PRELIMINARY ANALYSES ON THE MAINSHOCK OF THE AQUILANO EARTHQUAKE OCCURRED ON APRIL 06 2009 (*)

Comparison between response spectra evaluated close to the source and elastic demand spectra according to the 2008 Italian Seismic Code

(Rel. 1.0)

Angelo MASI, Leonardo CHIAUZZI

Department of Structures, Geotechnic and Engineering Geology

Faculty of Engineering, University of Basilicata

Via dell'Ateneo Lucano, Potenza, ITALY

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1. Introduction

On April 6, 2009 at 01:32:39 UTC (03:32:39, local time) a magnitude Ml=5.8 (M_w=6.3) earthquake hit a wide area in the Abruzzo region (Central Italy). The epicentre of the mainshock was localized very close to the urban centre of L'Aquila, capital town of the region, with a distance lower than 10 km. It is the third strongest earthquake recorded in Italy since 1972, after the 1976 Friuli (M_w=6.4) and the 1980 Irpinia (M_w=6.9) (Azzara *et al.*, 2009). Further, it is the strongest event providing strong motion recordings from accelerometric stations placed very close to the epicentre, that is 4-5 km.

In the following, some preliminary analyses on the strong motion recorded signals of the April 6, 2009 mainshock, have been made. Particularly, some comparisons between the response spectra derived from the recordings close to the source and the elastic demand spectra according to the new seismic Italian code (NTC-2008), have been proposed.

2. Studied stations of the National Accelerometric Network (RAN).

The mainshock has been recorded by 57 stations belonging to the National Accelerometric Network (RAN) managed by the Italian Department of Civil Protection (DPC) (http://www.protezionecivile.it/minisite/index.php?dir_pk=1046&cms_pk=15425).

In the following, some analyses of the mainshock signals have been performed on four strong motion stations close to the earthquake epicentre (epicentral distance lower than 6 km). Particularly, Figure 1 and Table 2 show the selected stations from RAN. In order to compare the recorded signals, in terms of spectral response, with the NTC-2008 code demand, the EC8 soil type classification, derived from geological/geophysical information, have been considered for the selected sites (Ameri *et al.*, 2009). More details on the recording stations can be found on the Italian Accelerometric Archive (Working Group ITACA, 2008).

Figure 1. A view of the recording stations considered in the present report (AQG, AQA, AQV and AQK) and the epicentre of the April 6 2009 mainshock.

Code	Name	Lat.	Long.	EC8 soil type	Ep. Distance
AQA	L'AQUILA - V. ATERNO -F. ATERNO	42.376	13.339	B	5.8 km
AQG	L'AQUILA - V. ATERNO -COLLE GRILLI	42.373	13.337	B	4.3 km
AQV	L'AQUILA - V. ATERNO - CENTRO VALLE	42.377	13.344	B	4.8 km
AQK	AQUIL PARKING	42.345	13.401	C	5.6 km

Table 1. Selected strong motion stations with site coordinates, EC8 soil type classification and epicentral distance.

3. Analysis of the mainshock in terms of time histories

The recorded signals have been processed in terms of acceleration, velocity and displacement time histories, thus the Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV) and Peak Ground Displacement (PGD) have been computed for each stations and for all the components.

The uncorrected recorded signals, available on the web site of Italian Department of Civil Protection (http://www.protezionecivile.it), have been corrected using the software SeismoSignal version 3.2.0. (http://www.seismosoft.com/en/SeismoSignal.aspx) with a linear baseline correction and adopting a Butterworth bandpass filter with Freq1=0.1, Freq2=25 and Order 4.

3.1 Acceleration time histories

Figure 2 shows, in terms of acceleration for each selected station, the corrected signals of the mainshock for horizontal and vertical directions.

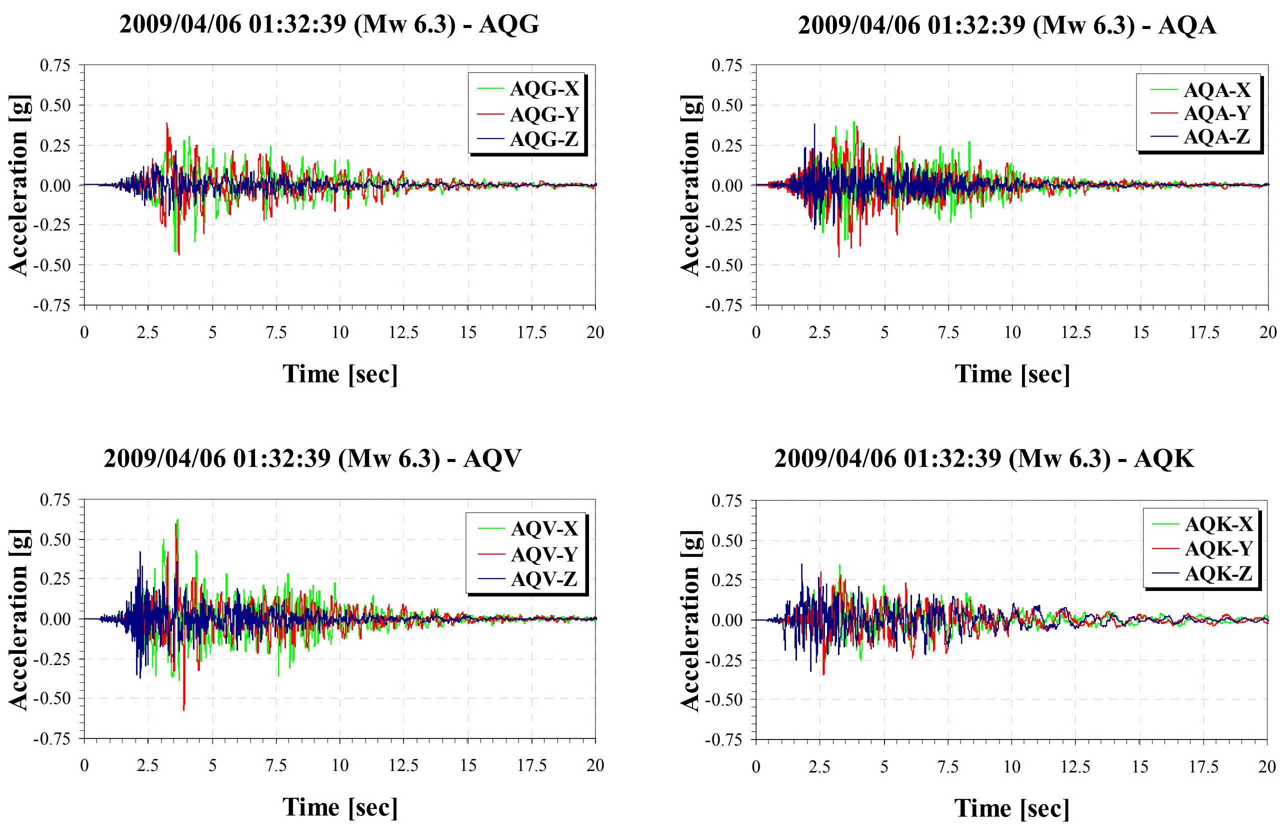

Figure 2. Corrected signals in terms of acceleration for the mainshock of the April 06 2009 Aquilano earthquake.

The Peak Ground Acceleration for the horizontal and vertical components has been computed for the corrected signals of each station. Table 2 shows the PGA values as a fraction of gravity acceleration.

ID station / direction analysis	PGA [g]		
	X - direction	Y- direction	Z - direction
AQG	0.42	0.43	0.22
AQA	0.39	0.45	0.38
AQV	0.63	0.60	0.42
AQK	0.34	0.34	0.35

Table 2. Peak Ground Acceleration (PGA) for each station (AQG, AQA, AQV and AQK) and for horizontal (X and Y) and vertical (Z) components. The values have been reported as fraction of gravity acceleration.

The maximum value of PGA has been recorded for the X horizontal direction (0.63g) at the AQV station, where also the vertical component showed the highest value equal to 0.42g. Lower values of PGA have been recorded in the other stations, specifically 0.45g for AQA and 0.43g for AQG. The smallest value has been recorded in AQK, where a higher value of the vertical component (0.35g) of the ground acceleration, in respect to the horizontal one (0.34g), has been found. Particularly, for vertical components, remarkable values of PGA have been observed also at the other stations, that is 0.22g, 0.38g and 0.42g for AQG, AQA and AQV, respectively.

