Comprehensive Risk Assessment of Basic Services and Transport Infrastructure

101004830 - CRISIS - UCPM-2020-PP-AG

Cross-Border Multi Hazard Assessment
Seismic Hazard Cross-Border Harmonization and Mapping

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1. Review of available seismic hazard assessments covering the target region

1.1. National perspective

1.1.1. N. Macedonia

Many national scientific efforts towards realistic seismic hazard assessment were made, dominantly throughout the research activities of the Institute of Earthquake Engineering and Engineering Seismology (IZIIS) since its establishment in 1965. Although many of those studies were related to the site-specific definition of the seismic hazard, a considerable number of the studies are related to the regional seismic hazard assessment. Accordingly, several seismotectonic models were proposed by different researchers or research groups.

a) Mihailov (1978)   b) Milutinovic et al. (1998)

c) Dojcinovski (2005)   d) Stamatovska and Paskaleva-Koytcheva (2013)

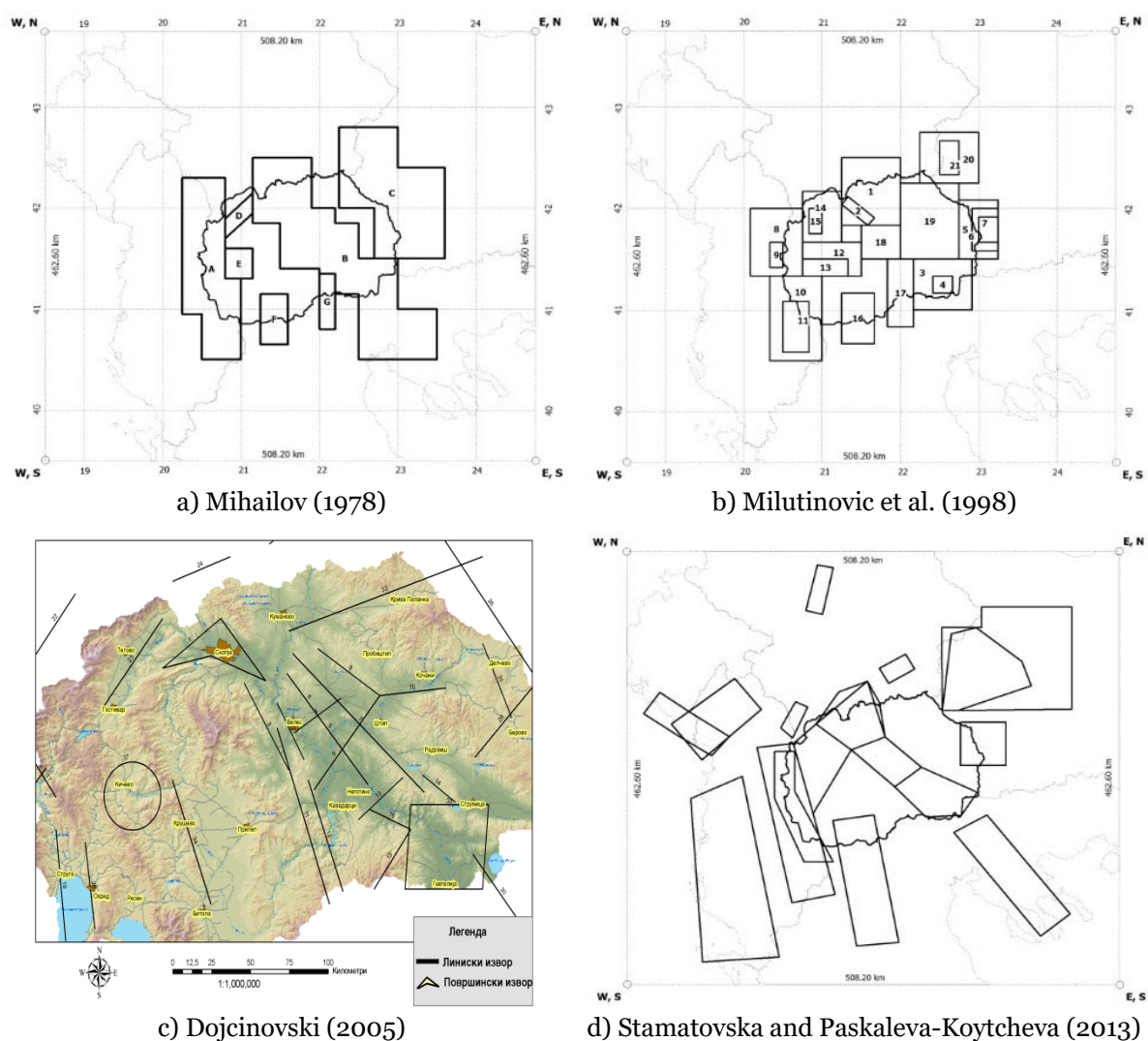Figure 1.1. Some of the proposed seismotectonic models for the purpose of regional seismic hazard assessment (1965-2013)

One of the first national models was proposed by Mihailov in 1978 (Figure 1.1, a) in his doctoral dissertation. 6 different types of seismotectonic models were analyzed and compared. Three more regional seismic hazard models were proposed in the period 1965-2013. The second one

is developed by Milutinovic et al. in 1998 (Figure 1.1, b) for the purpose of seismic hazard assessment for the Spatial Plan of Republic of Macedonia. The third one is proposed by Dojcinovski in 2005 in the frame of his doctoral dissertation for the purpose of damage assessment related to the road infrastructure in the Republic of N. Macedonia (Figure 1.1, c). The fourth one was proposed by Stamatovska and Paskaleva-Koytcheva (2013) for the purpose of lifeline hazard assessment (Figure 1.1, d), although with slightly different modifications, presented in other publications and reports.

One of the recent efforts towards seismic hazard modeling was done by Salic (2015), in the frame of her doctoral dissertation where three seismotectonic models (Figure 1.2) were proposed and compared with the aim to: a) reduce subjectivity implicitly embedded in the definition of classical zoned models; b) incorporate the latest knowledge about the accumulations of the deformations of the earth crust and the active tectonics in the South Balkan region based on GPS measurements (Dumurdzanov 2004, 2005; Burchfiel, 2006; Kotzev, 2008; Matev, 2011); c) incorporate the aleatory and epistemic uncertainties in the seismic hazard analysis; and, d) reduce non-complementarity of current methods and technologies for seismic hazard estimation in essence compatible with current design codes (JUS 31/81) to generate the products compatible with 1998 1:2004: Eurocode 8. The proposed Model-1 is gridded seismicity model, Model-2 is areal type source model and Model-3 is smoothed seismicity model where the delineation of the zones was made with the purpose to incorporate the available seismo-tectonic information as proposed by Lapajne (1997).

Model -1   Model - 2   Model - 3
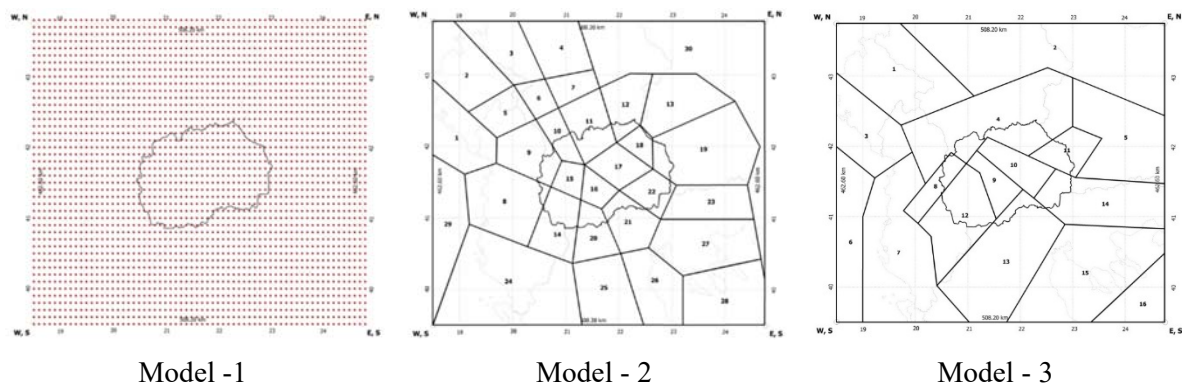
Figure 1.2. Proposed seismotectonic models by Salic (2015)

As part of building codes, up to now, six official seismic zonation maps/sets of maps have been published (1948, 1964, 1979, 1982, 1990 and 2020) for N. Macedonia (Table 1.1). All of these maps, except the 2020 maps which are acceleration maps (g), are intensity maps, presented in different intensity scales (MSC: Mercalli–Cancani–Sieberg or MSK-64: Medvedev-Sponheuer-Karnik) dominantly with the unknown/unavailable information about the methodology used for development of these maps. According to the authors' knowledge, intensities presented in the maps from 1948, 1964, 1979 and 1982 are based on available data on historic seismicity. The set of maps published in 1990 are maps where probabilistic seismic hazard assessment was used, proposing a set of maps for different return periods (50, 100, 200, 500, 1000 and 10000 years) out of which only the 500-year return period map was used into design process, i.e. for design of buildings of II and III category (residential, and administrative, public and industrial buildings not classified in category I). The latest map from 2020 was prepared for the purpose of National Annex to Eurocode8 (MKC EN 1998-1/HA:2020), based on state-of-the-art probabilistic methodology for seismic hazard assessment. The details about the modeling and related parameters are published in Milutinovic et al. (2016).

Table 1.1. Official Building Codes and Seismic Zoning Maps relevant for N. Macedonia

Building Code		Seismic Zoning Map	
Year	Building Code Title	Year	Seismic Zoning Map Title
1948	**Provisional Technical Regulations for Loading of Structures** OGoFNRY No. 61/48 of July 17, 1948	1948	**Division of territory of Federal People's Republic of Yugoslavia into seismological zones** OGoFNRY No. 61/48 of July 17, 1948
1964	**Provisional Technical Regulations for Construction in Seismic Regions** OGoSFRY No. 39/64 of September 30, 1964	1964	**S.F.R. Yugoslavia Seismological Map** OGoSFRY No. 39/64 of September 30, 1964
1981	**Technical Regulations for Construction of Buildings in Seismic Regions** OGoSFRY No. 31/81 of June 5, 1981 (Amendments 49/82, 29/83, 21/88 and 52/90)	1979	**Seismic Zoning Map of S.R. Macedonia** OGoSRM No. 2/79 of January 31, 1979
		1982	**Provisional Seismological Map of SFRY** OGoSFRY No. 49/82 of August 13, 1982
		1990	**Socialist Federal Republic of Yugoslavia, Seismological Maps for Return periods of 50, 100, 200, 500, 1000 and 10000 years** OGoSFRY No. 52/90 of September 7, 1990
2020	**Eurocodes (EN)** EN 1998-1	2020	MKC EN 1998-1/NA:2020

Milutinovic et al., 2016 (in the following text denoted as MK-EC8 model) is a combination of 2 seismo-tectonic models: M1 (Grid Source Model) and M2 (Area Source Model). Schematic representation of MK-EC8 seismo-tectonic models is given in Figure 1.3.

a) Model: M1   b) Model: M2
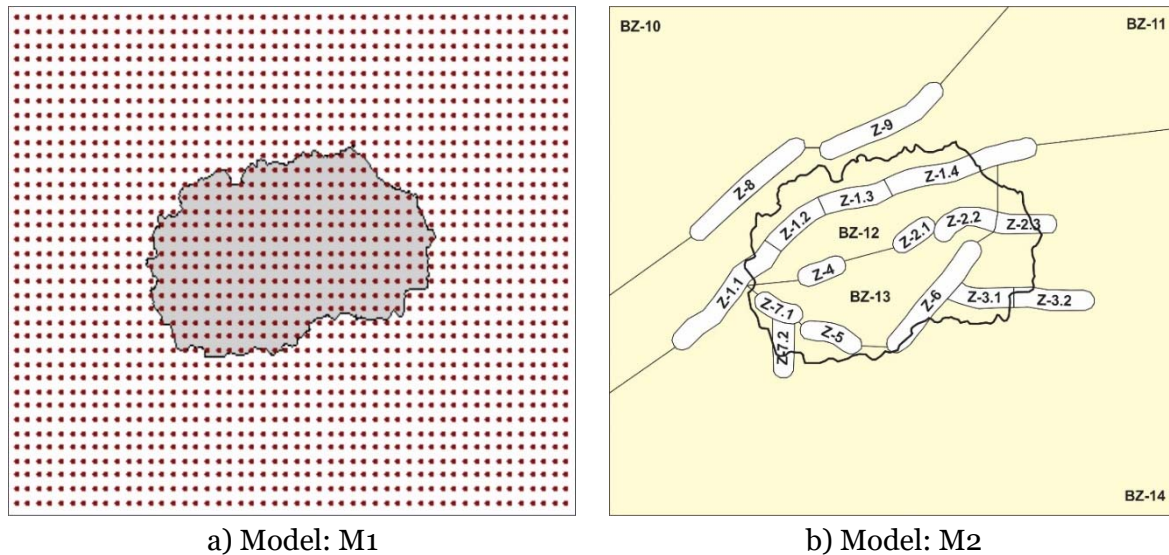
Figure 1.3. Proposed seismotectonic models by Milutinovic et al. (2016)

Model M1 is used to describe seismicity with a rapid geographic variation. The model assumes collection of point sources located at the nodes of a rectangular grid that is parallel to the surface of the Earth, that is, a grid in which all the nodes have the same depth. Each one of the nodes is a potential hypocenter. Seismicity is assumed to be of Modified Gutenberg-Richter type. M0 is assumed to be constant across the seismicity region, but λ, β and Mmax have an arbitrary geographical variation, defined for every grid point. The calculation of seismic hazard parameters is based on Kijko and Smith, 2012 procedure.

The proposed M2 seismotectonic model consists of 9 area (buffer zones) sources denoted with Z which represent the areas where the potentially active fault lines are placed (according to Dumurdjanov et al., 2020). The remaining 4 area sources denoted with BZ are representing the model background seismicity. Seismicity is assumed to be of Modified Gutenberg-Richter type. For every source values for M0, λ, β and Mmax are defined. Weichert (1980) procedure was used for definition of seismic hazard parameters.

Logic tree apparatus is chosen as a tool to capture the epistemic uncertainty associated with the seismo-tectonic sources and its parameters, as well as the ground-motion prediction models used in MK-EC8. The applied logic tree scheme accounts for the variability of: (1) Two seismo-tectonic models; (2) Different Mmax estimations; (3) Different M0 thresholds; and (4) Four attenuation models used.

According to the results of a study which was part of regional BSHAP effort (Salic et al., 2017), the following GMPEs are used in MK-EC8 hazard estimation: BSSA14 (Boore et al., 2014), CY14 (Chiou and Youngs, 2014), Aetal14 (Akkar et al., 2014) and Betal14 (Bindi et al., 2014).

Probabilistic seismic hazard analyses are performed using CRISIS v.2014 (Ordaz et al.) on a grid of 0.1 x 0.1 degrees.

The final zoning maps for the need of National Annex for the EC8 (МКС EN 1998-1/НА:2020) are derived for two return periods, 95 and 475 years respectively, and their final values are results of chosen interpolation model and rounding scheme in relation to the distribution of cadastral units/municipalities. Final MK-EC8 maps are given in Figure 1.4.

a) T_{DLR} = 95, P_{DLR}=10% in 10 years   b) T_{DLR} = 475, P_{DLR}=10% in 50 years
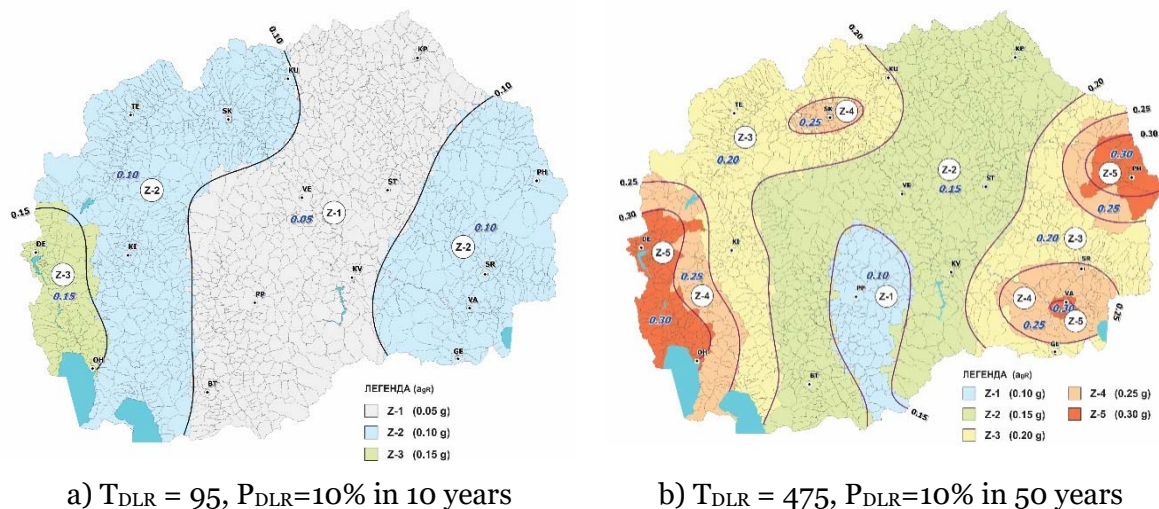
Fig. 1.4. МКС EN 1998-1/НА:2020Maps:
agR (g), ground type: A (Milutinovic et al., 2016)

1.1.2.   Albania

Based on the seismic design code in Albania (KTP-N2-89) used in design and still in power, the seismic hazard is defined in terms of seismic intensity (MSK-64). This map divides the territory into 3 zones of seismic intensity of 6, 7 and 8 (The map was proposed and approved with the DCM No. 371, date 20-12-1979). During 1984-1991, the seismic microzonation maps of the main cities and regions were completed (Fig. 1.5).
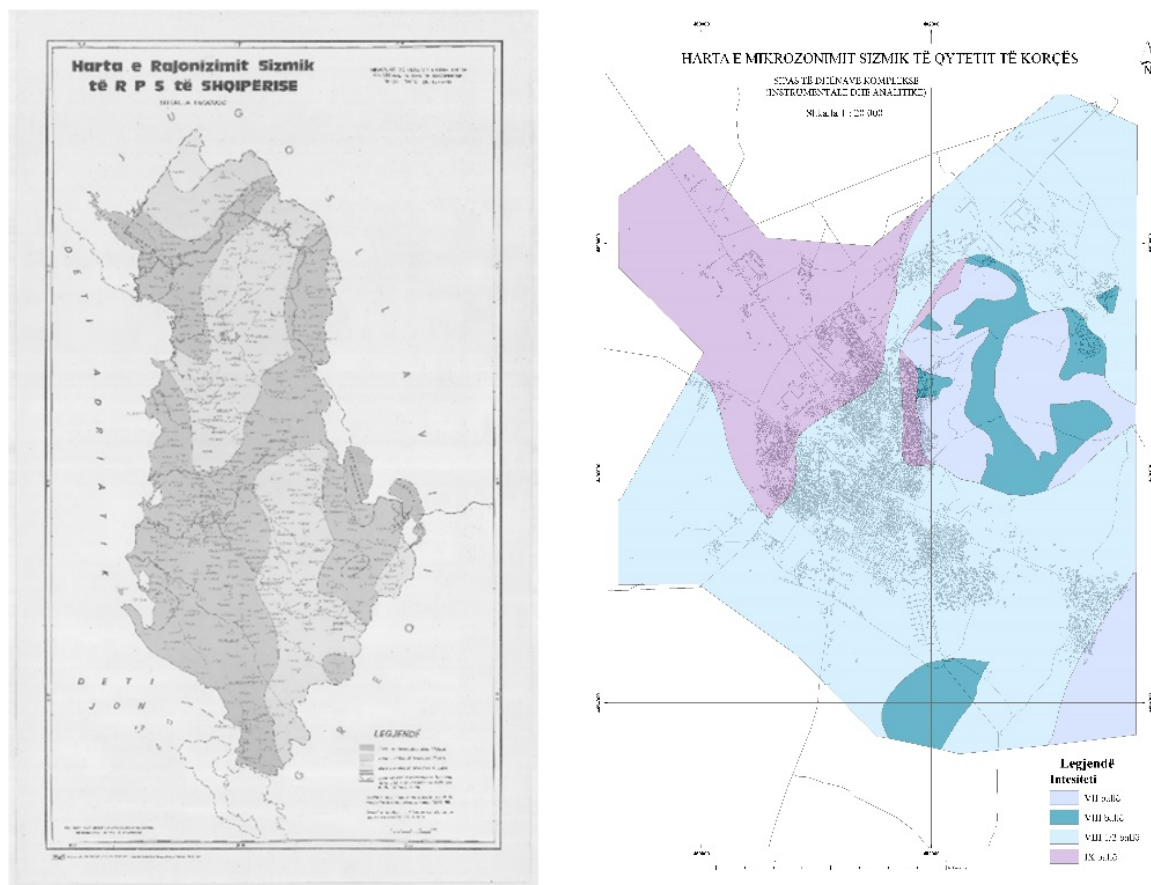
a) Seismic intensity map of Albania 1979　　　b) Seismic microzonation map of Korça

Fig. 1.5. Albania KTP-N2-89 seismic intensity maps

Since the in-power design code in Albania has not been updated since 1989, structural designers have started to use Eurocode in their design. The seismic hazard maps for Albania which are used in seismic design (when using Eurocodes) are three: a) the seismic hazard map proposed from the Academy of Science and accepted by the Faculty of Civil Engineering for the drafting of the National Annex of EN 1998-1 (Shyqyri Aliaj et. al.,2010), an updated version of the map of Sulstarova et al., 2005; b) the seismic hazard map proposed from IGEWE (Institute of GeoSciences, Energy, Water and Environment - https://geo.edu.al/newweb/?fq=brenda&gj=gj1&kid=44), an updated version of the map of Fundo et. al.,2012; and c) The seismic hazard map proposed from UNDP Project "Evaluation of risk in Albania", partially used for design until 2010. All three maps refer to a return period of 475 years (Fig. 1.6). The Academy of Science and IGEWE maps are in parallel use for the design of buildings.

