A three-dimensional numerical model for impact forces due to wheel flats

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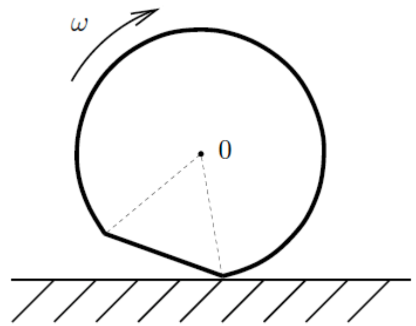
INTRODUCTION

Introduction

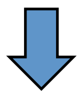


Wheel flats

- are caused by unintentional sliding of the wheel on the rail.
- are severe wheel defects
- result in high impact forces that lead to
  - high noise radiation
  - (further) wheel and track damage

Research questions

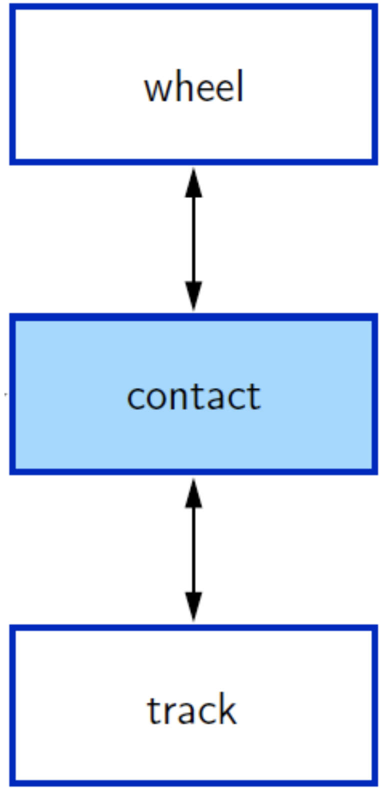
- What is the influence of flat shape, flat dimensions and train speed on simulated impact forces due to wheel flats?
- What is the influence of contact modelling?
- Which level of model complexity is required?



Comparison of results from different contact models:

– Non-Hertzian contact models: 3D, 2D

– Non-linear Hertzian contact spring



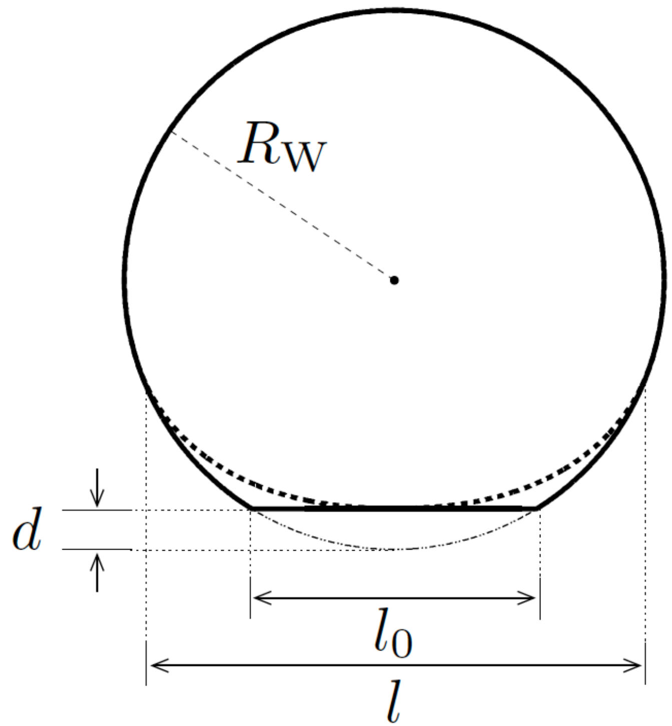
DESCRIPTION OF WHEEL FLATS

Description of wheel flats (2D)

Newly formed wheel flat:

- depth d, length l_0
- profile deviation:

$$z_{\mathrm{nf}} \approx d - \frac{x^2}{2\,R_{\mathrm{W}}}\,, \qquad -\frac{l_0}{2} \leq x \leq \frac{l_0}{2}$$



Rounded wheel flat:

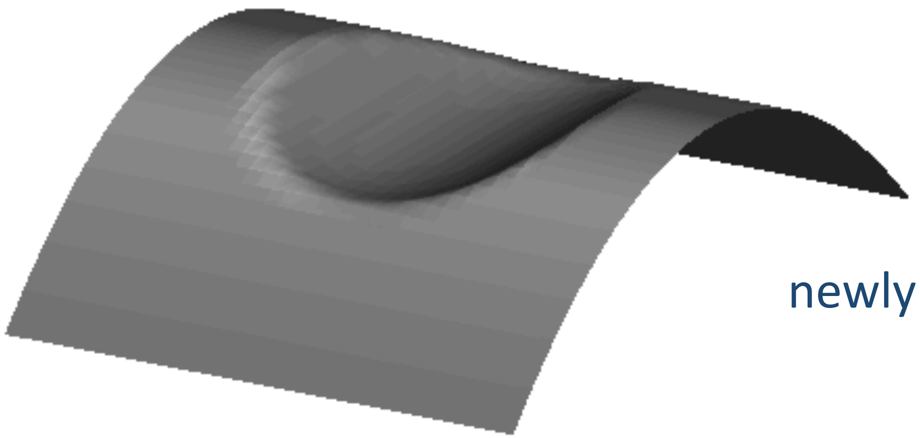
- depth d, length $l > l_0$
- profile deviation:

$$z_{\mathrm{rf}} = \frac{d}{2}\left(1 + \cos\left(2\pi\frac{x}{l}\right)\right)\,, \qquad -\frac{l}{2} \leq x \leq \frac{l}{2}$$

Description of wheel flats (3D)

Assumptions:

- The shape of the newly formed flat corresponds to the shape of the rail head on which it was formed (Baeza et al., 2006).
- The rounded wheel flat develops from the newly formed flat (as in the 2D case).



