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SEISMIC HAZARD AND REVIEW OF SEISMIC ACTIVITY OF THE OHRID EPICENTRAL AREA IN THE PERIOD JUNE – JULY 2017

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ABSTRACT

In the period June – July 2017, the Ohrid epicentral area experienced seismic activity manifested through a series of slight to moderate earthquakes, the duration and recurrence of which caused anxiety among the local population and the tourists. Mapping of the seismic hazard for the territory of Macedonia is made based on the available geological, tectonic, neotectonic, seismological, seismotectonic and other relevant data. This area is characterized by high seismic activity and a number of strong earthquakes happened in the past as a result.

Key words: Seismic activity, earthquake magnitude, seismic hazard

INTRODUCTION

The Ohrid epicentral area experienced seismic activity through a series of slight to moderate earthquakes during the period June – July 2017, duration and recurrence of which caused anxiety among the local population and the tourists. Considering the different statements, explanations and predictions made by the media, we believe that it is our obligation and duty to share relevant and scientifically supported knowledge that we have acquired as experts representing institutions that deal with this field. The information that we have provided through this report is descriptive and is generally intended for readers from the wider public.

The territory of Southeast Europe (Fig. 1), where Macedonia is situated, is one of the most seismically active regions on the continent and consequently it is a territory characterized by the highest seismic hazard and risk in Europe. Macedonia, as part of the Balkan Peninsula (Fig. 2), has been struck by a number of strong earthquakes during the past centuries. These have resulted in a considerable number of human fatalities and material losses. Noteworthy for their importance are the 1904 earthquake in the Pehchevo-Kresna epicentral area (one of the earthquakes with the largest magnitude on the territory of Europe) and certainly the 1963 earthquake that hit the capital - Skopje resulting in considerable material losses and the loss

of human lives (1,070 fatalities, 3,300 heavily injured and 15% damage to the Gross National Product of FPRY[15] for the year of 1962).

