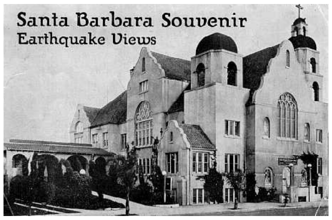

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3D NUMERICAL SIMULATIONS OF EARTHQUAKE GROUND MOTION IN SEDIMENTARY BASINS: THE CASES OF GUBBIO AND L'AQUILA, CENTRAL ITALY

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ABSTRACT

Many among the most important Italian earthquakes occurred close to intra-mountain alluvial basins, a typical surface expression of the extensional tectonic regime that dominates the seismic activity in Central/Southern Italy along the Apennines chain. The last ones, namely the Mw6.3 earthquake that devastated L'Aquila and the surrounding villages within the Aterno Valley on Apr 6, 2009, and the Mw6.0 Umbria-Marche event of Sep 26, 1997, both in Central Italy, provided a substantial amount of records that may be helpful to shed light on the seismic response of such basins and to provide benchmarks to calibrate numerical models. In this contribution, we summarize the experience and main results of the 3D numerical work carried out by the spectral element code GeoELSE, developed at Politecnico di Milano, to simulate the long period seismic amplification effects observed within the Gubbio basin during the Umbria-Marche earthquake, and the coupling of near-field ground motion and complex basin effects in the Aterno Valley during the L'Aquila earthquake. Attention is given to comparison with 1D and 2D approaches, and to sensitivity of results with respect to different kinematic models of the seismic source.

INTRODUCTION

Intra-mountain alluvial basins are a typical surface expression of the extensional tectonic regime that dominates the seismic activity in Central/Southern Italy along the Apennines chain, as shown by several examples in Fig. 1. A frequent feature of such basins is the relatively small spatial extension (up to few tens of km), their closed-shape and their association to a normal active fault system, capable to produce earthquakes up to magnitude 6.5-7.

Many among the most important Italian earthquakes were originated within normal fault related extensional basins, the last one being the M_w6.3 that devastated L'Aquila and the surrounding villages within the Aterno Valley in Central Italy on Apr 6, 2009, but it is worth to recall as well the M_w7 Marsica earthquake, just about 50 km S of L'Aquila in the Abruzzi region, that on Jan 13, 1915, devastated Avezzano and the villages surrounding the Fucino plain, causing more than 30,000 deaths, with consequences probably strongly magnified by the basin-induced ground motion amplification.

Several strong motion stations within the ITACA database (ITalian ACcelerometric Archive, http://itaca.mi.ingv.it) are located within such basins and typically show a seismic response tending to exceed significantly the median spectral ordinates at long periods, calculated by ground motion prediction equations calibrated on the ITACA stations [Bindi et al., 2011].

The complexity and multiplicity of factors influencing earthquake ground motion within alluvial basins, especially in the near-field of a major earthquake, make it difficult to represent and quantify its features in seismic hazard studies. This is due to a combination of (i) the limited availability of suitable accelerometer data, even at a worldwide scale, (ii) the difficulty to define quantitatively the geometry and mechanical properties of the basin at depth, and (iii) the difficulty to make proper numerical simulations involving the joint modeling of the extended fault rupture, the propagation of seismic waves in the shallow earth layers, the influence of local site conditions.

Standard approaches based on the assumption of vertical propagation of plane waves in horizontally layered media are generally not suitable for earthquake ground motion simulations in such basins, because they cannot account for the wave phenomena arising from

the vicinity to the seismic source, such as the polarization of motion related to the focal mechanism, the rupture directivity, and from the complex morphology of the basin, including resonance effects and the basin-edge induced surface wave propagation.
Figure 2, showing the simulated maps of peak ground velocity in the Grenoble Valley [Stupazzini et al., 2009] under different directivity assumptions (from left to right: neutral, forward and backward), yields a clear example on how coupling complex source and site effects may provide a definitely different picture of earthquake ground motion and of its consequences.

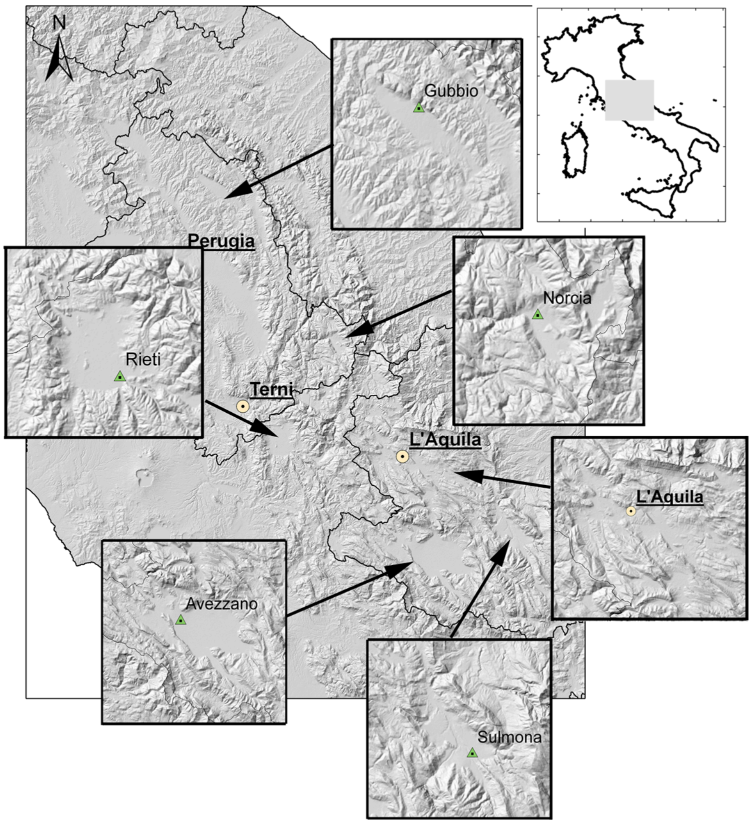

Fig. 1. Examples of closed-shape intra-mountain basins in Central Italy, related to an extensional tectonic regime.

