Simulation of Tsunami Generation by Asteroid Impact Using Smoothed Particle Hydrodynamics Method

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ABSTRACT
The famous shallow water impacts event at the Chicxulub in Mexico’s Yucatan Peninsula at the Cretaceous-Tertiary boundary 65 million years ago was considered as an important case for tsunami studies. The water entry of a sphere-like asteroid with different impact angle is simulated using a three-dimensional Weakly Compressible Smoothed Particle Hydrodynamic model (WC-SPH). The Froude number similarity is used to design a computational model of the scaled model in 1:10000. In order to reduce the computational cost, an Adaptive Particle Refinement (APR) is used. We focus on the evolution of free surface, the formation and propagation of tsunami. The results are compared with the work of Gisler (Gisler, et al., 2004). Though the cavity diameter, height of jet and initial height of tsunami agree well with that of Gisler’ work, the shape of cavity is quite different. This indicates that the fluid compressibility and thermodynamic effects should be considered, at least during the water entry process.

KEY WORDS: Water entry; asteroid impact; tsunami; Smoothed Particle Hydrodynamics.

INTRODUCTION
Water entry problem has been one of major concern in marine engineering. However, as a common phenomenon in nature, tsunami induced by an asteroid moving from air into water deserves more concern, because it may cause serious global disaster in the earth. People widely accept that the worldwide mass extinctions at the Cretaceous-Tertiary boundary 65 million years ago was caused by the impact of an asteroid at Chicxulub in Mexico’s Yucatan Peninsula, which was investigated as a shallow water entry problem (Gisler, et al., 2004). The impactor was a bolide of 10km, and its impact was oblique, about 30 degree with the horizon.

Impact energy like that may cause many secondary disasters, such as tsunamis, an asteroid the size of 10km fall into water deeper than 1000m, would have sent a 100m tsunami at 4000km distance from the impact location in ocean (Ward and Asphaug, 2002), and the tsunami generated by a 1km asteroid would run 100km and 500km before it was less than 100m and 10m (Crawford, and Mader, 1998).

In the present paper, we simulate an oblique impact of a sphere asteroid using Weakly Compressible Smoothed Particle Hydrodynamics (WC-SPH) method to understand the hydrodynamic effects of an asteroid impact compared with the numerical results of thermodynamics and compressibility of water. In order to reduce the computational cost, an Adaptive Particle Refinement (APR) is adopted, the diameter of asteroid and its impact velocity are obtained for the 1:10000 scaled model based on the Froude similarity. A discussion on the difference between the hydrodynamic model and the hydrodynamic/thermodynamic coupling model will be provided.

NUMERICAL METHOD AND SIMULATION SET UP

SPH Model
The continuity equation and momentum equation of two-phase SPH model can be written as below,

\[
\frac{D\rho}{Dt} = \rho \sum_j (U_i - U_j) \cdot \nabla \mathcal{W}_{ij} V_j + \delta \rho_c \sum_j \psi (r_i - r_j) \nabla \mathcal{W}_{ij} / (r_i - r_j)^2
\]

\[
\frac{DU}{Dt} = g - \frac{1}{\rho} \sum_j (|P| + P) \nabla \mathcal{W}_{ij} + \alpha \rho_c \sum_j (U_i - U_j) \cdot \nabla \mathcal{W}_{ij} / (r_i - r_j)^2
\]

where \( \rho, U, P, V, h, \) and \( g \) are density, velocity, pressure, volume, smoothed length and gravity. The second term of Eq. 1 is the density diffusive term (Antuono et al., 2010), which can smooth the pressure field in WC-SPH model. Coefficients \( \delta \) and \( \alpha \) are equal to 0.1 and 0.02 respectively. Subscript \( \theta \) means the reference value. In this paper, the sound speed \( c_0 \) and reference density \( \rho_0 \) of water are 1500m/s and 1000kg/m³.

Operator \( \psi \) in diffusion term can be written as