Parallel Level-Set DEM (LS-DEM) Development and Application to the Study of Deformation and Flow of Granular Media

Peng Tan and Nicholas Sitar

Department of Civil and Environmental Engineering
University of California, Berkeley

This project provides a systematical investigation of computational approaches to modeling of granular materials. Granular materials are ubiquitous in everyday life and in a variety of engineering and industrial applications. Despite the apparent simplicity of the laws governing particle scale interactions, predicting the continuum mechanical response of granular materials still poses extraordinary challenges. This is largely due to the complex history dependence resulting from continuous rearrangement of the microstructure of granular material, as well as the mechanical interlocking due to grain morphology and surface roughness. X-Ray Computed Tomography (XRCT) is used to characterize the grain morphology and the fabric of the granular media, naturally deposited sand in this study. The Level-Set based Discrete Element Method (LS-DEM) is then used to bridge the granular behavior gap between the micro and macro scale. The LS-DEM establishes a one-to-one correspondence between granular objects and numerical avatars and captures the details of grain morphology and surface roughness. However, the high-fidelity representation significantly increases the demands on computational resources. A parallel version of LS-DEM was therefore developed to significantly decrease the computational demands. The code employs a binning algorithm, which reduced the search complexity of contact detection from $O(n^2)$ to $O(n)$, and a domain decomposition strategy is used to elicit parallel computing in a memory- and communication-efficient manner. The parallel implementation shows good scalability and efficiency.

High fidelity LS avatars obtained from XRCT images of naturally deposited sand are then used to replicate the results of triaxial tests using the new parallel LS-DEM. Both micro- and macro-mechanical behaviors of natural materials were well captured and validated with experimental data. The results of the numerical modeling show that the primary source of peak strength of sand is the mechanical interlocking between irregularly shaped grains. Flexible membrane simulations with a rotatable loading platen were found to well match experimentally observed mobilized friction angle for naturally deposited sand as shown in Figure 1.

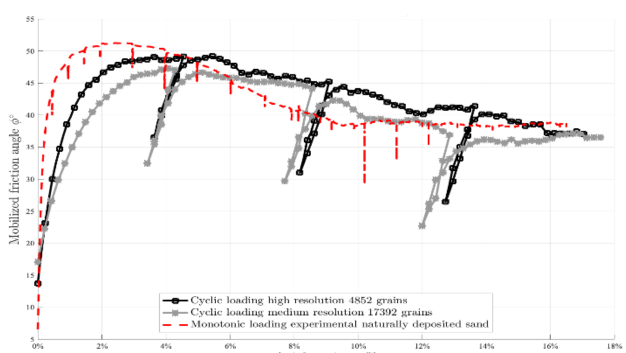

Figure 1. Comparison of observed and modeled sand behavior in triaxial test.

We also developed a new impulse-based LS-DEM code for the purpose of modeling dynamic phenomena. The new formulation is stable, fast and energy conservative and is particularly well suited for modeling of fast physical phenomena such as rock falls and rock avalanches. In addition, the code allows the modeling of flexible barriers such as used for rock fall protection, as shown in Figure 2.

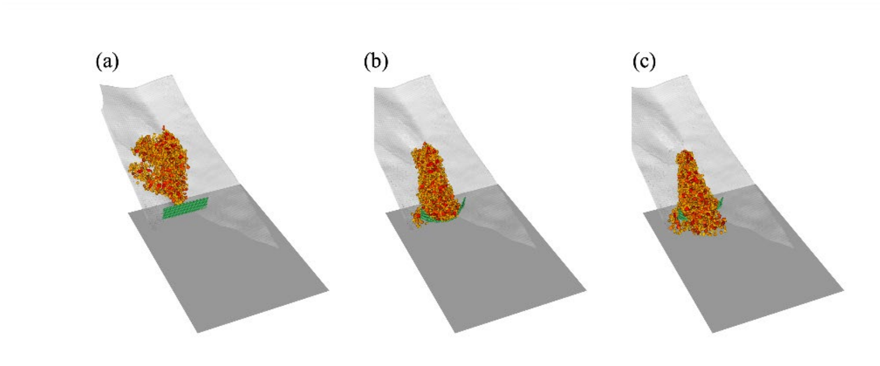

Figure 2. Rock avalanche and impacting a flexible barrier

Overall, we have demonstrated that high resolution reconstruction of the natural sand fabric allows the modeling of observed deformation behavior of naturally deposited sand with high fidelity. This opens further opportunities to explore including water as a pore fluid in future models in order to fully model sand liquefaction under different conditions. In addition, the newly developed impulse-based DEM shows excellent promise for development of computational tools for safety assessment of slopes in many different environments.

Keywords: Level-Set DEM (LS-DEM), parallel programming, modeling granular media, triaxial compression, rock falls and avalanches.