Alternative method for surface wave inversion
Méthode alternative d'inversion des ondes de surface

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Introduction

- 2D seismic near-surface imaging is a challenging task in civil engineering;
- 1.5D approaches have strong limitations when dealing with media with strong lateral variation;
- Full waveform inversion approaches require a consequent amount of data and an accurate initial model (local optimization) which can be difficult to obtain;
- an alternative method is proposed using a limited amount of data and an efficient global optimization method;

Particle swarm optimization

- meta-heuristic population-based method first proposed by Eberhart and Kennedy (1995);
- simple update formula:

$$v_i^k = \chi\left[v_i^{k-1} + r_p c_p (x_{p,i} - x_i^{k-1}) + r_g c_g (x_g - x_i^{k-1})\right] \quad (1)$$

$$x_i^k = v_i^k + x_i^{k-1} \quad (2)$$

- at each iteration k the position of the particle i (x_i) in the parameter space is updated using a velocity vector v_i;
- v_i is related to the best position reached by the particle $x_{p,i}$ and by the swarm (x_g);
- the balance between exploration and exploitation is controlled by the cognitive parameter (c_p) and the social parameter (c_g);
- r_p and r_g are random parameter ($r_p, r_g[0,1]$);
- at each iteration the particle position is evaluated using the $\mathcal{L}_2$ norm;

Two-grid approach

- to avoid the *curse of dimensionality* of stochastic methods the subsurface is parametrized with two grids (Mazzotti et al., 2016): (1) a *coarse* inversion grid using few points and (2) a *fine* modeling grid (finite-differences);
- each node of the inversion grid corresponds to a group of unknowns: position (x,z), S-wave velocity, volumic mass and Poisson's ratio;
- conversion to *fine* modeling grid (finite-differences) using discrete Sibson interpolation (Park et al., 2006) as shown in figure 1;

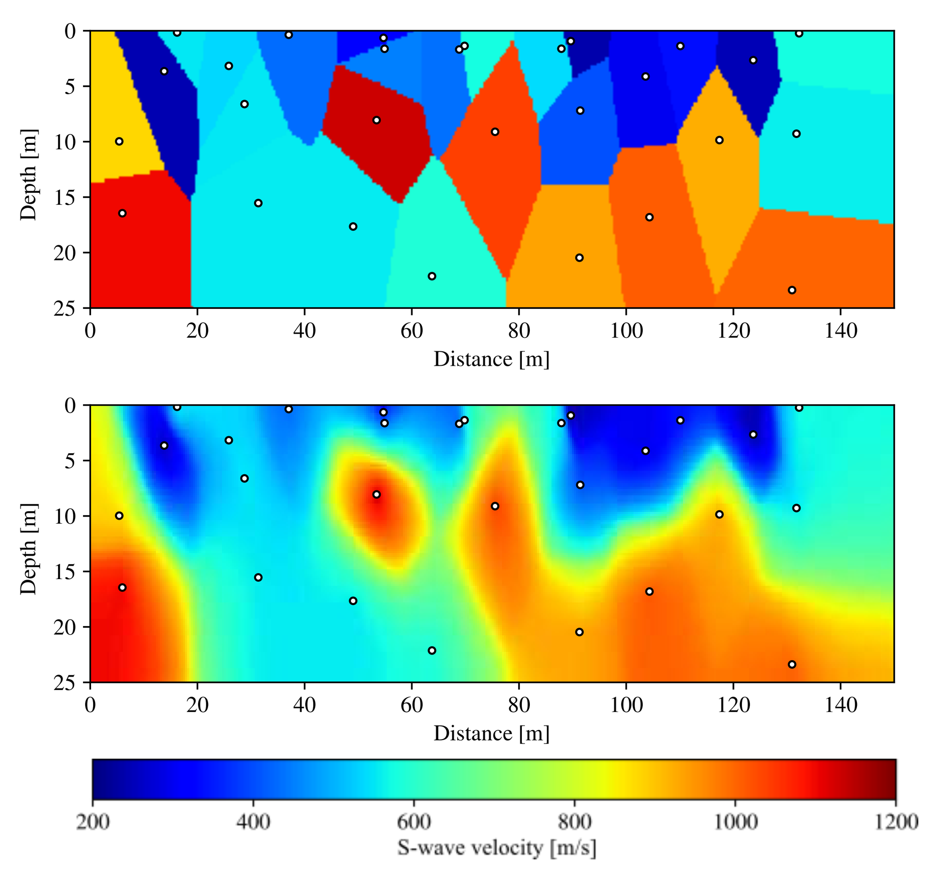

Figure 1: *fine* modeling grid from radomly generated *coarse* inversion grid using (top) Voronoi tesselation and (bottom) discrete Sibson interpolation.

