PRELIMINARY SEISMIC DEMAND ANALYSIS BY MEANS OF POLAR SPECTRA FOR THE CENTRAL ITALY EARTHQUAKE

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Introduction

As widely known, seismic demand is generally described through Pseudo-Acceleration Spectra which lead to a seismic response analysis of a structure using 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 behavior, however, is considered by means of the "Structural Factor" taking into account the overall ductility capacities of structures.

This report presents an analysis of the spectral demand evaluated for the Central Italy earthquake (date: 24/08/2016 – 01:36:32 AM - UTC – Magnitude 6.0) by means of polar spectra that give the opportunity to represent the seismic demand in any direction of the horizontal plane (1).

In particular, the record registered in Amatrice (the nearest station to the source) has been taken into account:

- 24th August event – *station AMT*, Amatrice site
  Soil profile type B, Topography factor ST=1.0, Epicenter distance R=9.58 km

Soil parameters have been preliminarily estimated from data made available from the ITACA (Italian Accelerometric Archive) (2).

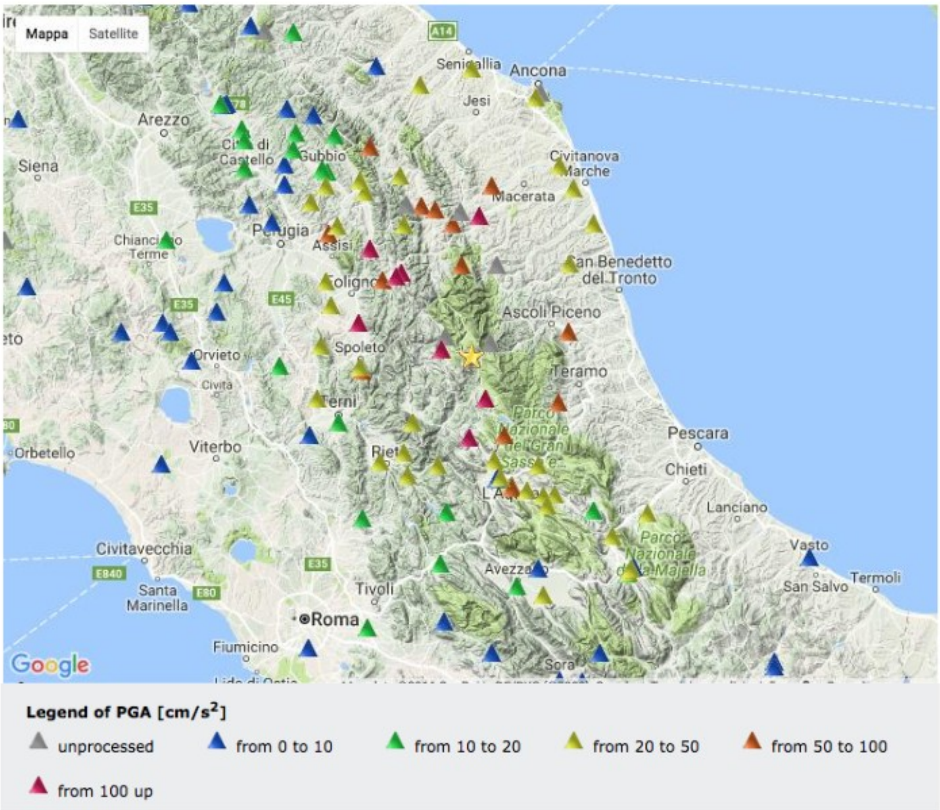


Figure 1. Map of the stations within 200 km from the epicentre (3)

The table below illustrates the Peak Ground Acceleration (PGA) for horizontal (X and Y) and vertical (Z) components registered in Amatrice (4).

Table 1. PGA for the main directions (4)

ID station/direction analysis	PGA [g]		
	EW – direction	NS – direction	Z – direction
AMT	0.433	0.187	0.198

The recorded horizontal and vertical Peak Ground Accelerations, for Amatrice station, present significant values.

