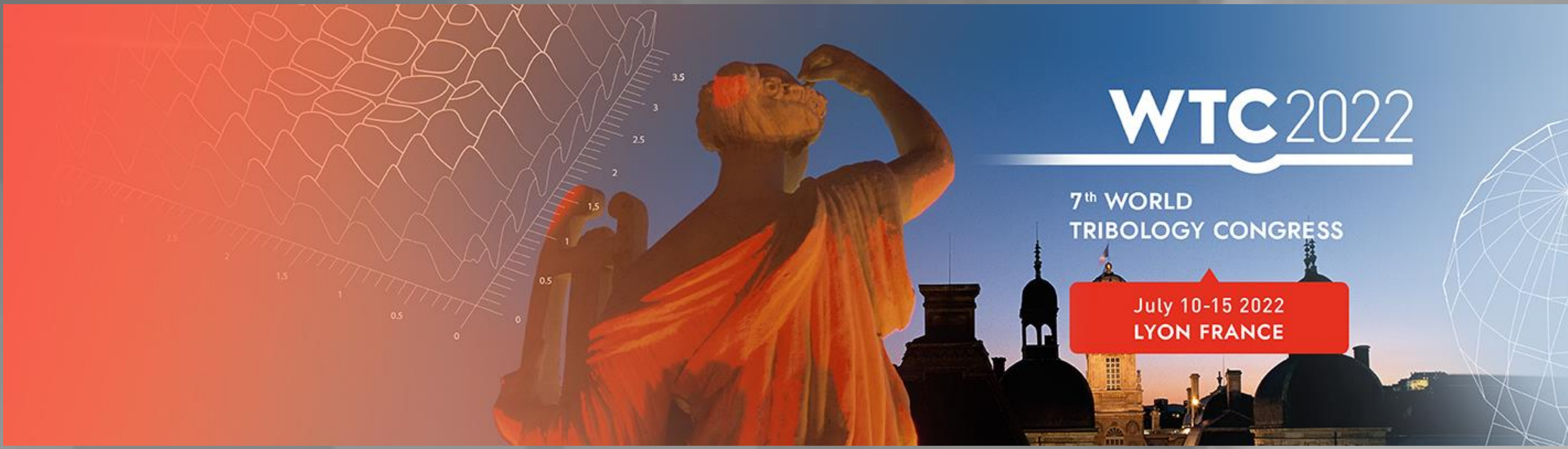

Investigation of Tire-pavement Interaction Based on Non-smooth Contact Dynamics Method

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1. Introduction

In a context where road networks are aging, and where resources for maintenance of these networks are decreasing, it is important to better control and understand the mechanisms of degradation of wearing courses in order to optimize their formulation and maintenance. To investigate the degradation of the surface layers, a deeper understanding of tire-pavement interaction is important for the accurate analysis of load-induced responses of the asphalt pavement.

2. Contact dynamics (CD) method

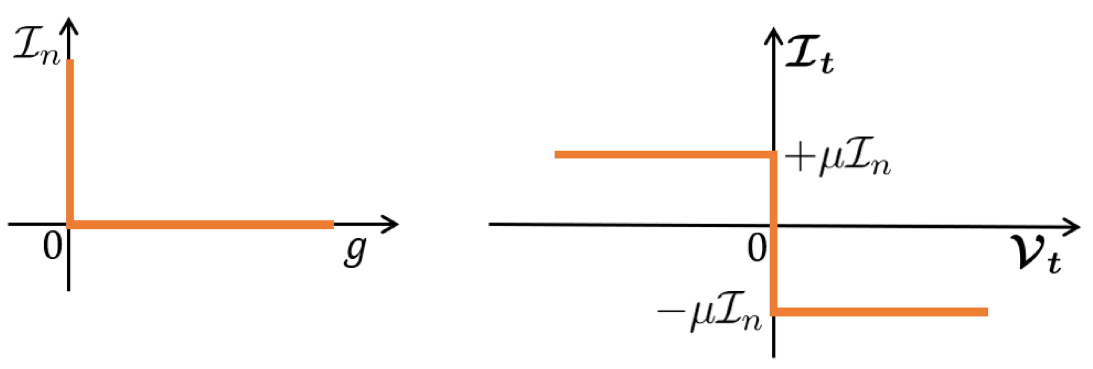
Implicit method for solving unilateral contact problem

Pioneered work:

J.J. Moreau, Unilateral contact and dry friction in finite freedom dynamics, in: Nonsmooth Mechanics and Applications, Springer, 1988, pp. 1–82.