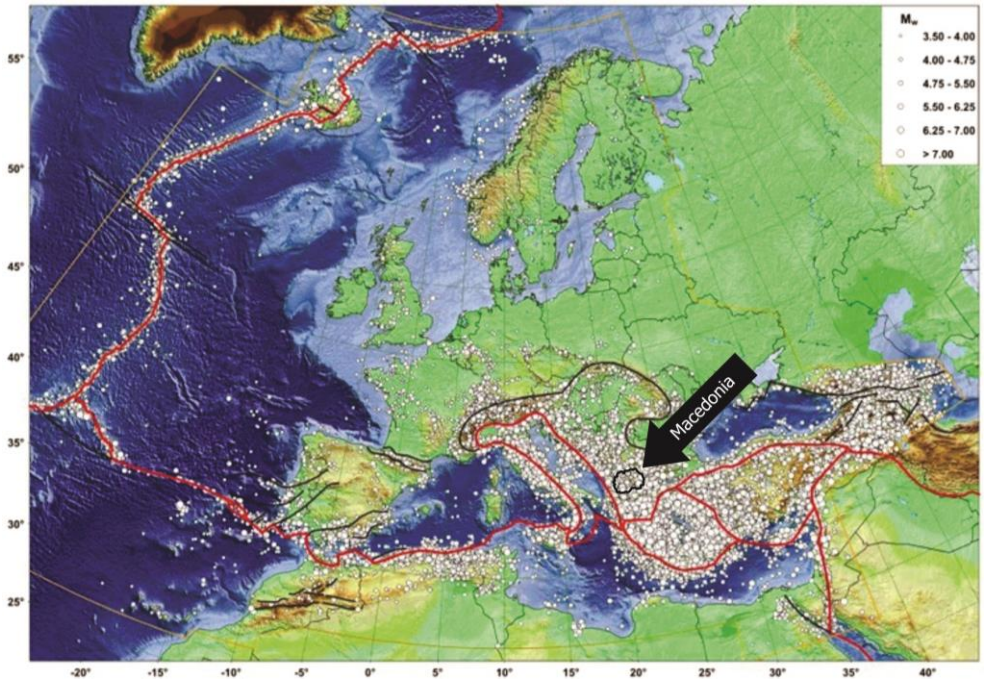


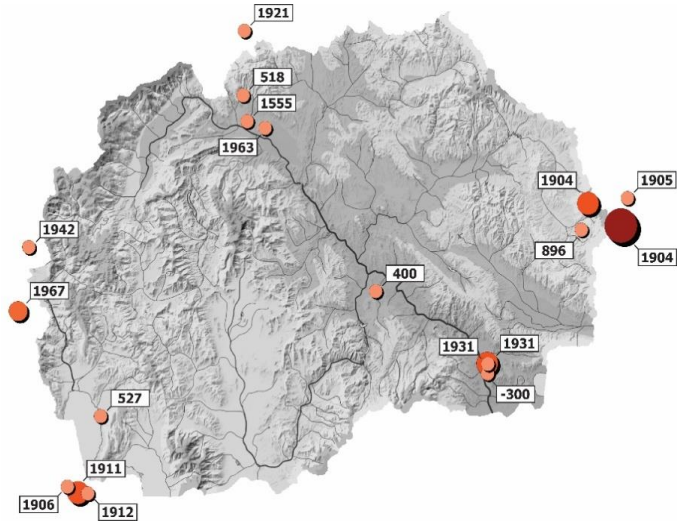
Figure 1: European-Mediterranean catalogue of earthquakes covering the last 1,000 years.
By courtesy of: Grunthal & Walhstrom, Journal of Seismology (2012).

It must be mentioned, however, that the earthquakes that occurred prior to the introduction of instrumental measurements (prior to 1900) have been defined based on macroseismic data and their parameters (magnitude, intensity, location and other) so, the accuracy of their definition varies and depends on the number and quality of available macroseismic data.

SEISMIC ZONNING

After the Second World War, living in a seismically active area where earthquakes are a frequent natural threat, required detailed research in the field of geology, tectonics, seismology and other related disciplines for the purpose of establishing a reliable definition of the seismic hazard and taking many accompanied measures for seismic risk mitigation. For that purpose, in the midst of the last century, two institutions were established with primary mandatory activity of monitoring seismic activity and investigating of seismicity parameters on the territory of Macedonia (Seismological Observatory at the Faculty of Natural Sciences and Mathematics within UKIM in Skopje, 1957) as well as researching and developming methods and techniques for seismic risk reduction (Institute of Earthquake Engineering and Engineering Seismology, UKIM-IZIIS from Skopje, 1965).

[15] FPRY – Federative People's Republic of Yugoslavia



Year	M_L	I_0
-300	6.10	IX
400	6.10	IX
518	6.10	IX
527	6.10	IX
896	6.10	IX
1555	6.10	IX
1904	6.70	IX
1904	7.50	X
1905	6.10	VIII
1906	6.00	VIII
1911	6.70	IX
1912	6.00	VIII
1921	6.10	IX
1931	6.70	X
1931	6.00	VIII
1942	6.00	IX
1963	6.10	IX
1967	6.50	IX

Figure 2: Strong earthquakes on the territory of Macedonia and neighboring regions ($M_L \geq 6.0$)
Elaborated by: Salic and Milutinovic, Data: Seismological Observatory (UKIM-PMF).

Based on the presently available geological, tectonic, neotectonic, seismological, seismotectonic and other relevant data, mapping of the seismic hazard for the territory of Macedonia started in the midst of the last century. In 1948, mapping was done for the first time in the form of a seismic zoning map of FPRY that was a constituent part of the then established first technical regulations for design of buildings (PTP-2).

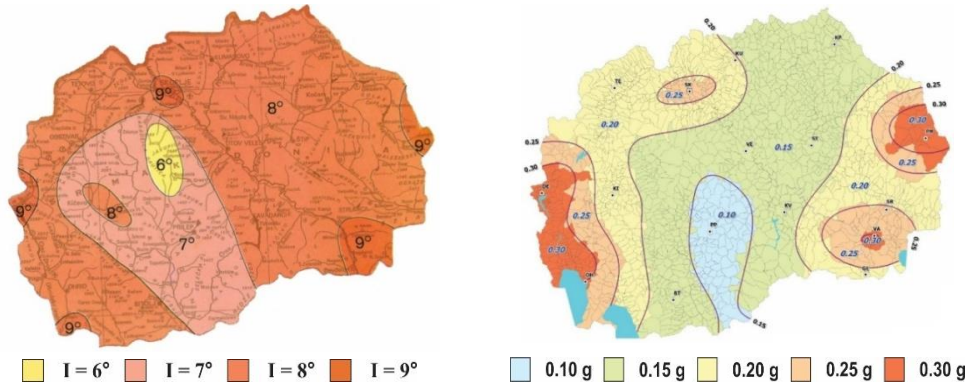


Figure 3: Seismic zoning maps of Macedonia.

a) Currently used map expressed in MSK-64 intensity degrees for a return period of 500 years and moderate soil conditions.

b) New map elaborated in compliance with the requirements of the MKC EN 1998-1:2012 Standard – Eurocode 8, expressed through peak ground acceleration *(PGA)* for a return period of 475 years and soil conditions type A.

