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ANALYSIS OF BUBBLE PULSATIONS OF UNDERWATER EXPLOSIONS BY THE SMOOTHED PARTICLE HYDRODYNAMICS METHOD

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***Key words**: Smoothed particle hydrodynamics (SPH), Underwater explosion (UNDEX), Shock wave, Bubble.*

Summary: *In this study, analysis of UNDEX variables (Density, pressure, internal energy and velocity[1, 2]) with respect to time and place in addition to bubble evolution are performed by a newly developed stabilized SPH method, which adopts an innovative velocity field smoothing technique to stabilize the process, in combination with an adaptive smoothing length and penalty force exertion scheme.*

1 INTRODUCTION

The underwater explosion (UNDEX) [1,2] produced by the detonation of a submerged high explosive (HE) poses a serious threat to the integrity of nearby structures, due to extreme sudden forces applied to them. Therefore, reliable efficient solutions are required in order to accurately simulate this complex behavior which consists of a number of interacting phenomena such as shock wave, gas-fluid interaction and bubble evolutions. Gases arise in an underwater explosion, may lead to bubbles formation[2]. The dynamics of explosive gas is the major difference between UNDEX and other types of explosions. The density difference between the water and explosion products, results in appearance of specific pressure fields in water, including the primary shock wave (first pulse) and the second pulses(so called bubble pulse) which are complicated to analyze[3].

Simulation of UNDEX problems has been a big challenge for both conventional element-based[4] and mesh free numerical methods[5], including special difficulties such as large distortions, moving material interfaces, deformable boundaries and free surfaces. The combination of adaptive, mesh free and Lagrangian natures of the smoothed particle hydrodynamics (SPH) method makes it very attractive and practical in treating highly dynamic phenomena that occur in the extremely transient HE explosion process[3].

2 GOVERNING EQUATIONS

The SPH formulation of the extremely fast phenomenon of underwater explosion is base don on the Euler equations [3,6]:

$$\begin{cases} \dfrac{D\rho}{Dt} = -\rho \nabla \cdot \boldsymbol{v} \\ \dfrac{D\boldsymbol{v}}{Dt} = -\dfrac{1}{\rho}\nabla p \\ \dfrac{De}{Dt} = -\dfrac{p}{\rho}\nabla \cdot \boldsymbol{v} \\ p = p(\rho, e) \end{cases} \tag{1}$$

*where **ρ** is the density, **v** is the velocity vector, **e** is the internal energy per unit mass, **p** is the pressure and **t** is the time.*
The SPH forms of differential equations (1) can be written as [3,6]:

$$\begin{cases} \dfrac{D\rho_i}{Dt} = \sum_{j=1}^{N} m_j (\boldsymbol{v}_i - \boldsymbol{v}_j) \cdot \nabla_i W_{ij} \\ \dfrac{D\boldsymbol{v}_i}{Dt} = -\sum_{j=1}^{N} m_j \left(\dfrac{p_i}{\rho_i^2} + \dfrac{p_j}{\rho_j^2} + \Pi_{ij}\right) \nabla_i W_{ij} \\ \dfrac{De_i}{Dt} = \dfrac{1}{2}\sum_{j=1}^{N} m_j \left(\dfrac{p_i}{\rho_i^2} + \dfrac{p_j}{\rho_j^2} + \Pi_{ij}\right) \left(\boldsymbol{v}_i - \boldsymbol{v}_j\right) \cdot \nabla_i W_{ij} \\ \dfrac{D\boldsymbol{x}_i}{Dt} = \boldsymbol{v}_i \end{cases} \tag{2}$$

*where **N** is the total number of participated particles in support domain of central node **i**, **m** is the particle mass, **W** is the SPH smoothing function and Π is the Monaghan-type of artificial viscosity stabilizer [3,5,6,7].*

Adopting appropriate equation of states (Gamma for explosive gas, and Mie-Gruneisen for surrounding water), the explosive core transition from solid into gaseous phase is performed, and the underwater explosion can be simplified as a fluid flow, which is governed by the following state variables: pressure, temperature, density and velocity[3,8]. Simultaneous solution of equations of conservation of density, internal energy, velocity and EOS, yields to determination of the four mentioned variables.

The gamma-type EOS is adopted for the TNT explosive gas [1,2,3,6],

$$p = (\gamma - 1)\rho e \tag{3}$$

where γ is the ideal gas coefficient (usually taken as 1.4)[2,6].

In addition to usual parameters affecting the SPH method, such as smoothing length, initial geometry and weight function generalization, three types of stabilizers: artificial viscosity[3], velocity field smoothing[6] and penalty force[3,7] have been added properly to improve the accuracy of results by preventing particles unphysical penetration.

3 NUMERICAL RESULTS

A 2D circular TNT explosive gas (radius=10cm) with surrounding water (outer radius=50cm, inner radius=10cm) [3], as depicted in figure 1, is simulated. Figure 2 illustrates the bubble boundaries positions just after the explosion. The radial distributions of pressure in three different times are shown in Figure 3, which are comparable to the reference results of Figure 4 [3].

