Locomotion on soft granular Soils

A Discrete Element based Approach for Simulations in Planetary Exploration

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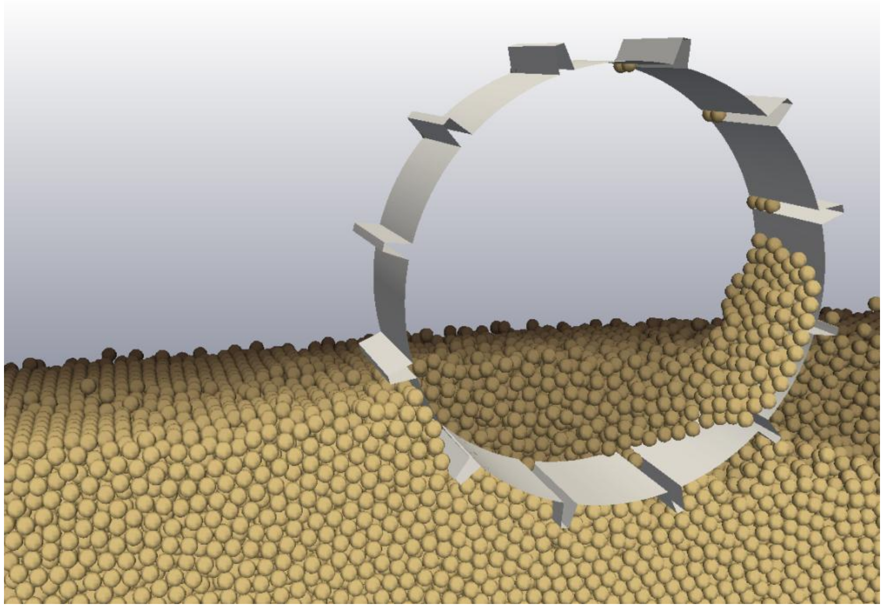
Outline

1. Introduction
2. Contact models
3. Parameter estimation
4. Models & Results
5. Conclusion & Further steps



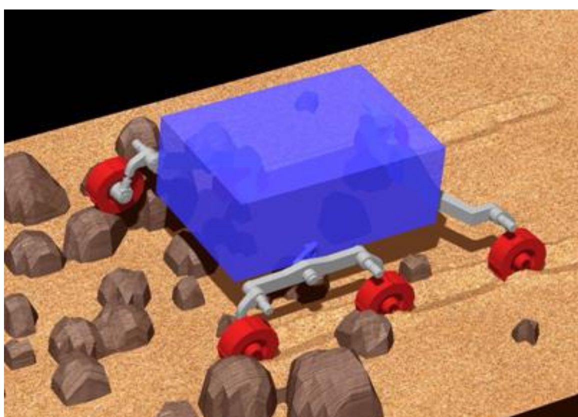
1. Introduction

State of the art models

Empirical – Bekker/Reece/Wong

Finite Element Method

Continuum based methods



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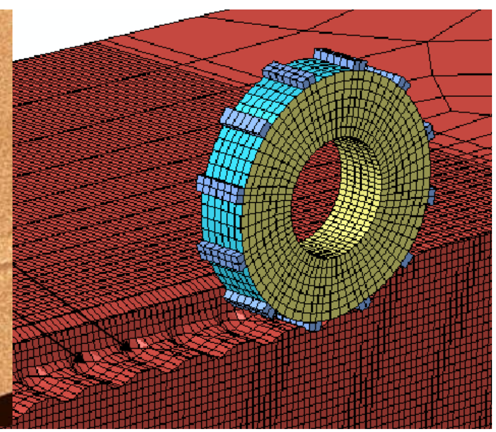

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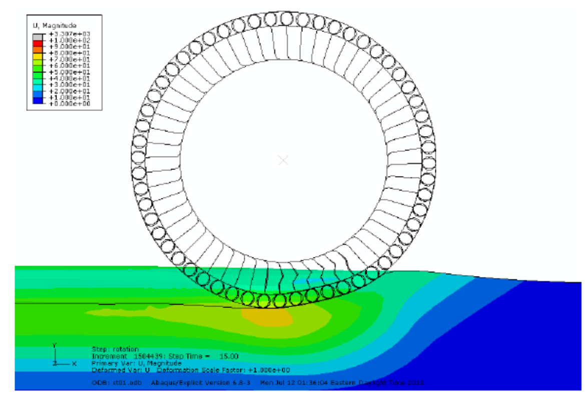

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1. Introduction

State of the art models

Empirical – Bekker/Reece/Wong

Finite Element Method

Continuum based methods

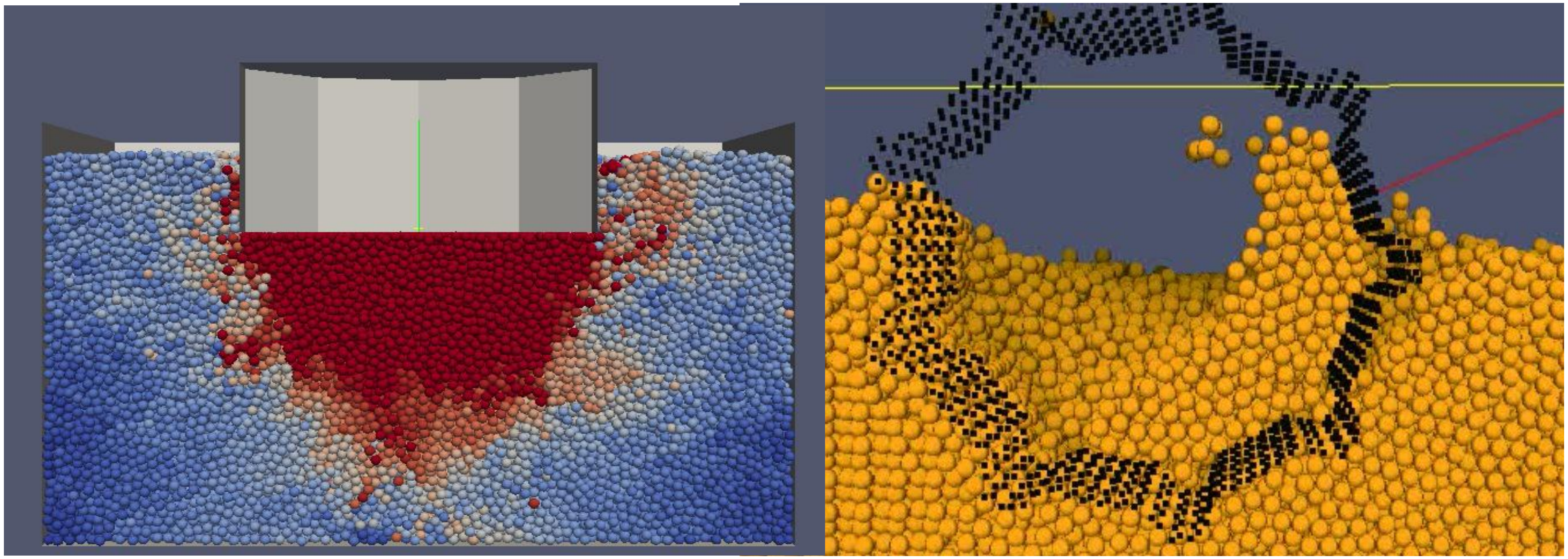
Discrete Element Method

Smoothed Particles Hydrodynamics

Particle based methods (discrete, meshfree)

