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GROUND MOTION MODELS FOR MOLISE REGION (SOUTHERN ITALY)

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SUMMARY

On October 31st and November 1st, 2002 two moderate earthquakes of moment magnitude M_w=5.7 (INGV-Harvard European-Mediterranean Regional Centroid-Moment tensor project) occurred in southern Italy. After the mainshocks, felt in many municipalities of the Molise and Puglia region, a strong motion and a seismic temporary network were installed in the epicentral area and surrounding regions. The strong motion network was composed by 9 stations, integrating the accelerometers of the permanent Rete Accelerometrica Nazionale (RAN network), and operated until December 2003. The strong motion data set is composed by 195 recordings from 51 earthquakes (2.5<M_l<5.4) recorded by 29 accelerometers (Dipartimento della Protezione Civile et al., 2004). In addition to the strong motion network, several Italian research institutions (Istituto Nazionale di Geofisica e Vulcanologia, INGV; Istituto Nazionale di Oceanografia e Geofisica, INOGS; Dipartimento per lo studio del Territorio e delle sue Risorse, University of Genoa, Dip.Te.Ris) installed a temporary regional network, composed by 35 seismic stations. This network aimed at monitoring and studying the evolution in time and space of the seismic sequence. More than 1900 aftershocks were recorded in the period November 1st - December 5th, 2002 (Chiarabba et al., 2005).
The unified velocity-acceleration data set has been considered to derive ground motion models for peak ground acceleration and peak ground velocity for both maximum horizontal and vertical components. The results obtained for the Molise area have been compared with the attenuation pattern of the Umbria-Marche region (central Italy), that was recently investigated by Bindi et al. (2006). The remarkable differences observed indicate the need of a regional attenuation relation for the area and the need of further investigations, to better identify the role of source characteristics, anelastic and geometric attenuation and site effects in the evaluation of peak ground motion values.

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1. INTRODUCTION

On October 31st and November 1st, 2002 two moderate earthquakes of moment magnitude M_w=5.7 (INGV-Harvard European-Mediterranean Regional Centroid-Moment tensor project) occurred in southern Italy (Molise and Puglia regions). Due to the moderate magnitude of the event only few villages were damaged and only one building collapsed, but it caused the death of 29 people. Before the occurrence of the event, the area was classified as not hazardous according to the seismic code and the earthquake was unexpected to the seismologists. Neither historical earthquakes nor instrumental events were recorded for the area.

After the mainshocks, a strong motion and seismic temporary network were installed in the epicentral area and surrounding regions. The temporary strong motion network was composed by 9 stations, integrating the accelerometers of the permanent Rete Accelerometrica Nazionale (RAN network), and operated until December 2003. In addition to the strong motion network, several Italian research institutions (Istituto Nazionale di Geofisica e Vulcanologia, INGV; Istituto Nazionale di Oceanografia e Geofisica, INOGS; Dipartimento per lo studio del Territorio e delle sue Risorse, University of Genoa, Dip.Te.Ris) installed a temporary regional velocimetric network, composed by 35 stations. This network aimed at monitoring and studying the time and spatial evolution of the seismic sequence. More than 1900 aftershocks were recorded in the period November 1st - December 5th, 2002 (Chiarabba et al., 2005).

A preliminary comparison of the peak values of the mainshocks with the ones predicted by the national attenuation relationship (Sabetta and Pugliese, 1996), shows a marked overestimation of the prediction. Therefore, this work was carried out in order to formulate an empirical attenuation relationship for peak ground motion parameters of this area, using both strong motion and velocimetric waveforms recorded during the monitoring period, in order to increase the magnitude-distance sampling.

2. DATA SET DESCRIPTION

The strong motion data set is composed by 195 recordings from 51 earthquakes in the local magnitude range 2.5-5.4 recorded by 29 accelerometers (Dipartimento della Protezione Civile et al., 2004). The recording sites are mostly installed on rock and stiff sites and the hypocentral distance of most recordings is less than 50km. Only few events triggered stations located at distances greater than 100 km. The mainshocks have been mainly recorded by analog instruments (SMA-1 and Teledyne) of the national accelerometric network, while the temporary network was entirely composed of digital instruments (Episensor, connected to Kinemetrics K2, Everest or Etna recorders), that recorded the aftershocks.

