A CONTRIBUTION IN SEISMIC RISK ASSESSMENT IN STRUMICA - A CASE STUDY FOR THE PHI “GENERAL HOSPITAL” STRUMICA

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The increase in the number of inhabitants in the cities as a result of increasingly pronounced rural-urban migration and their concentration in densely populated areas in modern societies, nowadays, has led to an increase in the need to be alert to the impact of catastrophic natural events, earthquakes in particular. The devastating earthquakes that have hit the territory of Europe in the last 20 years have led to an increase in interest and expansion of knowledge about the seismic vulnerability of buildings in Europe. In this study, a review of the seismic risk assessment in the city of Strumica (the largest town in the Southeastern planning region and the tenth largest city in North Macedonia [1]), regarding hazard, exposure, and vulnerability of buildings, with a focus on PHI “General Hospital Strumica” is presented. The proposed methodology for seismic risk assessment consists of defining hazard assessment method to estimate the maximum level of ground motion that could occur at the site, collecting and harmonizing available data for the existing build construction fund in the city and developing tools and methods, based on which an exposure model of the city is created and fragility models are applied to further estimate the expected damages to the buildings located in the city. The results will allow a better understanding of the level of vulnerability of the existing buildings in the analyzed region, emphasizing the importance of socio-economic variables. The collected database could be updated and further developed.

Keywords: seismic vulnerability, hazard, exposure, damages

1. INTRODUCTION

Looking back chronologically, the number of disasters worldwide in recent years has increased rapidly, causing more damage and deaths. Earthquakes, floods, landslides, and other natural disasters cause irreparable damage, threatening people's lives, crops material resources, and the built environment [2] [3]. With the rapid growth of earthquakes as natural disasters, their consequences are becoming more serious, including significant damage to buildings, existing infrastructure, and the societies themselves. To reduce the impact of earthquakes on engineering structures, a logical approach and assessment of the effects of earthquakes on buildings - and more importantly, on people - is required [4], [5]. To this end, various seismic risk assessment methods have been developed, by which the risk is measured. The first step in the seismic risk assessment process is to estimate the earthquake hazard in a given geographic area/region. For this study, two extreme earthquake scenarios from past earthquakes that affected the city were selected, with parameters of which hazard model is created: the Pehchevo-Kresna earthquake (1904) with a maximum rupture strength of 7.8 MCS and the Valandovo-Dojran earthquake (1931) with a maximum rupture strength of 6.7 MCS [6]. Then, based on the available data, building taxonomies for the building stock were created, using the taxonomy scheme of the Global Earthquake Model (GEM), which allows buildings to be classified according to several structural attributes, i.e., main construction material, number of stories, age of construction and seismic design level [7], and exposure model of the city was developed. The fragility assessment method was presented by choosing existing fragility curves for the building stock in the city which is expected to lead to creating damage maps of the city's stocks and analyzing uncertainties in earthquake risk assessment analysis. The applied methodology can be of particular interest to the national authorities as they implement new policies and strategies in the planning process.

2. SEISMIC HAZARD ASSESSMENT OF STRUMICA CITY

In this study, deterministic seismic hazard assessment (DSHA) is used as a method for estimating the maximum level of ground motion that could occur at a particular site [8]. To validate the seismic risk methodology for the city of Strumica and the PHI "General Hospital" two seismic scenarios are used, which represent the two most destructive past earthquakes that have affected the study area: the Pehcevo-Kresna (1904) Mw.7.8 earthquake and the Valandovo-Dojran (1931) Mw.6.7 earthquake [6]. The two events were simulated in OpenQuake Engine [9] as earthquake rupture scenarios. For both earthquakes, we used the ESHM20-Active faults model developed as an update of the European Database of Seismogenic Faults 2013 [10]. Strong ground motion modeling was performed using the ground-motion prediction equation (GMPE) by the Abrahamson EtAl2015Sinter model [11]. To account for local site conditions of Strumica City, the applied GMPE [11] uses as site parameters the Vs.30. i.e. the average shear wave velocity of the upper 30m of the soil profile, calculated from the total time needed for a shear wave to travel this 30 m. This parameter is contained in Site conditions North Macedonia that we use in our study as a required parameter for the earthquake rupture scenarios [12]. Figures 1 and 2 illustrate the spatial distribution of peak ground acceleration PGA (g) for the city of Strumica obtained from the Pehcevo-Kresna (1904) (Figure 1) and Valandovo - Dojran (1931) scenario (Figure 2) made with OpenQuake Engine, using the fault rupture model by ESHM20 [10], the Abrahamson EtAl2015Sinter GMPE [11] and the Vs.30 site parameter contained in Site Conditions North Macedonia [13]. It is observed that the PGA values estimated with the OpenQuake for the scenario Pehcevo-Kresna (1904) range between 0.198 g and 0.222 g and for the Valandovo - Dojran scenario range between 0.141 g and 0.159 g for the city of Strumica.