1. Introduction

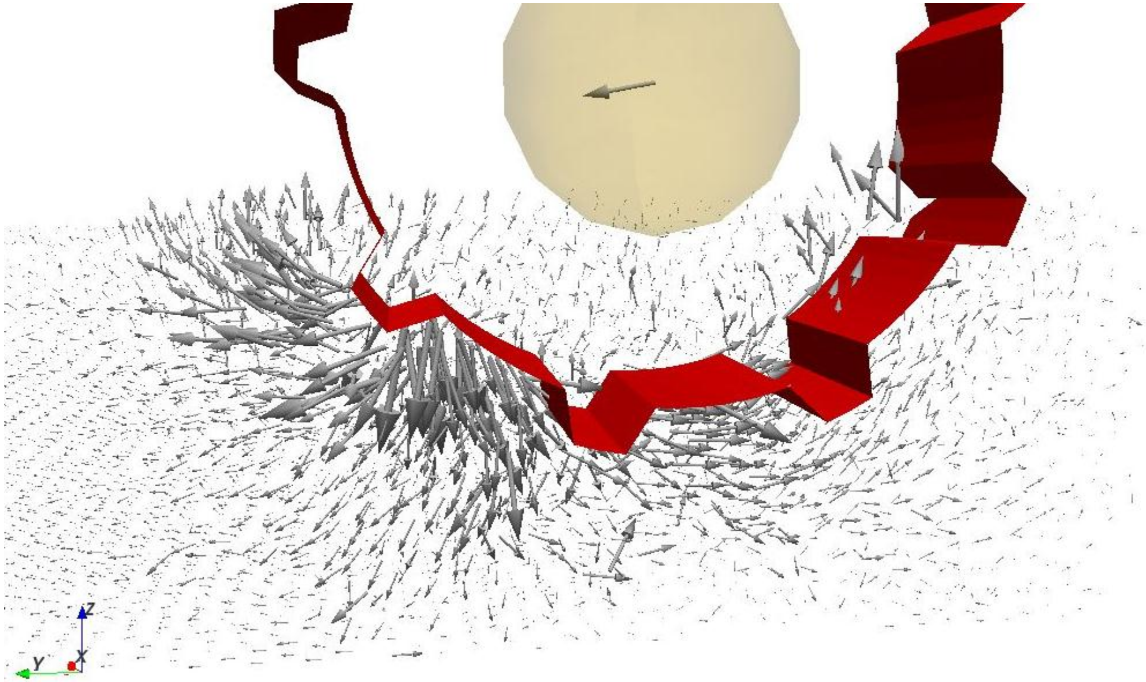
Discrete Element Method



- Particle based meshless method → No fixed neighbours
- Contact driven force/torque calculation
- Capable of covering high plastic deformation

1. Introduction

Discrete Element Method



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- Contact driven force/torque calculation
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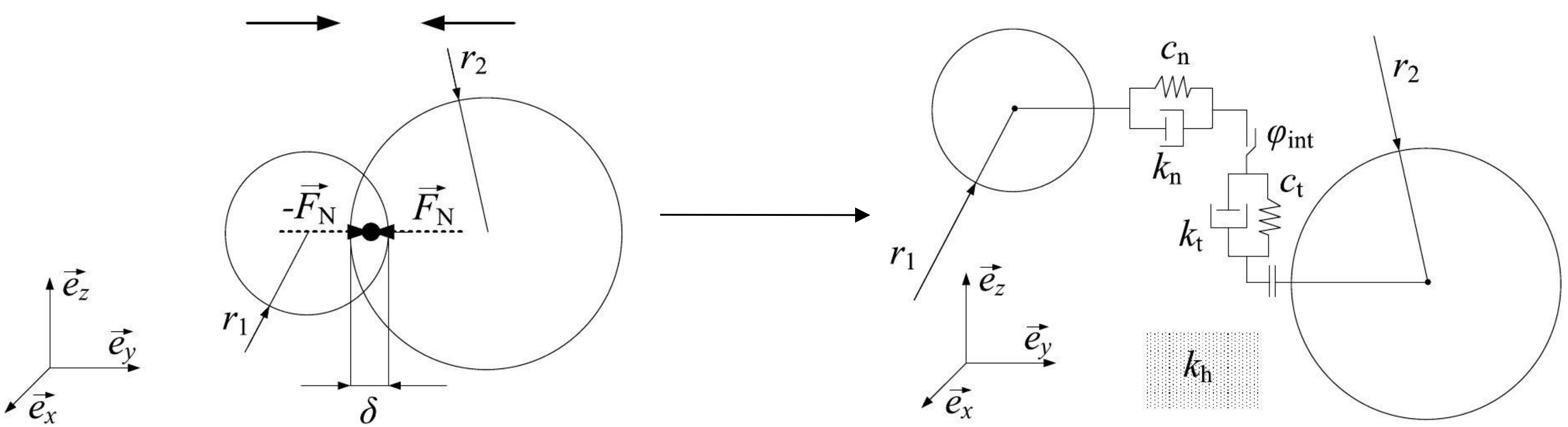
2. Contact models