Contact conditions are non-differentiable

Normal: Signorini condition — Tangential: Coulomb's condition

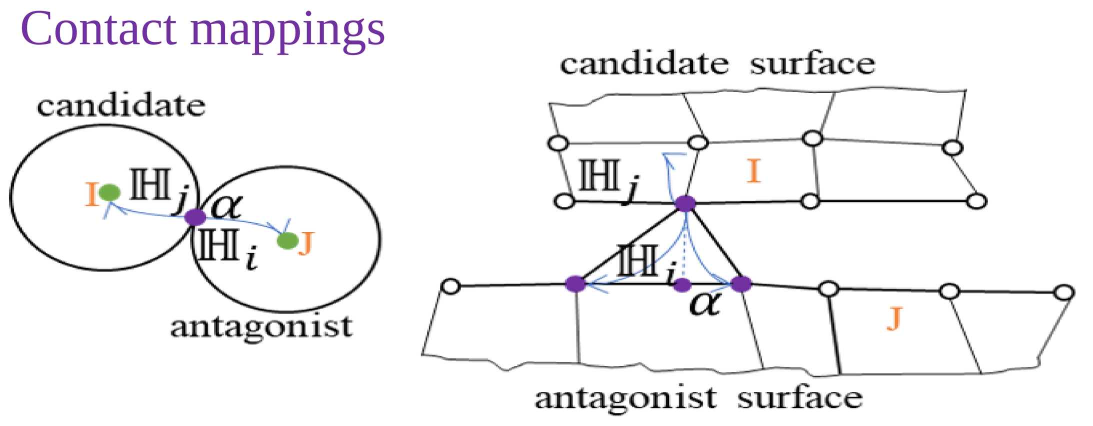


CD method: Contact formulation at velocity level

$$\mathbf{V} \longleftarrow \text{Dynamics equation} \longrightarrow \mathbf{I}$$
$$\downarrow^{T}\mathbb{H}(q) \qquad \uparrow\mathbb{H}(q)$$
$$\mathcal{V}^{\alpha} \longleftarrow \text{Contact laws} \longrightarrow \mathcal{I}$$

Implicit time-step frame: Big time step; No stiffness system; Stability; Polyhedron simulation; Rigid/deformable objects.