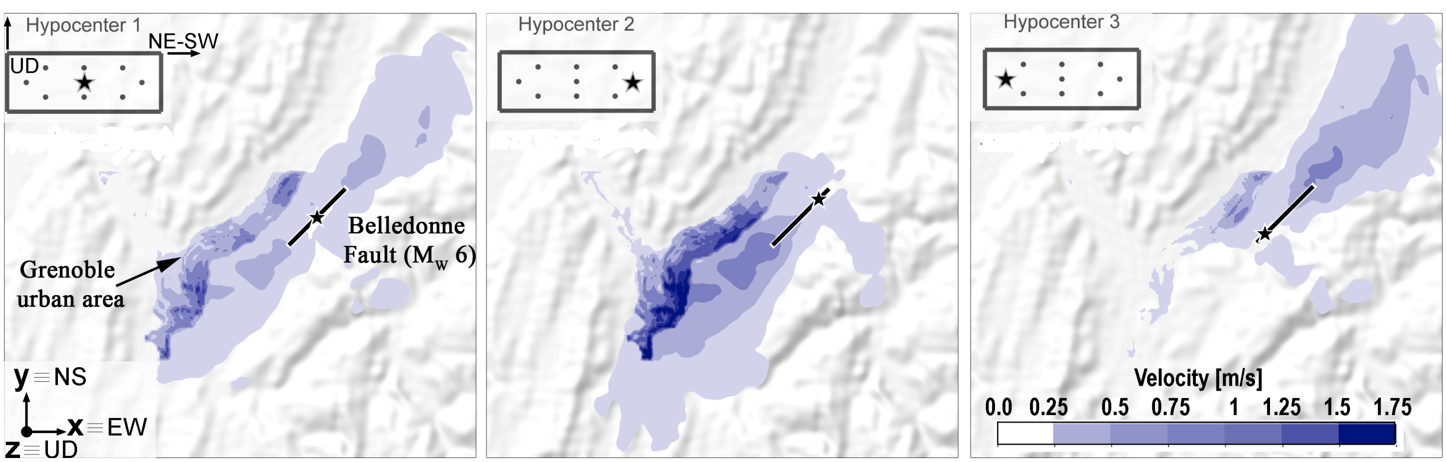

Fig. 2. Vertical PGV maps in the Grenoble Valley due to a Mw6 earthquake along the Belledonne fault. From left to right: neutral, foreward, backward directivity conditions with respect to the urban area of Grenoble.

In this paper we will illustrate two case histories on the numerical simulations of such effects. First, we will consider the long period amplification of ground motion within the Gubbio basin during the M_w6 Umbria-Marche earthquake on Sep 26 1997, and will investigate the capability of more simplified approaches, such as 1D and 2D models, to provide similar satisfactory agreement with

observations as the 3D numerical simulations. Second, we will consider the M_w6.3 L'Aquila earthquake, on Apr 6 2009, where the 3D numerical simulations will be mainly devoted to provide understanding on the frequency range that can be excited by heterogeneous kinematic models of the fault rupture with random variability of parameters.
For a more in-depth presentation of these case-histories and the numerical simulations, we will make reference to Smerzini [2010] and Smerzini et al. [2011]. We limit ourselves here to recall that the numerical simulations were carried out carried out by the software package GeoELSE (GeoELastodynamics by Spectral Elements, http://geoelse.stru.polimi.it), jointly developed by CRS4, Sardinia, and Politecnico di Milano, Italy, where the Spectral Element Method (SEM) developed by Faccioli et al. (1997) is implemented.

1D, 2D AND 3D NUMERICAL MODELING OF THE SEISMIC RESPONSE OF THE GUBBIO BASIN

In this Section we aim at describing the performance of different numerical approaches to simulate the large amplifications of long period earthquake ground motion within the Gubbio plain, a closed-shape alluvial basin in Central Italy, observed during the Umbria-Marche 1997 seismic sequence.
The Gubbio plain, related to the shallow extensional seismicity in the Umbria-Marche Appenines, is a 22 km long basin, aligned along the NW-SE directions, with a maximum width of approximately 5 km near the town of Gubbio. The basin is filled by fluvio-lacustrine clayey deposits, with estimated maximum thickness of about 600 m, overlain by superficial alluvial soil layers, mainly consisting of sandy silts and limy clays.
Among the observations of long period amplification obtained at stations of the Italian strong motion network and available in ITACA, the strong motion records obtained inside the Gubbio basin, at station GBP (Gubbio Piana, digital SSA instrument operating between 1991 and 2004), during the Umbria-Marche seismic sequence, provide the clearest examples of earthquake ground motion within intra-mountain basins in Central Italy. The sequence started on Sep 26, 1997 with two major shocks, the first one at 00:33 GMT, M_W 5.7 (referred to as Event 1), and the mainshock at 09:40, M_W 6.0 (Event 2), both at around 40 km epicentral distance (R_e) from GBP. An analog strong motion station (GBB), still in operation, was located at a rock site close to Gubbio downtown, at the Eastern edge of the basin. Figure 3 illustrates the epicenters of the two earthquakes, along with the surface fault projection and slip distribution of the mainshock, after Hernandez et al. [2004].