Discrete Element Modeling

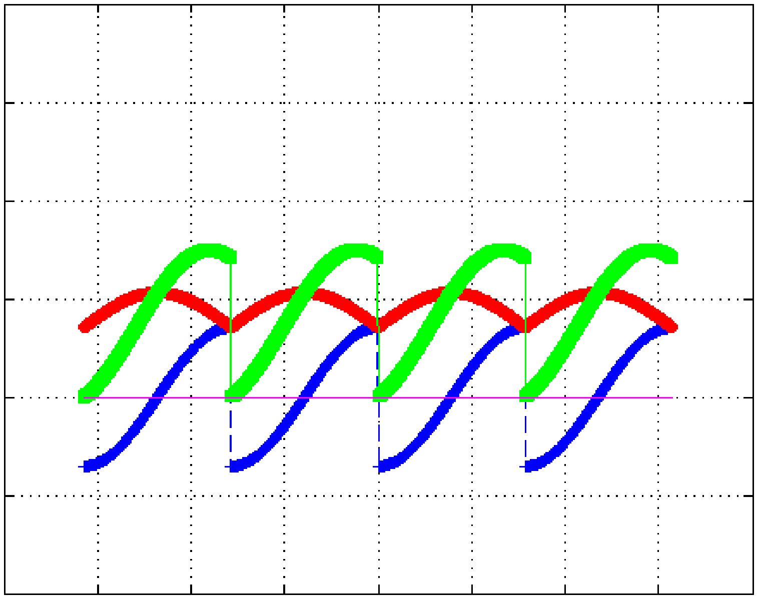
- Simulation domain consists of discrete particles
- Particle interaction based on contacts
- Forces and torques derived from contact models
- New position calculated from integration of the principles of linear and angular momentum

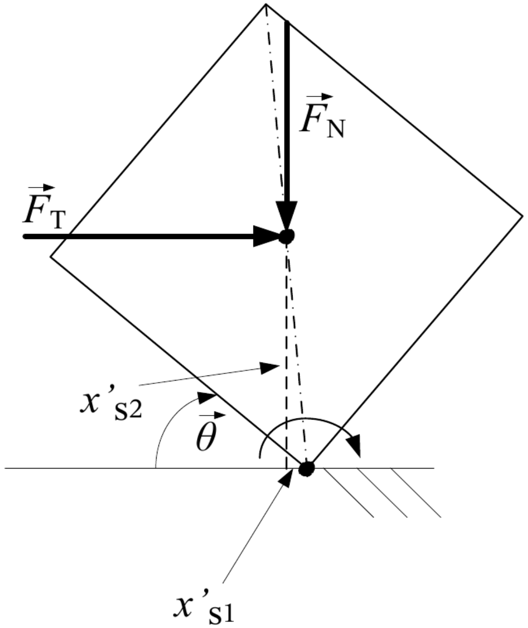


2. Tilting contact model

Resistance torque

- Resistance torque due to tilting
- Torque from tangential as well as normal forces
- 1 additional parameter: aspect ratio





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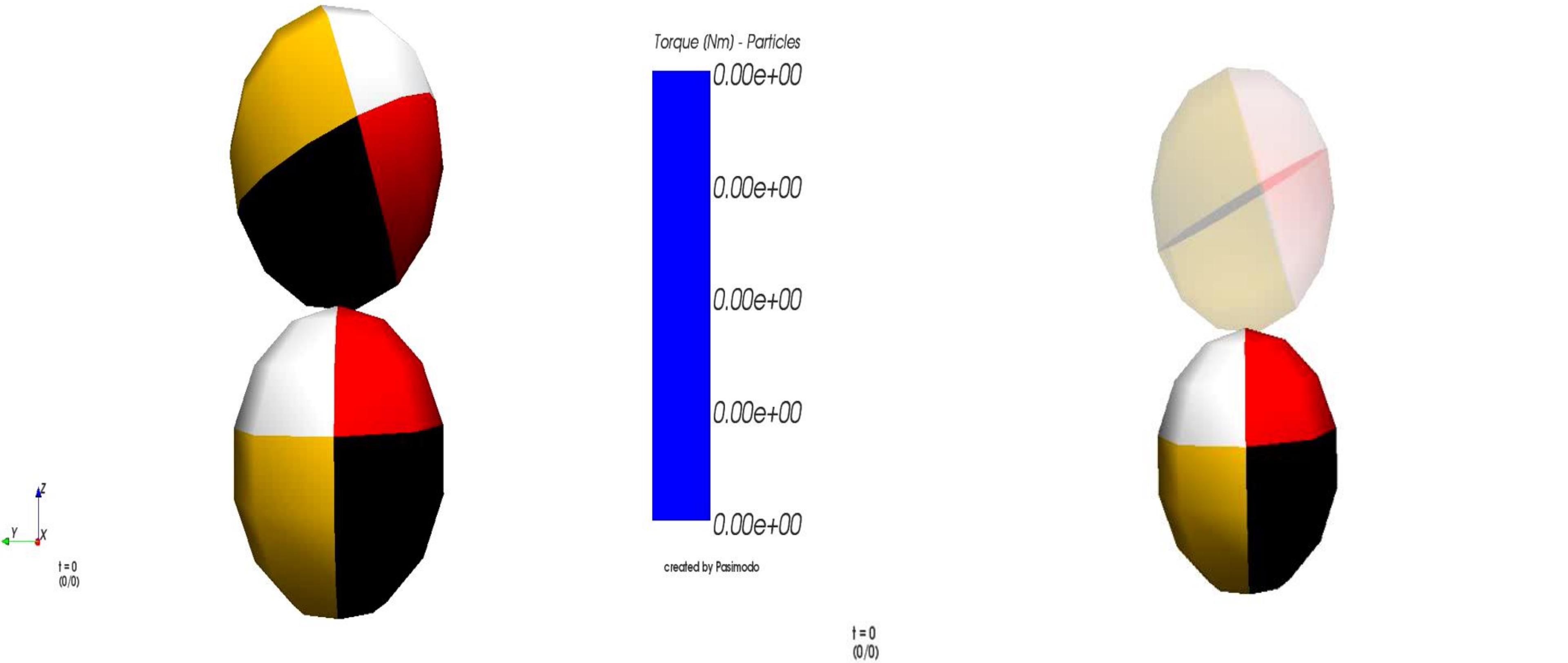
Resistance torque



