GIS-based Seismic Risk and Loss Estimation platform for Cyprus

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ABSTRACT

Earthquakes represent a major natural hazard, that can cause substantial human and economic losses, leading to a negative impact on the economic welfare and resilience of communities in seismic-prone areas worldwide, including Cyprus. Considering the significant increase in losses recorded in earthquake-vulnerable areas during the last decade and the requirement for countries to establish tailored civil protection mechanisms to align with EU objectives, there is a pressing socio-economic necessity to create a comprehensive tool for assessing earthquake risks and estimating potential losses in Cyprus.

This paper highlights the urgent need for the development of an innovative Seismic Risk and Loss Estimation GIS-based platform for Cyprus in which the expected damage level and economic loss of the built environment including critical infrastructures and cultural heritage (monuments and sites) for various seismic scenarios will be estimated. This paper also presents the methodology to be followed for developing this platform that incorporates well-established seismic risk and loss estimation methodologies with GIS data, aiming to quantify and visualize the damage state, the risk of significant damage as well as the direct economic loss of infrastructure systems in the aftermath of earthquakes.

The Cyprus Seismic Risk and Loss Estimation GIS-based Platform is expected to have a positive scientific, economic, and societal impact and it can be used as an important decision tool for the policymakers, the building owners and for insurance companies.

Keywords: Natural Hazard, Earthquakes, Seismic Risk and Loss Estimation, GIS data.

1. INTRODUCTION

The EU is facing an increasing number of natural disasters. Among them, earthquakes are the second deadliest after extreme temperatures. Earthquakes can cause substantial human and economic losses, leading to a negative impact on the economic welfare and resilience of communities in seismic-prone areas worldwide. These include casualties and injuries as a result of collapsed/damaged structures, whereas impacts on the economy may be associated, among others, with monetary losses due to repairs in damaged structures, as well as the associated downtime. Due to the significant increase

Tenth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2024), edited by
A. Christofe, S. Michaelides, D. Hadjimitsis, C. Danezis, K. Themistocleous, N. Kyriakides, G. Schreier,
Proc. of SPIE Vol. 13212, 1321219 · © 2024 SPIE · 0277-786X · doi: 10.1117/12.3037318

in socioeconomic losses recorded in earthquake-vulnerable areas during the last decade, the field of earthquake risk assessment and management has received great attention both from the scientific community and decision-making authorities and from EU policies such as the new EU civil protection mechanism [1].

Addressing the urgent need for performing prevention, preparedness, and recovery actions due to earthquakes, the engineering community proposed various seismic risk assessment methods [2,3], prediction models [4,5,6], and tools [7]. [8]. The methods and tools that have been proposed so far are critical components of earthquake risk mitigation strategies in EU policies In addition, the increasing need of the stakeholders and building owners to predict and minimize potential earthquake-induced economic losses motivated the Pacific Earthquake Research (PEER) to develop a performance-based earthquake engineering framework (PBEE) [9,10]. This framework aims to quantify the performance decision variables (DVs), such as expected annual losses and/or downtime associated with damage repairs of infrastructure systems. These DVs can aid effective design and/or retrofit decisions early on in the conceptual design phase. After that several computer-aided tools have been developed within the past decade to facilitate the PBEE process such as FEMA. The state-of-the-art approach for risk assessment is the FEMA P-58 methodology [11]. Following the work of the Applied Technology Council (ATC) and FEMA, other methods have been further developed based on different approaches. Recently, Smerzini and Pitilakis (2018) [12] presented a prototype of seismic risk assessment in the city of Thessaloniki, Greece synthesizing earthquake ground motion by 3D physics-based numerical simulations. Recently, the Global Earthquake Model Foundation (GEM) has developed the OpenQuake engine [13], state-of-the-art open software, for global seismic risk modeling.

At the European level, several initiatives have focused on different components of seismic risk assessment and loss estimation. The SHARE [14] (Seismic Hazard Assessment in Europe) project (2009-2013) delivered a European-wide probabilistic seismic hazard assessment. An Earthquake Loss Estimation Routine (ELER) was developed under the NERIES FP6 project (2006-2010) [15] for rapid estimation of earthquake damages and casualties. The SYNER-G [16] (Systemic seismic vulnerability and risk analysis for buildings, lifeline networks, and infrastructures safety gain) project (2009-2013) developed an innovative methodological framework for the systemic assessment of physical as well as socio-economic seismic vulnerability at the urban and regional level. The NERA [17] (Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation) project (2010-2014) aimed at integrating seismic and engineering infrastructures to establish an effective network of European research infrastructures for earthquake risk assessment and mitigation.