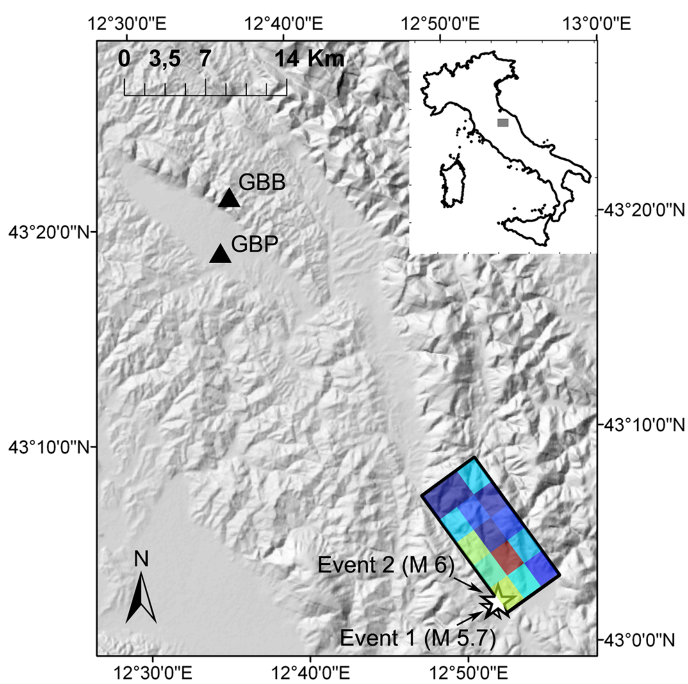

Fig. 3. Digital Elevation Model (DEM) around the Gubbio basin. Triangles denote the Gubbio (GBB) and Gubbio Piana (GBP) stations of the ITACA network (http://itaca.mi.ingv.it). Stars denote the epicenters of the M_W 5.7 (Event 1) and M_W 6.0 (Event 2) Sept 26 1997 earthquakes. The surface fault projection and the slip distribution of Event 2 according to Hernandez et al. [2004] are also shown.

Particularly, referring to the Sep 26 1997 M_W 6.0 mainshock, we considered the following numerical approximations:

i. 3D model, including a kinematic model of the extended seismic source, a layered crustal structure, and the basin itself with a simplified homogeneous velocity profile;

ii. 2D model of a longitudinal and transversal cross-section of the basin, subject to vertical and oblique incidence of plane waves with time dependence at bedrock obtained by the 3D simulations;

iii. 1D model subject to vertical plane wave propagation with the same input as for the previous point.

The numerical simulations were carried out using the spectral element code GeoELSE, exploiting in 3D its implementation in parallel computer architectures.

Results of 3D numerical simulations

To study the seismic response of the Gubbio basin in 3D, a simplified model of the plain was assumed, considering the 3D shape of the bedrock topography and a homogenous average soil profile, expressed as a function of depth *z* (measured in m from the topography surface) as follows:

$$V_P(z) = 1000 + 30 \cdot z^{0.5} \qquad V_S(z) = 250 + 30 \cdot z^{0.5} \text{ (m/s)} \tag{1a}$$

$$\rho = 1900 \text{ (kg/m}^3\text{)} \qquad Q_S = 50 \tag{1b}$$

where V_S and V_P denote the S- and P- wave velocity, respectively, ρ the soil mass and density and Q_S the S-wave quality factor at 1 Hz. The mechanical properties of the Gubbio sediments and the spatial variability of the alluvial-bedrock interface were retrieved from the experimental results of a comprehensive program of in-field investigations [Bindi et al., 2009].

Referring the reader to Smerzini et al. [2011] for further details about the 3D numerical model, we limit herein to recall that the numerical simulations include a proper characterization of the causative fault, located at about 40 km from the Gubbio town, based on the kinematic fault solution proposed by Hernandez et al. [2004].

Figure 4 depicts the comparison between strong motion observations and numerical simulations in terms of velocity time histories and corresponding Fourier amplitude spectra at GBB (a) and GBP (b). Synthetics and observations are both processed with a high-pass acausal Butterworth filter at f_h=0.1 Hz on the three components, for GBP, and at f_h=0.4 Hz on the horizontal components and f_h=0.6 Hz on the vertical one, for GBB. The comparison points out that there is a reasonable agreement both in time and frequency domain between simulations and observations, although the simulated waveforms display a stronger decay than the observed ones at frequencies larger than approximately 1.5 Hz.

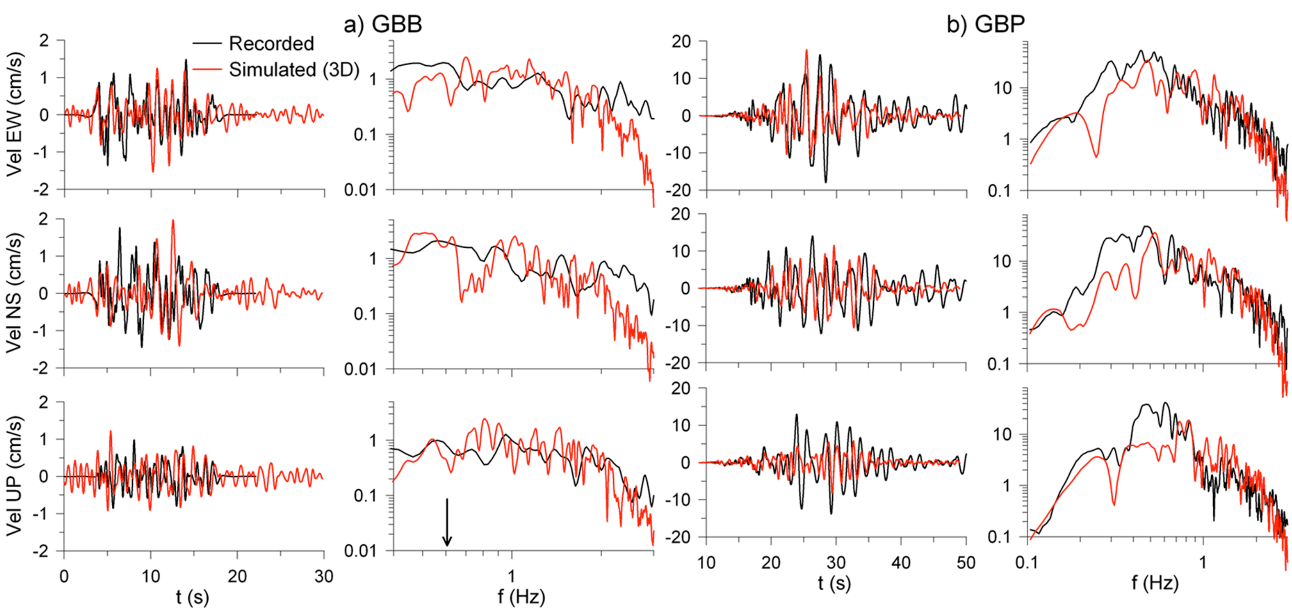

Fig. 4. Comparison between observed (black) and simulated (red) three component velocity time histories and corresponding Fourier amplitude spectra at GBB (a) and GBP (b) stations.

