Contributions and limitations of the Non Smooth Contact Dynamics for the simulation of dense granular systems.

In honour of J.J. Moreau.

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ABSTRACT

The numerical simulation of complex dynamical systems is an important way for studying phenomena that are difficult to investigate experimentally. We could then speak about numerical granular media as a specific scientific field similarly to the numerical fluids twenty years ago. The numerical investigation progresses so quickly with respect with the experiments that the comparison between simulations and experiments is often rather coarse. Moreover the numerical tools may be used beyond their limits of validity. We propose to analyse the contributions, but also the limits of the NonSmooth Contact Dynamics (NSCD), developed by J.J. Moreau [1], applied to the granular systems starting from some experiences and from the numerous remarks given by Moreau himself in his papers [2].

The NSCD method has been developed for dealing with large collections of packed bodies and then for simulating the behaviour of granular materials. The Nonlinear Gauss-Seidel (NLGS) algorithm is the generic solver applied to the NSCD formulation. This combination allows simulation of the behaviour of a collection of (especially rigid) bodies involving different and mixed regimes: static, slow dynamics (solid), fast dynamics (fluid). Some examples illustrate the ability of the Moreau's approach for dealing with a large range of granular problems.

For illustrating the limits of the NSCD approach we focus our attention on dense granular systems that are strongly confined. In order to respect the "elegant rusticity" of the Moreau's approach we restrict the analysis to a collection of rigid bodies without considering global or local deformations of the grains. Some simple examples highlight the issue of inconsistencies, i.e. some configurations for which no solution exists, as well as indeterminacies, i.e. configurations that lead to non-uniqueness of solutions. We recover here the *Painlevé paradox* underlined at the beginning of the twentieth century. The non existence of solutions is the more important challenge we have to face. We can first identify the situations leading to this non existence among them the granular systems submitted to moving walls. If such a case may not be avoided another response consists in changing the Coulomb friction law.

The NSCD approach is well adapted to inelastic shocks that predominate in granular media. However J.J. Moreau introduced the concept of *formal velocity* to account for an elastic restitution. This concept is richer than a restitution coefficient (Newton or Poisson type) involving a *binary shock*; this permits to deal with multicontact situations without introducing either deformable grains or elastic-plastic contact laws [3]. However this does not allow to reproduce shock propagation as it occurs for instance in the famous Newton's cradle. Is it then possible to propose an algorithmic solution in the NSCD framework?

REFERENCES

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[3] N.S. Nguyen, B. Brogliato, *Multiple impacts in dissipative granular chains*, Springer, (2014).