Despite all the previous efforts and the wealth of knowledge and data generated by research, none of the initiatives focused on assessing the seismic risk, the damage prediction, and loss estimation for Cyprus. Considering the requirement for countries to establish tailored civil protection mechanisms to align with EU objectives, there is a pressing socio-economic necessity to create a comprehensive tool for assessing earthquake risks and estimating potential losses in Cyprus. Thus, there is an urgent need for developing an innovative Seismic Risk assessment and Loss Estimation GIS-based platform for Cyprus. This tool will be able to estimate the expected damage level and economic loss of the properties for a given scenario of earthquake.

This paper highlights the urgent need for the development of an innovative Seismic Risk and Loss Estimation GIS-based platform for Cyprus as previously mentioned. This paper also presents the methodology to be followed for developing this platform that incorporates well-established seismic risk and loss estimation methodologies with GIS data, aiming to quantify and visualize the damage state, the risk of significant damage as well as the direct economic loss of infrastructure systems in the aftermath of earthquakes. At the same time, this paper presents the expected socio-economic impact of this platform.

2. METHODOLOGY

In this part of the paper the methodology to be followed to develop a GIS-based Seismic Risk and Loss Estimation platform for Cyprus (as presented in Figure 1) is described. To develop this platform an interdisciplinary approach is required bridging structural engineering, earthquake engineering, geological science and GIS science. This platform must be incorporated the well-established seismic risk and loss estimation methodologies with GIS data, aiming to quantify, and visualize the damage state, the risk of significant damage as well as the direct economic loss of infrastructure systems in the aftermath of earthquakes. To develop this platform the following steps (Figure2) must be followed:

1. Determination of the sub-seismic zones in Cyprus based on local microzonation
2. Classification of the building stock in Cyprus in order to define the most common types of buildings.
3. Setting the Engineering Demand Parameters (EDPs) of each type of building in Cyprus
4. Defining the fragility curves of each building type in Cyprus

5. Assessment of the seismic risk and loss estimation of each building type in Cyprus
6. Validation of the seismic risk and loss estimation of each building type in Cyprus

Figure 2 provides a graphical representation of the steps following to develop this platform. The following subsections describe in detail the above-mentioned methodology.

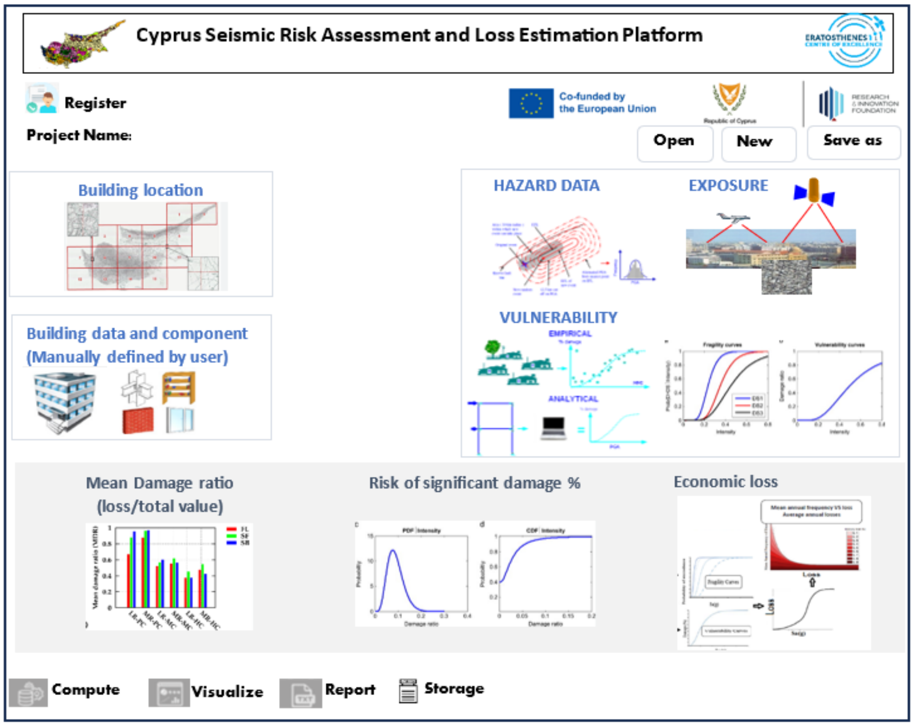

Figure 1: Graphical representation of the GIS-based Seismic Risk and Loss Estimation platform for Cyprus.

