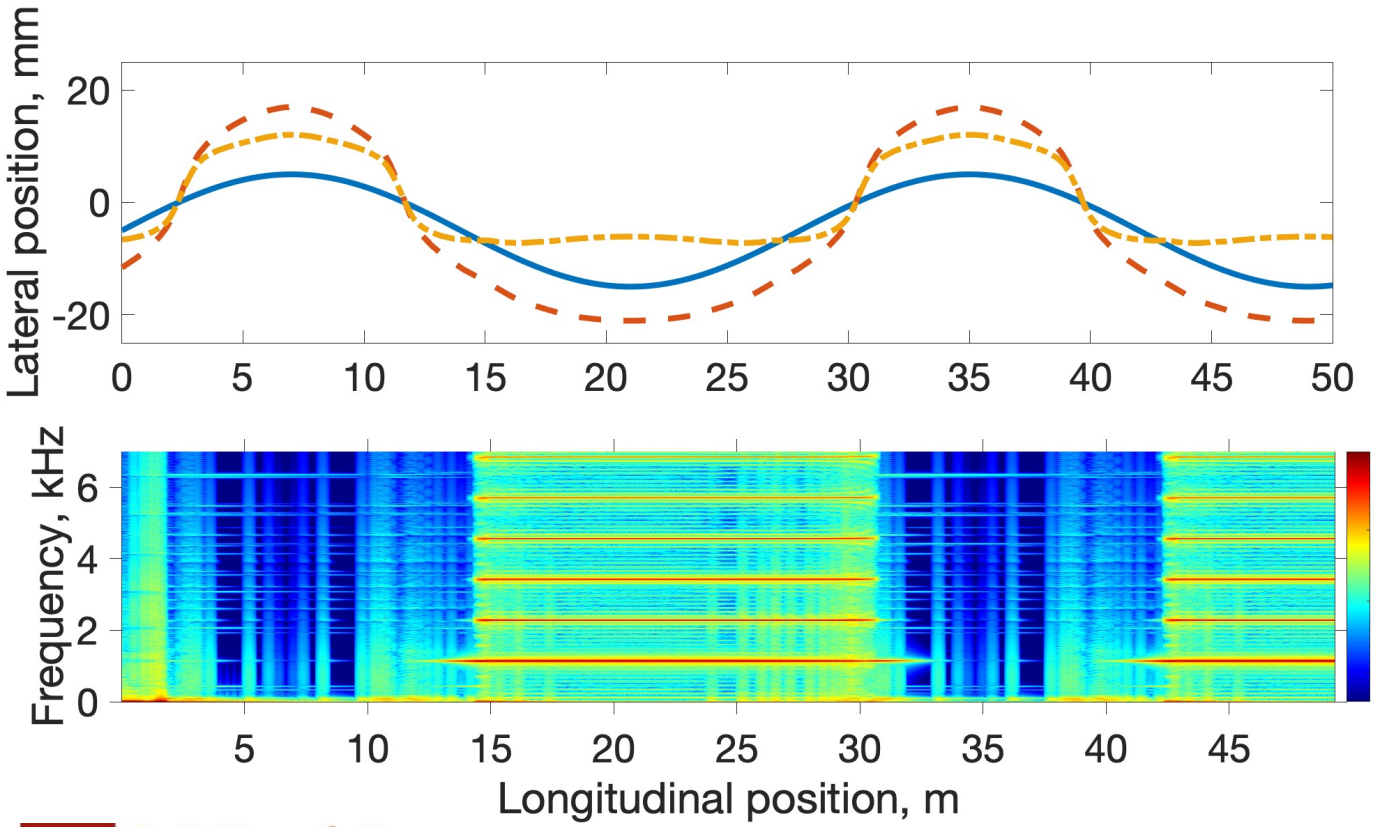

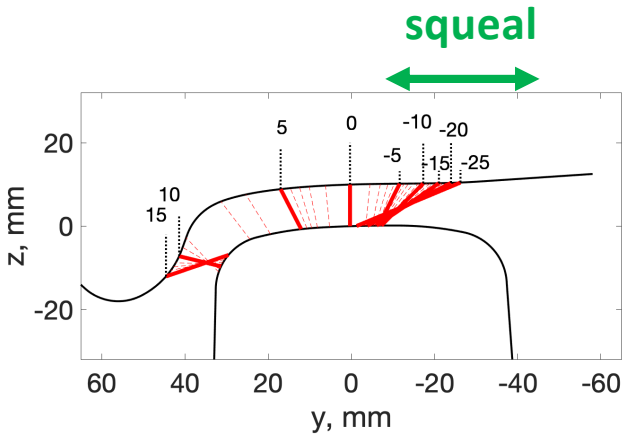