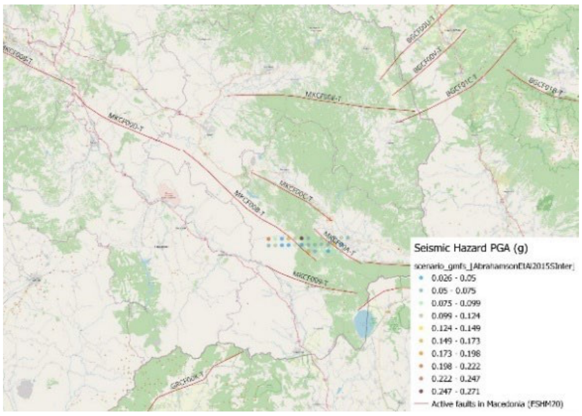

Figure 1. Pehchevo-Kresna Mw.8.7:PGA values obtained from scenario analysis with OpenQuake using the fault rupture model by ESHM20 [10]

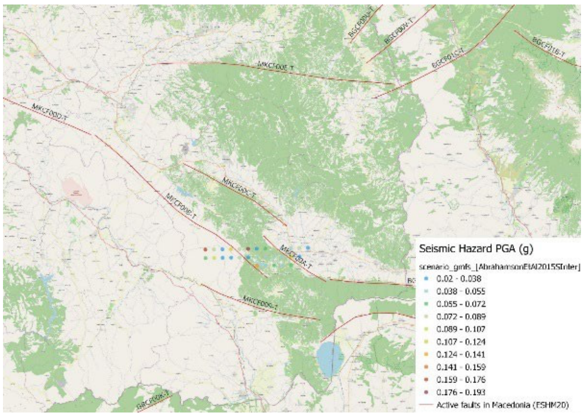

Figure 2. Valandovo-Dojran Mw.6.7.PGA values obtained from scenario analyses with OpenQuake using the fault rupture model by ESHM20 [10]

The range of ground shaking intensity according to the selected GMPE [11] shows that close to the fault we have a much higher intensity while the intensity decreases with increasing distance from the fault. What is important to mention is that each GMPE gives a very different prediction of the ground shaking because of the parameters contained [14].

3. EXPOSURE MODEL

3.1. A REVIEW OF EXISTING BUILDING TAXONOMIES IN THE CITY

A widely accepted qualitative definition of earthquake exposure is the tendency of a category of elements to be at risk of being damaged by potential earthquakes [15]. For large-scale assessments, to unequivocally demonstrate the assignment of a vulnerability model to an individual building, specific risk-oriented taxonomies are commonly applied. One of the most commonly used and also applied in this study is the taxonomy developed by GEM (Global Earthquake Model) [7], where single structures are described in detail from a functional and structural point of view. Using the building taxonomy scheme developed by GEM (GEM building taxonomy scheme) [7] the existing building stock in Strumica which contains a total of 4367 buildings is classified according to four (4) attributes: main constructional material, story height above the ground, year of construction (seismic code), or ductility of the building (Figure 3). The applied taxonomy used for creating an exposure model of the city is based on expert judgment, a combination of data collected by authorities, and field data collection.

