3D numerical simulations of the seismic response of Gubbio basin during the 26/09/1997 M_W6 Umbria-Marche earthquake

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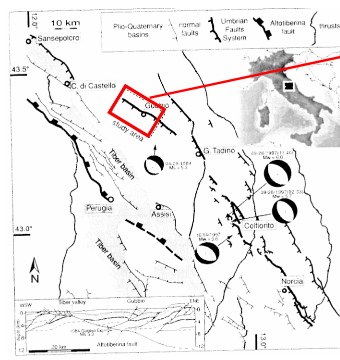
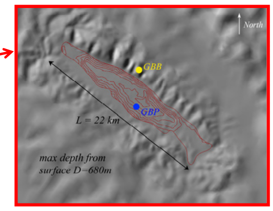
ABSTRACT

In the framework of Project S4 - Task 4 (Identification of ITACA sites and records presenting distinctive features in the seismic response) a considerable effort was devoted to the set up of large-scale 3D numerical model including the Gubbio sedimentary plain (Central Italy) and the causative seismogenetic source of the main shock of 1997 Umbria-Marche earthquake sequence (MW6.0 26.09.1997, time 09.40).
3D numerical modelling of seismic wave propagation aims at reproducing the seismic response of sites characterized by distinctive features induced by complex geological configurations and topographical irregularities. To this end, both the spectral element code GeoELSE (Stupazzini et al., 2009) and a hybrid Seismic rays-Finite Difference code (Oprsal et al., 2002) for seismic wave propagation analyses in 3D heterogeneous media were used.
The most recent results inherited from Project S3 of the previous DPC-INGV agreement about the 3D structure of the bedrock-soft deposits interface of the Gubbio plain were used to calibrate the numerical models. Fault rupture is modelled through a kinematic representation adopting the parameters and the slip distribution proposed by Hernandez et al. (2004). As a reasonable approximation, a simplified homogenous description of the dynamic properties of the Gubbio plain deposits was adopted, based on a linear gradient of the S- and P- wave velocity with depth.
The combination of a realistic model of the sedimentary plain with a proper characterization of the seismogenic source allows us to obtain numerical ground motion time histories that are in good agreement with the recordings at two representative accelerometric stations at Gubbio downtown (GBP) and inside the Gubbio plain (GBP), at least in the range of frequencies between 0 and 2 Hz. For both different computational codes, Peak Ground Displacement and Velocity values are in reasonable agreement with the estimates given by the most recently developed empirical attenuation relationships. Significant long period amplification and lengthening phenomena are found to occur inside the basin at GBP. The comparison between the recorded spectral ratios GBP/GBB with those obtained by both 1D and 3D numerical simulations underlines the need of realistic 3D numerical modelling to predict the combined effects of radiation pattern, propagation path in irregular geological structures and complex site effects, that may be strongly underestimated or neglected at all by standard approaches based on 1D wave propagation.

1 SEISMOTECTONICS AND GEOMORPHOLOGY OF THE AREA



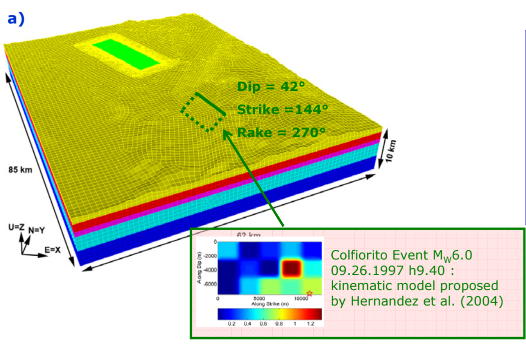


Gubbio is one of the numerous intramountain basins located in the Central Appennines, a region of extending continental crust within the zone of convergence between the Eurasian and African Plates characterized by mainly SW-dipping and normal-oblique faults (Boncio et al., 2004).

Left: sketch of the Umbria fault system highlighting the location of the investigated area (superimposed box). From Pucci et al. (2003).
Right: detail of the Gubbio basin, the position of the GBB (Gubbio downtown) and GBP (Gubbio plain) accelerometric strong motion stations is also indicated (filled dots).

