Probabilistic Seismic Hazard Assessment of Albania

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ABSTRACT

A new probabilistic seismic hazard assessment for Albania is carried out using the smoothed-gridded seismicity approach. It is based on the results obtained in the frame of NATO SPS 984374 project "*Improvements in the Harmonized Seismic Hazard Maps for the Western Balkan Countries* – BSHAP2*"*, as well as the new seismic hazard calculations carried out during the period January-March 2020. The BSHAP earthquake catalogue, which covers the time span 510BC-31/12/2012, is updated including the $Mw \geq 3.0$ events occurred within the area 38−48°N latitude and 12−24.5°E longitude during the period 1/01/2013-31/12/2019. Except OHAZ2015 software, the new calculations are performed using also the software NSHM2014r (https://github.com/usgs/nshmp-haz-fortran/tree/nshm2014r1.ch), developed by the NSHM program of USGS to generate the updated [2014] National Seismic Hazard Models of the USA (http://pubs.usgs.gov/of/2014/1091/).

The present estimation is a combination of the seismic hazard assessment obtained in the frame of BSHAP2 project with the new results obtained the last year using the OHAZ2015 and NSHM2014r software. The main output are the new probabilistic seismic hazard maps for Albania. They are prepared based on the updated BSHAP earthquake catalogue, four selected GMPEs and two alternative BSHAP seismotectonic models. Hazard calculations are carried out following a logic-tree structure describing the epistemic uncertainties associated with building of the seismic source model, and of the GMPEs selected for ground motion prediction. The results are expressed in terms of peak horizontal acceleration (PGA) for 95 and 475 years return periods. The assessment has been carried out for rock conditions with average velocity of shear waves $V_S \geq 800$ m/sec in the upper 30 meters of soil section (classified as soil type A according to Eurocode 8 soil definitions). Apart these seismic hazard maps, the seismic hazard is estimated also for every municipality and administrative unit in the country, in terms of PGA for 95 and 475 years return periods.

Thus, obtained results are in full agreement with the Eurocode 8 standard for seismic zonation and aseismic design. The main finding is that if these maps are accepted as a reference indicator to establish a new regulatory national seismic zonation, design acceleration will be much higher than that applied in the current regulation. This implies that the competent authorities should take into consideration the obtained results to improve the existing design code in a more reliable and realistic basis in order to increase the safety level of constructions in the country.

1. Introduction

Seismic design code regulations, seismic risk estimation and management, as well as seismic safety improvements should be based on reliable seismic hazard analysis, especially for the seismically active regions. The Albania is characterized by high earthquake hazard and risk when compared to the rest of Europe. The actual in force building code of Albania, KTP-N.2-89, is based on an outdated empirical seismic map compiled in 1979 (Sulstarova et al. 1980). This map it is not derived using a probabilistic approach, and is based on the macroseismic intensity (MSK-64 scale), and not on the nowadays intensity measures of ground shaking as PGA, PGV, SA, etc., used in the modern design codes (EC8, IBC, ASCE 7, etc.). The 26 November 2019 Mw 6.4 Durres destructive earthquake has further stimulated improvement of the Albanian design code. Thus, it is an evident need to upgrade these technical norms with provisions harmonized with EU standards (Eurocode 8).

In order to support the Western Balkan Countries to implement the European design standards, the NATO "Science for Peace and Security" program has funded two projects: NATO SfP983054 (2007-2011) and NATO SPS984374 (2013-2015), with participation of the relevant institutions from Albania, Montenegro, Croatia, Bosnia and Herzegovina, Serbia and North Macedonia. The main objective of these projects was compiling of the new regional seismic hazard maps, as a necessary step towards the seismic safety improvement and seismic risk management. This was achieved through compiling of an updated and unified earthquake catalogue for the region, homogenous in terms of moment magnitude, strong motion database compilation, proper selection of the ground motion prediction models (GMPM`), compilation of all relevant regional geological knowledge and development of an appropriate seismo-tectonic model for the area.

The derived maps are a good basis to characterize the seismic hazard of the Western Balkan area, but they are regional and cannot replace the national seismic hazard maps, which need to be much more detailed. Therefore, during the period January-March 2020, an additional effort is undertaken to update, detail and improve the seismic hazard assessment for the Albania territory. In the following we are presenting a brief description of the methodology applied, some information on the seismotectonic database compiled, and the main results achieved.

2. Mathematical background

The objective of the probabilistic seismic hazard analysis (PSHA) is to estimate the probability of exceeding a specified ground motion intensity, by taking into account the potential occurrence of earthquakes at all possible locations, having all possible magnitudes. Earthquake magnitude, source-site distance and ground motion intensity are the major random variables in the PSHA.

In a conventional PSHA, the task is to estimate $\mu(y^*)$, the mean rate of exceeding some ground motion intensity y^* at a specific site. Formally, $\mu(y^*)$ is calculated by:

$$\mu(y^*) = \sum_{i=1}^{N} \lambda_i \left[\int_{m_0}^{M_{\max}} \int_{0}^{d_{\max}} \int f_{M,R,\varepsilon}(m,r,\varepsilon) P(Y > y^* | m,r,\varepsilon) dm \cdot dr \cdot d\varepsilon \right]_i \qquad (1)$$

In equation 1, it is assumed that seismic hazard is contributed by N independent sources of earthquakes. The mean rate of earthquakes in each source is λ_i and $f_{M,R,\varepsilon}$ is the joint probability density of earthquake magnitude M, source to site distance R, and random error ε associated with ground motion prediction. $P(Y>y^*|m,r,\varepsilon)$ represents the conditional exceedance probability of a specified level of seismic intensity on a certain site, when on a source zone has occurred an earthquake with magnitude m and distance r from this site. Ground motions are predicted using a relation of the form:

$$\log(y) = f(m,r) + \varepsilon \cdot \sigma \qquad (2)$$

typically derived by regression analysis of strong motion data.

