KTH Engineering Sciences

COMPARISON OF NON-ELLIPTIC CONTACT MODELS: TOWARDS FAST AND ACCURATE MODELLING OF WHEEL-RAIL CONTACT

Matin S. Sichani, Roger Enblom, Mats Berg

Department of Aeronautical and Vehicle Engineering

School of Engineering Sciences

Royal Institute of Technology (KTH)

Stockholm, Sweden

KTH Engineering Sciences

Background

Introduction

Theory

Results

Conclusions

- Demands to investigate surface deteriorating phenomena
  → accurate contact patch and stress distr. prediction
- Online application of the contact model in MBS codes
  → limitations on computational time

Trade-off between accuracy and time efficiency

- Elliptic models:
  - Hertz, equivalent elastic
  - Non-physical patch estimation and inaccurate stress distr. in several contact cases
- Non-elliptic contact models:
  - Advanced models: using FEM or BEM
  - Fast models: simplified contact conditions

Fast non-elliptic contact models

Introduction
Theory
Results
Conclusions

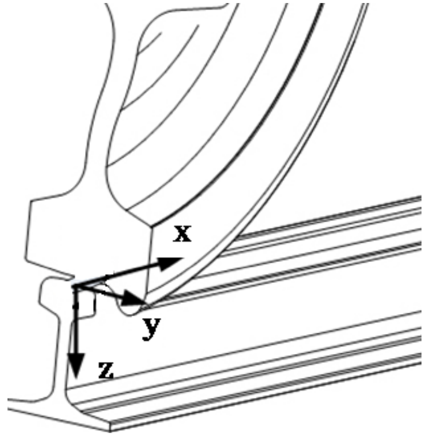
- Analytical estimation of the contact patch
- Based on virtual interpenetration (VI)
- Tangential part based on FASTSIM (Kalker 1982)
- Well-known models:
  - Kik-Piotrowski (1996)
  - Linder(1997)
  - Ayasse-Chollet (2005) (STRIPES)

Virtual interpenetration

- The exact contact equation:

$$z(x,y) = \delta_0 - \bar{u}_z$$

Separation ($z(x,y)$) · Penetration (δ_0) · Normal deformation ($\bar{u}_z$)



- Assume a rigid interpenetration: $\bar{u}_z = 0$

- Penetrate by a fraction of the prescribed pen.: $\delta_v = \epsilon\delta_0$

- Solve the new equation to find the patch boundaries:

$$z(x,y) = Ax^2 + f(y_i) = \epsilon\delta_0$$

Linder method

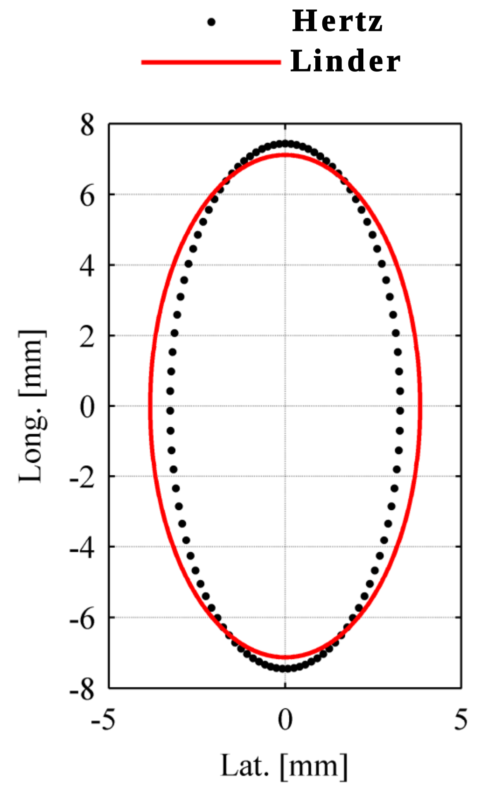
- The scaling factor is set to a constant: $\epsilon = 0.55$
- In a Hertzian case, the semi-axes are:

$$A_0 x^2 + f(0) = \epsilon\delta_0 \Rightarrow x = a = \sqrt{0.55\delta_0/A_0}$$
$$b = \sqrt{0.55\delta_0/B_0}$$

A_0, B_0 :
Curvatures at the point of contact

- The Hertz solution is:

$$a_H = m_0\sqrt{\frac{\delta_0}{r_0(A_0+B_0)}} \qquad b_H = n_0\sqrt{\frac{\delta_0}{r_0(A_0+B_0)}}$$



- The semi-axes ratio:

$$\frac{a}{b} = \frac{B_0}{A_0} \qquad \frac{a_H}{b_H} = \frac{m_0}{n_0}$$

m_0, n_0, r_0 :
Geom. coeff. based on curvatures

- Same results, only if: $B_0 = A_0$

Kik-Piotrowski method

- Same scaling factor but a correction is applied
- Axes ratio is set equal to Hertz's:

$$\frac{a_c}{b_c} = \frac{n_0}{m_0}, a_c b_c = ab$$

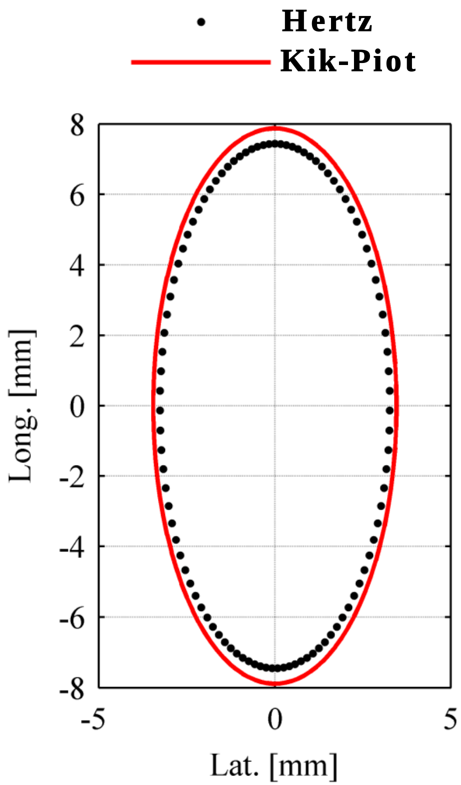
a_c, b_c :
Corrected semi-axes

- The semi-axes are then:

$$a_c = \sqrt{abn_0/m_0} = 0.55\delta_0\sqrt{\frac{n_0/m_0}{A_0B_0}}$$

$$b_c = \sqrt{\frac{ab}{n_0/m_0}} = 0.55\delta_0\sqrt{\frac{m_0/n_0}{A_0B_0}}$$

- Area may still be different from Hertz's!



KTH VETENSKAP OCH KONST
KTH Engineering Sciences

STRIPES (*A*-correction)

- Scaling factor is a constant based on the geometry:

$$\epsilon = \frac{{n_0}^2}{r_0(A_0 + B_0)} B_0$$

A_{ci} :
Corrected curvature at y_i

m_i, n_i, B_i :
Local values at y_i

- Local curvatures at y_i are corrected as well
- If only the long. curvature is corrected:

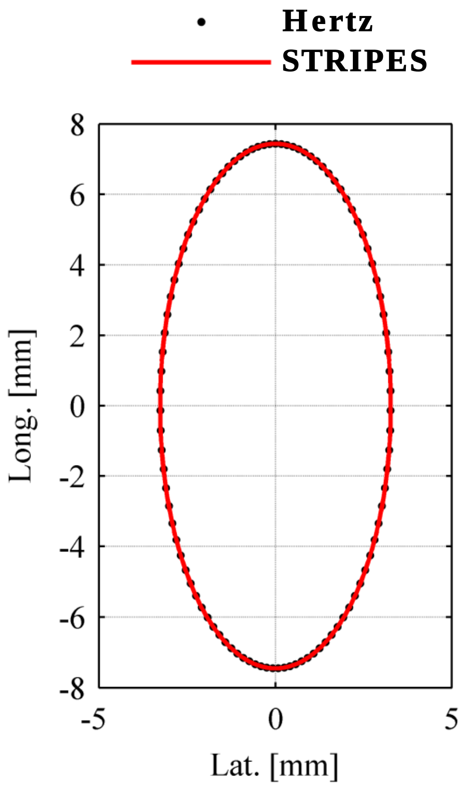
$$A_{c_i} = (n_i/m_i)^2 B_i$$

- Semi-axes are:

$$a = m_0 \sqrt{\frac{\delta_0}{r_0(A_0 + B_0)}}$$

$$b = n_0 \sqrt{\frac{\delta_0}{r_0(A_0 + B_0)}}$$

  - exactly the same as Hertz's !



Introduction
Theory
Results
Conclusions

KTH Engineering Sciences

Introduction

Theory

Results

Conclusions

STRIPES (*A&B*-correction)

- Scaling factor is based on the geometry:

$$\epsilon = \frac{{n_0}^2}{r_0(1 + (n_0/m_0)^2)}$$

- Both curvatures are corrected:

$$A_{c_i} = \frac{(A_i + B_i)(n_i/m_i)^2}{(1 + (n_i/m_i)^2)} \qquad B_{c_i} = \frac{(A_i + B_i)}{(1 + (n_i/m_i)^2)}$$

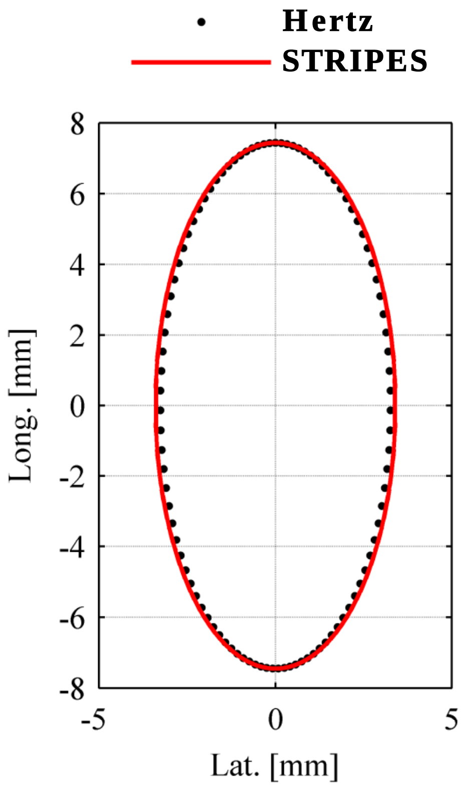
- Semi-axes are:

$$a = \sqrt{\epsilon \delta_0 / A_{c0}} = m_0 \sqrt{\frac{\delta_0}{r_0(A_0 + B_0)}}$$

$$b = n_0 \sqrt{\frac{\delta_0}{r_0(B_0 + B_0(n_0/m_0)^2)}}$$

  - Same length but different width from Hertz's!

