THE NEEDS FOR ADVANCED SEISMIC HAZARD ASSESSMENT OF THE REPUBLIC OF MACEDONIA

R.B. Salic, Z.V. Milutinovic & M.A. Garevski
Institute of Earthquake Engineering and Engineering Seismology (IZIIS)
"Ss. Cyril and Methodius" University, Skopje, Republic of Macedonia

ABSTRACT:
The paper is presenting the main needs for reevaluation of seismic hazard for the Republic of Macedonia. To achieve stated objectives, a profound review and reanalysis of all available data has been performed, or is in process, to reliably verify and/or redefine: (1) seismotectonic characteristics of the source zones; (2) adopt alternative recurrence relationships for identified seismic sources; (3) elaboration of adequate seismicity models with adequate, geologic condition dependent weighting factors; (4) adoption and testing of different ground motion prediction (GMP) models; and (5) implementation of GIS technology at all steps of the analyses. Implemented is 1995 "smoothed seismicity" Frankel's approach that accounts efficiently for migration of epicenters, i.e.: (1) errors in determination of epicenters and their non-vertical clustering; and (2) migration of the seismicity along the active tectonic structures. The research to be presented is supported by NATO SfP 983054 Project "Harmonization of Seismic Hazard Maps for the Western Balkan Countries" as well as Council of Europe, EUR-OPA MHAs' coordinated activity "Harmonization of Seismic Hazard Maps in Balkans".

Keywords: Seismic hazard, smoothed seismicity, seismic zoning, Eurocode 8, Macedonia.

1. INTRODUCTION

During past centuries, the southern part of Europe, Balkan Peninsula in particular, has been affected by devastating earthquakes, resulting in significant human casualty and property loss. The intense urbanization accompanied by mechanical migration of population and economic activities from remote to urbanized areas are unfavorably deepening already existing controversies and conflicts among natural, built and policy environments; threatening that consequences of repetition of such events would be even more drastic.

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.

