



CONSIDERAZIONI DI INGEGNERIA SISMICA SUL TERREMOTO DELL'ITALIA CENTRALE DEL 24 AGOSTO 2016



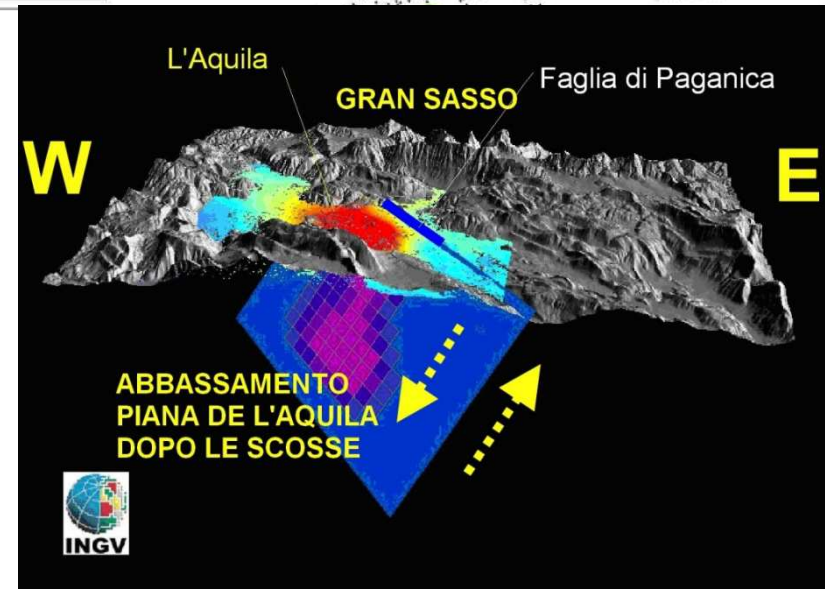
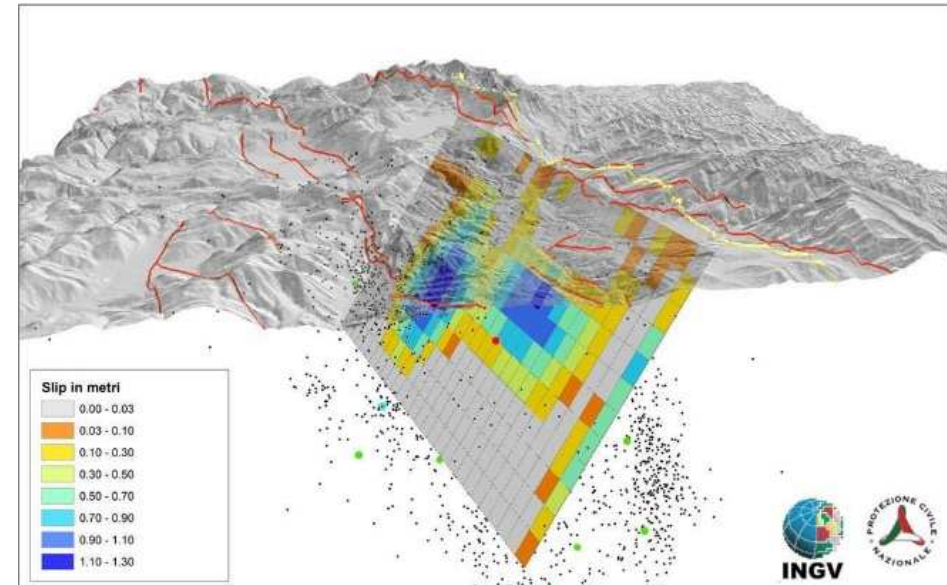
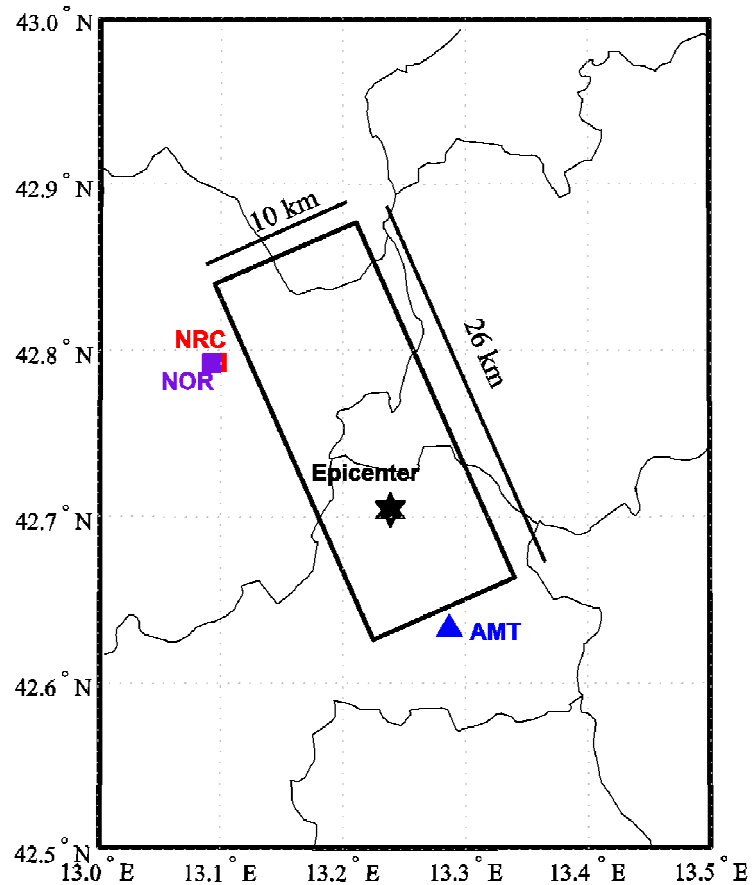
Italian Concrete Days, AICAP e CTE, 27-28 Ottobre 2016

Prof. Edoardo Cosenza

Dipartimento di Strutture per l'Ingegneria e l'Architettura - Università di Napoli Federico II



REMARKS ON THE GROUND MOTION DATA



- 24th August 2016: earthquake of Mw 6.0 - 6.2 (depending on the method adopted)
- Seismic classification:
“II Categoria” Amatrice 1927; Norcia 1962
- Fault rupture plane: lift towards Adriatic sea and slip down towards Tirrenio sea



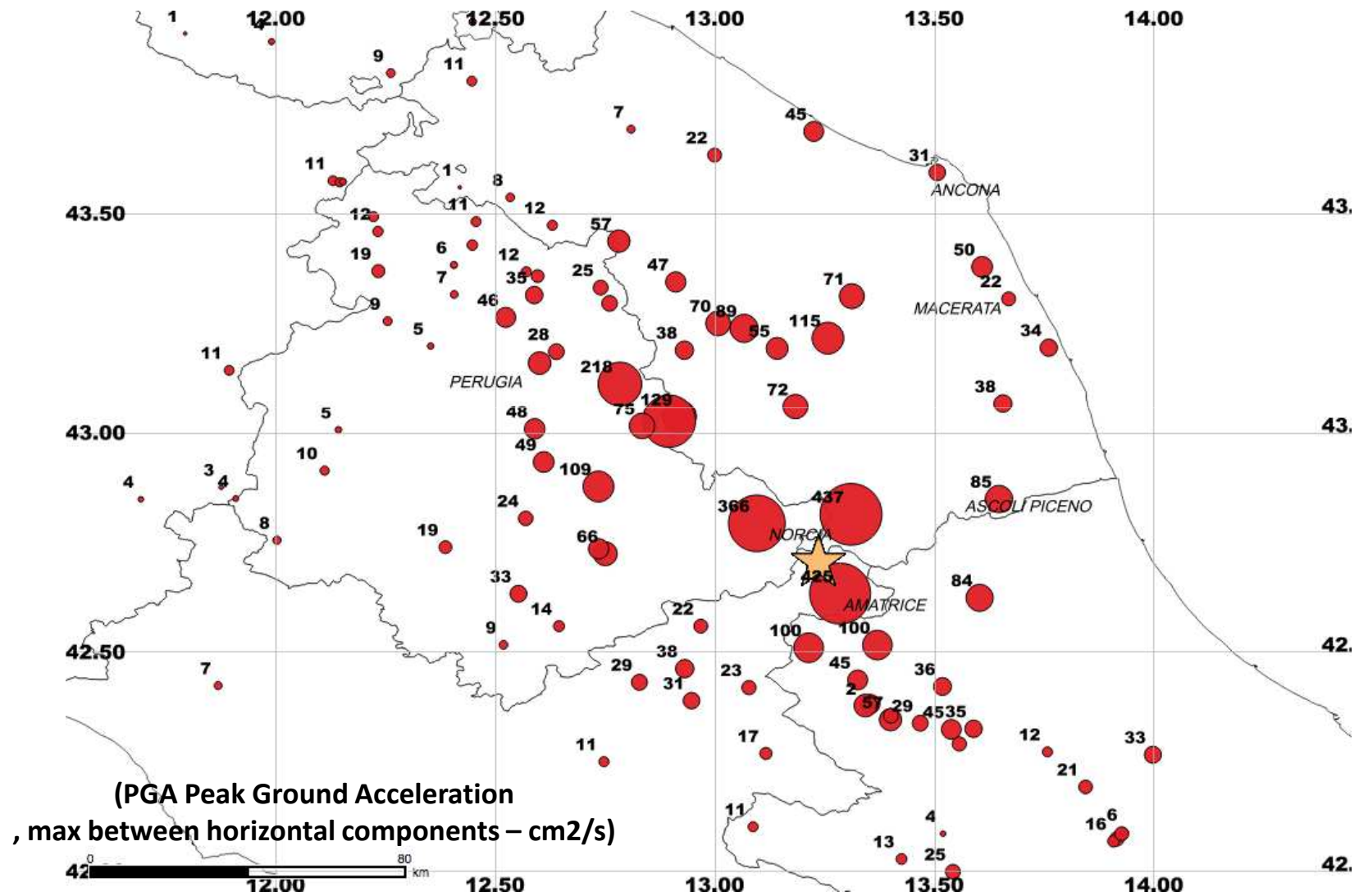
REMARKS ON THE GROUND MOTION DATA

Nome Stazione	R _{epj} [km]	R _{jib} [km]	Classe suolo	di	PGA _E [g]	PGA _N [g]	q _{PGA} [°]	Max PGA [g]	q _{PGV} [°]	Max PGV [cm/s]	q _{PGD} [°]	Max PGD [cm]
AMT	8.9	1.38	B*		0.43	0.19	91	0.43	74	22.37	1	4.26
NRC	13.7	2.01	B		0.36	0.37	145	0.45	80	30.21	38	8.19
NOR	15.6	2.31	C*		0.20	0.18	48	0.20	79	27.58	37	8.48
MMO1	23.5	9.7	A*		0.12	0.14	154	0.15	163	9.13	175	2.04
PCB	17.8	10.66	B*		0.19	0.31	0	0.31	150	14.77	159	3.23
CSC	18.3	11.64	B		0.11	0.08	117	0.12	15	8.00	65	2.33
RM33	22.3	13.01	B*		0.10	0.10	104	0.11	108	9.80	85	2.41
FEMA	32.9	13.92	B*		0.25	0.19	84	0.25	101	14.66	140	4.07
MSC	21.3	14.27	B*		0.11	0.08	120	0.11	111	8.26	125	2.36
MSCT	21.4	14.27	B*		0.11	0.08	118	0.12	110	8.49	124	2.42
SPD	23.7	16.12	B*		0.05	0.10	9	0.10	16	7.93	6	1.79
MNF	38.9	20.37	A*		0.07	0.04	69	0.08	96	4.79	169	1.45
TERO	32.9	22.12	B*		0.06	0.09	176	0.09	166	4.43	148	1.81
LSS	27.4	22.22	A		0.02	0.02	112	0.02	41	2.42	31	0.74
PZI1	30.7	22.73	B*		0.05	0.05	58	0.05	160	4.99	58	1.51
ANT	34.3	26.01	A*		0.01	0.02	25	0.03	17	3.99	179	1.46
CLF	43.8	26.11	D		0.13	0.13	129	0.14	27	13.06	23	2.19
FOC	44	26.3	C*		0.26	0.33	20	0.35	14	10.47	160	1.42
FOS	47.7	28.75	B*		0.06	0.08	40	0.09	37	5.37	1	1.54
AQF	37.2	29.28	B*		0.04	0.04	92	0.04	113	2.85	137	1.22
AQV	37.3	29.31	B		0.06	0.05	84	0.06	125	4.78	146	1.04
AQA	37.4	29.36	E		0.00	0.00	2	0.00	137	0.26	76	0.07
TRE	43.7	29.62	C*		0.06	0.11	33	0.12	40	9.20	179	2.09



REMARKS ON THE GROUND MOTION DATA

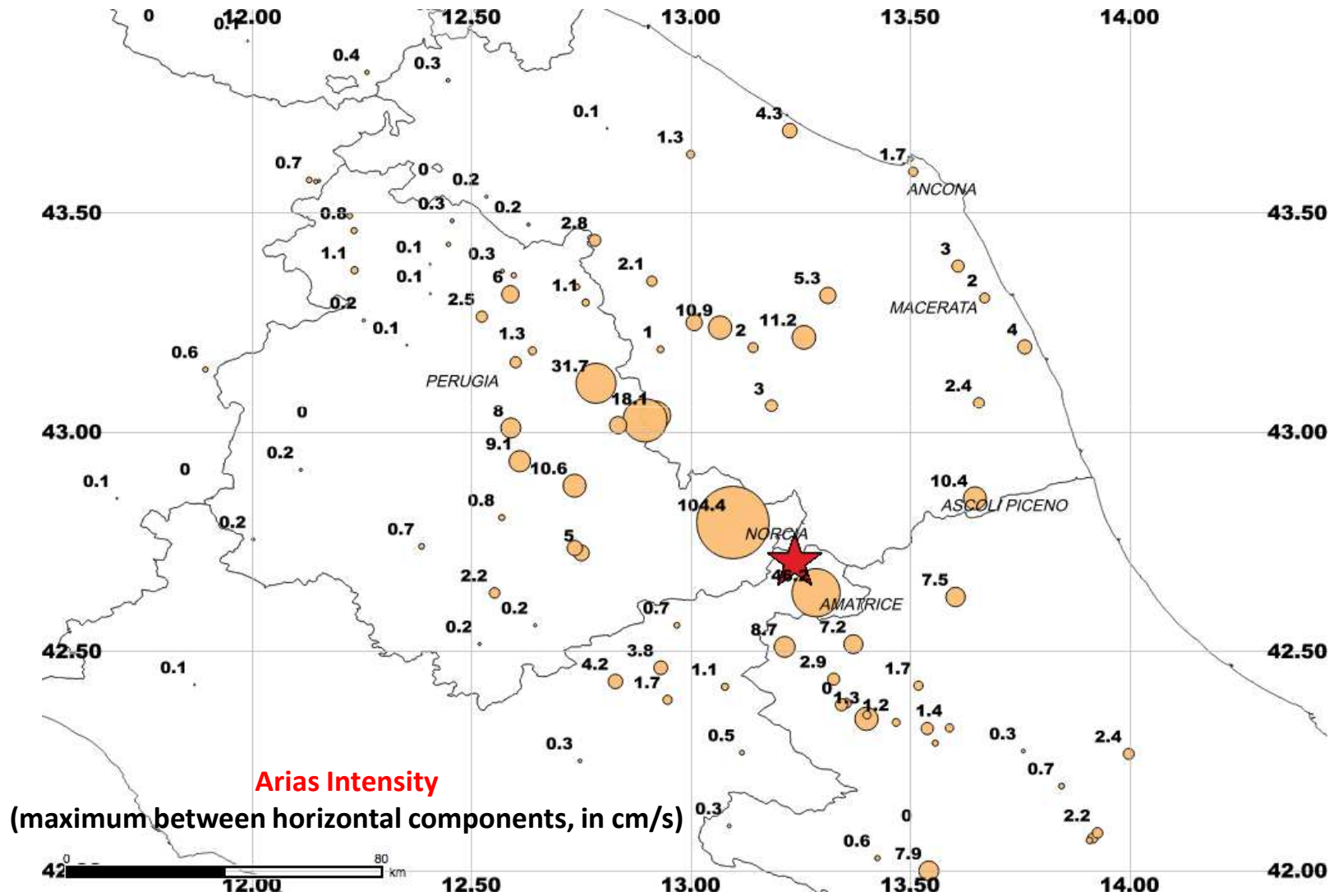
Source: Preliminary study of Rieti Earthquake ground data V5, DIST, INGV, CNR/ITC, Reluis





REMARKS ON THE GROUND MOTION DATA

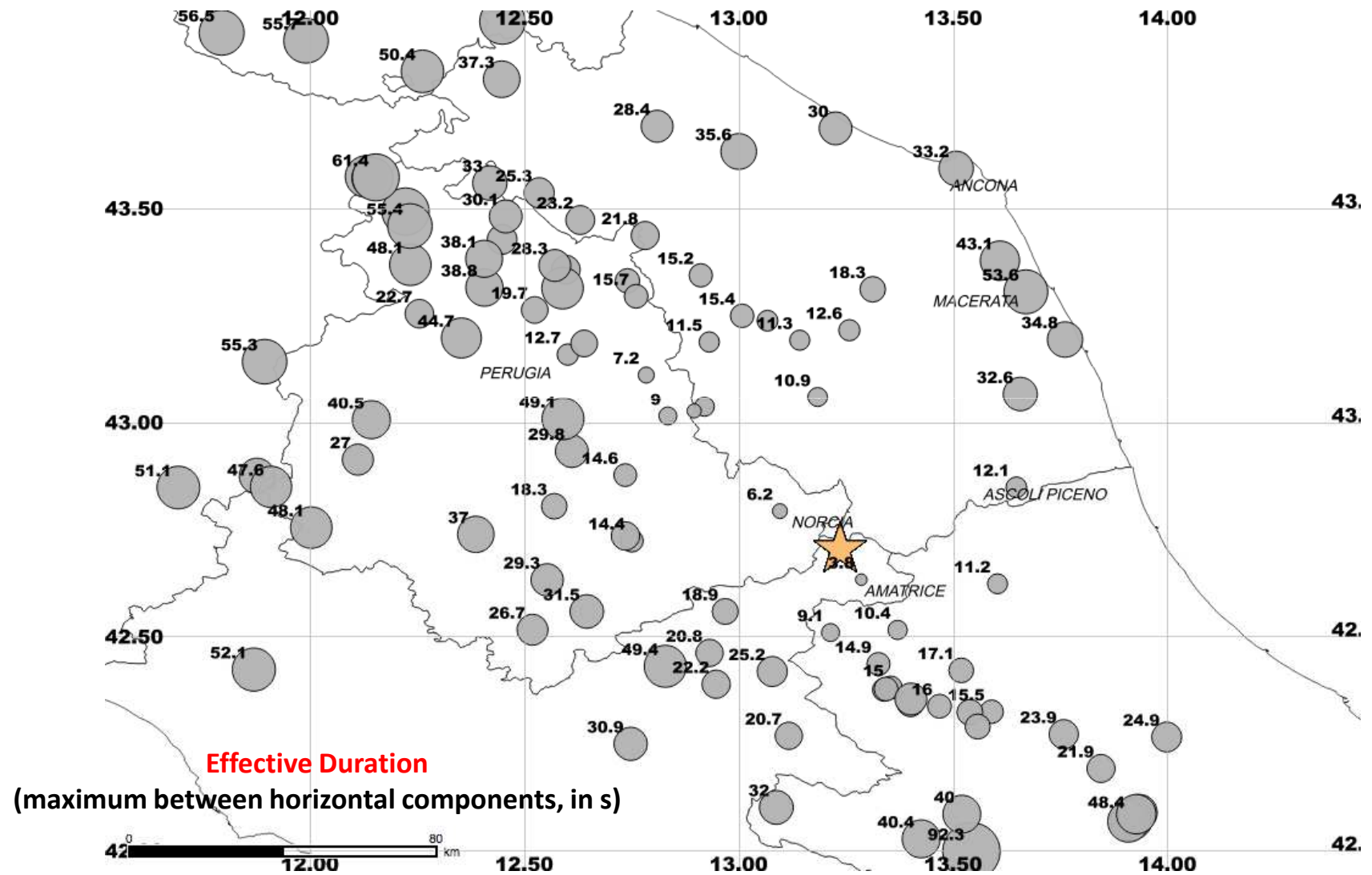
Source: Preliminary study of Rieti Earthquake ground data V5, DIST, INGV, CNR/ITC, Reluis