Authors: Milutinovic al. 2016
Elaborated by: Seismological Association of SFRY, 1987.

Since then, on several occasions, namely in 1950, 1967, 1979, 1982, 1987 (Fig. 3a) the official seismic hazard maps were permanently revised and synchronized as a result of the development of science, technical sciences and new knowledge until the last, i.e., the latest maps elaborated in 2016 (Fig. 3b) in compliance with the requirements of the MKC EN 1998-1:2012 Standard– Eurocode 8: Design of Earthquake Resistant Structures, Part 1: General Rules, Seismic Effects and Rules, which became normative after the adoption of the National Annex MKC EN 1998-1:2012/HA:2014.

The territory of Macedonia represents a complex geological, tectonic and seismotectonic environment where definition and characterization of seismic zones with a high reliability is quite complex. The territory of Macedonia and the neighboring areas in Bulgaria and Greece are presently undergoing the so called south extension regime (Fig. 4a).

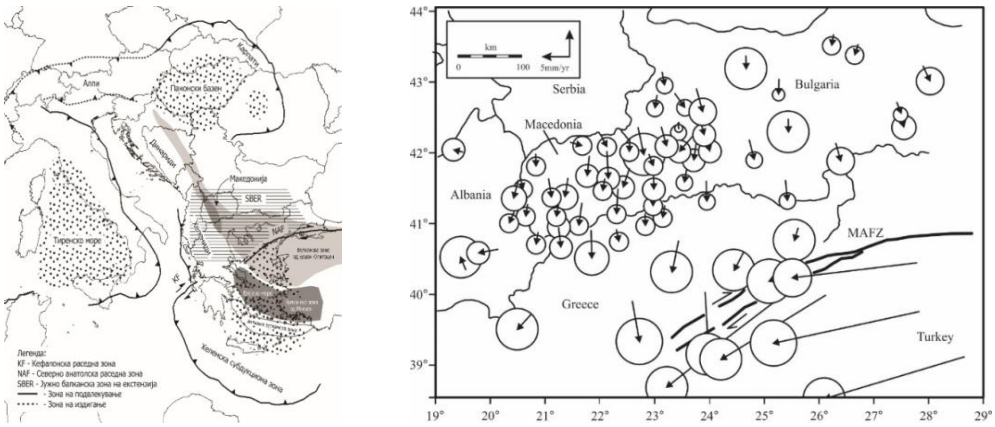


Figure 4: Tectonic extension regime for the territory of South Balkan.
a) Generalized tectonic map of the wider Balkan region *(Dumurdzanov et al., 2005)*
b) Results from GPS measurements done for Macedonia *(Burchfiel et al., 2006)*

The results from the GPS velocity measurements (Fig. 4b) show that the entire territory of Macedonia moves south – southeast with a velocity of 2 to 4 mm per annum. Such orientation and velocity of motion of the extension represents a potential for release of accumulated energy through activation of older, or formation of new, east-west to northeast-southwest superimposed fault structures that represent the foci of the present and could be the foci of future stronger earthquakes (Fig. 5). Due to the change of tectonic stresses in the western part of Macedonia, the seismically active zones change their predominant north – south stretching direction into northwest-southeast direction.

Hence, ten potentially active seismic zones with variable potential for generation of destructive earthquakes are generally distinguished on the territory of Macedonia and in its neighboring regions. They are schematically presented in Fig. 5, according to more significant toponyms. It is herewith noted that these zones are characterized by an increased potential for accumulation of energy that is released, in different time periods and depending on the characteristics of the zone, in the form of a seismic energy causing earthquakes. Unfortunately, due to the non-existence of a sufficient number of historical data, the recurrence of earthquakes in most of these zones cannot be defined with a sufficiently high reliability, despite the existence of different mathematical models for earthquake prediction.

