

High-velocity impact experiments on a cohesive layer covered with regolith with various thickness: Implication for crater morphology and impact induced vibration

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Crater formation on asteroids covered with regolith is controlled by gravity and this morphology varies depending on the thickness of regolith layer. Several researchers have carried out cratering experiments for a homogeneous target, however, few impact experiments on targets simulating layered-structure asteroids have been made and crater scaling law for such target is unclear.

Impact-induced seismic shaking is caused by high-velocity impacts on bodies; these seismic waves propagate through the subsurface and fluidize regolith, resulting in resurfacing of asteroidal surface. That's a notable effect of this vibration, but that on Ryugu is smaller than Itokawa and Eros. Richardson Jr. et al.(2005) modeled the impact-induced seismic motion on layered asteroid and found that impact-induced vibration spread far from the impact point, suggesting that differences in the degree of modification of asteroidal surfaces may be due to differences in the inner structure such as layered structure. On Eros and Itokawa, regolith and boulders cover a large bedrock that occupies most of the body, while Ryugu may have a relatively homogeneous rubble-pile structure without a large bedrock core. Yasui et al.(2015) and Matsue et al.(2020) conducted impact experiments on homogeneous targets, and measured the acceleration. However, seismic wave propagating through cohesive layer covered with regolith has not been studied.

To study the crater formation and resurfacing process due to this shaking on such asteroids, we carried out impact experiments using targets simulating the surface of layered asteroid and examined the effect of bedrock on the crater formation. We also observed accelerogram propagating through target surface and bedrock to reveal the effect of cohesive layer on the accelerogram and attenuation rate with the distance. We made cratering experiments in three impact velocity ranges: (A) low-velocity impact by free fall (impact velocity $v_i=3.3\text{m/s}$), (B) high-velocity impact using a vertical one-stage gas gun at Kobe Univ. ($v_i=12.1\text{--}171.2\text{m/s}$), (C) hypervelocity oblique impact using horizontal two-stage gas gun at Kobe Univ. and normal impact using a two-stage vertical gas gun at JAXA ($v_i=2\text{km/s}$). We used a gypsum-sand mixture in (A) and (C), and diorite in (B) as a bedrock, putting a regolith layer (100 and 500 μm -diameter-quartz sands or 100 μm -diameter-glass beads) on that with a thickness of 0-30mm. To observe impact-induced shaking, we measured accelerogram at the bedrock or surface of particle using accelerometers and displacement of the surface of a target using 1D laser displacement sensor.

As a result of (A) and (B), crater morphology changed from flat-bottomed to bowl-shaped crater as the regolith layer got thick. The radius of flat-bottomed crater was smaller, and in the transition region of crater shapes, it was larger than that of homogeneous target. Collapse of crater due to the vibration of the bedrock may be the cause of that. If a regolith thickness was much larger than the crater depth, the crater radius agreed with the homogeneous target.

As for impact-induced vibration, accelerogram of bedrock differed from previous research. In (A), as the particle layer became thicker, the acceleration decay time became shorter. We also measured the maximum acceleration of seismic waves, and these were larger than previous research. However, when a regolith layer thickness up to about twice the projectile diameter, the attenuation rate didn't depend on a thickness and a propagation distance. In (C), accelerogram had three stages: downward acceleration

just after impact, high-frequency acceleration, and acceleration with small amplitude and long duration. This duration may correspond to the time of rebound of projectile, oblique shear excavation flow, and crater formation, respectively. Using a laser displacement sensor, we observed the vibration of targets. Targets displaced downward right after the impact, then particle layer vibrate at higher frequency than bedrock. Acceleration of bedrock dissipated about 10ms whereas displacement of particle layer continued over 200ms, implying that vibration of bedrock induced regolith layer to vibrate, and this motion continued.

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