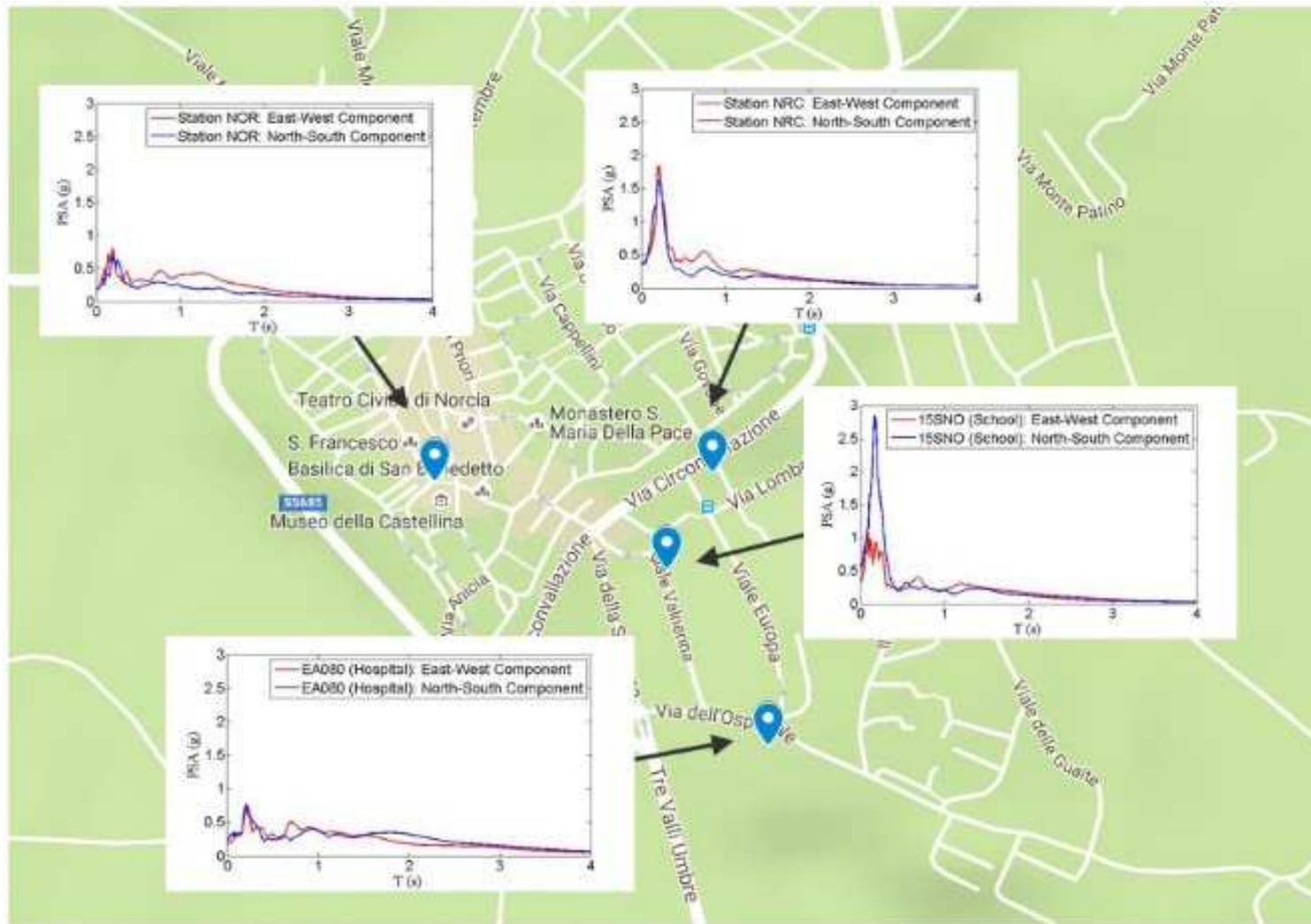
REMARKS ON THE GROUND MOTION DATA

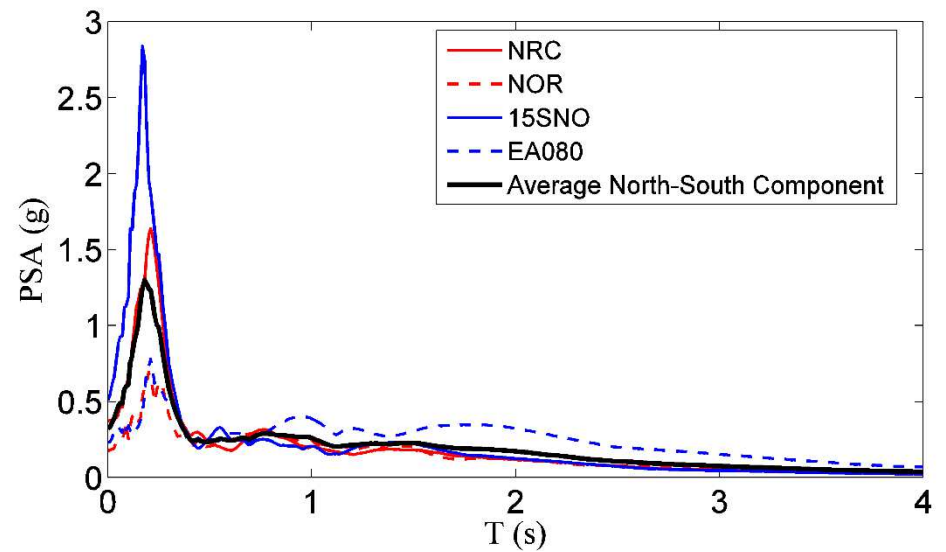
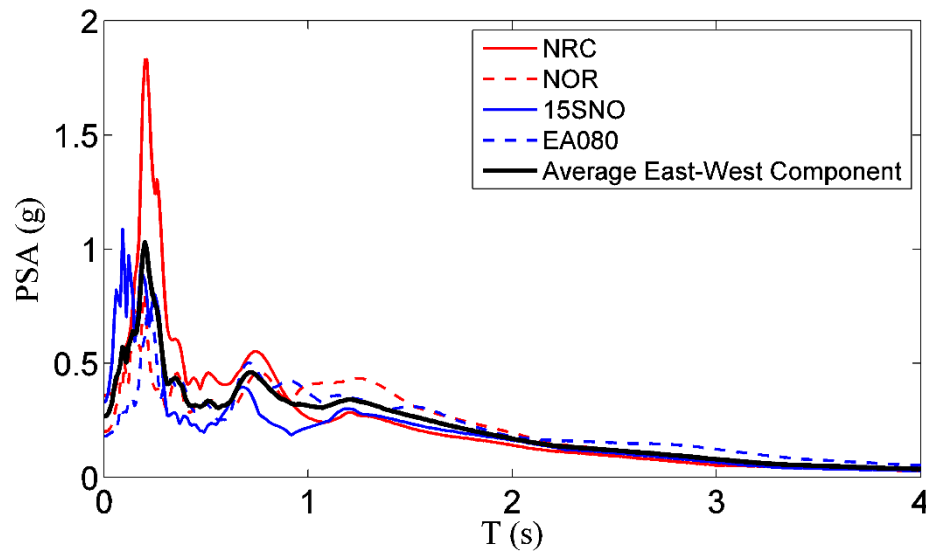
Source: Preliminary study of Rieti Earthquake ground data V5, DIST, INGV, CNR/ITC, Reluis





NORCIA, DIFFERENT ACCELERATION SPECTRA

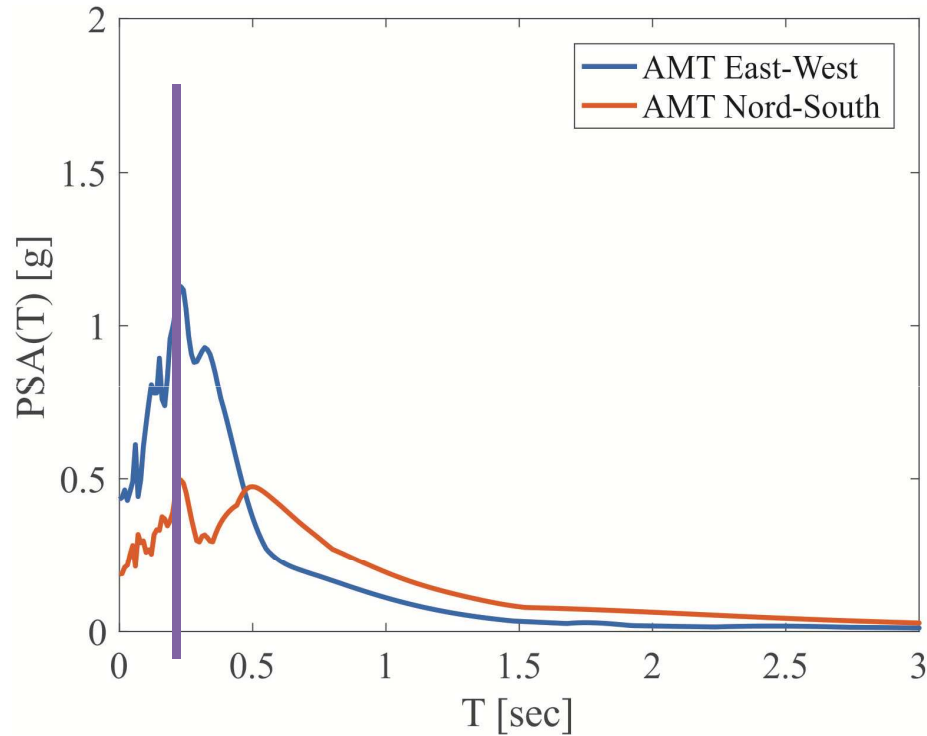




Component	Station	Station Code	PGA (g)	$T_{PSA_{max}}$ (s)	PSA_{max} (g)
East-West	Norcia	NRC	0.359	0.21	1.831
	Norcia le Castelline	NOR	0.202	0.20	0.804
	Scuola Media	15SNO	0.329	0.09	1.089
	Ospedale	EA080	0.181	0.22	0.744
North-South	Norcia	NRC	0.373	0.21	1.637
	Norcia le Castelline	NOR	0.180	0.20	0.694
	Scuola Media	15SNO	0.508	0.17	2.840
	Ospedale	EA080	0.231	0.21	0.779

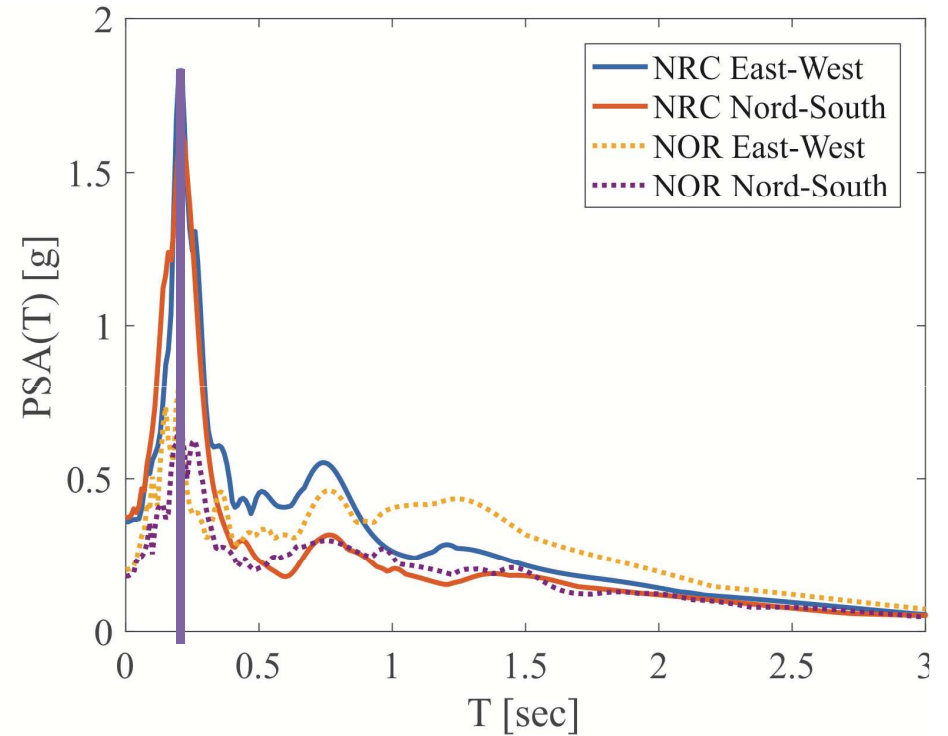


REMARKS ON THE GROUND MOTION DATA AND STRUCTURAL DYNAMICS



AMATRICE
(distanza 8,9 km)

Acc Peak at 0,23 sec

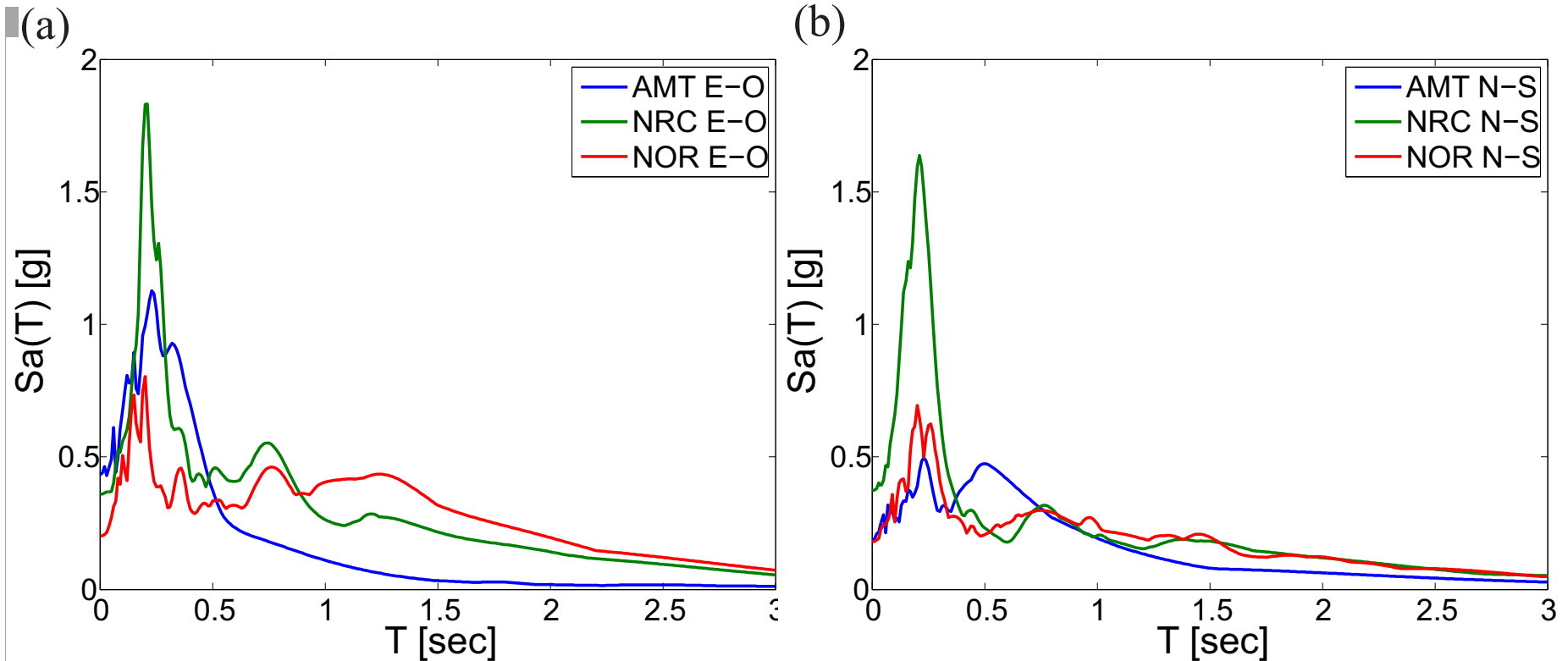


NORCIA
(distanza 13,7 km)

Acc Peak at 0,20-0,21 sec



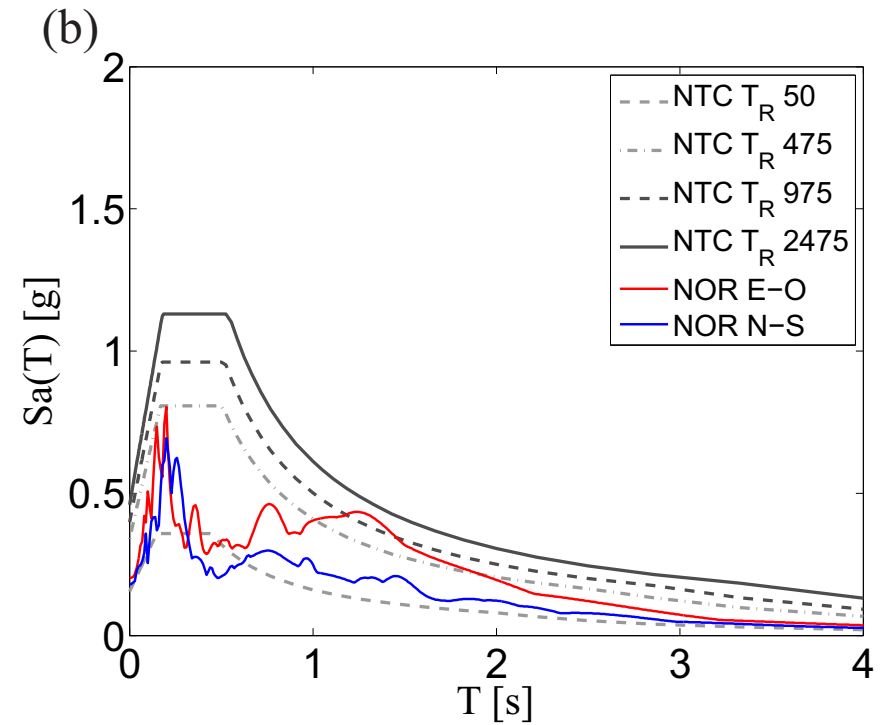
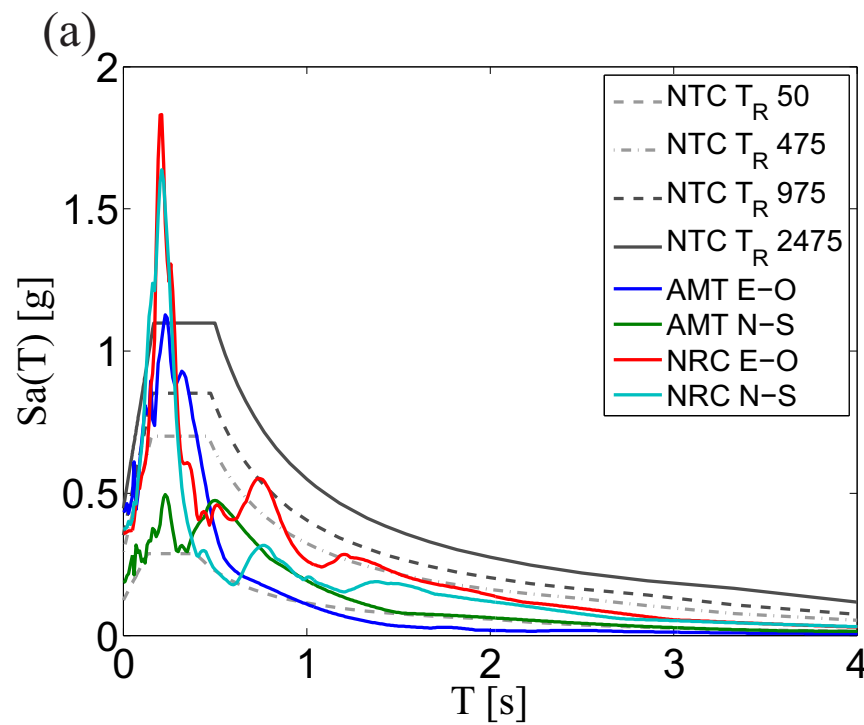
REMARKS ON THE GROUND MOTION DATA AND STRUCTURAL DYNAMICS



Acc Peak at 0,20- 0,23 sec



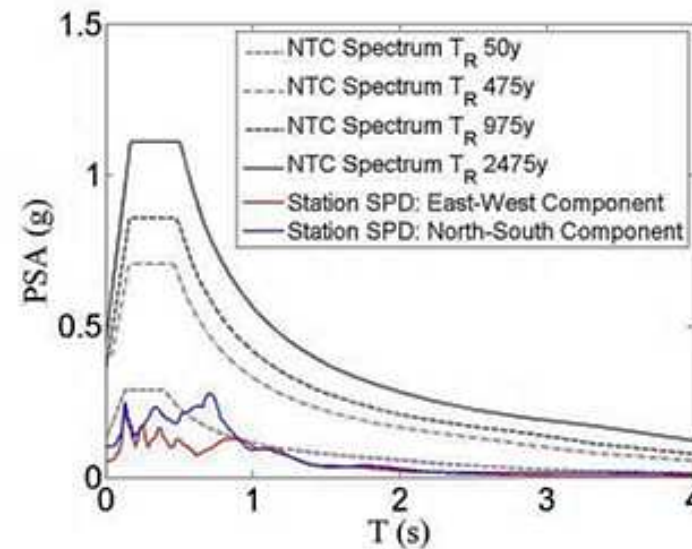
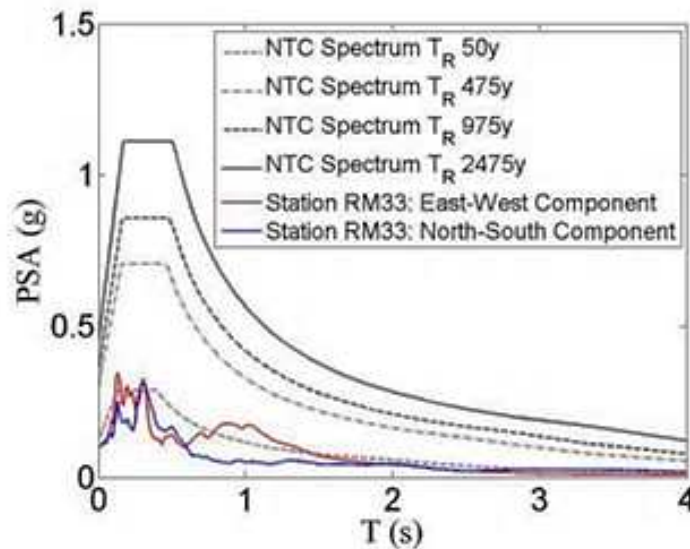
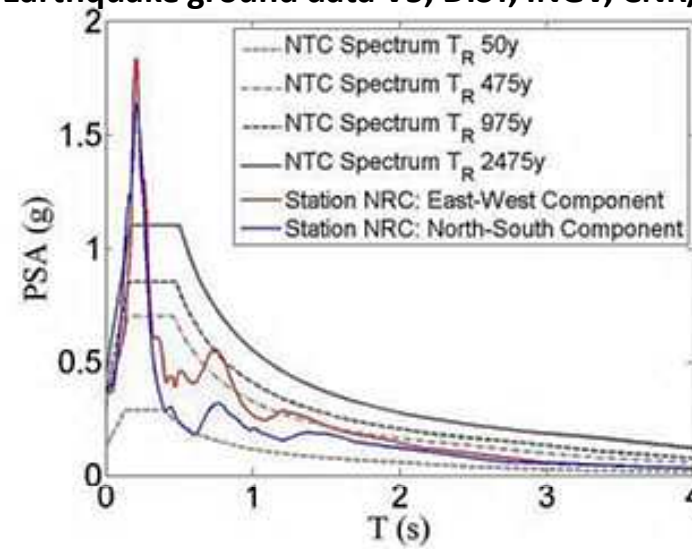
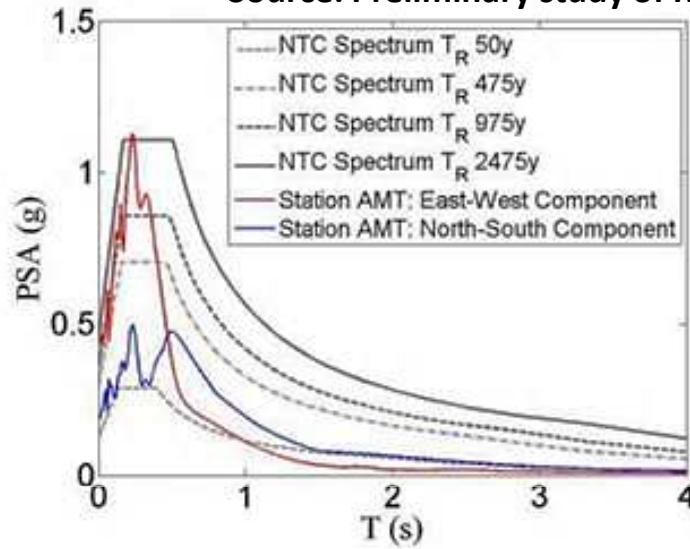
REMARKS ON THE GROUND MOTION DATA AND SEISMIC CODE





