PRELIMINARY COMPARISON BETWEEN RESPONSE SPECTRA EVALUATED AT CLOSE SOURCE FOR L'AQUILA EARTHQUAKE AND ELASTIC DEMAND SPECTRA ACCORDING TO THE NEW SEISMIC ITALIAN CODE

(V 2.00)

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Introduction

As is widely known, seismic demand is generally described through Pseudo-Acceleration Spectra which lead to an analysis of the seismic response of a structure by means of equivalent static forces evaluated through the use of dynamic parameters, i.e. main modal shapes, periods and damping factors.

Seismic Codes usually define elastic spectra for each assigned performance target level by considering the seismic hazard of the station. Non-linear behaviour however, is considered by means of the "Structural Factor" taking into account the overall ductility capacities of structures.

In the case of New Design Italian Code (NTC '08), elastic spectra have been defined at bedrock (Soil Type A) by considering the Seismic Hazard evaluated for several occurrence probabilities according to each performance level and to the relevance of construction; i.e. for ordinary and strategic buildings, the demand spectra are evaluated by considering the following return periods.

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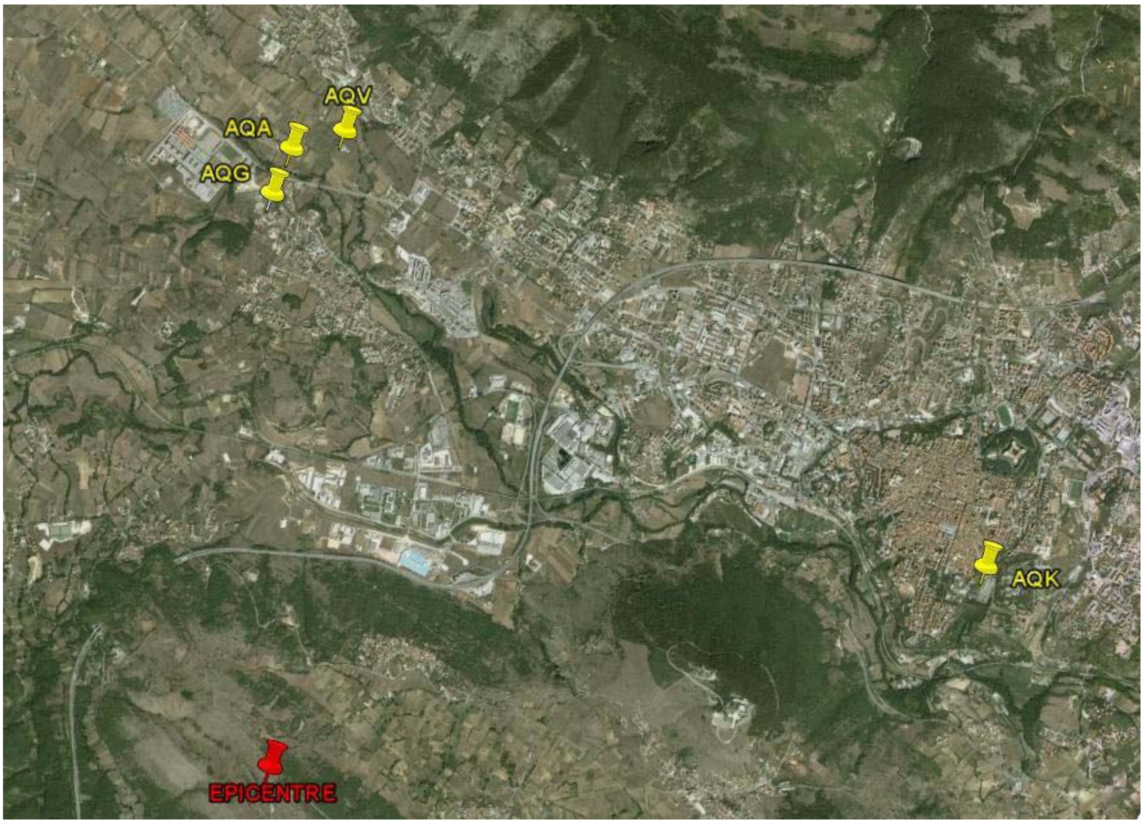
Target Performance Levels	**Return Period T_R** [yrs]	
	Ordinary Constructions *(V_R=50 yrs)*	***Strategic Constructions*** *(V_R=200 yrs)*
Immediate Operative (**SLO**)	30	120
Damage Control (**SLD**)	50	201
Life Safety (**SLV**)	475	1898
Collapse Prevention (**SLC**)	975	2475

This report presents a comparison between the response spectra evaluated at close source for the L'Aquila earthquake (date 06/04/2009 – 1.32AM UTC – Magnitude 5.8) and the elastic demand spectra according to the new Italian seismic code (NTC2008) for ordinary (*reference period* V_R*=50 yrs*) and strategic constructions (*reference period* V_R*=200 yrs*).

In particular, the following horizontal, corrected components (1), recorded for a distance from the epicentre which is less than 10 kms, have been taken into account:

- FA030 – *station AQG*, Colle dei Grilli site
  Soil profile type B, Topography factor ST=1,1
- GX066 – *station AQV*, Aterno Valley site
  Soil profile type C, Topography factor ST=1,0
- AM043 – *station AQK*, Aquila Car Park site
  Soil profile type B, Topography factor ST=1,1
- CU104 – *station AQA*, Aterno River site
  Soil profile type C, Topography factor ST=1,0

Soil parameters have been preliminarily estimated from data made available from the ITACA database (2) from the accelerometric RAN network (3), from the geographic database made available by the Regione Abruzzo (4), and from (6).



In-plane disposition of the recording stations (AQG, AQA, AQV and AQK)

In the following, Peak Ground Acceleration (PGA), for each station and for horizontal (X and Y) and vertical (Z) components are represented:

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

The recorded horizontal and vertical Peak Ground Accelerations, for each station, are significantly high. In the case of the AQK station vertical and horizontal components reached comparable peak values.

The recorded accelerations at AQV station could be due to local, geological and morphological amplification effects.

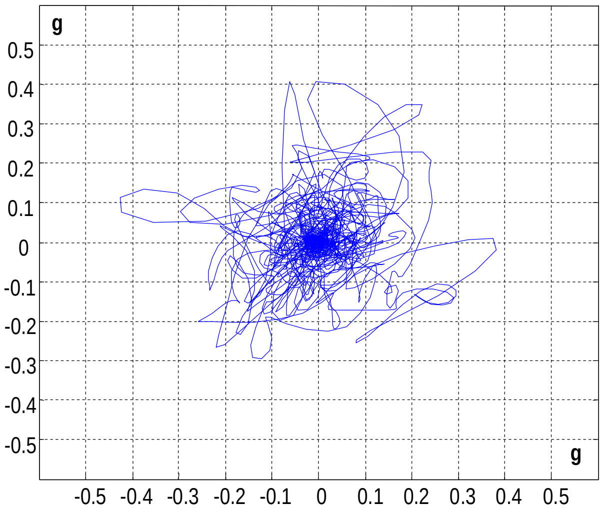
Spatial spectral analysis

To characterize horizontal seismic demand, pseudo-acceleration spectra for several in-plane directions have been evaluated. In particular, for each recording station the following have been represented:

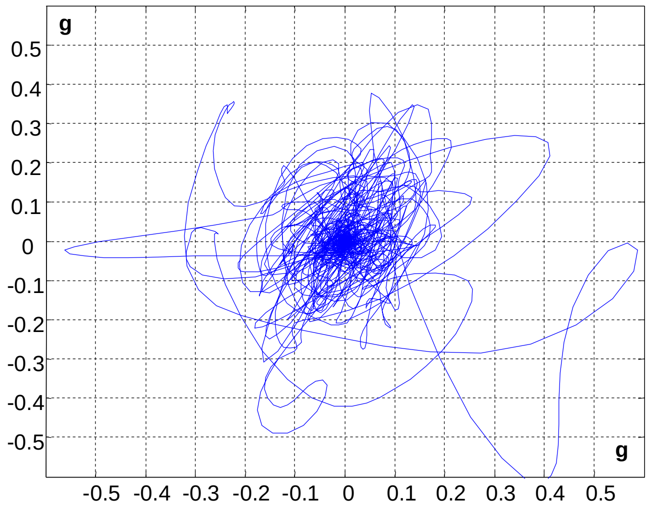
1. Plots of absolute acceleration path in terms of “g” in the NS-EW plan;
2. Overlapped spectra response in terms of pseudo-accelerations, evaluated for several directions in the horizontal plane;
3. Polar Spectra in terms of Pseudo-Acceleration, Pseudo-Velocities and Displacements.

In particular, the earthquake response spectra, for 40 in-plane directions (every 9°) in each recording station, have been evaluated by considering a 5% damping coefficient and logarithmic subdivision of the considered period range 0.0-5.0 sec.. The overlapped spectra figures compare the spectra evaluated in each direction by highlighting those evaluated for the main horizontal directions S_{ax} and S_{ay} and the envelope of all of them S_{aenv},

With regard to the Polar Spectra (7), the plots represent the seismic spectra demand in each horizontal directions by means of graduated color maps. In particular, in correspondence to each radius the in-plan projection of the spectrum response evaluated along that direction is represented. Instead, in correspondence to each circumference the spectral demand for a fixed period is plotted for each considered direction. In the represented Polar Spectra, the periods 0.5, 1.0 and 1.5 are marked by black thin circumference, the origin corresponds to 0 sec. period.