newly formed flat

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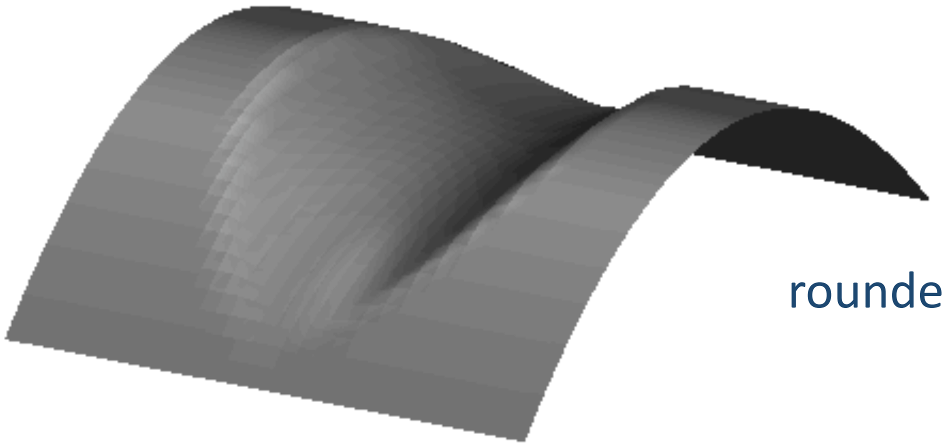
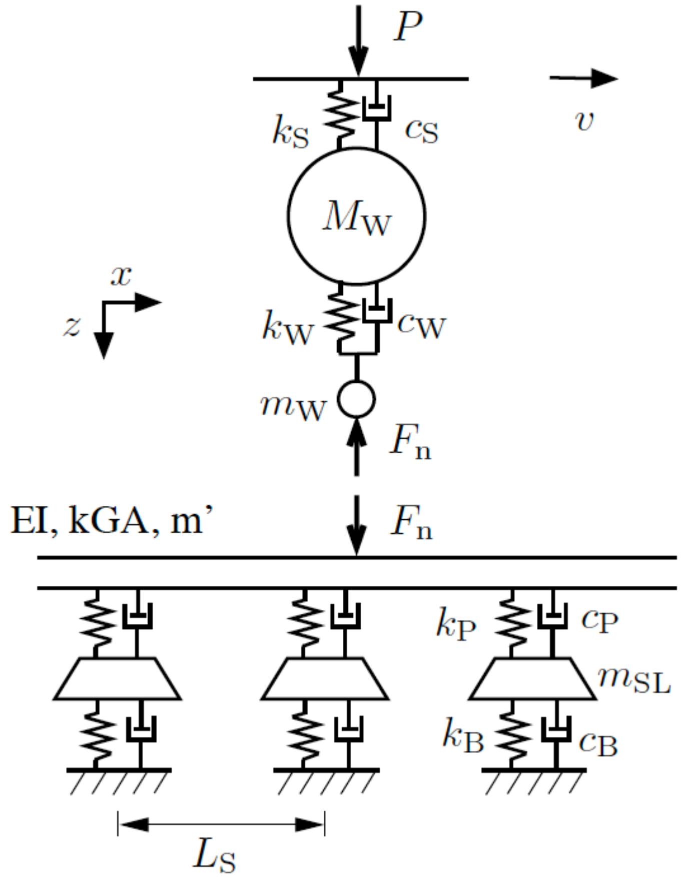


rounded flat

WHEEL/RAIL INTERACTION MODEL

Wheel/rail interaction model

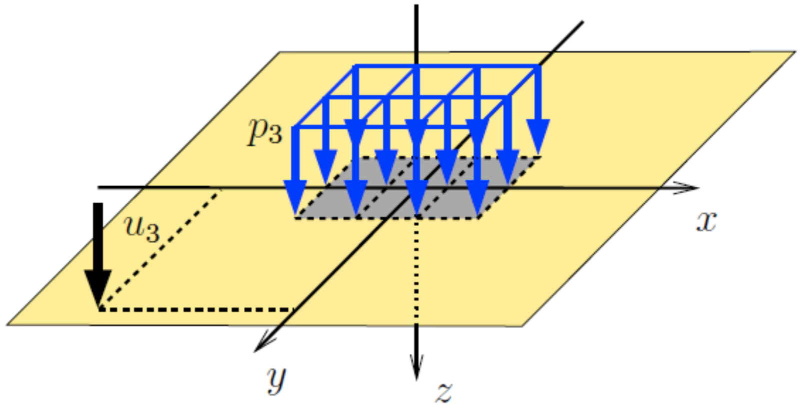
- time-domain model
- vertical interaction only
- linear wheel model: 2 dof model
- linear track model: FE model with discrete supports (Nielsen and Igeland, 1995)
- wheel and track are represented by pre-calculated impulse response functions
- non-linear contact model (4 different)



Wheel/rail interaction model

Contact model A: 3D model

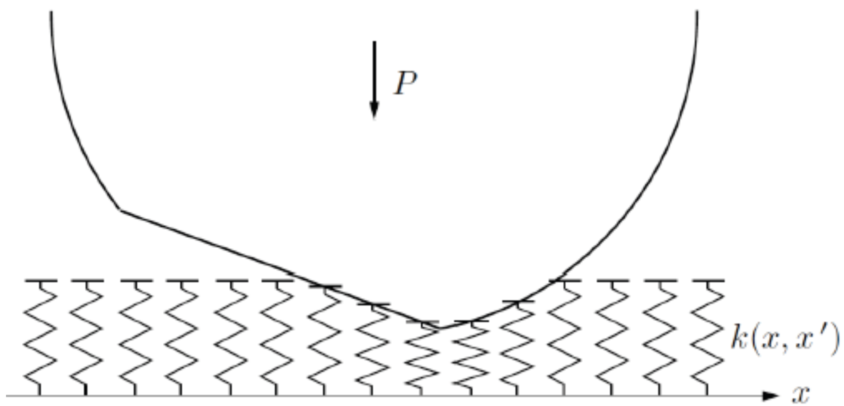
- implementation of Kalker's variational method (Kalker, 1990)
- local approximation of wheel and rail by elastic half-spaces
- consideration of 3D shape of the wheel flat



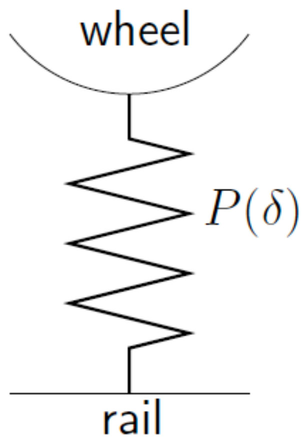
Wheel/rail interaction model

Contact model B: 2D model

- Winkler bedding of independent springs
- consideration of the wheel flat shape on one line in rolling direction
- correct wheel geometry (i.e. radius), contact load and contact deflection, but incorrect contact length



Wheel/rail interaction model

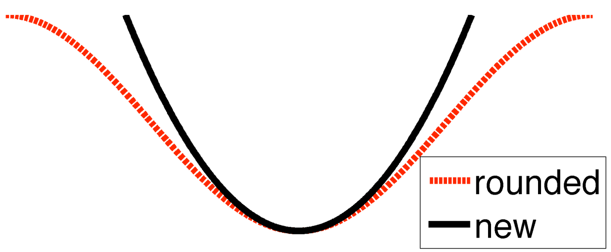


Contact model C and D: Hertzian spring

- one effective contact point
- two different versions of the model based on the relative displacement input between wheel and rail:

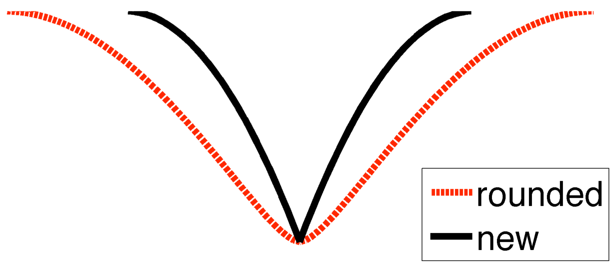
Version 1:

wheel profile deviation (pd)