REMARKS ON THE GROUND MOTION DATA AND STRUCTURAL DYNAMICS

Source: Preliminary study of Rieti Earthquake ground data V5, DIST, INGV, CNR/ITC, Reluis



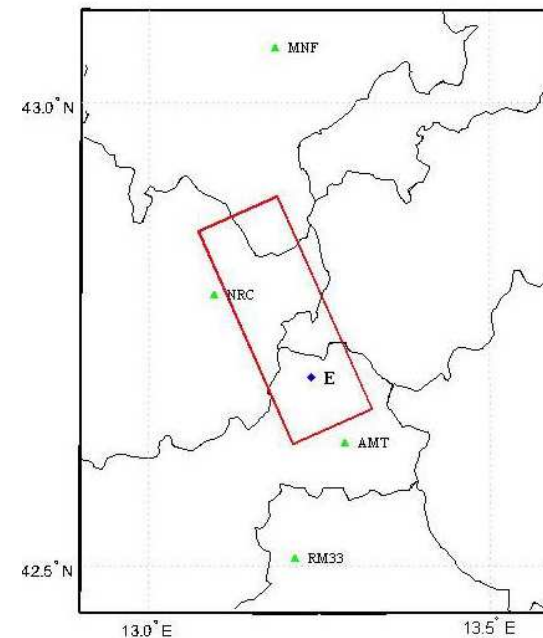
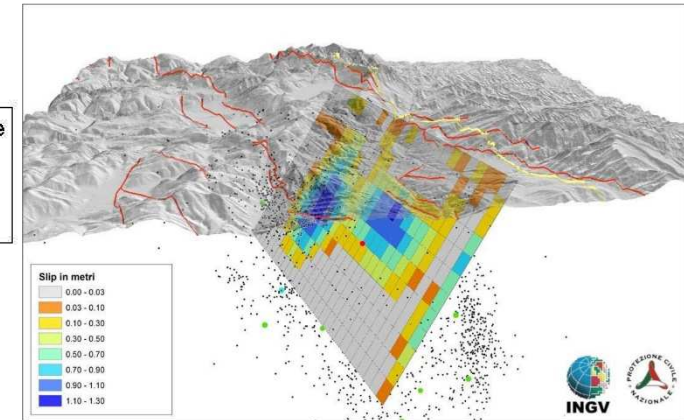
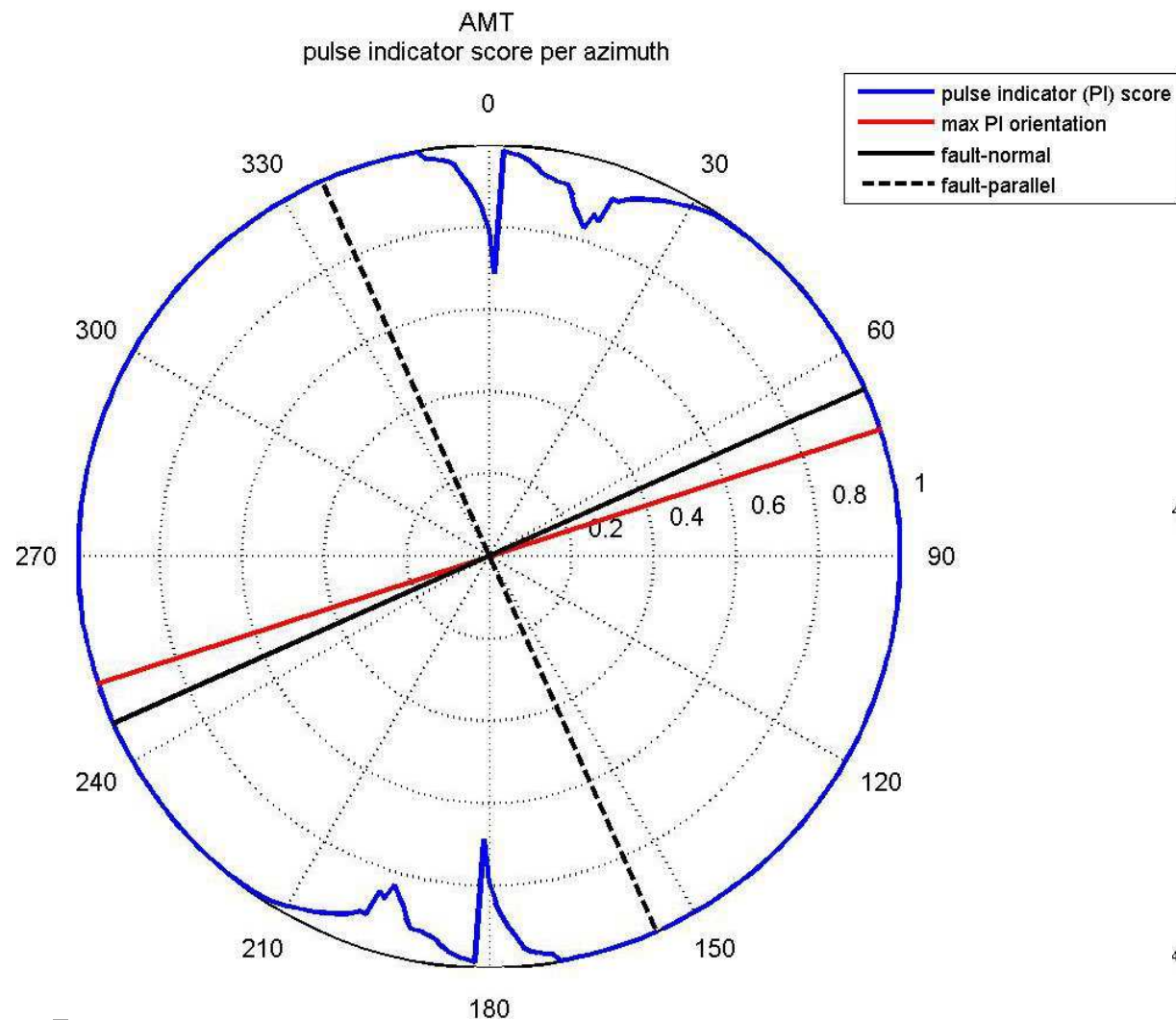


REMARKS ON THE GROUND MOTION DATA/PULSE-LIKE

Source: Preliminary study of Rieti Earthquake ground data V5, DIST, INGV, CNR/ITC, Reluis

AMATRICE

(distance: 8,9 km)

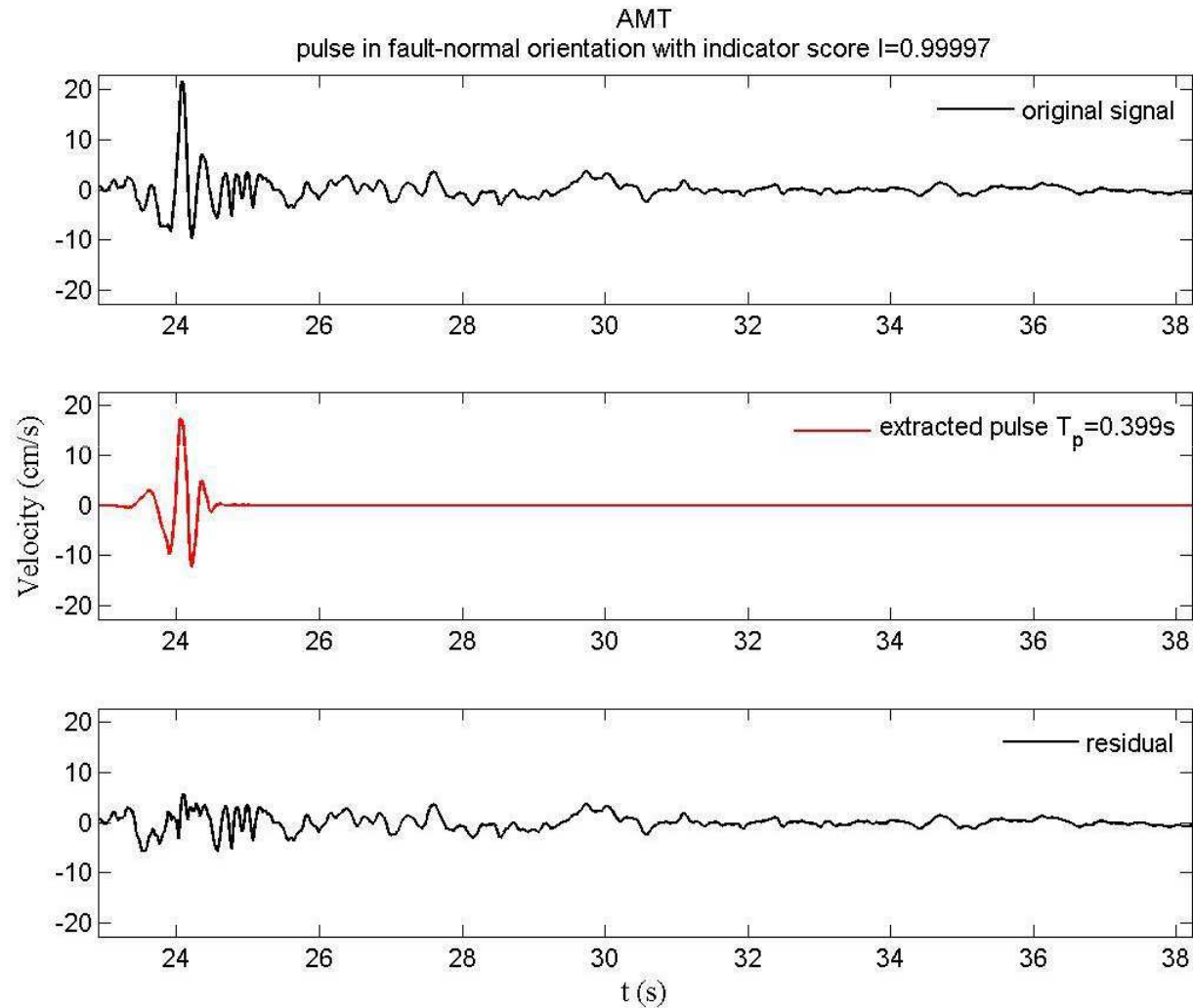




REMARKS ON THE GROUND MOTION DATA/ PULSE-LIKE

Source: Preliminary study of Rieti Earthquake ground data V5, DIST, INGV, CNR/ITC, Reluis

AMATRICE – in fault normal orientation (distance: 8,9 km)





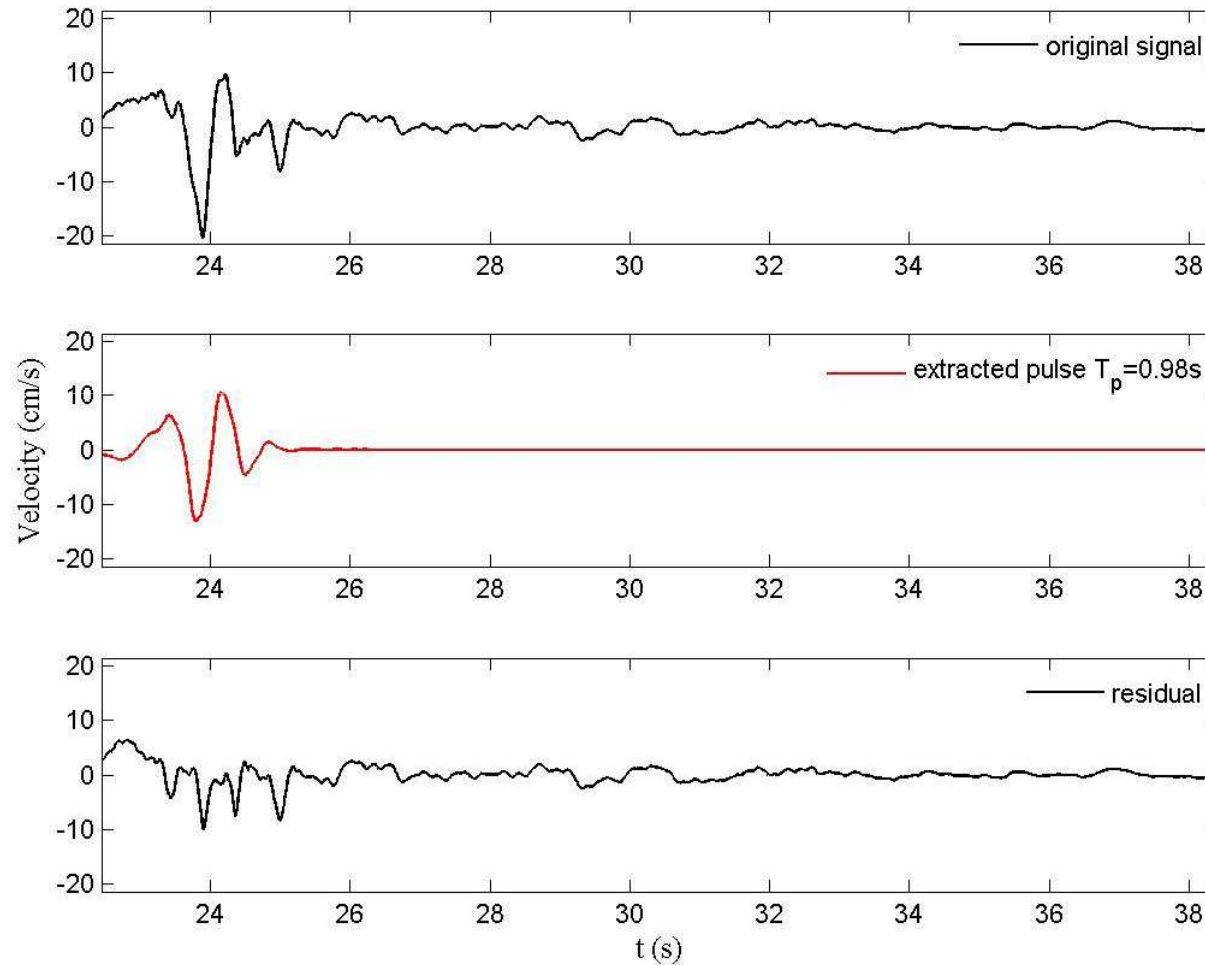
REMARKS ON THE GROUND MOTION DATA/ PULSE-LIKE

Source: Preliminary study of Rieti Earthquake ground data V5, DIST, INGV, CNR/ITC, Reluis

AMATRICE – in fault parallel orientation (distance: 8,9 km)

AMT

pulse in fault-parallel orientation with indicator score $I=0.99944$



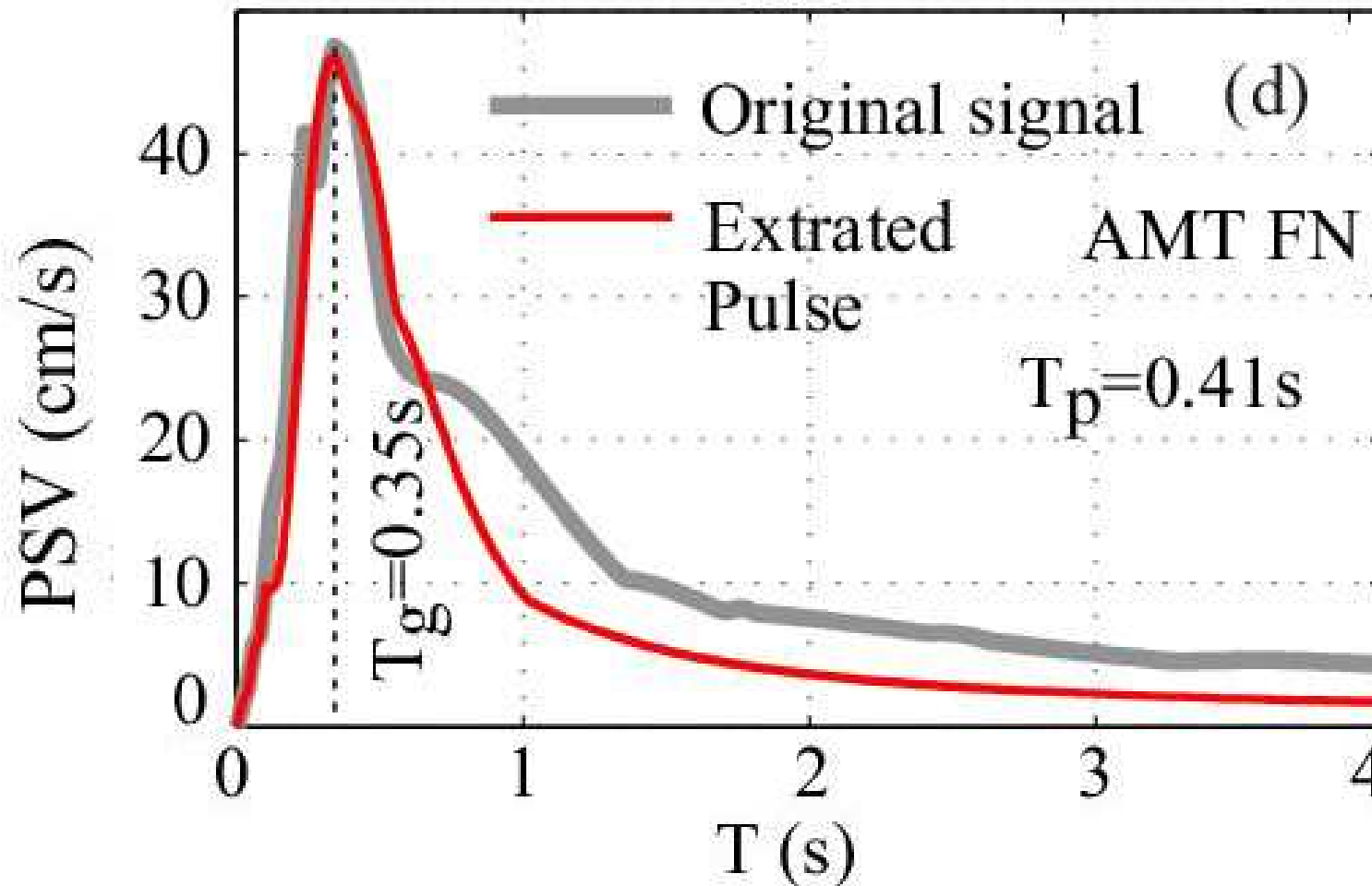


REMARKS ON THE GROUND MOTION DATA/ PULSE-LIKE

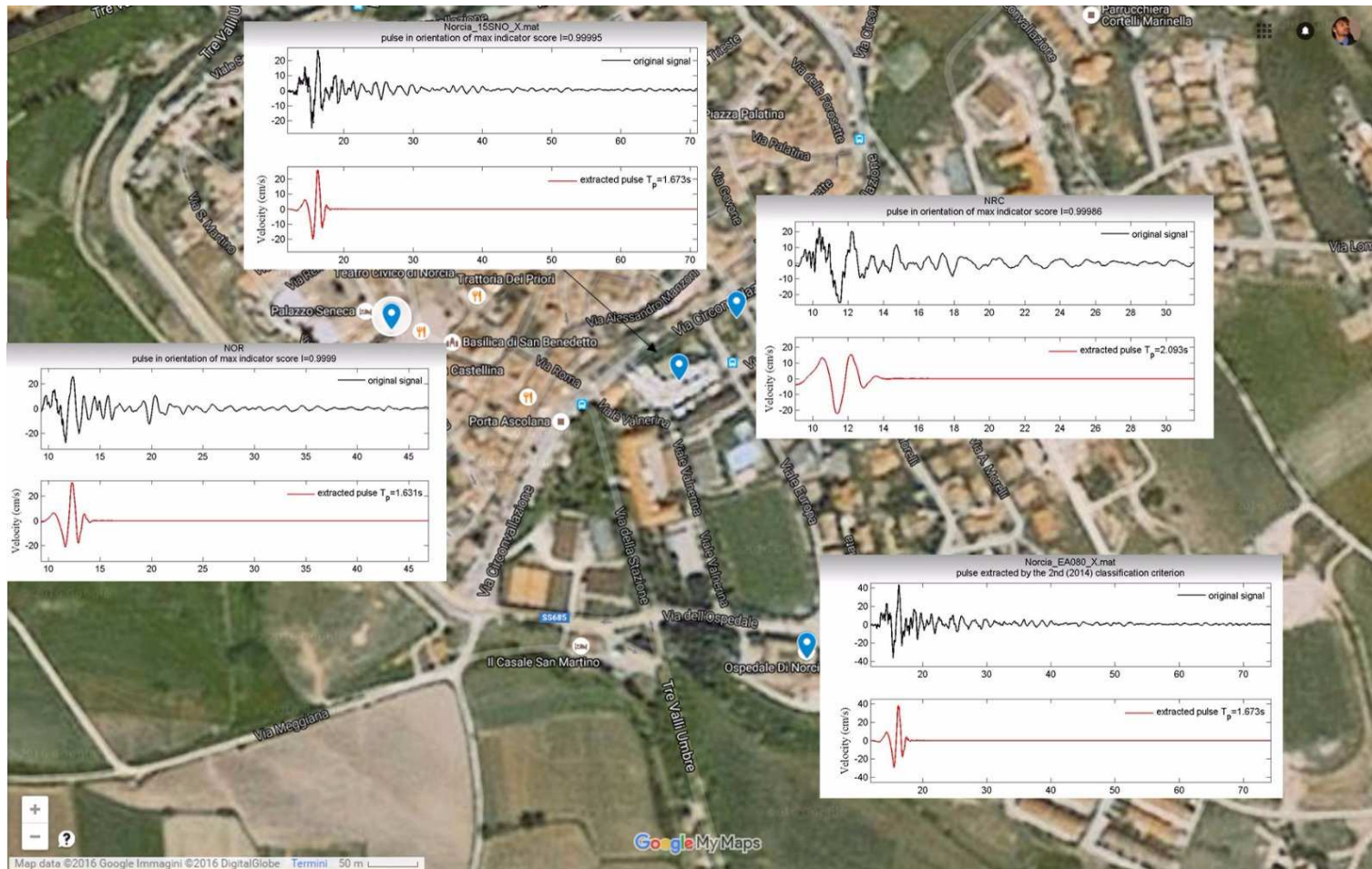
Source: Iervolino, Baltzopoulos, Chioccarelli, Annals of Geophysics, 2016