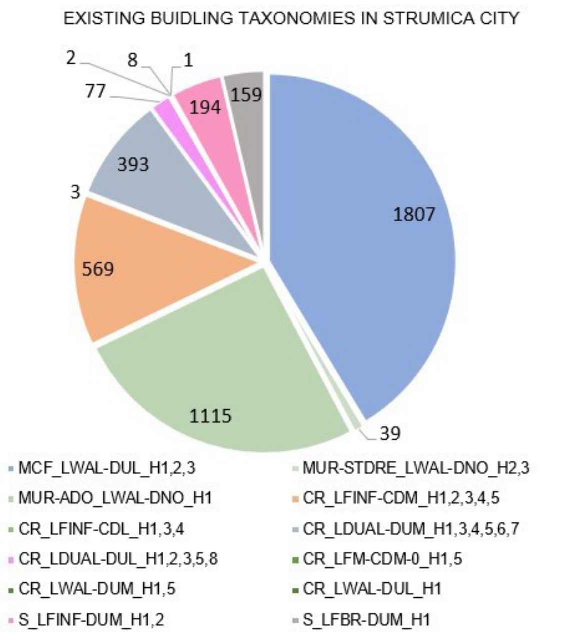

Figure 3. Displaying data from the Strumica database

Figure 4 Existing Building Taxonomies in Strumica Using QGIS classified by material and load-resisting structure

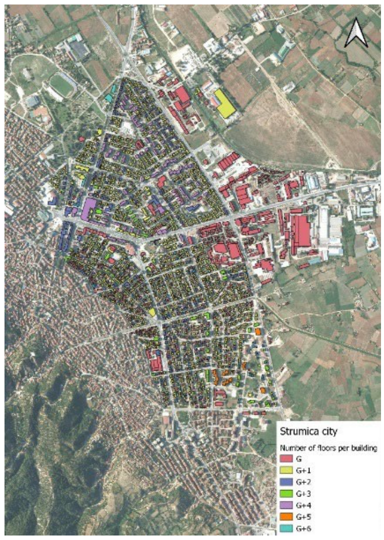

Figure 5. Existing Building Taxonomies in Strumica Using QGIS classified by the number of floors above ground

The obtained results for the building stock at a city level (4367 buildings) presented in Figure 3,4,5 show that in terms of construction material, masonry buildings are represented with a total number of 2961 buildings or 67.7%. Reinforced concrete buildings at the city level are represented by a total number of 1053 buildings or 34.4%. Steel constructions at the city level are represented by a total number of 353 buildings or 8.08%. Regarding the height of the buildings, the largest number of buildings at the city level: 1873 buildings are ground-floor buildings (G) (Figure 5). Regarding the ductility of the buildings, most of the analyzed buildings at the city level: 2181 buildings show low ductility (built in the period 1964-1981). Regarding the period of construction of the buildings and the implementation of the codes for seismic design, the largest number of buildings, or a total of 2184 buildings, were built in the period 1964-1981 (moderate code level) following the regulations for seismic design resistant buildings, adopted in 1964 (JUS39/64) [16].

3.2. BUILDING TYPOLOGIES FOR THE PHI "GENERAL HOSPITAL" STRUMICA

The first beginnings of the Hospital Campus are dated to 1970 [17]. To meet the increased demands of the growing city for healthcare facilities, from 1970 until today, 7 separate buildings as part of the pavilion-type hospital complex, were built: Infectious Disease Building (1), Administrative building (2), Dermatologic clinic (3), Main building (4), Admission - discharge (5), Physical therapy and rehabilitation with laboratory with pathology and Radiology (6), New Hospital wing (7). The taxonomy classification shown in Figure 6,7 was created online through GEM (Pavia) v.2.0 taxonomy of high-rise buildings according to the GEM building taxonomy [7]. Two important parameters such as structural cost for each building individually, a value obtained by using an Official form for determining the value of the building per m^2 prescribed in the Methodology for determining the value of the building [18], and an exact number of users/patients in each facility within the hospital complex at different times of the day, day/night/transit, obtained through field data collection and interviews with hospital campus employees were also used in creating a relevant exposure model. A general survey of the facilities at PHI "General Hospital" Strumica (Figure 6) shows that the total net building area belongs to RC buildings. In terms of building height (Figure 7), the hospital campus is dominated by G+1 buildings (1,2,3), but there are also ground-floor buildings (G) (5,6), and 5-story- buildings (4,7). The filed data collection process has shown that all the facilities in the PHI "General Hospital" Strumica (except the New Wing (7) which was built in 2021 and is still not in use) were built in the period 1964-1981, taking into consideration the first Seismic Design Code, the "Temporary Regulations for Construction in Seismic Regions", Official Gazette of SFRY No. 39/64, enforced in 1964 [16].

