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# Neo-deterministic seismic hazard assessment for Alborz Region, Iran

Mehdi Rastgoo[a], Habib Rahimi[a,*], Fabio Romanelli[b], Franco Vaccari[b], Giuliano F. Panza[c,d,e,f,1]

[a] Institute of Geophysics, University of Tehran, Tehran, Iran
[b] Department of Mathematics and Geosciences, University of Trieste, via E. Weiss 4, 34127 Trieste, Italy
[c] Accademia Nazionale dei Lincei, Roma, Italy
[d] Institute of Geophysics, China Earthquake Administration, Beijing, China
[e] International Seismic Safety Organization (ISSO), Italy
[f] Beijing University of Civil Engineering and Architecture (BUCEA), China

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ABSTRACT

Seismic hazard maps for Alborz region (north of Iran) and adjacent areas are prepared using the neo-deterministic seismic hazard assessment (NDSHA) based on the computation of synthetic seismograms at the regional scale. The study area is zoned according to different geophysical structural models delimited at the surface by polygons, used to define the mechanical properties of the source-site paths. We have refined the velocity structures of Iran, as obtained from surface waves tomography, to obtain the velocity structure of Alborz region by applying the joint inversion of the P-wave receiver functions (PRF) and surface wave's dispersion. The input data set consists of attenuation-velocity structural models (representing bedrock conditions), seismogenic zones, focal mechanisms and the catalog of past seismicity. The seismic hazard, expressed in terms of maximum displacement (PGD), maximum velocity (PGV) and design ground acceleration (DGA), is extracted from the synthetic seismograms and mapped on a regular grid of 0.2° × 0.2° over the entire region. The results of this first order NDSHA zoning indicate a high seismic hazard in the Alborz region and may represent an important knowledge basis towards detailed and comprehensive seismic microzonation studies.

## 1. Introduction

Insufficient information about historical seismicity of a region leads to the limitation in providing a seismic hazard assessment (SHA) based on the traditional methods (deterministic and probabilistic). The standard probabilistic method is the subject of criticisms by several authors (e.g. Castanos and Lomnitz, 2002; Klugel, 2007; Wang, 2008; Panza et al., 2014; Mulargia et al., 2017) since the results of Probabilistic SHA (PSHA) analysis are not always realistic nor reliable. Kossobokov and Nekrasova (2010, 2012) based on the fatal evidence of the deadliest earthquakes occurred since 2000, showed that the worldwide maps resulting from the Global Seismic Hazard Assessment Program, GSHAP (Giardini et al., 1999), are grossly misleading.

In view of the limited availability of seismological data, that undermine any statistical analysis of the seismic deformation, the neo-deterministic seismic hazard assessment (NDSHA) has been proposed for the definition of the seismic ground motion in an adequate and reliable way. NDSHA supplies realistic time history ground motions calculated as the tensor product between the tensor representing in a formal way the earthquake source and the Green's function of the medium. In this sense, physics-based synthetic seismograms can be computed through the knowledge of the earthquake generation process and of the seismic wave propagation in an inelastic medium.

NDSHA approach can be used at different scales. It was applied at regional scale first in Italy and Circum Pannonian region (Panza et al., 2001), then worldwide (e.g. North Africa, see Mourabit et al., 2014) and, after some updates (Panza et al., 2012; Magrin et al., 2016), was very recently re-applied to Egypt (Hassan et al., 2017) and India (Parvez et al., 2017). However, applications to local scale including microzonation were also proposed (e.g. Panza et al., 2001; Panza et al., 2012), suggesting to adopt an equivalent, in terms of possible utilization, uniform hazard spectrum, called MCSI (e.g. Fasan et al., 2016).

In this study, following the examples recently performed for other countries (e.g. Egypt and India) we propose for the first time NDSHA at the regional scale for the Alborz region (Fig. 1), a seismically and tectonically active mountain range in the North of Iran, in order to build the important knowledge basis towards microzonation at selected sites.

Iranian plateau is located between the lithospheric plates of Arabia and Eurasia, which converge at a rate of ~22 $mm yr^{-1}$ (Vernant et al., 2004a). In the Alborz Mountains, tectonic activity is due to two

* Corresponding author.
*E-mail address:* rahimih@ut.ac.ir (H. Rahimi).
[1] www.issoquake.org.

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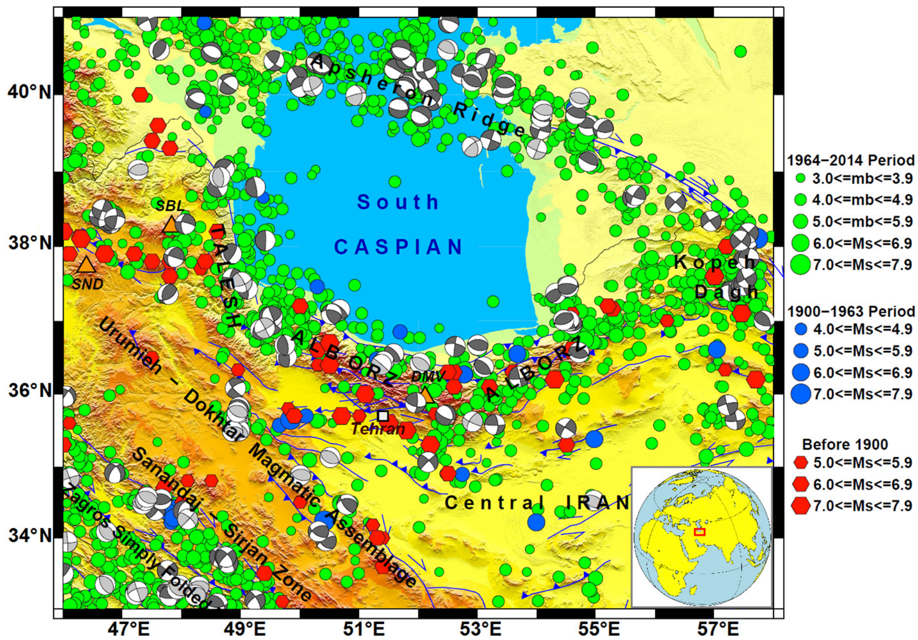