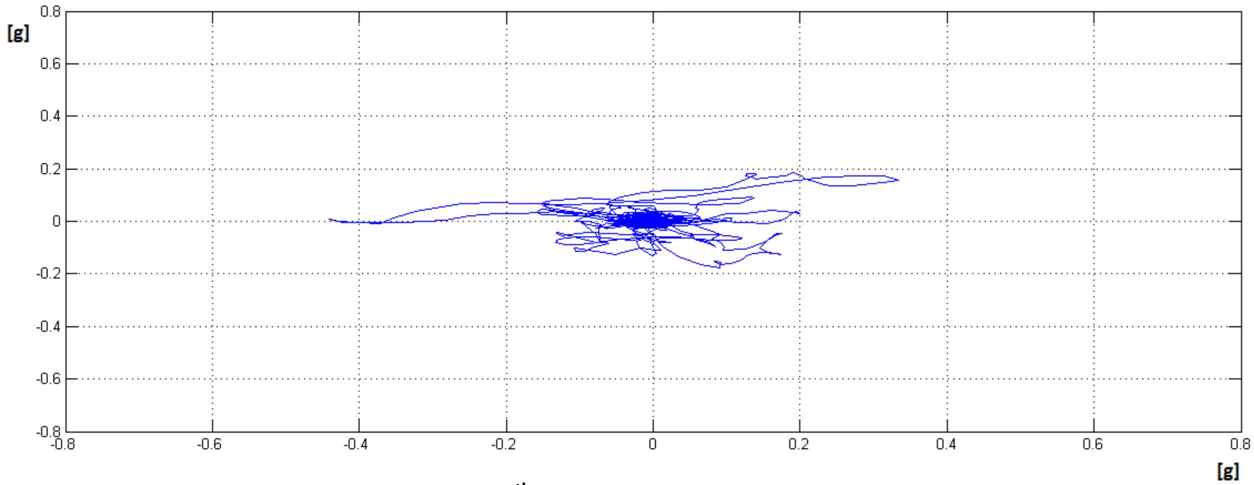
Spatial spectral analysis

To characterize the horizontal seismic demand, pseudo-acceleration spectra for several in-plane directions have been evaluated. In particular, for the Amatrice 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, have been evaluated for 40 in-plane directions (every 9°) in the chosen recording station, by considering a 5% damping coefficient and logarithmic subdivision of the considered period range 0.0-4.0 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 $S_{a,env}$.

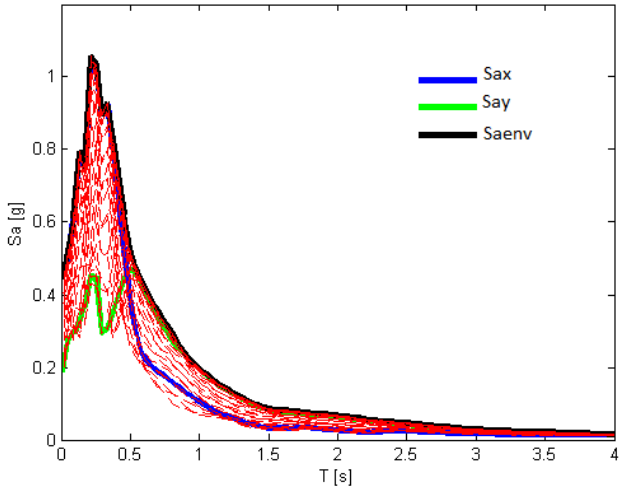
With regard to the Polar Spectra (1,5,6,7), the plots represent the seismic spectra demand in each horizontal directions by means of graduated color maps. In particular, the polar spectrum represents the spectral surface projection on the horizontal surface obtained by evaluating the spectra in each horizontal direction by considering the corresponding ground accelerations time histories. To the purpose, the accelerograms considered for each directions have been evaluated using the NS and EW recorded components of the seismic event. Each radius of the polar spectrum represents, thus, the response evaluated in that direction and each circumference, instead, the spectral demand for a fixed period in each directions. 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.



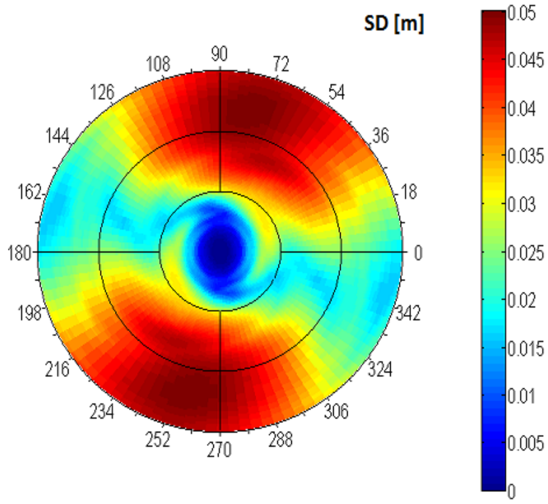
24th August event – station AMT

Figure 2. Earthquake horizontal acceleration plot in the NS-EW directions (North at the Top of Figure)

