Open position for an internship at *POEMS*

UMR 7231 CNRS/INRIA/ENSTA

2012/2013 Academic year

A Fast Multipole Accelerated Boundary Element Method for 3D visco-elastodynamics in the time domain

- **Scientific Context.** The modeling of seismic wave propagation to understand complex phenomena such as site-effects or soil-structure interaction is an active area of research. The difficulties are related to the complexity of the system to model and the large spatial scale of the problems. Currently, 3D simulations are still limited to simplified configurations. This internship is part of an effort towards the development of tools to simulate real-life problems related to seismic wave propagation.

  Various numerical methods can be used to simulate seismic wave propagation. The main advantages of the Boundary Element Method (BEM) are to reduce the discretization to the domain boundary and to exactly take into account radiation conditions at infinite. As a result, BEMs are well suited to deal with problems in (semi-)infinite domains. However standard BEMs lead to a fully-populated influence matrix, and are thus severally limited regarding problems with complex geometries or in a large frequency range [3]. To address these limitations, recent works, in our group, have concerned the Fast Multipole accelerated BEM for 3D visco-elastodynamics [1, 4]. The Fast Multipole Method (FMM) permits to reduce drastically the solution time and the memory requirements of the BEM and to considerably enlarge the BEM model size.

  Our developments so far have concentrated on frequency-domain formulations. However, for various applications (such as the introduction of non-linearities) it is necessary to simulate the propagation of elastic waves in the time domain.

- **Objectives.** The formulation of a time-domain BEM contains convolution integrals with respect to the time. Such convolutions can be directly computed in the time domain by using time-domain fundamental solutions. But the derivation of a FMM for such BEMs is not easy and such formulations are known to be very sensitive to the choice of the time step.

  An alternative approach is to solve the problem via a frequency-domain BEM and them apply a Fourier transform to synthesize the results in the time domain. The solution of the time-dependent problem is turned into the solution of a sequence of independent frequency-domain problems. However this method is known to suffer from instabilities related to the choice of the sampling parameters.

  Another promising avenue, which is intermediate between a direct time-domain approach and a frequency-time domain approach is to use the Convolution Quadrature Method (CQM) [5, 6]. CQM is used as a time stepping scheme in conjunction with the Laplace-transformed fundamental solution. The method has been successfully applied to a symmetric BEM for 3D elastodynamics [7].

The proposed work is decomposed into the following three steps:

(i) Formulation of the FM-accelerated BEM for 3D visco-elastodynamics in the time domain via the CQM and the Laplace transform.

(ii) Implementation of the method in the code COFFEE (solver for 3D visco-elastodynamic problems in the frequency domain based on the FM-BEM).

(iii) Assessment of accuracy and efficiency by comparing with previously published results and the frequency-time domain formulation.

▷ **Knowledge.** Solid backgrounds in applied mathematics or computational mechanics and scientific programming skills are expected. Prior knowledge on the boundary element methods will be appreciated. Scientific interest in Earth problems is an asset.

▷ **Contact and location.** The internship (expected duration 5-6 months) will take place in the POems team (Propagation d'ondes: études mathématiques et simulation) of the applied mathematics department at ENSTA (Palaiseau). It will be supervised by Stéphanie Chaillat (CNRS junior scientist) and Marc Bonnet (CNRS senor scientist). Applications including a CV and a cover letter have to be sent to stephanie.chaillat@ensta.fr.

▷ **Prospect.** Depending on progress and results, this internship work may result in a published peer-reviewed article. Moreover a PhD continuation on this topic is a possibility.

The position is open to an international student.

References

[1] S. Chaillat, M. Bonnet, J.F. Semblat, A multi-level Fast Multipole BEM for 3-D elastodynamics in the frequency domain. *Computer Methods in Applied Mechanics and Engineering*, 197: 4233-4249, 2008.

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[3] N. Delepine, J.F. Semblat, Site effects in an alpine valley with strong velocity gradient: Interest and limitations of the 'classical' BEM. *Soil Dynamics and Earthquake Engineering*, Vol. 38, 15-24, 2012.

[4] E. Grasso, S.Chaillat, M.Bonnet, J.-F. Semblat, Application of the multi-level time-harmonic fast multipole BEM to 3-D visco-elastodynamics. *Engineering Analysis with Boundary Elements*, Vol. 36, 744-758, 2012.

[5] C. Lubich, Convolution quadrature and discretized operational calculus I. *Numerische Mathematik*, Vol. 52, 129-145, 1988.

[6] C. Lubich, Convolution quadrature and discretized operational calculus II. *Numerische Mathematik*, Vol. 52, 413-425, 1988.

[7] M. Messner, M. Schanz, An accelerated symmetric time-domain boundary element formulation for elasticity. *Engineering Analysis with Boundary Elements*, Vol. 34, 944-955, 2010.