Hysteresis of a rotated sand-pile shape relating to the stability of a spinning top-shaped asteroid

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The C-type asteroid Ryugu, which has been probed by the Japan Aerospace Exploration Agency’s (JAXA) Hayabusa2 spacecraft, was found to be an oblate “spinning top” shape with a plominent circular equatorial ridge (Watanabe et al. 2019). Ryugu's bulk density (1.19 ±0.02 g / cm ^ 3) and boulder size distribution suggest that Ryugu has rubble-pile structure that was formed by disruption of its parent body. The equatorial cross section of Ryugu has an aspect ratio of 0.96 and its circularity is 0.93. The isotropic cross section suggests that the shape of Ryugu was formed by the spin-originated centrifugal force causing the migration of surface materials towords the equatorial region. However, the current rotation period of Ryugu (7.63 hours) is too long to form the current Ryugu’s top shape. Therefore, it is considered that the shape of Ryugu was formed during the rapid spin era in the past, and its shape is stably preserved even under the current slow spinning condition. However, details on the stability of top-shape asteroids are not well understood. In this study, we performed a small-scale laboratory experiment on the shape of the rotated sand pile to discuss the shape stability of top-shape asteroids.
In the experiment, a sand pile was formed in a quasi two-dimensional sample case (inner dimension: 100 mm in height, 100 mm in width, and 10 mm in thickness). The vertical section of an asteroid was mimicked by the laboratory-scale sand pile in this system, and the position of the peak of the sand pile is aligned with the rotational axis. Using this system, centrifugal force was applied to the sand pile by rotating the sample case. The rotation rate was varied in the range of 0 - 902 rpm which corresponds to the ratio (centrifugal force / gravity) at the end of the sample case is 0 –41.0. Specifically, the experiment was performed by gradually increasing the rotation rate from 0 to 41.0 and then gradually decreasing it to 0. The variation of the sand-pile shape due to the rotation was captured by a small camera mounted on the rotating part of the system, viz., the equilibrium shape of the sand pile under each centrifugal-force condition was recorded. Then, the local slope angle and sand flux were calculated by image analysis.
As a result, a hysteretic behavior of the sand-pile shape was observed. Namely, the angle of repose of the sand pile in the initial state was smaller than the angle of repose after experiencing the maximum centrifugal force. By using glass beads (diameter 1.5 –2.5 mm, angle of repose 25 ˚), the final angle after experiencing the maximum centrifugal force ranges in 25.2-36.5 ˚. Such hysteresis may be related to the stability of the current Ryugu, which keeps the top shape despite its slow spin.
In the presentation, we will present the details on the experimental results of the hysteretic behavior of the sand pile.

Keywords: rotation experiment, granular matter, gravity, centrifugal force, hysteresis, spinning top-shaped asteroid