Stress distribution in the tyre - road contact patch

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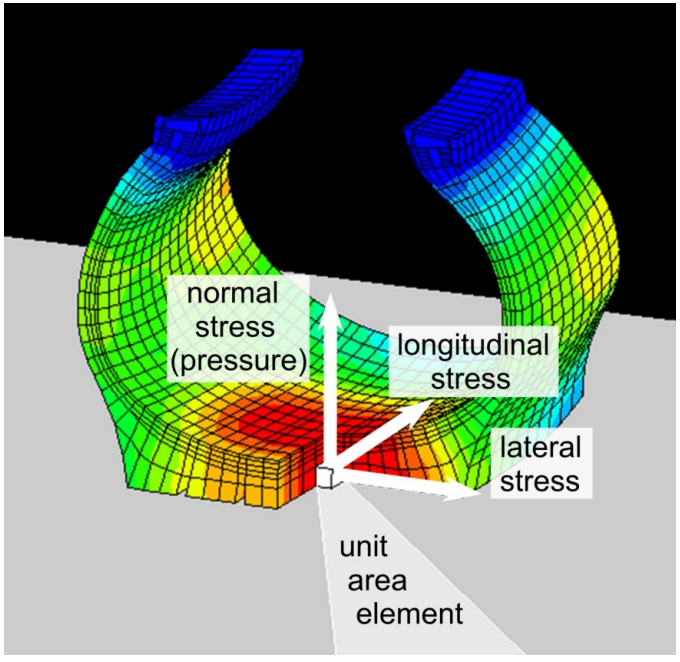
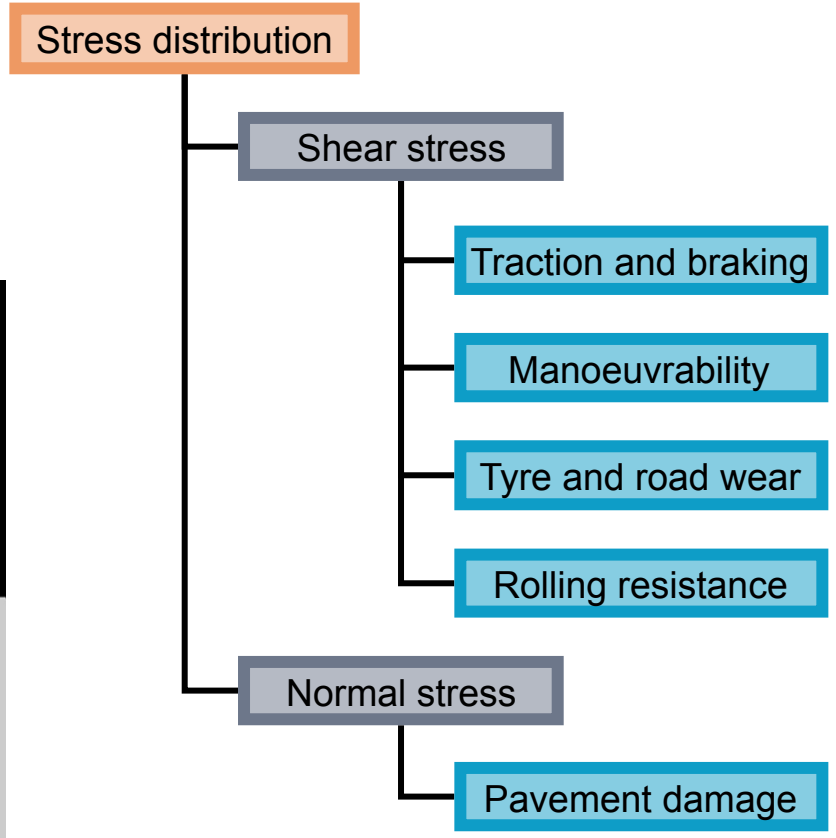
Topics

- Introduction to Tyre-Road Contact Stress
- Indoor Flat Bed Rig at UPB
- Road Embedded Set-Up at UPB
- Tracking and Optical Measurement of Kinematics
- Truck Tyre Stress Distributions
- Passenger Car Tyre Stress Distribution
- Bicycle Tyre Stress Distribution
- Conclusions

Introduction to Tyre-Road Contact Stress

- All loads for vehicle support and movement, excepting the aerodynamic forces, are developed in the contact patch





Tyre-Road Contact Stress Investigation Approaches

Research Methods
- Experimental
- Numerical

Tyre Rolling Conditions
- Static
- Free Rolling
- Driving / Braking
- Cornering

Tyre Types
- Truck Tyres
- Passenger Car Tyres
- Motorcycle / Bike Tyres

Road
- Rigid
- Deformable

Tyre-Road Contact Stress Experimental Investigation

Facility Location
- Indoor Rig
- Outdoor Facility

Sensing Elements Position
- Rolling Surface
- Tyre

Number of Sensing Elements
- Single
- Multiple (Array)

Directions
- Normal (1D)
- Shear Stresses (2D)
- Normal & Shear Stresses (3D)

Test Speed
- High
- Low
- Static

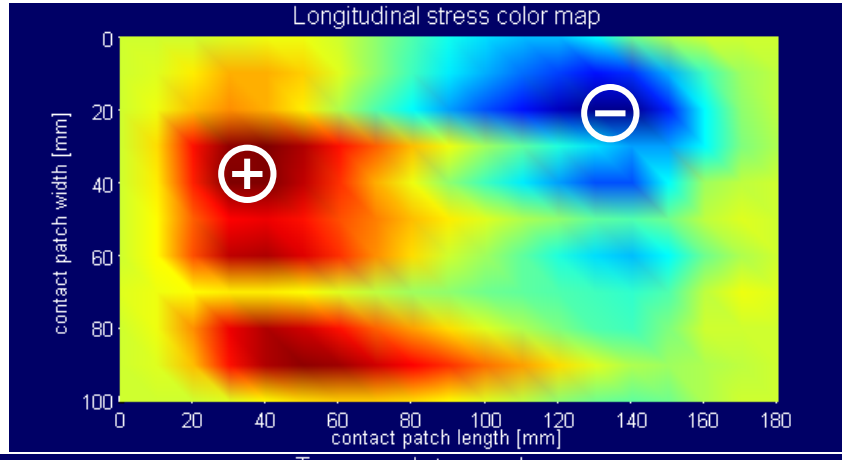
Indoor Flat Bed Rig at UPB

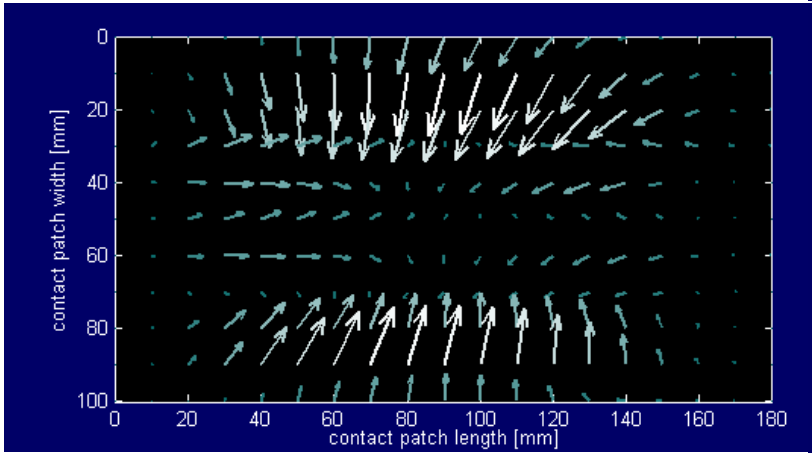
Main specifications

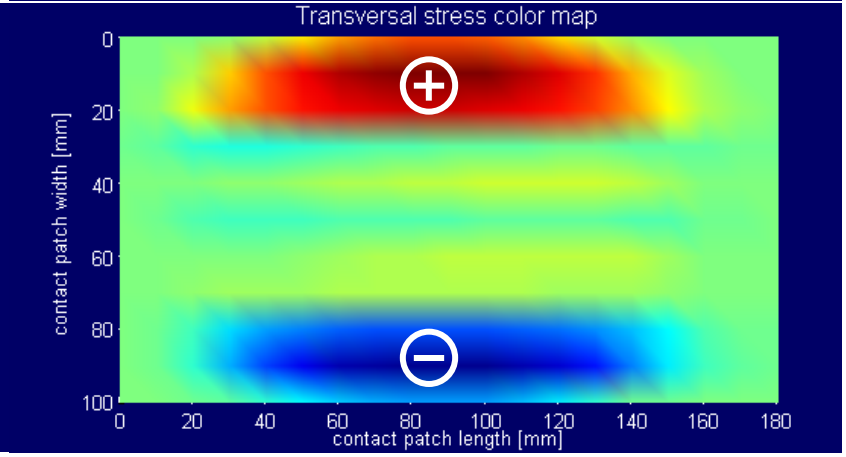
- shear stress measurement;
- sensing elements in flat bed surface;
- passenger car tyres 12” to 15”;
- freely rotating wheel without steer angle;
- low speed of flat bed;
- 1500 N to 7000 N tyre vertical load;
- different inflation pressures;
- different friction coefficients of road surface.

