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Data analysis for national parameters in compliance with EC8 in Bosnia and Herzegovina

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Abstract

Bosnia and Herzegovina is located in the center of the Western Balkans, occupying an area of 51,197 km². This area represents one of the active seismic zones in this region which is a part of the Trans-Mediterranean-Asian Seismic belt. Looking at the Euro Mediterranean Seismic Hazard Map, Bosnia and Herzegovina falls in the Moderate Seismic Hazard having the PGA in the range of 0.08 to 0.24g, while a south-west part of the country experiences a High Hazard (PGA>0.24g). Data about the seismicity of this region go back for even 2000 years. Bosnia and Herzegovina to the present day has not been hit by a large-scale earthquake, the earthquake which had the largest impact and caused numerous casualties was the 1969 Banja Luka earthquake of a magnitude 6.6 on the Richter scale, while levels of VII to IX were identified concerning its intensity. Due to a large number of existing masonry structures, the effect of a larger earthquake would most probably result in many casualties and a high level of damage.

Until 2018 the seismic map that was used in the building codes corresponded to the MCS Intensity Scale and the return period of 500 years. To be able to utilize Eurocode 8 it was necessary to produce the national annex to Eurocode 8 and in that respect, it was required to analyze the seismic data which refers to different parameters that have to be determined. Several elements had to be defined from soil type characteristics, horizontal elastic response spectra, the peak ground acceleration, and the seismic hazard map. The paper will briefly discuss the different parameters as well as the production of the first seismic hazard map which became a part of the national annex to Eurocode 8 and was published in 2018.

Key words: seismic data, earthquakes, seismic hazard, horizontal elastic spectra, peak ground acceleration

1 Introduction

Bosnia and Herzegovina (BIH) occupies an area of 51,197 km² and is located in the center of the Western Balkans. This area represents one of the active seismic zones in this region which is a part of the Trans-Mediterranean-Asian Seismic belt. Data about the seismicity of this region go back for even 2000 years. Fig. 1 shows that Bosnia and Herzegovina falls in the Moderate Seismic Hazard having the PGA in the range of 0.08 to 0.24g, while a south-west part of the country experiences a High Hazard (PGA>0.24g). Bosnia and Herzegovina has not been hit by large-scale earthquakes in the past. The strongest earthquake which hit BIH was the 1969 Banja Luka earthquake (magnitude 6.6 as per Richter's scale), with an intensity in the range of VII to IX (per MSC) which was soil dependent [1]. The level of destruction is connected as well to the focal depth. Usually, shallow earthquakes tend to be more damaging than deeper ones, as was the case with the 1969 Banja Luka earthquake. Almost 94 % of all registered earthquakes in Bosnia and Herzegovina have a focal depth of up to 20 km (64 % up to 10 km and 29.7 % from 11 to 20 km) [2]. Heavy damage was observed in schools, hospitals, residential buildings, etc.

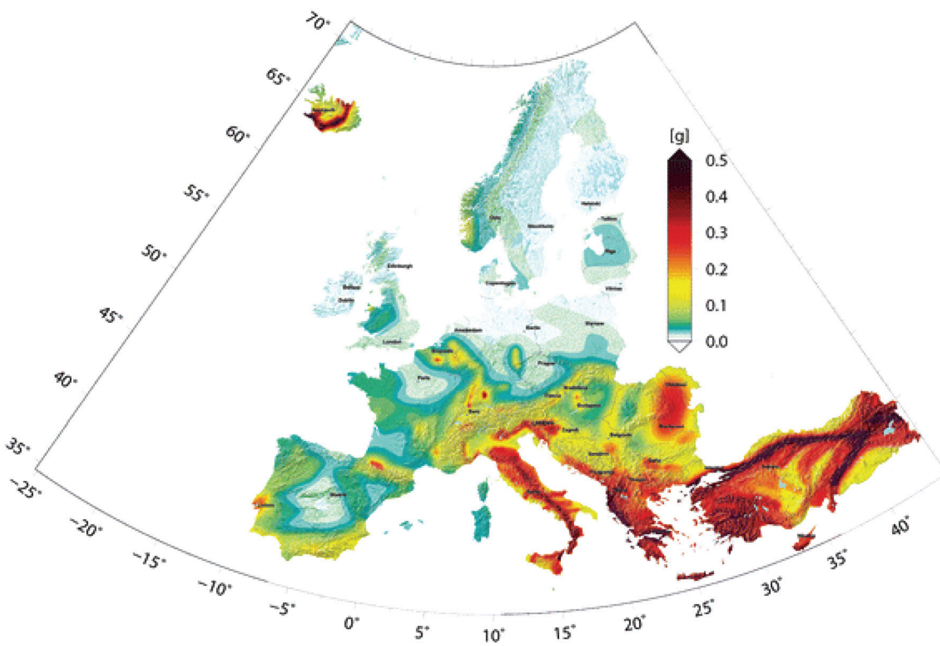

Figure 1. Euro-Mediterranean Seismic Hazard Model [3]