3.2 Velocity time series

Figure 3 shows, in terms of velocity and for each station, the corrected signals of the mainshock for the horizontal and vertical directions.

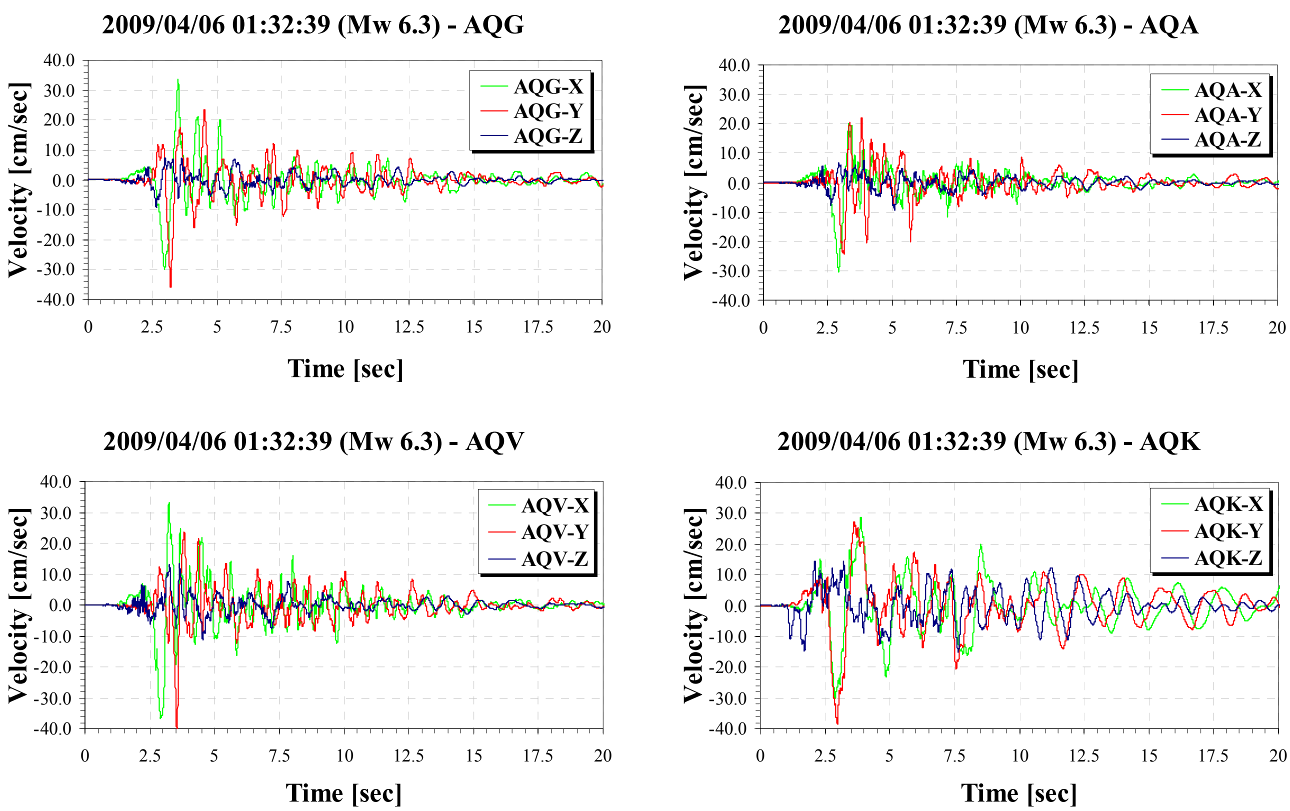

Figure 3. Corrected signals in terms of velocity for the mainshock of the April 06 2009 Aquilano earthquake.

The values of Peak Ground Velocity (PGV) for the horizontal and vertical directions have been reported in Table 3.

ID station / direction analysis	PGV [cm/s]		
	X	Y	Z
AQG	33.59	35.91	9.08
AQA	30.54	24.50	9.45
AQV	36.68	40.48	13.39
AQK	30.24	38.50	14.98

Table 3. Peak Ground Velocity (PGV) for each station (AQG, AQA, AQV and AQK) and for horizontal (X and Y) and vertical (Z) components.

AQV station (Y direction) shows the maximum value of PGV (40.48 cm/s). Other strong motion instruments detected smaller even though remarkable values of PGV. Specifically, values equal to 38.50 cm/s, 35.91 cm/s and 30.54 cm/s have been found at the stations AQK, AQG and AQA, respectively.

3.3 Displacement time series

Figure 4 shows, in terms of displacement and for each station, the corrected signals of the mainshock for the horizontal and vertical directions.

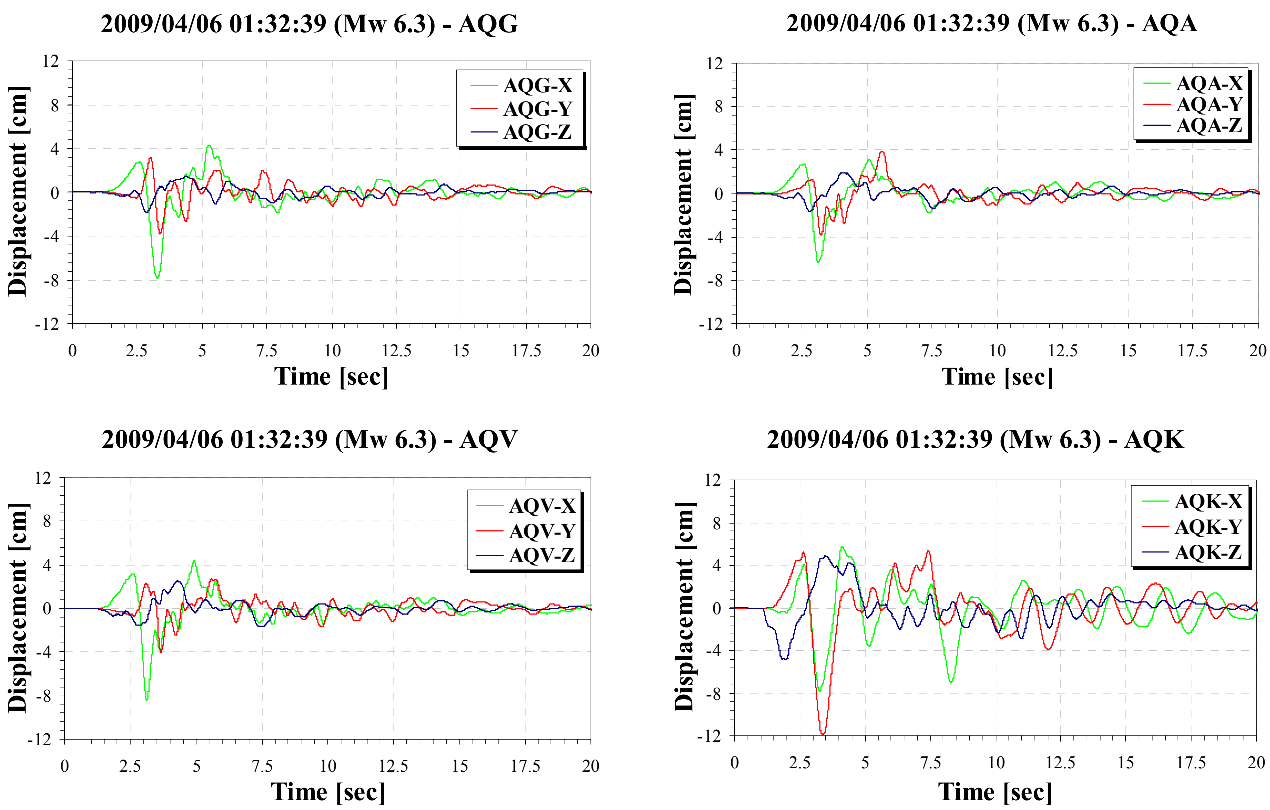

Figure 4. Corrected signals in terms of displacement for the mainshock of the April 06 2009 Aquilano earthquake.

Peak Ground Displacement (PGD) values for each station and for the horizontal and vertical directions have been reported in Table 4.

ID station / direction analysis	**PGD [cm]**		
	X	**Y**	**Z**
AQG	7.83	3.80	1.91
AQA	6.35	3.87	1.94
AQV	8.43	4.08	2.52
AQK	7.84	11.87	4.91

Table 4. Peak Ground Displacement (PGD) for each station (AQG, AQA, AQV and AQK) and for horizontal (X and Y) and vertical (Z) components.

