APPLICATION OF NEO-DETERMINISTIC ANALYSIS FOR NORTH MACEDONIA

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In this paper, a scenario-based neo-deterministic approach for seismic hazard assessment (NDSHA) giving a realistic description of the seismic ground motion due to an earthquake of a given distance and magnitude is applied to the territory of North Macedonia and the hazard maps are obtained. A comprehensive understanding of both the seismic source process and the propagation of seismic waves is a prerequisite in the process of the application of NDSA on a specific region. The procedure is based on the integration of the existing geological, seismotectonic and geotechnical databases relevant to the selected region. In the definition of scenario earthquakes, the available seismic data, as well as information for the geological active faults in North Macedonia are used. This multi scenario-based analysis simultaneously incorporates the known databases and with use of advanced physical modeling techniques provides the required ground motion data set.

The results are based on the computation of realistic synthetic seismogram. A reliable hazard map at regional scale, for the complete territory of North Macedonia are shown.

As a final result, Maximum Credible Seismic Input – MCSI is computed for various locations in North Macedonia and valuable response specrta for the selected locations are obtained.

These data (spectra and time histories) are set to be used as seismic input for the nonlinear analysis of the existing structures in North Macedonia in the process of seismic risk analysis on a regional scale.

Keywords: seismic hazard, neo-deterministic seismic hazard assessment, hazard maps, maximum credible seismic input

1. INTRODUCTION

The ground shakings that occur repeatedly remains as of the importance of the continues research in the field of hazard estimation on a region, as an input in the process of seismic design of buildings and a crucial requirement for performing the seismic risk analysis of a given characteristic building class.

Two approaches, probabilistic seismic hazard analysis (PSHA) and deterministic seismic hazard analysis (DSHA), are commonly used in the process of seismic hazard assessment.

The most frequently used method is the Probabilistic Seismic Hazard Assessment (PSHA). Eurocode defines the seismic design parameters in terms of PGA and probabilities of exceedance needed to satisfy the two fundamental requirements: (1) No-collapse and (2) Damage limitation for which the seismic action shall be associated with reference probability of exceedance (10%) in 10 and 50 years reference period [6]. In the deterministic approach (DSHA) seismic hazard assessment is done in terms of a fixed ground motion measure, given the magnitude and the location of a scenario event. In the neo-deterministic approach, NDSHA, the integration of all known information from seismological, geological, geophysical, and geotechnical databases for the site of interest are used [7]. Neo-deterministic seismic hazard (NDSHA) maps for the region of Kosovo-North Macedonia have been elaborated, based on the obtained ground motion parameters maximum values for frequencies up to 1Hz. [2].

2. NEO-DETERMINISTIC SEISMIC HAZARD ASSESSMENT AT REGIONAL SCALE

2.1 STRUCTURAL MODEL DEFINITION

For the purpose of structural model definition, the zoning proposed by Arsovski [1] was used. The map of geotectonic zoning from Arsovski was utilized for the definition of the structural polygons required by NDSHA. Each polygon is associated with a structural model, composed of a stack of flat anelastic layers, representing the average properties down to a depth of about 1000km. All of the defined polygons are characterized with the thickness of each layer, the density, P and S wave velocities and their attenuation factors. The results from the TRANSMED project were used, where the geology of the Mediterranean realm is represented in 9 sections across the tectonic structures. Of a great importance for the definition of the layers' properties [9] was the fact that the longest section crosses the whole territory North Macedonia.

2.2 HISTORICAL SEISMICITY AND SEISMIC ZONATION

The location of the North Macedonia, as part of the Balkan Peninsula is a territory characterized by relatively high seismic hazard and has been struck by a number of strong earthquakes during the past centuries. The earthquake catalogue that is used consists of all of the significant events registered from year 518 until 2015. For the earthquakes occurred before 1904 only the epicenters and the magnitudes are provided. The fault plane mechanism for all of the other events is calculated at the Seismological Observatory of the Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University, Skopje.

Having in mind the earthquake data only from the last century, in lacking information it can be reasonably concluded that more severe seismic events may have happened on this territory.

2.3 THE PROCEDURE

NDSHA at regional scale [7-8] incorporates together the knowledge of tectonic style of the considered region, the active fault characterization, the earth crust model and the historical seismicity. The modal summation techniques are used for wave propagation modeling. Synthetic seismograms are generated at all of the predefined grid points distributed over the region of interest. The calculated maximum values of ground horizontal velocity, horizontal displacement and design ground acceleration are used as seismic hazard parameters.