AMATRICE

(distance: 8,9 km)



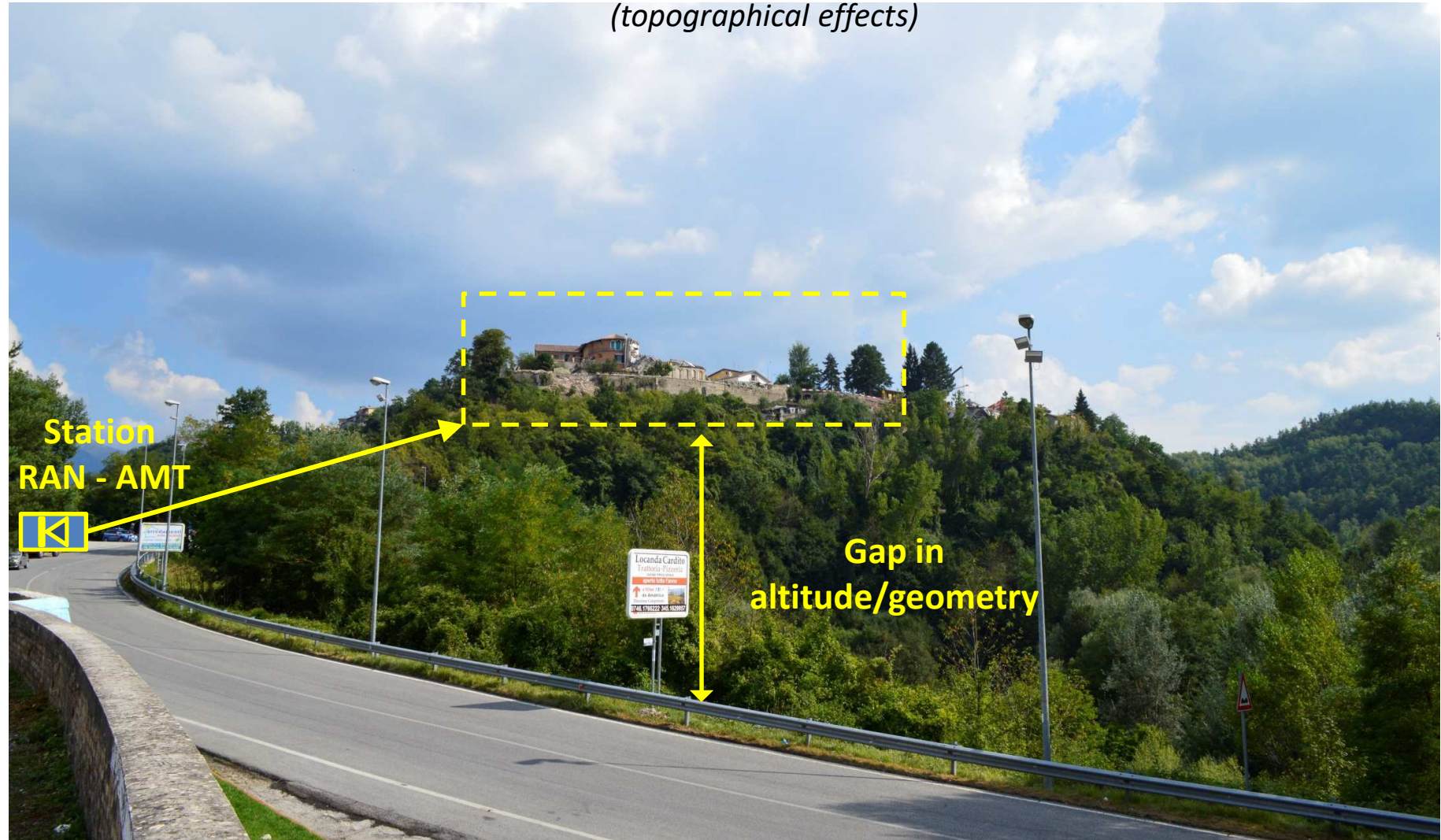
Source: Iervolino, Baltzopoulos, Chioccarelli, 2016





MAIN FEATURES OF AMATRICE MUNICIPALITY

*Position of the station RAN – AMT with reference to downtown/historic center
(topographical effects)*





SEISMIC DAMAGE OBSERVED IN AMATRICE MUNICIPALITY

Damage observed at the top of the gap in altitude

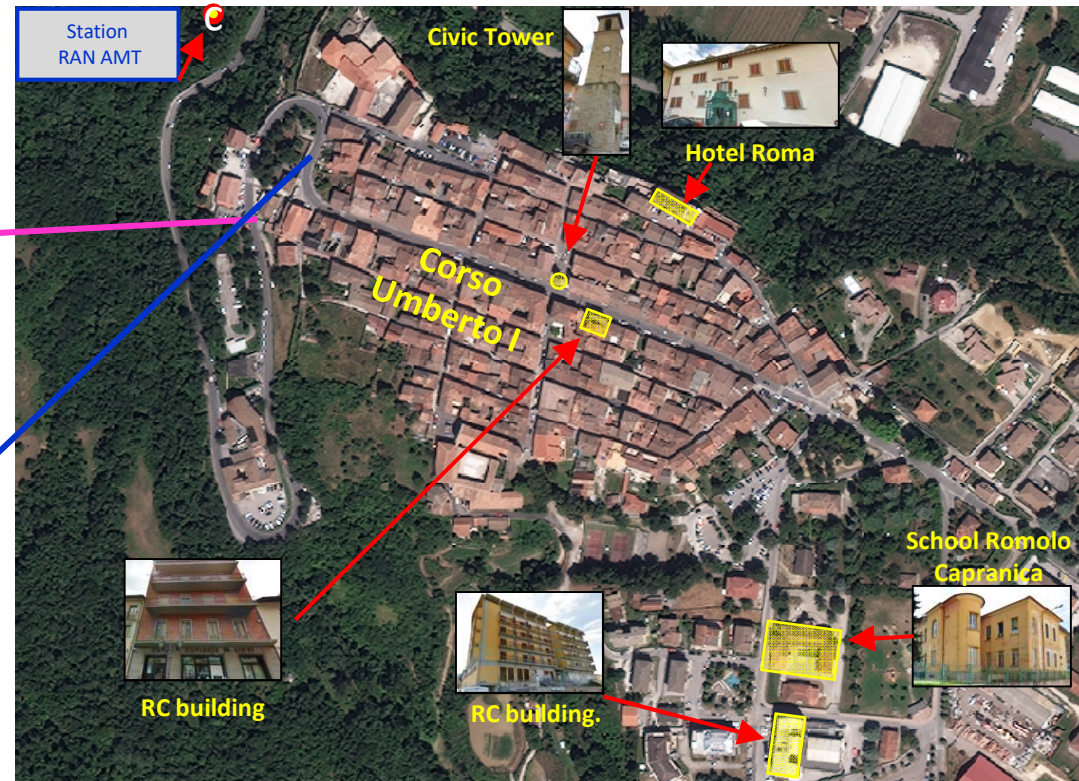






SEISMIC DAMAGE OBSERVED IN AMATRICE

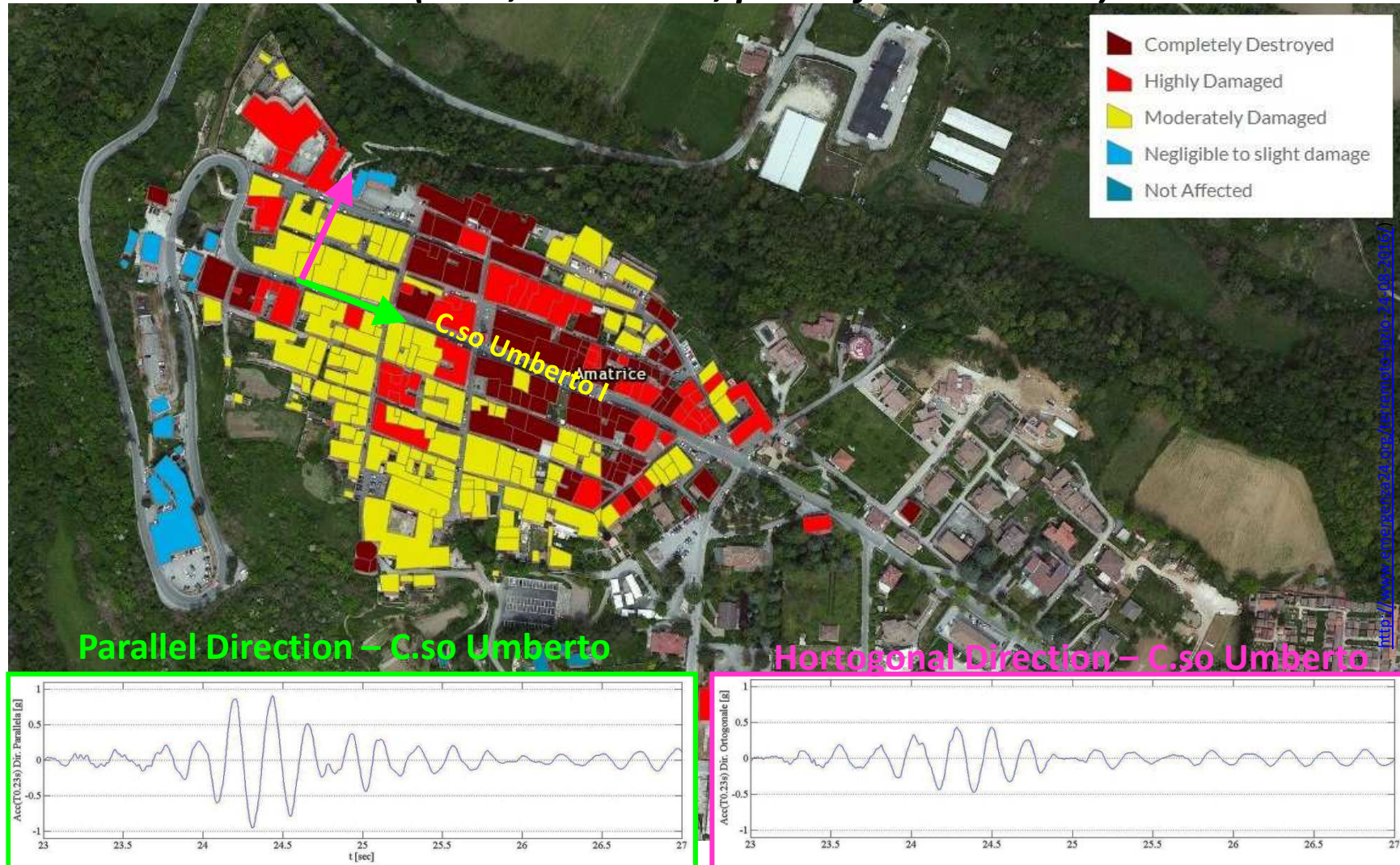
Damage of roads and perimeter masonry wall





SEISMIC DAMAGE OBSERVED IN AMATRICE

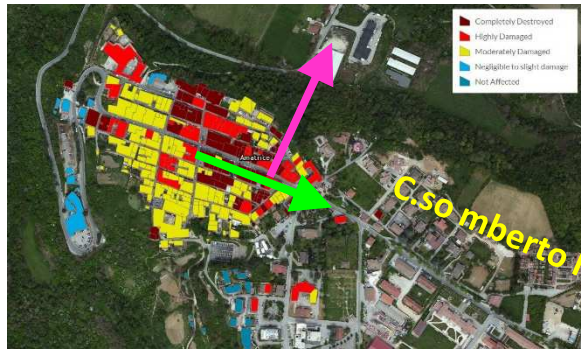
Acceleration history for parallel and normal direction with reference to Corso Umberto I
($T = 0,23$ seconds, peak of acceleration)



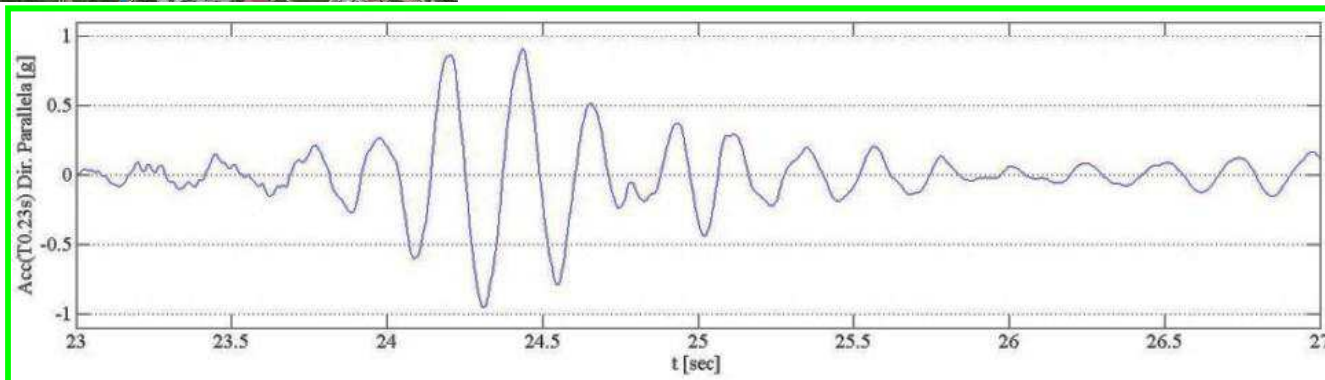


SEISMIC DAMAGE OBSERVED IN AMATRICE

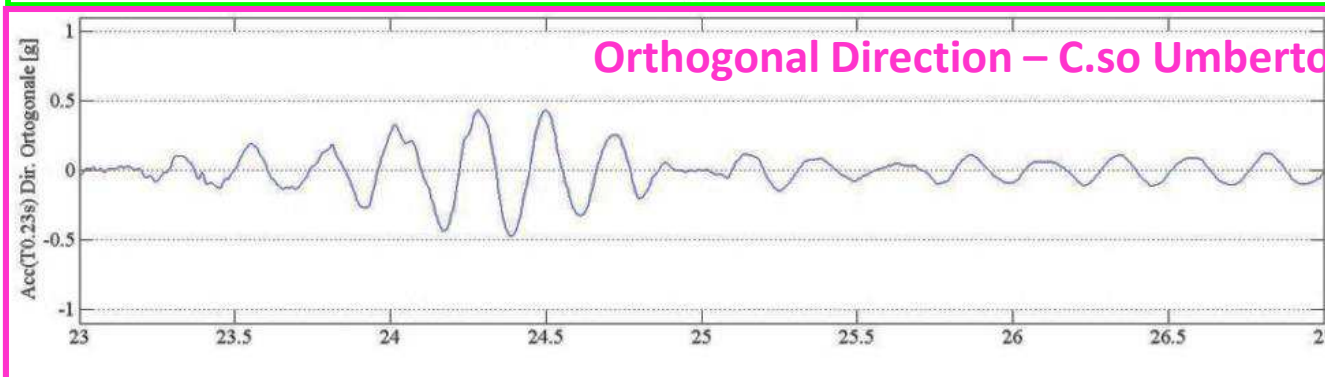
Acceleration history for parallel and normal direction with reference to Corso Umberto I
($T = 0,23$ seconds, peak of acceleration)



Parallel Direction – C.so Umberto



Orthogonal Direction – C.so Umberto

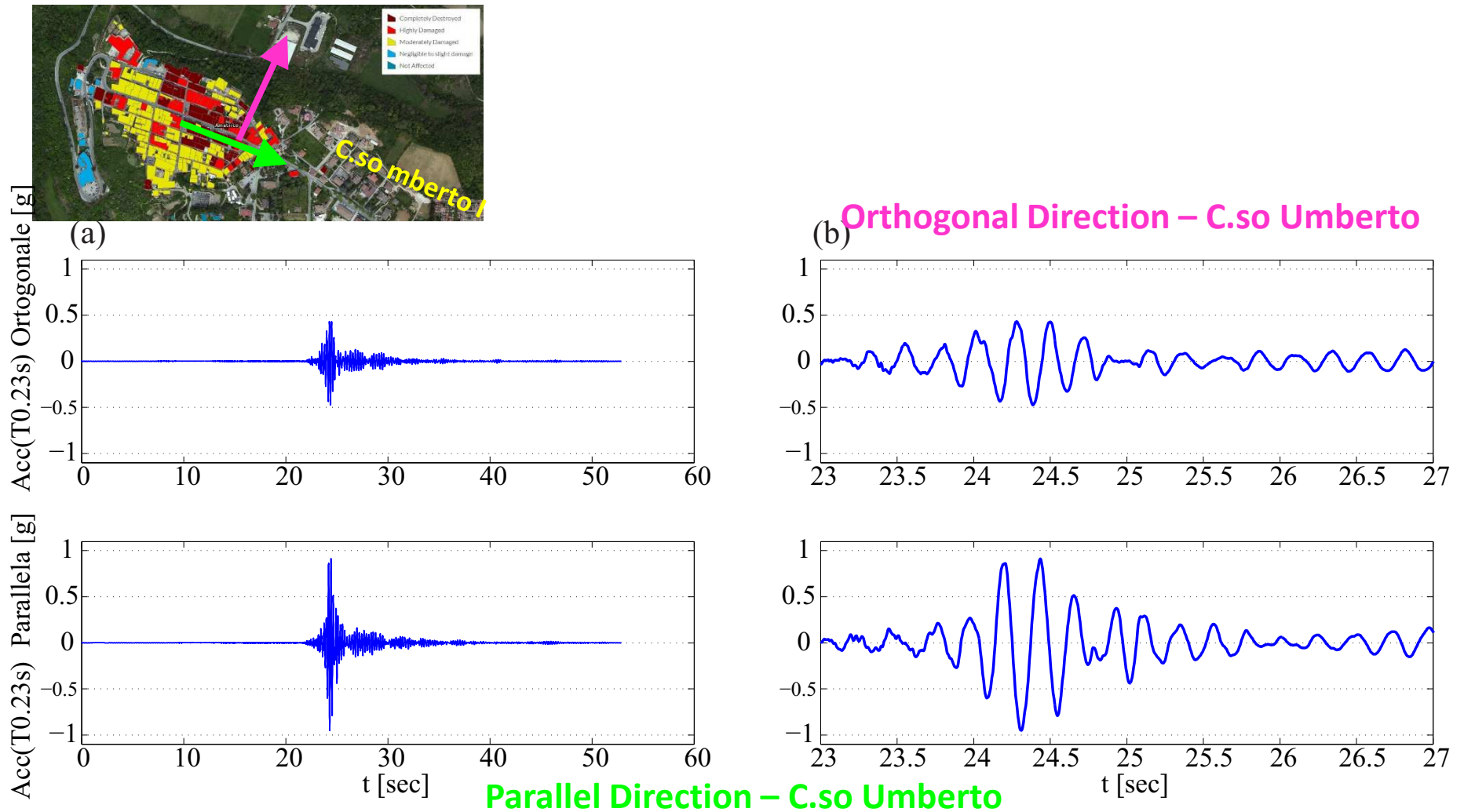


<http://www.emergenza24.org/terremoto-lazio-24-08-2016/>



SEISMIC DAMAGE OBSERVED IN AMATRICE

Acceleration history for parallel and normal direction with reference to Corso Umberto I
($T = 0,23$ seconds, peak of acceleration)





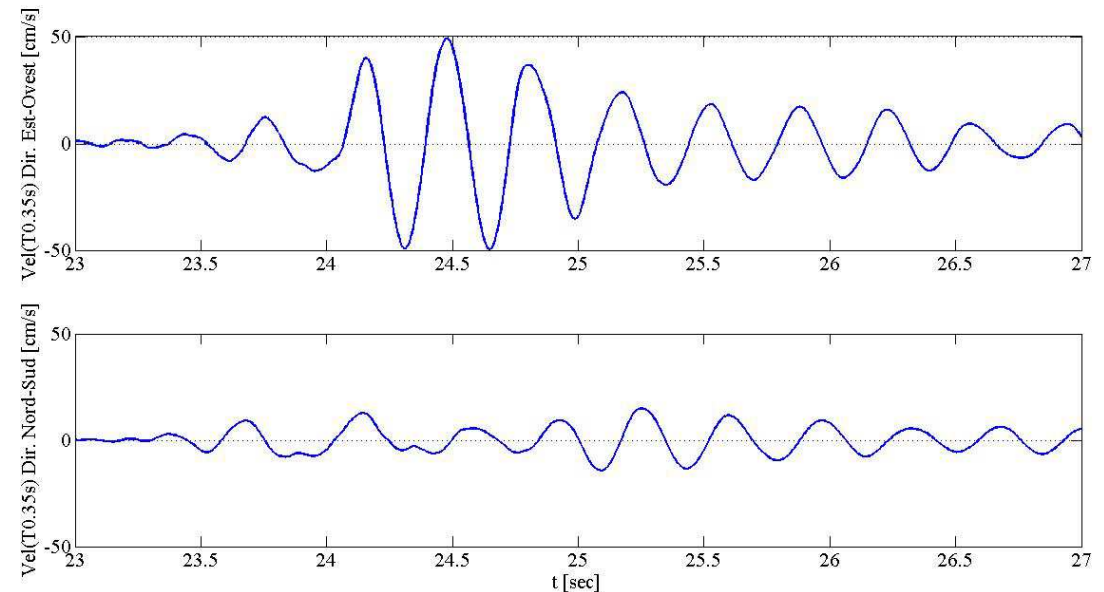
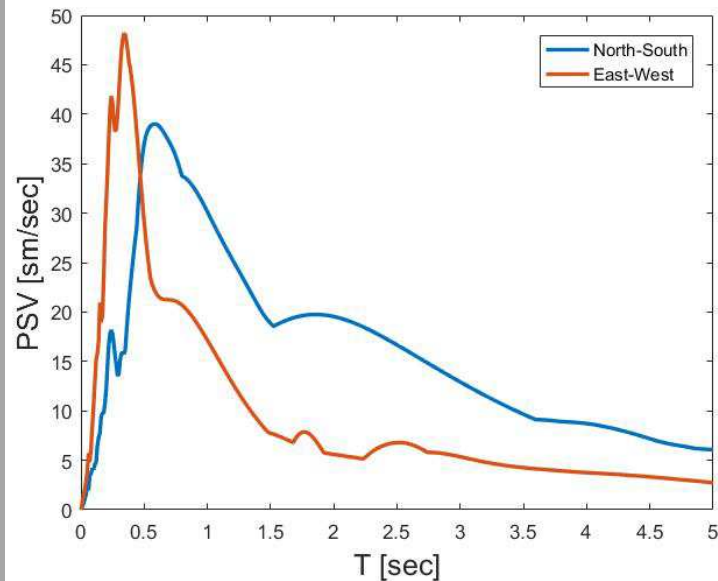
CONSIDERATIONS ABOUT VELOCITY RECORDS