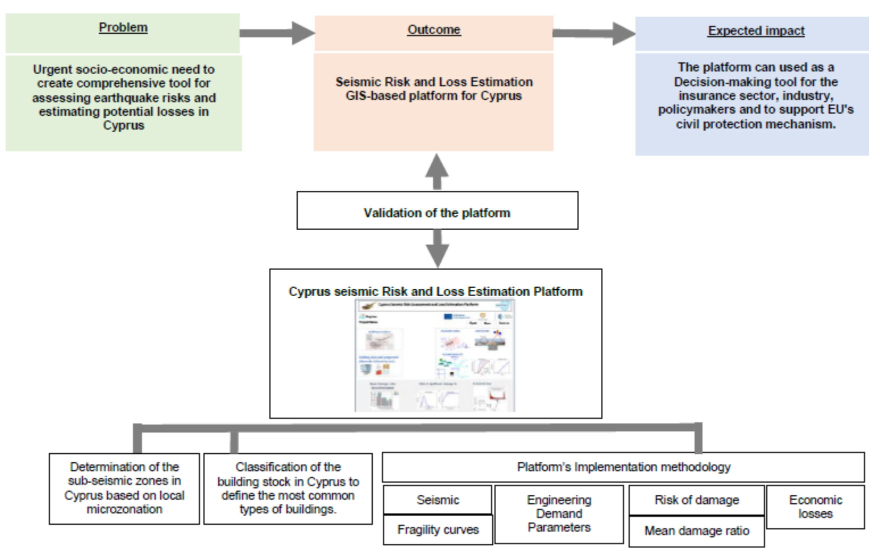

Figure 2: Graphical representation of the steps following to develop the GIS-based Seismic Risk and Loss Estimation platform for Cyprus.

2.1 Database of the platform

The most important step is the development of the database that will be incorporated into the platform. Firstly, the existing seismic zones in Cyprus must be divided into more detailed subzones based on local micro zonation. For each seismic subzone, the peak ground acceleration – PGA, seismic intensity, seismic wave propagation (attenuation), soil parameters, etc must be collected. Then, the major building characteristics (i.e., construction year, height, area, material types, etc.) of each building in Cyprus must be collected in order to determine the most common building type in Cyprus. The buildings must be classified according to their seismic performance using a building taxonomy international standard (the GEM Building Taxonomy, as updated by Silva et al.2022) that allows buildings to be classified according to several structural attributes (and structural resisting system, the number of stories, the construction period with respect to the seismic design code provisions, the building's use, the interaction with the adjacent building, the regularity of the building both in plan and elevation). The final step of the development of the database is to build the exposure model-spatial distribution of the existing building stock. The spatial distribution of the buildings' characteristics combined with the seismic hazard's characteristics allows for the recognition of the area at risk and supports risk management decisions.

2.2 Platform's Implementation methodology

The implementation methodology for this platform includes the definition of the seismic scenarios that will be incorporated in the platform, the estimation of the seismic Hazard of each of sub-seismic zones of Cyprus, the selection of the Engineering Demand Parameters (EDPs) of each type of building and the fragility curves for the representative buildings in Cyprus as well as the selection of the risk estimation methodologies and the methods for analysis Economic losses and mean damage ratio. Thus, firstly the ground motion set of low, medium and large-magnitude earthquakes recorded on either rock or firm soil sites (i.e., site class C or D) must be selected in order to define the three different response spectrum (Low, Medium, and High) that will be used in the platform. Then, the seismic Hazard of each of sub-seismic zones of Cyprus must be estimated according to the seismic scenarios selected and according to the existing seismic hazard map of Cyprus. Thus, the probability that a seismic scenario will occur at a given sub-seismic zone with ground motion intensity exceeding a given threshold must be defined. To define the seismic hazard for the purpose of this study, the island's seismic hazard as obtained from the study conducted by Kythreoti and Pilakoutas (2015) [18] can be used. The structural vulnerability level-damage of a given building must be estimated for a given ground motion. To achieve this, thresholds values of the Engineering Demand Parameters (EDPs) of each type of building must be selected according to the regional building codes, design standards, and engineering practices such as ASCE 41[19], IBC-International Building Code, Eurocode 8 [20], etc. The limit state thresholds must be quantified for the representative type of buildings selected. These values can be used to categorize the building into different damage levels. The fragility curves for the representative buildings in Cyprus that were developed and validated by Kyriakides [21] can be used. Otherwise, suitable fragility function will be selected from the OpenQuake library [22] that provides a comprehensive list of usable fragility curves for variety of structures. According to the limit state threshold definition of EDPs, and the fragility curves, the response of this types of buildings to different levels of the hazard, the damage level of the building can be obtained. Then, the risk of significant damage (high, medium, low risk) of each building type can be estimated according to the seismic hazard, vulnerability and exposure. The final step includes the selection of the practical methods for the analysis of economic losses and mean damage ratio. The final economic loss for the building for a given seismic event can be obtained by combination of the probability of occurrence per damage state and the respective assumed loss ratio per building typology. This is the ratio between the cost to repair a structure with respect to the cost of replacing it with a new construction, in a discrete scale per damage state. The economic loss impact is the most comprehensive outcome for assessing and mapping the spatial distribution of the most affected zones considering the assessed damage with actual building's value. The use of the damage functions representative of local construction and design practice are necessary. The mean damage ratio can be defined according to the total economic loss divided by the total value of the building.