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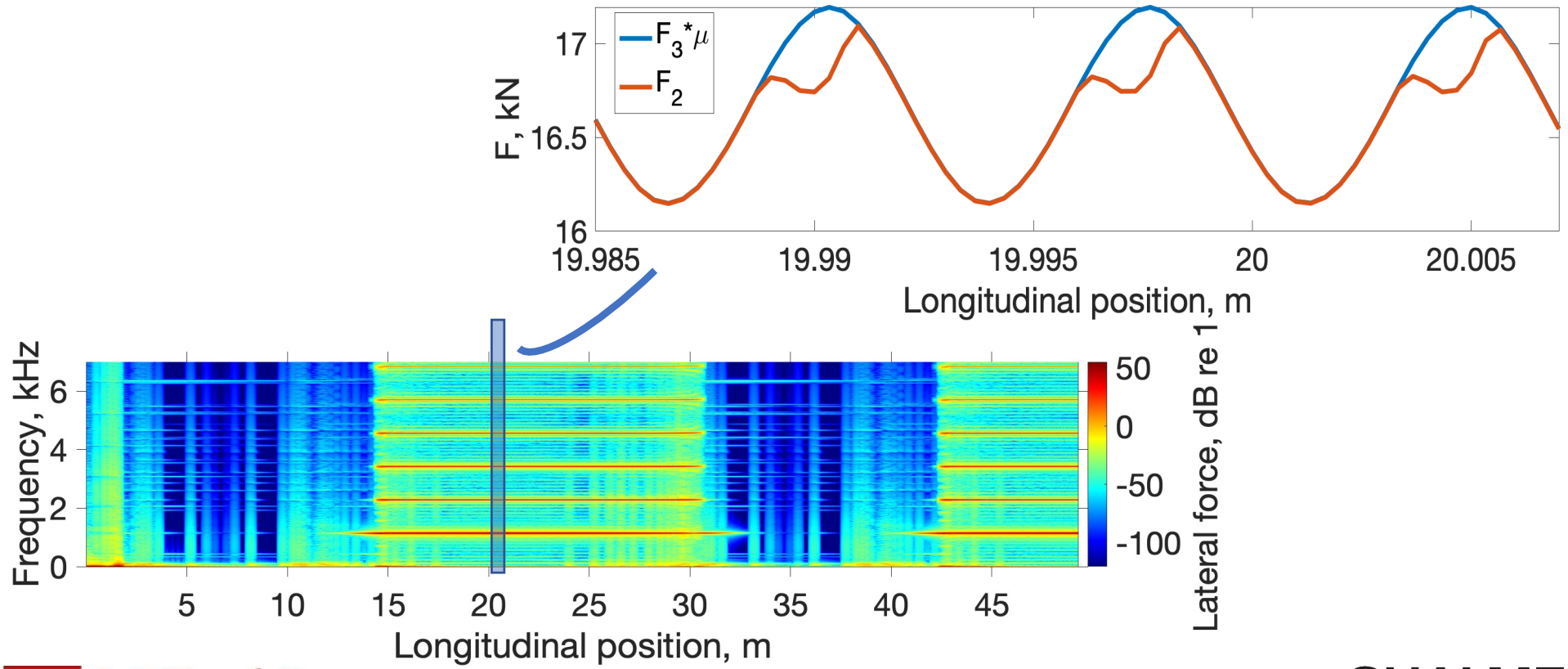