As an illustrative example of the complexity of seismic ground motion induced by an alluvial plain, Fig. 5 shows some snapshots of simulated fault parallel (azimuth = 144°) velocity wavefield. These snapshots clearly show the onset and propagation of long period surface waves within the basin, once the wavefront reaches its southern edge, with a considerable increase of amplitude and duration of ground motion.

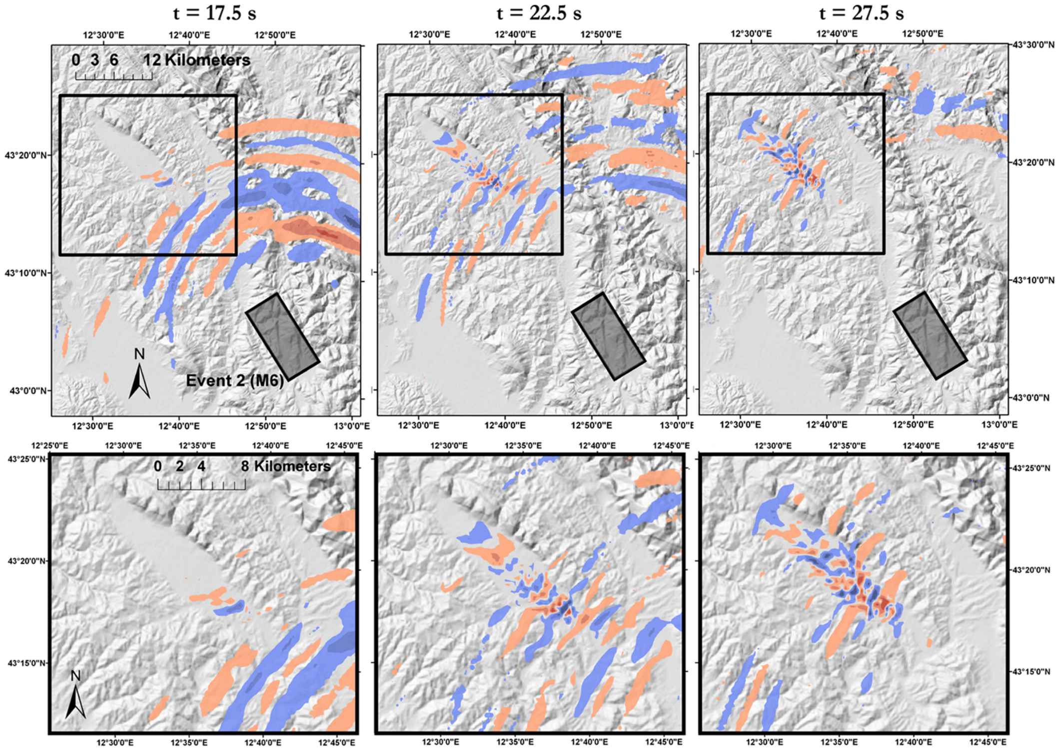

Fig. 5. Snapshots of fault parallel velocity wavefield obtained by 3D numerical simulations. Top panel: large view of the Gubbio area including the causative fault. Bottom panel: zoom inside the Gubbio plain.

Comparison with 2D and 1D numerical approaches

After having illustrated the main results of 3D numerical modeling, we address now the issue regarding the performance of 2D and 1D models of the Gubbio plain to reproduce the observed long period ground motion.
As regards 2D modeling, starting from the same numerical model as used for 3D numerical analyses, we considered two representative cross-sections of the basin, aligned on a longitudinal (LL') and transverse (TT') axis and passing through the GBP station. The seismic response of these cross-sections was analyzed under both vertical and oblique plane wave incidence (γ=20°, where γ is measured from the vertical), taking advantage of the implementation of a powerful sub-structuring method, named Domain Reduction Method [Bielak et al., 2003], in GeoELSE. For each 2D numerical model, the time dependence of input plane waves is provided by the 3D synthetics at outcropping bedrock.
As a representative comparison between 2D and 3D numerical results, Fig. 6 shows the Response Spectra Ratios (*RSR*s) computed at a set of receivers along the transverse cross-section with respect to the nearby reference station (T09). It turns out that the 2D vertical plane wave incidence provides levels of response spectral amplification within the Gubbio plain which are strongly underestimated with respect to the 3D case, over a broad range of periods. The hypothesis of oblique incidence does not lead to significant improvements of the 2D numerical simulation, although a better agreement between 2D and 3D results is found in the period range between about 0.5 s and 1.0 s.
To extend the comparison to 1D numerical results as well, a representative soil column beneath GBP was considered and its seismic response under vertical plane waves was computed through the standard propagator matrix method.
A comprehensive comparison between ground motion recordings and 3D, 2D and 1D synthetics is illustrated in Fig. 7, both in terms of displacement time histories at GBP and Standard Spectral Ratios (*SSR*s), the latter being computed as the Fourier spectrum at GBP divided by the one at a nearby rock reference station. The following remarks should be made: (i) long period earthquake ground motions at GBP can be reproduced by 3D numerical simulations with reasonable accuracy; (ii) at variance with the 3D approach, neither 1D nor 2D numerical simulations were capable to provide such satisfactory results, rather they tend to underestimate significantly the amplitude and duration of observed ground motion on soft sediments; (iii) 3D *SSR*s show amplifications over a range of frequency between 0.3 and 0.8 Hz in very good agreement with observations, while 2D and 1D *SSR*s predict a lower and narrower amplification at around 0.35 Hz, that is the fundamental 1D resonance frequency at GBP; (iv) nonetheless, 2D and 1D simulations provide a better agreement with the observations in the high frequency range, $f > 2$ Hz.

