Experimental study on the impact-induced seismic wave propagating through granular materials: Implications for a future asteroid mission

M. Yasui[1], E. Matsumoto[2], M. Arakawa[2], K. Matsue[2], and N. Kobayashi[3]

[1]Organization of Advanced Science and Technology, Kobe University
[2]Graduate School of Science, Kobe University
[3]Japan Aerospace Exploration Agency

Introduction: A seismic wave survey is a direct method to investigate the sub-surface structures of solid bodies, so we measured and analyzed these seismic waves propagating through these interiors. Earthquake and Moonquake are the only two phenomena that have been observed to explore these interiors until now, while the future surveys on the other bodies, (solid planets and/or asteroids) are now planned. To complete a seismic wave survey during the mission period, an artificial method that activates the seismic wave is necessary and one candidate is a projectile collision on the target body. However, to utilize the artificial seismic wave generated on the target body, the relationship between the impact energy and the amplitude and the decay process of the seismic wave should be examined. If these relationships are clarified, we can estimate the required sensitivity of seismometers installed on the target body and the possible distance from the seismic origin measurable for the seismometer. Furthermore, if we can estimate the impact energy from the observed seismic wave, we expect to be able to estimate the impact flux of impactors that collided on the target body. McGarr *et al.* (1969) did impact experiments by using the lexan projectile and two targets, quartz sand and sand bonded by epoxy cement, at 0.8–7 km/s. They found a difference of seismic wave properties between the two targets, and calculated the conversion efficiency to discuss the capability of detection of seismic waves on the Moon. However, they did not examine the excitation and propagation properties of the seismic waves in detail. In this study, we carried out impact experiments in the laboratory to observe the seismic waves by accelerometers, and examined the effects of projectile properties on the excitation and propagation properties of the seismic waves.

Experimental methods: We made impact experiments by using a one-stage gas gun at Kobe University. Projectiles were a polycarbonate cylinder with a diameter of 10 mm and a height of 10 mm, and stainless steel and alumina balls with a diameter of 3 mm. The stainless steel and alumina projectiles were accelerated with a sabot made of polyethylene. The impact velocity was from 20 to 100 m/s. The target was a non-cohesive glass bead with a mean particle diameter of 200 µm prepared by putting the particles into a container with a diameter of 300 mm and a height of 100 mm, up to 80 mm depth. The target porosity was about 40%. A chamber that we set the target in was evacuated below 1000 Pa. Three accelerometers (response frequency < 10 kHz) were set on the target surface at different distances from the impact point. The observed seismic waves were recorded on a data logger (A/D conversion rate 100 kHz).

Experimental results: First, we examined the propagation velocity of the seismic wave by using the traveling time from the impact point to the site of the accelerometer, then the impact velocity was obtained to be 105 ± 15 m/s. Next, we discovered that the maximum acceleration, $g_{\max}$, had a good relationship to the normalized distance, x/R (x: distance from impact point, R: crater radius) and it was fitted by the following equation, $g_{\max} = 268(x/R)^{-2.8}$, irrespective of projectile types. These results mean that the seismic wave attenuates with a similar waveform scaled by the crater radius on the same target. The duration keeping the maximum acceleration was measured to have a half width of $g_{\max}$ peak on the waveform, and it was estimated to be $\sim$0.3 ms. This value is almost consistent with the penetration time of projectiles estimated by the model proposed by Niimi *et al.* (2011). McGarr *et al.* (1969) studied the momentum conversion efficiency from the projectile momentum to the target momentum transferred by the seismic wave and obtained it as the ratio of the momentum calculated by the particle motion, I, to the projectile momentum, I_{p}. In our study, the I/I_{p} was obtained to be 0.23–1.56. This range was almost consistent with that of McGarr *et al.* (1969), 0.39–1.62. We can conclude that I/I_{p} is independent of the impact velocity.

Implications for planetary exploration: According to the previous results, we can discuss the sensitivity of the seismometer to detect the seismic wave induced by an artificial impactor on asteroids. We calculated the maximum acceleration on asteroids with two different sizes, such as the sizes of Eros and 1999JU3, by assuming that the projectile made of copper with a mass of 2 kg impacted at 2 km/s. In this calculation, we used the crater scaling law and the attenuation equation of $g_{\max}$ obtained in our study. As a result, the seismometer could detect the seismic wave only around the crater cavity on an Eros-sized asteroid while it could detect the wave globally on a 1999JU3-sized asteroid.