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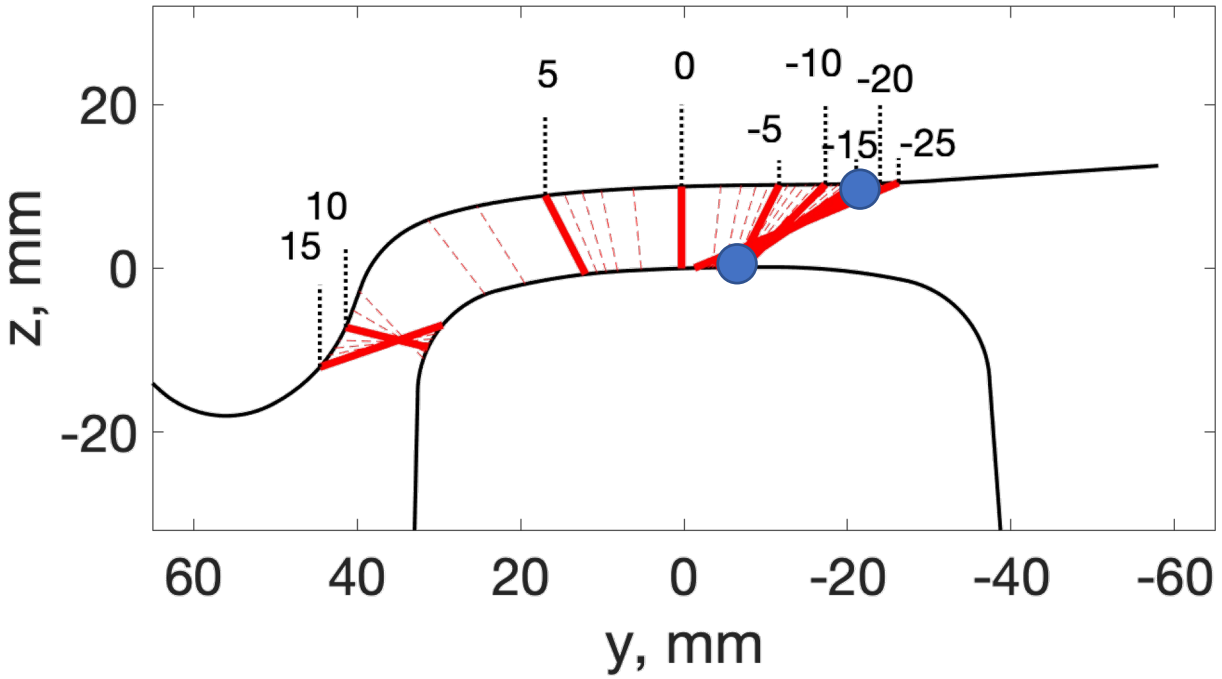
Systematic variation of contact parameters

Sinusoidal variation of the friction coefficient

- Pure lateral creepage 1%
- Relative wheel/rail displacement -15 mm
- Train speed 30 km/h
- Nominal wheel and rail profiles S1002/BV50