Numerical results

- modeling:
  - 3 source positions (20 m, 75 m and 130 m distance) and a receiver line of 48 receivers (centered on 75 m and spaced of 2 m) are used;
  - the source is Ricker (Gaussian second-derivative) with a peak frequency of 15 Hz;
  - a 2D elastic time-domain finite-differences engine is used for the forward modeling (Levander, 1988; Bohlen and Saenger, 2006);
- inversion:
  - each inversion grid (particle) contains 24 nodes;
  - position (x,z) and S-wave velocity are randomly generated ($200. < V_S < 1200.\ m/s$), density and Poisson's ratio are constants ($\rho = 1700\ kg.m^{-3}$ and $\nu = 0.35$);
  - 49 particles are generated and updated through 120 iterations;
- results:
  - assessed S-wave velocity model (figure 2) is an average of the best models reached by each particle at the last iteration;
  - the vertical velocity profiles shown in figure 3 and the comparison between dispersion diagrams in figure 4 show a good agreement between *observed* and *resulting* models;

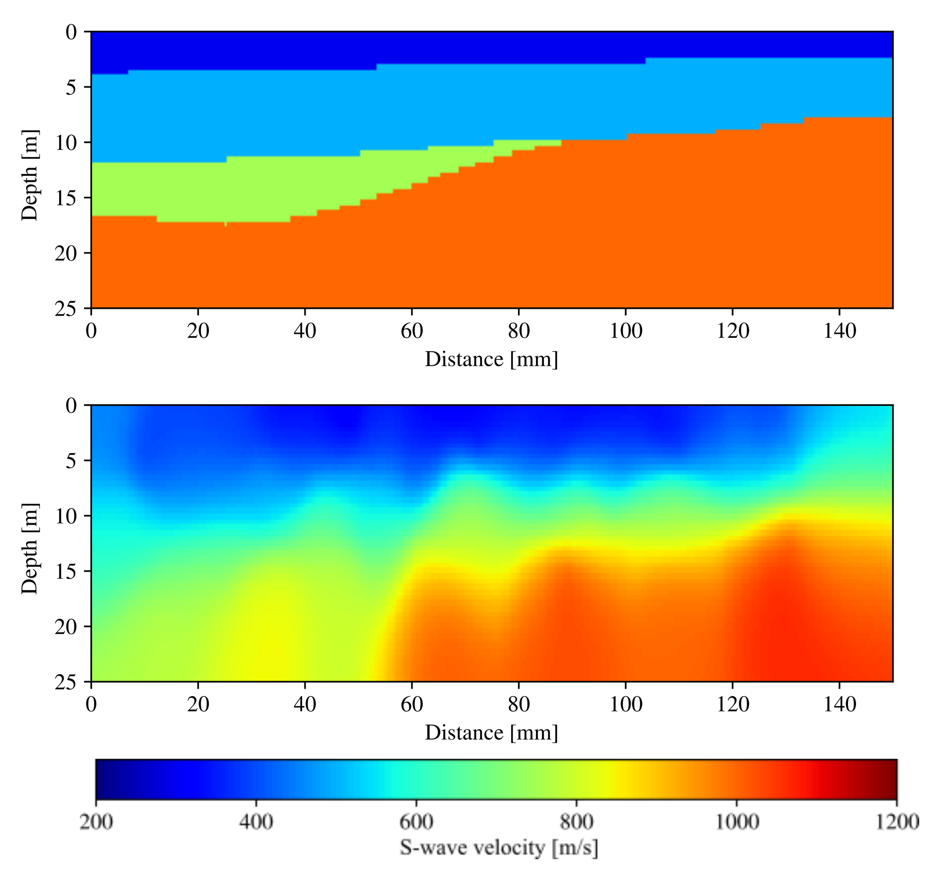

Figure 2: (top) True S-wave velocity model used to calculate the *observed* data. (bottom) Assessed S-wave velocity model using our inversion method.

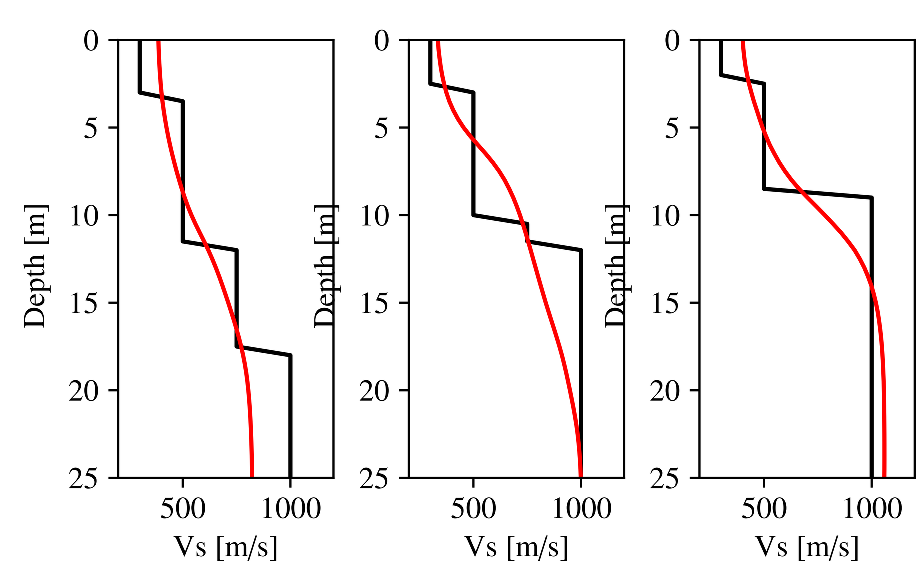

Figure 3: Velocity logs from the initial (black) and assessed (red) S-wave velocity models at (left) 25 m, (middile) 75 m and (right) 125 m.

