

3D HYBRID SIMULATION OF THE SOURCE AND SITE EFFECTS DURING THE 1999 ATHENS EARTHQUAKE

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I. Oprsal (1,2), J. Zahradnik (2), A. Serpetsidaki (3), G-A. Tselentis (3)

E-mail: ivo@seismo.ifg.ethz.ch

WWW: www.seismo.ethz.ch/~ivo/



ETH Eidgenössische
Technische Hochschule
Zürich

(1) Swiss Seismological
service, ETH Zurich



(2) Department of Geophysics,
Charles University, Prague



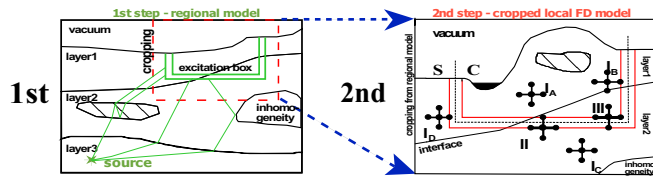
(3) Seismological Laboratory,
University of Patras, Greece

ABSTRACT

The damaging 1999 Athens earthquake of Mw=5.9 occurred at about 20km from the city center. The intensity distribution in the capital, ranging from V to IX, was quite irregular due to combination of the source, path and site effects. The 30-stations temporary network, installed in Athens by the University of Patras, recorded and located more than 400 aftershocks. The horizontal-to-vertical spectral ratios from the 20 selected aftershock recordings provided site classification. The most significant anomaly (H/V exceeding 4 in the frequency range 1-4 Hz) was found at the Ano Liosia site, belonging to the most heavily damaged zones with intensity IX. The site is situated in a shallow basin whose surface extent is about 4x4 km, and the maximum depth is of about 150 m. The basin is filled with basically 3 layers. The topmost layer includes alluvium and soft soil, the second one consists of stiff soil and alternations of conglomerates, clay and sand, while the third layer is represented by Neogene formations like marl, marly limestone and sandstone. The bedrock of the basin consists of Triassic limestone and schist. Borders of the basin, where the topmost layer directly overlies the bedrock, are locally quite steep. Based on geophysical data (Vp, Vs, Q) measured at the site, the numerical modeling of the seismic site response was carried out. The 2D and 3D finite-difference techniques were used, and significant edge effects were revealed. No recording of the mainshock is available in Ano Liosia. Nevertheless, based on the finite-extent composite source model, validated by the existing strong motion records in Athens, we found that the bedrock motion in Ano Liosia had its PGA ranging from 0.2 to 0.3 g, resulting from the relatively small epicentral distance (~10 km) and the forward source directivity. The source and site effects were combined with each other by a hybrid technique (Opsal and Zahradnik, JGR 2002), allowing fast full-wave 3D calculations up to 10-20 Hz on a standard personal computer, and showing that the combined source and site effect in Ano Liosia might provide the PGA values locally exceeding 0.6 g.

The 2-step hybrid method takes into account the source path and site effects:

- The 1st step is calculated by PEXT finite-source modeling
- The second step is computed by FD for a local site



The 1st step: The particle motion at the double-planned excitation-box is saved on disc. The computation may be performed up to relatively high frequency by any 3D-motion method as Discrete Wavenumber method (DWN or reflectivity), Ray method, Finite Difference method (FD) on a coarse grid, or it may be computed analytically. The structure and topography of the 1st step model are global or regional and they do not contain the local details. Thus the recorded excitation contains full source-path information without

The 2nd step: It is computed by FD method on a fine grid. The model contains the excitation box area from the 1st step. The local topography and complex structures are added inside the excitation box. The computation performs in three different areas (I,II,III) (see figure above). For details see [1,2].

A recipe :

- Calculate 3D wavefield due to source and crustal part
- Solve 3D site model by FD, thus you get combined source-path-site effects

Numerical methods:

1st step:

- Composite PEXT finite-extent source (see [3])
- Composite source modeling up to 2.8Hz yields deterministic envelope of accelerograms.
- Radial rupture propagation: rupture velocity varies up to 10% around mean constant value.
- The acceleration spectral plateau is extrapolated up to 6Hz from the deterministic part (2.0-2.8Hz) by a Gaussian noise, - which is constrained by the envelope.
- Complete Green's functions computed by DW in 1D structure (Bouchon, 1981).