- Approaches Hertz's when $A_0/B_0 \to 0$ or 1



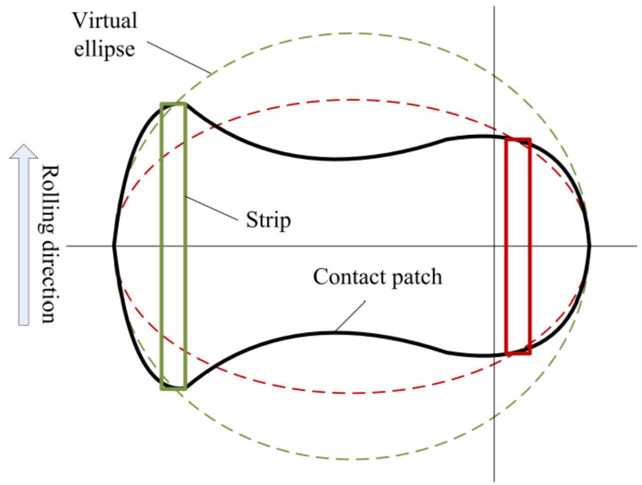
KTH Engineering Sciences

Tangential part

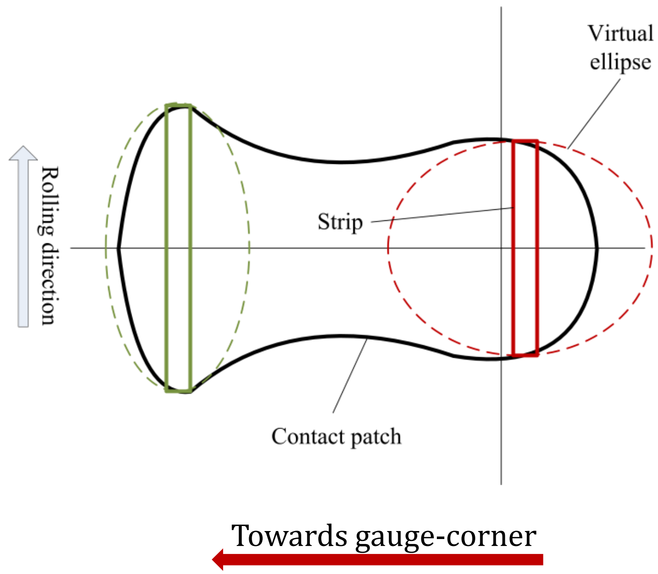
- Tangential part is treated using FASTSIM
- FASTSIM is originally used for elliptical patches
- Equivalent ellipse:
  - Kik and Piotrowski (1996)
  - Defining an equivalent ellipse for each zone, using elliptical flexibility parameters
- Local ellipses for each strip:
  - Linder (1997) , Ayasse and Chollet (2005)
  - Strip discretization of the patch
  - Assigning an ellipse into each strip and using its elliptical parameters

Local ellipse assignment

- Linder method:
    - o All local ellipses have the same lateral semi-axis.



- STRIPES method:
    - o Local ellipses are based on the local curvature values at the centre of the strip



Case study

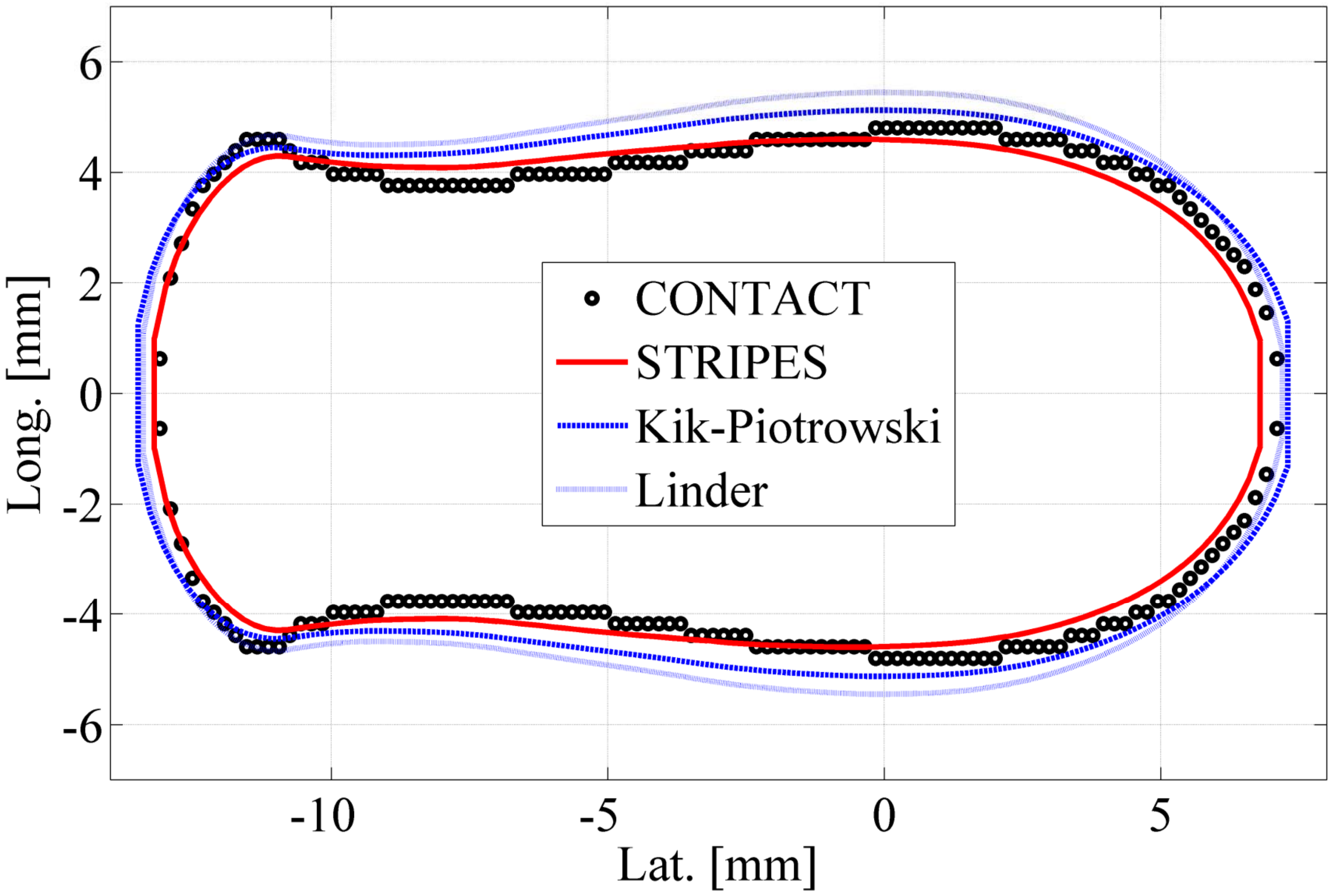
- Models are implemented using MATLAB
  - As documented in the literature
  - STRIPES model: *A*-correction approach