Record FA030 – station AQG



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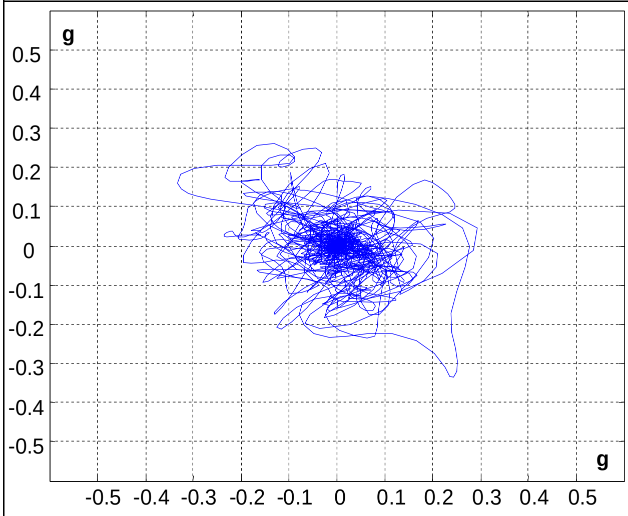
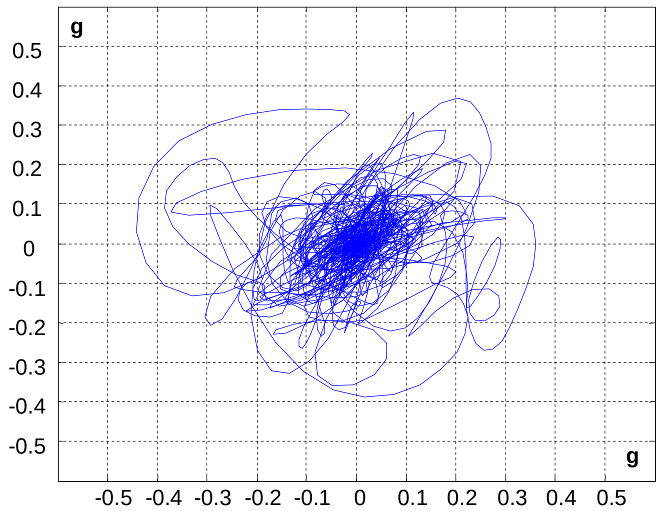


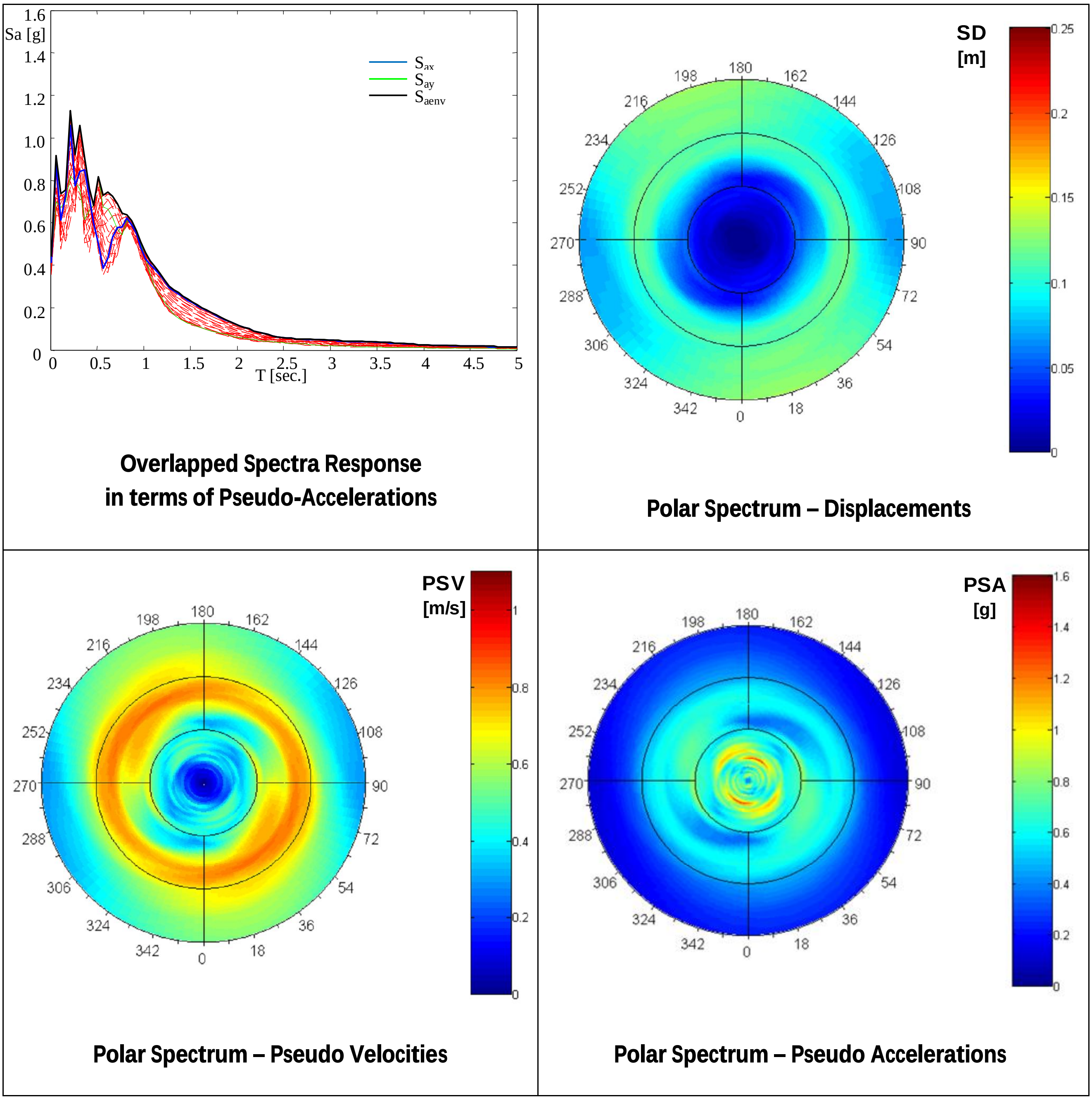
Record AM043 – station AQK



Record CU104 – station AQA

Earthquake horizontal acceleration plot in the NS-EW directions (North at the Top of Figures)

By analyzing a horizontal acceleration plot it is possible to observe a non-uniform seismic demand in the plane. The NW-SE path seems to be overall the main strike direction.



Overlapped Spectra Response in terms of Pseudo-Accelerations

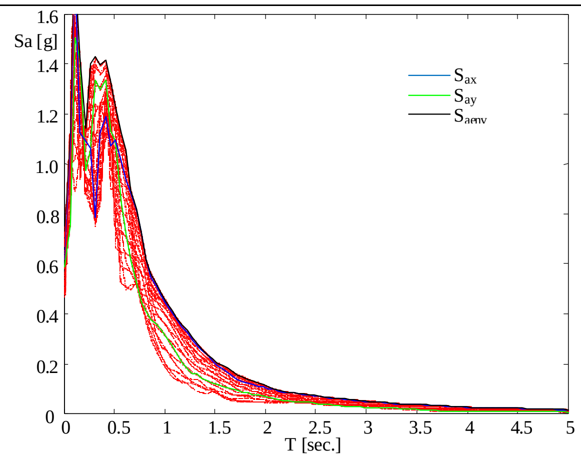
Polar Spectrum – Displacements

Polar Spectrum – Pseudo Velocities

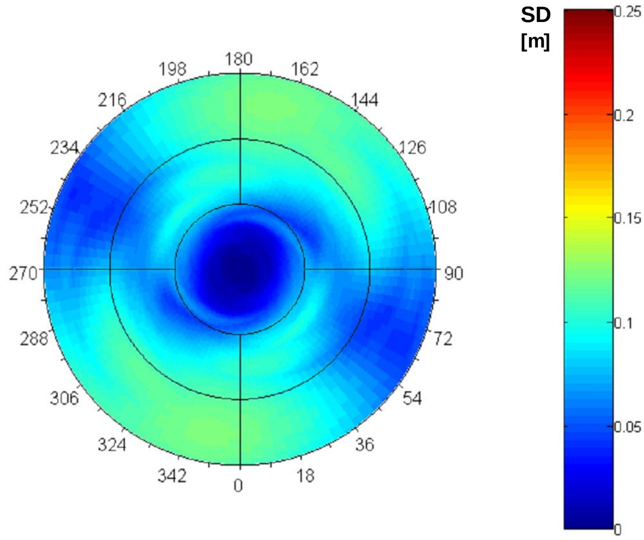
Polar Spectrum – Pseudo Accelerations

Record FA030 – Station AQG

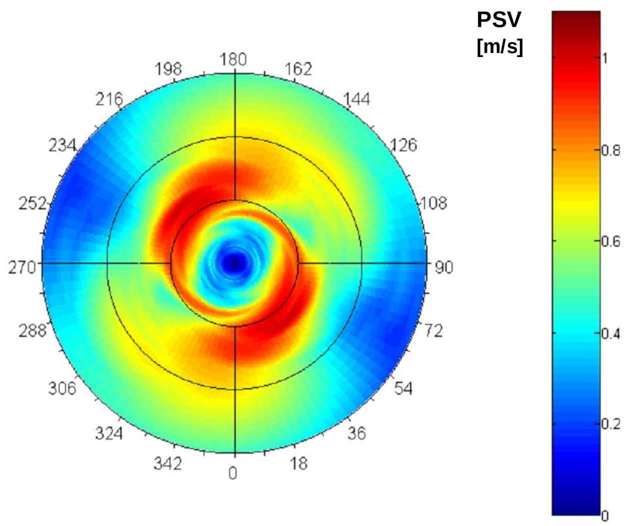
Spectra evaluated every 9° for several directions in the horizontal plane
Circular ring placed in polar spectra from inside to outside
at 0.5,1.0 and 1.5 sec. vibration periods, 0° corresponds to the South



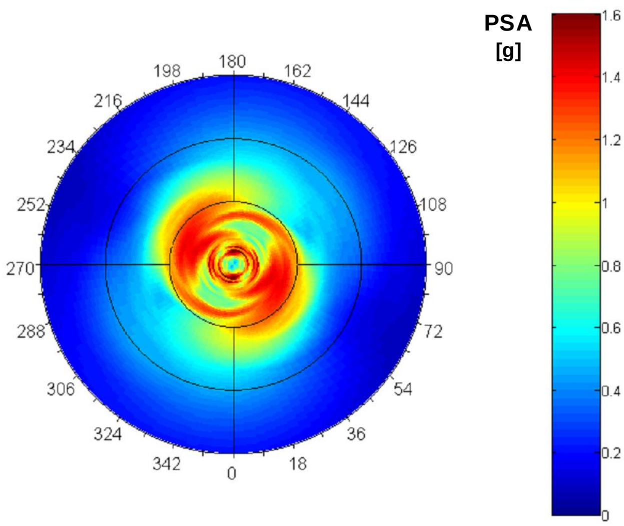
Overlapped Spectra Response in terms of Pseudo-Accelerations



Polar Spectrum – Displacements



Polar Spectrum – Pseudo Velocities



Polar Spectrum – Pseudo Accelerations

Record GX066 – station AQV

Spectra evaluated every 9° for several directions in the horizontal plane
Circular ring placed in polar spectra from inside to outside
at 0.5,1.0 and 1.5 sec. vibration periods, 0° corresponds to the South

