Wave energy focusing to target subterranean formations: a comparison between a time reversal and an inverse-source approach

Seungbum Koo / Pranav M. Karve / Loukas F. Kallivokas

Department of Civil, Architectural and Environmental Engineering,
The University of Texas at Austin, 301 East Dean Keeton St. Stop C1747
Austin, TX 78712, USA

Wave energy focusing in heterogeneous solids has potential applications in petroleum engineering (enhanced oil recovery), medicine (treatment of malignancies or therapeutic interventions), military (removal of unexploded ordnances), hydro-geology (removal of contaminants from aquifer), etc. Waves traveling to the target typically emanate from wave sources placed on the boundary of the solid. In order for the wave energy to focus successfully to the target formation, it is important that the spatio-temporal characteristics of the wave source be designed appropriately. In this presentation, we compare two methodologies which could be used for designing wave sources in order to focus and/or maximize energy delivery to a subterranean target: an inverse-source (IS) approach and an approach based on time reversal (TR) concepts. IS is based on a partial-differential-equation-constrained optimization methodology that attempts to maximize the wave energy delivery, while TR relies on reciprocity concepts afforded by the nature of the governing differential equation.

IS is formulated as a constrained optimization problem driven by the maximization of an energy functional, where the locations and the time signals of the wave sources are treated as unknown. The method requires a priori knowledge of the geometry and physical properties of the host and target formations.

By contrast, TR does not require a priori knowledge of the domain in question. TR consists of two steps: a forward step and a time reversal step. In the forward step, a source, embedded in the target formation, emits a signal, which is recorded at a sensor array on the boundary. The record is time-reversed and amplified during the time reversal step. The limited extent of the mirror array, the semi-infinite extent of the host formation, and quite importantly, the Dirichlet-to-Neumann data reversal during the time reversal step, pose constraints on the method's ability to maximize energy delivery, while still focusing on the target formation.

We discuss the wave energy focusing problem in a two-dimensional setting, where the target is embedded within a heterogeneous, semi-infinite host. We define an efficiency metric, report on numerical experiments (Fig. 1), and compare the two methods using synthetically-created data. We conclude with the relative strengths of the methods and provide recommendations for field implementations.

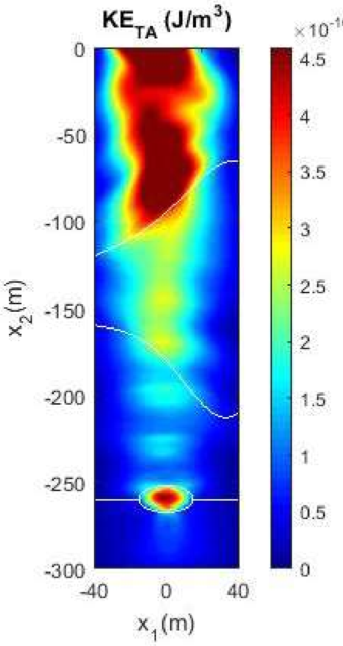

Fig. 1: Time-averaged kinetic energy distribution, showing energy focusing to target (TR case)