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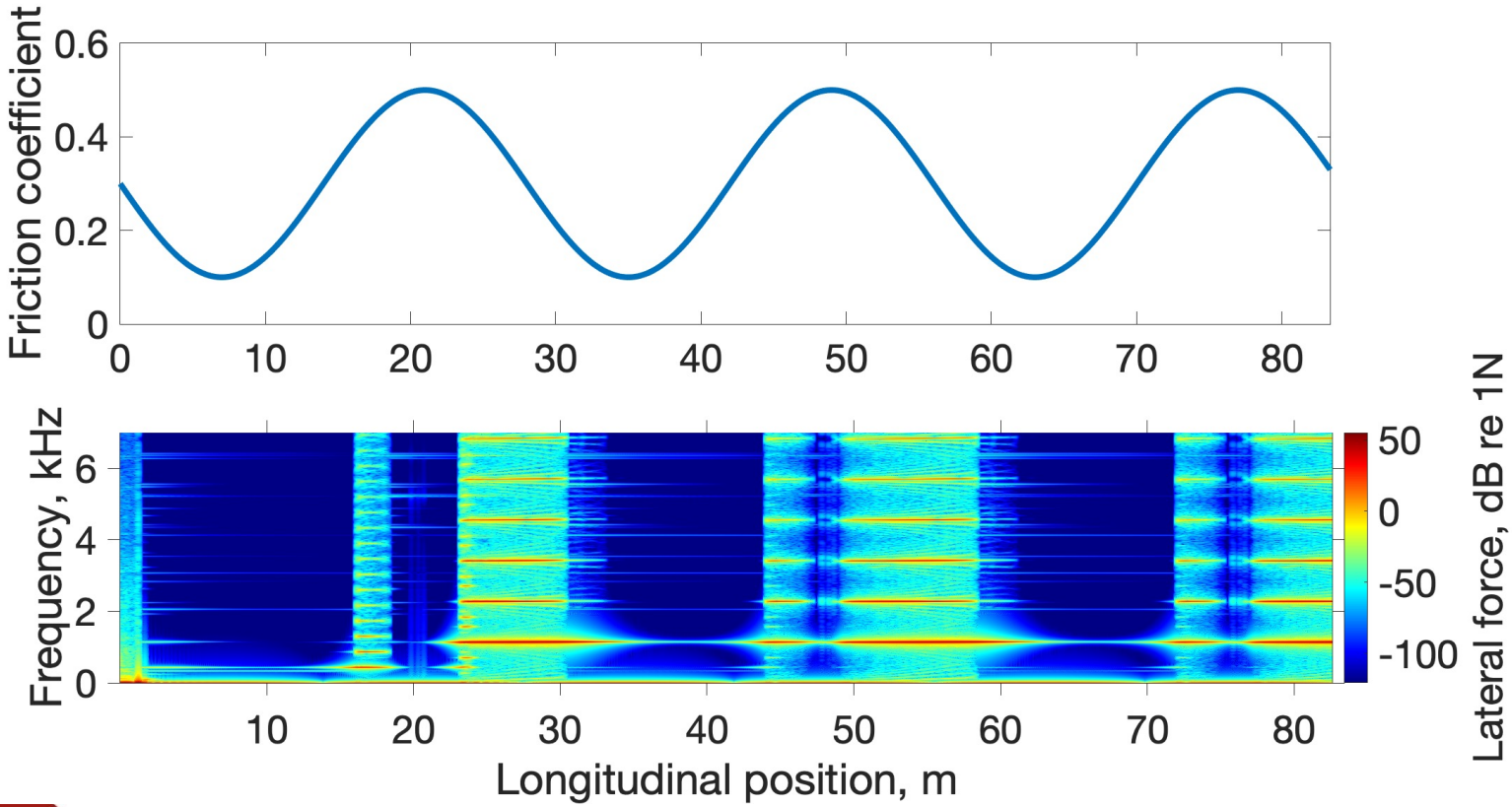

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Systematic variation of contact parameters

