8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineeering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

An infinite element description of Volterra dislocations in an elastic halfspace and its application in earthquake inversions

*** G.J. van Zwieten[1], R.F. Hanssen[2] and M.A. Gutiérrez[3]**

[1] Delft University of Technology
Faculty of Aerospace Engineering
2600 GB Delft, The Netherlands
G.J.vanZwieten@tudelft.nl

[2] Delft University of Technology
Faculty of Aerospace Engineering
2600 GB Delft, The Netherlands
R.F.Hanssen@tudelft.nl

[3] Delft University of Technology
Faculty of Aerospace Engineering
Faculty of Mechanical, Maritime
and Materials Engineering
2600 GB Delft, The Netherlands
M.A.Gutierrez@tudelft.nl

Key Words: *Infinite elements, Dislocation theory, Earthquake inversions*

ABSTRACT

This contribution presents a new finite element method for computing stress fields around tectonic faults, modelled as Volterra dislocations in semi-infinite elastic media. The method splits the computational domain into two parts; a convex, bounded part that contains the dislocations, and an unbounded part, both of which are in turn divided into finitely and infinitely many finite elements, respectively. Where conventional finite element methods would result in an infinite-dimensional system, infinite element theory [1] states that by carefully constructed self-similarity in the unbounded mesh, all its degrees of freedom can be condensed to a set of equations at the interface. Note that this should not be confused with the method that divides the unbounded part into finitely many infinite elements, which is also commonly referred to as infinite element method.

The past decades have seen a lot of development in what can be called the reverse problem; that is, to model dislocations in a finite domain by superposing infinite domain analytical solutions. An example is the discrete dislocation plasticity method proposed in [2], which complements the analytical fields by a continuous finite element solution to impose tractions on the finite domain boundary. The infinite domain has received far less attention, mainly because of the availability of analytical solutions to many problems of practical interest in, e.g., geophysics. It will be shown, however, that the proposed method offers many advantages over these classic solutions:

1. Flexibility

   Semi-infinite elastic media are used extensively in geophysics to model crustal co-seismic deformation in earthquake regions. Mostly used in this field are the solutions derived by Okada [3] for a rectangular shaped, constant slip dislocation in an elastic halfspace. Compared to existing methods the proposed method is expected to allow for much more freedom in describing both dislocation geometry and slip distribution. Furthermore, the finite element discretization of co-seismic elastic response obtained by this method can serve directly as initial condition to a time

dependent, post-seismic analysis of the region, for which visco-elastic material behaviour forces the use of finite element or other numerical tools.

2. Speed

   Evaluating analytical solutions can be more computationally expensive than solving a linear system, especially when many solutions are superposed. It is the relative insensitivity to the number of dislocations that drove the recent development of an XFEM based method [4] to replace the practice of superposition. Interestingly the accuracy tests in [4] were performed on an infinite medium by imposing analytical solutions at the boundary, similar to the method proposed in this contribution. The important difference is that boundary conditions are problem dependent, whereas infinite element interface equations can be reused for any fault configuration. The proposed method is therefore especially well suited for earthquake inversions such as the one performed in [5], in which many dislocation configurations are considered in search for the best match between predicted and measured surface displacements.

3. Accuracy

   Even in situations where differential equations can be solved exactly, the obtained solutions will be physically inaccurate when the assumptions underlying these equations are violated. Geometric linearity is one assumption that does not hold when displacements are discontinuous, with the result that analytical solutions in this case are (to some extent) non-physical. The effects of this are expected to manifest most strongly close to the discontinuity, hence close to the tectonic fault, which in general is also the region of strongest influence in the aforementioned inversion problem. To the authors' knowledge the impact of this effect on the inverted source model has not been investigated before.

This contribution compares the proposed infinite element method against commonly used methods in geophysics in terms of flexibility, speed and accuracy. The impact of geometric nonlinearity is investigated for its implications in inverse modelling.

REFERENCES

[1] Lung-an Ying. *Infinite Element Methods*, Peking University Press, 1995.

[2] E. van der Giessen, A. Needleman. "Discrete dislocation plasticity: a simple planar model". *Modelling and Simulation in Materials Science and Engineering*, Vol. **3**, 689–735, 1995.

[3] Y. Okada. "Internal deformation due to shear and tensile faults in a half-space". *Bulletin of the Seismological Society of America*, Vol. **82**, 1018–1040, 1992.

[4] T. Belytschko, R. Gracie. "On XFEM applications to dislocations and interfaces". *International Journal of Plasticity*, Vol. **23**, 1721–1738, 2007.

[5] T.J. Wright, Z. Lu, C. Wicks. "Source model for the Mw 6.7, 23 October 2002, Nenana Mountain Earthquake (Alaska) from InSAR". *Geophysical Research Letters*, Vol. **30**, 2003.