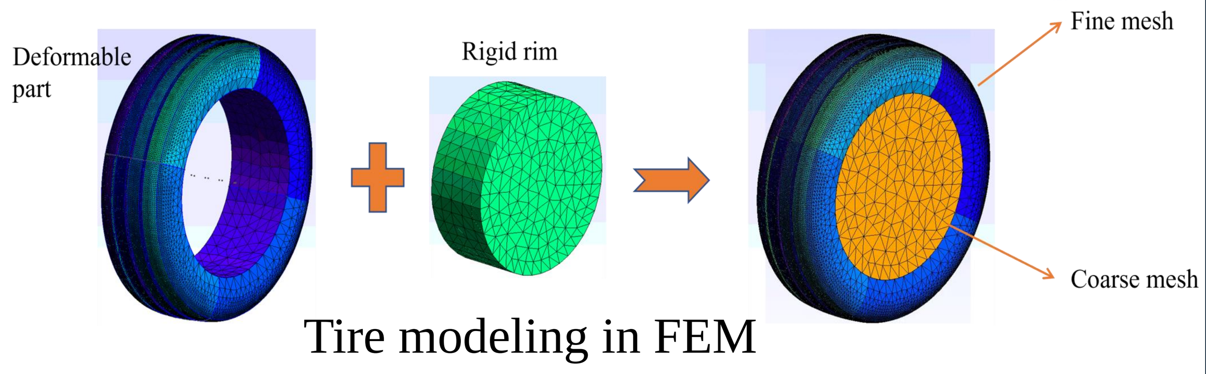
Contact mappings



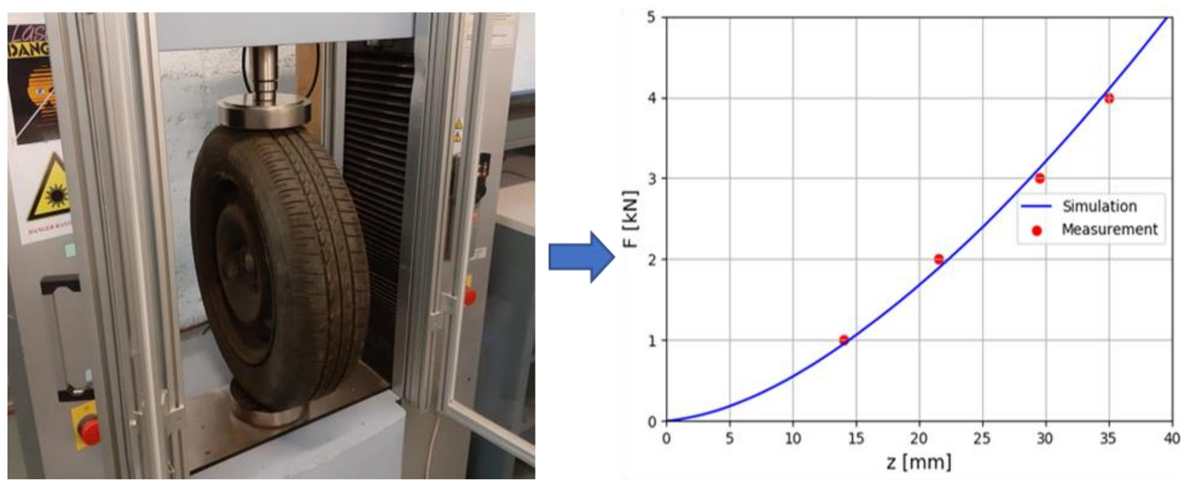
3. 3D laser scanning for tire

Tire geometry reconstruction

4. Numerical tire modeling

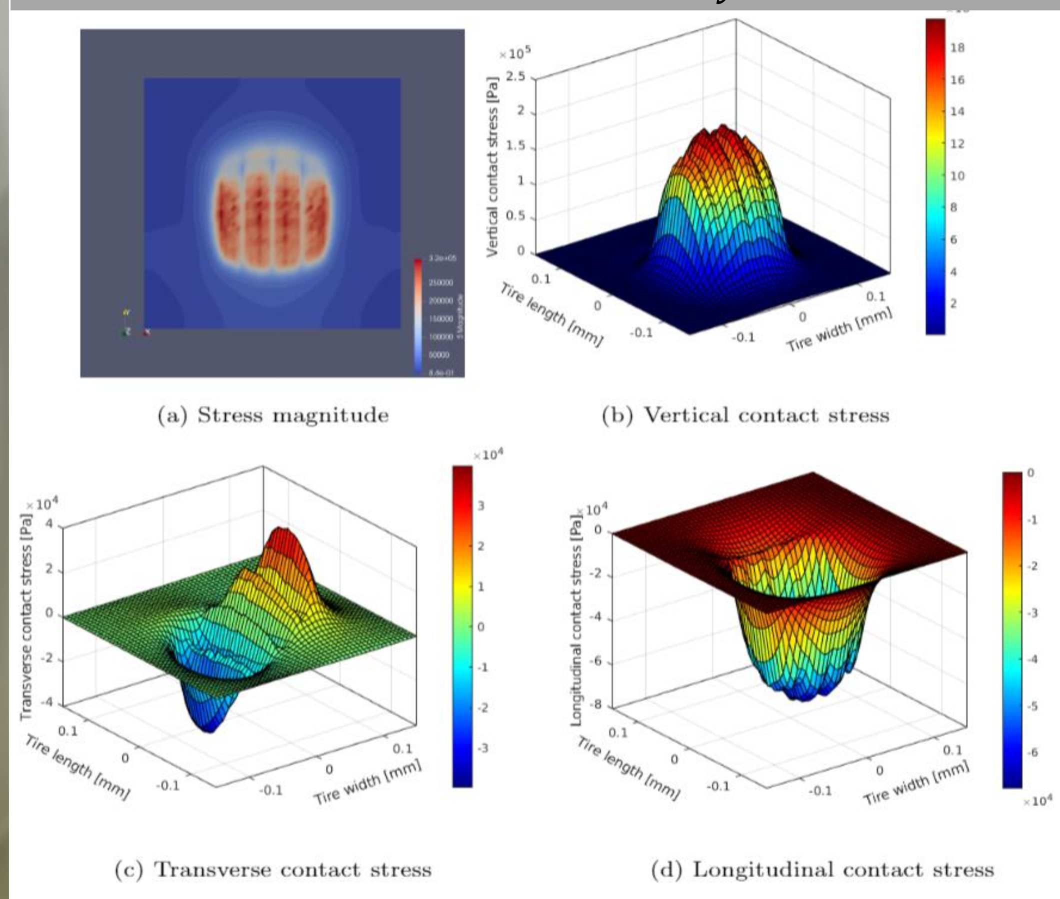


Tire modeling in FEM



Compression test - Tire model parameter identification

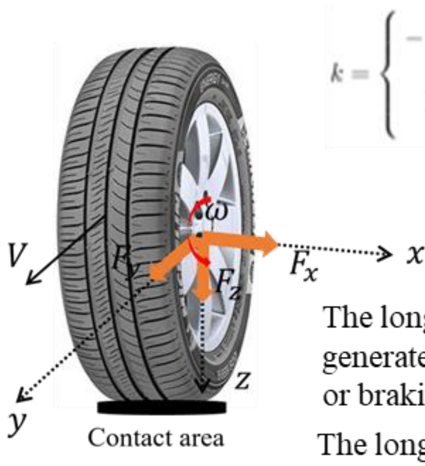
Full-braking condition: $F_y = \mu F_z$



A drastic increase of the longitudinal contact stress occurs because of the braking force.

5. Tire-pavement interaction

Tire driven forces



Rolling condition (slip k)