Indoor Flat Bed Rig at UPB

- Passenger car tyre with tread design
- Free rolling conditions
- Tyre action upon the road surface





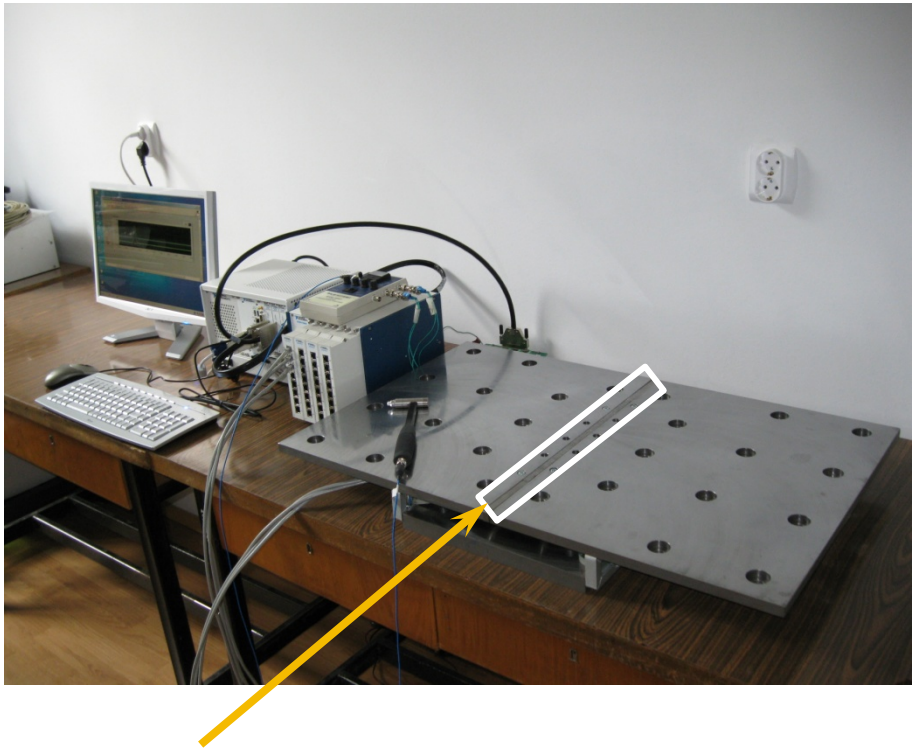


Road Embedded Set-Up at UPB

Main specifications

- 3D stress distributions
- adequate for truck tyres, also usable for other tyre types
- transversal array of 30 strain gauged sensing elements
- array of sensing elements wider than contact patch
- transversal resolution of 10 mm
- designed for free rolling/ driving/braking conditions
- designed for extended speed range

Rig dynamic calibration in laboratory



Transversal array of sensing elements

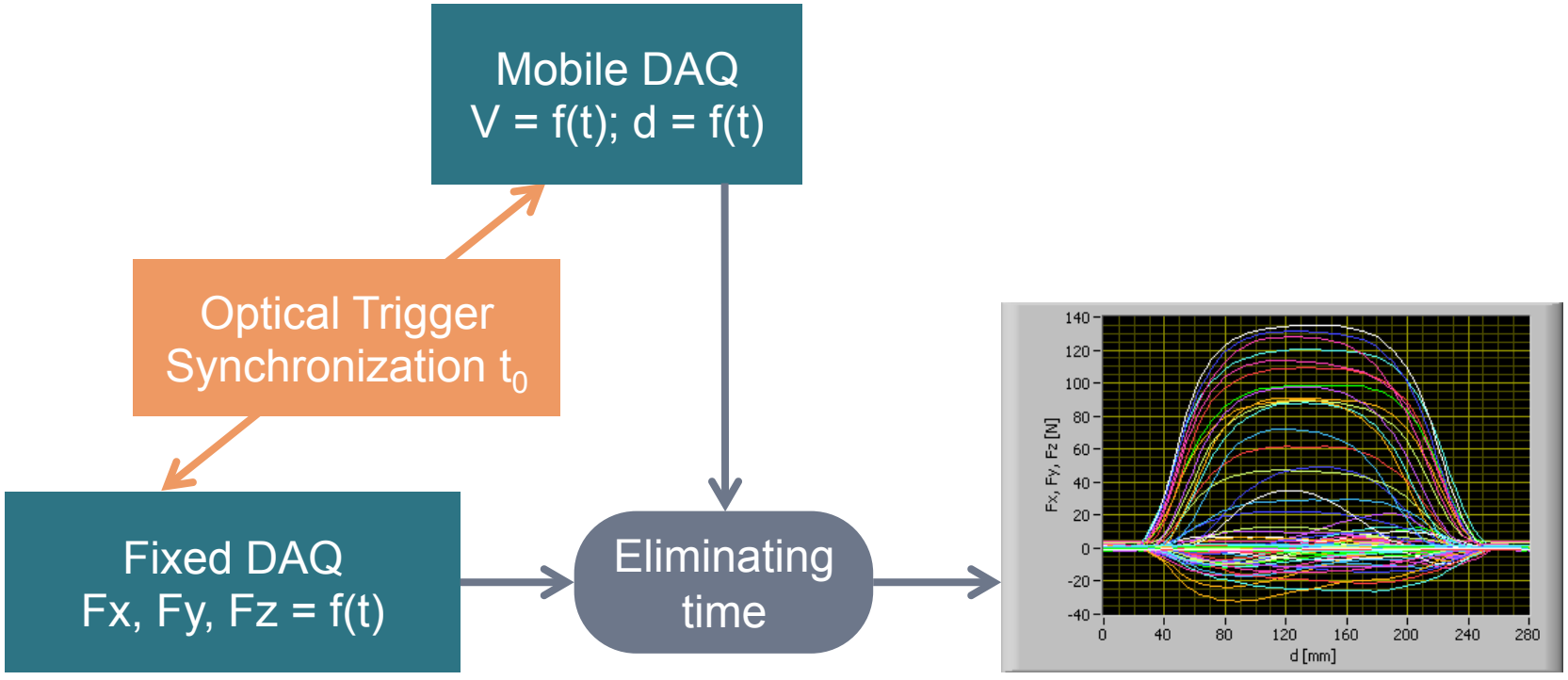
Road Embedded Set-Up at UPB

Optical devices
for synchronisation

Optical speed and
distance transducer

Fixed DAQ with road
embedded transducer

Data Acquisition and Initial Processing

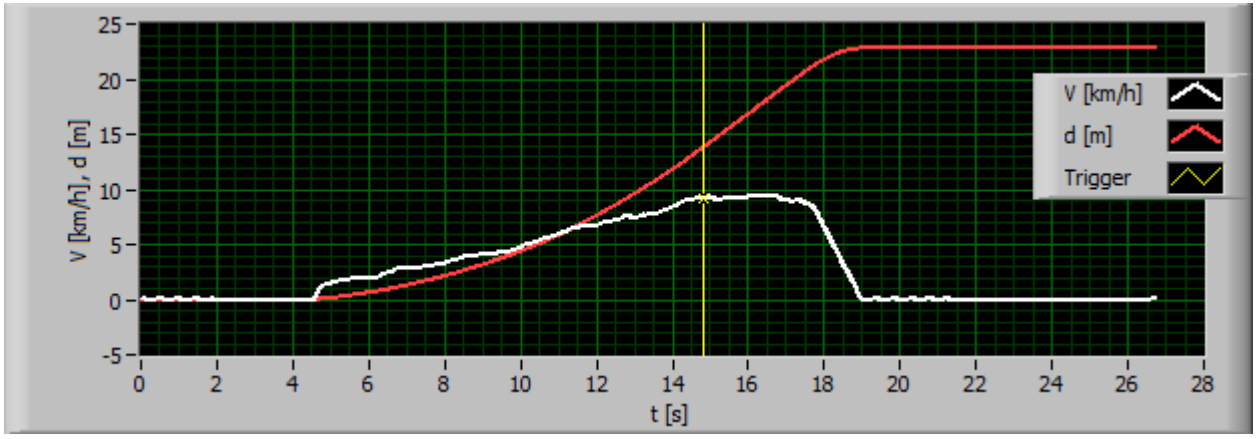


Fx, Fy, Fz = f(d)

