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An exact Riemann solver for wave propagation in arbitrary anisotropic elastic media with fluid coupling

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Abstract

We present a nonconformal mesh discontinuous Galerkin pseudospectral time domain algorithm for arbitrary anisotropic elastic/acoustic wave propagation problems. An exact Riemann solver is compactly derived to resolve the accurate coupling of multiple domains in the discontinuous Galerkin framework, including heterogeneous anisotropic solid-solid, acoustic-acoustic, and anisotropic solid-fluid interactions. We simplify the eigenvalue problem in the Riemann solution from the rank of 9 to 3, and introduce the generalized wave impedance with more physical insight. Validations and verifications with independent codes and analytical solutions illustrate the accuracy, flexibility, and stability of our algorithm.

Key words: Riemann solver; generalized wave impedance; solid-fluid coupling; nonconformal meshes; discontinuous Galerkin; pseudospectral time domain algorithm.

1. Introduction

Modern high performance computing facilitates the development of various advanced numerical methods toward accurate, efficient, and adaptive simulations of wave propagation in large-scale complex media, which include anisotropic, viscous, fractured, nonlinear, and multiphase materials [1, 2, 3, 4]. The pseudospectral time domain (PSTD) algorithm has been widely applied to electromagnetic waves, acoustic waves, and elastic waves due to its high efficiency and accuracy: only 2-3 points per wavelength are required and very low dispersion errors are involved even after a many-wavelength propagation [5, 6, 7, 8]. In addition, after first proposed by [9], the discontinuous Galerkin (DG) method attracts increasing attention due to its superior properties: easily parallelizable and highly scalable stencils [10, 11, 12]. In realistic geoscience applications, multi-scale complicated geometries and high contrasts in wave speeds are prevalent so that it is inevitable to require nonconformal mesh technique for better flexibility and efficiency. It is therefore necessary to develop an accurate and efficient algorithm, i.e., a nonconformal DG-PSTD method, to solve these challenging problems.

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