The velocimetric data set has been recorded by various sensors and recorders (Lennartz 5s or 1s sensors and Guralp CMG40T, see Table 1). The waveforms come from 78 events recorded by 22 stations for a total of 2895 recordings for hypocentral distances less than 50km.

The strong motion data have been corrected in different ways, depending on the nature of the instruments. The records obtained by analog instruments have been corrected for the baseline and instrument response and filtered in the average band-pass (0.5-20 Hz) in order to remove the low frequency noise, after a visual inspection of the Fourier amplitude spectra. The digital records have been corrected in order to remove the baseline and band-pass filtered in the average range (0.2-30 Hz). The sampling rate of the records is 200 Hz.

The velocimetric data have been corrected for the instrument response and band pass filtered in the average range (0.5-25 Hz). The sampling rate is 100 Hz.

The recording sites have been classified according to the local lithology, in order to account for amplification effects. According to the available information only two classes can be distinguished, namely rock (Vs > 800 m/s) and soil (Vs < 800 m/s). It should be pointed out that soil means all kind of superficial deposits, from weak rocks to alluvial deposits. The distribution of the events, the location of the temporary velocimetric stations and the accelerometric stations is shown in Figure 1, while Table 1 lists the characteristics of the velocimetric and accelerometric stations.

3. LOCAL MAGNITUDE CALIBRATION

The velocimetric waveforms have been used to calibrate a local magnitude (M_L) scale using synthetic Wood-Anderson amplitudes obtained from the horizontal components. The M_L scale (Richter, 1935) has been calibrated following the parametric approach of Bakun and Joner (1984):

$$M_L = \log A + n \log(R/17) + k(R-17) + 2 - S \qquad (1)$$

where A is the observed maximum Wood-Anderson amplitude, n and k are attenuation coefficients, S is a station correction, and R is the hypocentral distance. In the calibration procedure, n has been set to 1 and the sum of the station corrections was set to zero. The magnitude has been calibrated using 572 recordings from 16 stations and the linear system has been solved by applying the LSQR algorithm (Paige and Saunders, 1982) . The calibrated scale is characterized by a value of k equal to 0.030768. The station corrections range between -0.34 and 0.55, showing a good agreement with the local amplification effects estimated by computing the H-over-V spectral ratios (large positive magnitude corrections have been found for stations characterized by significant site amplification within the Wood-Anderson frequency band). Large standard deviation (up to 0.11 magnitude unit) have been obtained for stations that recorded few earthquakes. Finally, the obtained magnitudes range between 1.5 and 5.2. The recalculated magnitudes have been used to characterise all the events recorded by the velocimetric stations. Different choices were made to characterise the 51 events recorded by the accelerometric network. The localisation and moment magnitude determined by Chiarabba et al. (2005) were used for the 2 mainshocks, the recalculated magnitudes were assigned to the 35 events common to the velocimetric data set, while the localisation and magnitudes of the INGV bulletin were used to qualify the 16 events of the sequence occurred after the removal of the velocimetric network.

4. GROUND MOTION ATTENUATION MODEL

Following Bindi et al. (2006), the attenuation relationships are calibrated considering the following ground-motion model:

$$\log_{10} Y = a + bM + c\log_{10} R + s_{1,2} + \sigma \quad (2)$$

where Y is the derivative variable, M is the local magnitude, R is the hypocentral distance (in km), σ is the standard deviation of the logarithm of the derivative variable. We calibrated model (2) for peak ground acceleration (PGA) and peak ground velocity (PGV). The models are derived for both the maximum horizontal (H) and vertical (V) components. The ground motion model (2) accounts for the site classification through the site coefficients $s_{1,2}$. The coefficients a, b, c, d and $s_{1,2}$ are determined by applying the random effects model (Abrahamson and Youngs, 1992) that allows the determination of the inter-event, inter-station, and record-to-record components of variance (e.g, Bindi et al., 2006). In particular, the coefficient s_1 for the rock site is constrained to zero.

