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SEISMIC RISK IN BOSNIA AND HERZEGOVINA BASED ON BUILDINGS' VULNERABILITY

Abstract:
The region of South-East Europe is characterized by one of the most complex seismotectonic features in the World. Bosnia and Herzegovina is located in the heart of this region. The world is facing an increasing number of natural disasters among which earthquakes are on the top of the list. After extreme temperatures, it is earthquakes that cause the largest amount of deaths. To obtain an overview of the expected human and economic losses seismic risk assessment methods are used. In this paper, an example of a rapid assessment method is presented with the usage of the new hazard seismic map and its presentation, and census data for Bosnia and Herzegovina. Cities with a high-risk level are identified needing further detailed analysis.

Keywords: seismic risk assessment, seismic hazard map, BIH, urban areas

СЕИЗМИЧКИ РИЗИК У БОСНИ И ХЕРЦЕГОВИНИ НА ОСНОВУ ОШТЕТЉИВОСТИ ЗГРАДА

Сажетак:
Регија Југоисточне Европе има једну од најкомплекснијих сеизмотектоника на свијету. Босна и Херцеговина је смјештена у срцу ове регије. Свијет је суочен са све већим бројем природних катастрофа међу којима су земљотреси на врху листе. Након екстремних температура потреси су ти који узрокују највећи број жртава. Како би се добио преглед очекиваних економских и људских губитака користе се методе процјене сеизмичког ризика. У овом раду приказан је примјер брзе методе за процјену ризика уз примјену нове карте сеизмичког хазарда и њене израде, и података из пописа становништва Босне и Херцеговине. Идентифицирани су градови високог нивоа ризика који захтијевају даљњу детаљну анализу.

Кључне ријечи: процјена сеизмичког ризика, карта сеизмичког хазарда, БИХ, градска подручја

1. INTRODUCTION

Apart from floods, fires, and volcano eruptions, earthquakes are one of the most devastating natural phenomena that can be defined as frightening and disastrous phenomena [1]. This is confirmed with the data throughout the 20th century where the number of casualties caused by earthquakes was over 1.5 million due to the failure of buildings, this is 90% of direct deaths [2].

To determine the seismic risk of a particular region it is necessary to obtain necessary data about the overall region regarding seismicity, general properties and vulnerability features of the buildings, and exposure of the population. In this respect, the information that is needed is the seismic hazard map, the main features of buildings and the exposure of the population. To have more detailed information one needs to upgrade the fundamental information with the specific features, e.g. soil characteristics, age of the population, gender, etc. The seismic risk has increased in the urban regions due to the constant migration of people from rural to urban cities, leading to the concentration of citizens in zones that might be prone to earthquakes. On the other hand, the old building stock without adequate maintenance and inadequate seismic features increase the vulnerability. To be able to make priorities and identify regions that should be assessed in more detail it is of the utmost importance to conduct a rapid assessment of the existing building stock.

The seismic risk assessment in Bosnia and Herzegovina is in its initial stage. It is only in 2018 that the first seismic hazard map based on the peak ground acceleration was created replacing the seismic map based on the intensity and presented by the Mercalli–Cancani–Sieberg scale. In 2020 Ademović et al. [3] conducted a rapid seismic assessment for Bosnia and Herzegovina. In this paper, the new hazard map is presented together with the first rapid assessment method done in Bosnia and Herzegovina.

2. RELATIVE SEISMIC RISK

2.1. Seismic Hazard Map

The new Hazard Map for Bosnia and Herzegovina resulted as one of the outcomes of the cooperation project "Support of Capacities of the Institute for Standardization of Bosnia and Herzegovina in the Area of Implementation of EUROCODES" that was financed by the Czech Republic. Local experts and experts employed by UNMZ Czech Office for Standards, Metrology and Testing were involved in the entire process. Detailed information can be found in the paper [4] which is currently under review.

In this study two seismotectonic models were used, one areal and one fault model. The data that was used in this process was the earthquake catalogue (seismological data), information about the active faults and geological units (tectonic data).