Two of the abovementioned sources/studies (Academy of Science and IGEWE) also give in tabular form the seismic hazard for return periods of 95 and 475 year for each administrative unit.

The Academy of Sciences study also gives a map dividing Albania in two zones based on their surface-wave magnitude hazard (Figure 1.7).

For the sites located in the highlighted area EC8 Type 1 spectra shall be used, Type 2 spectra shall be used in the other areas. In sites located in a distance up to 2km from the border, it is recommended that both Types of spectra should be used. Also, in sites of ground type A or D, it is recommended that both Types of spectra should be used.

a)   b)   c)
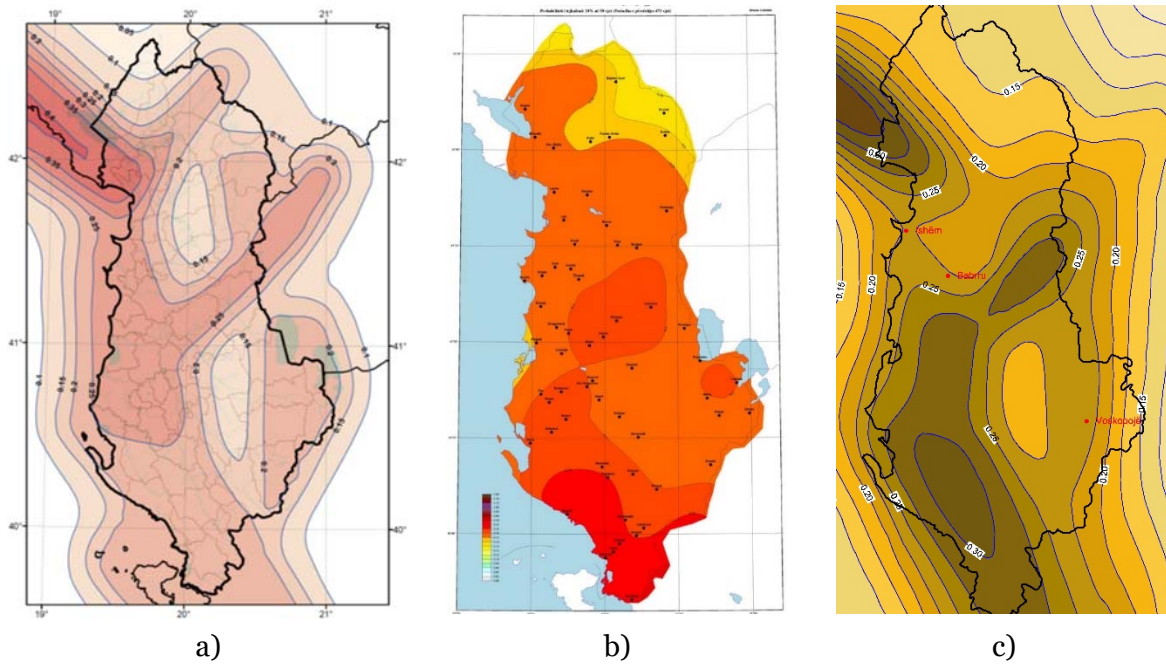
Fig. 1.6. Seismic hazard map for Albania for a return period equal to 475 years; a) Academy of Sciences map; b) IGEWE map; c) UNDP Project map.
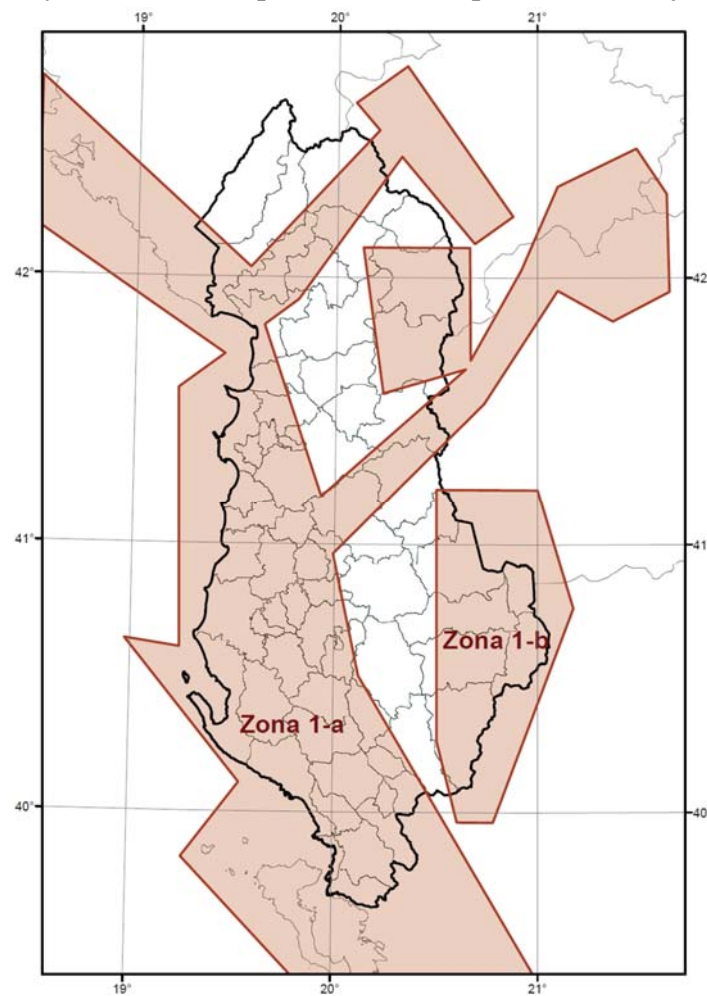
Fig. 1.7. Surface-wave magnitude hazard zonation

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1.1.3.   Greece

Based on the review on seismic hazard assessment in Greece by Tsapanos (2008), numerous studies were published between 1970 and 1980 on the spatial distribution of maximum observed intensity (Galanopoulos and Delibasis, 1972), maximum expected macroseismic intensity (Papaionannou, 1984), peak ground acceleration or velocity (among others Drakopoulos and Makropoulos, 1983; Papaioannou, 1984; Makropoulos and Burton, 1985).

A synthetic result of these publications was the separation of Greece in four zones, I, II, III and IV (Papazachos et al., 1985) of roughly equal hazard levels proposed by the four seismological research centers of Greece (University of Athens, Aristotle University of Thessaloniki, Geodynamic Institute of the National Observatory of Athens and Institute of Engineering Seismology and Earthquake Engineering-Thessaloniki) which was included in the New Seismic Code of Greece published in 1995 (NEAK, 1995). Each of the above-mentioned zones had equal seismic hazard parameters which were expressed in terms of the most probable maximum value of peak ground acceleration PGA as a function of the mean return period T_m. For return period of T_m = 475 years the calculated values of PGA (in g) for the four zones were: (1) for zone I = 0.12g, (2) for zone II = 0.16g, (3) for zone III = 0.24g and for zone IV = 0.36g. Figure 1.8, which was the official seismic hazard map of Greece until 2003, depicts the division of Greece in the four iso-acceleration zones I, II, III and IV.
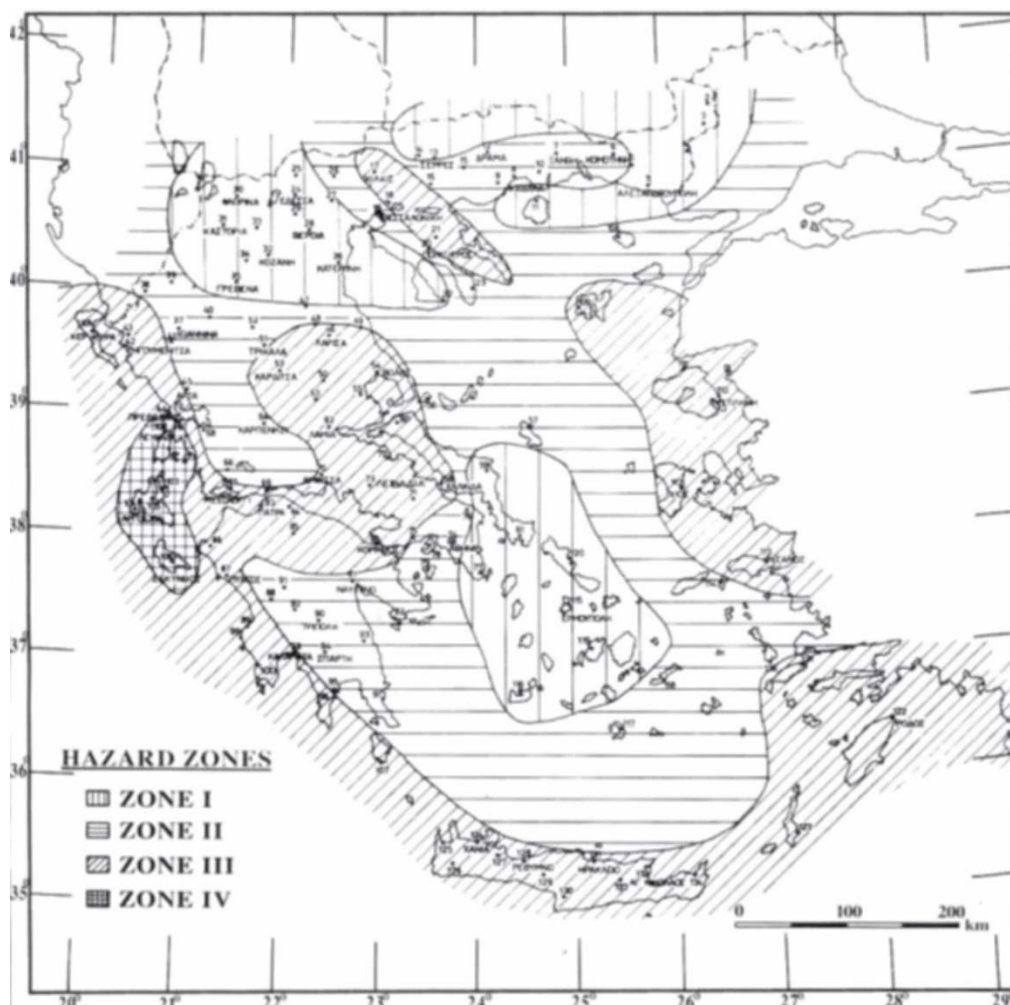
Fig. 1.8. Seismic hazard map for Greece for a return period equal to 475 years based on NEAK (1995)

The data obtained from the catastrophic earthquakes that occurred in Greece during the period 1986-2001, e.g. the Kozani-Grevena (1995, M=6.6), Aegio (1995, M = 6.4), Konitsa (1996, M = 5.7), Athens (1999, M = 5.9), Skyros (2001, M = 6.5) resulted in an update of the official seismic hazard map of Greece as of 1/1/2004 (EAK, 2003). The new map (Figure 1.9) has three zones instead of four. For return period of T_m = 475 years the values of PGA (in g) for the three zones are: (1) for zone I = 0.16g, (2) for zone II = 0.24g and (3) for zone III = 0.36g, i.e. the former areas with PGA values of 0.12g (zone I) were incorporated in the new zone I = 0.16g.

Some more recent studies on seismic hazard assessment for Greece are the works by Burton et al. (2003), Tsapanos (2004), Tselentis and Danciu (2010), Tselentis et al., (2010), while other works are focused on specific areas o Greece, such as Lesvos (e.g. Vavlas et al., 2019).

Fig. 1.9. Current official seismic hazard map for Greece for a return period equal to 475 years (EAK2003)

1.2.   Regional/European perspective

Target CBR is also covered by larger scale PSHA models (Regional, European, and Global).

A Regional model was produced in the framework of the BSHAP (Harmonization of Seismic Hazard Maps for the Western Balkan Countries) project, funded for seven years by NATO-Science for Peace (SfP) Program to support the preparation of new seismic hazard maps of the Western Balkan Region using modern scientific tools. It was divided in two sub-projects, namely BSHAP-1 (2011) and BSHAP-2 (2015), and involved institutions from Albania, Bosnia

and Hercegovina, Croatia, Macedonia, Montenegro, Serbia, Slovenia (as expert and data providing country) and Turkey.

The main outputs of BSHAP are probabilistic seismic hazard maps for Western Balkans, obtained by implementation of the smoothed-gridded seismicity approach. The results are expressed in terms of peak horizontal acceleration (PGA) for 95 and 475 years return periods (RP) aligned with Eurocode 8 requirements. They are shown in Figure 1.10.
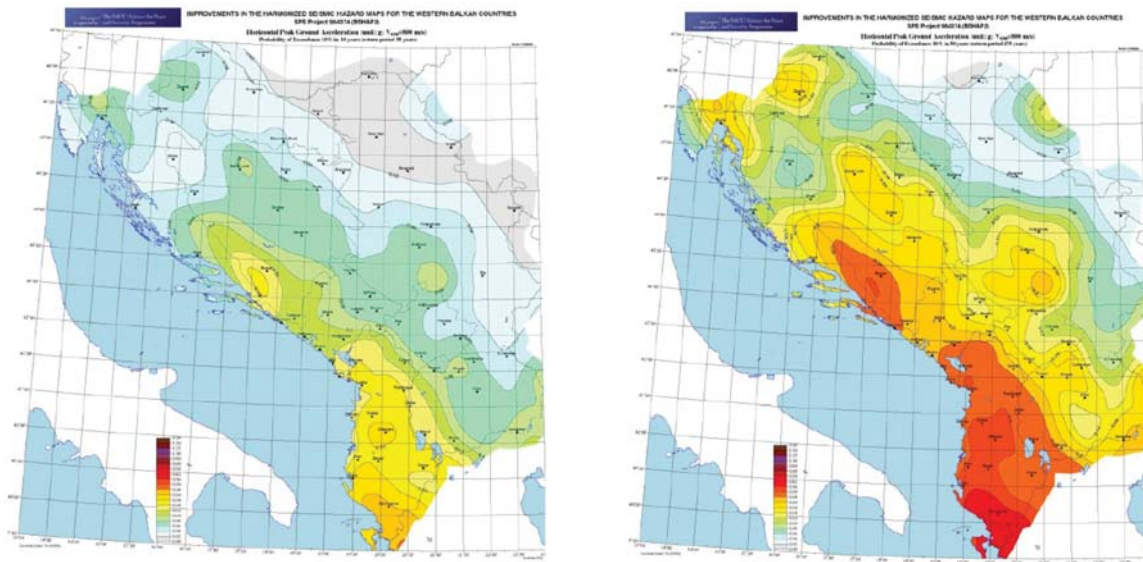
Figure 1.10. Seismic hazard maps (in terms of PGA) of Western Balkans produced in the framework of the BSHAP Project: (left) RP 95 years, (right) RP 475 years

At European level, the most updated model is represented by the ESHM13 (European Seismic Hazard Model), developed within the SHARE Project (Seismic Hazard Harmonization in Europe (www.share-eu.org, Giardini et al., 2014), founded by European Union under the Seventh Framework Programme for Research (FP7). ESHM13 is the result of a probabilistic seismic hazard assessment carried out for the Euro- Mediterranean region by 18 research institutions of 12 countries between 2009 and 2013. The model covers Europe and Turkey and is based on data compiled homogeneously across national borders. An overview of the ESHM13 model, data and results can be found in Woessner et al. (2015). The hazard results are provided for probabilities of exceedance in the range of 1 to 50% in 50 years (i.e. from 5000 to 73 years return period). The intensity measures adopted are PGA and Sa(T) for a range of vibration periods from 0.1 to 4 s. Mean, median and quantile results are freely accessible from the EFEHR website (http://www.efehr.org), for a grid of sites equally spaced with a 10 km resolution. The map expressed in terms of PGA with 10% probability of exceedance in 50 years is shown in Figure 1.11.

ESHM13 represents a community consensus hazard model for Europe, and it was the first contribution to the global mosaic of seismic hazard models compiled by Global Earthquake Model (GEM) Organization (www.globalquakemodel.org).

The ESHM13 is currently being updated in the framework of the SERA (Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe) H2020 EU Project. It will be released during the current year (2021).
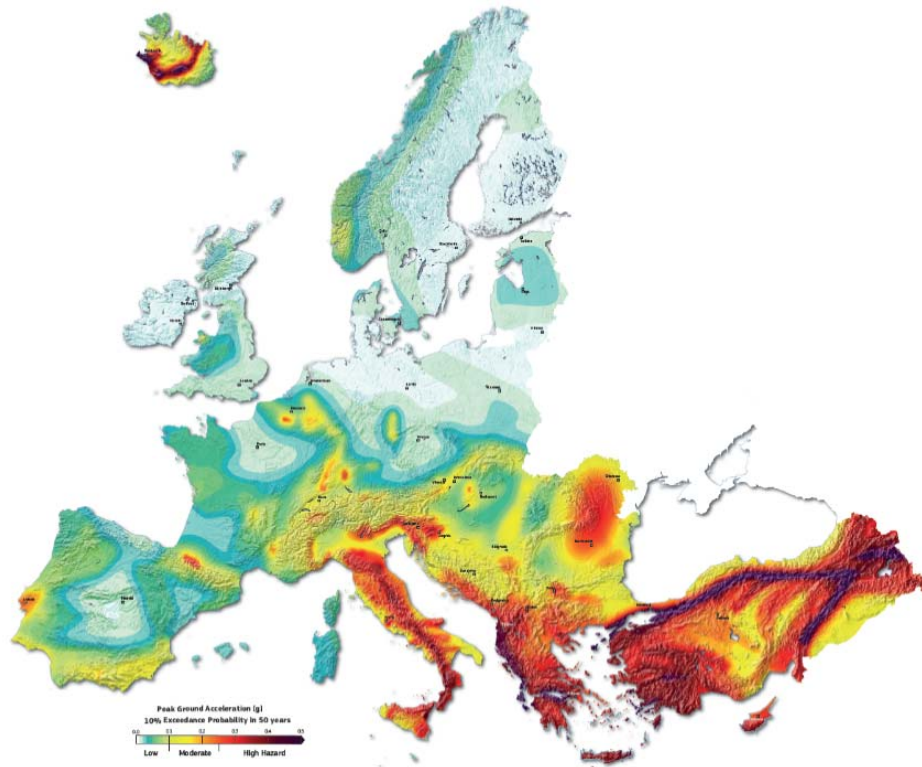
Figure 1.11. ESHM13 map in terms of PGA for RP 475 years

Even if not focused on the target area, it is worth mentioning the EMME14 model (Earthquake Model of the Middle East, Giardini et al., 2016), focused on the Middle East extending to the Afghan borders. It was developed within the EMME Project (Earthquake Model of the Middle East, www.emme-gem.org, Erdik et al., 2012) between 2010 and 2014, supported by the industry (JIT) for public safety against earthquakes. The model spans across region across eleven countries: Afghanistan, Armenia, Azerbaijan, Cyprus, Georgia, Iran, Jordan, Lebanon, Pakistan, Syria and Turkey. The results are freely accessible from the EFEHR website (http://www.efehr.org). The map expressed in terms of PGA with 10% probability of exceedance in 50 years is shown in Figure 1.12.
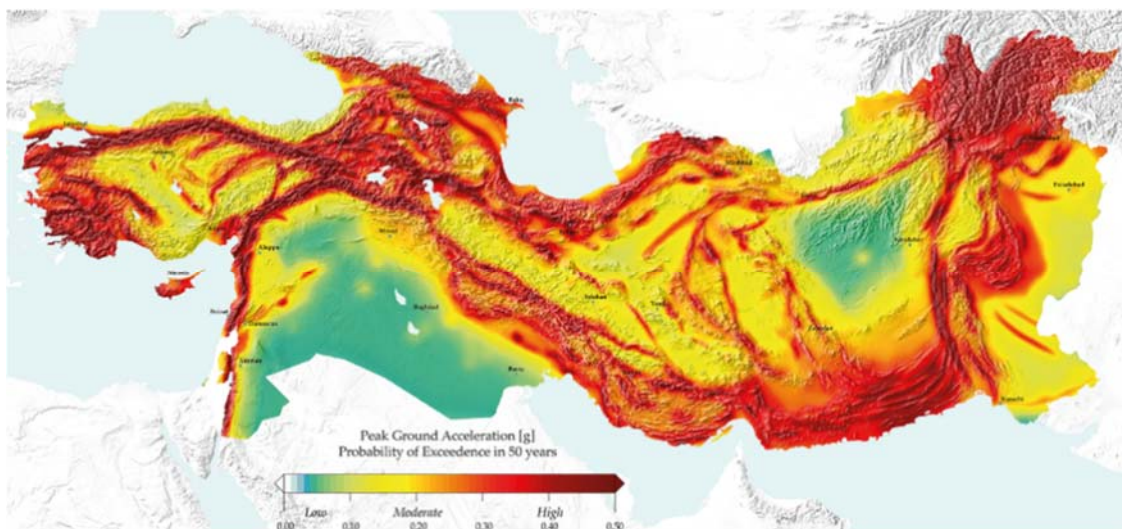
Figure 1.12. EMME map in terms of PGA for RP 475 years

SHARE and EMME projects started with a year of difference; SHARE being ahead, and they cooperated closely to exchange knowledge and expertise in different topics of regional probabilistic seismic hazard modeling. Turkish scientists actively involved in these projects for seismic source modeling, ground-motion characterization and hazard calculations as Turkey is the border country between the neighboring regions covered by SHARE and EMME.