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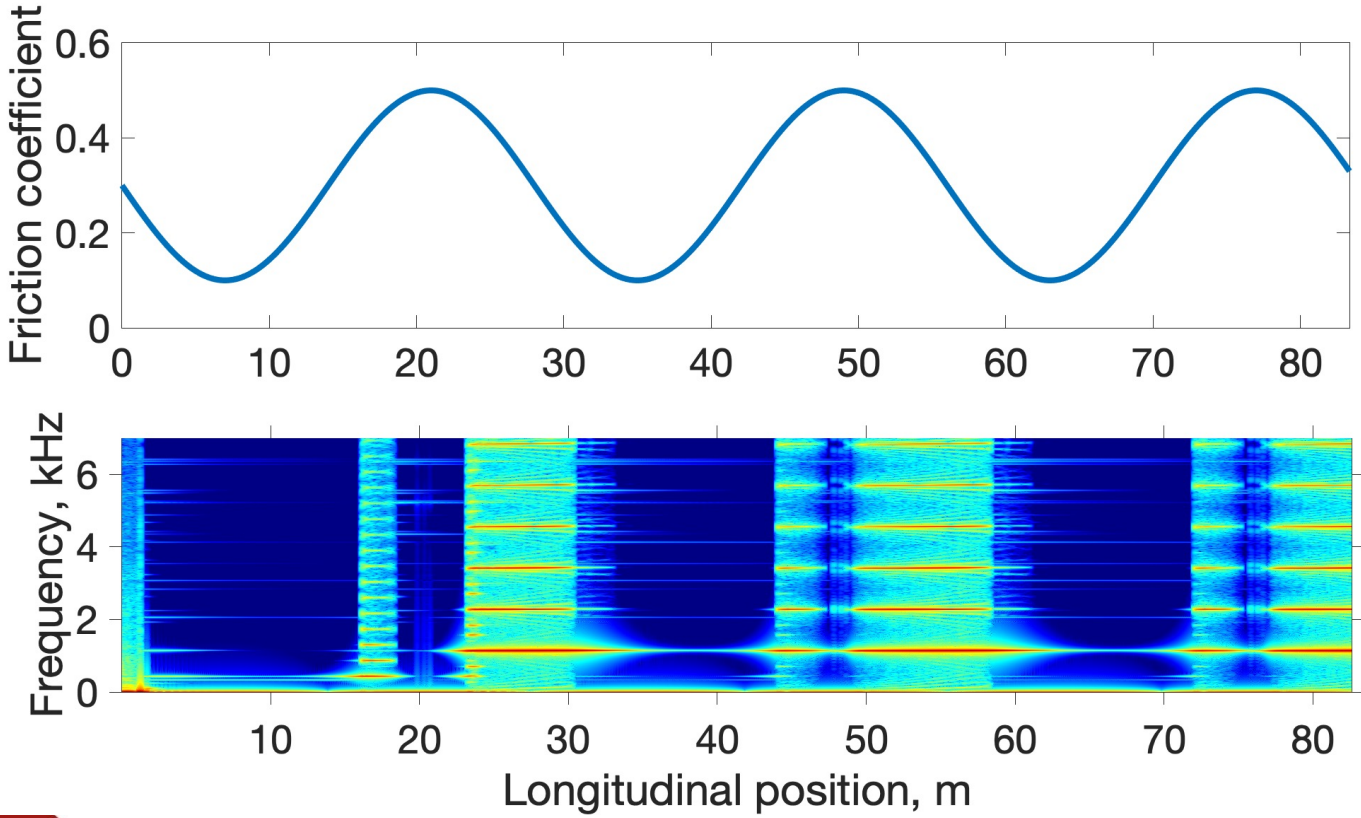