AQK station (Y direction) shows the maximum value of PGD (11.87 cm). Significantly smaller values of PGD have been found at the other stations, specifically 7.83 cm, 6.35 cm and 8.43 cm for AQG, AQA and AQV, respectively.

4. Analysis of the mainshock in terms of response spectra

Herein a preliminary analysis in terms of response spectra have been made for the strong motion signals recorded close to the source for the mainshock of the April 06 2009 earthquake.

Elastic response spectra in terms of pseudo-acceleration, pseudo-velocity and displacement have been computed for the recorded strong motion signals.

4.1 Pseudo-acceleration response spectra

Figure 5 shows for each strong motion station the pseudo-acceleration response spectra (5% of damping ratio) computed for the horizontal and vertical directions of the corrected signals.

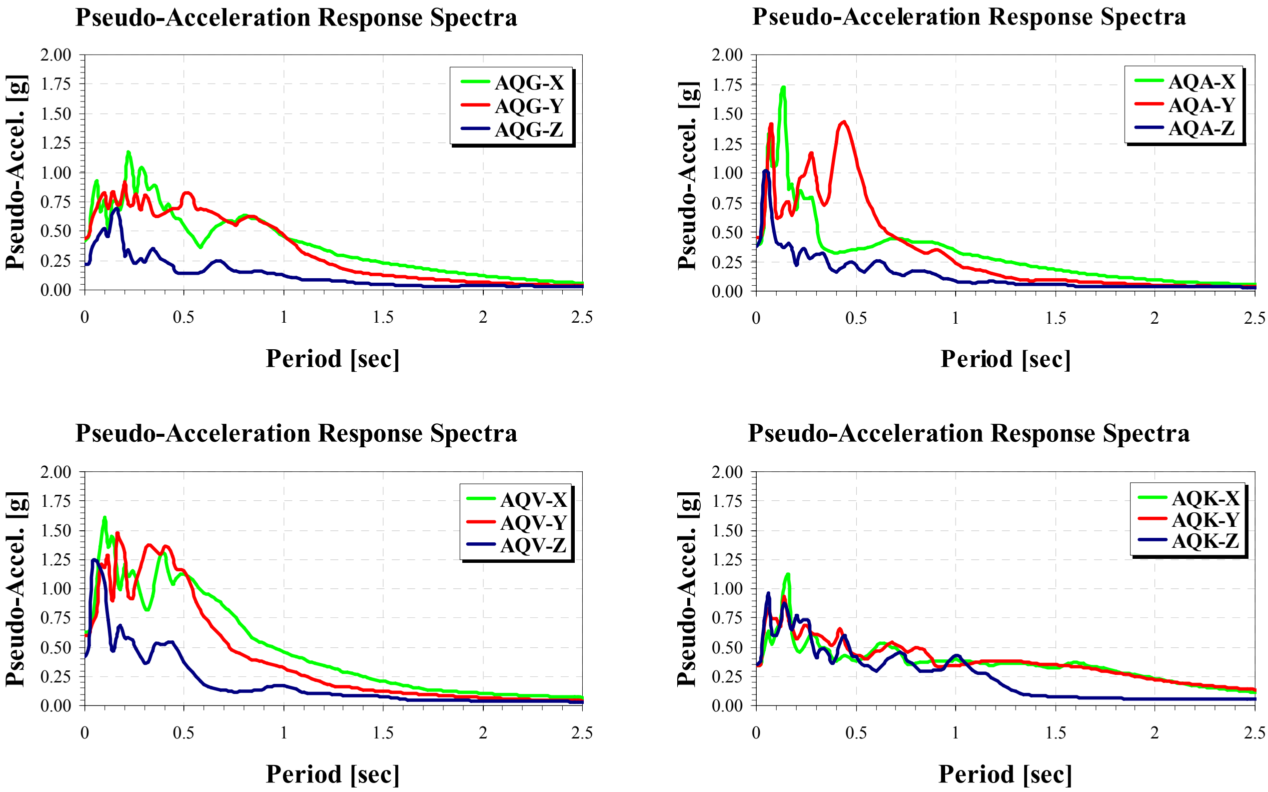

Figure 5. Pseudo-acceleration response spectra for the mainshock of the April 06 2009 Aquilano earthquake.

AQA station (X-direction) shows the maximum value of pseudo-acceleration, that is $S_{a\text{-}max}$=1.72g for a period T=0.14 s. Moreover, Y-direction AQA station shows the maximum value of S_a (1.44g) at T=0.44 s, even though also a remarkable value of S_a = 1.40g can be seen at T=0.08.

The record at the AQV station shows a value of 1.60g at the period T=0.10 s. Table 5 reports the maximum values of the pseudo-acceleration response spectra for the four stations and for each direction.

ID-Station	$S_{a\text{-}max}$ [g]	T ($S_{a\text{-}max}$) [sec]	ID-Station	$S_{a\text{-}max}$ [g]	T ($S_{a\text{-}max}$) [sec]
AQG-X	1.18	0.22	**AQV-X**	1.61	0.10
AQG-Y	0.92	0.20	**AQV-Y**	1.47	0.16
AQG-Z	0.69	0.16	**AQV-Z**	1.24	0.04
AQA-X	1.72	0.14	**AQK-X**	1.11	0.16
AQA-Y	1.44	0.44	**AQK-Y**	0.93	0.14
AQA-Z	1.00	0.40	**AQK-Z**	0.96	0.06

Table 5. Maximum pseudo-acceleration response spectra for each station (AQG, AQA, AQV and AQK) and for horizontal (X and Y) and vertical (Z) components.

4.2 Pseudo-velocity response spectra

Figure 6 shows for each strong motion station the pseudo-velocity response spectra (5% of damping ratio) computed for the horizontal and vertical directions of the corrected signals.

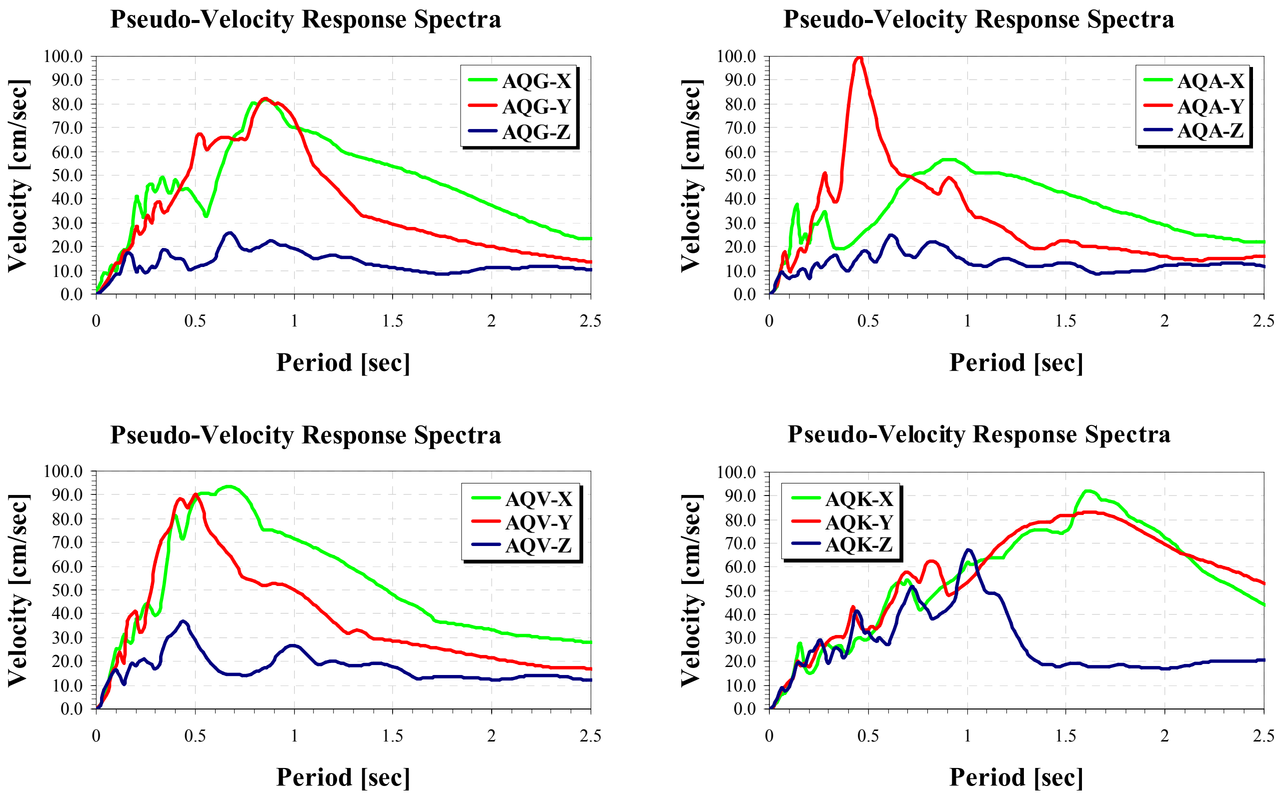

Figure 6. Corrected signals in terms of pseudo-acceleration response spectra for the mainshock of the April 06 2009 Aquilano earthquake.

