Free oscillations and surface waves of an asteroid excited by a collisional impact

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Recently ESA made a plan of a mission in that an artificial impactor (named Hidalgo) will collide with an asteroid. The aim of the plan (called the Don Quijote project) is to know how its orbit changes by the impact and to know some mechanical responses to the impact. Such knowledge is important in the view of guarding the earth from undesirable impacts of asteroids and comets as well as to obtain information on mysterious internal structure of asteroids. So, in the plan, several penetrators carring seismometers and other devices will be installed as a promising method onto the target asteroid to catch elastic waves excited by the artificial impact.

Stimulated by the project and to cooperate with it, we estimated amplitudes of free oscillations and surface waves of an asteroid excited by the Hidalgo impact in the Don Quijote project. As a first order estimate, we took very simple assumption that the target asteroid and the impactor Hidalgo both have spherical shapes and homogeneous elastic property. The elastic property of the target asteroid is set as a resemblance to that of the Moon surface regolith. The radius and the density of the asteroid are 1 km and 1500 kg/m**3 respectively. P wave and Swave velocities are 400 m/s and 200 m/s respectively. They collide head-on with an impulse of 10**6 kg m/s. Here we assume the mass of Hidalgo is 10**3 kg and the impact velocity is 10**3 m/s. The size of Hidalgo is about 1 m and its effective elastic wave speed is about 100 m/s. Then the cut off frequency of the impact is about 100 Hz. So we calculated fundamental free oscillation modes and the 1st over tone modes up to 100 Hz using the numerically efficient method recently developed by Kobayashi. The angular degree of the highest frequency mode is 3344. The skin depth of the elastic energy of the mode is less than 1 m. Note the surface gravity of the asteroid is very week but we include the self-gravitation effect on the oscillations. Anelasticity effects (phase lag and physical dispersion) are also included. The method is very stable under such extreme conditions.

The longest period mode 0S2 has a period about 12 seconds. The amplitude of 0S2 is ~10**-6 m/s which is capable of detection by a seismometer developed in the Lunar-A project and that of 0S3344 is about 10**-3 m/s. This result shows the usefullness of the penetrator technology of the project since the detection of 0S2 is important to know bulk property of the asteroid.

By summing up excitation of each normal mode, we calculated wave forms of surface wave. At the impact site, the initial velocity exceeds 100 m/s. Even at the equator, the velocity amplitude of the first Rayleigh waves (R1) is about 0.01 m/s. Amplitudes of Rayleigh waves passing through 8 times around the asteroid (R15) is about 10**-6 m/s which is still larger than the detection limit of the Lunar-A seismometer (~10**-9 m/s). The resultant oscillations are so large that we can easily detect them by the seismometer.

Thus we concluded the amplitudes of free oscillations and surface waves excited by Hidalgo impact with impulse of 10**6 kg m/s are sufficiently larger than the detection limit of the Lunar-A seismometer. Therefore a similar seismometer having the same performance installed onto the surface of the asteroid can easily detect such oscillations unless the impact break it to pieces.