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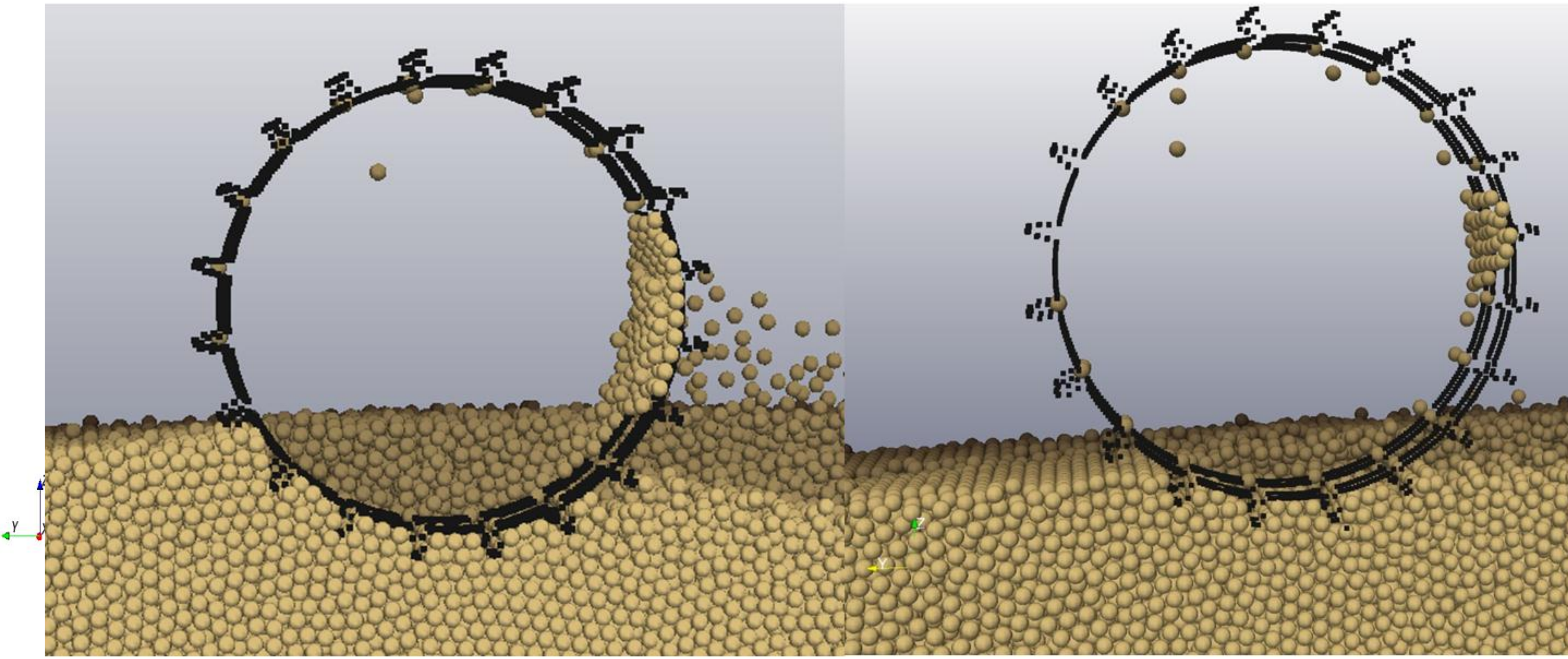
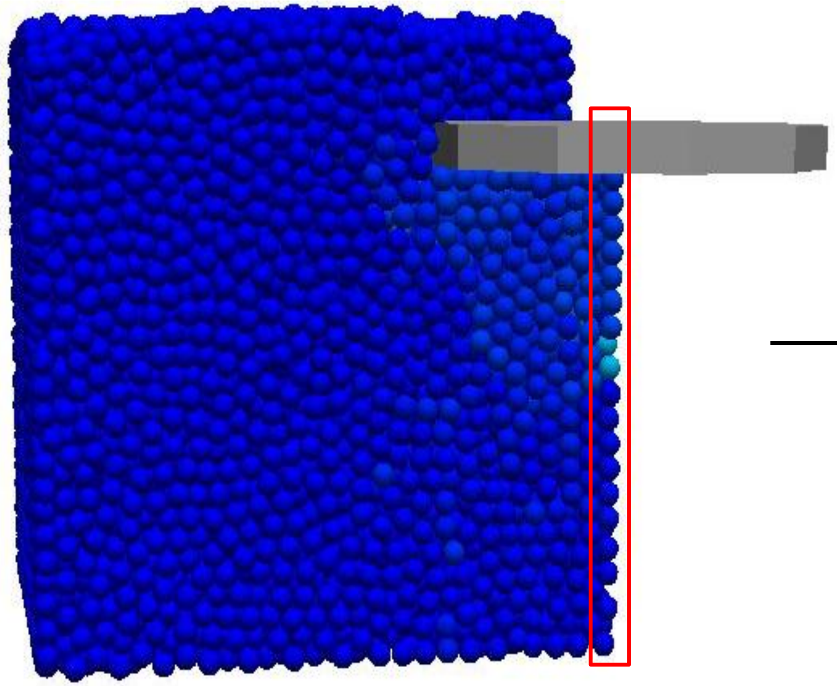
Resistance torque