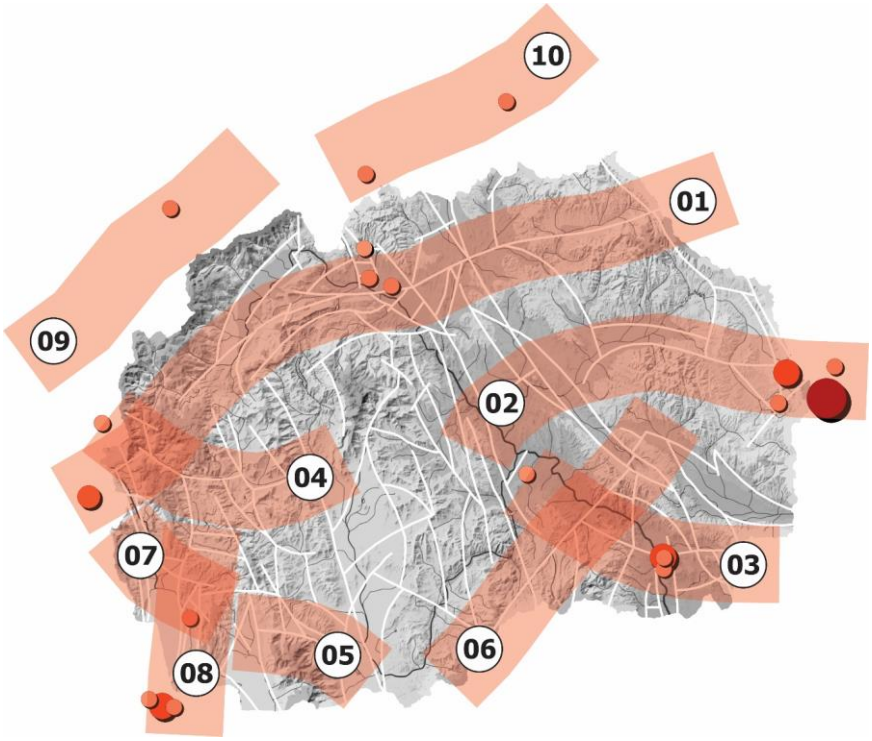


Figure 5: Potentially active fault zones as a result of tectonic extension processes
(The presented earthquakes are with $M_L \geq 6.0$)
Legend: 01) Kjustendil-Kriva Palanka-Kumanovo-Skopje-Gostivar-Mavrovo-Debar-Elbasan-Valona; 02) Kresna-Pehchevo-Vinica-Shtip-Stobi-Veles; 03) Valandovo-Gevgelija; 04) Kichevo; 05) Bitola-Prespa-Demir Hisar; 06) Nidze-Mrezhichko-Demir Kapija-Serta-Radovish; 07) Ohrid-Struga; 08) Peshtani-Korcha; 09) Prizren; 10) Uroshevac.
(By the courtesy of: Dumurdzanov, Milutinovic and Salic, 2016).

SEISMIC ACTIVITY OF THE OHRID REGION

The wider region of the Ohrid Lake is associated mainly with two epicentral areas 7 and 8, i.e. Pestani-Ohrid-Struga and the south part of the Ohrid-Korcha.

Peshtani-Ohrid-Struga epicentral area is represented by the Ohrid valley that subsides between the surrounding adjacent terrains which are typical horsts uplifted for more than 1,500-2,000 meters. This epicentral area is intersected by tectonic active faults that most frequently run in northeast-southwest and east-west direction approximately. Some of these faults are completely or partly expressed in the relief. The seismic activity of this epicentral area is conditioned by a number of faults: the Peshtani-Petrino faults that run along the east edge of the Ohrid depression, the Jablanica fault stretching along the west edge of this depression and the Drim and Sateska faults running to the north of this depression. All these faults intersect with transverse secondary faults (Fig. 6b). The vertical displacements along the deep Pesahtani-Petrino fault and the Jablanica fault amount up to 1,500 meters. In addition to the vertical dis-

placements that are the main carriers of seismicity for these faults, there are also lateral (horizontal) displacements from the right, in submeridian direction.

The strongest earthquakes that occurred (Table 1; Fig. 6, a and b) in this epicentral area in the period prior to 1900 and in the period 1901-2016 were those in the year of 527 with M_L=6.1 and epicentral intensity of I_0=IX degrees; 1905 and 1964 with magnitudes M_L=5.3 and M_L=5.0 and epicentral intensities of I_0=VII degrees according to the European Macroseismic Scale EMS-98.