Treating distance, magnitude and ε as statistically independent, the estimated rate of exceeding ground motion intensity y^* due to hazard posed by N independent, discrete sources is:

$$\mu(y^*) = \sum_{i=1}^{N} \lambda_i \left[\int_{m_0}^{M_{\max}} \int_{0}^{d_{\max}} \int f_M(m) f_R(r) f_\varepsilon(\varepsilon) P(Y > y^* | m, r, \varepsilon) dm \cdot dr \cdot d\varepsilon \right]_i \qquad (3)$$

If the number of earthquakes on a seismic source is modeled as a stationary Poisson process, it follows that the probability that ground motion at a site will be equal or greater than the target value y^* in the next t years can be expressed in terms of the annual rate of exceedance $\mu(y^*)$ by the equation:

$$P(Y > y^* | t) = 1 - \exp(-t \cdot \mu(y^*)) \qquad (4)$$

A standard probabilistic analysis only provides ground-motion exceedance probabilities. However, in order to estimate the earthquake scenarios that have high likelihood of occurrence, seismic hazard deaggregation should be accomplished, that means to develop the modal or the mean magnitude M influencing the site, and modal or mean distance, D. Identification of events, in terms of magnitude and distance that contribute most to seismic hazard for a given probability of exceedance has many practical applications.

3. Input for seismic hazard assessment

Exercising of a seismic hazard analysis requires the following data:

- Identification of potential sources of earthquakes.
- Evaluation of the characteristics of each potential earthquake source, such as geological conditions, magnitudes and earthquake rates.
- Empirical models to compute ground shaking amplitudes or intensities (i.e. attenuation equations).

3.1. Earthquake catalogue

The core seismological database that is used in this project is a regional earthquake catalogue compiled in the framework of the NATO SPS 984374 project (NATO SPS 9843754, 2015). The BSHAP catalogue is based on the national earthquake catalogues of the partner countries including Albania, and covers the geographic area limited by 38.0°-48.0°N latitude and 12.0°-24.5°E longitude. It comprises more than 26,000 earthquakes with $M_W \geq 3.0$ that occurred in the region between 510 BCE and 31/12/2012. The large extent of the area covered by this catalogue is necessary to account for the influence of regional seismicity on the seismic hazard of the country. The size of the earthquakes is given in terms of moment magnitude, *Mw*. The problems related to the compilation of the homogenous earthquake catalogue, uniform M_w scaling, completeness of magnitude levels, catalogue declustering, etc., are investigated in detail in the framework of the BSHAP2 project (Markusic *et al*, 2016).

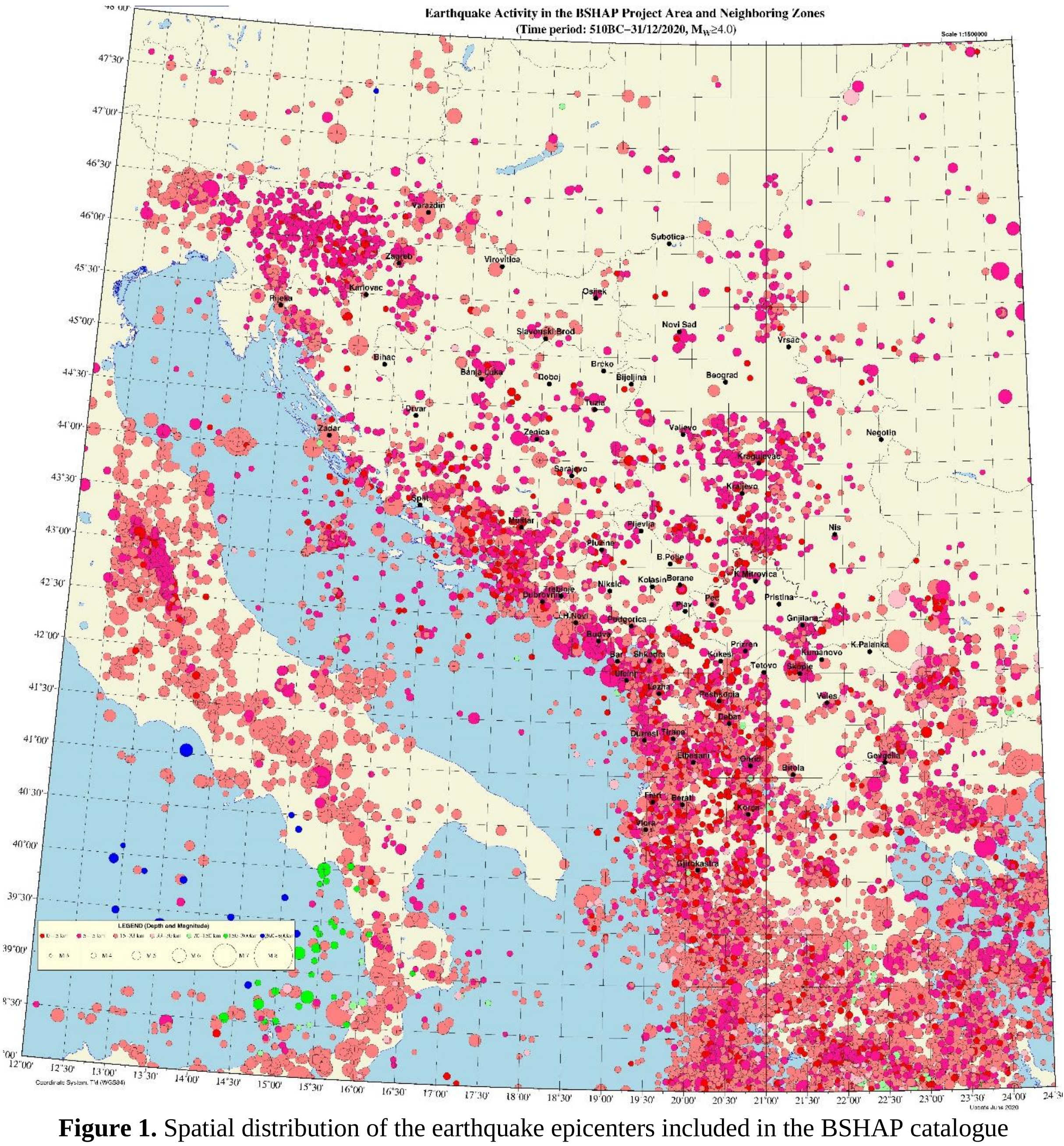


Figure 1. Spatial distribution of the earthquake epicenters included in the BSHAP catalogue (Time period: 510 BCE-31/12/2019; M_W≥4.0).