2.3 Development and validation of the Platform

This platform will use input data for a given building (provided by the user) and according to the seismic zone, seismic hazard, type of building, vulnerability and fragility curves can be able to provide the mean damage state, the risk of significant damage, and the direct economic loss of the building for a given scenario earthquake. The seismic vulnerability and exposure of the building stock can be considered automatically through a GIS tool. On an interactive map of Cyprus (connected with seismic zones and a geographical map) the user will be required to select the location of the examined building. A lot of tests must be performed to ensure the flexibility of the platform in adapting to different geographic regions and evolving seismic risk assessment methodologies. Implement capabilities for real-time monitoring of seismic activity and automatic updates to the GIS platform. Encryption, access controls, and other security measures can be implemented to protect both the platform and user data. Comprehensive documentation for the platform, including user manuals and technical documentation must be conducted. The results can be stored as a database of all individual buildings including damage level, cost, structural type (steel, reinforced concrete, and steel frame and reinforced concrete structures), and building occupancy (private, ordinary, office, and landmark buildings). Furthermore, optimization of results can be achieved using genetic algorithm, which will iteratively refine the parameters and models to ensure the most accurate and efficient predictions of damage and economic loss [23, 24]. Finally, the platform must be validated, and its accuracy must be assessed by comparing the results obtained from the platform with the economic losses incurred and the damage that occurred in more than ten buildings due to the earthquakes of 1995 and 1996 in Cyprus. This data can be obtained from Kyriakides, (2000) [25].

3. DISCUSSION AND CONCLUSIONS

This paper highlights the urgent need for the development of an innovative Seismic Risk and Loss Estimation GIS-based platform for Cyprus in which the expected damage level and economic loss of the built environment including critical infrastructures and cultural heritage (monuments and sites) for various seismic scenarios will be estimated. This paper also presents the methodology to be followed for developing this platform that incorporates well-established seismic risk and loss estimation methodologies with GIS data, aiming to quantify and visualize the damage state, the risk of significant damage as well as the direct economic loss of infrastructure systems in the aftermath of earthquakes. The methodology for the development of this platform includes the following :

1. Determination of the sub-seismic zones in Cyprus based on local microzonation
2. Classification of the building stock in Cyprus in order to define the most common types of buildings.
3. Setting the Engineering Demand Parameters (EDPs) of each type of building in Cyprus
4. Defining the fragility curves of each building type in Cyprus
5. Assessment of the seismic risk and loss estimation of each building type in Cyprus
6. Validation of the seismic risk and loss estimation of each building type in Cyprus

The Cyprus Seismic Risk and Loss Estimation GIS-based Platform is expected to have socio-economic impact and at the same time can be used as an important decision-tool to help the policymakers for the disaster mitigation measures and strategies, the building owners for seismic upgrading their building, the insurance companies for estimating the cost insurance premiums. Further this platform will have a significant and direct:

- scientific impact by creating new and needed knowledge in the very emerged field of Seismic Risk Assessment and Management,
- economic Impact by using this platform help to develop more targeted and effective prevention strategies, which help save millions in economic costs associated with uncontrolled earthquakes.
- societal impact by raising awareness and promoting resilience and safety, and by encouraging the real estate investors and the building owners to renovate their buildings. The most significant impact of earthquakes relates to social effects such as death, health issues, property loss of livestock, etc. Therefore, developing this tool will promote social confidence, development towards the authorities, and a feeling of reassurance.
- structural safety impact on the built environment by increasing the rate of renovation.

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