Quantification of the spatially variable ground motion and its influence on the linear and non-linear structural response of a single degree of freedom. Application to the shallow sedimentary valley of Argostoli, Greece

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QUANTIFICATION OF THE SPATIALLY VARIABLE GROUND MOTION AND ITS INFLUENCE ON THE LINEAR AND NON-LINEAR RESPONSE OF A SINGLE DEGREE OF FREEDOM. APPLICATION TO THE SHALLOW SEDIMENTARY VALLEY OF ARGOSTOLI, GREECE.

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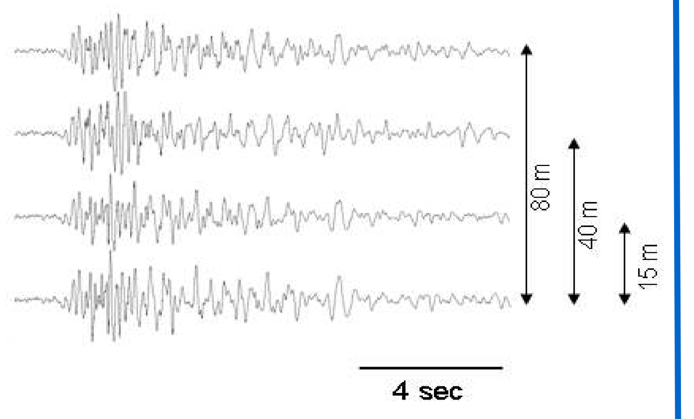
Introduction

Motivation

Spatial variability of seismic ground motions:difference in terms of **amplitude** and **phase** content of seismic motions recorded over extended areas but even within the dimensions of a structure.
At few tens of meters scale, such spatial variability may have important effect on the response of extended lifelines because of the spatially variable contributions applied at different supports of the structure.

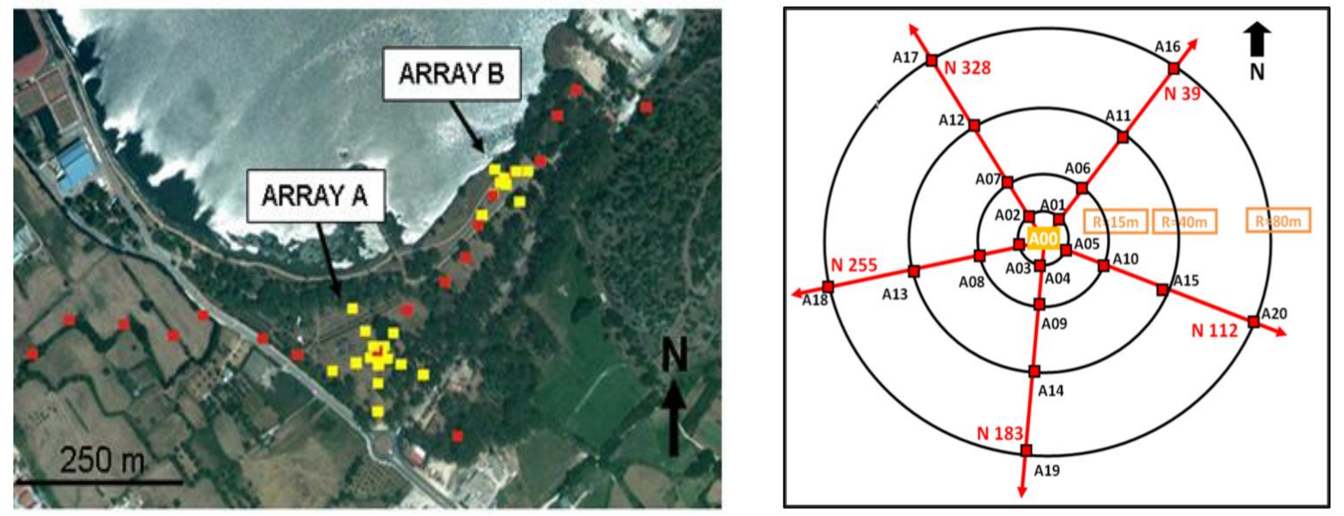


Goals

1. Characterization of the spatially variable ground motion in the shallow sedimentary basin of Argostoli, Greece.
2. Effect of the spatially variable ground motion on the linear elastic and non linear elastoplastic response of a Single Degree of Freedom (SDOF) system with varying fundamental period.