Table 1: The strongest earthquakes in the Peshtani-Ohrid-Struga epicentral area prior and after 1901

Year	Month	Day	Hour	Min.	Sec.	φ	λ	h(km)	ML	Io
The strongest earthquakes prior to 1901										
527	00	00	00	00	0	41.10	20.79	0	6.1	IX
1893	05	02	07	00	0	41.10	20.80	0	5	VII
1893	05	02	15	15	0	41.09	20.80	0	5.6	VIII
The strongest earthquakes after 1901										
1905	04	04	10	24	41.8	41.16	20.82	25	5.3	VII
1964	12	09	19	06	16.3	41.06	20.81	15	5	VII
1962	09	17	19	44	46.7	41.17	20.74	18	4.6	VI
1964	12	09	18	28	34.4	41.00	20.79	10	4.6	VII
1911	03	05	00	55	0	41.00	20.69	15	4.4	VI-VII
1954	04	19	05	37	0	41.14	20.77	18	4.4	VI
1932	03	24	01	35	0	41.02	20.74	14	4.2	VI
1906	11	29	08	40	0	41.00	20.80	15	4.1	VI
1965	02	12	04	52	58.3	40.99	20.83	15	4	VI

The activity of the south parts of Peshtani-Petrino faults and the Jablanica fault defines the epicentral area so called the South Part of the Ohrid Lake. This area is characterized by high seismic activity (frequent earthquakes with magnitudes below and over M_L=4.0) and a number of strong earthquakes that happened in the past. The strongest earthquakes that occurred in this epicentral area in the period prior to 1900 and the period 1901-2016 date back to 1896 with a magnitude of M_L=5.6 and epicentral intensity of VIII degrees, 1906 with a magnitude of M_L=6.0 and epicentral intensity of VIII degrees, 1911 with a magnitude of M_L=6.7 and epicentral intensity of IX degrees and 1912 with a magnitude of M_L=6.0 and epicentral intensity of VIII degrees according to the European Macroseismic Scale EMS-98, respectively.

According to the data available at the Seismological Observatory of PMF-UKIM, by 18th June 2017, the seismicity in the Peshtani-Ohrid-Struga epicentral area was characterized by the occurrence of earthquakes of low magnitudes and rare occurrence of earthquakes with moderate to moderately strong magnitudes. The earthquakes that occurred were characterized by depths of about 25 km (upper, granite layer of the earth's crust) and most frequently a depth of 15 km. Since the 527y earthquake whose magnitude was estimated at 6.1, there has not been an earthquake of the same or higher magnitude. That earthquake can therefore be considered as the strongest earthquake that has occurred in the Peshtani-Ohrid-Struga epicentral area in a 2000 years period.

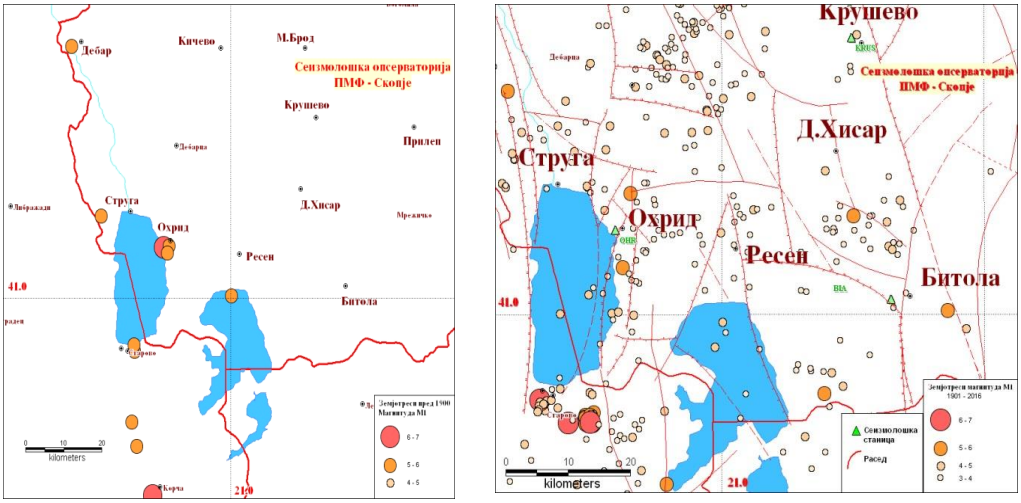


Figure 6: Earthquake epicenters in the Peshtani-Ohrid-Struga epicentral area
a) Period: Prior to 1900. b) Period: 1900-2016.
Elaborated by: Chernih and Drogreshka, Data: Seismological Observatory (UKIM-PMF).