Version 2: (Wu and Thompson, 2002)

wheel centre trajectory (ct)



NUMERICAL RESULTS

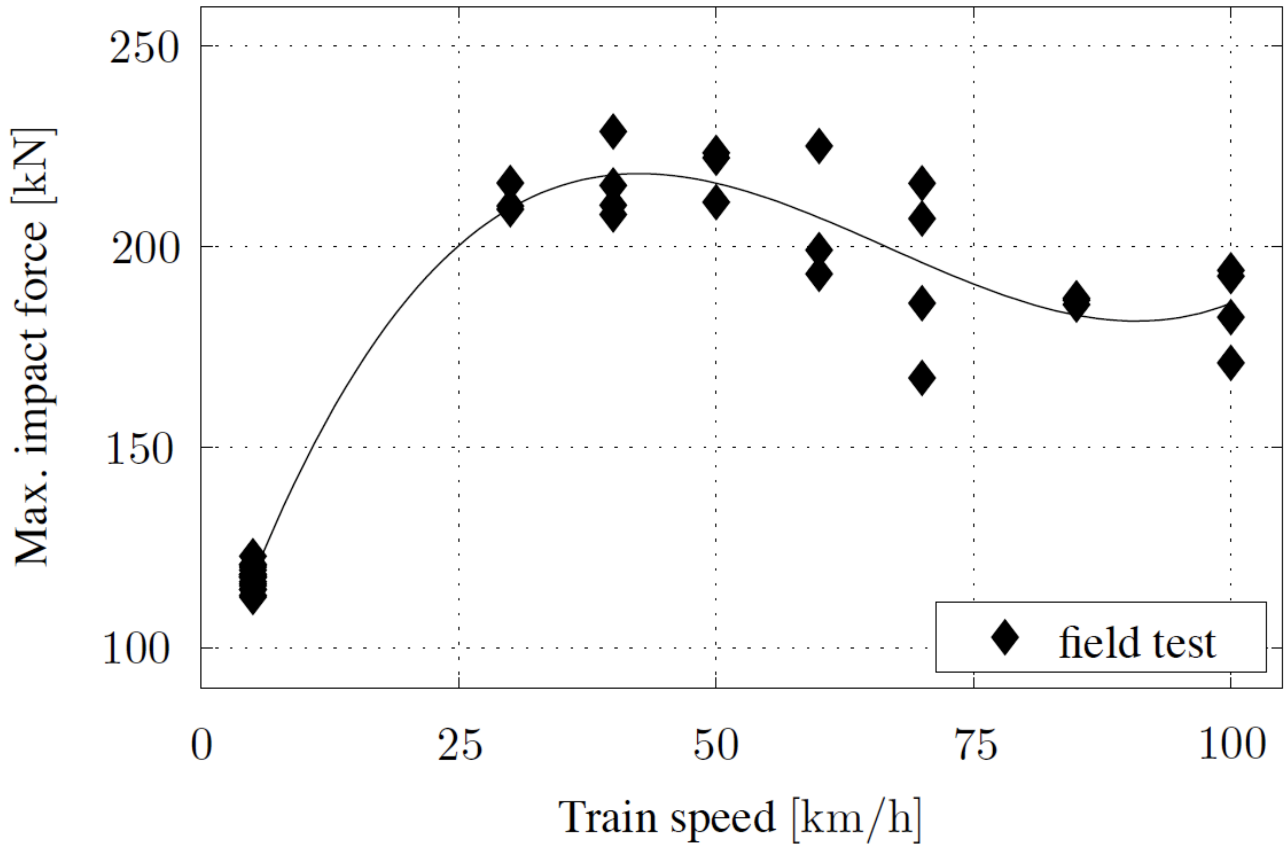
Comparison to field measurements

Field measurements of impact forces on "Svealandsbanan"

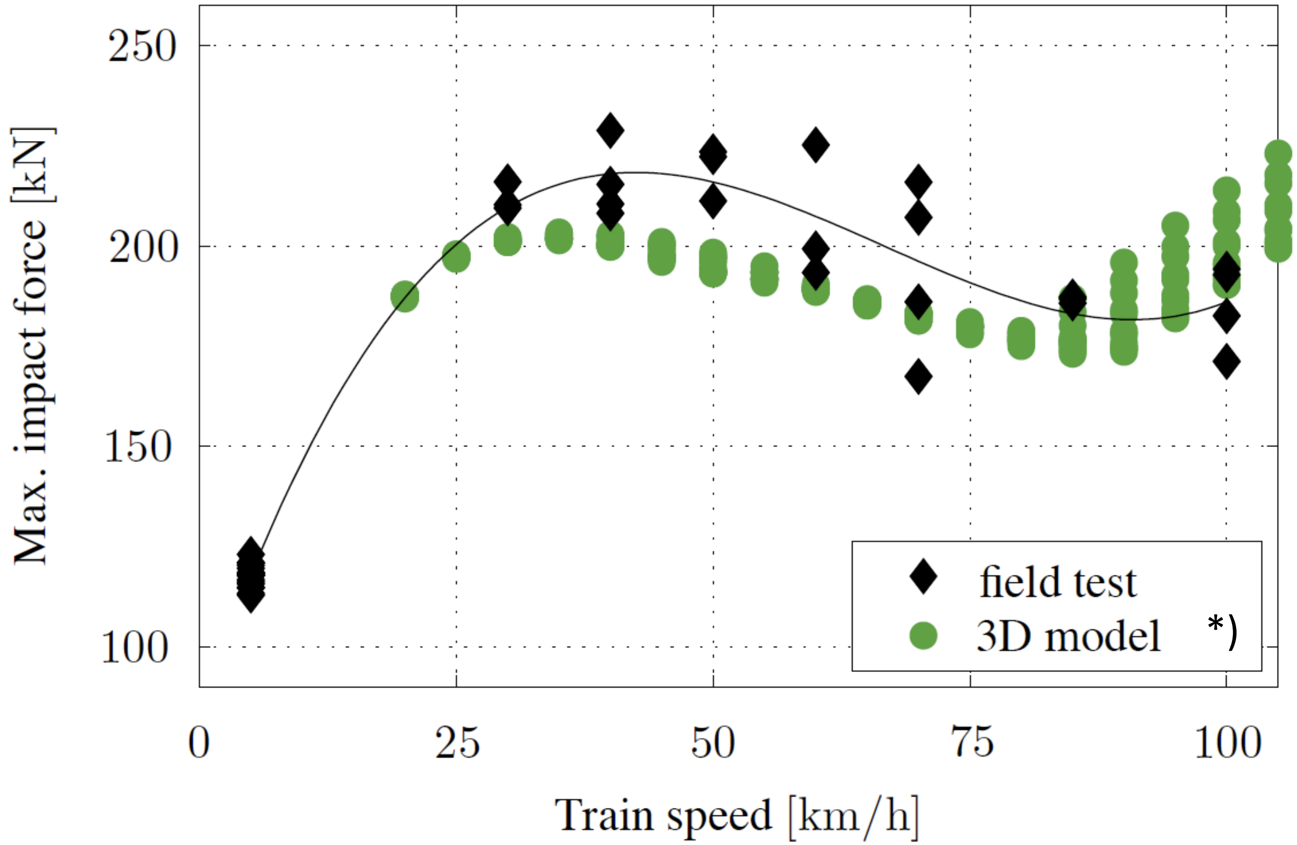
(Johansson and Nielsen, 2003)

