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# Experimental study on impact-induced seismic wave propagating in granular materials

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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 propagated 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 the seismic wave survey during the mission period, the artificial method that activates the seismic wave is necessary and the one candidate for the artificial one 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 distance from the seismic origin measurable for the seismometer. Furthermore, if we can estimate the impact energy from the observed seismic wave, it is expected to estimate the impact flux of impactors collided on the target body. In this study, we carried out impact experiments in the laboratory, observed the seismic waves by accelerometers, and examined the effects of projectile properties on the amplitude and the decay process of the seismic wave.

Experimental methods:

We did impact experiments by using the one-stage gas gun at Kobe University. The projectile was a polycarbonate cylinder with the diameter of 10 mm and the height of 10 mm, and a stainless and an alumina ball with the diameter of 3 mm. The stainless and the alumina balls was accelerated with the sabot made by polyethylene. The impact velocity was $\sim$100 m/s. The target was prepared by putting 200 $\mu$m glass beads into the container with the diameter of 300 mm and the height of 100 mm, up to 80 mm depth. 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 as voltage on the data logger (A/D conversion efficiency 100 kHz).

Experimental results:

We calculated the propagation velocity of seismic wave by using the traveling time from the impact point to the site of accelerometer and the impact velocity, and obtained 105 $\pm$ 15 m/s. Additionally, the relationship between the maximum acceleration, $g_{max}$, and the normalized distance, $x$/R ($x$: distance from impact point, $R$: crater radius), was determined as $g_{max}$ =268$(x/R)^{-2.8}$. From these results, it is found that the seismic wave attenuates with similar waveform on the same target, irrespective of projectile type. The duration keeping the maximum acceleration was estimated to be $\sim$0.3 ms, and this value was almost consistent with the penetration time of projectile estimated by using the model proposed by Niimi *et al.* (2011). McGarr *et al.* (1969) studied the energy conversion efficiency from impact energy to seismic momentum and obtained the ratio of the impulse of projectile during the penetration, $I$, to the kinetic energy of projectile, $E_k$. As a result of this study, the $I/E_k$ was obtained to be $1.6 \times 10^{-2} \pm 1.0 \times 10^{-2}$. On the other hand, McGarr *et al.* (1969), which the lexan projectile collided on the sand target with the impact velocity of 2-8 km/s, was obtained to be $6 \times 10^{-6} \pm 4 \times 10^{-6}$. This difference might be caused by the dependence of impact velocity on the energy conversion efficiency.

Keywords: impact-induced seismic wave, granular materials, decay process, planetary exploration, crater formation, accelerator