Variability of earthquake ground motion due to small scale heterogeneities: comparison of 2D and 1D probabilistic approaches

Presented by:
Elias EL HABER
16/11/2018

Influence of 2D heterogeneous elastic soil properties on surface ground motion spatial variability.

Definition and near surface causes

Spatial variability of earthquake ground motion (SVGM)

Difference in amplitude and phase between two recordings on surface

Argostoli geology basin

- Calcaire dur
- Grès
- Calcaire
- Sable

Rock seismic response

E. Koufoudi

Same signal at supports

4 different signals at supports

Theodulidis et al. 2018

350 m

2 s
Definition and near surface causes

Spatial variability of earthquake ground motion (SVGM)

Difference in amplitude and phase between two recordings on surface

Large scale heterogeneities
[ few hundred of m -> few kms ]

Lithology

Small scale heterogeneities
[ few cms -> few hundred of m ]

Argostoli geology basin

Rock seismic response

Theodulidis et al. 2018
Small scale heterogeneities and site response prediction – Example (1)

Thompson et al. (2009)

Importance of the small scale heterogeneities in the site response prediction

Not all the 1D profiles can predict the seismic response recorded on surface
Small scale heterogeneities and seismic response prediction – Example (2)

**Introduction**

Seismic response prediction

Generation of 1D random soil profiles

For a given site

Definition of a mean and std for the soil properties

1D calculations

Seismic response prediction

Rodriguez-Marek et al. (2014)
Strategy and objectives

Evaluate the impact of small Scale Heterogeneities on SVGM

Compare 1D and 2D simulations

Simplified Parametric Study

Sediment Layer over a Bedrock

Only linear Analysis

Variability anisotropic of $V_s$

Attenuation Non-Linearity

Single station ground motion indicators
Outline

Small scale heterogeneities modeling and waves propagation simulation

Effect of the 2D heterogeneities on single station ground motion indicators

2D and 1D comparison

Conclusions and perspectives.
2D modeling of small scale heterogeneities

Probabilistic approaches

Soil structure with uncertainties

Multiple possible scenarios/probabilistic realizations

How to apply this method in our study?
Probabilistic approach - Definition

Definition of the deterministic model

Modeling Vs as a random field

Variability = 0%

- Sediment
  - $\rho = 1600 \text{ Kg/m}^3$
  - $\mu_{Vs} = 220 \text{ m/s}$
  - $V_p = 1500 \text{ m/s}$

- Bedrock
  - $\rho = 2500 \text{ Kg/m}^3$
  - $V_s = 1000 \text{ m/s}$
  - $V_p = 3000 \text{ m/s}$

Proability distribution function
- Log-normal (for soil properties)

$$COV = \frac{\sigma}{\mu}$$

Statistical parameters
- $COV$, $\theta_x$ et $\theta_z$

Salloum et al. 2014

Autocorrelation function
Statistical parameters – range of values

Over 33 characterization studies of near surface soil properties

Spatial sampling not respected in most of the studies
Statistical parameters – chosen values

### Numerical simulations

- **Single station variability**
- **Comparison 2D/1D**
- **Conclusions**

#### Statistical Parameters

- $COV$
- $\theta_x$
- $\theta_z$

<table>
<thead>
<tr>
<th>Value</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>5 m</td>
</tr>
<tr>
<td>20%</td>
<td>10 m</td>
</tr>
<tr>
<td>40%</td>
<td>20 m</td>
</tr>
<tr>
<td>1 m</td>
<td></td>
</tr>
<tr>
<td>2 m</td>
<td></td>
</tr>
</tbody>
</table>

#### Probabilistic Models

- 20%–10 m– 2m
- 100 scenarios

#### Soil Layer

- $V_s$ [m/s]
  - Blue: 150
  - Green: 200
  - Yellow: 250
  - Orange: 300

#### Bedrock
Random field discretization and waves propagation simulation

Expansion Optimal Linear Estimation (EOLE)
- Krigging method
- Account for the 2D spatial correlation in the soil

Li et Der Kiureghian, 1993

FLAC2D: Finite difference code
- Linear analysis
- No attenuation

Absorbent boundaries
Soil layer
Bedrock
Plane wave of type SV
Synthetic simulation - Example

\[ COV = 40\%, \theta_x = 10 \text{ m et } \theta_z = 2 \text{ m} \]
Single station ground motion indicators – time and frequency domains

**Time domain**

- **Energie du signal (ou Intensité d’Arias):**
  \[ A_b I = \int_{0}^{\infty} v(t)^2 dt \]

- **Durée du Signal:**
  \[ DA_b I = t_E=0.95A_b I - t_E=0.05A_b I \]

**Frequency domain**

- **Amplification:**
  \[ AF_{f_0} \]
Average and standard deviation at single station (1)

Time domain

<table>
<thead>
<tr>
<th>COV [%]</th>
<th>Arias Intensity [-]</th>
<th>Duration [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Deterministic values

- COV is controlling the ground motion variability on surface

Conclusions
For the average, no large difference between probabilistic and deterministic approaches.

- COV controls the ground motion variability.

- A shift in the fundamental frequency is observed for COV 40%.
Comparison 2D/1D – Time domain

1D calculations clearly underestimate the energy and the duration of the ground motions recorded on surface.
- The 1D approach can predict the $f_0$ and $AF_{f_0}$ average values.
- The 1D approach under estimate the variability of $AF_{f_0}$
Comparison 2D/1D – Spectral amplification

The 1D approach underestimate the amplification variability especially at high frequencies.
Main conclusions

- Small scale heterogeneities generate diffracted surface waves that increase the duration and energy of the seismograms on surface. Waves scattering is more highlighted in 2D approaches than the 1D analysis.

- COV is the statistical parameter mainly controlling the variability of the single station ground motion indicators.

- Even though 1D probabilistic approaches can predict the fundamental frequency and corresponding amplification, however, they under estimate the spectral amplification variability especially at high frequencies.

- 1D approaches may not be appropriate to replace the 2D ones in the prediction of site response.
Some perspectives

- Account for attenuation and non-linearity behavior in the wave propagation simulation.
- More realistic Vs profiles.
- More complex soil structures (different geology layers, 3D modeling, ...)

Numerical simulations

Single station variability

Comparison 2D/1D

Conclusions Perspectives
Thank you for your attention