5. RESULTS

The regression analysis has been carried out for the peak ground motion parameters. In particular, the maximum between the horizontal and vertical components for peak ground motion acceleration (g) and peak ground motion velocity (cm/s) have been considered.

In totality 886 records were selected recorded by 37 stations in the hypocentral distance range from 10 to 50 km. The magnitude-distance distribution of the records is shown in Fig. 2. The acceleration data sample a wider range of magnitude and distances, while, on the contrary, almost the totality of velocimetric data have been recorded at hypocentral distances between 20 and 30km.

The coefficients of equation (2) are listed in Tables 2-3, which refers to the inter-event and inter-station analysis, respectively. The total standard deviation is mainly determined by the record-to-record variability. In particular, the inter-event distribution of error shows that the calibrated local magnitudes and the bulletin ones provide errors of comparable size.

Figure 3 shows the PGA and PGV attenuation curves for local magnitude 4.4 and soil sites, together with the observed velocimetric and accelerometric data. Data obtained by different sensors demonstrate an acceptable agreement.

Figure 4a shows that horizontal and vertical components are similar in attenuation pattern but not in amplitude, and a dependence on magnitude can be observed. Figure 4b points out the importance of distinguishing soil classes, as soil sites amplify peak values.

6. COMPARISON WITH THE UMBRIA-MARCHE AREA

The results found for the Molise area are compared with the attenuation characteristics of the Umbria-Marche area, that were recently investigated by Bindi et al. (2006). Figure 5 shows that the PGA and PGV values predicted by the Umbria-Marche model strongly overestimate the ground motion predicted in Molise region..

The over-prediction has been estimated following the method proposed by Spudich et al. (1999), based on the concept of the maximum likelihood estimator, which is used to characterise the distribution of the residuals and its central tendency. With the term residual we mean the difference between the logarithms of the observed and predicted values, assumed to be normally distributed.

Figure 6 shows the residuals in function of magnitude and distance (gray line shows the bias) for PGA recorded on rock sites. When the attenuation coefficients for the Umbria-Marche area are used to predict PGA, the mean of the residuals gives a bias of -0.84 ±0.02, that means a strong overestimation of the prediction. A direct correlation with magnitude can be observed while the dependence on distance is negligible. In case of horizontal PGV (Figure 7) the bias is -0.82±0.03, and similar considerations can be drawn for the dependence on distance and magnitude.

The high biases confirm the remarkable overestimation of the Umbria-Marche coefficients in determining the Molise ground motion peaks. This result confirms the anomalous behaviour of the ground shaking associated to the 2002 Molise seismic sequence.

Future studies will be devoted to understand whether this behaviour has to be ascribed to the source characteristics or to the strong attenuation of the propagation medium. The spectral characteristics of source attenuation and site should be obtained by a generalised inversion that will allow the definition of the source characteristics, the geometric and anelastic attenuation and the soil transfer function, that can explain the low acceleration values observed.

7. REFERENCES

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Table 1: Characteristics of the recording stations

