Results Achieved and Improvements Needed in the Field of Seismic Hazard Assessment of Republic of Macedonia

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SUMMARY:
The territory of Macedonia is belonging to the Balkan Peninsula which is well known as an area with highest seismic hazard and risk in South Eastern Europe. In absence of modern and dense seismic networks with high detectability capability, rear geophysical profiling and other relevant data necessary to improve more than 20 years old seismic hazard models, joint regional effort through BSHAP Project was made to overcome current situation and harmonize the maps for seismic hazard. This process includes verification and/or redefinition of seismotectonical characteristics of the source zones; adopt alternative recurrence relationships for identified seismic sources; elaboration of adequate seismicity models; adoption and testing of different ground motion prediction models; and GIS implementation in all steps of the analyses. The research has been performed under the NATO SfP-983054 Project "Harmonization of Seismic Hazard Maps for the Western Balkan Countries" (BSHAP) as well as Council of Europe, EUR-OPA MHAs' coordinated activity "Harmonization of Seismic Hazard Maps in Balkans". The paper presents extract from the joint effort of outstanding national institutions-partners from Albania, Bosnia and Herzegovina, Croatia, Montenegro, Serbia and Turkey, relevant for territory of Macedonia that in this project has been represented by IZIIS-Skopje.

Keywords: Seismic Hazard, Smoothed Seismicity, Macedonia, BSHAP, NATO SfP-983054

1. RATIONALE

There were numerous important rationales for the realization of the BSHAP project: (1) Existing seismic hazard maps were out of date and need to be updated and improved, (2) Seismic, seismotectonical, geophysical and other acquired data in recent years need to be integrated and implemented in the hazard assessment, (3) New methodological approach and new empirical seismic models for hazard assessment need necessary to be implemented, (4) Local seismic code regulations, seismic risk estimation and risk management need to be based on reliable hazard maps; (5) Seismic hazard need to be harmonized with EU standards (EUROCODE 8), (6) National seismic network need to be improved; (7) Strengthening the regional cooperation.

2. CURRENT STATUS

2.1. Up-to-date Official Seismic Zoning Maps for Republic of Macedonia

Modern urban regions in the country, despite ample engineering and technical measures that have been taken to protect them from adverse effects of natural events, due to rapid growth and increasing concentration of population and material property become increasingly vulnerable. Consequences that may occur and problems of potential rehabilitation of regions affected will become substantially larger and complex, especially when the urban regions are exposed to natural disasters that in short time interval, or instantaneously, release tremendous destructive power, as is the case with earthquakes.

Realistic estimation of seismic hazard and its implementation in the prevention, mitigation and development are key factors for reducing the human casualties, loss and damage to property, social and economic disruption in the future seismic events.

Complex geological, tectonic and seismotectonic environment of the Republic of Macedonia influences the definition of seismic source zones with unacceptable confidence levels. The lack of relevant data as a consequence of the lack of modern and dense seismological network with high capacity and detection sensitivity, appropriate deep geophysical profiling, records of strong earthquakes that are qualitatively and quantitatively related to known tectonic structures are the principal reasons contributing to the subjectivity in the application of established methods for seismic hazard assessment.