$$k = \begin{cases} -\dfrac{V_{y0} - r_w \cdot \Omega}{V_{y0}} = -\dfrac{\Omega_0 - \Omega}{\Omega_0}, a_v < 0 \\ \dfrac{r_w \cdot \Omega - V_{y0}}{r_w \cdot \Omega} = \dfrac{\Omega - \Omega_0}{\Omega}, a_v > 0 \end{cases}$$

Free-rolling: k = 0

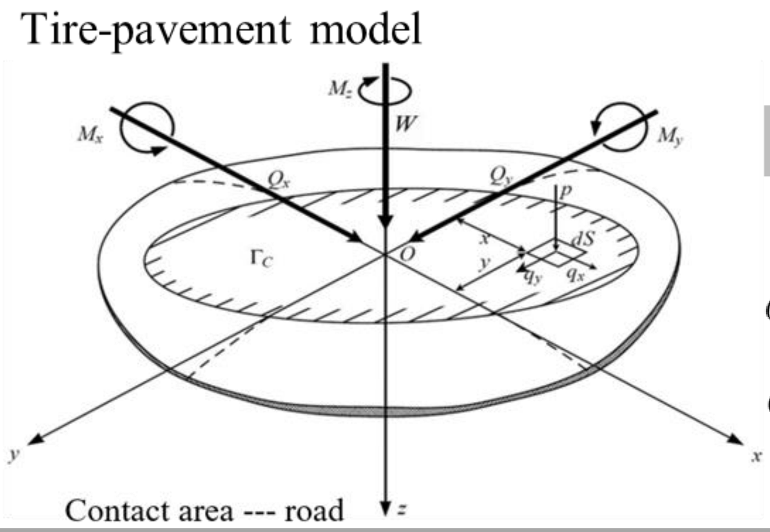
Full-braking: k = -1

The longitudinal force (F_y) is generated during the tire acceleration or braking.

The longitudinal force of tire acceleration and braking are similar

Numerical platform: LMGC90 (https://git-xen.lmgc.univ-montp2.fr/lmgc90/lmgc90_user/-/wikis/home), where the CD method is built-in.