At global scale, the first seismic hazard model is represented by the 2001 GSHAP (Global Seismic Hazard Assessment) Program (Giardini et al., 1999, http://static.seismo.ethz.ch/GSHAP/), whose primary goal was to create a global seismic hazard map in a harmonized and regionally coordinated fashion, based on advanced methods in PSHA.. The compilation of the Global Seismic Hazard Map was based on the integration of all results from GSHAP regions and test areas in three greater GSHAP areas: the Americas (Shedlock & Tanner, 1999), Asia, Australia and Oceania (Zhang et al., 1999; McCue, 1999), Europe, Africa and the Middle East (Grünthal et al., 1999) (Figure 1.13).
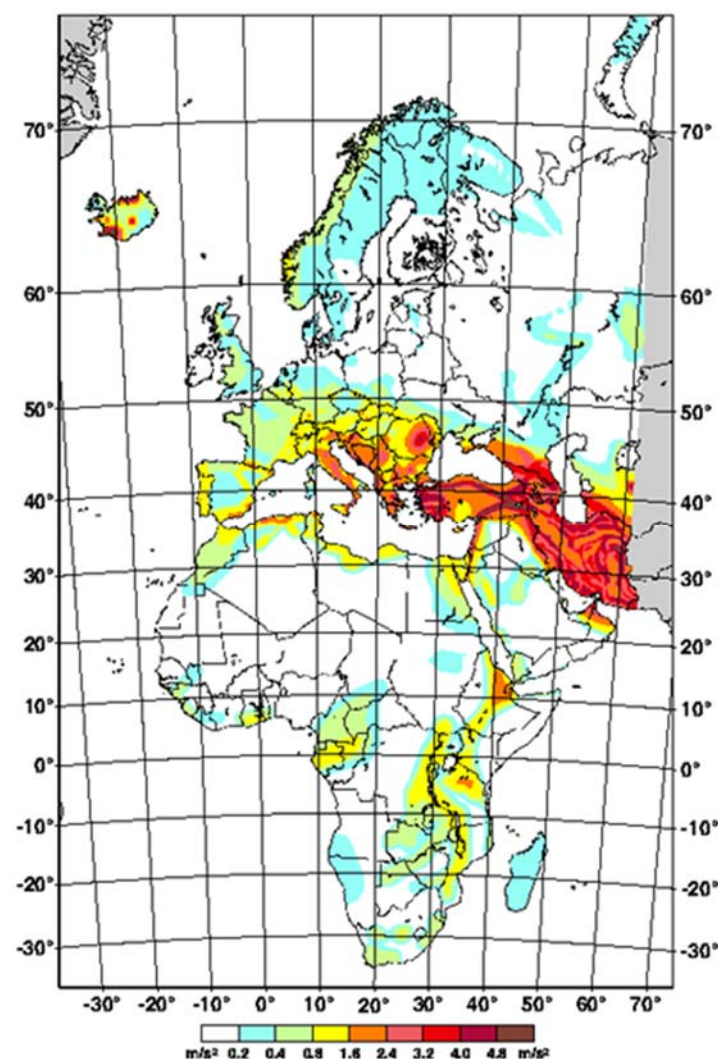
Figure 1.13. GSHAP map for Europe-Africa-Middle East in terms of PGA for RP 475 years

The output is a map depicting PGA with 10% probability of exceedance in 50 years (Giardini et al., 2003), which is given in **Error! Reference source not found.** and is also distributed by the EFEHR website (http://www.efehr.org).

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A more recent model at global scale was released by GEM (https://www.globalquakemodel.org/gem). The Global Seismic Hazard Map version 2018.1 (Pagani et al., 2018; Pagani et al., 2020) depicts the geographic distribution of PGA with a 10% probability of being exceeded in 50 years. It consists in a mosaic/collection of 30 national and regional seismic hazard models covering the entire globe and developed by various institutions, within collaborative projects, and by the GEM Foundation. For Europe, the ESHM13 model was adopted, while for Turkey, the more recent EMME model was selected.

2. Seismic Hazard Cross-Border Harmonization and Mapping

2.1. Rationales on seismic hazard model selection

Considering national official zonation, both Greece (since 2003) and North Macedonia (since 2018) have national annexes providing seismic zoning maps for Eurocode 8. For Albania, although Eurocode 8 is in parallel use, today two alternative maps exist (Fundo et. al., 2012 and Sulstarova et al., 2005). The mosaic of EC8 maps used for design in Greece, N. Macedonia and Albania is provided in Figure 2.1. None of those maps provides harmonized regional assessment. Considerable differences are evident especially at the Albania-N. Macedonia, as well as at the Albania-Greece border regions. Therefore, the ESHM13 model was ultimately used for CRISIS since it represents the most updated homogenized model covering all the three countries involved in it.
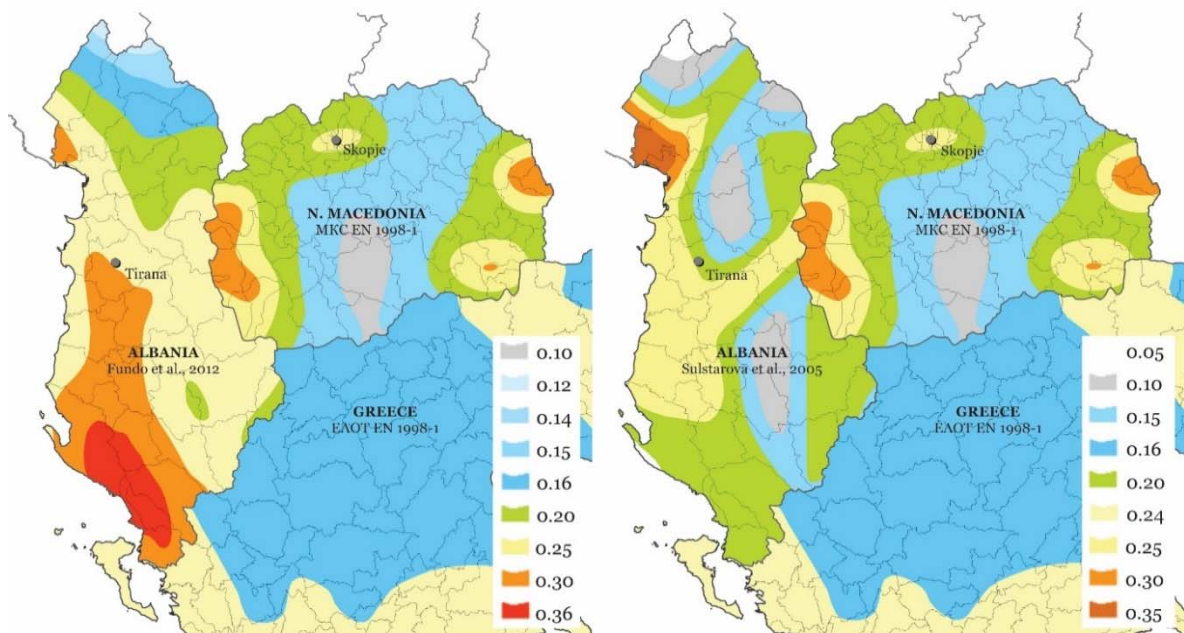
Fig. 2.1.EC8 maps used in design process for RP 475 years. The map on the left adopts the Fundo et. al. (2012) map for Albania, while the map on the right adopts the Sulstarova et al.(2005) map for Albania

EMSH13 is a probabilistic, time-independent seismic hazard model. It is based on three different earthquake source models that provide a different description of earthquake activity: a) an area source model; b) a smoothed seismicity model; and c) a fault and background sources model. For each of these source models, different methods were used to estimate the maximum magnitude. The model spans different tectonic environments (e.g. active shallow crust, subduction, volcanic), therefore different sets of Ground Motion Prediction Equations (GMPEs) suitable for each tectonic environment are used. The epistemic uncertainty of the earthquake source model, maximum magnitude and GMPEs is modelled through a logic tree

framework. Most of the source zones of the considered countries belong to the active shallow crust tectonic regime and adopt the corresponding GMPEs (i.e. the Akkar and Bommer, 2010; Cauzzi and Faccioli, 2008; Chiou and Youngs, 2008 and Zhao et al., 2006). For the subduction zones, the ESHM13 model selects the Youngs et al. (1997), Atkinson and Boore (2003), Zhao et al. (2006) and Lin and Lee (2008) GMPEs. The map in terms of PGA for RP 475 years focused on the three countries of interest is displayed in 2.4.

By comparing **Error! Reference source not found.** with **Error! Reference source not found.**, it can be seen that the ESHM13 results for N. Macedonia are higher in the West, while they are lower in the North-East. For Greece, characterized in Figure 2.1 dominated by the values of 0.16 and 0.24g value over all considered territory, ESHM13 values turned out to be from similar (in the north-central area) to larger. Also, for Albania, the pattern of ESHM13 hazard values is different from that shown in both maps of 2.1, with larger values associated to the ESHM13 map. Therefore, the ESHM13 map associated to RP 475 provides conservative estimates with respect to those of the EC8 maps used for design.

2.2.   Seismicity data

Seismicity data available from the historical and instrumental archives (ex. ESHM-SHEEC catalogue, Fig. 2.2), indicate that the target cross border region in the past was affected with strong damaging earthquakes, affecting population and material goods in the wider region.
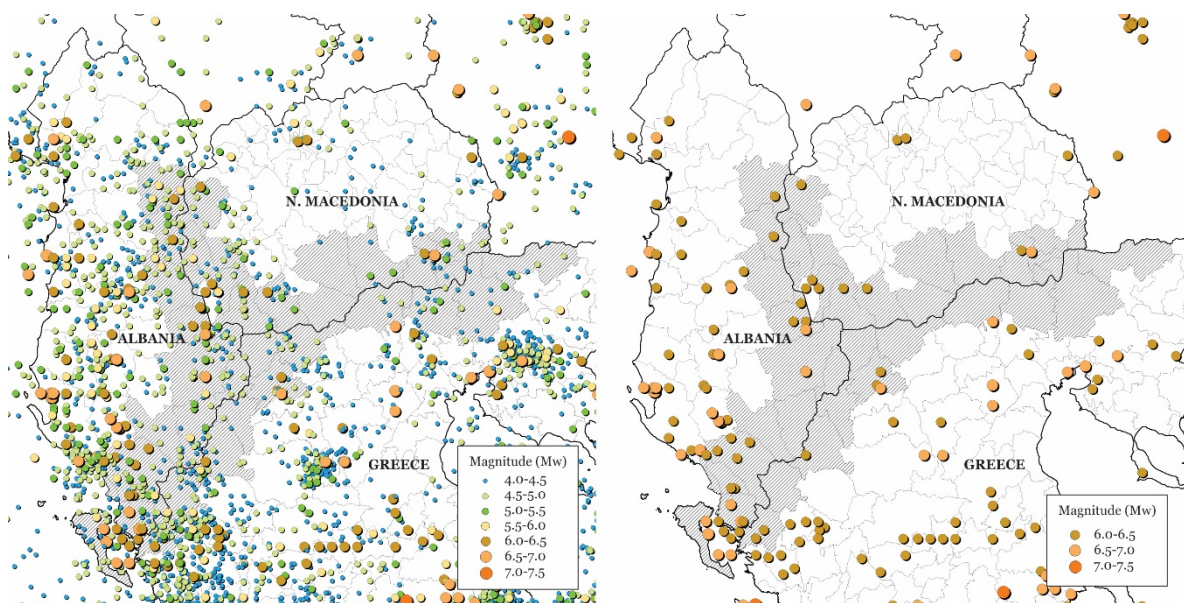
Fig. 2.2. ESHM13 (SHEEC) epicentral map (1000-2006)

The following zones can be extracted as most potential seismic hazard zones, supported by the seismicity data:

Ionian Coast – Strong earthquakes have been recorded in this region, such as: Year 358 – Ms=6.6; Year 1153 – Ms=6.6; April 16, 1601 – Ms=6.6; January 1, 1674 – Ms=6.6; April 5, 1701 – Ms=6.6; February 20, 1743 – Ms=7.0; December 10, 1813 – Ms=6.6; June 19, 1823 – Ms=6.6; January 19, 1833 – Ms=6.6; October 12, 1851 – Ms=6.6; January 2, 1866 – Ms=6.6; December 4, 1866 – Ms=6.6; February 11, 1872 – Ms=6.6; June 14, 1893 – Ms=6.6; November 26, 1920 – Ms=6.4. The future earthquakes may occur in the Ionian coastal fault zone with Mmax=7.0.

Kukësi-Peshkopi – Strong earthquakes have been generated in this region, such as: December 7, 1922 – Ms=5.7; March 30, 1921 – Ms=5.8; August 27, 1942 – Ms-6.0. The future earthquakes may occur in the Kukësi-Peshkopi zone with Mmax=6.5.

Ohrid-Korça - Strong earthquakes have been generated in this region, such as: Year 526 – I0=IX MSK-64; February 18, 1911 – Ms=6.7; December 22, 1919 – Ms=6.1; January 28, 1931 – Ms=5.8; May 26, 1960 – Ms=6.4. The future earthquakes may occur in the Ohrid-Korça zone with Mmax=6.9.

Elbasani-Debar-Tetovo - Strong earthquakes have been generated in this region, such as: Year 1380 – Ms=6.6; September 5, 1843 – Ms=6.3; August 16, 1907 – Ms=6.2; March 31, 1935 – Ms=5.7; March 12, 1960 – Ms=5.8; November 30, 1967 – Ms=6.6. The future earthquakes may occur in the Elbasani-Debar-Tetovo zone with Mmax=6.8.

Valandovo-Gevgelija - Strong earthquakes have been generated in this region, such as: Year 1931, Ms=6.7. The future earthquakes may occur in the Valandovo-Gevgelija zone with Mmax=6.9.

Due to the strong seismicity, CBR has experienced considerable human and material losses. The loss data related to the strongest earthquakes are systemized bellow.

Historical seismicity

Some descriptions of the strongest historical earthquakes are given here:
The earthquake of October 12, 1851 – Occurred in Vlora. According to the news of that time the number of casualties was about 200. Kanina village was heavily damaged. The intensity of this earthquake was IX degrees.

The earthquake of October 17, 1851 – Occurred in Berat. The fortress of the town was damaged and under its ruins 400 soldiers were buried. Cracks of the ground were observed together with fountains of sands and water mixed together, and a kind of a sulfur dust, which made the respiration difficult, was observed. The intensity of this earthquake was IX degrees.

The earthquakes of 1855 – Started in February in Shkodra and reached their peak at July and August. The strongest shocks destroyed the villages of Bushat, Juban, Kozmac, Vau-Dejes. The intensity of these earthquakes was VII÷VIII degrees.

The earthquake of October 10, 1865 – Hit the villages Izvor, Rabije (Tepelenë), Osmanzezë, Velçan (Berat and Klos (Fier)). In Rabije and Klos villages big destructions and human victims were observed (in Rabije 14 deaths and in Klos 13 deaths). The intensity of this earthquake was VIII degrees.

The earthquake of June 14, 1893 – Hit Himara and especially the village Kudhës which was totally destroyed. Majority of dwelling houses was destroyed in Kuç village. In the epicentral area all the buildings were destroyed. The intensity of this earthquake was VII degrees.

Instrumental Seismicity

The earthquake of 1905 (Shkodra earthquake) – The strongest shock occurred on June 1, 1905. The magnitude of this earthquake was determined as Ms=6.6. About 1500 dwelling houses were completely destroyed, all other buildings of this town were heavily damaged. The shock caused about 200 deaths and about 500 injuries.

The earthquake of February 18, 1911 – Occurred in the region of Ohrid Lake. The magnitude of this earthquake was Ms=6.7. The earthquake caused destruction of many houses in Pogradec town and villages Starova, Tushemisht, Zagorçan. There were a lot of human casualties.

The earthquake of December 22, 1919 – Occurred in the region of Leksovik (Albania) and Konica (Greece). The magnitude of this earthquake was Ms=6.1. In Leksovik many houses collapsed and all others were heavily damaged. In Greece the villages Isboros, Plavoli, Belthonsi and Kapaztiko were destroyed completely.

The earthquake of November 26, 1920 – Occurred in Tepelena. The magnitude of this earthquake was Ms=6.4. In Tepelena all houses were destroyed, except a wooden house. There were 36 deaths and 102 injuries.

The earthquakes of Durrës 1926 – The strongest shock was Ms=6.2, other strong shocks were Ms=5.8, Ms=4.6, Ms=4.2 and Ms=4.4. The majority of the houses were destroyed, the minarets of mosques fall down, an old gate of the fortress was destroyed completely. In Kavaja all houses were damaged. Despite the high intensity the number of human victims was rather small.

The earthquake of November 21, 1930 – Occurred in Llogara Pass of Çika mountain (Vlora). The magnitude of the earthquake was Ms=6.1. The earthquake caused 30 deaths and over 100 injuries.

The earthquake of March 8, 1931 - Occurred in Valandovo. The magnitude of the earthquake was Ms=6.7. In this earthquake lost their lives 31 people and 82 were injured. In total 45 towns suffers damages, out of which 29 with severe damages.

The earthquake of August 27, 1942 – Occurred in Peshkopia. The magnitude of the earthquake was Ms=6.0. More than 80% of the buildings were damaged in Peshkopia. The earthquake caused 44 deaths and 119 injuries.

The earthquake of September 1, 1959 – Hit the towns of Lushnja, Fier, Rrogozhina, Peqin, Kuçova and Berat, and the villages close to Kuçi bridge (Lushnja district). The magnitude of the earthquake was Ms=6.2. All dwelling houses in the villages of Karbunara (Lushnja) were damaged. In "Karbunara e Vogël" 32 houses collapsed, 44 houses suffered severe damage and 15 were slightly damaged. In "Karbunara e Madhe" 26 houses collapsed, 17 suffered severe damage and 23 were slightly damaged. In Lushnja 51 houses collapsed, 407 suffered severe damage and 235 were slightly damaged.

The earthquake of May 26, 1960 – Occurred in Korça. The magnitude of the earthquake was Ms=6.4. The earthquake caused 7 deaths and 127 injuries. In Korça 103 houses collapsed, 878 suffered heavy damage and 498 were slightly damaged.

The earthquake of March 18, 1962 – Occurred in Fier. The magnitude of the earthquake was Ms=6.0. The earthquake caused 5 deaths and 77 injuries. 1000 houses collapsed and 1700 were damaged.

The earthquake of November 30, 1967 – Occurred in the district of Librazhd and Dibra in Albania and in Western Macedonia. The magnitude of the earthquake was Ms=6.6. In the district of Dibra and Librazhd the earthquake caused 12 deaths and 174 injuries. 6336 houses were damaged: 5664 dwelling houses, 156 social-cultural objects (133 schools), 534 houses collapse, 1623 suffered heavy damage and 4179 suffered moderate damage.

The earthquake of April 15, 1979 – Occurred in the region of Montenegro. The magnitude of the earthquake was Ms=6.9. More than 100'000 inhabitants (mostly in the districts of Shkodra and Lezha) were left homeless. The earthquake caused 35 deaths and 382 injuries in Albania.

2.3.   Seismo-tectonic model

The ESHM13 model uses a logic-tree approach (e.g. Kulkarni et al., 1984) for seismic hazard assessment with three branching levels: (1) the earthquake source models, (2) the maximum magnitude, and (3) the ground motion models. Regarding the earthquake source models, three alternative earthquake source models are used in ESHM13, relying on different assumptions and providing a diverse description of the earthquake activity (Woessner et al., 2015):

1. An Area Source model (hereinafter AS-model) based on the definition of areal sources for which earthquake activity is defined individually. The ESHM13 AS-model is based on the latest national area source models and on the former Euro-Mediterranean model (Jimenez et al., 2001) that have been merged and harmonized at national borders (Arvidsson and Grünthal 2010). The final area model consists of 432 area sources. Activity rates were estimated using a Bayesian penalized maximum likelihood.
2. A kernel-smoothed, zonation-free stochastic earthquake rate model that considers SEIsmicity and accumulated FAult moment (hereinafter SEIFA-model). Activity rates are based on the frequency–magnitude distribution model of the SHARE European Earthquake Catalogue (SHEEC; Grünthal et al., 2013), while the spatial distribution of model rates depends on the density distributions of earthquakes and fault slip rates.
3. A Fault Source and BackGround model (hereinafter FSBG-model), based on the identification of large seismogenic sources using tectonic and geophysical evidence. Activity rates are based on documented fault slip-rates.

These earthquake source models (AS, FSBG, SEIFA) represent established approaches to model earthquake occurrences based on seismological, geological, tectonic and geodetic information, with a varying degree of importance represented in the source typologies (Figure 2.3). The three earthquake source models are characterized by alternative options to calculate and spatially distribute future seismic activity and were used to model crustal seismicity with depth ≤40 km, while the seismicity of subduction zones and of the Vrancea region was modelled separately.
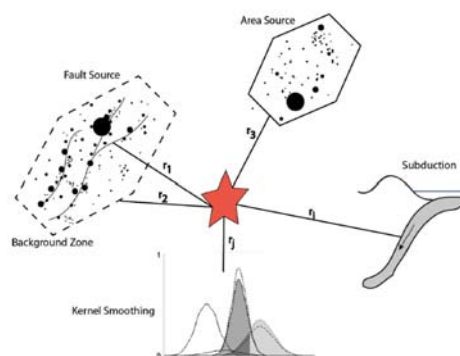
Fig. 2.3. Schematic illustration of the four contributing source typologies used in ESHM13: area sources with homogeneous distribution of rates; fault and background sources with $M_W{\geq}6.5$ constrained to occur on fault sources and $M_W{<}6.5$ events throughout the background zone; Kernel-smoothed model; and subduction zones model with seismicity on the interface modeled as complex fault, while in-slab seismicity is modeled as volumes at depth (Woessner et al., 2015).

The ESHM13 AS model and FSBG model for the wider area which includes the cross-border region are shown in Figure 2.4 and 2.5 respectively, while the main parameters for the area sources and faults shown in Figure 2.4 and 2.5 are included in Tables 2.1 and 2.2. The ID labels included in Tables 2.1 and 2.2 refer to the original ESHM13 databases and the reader can use these IDs to retrieve more information on the specific area sources and faults.