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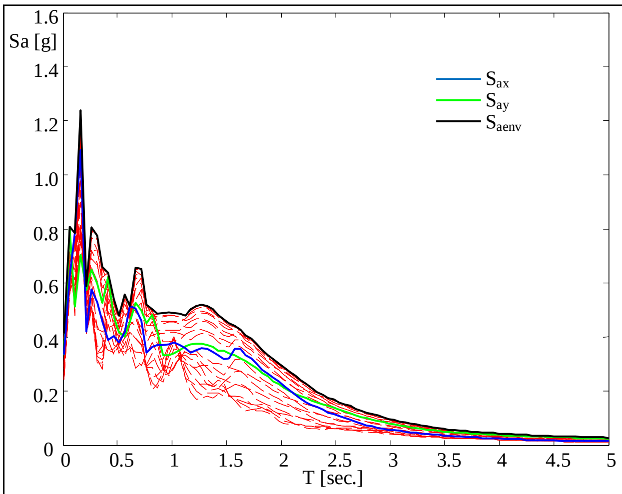
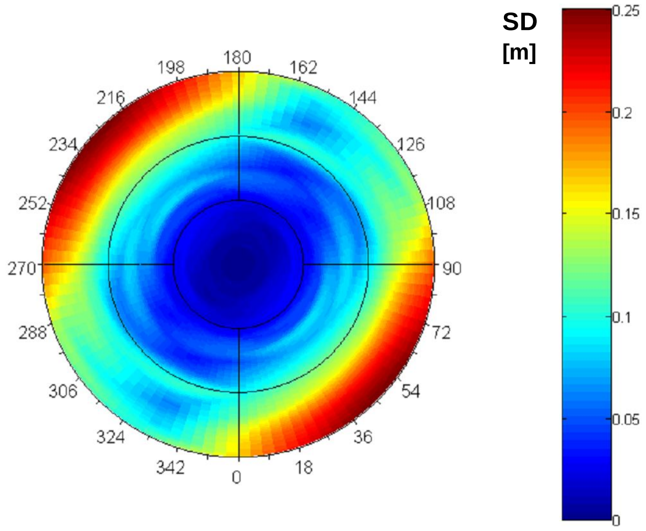
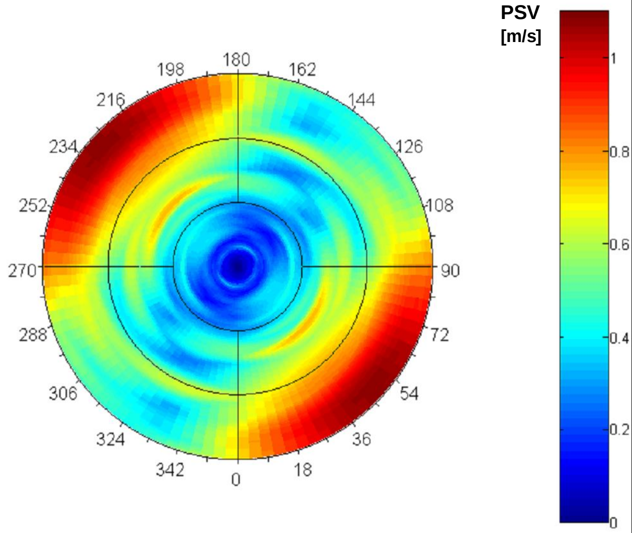


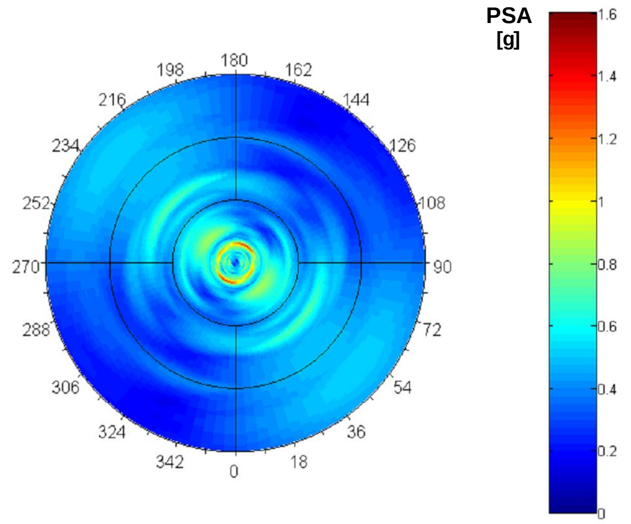
Overlapped Spectra Response in terms of Pseudo-Accelerations



Polar Spectrum – Displacements



Polar Spectrum – Pseudo Velocities



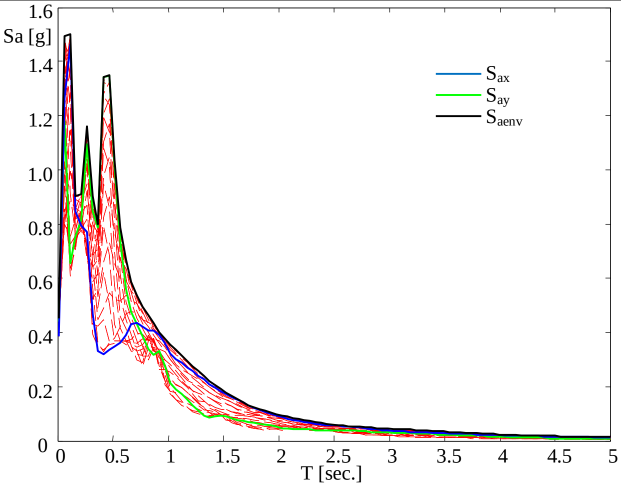
Polar Spectrum – Pseudo Accelerations

Record AM043– station AQK

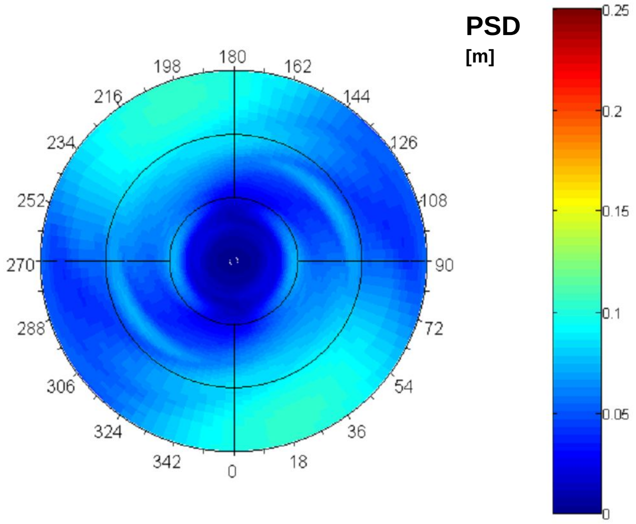
Spectra evaluated every 9° for several directions in the horizontal plane

Circular ring placed in polar spectra from inside to outside

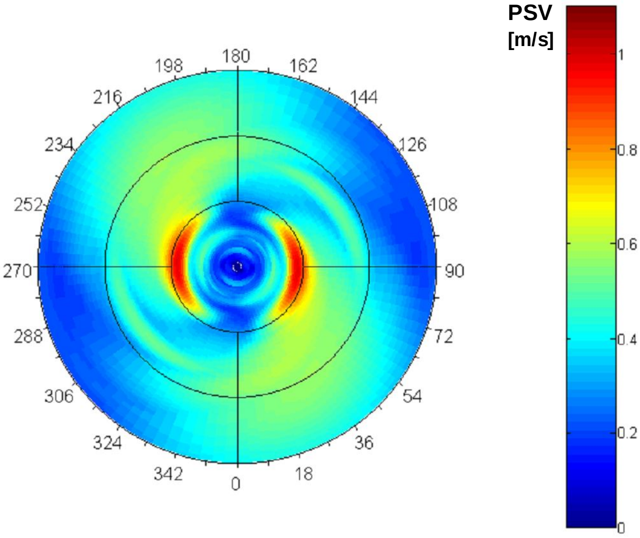
at 0.5,1.0 and 1.5 sec. vibration periods, 0° corresponds to the South



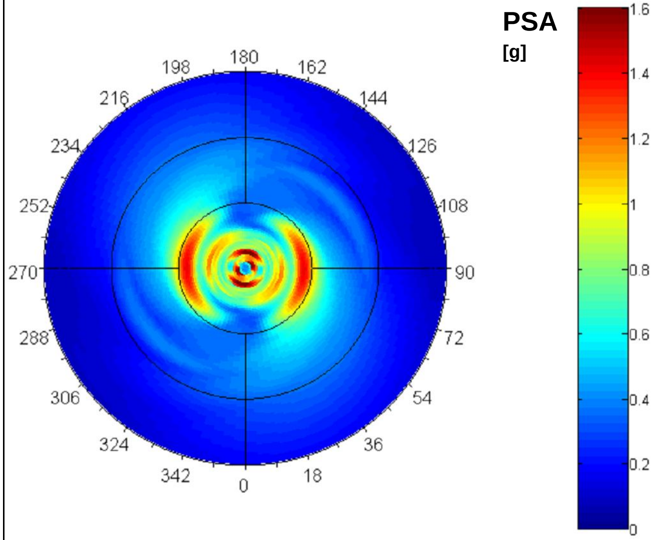
Overlapped Spectra Response in terms of Pseudo-Accelerations



Polar Spectrum – Displacements



Polar Spectrum – Pseudo Velocities



Polar Spectrum – Pseudo Accelerations

Record CU104 – station AQA

Spectra evaluated every 9° for several directions in the horizontal plane
Circular ring placed in polar spectra from inside to outside
at 0.5,1.0 and 1.5 sec. vibration periods, 0° corresponds to the South

Results show that in the case of recording station AQG spectral responses are characterized by the highest values in the range of periods around 0.3 sec for PSA and 0.9 sec for PSV. Moreover, response spectra show large demand in the NW-SE direction.

In the case of recording station AQV it is possible to observe larger PSA and PSV demand around 0.5 sec. in the NW-SE direction. In the case of PSA the highest demand is generally aligned along the same direction for all the periods. Instead, PSV presents the highest values varying between the NW-SE direction at 0.5 sec. and the NE-SW direction at 1.5 sec. SD presents high values generally in the NE-SW direction.

For the registration station AQK the largest demand is generally attained along the NW-SE direction with the highest value around 1.5 sec. for PSV and SD. Instead, PSA presents peaks around 0.2 sec and high values until 1.5 sec..

In the case of the registration station AQA, the directions of largest demand for PSA vary in the range 0.0-0.5 sec. from N-S to W-E directions. Otherwise, PSV presents the largest demand in the W-E direction for 0.5 sec. and NW-SE direction for 1.5 sec.

The results analysis leads to the following main comments:

- The spectra evaluated along the main directions NS and EW do not always represent the highest seismic demand;
- The spectral demand in the main horizontal direction does not provide a satisfactory evaluation of the seismic demand as a polar spectrum which, instead, better describes the spatial features of the seismic demand. In particular, analysis of the polar spectra shows that the seismic shaking generally presents non-uniform seismic demand for a fixed vibration period by varying directions;
- For this seismic event, although a main shock direction could be found in the polar spectra for all the recording stations, i.e. the NW-SE one, every station presents peculiar characteristics which differ from each other.