However, the BSHAP catalogue doesn’t include the earthquakes occurred after 31/12/2012. Involvement of these events for the seismic hazard analysis is very important, especially if we have in mind the 26 November 2019 *Mw 6.4* Durres destructive earthquake, and the 29 December 2020 with *Mw=6.4* which hit the central Croatia. Therefore, much efforts were concentrated to comprise in the BSHAP catalogue more than 5000 events occurred in the

BSHAP area (12.0-24.5°E, 38.0-48.0°N) during the period 1/01/2013-31/12/2019. Because most of the new events reported by the responsible seismological institutions are quantified in terms of *ML*, *Mlh*, *MS*, *mb*, and *Md*, they are converted to the proxy *Mw* using the regression relations derived in the frame of BSHAP2 project, or the new regression relations *Mw=f(ML)*, *Mw=f(Mlh)* and *Mw=f(Md)* we have derived after 2015 for the events reported by the seismological agencies of the region: TIR (IGEO), AUTH (Thessaloniki), NOA (Athens), and INGV (Rome). The present updated earthquake catalogue is homogenous and uniform in terms of the moment magnitude, *Mw*. It comprises the events with $Mw \geq 3.0$, occurred within BSHAP area (12.0-24.5°E, 38.0-48.0°N), during the time period 510 BCE – 31/12/2019. This catalogue is used to estimate the present seismic hazard of Albania. The spatial distribution of the earthquake epicenters comprised in the updated BSHAP catalog is showed in the Figure 1.

To identify Poissonian rate of seismicity, it is necessary to remove foreshocks, aftershocks and swarms from the earthquake catalogue. Among different declustering algorithms proposed, we have chosen that of Gardner and Knopoff (Gardner and Knopoff, 1974), which is the most widely applied windowing method. It simply identifies aftershocks by virtue of fixed time-distance windows proportional to the magnitude of the main shock. Declustering of the updated BSHAP catalogue using Gardner and Knopoff (Gardner and Knopoff, 1974) algorithm has identified about 10500 main shocks with magnitude Mw≥4.0.

Another important task to derive the inputs for hazard analysis is to determine the magnitude completeness threshold, *Mc,* of catalogue, i.e. the "lowest magnitude at which 100% of the events in a space-time volume are detected (Woessner and Wiemer, 2005)". Incompleteness of an earthquake catalogue will produce bias when determining models of earthquake recurrence, which may have a significant impact on the estimation of hazard at a site. Identification of the completeness magnitude is therefore a clear requirement for the processing of input data to be used for seismic hazard analysis. The updated BSHAP catalogue includes the earthquakes with $M_W \geq 3.0$, but we cannot confirm 100% of the events with $M_W \geq 3.0$ are included. Using ZMAP software (Wiemer S., 2001), we found $Mc = 4.0$ for the updated catalogue.

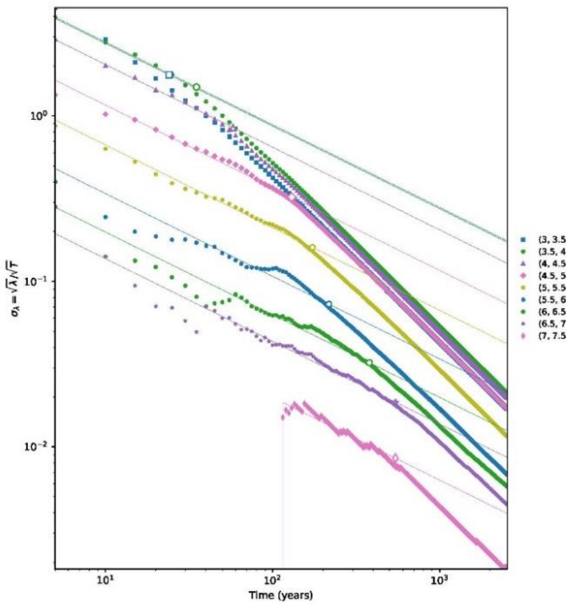


Figure 2. Completeness estimation by the Stepp (1971) methodology.

To estimate the temporal variation in the completeness of the BSHAP catalogue the Stepp (1971) methodology is used. The results obtained are shown in the Table 1, and the Figure 2. This data is later incorporated into the seismotectonic model developed for the seismic hazard analysis.

Table 1. Catalogue completeness intervals of BSHAP catalogue.

M_w	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
Year	1996	1985	1962	1890	1847	1803	1641	1477	1400

3.2. Seismicity parameters and seismic source characterization

Identification and characterization of the seismic sources (SSC), influencing the seismic hazard of the BSHAP area and the surroundings, is based on the results derived in the framework of BSHAP projects (Mihaljevic *et al,* 2017). To develop the SSC models, the updated BSHAP earthquake catalogue is used, utilizing also the relevant knowledge about the geological and seismotectonic structure of Western Balkans, as well as the stress information indicated by the BSHAP Fault Plane Solution (FPS) database. Analysis of the FPS indicates that the majority of the earthquakes observed along the coastlines of Croatia, Montenegro and Albania have reverse mechanism, correlated to the thrusting in the most part of the External Dinarides and Albanides. Tectonic compressions are directed in SW–NE direction in the southern and eastern parts, and in S–N direction in the northern and western parts of the coastline. In the continental part the faults are active as strike-slip to oblique strike-slip or even as reverse faults. This distribution reflects the counter-clockwise motions of Adria and its compression against the Dinarides. In the Albanides, the boundary between normal faulting to east and thrust faulting to west runs through central Albania. The extension is observed in eastern Albania and Macedonia.

Because it is well known that hazard results are sensitive to the seismic sources comprised within, as well as outside the area of calculation, the broader area 12-24.5°E and 38-48°N has been considered in the seismic sources modelling (SSC). The SSC models (SSM1 and SSM2) used in our seismic hazard analysis are presented in the Figure 4. The frequency-magnitude distribution varies across the zones, being a truncated Gutenberg-Richter distribution with different maximum magnitudes derived from the historical and contemporary seismicity:

$$\lambda_m = \lambda_{m_0} \times \frac{\exp[-b(m-m_0)] - \exp[-b(m_{max}-m_0)]}{1-\exp[-b(m_{max}-m_0)]} \qquad (5)$$

where:

- λ_m: the mean annual number of earthquakes with $M \geq m$,
- λ_{m0}: the mean annual number of earthquakes with $M \geq m0$,
- m_0: minimum magnitude with engineering interest (m_0=4.0 is used in our case),
- m_{max}: maximum magnitude that can be generated in the seismic source.

