Analysis of beam structures by combined 3D peridynamics and refined 1D finite elements

ANALYSIS OF BEAM STRUCTURES BY COMBINED 3D PERIDYNAMICS AND REFINED 1D FINITE ELEMENTS

M.Enea[a], F. Scabbia[b,c], A. Pagani[a], M. Zaccariotto[b,c], E. Carrera[a]

[a] Mul2 Team, Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino, Italy
[b] Industrial Engineering Department, University of Padova, Padova, Italy;
[c] Center of Studies and Activities for Space (CISAS)-G. Colombo, University of Padova, Padova, Italy

Summary: Previous literature has demonstrated that the Carrera Unified Formulation (CUF) can be used to generate higher-order finite elements with unprecedented accuracy. As a matter of fact, either 1D CUF elements can provide accurate 3D internal stress states within simple to complex structures and still preserve a high computational efficiency. The objective of this work is to present the latest developments in the coupling of refined 1D CUF-based finite elements with 3D peridynamics grids. The effectiveness of the proposed models is tested with both static and fracture analysis.

ABSTRACT

The peridynamic theory is a continuum version of molecular dynamics [1]. Essentially, it assumes that a solid body is composed by material particles and each pair of those interacts if their distance is less than a prescribed material horizon of radius δ. The physical interaction between the particles at $\boldsymbol{x}$ and $\boldsymbol{x}'$ is called a *bond*, which extends over a finite distance. Bonded particle $\boldsymbol{x}$ exerts a force $\boldsymbol{T}(\boldsymbol{\eta}, \boldsymbol{\xi})$ on particle $\boldsymbol{x}'$, where $\boldsymbol{\eta}$ and $\boldsymbol{\xi}$ are the relative displacement and initial distance vectors of the two particles. Evidently, peridynamics is a non-local theory and recently has attracted the attention of the scientific community for being successfully applied to solid mechanics and crack propagation problems. Nevertheless, this method can be computationally prohibitive for many applications, because the resulting matrices are sparse (not generally banded) and large. In this context, researchers have been extensively working in coupling models, in which peridynamics coexists with classical finite element (FE) approximations [2].

In the present work, the first step has been the coupling of 3D bond-based peridynamics (PD) is with refined 1D finite elements based on the Carrera Unified Formulation (CUF) [3]. In essence, by expressing the 3D displacement field as a generic expansion of the 1D generalized unknowns, CUF allows to generate low to high order finite elements in a general and unified manner. The theory approximation, i.e. the accuracy of the model, is a free parameter in CUF, which has been demonstrated to provide efficient (tunable) models able to describe accurately the 3D strain/stress states of structures with simple to complex geometry and for any material anisotropy.

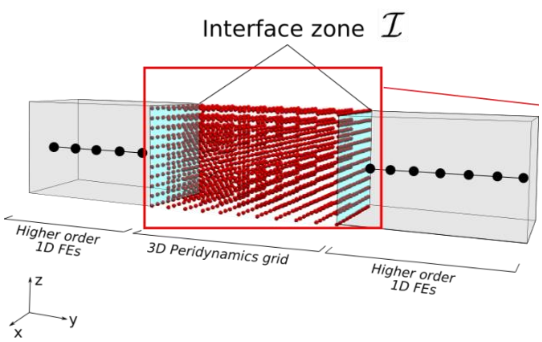

Figure 1 Coupling 3D peridynamics with refined 1D CUF finite elements

Figure 1 shows a solid beam in a Cartesian reference system. A portion of the solid body is modelled by 3D peridynamics, whereas the rest of the domain is discretized by high order 1D elements. Given an interface (contact) zone, denoted by $\mathscr{I}$ in the figure, between the peridynamic domain and the 1D FEs, Lagrange multipliers are used in this work to satisfy the congruence conditions on $\mathscr{I}$ and eliminate the singularity of the global stiffness array. Pagani and Carrera [4] showed that the coupled models have low computational costs and have demonstrated to be effective for a wide range of structures.

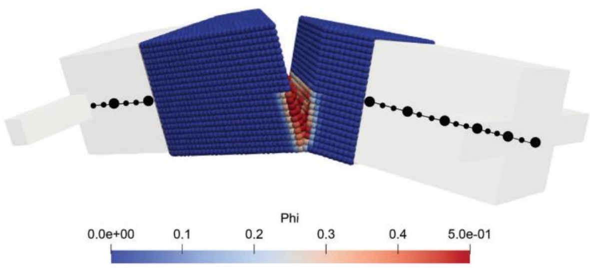

Figure 2 Damage distribution in a beam under torsion load by 1D CUF – 3D PD coupling [5].

Thus, this coupling method has been applied for quasi-static fracture analysis, providing good results for both the failure load of a structure and the shape of the crack pattern, as shown in Figure 2 [5]. Then, the method has been extended to the state-based peridynamics formulation [6], which allows the removal of any constraint on the Poisson ratio's value. Moreover, the method proposed by Galvanetto et al. in [2] has been implemented for the coupling of 3D state-based PD and refined 1D finite elements based on CUF. This method considers that peridynamics bonds act only on peridynamics nodes, while finite elements apply forces only on FE nodes, and it has proven to be very effective for a large number of case study. These aspects may bring to further and more in-depth studies on fracture analysis by coupled PD-FE models for problems of practical interest.

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