- freight train with axle load 24 metric tonnes
- rounded wheel flat
  - depth d = 0.9 mm
  - length l = 10 cm
  - exact shape of wheelflat unkown
- receptance of the loaded track could not be measured in the frequency range of interest

Comparison to field measurements



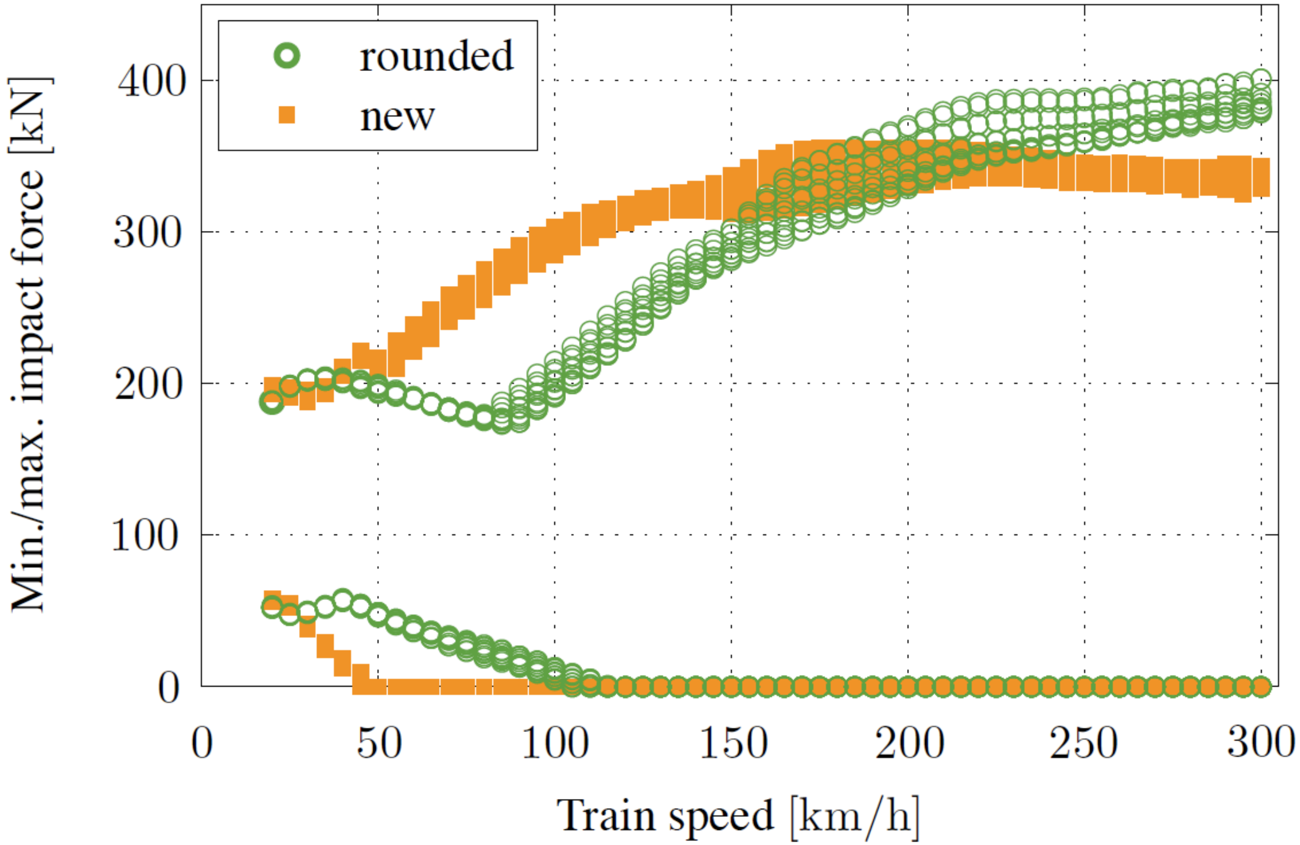
Comparison to field measurements



*) Results for 10 different impact positions on the discretely supported rail

Parameter study: 3D contact model

Influence of train speed and impact position

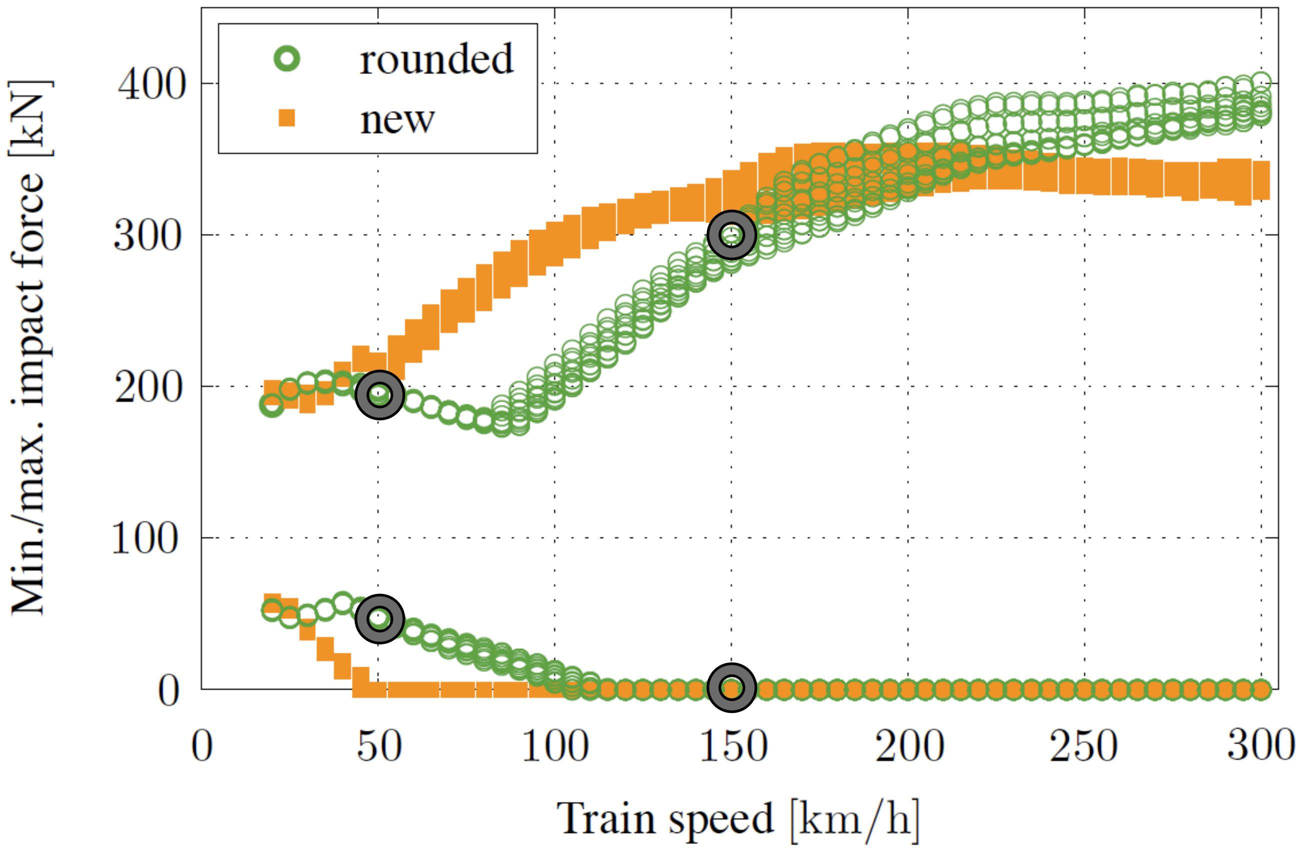


Rounded wheel flat:
- d=0.9 mm
- l=1.76 l_0=10 cm

Newly formed wheel flat:
- d=0.9 mm
- l_0=5.7 cm

Parameter study: 3D contact model

Influence of train speed and impact position



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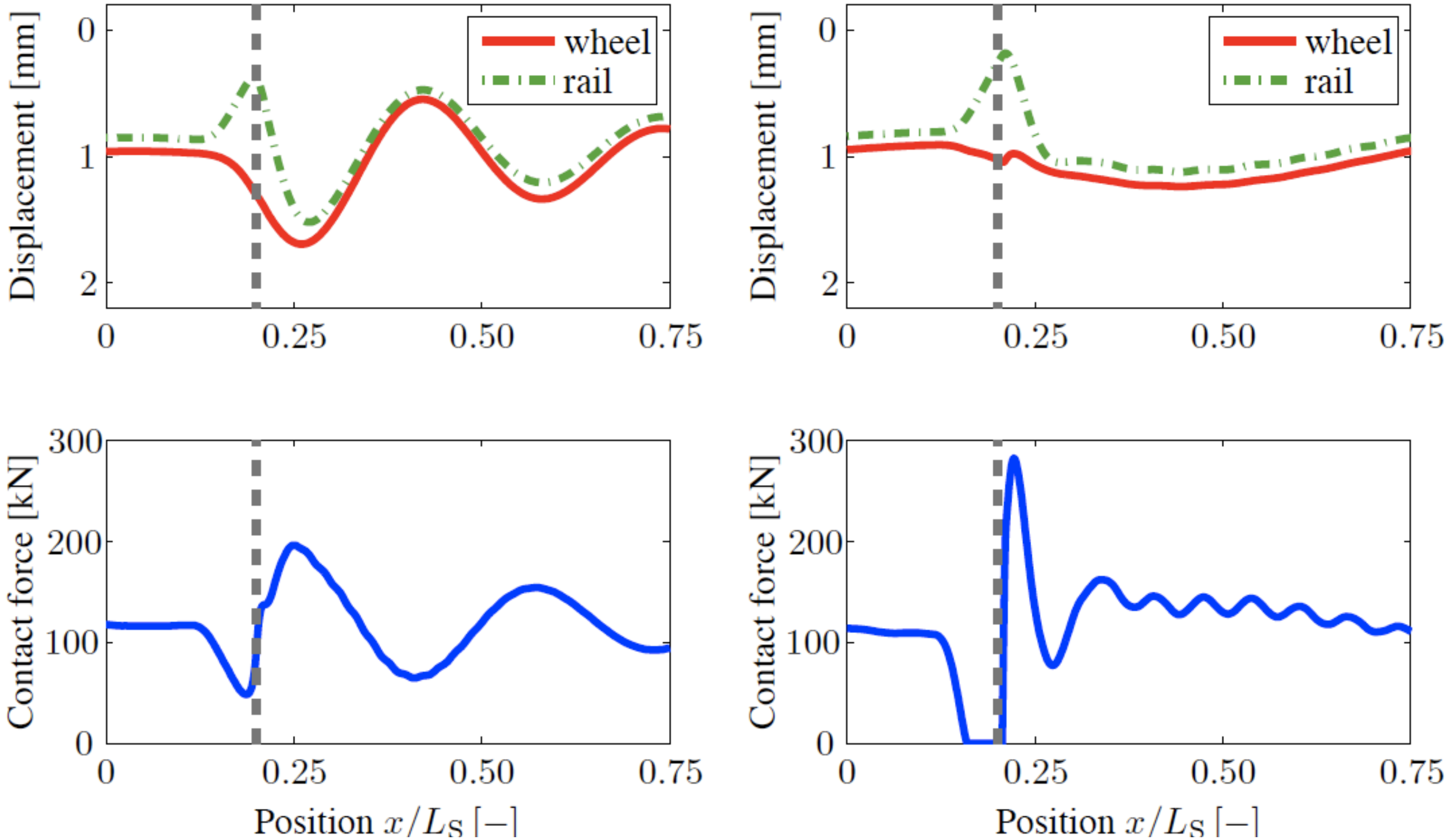
Parameter study: 3D contact model