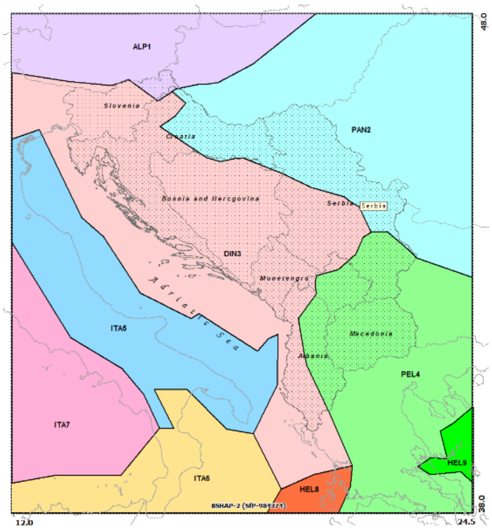
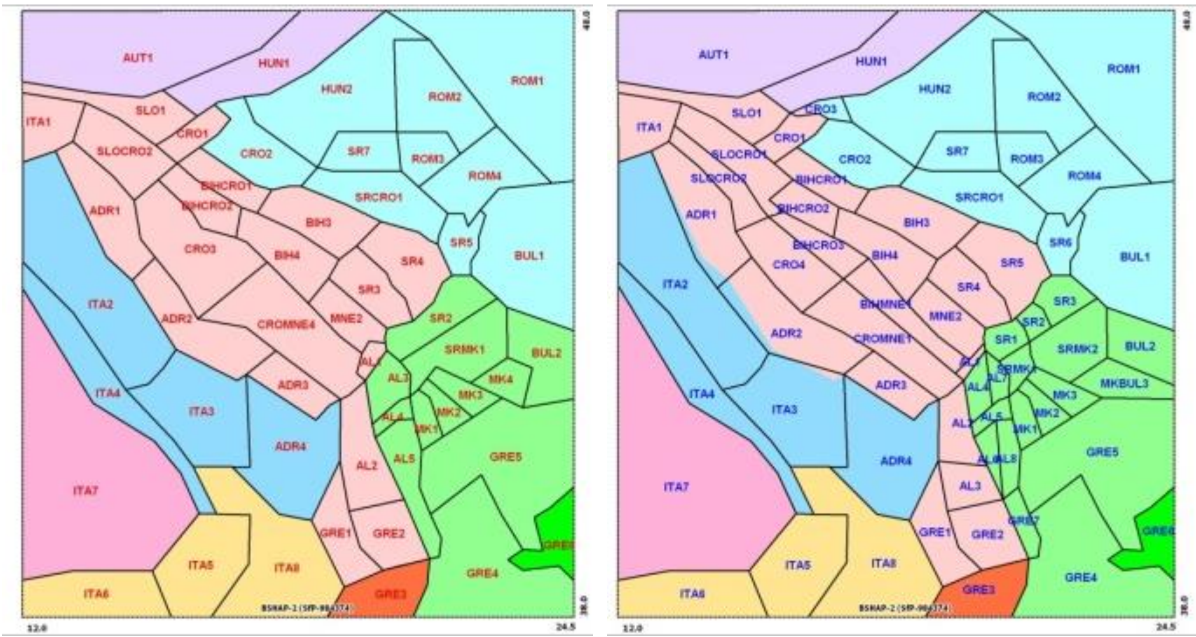


Figure 3. Super zone model (SZM) used to calculate b-values (Mihaljević et al., 2017).

In order to avoid undue fluctuations in the recurrence model parameters (b-value, mean annual rate of earthquake occurrence, etc.) that are commonly present when addressing smaller areas, particularly in the zones of low seismicity, the super zone model (SZM) (Figure 3) was proposed. The SZM model consists of seven larger and two smaller zones that were delineated based on the seismotectonic characteristics. The b-values estimated using the events within a super-zone, are applied for the source zones of SSC model, included within this super-zone.

Estimates of the *a*- and *b*-values, as well as λ_m, for every seismic source zone are calculated using the maximum likelihood method proposed by Weichert (1980), which accounts for the unequal completeness intervals for different magnitude ranges (Table 1). Two alternative estimates for the *b*-value are used for each source zone: (1) the relevant estimate derived using the super zone sub-catalogs; and (2) *b=1.0*, which is obtained using the Weichert method for the BSHAP area [12-24.5°E, 38-48°N] as a whole (Figure 5).

While the super zone model has been implemented with the purpose of estimating statistically-stable *b*-values, the other seismicity parameters (m_{max}, dominant style of faulting and fault directions) were estimated for smaller areas, delineated within two alternative zonation models. SSM1 and SSM2, representing the local tectonic features, provided input data for the two-stage (circular and elliptical) smoothing procedure of the seismicity rates.



a) SSM1 ***b) SSM2***

Figure 4. Seismic source models SSM1 and SSM2, and their position vs. super-zone model. (Mihaljević et. al, 2017).

In Western Balkans, SSM1 and SSM2 were delineated considering a detailed analysis of tectonic settings, known active faults, activity rates, observed magnitudes, and foci depths. Zones covering the neighboring (out-of-BSHAP) region are preserved in both models and were delineated considering SHARE project (Basili et al., 2013, Giardini et al., 2014), and according to Vamvarakis et al., 2013. Borders of the source zones are mostly consistent with the borders of the super zones since the *b*-value estimated for the corresponding super zone is directly implemented for the zones included in the SM1 and SSM2 models. Each zone is attributed by a zone ID, maximum observed magnitude, average foci depth, and sets of weighted parameters: *b-value*, m_{max}, style of faulting and fault strike angle. To assign the weights related to tectonic information, faults were grouped based on the mechanism and the median strike azimuth. Their weights were calculated based on measured length of the (grouped) faults (Lapajne et al., 2003).

The maximum possible earthquake, m_{max}, is recognized as a parameter with substantial impact on the seismic hazard, at least for long return periods. However, it is a difficult parameter to assess, because the physical understanding of m_{max} is poor, and because the database to derive this parameter is statistically very limited. In SSM1 and SSM2, the m_{max} for each source zone was chosen by considering the largest observed magnitude in the zone. It is evident the prehistoric and historical earthquakes in each source zone provide a lower bound on the maximum considered magnitude, m_{max}. That is, m_{max} must be at least as large as the largest observed earthquake. We cannot know, however, if the largest observed earthquake is the largest possible earthquake. Taking into account the uncertainties related to this parameter, two alternative estimates of m_{max}, with weights 0.6 and 0.4 in the relevant logic-tree branch, are included by adding respectively 0.25 and 0.5 magnitude units to the largest observed magnitude in each zone. We assumed that the minimum m_{max} value in any zone cannot be lower than Mw=6.0, even if the largest observed magnitude is much smaller.