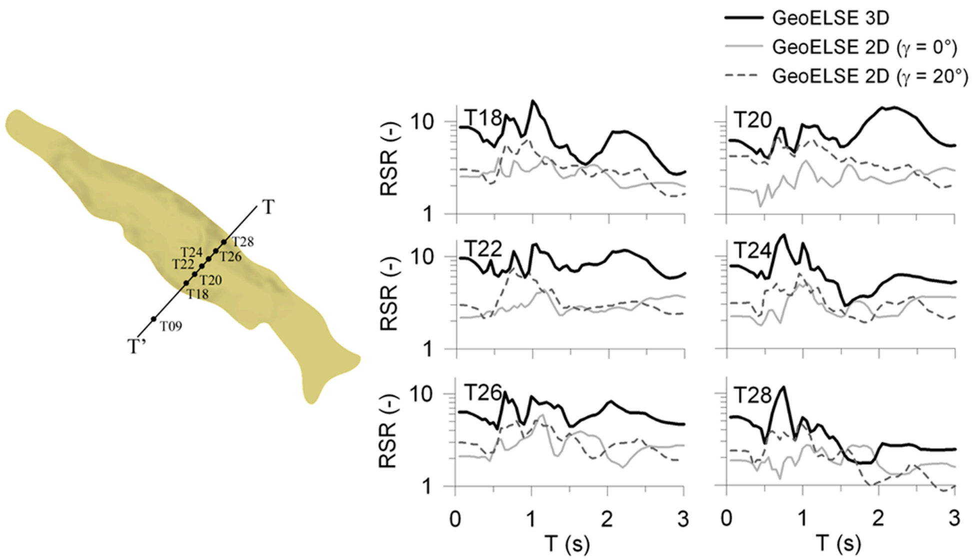

Fig. 6. Comparison between 3D (thick line) and 2D numerical results under vertical (grey line) and oblique (dashed line) plane wave incidence: Response Spectra Ratios, RSRs, for a set of receiver located along a representative transverse cross-section of the Gubbio basin, with respect to the reference station (T09).

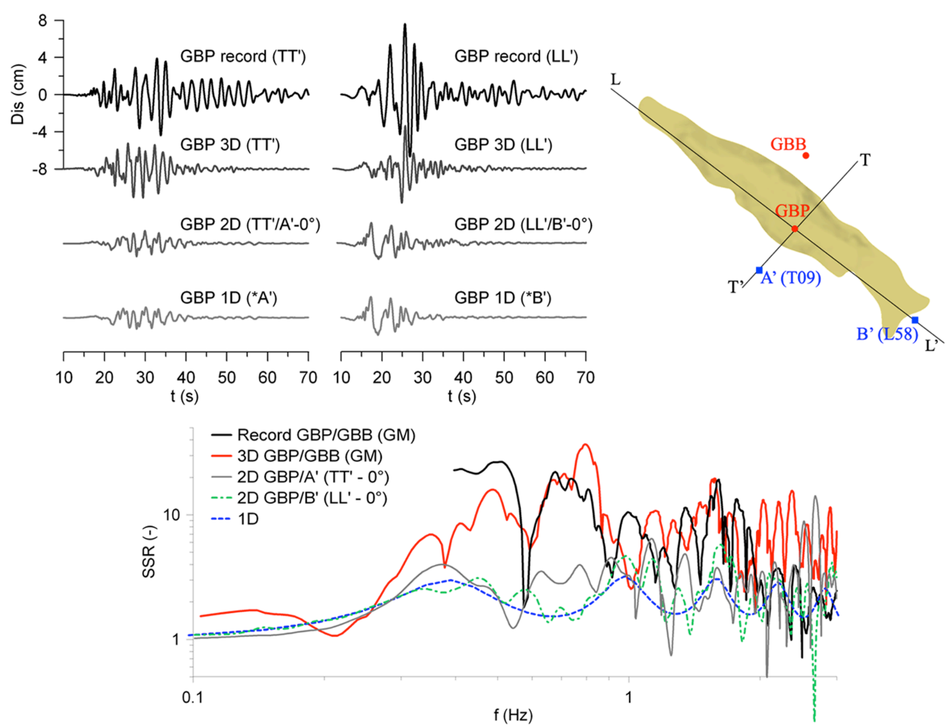

Fig. 7. Comparison between observations and 3D, 2D and 1D numerical results, in terms of horizontal displacement time histories at GBP (top) and Standard Spectral Ratios (SSR) of GBP over a nearby reference station at outcropping bedrock (bottom).

3D NUMERICAL SIMULATIONS OF NEAR FAULT EARTHQUAKE GROUND MOTION IN THE ATERNO RIVER VALLEY, L'AQUILA

In the night of Apr 6 2009, at 3:32 am local time, a M_W 6.3 earthquake struck the Abruzzi region and the whole Central Italy, causing about 300 deaths and vast destructions in the town and surroundings of L'Aquila, one of the largest urban centers in Central Italy, with about 80,000 inhabitants. The earthquake followed a seismic sequence that initiated in October 2008 and culminated with the M_L = 4.1

event of March 30, and the M_W =4.2 earthquake a few hours before the mainshock. The epicenter of the M_W 6.3 earthquake was located at less than 6 km from the town of L'Aquila, leading to maximum Peak Ground Velocity (*PGV*) of about 40 cm/s in the urban area.

The aftershock distribution [Chiarabba et al, 2009] and the analysis of geodetic and geological data [Anzidei et al, 2009; Atzori et al, 2009] suggest that L'Aquila earthquake was generated by the Paganica fault, NW-SE striking, dipping at nearly 50° and passing directly beneath the town of L'Aquila.

The epicentral area corresponds to the upper and middle Aterno river valley, which is, similarly to the Gubbio basin, a typical Quaternary basin produced by the extensional tectonic regime along the Central Appenines chain and characterized by a complex tectonic evolution reflected by the high variability of the geologic and geomorphologic patterns [see e.g. Lanzo et al, 2011]. The depth of the Quaternary deposits inside the valley is variable, from about 60 m in the upper Aterno valley to about 250 m in the middle Aterno valley. The town of L'Aquila lies on a fluvial terrace, some tens of meters thick, formed by calcareous breccias consisting of limestone clasts in a marly matrix. The terrace lies on the top of lacustrine sediments, mainly consisting of silty and sandy layers and minor gravel beds, that are recognized to be responsible of the amplification at about 0.50-0.6 Hz [De Luca et al, 2005].