Speed and Distance Measurement and Tracking

V= f(t)
d=f(t)

triggered by
optical system



Wheel Tracking

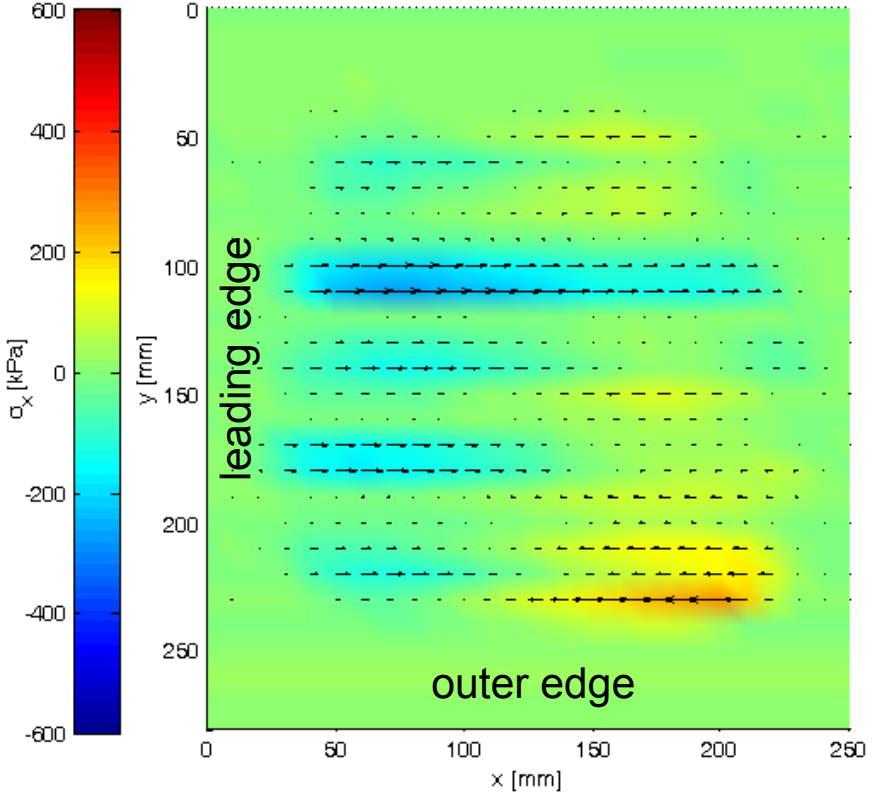
Stress, Speed and Distance Measurement

Optical Measurement of Kinematics

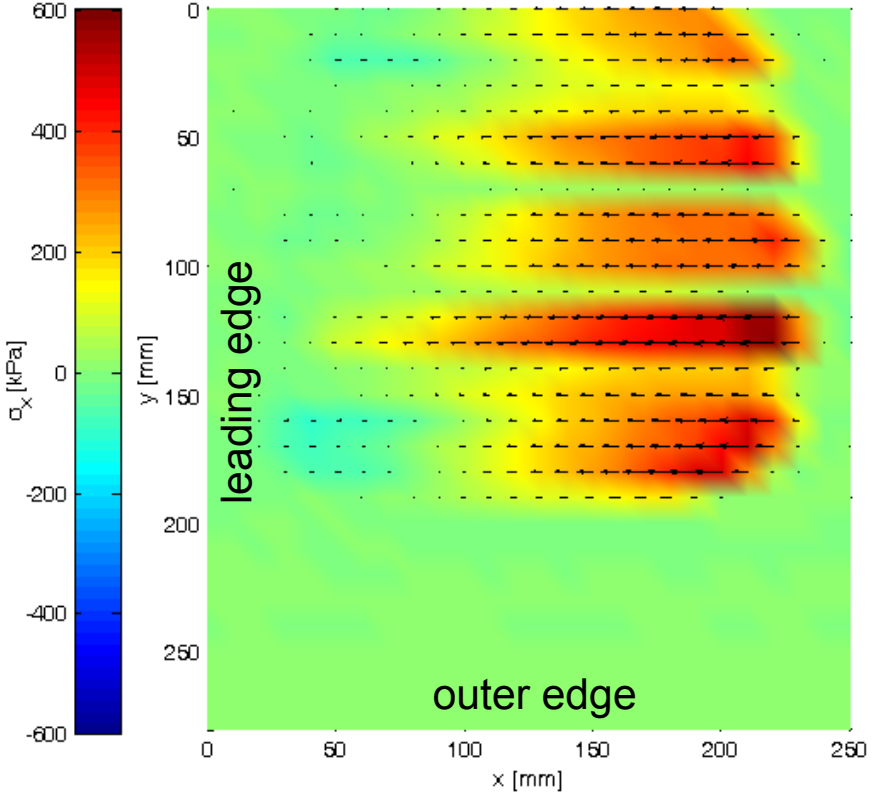
- Alternative measurements with high speed camera – derived parameters:
  - Vehicle speed and distance
  - Wheel angular velocity
  - Longitudinal wheel slip