Earthquake catalogue of Bosnia and Herzegovina has been drafted by Snježana Cvijić Amulić from the Republic Hydrometeorological Service of Republic of Srpska, within the preparatory work for an edition of the national annex to the BAS EN 1998-1 [5]. The catalogue covers a period from the year 306 to 2015 covering the entire territory of Bosnia and Herzegovina and surroundings up to about 100 km. The catalogue consists of 1944 earthquake records of M_w magnitude from 3.5 to 7.1. The map of earthquake epicenters is shown in Figure 1. The strongest event was the so-called "Ragusa earthquake" (today's Dubrovnik) which occurred on 6th April 1667. This event is of great importance for the southern part of Bosnia and Herzegovina territory, since it significantly affects the seismic hazard assessment. The latest assessment of this event has been done Albini [6] and subsequently by Markušić et al. [7]. For computing the seismic hazard it was necessary to eliminate the foreshocks and aftershocks from the catalogue, i.e. to carry out a procedure of declustering. This was done with the application of the automated algorithm developed by Hakimhashemi and Grünthal [8]. This is a statistical approach based on a deviation criterion, which applies to stationary, nonstationary, and even multimodal nonstationary seismicity rates. The preceding methods used a Poisson process, as a predefined stationary pattern for the seismic rate, or a specific distribution for determination of the catalogue completeness. The new method is simple to apply, as the only parameter used for determining the completeness time is the variance of earthquake interevent times [9].

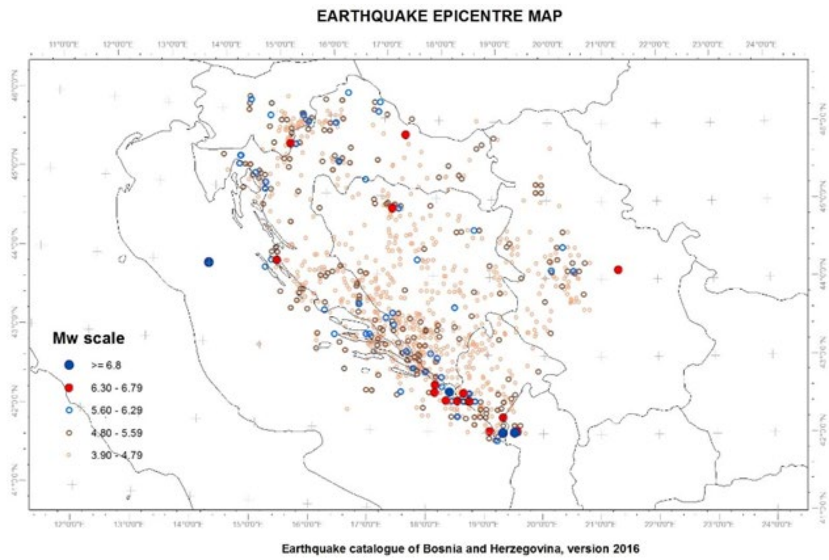

Figure 1. *Map of earthquake epicenters [5]*

Two seismotectonic models were created and used during the seismic hazard computation. The first model was based on an approach, where the source zones of the size of hundreds of km^2 are delineated using the depicted earthquake catalogue. Areas with scattered weak events (in any case lower than M_w magnitude 5) are pronounced as the zone with diffuse seismicity. An advantage of this approach (using wide source zones) is an easier and more accurate determination of the distribution parameters of the source zones – the *b* parameter of the Gütenberg-Richter distribution or *a* parameter, which is defined as a mean value of the earthquake occurrence in the time unit with magnitude higher than 0.0. As a result of this approach, an areal model was obtained. On the other hand, accepting the theory that strong earthquakes are nearly always connected with an activity of the particular seismogenic fault, it is necessary to delimit the source zone as a linear zone representing the individual significant seismogenic fault or fault system. This approach resulted in the linear source model. In this study, ground type A was taken into account characterized by the shear wave velocity $v_{s,30}$ = 800 m.s^{-1} for peak ground acceleration (PGA) values presented in the resulting seismic zoning maps.

The Probabilistic Seismic Hazard Analysis (PSHA) was calculated by the OpenQuake Engine, developed by the Global Earthquake Model Foundation's (GEM). It is state-of-the-art, free, open-source and accessible software collaboratively developed for earthquake hazard and risk modeling. The calculation was based on the logic tree which was able to capture and quantify the epistemic uncertainty associated with the inputs to PSHA and enabled the estimation of the resulting uncertainty in the hazard. More details can be found in [4] that is under review.

As a final output new seismic hazard maps based on the peak ground acceleration were obtained for return periods (95, 475 and 2475 years) and different percentiles (16% percentile; 50% percentile; mean value; 84% percentile). The map which is used in the rapid risk assessment is presented in Figure 2.