2 NUMERICAL MODEL OF GUBBIO ALLUVIAL BASIN BY SPECTRAL ELEMENTS (GeoELSE)

a)

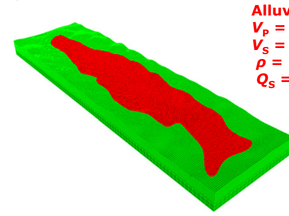


(a) 3D hexahedral spectral element mesh adopted for the computation of the Gubbio case study, with the GeoELSE software package (http://geoelse.stru.polimi.it). The computational domain is subdivided into small chunks, each of them is sequentially meshed starting from the alluvial basin down to the bedrock. For simplicity, the spectral elements are shown without the LGL nodes. b) Detailed view of the Gubbio mesh in the surroundings of the alluvial basin.

Layered crustal model:

Layer #	H (m)	V_P [m/s]	V_S [m/s]	ρ [kg/m³]	Q_S
B1	1100	3500	1800	2200	80
B2	1586	4000	2200	2400	100
B3	1000	4800	2666	2600	150
B4	3000	5500	3055	2800	250
B5	-	6300	3500	2900	300

b)



Alluvial basin, mechanical properties:
$V_P = 1000+30\,z^{1/2}$
$V_S = 250+19z^{1/2}$
$\rho = 1900$
$Q_S = 50$

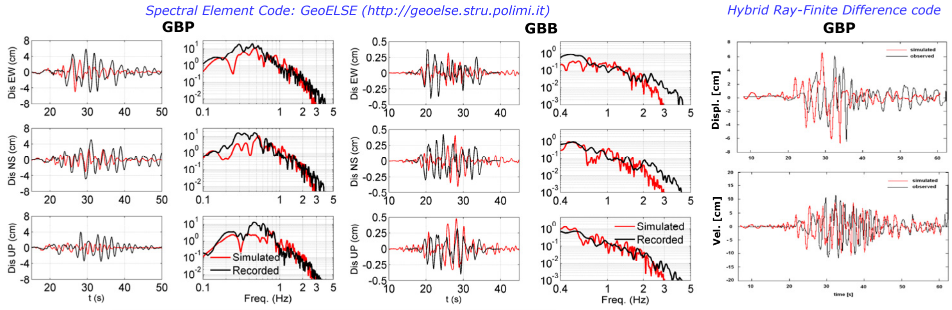
Computational costs:

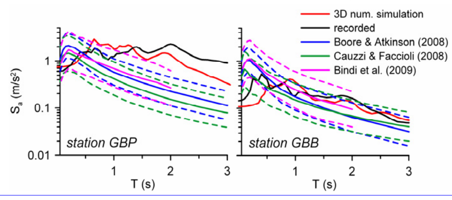
SD	Elements #	Nodes #	$\Delta t_{simulation}$ [sec.]	Δt_{CFL} [sec.]	Total simulated time [s.]	Total CPU time (48 CPUs) [min]	Set-up time [sec.]
4	361,752	2,3498,665	$3.4483\cdot10^{-4}$	$1.831\cdot10^{-3}$	100	8,962 (~149.4 hours)	8640 (~144 min)

3 RESULTS

NUMERICAL TIME HISTORIES VS. RECORDINGS AT GBB AND GBP

Spectral Element Code: GeoELSE (http://geoelse.stru.polimi.it) — *Hybrid Ray-Finite Difference code*



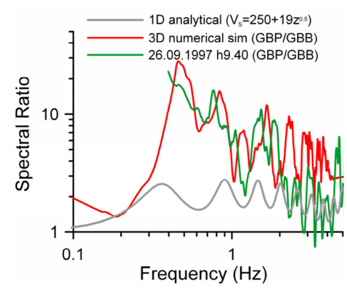


COMPARISON WITH GROUND MOTION ATTENUATION RELATIONSHIPS

Acceleration response spectra at 5% damping at GBP (left) and GBB (right): comparison of the numerical simulation (red line) with the recordings (black line) and the spectral ordinates as predicted by Boore & Atkinson (2008), Cauzzi & Faccioli (2008) and Bindi et al. (2009).

1D VS. 3D NUMERICAL SIMULATIONS

The numerical results clearly point to the need of realistic 3D numerical modelling to predict the combined effects of radiation pattern, propagation path in irregular geological structures and complex site effects, that may be strongly underestimated or neglected at all by numerical approaches based on 1D wave propagation theory.



Comparison between observed and simulated spectral ratios of GBP with respect to the nearby reference rock station GBB. The analytical 1D transfer function, obtained assuming a parabolic distribution of Vs with z is also superimposed.

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