Discrete element model for soil–tool interaction forces

Martin Obermayr, Klaus Dreßler
Fraunhofer Institut für Techno- und Wirtschaftsmathematik ITWM
Fraunhofer Platz 1, 67663 Kaiserslautern
martin.obermayr@itwm.fraunhofer.de

Motivation

- Prediction of soil–tool interaction forces in early stage of product development
- Experiments are complex and expensive
- Simulation can help to improve trajectories, bucket geometries, and reliability of machines
- Simple classification of soils into *granluar*, *cohesive*, and *cemented*



Discrete element model

- Model is simple and numerically efficient
- Formulation is scale invariant, i.e. scaling all geometric lengths does not change results
- Parameterization with macromechanical properties of bulk material [1]
- Based on PASIMODO software [2]

Granular soil

1. Normal repulsive force model with normal stiffness as a function of the particle size [3]

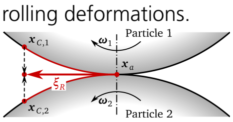
$$f_N = \frac{\pi}{2} \hat{E}\, r\, \delta + d_N \dot{\delta}. \qquad (1)$$

2. Tangential force from spring-dashpot model

$$\mathbf{f}_T = -k_T \boldsymbol{\xi}_T - d_T \dot{\boldsymbol{\xi}}_T \qquad (2)$$

is limited to $\|\mathbf{f}_T\| \le \mu f_N$ to account for Coulomb friction.

3. Rolling resistance is important for realistic values of internal friction. Vector $\boldsymbol{\xi}_R$ accumulates incremental rolling deformations.

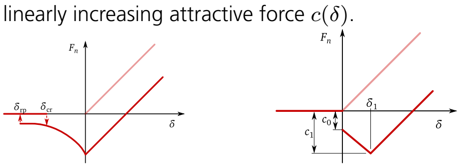


Rolling resistance torque from

$$\boldsymbol{t} = (\boldsymbol{x}_a - \boldsymbol{x}_1) \times (k_T\, \boldsymbol{\xi}_R) \qquad (3)$$

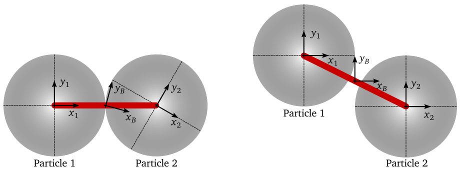
Cohesive soil

Simplified model of capillary cohesion with a linearly increasing attractive force $c(\delta)$.



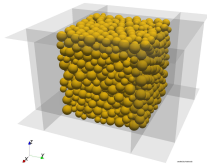
Cemented soil

Cemented soils, rock or asphalt are modeled by bonded particles [4]. Beam theory is used to derive a numerically efficient model for the bonded particles.

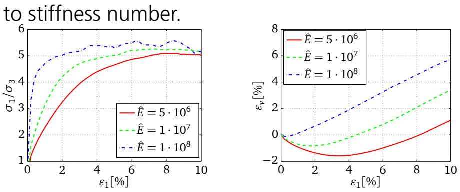


Parameterization

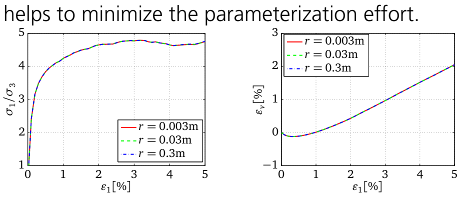
Parameterization is based on simulation of triaxial compression tests.



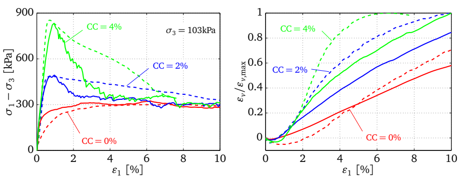
Non-dimensional numbers help to find good initial guess, e.g. shear strength is almost insensitive to stiffness number.



The discrete element model is scale invariant. This helps to minimize the parameterization effort.

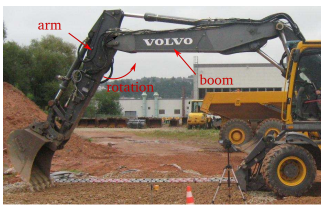


Results of measurements are used to fit the peak and residual strength of the material. One set of parameters can capture the material behavior over a wide range of boundary conditions.

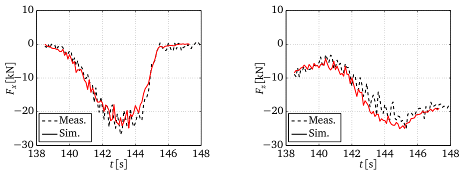


Application

Simulation of a digging in gravel is simulated and compared to measurements.

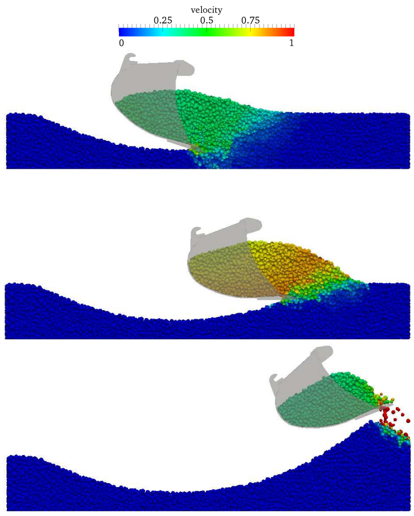


The trajectory of the bucket and material properties are given. Comparison of horizontal and vertical forces



and bucket filling show good agreement between simulation and experiment.

Simulation allows a better insight into the filling process than measurements do. Here, the velocity profile in a longitudinal section is shown.



References

[1] M. Obermayr, K. Dressler, C. Vrettos, P. Eberhard: *Prediction of draft forces in cohesionless soil with the discrete element method*, Journal of Terramechanics 48 (2011) 347–358.
[2] F. Fleissner. *Parallel Object Oriented Simulation with Lagrangian Particle Methods*, Shaker, Aachen, 2010.
[3] C. Ergenzinger, R. Seifried, P. Eberhard: *A discrete element model to describe failure of strong rock in uniaxial compression*, Granular Matter 13 (2010) 1–24.
[4] M. Obermayr, K. Dressler, C. Vrettos, P. Eberhard: *A bonded-particle model for cemented sand*, Computer & Geotechnics (Accepted for publication).

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