Examining smooth and nonsmooth discrete element approaches to granular matter

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ABSTRACT

Simulation of granular matter in terms of distinct rigid elements may be done either using *smooth* [1] or *nonsmooth* [2] discrete element methods (DEM). The main difference in the smooth and nonsmooth approach lies in whether the viscoelastic nature of contacts is resolved in time or not. The nonsmooth approach considers collisions and stick-slip frictional transitions as instantaneous events according to a given contact law. This approximation reduces some information about the dynamics but requires potentially less computational effort as large time-step integration is possible. The nonsmooth approach is most favourable in dense, quaststatic systems with high ratio of material stiffness over element mass. The smooth approach becomes increasingly favourable with increasing granular temperature and decreasing material stiffness, c.f., Eq. (37) and Fig. 6 in Ref. [3]. In a general situation, however, the granular temperature may vary over time and space and it is hard to judge in advance which approach is most appropriate. The situation is complicated further when considering that nonsmooth DEM implementations usually employ iterative solvers and the number of iterations to achieve a given accuracy depends on both the state and topology of the system as well as on the choice of initial guess [4]. Both empirical data and mathematical analysis is needed to add more knowledge regarding choice of simulation approach for different problems.

It is possible to regularize the nonsmooth approach and obtain methods that share properties of both the smooth and nonsmooth DEM [5-7]. We present a regularized version of nonsmooth DEM that easily may be tuned between the smooth and nonsmooth mode as well as various intermediate, or *semi-smooth*, modes. The regularization parameters can be derived from conventional viscoelastic interaction models. We simulate a set of standard test systems representing a wide class of states of the granular media, ranging from quasistatic state under external load to rapid shear flow with free surfaces. The resulting stresses and strain rates are compared to documented reference solutions. The collected data shows how accuracy and computational efficiency depends on the degree and mode of smoothness as well as on the state of the system, represented by the inertial number and granular temperature. Guidelines for when to choose a smooth or nonsmooth approach are suggested. Finally, the possibility of constructing a DEM with adaptive smoothing is discussed.

REFERENCES

[1] P.A. Cundall, O.D.L. Strack, "A discrete numerical model for granular assemblies", *Geotechnique*, **29**:47–65, (1979).

[2] M. Jean, "The non-smooth contact dynamics method", *Comput. Methods Appl. Mech. Eng.*, **177**, 235-257 (1999).

[3] L. Brendel, T. Unger, D. Wolf, "Contact Dynamics for Beginners", in *The Physics of Granular Media*, pp. 325-343, eds. H. Hinrichsen and D. E. Wolf, Wiley-VCH, Weinheim, (2004).

[4] F. Radjai, V. Richefeu, "Contact dynamics as a nonsmooth discrete element method", *Mechanics of Materials*, **41** (6) p. 715-728, (2009).

[5] C. Lacoursière, M. Servin, A. Backman, "Fast and stable simulation of granular matter and machines", *DEM5 - The Fifth International Conference on Discrete Element Methods*, London 25-26 Aug (2010).

[6] C. Lacoursière, "Ghosts and Machines: Regularized Variational Methods for Interactive Simulations of Multibodies with Dry Frictional Contacts", PhD thesis, Dep. of Computing Science, Umeå University, Sweden, (2007).

[7] R. I. Leine and H. Nijmeijer, "Dynamics and Bifurcations of Non-smooth Mechanical Systems", volume 18 of Lecture Notes m Applied and Computational Mechanics. Springer, Berlin (2004).