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Review

A finite element formulation to model extrinsic interfacial behavior

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ABSTRACT

A finite element formulation is proposed to implement the Discontinuous Galerkin method in commercial FE code (here, Abaqus). Such an implementation leads to the definition of perfect interfaces, and then, allows the definition of extrinsic cohesive zone. The proposed element is tested in a simple mechanical configuration, and the influence of several parameters is focused on. Formulation limitations are last explained.

Contents

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1. Introduction

A commonly used method to allow cracks to appear and to propagate in finite element models is based on the cohesive zone approach. Since their first development by Dugdale [1] and Barrenblat [2], various formulations have been proposed, based on inverse identification (depending on the studied problem) or thanks to atomic theoretical considerations.

Cohesive finite elements are interfacial ones, which are inserted between two classical FE; their mechanical behavior (Traction-Separation Law, or TSL) models the progressive damage of the interface, from undamaged state up to total failure.

Cohesive zone elements might be implemented in various commercial Finite Element (FE) codes thanks to user subroutines, or are even included as standard procedures. Accounting for potential convergence problems [3], the failure of numerical structures is then possible.

The use of these elements, however, induces several artifacts, directly linked to the pre-debonding part of the TSL, which corresponds to a – very tough – spring-like interfacial element: while inserted in a mesh, cohesive elements lead to a global deterioration of the Finite Element structure mechanical properties [4,5]. For certain configurations, where a crack path is not *a priori* supposed, numerical failure might also exhibit a mesh-dependency [6].

To avoid such problems, several strategies might be used. One of them is based on the use of extrinsic cohesive elements, for which the undamaged interface cannot open, whatever the interfacial stress [7,8]. The extrinsic TSL, however, is not an application, and the implementation of such an element in Finite Element programs is highly problematic, being dependent on the way the mechanical solution is computed by the FE program [9]. Extrinsic behavior can nevertheless be defined thanks to an implicit pre-debonding TSL definition, based on the use of the Discontinuous Galerkin (DG) method.

The discontinuous Galerkin Method has been introduced by Reed [10] in 1973 to solve transport problems, and to get solutions in which potential discontinuities do not create artificial oscillations. The DG method has then been extensively used for a large game of problems (see [11] for a review). Because the DG method deals with unknown fields discontinuities, it is well adapted to crack initiation problems, in which a crack path is defined in a solid which remains undamaged up to a critical stress value. Across this potential discontinuity surface, the unknown displacement field has to remain continuous until the onset of failure. This method has then been developed for crack initiation and propagation problems [12] and applied to various configurations [13–19].

Because of its formulation and its implicit properties, the integration of such a method in commercial programs is not easy due to the available data which are transferred to user subroutines, and its implementation is mainly performed in home-made FE codes or open sources ones (e.g., [20]). We aim in the present paper at proposing a finite element formulation which allows the DG method implementation in FE commercial programs, avoiding the problem due to the implicit pre-debonding TSL formulation. Such an element consequently allows the definition of perfect interfaces. This element was implemented in Abaqus, using a User ELement subroutine (UEL).

The DG method is first presented, and, based on a simple 1D analytical problem, the finite element configuration is derived. The interfacial pre-debonding TSL is then focused, and especially, the influence of mechanical parameters. Last, formulation limitations are pointed out. Vectors will be denoted thanks to bold letters, while italic letters are associated to scalar variables. Tensors will be written as $[\mathbf{X}]$ or $\mathbf{X}$, depending on the context. ":" denotes double tensorial contraction, and "." simple contraction.

2. Resolution of a cracked body problem: the discontinuous Galerkin method

2.1. General mechanical problem

Let us consider an elastic body Ω, whose boundary $\partial\Omega$ is partitioned in two $\partial\Omega = \partial\Omega_u \cup \partial\Omega_T$. This body is submitted to both imposed displacement $\overline{\mathbf{u}}$ and stress $\overline{\mathbf{T}}$ on $\partial\Omega_u$ and $\partial\Omega_T$ respectively (Fig. 1).

If $\mathbf{u}$ denotes the (unknown) displacement at each body material points, the strain tensor $\boldsymbol{\epsilon}$ being so that

$$\boldsymbol{\epsilon} = \frac{1}{2}(\nabla\mathbf{u} + {}^{T}\nabla\mathbf{u}), \tag{1}$$

where ∇ is the Nabla operator. The stress field $\boldsymbol{\sigma}$ is then deduced from the strain one through the material behavior (e.g., for an elastic body, $\boldsymbol{\sigma} = \boldsymbol{C} : \boldsymbol{\epsilon}$, $\boldsymbol{C}$ being the elasticity tensor).

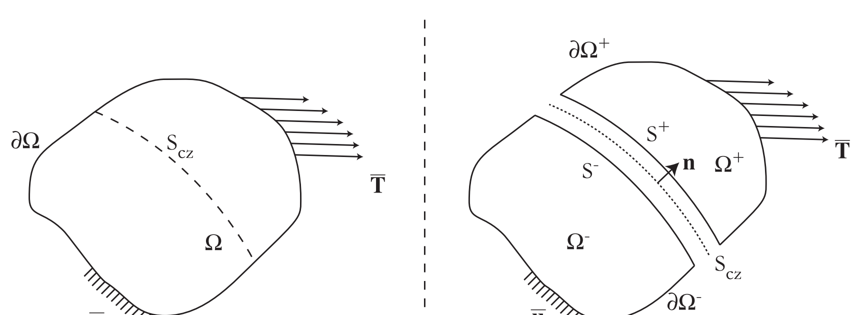

Fig. 1. Presentation of the problem.