- A single wheel on rail example is solved:
  - Right wheel-rail pair
  - S1002/UIC60 (1:40)
  - Zero lateral displacement (central wheelset position)
  - Normal load: 78.5 kN
  - Spin= 0.052 rad/m (pure spin)

- CONTACT software (BEM) results are taken as reference
  - Since, it is bound to half-space assumption, this case study is confined to tread contact

KTH Engineering Sciences

Contact patch



Towards gauge-corner

KTH VETENSKAP OCH KONST

KTH Engineering Sciences

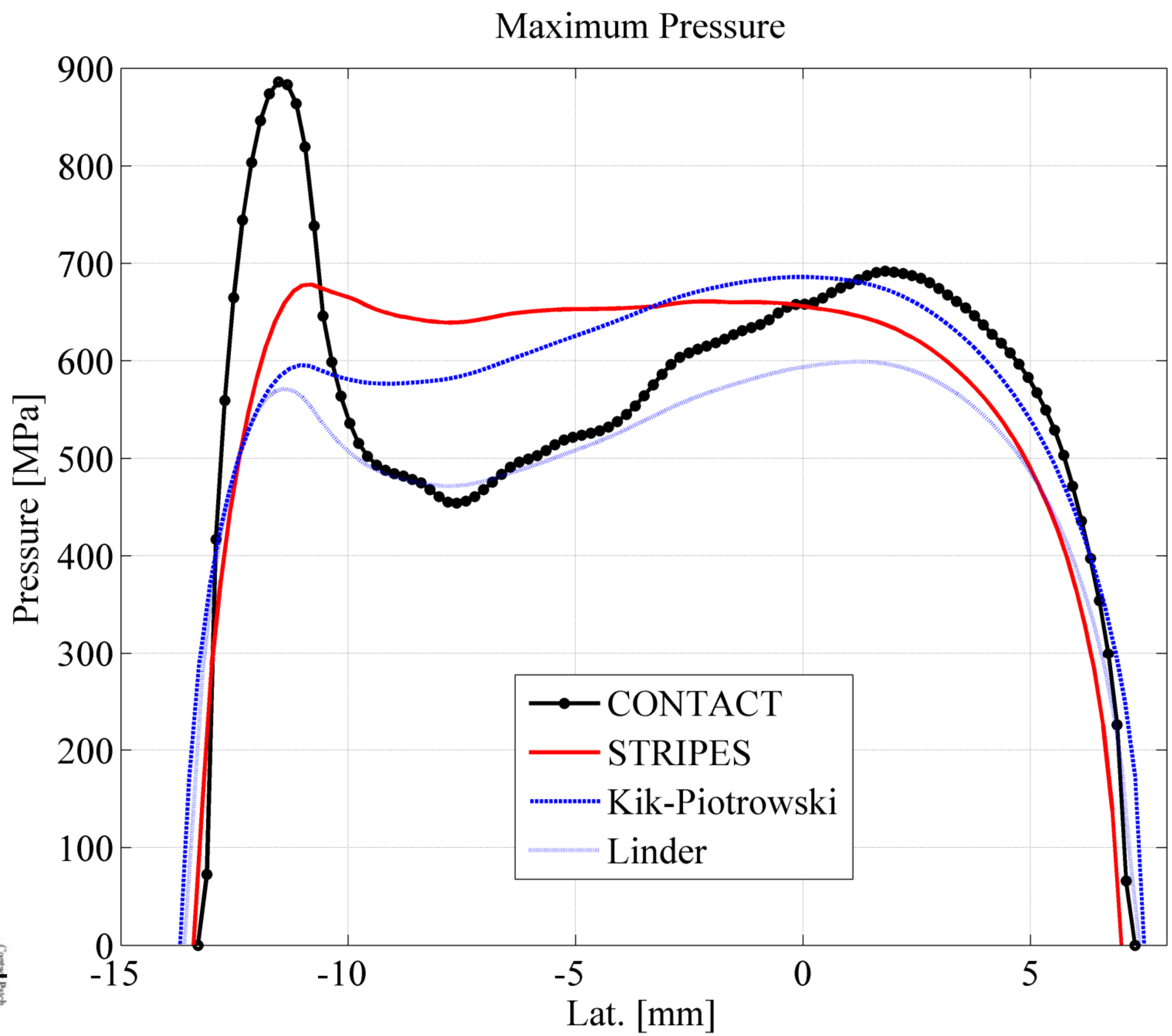
Contact pressure distribution

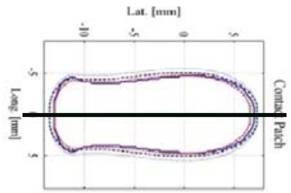
Introduction

Theory

Results

Conclusions



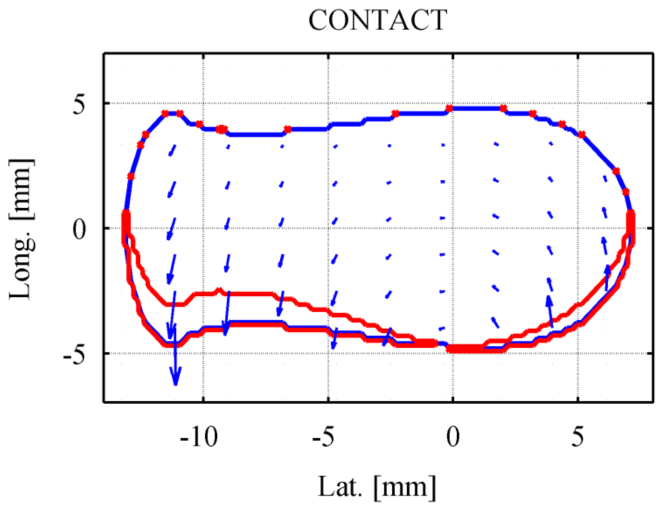


KTH Engineering Sciences

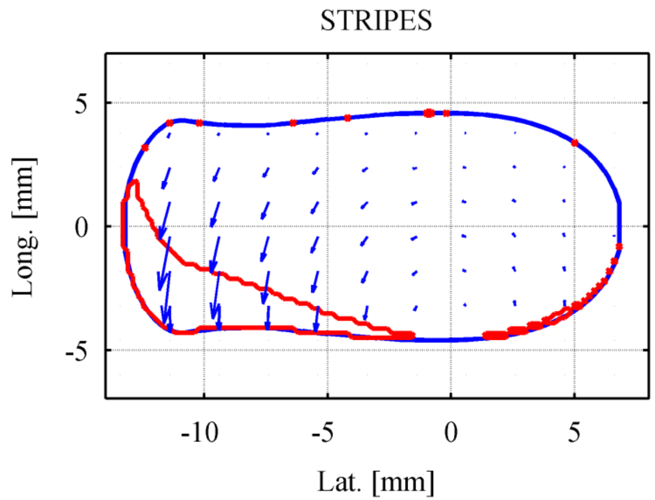
Creep forces

Model	Long.[N]	Lat.[N]	Tot.[N]
CONTACT	-2459	-1558	2916
STRIPES	-5333	-2843	6063
Kik-Piotrowski	-2333	-1258	2650
Linder	-2870	-1672	3322

- Introduction
- Theory
- **Results**
- Conclusions



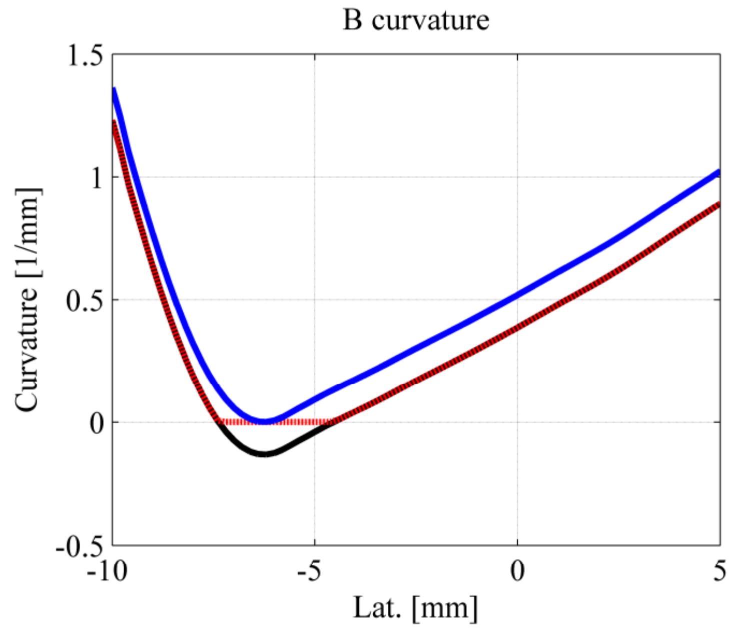
CONTACT: same spin throughout the patch



STRIPES: spin calculated at the center of each strip

Improving pressure distribution

- In STRIPES, negative *B* values are not allowed.
  - The negative *B* is replaced by a minimal positive value
  - Smoothing filter is then applied to achieve smooth patch boundaries

