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Weak form of peridynamics for nonlocal essential and natural boundary conditions

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Abstract

This study presents the weak form of peridynamic (PD) governing equations which permit the direct imposition of nonlocal essential and natural boundary conditions. It also presents a variational approach to derive the PD form of first- and second-order derivatives of a field variable at a point which is not symmetrically located in its domain of interaction. This capability enables the nonlocal PD representation of the internal force vector and the stress components without any calibration procedure. Furthermore, it removes the concern of truncated domain of interaction for a point near the surface. Thus, the solution is free of nonlocal boundary forces and surface effects. The numerical solution of the resulting equations can be achieved by considering an unstructured nonuniform discretization. The implicit solution to the discrete form of the equations is achieved by employing BiConjugate Gradient Stabilized (BICGSTAB) method which is an iterative technique for solving sparse non-symmetric linear systems. The explicit analysis is performed by constructing a global diagonal mass matrix, and using a hybrid implicit/explicit time integration scheme. The accuracy of this approach is demonstrated by considering an elastic isotropic plate with or without a cutout subjected to a combination of different types of boundary conditions under plane stress conditions.

Key words Peridynamic, weak form, nonlocal, essential, natural, variational, derivatives

1 Introduction

Peridynamics (PD), a nonlocal continuum theory, was introduced by Silling [1]. It was later generalized by Silling at al. [2] to include general material models. The resulting equations of motion appear in the form of an integro-differential equation. The domain of spatial integration defines the extent of nonlocal interactions, and its integrand expressed in terms of the force density vector does not involve any spatial derivatives. Therefore, it does not present singularities when discontinuities such as cracks appear in the material. Silling et al. [2] derived the PD equations of motion for a point which is symmetrically located in its domain of interaction (family). These equations are classified as “Bond-based (BB)”, “Ordinary State-Based (OSB)” and “Non-Ordinary State-Based (NOSB)” PD. The BB PD does not distinguish between dilatation and distortional parts of deformation, and presents a constraint on the Poisson’s ratio.

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