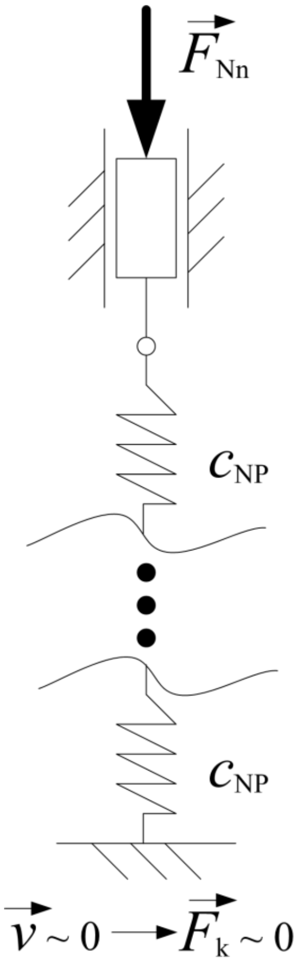


3. Parameter estimation

Determining the contact parameters

- Stiffness calculation dependent on the overlap

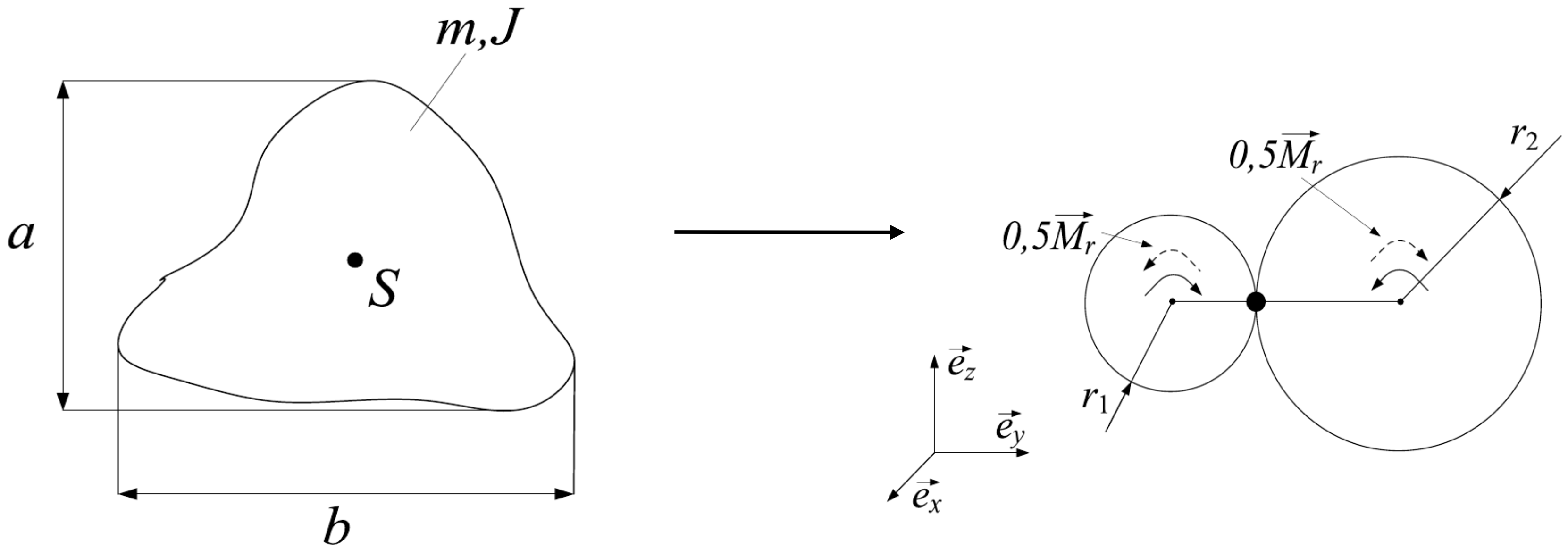




3. Parameter estimation

Determining the contact parameters

- Stiffness calculation dependent on the overlap
- Damping is derived as a fraction of critical damping
- Tangential stiffness and damping derived from normal direction
- Particle size determined by min. resolution
- Particle shape approximated by torque law



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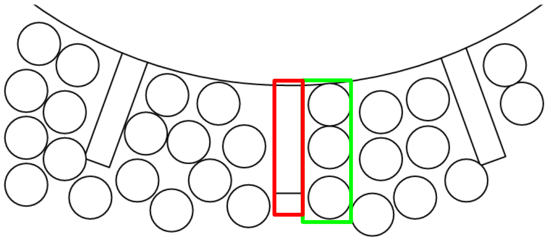
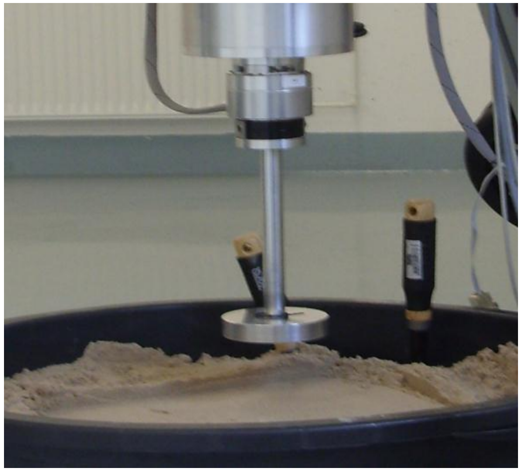
$$\Gamma := \frac{\boxed{L_{\mathrm{min}}}}{\boxed{2r_{\mathrm{max}}}}$$

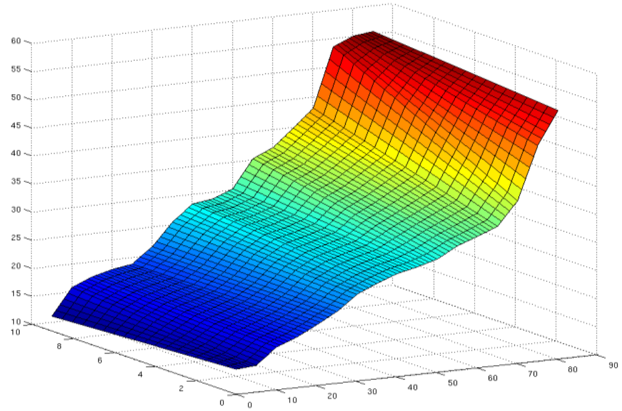


3. Parameter estimation

Determining the contact parameters

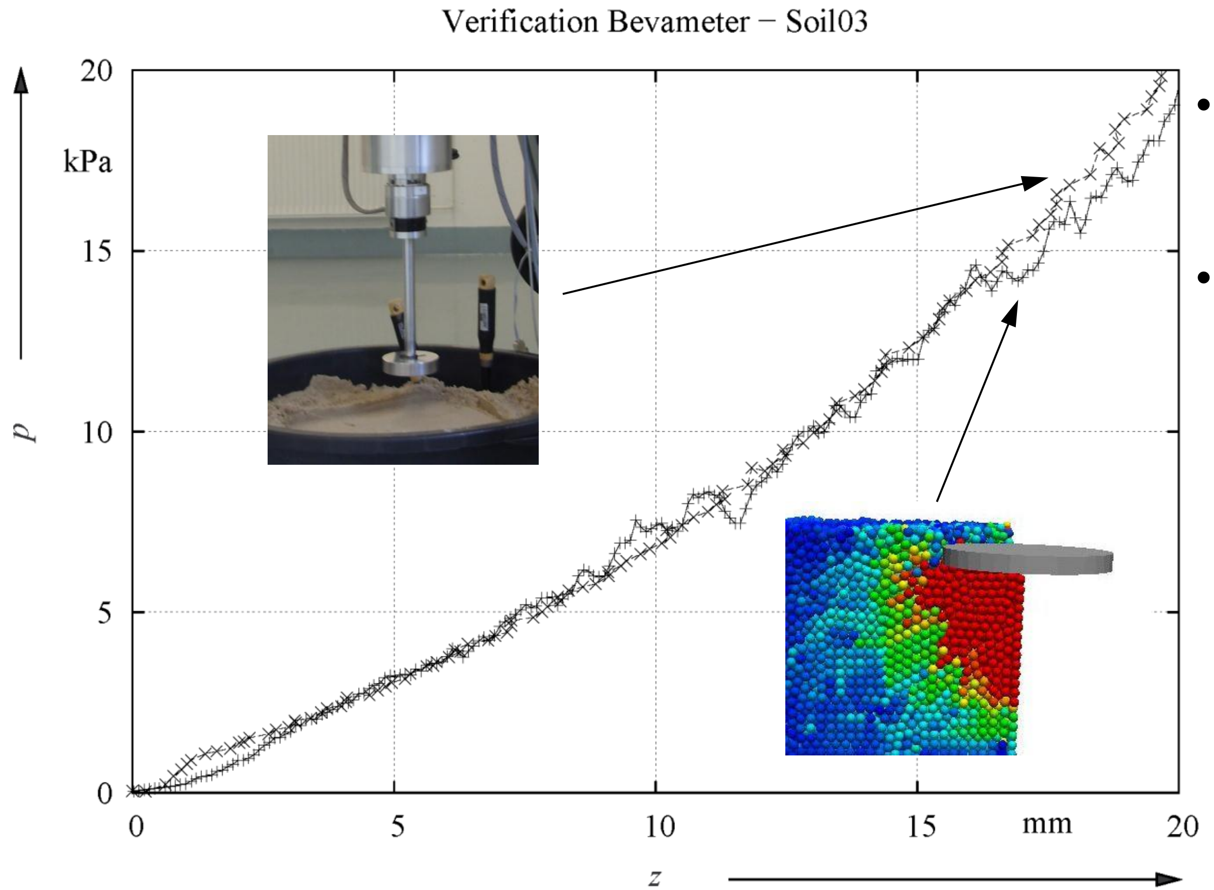
- Stiffness calculation dependent on the overlap
- Damping is derived as a fraction of critical damping
- Tangential stiffness and damping derived from normal direction
- Particle size determined by min. resolution
- Particle shape approximated by torque law
- Friction and rolling parameters stored in look-up tables