Name	Code	Latitude	Longitude	Site	type	Recorder	Sensor	Network
S.Elia a Pianisi	CIGN	41.654	14.904	R	d	LE5800	Lennartz5s	OGS mobile
Casacalenda	DIF9	41.758	14.837	S	d	LE5800	Lennartz5s	INGV mobile
S.Elia a Pianisi	ELIA	41.618	14.861	S	d	Mars	Lennartz5s	DipTeRis mobile
Guardalfiera	GUAL	41.802	14.804	S	d	Mars	Lennartz5s	DipTeRis mobile
Campolieto	LIET	41.631	14.768	S	d	Mars	Lennartz5s	DipTeRis mobile
Lupara	LUPA	41.765	14.750	S	d	Mars	Lennartz5s	DipTeRismobile
ColleTorto	MACA	41.663	14.959	R	d	Reftek-72A	CMG40T	INGV mobile
Matrice	MATR	41.611	14.705	S	d	Orion	Lennartz1s	OGS mobile
Larino	MNT9	41.795	14.887	R	d	LE5800	Lennartz5s	INGV mobile
Monacilioni	MONA	41.601	14.823	S	d	Marslite	Lennartz1s	OGS mobile
Montelongo	MON9	41.735	14.933	S	d	LE5800	Lennartz5s	INGV mobile
Morrone del Sannio	MORO	41.711	14.780	S	d	Mars	Lennartz5s	DipTeRis mobile
Morrone del Sannio	MORR	41.657	14.775	S	d	Reftek-72A	Lennartz5s	INGV mobile
Monte Rotaro	MTV9	41.608	15.062	S	d	Orion	Lennartz1s	INGV mobile
Ripabottoni	PEP9	41.659	14.826	S	d	LE5800	Lennartz5s	INGV mobile
Putrella	PETR	41.691	14.703	R	d	Mars	Lennartz5s	DipTeRis mobile
Roccavivara	ROC	41.831	14.601	S	d	Marslite	Lennartz1s	OGS mobile
Rotello	ROT2	41.759	15.029	S	d	Reftek-130	CMG40T	INGV mobile
Ururi	RURI	41.812	15.026	R	d	Reftek-130	CMG40T	INGV mobile
Toro	TORO	41.572	14.766	R	d	Mars	Lennartz5s	DipTeRis mobile
Bonefro	TORR	41.691	14.936	S	d	Reftek-72A	CMG40T	INGV mobile
Triveneto	TRI	41.765	14.524	S	d	Orion	Lennartz1s	OGS mobile
Cast. Messer Marino	CMM0	41.868	14.449	R	d	Altus Etna	Episensor	RAN
S. Marco dei Cavoti	SCV0	41.306	14.88	S	d	Altus Etna	Episensor	RAN
Gildone	GLD0	41.51	14.757	S	a	Teledyne RFT250		RAN
Sannicandro Garg.	SNN0	41.833	15.572	R	a	SMA1		RAN
San Severo	SSV0	41.679	15.386	S	a	SMA1		RAN
Vasto Europa	VSE0	42.111	14.71	S	a	Teledyne RFT250		RAN
Lesina	LSN0	41.853	15.36	S	a	SMA1		RAN
Casalnuovo M.	CAMO	41.617	15.102	S	d	Altus Etna	Episensor	RAN mobile
Casacalenda	CASA	41.739	14.846	S	d	Altus Etna	Episensor	RAN mobile
Castellino del B.	CAST	41.701	14.732	S	d	Altus Etna	Episensor	RAN mobile
Larino	LARI	41.805	14.919	R	d	Altus Etna	Episensor	RAN mobile
Santa Croce di M.	SCRO	41.71	14.99	S	d	Altus Etna	Episensor	RAN mobile
S. Elia a Pianisi	SELI	41.621	14.875	R	d	Altus Etna	Episensor	RAN mobile
S. Giuliano di P. (A)	SGIA	41.684	14.964	R	d	Altus Everest	Episensor	RAN mobile
S. Giuliano di P. (B)	SGIB	41.688	14.963	S	d	Altus Everest	Episensor	RAN mobile
S. Martino in P.	SMAP	41.869	15.011	S	d	Altus Etna	Episensor	RAN mobile

Table 2 regression coefficients to detect the sigma intra-event (HPHA = horizontal PGA; VPGA = vertical PGA; HPGV = vertical PGV; VPGV = vertical PGV)

A	b	c	s	s1	σ_eve	σ_rec	σ_tot
HPGA							
-4.417	0.770	-1.097	0	0.123	0.069	0.339	0.345
VPGA							
-4.128	0.722	-1.250	0	0.096	0.085	0.338	0.348
HPGV							
-3.186	0.902	-1.317	0	0.155	0.085	0.312	0.323
VPGV							
-3.039	0.836	-1.408	0	0.100	0.109	0.283	0.303

Table 3 regression coefficients to detect the sigma intra-station (HPHA = horizontal PGA; VPGA = vertical PGA; HPGV = vertical PGV; VPGV = vertical PGV)

a	b	c	s	s1	σ_sta	σ_rec	σ_tot
HPGA							
-4.367	0.774	-1.146	0	0.119	0.077	0.337	0.346
VPGA							
-4.066	0.729	-1.322	0	0.090	0.105	0.335	0.351
HPGV							
-3.129	0.905	-1.373	0	0.151	0.086	0.313	0.325
VPGV							
-2.988	0.839	-1.460	0	0.094	0.096	0.289	0.305