Truck Tyre Longitudinal Stress Distribution

Free rolling, speed 9.3 km/h

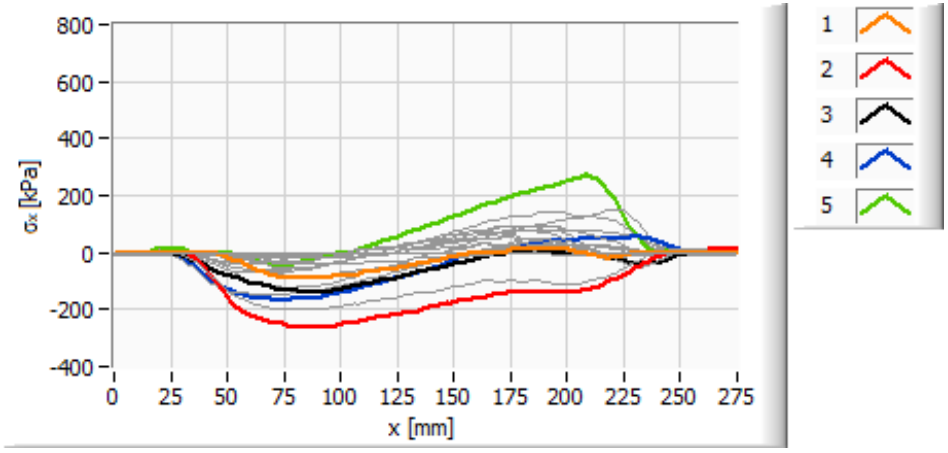


Braking, speed 7.8 km/h

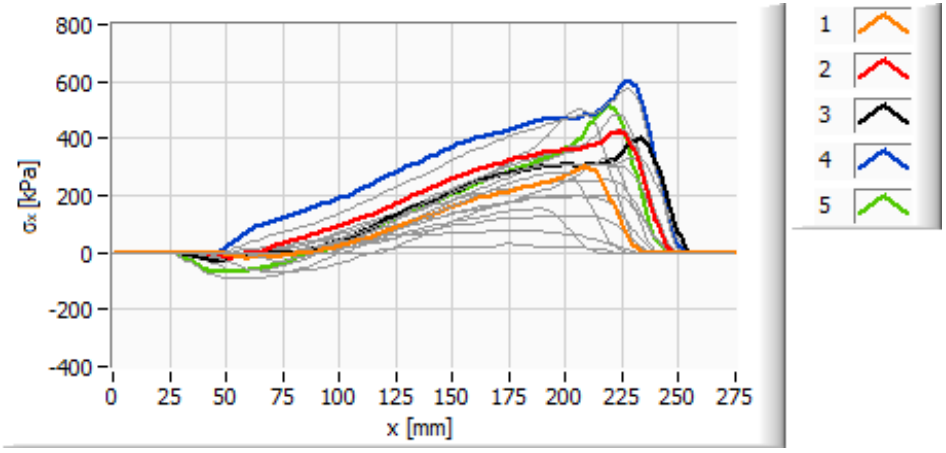


11R22.5 tyre, steering axle wheel with camber
780 kPa inflation pressure

Truck Tyre Longitudinal Stress Distribution

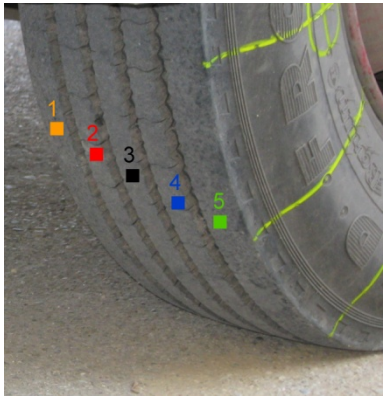


Free rolling, speed 9.3 km/h



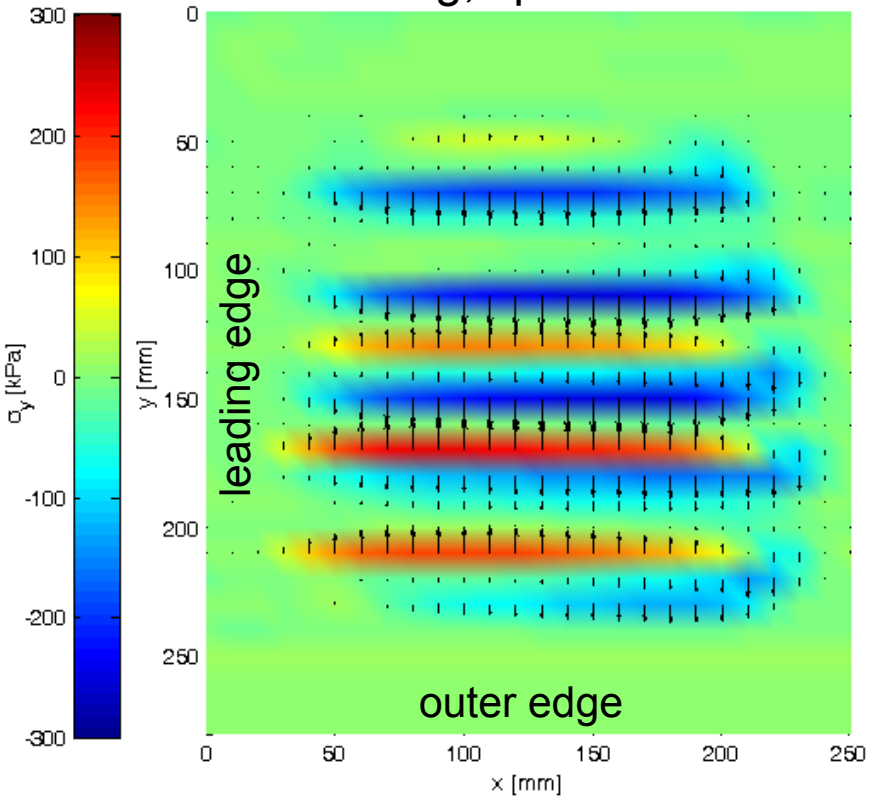
Braking, speed 7.8 km/h

- Free rolling conditions:
  - quasi-sinusoidal distribution of longitudinal stress (vectors are generally oriented towards the centre of the contact patch)
  - notable differences in shapes of longitudinal stresses on continuous ribs (1, 3 and 5) vs. discontinuous ribs (2 and 4)
- Braking conditions:
  - quasi-triangular distribution of longitudinal stress oriented towards the leading edge of the contact patch

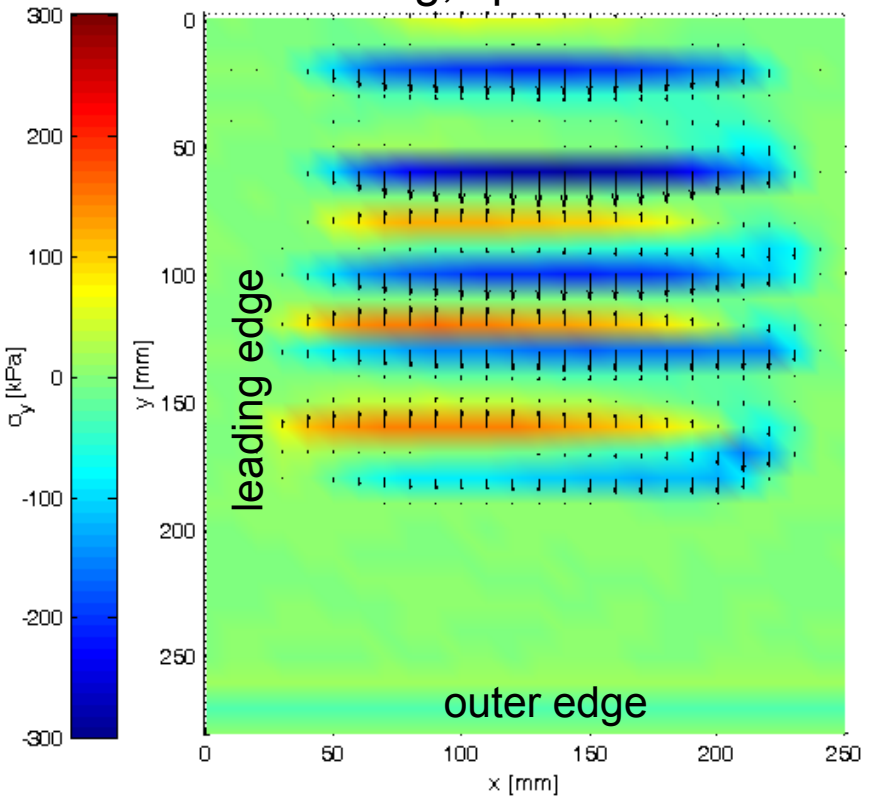


Truck Tyre Lateral Stress Distribution

Free rolling, speed 9.3 km/h



Braking, speed 7.8 km/h



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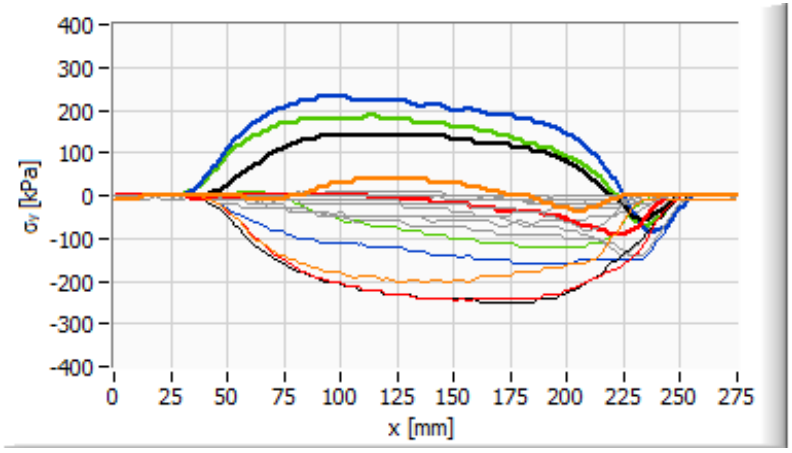
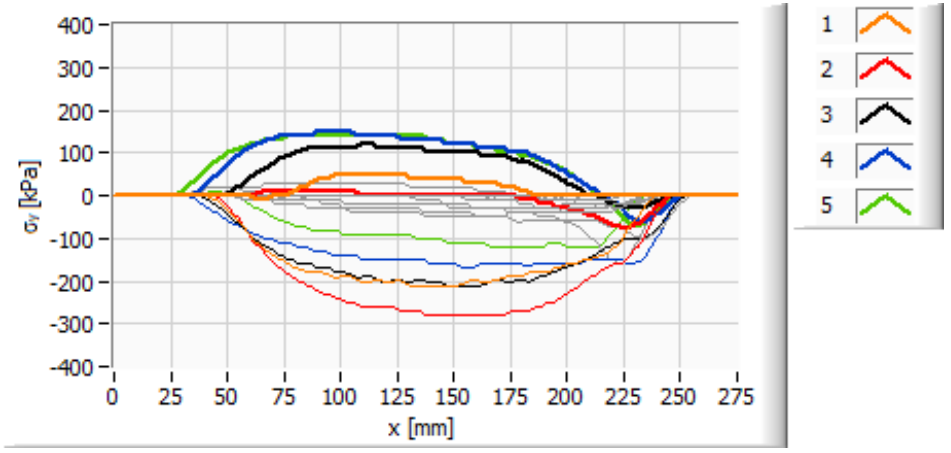
Truck Tyre Lateral Stress Distribution

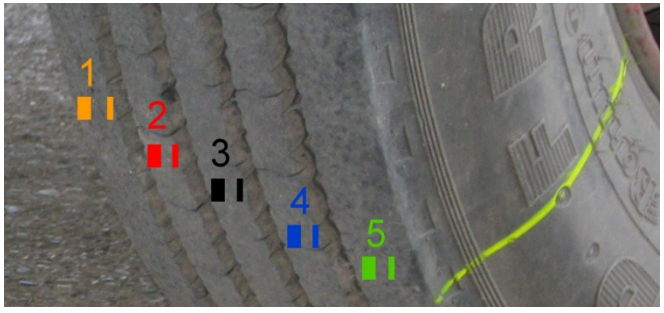


Free rolling, speed 9.3 km/h



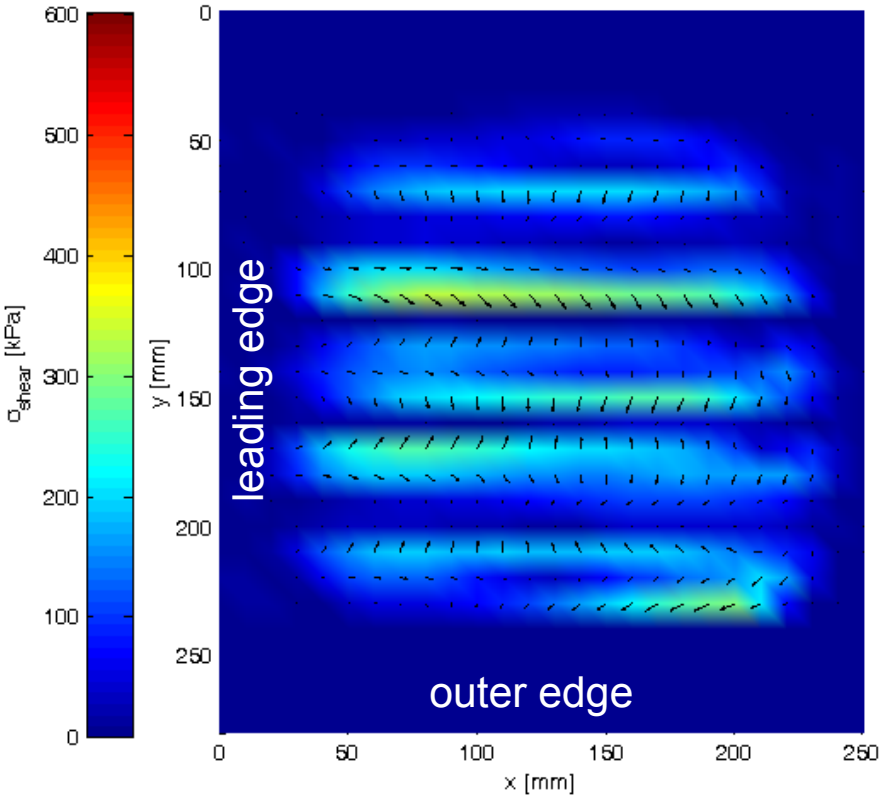
Braking, speed 7.8 km/h

- Free rolling and braking conditions:
  - flattened bell shape of lateral stress distribution
  - the lateral stress vectors on the sides of every rib are opposite and oriented towards the grooves
  - the resultant lateral stress distribution is predominantly oriented towards the centre of the contact patch