Fig. 2.4. ESHM13 seismo-tectonic model - Area Source Model
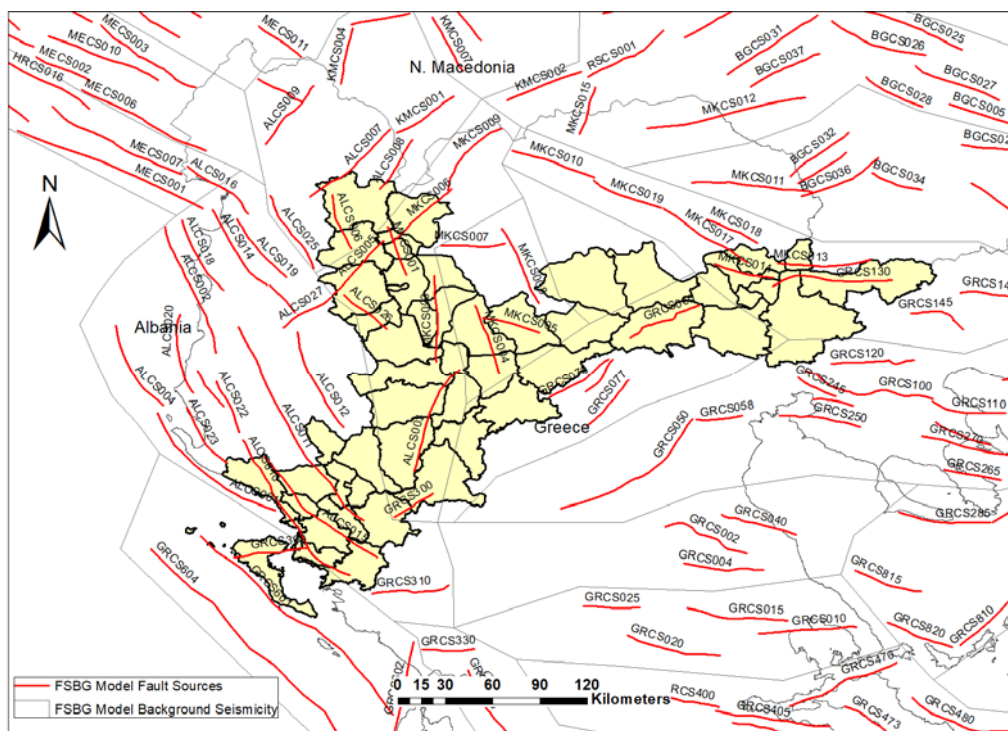
Fig. 2.5. ESHM13 seismo-tectonic model - FSBG model

Table 2.1. Main parameters for area sources of ESHM13 AS model shown in Figure 2.4, which affect the cross-border region.

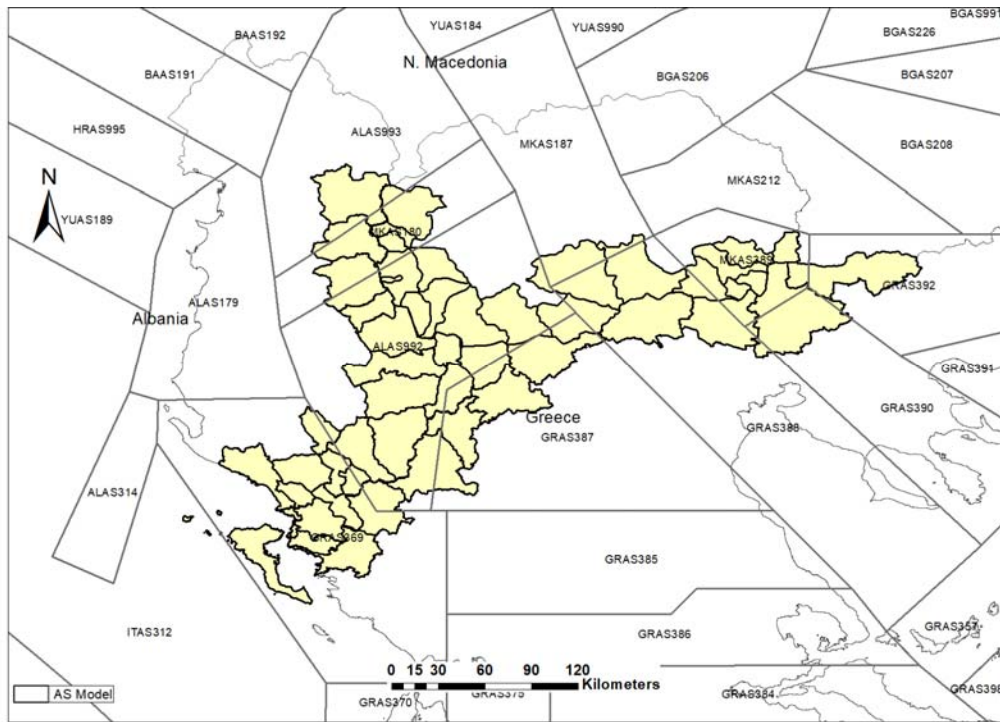| ESHM13 ID	Strike-Slip (%)	Normal faulting (%)	Thrust faulting (%)	max M	Min Depth (km)	Max Depth (km)
ALAS179	20	60	20	7.58	1	15
MKAS180	20	60	20	7.68	2	15
YUAS184	20	60	20	7.08	1	12
MKAS187	20	60	20	7.68	2	7
YUAS189	40	10	50	6.78	1	25
BAAS191	20	60	20	7.48	1	12
BAAS192	20	60	20	7.08	1	15
BGAS206	20	60	20	7.68	1	13
BGAS207	20	60	20	7.68	1	15
BGAS208	20	60	20	7.68	4	25
MKAS212	20	60	20	7.68	5	25
BGAS226	20	60	20	7.68	1	11
ITAS312	35	15	50	6.78	1	6
ALAS314	40	10	50	7.58	5	25
ITAS318	35	15	50	8.18	1	12
GRAS369	20	60	20	7.58	1	10
GRAS370	40	10	50	7.68	2	10
GRAS375	40	60	0	7.68	1	10
GRAS384	40	60	0	7.68	1	9
GRAS385	20	60	20	7.68	1	8
GRAS386	20	60	20	7.68	2	18
GRAS387	20	60	20	7.68	1	10
GRAS388	40	60	0	7.68	1	12
MKAS389	20	60	20	7.68	1	13
GRAS390	20	60	20	7.68	1	25
GRAS392	20	60	20	7.68	1	12
HRAS995	40	10	50	7.48	1	12
GRAS357	40	60	0	8.18	1	15
GRAS391	20	60	20	7.68	1	15
GRAS398	40	60	0	8.18	1	15
ALAS993	20	60	20	7.68	0	15
ALAS992	20	60	20	7.68	0	10

| BGAS991 | 20 | 60 | 20 | 7.08 | 0 | 15 |
| YUAS990 | 20 | 60 | 20 | 7.08 | 0 | 15 |

Table 2.2. Main parameters for faults of ESHM13 FSBG model shown in Figure 2.5, which affect the cross-border region.

ESHM13 ID	Fault type	Max M	Total Length (km)
ALCS001	RR	7.43	86.9
ALCS002	RR	7.38	84.2
ALCS003	NN	6.95	69.2
ALCS004	RR	6.78	57.1
ALCS005	RL	7.56	41.8
ALCS006	NN	6.82	35.6
ALCS007	NN	7.16	57.8
ALCS008	NN	6.81	35.1
ALCS009	NN	6.97	44
ALCS010	RR	7.57	102.9
ALCS011	RR	7.59	138.8
ALCS012	RR	7.09	65
ALCS014	RR	6.78	54.9
ALCS015	RR	7.46	85.8
ALCS016	RR	6.95	42.5
ALCS017	NN	6.6	26.1
ALCS018	RR	6.93	49.3
ALCS019	RR	6.97	44.2
ALCS020	RR	7.08	51.5
ALCS021	RR	6.6	26.3
ALCS022	RR	7.17	34.5
ALCS023	RR	6.92	41.3
ALCS025	NN	6.95	51.4
ALCS026	NN	6.81	30
ALCS027	RL	7.56	30.6
ALCS029	RR	7.08	21.1
BACS016	RR	6.99	45.4
BACS018	RR	7.12	55.3
BGCS005	NN	7.16	68.5
BGCS022	LL	6.96	46.7
BGCS025	NN	7.12	70.4

BGCS026	NN	6.82	50.1
BGCS027	NN	6.99	45.3
BGCS028	NN	6.78	32.9
BGCS029	NN	6.95	46.3
BGCS030	NN	6.97	43.8
BGCS031	NN	7.15	56.2
BGCS032	NN	6.89	39
BGCS033	NN	6.7	29.9
BGCS034	NN	6.6	26.6
BGCS035	NN	6.83	35.9
BGCS036	NN	6.97	44.6
BGCS037	NN	6.88	38.6
GRCS002	NN	6.95	46.9
GRCS004	NN	6.9	39.9
GRCS010	NN	7.04	48.5
GRCS015	NN	7.07	50.3
GRCS020	NN	7.05	48.1
GRCS025	NN	6.68	27.6
GRCS040	NN	6.88	38.7
GRCS050	NN	7.27	89.1
GRCS058	NN	6.75	22.5
GRCS060	NN	6.89	41.2
GRCS070	NN	6.86	38.2
GRCS072	NN	6.56	25.3
GRCS077	NN	6.82	35.5
GRCS100	NN	7.25	68.6
GRCS110	NN	6.83	36.9
GRCS120	NN	6.9	41.1
GRCS130	NN	7.15	59.3
GRCS140	NN	7.03	48.1
GRCS145	NN	6.72	31.1
GRCS155	NN	6.77	30.1
GRCS240	NN	6.89	20.3
GRCS245	NN	6.88	21.5
GRCS250	NN	7.16	40
GRCS260	NN	6.71	30.6

GRCS265	NN	6.71	28.5
GRCS270	NN	7.19	59.7
GRCS280	NN	7.14	87.4
GRCS285	NN	7	46
GRCS300	NN	6.64	24.2
GRCS310	LL	6.93	39.1
GRCS330	NN	6.6	26
GRCS350	LL	6.97	60.3
GRCS390	RL	6.77	36.9
GRCS400	NN	6.87	38.5
GRCS405	NN	7.04	57.7
GRCS410	NN	7	88.5
GRCS470	NN	6.94	60.4
GRCS473	NN	6.9	40.2
GRCS480	NN	7.01	95.5
GRCS601	RR	7.28	149.1
GRCS602	RL	7.25	73.5
GRCS604	RR	7.67	175.9
GRCS810	RL	7.62	143.1
GRCS815	NN	6.8	35.2
GRCS820	NN	6.82	35.9
GRCS835	LL	7.38	56.3
HRCS001	RR	7.28	131.2
HRCS016	RR	7.01	149.6
KMCS001	NN	7.14	35.6
KMCS002	NN	6.89	39.2
KMCS003	NN	6.65	28
KMCS004	RL	6.82	36.1
KMCS005	RL	6.6	27.6
KMCS007	RL	6.64	36.9
MECS001	RR	7.57	100.7
MECS002	RR	6.69	29.6
MECS003	RL	7.13	60.5
MECS005	RL	6.83	47.9
MECS006	RR	7.31	70.5
MECS007	RR	7.14	75.1

MECS008	RL	6.84	31
MECS010	RR	7.18	58.6
MECS011	RL	6.71	27.7
MECS014	RR	6.88	38.7
MKCS001	NN	6.75	32.3
MKCS003	NN	7.13	55
MKCS004	NN	6.99	45
MKCS005	NN	6.67	28.7
MKCS006	RL	7.56	44
MKCS007	NN	6.71	30.8
MKCS008	LL	6.76	50.5
MKCS009	NN	7.02	49
MKCS010	NN	6.95	42.5
MKCS011	NN	6.85	57.2
MKCS012	NN	7.07	77.3
MKCS013	NN	6.86	44.9
MKCS014	NN	6.67	29.1
MKCS015	RL	6.97	30.7
MKCS017	LL	6.65	52.7
MKCS018	LL	6.62	28.5
MKCS019	NN	6.84	37
RSCS001	NN	6.89	46.7
RSCS009	NN	6.89	44.3
NN – Normal Fault; RR – Reverse Fault; RL – Right Lateral Strike-Slip Fault			

2.4.   Results and Mapping

In this section we present the ESHM13 seismic hazard results for the cross-border region, in terms of hazard maps for different return periods, hazard curves and Uniform Hazard Spectra (UHS) for 475 years return period (RP), obtained from EFEHR portal (http://www.efehr.org/en/home/). The results presented herein refer to the ESHM13 mean hazard model and to rock site conditions ($V_{s,30}$=800 m/s).

Figures 2.6, 2.7 and 2.8 illustrate the spatial distribution of Peak Ground Acceleration (PGA) for the cross-border region, obtained from the ESHM13 mean hazard model, for return periods equal to 475 years (10% probability of exceedance in 50 years), 102 years (39% probability of exceedance in 50 years) and 975 years (5% probability of exceedance in 50 years), respectively, for rock site conditions.
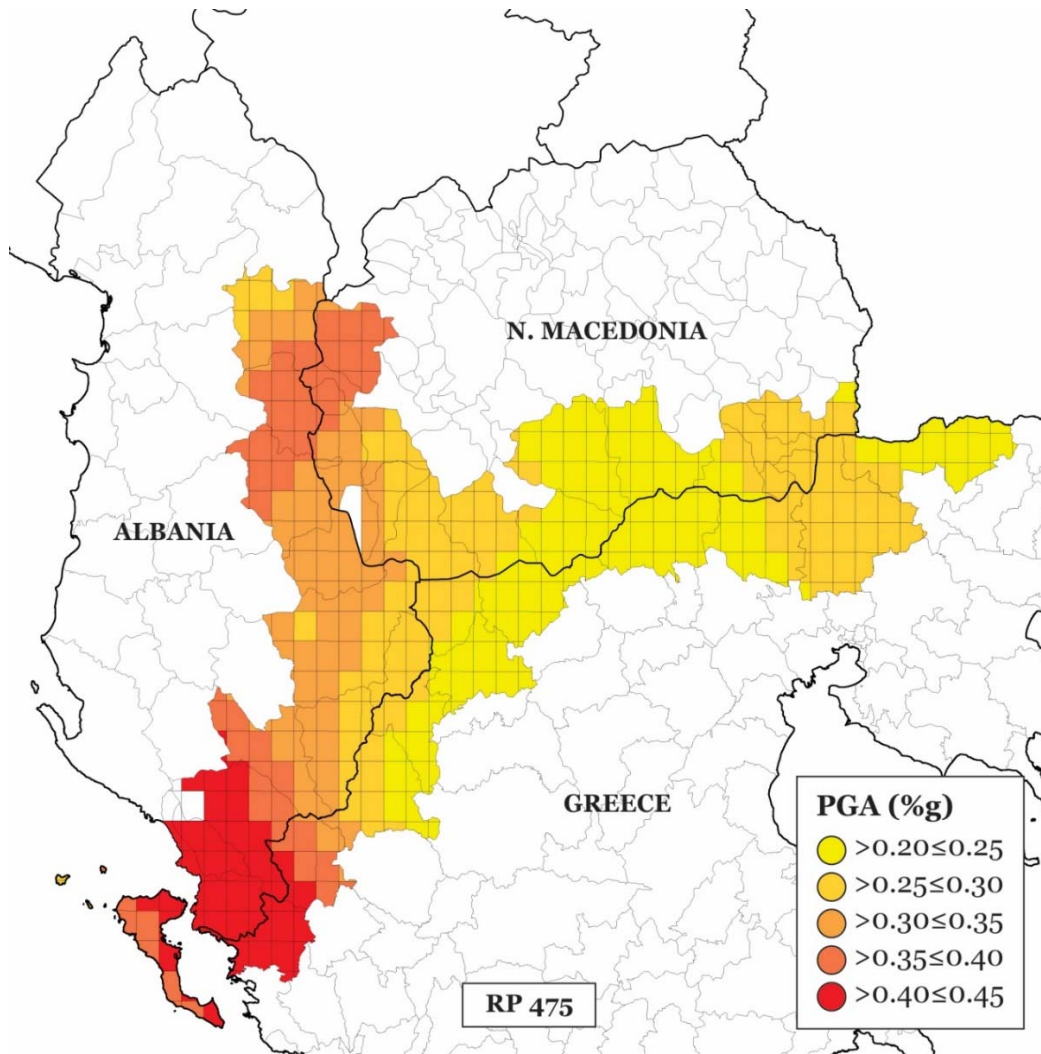
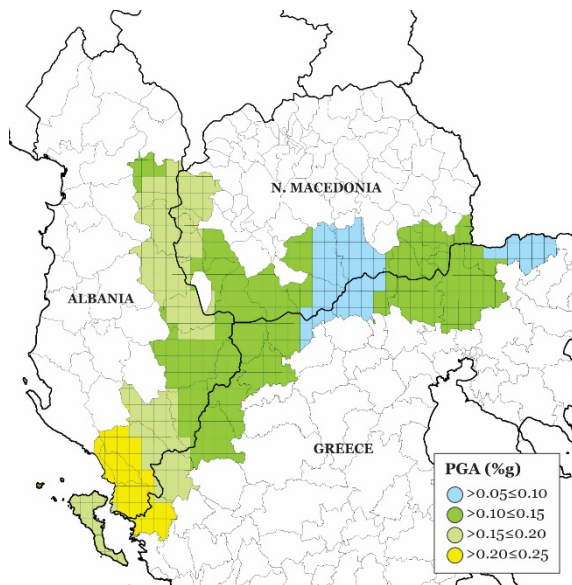Fig. 2.6. ESHM13 475 RP Map (Mean Hazard Model)

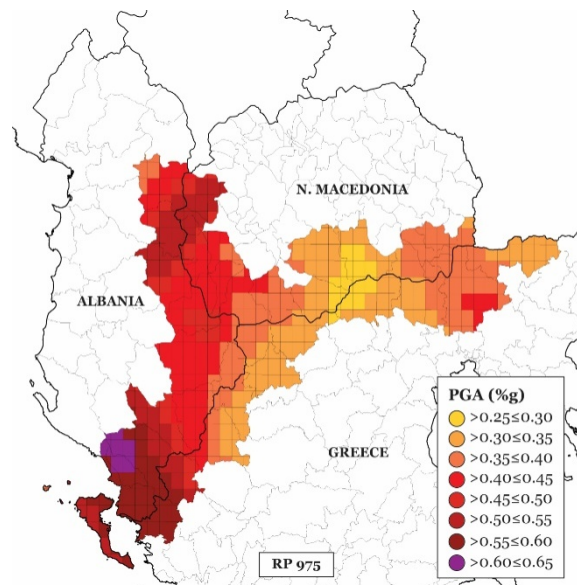Fig. 2.7. ESHM13 102 RP Map (Mean Hazard Model)

Fig. 2.8. ESHM13 975 RP Map (Mean Hazard Model)