AMATRICE

(distance: 8,9 km)

SDoF - $T = 0.35$ second (Peak of Velocity Spectra)

East-West e North-South components





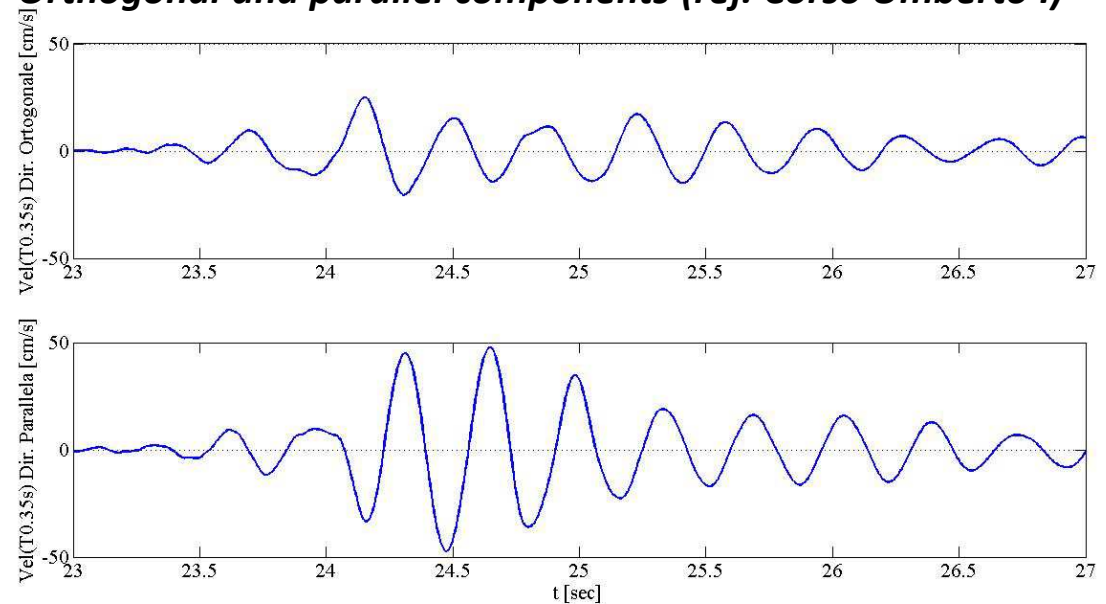
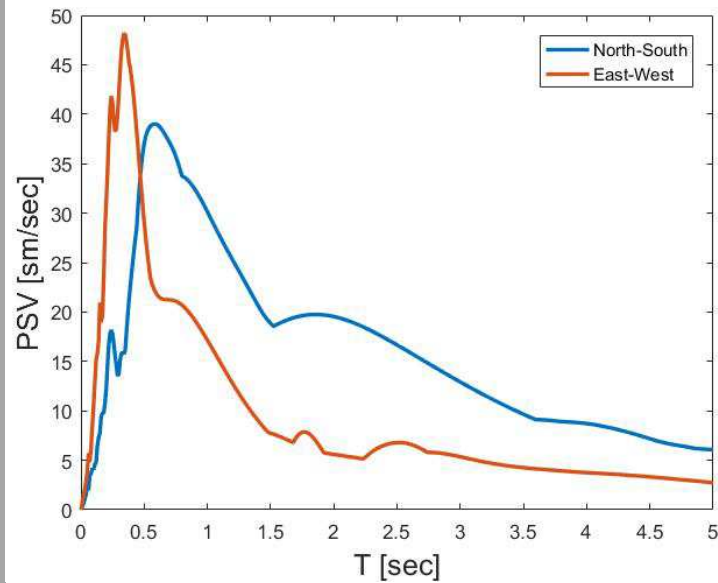
CONSIDERATIONS ABOUT VELOCITY RECORDS

AMATRICE

(distance: 8,9 km)

SDoF - $T = 0.35$ second

Orthogonal and parallel components (ref. Corso Umberto I)





SEISMIC DAMAGE OBSERVED IN AMATRICE

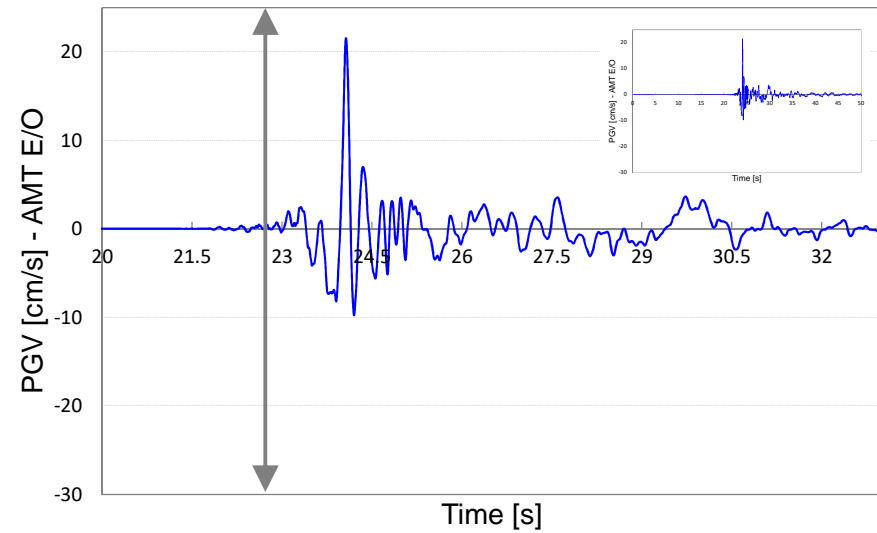
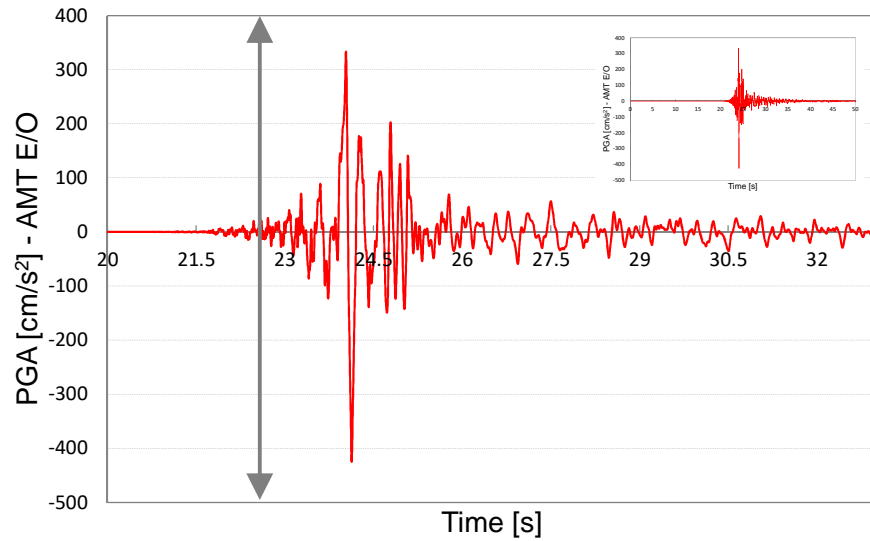
Video recordings in a supermarket located nearby Corso Umberto I (piazza centrale)





SEISMIC DAMAGE OBSERVED IN AMATRICE

Video recordings in a supermarket located nearby Corso Umberto I (piazza centrale)





SEISMIC DAMAGE OBSERVED IN AMATRICE

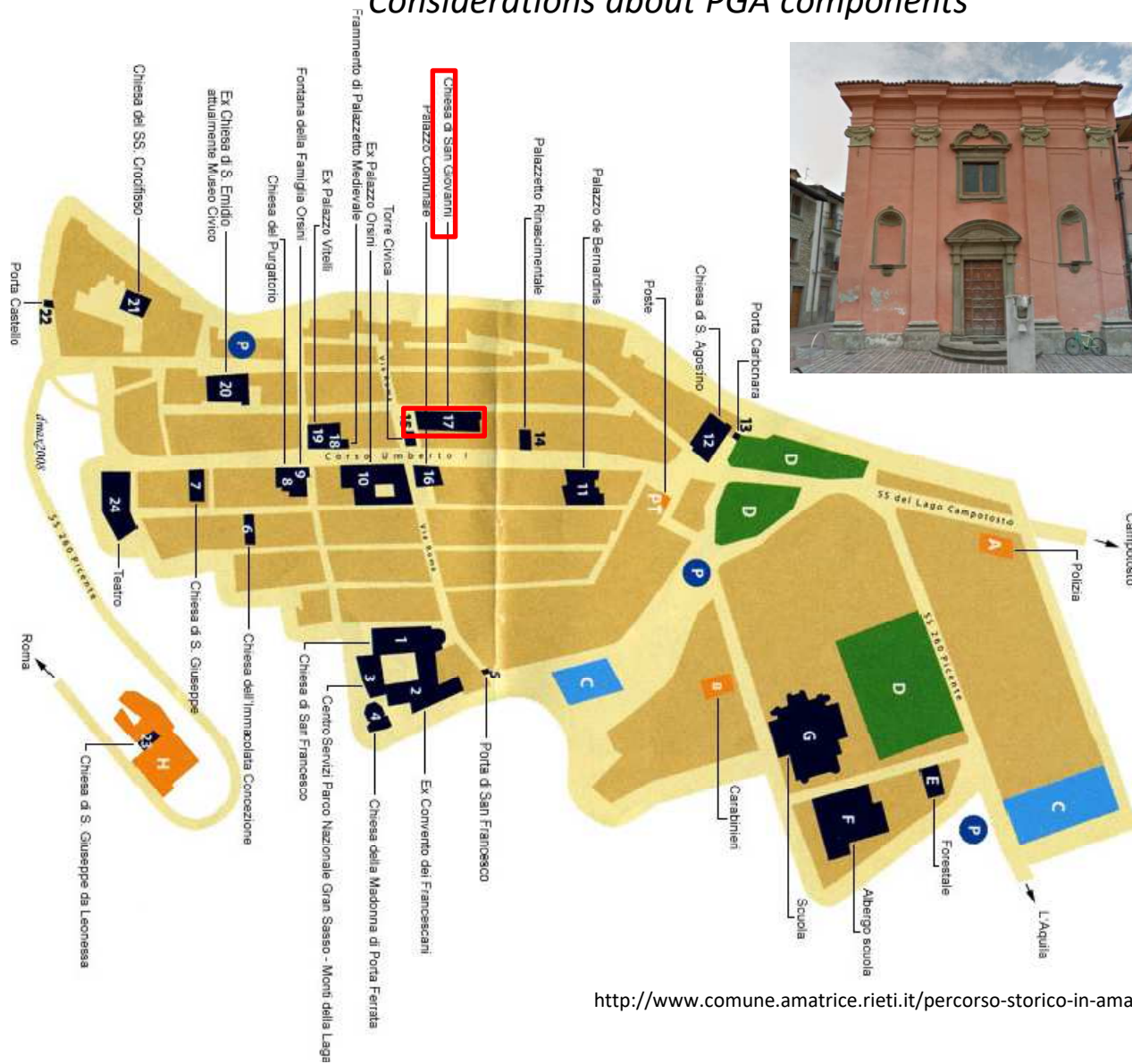
Video recordings in a supermarket located nearby Corso Umberto I (piazza centrale)





SEISMIC DAMAGE OBSERVED IN AMATRICE

Considerations about PGA components

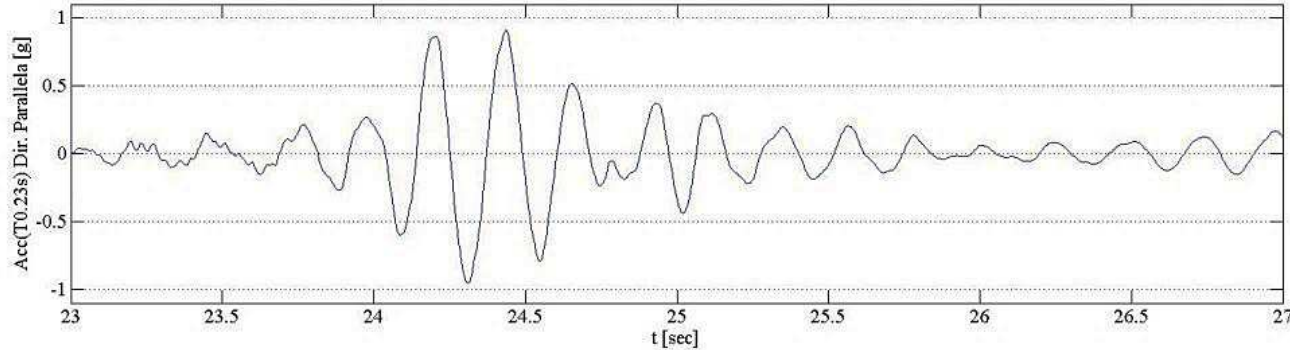
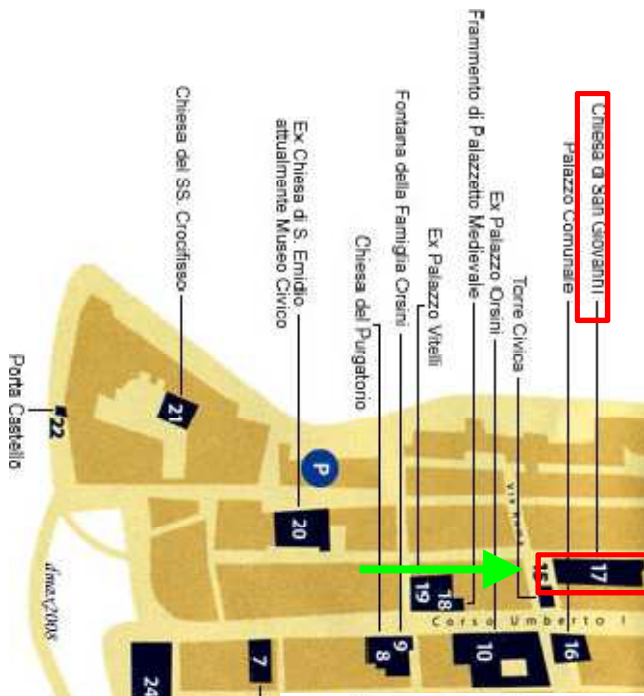


<http://www.comune.amatrice.rieti.it/percorso-storico-in-amatrice/>



SEISMIC DAMAGE OBSERVED IN AMATRICE

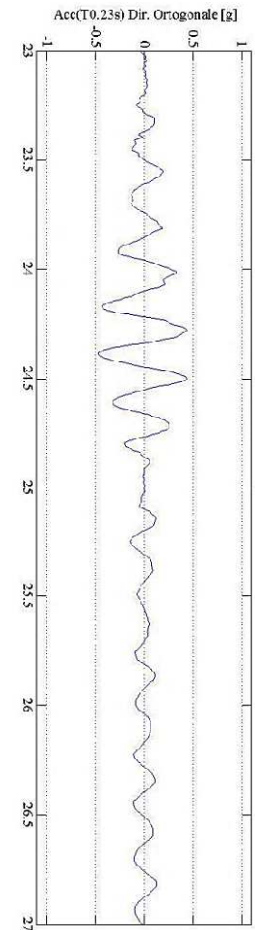
Facade overturning due to the parallel component (with reference to Corso Umberto I) of the seismic action





SEISMIC DAMAGE OBSERVED IN AMATRICE

*Loss of roof support due to the normal component (with reference to Corso Umberto I)
of the seismic action*

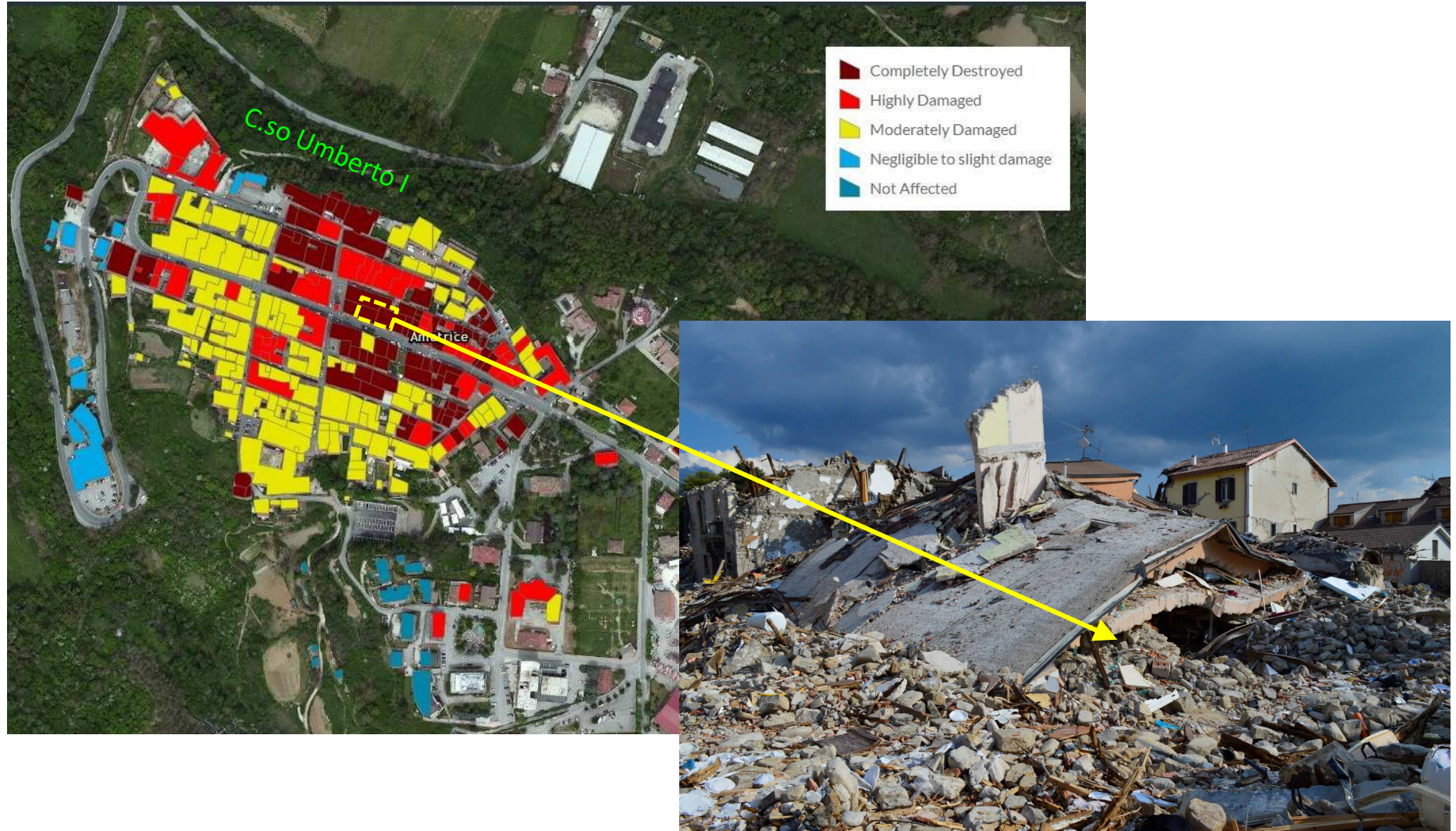






SEISMIC DAMAGE OBSERVED IN AMATRICE

Building collapse showing a remarkable deformation of the RC slab (Corso Umberto I)





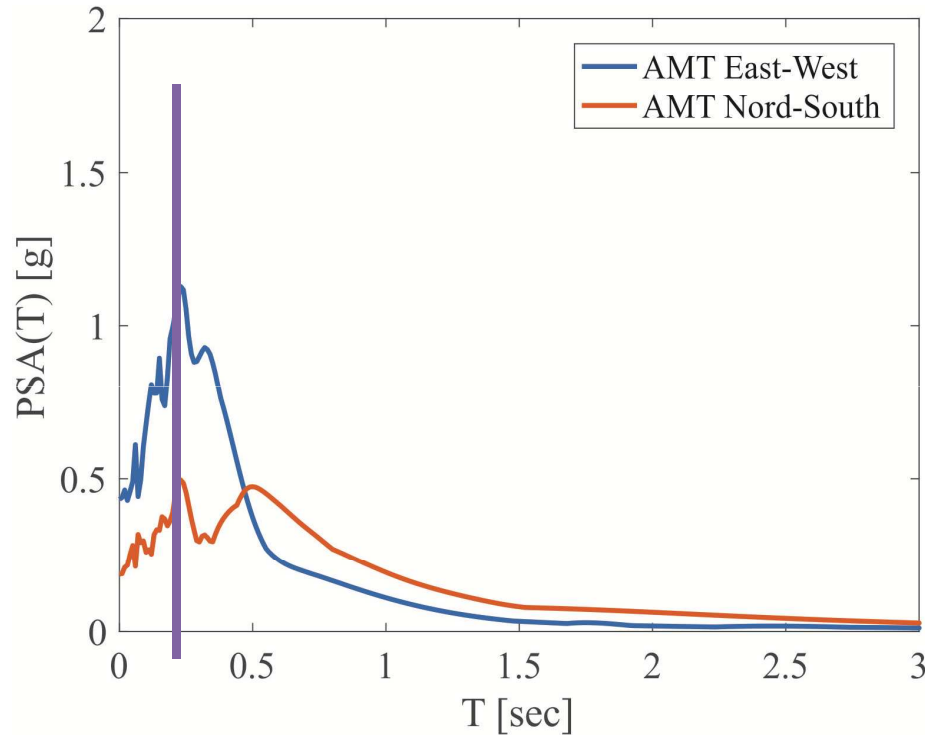
SEISMIC DAMAGE OBSERVED IN AMATRICE

Building collapse showing a remarkable deformation of the RC slab (Corso Umberto I)



