



Coupling of smoothed particle hydrodynamics and finite element method for impact dynamics simulation

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ABSTRACT

This paper presents an alternative method for coupling smoothed particle hydrodynamics (SPH) and finite element method (FEM) in a Lagrangian framework. The attachment and contact between SPH particles and finite elements are calculated. FE nodes are added to the SPH neighbor list for the attachment, and the continuity of the interface is guaranteed. The contact force on SPH particles and FE nodes is calculated with the same approach used in SPH particle to particle contact algorithm, and the identification of the contact surface and the surface normal is not required. Background particles are assigned in the position of FE nodes to facilitate particle approximation. The perforation of a cylindrical Arne tool steel projectile impacting a plate Weldox 460 E steel target is simulated in 3D to demonstrate the performance of the SPH–FEM coupling algorithm. The coupled computational model of viscoplasticity and ductile damage and Gruneisen EOS are used for the target plate. A particle-kill algorithm is used to invalidate the damage particles. Good agreement between the numerical simulations and the experimental results is obtained, and the ballistic limit velocity obtained from the SPH–FEM coupling algorithm gives a deviation of 2% from the experimental data.

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1. Introduction

Finite element method (FEM) has been used extensively for the analysis of computational solid mechanics, and it can provide robust capabilities for a wide range of problems. For the problem with extreme distortions, the accuracy of FEM is not always adequate [1–3]. More recently, smoothed particle hydrodynamics (SPH) has been developed and applied to solid mechanics problems [4–6]. The formulation of SPH is not affected by the arbitrariness of the particle distribution due to the adaptive nature of the SPH approximation. And it can naturally handle problems with extremely large deformation. However, SPH is not generally as good as FEM for dynamics problems with mild distortions, and worse still, SPH encounters several difficulties: (1) the tensile instability [7,8]; (2) Dirichlet boundary conditions [9]; (3) comparatively high computational cost [9]. Therefore, coupling SPH and FEM seems a reasonable approach to take advantage of the best properties of both methods, which can provide a tool capable of modeling the interaction of bodies subjected to extreme deformation. This approach allows for the use of accurate and efficient finite elements in the lower distortion regions, and for the use of SPH particles in the higher distortion regions. The attachment and contact between SPH particles and finite elements should be calculated according to the application field.

An important effort has been dedicated to the coupling of SPH and FEM in the past years. For the attachment between SPH particles and finite elements, Johnson et al. [10,11] developed a rigid coupling method where SPH particles were fixed to FE nodes in the interface zone. The computation of the stresses at an interface particle (node as seen from the FE region) was done with contributions from the interface particles and from other standard particles, but there was no contribution from the neighboring FE nodes. Consequently, the continuity of the interface between SPH and FEM was not guaranteed with this approach [12]. Sonia Fernández-Méndez et al. [12] developed a transition region between SPH and FE domains, and shape function of the coupled SPH and FE interpolations was used in this region. However, the interpolation shape function is hard to get, and the computational cost is high. For the contact between SPH particles and finite elements, Attaway [13] and Johnson et al. [10,11] developed a master–slave method to describe the contact between SPH particles and finite elements. In every time step, they checked whether particles penetrate element faces. The calculated contact forces that prevent the interpenetration are always normal to the corresponding element surface. Sliding between particles and elements in tangential direction is allowed. However, this master–slave method needs to define the contact surface and the surface normal in every time step, which is complex in 3D.

The aim of this paper is to present an alternative SPH–FEM coupling algorithm to deal with the attachment and contact between SPH and FEM, and to simulate the perforation of a

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