PGA values for the main cities of the cross-border region (Figure 2.9) for mean return periods equal to 475 years and 975 years are summarized in Table 2.3.
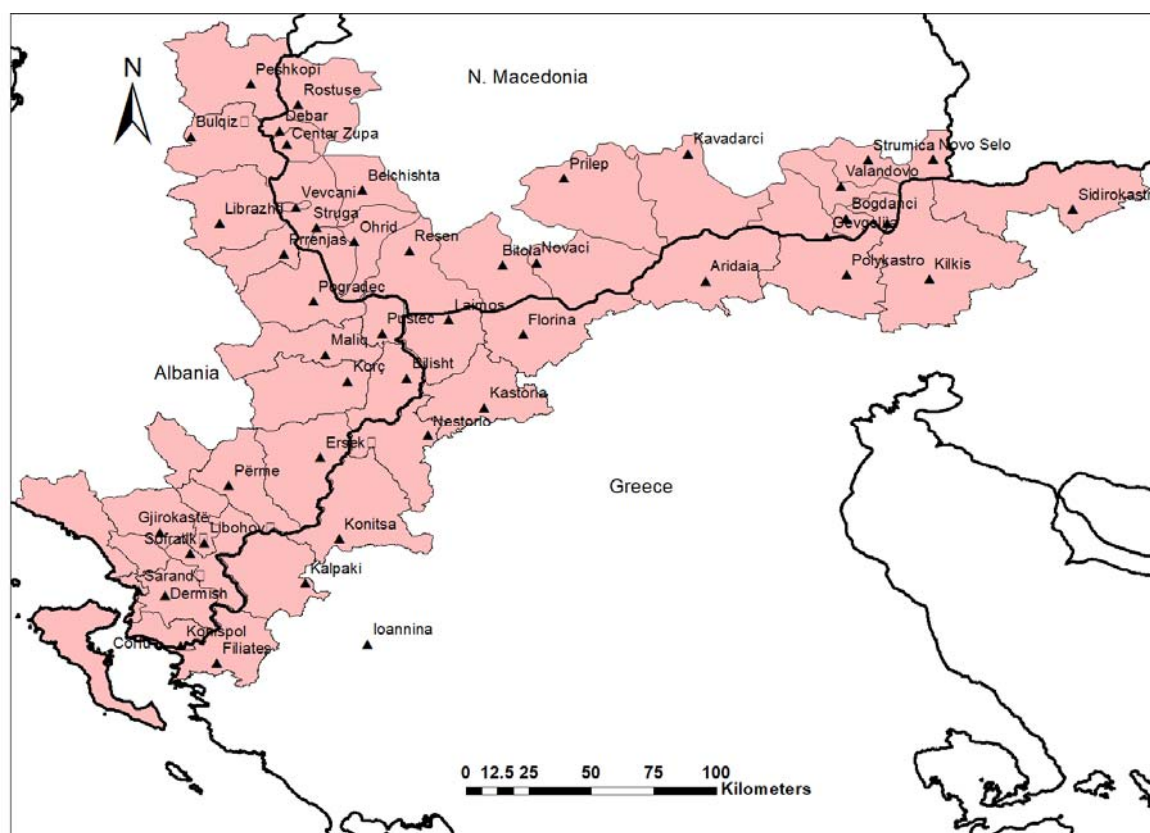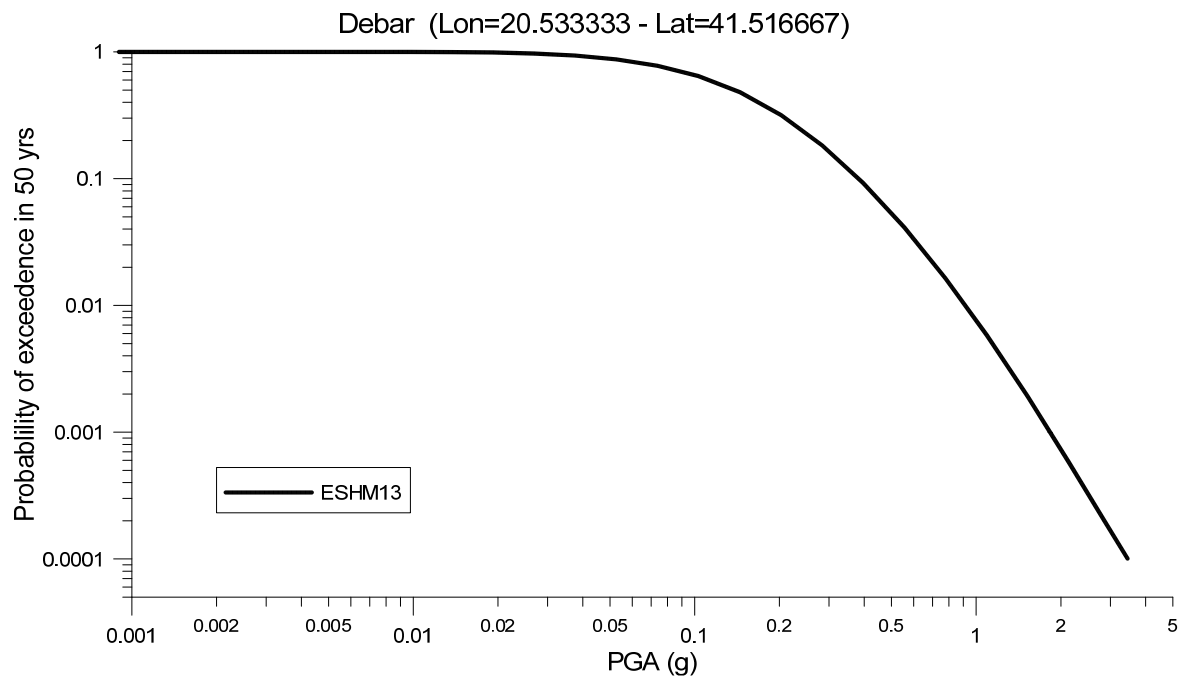

Fig. 2.9. Main cities in the cross-border region

Table 2.3. Peak Ground Acceleration (PGA) for rock site conditions at the main cities of the Greek cross-border region for mean return periods equal to 475 years and 975 years based on ESHM13
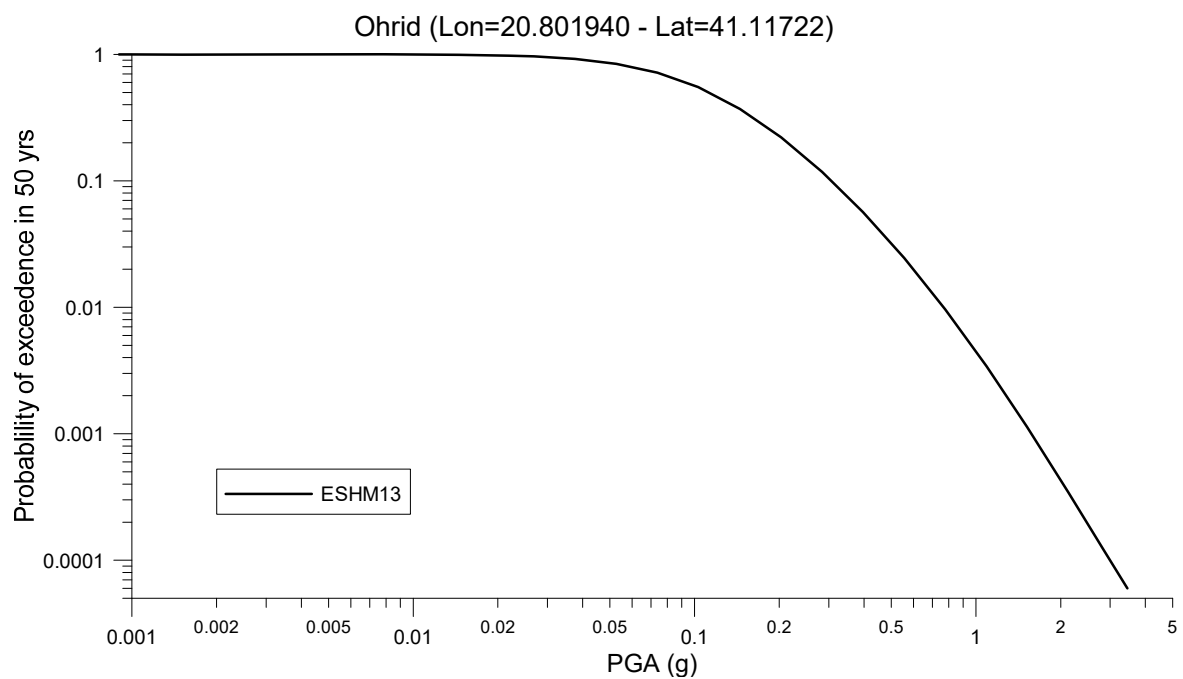
Country	Main city	Latitude (°)	Longitude (°)	PGA (g) T=475 years	PGA (g) T=975 years
N. Macedonia	Ohrid	20.80194	41.11722	0.30	0.42
N. Macedonia	Rostuse	20.6	41.61	0.38	0.52
N. Macedonia	Bogdanci	22.56667	41.2	0.26	0.38
N. Macedonia	Star Dojran	22.71667	41.18333	0.27	0.38
N. Macedonia	Bitola	21.33472	41.03194	0.26	0.37
N. Macedonia	Novaci	21.45583	41.04167	0.25	0.35
N. Macedonia	Vevcani	20.59306	41.24028	0.32	0.45
N. Macedonia	Kavadarci	22	41.43333	0.22	0.31
N. Macedonia	Valandovo	22.55	41.31667	0.27	0.38
N. Macedonia	Gevgelija	22.5	41.13333	0.25	0.35
N. Macedonia	Prilep	21.55556	41.34444	0.24	0.34
N. Macedonia	Debar	20.53333	41.51667	0.38	0.52

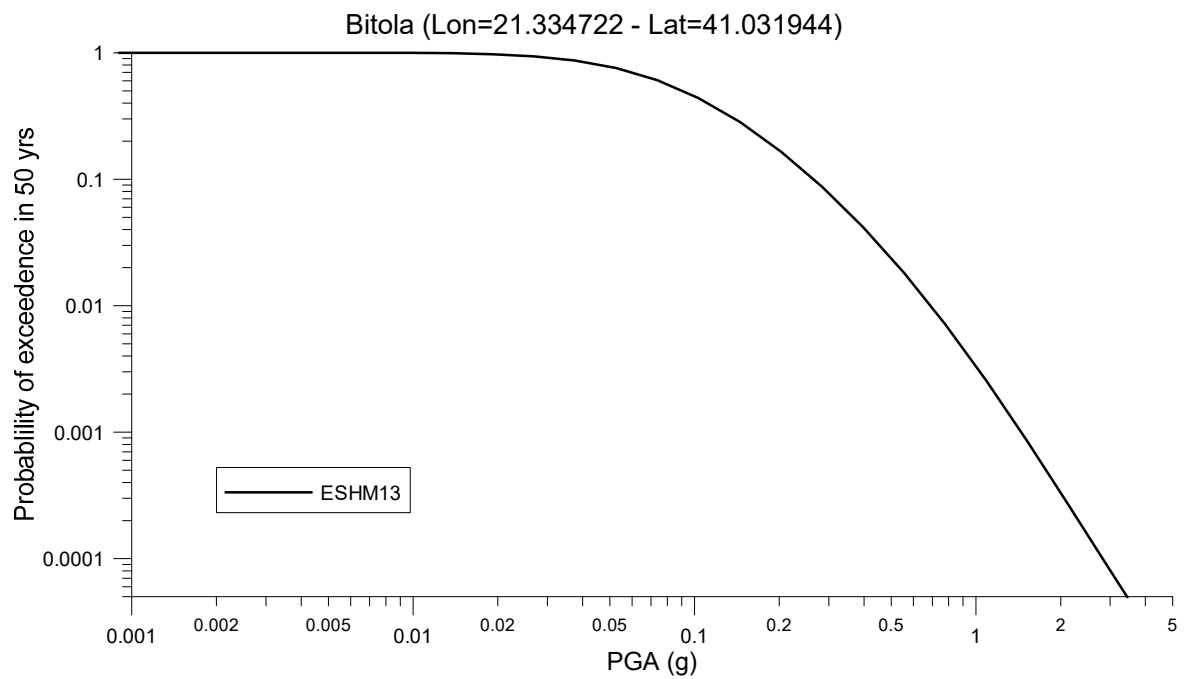| N. Macedonia	Centar Zupa	20.55889	41.46806	0.38	0.52
N. Macedonia	Strumica	22.64639	41.41111	0.27	0.38
N. Macedonia	Resen	21	41.08333	0.29	0.40
N. Macedonia	Belchishta	20.83028	41.30278	0.30	0.41
N. Macedonia	Struga	20.66667	41.16667	0.31	0.43
N. Macedonia	Novo Selo	22.88083	41.41389	0.25	0.36
Greece	Filiates	39.599997	20.30912	0.43	0.57
Greece	Konitsa	40.045556	20.74889	0.28	0.39
Greece	Kalpaki	39.886111	20.62611	0.36	0.50
Greece	Florina	40.7824	21.4089	0.24	0.33
Greece	Kastoria	40.518131	21.26876	0.23	0.33
Greece	Nestorio	40.4167	21.0667	0.23	0.33
Greece	Laimos	40.836389	21.14056	0.25	0.36
Greece	Aridaia	40.975278	22.06278	0.21	0.30
Greece	Kilkis	40.9833	22.8667	0.28	0.40
Greece	Polykastro	40.997881	22.5709	0.25	0.36
Greece	Sidirokastro	41.233333	23.38333	0.24	0.34
Greece	Corfu	39.616667	19.91667	0.41	0.55
Greece	Ioannina	39.666667	20.85	0.34	0.48
Albania	Dermish	20.122	39.8425	0.43	0.58
Albania	Korçë	20.7778	40.6141	0.29	0.40
Albania	Konispol	20.179	39.6611	0.43	0.58
Albania	Gjirokastër	20.1045	40.0673	0.44	0.60
Albania	Ersekë	20.6795	40.3373	0.29	0.41
Albania	Librazhd	20.3175	41.1829	0.38	0.52
Albania	Pustec	20.9015	40.7863	0.30	0.41
Albania	Peshkopi	20.4292	41.6849	0.33	0.44
Albania	Maliq	20.6973	40.7094	0.31	0.42
Albania	Pogradec	20.6556	40.9015	0.34	0.47
Albania	Sofratikë	20.2132	39.9922	0.44	0.59
Albania	Prrenjas	20.5484	41.0715	0.31	0.43
Albania	Bulqizë	20.2147	41.4943	0.33	0.44
Albania	Sarandë	20.0271	39.8592	0.44	0.59
Albania	Libohovë	20.2624	40.0313	0.42	0.57
Albania	Bilisht	20.9894	40.6252	0.26	0.37
Albania	Përmet	20.3517	40.2362	0.36	0.50

In the following we present the ESHM13 hazard curves for PGA (Figures 2.10 – 2.12) and Uniform Hazard Spectra (UHS) for 475 years RP (Figures 2.13-2.15) for the most important cities of the cross-border region.
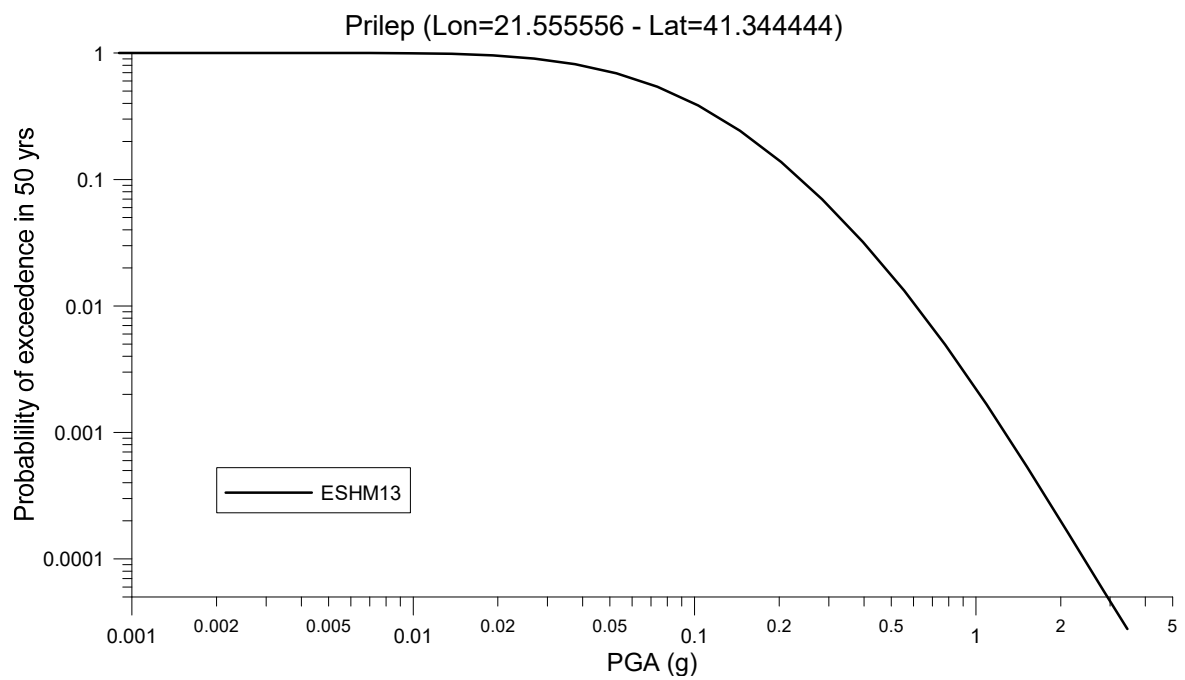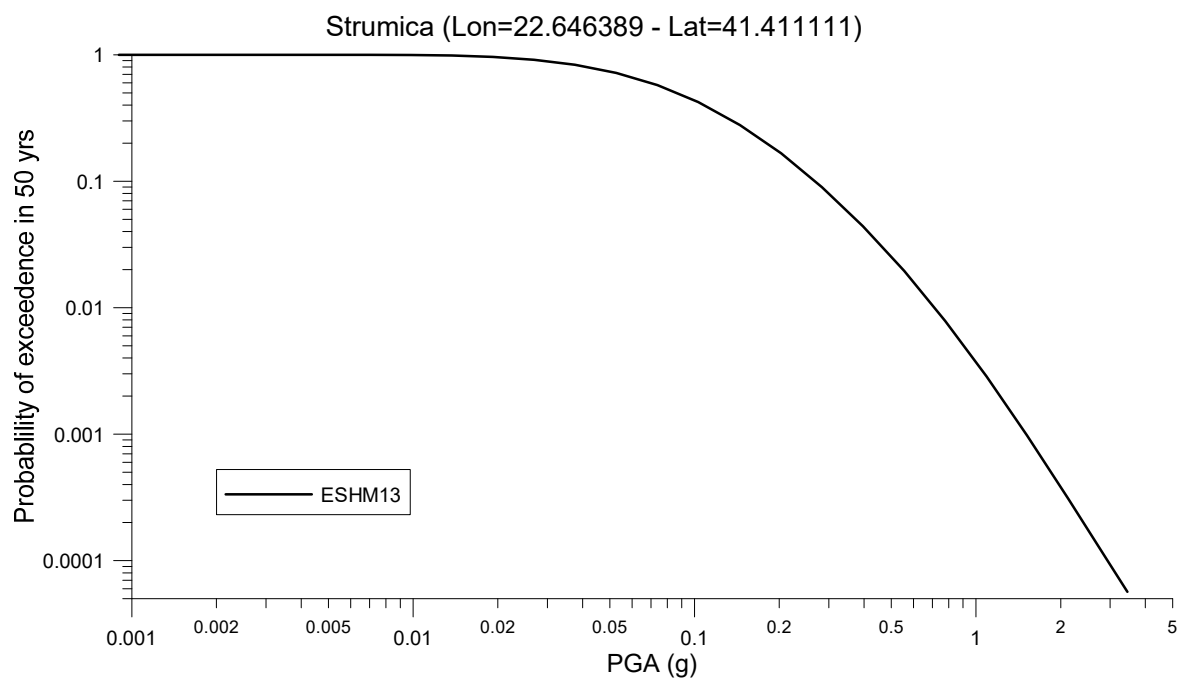

a) Hazard Curve for Debar (MKD)

b) Hazard Curve for Ohrid (MKD)

Bitola (Lon=21.334722 - Lat=41.031944)
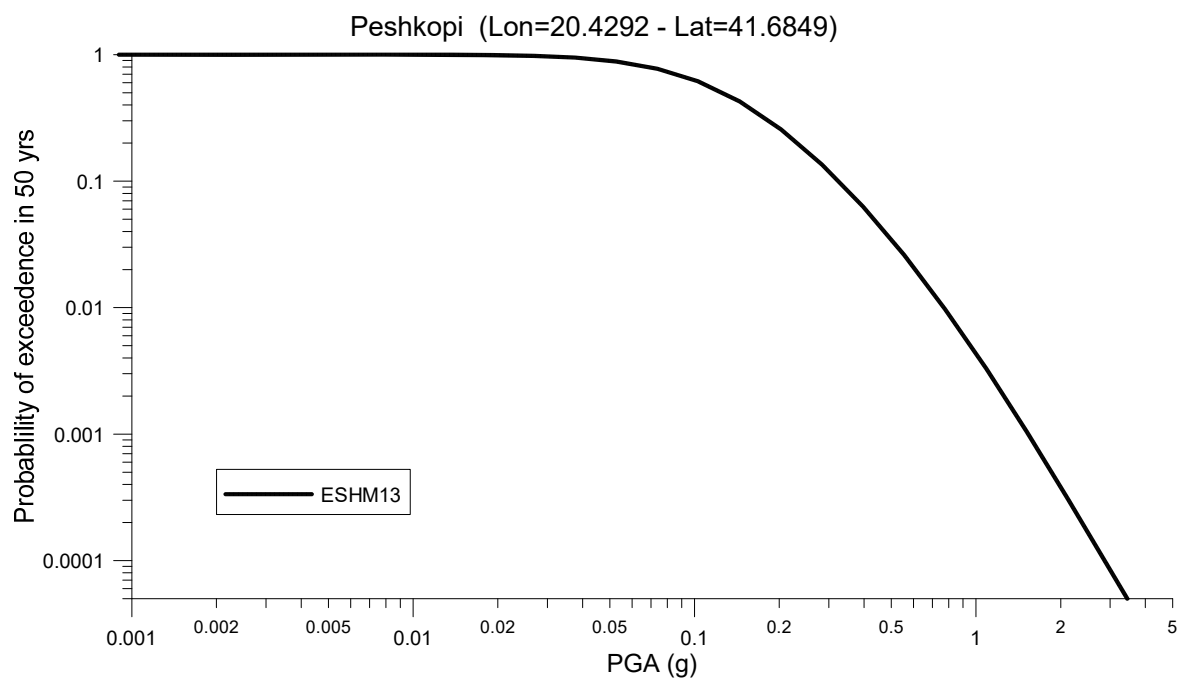

c) Hazard Curve for Bitola (MKD)

Prilep (Lon=21.555556 - Lat=41.344444)

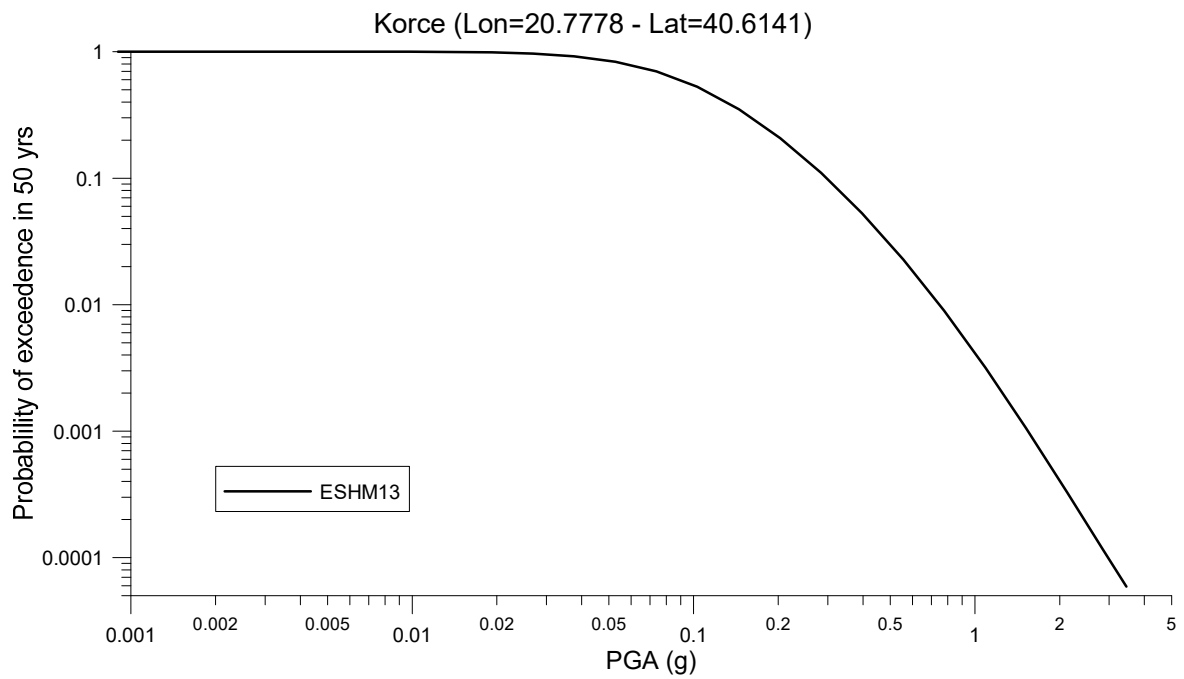d) Hazard Curve for Prilep (MKD)