Y-direction of AQA shows the maximum pseudo-velocity value, that is $S_{v\text{-}max}$=99.71 cm/s for a period T=0.46 s. AQV station shows a significantly high value of pseudo-velocity equal to 93.60 cm/s for T=0.66 s, while AQK station returns the maximum value 92.19 cm/s at a very high period value, that is T=1.62 s.

Table 6 reports the maximum values of pseudo-acceleration response spectra for the four stations and for each direction.

ID-Station	$S_{v\text{-}max}$ [cm/sec]	T ($S_{v\text{-}max}$) [sec]	ID-Station	$S_{v\text{-}max}$ [cm/sec]	T ($S_{v\text{-}max}$) [sec]
AQG-X	81.70	0.86	**AQV-X**	93.66	0.66
AQG-Y	82.28	0.86	**AQV-Y**	90.15	0.50
AQG-Z	25.82	0.68	**AQV-Z**	37.08	0.44
AQA-X	56.77	0.90	**AQK-X**	92.19	1.62
AQA-Y	99.71	0.46	**AQK-Y**	83.14	1.62
AQA-Z	24.84	0.62	**AQK-Z**	67.33	1.00

Table 6. Maximum pseudo-velocity response spectra for each station (AQG, AQA, AQV and AQK) and for horizontal (X and Y) and vertical (Z) components.

4.3 Displacement response spectra

Figure 7 shows for each strong motion station the displacement response spectra (5% of damping ratio) computed for the horizontal and vertical directions of the corrected signals.

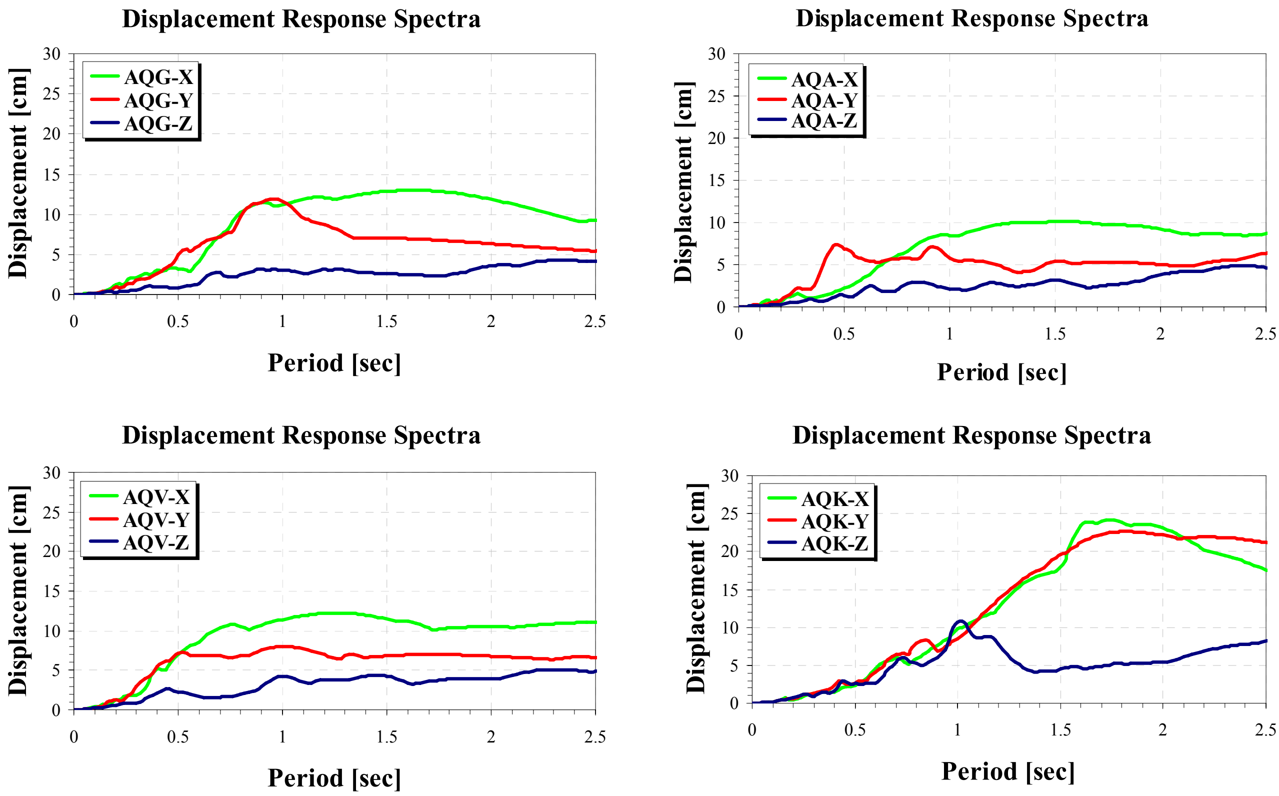

Figure 7. Corrected signals in terms of displacement response spectra for the mainshock of the April 06 2009 Aquilano earthquake.

The maximum values of the spectral displacement $S_{d\text{-}max}$ are, at the sites AQA, AQG and AQV, averagely equal to 10 cm for the horizontal components, and equal to 5 cm for the vertical one. On the contrary, significantly higher values have been found at the station AQK, where the maximum values of S_d are 24.20 cm and 22.60 cm for the X and Y direction, respectively, while for the vertical component $S_{d\text{-}max}$ is about 10 cm. In Table 7 the maximum values of the displacement response spectra for each station and for all the components are reported.

ID-Station	$S_{d\text{-}max}$ [cm]	T ($S_{d\text{-}max}$) [sec]	ID-Station	$S_{d\text{-}max}$ [cm]	T ($S_{d\text{-}max}$) [sec]
AQA-X	10.13	1.54	**AQV-X**	12.23	1.24
AQA-Y	7.30	0.46	**AQV-Y**	8.00	1.00
AQA-Z	4.89	2.40	**AQV-Z**	5.13	2.64
AQG-X	12.97	1.62	**AQK-X**	24.20	1.74
AQG-Y	11.94	0.96	**AQK-Y**	22.60	1.82
AQG-Z	4.26	2.32	**AQK-Z**	10.85	1.00

Table 7. Maximum displacement response spectra for each station (AQG, AQA, AQV and AQK) and for horizontal (X and Y) and vertical (Z) components.

5. Comparison of recorded signals with NTC-2008 Italian Code

In the following a preliminary comparison between the response spectra evaluated close to the source for the mainshock of the April 06 2009 earthquake and the elastic demand spectra provided by the new seismic Italian code (NTC-2008), has been performed.

Particularly, the elastic response spectra in terms of pseudo-acceleration, pseudo-velocity and displacement, have been compared with those ones of the NTC-2008 Code for the return periods of 475 and 2475 years, considering the soil type conditions of the relevant station. Further, a comparison based on an integral seismic parameter, that is the Housner Intensity (Housner, 1952), has been carried out.

5.1 Pseudo-acceleration response spectra

Figure 8 shows the pseudo-acceleration response spectra for the horizontal directions (at 5% damping ratio) observed at the different stations and compared with the NTC-08 Italian Code spectra computed considering the soil type assigned to the recording station (Table 1).