4. Models & Results

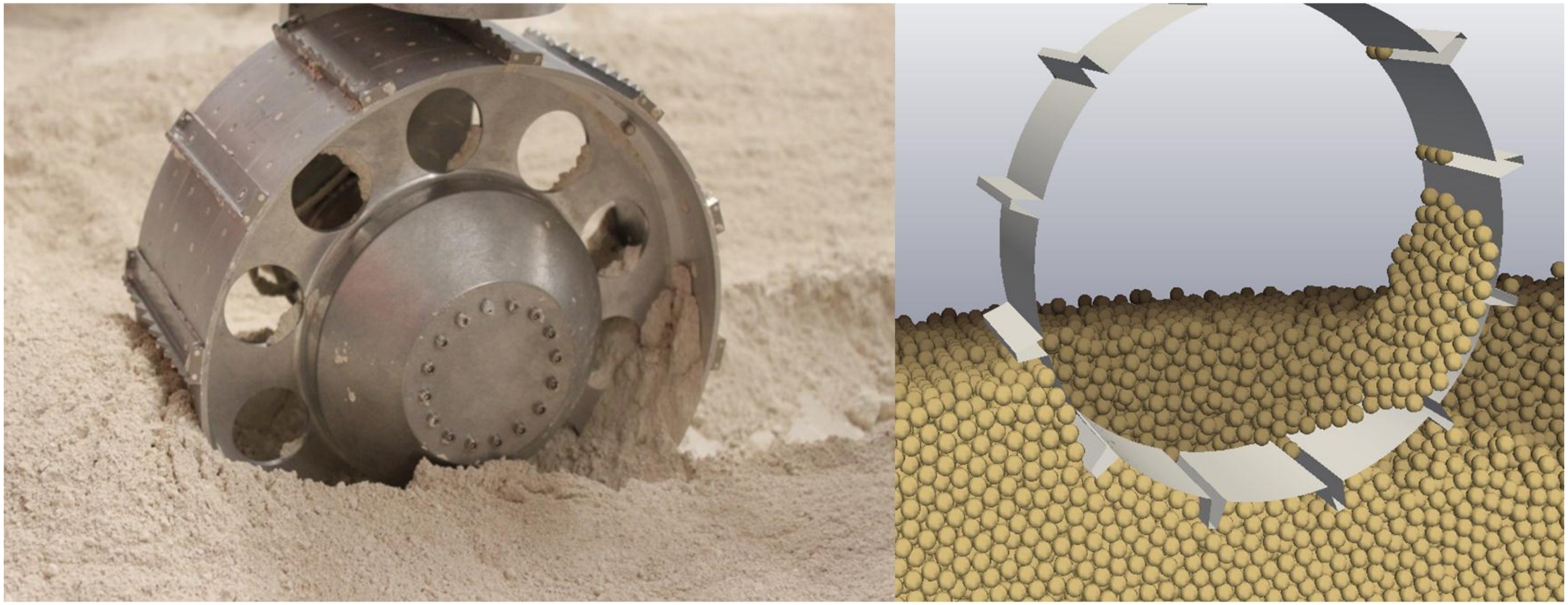
Verification: Bevameter pressure sinkage test



- Pressure sinkage test performed in simulation and measurement
- RMC-Soil_03 → milled lava soil

