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], Jiangchuan Huang[2], [1]School of Aeronautic Science and Engineering, Beihang University, Beijing, 100191, China; chenyangh@buaa.edu.cn; [2]China Academy of Space Technology, Beijing, 100094, China; [3]School of Aerospace Engineering, Tsinghua University, Beijing, 100084, China; [4]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France

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Introduction: Recent in situ explorations to asteroids have attracted concerns of leading space agencies. Huge amount of information about the origin and evolution of small bodies was obtained via these missions. The asteroid (469219) Kamo'oalewa, known as a quasi-satellite of the Earth, is observed to have a tiny size ($\sim$ 36 m) based on the absolute magnitude and S-type albedo [1], and a high spin rate of 28 min, which is far beyond the critical spin limit [2]. It is predicted to remain 38-100 lunar distance from us over the next centuries [3] and thus viewed as an interesting target for future exploration mission [4]. The state of tension under a super fast spin rate suggests a highly probable interior structure as a monolithic boulder. However, rubble-pile structures with moderate cohesion cannot be simply excluded. Previous works verified the existence of cohesive regolith on a fast-spinning asteroid [1, 5]. A global cohesion in normal level can 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. We found that the global macro shape, interparticle effective contact area and friction coefficient are the main influential factors for the disintegration bulk cohesion.

Methods: The parallel gravitational N-body tree code, *pkdgrav* [6, 7], 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 [8] guaranteed the feasibility of this method capable of assessing the cohesive strength of rubble-pile bodies.

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 [8] 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 in Ref.[8].

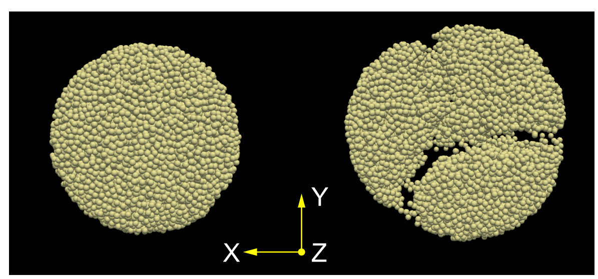

Figure 1: Capturing the disaggregation of global rubble-pile model.

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 [1] (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 parti-

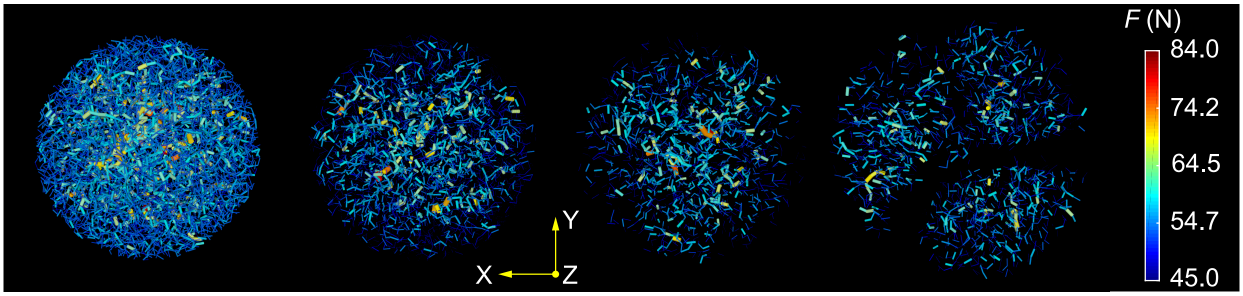

Figure 2: **Visualization of the force networks before and after the disaggregation. Color and radius of cylinders indicate the magnitude of normal contact force that is proportional to the embedding length between two particles in contact. Only force chains whose values are between 45.0 and 84.0 N are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

Table 1: **Benchmark parameter setup.**

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

cle 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.

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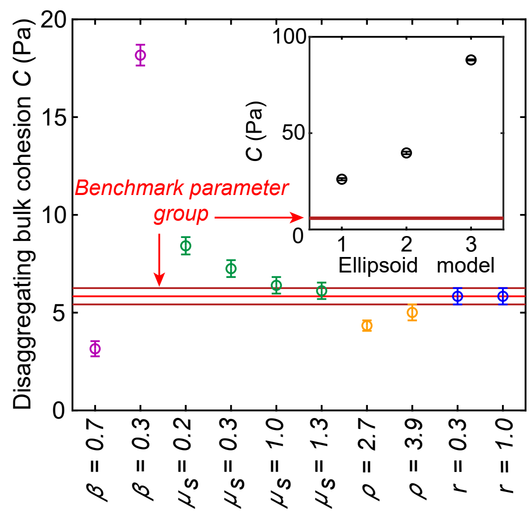

Figure 3: **Lower limit of disaggregating bulk cohesion with error bar for different parameter setup. The single variable relative to the benchmark parameter setup is denoted in x-axis. Inset: Results of three ellipsoid models with ratios: b/a=0.4786, b/c=1; b/a = 0.4786, b/c = 1.4142; b/a = 0.3063, 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.**