The first seismic hazard map for the territory of the Federal People's Republic of Yugoslavia was produced in 1950 by the Seismological Institute of the Federal People's Republic of Yugoslavia. After the 1979 Montenegro earthquake, a significant update was made to the Seismic Design Code in 1981. This was followed by amendments in 1982, 1983, 1988, and 1990. As part of these codes, in 1982 preliminary seismological map of the Social Federal Republic of Yugoslavia (SFRJ) was created, and in 1987 maps for various return periods (50, 100, 200, 500, 1000, 10000) were constructed. All of the above maps refer to the maximum occurring intensities because in the former Yugoslavia there were no maps that referred to the maximum values of horizontal accelerations. According to Eurocode 8, (in BIH [4]) seismic hazard is represented via maximum horizontal acceleration, PGA (Peak Ground Acceleration) on type A ground. Type A is defined as rock or other rock-like geological formation, including at most 5 m of weaker material at the surface with a shear wave velocity $v_{s,30}$ = 800 m/s as defined in Eurocode 8.

2 Seismic Hazard Maps

To compile the seismic hazard map of a certain region it is necessary to have a list of major earthquakes as main independent events (without foreshocks and aftershocks). The catalog of earthquakes aims to present the seismicity of the space as completely and reliably as possible. To proceed, a homogenized earthquake catalog covering the entire Bosnia and Herzegovina was created. The data was taken from different sources covering the period from 1900 to 2015 and consists of 1944 earthquake records of M*w* magnitude from 3.5 to 7.1 [2]. The utilized catalog is homogenous for magnitude 3.5 since 1990. All the magnitudes were transformed into the moment magnitude M*w* as it delivers a more up-to-date and complete description of the dynamic and energy characteristics of an earthquake in the hypocenter [5]. Hakimhashemi and Grünthal [6] method was used for the de-clusterization of the catalog. This method resulted in a reduction of 39 % of all events and a decrease in the cumulative seismic moment by 6 %. Two types of seismotectonic models were used: an areal and a linear model. A source zone was formed in the sense that it consisted of all the earthquakes having similar hypocentre depth, focal mechanism, and magnitude-frequency relationship. A further step was the determination of the parameters of the frequency-magnitude Gutenberg-Richter (GR) distribution for each zone, for more details see [5]. For this region, several Ground Motion Prediction Equations (GMPEs) have been determined. In this case, the GMPE set, based on Šalić et al. [7] which was developed in the framework of the NGA-West 2 project by Boore et al. [8] and Chiou and Youngs [9] with 30 % weight each and two GMPEs developed for Pan_European region developed within the context of SIGMA project by Akkar et al. [10-12] and Bindi et al. [13] with 20 % weight each was implemented.

As a result of all this input data, earthquake hazard maps presented by the values of PGA expected to be exceeded on average every 95 and 475 years were created (Fig. 2.).

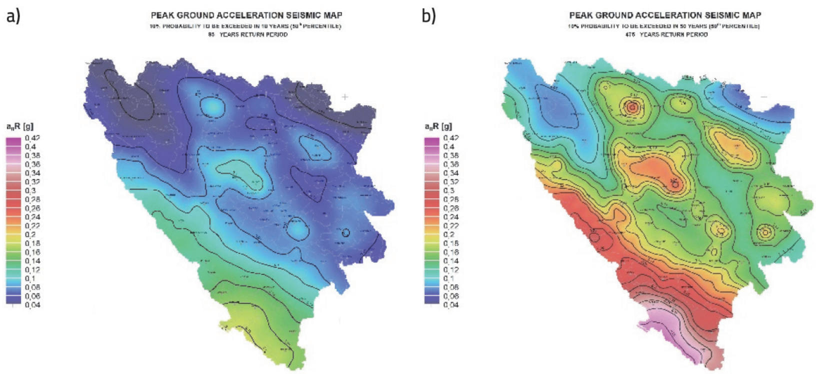

Figure 2. a) PGA Seismic map for the 95-year return period; b) PGA Seismic map for the 475-year return period [14]

As previously stated the selected ground type was A and the amplification due to local soil conditions are determined by applying the soil factor S [4]. No detailed microzonation has been done for most of the territory of Bosnia and Herzegovina, except for Banja Luka which was done by Lee et al. [15].