The L'Aquila earthquake provides an unprecedented dataset of good quality strong ground motion data in the near source region of a normal fault earthquake. Table 1 summarizes the main features of the near fault strong ground motion dataset for the L'Aquila mainshock. Stations AQA, AQG and AQV are part of a seismic array installed by DPC across the upper Aterno Valley, while stations AQK and AQU are located close to town of L'Aquila. Ground motion recordings in the near source region show clear near-field effects with static offsets and pulse velocity waveforms, especially close to the urban center [for further details we refer the reader to Ameri et al, 2009; Paolucci and Smerzini, 2010].

Table 1. Near fault strong ground motion dataset for the L'Aquila mainshock. R_e denotes the epicentral distance (data from http://itaca.mi.ingv.it). The star indicates that the soil class according to Eurocode 8 [CEN, 2004] is based on geological information (V_{S30} not available).

Station Code	Lat (°N)	Long (°E)	Elevation (m)	Soil Class (EC8)	R_e (km)
AQA	42.37553	13.33930	693	B	4.63
AQG	42.37347	13.33703	721	B	4.39
AQV	42.37722	13.34389	692	B	4.87
AQK	42.34497	13.40095	726	B	5.65
AQU	42.35388	13.40193	729	B*	6.02

3D numerical modeling by Spectral Elements

A 3D numerical model of the L'Aquila mainshock was built, including the following features:

i. 3D shape of the alluvial-bedrock interface, based on the geological, geophysical and geotechnical data collected at several locations in the surrounding of the L'Aquila town within the Seismic Microzonation studies, promoted by the DPC [see e.g. Milana et al, 2011];

ii. a simplified description of the mechanical properties of the Aterno Valley, based on the following expressions:

$$V_S(z) = 500 + 10 \cdot z^{0.5} \qquad V_P(z) = 3^{0.5} \cdot V_S \quad \text{(m/s)} \tag{2a}$$

$$\rho = 2000\ (\text{kg/m}^3) \qquad Q_S = 50 \tag{2b}$$

iii. a horizontally layered deep crustal model [from Melini and Casarotti, Pers. Comm., 2009];

iv. a linear visco-elastic behavior of the Quaternary soil deposits with a Q factor proportional to frequency [see Stupazzini et al, 2009];

v. four different kinematic models, referred to as M1 to M4 hereafter, for the causative fault, based on recent seismic source inversion studies (see Table 2 for further details).

As regards the latter point, GeoELSE adopts a kinematic representation of the seismic source via the well known concept of seismic moment tensor density [for the algorithmic details see Faccioli et al, 1997]. As a further option of the code, fault complexity may be simulated by defining source parameters, such as rise time τ_R, rupture velocity V_R and rake angle λ, as stochastic spatial fields obeying to a prescribed Power Spectral Density (PSD) in the wavenumber domain [see Mai and Beroza, 2002] and with a certain degree of correlation with the slip distribution [Liu et al, 2006; Schmedes et al, 2010]. In the sequel, the main effects of such a kinematic source description will be highlighted and discussed. Referring to Smerzini [2010] for further details, we recall herein that such stochastic distributions are generated with physical constraints on the total seismic moment and the spatial coherence across the fault plane.

Figure 8 shows the 3D hexahedral grid adopted for the numerical simulations of the L'Aquila mainshock (model M1). The mesh consists of about 3.8 10^5 elements, the size of which ranges from a minimum of about 150 m, inside the alluvial basin, up to around 600 m at outcropping bedrock, yielding around 30 10^6 degrees of freedom. Note that the mesh is designed to propagate up to about 2.5 Hz. The simulations were performed on the Lagrange cluster located at Consorzio Interuniversitario Lombardo per L'Elaborazione Automatica (CILEA, http://www.cilea.it/), making use of 64 CPUs in parallel.

Table 2. Main features of the kinematic fault solutions adopted in the numerical simulations. M1: Walter et al, 2009; M2: Cirella et al, 2009; M3: Yano et al, 2010; M4: Serpelloni et al, 2010. The epicenter location (42.35°N, 13.38°E) is common to all models.

	M1	M2	M3	M4
Focal Depth (km)	9.6	9.5	9.1	7
Length (km)	20	28	26	26.1
Width (km)	18.5	17.5	21	18.0
Strike (°)	144	133	133	129
Dip (°)	54	54	50	53
Rake λ (°)	255	258	247	255
Rise time τ_R (s)	0.9	1.5	0.9	0.9
V_R (km/s)	2.5	2.5	2	2.5

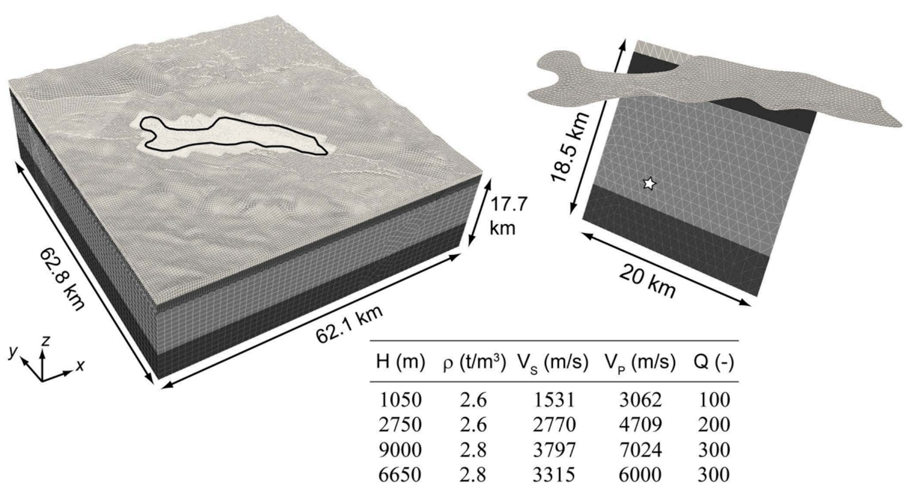

Fig. 8. 3D numerical mesh by hexahedral spectral elements adopted for the numerical simulations by GeoELSE. The right-hand side map highlights the fault discretization (M1 source model, see Table 1), while the bottom table summarizes the main features of the deep crustal model.