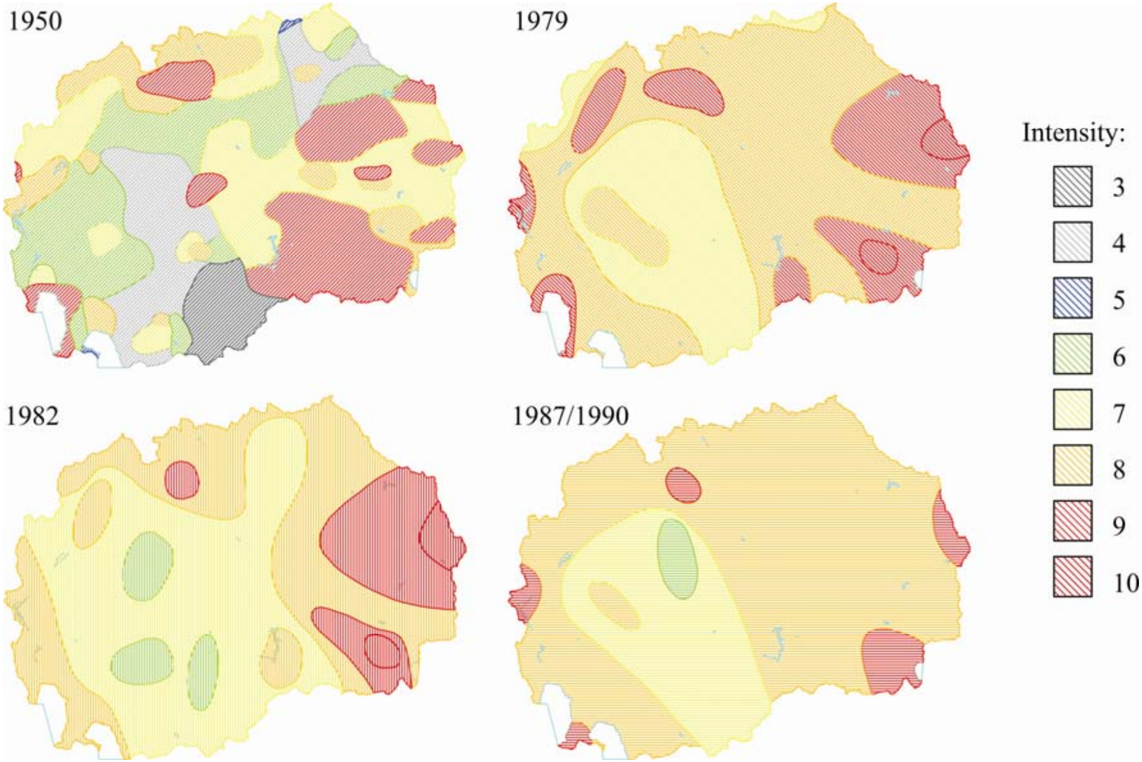

Figure 1. Official seismic zoning maps for the Republic of Macedonia

2. NEEDS FOR ADVANCED SEISMIC HAZARD ASSESSMENT

The necessity for redefinition of the seismic hazard for the territory of the Republic of Macedonia is due:

1. The inconsistency in the existing methodologies and data used for seismic hazard assessment; and,
2. Elaboration of seismic hazard zoning as a National annex for the new European regulation (Eurocode 8).

2.1. Up-to-date Official Seismic Zoning Maps

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
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)**
	1950: Seismic Zoning Map of Yugoslavia, Seismological Bureau of F.N.R.Y., Belgrade. *(Author: Jelenko MIHAJLOVIC)* <u>*Base:*</u> *Compilation of intensities of earthquakes occurred in the period 360AD-1950AD*
Temporary Technical Regulations for Construction in Seismic Regions", Official Gazette of SFRY No. 39/64 (1964).	**1967: Engineering Geology Map of SFR Yugoslavia (1:500,000), Federal Geological Institute, Belgrade.** *(Authors: P. CUBRILOVIC, L. PALAVESTRIC i T. NIKOLIC)* <u>*Base:*</u> *Compilation of seismicity data for the territory of Yugoslavia, Intensities by MCS Seismic Intensity Scale.*
	1979: Seismic Zoning Map of Macedonia, Seismological Observatory, Skopje. *(Author: D. Hadzievski, Official Gazette of SRM No. 2/79)* <u>*Base:*</u> *Compilation of seismicity data for the territory of Macedonia, Intensities by MCS Seismic Intensity Scale.*
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.	**1982: Provisional Seismic Zoning Map of Yugoslavia (Official Gazette of SFRY no. 49/82)** <u>*Base:*</u> *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: <u>Article 6:</u> 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).

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 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 technical 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