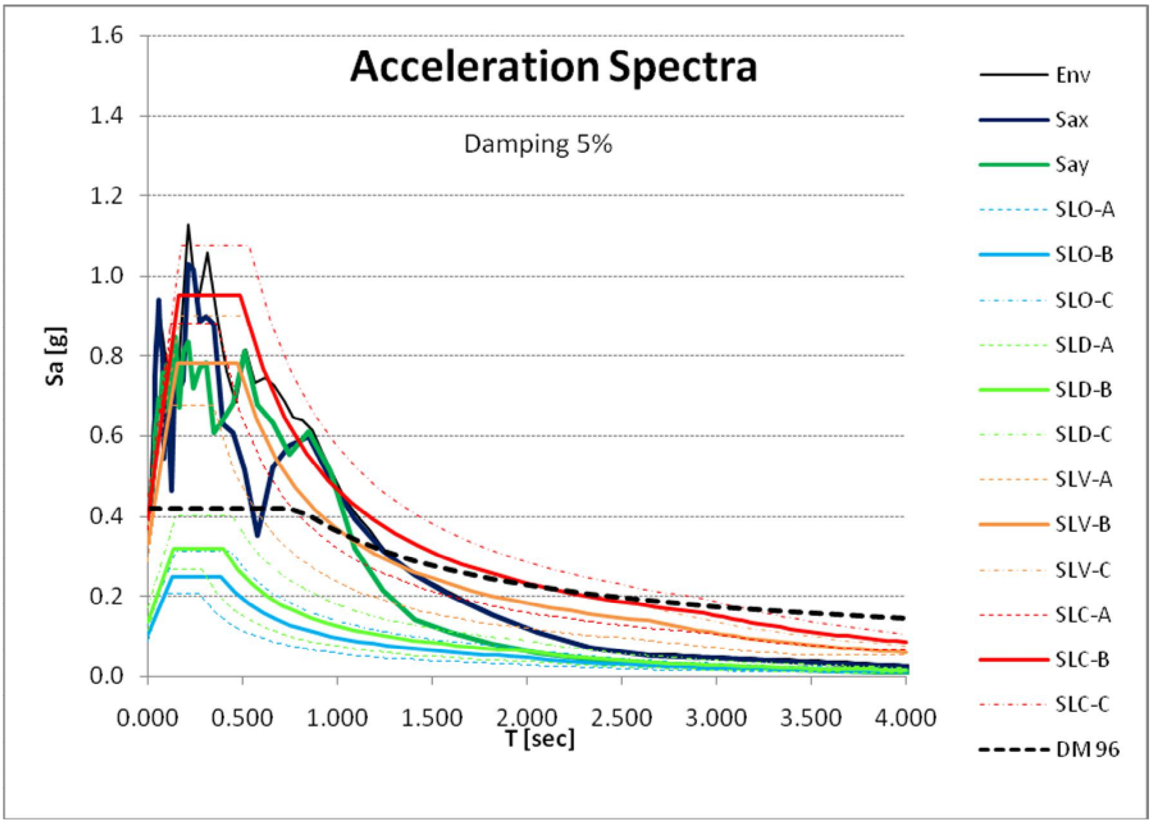
Spectra Comparison

In the following, the obtained spectra for the main horizontal direction S_{ax} and S_{ay} and the envelope spectra(Env) have been compared with the elastic demand spectra according to the new Italian seismic code (NTC2008) and the old code (DM96). In the case of NTC2008, the demand spectra are evaluated, for soil types A, B and C, by considering the following return periods:

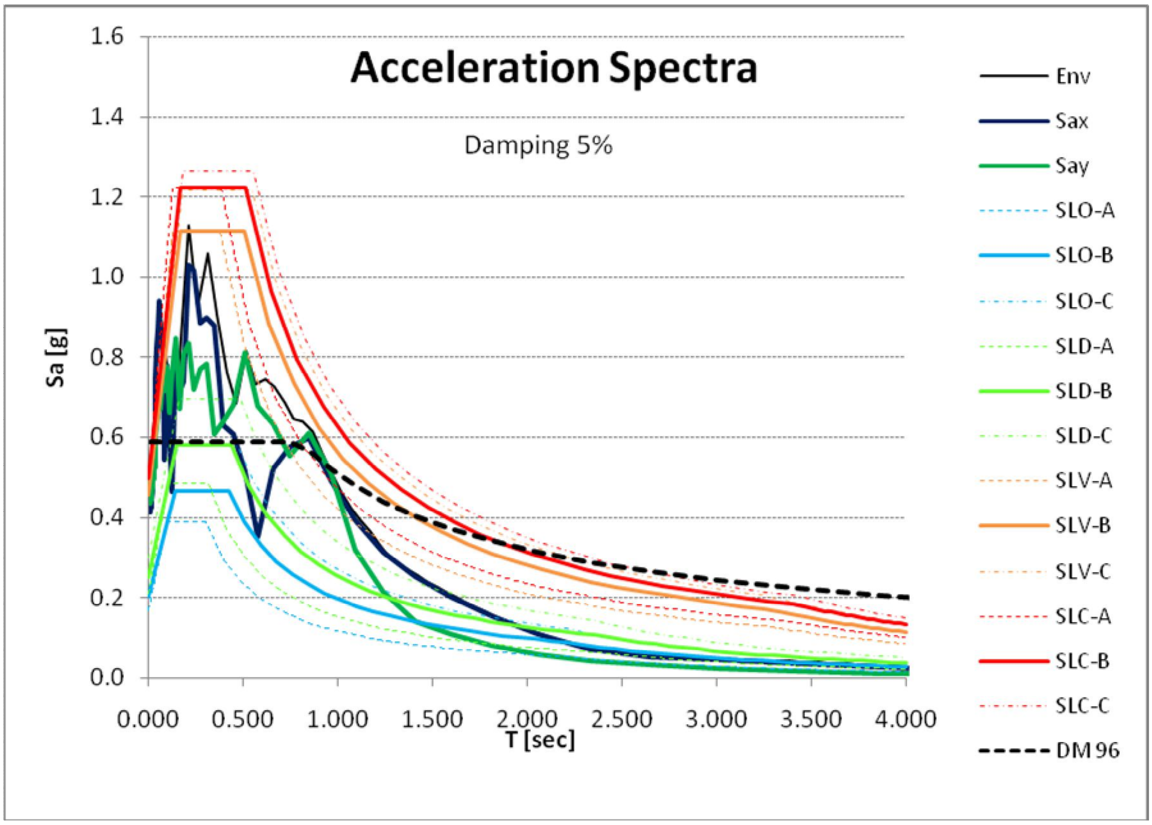
Target Performance Levels NTC2008	**Return Period T_R** [yrs]	
	Ordinary Constructions *(V_R=50 yrs)*	***Strategic Constructions*** *(V_R=200 yrs)*
Immediate Operative (**SLO**)	30	120
Damage Control (**SLD**)	50	201
Life Safety (**SLV**)	475	1898
Collapse Prevention (**SLC**)	975	2475

A structural factor q=4, a partial safety factor γE=1,5, to take into account limit state design procedure, and the importance factors I=1,0 and I=1,4, respectively for ordinary and strategic constructions have been considered in the case of the old code (DM96) to calculate the elastic demand spectra.

Moreover, for each station, the obtained spectra for the vertical direction S_{az} have been compared with the elastic demand spectra according to the new Italian seismic code (NTC2008), which, in this case, assumes the same spectrum response for each soil category.



Record FA030 – station AQG – Earthquake Spectra Resp. vs. NTC2008 Elastic Spectra for Ordinary Const.