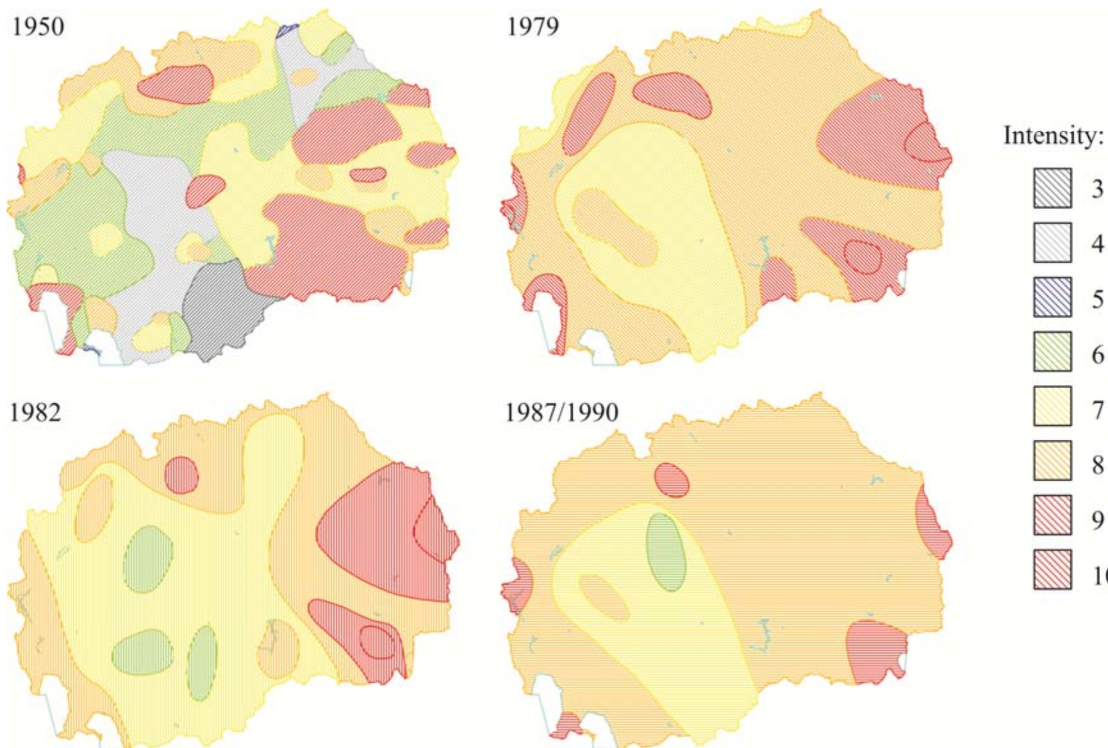

Figure 1. Official seismic zoning maps of Republic of Macedonia

Standard legislation, defining the procedures and the demands for seismic protection, dominantly refers to problems of cost-effective damage prevention (acceptable risk) of buildings, engineering structures and other facilities.

The first standards addressing the seismic requirements are “Temporary Technical Regulations for Loading of Building Structures” (1948). The first Seismic Design Code, the “Temporary Regulations for Construction in Seismic Regions”, Official Gazette of SFRY No. 39/64, was enforced in 1964, i.e., immediately after the Skopje earthquake of July 26, 1963. Presently in effect are the “Technical Regulations for Construction of Buildings in Seismic Regions”, Official Gazette of SFRY No. 31/81 (including several amendments 49/82, 29/83, 21/88, and 52/90), adopted in the period 1981-1990. The synthesis of the official regulations and seismic zone maps is given in Table 2.1.

Maximum expected intensity maps where integral part of all official regulations for design and construction. They were result of applying of different hazard methodologies based on different seismological data with varying, in principle unknown, confidence levels. Maximal expected intensities were expressed in different intensity scales (MCS, MSK-64) and methods used vary from deterministic (Map of 1950) to probabilistic (Maps of 1987/90).

Table 2.1. Official building codes and seismic zoning maps for the Republic of Macedonia

Code	Seismic Zoning Map
1948: Temporary Technical Regulations (PTP) for Loading of Structures", Part 2, No. 11730, 12 July 1948.	**1948: Seismic Zoning Map of FNR Yugoslavia, (Official Gazette of FNRY no. 61/48 of June 17, 1948)**
1964: Temporary Technical Regulations for Construction in Seismic Regions", Official Gazette of SFRY No. 39/64 (1964).	**1950: Seismic Zoning Map of Yugoslavia, Seismological Bureau of F.N.R.Y., Belgrade.** *(Author: Jelenko MIHAJLOVIC)* *Base: Compilation of intensities of earthquakes occurred in the period 360AD-1950AD*
	1967: Engineering Geology Map of SFR Yugoslavia (1:500,000), Federal Geological Institute, Belgrade. *(Authors: P. CUBRILOVIC, L. PALAVESTRIC and T. NIKOLIC)* *Base: Compilation of seismicity data for the territory of Yugoslavia, Intensities by MCS Seismic Intensity Scale.*
1981: Technical Regulations for Construction of Buildings in Seismic Regions", Official Gazette of SFRY No. 31/81 (Amendments 49/82, 29/83, 21/88, and 52/90), adopted in 1981.	**1979: Seismic Zoning Map of Macedonia, Seismological Observatory, Skopje.** *(Author: D. Hadzievski, Official Gazette of SRM No. 2/79)* *Base: Compilation of seismicity data for the territory of Macedonia, Intensities by MCS Seismic Intensity Scale.*
	1982: Provisional Seismic Zoning Map of Yugoslavia (Official Gazette of SFRY no. 49/82) *Base: Statistical analysis of known earthquakes that had struck the territory of Yugoslavia in the past.*
	1987/1990: **Seismic Zoning Maps of SFRY (1:1,000,000) for Return Periods of 50, 100, 200, 500, 1000 and 10000 years**. (Author: Seismological Association of SFR Yugoslavia, 1987; Degrees by MSK-64 Seismic Intensity Scale). Official Gazette No. 52/90: Article 6: Map for Return Period of 500 years is adopted for design of buildings of II and III category (residential, and administrative, public and industrial buildings not classified in category I).
2012	**2012**