Strumica (Lon=22.646389 - Lat=41.411111)

e) Hazard Curve for Strumica (MKD)

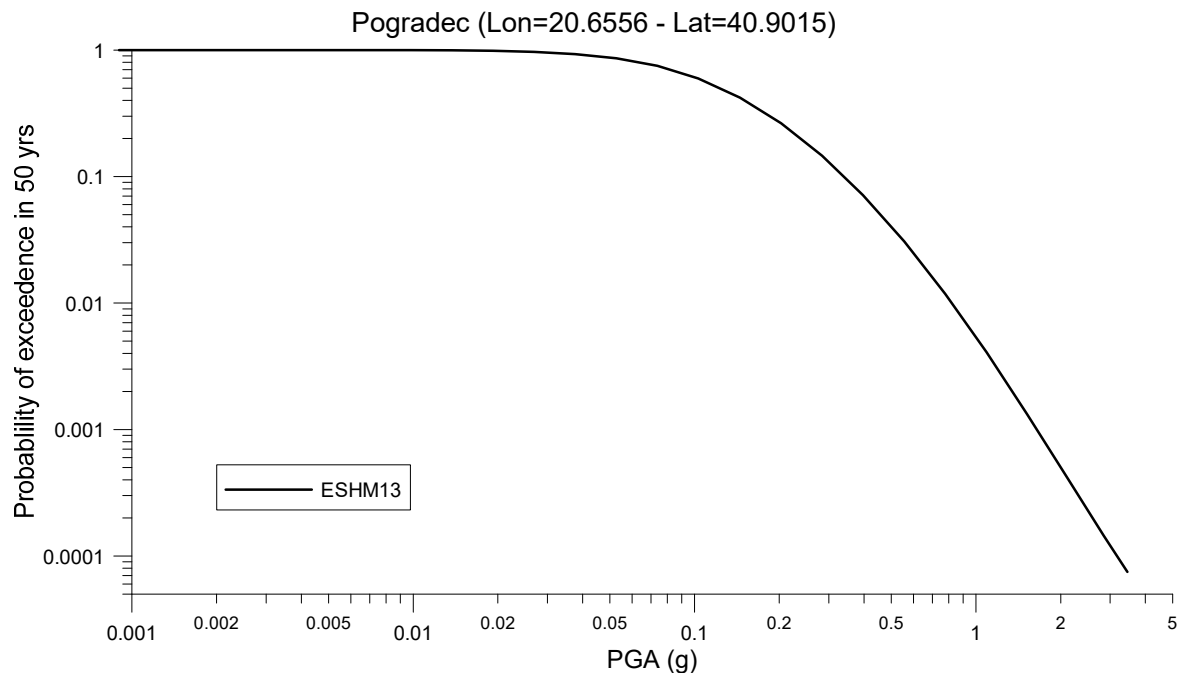Figure 2.10. ESHM13 hazard curves for selected cities of the cross-border region in N. Macedonia
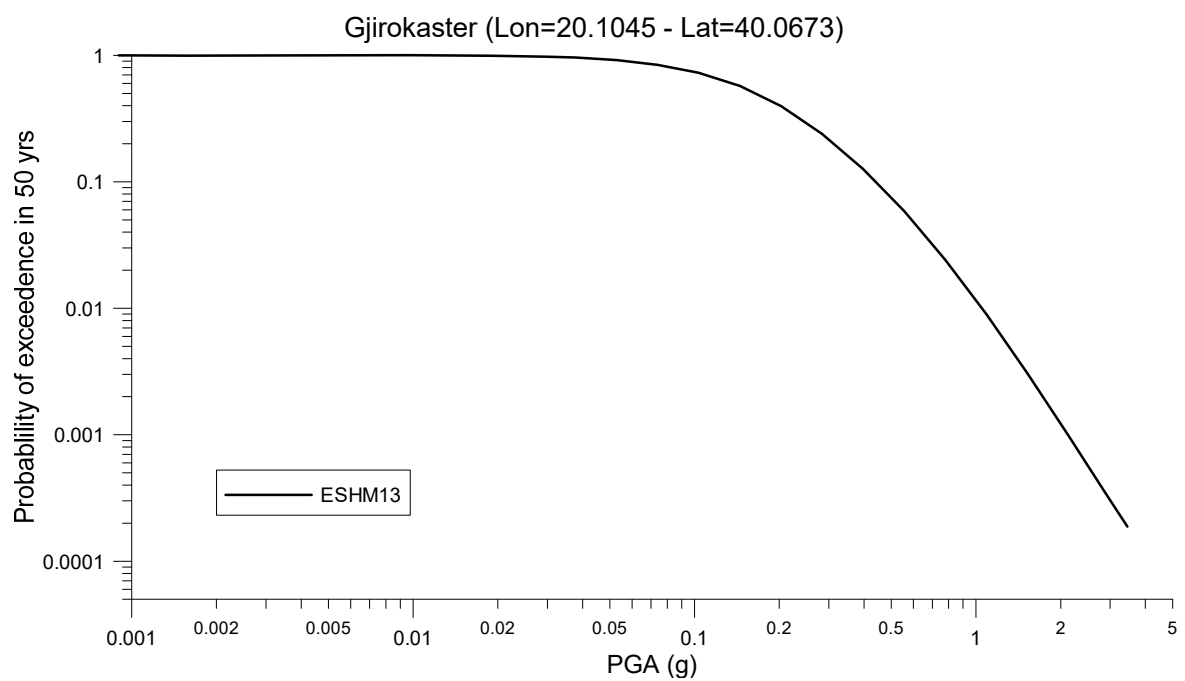
Peshkopi (Lon=20.4292 - Lat=41.6849)

a) Hazard Curve for Peshkopi (ALB)

Korce (Lon=20.7778 - Lat=40.6141)
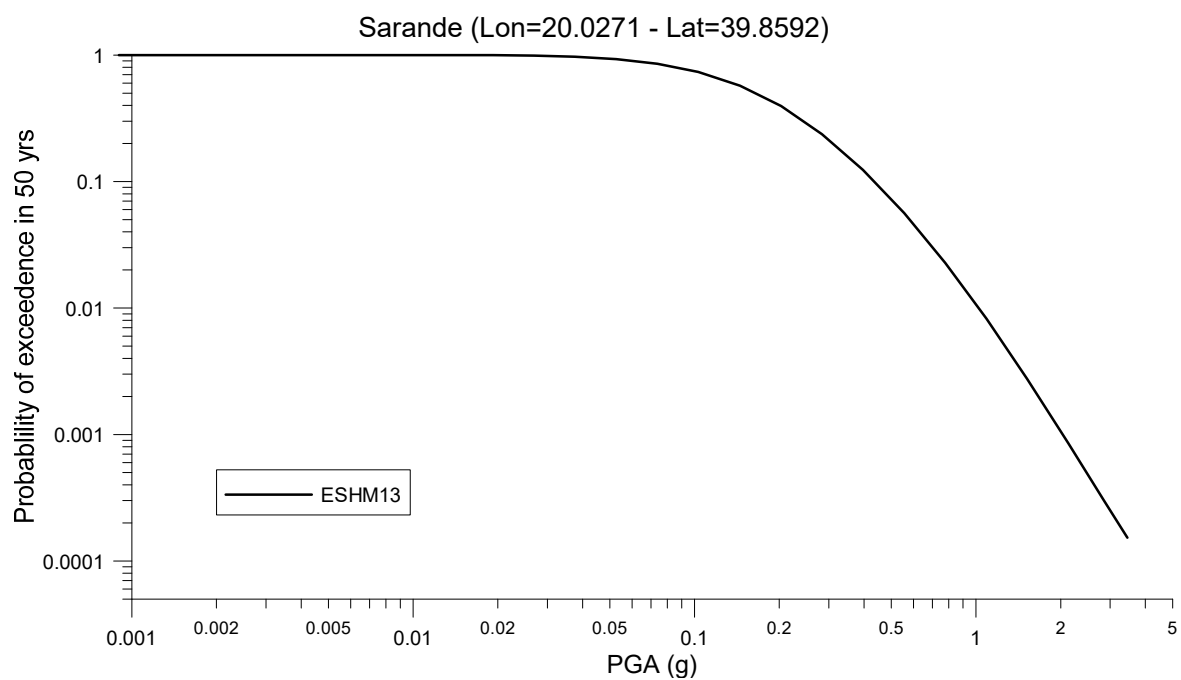

b) Hazard Curve for Korce (ALB)

Permet (Lon=20.3517 - Lat=40.2362)
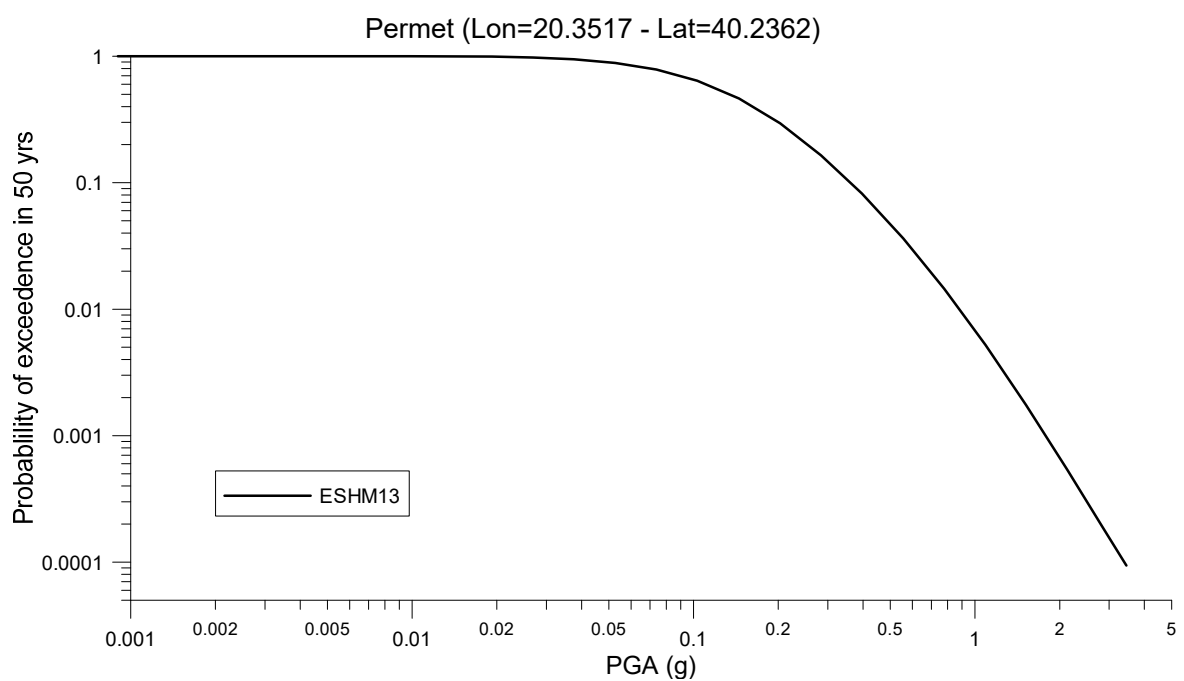
c) Hazard Curve for Permet (ALB)

d) Hazard Curve for Pogradec (ALB)

e) Hazard Curve for Gjirokaster (ALB)

Sarande (Lon=20.0271 - Lat=39.8592)

f) Hazard Curve for Sarande (ALB)

Fig. 2.11. ESHM13 hazard curves for selected cities of the cross-border region in Albania

Florina (Lon=21.4089 - Lat=40.7824)

a) Hazard Curve for Florina (GRC)

b) Hazard Curve for Kastoria (GRC)
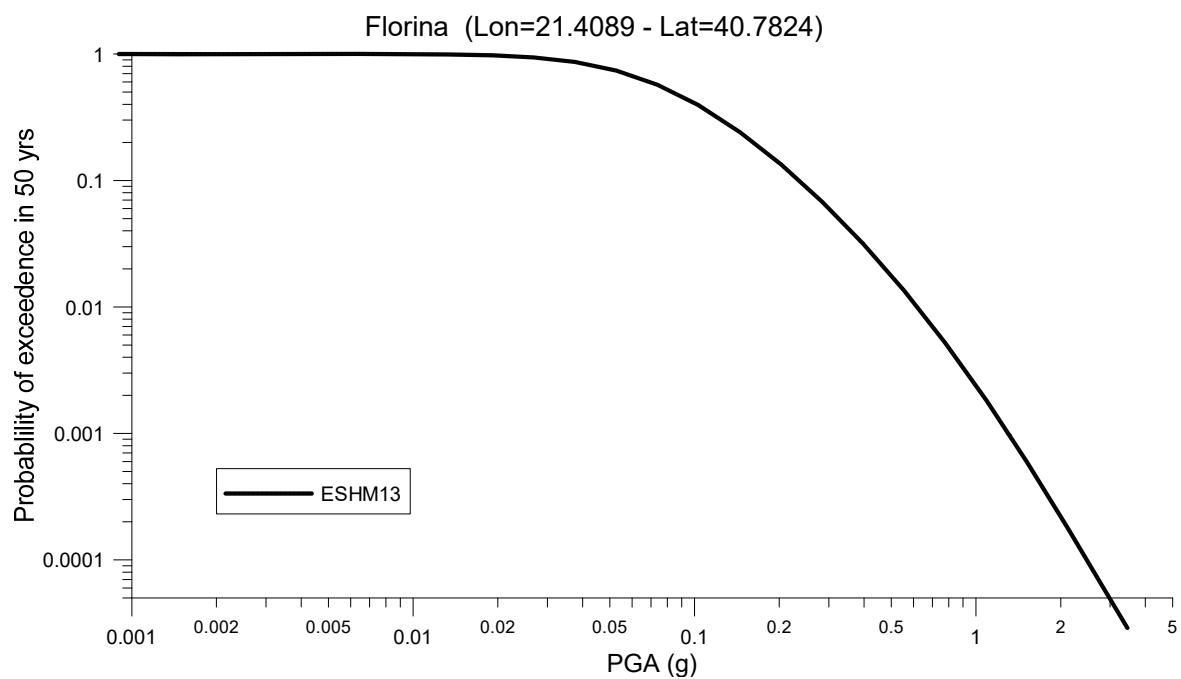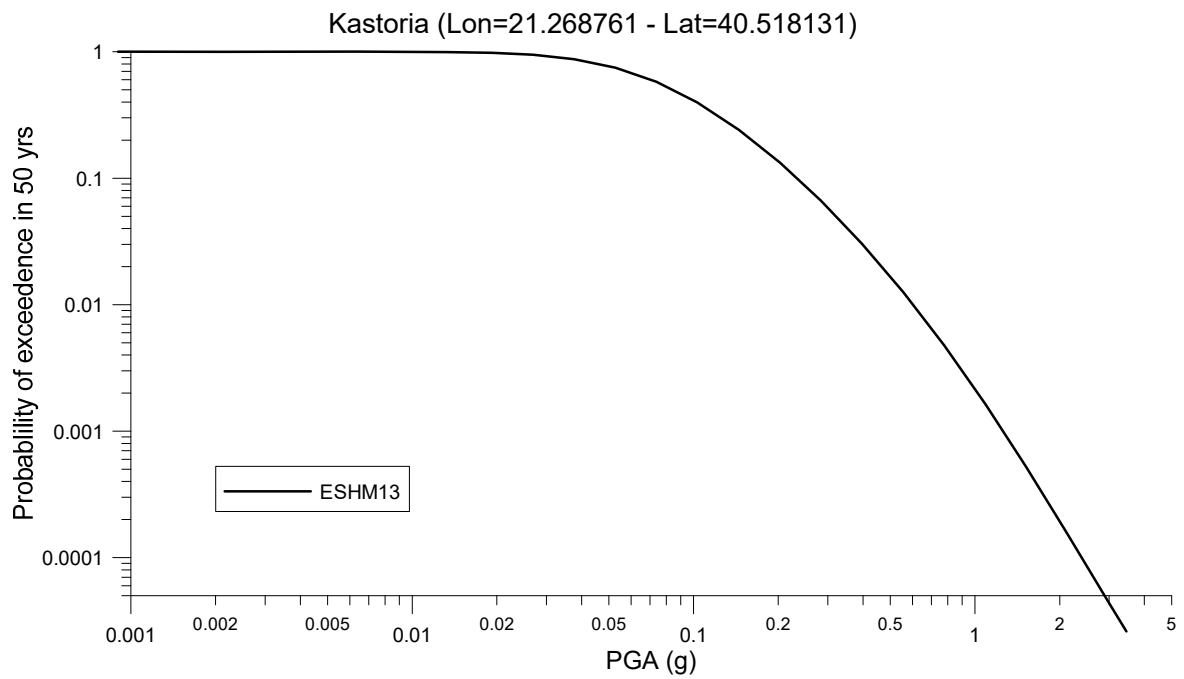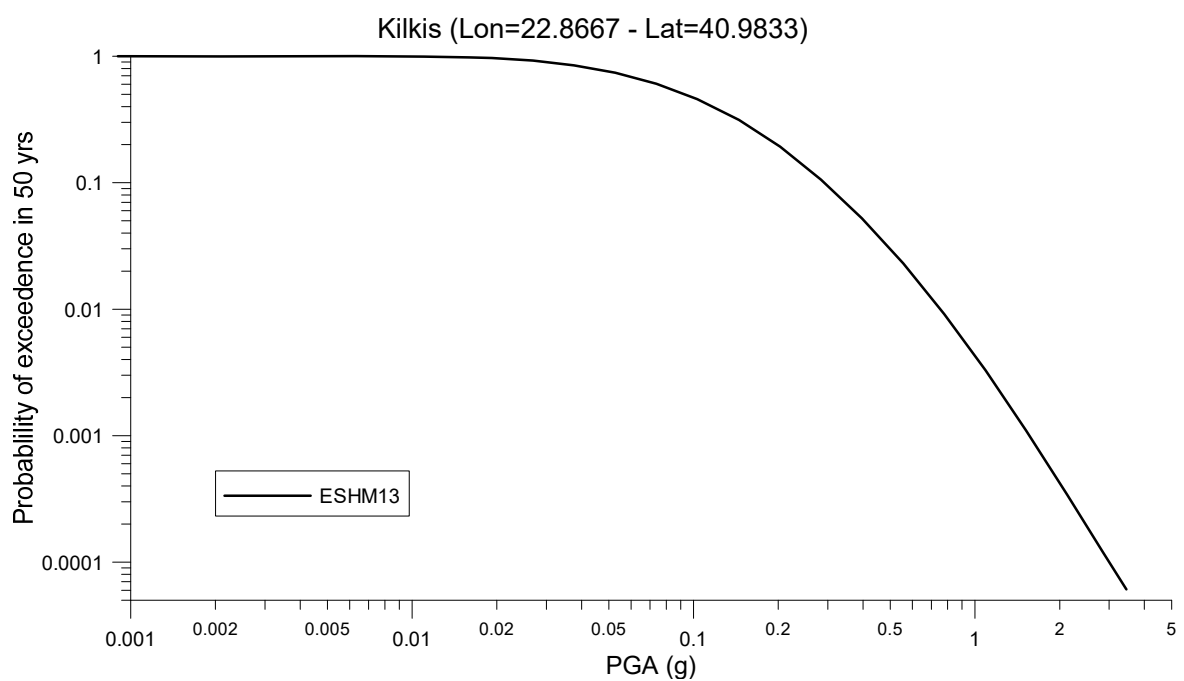

