# Elastic wave propagation in heterogeneous media using the spectral element method


Dr. M. Stupazzini[1,2] , Prof. F. Sanchez-Sesma[3], Prof. E. Faccioli[2] and Dr. F. Maggio[4]

(1) Ludwig-Maximilians-Universität München

(2) Dipartimento di Ingegneria Strutturale - Politecnico di Milano

(3) Universidad Nacional Autonoma de Mexico

(4) Center for Advanced Studies, Research and Development in Sardinia


## Synthetic description of Geo-ELSE code

**GEO-ELSE (GEOtechnical – ELasticity by Spectral Elements)**

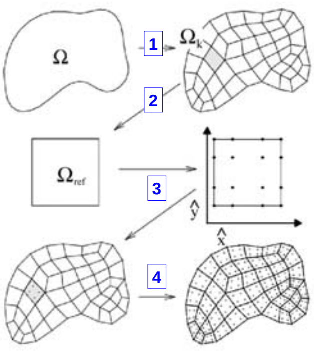
- GEO-ELSE is a Spectral Elements code for the study of wave propagation phenomena in 2D or 3D complex domain
- Developers:
  - CRS4 (Center for Advanced, Research and Studies in Sardinia)
  - Politecnico di Milano, DIS (Department of Structural Engineering)
- Native parallel implementation
- Naturally oriented to large scale applications ( > at least $10^6$ grid points)

Spatial discretization

- Spectral element method SEM (Faccioli et al., 1997)

Time advancing scheme

- Finite difference 2nd order (LF2 – LF2), conditionally stable




Spectral discretization of the spatial domain

1. The domain is split into quadrilaterals (hexahedra)
2. Each subdomain is mapped onto a reference element
3. LGL nodes are introduced
4. Spectral grid-points are mapped back onto the domain

Why using spectral elements ?

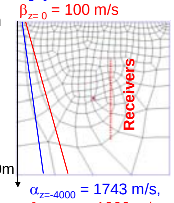
- Suitable for modelling a variety of physical problems (acoustic and elastic wave propagation, thermo elasticity, fluid dynamics)
- Accuracy of high-order methods
- Suitable for implementation in parallel architectures
- Great advantages from last generation of hexahedral mesh creation program (e.g.: CUBIT, Sandia Lab.)

## Validation of SEM with gradient material properties

The results of the comparison between an approximate analytical formulae for elastic 2-D and 3-D Green's functions for a constant gradient propagation velocity medium (Sesma et al., 2001) and GEO-ELSE implementation of the gradient material properties is here presented. The excitation is an applied triangular force located in the center, along the vertical direction.

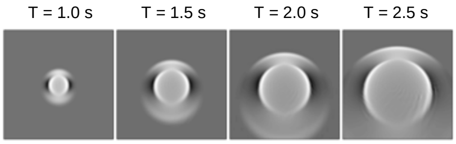
Unstructured mesh:

$\alpha_{z=0}$ = 174.3 m/s,
$\beta_{z=0}$ = 100 m/s

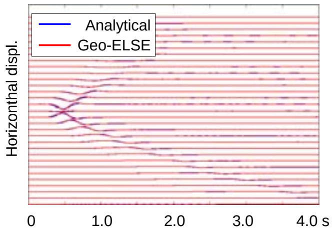


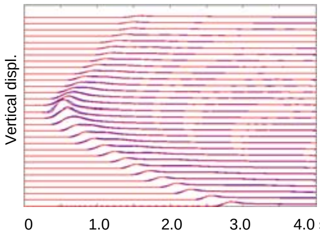

$\alpha_{z=-4000}$ = 1743 m/s,
$\beta_{z=-4000}$ = 1000 m/s

Snaphots of vertical displacement




Time histories comparison

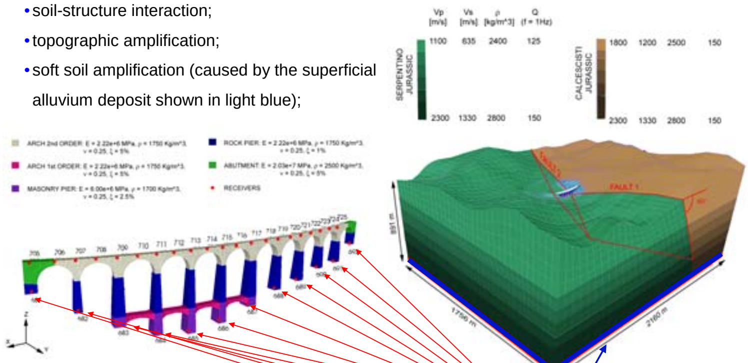


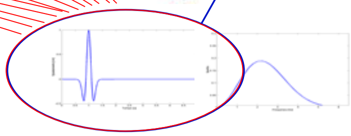

## Applied study case: Acquasanta viaduct (Genova, Italy)

3D model characteristics (Stupazzini, 2004):

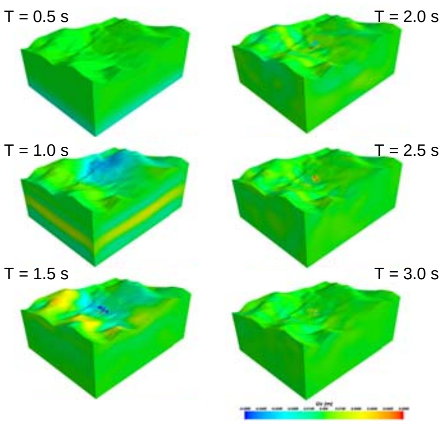
- Constant gradient of mechanical properties for the schists and the serpentine rock;
- subvertical fault (red line) between the schists, on the Ovada side, and serpentine rock, on the Genoa side;
- soil-structure interaction;
- topographic amplification;
- soft soil amplification (caused by the superficial alluvium deposit shown in light blue);



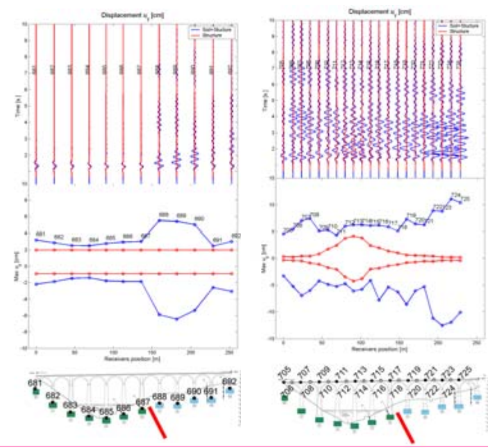

Structural analysis vs soil-structure analysis:
The excitation is first imposed to the bottom of each viaduct pier (red line) and then as a shear plane wave, propagating vertically from the bottom (blu line); Ricker wavelet, $f_{max}$=6 Hz, $t_0$ = 1.2s and amplitude = 1cm.



## Snapshot of displacement ($u_y$)




## Time histories ($u_y$)



## CONCLUSIONS:

- *SEM technique is able to handle complex geometries involving strongly heterogeneous media.*
- *Soil-structure interaction can be studied and could lead to important consequences in seismic design code*


Faccioli E., Maggio F., Paolucci R., Quarteroni A. (1997) – *"2D and 3D elastic wave propagation by a pseudo-spectral domain decomposition method"*. Journal of seismology, 1, pp. 237-251.

Sanchez-Sesma F.J., Madariaga R. and Irikura K. (2001) – *"An approximate elastic two-dimensional Green's function for a constant-gradient medium"*, Geophys. J. Int. 146, 237–248

Stupazzini M. (2004) – *"A spectral element approach for 3D dynamic soil-structure interaction problems"*. Milan University of Technology: PhD thesis.