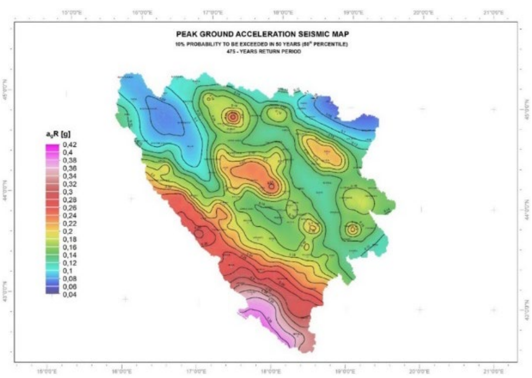

Figure 2. *Seismic hazard map for Bosnia and Herzegovina (475 years) in the function of PGA [3, 5]*

2.2. Exposure of Population and Building Vulnerability

The information from the census data [9] from 2013 was used for the determination of population exposure and building's vulnerability. The feature that was taken into account concerning population was the population density (Figure 3).

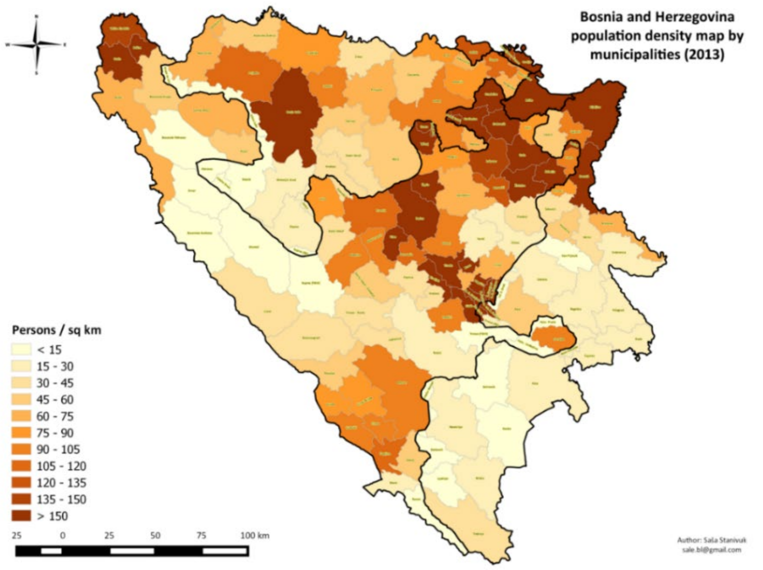

Figure 3. *Population density map by municipalities in Bosnia and Herzegovina from Census 2013 [3]*

The features that were take into account in the process of determination of the seismic vulnerability of buildings were the construction age as this is directly connected to the enforced codes and regulations valid at a certain time, the material of the loadbearing structure and the number of storeys as it has a direct implication on the response of the structure on the earthquake motion. It is quite difficult to determine the vulnerability of the building before an earthquake as one is dealing with many unknowns. In this respect, statistical probability methods have to be combined with the subjective expert judgment, however in these cases, one may argue rather mandatory. In total 1,078,156 buildings were taken into account which were classified depending on the construction age (Figure 4) which was connected to certain building codes. In total six groups were formed. The material was divided into three groups. The first group consists of structures made of stone, brick, and concrete, which makes up to 60% of all structures, the second group consist of reinforced concrete structures and steel frames which make more than a third of all the structures, and the remaining, around 4%, are wooden structures (Figure 5). With respect to the number of stories, 98.88% of all buildings are up to two stories, only 0.88% are building having four to six stories, and the remaining 0.23% are structure having more than 7 stories.