In accordance with the latest investigations for assessment of the seismic hazard for the territory of Macedonia (Fig. 3b), it can be expected that this epicentral area will be exposed to macroseismic effect of VII-VIII degrees according to EMS-98[16] for a return period of 95 years (PGA=0.15g), or IX degrees according to EMS-98 for a return period of 475 years (PGA=0.30g).

A series of tectonic earthquakes started in the Peshtani-Ohrid-Struga epicentral area on 18th June 2017 (Fig. 7). The strongest earthquake occurred on the 3rd July 2017, at 13:00 h and 18 min local time. As defined by the Seismological Observatory at PMF-UKIM, this earthquake was characterized by a local Richter magnitude of M_L=4.9 and an epicentral intensity of about seven degrees according to EMS-1998. The epicenter of this earthquake was 10km east from Ohrid city, in the vicinity of the village of Skrebatno. The earthquake caused panic among the citizens of Ohrid, Struga and Resen as well as the surrounding villages.

[16] EMS-98: European Macroseismic Scale of Intensity

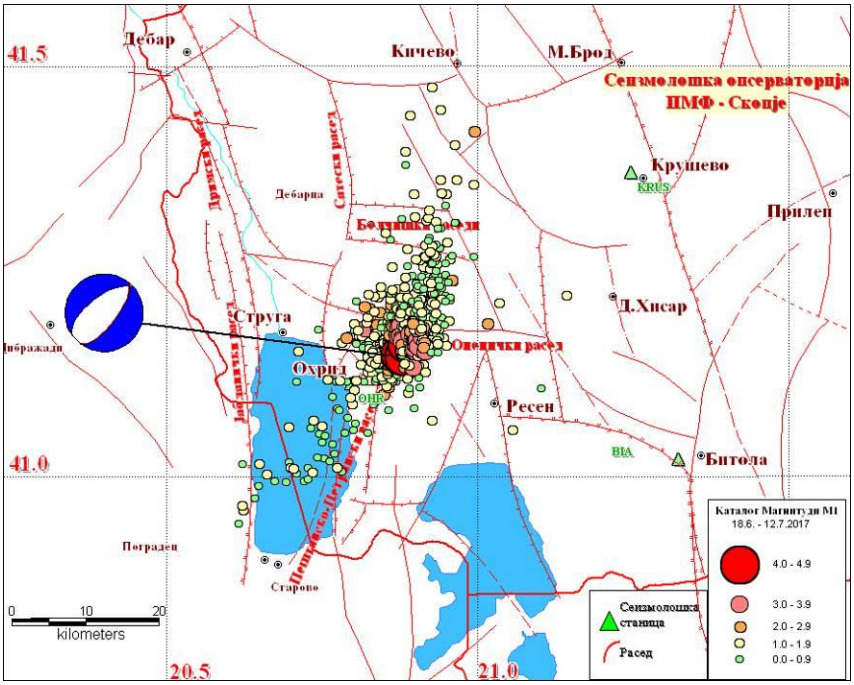


Figure 7: Earthquake epicenters in the Peshtani-Ohrid-Struga epicentral area in the period 18th June – 12 July 2017, along with the earthquake focus mechanism (*BeachBalls*)
Elaborated by: Chernih, Drogreshka and Pekevski, Data: Seismological Observatory (UKIM-PMF).

GEOLOGICAL SETTINGS

During the recent series of earthquakes in the Ohrid area, the media were flooded with speculations about the activation (reactivation) of a volcano at the village of Kosel. However, the earthquakes that occurred can, in no way, be associated with the occurrence of a volcano. In this case the subject of concern was the break out of underground gasses from a number of holes (Fig. 8). For a longer time, the small quantities of H_2S[17] have led to the opinion that the phenomenon should be referred to as volcanic solfatara, i.e., "volcano". This is wrong since, according to the definition, solfatara represents a discharge of volcanic gases upon the surface. These are composed of water steam and mainly H_2S, SO_2[18], CO_2[19], with temperatures of 90-250°C. At the village of Kosel and along the entire fault, there are no traces of volcanic rocks, which additionally proves that a volcano is not the cause. The whitening and the disintegration (alteration) upon the surface that occur in the surrounding Paleozoic shales and other rocks are caused by the low contents of H_2S that, in contact with rain waters, create a diluted sulfuric acid that erodes and alters the surrounding rock masses. Hence, the holes at the village of Kosel do not represent phenomena associated with volcanic activity, but a space where gases of unknown origin break out from the depth at a number of places. According to the