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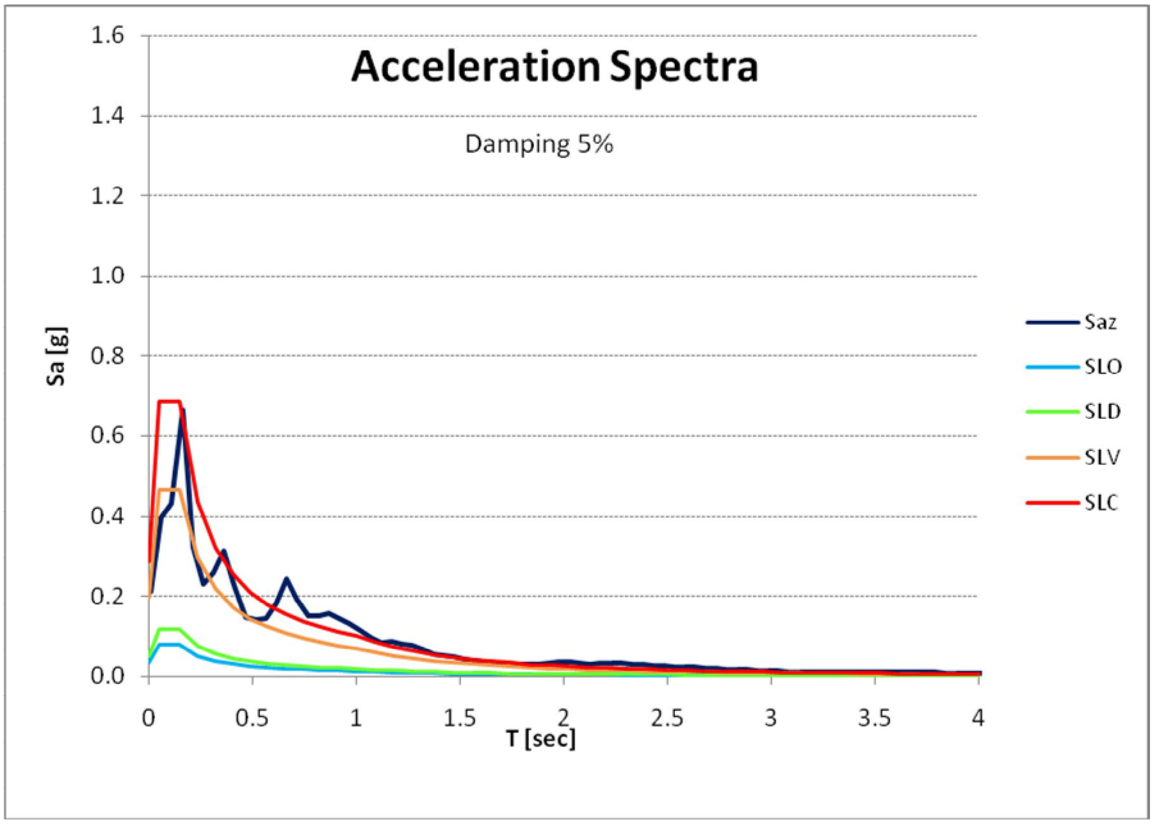
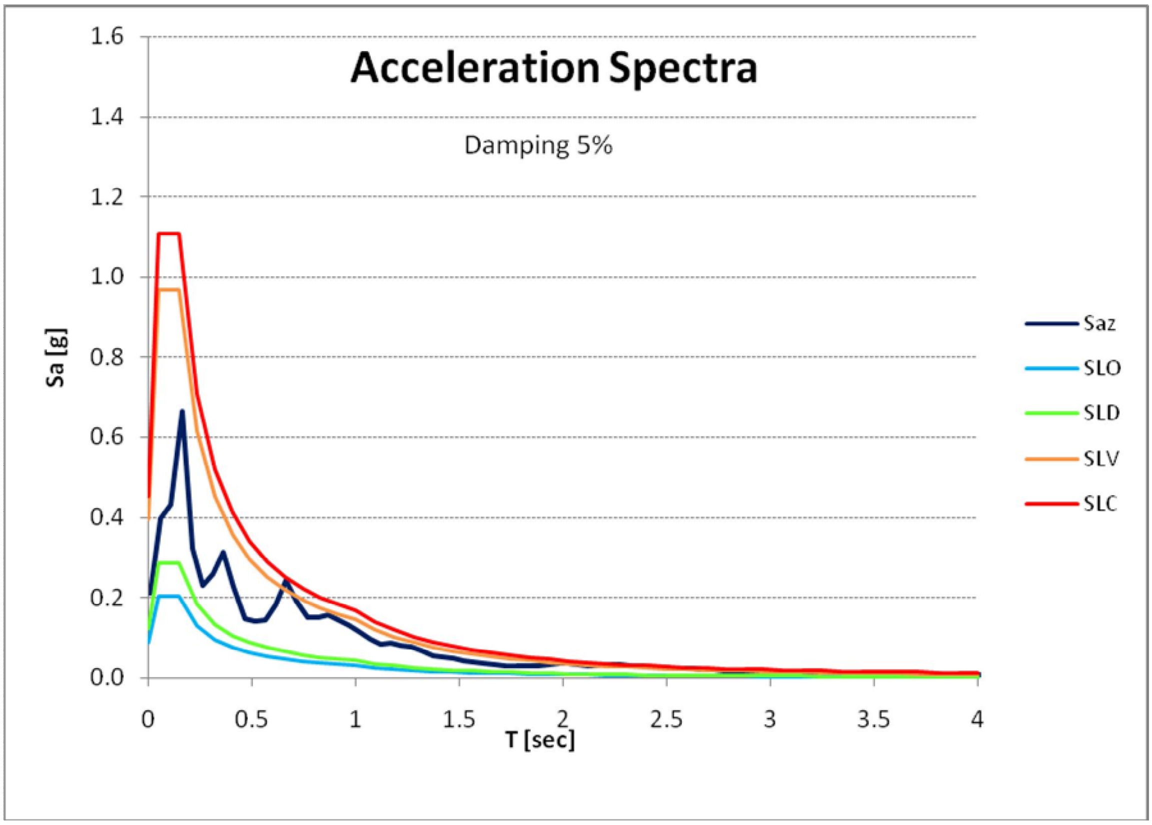
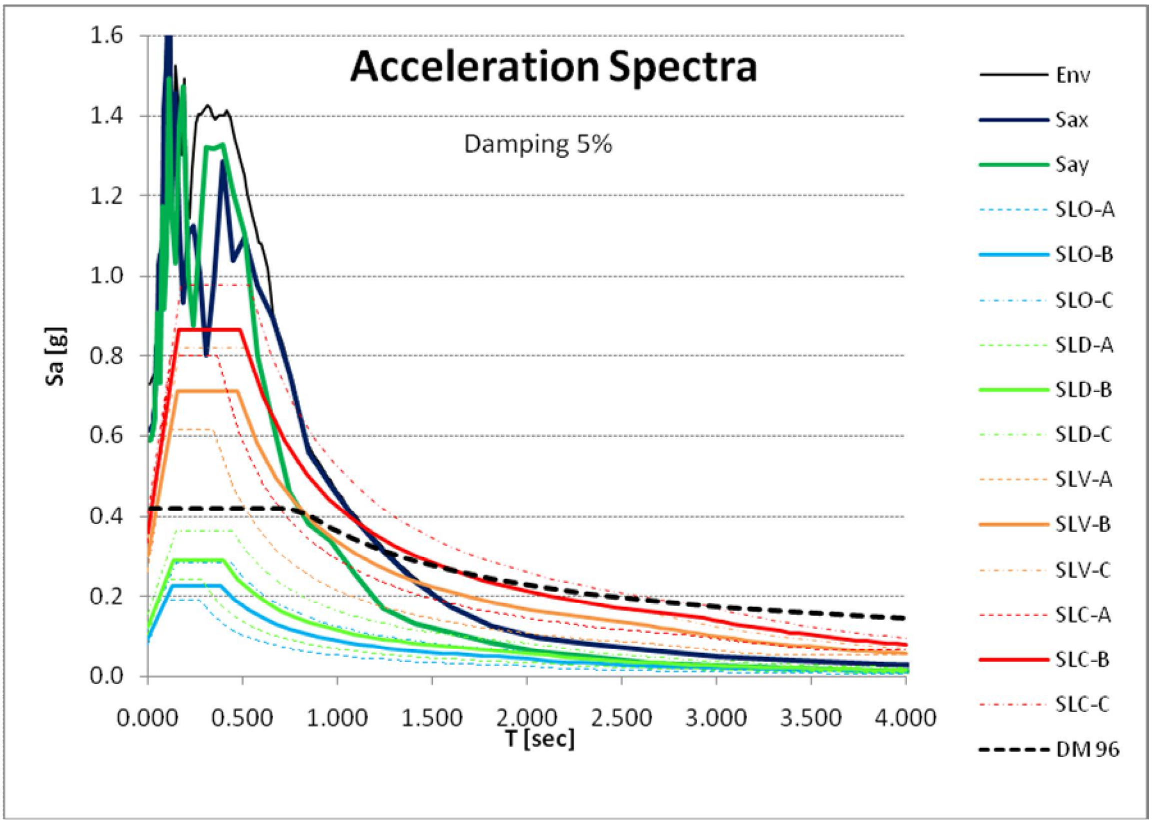


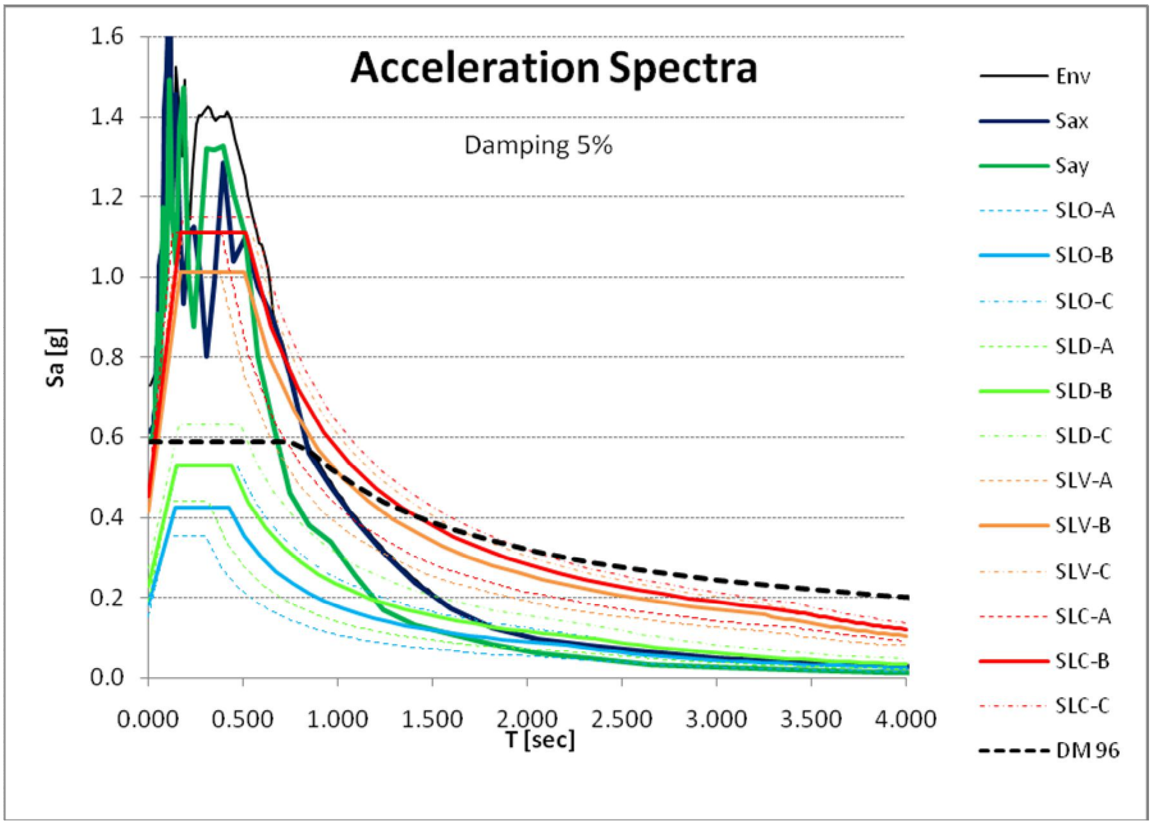
Record FA030 – station AQG – Earthquake Spectra Resp. vs. NTC2008 Elastic Spectra for Ordinary Const.



Record FA030 – station AQG – Earthquake Spectra Resp. vs. NTC2008 Elastic Spectra for Strategic Const.



Record GX066 – station AQV – Earthquake Spectra Resp. vs. NTC2008 Elastic Spectra for Ordinary Const.



Record GX066 – station AQV – Earthquake Spectra Resp. vs. NTC2008 Elastic Spectra for Strategic Const.