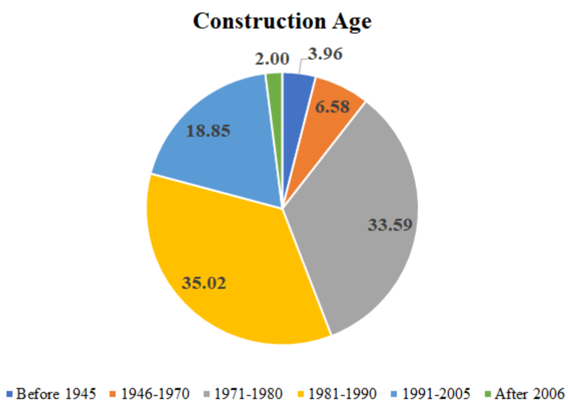

Figure 4. *Buildings in respect to their construction age given in percentage*

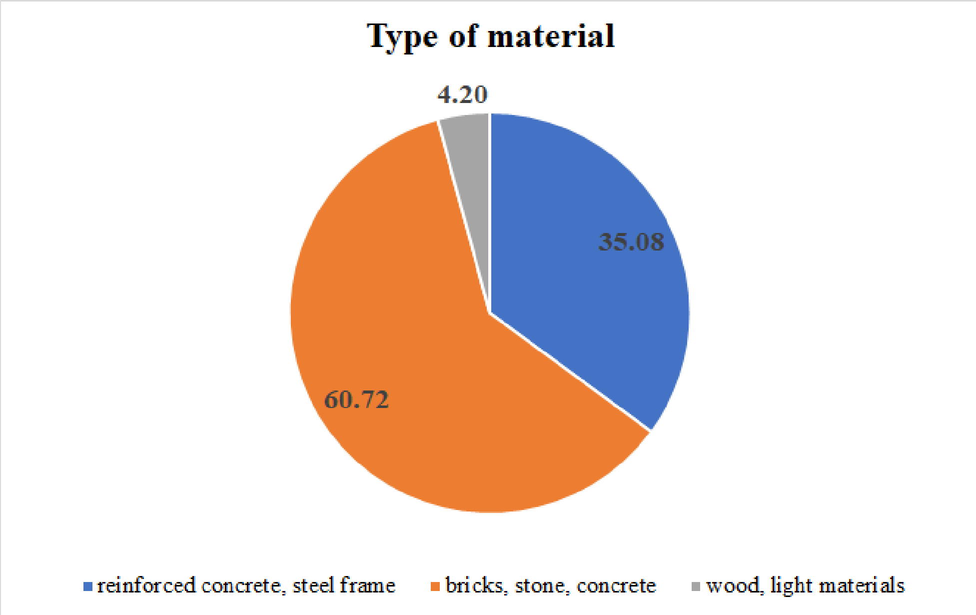

Figure 5. *Type of material of the structural system given in percentage*

2.3. Risk Assessment Methods

Depending on the available data and the purpose of the seismic risk assessment different methods can be applied. In the last years, seismic risk assessment of large cities has been done, from Kolkata City in India [10], Quebec [11] and Montreal [12] in Canada, to European cities like Sion and Martigny [13], Barcelona [14], Lorca [15], Athens [16]. In many of these cases, a large amount of different data was used. The collection of such a large value of data is possible in the case of some cities and mainly for developed ones. However, in the case of undeveloped countries with inadequate database and lacking information it is not possible to conduct very refine and detailed seismic vulnerability assessments.

However, in the case of limited resources and data, as well as lack of historical information regarding earthquake damages fast seismic risk assessment found its application especially for risk management in developing counties [17]. A rapid risk assessment was done for several cities like Eskisehir [18] which is located in the northwestern part of Turkey which is seismically quite active zone. In this case, a screening technique developed by [19, 20] was used. It has been shown that this is a simple and effective method for rapid seismic risk assessment of building stock in the urban cities. Additionally, rapid assessment methods can be used for single buildings. Işık [21] applied three rapid assessment methods for a single building that was damaged after the 2003 Bingöl earthquake. In his work, he used Japan Seismic Index Method, Canadian Seismic Screening Method, and Turkish First Stage Evaluation Method. The rapid seismic assessment method used for Croatia [22] was used as the basis for the development of a new i-rapid method for Bosnia and Herzegovina [3].

In this respect, risk is defined as a function of the convolution between hazard H_i and vulnerability V_e during and exposition period T.

$$Rie|_T = f(H_i \otimes V_{e)}|_T \qquad (1)$$

where ⊗ is convolution [23]. In that respect, the risk is seen as a product of the seismic hazard, building vulnerability, and population exposure.

The most frequently used function for determination of the fragility curves and seismic risk is the lognormal distribution function [24]. The cumulative seismic hazard impact factor which is a function of the peak ground acceleration is denoted as F_H and the function is presented in Figure 6.

