7th IAA Planetary Defense Conference
26-30 April 2021

STRUCTURAL STABILITY OF (469219) Kamo'oalewa: DEPENDENCIES ON MATERIAL PARAMETERS

Chenyang Huang[1], Yang Yu[1], Fan Guo[2], Bin Cheng[3], Yun Zhang[4] and Jiangchuan Huang[2]

[1]School of Aeronautic Science and Engineering, Beihang University, Beijing, China
[2]China Academy of Space Technology, Beijing, China
[3]School of Aerospace Engineering, Tsinghua University, Beijing, China
[4]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France

Overview

The asteroid (469219) Kamo'oalewa, an interesting target for future exploration mission [1], is observed to have a high spin rate of 28 min, which is far beyond the critical spin limit [2]. The state of tension suggests a highly probable interior structure as a monolithic body. However, rubble-pile structures with moderate cohesion cannot be simply excluded because of its tiny size (~ 36 m) [3]. Thus a global cohesion in normal level can still be sufficient to maintain the rubble-pile structure.

In this work, we simulated the dynamical evolution of a global rubble-pile model following the spin-up path and captured the disaggregating state. We calculated the lower limit of bulk cohesion capable of sustaining the global structural stability, and checked its dependency on several concerned parameters, including the macro shape and the granular properties. For each parameter setup, we decrease the interparticle cohesive strength c continuously using the observed spin period and the lower limit of bulk cohesion C that could maintain structural stability is determined at the moment when a global failure occurs. A search over the parameter space confirms that a moderate global cohesion as determined by previous missions is sufficient to keep a rubble-pile structure stable under the observed spin rate. Our simulations also show that the global macro shape, interparticle effective contact area and friction coefficient are the main influential factors for the disaggregating bulk cohesion. Besides, the granular packing proves to be a key factor to the structural stability.

Methods

The parallel gravitational N-body tree code, *pkdgrav* [4, 5], has been widely used to simulate the evolution process of celestial bodies. Yu employed the soft-sphere discrete element method (SSDEM) of *pkdgrav* package to mimic the dynamic response of cohesive self-gravitating rubble pile while it is spun up to the observed high spin rate. The cohesion module added to the soft-sphere model by Zhang [6] guaranteed the feasibility of this method capable of assessing the cohesive strength of rubble-pile bodies.

Parameter	Value	Parameter	Value
Global model diameter (D)	36 m	Particle radius (r)	0.6 m
Global model shape	Sphere	Particle shape parameter (β)	0.5
Granular material density (ρ)	3.54 g/cc	Friction coefficient (μ_S)	0.58

Table 1:Benchmark parameter setup.

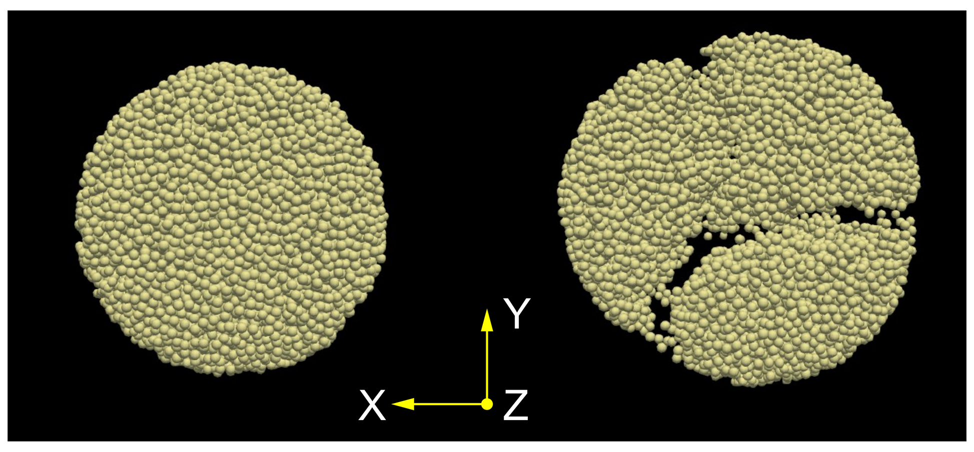

Figure 1: Capturing the disaggregation of global rubble-pile model.