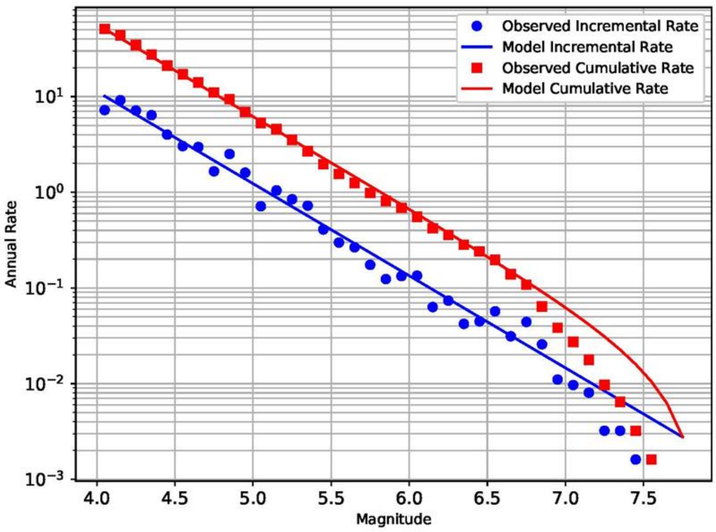


Figure 5. Magnitude-frequency distribution for the whole BSHAP area [12-24.5°E, 38-48°N).

For the adopted BSHAP seismic source characterization models, the incorporated epistemic uncertainties associated with construction of the seismic source models (choice of SSM, determination of the b-value, accounting for maximum magnitude uncertainty, and selection of smoothing method) is provided in the logic tree scheme (Figure 6).

3.3. Ground Motion Predictive Models

Ground motion prediction models (GMPM) provide the median and standard deviation of ground motion Intensity Measure (IM) conditional on parameters related to source (magnitude, focal mechanism, etc.), path (source-to-site distance, position relative to hanging wall, etc.), and site effects (average shear wave velocity in upper 30 m of site, basin depth, etc.). A large number of global and regional GMPMs were developed in the last 20 years that are applicable to different tectonic regimes (Douglas, 2011). Local GMPMs are developed from regional datasets, so they are expected to reflect the regional tectonic characteristics better than the others. On the other hand, the statistical uncertainties introduced by local GMPMs can be higher than those of the global GMPMs when they are based on statistically less stable and limited datasets.

Due to the limited regional free field strong motion network capacity, only a small number of the regional strong-motion recordings were available before 2010 in the Western Balkan region. Consequently, a reliable ground-motion model is not yet derived for Albania or surrounding region. Therefore, to perform any seismic hazard analysis, appropriate contemporary ground motion prediction models are required. We considered several GMPMs derived based on the pan-European or global datasets, that feature similar seismotectonic characteristics as of the study area.

In the framework of BSHAP2 project, a regional strong motion database was compiled, which includes uniformly processed strong motions along with the related earthquake metadata and station information within the BSHAP project area. So, it provides a solid base for the ground motion characterization studies in the region. The established database is used for selection of the ground motion prediction models (GMPM) to be employed in the probabilistic seismic hazard analysis by comparing the compiled strong ground motions records with the predictions of candidate global and Euro-Mediterranean GMPMs in a systematic manner. The detailed relevant analysis shows that for the Western Balkan region more appropriate are the following models:

- *ASB14* (Akkar *et al*. 2014)
- *BietAl14* (Bindi *et al*. 2014)
- *BSSA14* (Boore *et al*. 2014)
- *CY14 (*Chiou and Young, *2014)*

Two first models, ASB14 and BietAl14, are derived using the strong motion records in the European region, whereas the BSSA14 and CY14 are worldwide global models derived within the framework of the PEER NGA-West2 project.

All these models provide ground motion prediction equations (GMPE) for computing medians and standard deviations of average horizontal component intensity measures (IM) for shallow crustal earthquakes in active tectonic regions. According to this investigation (Salic et al. 2016), NGA West2 models are a little more appropriate, and can be used for a wide range of periods, from 0.0 (PGA) up to SA 10 sec. European models can be used for the periods 0.0 (PGA) up to SA 4 sec. The consensus decision of the BSHAP team was to additionally stipulate the CY14 and BSSA14 GMPEs attributing them the equal weights of 0.3 in respect to ASB14 and BietAl14, being de-stipulated to weights of 0.2. In conclusion, for the seismic hazard assessment of Albania, we decided to use a logic-tree approach comprising these four GMP models, assigning the above weights to them.

4. Seismic Hazard Analysis

Because very little information on active faults and their corresponding slip rates is known in the BSHAP region, it was impossible to define a reliable fault-based source model. Therefore, for seismic hazard assessment we decided to use the background-gridded source models, which account for crustal earthquakes not occurring on modeled faults. The model was developed based on the assumption that future earthquakes will occur near locations of historical earthquakes; it does not take into account any information from tectonic, geological, or geodetic data. The overall method for modeling of background-gridded seismicity is based on the spatial smoothing approach, whereby the rate of past earth quakes and a regionally consistent magnitude-frequency distribution (MFD) are used to forecast the rate of future earthquakes. The method accounts for the spatial variability of seismicity rate, and is used for areas where faults are not known or cannot be parameterized.

Development of the background-gridded source model consists in the following steps: specification of a magnitude-frequency distribution (MFD), development of a model for the maximum magnitude, estimation of earthquake rates, and specification of locations and source zone geometries. For all smoothed seismicity models, we assumed the Gutenberg-Richter (GR) relationship between earthquake magnitude and frequency:

$$\log_{10} N(m) = a - bm \qquad (6)$$

where N(m) is the number of earthquakes with $M \geq m$, and a and b are the GR parameters controlling the seismicity rate and the relative proportion of earthquakes with different magnitudes, respectively. BSHAP-SSC employs a truncated form (5) of the GR relation whereby the earthquake magnitudes are constrained to the range, $m_{min} \leq m \leq m_{max}$. m_{min} is the minimum magnitude capable of producing structural damage, and m_{max} represents the largest considered magnitude that can occur within a defined source zone. For all seismic sources in the BSHAP region, we accepted $m_{min}=4.0$. So, for description of the recurrence of seismic sources, given the truncated exponential model (5), three parameters are required for every seismic source: the rate of earthquake activity, λm_{min}, the b-value, and m_{max}. Estimation of b-values and m_{max} are described in the section 3.2.