4. SEISMIC FRAGILITY CURVES FOR THE EXISTING BUILDING STOCK IN THE HOSPITAL COMPLEX

Assessing seismic fragility is an important step in determining the likelihood of seismic hazards [19]. Therefore, the methodology adopted in this study was based on the fragility curves derived from the database of existing fragility curves for European building classes [20] (classified using

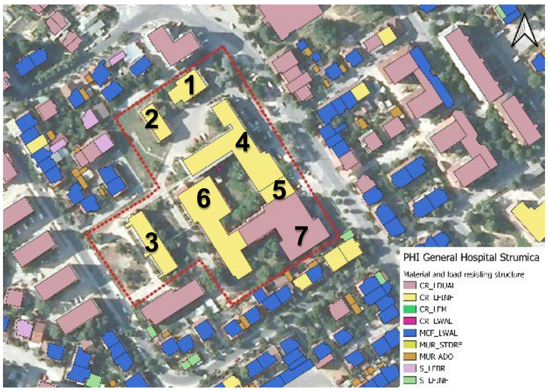

Figure 6. Existing Building Taxonomies in PHI "General Hospital" Strumca using QGIS classified by material and load-resisting structure

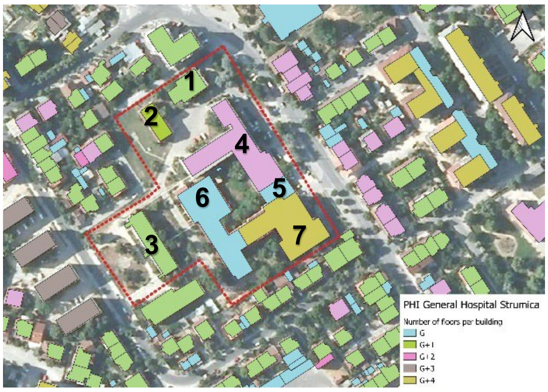

Figure 7. Existing Building Taxonomies in PHI "General Hospital" Strumca using QGIS classified by the number of floors above ground

GEM Building Taxonomy [7]) developed as part of the SERA project, using publicly available resources and information for 44 European countries, covering the territory of RNM. It is based on ground motion records from both active subduction and shallow tectonic situations [20] for the covering areas. For the Hospital complex, in particular, it was decided to apply the following fragility curves: first, the fragility curve developed for building taxonomy CR/LFINF by Kostov et al.[21] which contains 1-6 story CR buildings with infilled frames constructed after 1945, with a defined geographical origin Republic of Bulgaria (Figure 8) and the fragility curve developed for building taxonomy CR/LDUAL by Kappos et al. [22] with infilled dual systems with a defined geographical origin Republic of Greece (Figure 9). Both of them include building classes which seem to correspond well with the building stock of Strumica city. In the first curve, four damage states were considered ranging from light to complete damage, compared to the second one where 5 damage states were considered: from no damage (Grade 1) to complete damage (Grade 5). According to the building class properties, one intensity measure (PGA) has been considered. Both curves adopted in this study, adopt the same damage states and