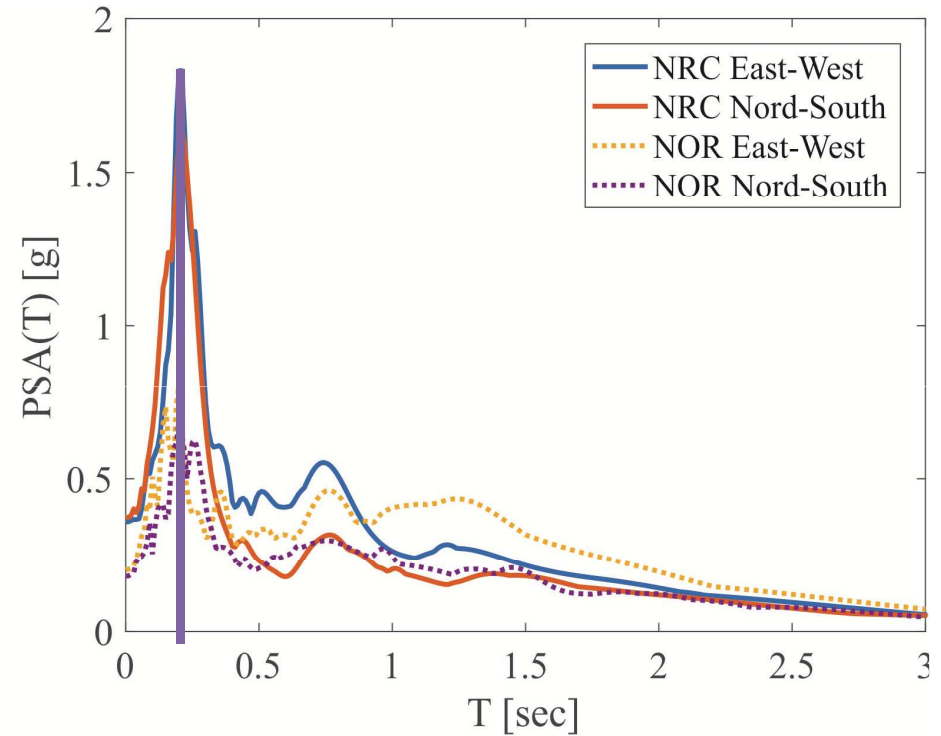


REMARKS ON THE GROUND MOTION DATA AND STRUCTURAL DYNAMICS



AMATRICE
(distanza 8,9 km)

Acc Peak at 0,23 sec



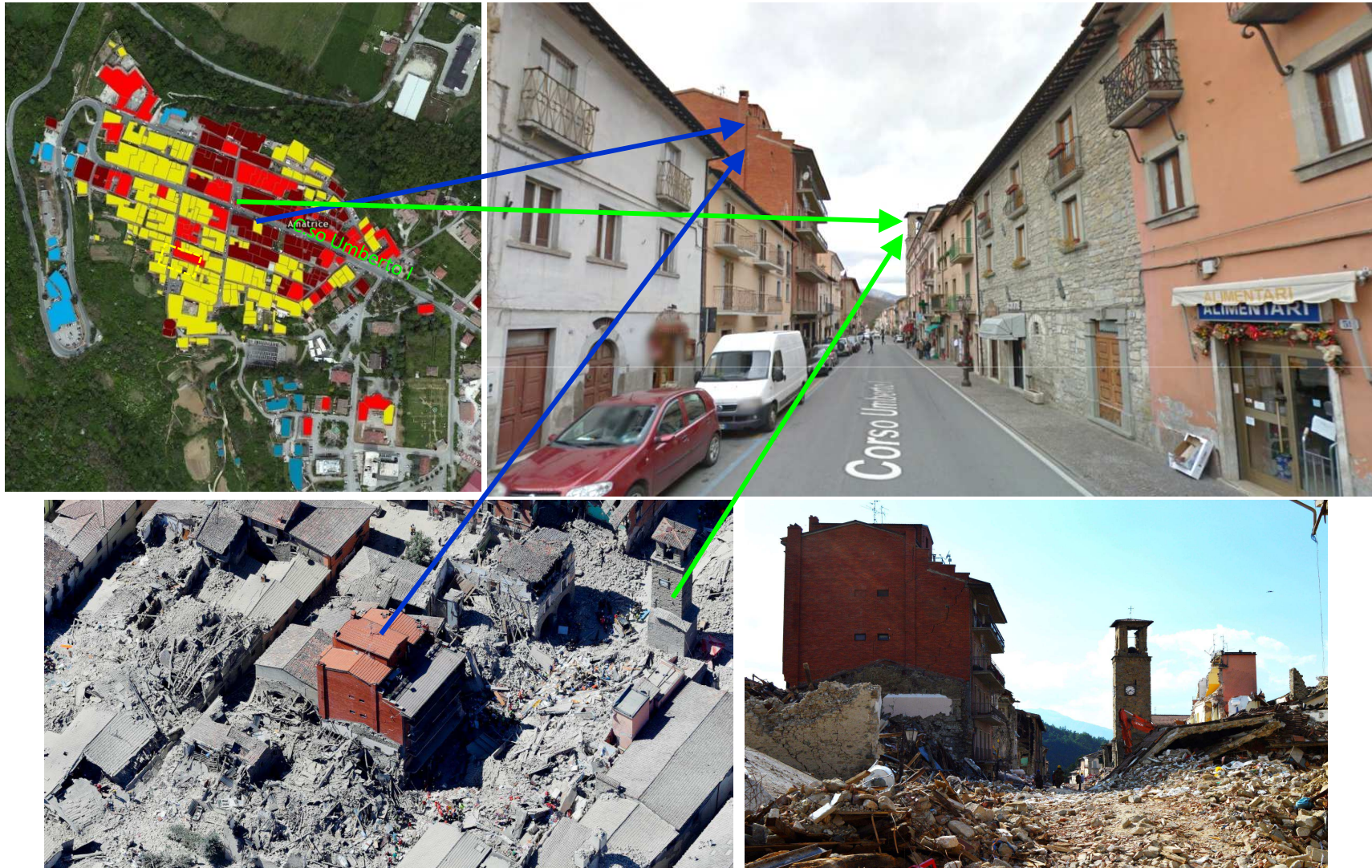
NORCIA
(distanza 13,7 km)

Acc Peak at 0,20-0,21 sec



SEISMIC DAMAGE OBSERVED IN AMATRICE

Tall structures along Corso Umberto I





SEISMIC DAMAGE OBSERVED IN AMATRICE

Tall structures along Corso Umberto I: Civic Tower



Spread masonry damage and detachment of the bell from the roof unit



SEISMIC DAMAGE OBSERVED IN AMATRICE

Tall structures along Corso Umberto I: RC building



Damage affecting building cladding and infills in the normal direction with respect to corso Umberto I





SEISMIC DAMAGE OBSERVED IN AMATRICE

Tall structures along Corso Umberto I: RC building



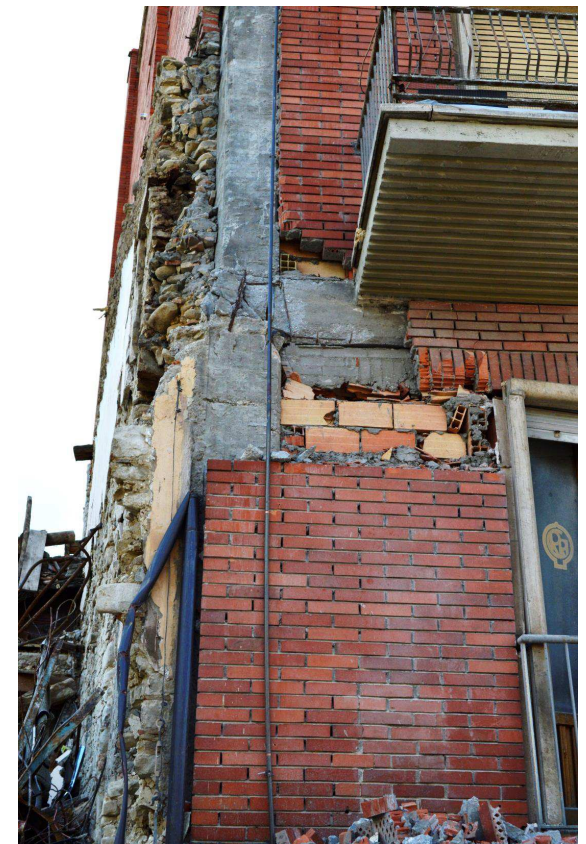
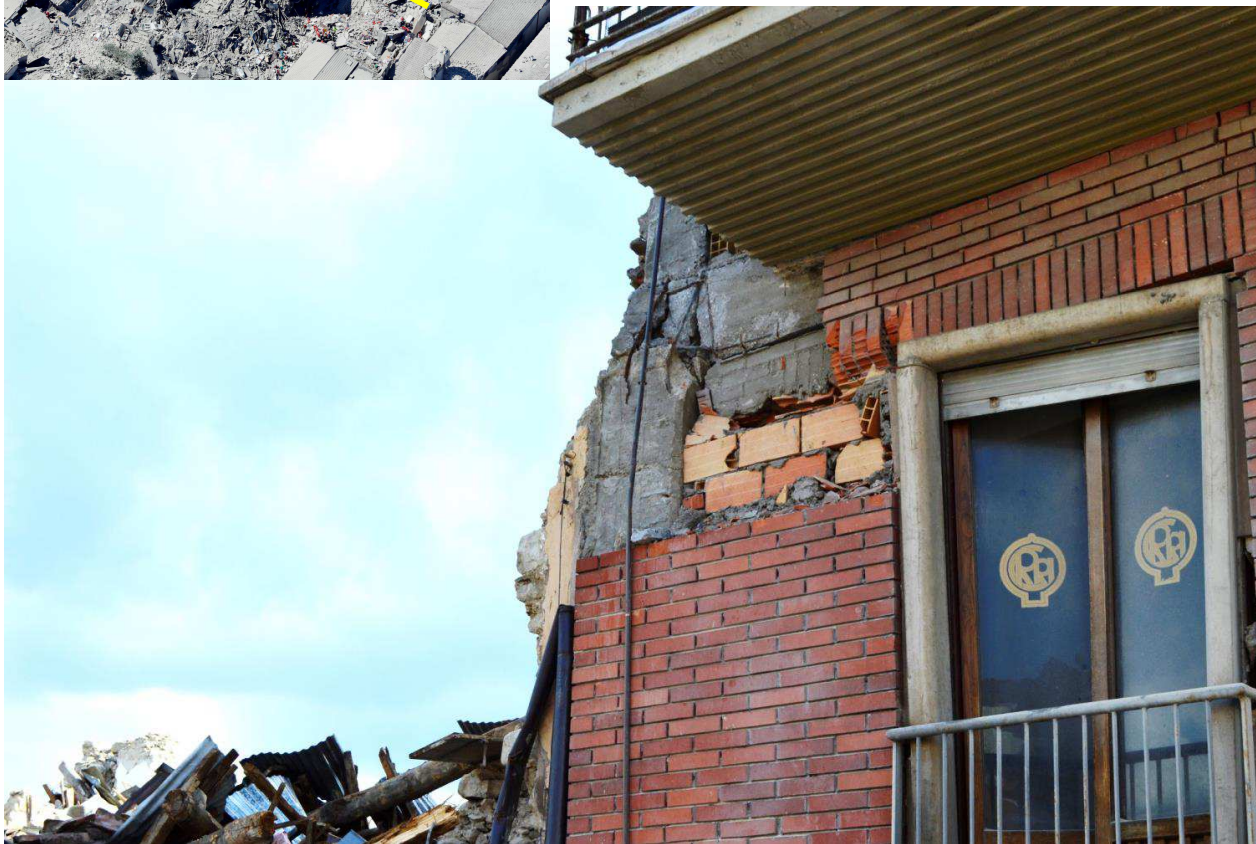


SEISMIC DAMAGE OBSERVED IN AMATRICE

Tall structures along Corso Umberto I: RC building



Focus on the damage occurred to the RC joint at the 1° storey due to in the parallel component of the seismic action with respect to corso Umberto I





SEISMIC DAMAGE OBSERVED IN AMATRICE

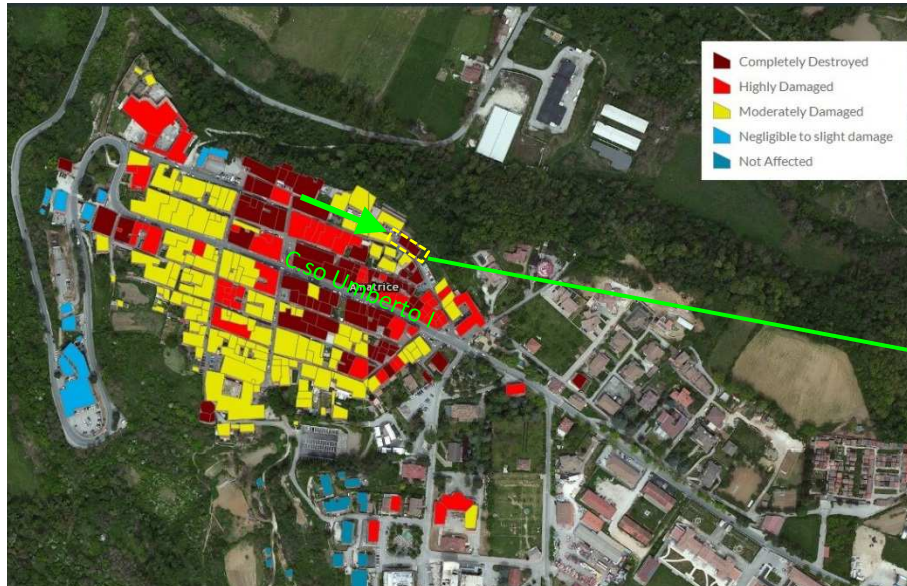
Steel (flexible) structure





SEISMIC DAMAGE OBSERVED IN AMATRICE

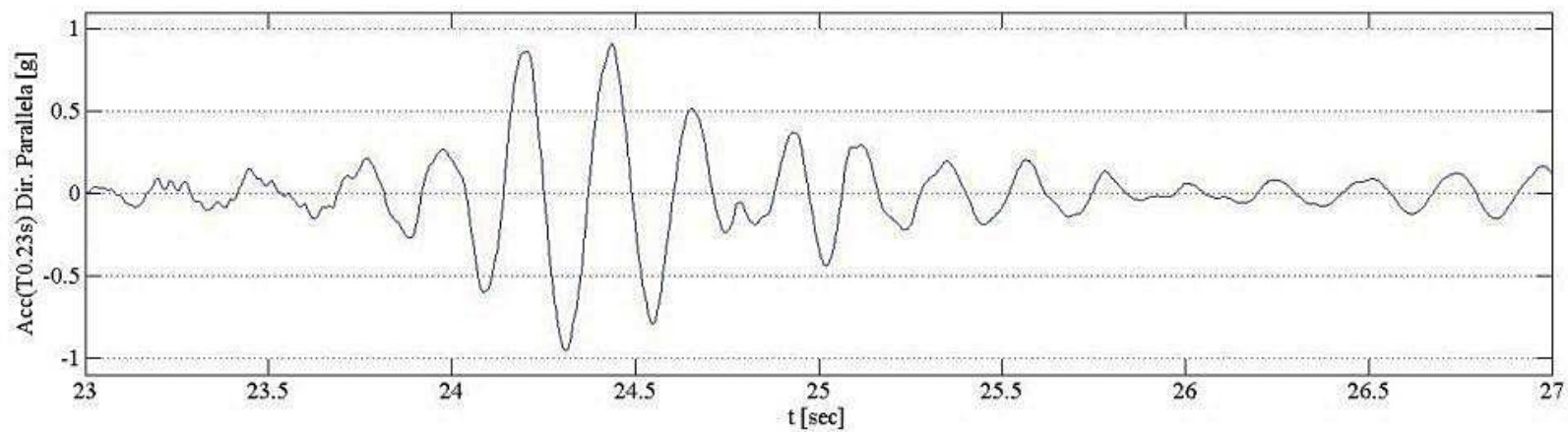
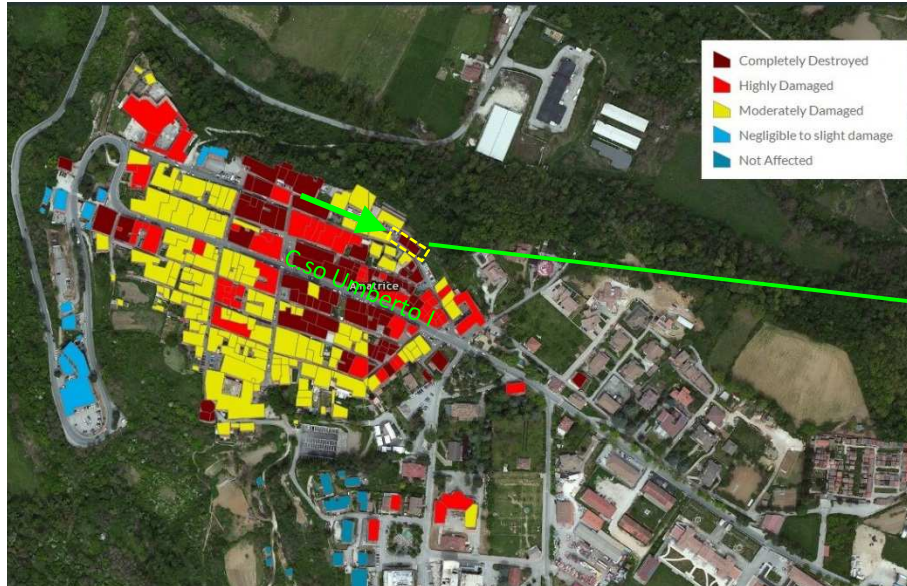
Buildings located in the parallel roads of Corso Umberto I: Hotel Roma (c.a.)





SEISMIC DAMAGE OBSERVED IN AMATRICE

Buildings located in the parallel roads of Corso Umberto I: Hotel Roma (c.a.)



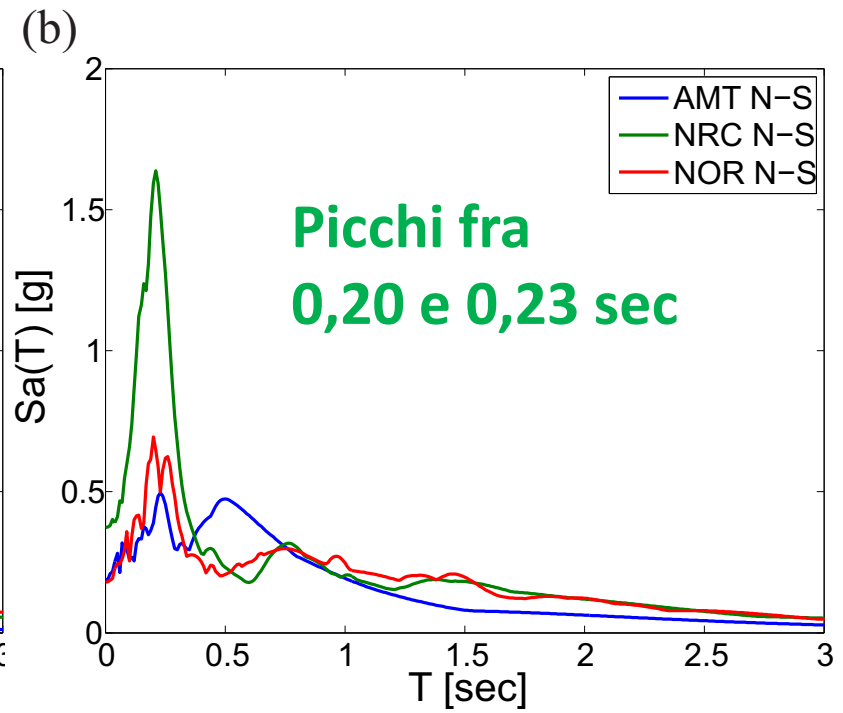
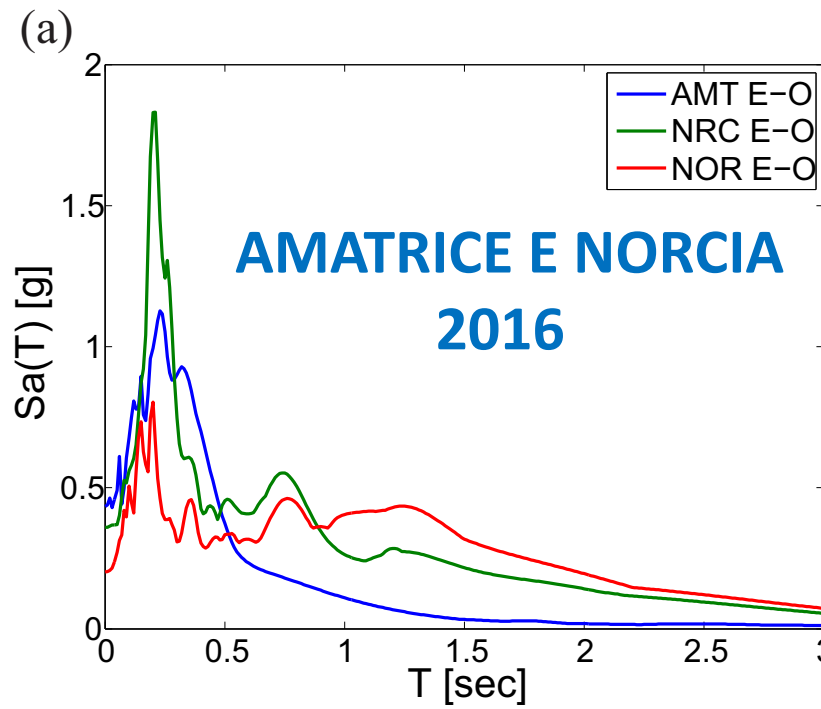


SEISMIC DAMAGE OBSERVED IN AMATRICE

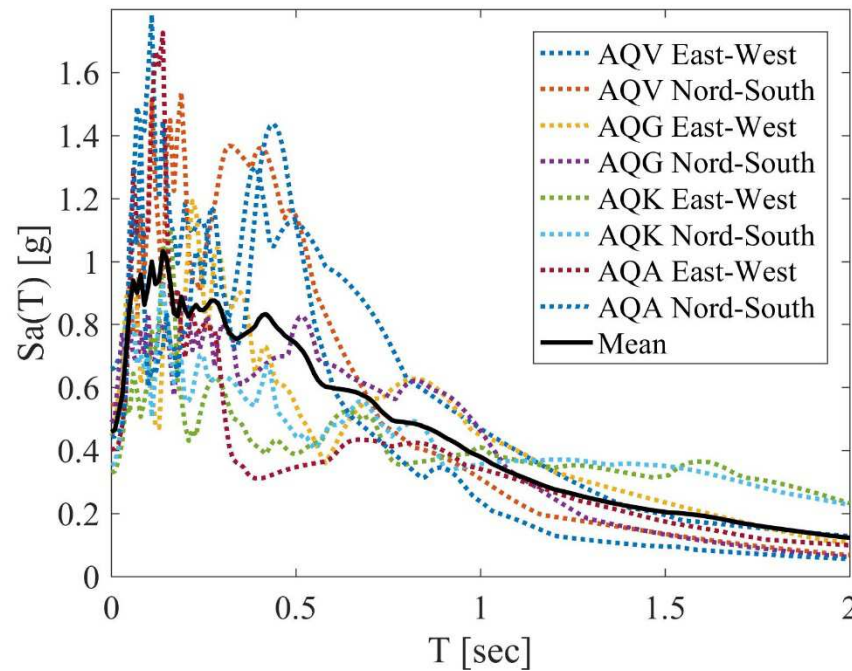
Tall RC buildings nearby the school Romolo Capranica



- The tallest building in Amatrice (RC structure) showed no significant damage.
- The dynamic behaviour of the structures largely influenced the structural behavior of buildings in Amatrice.
- Best was, in general, the behavior of tall RC framed structures, being more deformable and thus subjected to much smaller spectral accelerations.