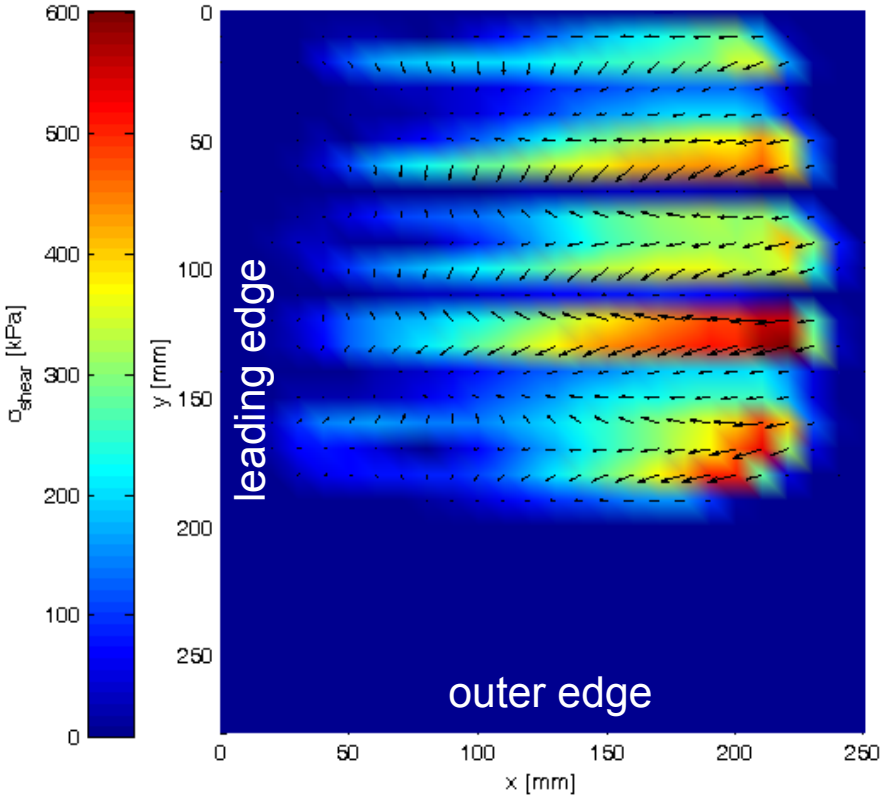


Truck Tyre Shear Stress Distribution

Free rolling, speed 9.3 km/h



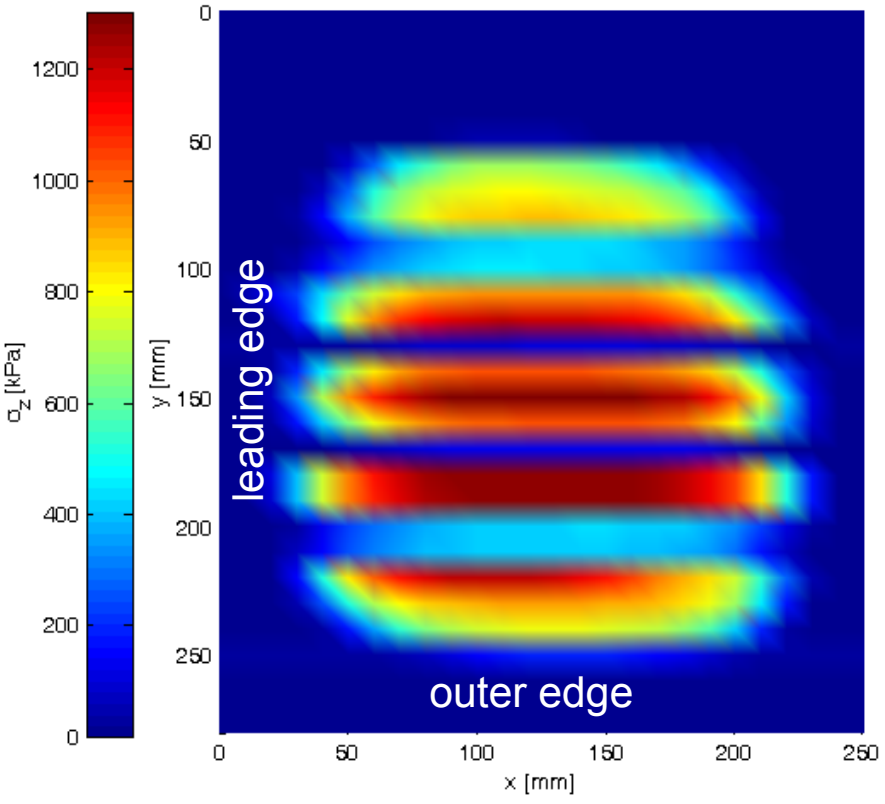
Braking, speed 7.8 km/h



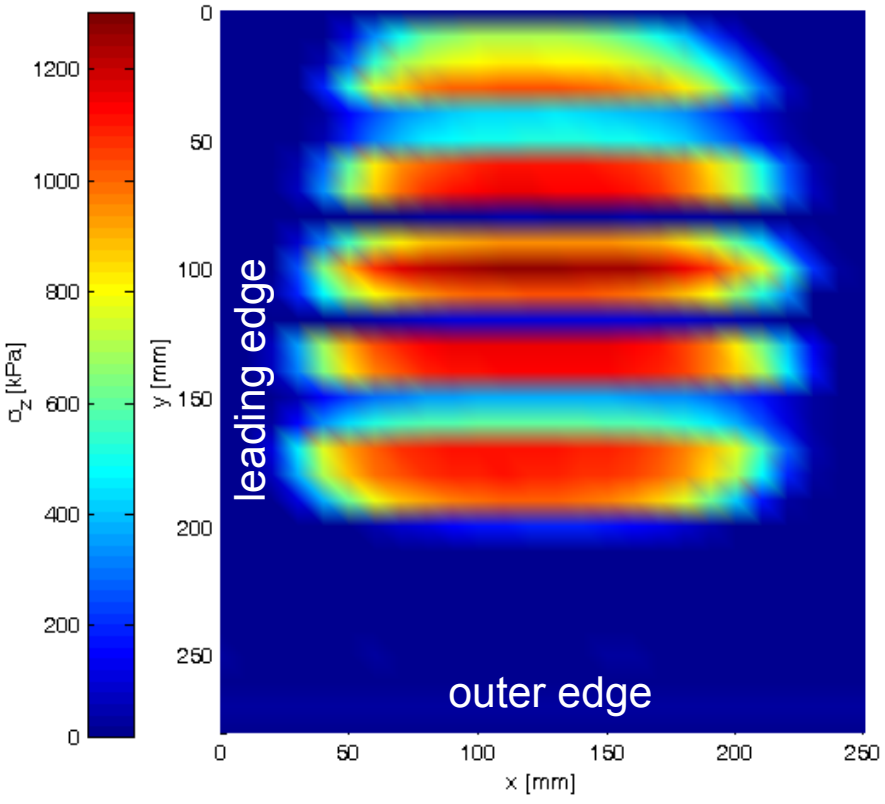
11R22.5 tyre, steering axle wheel with camber
780 kPa inflation pressure