⇒ coarse 1st step excitation points are interpolated into the 2nd step excitation points ⇒

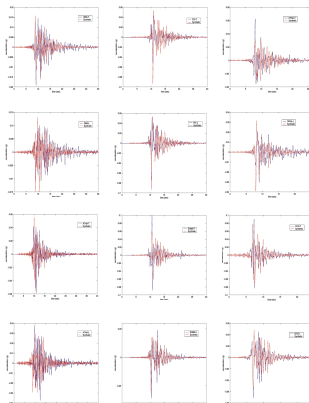
2nd step:

- The PSI-3D FD SCHEME (see [1]); $f = (0 \rightarrow 6.0)$ Hz
- the FD algorithm is easy to implement:
 - one formula everywhere
 - free surface by vacuum formalism
- Easy employment of topography
- Highly effective on irregular grids

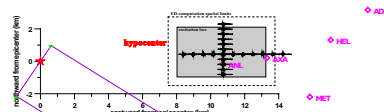
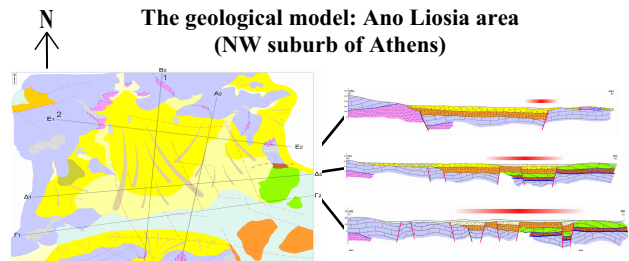
Other features:

- (!) stable at high (v_p/v_s) contrasts
- (!) stable at high (v_p/v_s) ratio contrasts

The comparison of the PEXT synthetics with strong motion data verifying the source model.



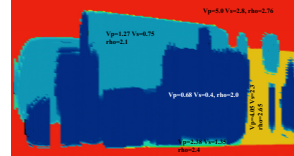
Ano Liosia area



view southwards (approx. A2-A1 direction)

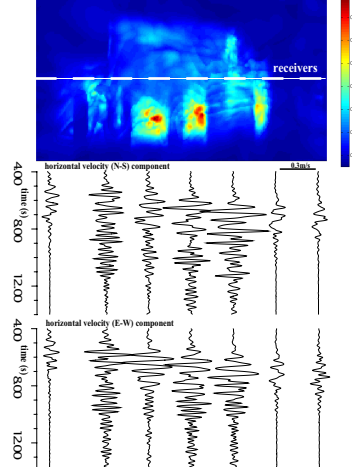


Outcropping structure on the free surface

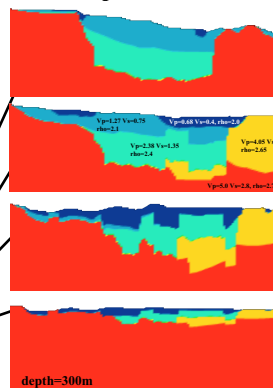


The animation of the horizontal-velocity wavefield is available at <http://www.seismo.ethz.ch/~ivo/greece-an-li/>

Peak horizontal velocity (m/s)

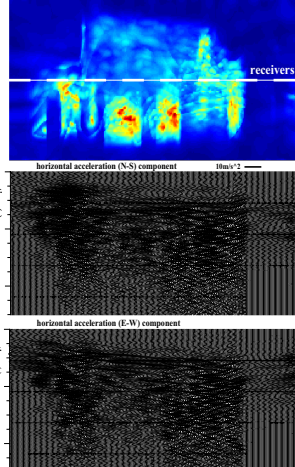


The computational model

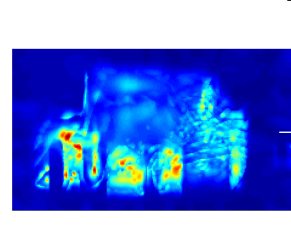
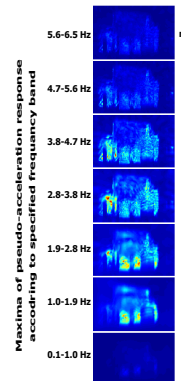


The animation of these Vp-vs-vertical slices is available at <http://www.seismo.ethz.ch/~ivo/greece-an-li/>

Peak horizontal acceleration (m/s^2)



Overall maxima of pseudo-acceleration response



Conclusions:

- 1) HYBRID approach allows joint treatment of finite-extent source, path and site effect (here up to 6 Hz)
- 2) The 3D input (bedrock) motion calculated by PEXT method validated by comparison of synthetic and observed strong motion records in the other sites in Athens
- 3) Ano Liosia, strong damage and intensity IX - proved to be combined effect of proximity and directivity of source, and complex 3D site effects.

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