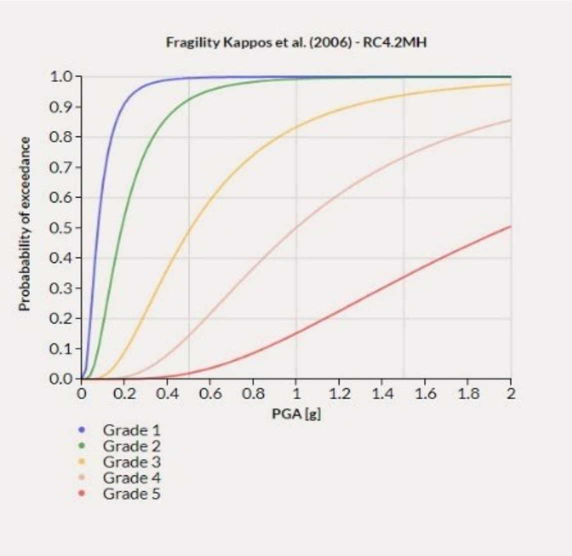

Figure 8. Existing fragility curve for structure class-building taxonomy CR_LFINF [21]

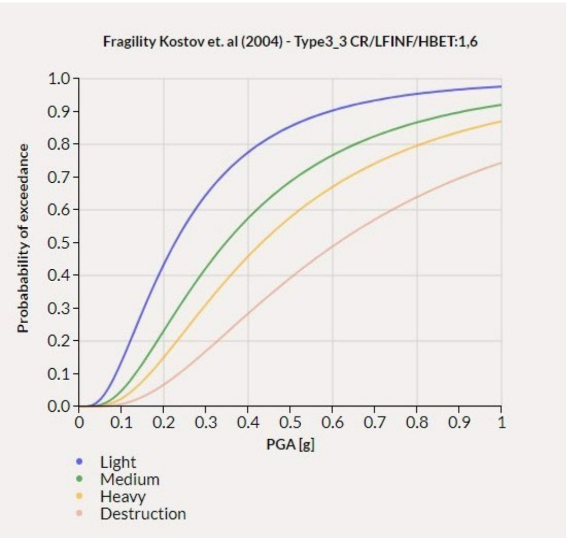

Figure 9. Existing fragility curve for structure class-building taxonomy CR_LDUAL [22]

fragility curves are derived in terms of peak ground acceleration.

5. CONCLUSION

Advanced disaster risk management recommends using risk-based data to develop strategies and measures based on scientific evidence [19]. Effective risk outcomes inform capacity building and management during the response and preparedness phases. The methodology presented in this study ensures the creation of a framework for further development of seismic risk analysis in the form of damage and loss maps for the existing building stock in the city. Based on seismic records from two seismic scenarios which represent the two most destructive past earthquakes that have affected the study area: the Pehcevo-Kresna (1904) Mw.7.8 earthquake and the Valandovo-Dojran (1931) Mw.6.7 earthquake [6], simulated in OpenQuake Engine software [14], as earthquake rupture scenarios, and with the use of the ESHM20- Active faults model as a layout, strong ground motion modeling was performed using the ground-motion prediction equation (GMPE) by the Abrahamson EtAl2015Sinter model [11] and the spatial distribution of peak ground acceleration PGA (g) for Strumica obtained from both scenarios was presented (Figure 1,2). After validating the seismic hazard methodology, the second step was to collect the building classes of interest. The output of the survey allowed us to identify the initial building classes in the Strumica database, and their classification according to the building taxonomy scheme developed by GEM [7] to be made. Collected data such as main building material, lateral load resisting system, period of construction and number of stories (height), structural cost, and occupants per building were used in the creation of the exposure model of the city, and through a process of vectorization and attribution of the real estate (objects) performed in two software platforms (CAD and GIS), analysis of the stock were made. The list of data can be further expanded to meet the requirements of the growing city in the future. In the final step, fragility models from the European Seismic Risk Model (ESRM20) [20] database, which comprises the building classes in the chosen area, was assessed and applied. The hazard, exposure, and fragility models, presented in this paper, can be applied to estimate the expected damages to the buildings located in Strumica city, for the Pehcevo- Kresna (1904) and Valandovo-Dojran (1931) earthquakes, respectively. The adoption and use of the described methodology can greatly contribute to increasing the resilience of cities.

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