Effective reference and current integration for large displacement interface

Francesco Parrinello[1], Guido Borino[1], Roberto Caserta
[1]*DICAM, University of Palermo, Italy*
E-mail: francesco.parrinello@unipa.it, guido.borino@unipa.it

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The most common interface formulations proposed in literature are generally based on the restrictive hypothesis of small strains and small displacements and, even though their application to geometrically nonlinear problems is of paramount interest, only few contributions are available in literature. Motivations are probably due to the difficulties encountered on such formulation, as already mentioned by several authors.

A pioneering formulation is the finite displacement three-dimensional interface developed by Ortiz and Pandolfi in [1], where normal and tangential traction components are evaluated with respect to the middle surface in the current configuration, producing a non-symmetric geometric stiffness matrix.

More recently, an interface element formulation for geometrical non-linearity and material nonlinearity, which is developed in the reference configuration, has been proposed by Reinoso and Paggi in [2]. The constitutive model is formulated on the local reference, defined by normal axis and tangential axis with respect to the middle surface in the current configuration. The interface formulation generates a non symmetric geometric stiffness matrix, which is simplified by neglecting the non symmetric contribution, in order to reduces computational cost by the use of symmetric solver.

The state of the art of cohesive models for the material separation is presented by Mosler and Scheider in [3], focusing the attention on the thermodynamics and variational consistency. In [3] the authors state that many proposed models do not verify fundamental requirements such as thermodynamic principles, frame invariance, equilibrium conditions. Such problems are magnified for anisotropic models in geometrically nonlinear context. Attention is also focused on the unphysical dissipation produced in elastic paths due to unsymmetrical stiffness matrix.

Some existing cohesive-zone models are analyzed under conditions of large displacement and large strain by Ottosen et al in [4], and CZMs are also evaluated with respect to thermodynamic consistency and the fundamental laws such as balance of angular momentum and frame invariance. It is shown that in elastic regime only isotropic models, with traction vector aligned to separation displacement vector, fulfill the physical principles, as already shown in [5].

In [6] some cohesive-zone models are compared at finite strain condition, by a wedge test and by a peel test. The paper [6] shows that some models available in literature, or implemented in commercial finite element codes, which integrate the weak form equilibrium condition over the current configuration, produce significant error in terms of fracture energy. On the contrary, models integrated over the reference configuration produce negligible numerical error.

The present paper investigates reasons of the different results between current and reference integration schemes. It is shown that interface formulations integrated over current configuration violate energy conservation principle, due to the elastic energy generated by the finite interface elongation with constant elastic stiffness parameters. Moreover, an original mechanical interpretation of the elastic stiffness parameters, defined as a density of elastic springs between the two interface edges, can be considered an effective solution for interface integrated over the current configuration. In fact, the interface elongation modify the density of springs, as well as volume change modifies the mass density, and integration over current configuration and integration over the reference one produce two identical solutions.

In the present paper the interface formulation is rigorously developed under large displacement conditions, assuming as local reference for the constitutive model, normal and tangential axes to the middle surface, as already proposed in [1]. The geometric operators in the current configuration, such as the normal and tangential axes to the middle surface and elongation of the middle surface, are defined as functions of nodal displacements, and first order and second order derivatives, with respect to nodal displacements, are developed. Finally, nodal force vector and consistent stiffness matrix are developed for a two-dimensional interface element, showing the symmetry condition of the geometric stiffness matrix, if the second order derivative are not neglected.

The proposed interface formulation is implemented in the FEAP finite element code [7] and the cohesive formulation proposed in [8] is considered as constitutive model. Results of numerical some simulations are proposed with times of convergence obtained with a symmetric solver.

References

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