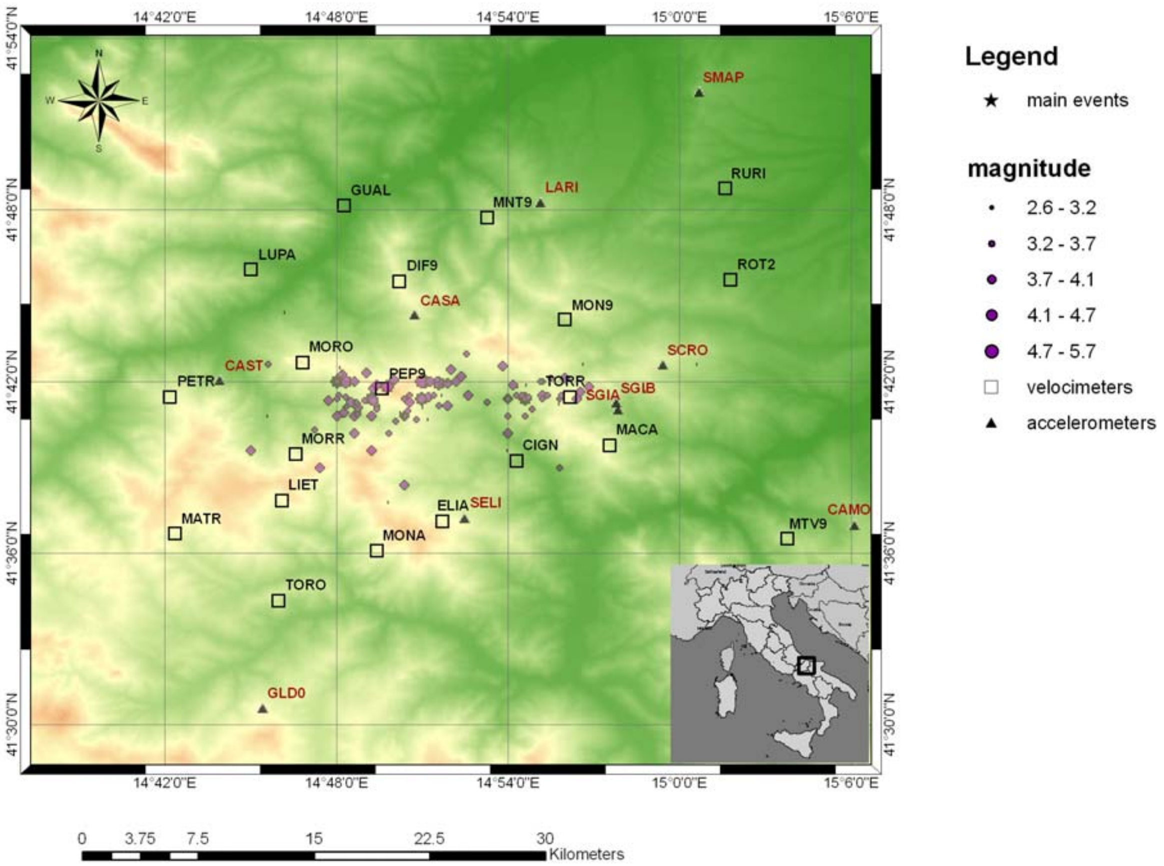


Figure 1: Distribution of the events, location of the temporary velocimetric and accelerometric stations.