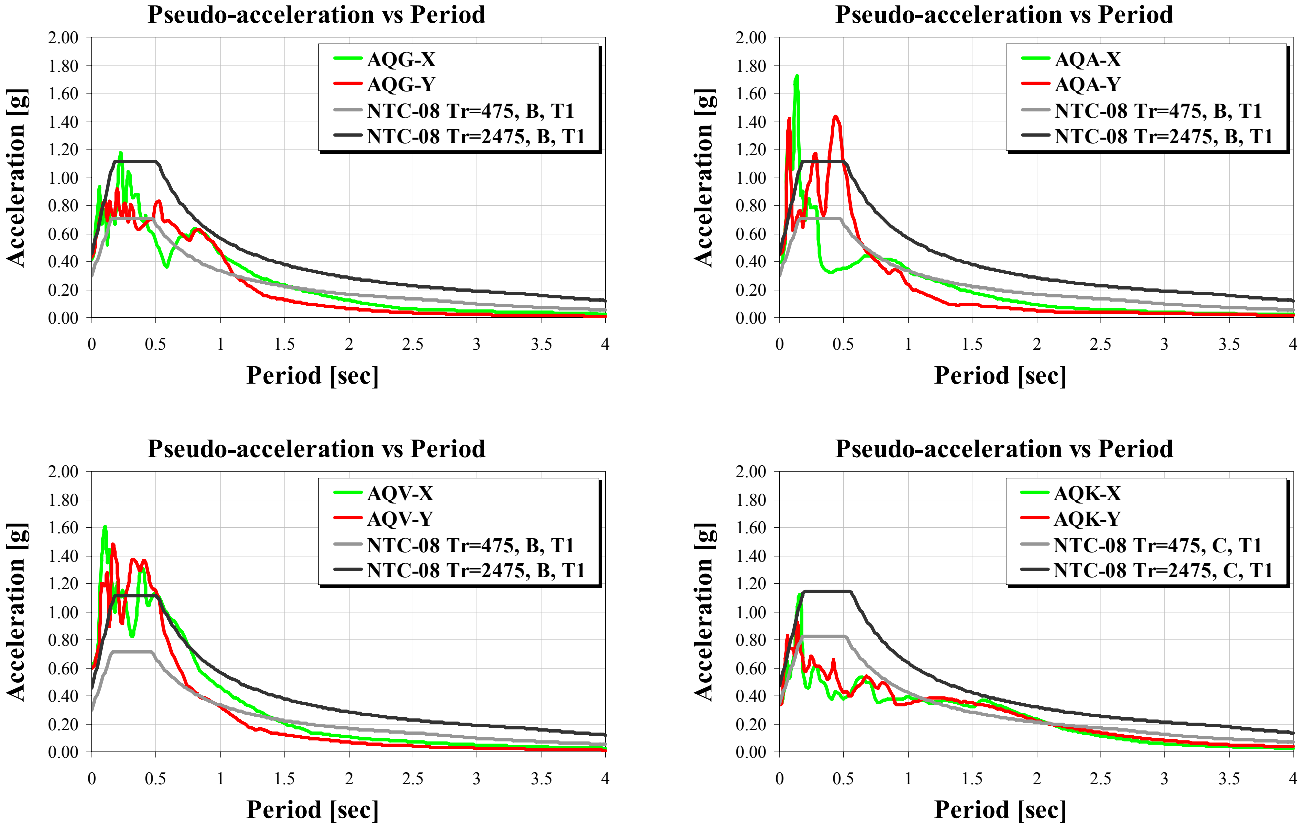

Figure 8. Comparison of the pseudo-acceleration response spectra of the Aquilano mainshock and of the NTC-08 Italian Code (<u>horizontal components</u>).

When the return period Tr=475 years is considered, NTC-08 Italian Code generally underestimates the spectral values of the recorded signals. On the other hand, for Tr=2475 years, the pseudo-acceleration response spectra returned by NTC-08 are comparable with those ones from the recorded signals, showing higher plateau values at the stations AQA and AQV.

In Figure 9 the comparison relevant to the vertical component (at 5% damping ratio) is shown. Also in the vertical direction NTC-08 Italian Code generally underestimates the spectral values of the recorded signals when the return period Tr=475 years is considered.

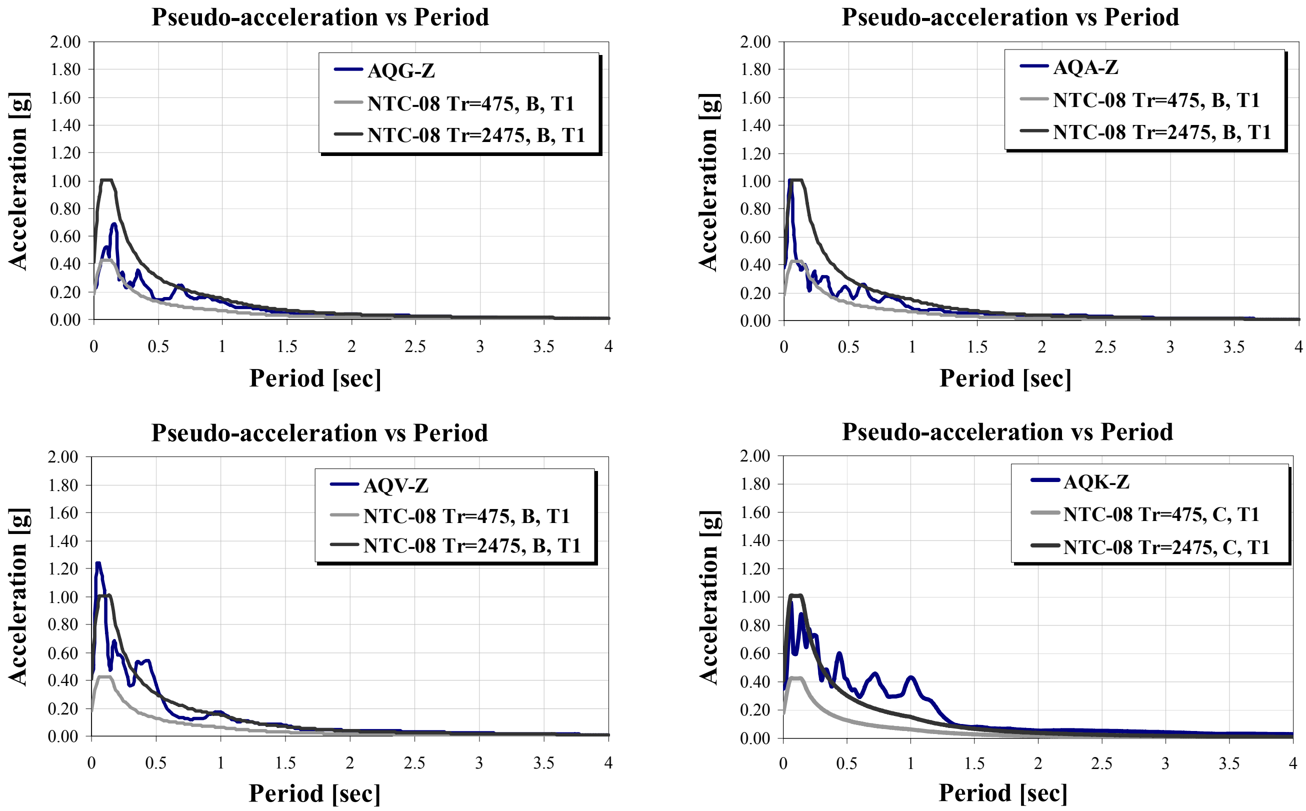

Figure 9. Comparison of the pseudo-acceleration response spectra of the Aquilano mainshock and of the NTC-08 Italian Code (vertical component).

5.2 Pseudo-velocity response spectra

Figure 10 shows the pseudo-velocity response spectra for the horizontal directions (at 5% damping ratio) observed at the different stations and compared with the NTC-08 Italian Code spectra computed considering the soil type assigned to the recording stations (Table 1).

When the return period Tr=475 years is considered, NTC-08 generally underestimates the spectral values of the recorded signals for values of the period T lower than 1.0 seconds. For Tr=2475 years, the pseudo-velocity response spectra returned by NTC-08 provide values always higher than those ones from the recorded signals. In both cases, NTC-08 and recorded pseudo-velocity spectra have very different shapes.