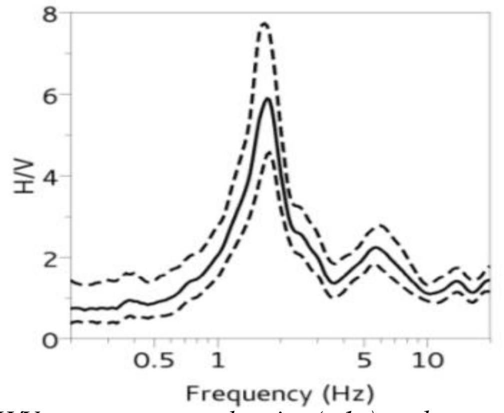
Temporary seismological network

Dense seismological network deployed in the alluvium valley of Argostoli (island of Cephalonia, Greece) from mid September 2011 to mid April 2012.



Location of NERA seismological stations (broad-band velocimeters). The 21 stations of Array A are located around the central station A00 in four concentric circles (5 at each circle) at radii 5, 15, 40 and 80 m.

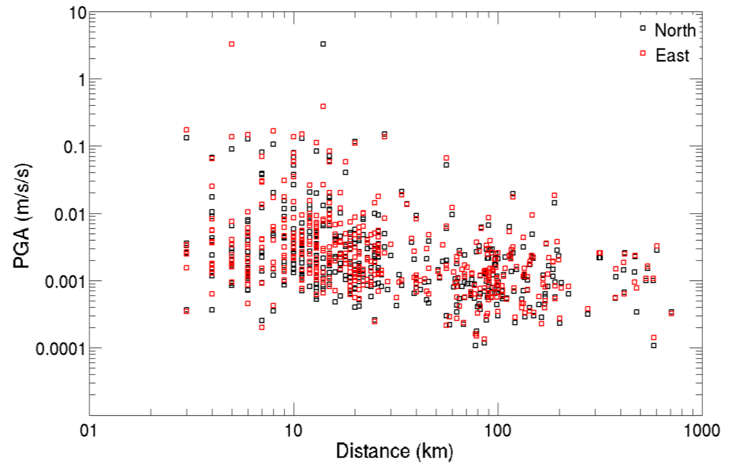
Located on a flat area, the 21 stations lie on the same geological unit and exhibit the same resonance frequency which is ~1.5-1.7 Hz.



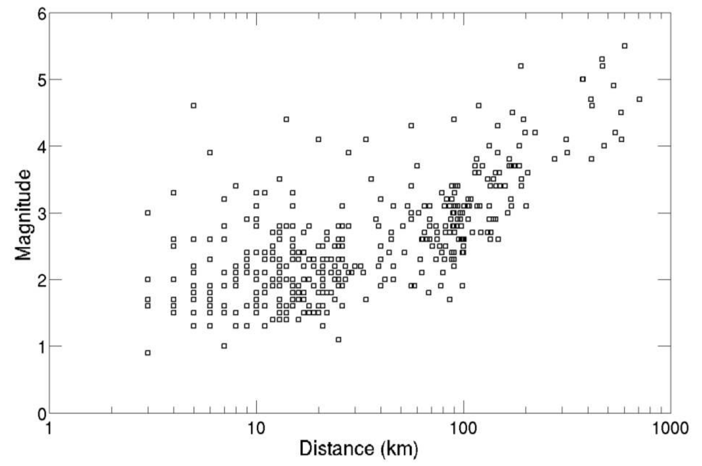
H/V average spectral ratios (±1σ) at the center of the valley based on ambient noise recordings of about 1 hour.