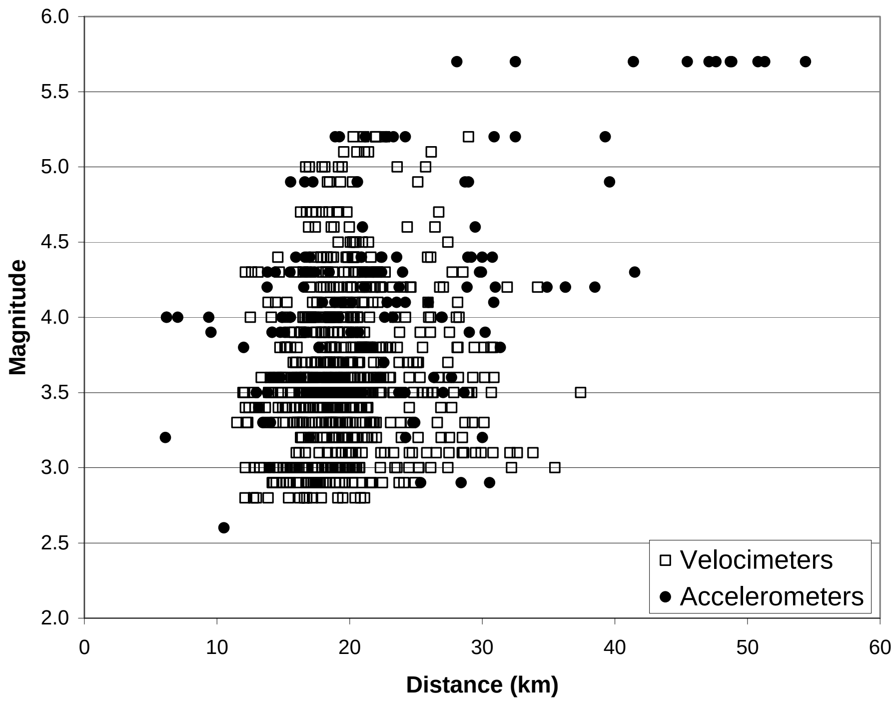


Figure 2: Magnitude-distance distribution of the records used for the regression.