BSHAP smoothed seismicity models are defined on a 10km x 10km grid for the latitude range 38.0°-48.0°N and the longitude range 12.0°-24.5°E. The areal seismic sources are modelled as set of the grid points included within the relevant seismic source zones. Earthquakes with magnitude greater than or equal to m_{min} that passed the completeness test of BSHAP catalogue (Table 1) are counted in each grid cell. Then, the annual rate of earthquakes occurrence was computed using a maximum-likelihood method (Weichert, 1980), using the selected b-value and the number of the events in each grid-cell, adjusted to account for the magnitude completeness levels. The smoothed seismicity models are obtained by smoothing earthquake rates to produce a spatially varying estimate of seismicity rates.

To evaluate the effects of spatial smoothing on the seismic hazard, two alternative seismicity smoothing methods are investigated. At first, a two-dimensional isotropic Gaussian function with a 30 km correlation distance, hereinafter circular smoothing (CS), is applied to smooth the annual rates of earthquake occurrence in each grid cell. Based on the sensitivity analysis, a fixed 30 km correlation distance is applied for the circular smoothing. The error in the epicenter location was assumed to 3 times larger than the correlation distance (Frankel, 1995). In the second alternative, referred as CES in the following, aside from the circular smoothing with 30 km correlation distance, an anisotropic fault-oriented smoothing (Lapajne et al., 2003), hereinafter elliptic smoothing (ES), is also applied on the grid of circular smoothed seismicity rates. The elliptic smoothing considers the rupture directions and the respective lengths, estimated by Wells & Coppersmith magnitude scaling relationships, of the main tectonic structures within the seismic source zones, provided by the BSHAP seismotectonic database. Spatial smoothing is considered as a branch in the logic-tree structure, to account for the epistemic uncertainties associated with construction of the seismic source model. We assigned the same weight (0.5) to both CS and CES smoothing approaches. These smoothed seismicity models are therefore stored as grids of the annual rate of earthquakes ($Mw \geq m_{min}$), and are used later in the hazard calculations.

4.1. Accounting for epistemic uncertainties

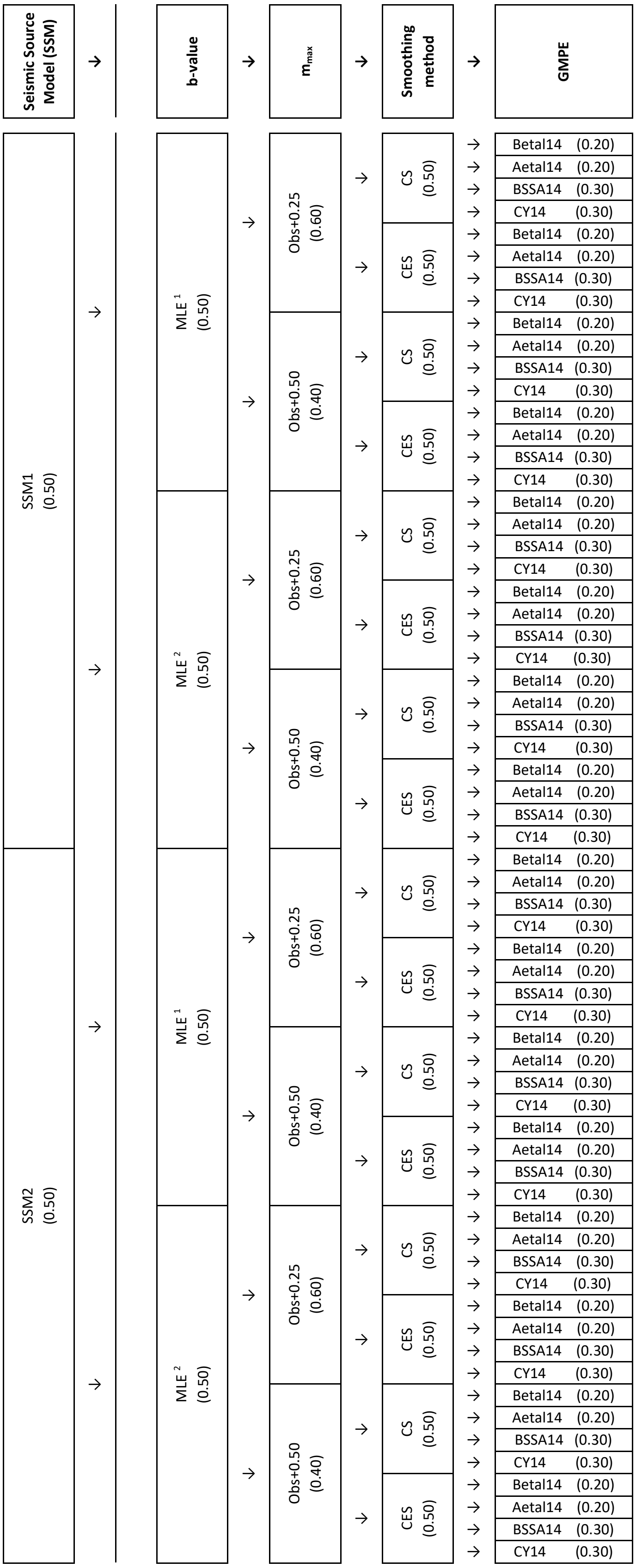


Figure 6. Logic-tree for the seismicity-based background source model in the Western Balkans. [1]) MLE for super-zones; [2]) MLE for the whole BSHAP area.

A logic tree with 64 branches has been designed to combine models in the hazard analysis and to derive the hazard maps for the Western Balkans, using the background-gridded source model. Each node in the logic tree defines alternative models or 'branches' in the logic-tree, with weights that sum to one.

As described in the section 3.2, the nodes in this logic tree includes: (1) two seismic source models (SSM1, and SSM2), (2) two alternative estimates for the *b*-value, (3) two alternative estimates of the maximum considered magnitude for each source zone, (4) two alternative algorithms for smoothing of the seismicity rates (CS with 30 km correlation distance, and CS+ES), and (5) four GMPEs (Aetal14, Betal14, BSSA14 and CY14) for ground motion prediction. The weights assigned to each branch are indicated in parenthesis.

Hazard calculation for each branch of logic tree are performed using the computer code OHAZ (Zabukovec et al., 2007), jointly developed by ARSO (Slovenian Environment Agency) and IGEO (Institute of GeoSciences, Albania), and upgraded the recent years by Kuka (OHAZ 2015), to fulfil requirements of the BSHAP project. Hazard assessment is applied for firm rock conditions, with 800 m/sec shear-wave velocity in the upper 30 m of the soil section, (classified as soil type A according to Eurocode 8 soil definitions) (CEN, 2004).

