Accepted Manuscript

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PII: S0045-7825(18)30226-3
DOI: https://doi.org/10.1016/j.cma.2018.04.041
Reference: CMA 11892

To appear in: *Comput. Methods Appl. Mech. Engrg.*

Received date : 27 December 2017
Revised date : 21 April 2018
Accepted date : 23 April 2018

Please cite this article as: W. Yang, P. Arduino, G.R. Miller, P. Mackenzie-Helnwein, Smoothing algorithm for stabilization of the material point method for fluid-solid interaction problems, *Comput. Methods Appl. Mech. Engrg.* (2018), https://doi.org/10.1016/j.cma.2018.04.041

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Smoothing Algorithm for Stabilization of the Material Point Method for Fluid-Solid Interaction Problems

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Abstract

Phenomena involving general solid-water interactions such as flows with debris are challenging to model numerically because they are not easily represented using solid- or fluid-oriented methods. The material point method (MPM) provides a unified multi-material interaction platform potentially capable of modeling complex solid-water flow phenomena. However, it is necessary to address volumetric locking for (nearly) incompressible materials when modeling fluids, while also stabilizing integration errors that arise in standard MPM. This paper examines these challenges in depth, and presents a flux-based smoothing algorithm designed to address integration-error-induced destabilization via controlled strain energy dissipation. The effectiveness of the algorithm is demonstrated with two simple but fundamental fluid/solid problems, and with an application to a complex solid-water dynamic interaction problem. Results show the flux-based smoothing algorithm is capable of stabilizing the side-effects of numerical integration errors, while at the same time remaining inactive if there is no integration-error-induced oscillation. Based on this study, the flux-based smoothing algorithm is suggested as a stabilization scheme for MPM when using constant-interpolated hybrid elements.

Keywords: Material Point Method, fluid-solid interaction, anti-locking and stabilization, meshfree methods

1. Introduction

Flood and tsunami flows can contain sufficient momentum to transport large debris, and many researchers have demonstrated experimentally that such debris in flows can cause large impact forces on structures and structural components (e.g., Hiraishi et al., 2010; Ko et al., 2014; Piran Aghl et al., 2014). Modeling such problems numerically is challenging because the associated solid-fluid interactions are not easily represented using typical fluid- or solid-oriented methods. The material point method (MPM), originally introduced by Sulsky et al. (1995), provides a unified multi-material interaction platform potentially capable of modeling

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