c) Hazard Curve for Kilkis (GRC)
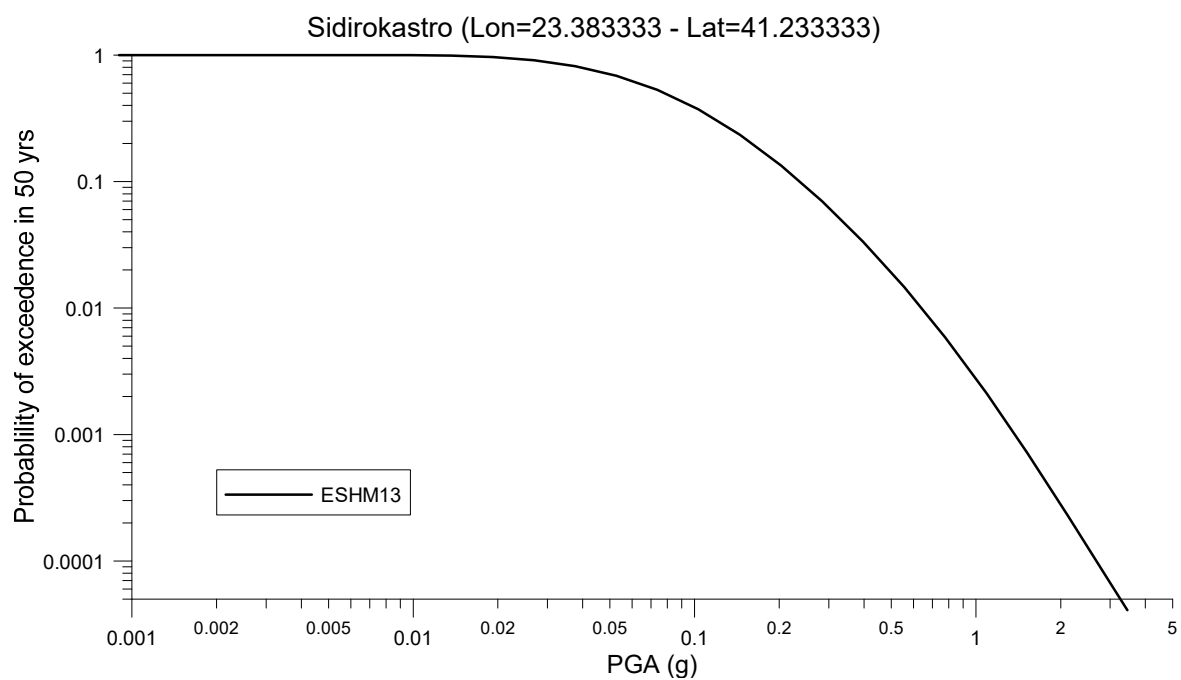
d) Hazard Curve for Sidirokastro (GRC)
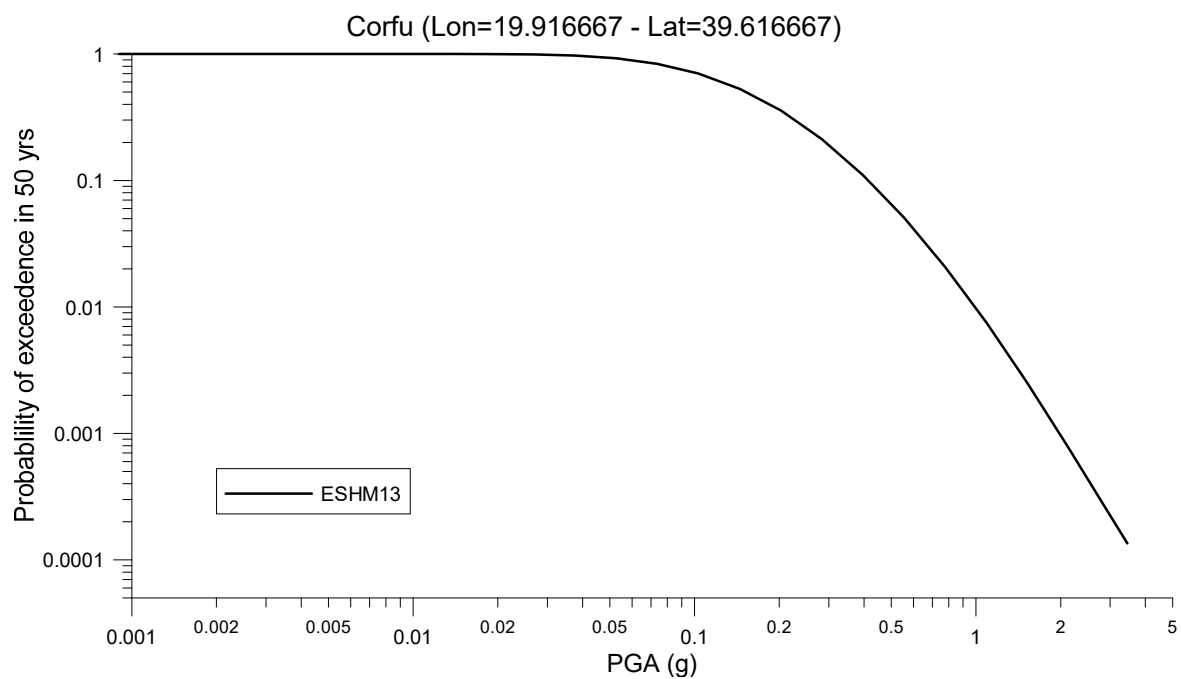
e) Hazard Curve for Corfu (GRC)

Figure 2.12. ESHM13 hazard curves for selected cities of the cross-border region in Greece

Debar (Lon=20.533333 - Lat=41.516667)

a) 475 UHS for Debar (MKD)

Ohrid (Lon=20.801940 - Lat=41.11722)

b) 475 UHS for Ohrid (MKD)

Bitola (Lon=21.334722 - Lat=41.031944)

c) 475 UHS for Bitola (MKD)

Prilep (Lon=21.555556 - Lat=41.344444)
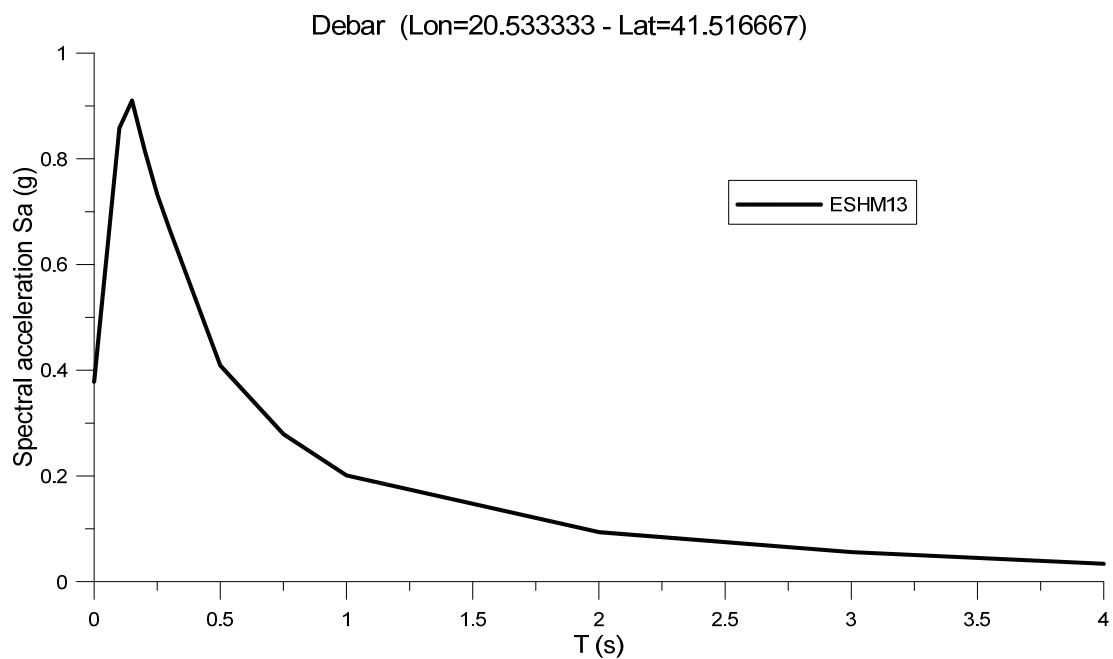
d) 475 UHS for Prilep (MKD)

e) 475 UHS for Strumica (MKD)

Figure 2.13. ESHM13 UHS for 475 years RP for selected cities of the cross-border region in N. Macedonia

a) 475 UHS for Florina (GRC)

Kastoria (Lon=21.268761 - Lat=40.518131)
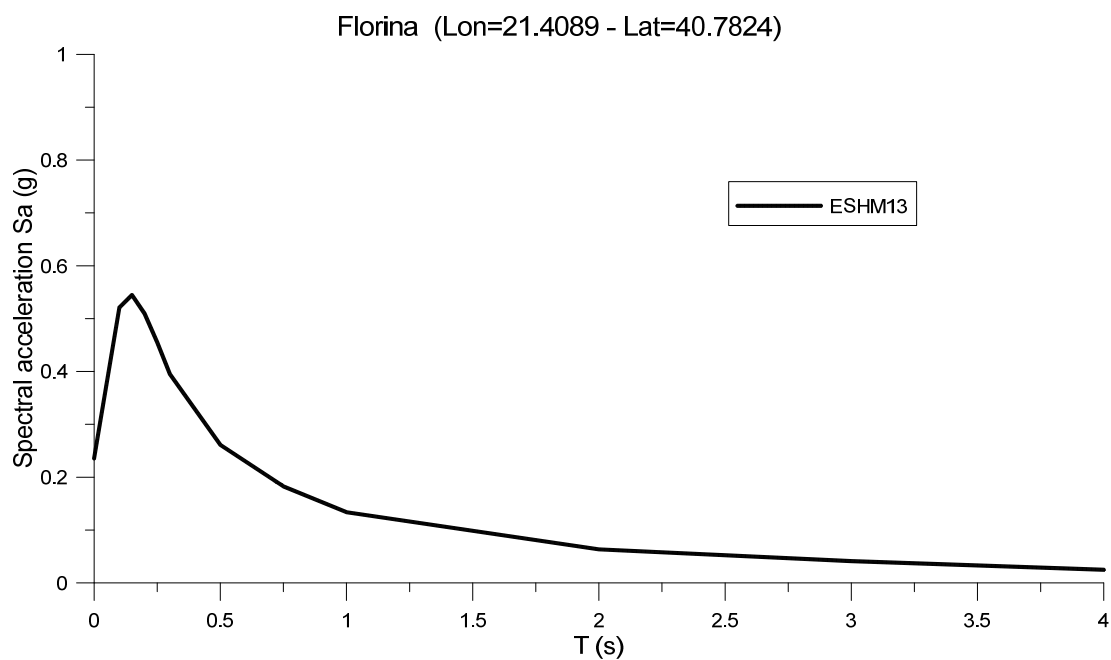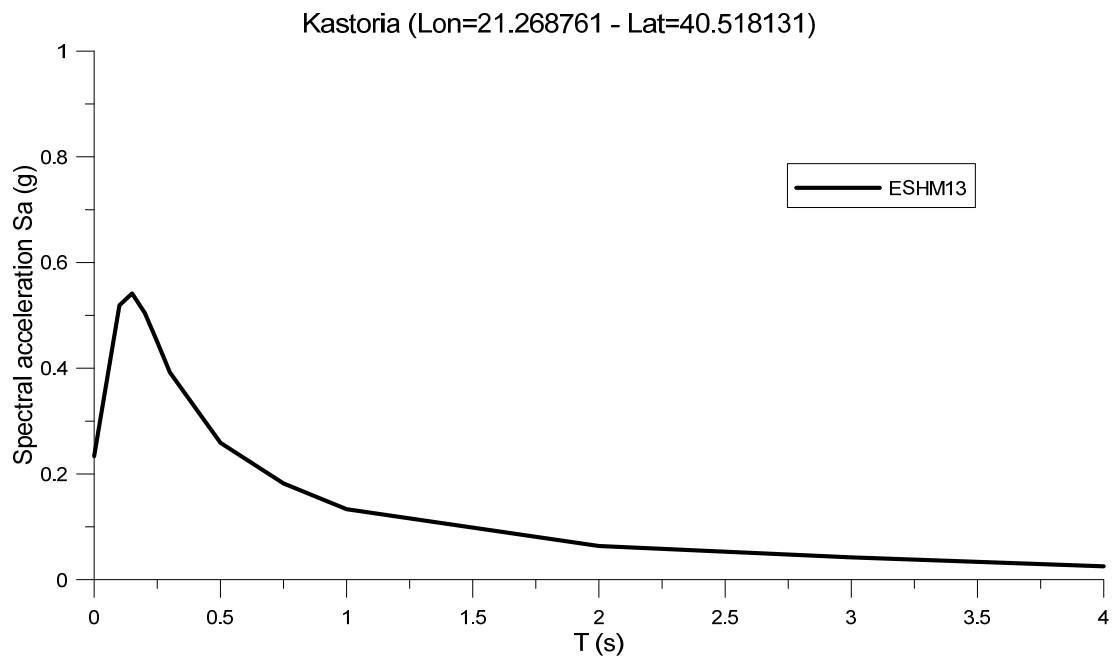
b) 475 UHS for Kastoria (GRC)

Kilkis (Lon=22.8667 - Lat=40.9833)

c) 475 UHS for Kilkis (GRC)

Sidirokastro (Lon=23.383333 - Lat=41.233333)

d) 475 UHS for Sidirokastro (GRC)

Corfu (Lon=19.916667 - Lat=39.616667)
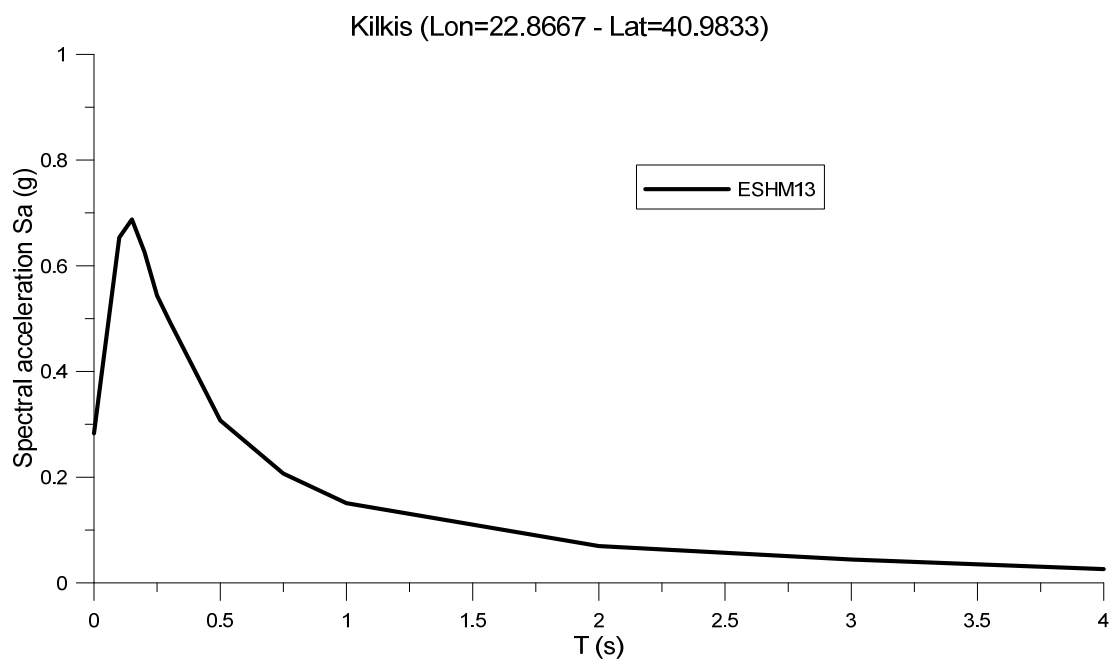
e) 475 UHS for Corfu (GRC)
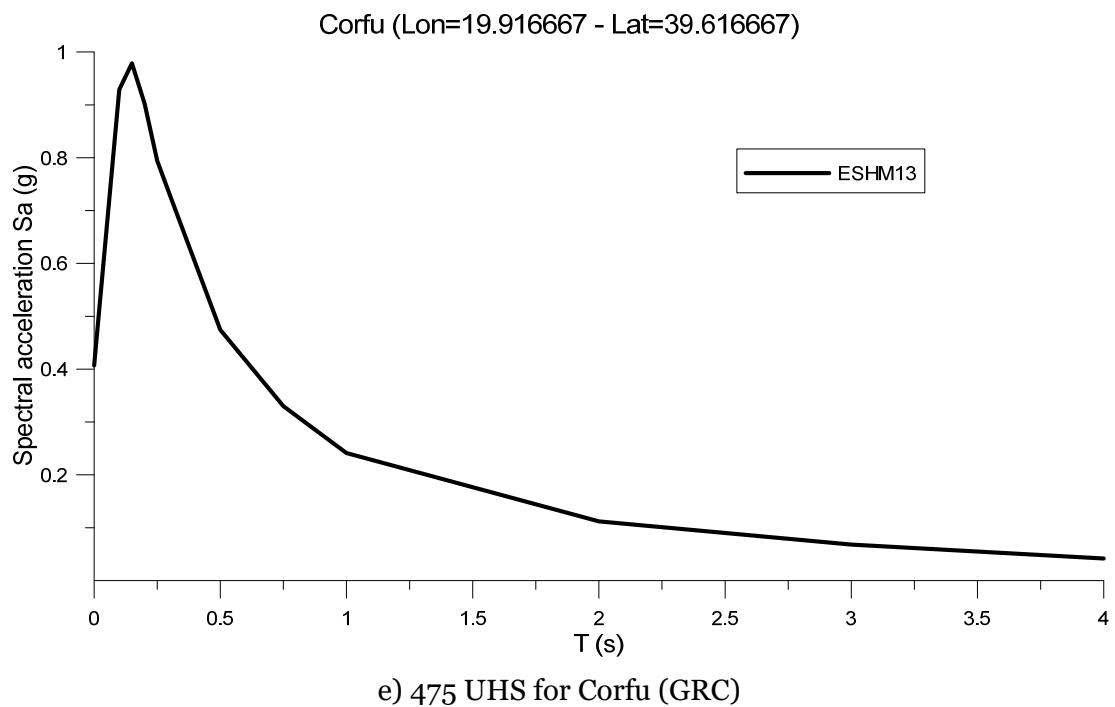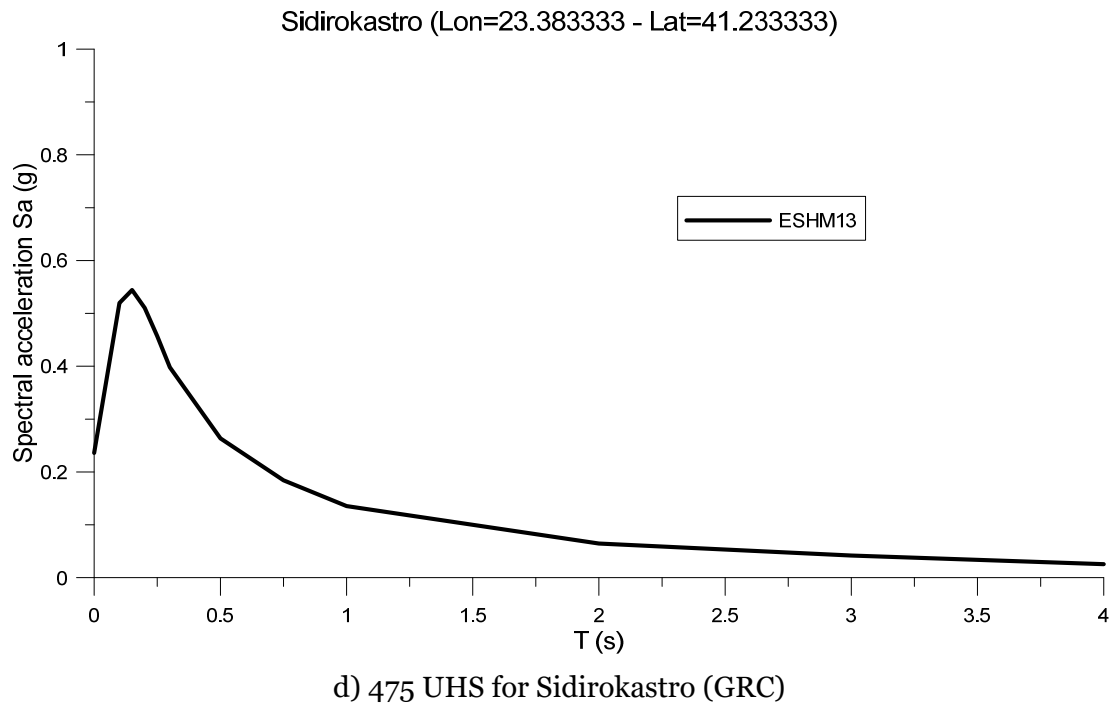
Figure 2.14. ESHM13 UHS for 475 years RP for selected cities of the cross-border region in Greece
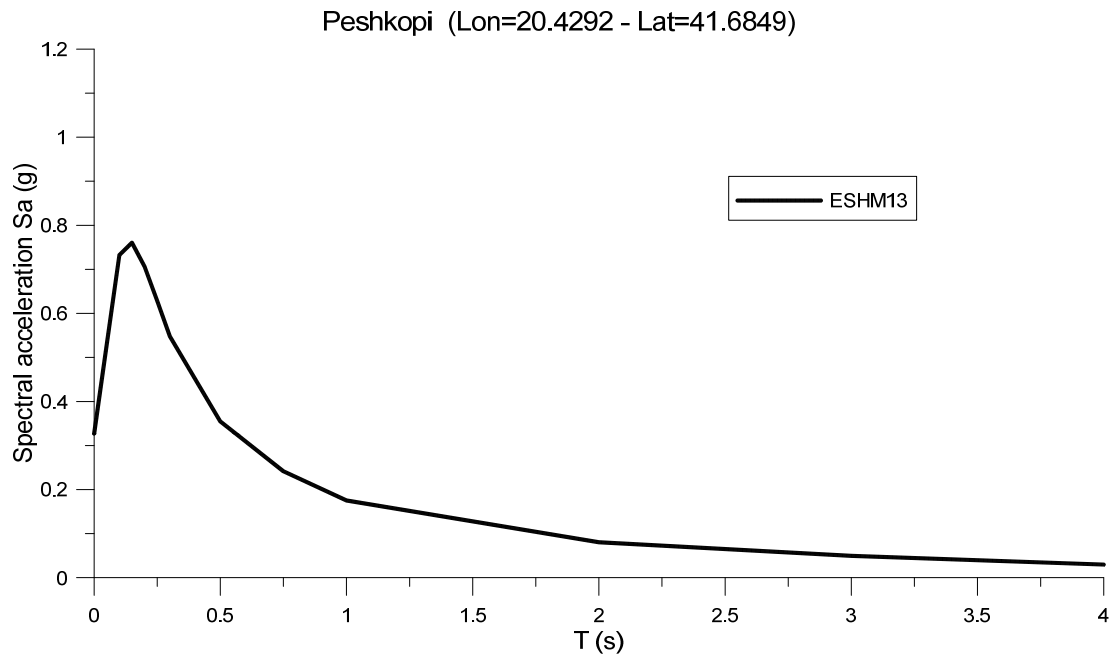
a) 475 UHS for Peshkopi (ALB)

b) 475 UHS for Korce (ALB)