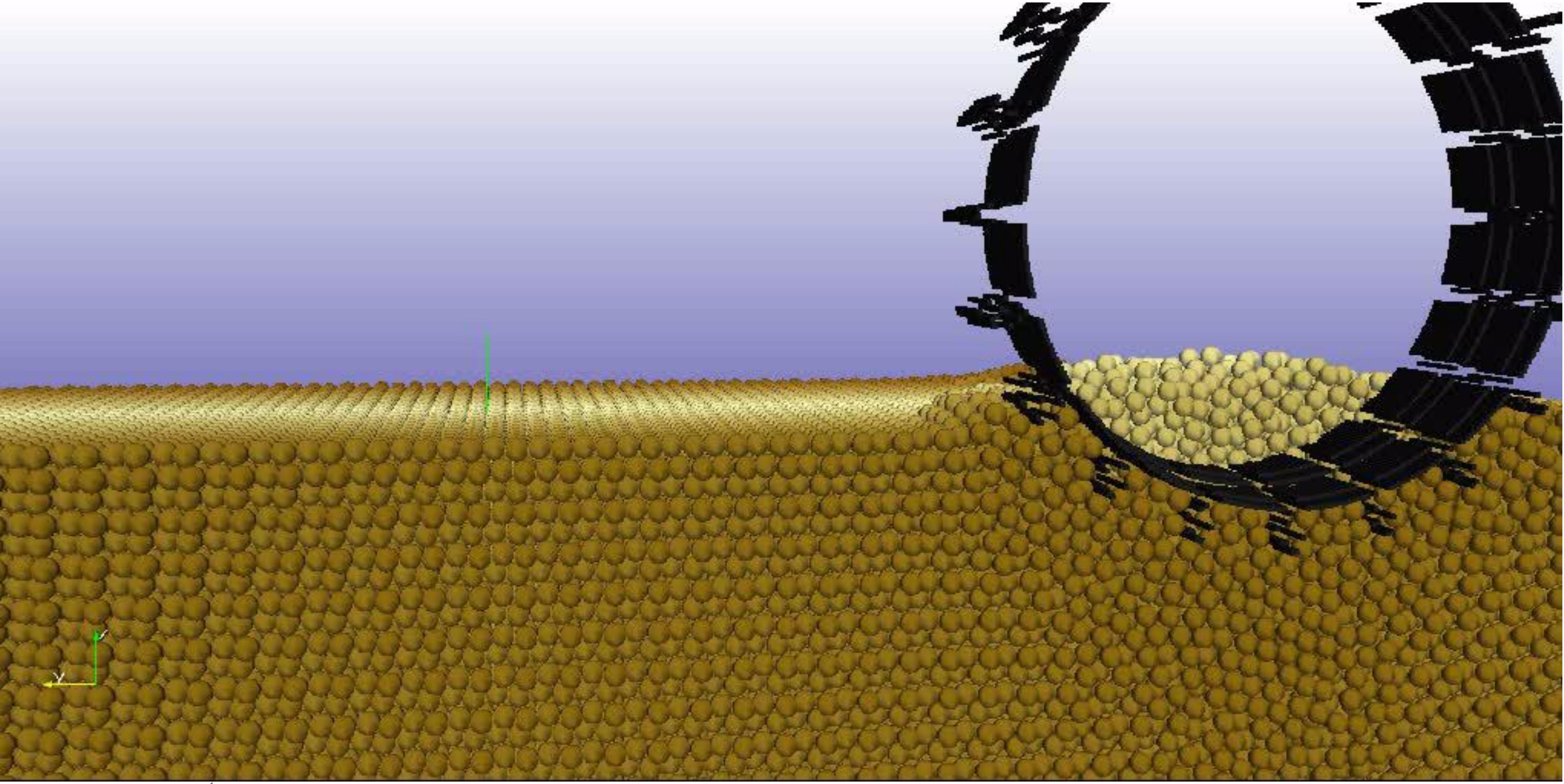
4. Models & Results

Simulations for planetary rover wheels



- Wheel modeled as fully dynamic triangulated surface
- Symmetry conditions used to decrease computation time
- Covering macroscopic soil deformation by grain relocation

4. Models & Results



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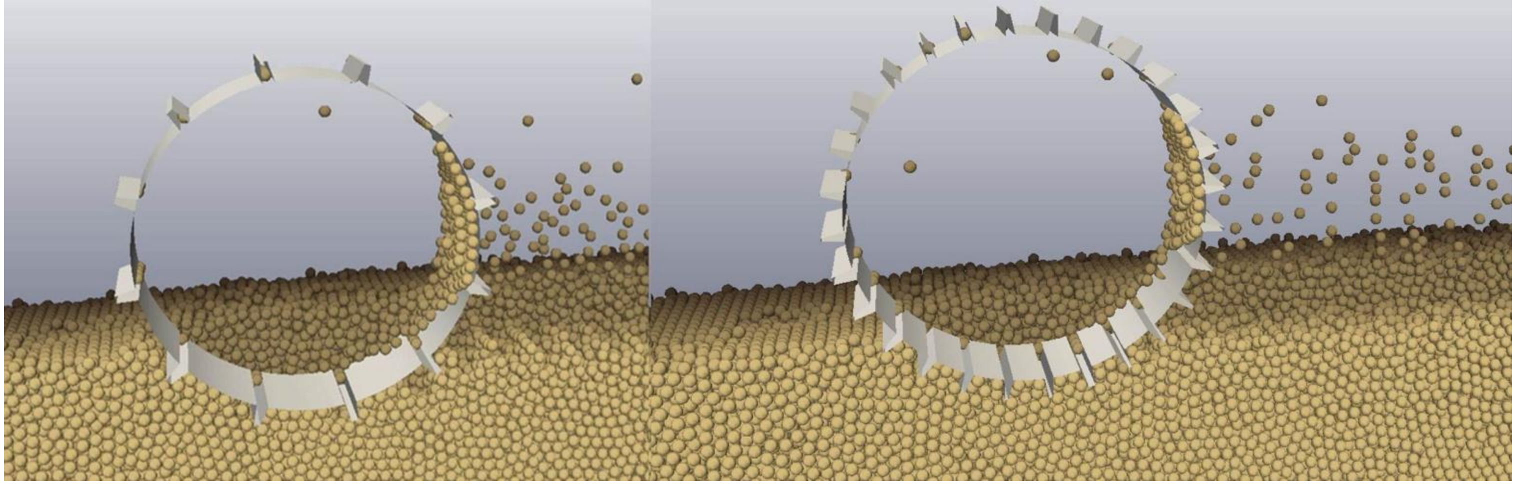
4. Models & Results