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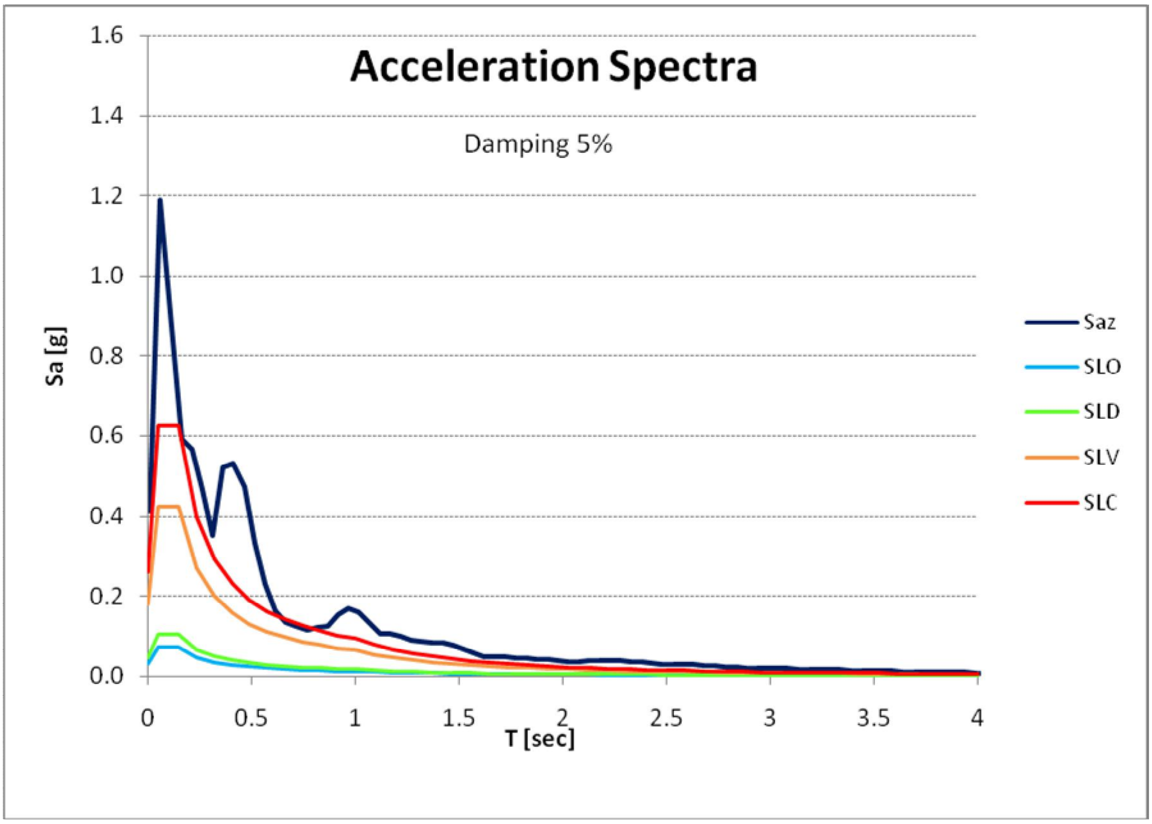

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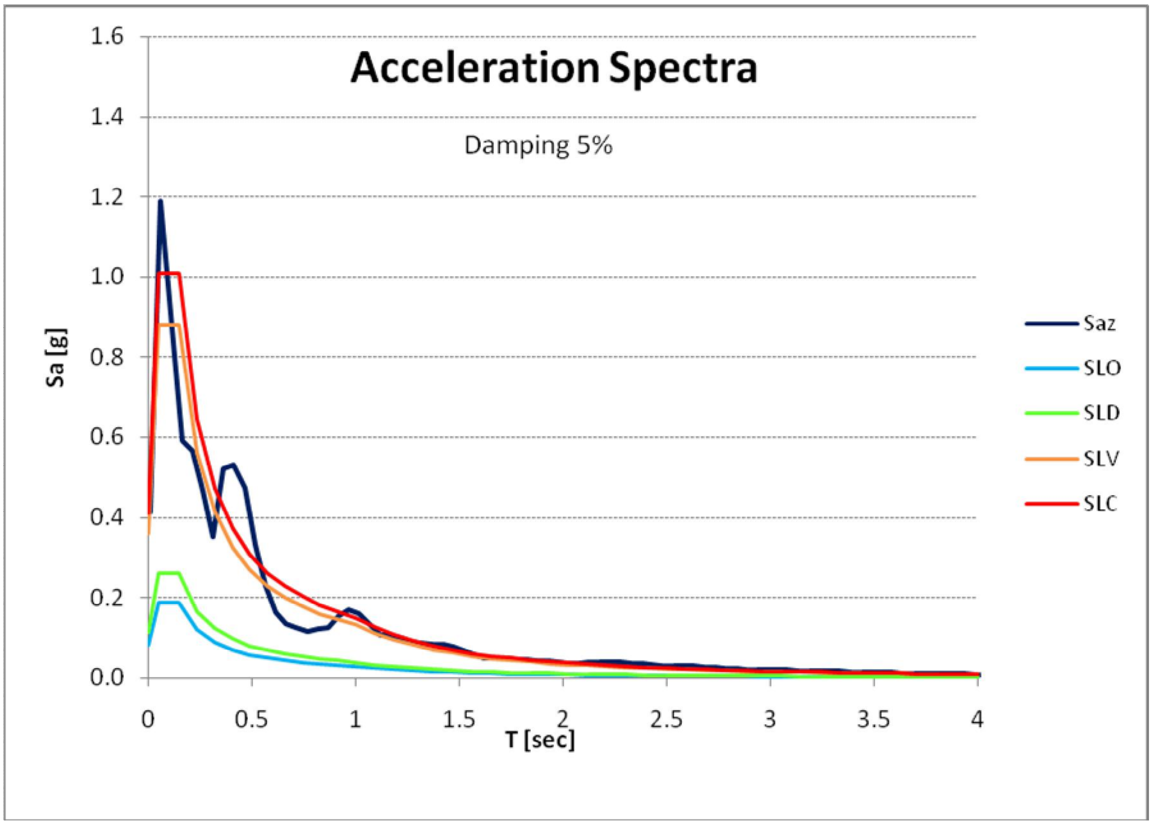

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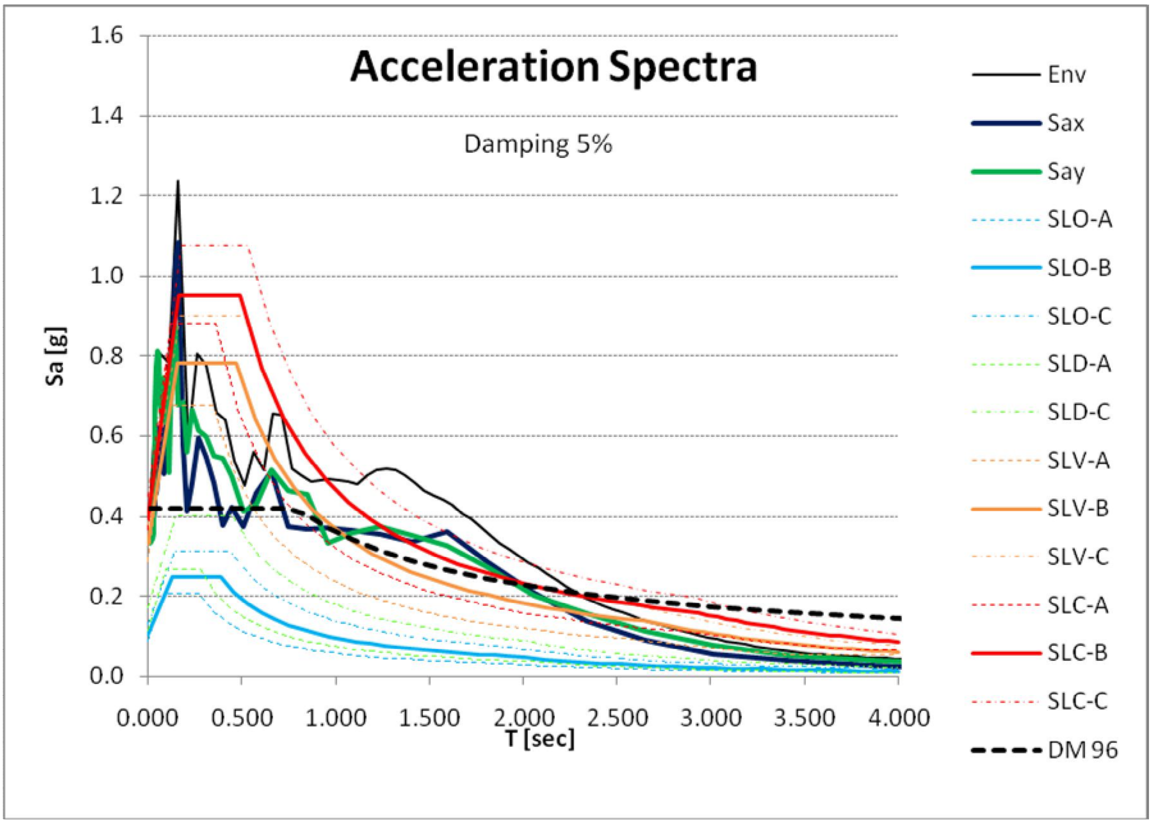
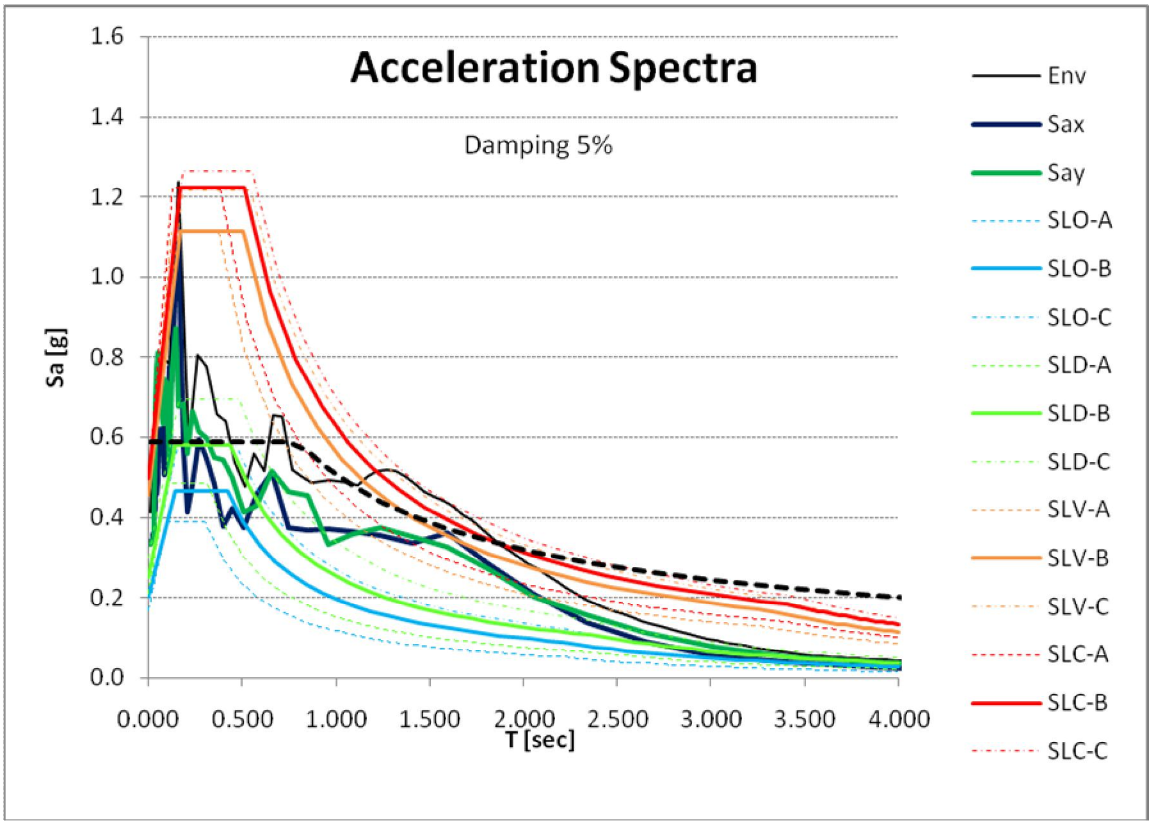


Record AM043 – station AQK – Earthquake Spectra Resp. vs. NTC2008 Elastic Spectra for Ordinary Const.