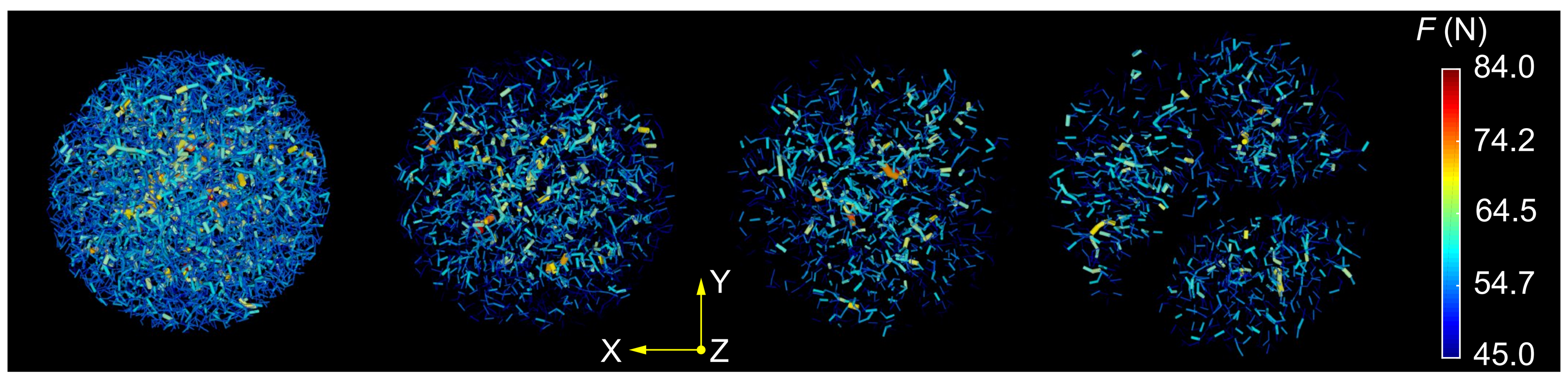

Figure 2: Visualization of the force networks before and after the disaggregation. Color and radius of cylinders indicate the magnitude of normal contact force that is proportional to the embedding length between two particles in contact. Only force chains whose values are between 45.0 and 84.0 N are plotted. Data are from benchmark parameter group.

A benchmark parameter group (Table.1) was chosen firstly, around which the parameter space was spanned by the macro parameters of rubble pile and key mechanical parameters of granular media. For each parameter set, a four-stage procedure was applied to examine the lower limit of cohesion that could maintain the structural stability (see [6] for a detailed description). First the rubble pile with given SSDEM parameters (initial interparticle cohesive strength c is sufficiently large) settles down under self-gravity at a slow spin period 5 h (rotating around z-axis). Global granular model subsequently evolves following a spin-up path from 5 h to 28 min and maintains at the final spin rate. Next the interparticle cohesive strength c decreases continuously and the global structural failure is captured (see Fig.1 and 2), by which a rough interval of interparticle cohesive strength c that cannot sustain structural stability is identified. We obtain the final refined range of c by releasing the global granular model with cohesion values acquired in previous stage. The bulk cohesion C estimated in terms of Drucker-Prager failure criterion is determined approximately using the fitting results between interparticle cohesive strength c versus C [6].