Seismological data

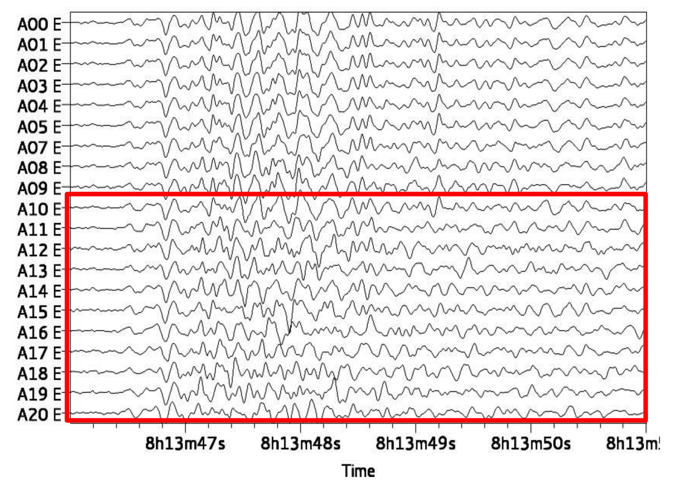
Out of 3000 local and regional events recorded, with M ≥ 2.0, 398 events were considered in this study for their very high signal to noise ratio.



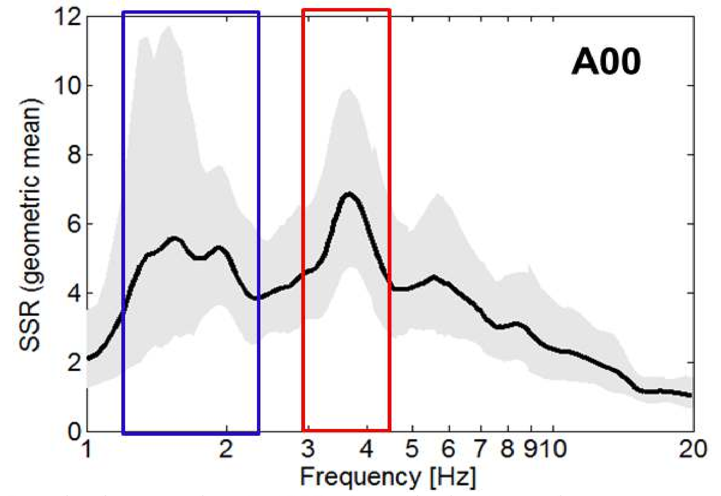
Peak Ground Acceleration (PGA) as a function of magnitude (EW – NS components) for the 398 events.



Magnitude as a function of hypocentral distance for the 398 events.



Acceleration recordings of the 21 stations for one event (M_w 4,1 and R_{hypo} = 22 km, EW component). After ~10-15 m of separation distance the motions start to differ significantly both in amplitude and phase content.



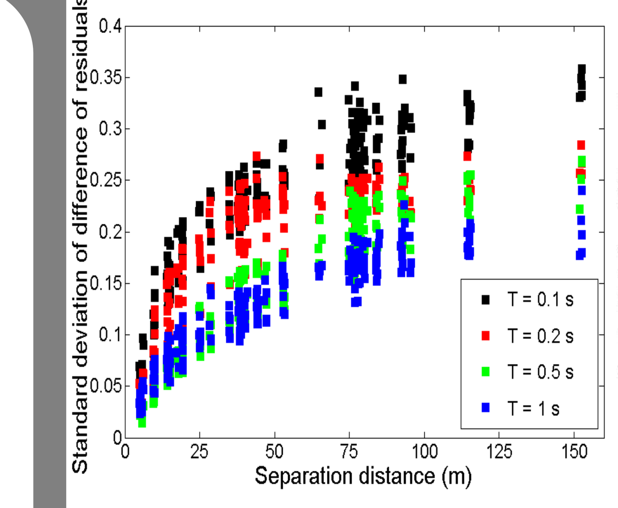
Standard spectral ratio (SSR) from the horizontal components of A00 station obtained by averaging SSRs (Cultrera et al., 2014). Black line shows the geometric mean of SSR and grey-shaded region indicates ±1σ. Blue rectangle indicates the frequency range dominated by the fundamental mode of Love waves while the red one the first higher mode of Rayleigh waves. (Imtiaz, 2015a)