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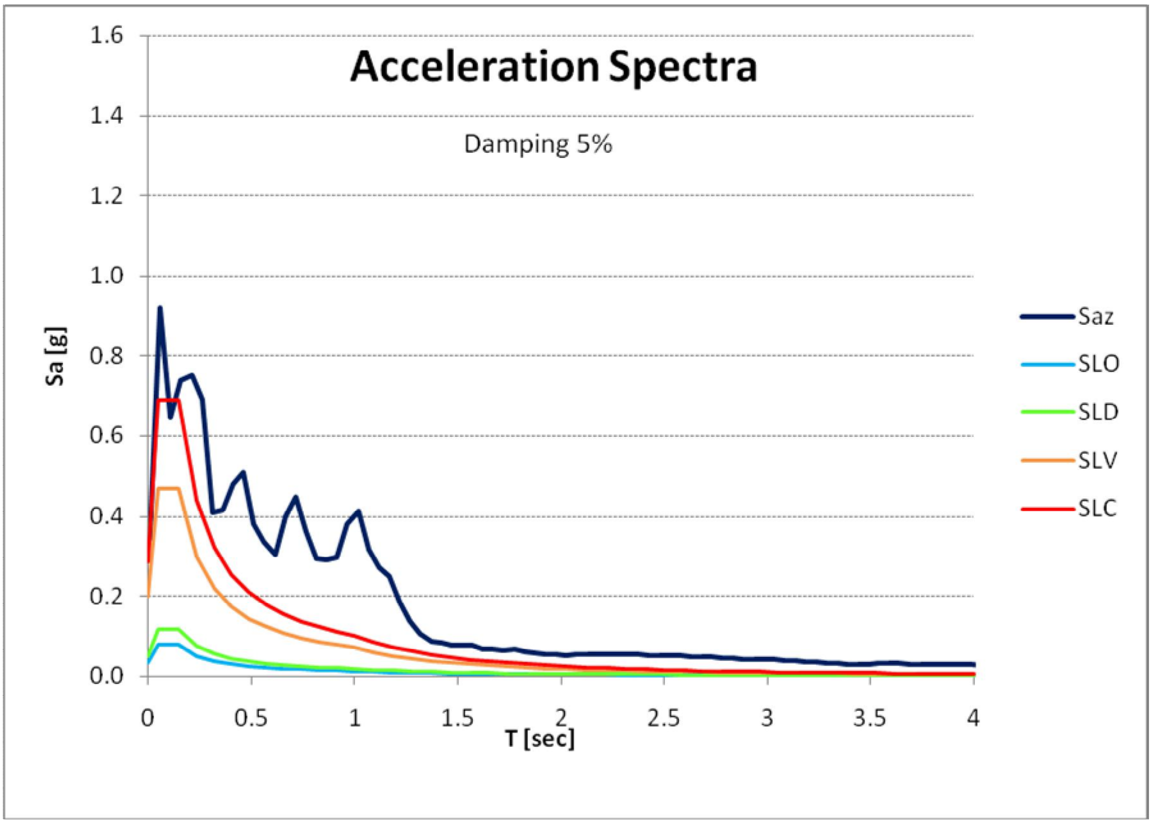

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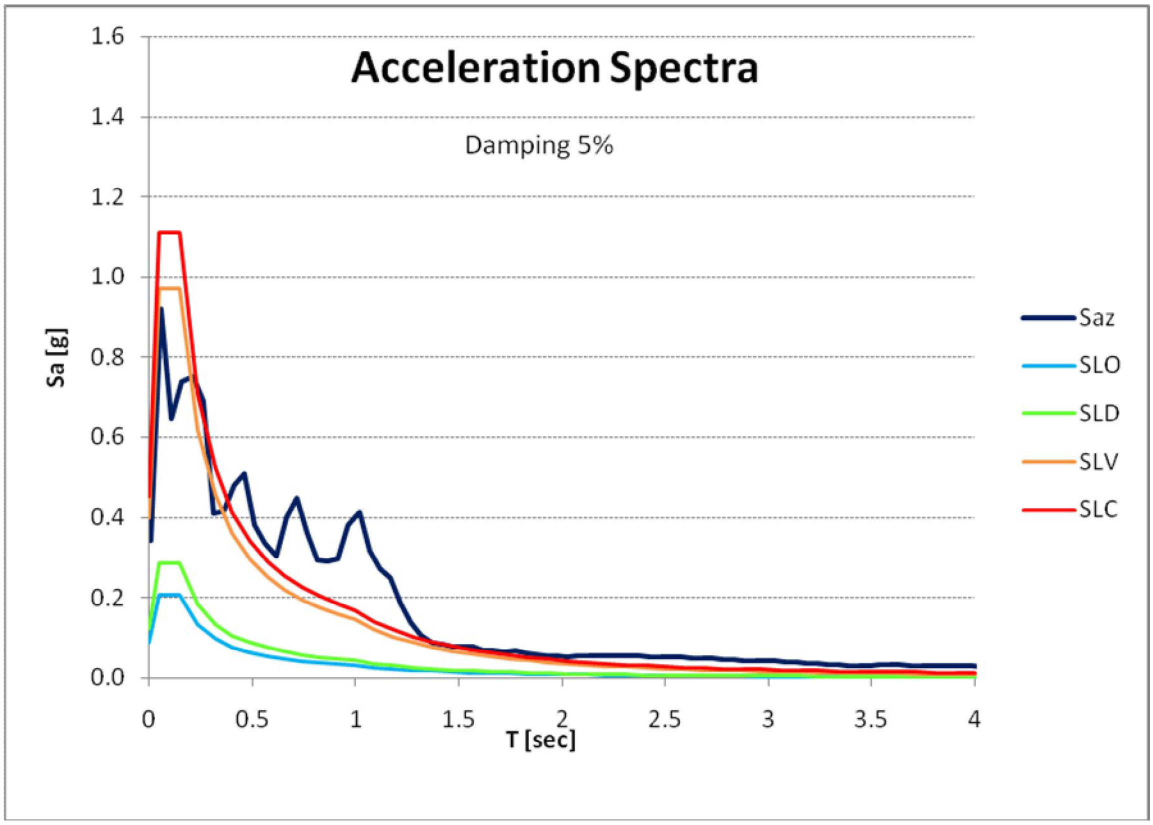

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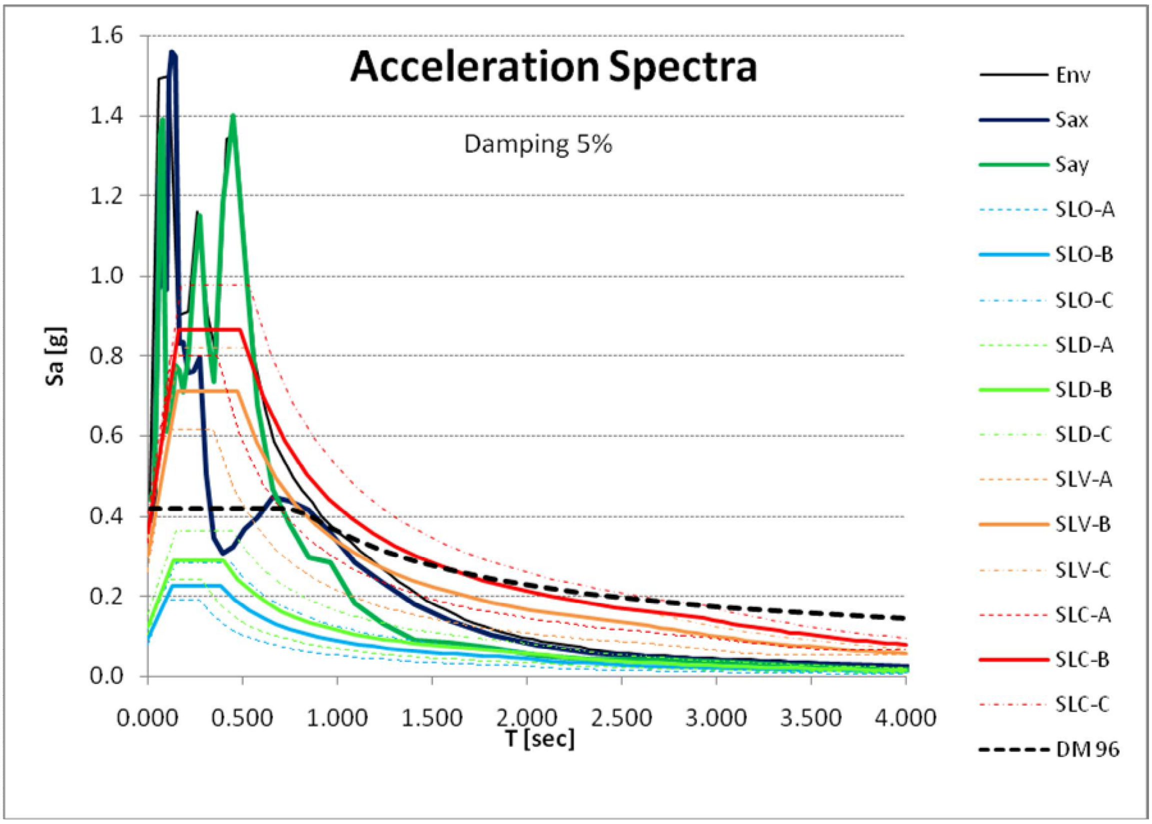