The region is divided into 0.2°x0.2° grid cells and at every node in the grid is given the maximum value of the magnitudes reported in the earthquake catalogue (Figure 1). The smoothing procedure defined by NDSHA is than applied in order to account for the uncertainties connected with the exact location of the epicenters, for the fault dimensions and for the location of possible future events within the seismically active areas. The smoothing procedure consists of several steps [7]. First, a running window with radius of 3 cells is defined. Second, all of the points in the window are assigned with the magnitude of the central cell, if their magnitude is lower than the magnitude of the central cell. The seismicity obtained after the smoothing procedure (Figure 2) is then cut within the seismogenic zones that represent the seismically active regions (Figure 3). Each dot inside a seismogenic zone represents a source. The characteristic focal mechanisms from the dominant earthquake of each seismogenic zone are assigned to each source belonging to the zone itself.

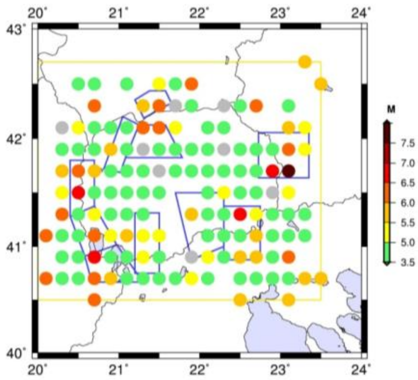


Figure 1. Discretization of seismicity

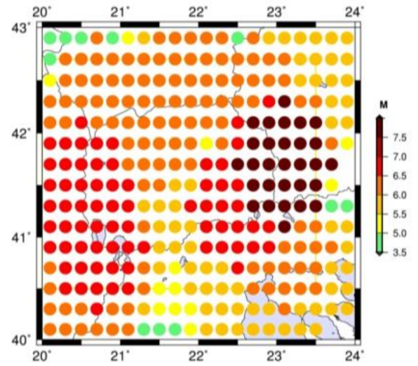


Figure 2. Smoothing

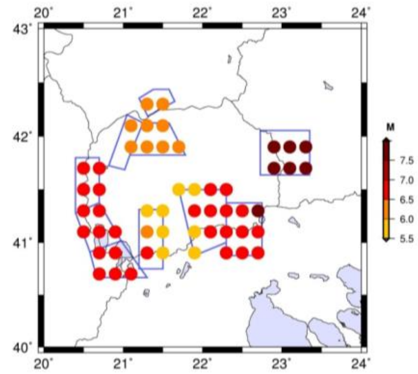


Figure 3. Seismogenic zones with sources

3. MAXIMUM CREDIBLE SEISMIC INPUT – MCSI

Maximum Credible Seismic Input (MCSI) [3-4] is a procedure that calculates the response spectra at a selected site, taking into account the uncertainties of the rupturing process on the fault. Several ground shaking scenarios are modeled [4] at the site of interest by making the variations in the nucleation point of the rupture, in the rupture velocity pattern and in the distribution of the slip on the fault, taking account also the directivity effects. Additionally, the methodology has been implemented in such a way that it allows to take into account scenarios obtained varying any parameter that defines the model, like focal mechanism of the sources, hypocentral depth, layering of the lithosphere etc.

Maximum Credible Seismic Input (MCSI) is obtained as the envelope of the response spectra computed at each site. By applying this procedure to the six cities of interest in North Macedonia, the response spectra are computed. MCSI is calculated for 5% damping of the response spectra. Six families of scenarios are taken into account: bilateral rupturing style with 0° directivity, bilateral rupturing style with 90° directivity, bilateral rupturing style with 180° directivity, unilateral rupturing style with 0° directivity, unilateral rupturing style with 90° directivity and unilateral rupturing style with 180° directivity. For each family 50 realizations of the rupturing process have been modeled. Response spectra are obtained separately for each scenario event, and then properly merged to have a comprehensive estimate of the seismic input.

4. RESULTS

On Figure 4 the results from a single execution (source realization) of the NDSHA analysis for the maximum ground shaking for the horizontal directions acceleration are shown.