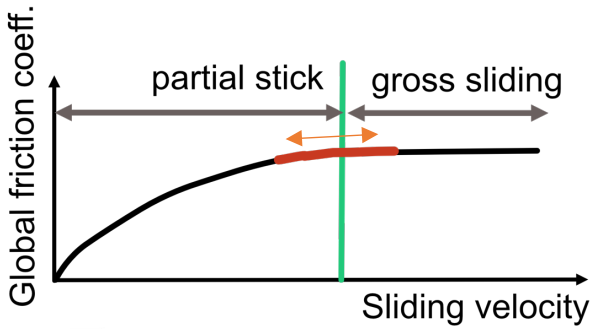

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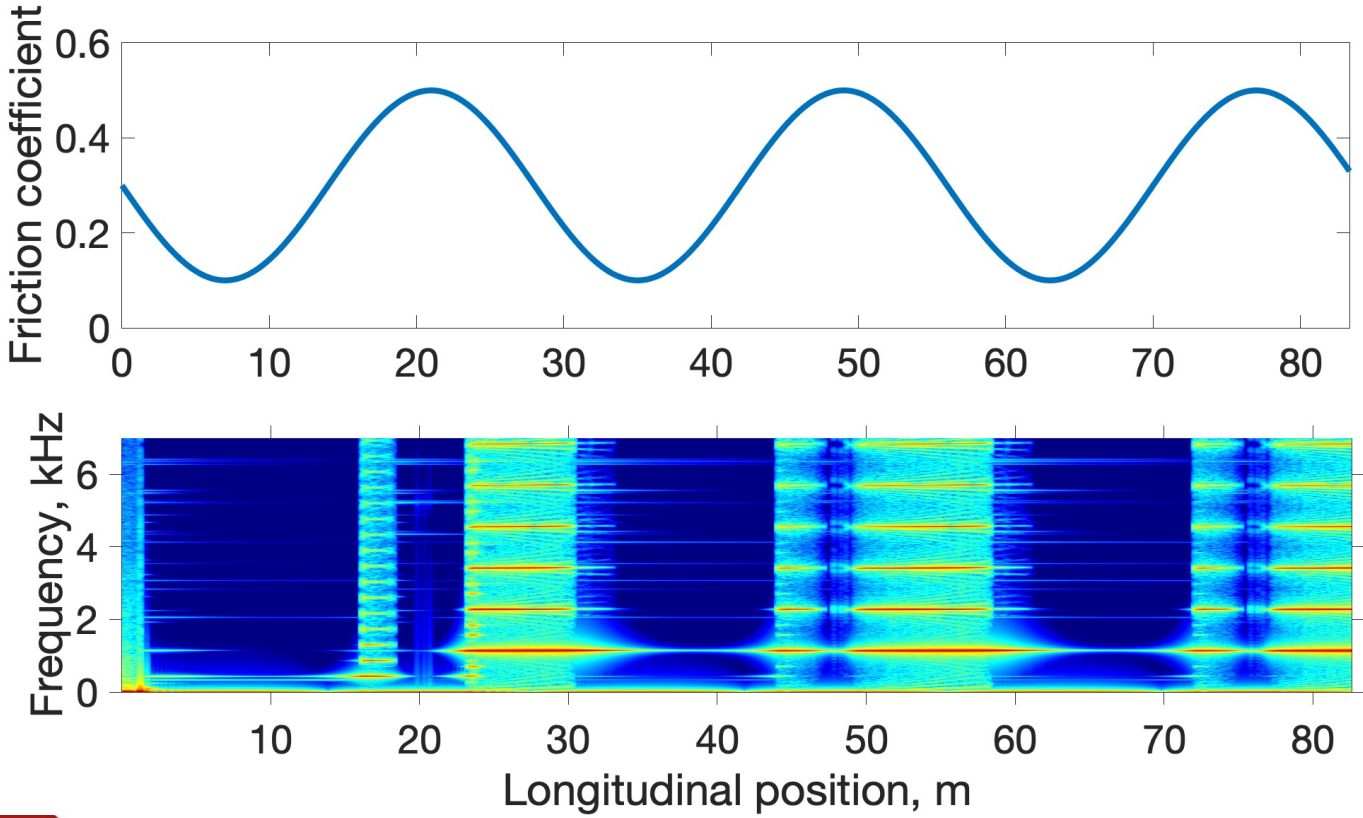