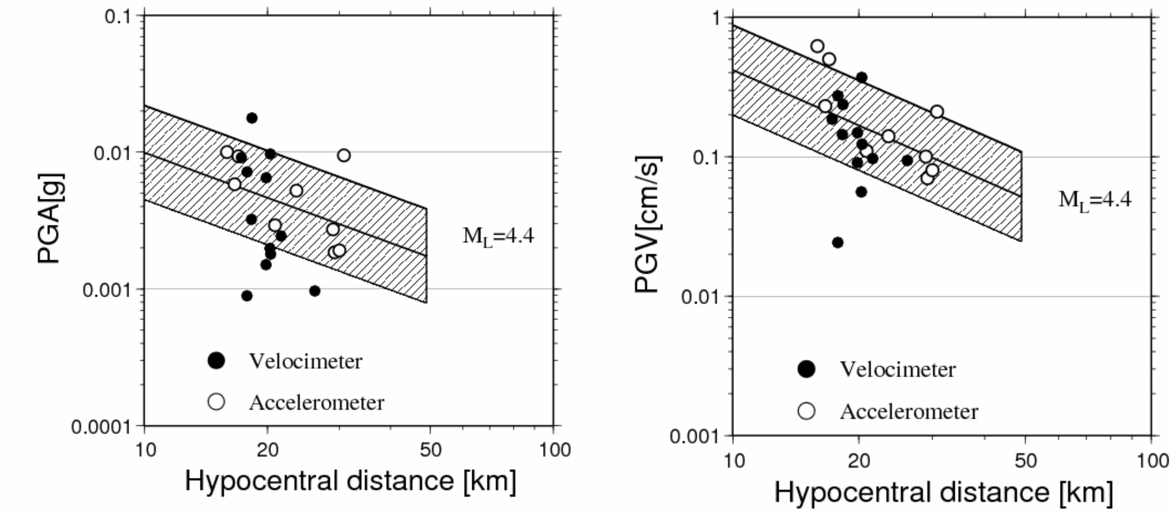
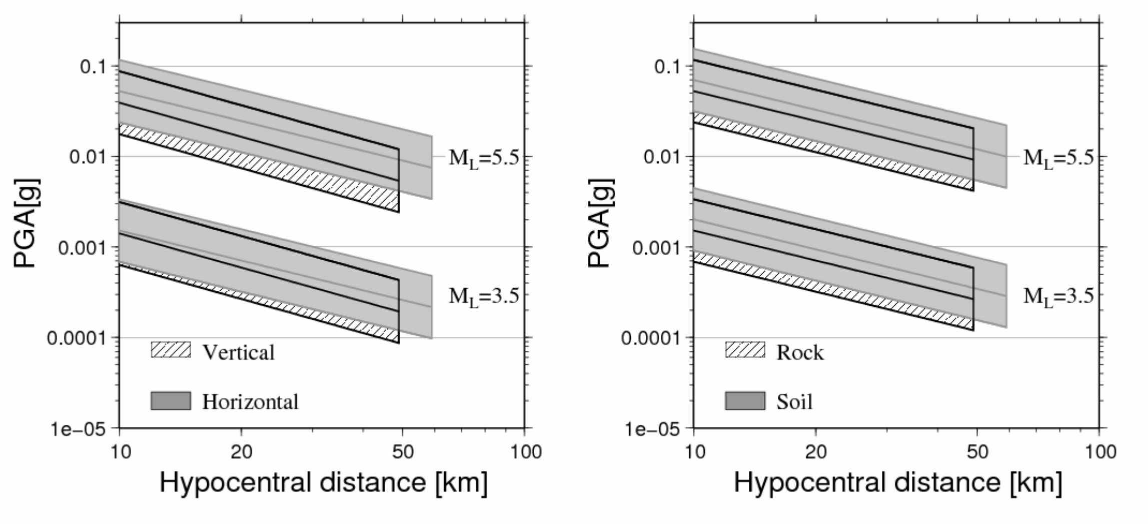
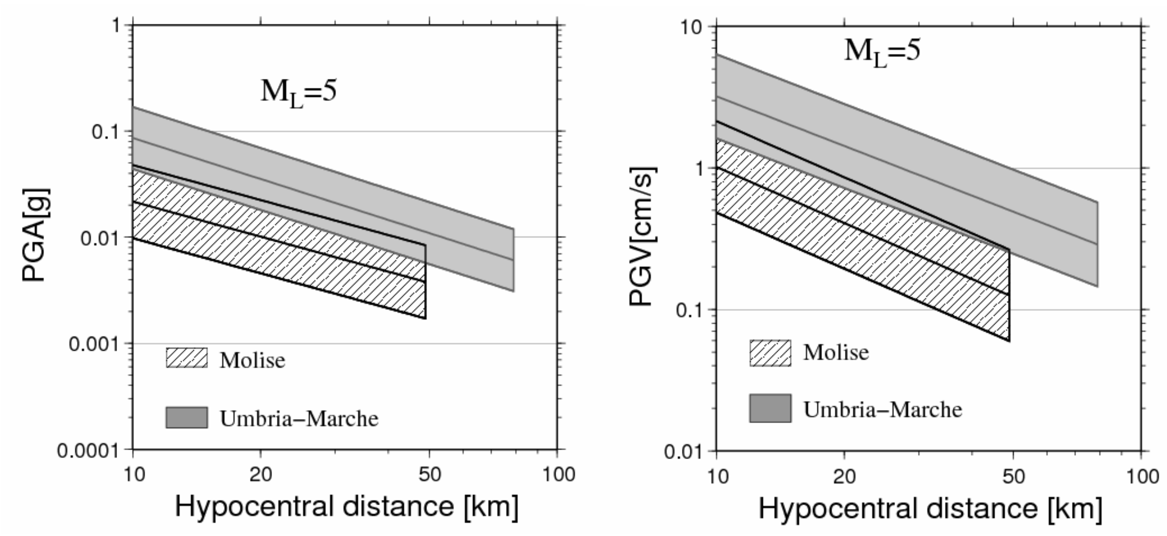


Figure 3: PGA and PGV Attenuation curves for soil sites (Ml = 4.4). Black and white dots represent observed data.



(a) (b)

Figure 4. Horizontal and vertical PGA for rock sites (a); horizontal PGA attenuation curves for rock and soil sites (b)



(a) (b)

Figure 5. Comparison between the horizontal attenuation relationships for Umbria-Marche (Bindi et al., 2006) and Molise (this study) regions. PGA (a) and PGV (b) versus distances are shown for rock sites considering a magnitude 5 earthquake.