**Fig. 1.** Seismicity of the Alborz region including instrumental (ISC catalog, 2014) and historical earthquakes (Ambraseys and Melville, 1982; Berberian, 1994) with mapped active faults.
Focal mechanisms (beach balls) for earthquakes with Mw > 4.6: black - online Global Centroid Moment Tensor catalog (Dziewonski et al., 1981; Ekstrom et al., 2012); gray - online Regional Moment Tensor Catalog of the Swiss Seismological Service (SRMT Catalog, 2006).
DMV: Damavand volcano, SBL: Sabalan volcano, SND: Sahand volcano.

different kinds of relative motions (Ritz et al., 2006): the convergence of Central Iran towards Eurasia and also the northwest motion of the South Caspian basin with respect to Eurasia. The Alborz region accommodates some of the motion between the rigid blocks of Central Iran and the South Caspian Basin, in the form of oblique left lateral movement (Jackson et al., 2002). Vernant et al. (2004b) have reported $5 \pm 2$ mmyr$^{-1}$ north-south shortening across the central part of Alborz, whilst left lateral shear occurs at a rate of $4 \pm 2$ mmyr$^{-1}$. The Alborz Mountains form an arc around the southern shoreline of the South Caspian basin, between 49°E and 56°E (Jackson et al., 2002). The northern and southern boundaries of the Alborz are defined by thrust faults, which are dipping towards the center of the range. These faults are relatively close, producing a narrow (60–120 km), steep sided range, with an abrupt edge with the Central Iranian Plateau to the south, and the narrow coastal plain of the Caspian Sea to the north. The range has many peaks between 3600 and 4800 m, reaching a maximum of 5671 m with the volcano Damavand, the highest peak in Iran (Jackson et al., 2002).

## 2. NDSHA methodology at regional scale

NDSHA, when applied to regional scale (first-order seismic zonation), takes into account the source characteristics and the path conditions, according to the general scheme shown in Fig. 2. Once models have been defined for seismic wave velocity and attenuation and for the seismic sources, the sites where the ground motion is computed are chosen at the nodes of a regular grid (0.2° × 0.2°), which covers the whole considered territory. The synthetic seismograms can be computed at the surface of a 1D bedrock model for different epicentral distances, with a 1 Hz cut-off frequency. In this context, a bedrock model qualifies as hard rock in the soil categories defined by seismic codes (e.g. for Eurocode-8 (2004) the weighted average shear wave velocity in the top 30 m of soil profile, $V_{S30}$, must be higher than 800 m/s). As reported in Panza et al. (2012), to compute synthetic seismograms at 1 Hz, the size and time scaled point source (STSPS) model (described by Parvez et al., 2011) can be used. This model is more realistic than the point source approximation and can take into account the directivity effects, due to the rupturing process at the finite fault, as described in Section 4. The Fourier spectra of earthquake ground motion displacements and velocities show that the dominating part of their seismic energy is concentrated in the range of frequencies smaller than 1 Hz, while for accelerations the maxima are concentrated around frequencies larger than 1 Hz (Panza et al., 1997). Therefore, considering an upper frequency limit of 1 Hz for the computation of seismograms, the peak ground displacement (PGD) and peak ground velocity (PGV) can be estimated directly from the synthetic seismograms.

On the other hand, the knowledge about seismic sources and lateral heterogeneities required to extend computation to higher frequencies is not usually available at the scale of the areas generally considered in the zoning. Thus, it is not possible to refine the results obtained with first-order zoning by simply assuming a higher cutoff frequency (> 1 Hz) in the computation of synthetic seismograms. This is not a technical limitation of the computational algorithms, but a deliberate choice, originally adopted in Panza et al. (2001): a more detailed zoning requires a better knowledge of the seismogenic process and of the geophysical models in the region.

For accelerations, computational results may be extended to frequencies higher than 1 Hz by using the normalized elastic acceleration response spectra. In absence of normalized spectra derived from specific regional recorded signals, coded spectral shapes can be used as, for instance, Eurocode-8 (2004), which defines the normalized elastic acceleration response spectrum of the ground motion for 5% critical damping. Based on this, the design ground acceleration (DGA) is defined as the value of absolute acceleration response spectrum of the ground motion at period 0 s (Panza et al., 1996, 2001).Thus, it is possible to obtain DGA, by computing the response spectrum for each synthetic accelerogram for periods of 1 s and longer and the matching it with the long-period portion of the normalized elastic acceleration response spectrum of the ground motion corresponding to sites on rock of type A (following the ground classification of building codes). The procedure to estimate DGA at regional scale was described and validated by Panza et al. (1996, 2001) and Markušić et al. (2000), and later applied worldwide to several countries, like Egypt (Hassan et al., 2017) and India (Parvez et al., 2017).

## 3. Geophysical structural models

To compute the synthetic seismograms at a regional scale, the physical properties of the different source-site paths should be taken into account. For this purpose, the investigated territory is divided into several polygons corresponding to different geophysical structural models, each one represented by a number of flat anelastic layers with