2.1 Accelerometric networks

The accelerometric network is important for determining the parameters of soil vibration under the action of strong earthquakes, which are necessary for the process of seismic safe design, planning, and construction of facilities in BIH, as well as for the needs of determining the real degree of seismic hazard and later on the expected level of seismic risk. According to the Federal Hydrometeorological Institue, the seismological network is formed from six stations (broadband and short-period stations) in the Federation of BIH (Sarajevo, Zenica, Tuzla, Livno, and Bihać) and one strong motion recorder in Mostar [16]. In the Republik of Srpska, the first accelerometer was installed in Banja Luka, and other accelerometers were installed on two power plants in Gacko, one dam (Alagovac), one factory in Zvornik, Bočac Hydroelectric Power Plant, and Nevesinje [17], and 15 stations (broadband, short period, and AlpArray stations).

2.2 Elastic response spectrum for soil type A

The devastating effect of stronger earthquakes is especially pronounced in densely built-up urban environments where the most severe consequences can be expected for both people and buildings [18]. In urban areas, most of the structures are existing ones that in most cases do not meet the requirements set by the latest technical regulations for the design and construction of buildings exposed to earthquakes. The main goal of proper design and construction of buildings is the protection of human lives, limitation of damage, and structures important for civil protection are to remain operational [4]. This means that buildings, even during the strongest earthquakes, which are expected throughout their service life should not collapse. In this case, a certain level of damage is acceptable, as damage cannot be avoided. The response of the structure exposed to earthquake action depends on its load-bearing capacity, stiffness, and ductility.

Within the scope of BAS EN 1998-1 [4], the earthquake motion at a given point on the surface is represented by an elastic ground acceleration response spectrum, called an “Elastic response spectrum”. The elastic response spectrum for soil type A for the territory of Bosnia and Herzegovina was calculated based on the available acceleration data. BAS EN 1998-1 [4] suggests two types of response spectra as a function of earthquake magnitude, type 1 for the surface magnitude, $M_s > 5.5$, and Type 2 for $M_s \leq 5.5$, and either should be used as dynamic inputs from earthquake actions. The shape of the response spectra is a function of the ground type and damping factors. In the standard calculations, the damping is taken to be equal to 5 %, so the shape of the response spectra is only dependent on the ground characteristics at the site, M_s, connected with the seismic hazard of the specific region.

The accelerogram database of Bosnia and Herzegovina contains only accelerogram records for Type 2, ie. earthquakes of magnitude $M_s \leq 5.5$. From the total accelerogram database for the area of Bosnia and Herzegovina, accelerograms recorded from 2009 to May 2015 for soil type A and Type 2 were selected. The elastic response spectra were calculated by the computer program which was developed in the Seismology Sector, Department of Hydrometeorology and seismology of Monte Negro, based on the numerical approach and solution as proposed by Nigam and Jennings [19]. The goal was to compare the spectra obtained from the recorded accelerograms of real earthquakes with the elastic response spectra proposed in Eurocode 8 (Fig. 3).

The calculated mean value of the elastic response spectrum obtained from the recorded accelerograms is indicated in the red color, the standard deviation of that function is represented by the green line, while the elastic response spectra of Type 2 per Eurocode 8 is shown in blue. From the database, 140 accelerograms were selected which were recorded at stations that were at a distance less than 100 km from the epicenter of the occurred earthquakes. By analyzing the obtained mean values of the calculated elastic response spectra for 140 different soil acceleration, for soil type A and Type 2, a good correlation is obtained for the largest period range as proposed by Eurocode 8.

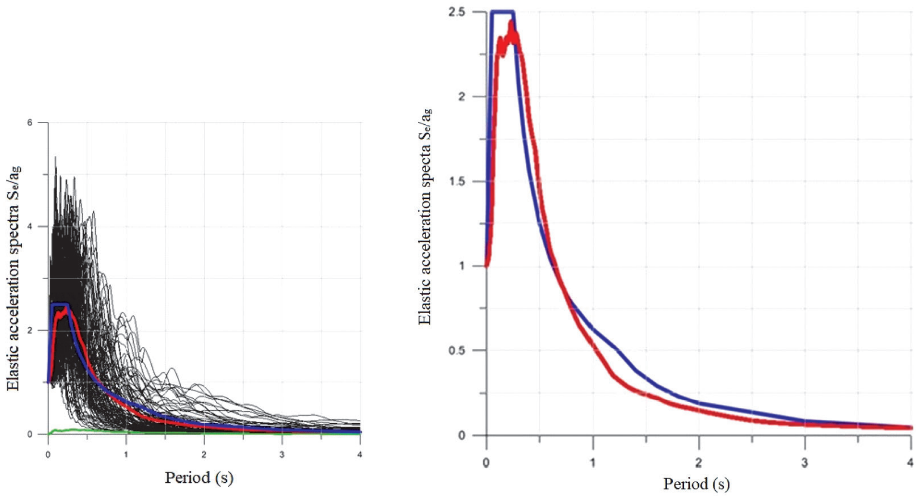

Figure 3. The normalized horizontal elastic response spectrum for 140 soil acceleration and Type 2 earthquakes [17]