Permet (Lon=20.3517 - Lat=40.2362)

c) 475 UHS for Permet (ALB)

Pogradec (Lon=20.6556 - Lat=40.9015)
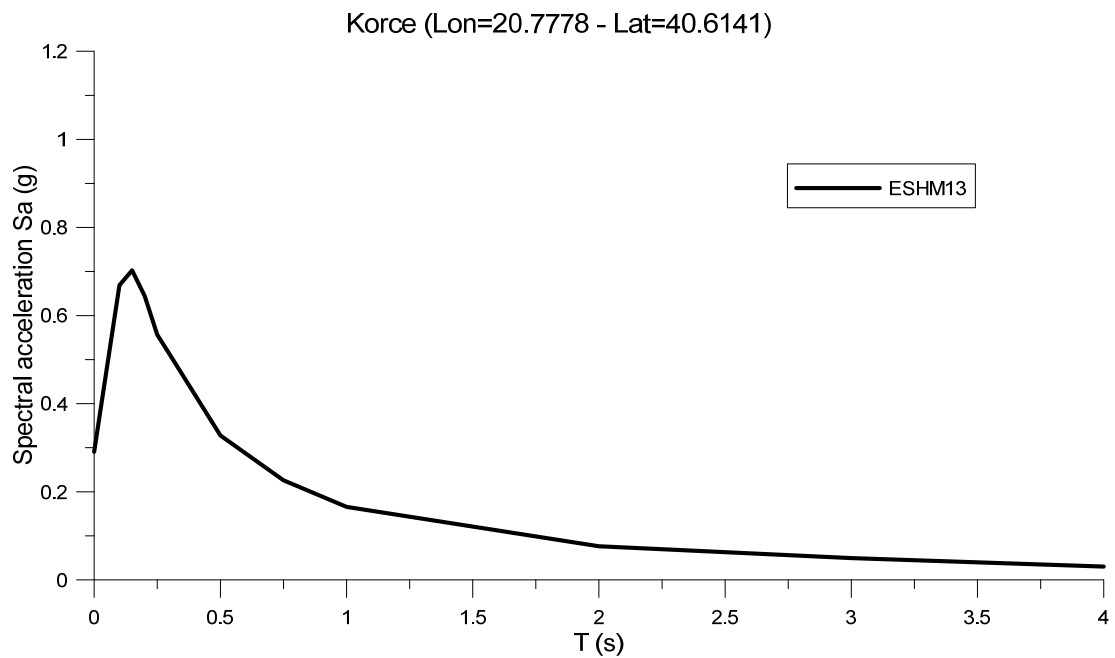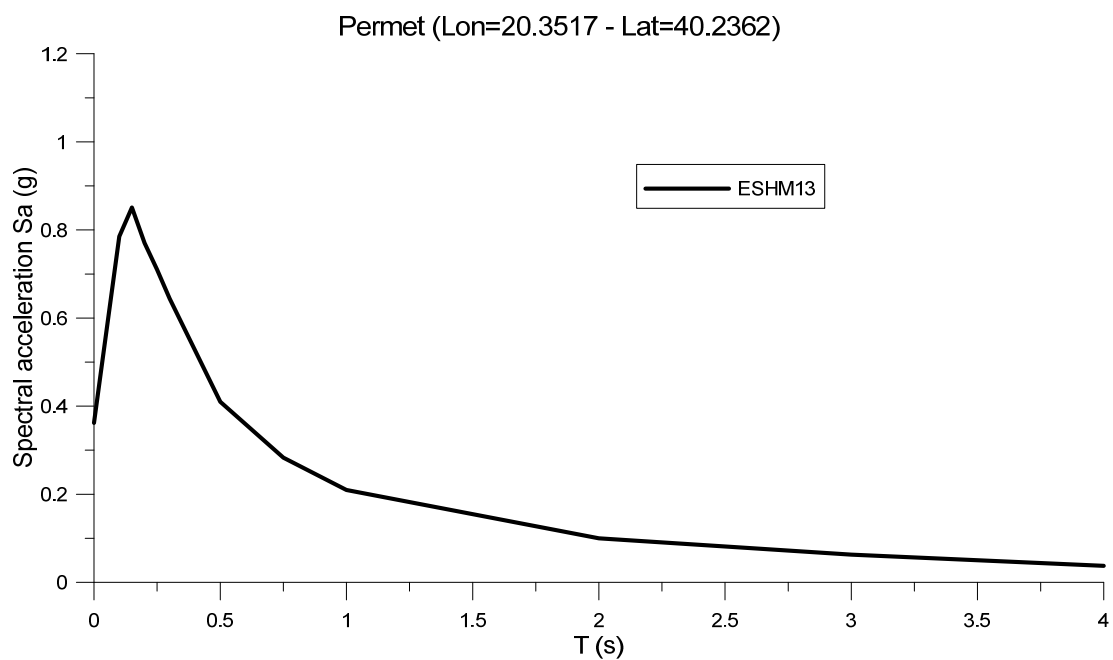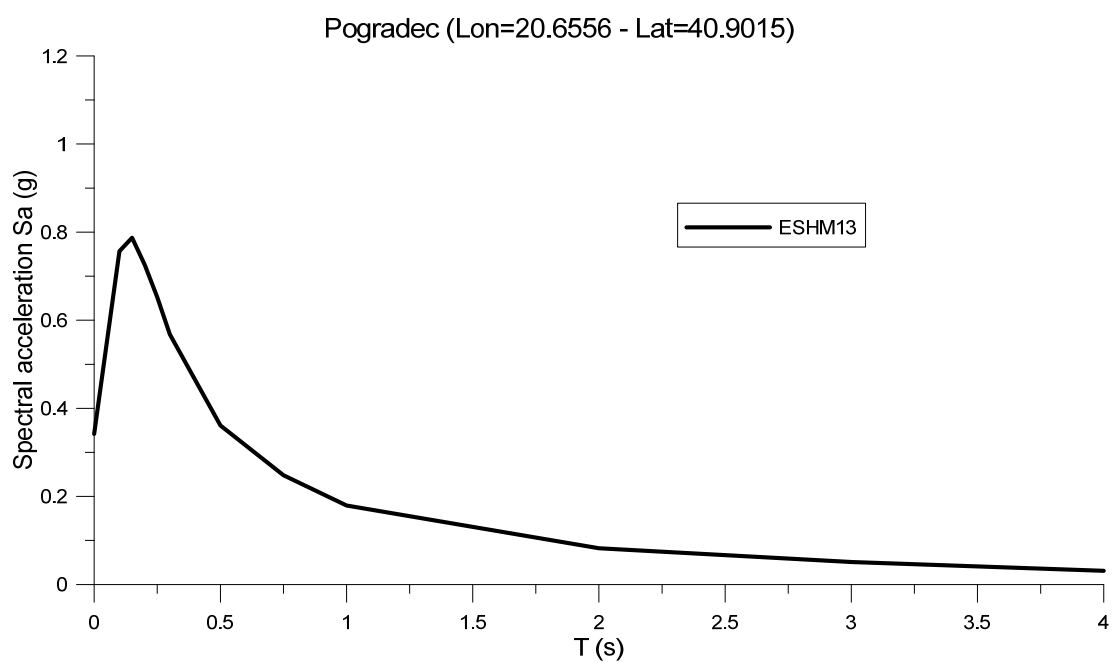
d) 475 UHS for Pogradec (ALB)

Gjirokaster (Lon=20.1045 - Lat=40.0673)

e) 475 UHS for Gjirokaster (ALB)

Sarande (Lon=20.0271 - Lat=39.8592)

f) 475 UHS for Sarande (ALB)
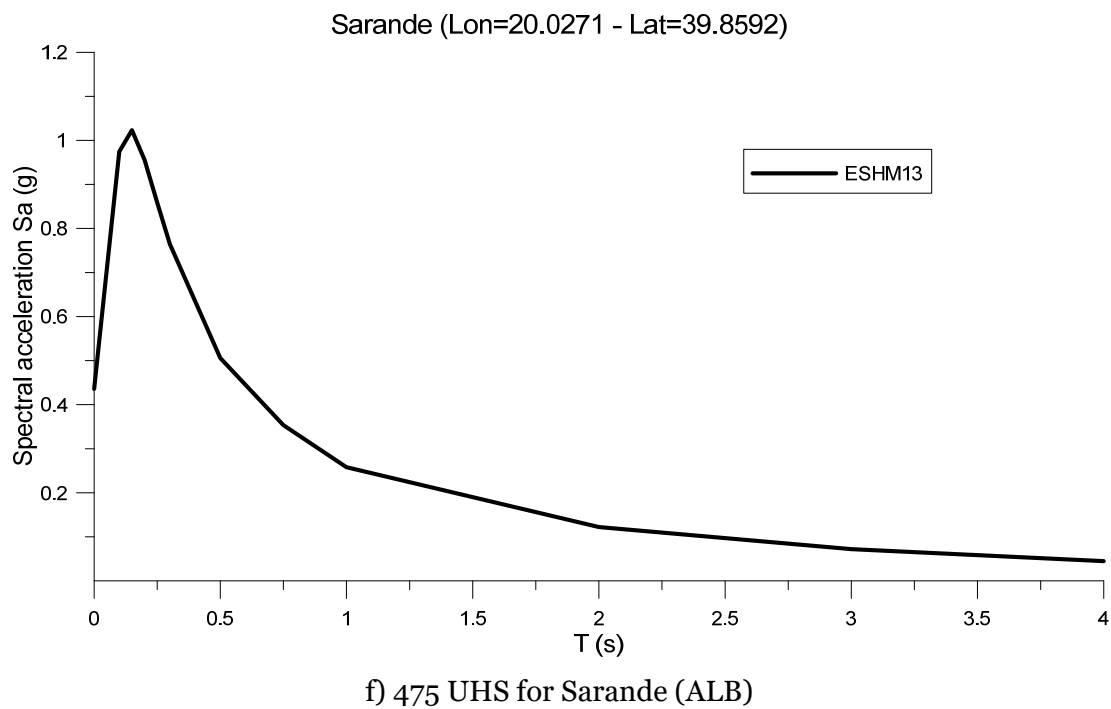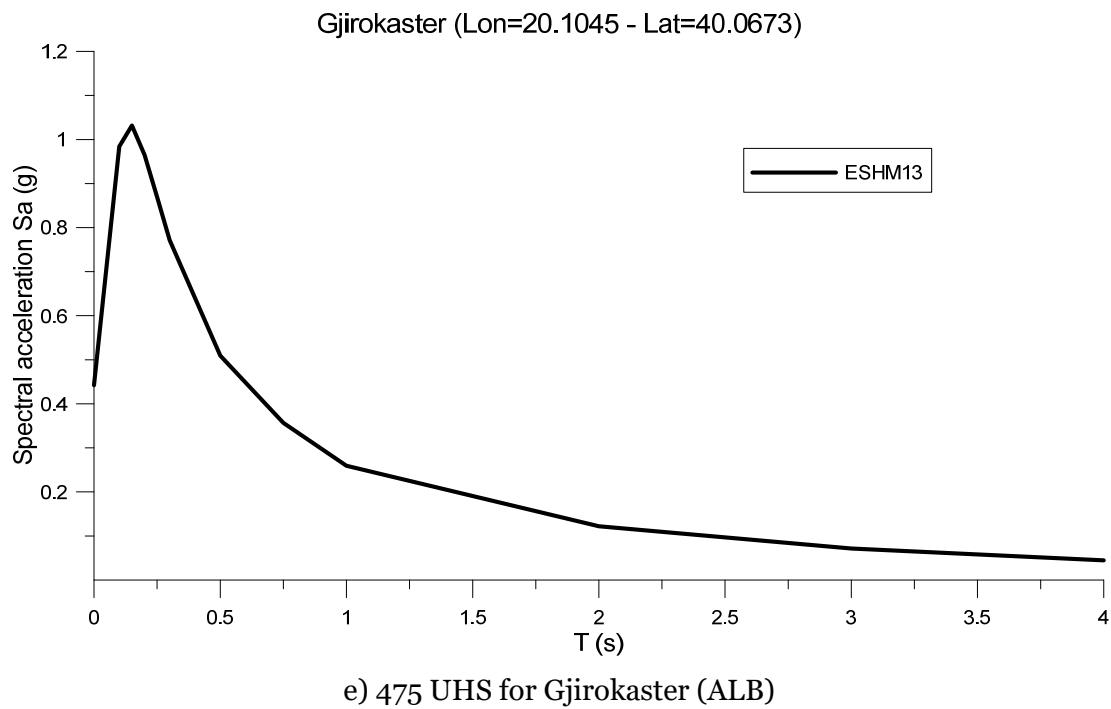
Figure 2.15. ESHM13 UHS for 475 years RP for selected cities of the cross-border region in Albania

2.5.   Determination of characteristic earthquake scenarios

Scenario-based earthquake disaster risk assessment is one of the most effective ways to reduce the impact of earthquake disaster on people, property, and environment (Dubos et al., 2004; Marulanda et al., 2014). Scenario-based earthquake disaster risk assessment can provide good

support to local governments for budget planning, determining appropriate levels of relief supply reserves, raising public awareness, allocating human resources for mitigation and disaster management operations, educating the public and professionals on preparation and mitigation, and the prioritization of retrofit applications (Riga et al, 2017). Thus, according to EERI (1997) scenario-based seismic disaster risk assessment is an important tool for reducing earthquake-induced losses (Zhuang et al., 2019).

For the purpose of scenario-based earthquake disaster risk assessment, definition of possible earthquake scenarios that may seriously affect CBR is of the outmost importance. The definition of scenarios (Table 2.4, Fig. 2.16) is primarily based upon available seismological and seismo-tectonic data for the CBR, i.e., related databases provided in the frame of 2013 Euro-Mediterranean Seismic Hazard Model (ESHM13). For that purpose, 11 real earthquakes that have happened in the CBR and its vicinity were selected, as well as 9 seismogenic faults, considering the spatial distribution, level of seismic hazard and frequency of the earthquakes.

Table 2.4. Selected earthquake scenarios

SHARE European Earthquake catalogue (SHEEC)					
#	Lon (Deg)	Lat (Deg)	Magnitude (Mw)	Depth (km)	Date
E01	20.30	39.20	7.0	-	05.02.1786
E02	20.00	39.50	6.6	-	01.01.1674
E03	20.00	40.30	6.7	-	4.12.1866
E04	20.70	40.10	6.3	10	22.12.1919
E05	20.10	41.10	6.7	-	--.--.1380
E06	20.70	40.85	6.8	21	18.02.1911
E07	21.30	40.50	6.5	-	29.05.1812
E08	20.66	41.72	6.1	15	7.12.1922
E09	21.19	41.10	6.0	12	01.09.1994
E10	22.20	40.90	6.7	-	--.10.1395
E11	22.51	41.32	6.7	-	08.03.1931
European Database of Seismogenic Faults (EDSF13)					
#	EDSF13idsource	Mw(max)	Fault Type	Depth(min)	Depth(max)
F01	GRCS601	7.28	RR	2	12
F02	ALCS011	7.59	RR	5	25
F03	ALCS003	6.95	NN	1	12
F04	ALCS005	7.56	RL	1	25
F05	MKCS006	7.56	RL	1	25
F06	MKCS003	7.13	NN	1	15
F07	MKCS004	6.99	NN	1	12
F08	GRCS060	6.89	NN	0	12
F09	GRCS130	7.15	NN	0	15
NN – Normal Fault; RR – Reverse Fault; RL – Right Lateral Strike-Slip Fault					

Although the parameters related to the selected earthquakes from SHARE European Earthquake catalogue (SHEEC) differ more or less in relation to the parameters given in the official national earthquake catalogues (ex. for E09 Mw in MKD catalogue is 5.18), in order to keep a harmonization pattern the parameters are not corrected or modified. Same applies for the parameters related to seismogenic faults.
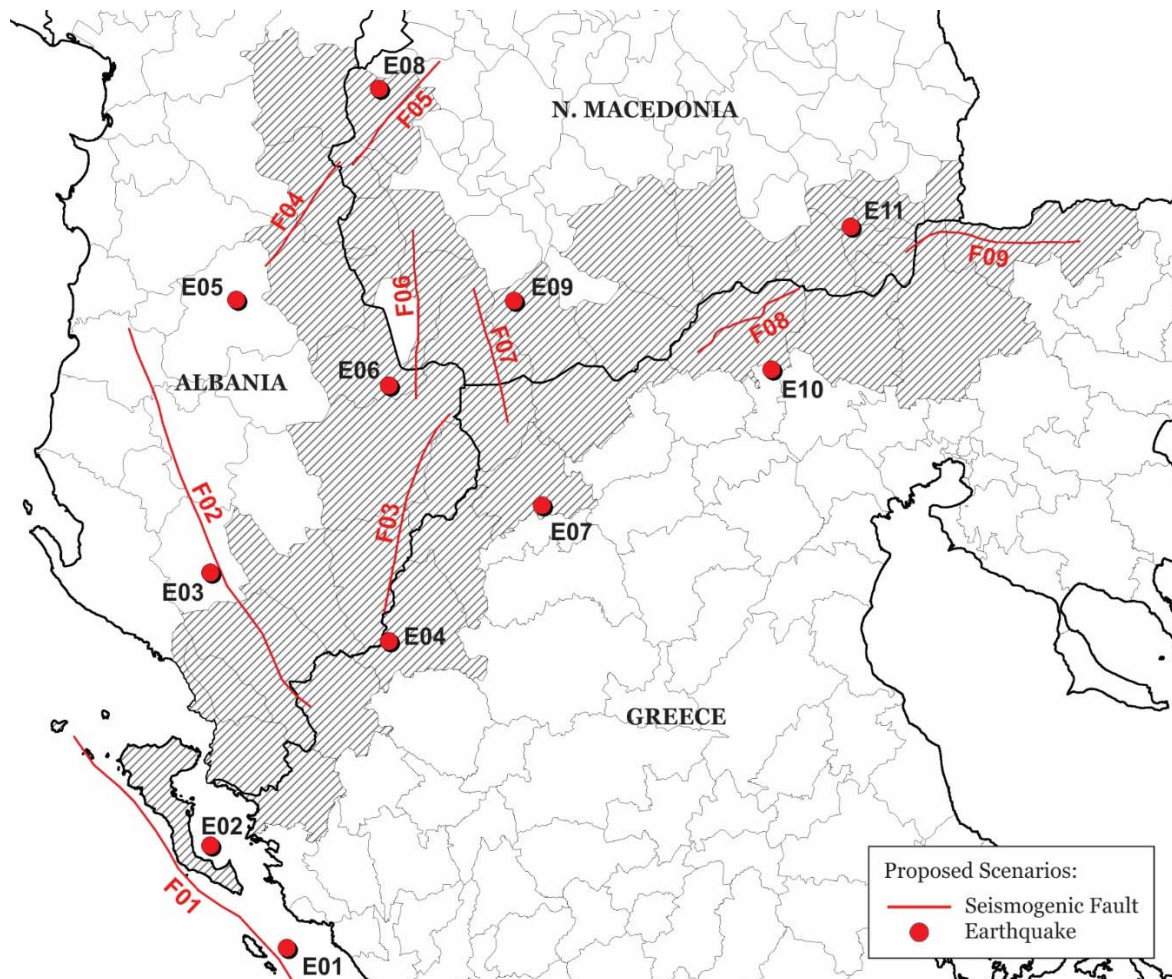
Fig. 2.16. Spatial representation of earthquake scenarios

3. Conclusions

This deliverable provides seismic hazard assessment and mapping, harmonized for the territory of the target CBR. Evaluation of seismic hazard was based upon the latest published seismic hazard model for Europe (ESHM13), Giardini et al., 2014.

The national and regional review of seismic hazard models and zonation's leads to conclusion that although many models are developed and are available, ESHM13 is the only available model that provides regionally harmonized approach based on the state-of-the-art practices in domain of probabilistic seismic hazard assessment. Selection of this model was made by consensus of all partner institutions.

Hazard mapping results (Fig. 2.6, 2.7 and 2.8) clearly shows that CBR is characterized with very high seismic hazard estimates ranging from 0.20-0.45g (RP475, mean hazard model and

to rock site conditions). Zone with highest seismic hazard is the zone in the most southern-western part of the CBR (Gjorokaste-Cofru-Fillates) where PGA is reaching values of 0.45g. Another very high seismic hazard zone is at the border region ALB-MKD, where in the zone Debar-Librazd the PDA values reaches 0.40g. Also, the southern-eastern part of CBR, border zone between MKD-GRC, Valandovo-Kilkis zone shows relatively high seismic hazard with values reaching 0.30g.

For a total of 48 towns in the CBR, hazard PGA values are analyzed in respect to three return periods (102, 475 and 975) (Table 2.3; Fig. 2.6, 2.7 and 2.8). The most extreme seismic hazard values are related to the towns of Fillates, Dermish, Gjirokaster, Sofratike and Sarande.

Depending on the concentration of population, built environment and infrastructure, 16 towns in the CBR were selected as of primary regional importance. For those selected towns, seismic hazard curves and uniform hazard spectra were extracted, through which seismic hazard regime is defined in relation to the probability of exceedance as well as spectral periods (Figures 2.10 – 2.15).

For the purpose of scenario-based earthquake disaster risk assessment, 20 earthquake scenarios were defined (Table 2.4), out of which 11 real earthquakes that have happened in the CBR and its vicinity, as well as 9 seismogenic faults were selected , considering their spatial distribution, level of seismic hazard and frequency of the earthquakes.

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