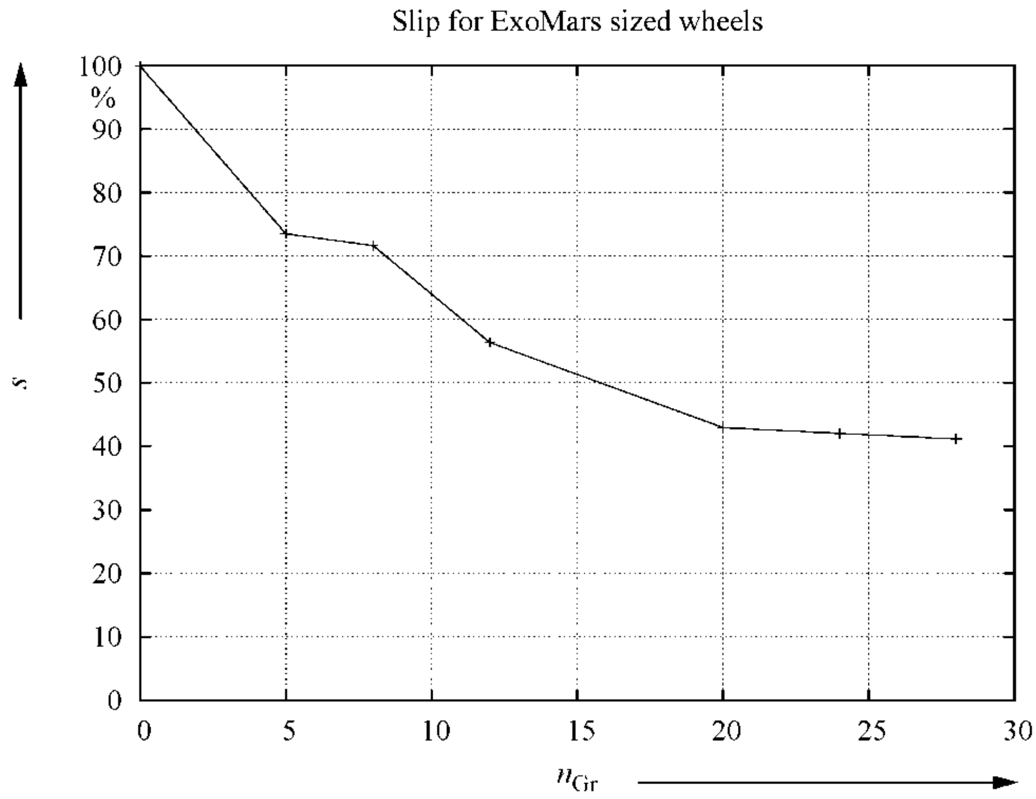
Parametric wheel development



- Usage of simulations for virtual prototyping
- Better understanding of the influence of the design parameters on the wheel’s performance
- First example: steady state slip for different grouser numbers

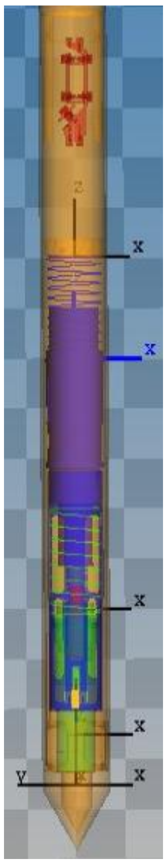
4. Models & Results

Parametric wheel development



4. Models & Results

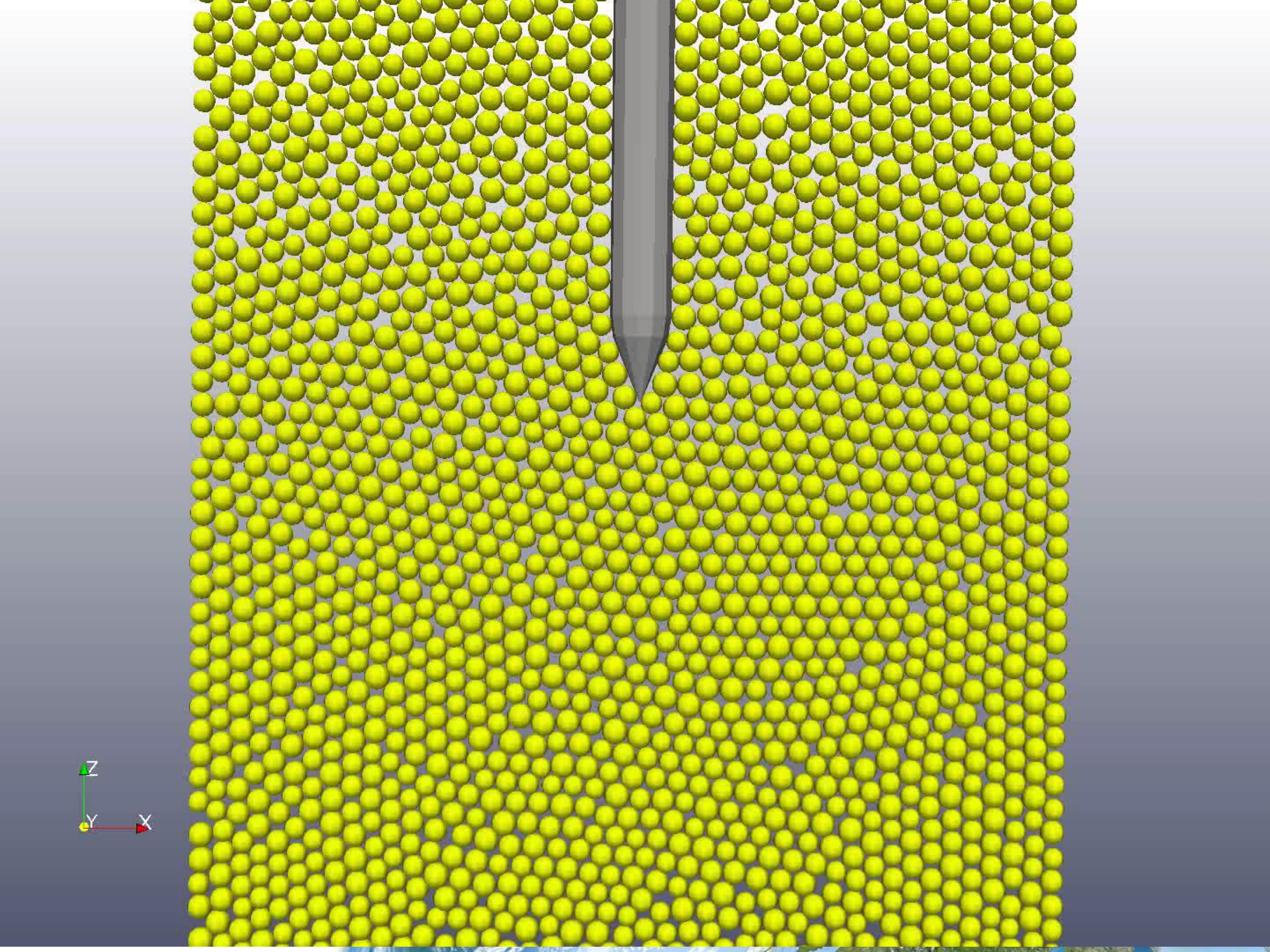
HP³-Mole Analysis & Optimization



co-simulation

mechanism behaviour
is soil dependent

find design optimum suitable
for a variety of soils
+
better understanding of the
interaction


Z
Y
X

5. Conclusion & Further steps

DEM

Rover wheels

- Discrete Element Method applied to rover wheels
- Efficient modeling of interparticle contact and rolling behaviour
- Parameter estimation strategy
- First verification using the bevameter test
- Parametric wheel development

HP^3-Mole

- Multibody Simulation & Optimization of the hammering mechanism
- Modeling of the soil interaction using Discrete Element Method

5. Conclusion & Further steps

DEM

Rover wheels

- Computational efficiency
- Validation → Single Wheel Testbed
- Influences & wheel development
- New analytical & empirical models

HP^3-Mole

- Co-simulation MBS-DEM
- Further optimization

Thank you for your attention!

Quellen:

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