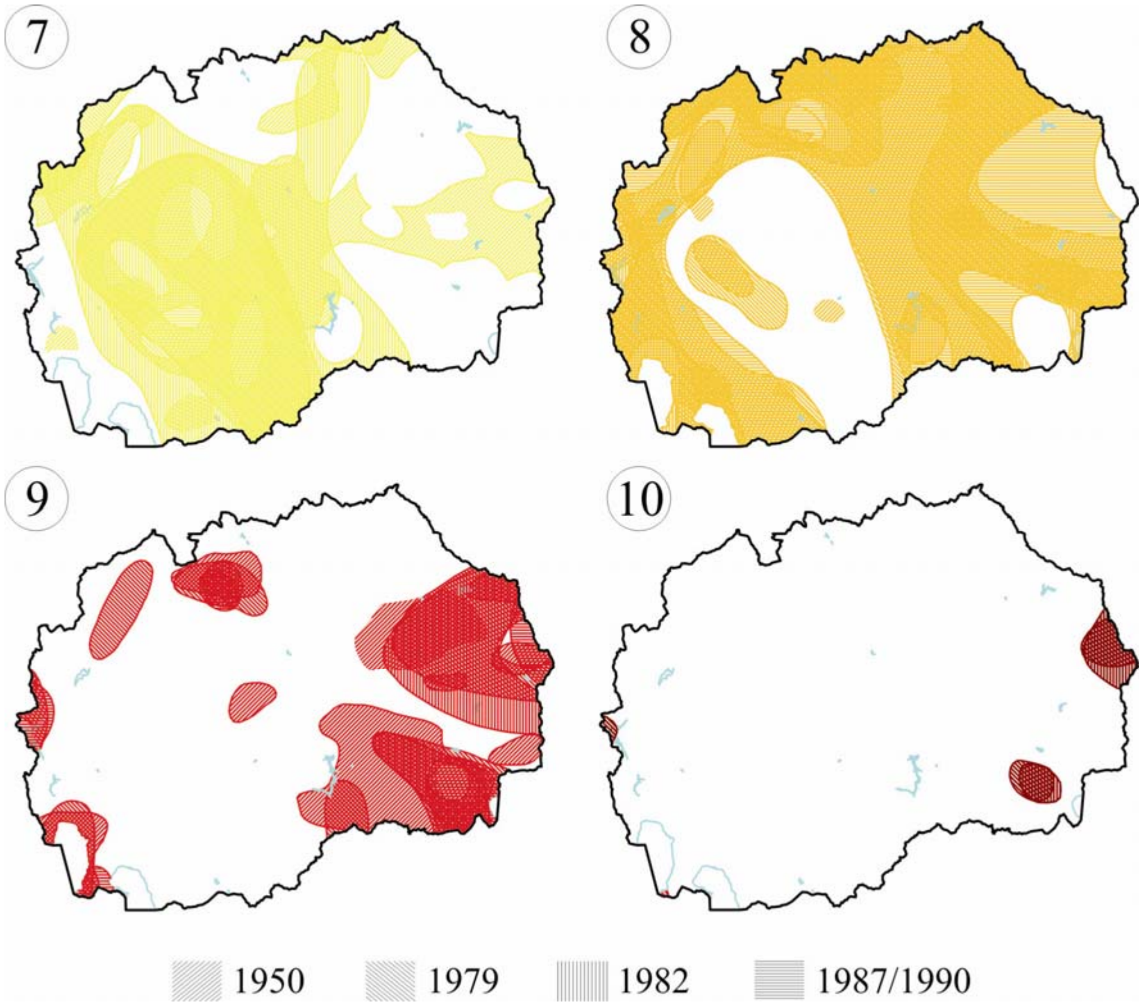

Figure 2. Differences in the disposition of the intensity areas (for I>7)

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 (Figs. 1 and 2) as well as in the percentages of total country area covered by a particular intensity (Fig. 3).

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 benchmark 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.

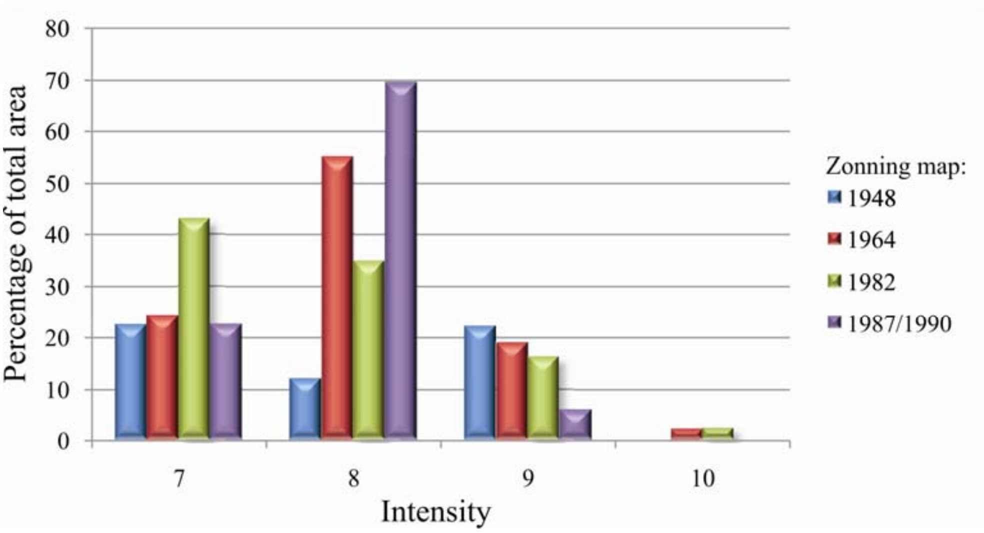

Figure 3. Differences in the intensity areas (for I>7)

2.2. Implementation of New European Regulation

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.