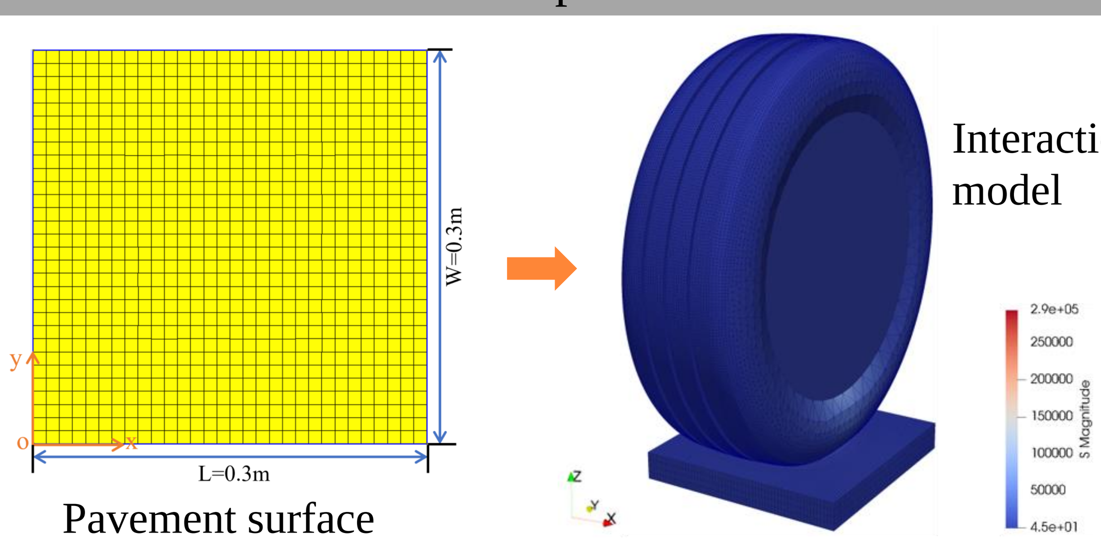
Tire-pavement model



Balance formulations

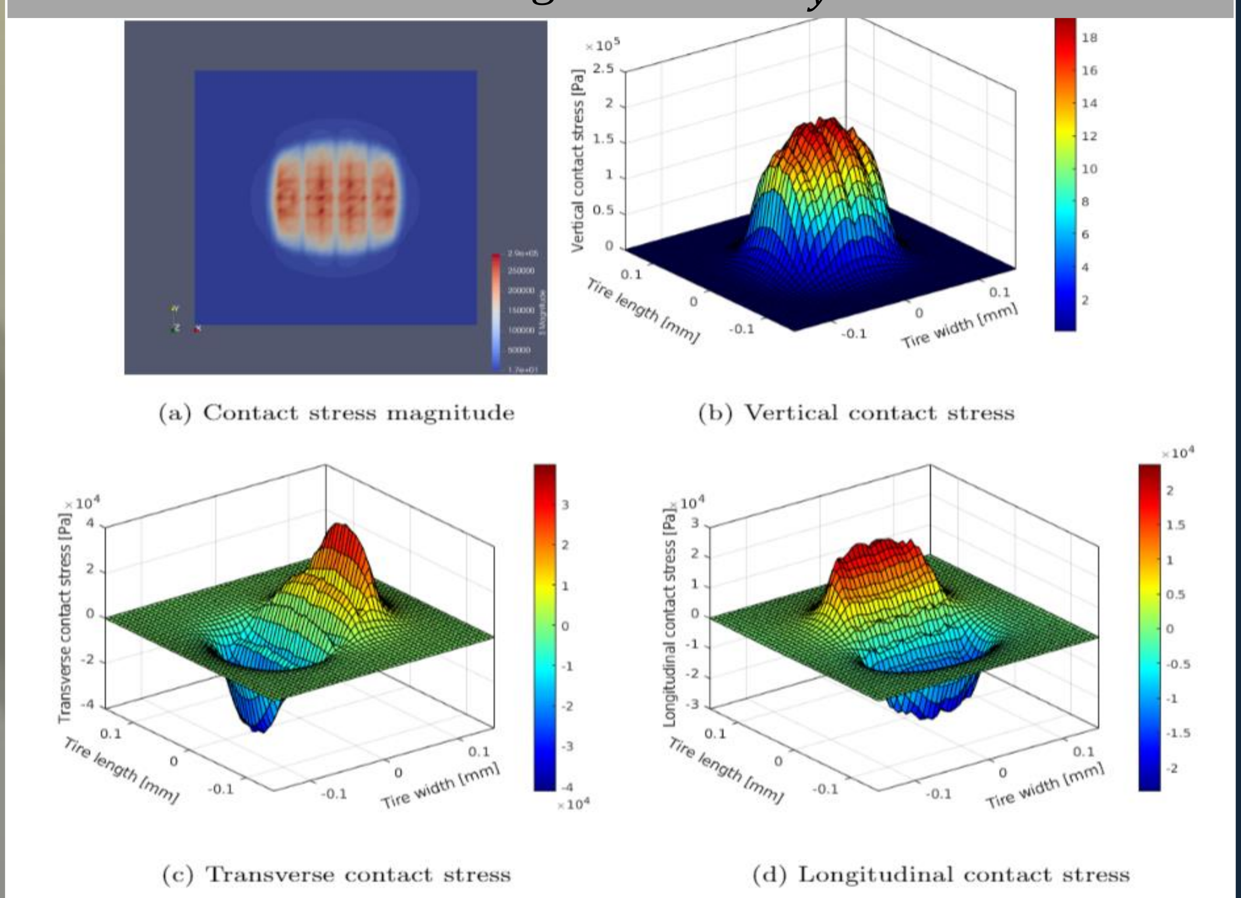
$$W = \int_{\Gamma c} p(x,y)dS = F_z$$
$$Q_x = \int_{\Gamma c} q_x(x,y)dS = F_x$$
$$Q_y = \int_{\Gamma c} q_y(x,y)dS = F_y$$