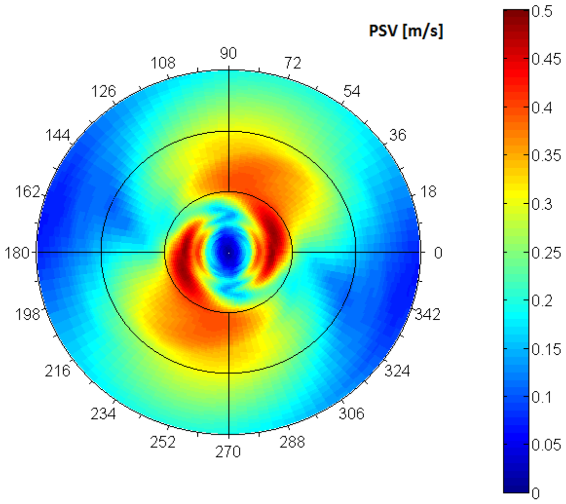
By analyzing the horizontal acceleration plot it is possible to observe a non-uniform seismic demand in the plane with the W-E path as the main strike direction.



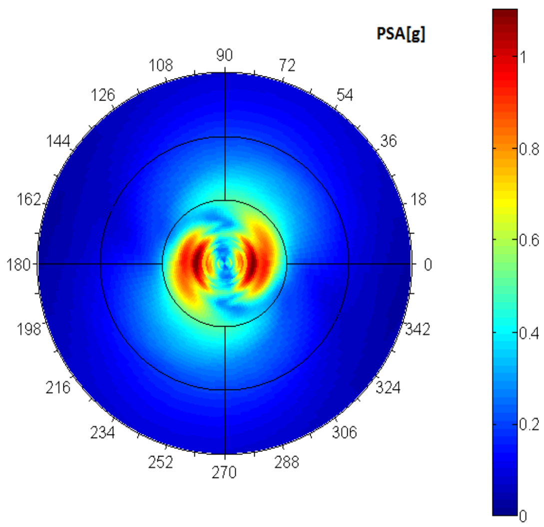
Overlapped Spectra Response
in terms of Pseudo-Accelerations



Polar Spectrum – Displacements



Polar Spectrum – Pseudo Velocities



Polar Spectrum – Pseudo Accelerations

Figure 3. 24th event Polar Spectra – Station AMT
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, 270° corresponds to the South

Results show that in the case of the recording station AMT, spectral displacements are generally characterized by the highest values in the NNW-SSE direction for periods between 0.5 sec and 1.5. sec. More complex appears the seismic demand in terms of PSA where maximum values are reached in range of periods 0.2 and 0.4 sec for PSA in the E-W direction. The demand in terms of PSV reaches his highest values in the range 0.2÷0.5 sec for the E-W direction.

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.

Damage Indexes Evaluation

It has been carried out a further study on seismic demand of central Italy earthquake using the indexes Park and Ang (8) damage index (P&A index). As is known, the seismic performance of a structure can be estimated by means of the P&A index which allows for a consideration of both the effect of the maximum plastic excursion and the overall hysteretic energy. This index consists of a simple linear combination of normalized deformation and energy absorption as in the following:

$$D_{P.A.} = \frac{x_{\max}}{x_{u,mon}} + \beta \frac{E_H}{F_y x_{u,mon}}$$

where $x_{\max}$ is the maximum seismic displacement; $x_{u.mon}$ is the maximum displacement for a monotonic load test, E_H is the hysteretic energy and F_y the strength of the considered structure.

The coefficient b can be seen as a decay model parameter related to the dissipated plastic energy (9). In the analyses β is set equal to 0.15 (10).

In the following table the P&A index is reported for each level of estimated structural damage.