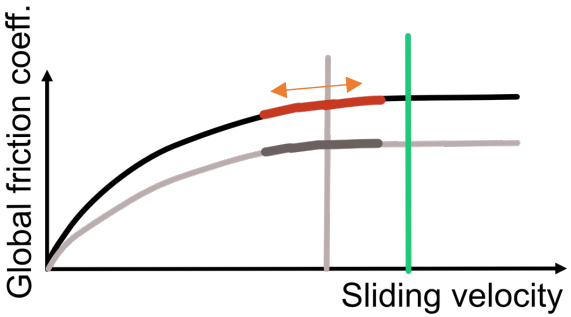

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Realistic curving scenario

- 120 m radius curve on Stockholm metro
- Transition curve (0-50 m) + circular curve
- Precalculation of contact position and lateral creepage with SIMPACK
- Focus on leading inner wheel
- Constant rail profile, constant friction

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Realistic curving scenario

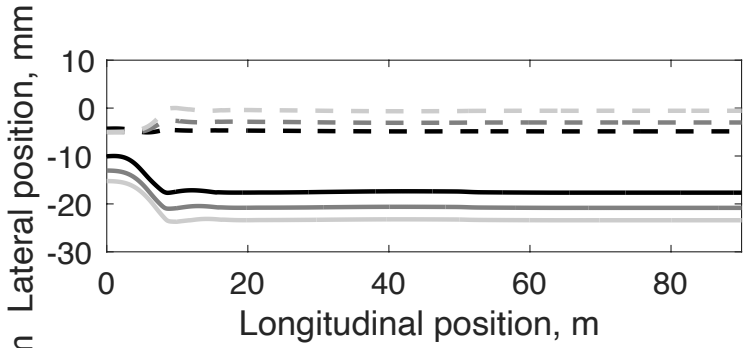
Result from SIMPACK

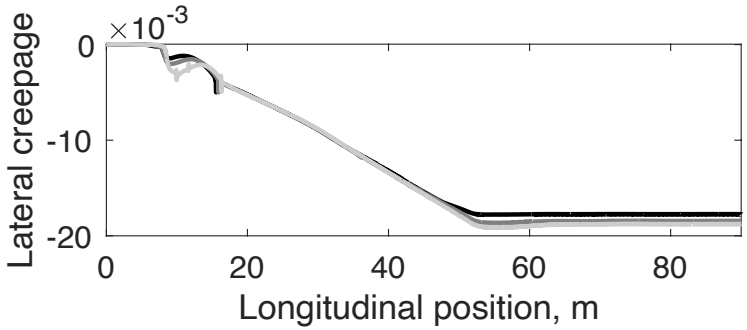
Gauge in mm
1435
1440
1445

Contact on wheel (—) and rail (- - -)