MCS: Mercali-Cancani-Sieberg Seismic Intensity Scale
MSK-64: Medvedev-Karnik-Sponheurer 1964 Seismic Intensity Scale

Seismic zoning map tied to the 1948 design regulations (Map of 1950, Fig. 1, Table 2.1) is based on compilation of maximum occurred intensities, thus it is the spatial distribution of maximum intensities with temporal reference 360 - 1950. Similar is the 1948 Seismic Zoning Map which was a base for the 1950 Seismic Zoning Map.

Skopje 1963 earthquake displayed inconsistencies and omissions in 1948 design regulations and was the main reason for introducing new "Temporary Technical Regulations for Construction in Seismic Regions" (1964). For a long period, the 1950 Seismic Zoning Map was tied to these regulations, until in 1979, for territory of Macedonia only, it was replaced by 1979 Seismic Zoning Map of Macedonia. Although for the entire territory of former SFRY a new Seismic Zoning Map was compiled in 1967, it has not officially been legalized.

The latest seismic design regulations (1981) are tied to a set of six Seismic Zoning Maps related to maximum expected intensities for return periods of 50, 100, 200, 500, 1000 and 10 000 years with a 63% probability of occurrence, out of which the 500 years return period Seismic Zoning Map with a 63% probability of occurrence has been, and still is, the official one for seismic design of buildings. The Commentary to these maps indicates that they are related to "medium ground" conditions, which are not defined and are extremely unclear.

Since 1964 the built environment in Macedonia is legally protected by Seismic Design Provisions. However, genesis of knowledge and know-how at certain territories of Macedonia are undermining the achieved levels of seismic protection. Comparing the presented and discussed set of Seismic Zoning Maps there are obvious differences in the dispositions and the size of the territory covered by particular seismic intensity zone (Fig. 1).

A ratio between areas of maximum vesus areas of minimum intensity, irrespective to which map the maximum or minimum intensity is alocated to is used as a rough measure of changes generated by genesis of seismic zonation. In general, for intensity areas of engineering interest (I > 7) the agregate ratio is showing differences up to 100%. Specifically, for intensities I = 7, 8, 9 and 10, about 51.9%; 17.3%; 26.8% and 100%, respectively.

Observed differences pose a serious question of underestimation/overestimation of the seismic loads according to which structures were designed at particular period as well as the levels of seismic safety and stability assured by implementation of particular Seismic Design Code. In other words, the benchmarks is needed for estimating the influence of previous systemic solutions on current physical and socio-economic vulnerability of the country and as a base for present and future seismic disaster free design process.