[17] H_2S: Hydrogen sulfide
[18] SO_2: Sulfur dioxide
[19] CO_2: Carbon dioxide

composition of the gases characterized by dominant content of CO_2 and negligible presence of H_2S, as well as their low temperatures, the phenomenon is more likely to be associated with mofeta – discharge of dry CO_2 of different origin, with temperature of up to 100°C. It is possible to associate these gases with the diapir gypsum masses on the Deshat (Debar) mountain where there are geothermal springs with low content of H_2S (Kosovrasti spa and Debar spa).



Figure 8: Hole resulting from a mofeta in the village of Kosel
Source: https://mk.wikipedia.org/wiki/Косел.

The Ohrid epicentral area along with Skopje, Debar, Gevgelija and Pehchevo areas are characterized by the highest seismic hazard in Macedonia (Fig. 3b). Since the modern world science has so far not defined a precise method for prediction of earthquakes, one cannot say with certainty when such an event will occur and with what magnitude. What science has done so far is development of a great number of mathematical models based on statistic computations which define the seismic hazard for a certain region/location through a defined level of probability of occurrence of earthquakes within a certain time period. Being aware of the existence of the seismic hazard and its scale, what should be intensively and permanently worked on, are the measures and activities for seismic risk reduction through construction of seismically resistant structures and development of a resilient society that will be able to manage the challenges arising from the seismic hazard.

Scientific-research and engineering-applicative projects are permanently realized at the Seismological Observatory and the Institute of Earthquake engineering and Engineering Seismology (IZIIS) at UKIM for the purpose of acquiring new knowledge on seismicity and behavior of structures in order to take corresponding measures for seismic risk reduction. More precisely, for the purpose of exploring the seismic characteristics of the Ohrid epicentral area, the mechanisms of seismic wave propagation and the effect of the surface deposits upon the frequency-amplitude modification of the regional seismic motions and response of structures, as early as in 1976, IZIIS installed a 3D (three-dimensional) network of 19 three-componential accelerographs for real time monitoring of strong earthquakes that was the first of this kind in Europe and one of the first in the world (8 accelerographs in boreholes with a depth of 9÷125m; 4 accelerographs on ground as well as 6 accelerographs on a selected ten-storey

residential structure and 1 accelerograph on a free rock location)., Upgraded and modernized in 2009, the Ohrid 3D strong motion network was one of the most visionary ones, but also the most costly projects of IZIIS.

Out of the three parameters that quantify the earthquake prediction (location, intensity and time), the population as well as the media are most frequently and exclusively interested in obtaining information about when a strong earthquake will happen. Although the stated information is useful for taking certain systemic preventive measures as well as raising the preparedness of the systems for protection and rescue, time as a prognostication parameter does not have that exclusiveness for the economy of a country and the engineering practice. Namely, systemic, technically consistent and economically sustainable protection of the population and created values against strong and catastrophic seismic effects started immediately after the Skopje earthquake, i.e., in September 1963 (Seismic Regulations of SRM[20]), that were replaced by the Federal Regulations, i.e., Temporary Technical Regulations for Construction in Seismic Areas in September 1964. In June 1981, the regulations of 1964 were replaced by updated ones which, with some negligible modifications and amendments, have been valid until today and will be valid until the introduction of the Eurocodes. The common denominator of the stated regulations is that structures are designed to suffer any kind and intensity of damage, but not collapse under the maximum expected (not maximum possible) seismic effect considering that failure of structures causes fatalities and deadly injuries. In fact, this concept, is incorporated also in all world regulations for design and construction in seismic areas, is known as "life safety". In Macedonia, it has been implemented since September 1963.

The difference among the stated regulations is the extent to which depending on the typology of structures, damages occur and the gradient by which they are increased with the increase of the seismic forces. Coupled, both criteria define the technical-administrative level of the nationally acceptable seismic risk by which the state and the society defend themselves against seismic catastrophes. The prescribed level of nationally acceptable seismic risk is the minimum under which no design engineer and developer may design, i.e., construct. However, what the regulations allowed, allow and stipulate, is the discretional right of any investor/owner to invest in any level of seismic protection greater than the nationally accepted level, i.e., the prescribed seismic risk.