Numerical tire-pavement model



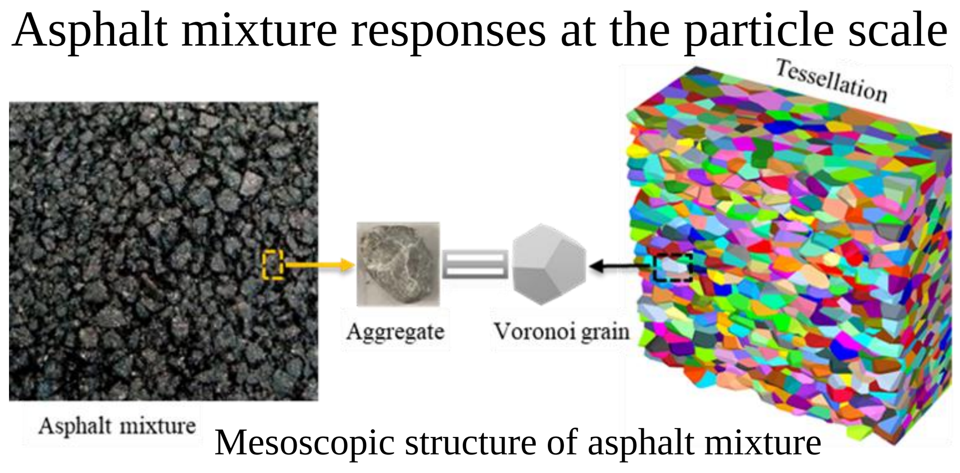
Pavement surface

Free-rolling condition: $F_y = 0$



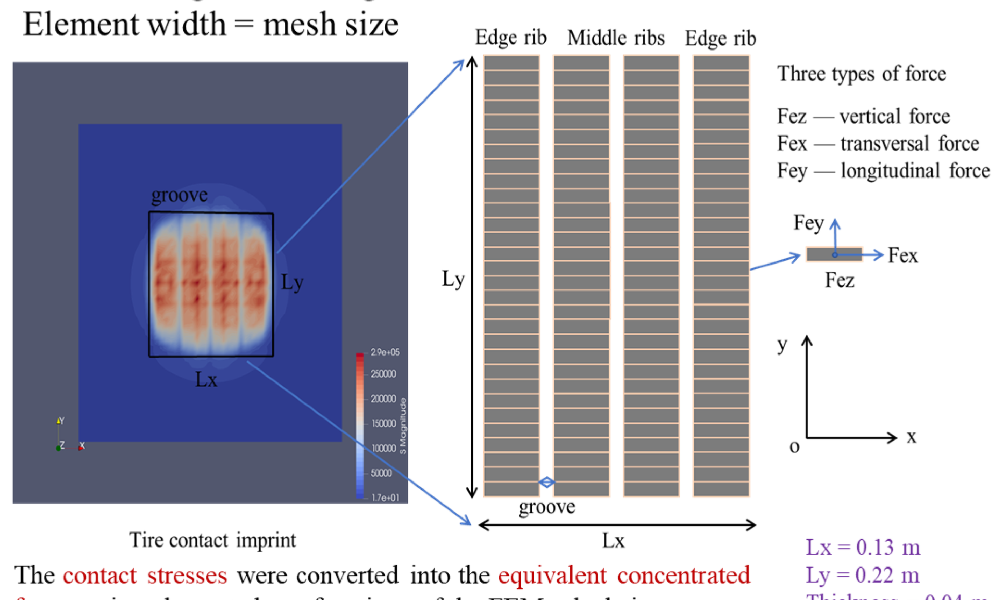
6. Extending work

Asphalt mixture responses at the particle scale



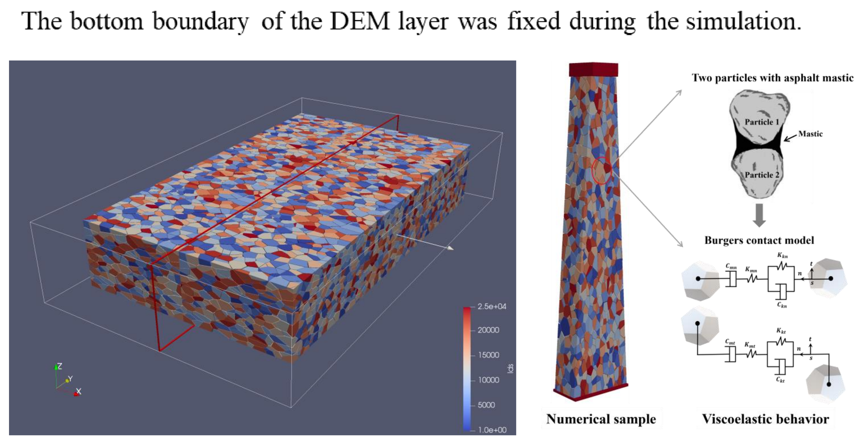
Mesoscopic structure of asphalt mixture

Element length = rib length
Element width = mesh size



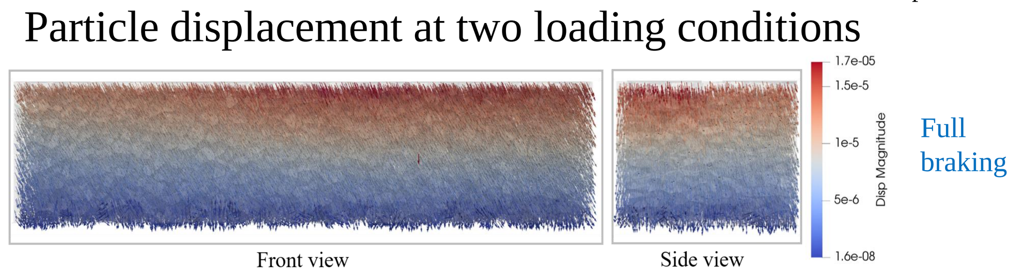
The contact stresses were converted into the equivalent concentrated forces using element shape functions of the FEM calculation.

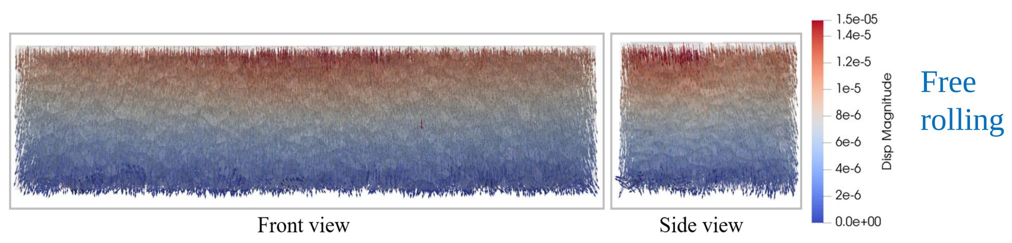
The bottom boundary of the DEM layer was fixed during the simulation.



In the DEM model, the converted 3D tire-pavement contact force (vertical, transverse, and longitudinal) under each rib element were applied, respectively, on the tire imprint area.

Particle displacement at two loading conditions





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[1] H. Ge, et al. Three-dimensional simulation of asphalt mixture incorporating aggregate size and morphology distribution based on contact dynamics method[J]. Construction and Building Materials, 2021, 302: 124124.

[2] H. Ge, et al. Multiscale analysis of tire and asphalt pavement interaction via coupling FEM–DEM simulation[J]. Engineering Structures, 2022, 256: 113925.