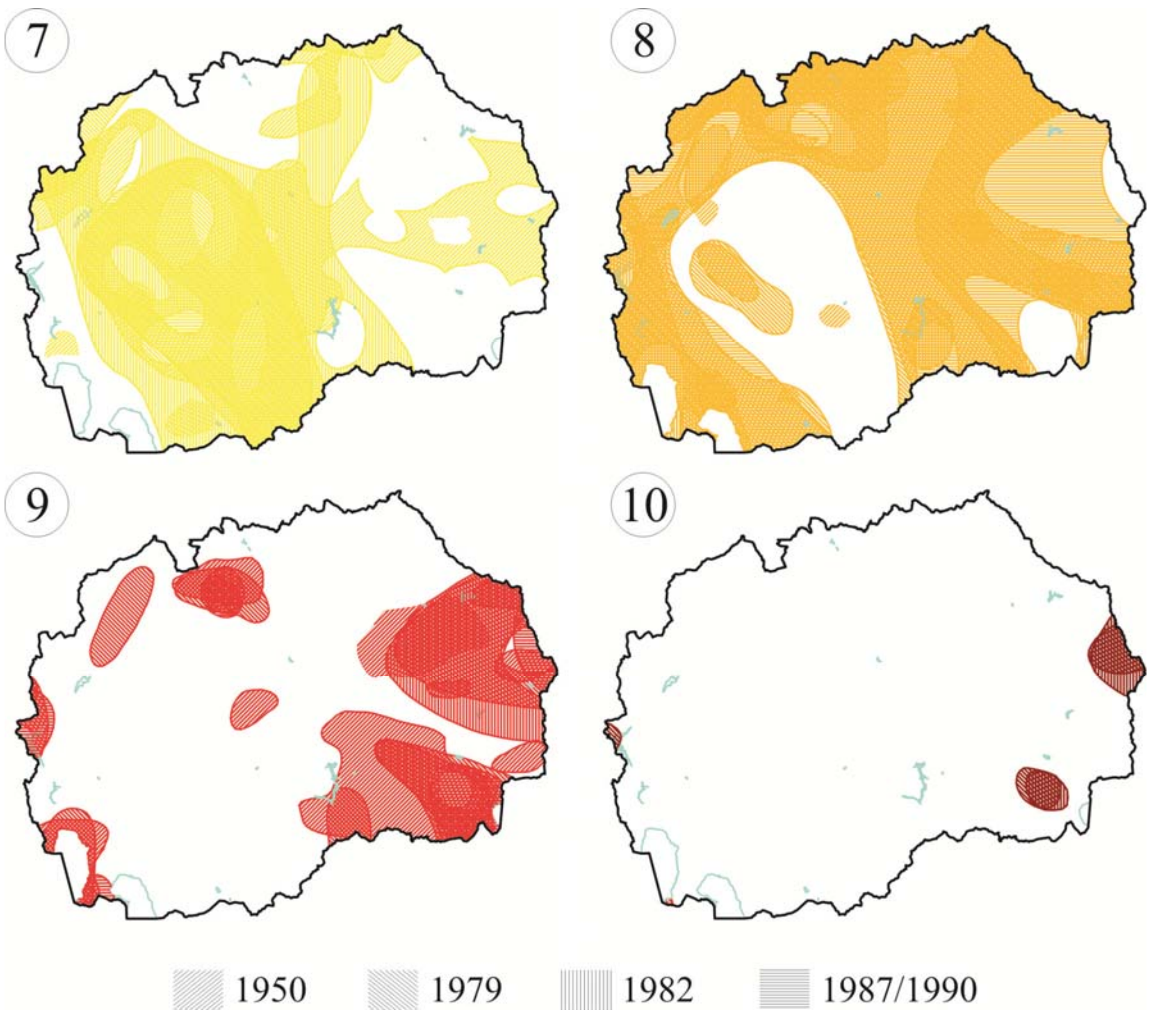

Figure 2. Differences in the disposition of the intensity areas (for I>7)

2.2. Implementation of New European Regulations

The part of structural EUROCODE Programme, EN 1998-1 document of the EUROCODE 8: Design of structures for earthquake resistance, as one of the fundamental issues, contains the definition of seismic action. The seismic action itself is defined in accordance to results of seismic hazard analysis performed on national level. Given the wide differences in seismogenetic characteristic, potential seismic hazard levels and protection policies represented by the level of nationally acceptable risk in different member countries, the EUROCODE defines seismic action in general terms and provides some template values. However, it also allows modification of these parameters with nationally defined and adopted ones which are confirmed and adopted by National Annexes.

EUROCODE requires definition of 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 (Table 2.2).

