Complex frequency-domain seismic computation for modelling and inversion; Elastic isotropic full waveform inversion via quantitative stability estimates

Florian Faucher*, Jia Shi†, Maarten V. de Hoop†, Henri Calandra§ and Hélène Barucq‡

*‡INRIA Bordeaux Sud-Ouest Research Center, Project-Team Magique-3D, LMA – UMR CNRS 5142
Université de Pau et des Pays de l'Adour, Avenue de l'Université, BP 1155, 64013 Pau Cedex, France
florian.faucher@inria.fr; helene.barucq@inria.fr

† Department of Mathematics, Purdue University
150 N. University Street, West Lafayette IN 47907, USA
shi126@purdue.edu ; mdehoop@purdue.edu

§ TOTAL Exploration & Production, Depth Imaging and High Performance Computing
1201 Louisiana St., Suite 1800, Houston, TX 77002, USA
henri.calandra@total.com

ABSTRACT

We study the seismic inverse problem in the complex frequency-domain. Seismic inversion is realised for depth imaging and standardly uses the Full Waveform Inversion (FWI) method. FWI utilizes surface observation of waves phenomena, and minimize their difference with a simulated propagation, which makes use of an approximate model. The following iterative minimization of those residuals leads to the update of the approximated model and eventually the reconstruction of the targeted parameter (velocity, density).

We focus on the inverse problem for the elastic isotropic case and recovery of the Lamé parameters and density. Our FWI algorithm is based on the projected descent method. Recent results on the conditional well-posedness [1] show that the problem follows a Lipschitz type stability where the Fréchet derivative has a strictly positive lower bound. This bound is connected to the stability constant and can be approximated using the Gauss-Newton Hessian. Then we effectively estimate the stability by computing the smallest singular value of the Gauss-Newton Hessian. The successive stability estimates provide a control of the convergence of our algorithm, it decides on the parametrization (quantities to inverse) and the model representation (partitioning). Hence we develop a multi-level approach with a hierarchical compressed reconstruction. The compression is based on a structured domain partitioning of the sub-surface, while the hierarchy is established through successive refinements of the partitioning. The coefficients (Lamé parameters and density) are assumed to be piecewise constant functions following the domain partitioning. The partitioning is naturally defined with the successive stability estimates in order to maintain the radius of convergence, while refinement provides resolution. It allows us to start with minimal prior information for the coefficients. Moreover the multi-parameters FWI follows two stages driven by the stability and convergence analysis: the Lamé parameters are reconstructed jointly while assuming an unknown fixed density model; we can also reconstruct the density assuming the knowledge of the Lamé parameters. The algorithm is perfectly suitable for complex frequency and we carry out numerical experiments for elastic reconstruction in two and three dimensions.

REFERENCES

[1] E. Beretta, E. Francini and S. Vessella, "Uniqueness and lipschitz stability for the identification of Lamé parameters from boundary measurements", *arXiv preprint arXiv:1303.2443* (2013).