Ground movement at a given point of the surface, as required by Eurocode 8, is determined by the elastic response spectrum (Fig. 4), defined by Se (T) - ordinate of the elastic spectrum, a_g - design ground acceleration for the reference period, β_0 - amplification factor of spectral acceleration for viscose damping of 5%, T_B, T_C - constant spectral acceleration limits, T_D - a value which defines the beginning of the constant displacement field, S - parameter that depends on the ground, η - weighting factor depending on the damping with a reference value of 1.0 for viscose damping of 5%.

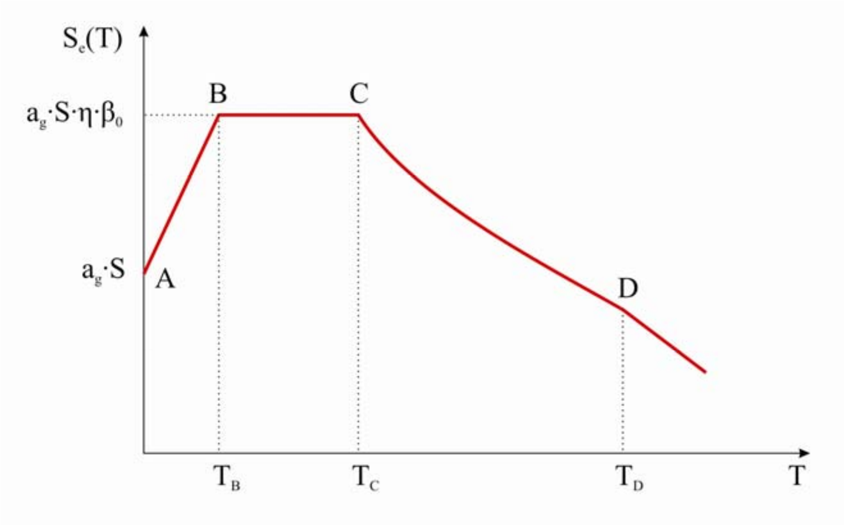

Figure 4. EC-8 Elastic response spectra

3. SEISMIC HAZARD ASSESSMENT - METHOD

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.

4. REDEFINITION AND REANALISYS

Within the NATO SfP-983054 Project "Harmonization of Seismic Hazard Maps for the Western Balkan Countries" as well as Council of Europe, EUR-OPA MHAs' coordinated activity "Harmonization of Seismic Hazard Maps in Balkans" extensive research activities have been and are still underway. They have been carried out in three phases, out of which some are completed:

- Analysis and synthesis of all existing data and results from previous hazard analyses for the territory of the Republic of Macedonia:
  - Geological, tectonic, neotectonic, seismological and seismotectonic data.