Table 2.2. EUROCODE 8 requirements

No-collapse requirement	Damage limitation requirement
….. The design seismic action is expressed in terms of: a) the reference seismic action associated with a reference probability of exceedance, *P*NCR, in 50 years or a reference return period, *T*NCR, and b) …..	….. The seismic action to be taken into account for the "damage limitation requirement" has a probability of exceedance, *P*DLR, in 10 years and a return period, *T*DLR…..
The values to be ascribed to ***P*NCR** or to ***T*NCR** for use in a country may be found in its ***National Annex of this document.*** The recommended values are ***P*NCR =10%** and ***T*NCR = 475** years.	The values to be ascribed to ***P*DLR** or to ***T*DLR** for use in a country may be found in its ***National Annex of this document.*** The recommended values are ***P*DLR =10%** and ***T*DLR = 95** years.

CEN, EN 1998-1:2004:E (2004) "Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings", December 2004.

EUROCODE 8 requires that seismic areas are defined by seismic hazard maps expressing the seismic action in terms of maximum effective ground acceleration (a_g, the design acceleration) at the bad rock level with a 10% exceedance probability for periods of 10 (return period 95 years) and 50 (return period 475 years) years.

3. METHODOLOGY USED AND RESULTS ACHIEVED

To avoid physical inconsistencies involved in the classical PSHA approach based on "zoned seismicity" modelling, for regions where earthquake catalogue predominantly comprise data derived from macroseismic observations and where is no sufficient number of mutually correlated geological, tectonic, neotectonic and seismological data, the method of spatially smoothed and/or spatially oriented seismicity is more consistent and subjectivity-free physical approach for modelling seismicity (Frankel 1995, Lapajne et al., 2003).

The method takes into account the 3D character of the seismicity within the seismic zone as a spatial unit of the seismically active earth's crust. It allows minimizing the errors arising from the determination of the epicentres and migration of seismic sources along the active tectonic structures. The implementation of smoothed seismicity method together with the integration of all existing data on active seismotectonic structures is the latest trend in evaluation of seismic hazard. More details are presented in Duni at all, 2010.

Hazard calculations are performed by OHAZ 6.0 software (Zabukovec et al., 2007), improved by Institute of Geosciences, Polytechnic University of Tirana, Albania in collaboration with the Seismological Office of the Environmental Agency of Slovenia.

3.1. Earthquake Catalogue

The final BSHAP catalogue is a result of manual check-out of all national and available catalogues compilation. The earthquake catalogue is based on the compilation of the catalogues from: Albania; Bosnia and Herzegovina; Bulgaria; Croatia; Greece; Hungary; Italy; Macedonia; Montenegro; Romania; Slovenia; Serbia; as well as: Karnik 1996; Shebalin & Leydecker; ISC; NEIC; CMT Harvard Catalog; RCMT, INGV, Roma; RCMT, ETHZ, Zurich; EMMA database, Version 2.

The BSHAP regional catalogue contains total number of 13,341 earthquake events with magnitude larger than 3.5, for the period 510 BC-31/12/2010.

3.1.1. Magnitude Unification

Seismological institutions in the region report the magnitude information in different scales (M_L, M_S, m_b, M_W, etc.). The M_W unification was performed with anticipating detailed statistical investigation regarding the relationships between different magnitude scales used by the seismic networks in the region.

The converted, or re-estimated macroseismic magnitudes from Karnik and Shebalin catalogues, were converted in M_W using the relevant regression relations of Scordilis (2006), Table 3.1 (a). Ms and mb magnitudes reported in the bulletins of ISC are converted in M_W using relations given in Table 3.1 (b). To enable conversion to M_W of the local magnitudes M_L calculated by the seismological centres of the region, empirical relations derived by Duni et al., 2010 are used, Table 3.1 (c).