By a detailed analysis, the following can be concluded:
The proposed value of the period T_B in the elastic response spectra as presented in Eurocode 8 is equal to 0.05 seconds, while for the real earthquake accelerograms the obtained value was around 0.10 seconds. The proposed value of the period T_c in the elastic response spectra as presented in Eurocode 8 is equal to 0.25 seconds, while for the real earthquake accelerograms the obtained value was around 0.30 seconds. Thus, the results of the processed accelerograms for type A soil, in case of an earthquake of Type 2, showed a small but consistent increase in period value for T_B and Tc in relation to the elastic response spectra proposed in Eurocode 8 (Fig. 3). These results refer to the earthquakes recorded at stations at a distance up to 100 km from the epicenter of the occurred earthquake.
Additionally, earthquakes recorded on accelerometric stations at a distance larger than 100 km were taken into consideration as well. In this case, 176 accelerograms were analyzed for the same type of soil and surface magnitudes lower or equal to 5.5 (Fig. 4). The recordings of the accelerograms were taken from the accelerometer station in Banja Luka (BLY).
The calculated mean value of the elastic response spectrum is indicated in the red color, the standard deviation of that function is represented by the green line, while the recommended shape as per Eurocode 8 is shown in blue. Results of the elastic response spectrum for the 176 accelerograms, for soil type A, and Type 2 earthquake, measured on the accelerometer station Banja Luka (BLY) showed a significant increase in the value of the period for characteristic points T_B and Tc in comparison with the proposed elastic response spectra in Eurocode 8. As it can be seen from Fig. 4 the plateau of amplification is shifted to higher values of the period, and the T_c value is shifted for around 0.095 sec.

Due to the lack of acceleration records for earthquakes larger than the surface magnitude M_s = 5.5 it was not possible to determine the elastic response spectrum.

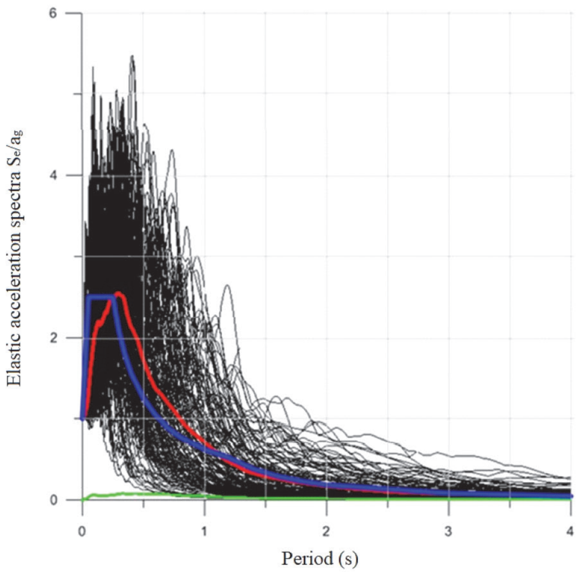

Figure 4. The normalized horizontal elastic response spectrum for 173 soil acceleration and type 2 earthquakes [17]

3 Conclusion

One of the requirements for the application of Eurocode 8 is the production of the national annex which consists of the seismic hazard maps, which is presented in the form of the PGA during an earthquake, which is exceeded on average once in 95 or 475 years. The maps have been accepted as a part of the National Annex in BAS EN 1998- 1/NA [14]. The map with a return period of 475 years and with a probability of exceedance of 10 % in 50 years is used for designing earthquake-resistant buildings. Damage limitation requirement is obtained with the application of the map with a return period of 95 years and with a probability of exceedance of 10 % in 50 years.
By analyzing the obtained results for the calculation of the horizontal elastic response spectrum for the ground type A and Type 2 earthquakes, ie. earthquakes of magnitude $M_s \leq 5.5$ obtained from the real accelerograms and their comparison with the recommended horizontal elastic spectrum by Eurocode 8, a good correlation was observed regarding the shape of the spectrum. A difference has been noted in the values of characteristic periods T_B and Tc. This is something that should be further investigated and then possible recommendations could be proposed in the updated version of the National Annex of Eurocode 8.

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