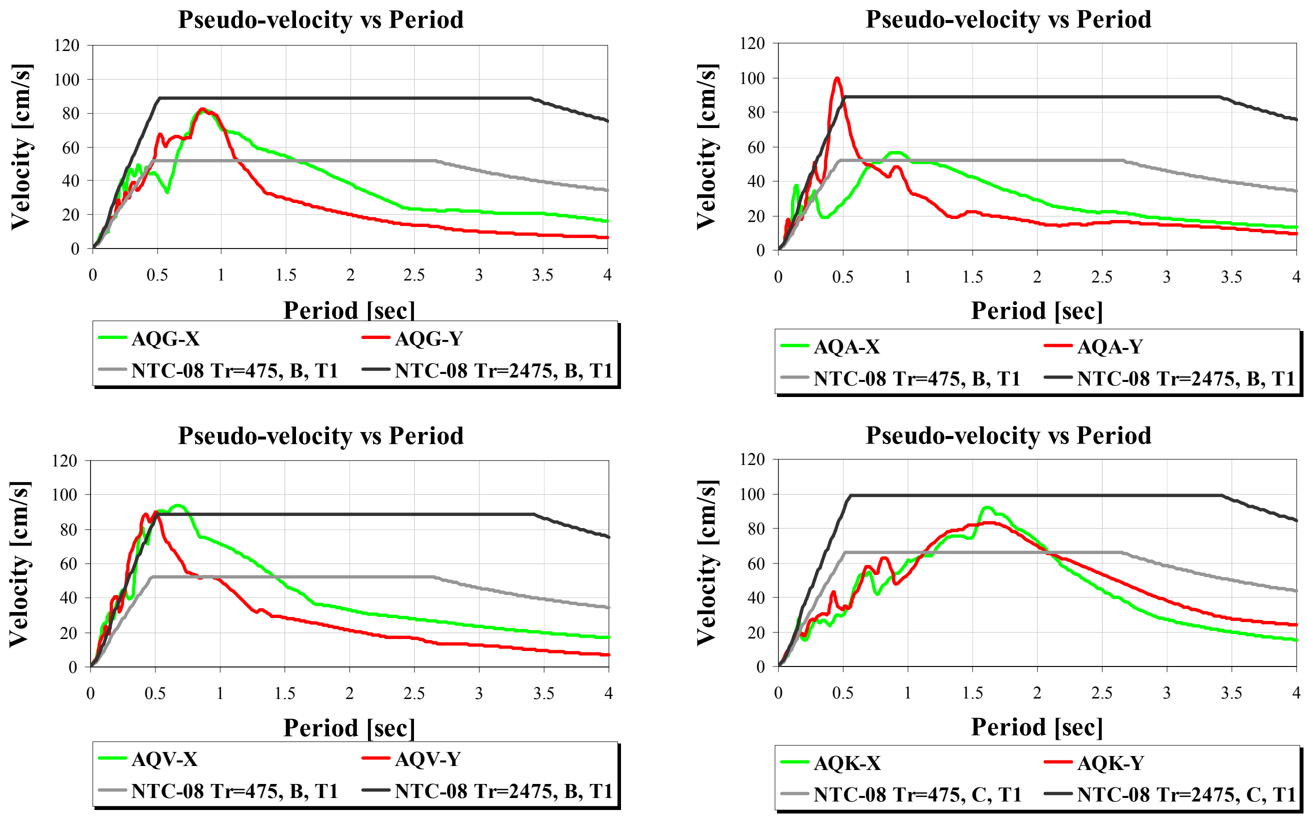

Figure 10. Comparison of the pseudo-velocity response spectra of the Aquilano mainshock and of the NTC-08 Italian Code (horizontal component).

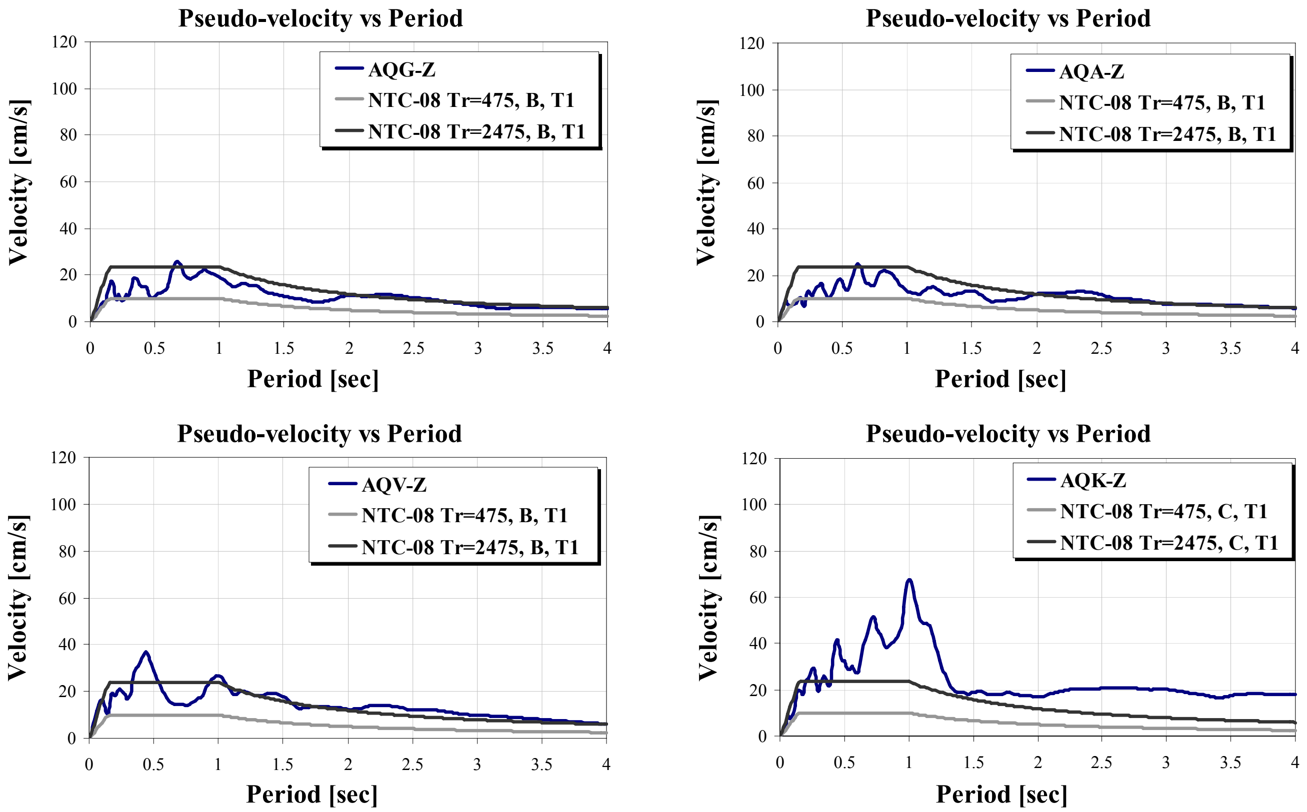

Figure 11. Comparison of the pseudo-velocity response spectra of the Aquilano mainshock and of the NTC-08 Italian Code (vertical component).

In Figure 11 the comparison relevant to the vertical component (at 5% damping ratio) is shown. Also in the vertical direction NTC-08 Italian Code generally underestimates the spectral values of the recorded signals, when the return period Tr=475 years is considered.

5.3 Displacement response spectra

Figure 12 shows the displacement response spectra for the horizontal directions (at 5% damping ratio) observed at the different stations and compared with the NTC-08 Italian Code spectra computed considering the soil type assigned to the recording stations (Table 1).