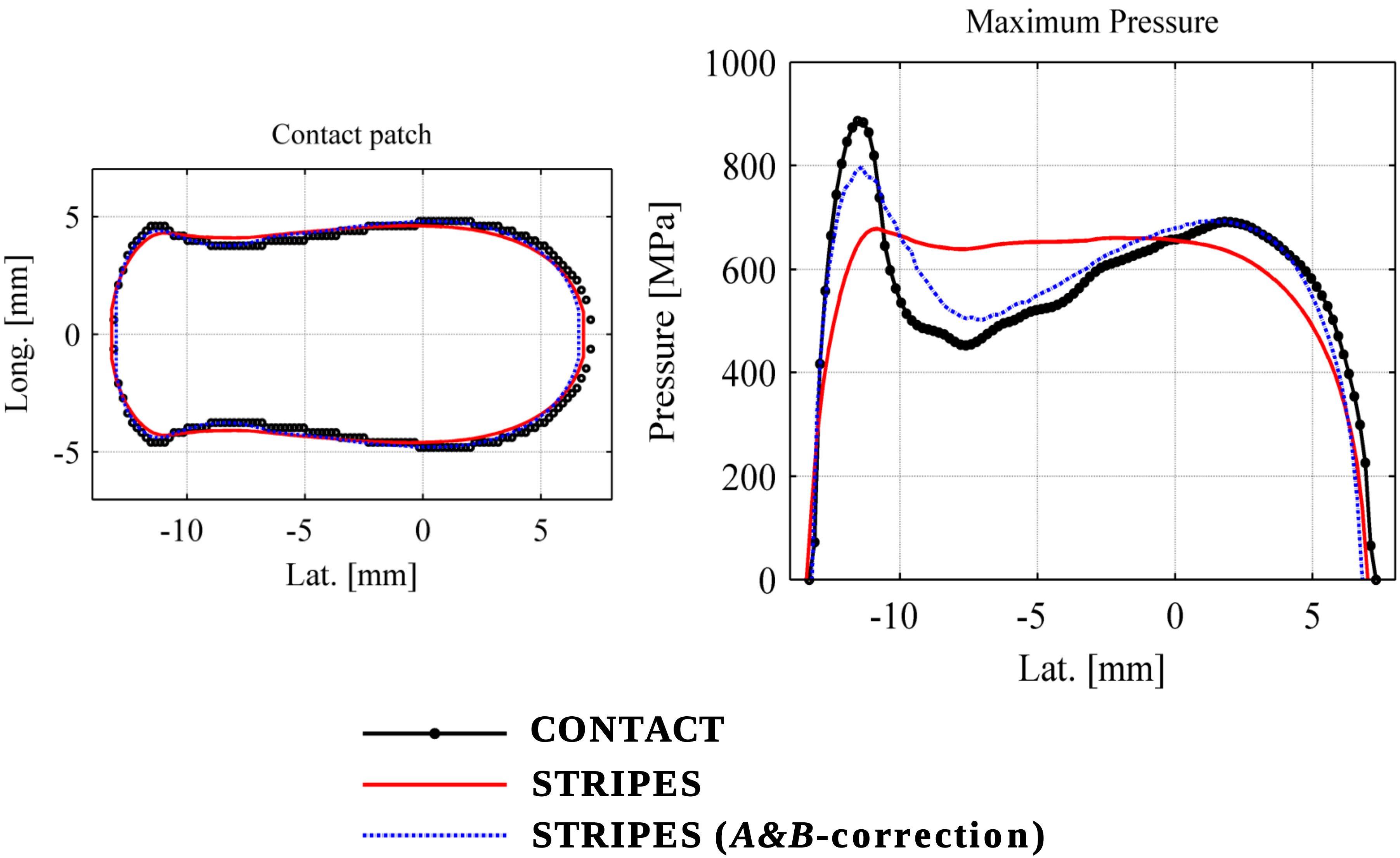


- Smoothing also affects the pressure values and smears out the peaks

- To **avoid smoothing**, a new correction of negative B values is suggested
  - Instead of cutting negative *B* values out, shift them upward
  - Avoid sharp changes in *B*
- Since *A*-correction is sensitive to low *B* values, *A&B*-correction is also of interest.