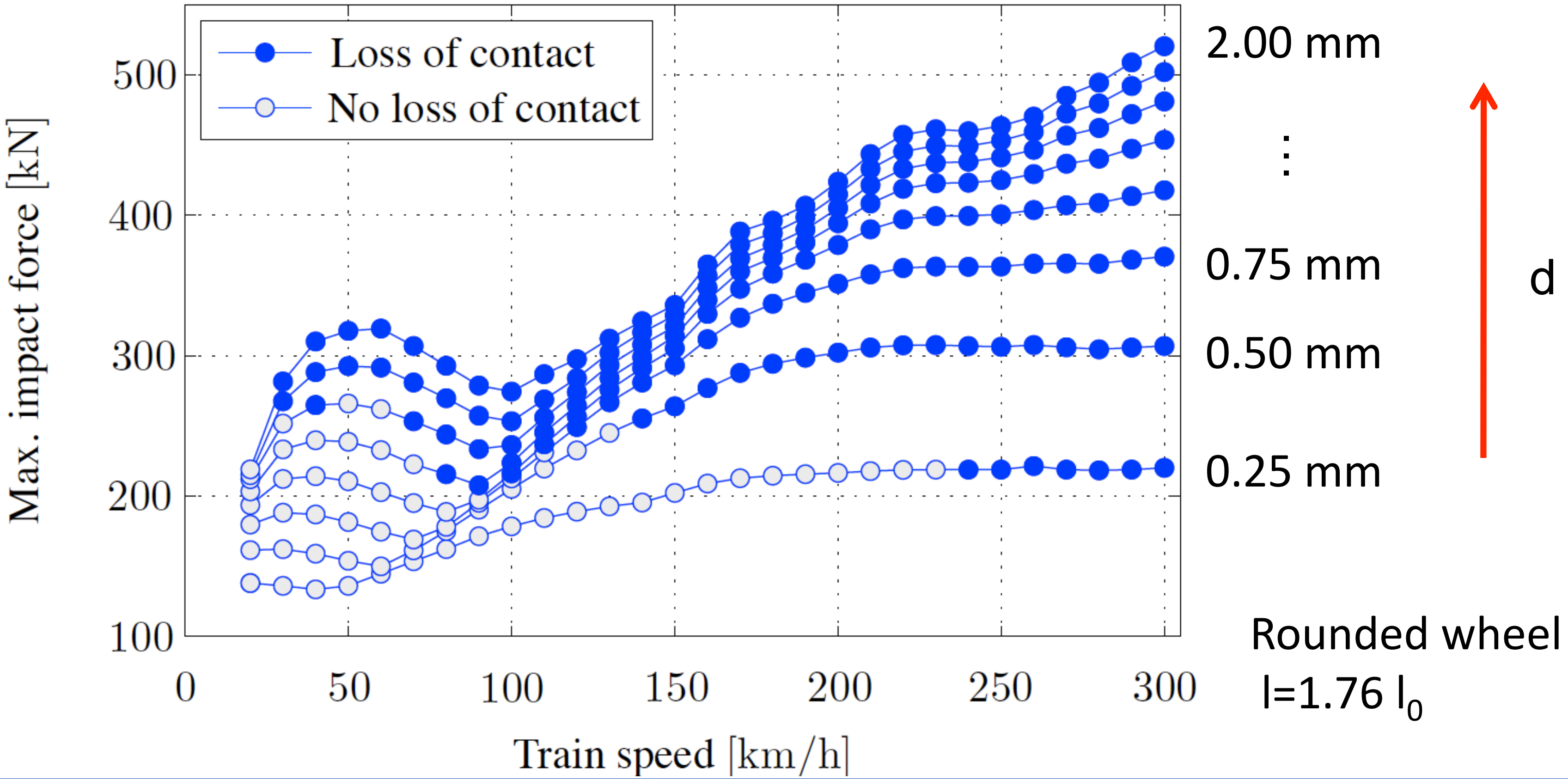
Examples of time series: rounded wheel flat

50 km/h 150 km/h



Parameter study: 3D contact model

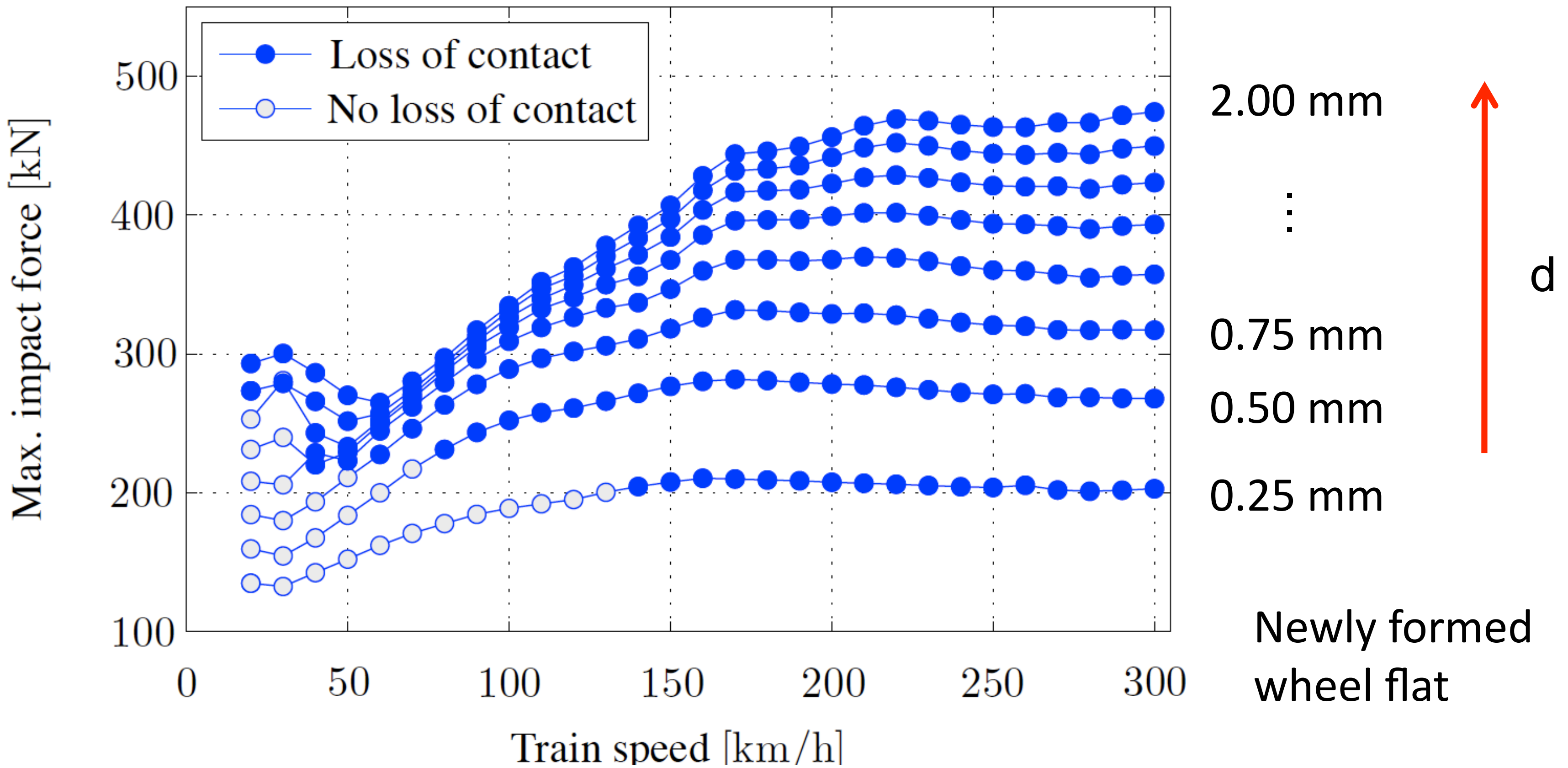
Influence of wheel flat depth and train speed



