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LS-DEM: A NEW PARADIGM FOR DISCRETE ELEMENT SIMULATIONS

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Summary. The level set discrete element method (LS-DEM) is a discrete element method (DEM) variant capable of simulating particles of arbitrary shape in three dimensions using level set functions as a geometric basis. LS-DEM's formulation allows seamless interfacing with level set-based characterization methods from X-ray computed tomography (XRCT) images as well as computational ease in contact calculations. For the first time, we are able to simulate tens of thousands of grains whose morphologies occur in nature.

1 Level Set Discrete Element Method

The level set discrete element method (LS-DEM) is a discrete element method (DEM) variant capable of simulating particles of arbitrary shape using level set functions as a geometric basis, which are scalar-valued implicit functions $\phi(\boldsymbol{p})$ whose values, in the context of LS-DEM, are the signed distance from a point $\boldsymbol{p}$ to a particle's surface [3]. Level set functions can be generated through application of level set-based imaging techniques to XRCT images [4], allowing for a complete 'tomography-to-simulation' paradigm where simulations are carried out using grain morphologies identical to those occurring in nature.

In addition to its synergy with morphological characterization from XRCT images, LS-DEM is also computationally efficient thanks to its formulation. Generally, in DEM or any of its variants, penetration distances and surface normals are the two most important and time-consuming quantities to compute from contact detection. In LS-DEM, these quantities are easy to compute as the penetration distance at any point $\boldsymbol{p}$ is equal to $\phi(\boldsymbol{p})$ and its corresponding contact normal is equal to $\nabla\phi(\boldsymbol{p})$, both of which can be found through simple linear interpolation.

LS-DEM has been validated through two full 'tomography-to-simulation' processes consisting of simulations of two triaxial tests, whereby each grain was numerically represented one-to-one from an experimental specimen, and computational stress-strain and volume-strain curves were verified with corresponding experimental data [2].

2 Numerical Simulations

We applied LS-DEM to simulate a triaxial specimen consisting of 22,351 grains. 100 unique morphologies, extracted from a 3D XRCT image of Quikrete sand, were used as the grain shapes. The computational specimen, measuring 4.2 cm in height and 2.1 cm in diameter, was isotropically compressed to $\sigma_3 = 300kPa$, then triaxially compressed to $\varepsilon_1 = 20\%$. To simulate membrane behavior, we used a cylindrical wall system comprised of bonded spheres as in [1].

The results are shown in Figure 1. Bulging can be seen in the deformed specimen, and no shear band appears to have developed.

REFERENCES

[1] J. de Bono, G. Mcdowell, and D. Wanatowski. Discrete element modelling of a flexible membrane for triaxial testing of granular material at high pressures. *Gotechnique Letters*, 2(4):199–203, 2012.

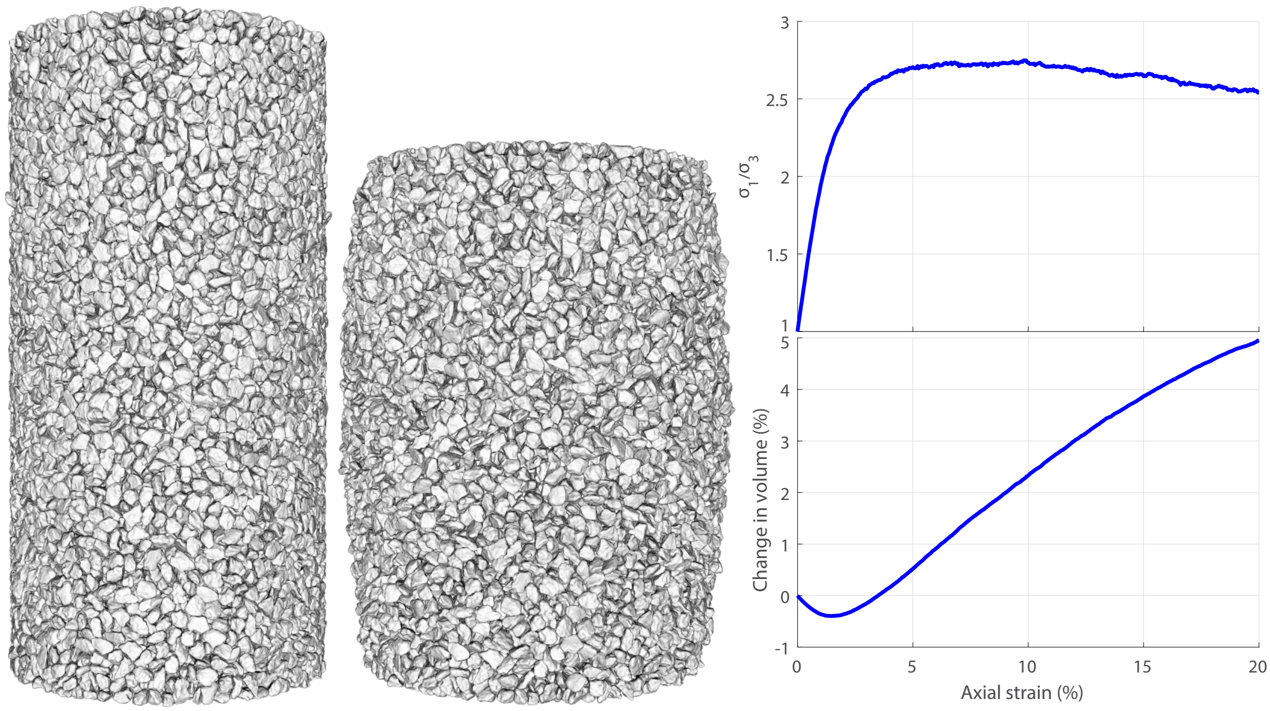

Figure 1: Results of triaxial compression of 22,351 grain LS-DEM specimen. Left: Before and after images. Right: Stress-strain and volume-strain curves.

[2] R. Kawamoto, K. Lim, E. Andò, G. Viggiani, and J. Andrade. Level-set discrete element modeling of martian simulant. *Journal of the Mechanics and Physics of Solids*, in review.

[3] S. Osher and R. Fedkiw. *Level Set Methods and Dynamic Implicit Surfaces*. Springer, 2003 edition edition, 2003.

[4] I. Vlahinic, E. Ando, G. Viggiani, and J. E. Andrade. Towards a more accurate characterization of granular media: extracting quantitative descriptors from tomographic images. *Granular Matter*, pages 1–13, 2013. doi:10.1007/s10035-013-0460-6.