Truck Tyre Normal Stress Distribution

Free rolling, speed 9.3 km/h

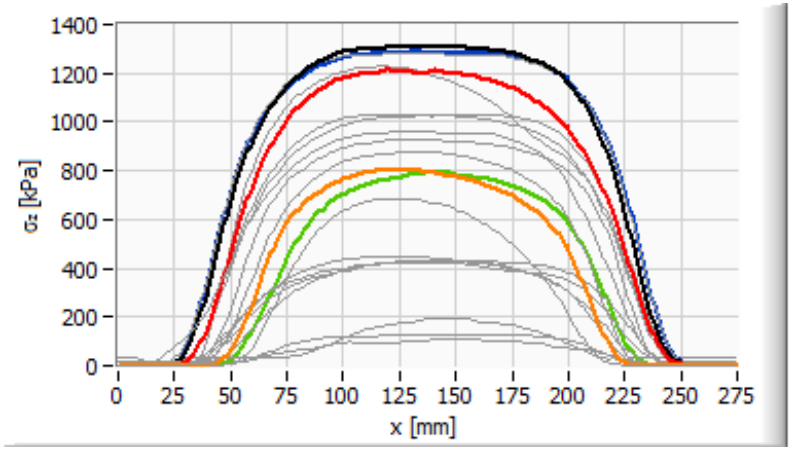


Braking, speed 7.8 km/h

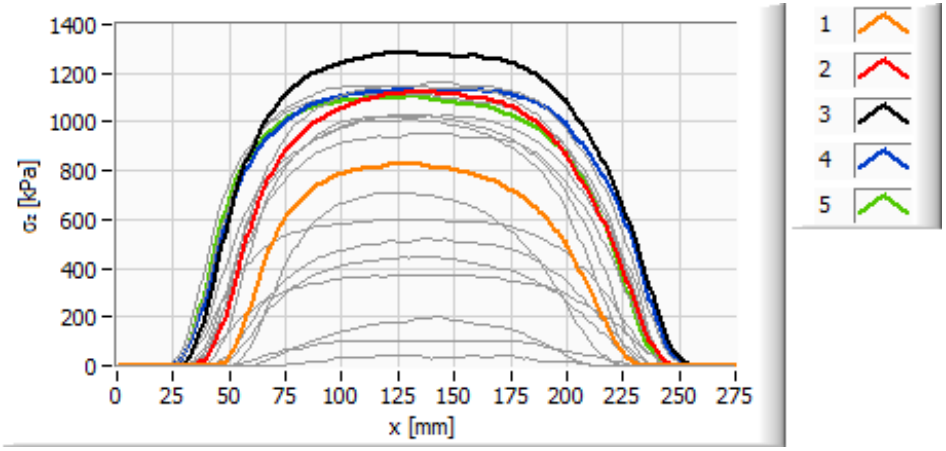


11R22.5 tyre, steering axle wheel with camber
780 kPa inflation pressure

Truck Tyre Normal Stress Distribution

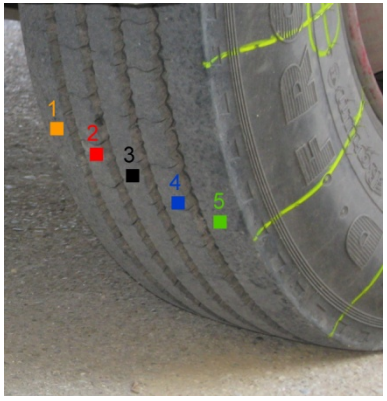


Free rolling, speed 9.3 km/h



Braking, speed 7.8 km/h

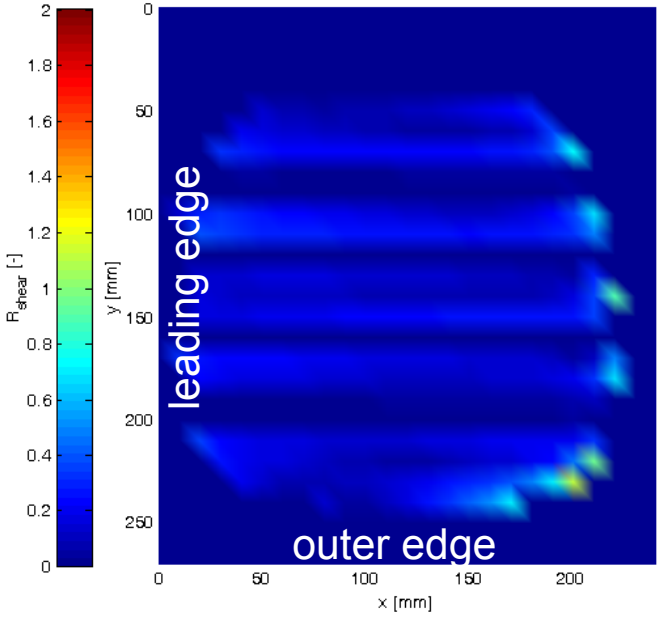
- Free rolling and braking conditions:
  - normal stresses have rounded trapezoidal or bell-shaped distributions
  - normal stress distribution is not symmetrical across the width of the contact patch because of wheel camber angle



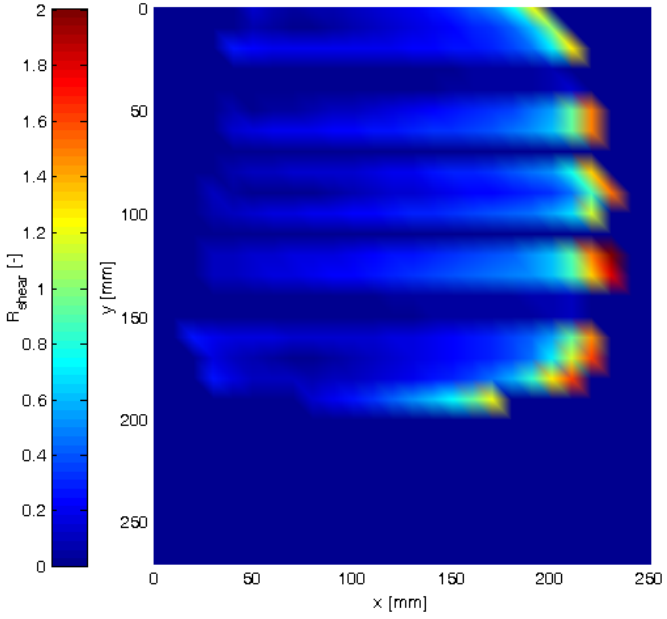
Shear to Normal Stress Ratio Distribution for Truck Tyre

$$R_{shear} = \frac{\sigma_{shear}}{\sigma_z}$$

Free rolling, speed 9.3 km/h



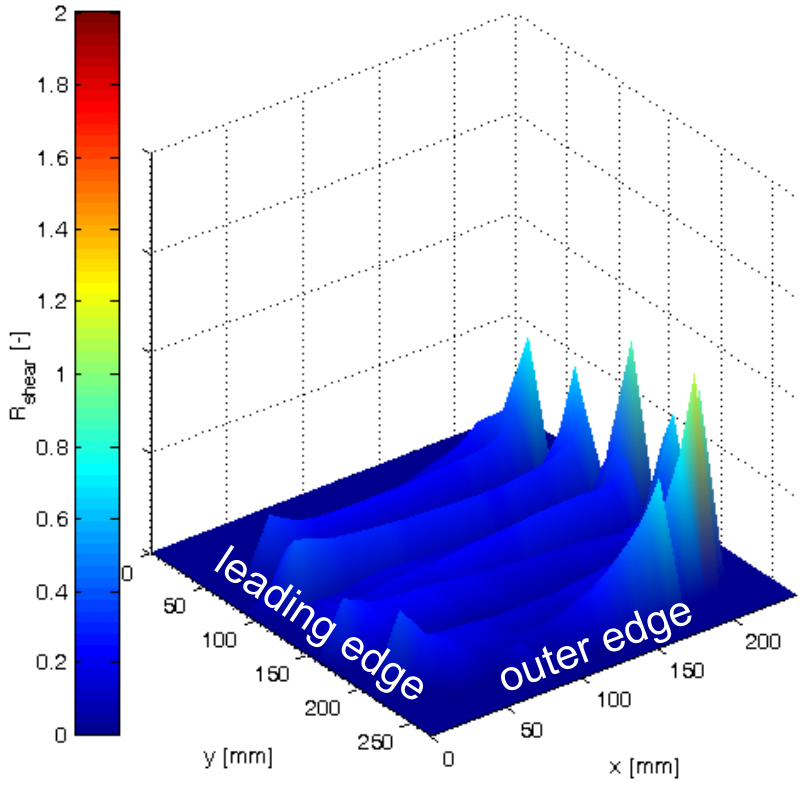
Braking, speed 7.8 km/h



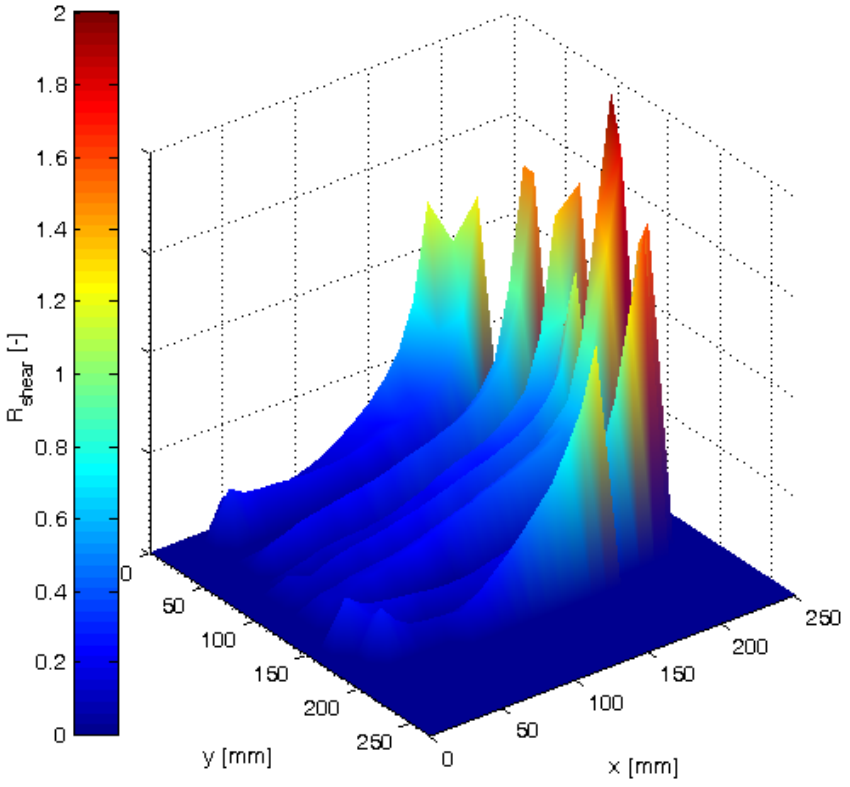
- Physical meaning of R_{shear} could be local sliding friction coefficient
- High R_{shear} in trailing area could imply that slip occurs between tread rubber and road
- Significant difference of R_{shear} values between free rolling and braking conditions