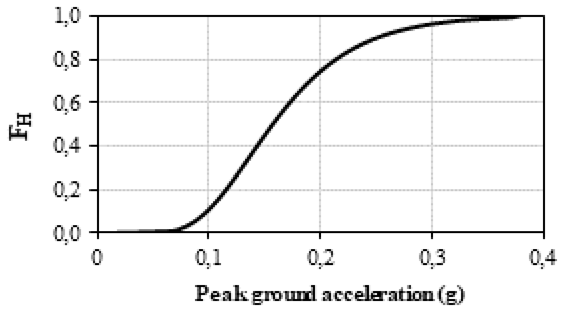

Figure 6. *Seismic hazard impact factor F_H for Bosnia and Herzegovina*

From equation (1) it is clear that a low seismic hazard does not automatically lead to low seismic risk and vice versa. If an area is densely populated and the structures are made in a period during which seismic regulations were not very strict, even locations with low PGA may lead to medium seismic risk. In that respect, these elements have to be elaborated. On one side the risk of buildings being damaged due to the earthquake action (Equation 2) and on the other the exposure of population which is connected to the population density (Equation 3).

$$R_b = F_H \cdot V_b \quad (2)$$

$$R_p = F_H \cdot E_p \quad (3)$$

The lognormal distribution function was used for each building class and weigh factors were taken into account to cover each class, with the application of the Pairwise Comparison Method (PCM). This method transfers the comparisons of all pairs of factors to quantitative weights under the matrix containing the pairwise comparison judgments for certain criteria (age of buildings for the vulnerability of buildings) [3]. The same principle was utilized for different types of material and number of stories. As a final result of these calculations, a relative seismic risk in Bosnia and Herzegovina was obtained (Figure 7).

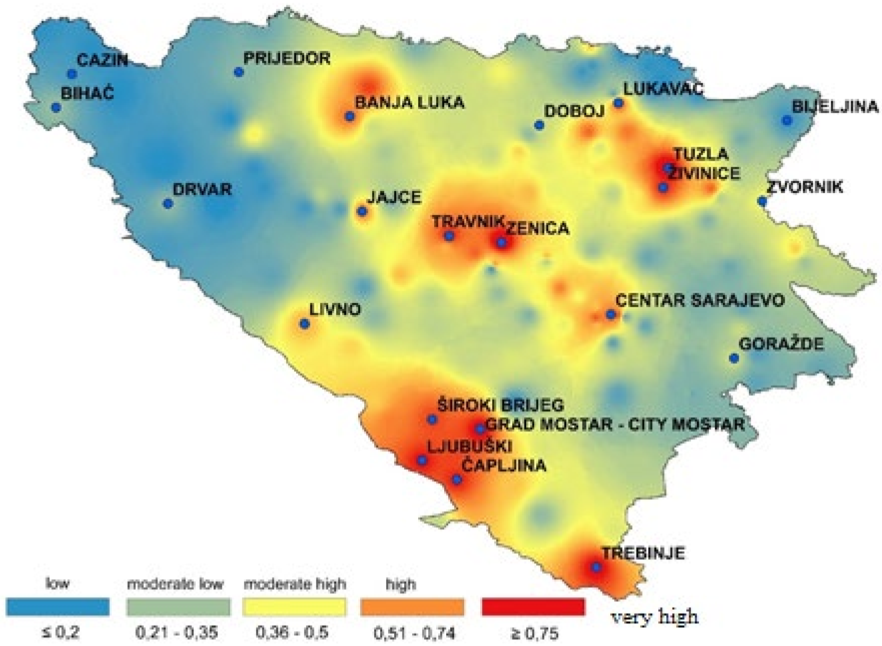

Figure 7. *Distribution of relative seismic risk in Bosnia and Herzegovina [3]*

From Figure 7 several areas are marked as areas of very high risk:

- The area around the city of Banja Luka
- The area around Jajce
- The area around Tuzla, Živinice, Lukavac

- The area around Zenica and Travnik
- The area around Sarajevo and Visoko
- The area around Livno
- A large area including cities Široki Brijeg, Mostar, Ljubuški, Čapljina and their surroundings
- The area around Trebinje

3. CONCLUSION

Until today no rapid seismic risk assessment was done for Bosnia and Herzegovina. The first research activity was conducted by Ademović et al. [3]. As Bosnia and Herzegovina is an earthquake-prone country, this is a very important step as it can be used as preliminary information for further studies and more detailed studies for the cities with higher seismic risk. Additionally, this information can be used for better preparedness for emergency response. This analysis identified cities and areas in Bosnia and Herzegovina which have a high risk of seismic actions and these cities and areas should be analyzed in more detail and with the application of a more detailed seismic assessment method. In the near future, it is planned to extend this new i-rapid analysis and to conduct detailed analysis in several cities of high exposure to earthquake actions.

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