Rounded wheel flat:
$l=1.76\ l_0$

Parameter study: 3D contact model

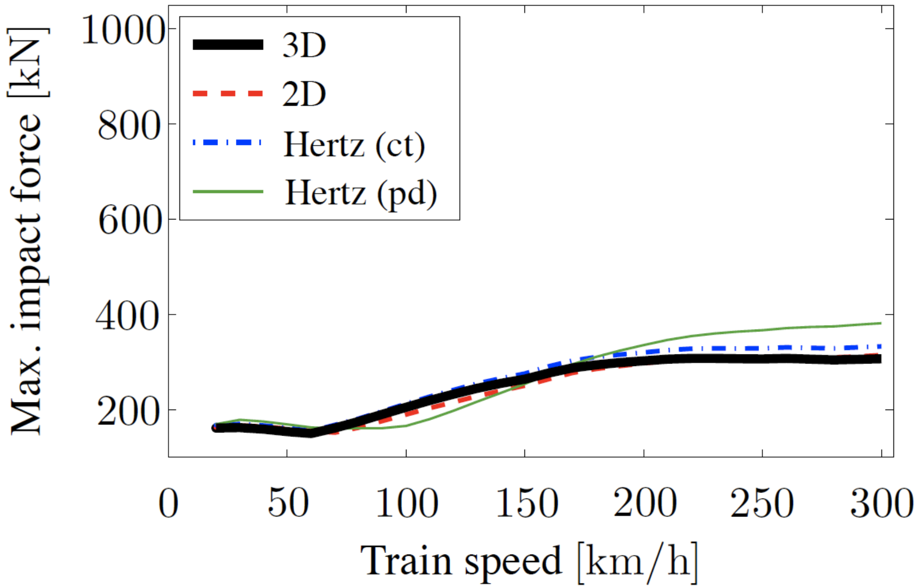
Influence of wheel flat depth and train speed



