An immersed multi-material finite volume-material point method for structural damage under blast loading

Ruichen Ni[1] and †*Xiong Zhang[1]

[1]School of Aerospace Engineering, Tsinghua University, China

*Presenting author: xzhang@tsinghua.edu.cn
†Corresponding author: xzhang@tsinghua.edu.cn

Abstract

Structural blast problems involve complex structure geometry, nonlinear material constitutive relation and nonlinear shock-structure interaction. Besides, these problems are always accompanied with dynamic fracture phenomena and structural damage, resulting in small fragments of thin geometry and fresh FSI interface, which bring great numerical difficulties and challenges to traditional FSI algorithms. Therefore, the development of efficient and powerful algorithms to simulate these phenomena remains a challenging task.

This talk will present our recent developed immersed multi-material finite volume-material point method (iMMFVMPM)[1][2] for structural blast damage problems. The multi-material finite volume method (MMFVM)[3] based on diffused interface method (DIM) is adopted as fluid solver to simulate the propagation process of detonation waves, while the material point method (MPM)[4] is employed as solid solver to simulate the structure extreme deformation. To couple the MMFVM and MPM, we developed an immersed boundary method (IBM)[5], named as Lagrangian continuous-forcing IBM (lg-CFIBM), in the frame of continuous forcing approach with a compact support area for the immersed boundary conditions. The lg-CFIBM can guarantee the boundary velocity conditions strictly at each time step and thus reproduce the shock wave structure exactly. Meanwhile, it has no need to reconstruct the FSI interface anymore, which avoids the numerical difficulty with the treatment of freshly generated FSI interface in traditional IBM.

The proposed iMMFVMPM is capable of simulating the dynamic fracture process under blast loading, in which small fragments of thin geometry and fresh FSI interfaces will be generated. Several numerical examples are studied to verify and validate the proposed method, and numerical results are in good agreement with available experiments.

Keywords: structural blast damage, material point method, immersed boundary method, multi-material finite volume method

References

[1] Ruichen Ni, Jiasheng Li, Xiong Zhang, Xu Zhou, Xiaoxiao Cui. An immersed boundary-material point method for shock-structure interaction and dynamic fracture. Journal of Computational Physics, 470:111558, 2022.

[2] Ni Ruichen, Sun Zixian, Li Jiasheng, Zhang Xiong. An immersed multi-material finite volume-material point method for structural damage under blast loading. Chinese Journal of Theoretical and Applied Mechanics, 2022, 54(12): 3269-3282. (in Chinese).

[3] Richard Saurel, Fabien Petitpas, Ray A. Berry. Simple and efficient relaxation methods for interfaces separating compressible fluids, cavitating flows and shocks in multiphase mixtures. Journal of Computational Physics, 2009, 228: 1678-1712.

[4] D. Sulsky, Z. Chen, H.L. Schreyer. A particle method for history-dependent materials. Comput. Methods, Appl. Mech. Eng., 118:179–186, 1994.

[5] Charles S Peskin. Numerical analysis of blood flow in the heart. Journal of Computational Physics, 25:220–252, 1977.

Dr. Xiong Zhang is currently a professor of the School of Aerospace Engineering, Tsinghua University, China. His research interests focus on numerical modeling of extreme events, such as hypervelocity impact, blast, bird impact, penetration and perforation, fluid-structure interaction. He has developed several new efficient and stable meshless methods for extreme events simulation, and has published 4 monographs, 4 textbooks, and more than 170 journal papers.

He was included in the list of Elsevier's "Most Cited Chinese Researchers" since 2015, and included in the list of "World's Top 2％ Scientists, career-long citation impact" in 2022. He served as the Associate Editor of the International Journal of Mechanics and Materials in Design since 2014.