Conclusions

- a 2D image of the near-surface has been assessed using few sources, few receivers and an efficient global optimization method;
- the resulting smooth model is accurate enough to be used as an initial model in high-resolution seismic imaging methods such as full waveform inversion;

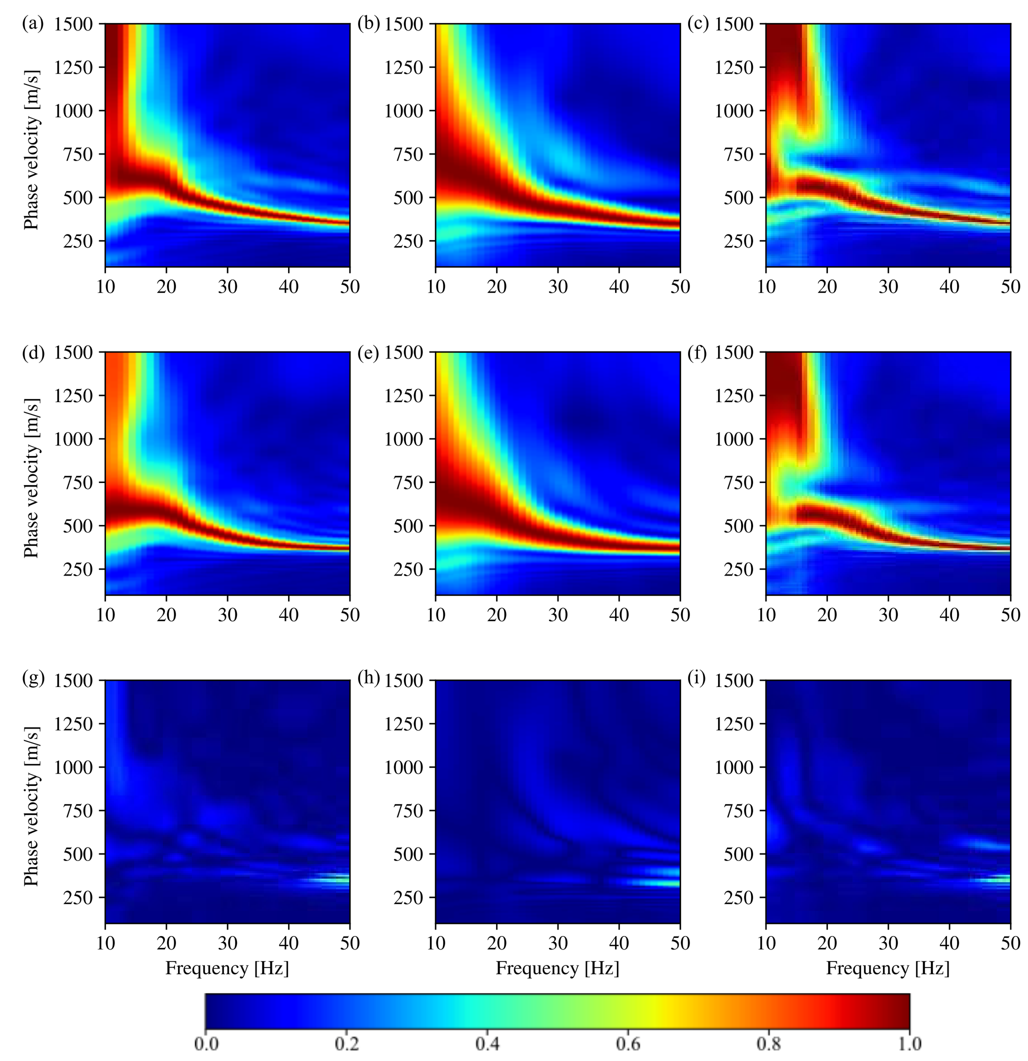

Figure 4: (a,b,c) Dispersion diagrams calculated using *observed* data for the three source positions. (d,e,f) Same as (a,b,c) but using data calculated in the assessed model. (g,h,i) Differences between (a,b,c) and (d,e,f).

Forthcoming Research

- inversion for shallow water acquisition;
- adding attenuation (Q_p, Q_s);
- effects of S/N ratio;
- application on small-scale experimental data (MUSC laboratory-IFSTTAR);

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