<u>Main results of numerical simulations</u>

In this Section we aim at showing the most meaningful results obtained through ground motion simulations of the L'Aquila earthquake. First, the results of source model M1 will be presented with particular care to the study of the effects of seismic source heterogeneity on the simulated waveforms. Afterwards, the results of the different fault solution under consideration (see Table 2) will be discussed to check the possible dependence of results on the kinematic source model.

Figure 9 shows the comparison of the simulated results for source model M1 with the strong ground motion observations in terms of EW velocity waveforms (left-hand side panel) and corresponding Fourier Amplitude Spectra (right-hand side panel) for stations AQK (top) and AQV (bottom). The simulated and recorded waveforms have been band-pass filtered between 0.1 and 2.5 Hz. It is found that there is a satisfactory agreement at AQK, while major discrepancies are found at AQV, located along the Aterno transect, with simulated amplitudes significantly smaller than the observed ones. We underline that the, for model M1, rise time, rupture velocity and rake angle are assumed to be homogeneous across the fault plane (see Table 2).

As mentioned previously, to make a quantitative evaluation of the effect of seismic source complexity, the results for a complex source model, referred to as CM1, where τ_R, V_R and λ are described as spatial random fields with Von Karman (VK) PSD with correlation lengths in both direction equal to 4 km, are also shown in Fig. 9. The following parameters are assumed for each stochastic field: (i) for τ_R, mean value μ_τ= 0.9 s, maximum dimensionless variation around the mean $\Delta\tau$= 0.5, and correlation coefficient with slip η_τ= 0.5; (ii) for V_R, μ_V = 2500 m/s, ΔV = 0.12 and η_V = 0.2; (iii) for λ, μ_λ = 255°, and η_λ = 0.1.
From Fig. 9, it is apparent that accounting for a more realistic kinematic fault model, with spatial heterogeneities, tends to excite high frequency components of ground motion above about 0.7 Hz. CM1 yields some improvements of the performance of the numerical simulations especially for station AQV, although the differences with the observed amplitudes are still fairly pronounced over a broad range of frequencies.

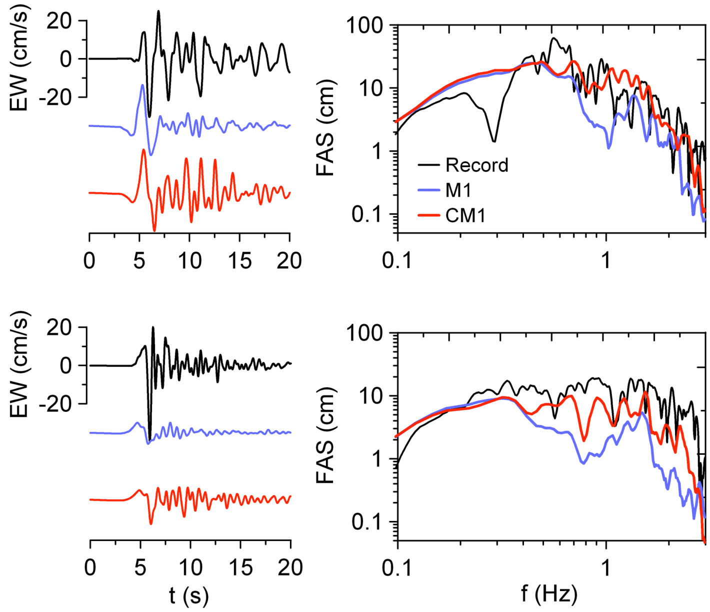

Fig. 9. Comparison between numerical results and recordings at stations AQK (top) and AQV (bottom) in terms of EW velocity time histories (left-hand side panel) and corresponding Fourier Amplitude Spectra (right-hand side panel). The results for both source model M1 (homogeneous values for τ_R, V_R and λ) and complex source model CM1 (stochastic distribution for τ_R, V_R and λ) are highlighted.

Figure 10 illustrates the comparison between the recordings (black line) and the numerical results, obtained at stations AQK and AQV, for the different source models under consideration, in terms of three-component velocity time histories. Note that for each complex source model, from CM1 to CM4, stochastic spatial fields with VK PSD were generated, according to the procedure illustrated in the previous paragraphs. It is noted that at AQK (and at AQU as well, although it is not reported for brevity) the agreement between recorded and simulated waveforms is good, in terms of both first arrivals, duration and amplitude. On the other hand, the agreement between simulation and observations is less satisfactory at AQV and, similarly, to the stations of the Aterno valley transect (AQA and AQG), regardless of the kinematic source model considered. As a matter of fact, the numerical simulations tend to underestimate significantly the recorded ground motion amplitudes, most likely due to the some approximations of the geological model and to adopted source models, which radiate most energy in the SE direction.