Table 3.1. Magnitude conversion relationships

a) MSK-M_W	**b) MS & mb – M_W**	**c) M_L- M_W**
M_W=0.80xM_{SK}+1.31; 4.0 ≤ M_{SK} < 5.4	Mw = b0+b1xM+b2xM2	Mw = 1.423 + 0.768ML; Tirana
M_w=0.70xM_{SK}+1.80; 5.4 ≤ M_{SK} < 6.3	Mw = 3.948 - 0.177Ms + 0.08626Ms2	Mw = 0.690 + 0.900ML; Podgorica
M_w=1.04xM_{SK}-0.33; 6.3 ≤ M_{SK} ≤ 8.1	Mw = 5.887 - 1.433mb + 0.25512mb2	Mw = 0.489 + 0.853ML; Zagreb
	Mw = 1/(b0+b1xM)	Mw = 0.414 + 0.938ML; Belgrade
	Mw = 1/(0.31304 – 0. 024282Ms)	Mw = 0.684 + 0.907ML; Skopje
	Mw = 1/(0. 40266 – 0. 041342mb)	Mw = 0.383 + 1.010ML; Thessaloniki

3.1.2. Completeness levels

Completeness levels of the catalogue are estimated by using the cumulative number of events – time graphs to evidence slope changes, assuming that the most recent change in the slope occurs when the data became complete for magnitudes above the reference one (Gasperini and Ferrari, 2000).

The identified state of the completeness of BSHAP catalogue is from: (1)1965 for $M_W \geq 4.0$; (2) 1955 for $M_W \geq 4.5$; (3) 1905 for $M_W \geq 5.0$; (4) 1830 for $M_W \geq 5.5$; (5) 1600 for $M_W \geq 6.0$; (6) 1400 for $M_W \geq 6.5$; and, (7) 1150 for $M_W \geq 7.0$. Thus, the overall BSHAP catalogue has been considered complete for magnitudes $M_W \geq 4.0$.

3.2. Seismicity Parameters

3.2.1. Seismic activity rate

Seismic activity rate is estimated using the double truncated exponential recurrence relationship, in order to confine the range of magnitudes, eliminating the contribution of very small earthquakes at the lower end and unrealistic high magnitude earthquakes at the high end:

$$\lambda_m = \lambda_{m_0} \cdot \frac{\exp[-\beta(m - m_0)] - \exp[-\beta(m_{\max} - m_0)]}{1 - \exp[-\beta(m_{\max} - m_0)]}, \quad m_0 < m < m_{max}$$

λ_m : the mean annual number of earthquakes with $M \geq m$.

λ_{m0} : the mean annual number of earthquakes with $M \geq m_0$.

m_0 : minimum magnitude with engineering interest.

m_{max} : maximum magnitude that can be generated in a seismic source.

3.2.2. Maximum magnitude

For the estimation of M_{max} the historical-parametric approach of Kijko-Selevoll (1989, 1992) was used, based on the observed seismicity. Except the above mentioned principles, the calculation of M_{max} took into account previous evaluations based on geological considerations of seismogenic potential of seismotectonic zones (Aliaj *et al.*, 2004). These estimations are used for the seismic hazard calculation. The maximum magnitude ever observed in the region is $M_W=7.7$ for the entire historically and instrumentally documented period.

3.3. Ground Motion Prediction Models

Due to the absence of regional strong-motion data, an indigenous ground-motion model is not available for the Balkan region. In these circumstances it is necessary to consider ground-motion predictive models developed for regions with similar geological and tectonical features, or models accepted and used worldwide, such are those generated recently by the NGA project (USA, EERI, 2008) or recommended by a scientific working group on GMPEs to be used in the Project SHARE (Seismic Hazard of Europe).

Based on the evaluation of the SHARE project (Segou and Akkar, 2010) on the validity and ranking of the different GMPEs which can be used in the Europe, the selected GMPEs for this study are the pan-European model derived by Akkar and Bommer (2010), the global models of Boore and Atkinson (2008) and Cauzzi and Faccioli (2008), as well as the Italian ground-motion model proposed by Bindi et al. (2009). These models are valid for active shallow crustal regions; the seismotectonic setting suitable for the BSHAP area. The seismic hazard outputs obtained from these models are combined according to a weighting scheme implemented in the logic-tree approach.

3.4. Results

To calculate hazard from a particular source, doubly-truncated exponential magnitude-frequency distribution was applied, with *b*-value corresponding to the relevant zone. The lower bound magnitude M_{min} is fixed at $M_W=4.0$, while M_{max} varies according to the respective zones from 5.6 up to *7.5*.