Spatial Variability

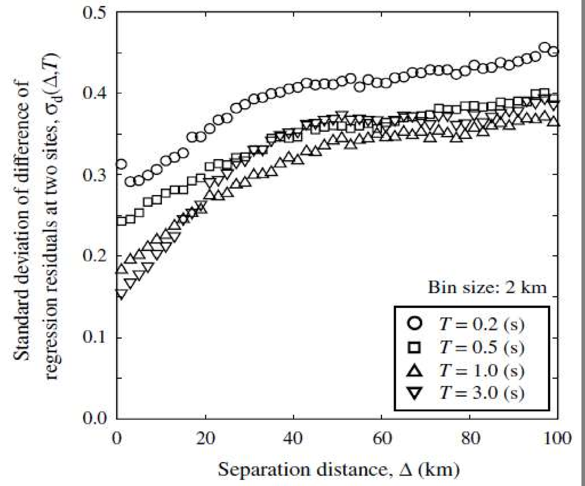
Methodology

For each event k, we calculate the residual δ_k of each station recording from the median value of all stations. Then, for a given separation distance between station i and j, we compute the difference of residuals ($\delta_{k,i}$ - $\delta_{k,j}$). By using all events, the standard deviation of the difference of residuals as a function of separation distance is then estimated.

Results



Standard deviation of difference of residuals (spatial correlation) with separation distance for periods 0.1, 0.2 , 0.5 and 1 s.



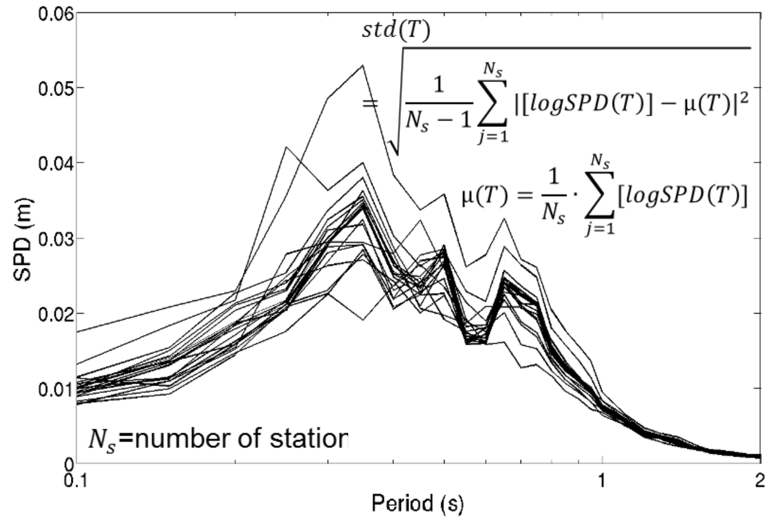
Goda and Atkinson (2010) study. Minimum station separation distance is 2 km.

Effect on the response of a SDOF system

Methodology

- Linear Elastic Response

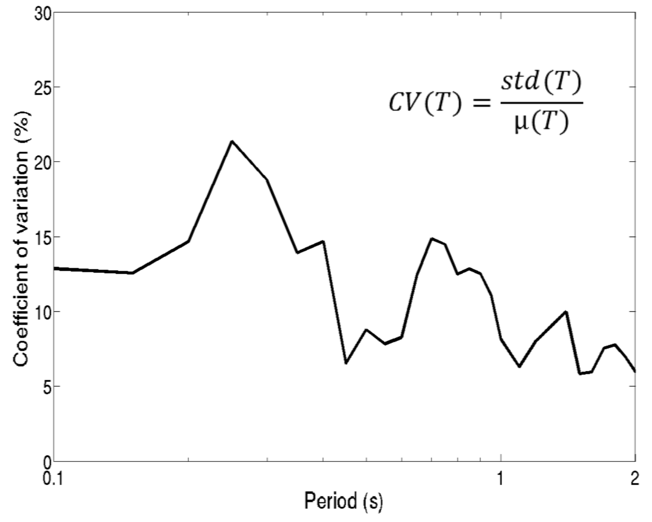
Max. top displacement = spectral displacement considering 5 % damping



