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# Efficient rubble pile dynamics simulation using constraint projections

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It is generally accepted that many, if not most, Near Earth Asteroids (NEAs) are rubble-pile bodies. A thorough understanding of the unique dynamical characteristics of such bodies is needed in order to determine the efficacy of various mitigation techniques, e.g. nuclear burst, impact or method, etc. In the first part of this analysis, we follow Lankrani and Nikravesh by including contact forces (between the constituent boulders) in the equations of motion. Under (Apophis-sized) self-gravity, elastic penetrations are very small compared to boulder size. With reasonable hysteretic damping factors, collisions are essentially inelastic i.e. the coefficient of restitution can be ignored. In addition the very short-range and stiff contact forces necessitate very small integration time steps. To remove this problem, we can treat inelastic contacts algebraically. Specifically, inelastic, hard sphere contact constraints are handled by introducing algebraic projections (idempotent matrices) into the integration routine. We illustrate results with a 64-boulder rubble pile hit with a kinetic imp actor. For the intervals of continuous motion, the integration routine need only deal with the relatively weak gravitational forces. This allows much larger integration time steps. When contacts occur, the projections effectively reduce the system degrees of freedom. This also speeds integration – especially, when large groups of boulders settle into a stable, static configuration. The above features allow for simulation of much larger systems. Extensions to non-uniform sized boulders and tangential friction are planned.

## Biography

Abdullah Ibrahim Alghalaiqah completed his education in the area of Electrical Engineering at King Saud University, Riyadh, the Kingdom of Saudi Arabia (KACST). He then joined King Abdulaziz City for Science and Technology as Senior Engineer and Research Professor in 2002. He is presently working within the Space Research Institute of KACST. His research interests include Lunar and asteroid science, development of methods for the discovery, characterization, and deflection of potentially hazardous Near Earth Asteroids. He is responsible for the management of several projects in these areas of interest.

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