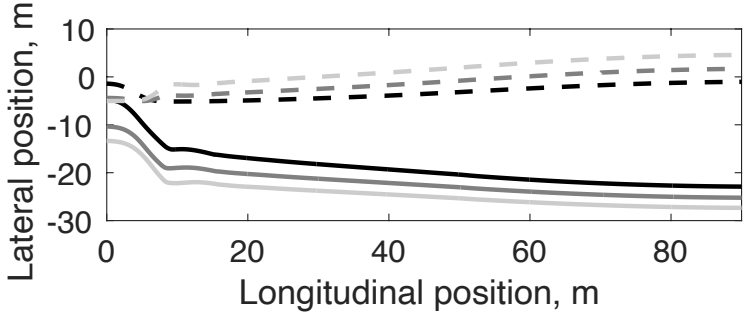
Lateral creepage

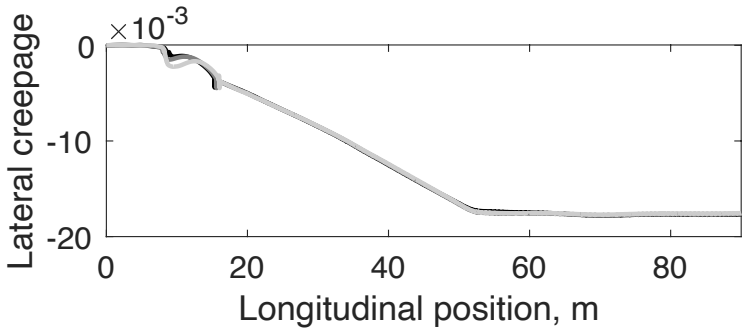
30 km/h





40 km/h





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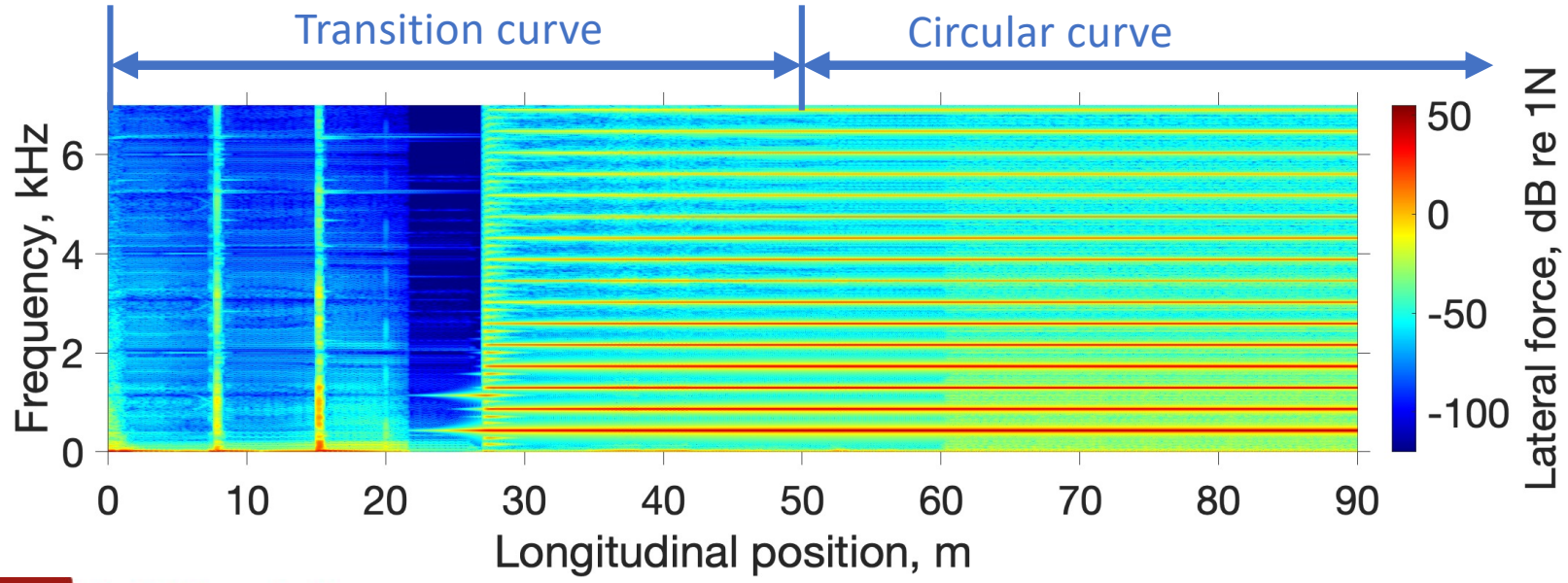
Realistic curving scenario

Result from WERAN

- Similar results in all 6 cases
- Slightly different squeal amplitudes



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Conclusions

- A detailed time-domain model for curve squeal has been extended to allow for transient curving.
- Time-varying contact parameters such as contact position, lateral creepage, and friction coefficient can lead to on- and offset of squeal.
- The history of the wheel/rail dynamics can also have an influence on the occurrence of squeal and the selection of the squeal frequency.

Acknowledgements

Funding from

- the EU's Horizon 2020 research and innovation programme in the **In2Track3** project (grant agreement no 101012456)
- the **Swedish Transport Administration** in the project "Curve squeal – Influence of track design and maintenance status" (TRV 2020/49829)

is greatly acknowledged.

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TRAFIKVERKET

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