4.2. Update of seismic hazard analysis

The derived results in the frame of NATO SPS projects are a good basis to characterize the seismic hazard of the Western Balkan area, but they are regional and cannot replace the national seismic hazard maps, which need to be much more detailed. Therefore, driven also from the large damages and human losses of the 26 November 2019 Mw 6.4 Durres destructive earthquake, during the period January-March 2020, an additional effort is undertaken to update, detail and improve the seismic hazard assessment for the Albania territory. We followed the methodology conducted in the frame of NATO SPS 984374 project, using the new data collected the recent years, and the updated BSHAP earthquake catalogue. Besides, we have implemented a new hazard analysis using the GMPE of Boore et al., 2014 (BSSA14), and Chiou & Young 2014 (CY14). Again, the hazard assessment is carried out for firm rock conditions, with 800 m/sec shear-wave velocity in the upper 30 m of the soil section. The new calculations are performed using the software NSHM2014r (https://github.com/usgs/nshmp-haz-fortran/tree/nshm2014r1.ch), developed by the NSHM program of USGS to generate the updated [2014] National Seismic Hazard Models of the USA (http://pubs.usgs.gov/of/2014/1091/). There are some differences between OHAZ2015 and NSHM2014r software although both apply the smoothed-gridded seismicity methodology, especially regarding the magnitude-frequency distribution, calculation of the seismicity rates and their smoothing, as well as the GMPEs implemented. We attempted the calculation to be carried out in the most approximate conditions related to the input data (the same updated BSHAP catalogue, magnitude-completeness levels, *b*-values, and m_{max}).

The new results obtained using the OHAZ2015 software with the GMPEs Aetal14 and Betal14, and those obtained through the NSHM2014r software with BSSA14 and CY14 GMPEs, are combined using the recommended weights (Salic et al., 2016), 0.2, 0.2 for Aetal14 and BetAl14, and 0.3, 0.3 for the GMPEs BSSA14 and CY14. The assessment has been carried out for firm rock conditions with average velocity of shear waves $V_{S30=}$800 m/sec in the upper 30 meters of soil section (classified as soil type A according to Eurocode 8 soil definitions). The main output are the new probabilistic seismic hazard maps for Albania (Fig. 7a, 7b). The results are expressed in terms of peak horizontal acceleration (PGA) for 95- and 475-years return periods, which correspond to the exceeding probabilities 10% in 10 years, and 10% in 50 years, respectively. According to the Eurocode 8 standard (CEN, 2004), the return periods 95- and 475-years are associated with the damage limitation requirement (PDLR=10%; TDLR=95-years), and no-collapse requirement (P_{NCR}=10%; T_{NCR}=475-year), respectively. Apart these seismic hazard maps, the seismic hazard is estimated also for every municipality and administrative unit in the country, in terms of PGA for 95 and 475 years return periods.

Thus, obtained results are in full agreement with the Eurocode 8 standard for seismic zonation and aseismic design. As one can see from the figures 7a and 7b, higher hazard reveals in the northwestern part of the country (around Shkodra city), in the Elbasani-Librazhdi area, as well as in the southwestern part of Albania. The seismic hazard maps derived in this project are a good basis to characterize the seismic hazard of Albania. They will help the national authorities, public and private institutions, civil emergencies agencies, etc., for urban planning, disaster preparedness, and seismic hazard mitigation. The main finding is that if these maps are accepted as a reference indicator to establish a new regulatory national seismic zonation, design acceleration will be much higher than that applied in the current regulation. This implies that the competent authorities should take into consideration the obtained results to improve the existing design code in a more reliable and realistic basis in order to increase the safety level of constructions in the country.

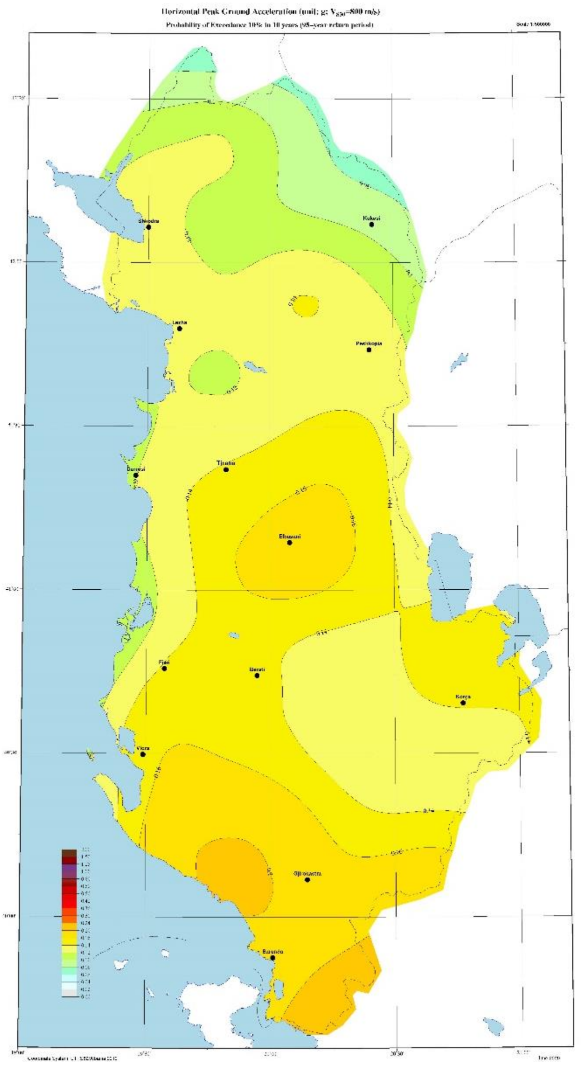


Figure7a. Seismic hazard map of Albania showing peak ground acceleration for 10-percent probability of exceedance in 10 years and V_{S30} site condition of 800 meters per second.

