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DEM modelling of the penetration process of the HP³ Mole

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Abstract

The NASA InSight Mission will be launched in March 2016 and will reach the surface of Mars roughly nine months later in the Elysium Region. One of the instruments on board is the HP³ Mole to measure the planetary heat flow. For this purpose it needs to penetrate five meters deep into the surface of Mars and thus offers also the possibility to analyse the soil properties. For the reconstruction of the soil behaviour and also to predict the mole performance and maximum reachable depth in advance, numerical simulations are used. The simulation of the soil during the hammering process of the HP³ Mole requires a substantial numerical effort due to the local high dynamics and large soil deformations that occur. After comparing the capability of various simulation methods (FEM, MPM and DEM) a discrete element method (DEM) was chosen.

1. Introduction

The mechanical characterization of Martian soil is not yet accurate and complete and has to be further investigated to understand the processes and history of the planet and also to get better information for planning space missions in future. Until now the mechanical properties of the soil are tried to be captured indirectly by analysing the stability of natural slopes which can be measured by images of the surface of Mars and by measuring the imprint of the wheels of the Mars Exploration Rovers. Due to slope stability analyses it was obtained that the soil behaves like cohesionless dry silts and sands [1]. The studies of the imprint by the wheels of the Mars Exploration Rovers provide an estimated stiffness of the shallow surface on the Mars [2]. However, it needs to be kept in mind that these results are not very precise. Therefore, the penetration response of the HP³ Mole will be a great opportunity to get a better mechanical characterization of the Martian soil. The mechanical soil behaviour as response due to the mole penetration is very complex and cannot be calculated in a closed form solution. Numerical simulations are needed to reconstruct the material properties from the penetration process. Also a first prediction of the maximum reachable depth of the Mole shall be done by simulations.

2. Numerical Simulation

The discrete element method is used to simulate the dynamic penetration process of the HP³ Mole. In the DEM the granular material is represented by a finite amount of discrete spherical particles that interact amongst themselves. The advantages of the DEM in comparison to a FEM-based simulation software is that the material is not implemented as a continuum and therefore it is not required to provide a suitable soil mechanical constitutive model. The mechanical soil effects, like hardening and dilation, are captured automatically by the structure of the particles and the rearrangement of particles. The particle approach allows local high dynamics and distortions inside the soil.

2.1 Calibration of Materials

In order to be representative, the numerical properties of the particles in the simulation need to be calibrated against real soil behaviour. The calibration of materials in DEM is quite different to continuum based methods. In the DEM it is necessary to define the micro-scale parameters of a single grain. This can be done by comparing the soil response of macro-scale laboratory experiments with numerical models. The calibration of the material is done with four different laboratory experiments:

- Angle of repose experiments
- Oedometer test
- Triaxial compression test
- Particles on an inclined plane

Here, the first three experiments are used to determine the interparticle soil behaviour and the last experiment is used to determine the frictional parameters between soil particles and the penetrator.

2.2 Dynamic Cone Penetration

The dynamic cone penetration generates locally a high acceleration of particles, which will result in a pressure wave propagation through the soil. This in turn leads to undesirable wave reflections at the boundaries of the specimen. With a large specimen size these reflections could be avoided, but this will result in a large amount of particles and thus a high computational effort. A promising solution is the usage of absorbent boundaries. This has already been done for some test cases, and needs to be verified for the dynamic penetration case. The force profile, representing the stroke of the mole internal hammer mechanism forcing the penetrator, is approximated as half of a sine curve with a certain time interval and magnitude. This profile has been taken from calculations of an one dimensional pile drive model [3]. For the first assumptions on the reachable depth, a small chamber with absorbent sides and bottom boundaries and a top plate with a defined mass, to approximate the overburden pressure, has been used. The resulting acceleration force on each particle due to the hammer stroke during penetration can be seen in Figure 1.

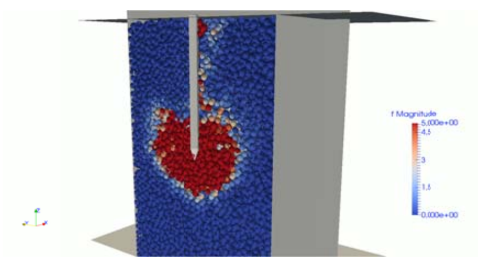

Figure 1: Simulation of a dynamic cone penetration in DEM

6. Summary and Conclusions

The progress data from the penetration of the HP³ Mole in the Martian soil provide an unique opportunity to derive an accurate mechanical characterization of the Martian soil at the landing site. The simulation of the initial penetration process will provide a first prediction of the maximum reachable depth and gives a better understanding of the mechanical soil behaviour on Mars by back-calculations afterwards. The DEM allows insights into the particle scale interactions and is able to simulate high dynamics within the soil.

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