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A new fluid–solid interface algorithm for simulating fluid structure problems in FGM plates

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ABSTRACT

The capability to track material interfaces, especially in fluid structure problems, is among the advantages of meshless methods. In the present paper, the Smoothed Particle Hydrodynamics (SPH) method is used to investigate elastic–plastic deformation of AL and ceramic–metal FGM (Functionally Graded Materials) plates under the impact of water in a fluid–solid interface. Instead of using an accidental repulsive force which is not stable at higher pressures, a new scheme is proposed to improve the interface contact behavior between fluid and solid structure. This treatment not only prevents the interpenetration of fluid and solid particles significantly, but also maintains the gap distance between fluid and solid boundary particles in a reasonable range. A new scheme called corrected smooth particle method (CSPM) is applied to both fluid and solid particles to improve the free surface behavior. In order to have a more realistic free surface behavior in fluid, a technique is used to detect the free surface boundary particles during the solution process. The results indicate that using the proposed interface algorithm together with CSPM correction, one can predict the dynamic behavior of FGM plates under the impact of fluid very promisingly.

1. Introduction

The fluid structure problems have a wide range of applicable tasks. Some samples are prediction of exact mechanical behavior of aircraft bodies under the unwanted impact of birds in high altitudes of flight and damage study in water ditching problems. In the years 2007–2010, many researchers have investigated the fluid–solid interaction over an elastic body in a dam breaking problem (Antoci et al., 2007; Farahani et al., 2008; Potapov et al., 2009; Rebouillat and Liksonov, 2010; Rafiee and Thiagarajan, 2009; Amini et al., 2010). Jianming et al. (2010) have studied the water jet machining process using the coupled SPH/FEM methods. High velocity impact in fluid-filled containers has been studied by Sauer (2010). Recently, Guida et al. (2011), have investigated the bird impact on a composite structure. Marsh et al. (2010) have studied the shallow-depth sloshing absorber for structural control. Tassin et al. (2011) have investigated about the hydrodynamic loads during water impact of three-dimensional solids. Kang et al. (this issue) have studied the impulsive plunging wave breaking downstream of a bump in a shallow water flume.

Smoothed particle hydrodynamics (SPH) is a particle and meshless method with promising advantages in modeling extreme large deformations that include brittle damage and fracture in ceramics. SPH was first proposed to solve cosmological problems in three-dimensional open space such as the simulations of binary stars and stellar collisions

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(Lucy, 1977; Gingold and Monaghan, 1977). The SPH method has also been applied extensively in computational fluid dynamics related areas that include multi-phase flows (Monaghan and Kocharyan, 1995), incompressible flow simulations (Monaghan, 1994; Morris et al., 1997) and free surface flow analysis (Antuono et al., 2010; Adami et al., 2010). Benz and Asphaug (1993, 1994, 1995) applied SPH to simulate fracture in brittle solids. Johnson et al. (1993, 1996), Randles and Libersky (1996) have made outstanding contributions in the application of SPH in impact problems. Chen et al. (1999) presented an improvement for tensile instability in smoothed particle hydrodynamics using renormalization schemes which could improve the accuracy of results in free surfaces. Young (2008), have performed a study on the fluid–structure interaction analysis of flexible composite marine propellers. Marsh et al. (2011) have studied the sloshing absorber geometry for structural control using SPH method.

In this paper, the Smoothed Particle Hydrodynamics (SPH) particle method is used to investigate elastic–plastic deformation of AL and ceramic–metal FGM 2D plates under the impact of water in a fluid–solid interface. Instead of using an accidental repulsive force which is not stable at higher pressures, a new scheme is proposed to improve the interface contact behavior between fluid and solid structure. This treatment not only prevents the interpenetration of fluid and solid particles significantly, but also maintains the gap distance between fluid and solid boundary particles in a reasonable range. A new scheme called corrected smooth particle method (CSPM) is applied to both fluid and solid particles to improve the free surface behavior. CSPM correction is applied to both fluid and solid particles to improve the free surface behavior. In order to have a more realistic free surface behavior in fluid, a technique is used to detect the free surface boundary particles during the solution process. The results show that using the proposed interface algorithm together with CSPM correction, one can predict the dynamic behavior of FGM plates under the impact of fluid very promisingly.

2. Fluid simulation

2.1. Equation of state of water

In order to simulate water as a weakly compressible fluid, the following linear equation of state (EOS) is used which defines the relation between pressure, density and sound speed:

$$p = c^2(\rho - \rho_0), \tag{1}$$

where p, c, ρ, define the pressure, the sound speed and the density, respectively. The subscript zero defines the reference value of the related property. The sound speed in water can be obtained using the following equation:

$$c = \sqrt{\zeta/\rho}, \tag{2}$$

where ζ is the compressibility modulus of water and has a constant value of 2.2×10^9 Pa for a large range of pressures.

2.2. Governing equations in fluid

Continuity, momentum and energy conservation laws in SPH discretized form are (Implicit summation convention over repeated indices is used).

2.2.1. Continuity

The continuity equation can be written as the following:

$$\frac{D\rho}{Dt} = -\boldsymbol{\rho}\nabla \cdot \boldsymbol{v}, \tag{3}$$

where ρ and $\boldsymbol{v}$ define the density and the velocity vector, respectively. The continuity equation in SPH discretized form can be represented as

$$\frac{D\rho_i}{Dt} = \rho_i \sum_j \frac{m_j}{\rho_j}(v_i^\beta - v_j^\beta)\frac{\partial W(r-r_j,h)}{\partial x_i{}^\beta}, \tag{4}$$

where r, m, W indicate the distance vector, the mass and the kernel function, respectively.

2.2.2. Momentum

The momentum equation has the following form:

$$\frac{Dv}{Dt} = \frac{1}{\rho}\nabla \cdot \boldsymbol{\sigma}. \tag{5}$$

In above equation, the parameter $\boldsymbol{\sigma}$ denotes the stress tensor. The SPH discretized form of momentum equation can be written as follows:

$$\frac{Dv_i}{Dt} = \sum_j m_j \left(\frac{\sigma_i{}^{\alpha\beta}}{\rho_i{}^2} + \frac{\sigma_j{}^{\alpha\beta}}{\rho_j{}^2} + \Pi_{ij} \right) \frac{\partial W(r-r_j,h)}{\partial x_i{}^\beta}, \tag{6}$$