Seismic hazard assessment has been performed for:

- Rock conditions, with 800 m/sec shear-wave velocity in the upper 30 m of the soil section (Class A of Eurocode 8 soil classification scheme);
- Four PGMEs (Table 3.2); and,
- Logic tree model with PGME weighted averages as presented in Table 3.2.

Table 3.2. Characteristics of Adopted PGMEs

PGME relation	Abbreviation	D_{max} (km)	Magnitude Range	Weighted Average (w)
Bindi *et al*. 2009	Bi09	100	$5 \leq M \leq 7.5$	0.3
Akkar and Bommer, 2010	AB10	100	$5 \leq M \leq 7.5$	0.3
Boore and Atkinson, 2008	BA08	200	$5.0 \leq M_S \leq 7.5$	0.2
Cauzzi and Faccioli, 2008	CF08	150	$5 \leq M_W \leq 7.5$	0.2

The results of this seismic hazard estimate are consistent to many other previous studies of seismic hazard, such are Giardini (1999) (GSHAP - Global Seismic Hazard Assessment Program), Musson (1999), Husebye (2005), Duni and Kuka (2010), Kuka et al. (2003), Glavatovic (1985), etc.

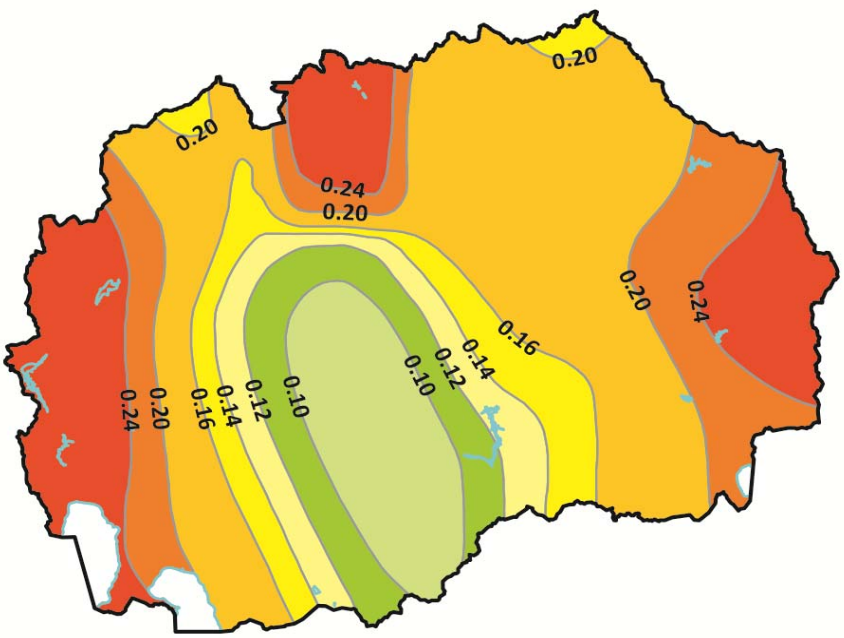

Figure 3. PGA Levels for 10% probability on non-exceedance in 50 years (475 years return period).

4. IMPROVEMENTS NEEDED

Recommended improvements of the seismological and seismotectonic databases are foreseen as:

- Completing the BSHAP catalogue with events $M_W \geq 3.5$ (better for $M_W \geq 3.0$); eliminating of possible inaccuracies; completing of the extended database in format already agreed and defined among BSHAP Project partners.
- Improving of the BSHAP seismotectonic database (some zones are too small and difficult to estimate reliably the seismicity parameters, especially for the low seismicity areas).
- Identifying and characterization of the large faults in the BSHAP region, which have generated earthquakes with $M_W \geq 6.5$; combining the smoothed gridded seismicity with the fault generated seismic hazard.
- Creating of the strong motion database for the BSHAP area; deriving a GMPE model - more adequate for our region.

ACKNOWLEDGEMENT

This article is based on the work done in the framework of NATO SfP 983054 project "Harmonization of Seismic Hazard Maps for the Western Balkan Countries" funded by Science for Peace and Security Programme of NATO. Authors grateful to the authorities of this programme for their strong support as well as recognize and highly appreciate inputs from countries partners in this project (Albania, Bosnia and Herzegovina, Croatia, Montenegro, Serbia and Turkey) and Greece and Slovenia.

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