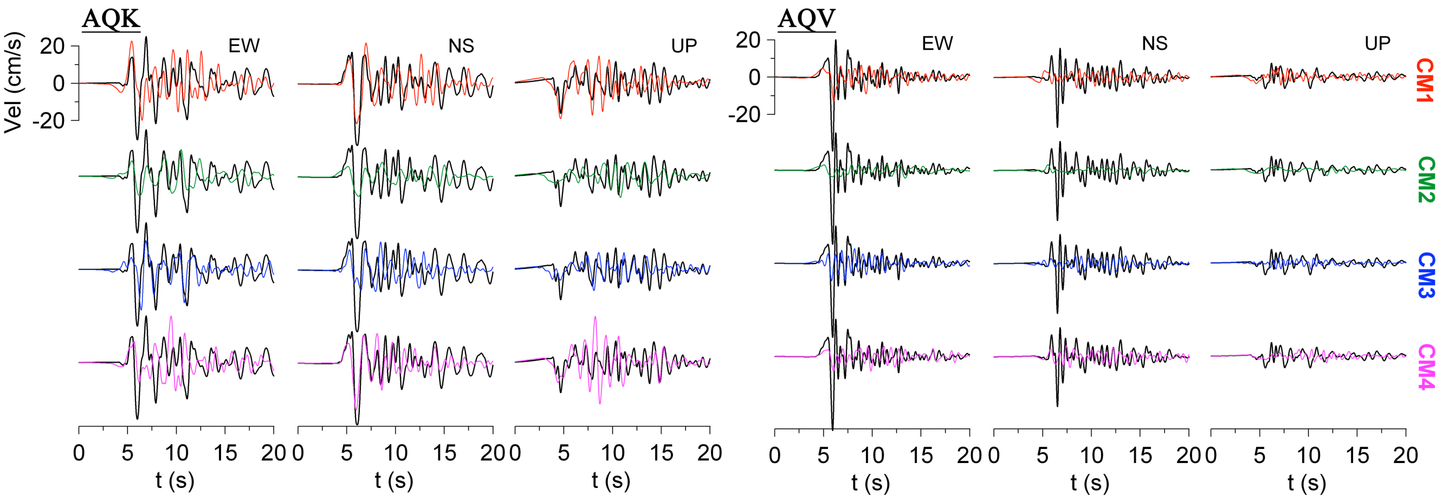

Fig. 10. Comparison between recorded and simulated three component velocity time histories for all source models under consideration at stations AQK and AQV.

Generation of ground motion shaking maps.

Stimulated by the increasing computation resources, 3D numerical simulations represent now a powerful tool to estimate the spatial variability of earthquake ground motion over a large territorial area and, indeed, to generate realistic ground shaking maps in complex geological configurations for future damaging earthquakes. As an illustrative example, Fig. 11 shows the comparison between the spatial distribution of macroseismic intensity (Mercalli-Cancani-Sieberg) values I_{MCS} (left-hand side, data from http://emidius.mi.ingv.it/DBMI08/aquilano/query_eq/) and the one of *PGV*s, computed as the geometric mean of horizontal components, from the numerical simulations for source model CM1 (right-hand side). The synthetic *PGV* map shows strong directivity effects in the SE direction, in agreement with the observed pattern of damage.

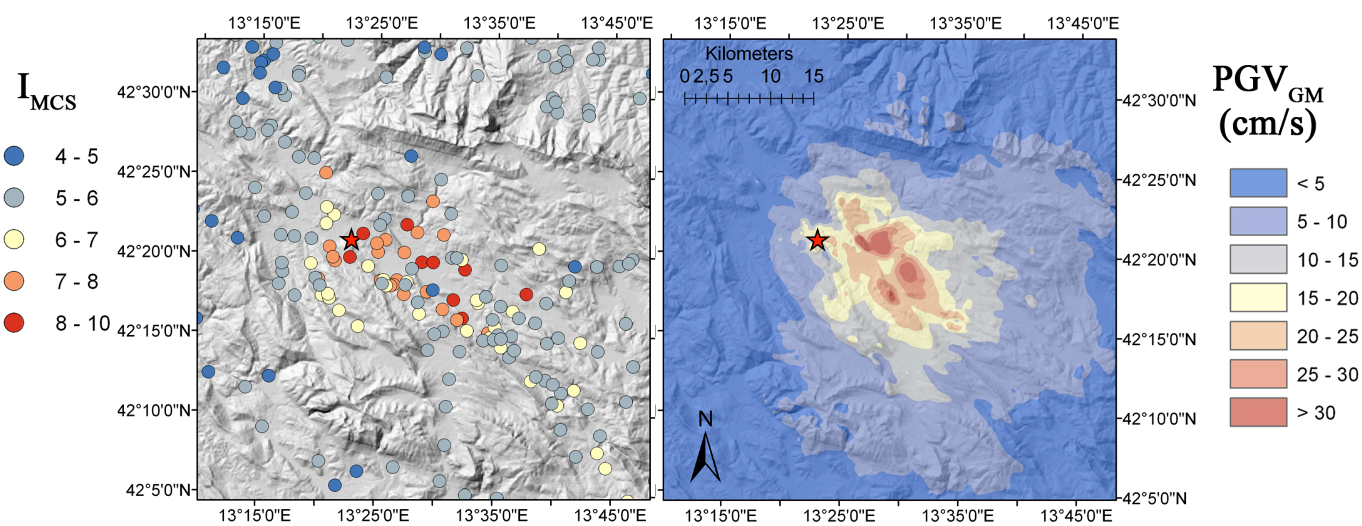

Fig. 11. Comparison between the spatial distribution of observed macroseismic intensity (Mercalli-Cancani-Sieberg) values (left-hand side) and the one of PGV, geometric mean of horizontal component, as obtained through numerical simulations for source model CM1.

CONCLUSIONS

Starting from two well documented case histories in Central Italy, i.e., the seismic response of the Gubbio and Aterno river basins during the 1997 Umbria-Marche and 2009 L'Aquila earthquakes, respectively, we have highlighted the following main conclusions:

- 3D numerical simulations of earthquake ground motion in near-fault conditions and accounting for complex geological and morphological conditions are suitable to provide realistic seismic scenarios, up to frequencies of 2 – 3 Hz;
- the frequency limit is mainly related to insufficient details in the source kinematic models, as well as on the local geology description, but it can be overcome by hybrid deterministic/stochastic approaches as proposed by Miyake et al [2003], Aagaard et al [2010], Graves and Pitarka [2010], Mai et al [2010], Mena et al [2010], Villani [2011], among others. In this work, we have shown that a moderate random variability of the kinematic source parameters may significantly improve the high-frequency energy radiation, improving as well the agreement with observed records during L'Aquila earthquake;
- the typical features of long period ground motion amplification and propagation of surface waves within sedimentary basins in Central Italy can be captured well by 3D numerical simulations, while the performance of both 1D and 2D numerical simulations was not satisfactory in the Gubbio case;
- generation of realistic earthquake ground motion scenarios for future damaging earthquakes within complex tectonic and geological environments is becoming more and more feasible thanks to advanced numerical tools for seismic wave propagation studies.

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