Shear to Normal Stress Ratio Distribution for Truck Tyre

Free rolling, speed 9.3 km/h



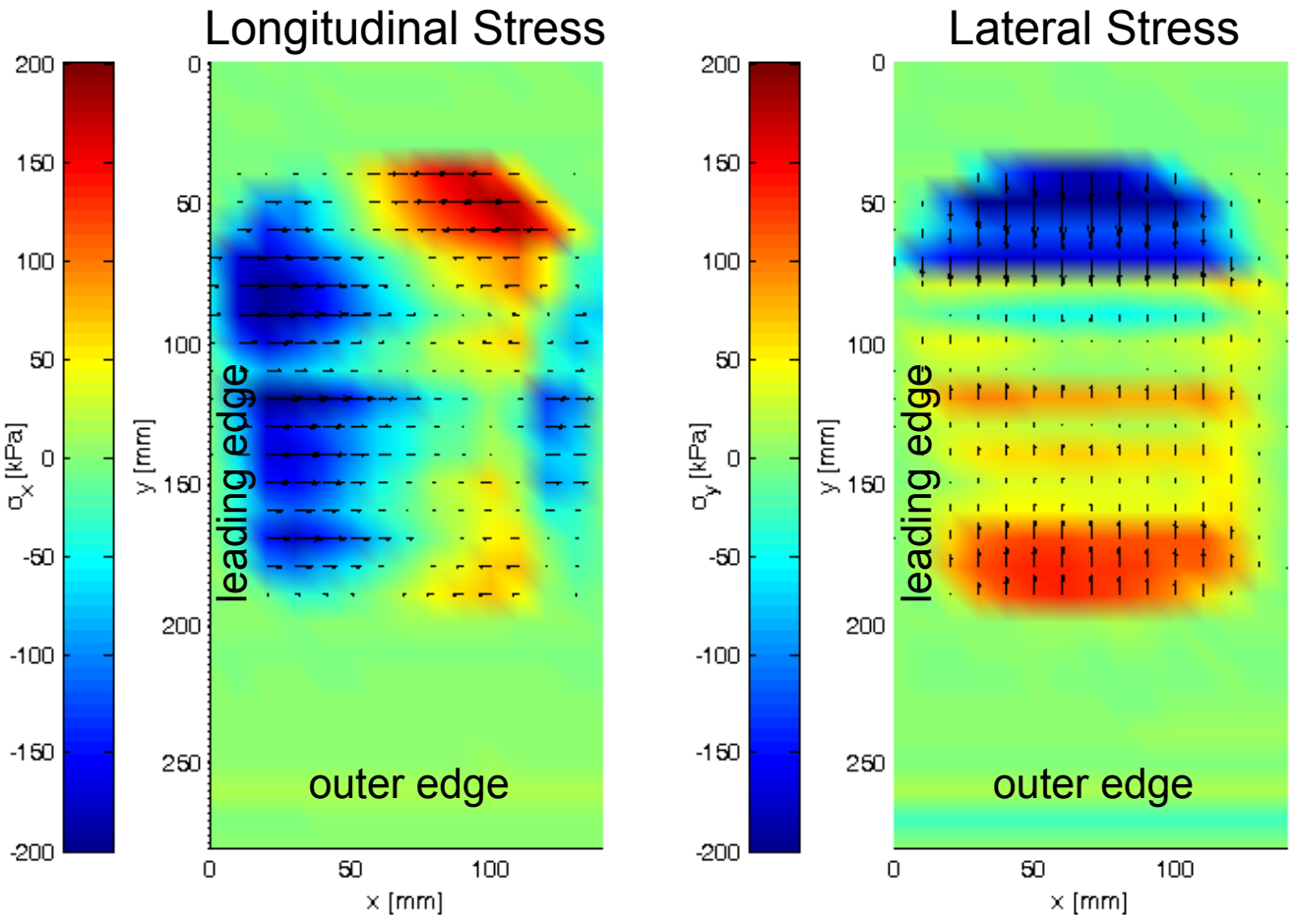
Braking, speed 7.8 km/h



11R22.5 tyre, steering axle wheel with camber
780 kPa inflation pressure

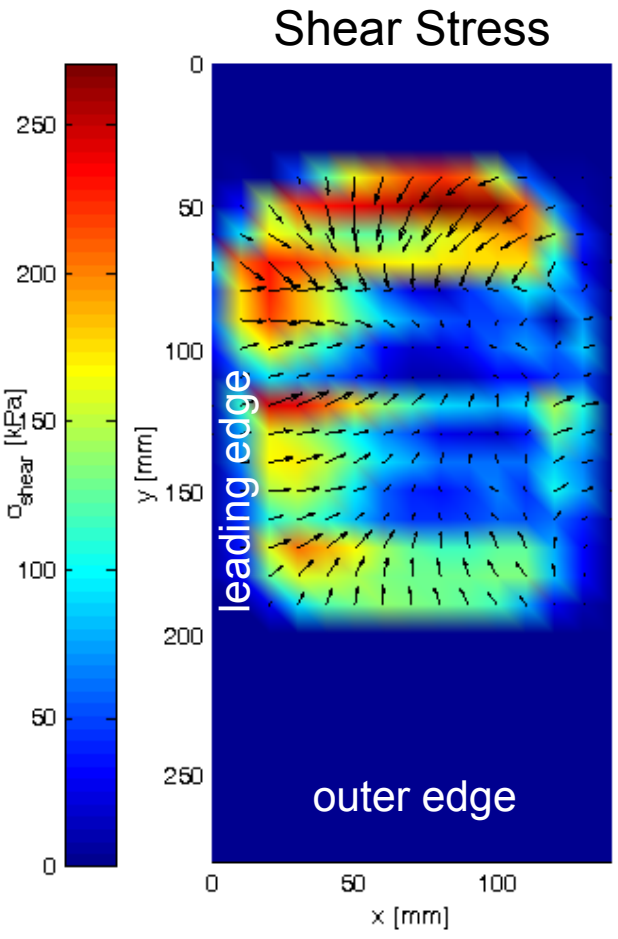
Passenger Car Tyre Stress Distribution

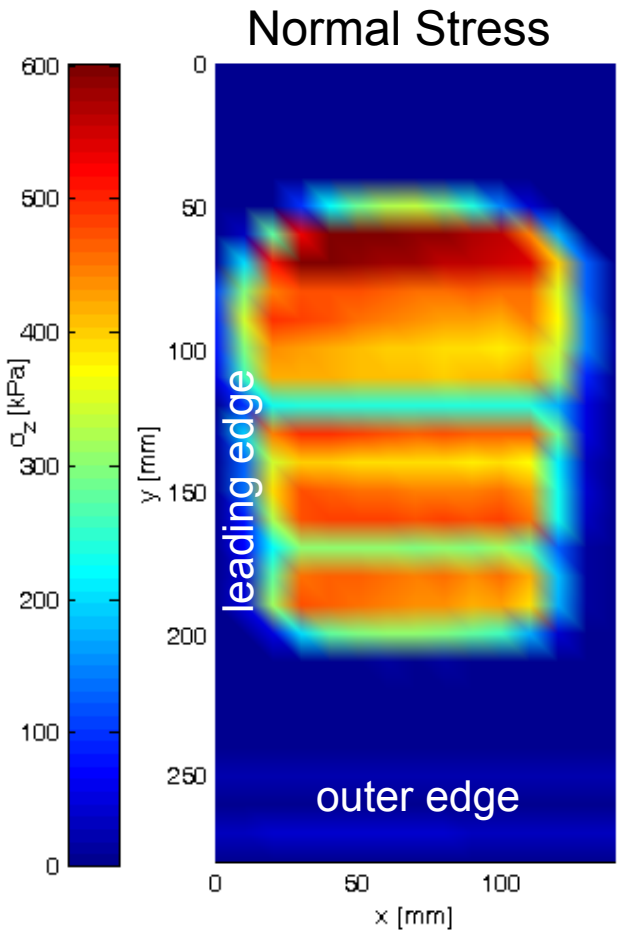
- 205/55R16 tyre
- wheel with negative camber angle
- free rolling
- 1.4 km/h speed
- 240 kPa inflation pressure