L'AQUILA 2009
(4 stazioni e media
delle 8 registrazioni)



Scuola Capranica di Amatrice

- BEFORE



- AFTER



Scuola Capranica di Amatrice

• BEFORE



• Poor quality of concrete;

• RC PORTION

• MASONRY PORTION



• AFTER

Amatrice (2016)

Scuola Capranica, Amatrice





CONSIDERATIONS ABOUT INELASTIC SPECTRA

Source: Preliminary study of Rieti Earthquake ground data V5, DIST, INGV, CNR/ITC, Reluis

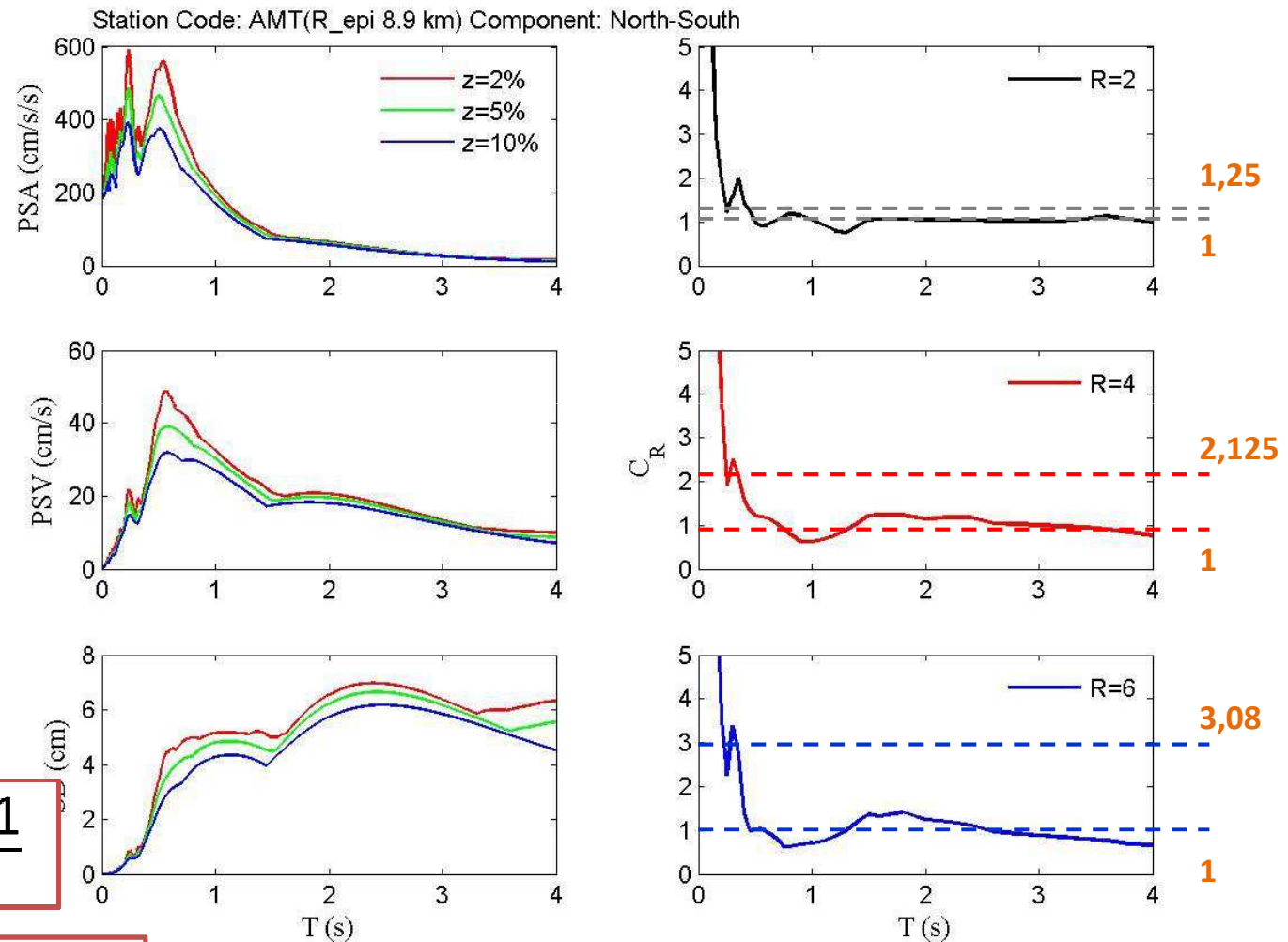
AMATRICE (distance 8,9 km) - North – South components

$$C_R = \frac{\delta_{inelastic}^{max}}{SD(T)}$$

$$R = \frac{PSA(T)}{PSA_{yield}(T)}$$

Energy: $C_R = \frac{R^2 + 1}{2R}$

Equal Displac.: $C_R = 1$



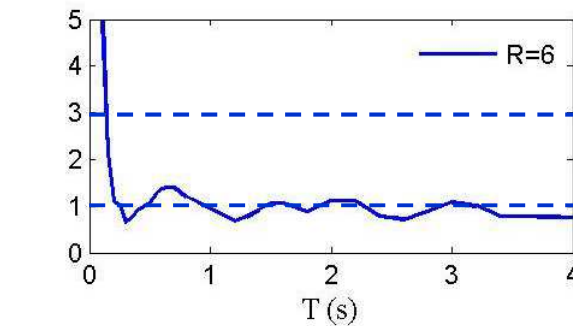
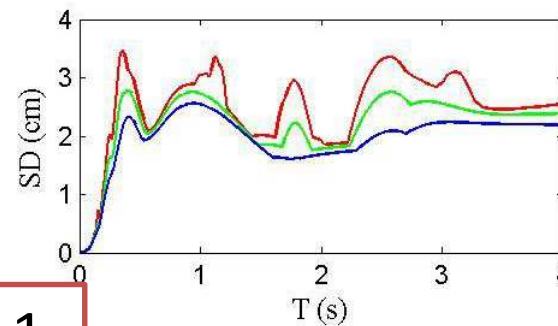
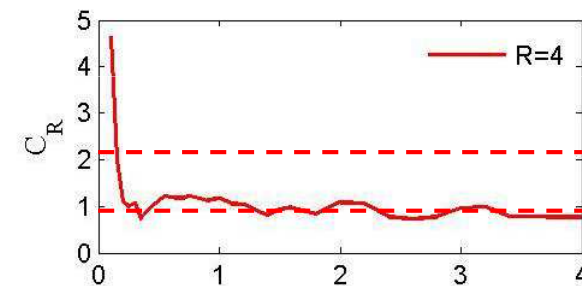
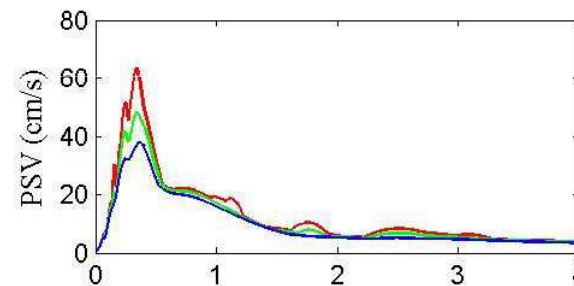
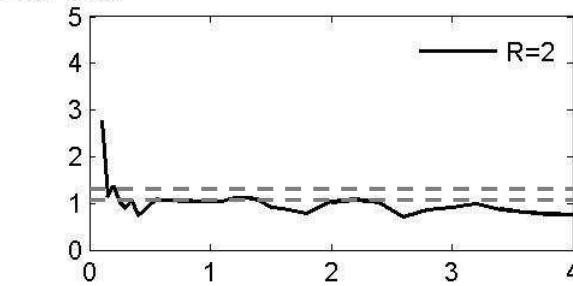
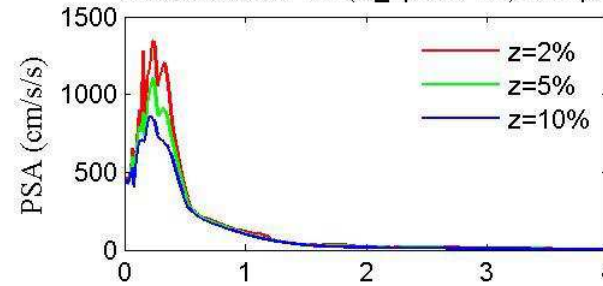


CONSIDERATIONS ABOUT INELASTIC SPECTRA

Source: Preliminary study of Rieti Earthquake ground data V5, DIST, INGV, CNR/ITC, Reluis

AMATRICE (distance 8,9 km) - East - West components

Station Code: AMT(R_epi 8.9 km) Component: East-West



$$C_R = \frac{\delta_{inelastic}^{max}}{SD(T)}$$

$$R = \frac{PSA(T)}{PSA_{yield}(T)}$$

Energy: $C_R = \frac{R^2 + 1}{2R}$

Equal Displac.: $C_R = 1$

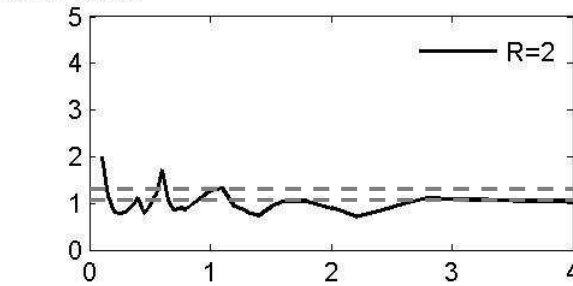
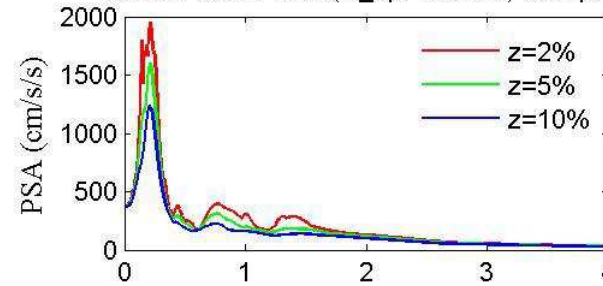


CONSIDERATIONS ABOUT INELASTIC SPECTRA

Source: Preliminary study of Rieti Earthquake ground data V5, DIST, INGV, CNR/ITC, Reluis

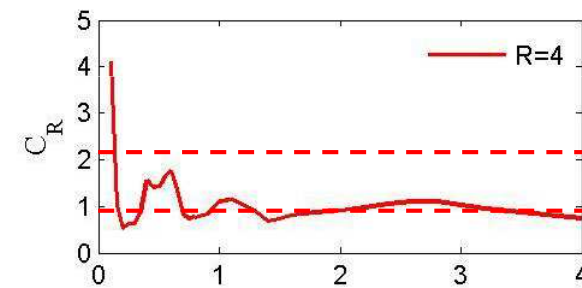
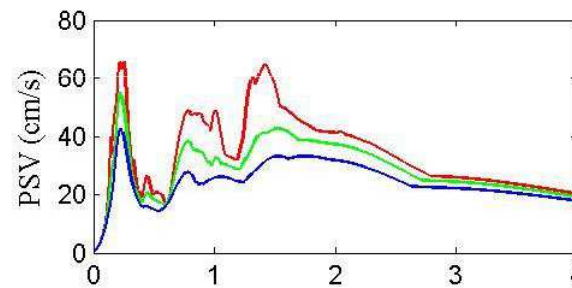
NORCIA (distance 13,7 km) - North – South components

Station Code: NRC(R_epi 13.7 km) Component: North-South



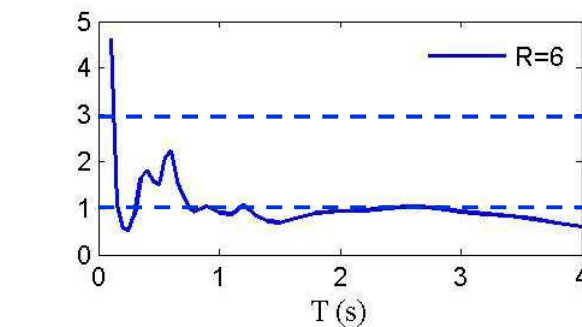
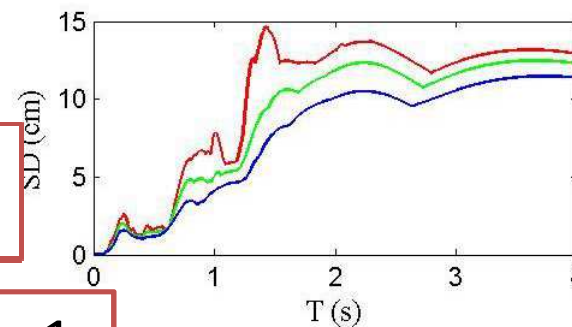
1,25

1



2,125

1



3,08

1

$$C_R = \frac{\delta_{inelastic}^{max}}{SD(T)}$$

$$R = \frac{PSA(T)}{PSA_{yield}(T)}$$

Energy: $C_R = \frac{R^2 + 1}{2R}$

Equal Displac.: $C_R = 1$

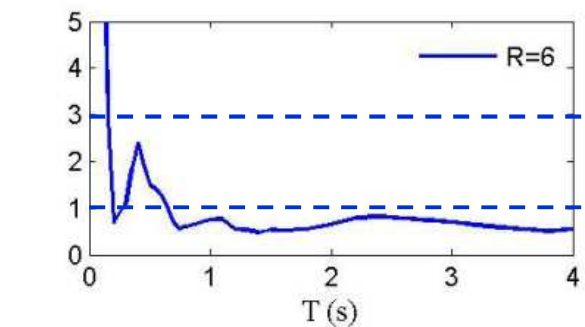
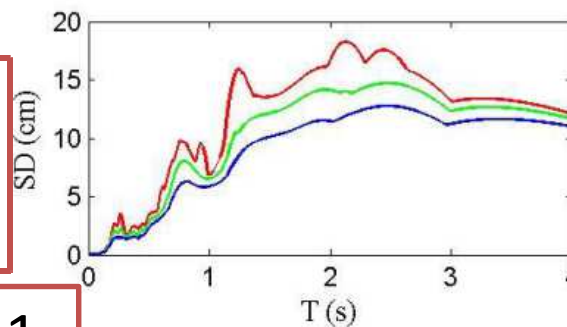
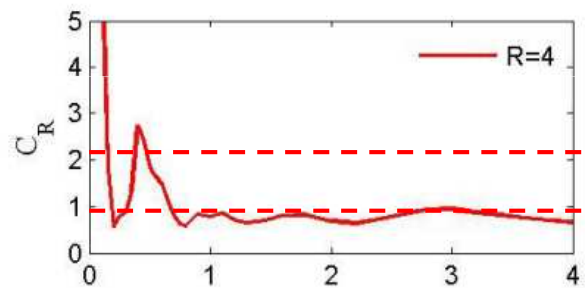
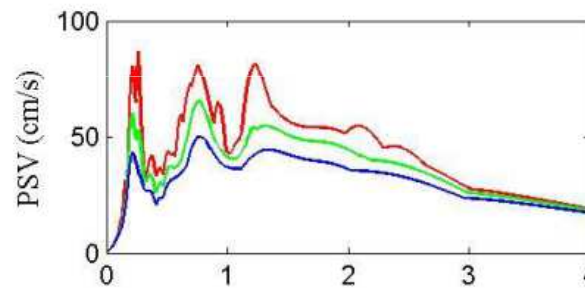
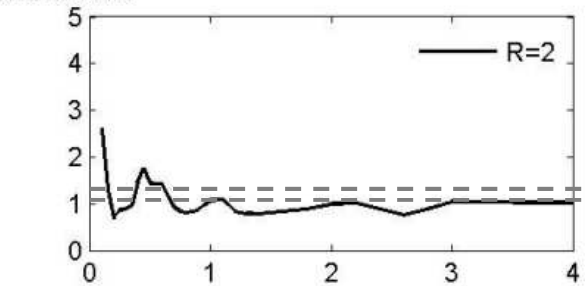
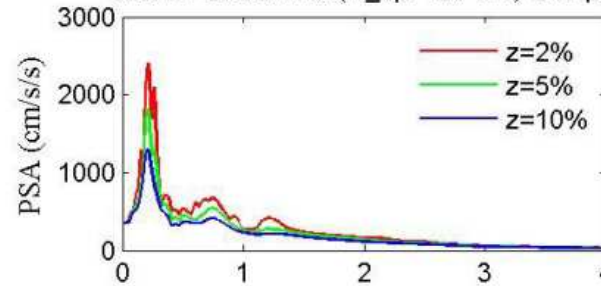


CONSIDERATIONS ABOUT INELASTIC SPECTRA

Source: Preliminary study of Rieti Earthquake ground data V5, DIST, INGV, CNR/ITC, Reluis