KTH Engineering Sciences

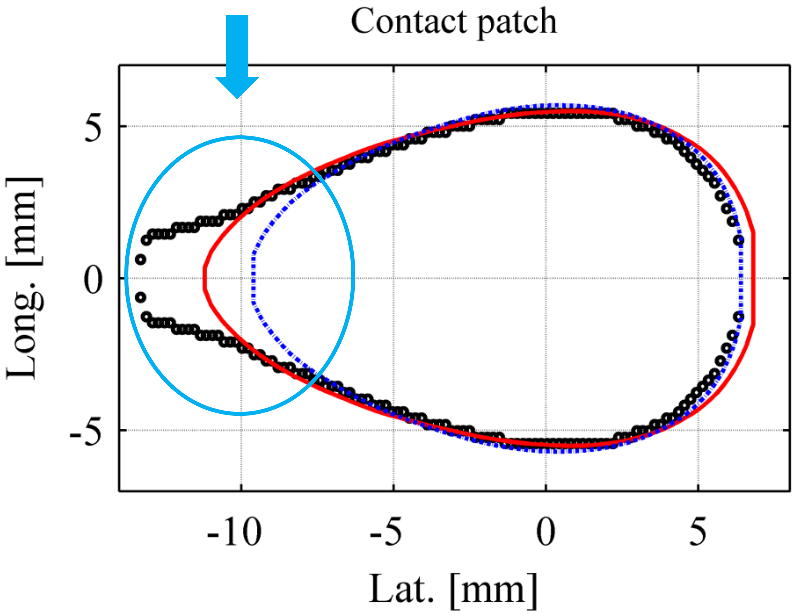
Wheelset central position

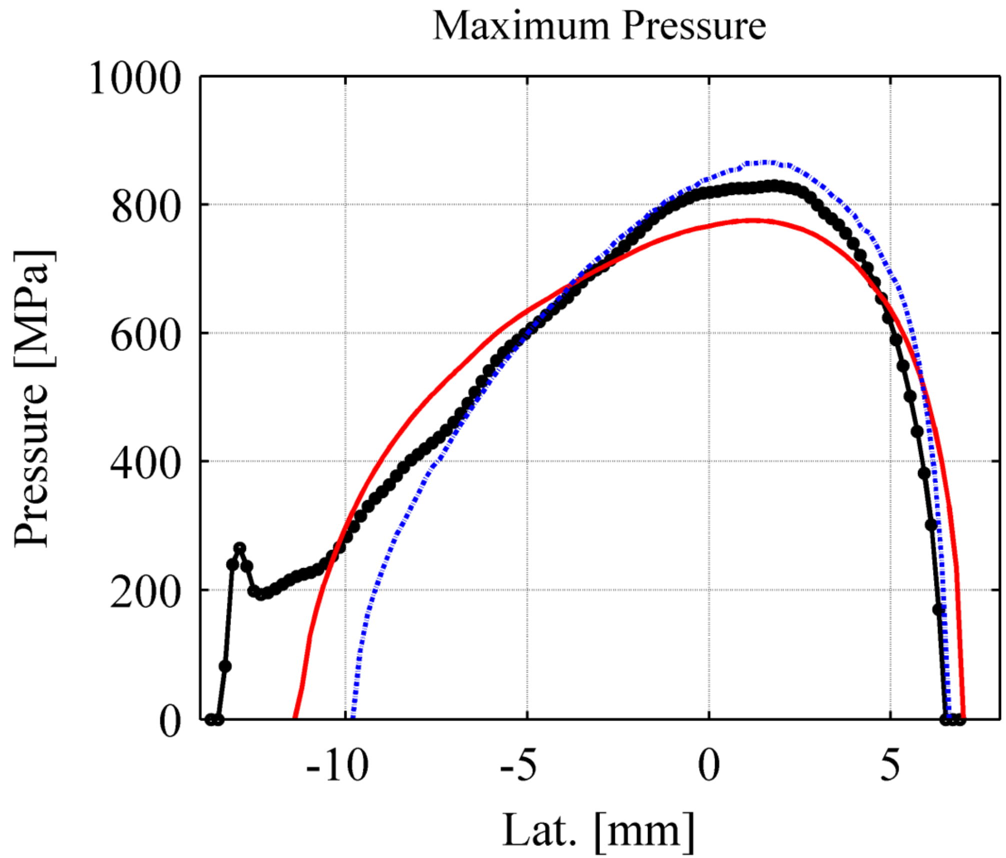


KTH Engineering Sciences

Off-set case: Δy = -1 mm