$$std(T) = \sqrt{\frac{1}{N_s - 1}\sum_{j=1}^{N_s} |[logSPD(T)] - \mu(T)|^2}$$

$$\mu(T) = \frac{1}{N_s} \cdot \sum_{j=1}^{N_s} [logSPD(T)]$$

Displacement response spectra of the 21 stations for one event (M_w 4,4 and R_{hypo}= 144 km).



$$CV(T) = \frac{std(T)}{\mu(T)}$$

Coefficient of variation of the maximum top displacement (in %) as a function of period (T).

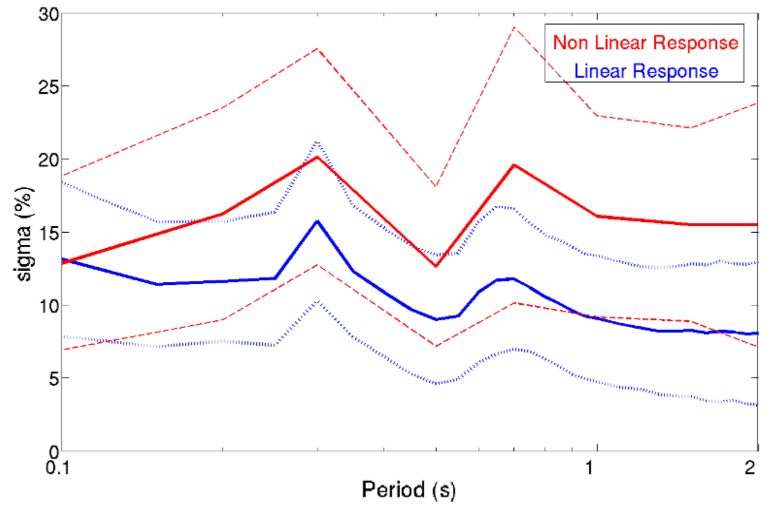
- Non Linear Elastoplastic Response

The maximum top displacement of the NL SDOF system with varying fundamental period was evaluated. Being weak, most of the events would not lead the SDOF to behave non linearly. However, in order to keep the input ground motion properties (amplitude, phase), the structure was modified such that the yielding displacement (dy) at each period allows the SDOF system to enter non linearity. This procedure leads to select 50% of the events.

Results

$$\mu\_CV(T) = \frac{1}{N_{events}} \cdot \sum_{j=1}^{N_{events}} CV(T)$$

$$sigma(T) = \sqrt{\frac{1}{N_{events} - 1} \sum_{j=1}^{N_{events}} |CV(T) - \mu\_CV(T)|^2}$$



Standard deviation of CVs (sigma %) for SDOF system with linear (blue) and non linear (red) behavior (±1σ) as a function of fundamental period (T). The two picks indicate the period range of increased variability most probably related to the propagation of the first higher mode of Rayleigh waves and fundamental mode of Love waves, respectively.

Discussion - Conclusions

- Significant spatial variability of ground motion amplitude at local scale. Dense arrays, like the one deployed in Argostoli, can be useful to extend the spatial correlation models to very small interstation distances.
- Increase of the variability of the linear elastic response of the SDOF with frequency increasing from 0.5 to 10 Hz. This is consistent with a decrease of the correlation between peak ground motion values with increasing frequencies.
- Larger variabilities are observed within two narrow frequency ranges: between 1 and 2.5 Hz (0.4 – 1 s) and between 3 and 4 Hz (0.25 – 0.33 s).

  Such variabilities are most probably due to locally edge-generated diffracted surface waves: the fundamental mode of Love waves (1-2,5 Hz) and the first higher mode of Rayleigh waves (3-4 Hz).
- The variability of the response of non linear elastoplastic SDOF system is increased by 5% compared to the response of the elastically behaving SDOF system.

Bibliography

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