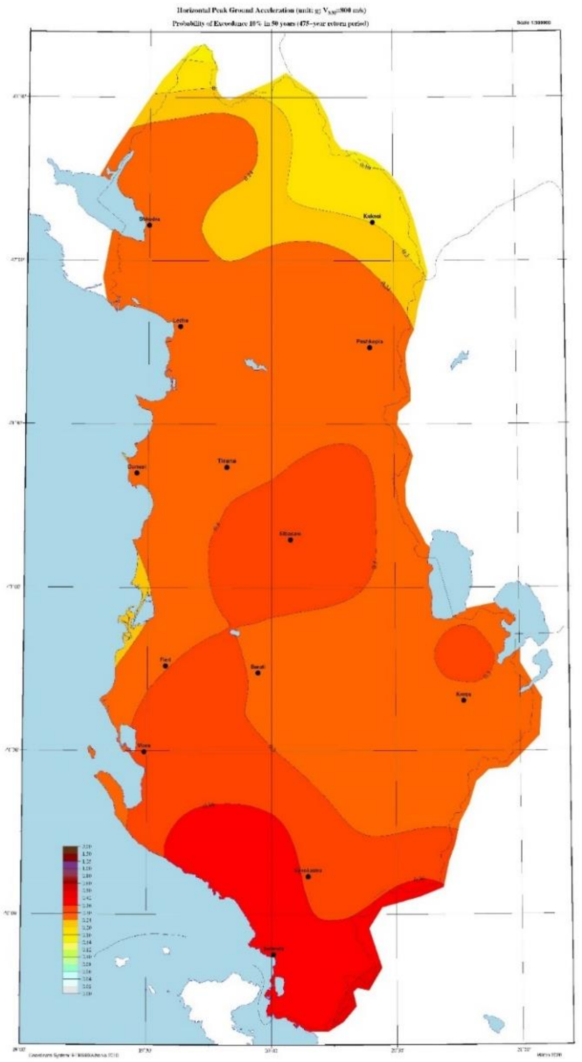


Figure 7b. Seismic hazard map of Albania showing peak ground acceleration for 10-percent probability of exceedance in 50 years and V_{S30} site condition of 800 meters per second.

Conclusions

The earthquakes represent a natural risk with high damage potential, and it is impossible to prevent or predict them reliably. The best protection against earthquakes consists in implementing the adequate measures to mitigate their consequences to the buildings and infrastructure. It is impossible to achieve that without a reliable analysis of the seismic hazard. The seismic hazard analysis is the primary and sole seismological information used for risk mitigation, being at the root of the building code definition. The aseismic design codes, assessment and management of seismic risk, as well as improvement of the earthquake safety, have to be based on the adequate models and reliable seismic hazard maps.

Our actual in force design code KTP-N.2-89, is based on the seismic zonation map compiled in 1979 (Sulstarova et al. 1980), which is an outdated empirical map, without any probability basis. This map depicts the macroseismic intensity (MSK-64 scale) and not the ground motion intensity measures used nowadays in the modern design codes (EC8, IBC, ASCE 7, etc.), such as PGA, PGV, SA, etc. Therefore, it is indispensable an accurate seismic hazard analysis, and deriving of a new seismic hazard map which will be used as a basis for the new aseismic design code following the Eurocode 8 standard. The 26 November 2019 Mw 6.4 Durres destructive earthquake has further stimulated improvement of the Albanian design code. So, it is an evident need to upgrade these technical norms with provisions harmonized with EU standards (Eurocode 8).

In order to support the Western Balkan Countries to implement the European design standards, the NATO "Science for Peace and Security" program has funded two projects: NATO SfP983054 (2007-2011) and NATO SPS984374 (2013-2015), with participation of the relevant institutions from Albania, Montenegro, Croatia, Bosnia and Herzegovina, Serbia and North Macedonia. The main objective of these projects was compiling of the new regional seismic hazard maps, as a necessary step towards the seismic safety improvement and seismic risk management. This was achieved through compiling of an updated and unified earthquake catalogue for the region, homogenous in terms of moment magnitude, strong motion database compilation, proper selection of the ground motion prediction models, compilation of all relevant regional geological knowledge and development of an appropriate seismo-tectonic model for the area.

The derived results in the frame of NATO SPS projects are a good basis to characterize the seismic hazard of the Western Balkan area, but they are regional and cannot replace the national seismic hazard maps, which need to be much more detailed. Therefore, driven also from the large damages and human losses of the 26 November 2019 Mw 6.4 Durres destructive earthquake, during the period January-March 2020, an additional effort is undertaken to update, detail and improve the seismic hazard assessment for the Albania territory. The BSHAP earthquake catalogue, which covers the time span 510BC-31/12/2012, is updated including the $Mw \geq 3.0$ events occurred within the area 38−48°N latitude and 12−24.5°E longitude during the period 1/01/2013-31/12/2019. The new calculations are performed using the OHAZ2015 software on the updated BSHAP catalogue, as well as the software NSHM2014r (https://github.com/usgs/nshmp-haz-fortran/tree/nshm2014r1.ch), developed by the NSHM program of USGS to generate the updated [2014] National Seismic Hazard Models of the USA (http://pubs.usgs.gov/of/2014/1091/).

The present estimation is a combination of the seismic hazard assessment obtained using the methodology followed in the frame of BSHAP2 project on the updated BSHAP catalogue, with the new results obtained the last year using the NSHM2014r software. Both estimations are obtained by implementation of the smoothed-gridded seismicity approach. The main output are the new probabilistic seismic hazard maps for Albania. They are prepared based on the updated BSHAP earthquake catalogue, four selected GMPEs and two alternative BSHAP seismotectonic models. Hazard calculations are carried out following a logic-tree structure describing the epistemic uncertainties associated with building of the seismic source model, and of the GMPEs selected for ground motion prediction. The results are expressed in terms of peak horizontal acceleration (PGA) for 95 and 475 years return periods. The assessment has been carried out for rock conditions with average velocity of shear waves $V_{S30} \geq 800$ m/sec in the upper 30 meters of soil section (classified as soil type A according to Eurocode 8 soil definitions). Apart these seismic hazard maps, the seismic hazard is estimated also for every municipality and administrative unit in the country, in terms of PGA for 95 and 475 years return periods.

Thus, obtained results are in full agreement with the Eurocode 8 standard for seismic zonation and aseismic design. The seismic hazard maps derived in this project are a good basis to characterize the seismic hazard of Albania. They will help the national authorities, public and private institutions, civil emergencies agencies, etc., for urban planning, disaster preparedness, and seismic hazard mitigation. The main finding is that if these maps are accepted as a reference indicator to establish a new regulatory national seismic zonation, design acceleration will be much higher than that applied in the current regulation. This implies that the competent authorities should take into consideration the obtained results to improve the existing design code in a more reliable and realistic basis in order to increase the safety level of constructions in the country.

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