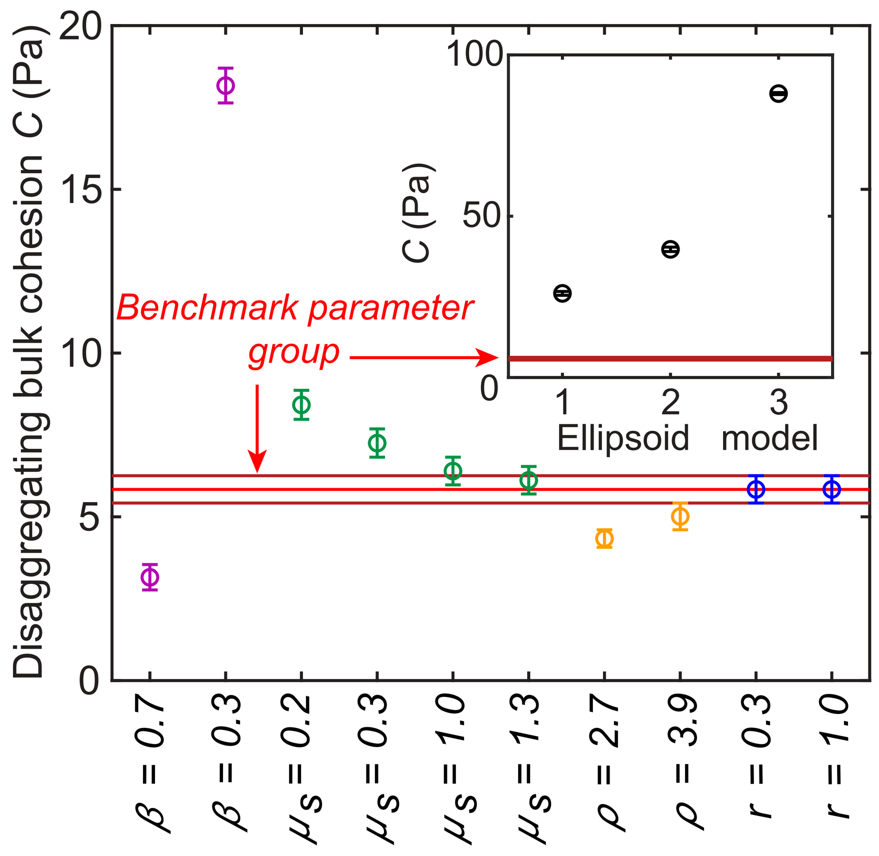

Figure 3: Lower limit of disaggregating bulk cohesion with error bar for different parameter setup. The single variable relative to the benchmark parameter setup is denoted in x-axis. Inset: Results of three ellipsoid models with ratios: b/a=0.4786, b/c=1; b/a = 0.4786, b/c = 1.4142; b/a = 0.3063, b/c = 1.4142 (corresponding to the number 1-3 below x-axis) are plotted. Red and crimson lines both in main graph and inset represent the disaggregating bulk cohesion and its error intervals for benchmark parameter setup.

Results

The dependencies of the lower limit of bulk cohesion C on the parameters in Table.1 are investigated. The macro shape, which is defined to be triaxial ellipsoids as constrained by radar observation [3] (the 1:1:1 ellipsoid is used in the benchmark parameter group), was found to be a major factor to determine the magnitude of disaggregating bulk cohesion. A more prolate shape corresponds to a higher limit of bulk cohesion (see Fig.3 inset). For the same overall shape, the particle shape parameter denoting the interparticle effective contact area and the friction coefficient remarkably affect the global stability of the rubble-pile structure. The granular material density and particle size show little effect on the lower limit of bulk cohesion (see Fig.3). Thus generally speaking, the interparticle effective contact area, friction coefficient and interparticle cohesive strength crucially affect the macro strength. Figure 2 illustrates the force chains before and after the disaggregation, from which we find that the contact force gradually weaken but the disruption occurs abruptly. Besides, the capability of resisting structure deformation of three typical packings was compared and the results show: simple hexagonal packing > simple random packing > polydisperse random packing.

Acknowledgements

Y.Y. acknowledges financial support provided by the National Natural Science Foundation of China [grant numbers 12022212 and 11702009].

References

[1] X. Zhang, et al. in *Lunar and Planetary Science Conference* The Woodlands, Texas march 18-22, 2019. Paper number 2132.
[2] B. D. Warner, et al. (2009) *Icarus* 202(1):134.
[3] X. Li, et al. (2021) *Icarus* 357:114249.
[4] D. C. Richardson, et al. (2000) *Icarus* 143(1):45.
[5] S. R. Schwartz, et al. (2012) *Granular Matter* 14(3):363.
[6] Y. Zhang, et al. (2018) *The Astrophysical Journal* 857(1):15.