Passenger Car Tyre Stress Distribution

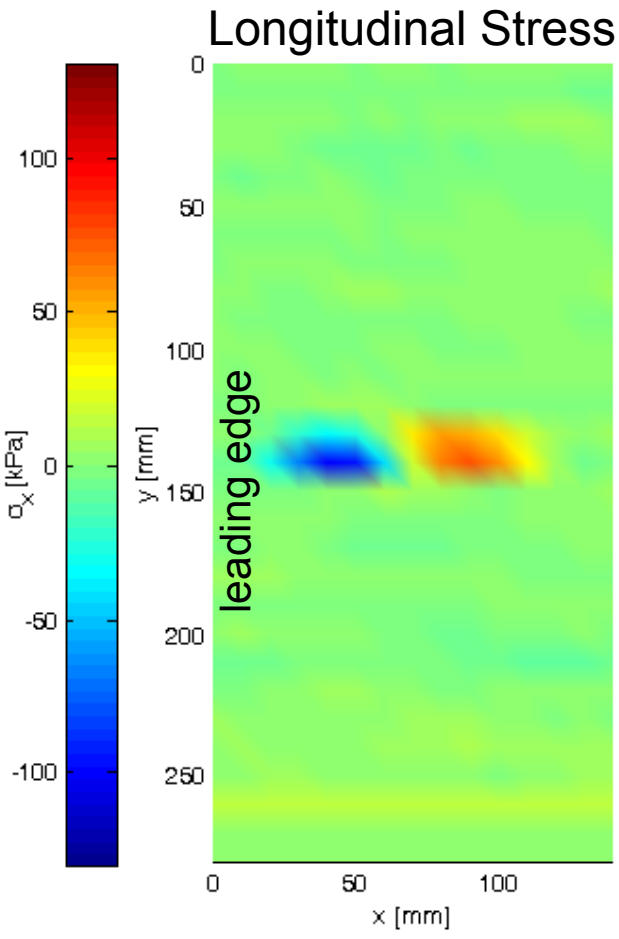
- Shear stress vectors are generally oriented towards the centre of the contact patch
- The maximum value of normal stress is 2.5 times greater than the inflation pressure

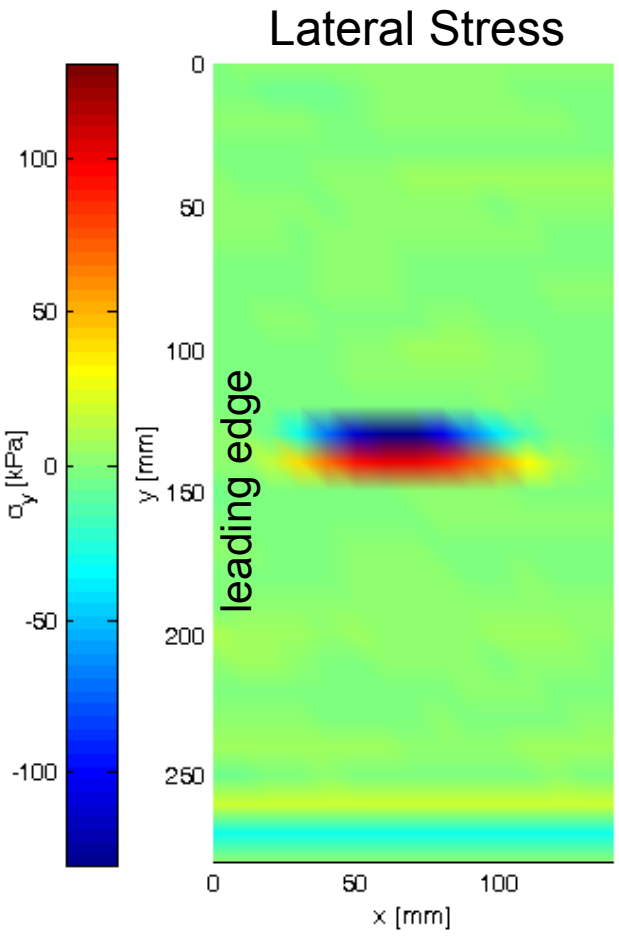




Bicycle Tyre Stress Distribution

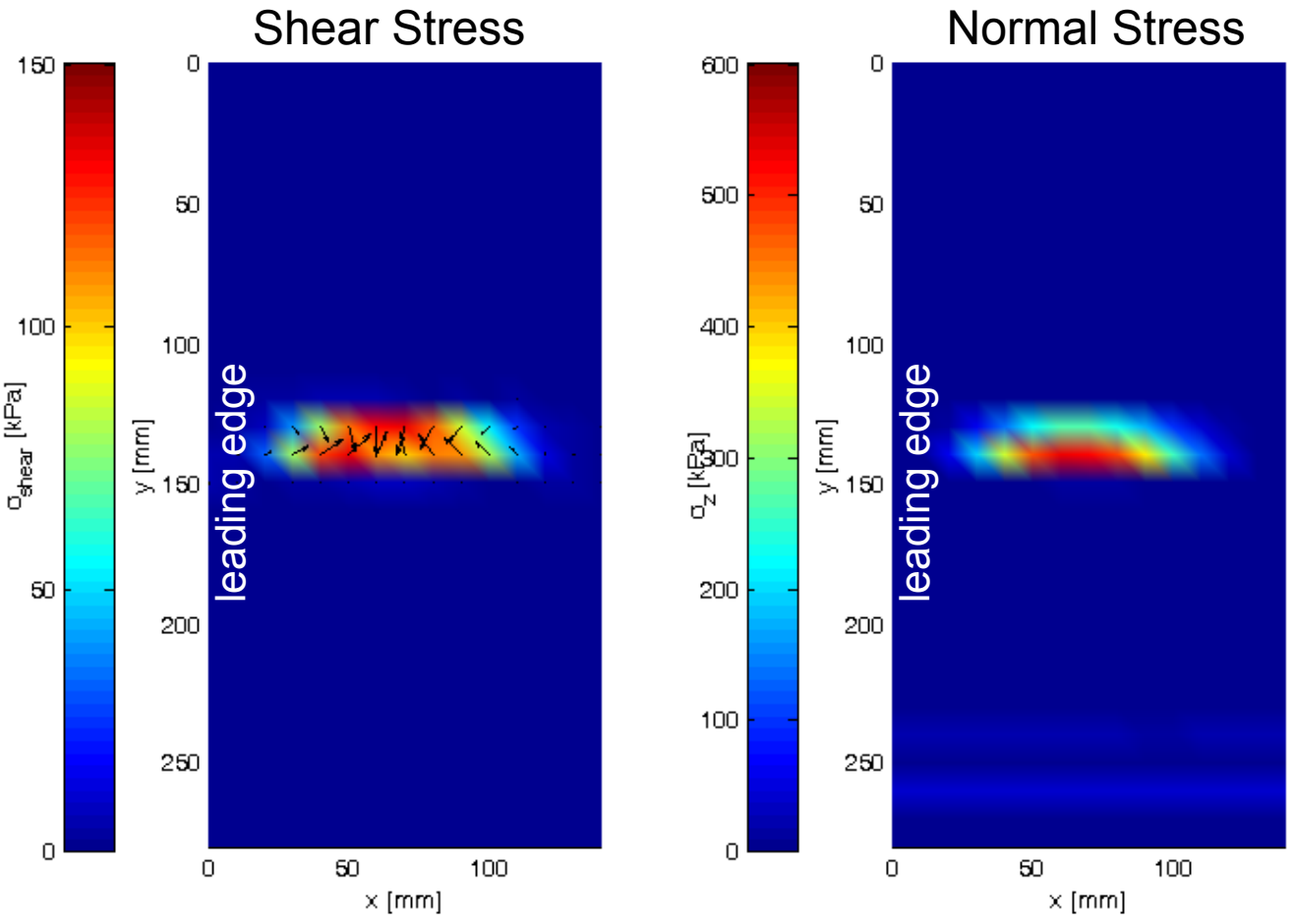
- 20x1.50 bicycle tyre
- free rolling
- 16.9 km/h speed
- 350 kPa inflation pressure





Bicycle Tyre Stress Distribution

- Shear stress vectors are generally oriented towards the centre of the contact patch
- The maximum value of normal stress is comparable with that of the passenger car tyre



Conclusions

- The rigs at University POLITEHNICA of Bucharest are capable of measuring stress distributions in the tyre-road contact patch in laboratory and road conditions
- The road embedded set-up is designed for truck tyres, also usable for other tyre types
- The road embedded set-up provides 3D stress distributions measured simultaneously on entire width of contact patch
- Stress distributions require wheel tracking and precise measurement of vehicle and wheel kinematics
- An alternative optical method (high speed camera) was used for measuring wheel kinematics
- The road embedded set-up can be used for measuring stress distributions also for wheels rolling with slip angle

Thank you for your attention!

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