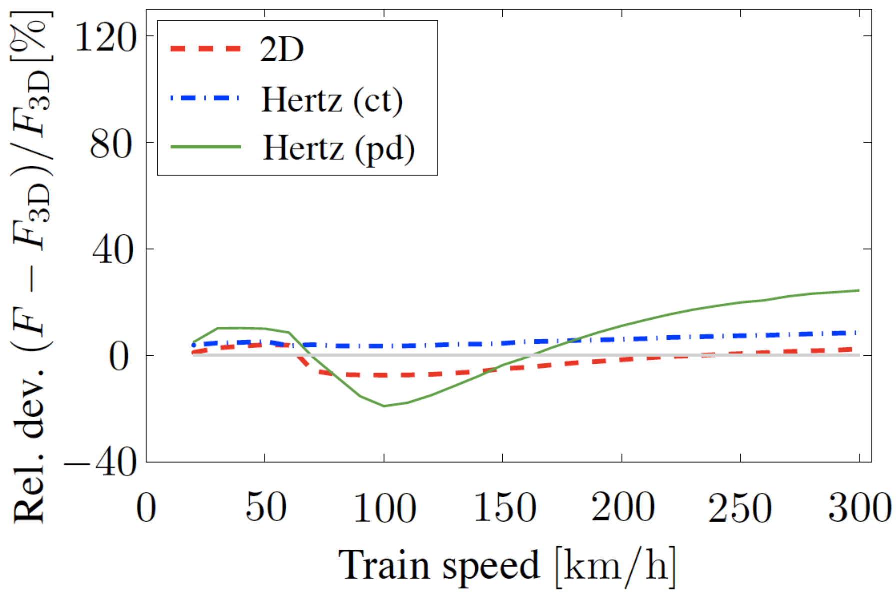
Comparison of contact models

Rounded wheel flat, depth d=0.5 mm

Absolute results

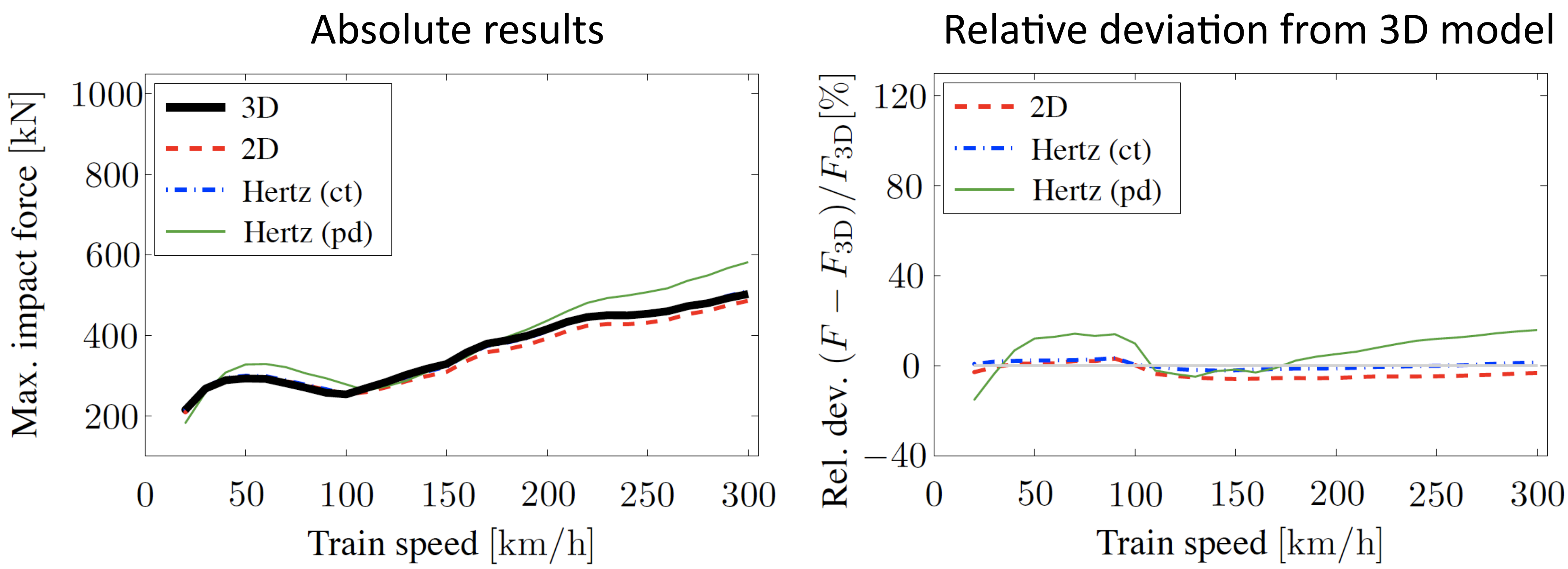


Relative deviation from 3D model



Comparison of contact models

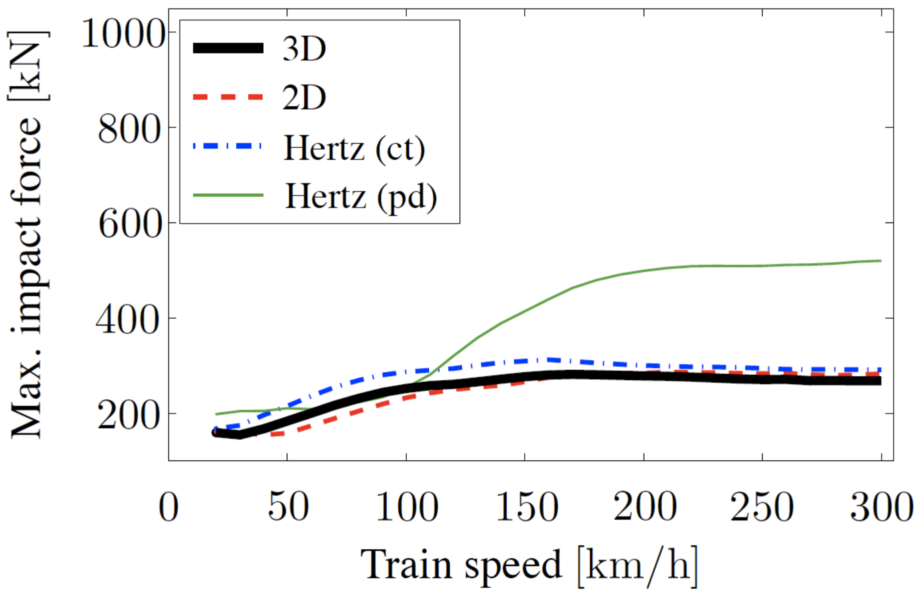
Rounded wheel flat, depth d=1.75 mm



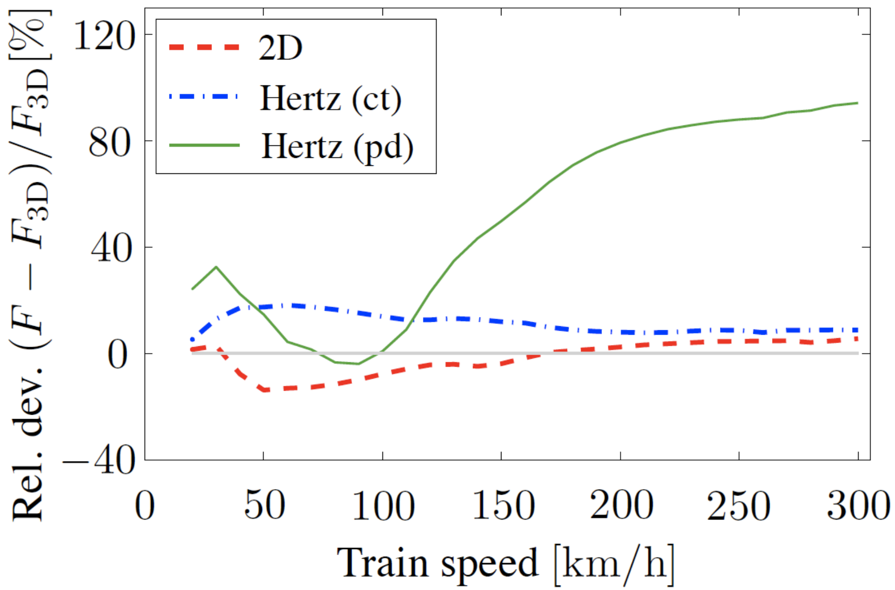
Comparison of contact models

New wheel flat, depth d=0.5 mm

Absolute results



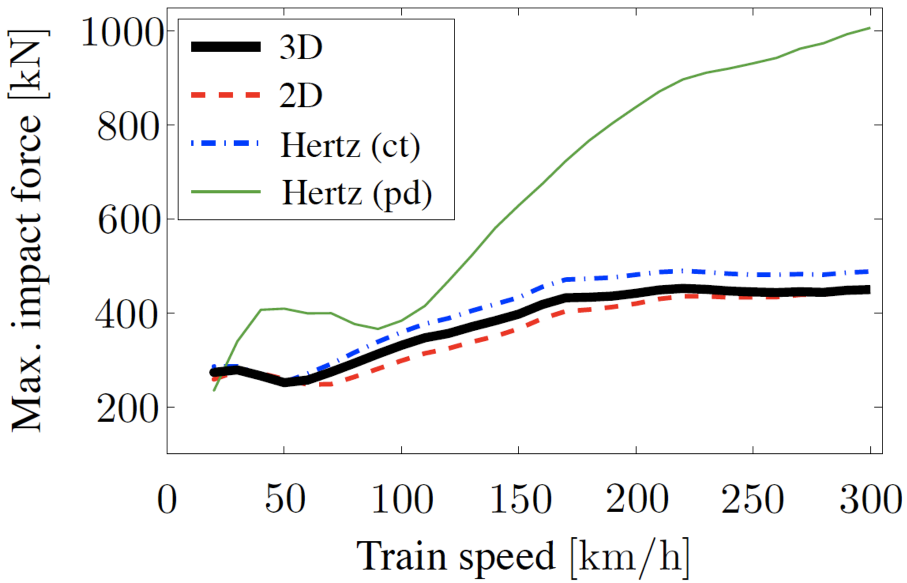
Relative deviation from 3D model



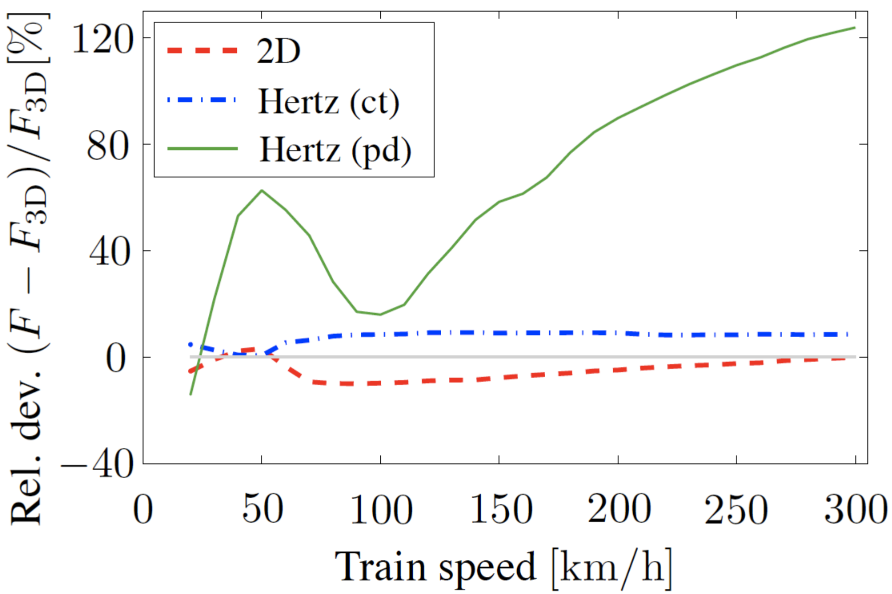
Comparison of contact models

New wheel flat, depth d=1.75 mm

Absolute results



Relative deviation from 3D model



CONCLUSIONS

Conclusions

Dynamic wheel/rail interaction caused by wheel flats has been studied with four different contact models:

- Non-Hertzian 3D
- Non-Hertzian 2D
- Hertzian with the pre-calculated wheel centre trajectory (ct) as input
- Hertzian with the wheel profile deviation (pd) as input

Results:

- The 2D contact model generally slightly underestimates the maximum impact force.
- The Hertzian model (ct) generally slightly overestimates the maximum impact force.

Conclusions

- The Hertzian model (pd) may lead to a substantial overestimation of the results (especially for new wheel flats).
- The wheel flat depth and the wheel flat shape in rolling direction (newly formed or rounded) have a strong influence on the maximum impact force.

⇓

The calculated impact forces are more sensitive to differences in shape of the wheel flat than the formulation of the contact (excluding the Hertzian model with the wheel profile deviation as input).