20th European Mechanics of Materials Conference - EMMC20
Florence, Italy | May 27th-29th, 2026
www.emmc20.unifi.it

Data-Driven Component-Wise Hyper-Reduction for Nonlinear Finite-Strain Mechanics

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Paper ID: 550
Symposium S18: Advanced modelling techniques: Data-driven mechanics of materials

Abstract

Many mechanical systems made of advanced materials, such as composites, metamaterials, or additively manufactured structures, consist of interacting substructures. This modularity enables reduced-order modeling, particularly when components are reused across different assemblies or repeated within a larger structure. In this contribution, we present a component-wise reduced-order modeling framework for nonlinear mechanics in which each substructure is reduced independently and subsequently assembled into a global reduced system. The reduction strategy consists of two main ingredients. First, reduced models of the individual components are constructed using Proper Orthogonal Decomposition (POD) combined with hyper-reduction through Energy-Conserving Sampling and Weighting (ECSW). Second, the reduced components are coupled at the system level using a mortar-based tied-contact formulation, which allows the connection of substructures with non-matching interface meshes. The component-level POD bases are obtained from snapshot data generated in an offline stage. The basis must represent both finite-strain deformations and finite rigid-body motions. Deformation modes are computed either from isolated substructure simulations or from small training subsystems with loads applied at possible contact interfaces. Since linearized rotation modes are not sufficient when large rotations occur, we introduce additional modes that capture finite rigid-body rotations within a finite-strain setting. Once computed, the reduced bases and ECSW data can be stored and reused for different structural configurations and loading scenarios without recomputation.

We demonstrate the performance of the method by numerical examples involving finite strains, plasticity, and viscoelasticity.

Keywords:

hyper-reduction substructuring finite train mechanics nonlinear materials