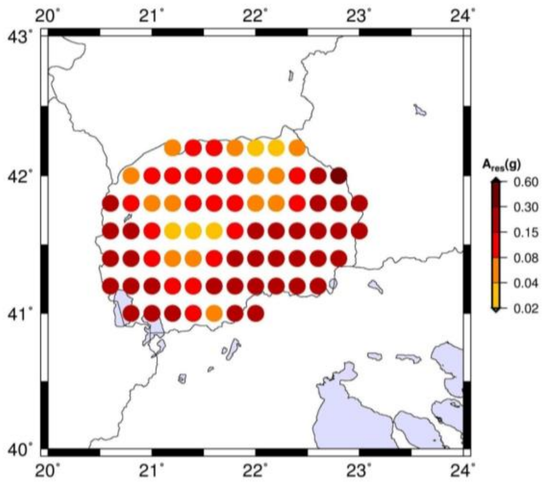
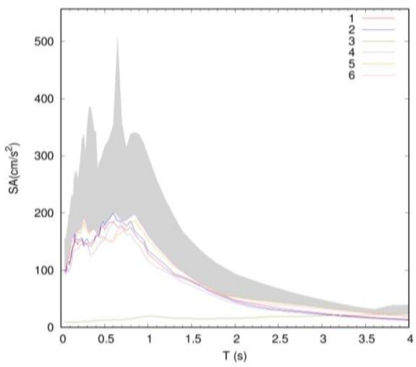
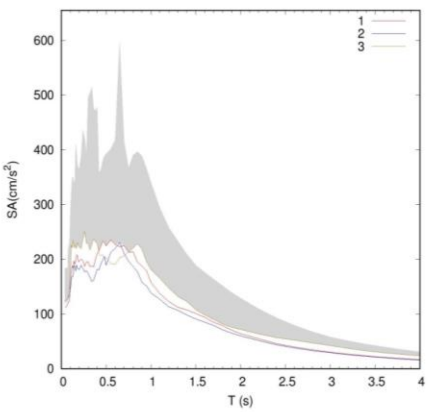


Figure 4. Peak horizontal acceleration

As a result from MCSI, Two components can be considered when combining the results, shown in Figure 5 as Max and Res. Both of them represent the amplitude of the calculated spectra: the plot Max considers the maximum horizontal component, while the plot Res takes into account the resultant of the two horizontal components, and therefore provides a more conservative hazard estimate. In the plots of Figure 5, each colored curve represents the median response spectrum of 50 realizations of the rupturing process for one scenario that contributes to the envelope. The six scenarios listed for MCSI Max correspond to three sources located at different azimuth and/or distance with respect to the site (*sre* and *edi* parameters). In the MCSI Res plot only one source contributes to MCSI, with three different directivity effects. In each plot, the shaded areas represent the spectral accelerations comprised, at each period, between the median and the 95th percentile of the distribution.



	source	profile	M_w	edi (km)	depth (km)	strike (°)	dip (°)	rake (°)	sre (°)	slon (°N)	slat (°E)
1	sz 0001 bf	-	6.1	13.9	10.0	303	74	339	266	21.5	41.9
2	sz 0001 bf	-	6.1	13.9	10.0	303	74	339	159	21.5	42.1
3	sz 0010 bf	-	7.5	145.1	15.0	22	56	40	98	23.3	41.7
4	sz 0001 bb	-	6.1	13.9	10.0	303	74	339	159	21.5	42.1
5	sz 0001 uf	-	6.1	13.9	10.0	303	74	339	266	21.5	41.9
6	sz 0001 uf	-	6.1	13.9	10.0	303	74	339	159	21.5	42.1



	source	profile	M_w	edi (km)	depth (km)	strike (°)	dip (°)	rake (°)	sre (°)	slon (°N)	slat (°E)
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3	sz 0001 uf	-	6.1	13.9	10.0	303	74	339	266	21.5	41.9

Figure 5. MCSI obtained at one selected site of interest. Maximum (top) and Resultant (bottom) horizontal components are considered

In the source label, *bf* indicates bilateral rupture with forward directivity, *bb* bilateral rupture with backward directivity, *uf* unilateral rupture with forward directivity. At this site, no part of the MCSI spectrum is associated with the scenarios generated with neutral directivity (*bn* or *un*), or unilateral rupture with backward directivity (*ub*).

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