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SCHWARZ METHOD FOR SLIP WEAKENING FRICTION WITH APPLICATIONS TO EARTHQUAKE SOURCE DYNAMICS

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ABSTRACT

The dynamic evolution in in-plane and 3D configurations of a linear elastic body with cracks under slip-dependent friction is considered. The aim is to propose an efficient numerical scheme to model the initiation and propagation of ”rupture” front (i.e. slip/stick boundary) in a heterogeneous medium, on fault systems of complex geometry and heterogeneous frictional properties.

This paper is a sequel to [1], which presented the first domain decomposition method to model dynamic faulting under slip-dependent friction in the anti-plane shearing configuration. Even if important features of the physical phenomenon (like stress interactions) are active in this configuration, only a limited number of geophysical faults (e.g. “normal” faults) are satisfactorily described by the anti-plane geometry. Moreover, in the anti-plane description of the friction phenomenon, the normal stress can be considered constant, which is a very important simplification. A remarkable consequence of this assumption is that we can associate the physical problem to the minimization of the energy function. By contrast, in the full 3D and in-plane configurations, studied in the present paper, the nonlinear problem at each time step cannot be associated to an optimization problem. Many important difficulties arise from the resolution of a quasi-variational problem instead of a variational problem, from both mathematical and computational points of view. However, the challenges in 3D modeling of earthquake source dynamics are worth the efforts of the present paper to overcome these difficulties.

We use here an implicit time-stepping scheme (Newmark method) which allows much larger values of the time step than the critical CFL time step, and higher physical consistency with respect to the friction law. Since the friction laws involved in dynamic faulting models are strongly non-linear, the use of an implicit time-stepping scheme leads to solve a nonlinear elliptic problem at each time step. Domain decomposition is one of the efficient methods to solve this type of quasi-variational problems. Using a Schwarz method to solve the quasi-variational problem induced by an implicit time-stepping scheme, the original problem splits in two subproblems. The first subproblem is linear and its unknowns are

the nodal values from the intact domain (i.e. excluding the faults). The unknowns of the second subproblem are the degrees of freedom of the mesh nodes lying on the faults, i.e. on the domain boundary where conditions of contact and friction are imposed. Evidently, this second subproblem is nonlinear; it is solved by the same Schwarz algorithm by splitting it into local nonlinear subproblems of a very small size (they have three unknowns in the in-plane problem and five unknowns in the 3D problem), so that quasi-explicit efficient solvers can be used. In fact, the resulting method is simply a non-linear Gauss-Seidel method for the non-smooth subproblem, which exhibits a strongly local non-linearity. Consequently, the solution procedure at each time step consists in the iterative resolution (until convergence) of one large linear subproblem and some very small nonlinear subproblems. The number of Schwars iterations depends on the number of subdomains, hence on the number of nodes on the fault, which is always significantly smaller than the total mesh size.

Numerical experiments are performed to illustrate convergence in time and space, instability capturing, energy dissipation and the influence of normal stress variations. We have used the proposed numerical method to compute source dynamics phenomena on complex and realistic 2D fault models (branched fault systems).

REFERENCES

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