- Introduction
- Theory
- **Results**
- Conclusions



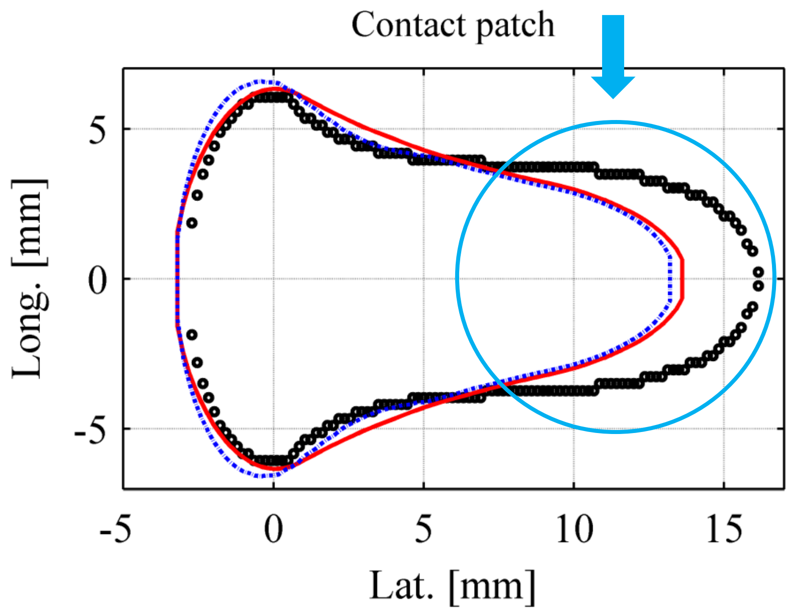


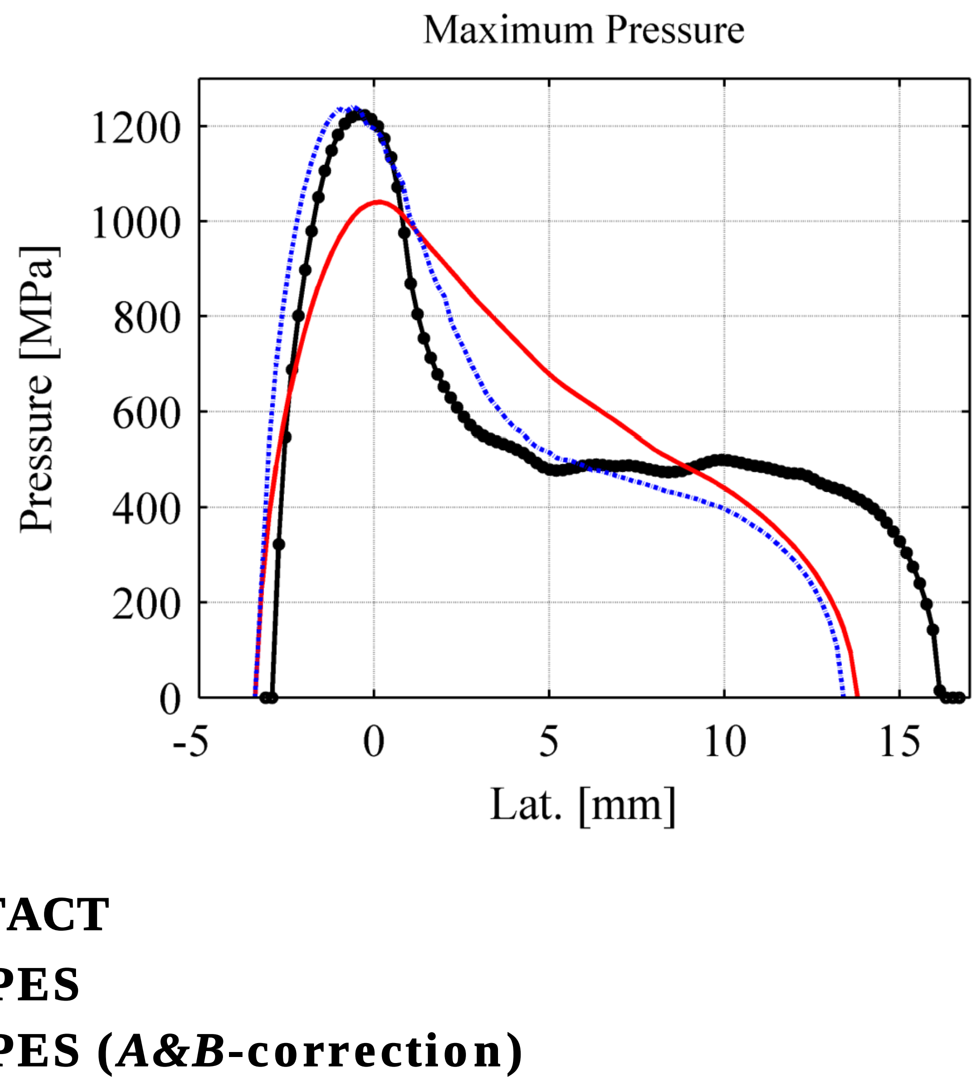
CONTACT
STRIPES
STRIPES (*A&B*-correction)