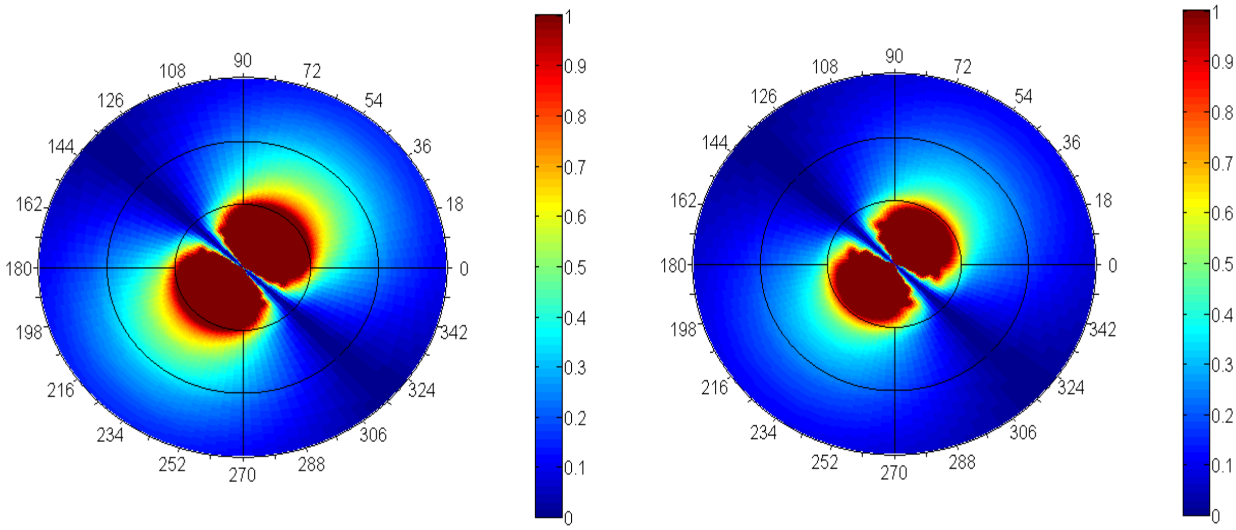
Table 2. Park and Ang Index values

P&A index values	Estimated structural damage
PA≤0.1	No damage or localized cracking
0.1≤PA≤0.25	Minor damage
0.25≤PA≤0.40	Moderate damage
0.4≤PA≤1	Severe damage
PA≥1	Collapse

Within the scope of the present study the case of a structure designed according to the old Italian Seismic Code DM ’96 (11) has been considered (12).

For the analysis it has been assumed an overstrength factor γ=1.5, a partial safety factor γ_E=1.5 and a ductility capacity μ=3, taking into account the importance factors I=1.0 and I=1.4.

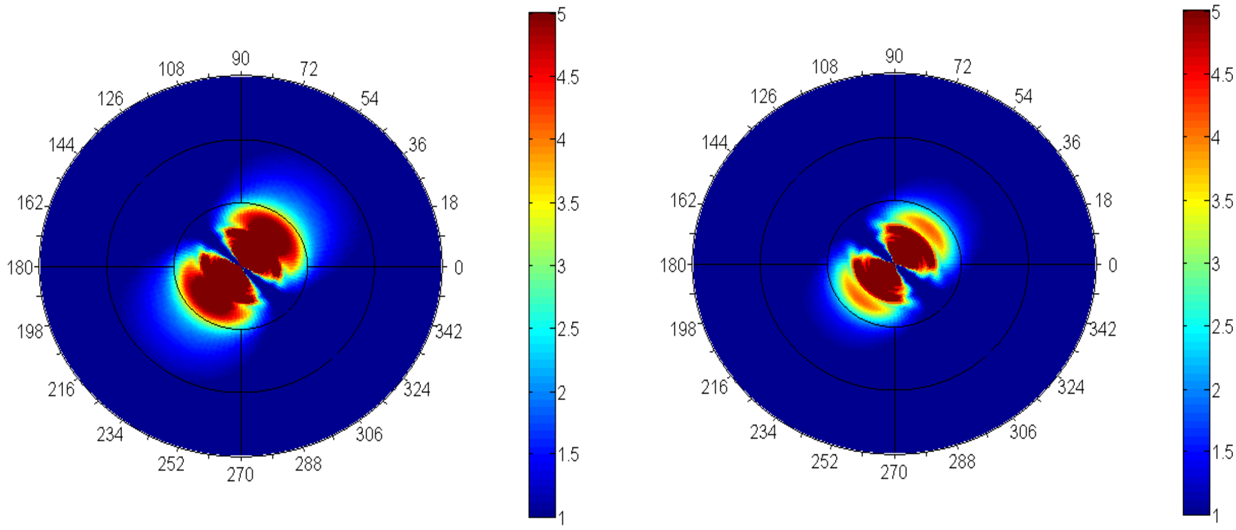
In the following graphs the polar spectra of the P&A index and ductility demand (ratio of the maximum displacement over the displacement at the elastic limit) for the seismic registration of station AMT in Amatrice are shown. The periods 0.5, 1.0 and 1.5 are marked by black thin circumference, the origin corresponds to 0 sec period. The South is located at 270°.



(a) (b)

Figure 4. Polar Spectra – Station AMT

Spectra in terms of P&A index assuming an overstrength factor γ=1.5, a partial safety factor γ_E=1.5 and a ductility factor μ = 3 for (a) ordinary structures (I=1) and (b) strategic structures (I=1.4)



(a) (b)

Figure 5. Polar Spectra – Station AMT

Spectra in terms of ductility demand assuming an overstrength factor γ=1.5, a partial safety factor γ_E=1.5 and a ductility factor μ = 3 for (a) ordinary structures (I=1) and (b) strategic structures (I=1.4)

The results show that in the short range period (maximum seismic spectral demand) the theoretical analysis of the expected response highlights strong levels of damage.

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