NORCIA (distance 13,7 km) - East – West components

Station Code: NRC(R_epi 13.7 km) Component: East-West



$$C_R = \frac{\delta_{inelastic}^{max}}{SD(T)}$$

$$R = \frac{PSA(T)}{PSA_{yield}(T)}$$

$$\text{Energy: } C_R = \frac{R^2 + 1}{2R}$$

Equal Displac.: $C_R = 1$

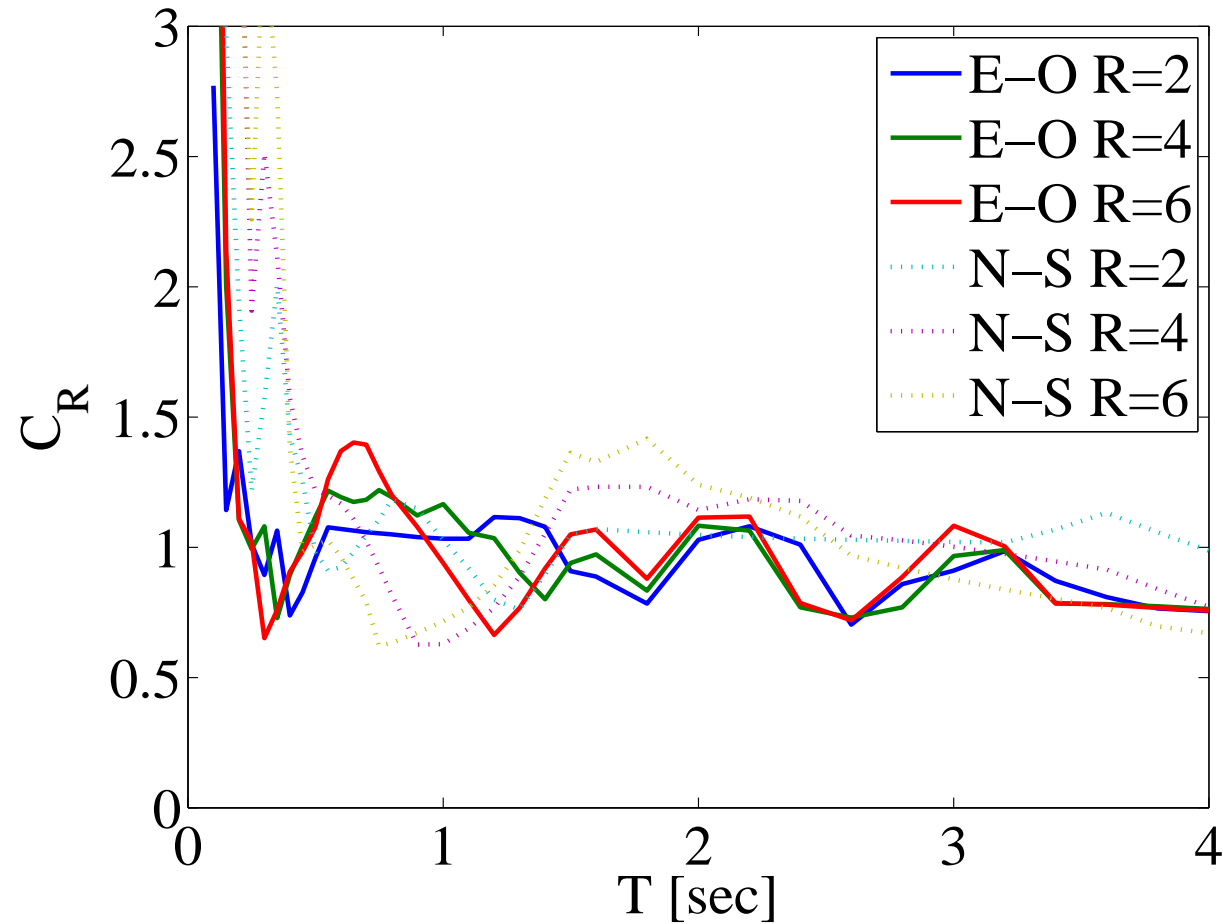


CONSIDERATIONS ABOUT INELASTIC SPECTRA

AMATRICE E-O e N-S

$$C_R = \frac{\delta_{inelastic}^{max}}{SD(T)}$$

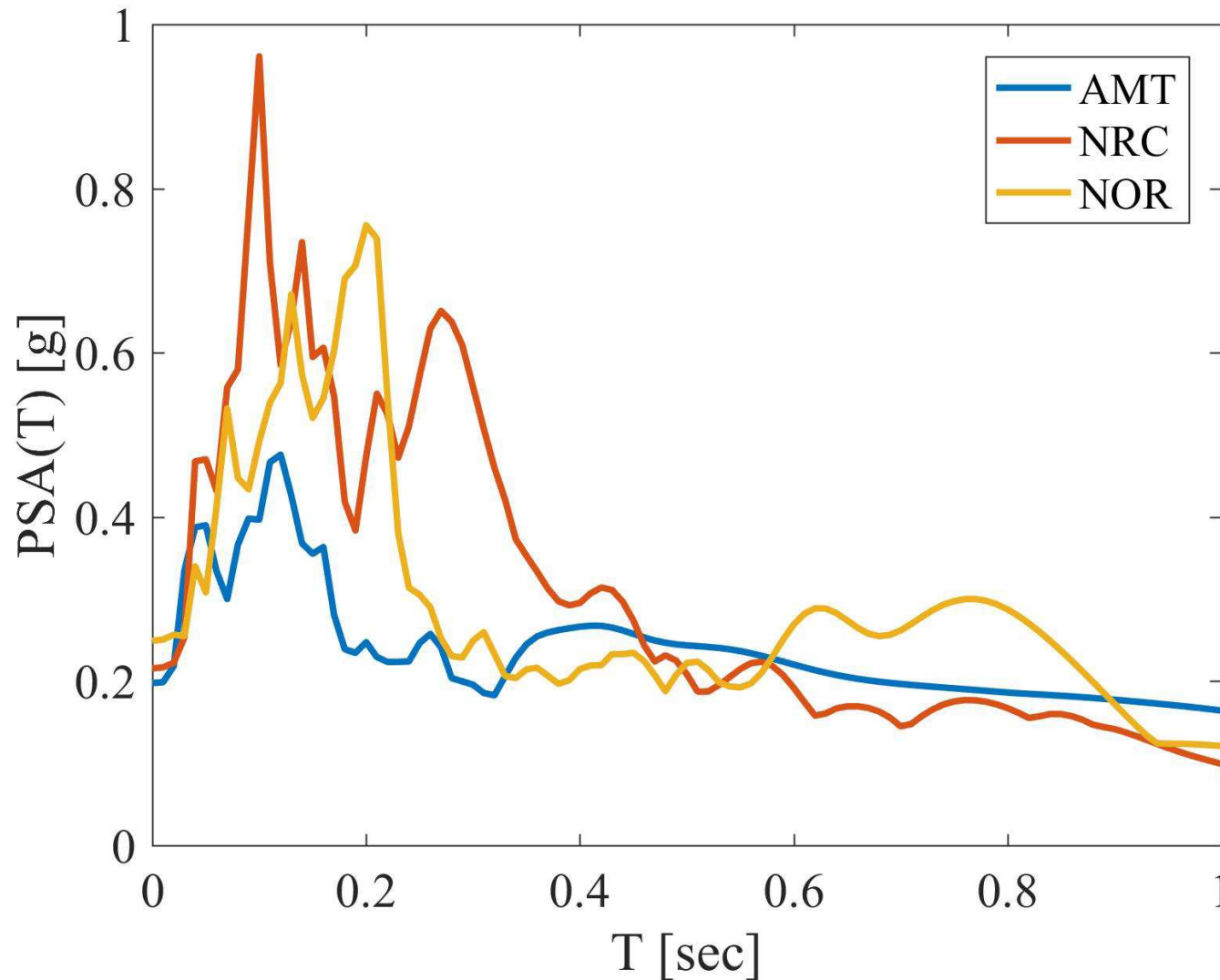
$$R = \frac{PSA(T)}{PSA_{yield}(T)}$$





CONSIDERATIONS ABOUT SPECTRA

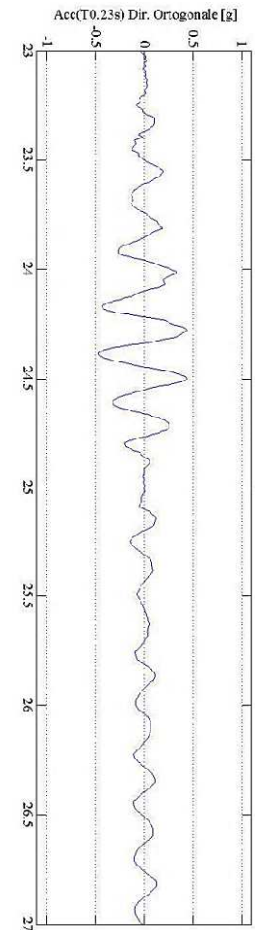
Vertical component of the seismic action

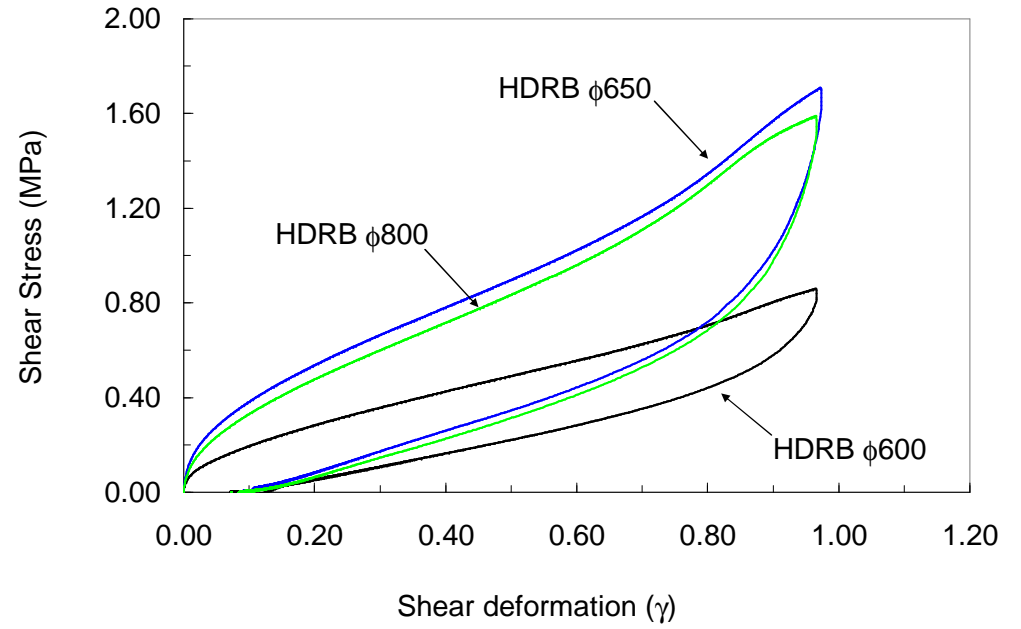




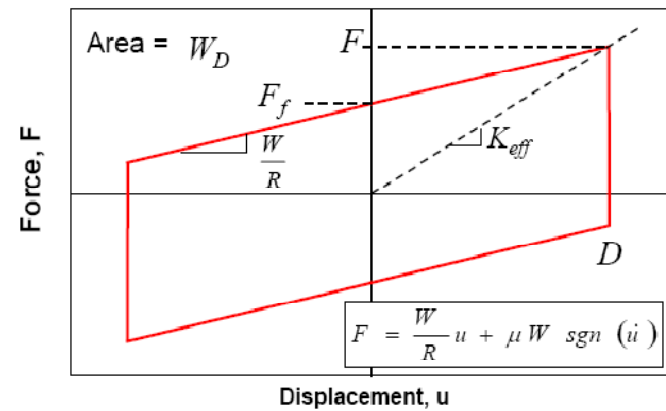
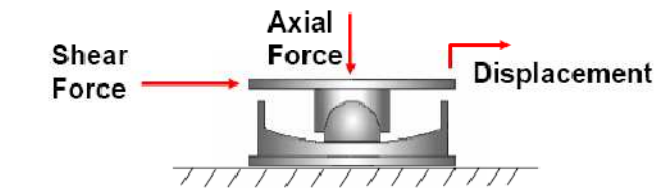
SEISMIC DAMAGE OBSERVED IN AMATRICE

*Loss of roof support due to the normal component (with reference to Corso Umberto I)
of the seismic action*

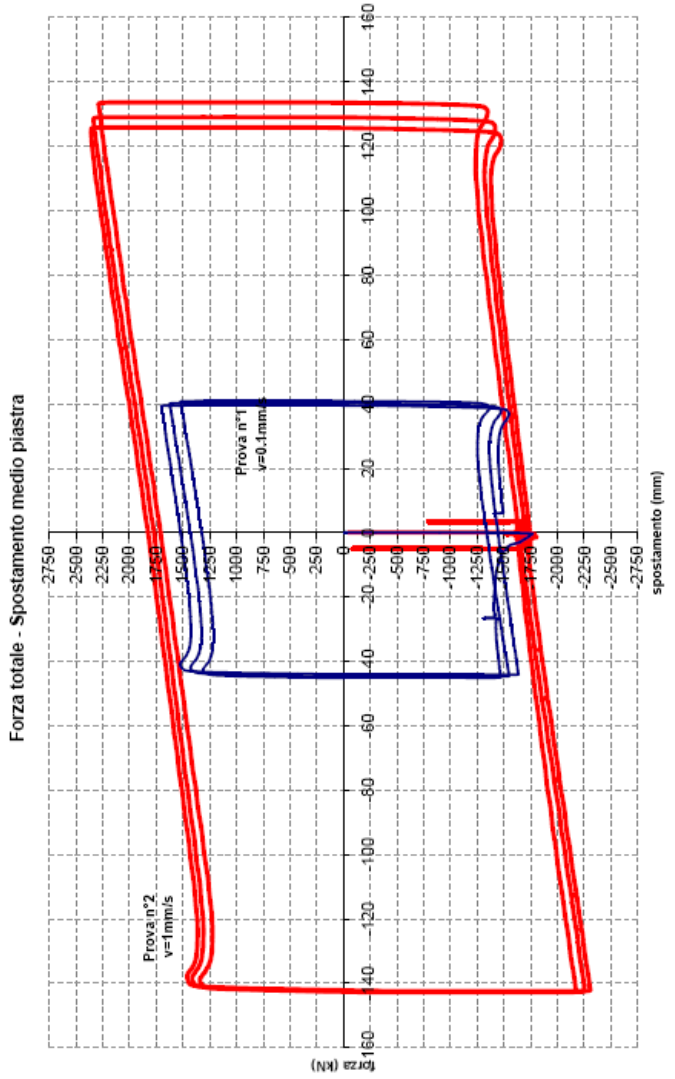
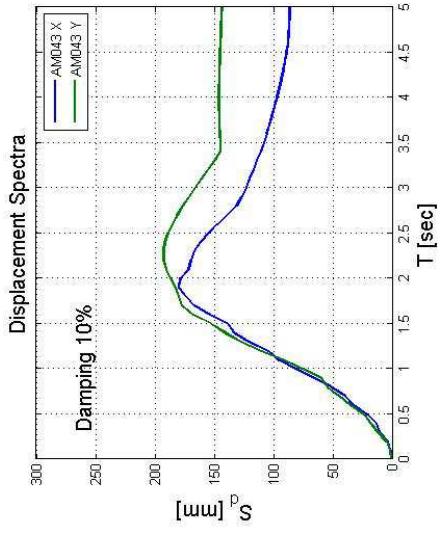
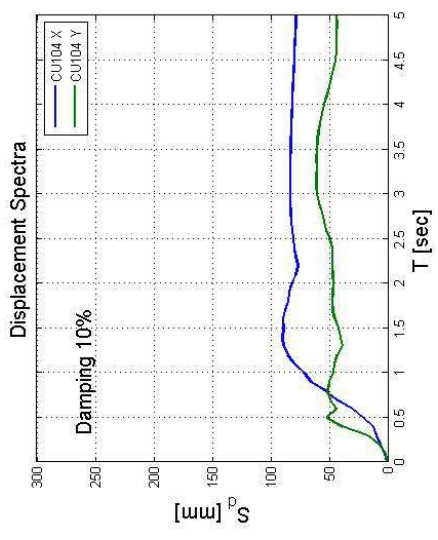
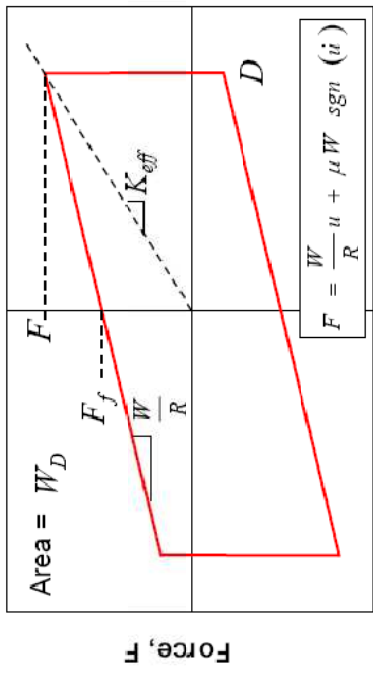
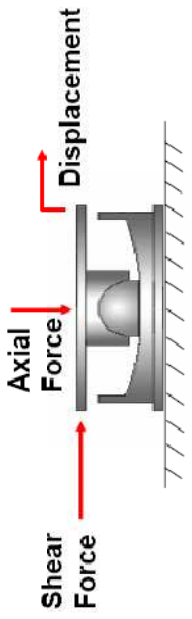




Idealized FPS Bearing Hysteresis Loop

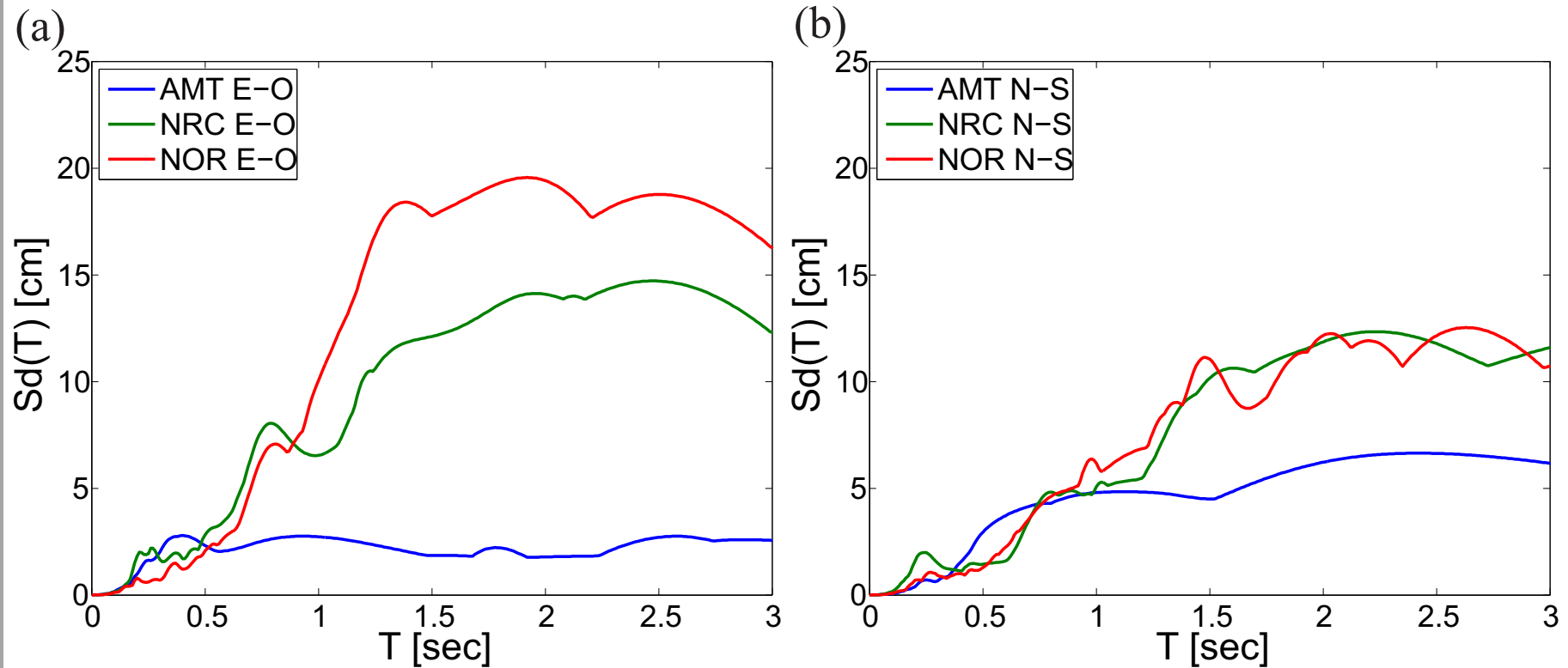


Realized FPS Bearing Hysteresis Loop





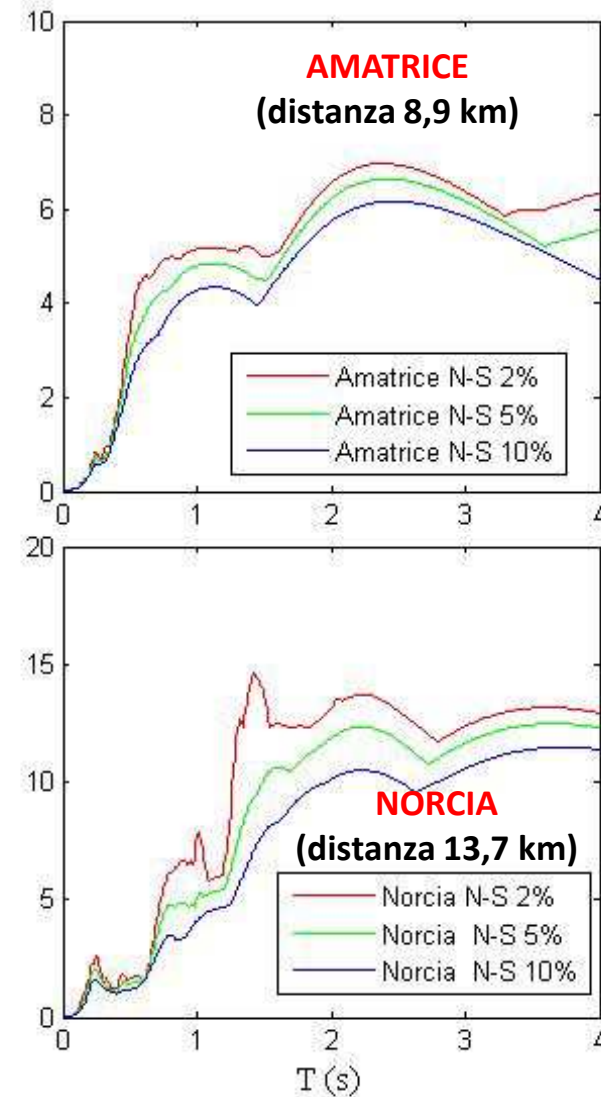
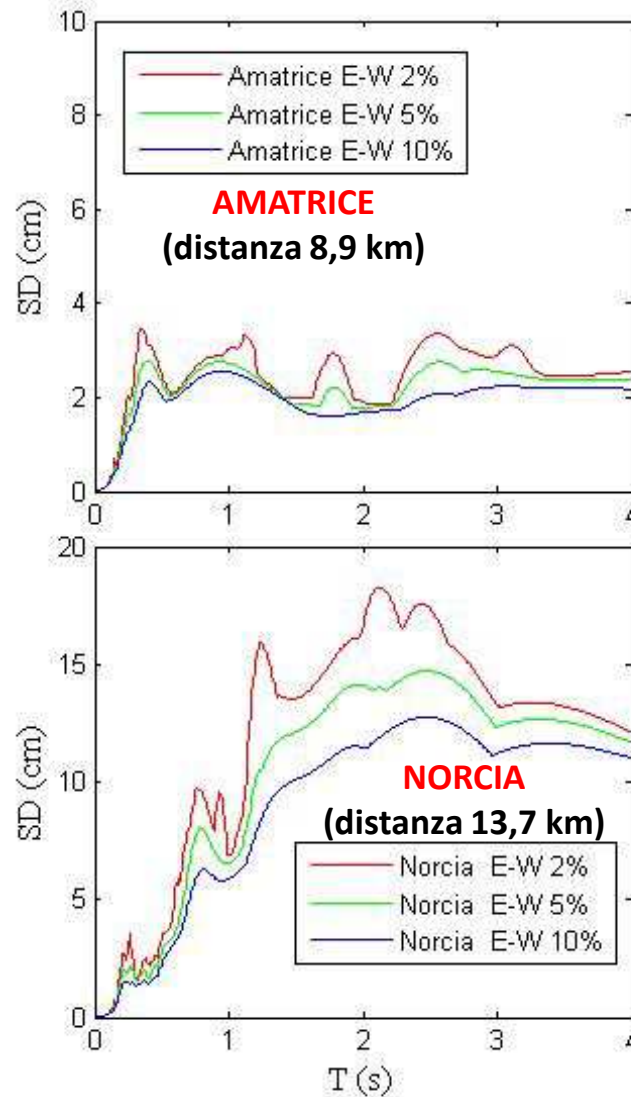
CONSIDERATIONS ABOUT DISPLACEMENT RECORDS (5% damping)





CONSIDERATIONS ABOUT DISPLACEMENT RECORDS

Use of seismic isolators





CONSIDERAZIONI DI INGEGNERIA SISMICA SUL TERREMOTO DELL'ITALIA CENTRALE DEL 24 AGOSTO 2016



Italian Concrete Days, AICAP e CTE, 27-28 Ottobre 2016

Prof. Edoardo Cosenza

Dipartimento di Strutture per l'Ingegneria e l'Architettura - Università di Napoli Federico II