KTH VETENSKAP OCH KONST

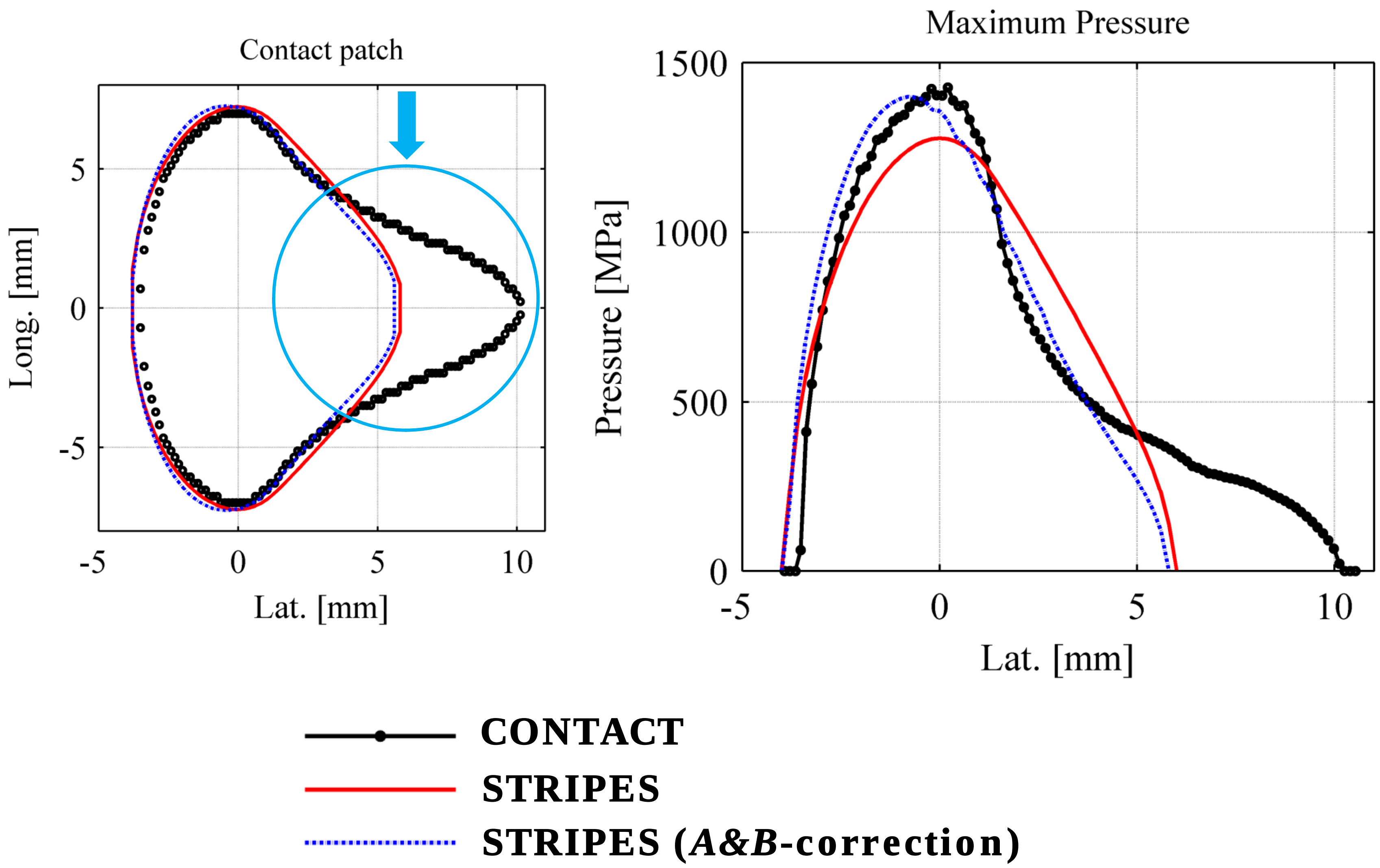
KTH Engineering Sciences

Off-set case: Δy = 1 mm





Off-set case: Δy = 2 mm



Conclusions

KTH Engineering Sciences

- Patch prediction by VI-based models should be improved in off-set cases

- Contact pressure distr. deviates from reference in wheelset central position

- The *A&B*-correction strategy and avoidance of smoothing leads to improved pressure distr. prediction

- Non-planar patch and spin variation considered by STRIPES. Pronounced effects in the gauge-corner contact

KTH Engineering Sciences

Future work

- Comparison of fast non-elliptic models to FEM results in gauge-corner contact
- Improve the contact patch estimation of models based on virtual interpenetration (in off-set cases)
- Investigate the non-elliptic model based on semi-Winkler approach (Telliskivi 2004)

KTH Engineering Sciences

Thanks for your attention!

Any questions or comments?

Matin S. Sichani
Email: matinss@kth.se