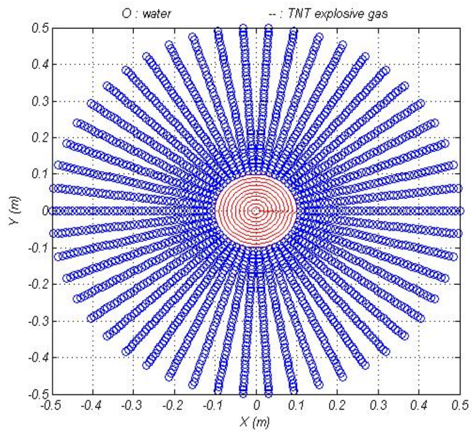

Figure 1: Initial geometry.

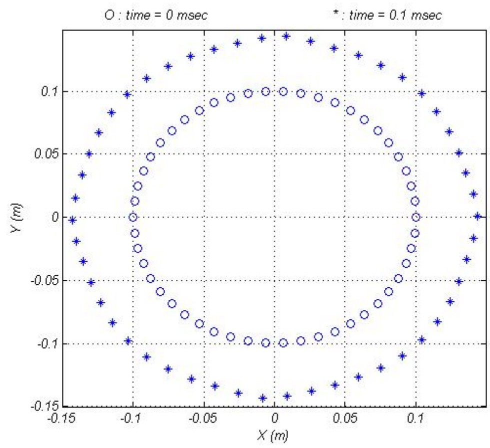

Figure 2: Bubble boundary particles after the explosion.

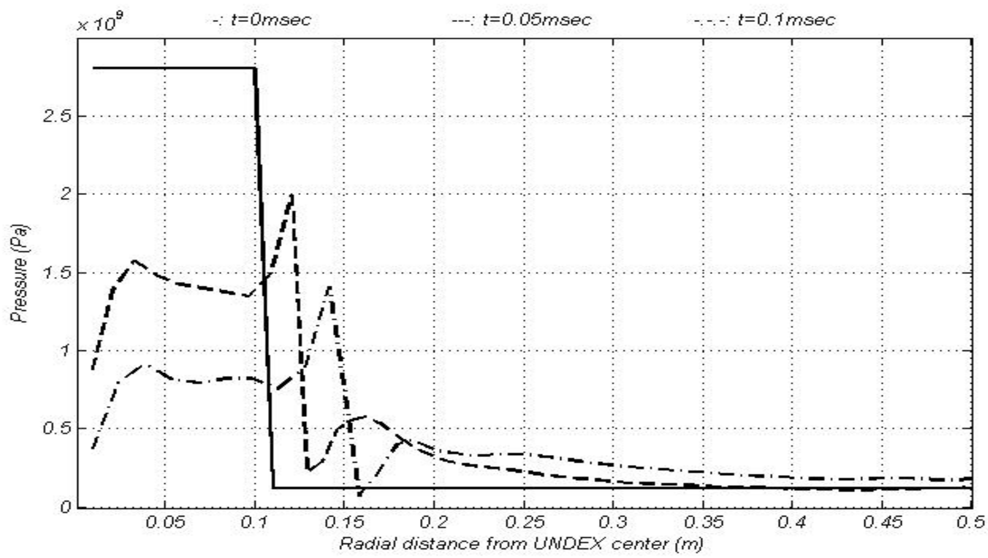

Figure 3: Radial distributions of pressure.

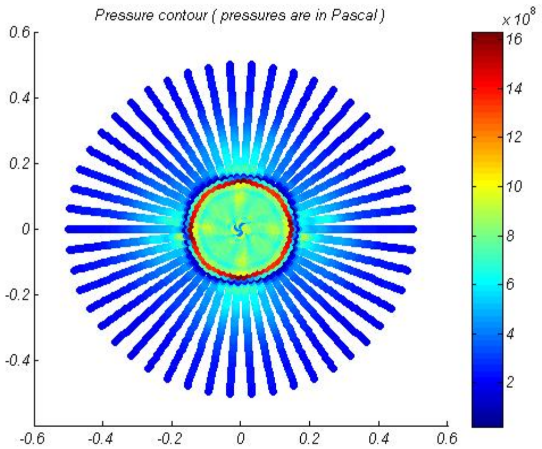

Figure 5: Pressure contour at time = 0.1 msec

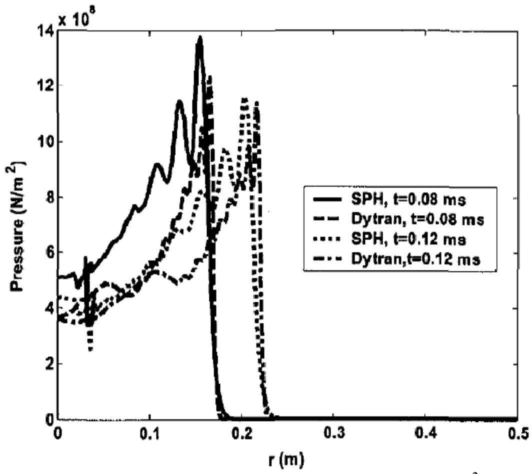

Figure 4: Reference pressure distribution [3]

Obviously, the particles related with the pressures range of 14~16 × 10^8 in Figure 5, describe the high-pressure boundary of TNT explosive gas (Bubble) which moves radially outward in time[8].

4 CONCLUSIONS

Numerical simulations, have demonstrated that the SPH method, after proper stabilization, can be used for modeling UNDEX shocks.
Though there are some oscillations around the gas-water interface due to nature of SPH numerical approach and probable instability near the boundaries, they do not influence the global shock response.

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