Wave and Rupture Propagation in a Brittle Solid Sphere

*上西 幸司[1]、吉田 友弥[1]、イオネスク イオアン　R.[2]、鈴木 宏二郎[3]
*Koji Uenishi[1], Tomoya Yoshida[1], Ioan R. Ionescu[2], Kojiro Suzuki[3]

1. 国立大学法人東京大学大学院工学系研究科航空宇宙工学専攻、2. パリ13大学ガリレイ研究所、3. 国立大学法人東京大学大学院新領域創成科学研究科先端エネルギー工学専攻
1. Department of Aeronautics and Astronautics, The University of Tokyo, 2. Galilee Institute, University Paris 13, 3. Department of Advanced Energy, The University of Tokyo

Although earthquakes do occur in the sphere-like earth, seismic waves are in most cases treated only in light of ray paths that are essentially based on wave radiation from a point source in an infinitely extending medium. Even when wave reflection at a free surface is incorporated in analyses, usually an (approximated) flat surface is assumed. That is, the physical and mathematical characteristics of transient wave motion and interaction as well as those of rupture generation and propagation due to sudden energy release at a source located at or near a curved surface in a sphere are not analyzed fully precisely. Our recent fundamental experiments to study the real three-dimensional effect of curvature of a free surface on dynamic rupture of a monolithic sphere made of brittle solid ice (diameter 25, 50 or 60 mm) show two specific final rupture patterns due to impact at the bottom of the sphere, from which we can inversely evaluate the properties of the impact-induced waves existing at two dissimilar spatiotemporal scales. The first rupture pattern is so-called the "top"-type and generally recognized with a relatively smaller impact energy where only the bottom surface section of a sphere is broken into small pieces by the impact and a relatively large top-shaped part remains unruptured. This pattern seems to have been produced by the surface waves with relatively shorter wavelengths that propagate from the bottom along the curved free surface of the sphere and generate rupture only near the bottom surface section. The second pattern is named the "orange segments"-type, in which a sphere is split into three or four larger segments of comparable size by rather flat rupture planes extending approximately along the central axis of the sphere. Higher impact energy, or more exactly, a longer duration of impact compared with that for the previous "top"-type pattern, seems to have enlarged strongly stressed regions more slowly and widely from bottom to top (like quasi-static stress development by a point load) that induce rupture planes along the axis of the sphere. The above experimental observations on rupture development using high-speed digital video cameras at a frame rate of up to 150,000 frames per second and the mechanical speculations on time-dependent (stress) wave field are supported by two different numerical simulations employing the simple three-dimensional finite difference method and the discontinuous Galerkin (DG) method that handles more carefully the mechanics of axi-symmetric dynamic impact acting at the bottom section of a sphere.

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