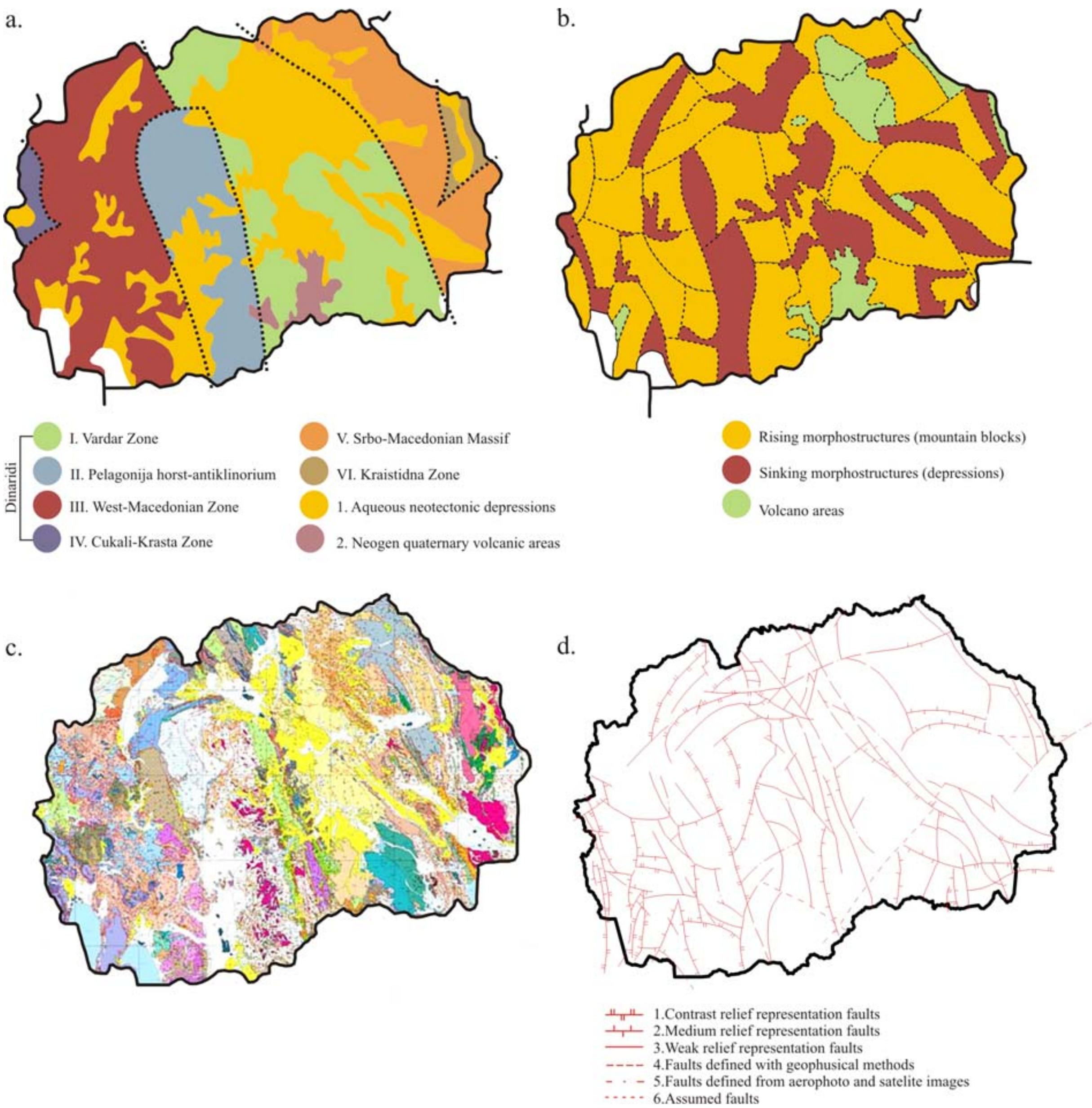

Figure 5. a. Tectonic map of Republic of Macedonia, **b.** Neotectonic map of Republic of Macedonia, **c.** Geological map, **d.** Seismotectonic map

- Preparation and data compilation for earthquake catalogue.
- Review of used methods and procedures for determination of seismic hazard.

- Seismic hazard analysis:
  - Seismic zones determination.
  - Determination of ground motion prognostic model.
  - Assessment of seismic hazard.

- Preparation of GIS layers and construction of additional thematic maps.

5. RESULTS

- Qualitatively new approach in modeling seismicity and development of adequate procedure for calculating the seismic hazard;

- Seismic zoning of Macedonia harmonized with European standards - as a basis for improving the seismic safety, seismic risk management and replacement of existing regulations for seismic design in terms of characteristic seismic conditions for the Republic of Macedonia;
- Qualitatively new, regionally verified and adopted spatial seismicity model for the territory of Macedonia and bordering region;
- Integrated GIS data base on tectonic, neotectonic, seismicity and other data for the territory of the Republic of Macedonia: national earthquake catalog, seismotectonic data, data on focal mechanisms, morphological and geological data, etc.;
- Integrated GIS data base on the results obtained from the performed research.

Specific contribution is in the domain of treatment of modeling of seismic sources, i.e. the spatial modeling of the seismicity. The classical PSH approaches favoring zoned seismicity, modeled by point, line and/or area seismic sources, is replaced with "spatially smoothed seismicity" which effectively covers errors in determination of epicenters location of historical and instrumental earthquakes, migration of the epicenters along active tectonic structures, scarcity of interrelated tectonic-seismic data and decreases seismic hazard analyst's subjectivity.

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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