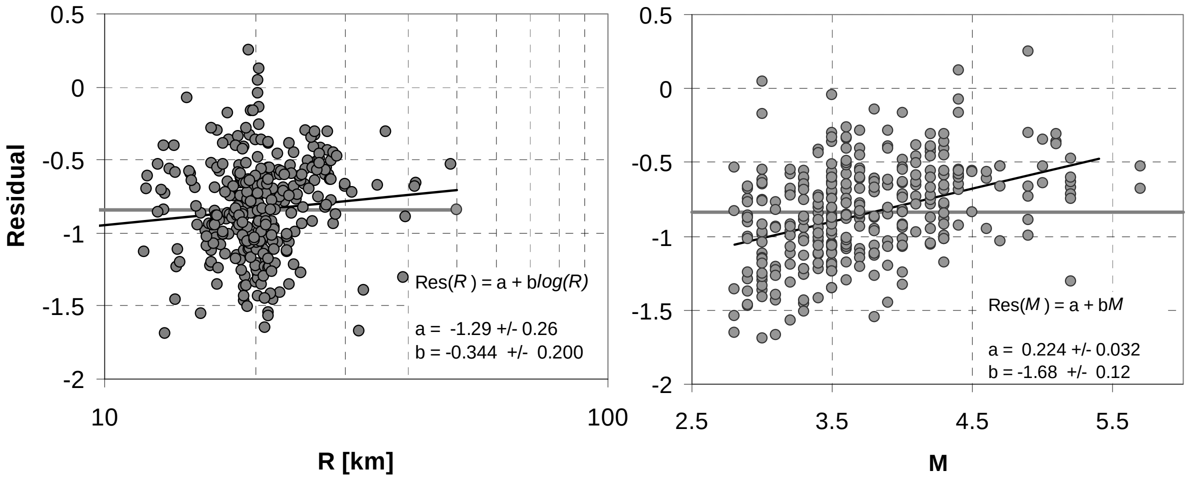


Figure 6 Residuals in function of distance and magnitude (gray line shows the bias) for PGA recorded on rock sites

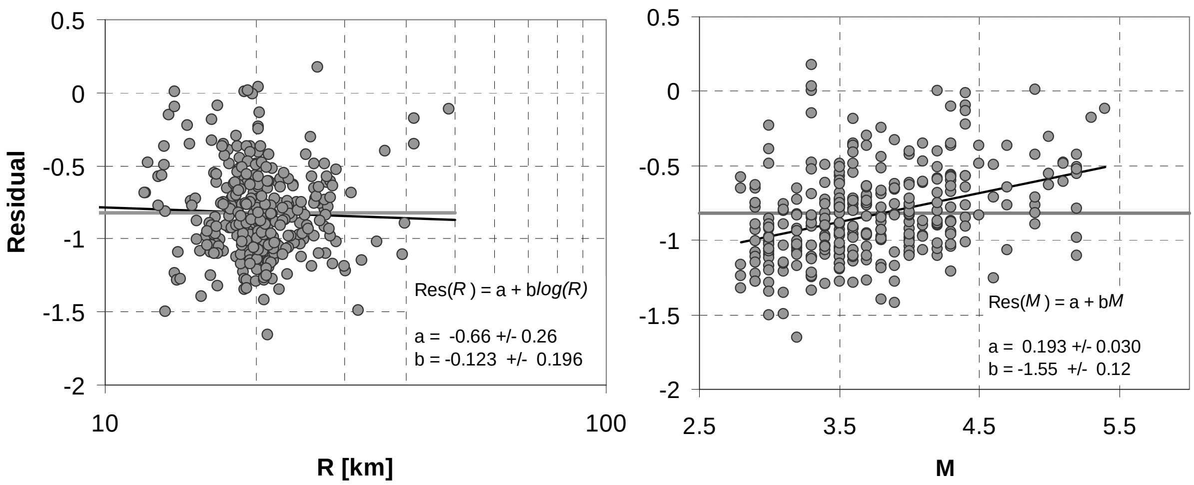


Figure 7 Residuals in function of distance and magnitude (gray line shows the bias) for PGV recorded on rock sites