One of the positive steps that have recently been taken by the Government of R. Macedonia in the domain of protection of the population and the created values, i.e., seismic risk reduction, were the modifications of the Law on Construction in 2013 by which control of the process of design and construction of the structures was considerably intensified. Namely, since 2013, a compulsory document for issuance of construction permits has been a positive opinion about the mechanical resistance, stability and seismic protection of the structure as well as a positive opinion about the as-built level of mechanical resistance, stability and seismic protection of the structure that must be possessed by each investor prior to putting a constructed structure into operation.

The prognostic parameters of location and intensity of expected seismic effects are known to the competent institutions in Macedonia. Elaborated and updated on this basis are seismic zoning maps (Fig. 3) that represent the basic document that enables definition of the design seismic force, i.e., realization of the national strategy regarding acceptable seismic risk and

[20] SRM: Socialistic Republic of Macedonia

protection of the population and the created values against the seismic effects. Having in mind the discussed strategy, the time of occurrence of earthquakes as a predictive parameter becomes irrelevant considering that an efficient and technically consistent as well as economically justified protection of structures against seismic effects also enables protection of their contents, including the human as the greatest ethical value.

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СЕИЗМИЧКА ОПАСНОСТ СО ОСВРТ НА СЕИЗМИЧКАТА АКТИВНОСТ ВО ОХРИДСКОТО ЕПИЦЕНТРАЛНО ПОДРАЧЈЕ ВО ПЕРИОДОТ ЈУНИ-ЈУЛИ 2017 ГОДИНА

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ИЗВОД

Во периодот јуни-јули 2017 година, Охридското епицентрално подрачје манифестираше сеизмичка активност која започна на 18 јуни 2017 г. изразена преку серија на слаби до умерени земјотреси. Најсилниот од нив се случи на 3 јули 2017 г., во 13 часот и 18 минути по локално време, со локална Рихтерова магнитуда ML=4.9 и епицентрален интензитет околу седум (VII)

степени според EMS-1998. Епицентарот на овој земјотрес се наоѓаше на 10km источно од градот Охрид, во непосредна близина на с.Скребатно. Земјотресот предизвика паника меѓу жителите на Охрид, Струга и Ресен како и на околните села.

Епицентралното подрачје Пештани-Охрид-Струга е претставено со Охридската котлина, која тоне помеѓу околните соседни терени кои се типични хорстови издигнати на повеќе од 1,500-2,000 метри и е испресечено со тектонски активни раседи најчесто ориентирани приближно долж правците североисток–југозапад и исток–запад. Тоа се Пештанско-Петринските раседи и Јабланичкиот расед. Ова подрачје се одликува со висока сеизмичка активност каде во минатото се случиле повеќе деструктивни силни земјотреси. Најсилните во периодот пред 1900 г., и периодот 1901-2016 г. датираат од 1896 г. со магнитуда ML=5.6 и епицентрален интензитет VIII степени, 1906 г. со магнитуда ML=6.0 и епицентрален интензитет VIII степени, 1911 г. со магнитуда ML=6.7 и епицентрален интензитет IX степени и 1912 г. со магнитуда ML=6.0 и епицентрален интензитет VIII степени според Европската макросеизмичка скала EMS-98, соодветно.

Согласно последните истражувања за оцена на сеизмичката опасност на територијата на Македонија може да се очекува дека ова епицентрално подрачје ќе биде изложено на макросеизмичко дејство од VII-VIII степени според EMS-98 за повратен период од 95 години (PGA=0.15g) или IX степени според EMS-98 за повратен период од 475 години (PGA=0.30g).

Во таа насока, во Сеизмолошката обсерваторија и Институтот за земјотресно инженерство и инженерска сеизмологија (ИЗИИС) при УКИМ, перманентно се работат научно-истражувачки и инженерско-апликативни проекти со цел стекнување на нови сознанија за сеизмичноста и однесувањето на конструкциите, а со цел превземање на соодветни мерки за намалување на сеизмичкиот ризик.

Прогностичките параметри локација и јачина на очекуваните сеизмички дејства им се познати на надлежните институции во Македонија. Врз основа на тоа се изработувани и се ажурираат карти на сеизмичко зонирање (Слика 3) кои се основен документ со кој се дефинира сеизмичката проектна сила, односно реализира националната стратегија на прифатливиот сеизмички ризик и заштита на населението и создадените вредности од сеизмичките влијанија.