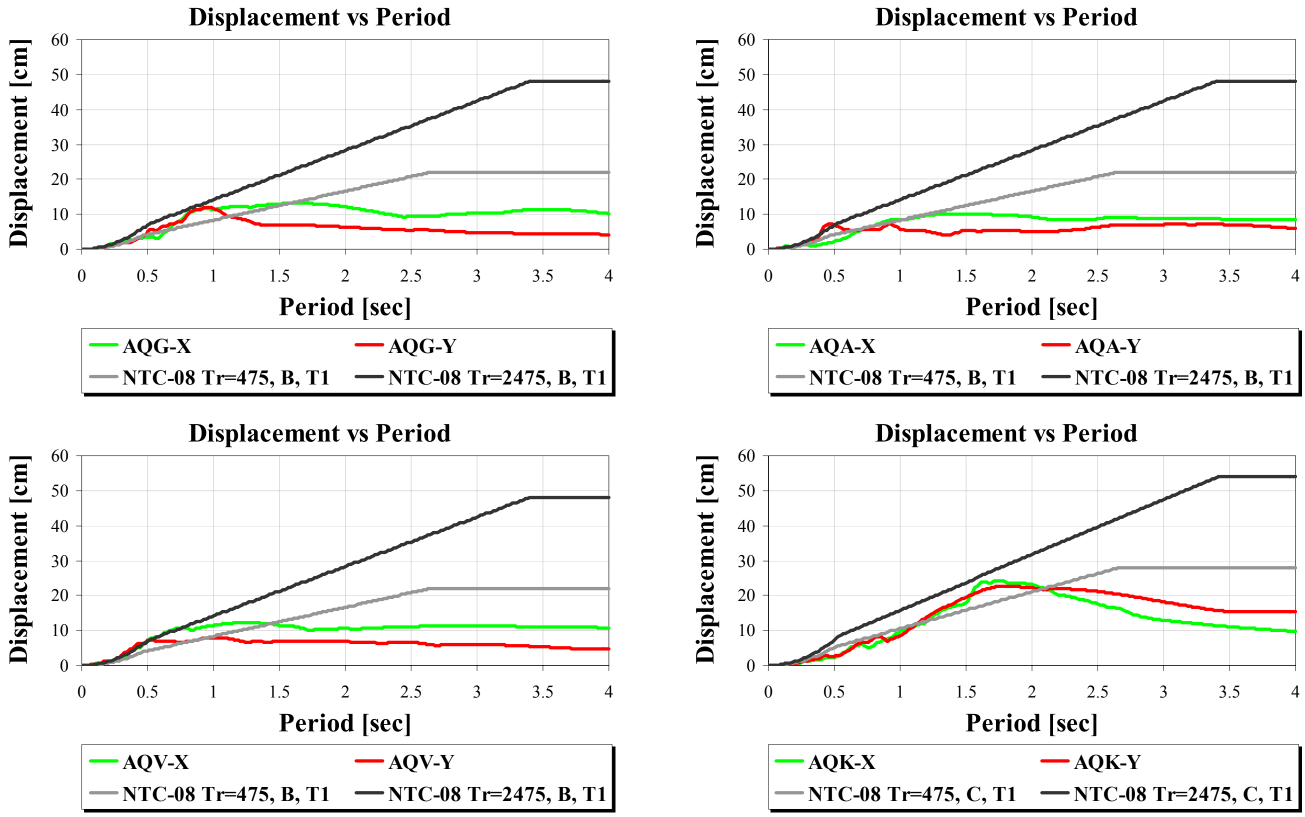

Figure 12. Comparison of the displacement response spectra of the Aquilano mainshock and of the NTC-08 Italian Code (horizontal component).

When the return period Tr=475 years is considered, the displacement response spectra returned by NTC-08 are comparable with those ones from the recorded signals. On the contrary, Code values are higher considering Tr=2475 years.

In Figure 13 the comparison relevant to the vertical component (at 5% damping ratio) is shown. Also for the vertical direction, NTC-08 generally underestimates the spectral values of the recorded signals when a return period Tr=475 years is considered.

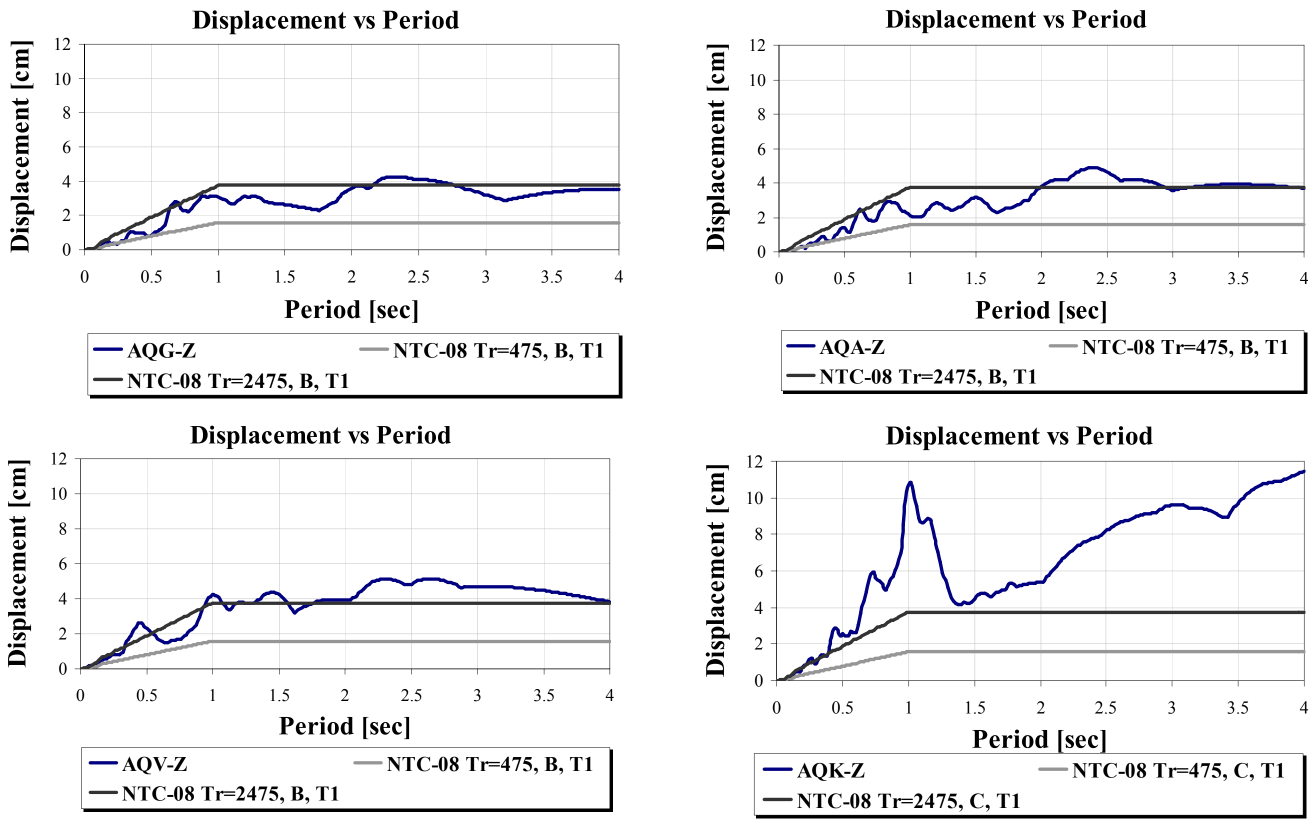

Figure 13. Comparison of the displacement response spectra of the Aquilano mainshock and of the NTC-08 Italian Code (vertical component).

5.4 Comparison in terms of Peak Ground Acceleration (PGA)

In Table 8 the values of Peak Ground Acceleration (PGA), as recorded at each site, and the respective values provided in the NTC-08 considering the specific soil type conditions (Ameri *et al.*, 2009) have been reported. PGA values have been expressed as a fraction of gravity acceleration and, for NTC-08, two return periods Tr have been considered, that is 475 and 2475 years.

	PGA_{rec} [g]	PGA_{Code} (Tr=475) [g]	PGA_{Code} (Tr =2475) [g]	Δ_PGA(Tr=475) [g]	Δ_PGA(Tr=2475) [g]
AQG – X	0.42	0.30	0.45	-0.12	+0.03
AQA – X	0.39	0.30	0.45	-0.09	+0.06
AQV – X	0.63	0.30	0.45	-0.33	-0.18
AQK – X	0.34	0.35	0.47	0.01	+0.13
AQG – Y	0.43	0.30	0.45	-0.13	+0.02
AQA – Y	0.45	0.30	0.45	-0.15	0.00
AQV – Y	0.60	0.30	0.45	-0.30	-0.15
AQK – Y	0.34	0.35	0.47	+0.01	+0.13
AQG – Z	0.22	0.18	0.41	-0.04	+0.19
AQA – Z	0.38	0.18	0.41	-0.20	+0.03
AQV – Z	0.42	0.18	0.41	-0.24	-0.01
AQK – Z	0.35	0.18	0.41	-0.17	+0.06

Table 8. Comparison of the Peak Ground Acceleration (PGA) values of the Aquilano mainshock and of the NTC-08 Italian Code for return periods equal to 475 and 2475 years (horizontal and vertical directions).

The absolute differences Δ_PGA = (PGA_{Code} - PGA_{rec}) between the Code and the recorded peak values have been reported in the last two columns of Table 8, respectively for Tr=475y and Tr=2475y. As can be seen, Code values are generally lower for Tr=475 years, and in some cases also for Tr=2475 years.