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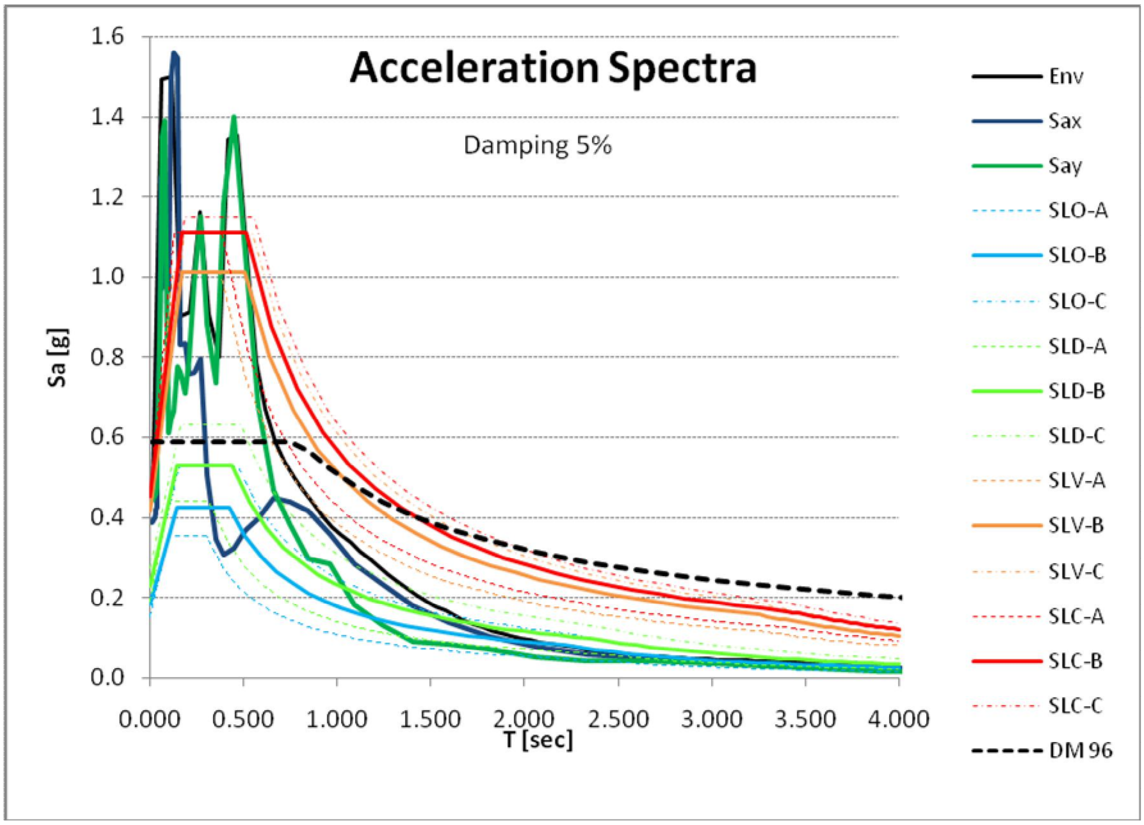

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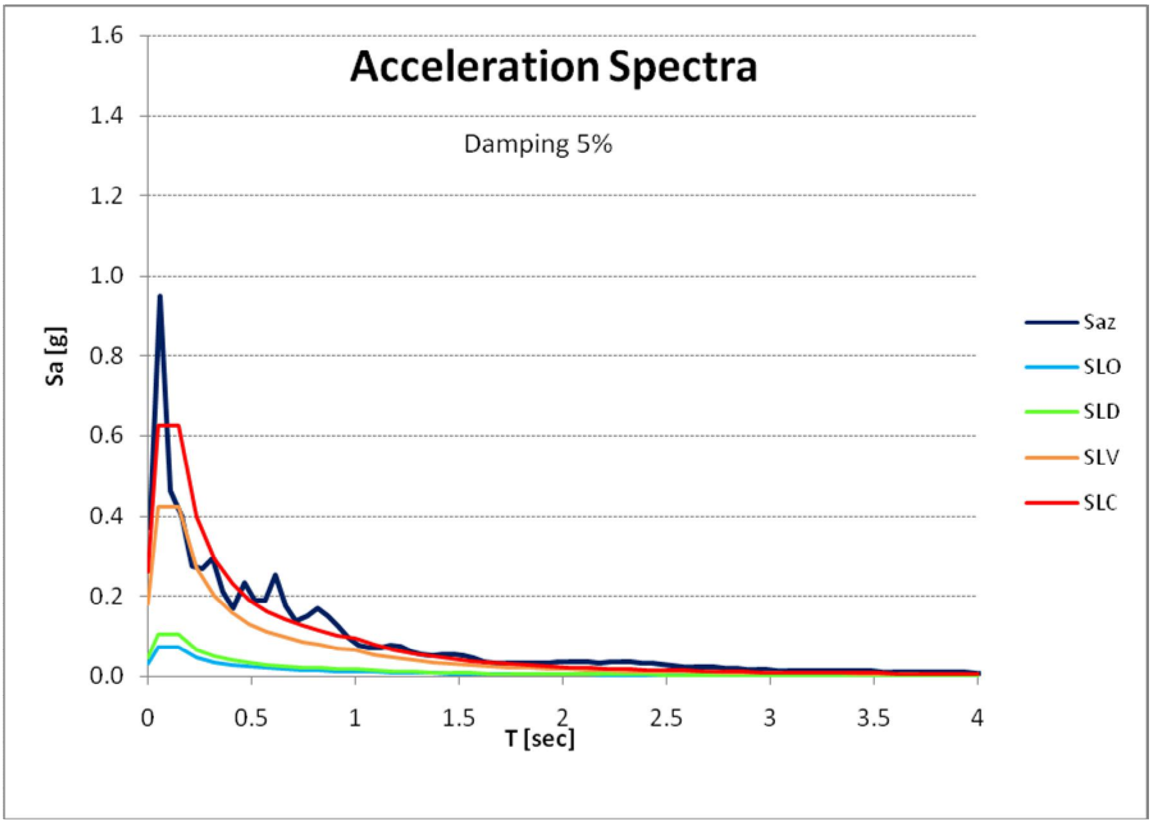

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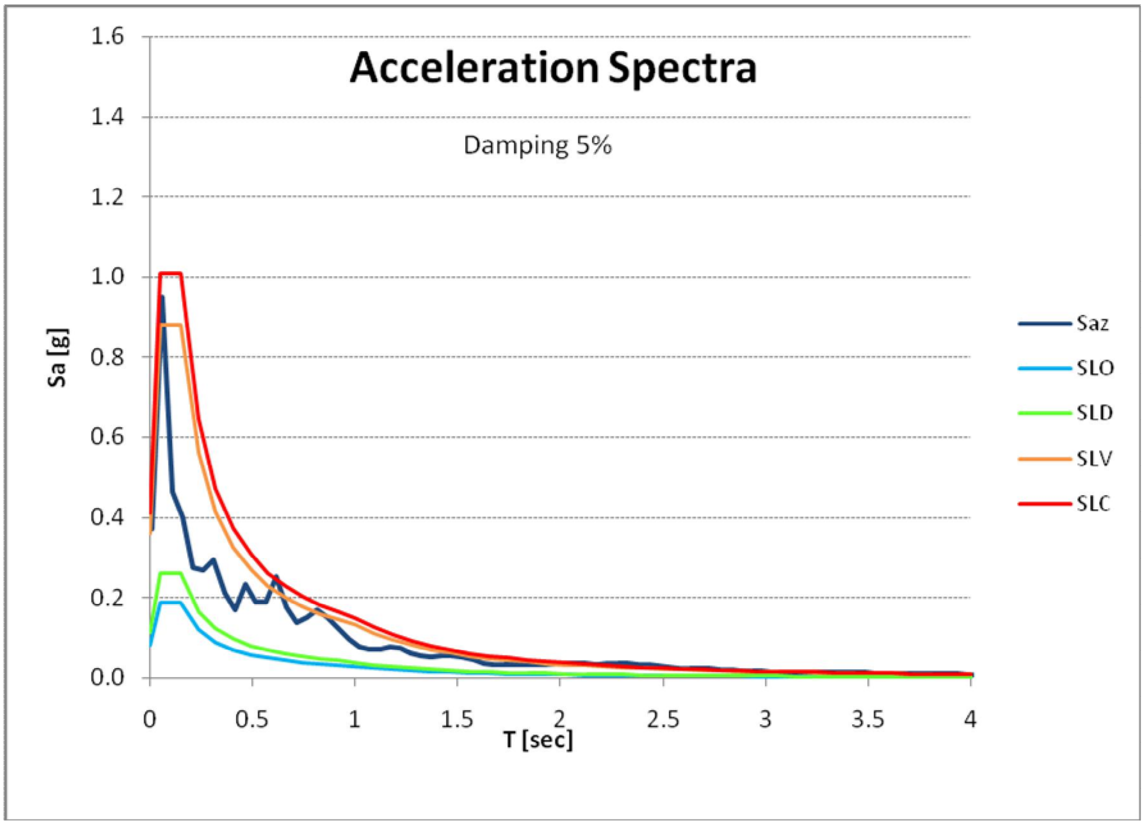

Record CU104 – station AQA – Earthquake Spectra Resp. vs. NTC2008 Elastic Spectra for Strategic Const.

An analysis of the results leads to the following main considerations:

- The horizontal and vertical seismic demands evaluated by means of pseudo-acceleration spectral response are particularly severe in the short period range;
- Generally the evaluated spectra in the short period range are higher than those considered by the NTC 2008 for the Collapse Prevention performance target, particularly in the case of the ordinary constructions;
- For each station, the obtained demand spectra and those evaluated according to the old code (DM96) are markedly different;
- In a wide range of periods the Control Damage target is greatly exceeded for the strategic constructions as well.

Considering the marked difference between the seismic spectral demand and that according to the old code (DM96) for all the recording stations, the observed damage is unexpectedly limited. Therefore, spectral response is not by itself sufficient to describe the seismic demand for this near fault event.

Moreover, analyses show that the vertical spectral demand, although not generally considered in the design, played an important role for this event having, in some cases, recorded vertical accelerations comparable to horizontal accelerations.

References

(1) E. Cosenza, E. Chioccarelli, I. Iervolino (2009), *Preliminary study of displacement and accelerations at close source distances for L'Aquila earthquake* V1.00 (http://www.reluis.it)

(2) ITACA, Italian Accelerometric Archive (http://itaca.mi.ingv.it/ItacaNet)

(3) RAN – National Accelerometric Network – DPC Dipartimento di Protezione Civile (http://www.protezionecivile.it)

(4) Ufficio sistema informativo geografico – Regione Abruzzo (http://www.regione.abruzzo.it/cartografianew/)

(5) NTC2008, *Norme tecniche per le costruzioni*, D.M. 14 Gennaio 2008

(6) E. Chioccarelli, F. De Luca, I. Iervolino (2009), *Preliminary study of L'Aquila earthquake ground motion records V5.20* (http://www.reluis.it)

(7) L. Petti, I. Marino, L. Cuoco (2008), *Seismic response analysis of 3d structures through simplified non-linear procedures*, 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China

(8) DM96, Norme tecniche per le costruzioni in zona sismica, D.M. 16 Gennaio 1996

Report history

V1.00 – 22/04/09 *preliminary comparison by means of spectral response in terms of pseudo-acceleration;*

V 2.00 – 01/06/09 *added spatial analysis of seismic registrations by means of Polar Spectra, added vertical spectra, added results description.*