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The Modified Ghost Method for Compressible Multi-Medium Interaction with Elastic-Plastic Solid

Zhiwei Feng[1], Jili Rong[1,*], Abouzar Kaboudian[2] and Boo Cheong Khoo[3]

[1] *School of Aerospace Engineering, Beijing Institute of Technology, Beijing 100081, P.R. China.*
[2] *School of Physics, Georigia Institute of Technology, Atlanta GA 30332-0400, USA.*
[3] *Department of Mechanical Engineering, National University of Singapore, 5A Engineering Drive 1, 02-02, Singapore.*

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Abstract. In this work, a robust, consistent, and coherent approach, termed as Modified Ghost Method (MGM), is developed to deal with the multi-medium interaction with elastic-plastic solid. This approach is simple to implement and keeps the solvers intact, and can handle multi-medium problems which involve various media including gas, liquid and solid. The MGM is first validated by two-dimensional (2D) cases and then is applied to study the interaction between elastic-plastic solid structure and the underwater explosion. The development of the wave system is described and analyzed. Furthermore, two kinds of complex solid structure subjected to underwater explosion are simulated. Finally, a complex solid structure immersed in water subjected to underwater explosion is simulated and analyzed. The numerical experiments show the viability, effectiveness and versatility of the proposed method which is able to accurately predict the wave pattern at various interfaces.

AMS subject classifications: 35Q31, 74F10, 74S20, 76T99

Key words: Multi-medium interaction, modified ghost method, elastic-plastic solid, complex solid structure.

1 Introduction

Fluid-structure interaction (FSI) includes numerous applications ranging from civil engineering [1], hemodynamics [2], the design process of bridges [3] and lightweight membrane structure [4] to submerged structure subjected to underwater explosion [5]. The numerical realization of coupling is classified by Schafer as weak or strong [6]. The term

*Corresponding author. *Email addresses:* 645219868@qq.com (Z. W. Feng), rongjili@bit.edu.cn (J. L. Rong), abouzar.kaboudian@gmail.com (A. Kaboudian) mpekbc@nus.edu.sg (B. C. Khoo)

"weak coupling" refers to the partitioned approaches where the solver for one physical field is explicitly independent of methods for other physical fields. The coupling is achieved by passing the force and displacement between the solvers back and forth and satisfying the interfacial conditions. However, the interfacial conditions have not been taken into account for to consider the wave refraction occurred at the interfaces, which may lead to unreasonable and inaccurate wave refraction at the interface. The strong coupling refers to monolithic approaches where the solver is extensively modified such that the unknowns are calculated simultaneously for all the fields by properly constructing the coupled equations. Some other methods that are not necessarily fully monolithic or fully-partitioned approaches, like immersed interface method [7], immersed boundary method [8], volume of fluid method [9] and phased-field method [10], have been developed to simulate the multi-medium problems. This means that the fields are decoupled using special techniques that will make the coupling more stable, and at the same time, satisfy the interfacial conditions as accurately as possible. In this work, the weak coupling strategy is chosen by the fact that we can use independent fluid and solid solver and the interaction is achieved by applying boundary condition at the interface. In order to achieve the interaction, Modified Ghost Fluid Method (MGFM) is further developed to deal with the 2D FSI problems with the elastic-plastic solid.

The Ghost Fluid Method (GFM) has been first proposed by Fedkiw [11] and named as original GFM (OGFM) to distinguish it from other modified versions. Since the OGFM appears to be rather problem related, to overcome the limitation, Liu et al. [12] proposed the modified GFM (MGFM) algorithm. Subsequent to that, the real GFM (RGFM) was developed by Wang et al. [13] The MGFM and RGFM have been successfully applied to different extreme cases of gas-gas, gas-water, and even fluid-elastic structure problems [14]. In this paper, we develop the MGFM so that it can deal with the 2D FSI with elastic-plastic solid. Very recently, Kaboudian et al. [15, 16] proposed the modified Ghost Solid Method (MGSM) based on the characteristic features of MGFM, which was applied to the solid-solid interaction problems where elastic-elastic, elastic-plastic and plastic-plastic deformations take place. To facilitate subsequent discussion, the MGFM and MGSM are conjunctively termed as the Modified Ghost Method (MGM). Thus, the truly multi-medium interaction problems involving various phases of material, namely fluid phase (liquid and gas) and solid phase, can be solved with the MGM, which is the main focus of this paper and leads to a consistent, robust, and coherent approach that can numerically model various interactions: liquid-liquid, gas-liquid, gas-gas, fluid-solid, solid-solid interactions. In this paper, as usual, structural equations are solved in a Lagrangian formulation and on the other hand, flow equations are solved in an Eulerian formulation.

The remainder of this paper is organized as follows. In Section 2, we describe the governing equations, the fundamental theory of plasticity for solid and the details about MGM for the 2D multi-medium interaction problems. In Section 3, several numerical experiments are carried out, which demonstrate the accuracy and corroboration of the MGM. Conclusions are provided in Section 4.