The values reported in Table 8 have been also displayed in the figures 14 and 15 for the horizontal components and the vertical component, respectively.

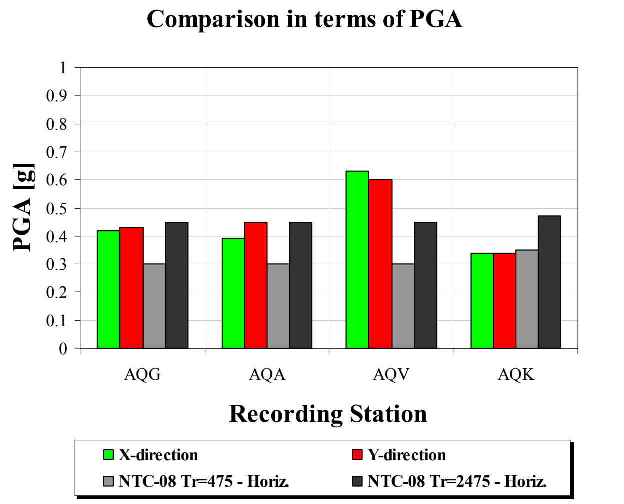

Figure 14. Comparison of the Peak Ground Acceleration (PGA) values of the Aquilano mainshock and of the NTC-08 Italian Code for return periods equal to 475 and 2475 years (horizontal directions)

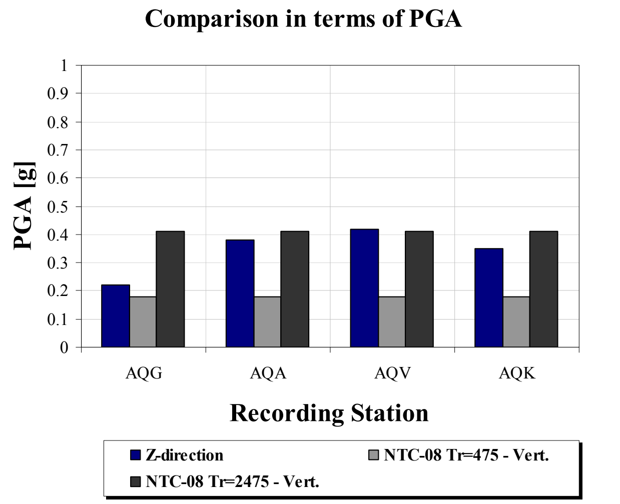

Figure 15. Comparison of the Peak Ground Acceleration (PGA) values of the Aquilano mainshock and of the NTC-08 Italian Code for return periods equal to 475 and 2475 years (vertical direction).

5.5 Comparison in terms of Housner Intensity (I_H)

In order to better understand the differences between the Aquilano earthquake signals and the seismic design actions provided in the NTC-08 Code, the relevant values of the Housner intensity (Housner, 1952) have been computed.

Masi *et al.* (2009) have shown how the Housner Intensity (I_H) is an effective parameter to correlate the severity of seismic events with structural damage, particularly in case of existing non-ductile Reinforced Concrete (RC) buildings. Also other studies (Pergalani *et al.*, 1999; Decanini *et al.*, 2002; Marcellini *et al.*, 2004) have already proposed I_H as a parameter better than PGA, PGV and Arias Intensity to represent the severity of earthquake ground motion.

I_H has been computed as the area under the pseudovelocity (PSV) spectrum in the period interval 0.2-2 seconds, as shown in the expression (1):

$$I_H = \int_{0.2}^{2} PVS\ (T, \xi)\, dT \qquad (1)$$

where T is the fundamental period of the structure under examination and ξ is the fraction of critical damping (5% in this case).

It is worth noting that, while I_H is usually computed in the period range between 0.1 and 2.5 s, in the present work a period range between 0.2 and 2 seconds has been used, deeming such range better able to provide values well correlated with the damage potential of typical existing building structures. This is in accordance with the choice adopted in the studies carried out for the seismic reclassification of the national Italian territory proposed some years ago by the GNDT Working Group (1999).

In Table 9 the values of Housner Intensity (I_H) as recorded at each site and the respective values provided in the NTC-08 Code considering the specific soil type conditions (Ameri *et al.*, 2009) have been reported. The absolute differences $\Delta\_I_H = (I_{H\_Code} - I_{H\_rec})$ between the Code and the recorded integral values have been reported in the last two columns of Table 9, respectively for Tr=475y and Tr=2475y.

	I_{H_rec} [m]	I_{H_Code} (Tr = 475) [m]	I_{H_Code} (Tr = 2475) [m]	Δ_I_H (Tr=475) [m]	Δ_I_H (Tr=2475) [m]
AQG – X	0.99	0.90	1.51	-0.09	0.52
AQA – X	0.73	0.90	1.51	0.17	0.78
AQV – X	1.10	0.90	1.51	-0.20	0.41
AQK – X	1.08	1.13	1.67	0.05	0.59
AQG – Y	0.81	0.90	1.51	0.09	0.70
AQA – Y	0.66	0.90	1.51	0.24	0.85
AQV – Y	0.82	0.90	1.51	0.08	0.69
AQK – Y	1.10	1.13	1.67	0.03	0.57
AQG – Z	0.26	0.15	0.35	-0.11	0.09
AQA – Z	0.25	0.15	0.35	-0.10	0.10
AQV – Z	0.34	0.15	0.35	-0.19	0.01
AQK – Z	0.56	0.15	0.35	-0.41	-0.21

Table 9. Comparison of the Housner Intensity (I_H) values of the Aquilano mainshock and of the NTC-08 Italian Code for return periods equal to 475 and 2475 years (horizontal and vertical directions).

The values reported in Table 9 have been also displayed in the figures 16 and 17 for the horizontal components and the vertical component, respectively.

As can be seen, dealing with the Housner Intensity it is confirmed that Code values are generally lower for the return period Tr=475 years, but, contrary to the PGA values, I_H Code values are remarkably higher considering Tr=2475 years. These results need to be further studied to better understand the above differences and their role on the seismic response of buildings, also taking into account the very different shapes of the pseudo-velocity spectra relevant to Code and recordings, particularly for the horizontal components, as shown in Figure 16.

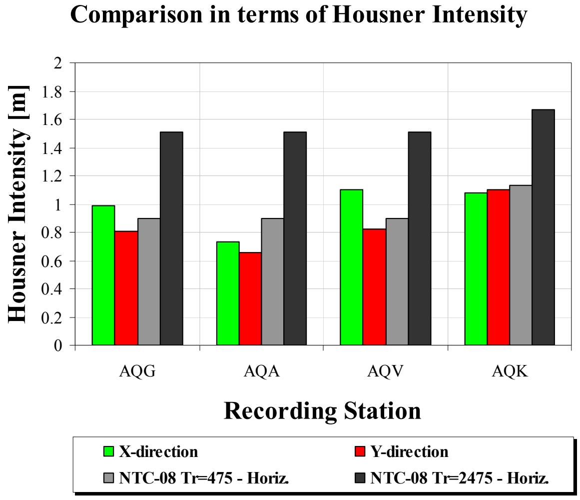

Figure 16. Comparison of the Housner Intensity (I_H) values of the Aquilano mainshock and of the NTC-08 Italian Code for return periods equal to 475 and 2475 years (horizontal directions).

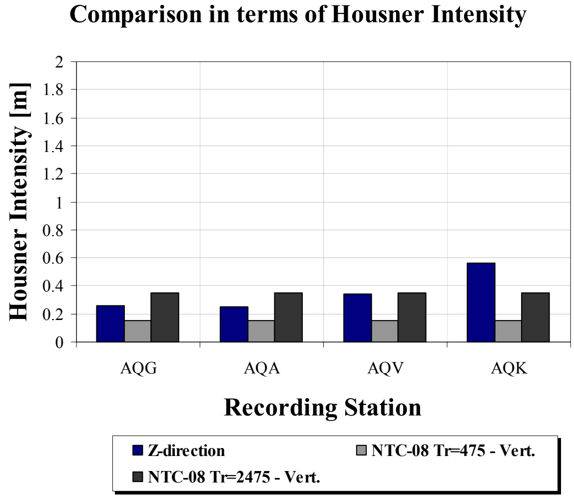

Figure 17. Comparison of the Housner Intensity (I_H) values of the Aquilano mainshock and of the NTC-08 Italian Code for return periods equal to 475 and 2475 years (vertical directions).

References

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