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AN OVERVIEW OF EXPOSURE RISK ASSESSMENT METHODOLOGY. A CASE STUDY OF: PHI ''GENERAL HOSPITAL'' STRUMICA

Nadica ANGOVA KOLEVSKA[1]

[1*]*Department of Architecture, Faculty of Engineering*
[*]*nadica.angova@ibu.edu.mk*

Abstract

The assessment of earthquake risk and vulnerability of healthcare facilities, hospitals in particular, which serve as critical components of the system, requires the development of a relevant exposure model, which is actually one of the three key components that along with hazard and vulnerability model define the overall risk. It is the exposure model that describes the spatial distribution of the population and quantifies the existing building stock, providing information on the geographic distribution, structural characteristics, year of construction, ductility, number of above-ground floors and structural costs of the analyzed existing building stock in cities today.
This paper presents the development of an exposure model for PHI "General Hospital" Strumica, one of the largest hospital complexes in the southeastern part of North Macedonia. To support this research, an exposure database was created, cataloging seven existing buildings in the hospital complex using the building taxonomy developed by the Global Earthquake Model (GEM) for natural hazard risk assessment.
In addition to the building taxonomy, the structural cost of each building was included as an input attribute in the exposure model, obtained using an official template from the "Joint Stock Company for Management of State-Owned Business Permises" – Strumica. The occupant data for each hospital building, the third input attribute, was collected in situ by the author.
Considering that hospital seismic safety must be addressed separately from that of other buildings — as hospitals need to operate at full capacity and functionality during external disasters — this article highlights the methodology applied in developing the hospital exposure model, emphasizing the importance of increased awareness and preparedness among local authorities and the population for future seismic events or disasters.

Keywords: risk, vulnerability, exposure model, hazard, risk assessment

1. Introduction

Health facilities, hospitals in particular, are highly complex structures that serve multiple functions: they provide healthcare services while simultaneously operating as hotels for patients, an office buildings for medical staff and administration, laboratories, and storage facilities. Given their critical role, hospitals must remain fully operational before, during, and after seismic events or disasters (Milutinovic, Trendafiloski, Davoli, & Olumceva, 2004).
Although hospitals are essential in managing crisis situations and disasters, their complexity, high utilization rates, specialized equipment, and integrated systems make them vulnerable in various aspects: the structural system, non-structural components (e.g. architectural elements, infrastructure protection, accessibility, critical systems, installations, equipment, and supplies), and administrative factors (e.g. space organization, functional operations, and hospital management).

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In areas/regions prone to seismic activity and impact, existing and newly designed healthcare facilities should strictly comply with seismic design codes. This codes primarily intend to ensure the safety of the hospital facility, patients, and staff and enable the facility to continue functioning before, during, and after a seismic event or disaster (Milutinovic, Trendafiloski, Davoli, & Olumceva, 2004). The structural system of the building, governed by the proper application and implementation of building codes and building practices, is particularly crucial for the survival of the building during an earthquake.

For the purposes of this research, the PHI "General Hospital" in Strumica was selected as a case study. To gather the most relevant data on the existing building stock within the hospital complex, the open-source software tool Open Quake Engine (Pagani, et al., 2014) developed by the Global Earthquake Model (GEM) Foundation in 2012 (https://www.globalquakemodel.org/, n.d.), was used. This tool facilitated the creation of an exposure model for the hospital complex, representing one of the three essential components necessary for comprehensive risk assessment.

When developing the exposure model for all buildings in the hospital complex (built in the period 1969-2021), the Global Earthquake Model (GEM) taxonomic scheme was applied which actually implies classifying buildings according to several constructive attributes: the primary building material, floor height, year of construction in relation to the applicable design code, and the structure's ductility (Brzev, et al., 2013). In parallel with the structural attributes, and with the aim of creating a comprehensive hospital exposure model, additional attribute data were collected. These include the number of occupants or patients in each hospital building and the replacement costs of the structures, expressed in euros as a globally recognized reference currency.

Collecting data for all existing buildings within the hospital complex, with the aim of creating a relevant exposure model for the medium and long term, will contribute to building a comprehensive database of the existing building stock at the local and/or regional level. Timely updates and expansions of this database will support the development of a unified seismic risk assessment model within North Macedonia, with a particular focus on healthcare facilities. This, in turn, will aid in updating existing plans and developing new strategies for effectively managing earthquakes as natural disasters throughout all phases of disaster response, ultimately enhancing the resilience of urban hospital systems.

2. Case study: PHI “General Hospital Strumica”

The healthcare services in the city of Strumica, which provide primary healthcare, takes place in three locations: the PHI “General Hospital” Strumica, the “Health Center” Strumica, and the “Inpatient Hospital for Nervous Diseases” (Влада на РСМ Дирекција за заштита и спасување Подрачно одделение, 2015). The “Health Center” and the PHI “General Hospital” are located at the same location, while the “Inpatient Hospital for Nervous Diseases” is situated outside the urban area. The majority of the healthcare needs of the city's residents and the surrounding municipality are met at the “General Hospital” complex, located on Mladinska street. There is also an addition entrance from Pance Peshev street (**Figure 1**). The hospital has a usable area of 6,783 m² and a plot area of 20,260 m² (2.02 ha). This location also houses the Children’s Hospital and several other wards.

Figure 1. External traffic accesses to the PHI "General Hospital" Strumica (a) st.Mladinska (red), (b) st.Panche Peshev (yellow)

2.1 Positioning of Buildings within the "General Hospital" Strumica

The PHI "General Hospital" Strumica, as a secondary healthcare facility serving over 220,000 residents (Влада на РСМ Дирекција за заштита и спасување Подрачно одделение, 2015), is a pavilion-type hospital complex consisting of the following structural-functional units (**Figure 2**):

1. Infectious Diseases Department
2. Administrative Building
3. Dermatology Clinic
4. Main Building (4 departments, 6 clinics, X-ray service)
5. Admissions and Discharges
6. Physical Therapy and Rehabilitation; Pathology Laboratory; Radiology
7. New Hospital Wing

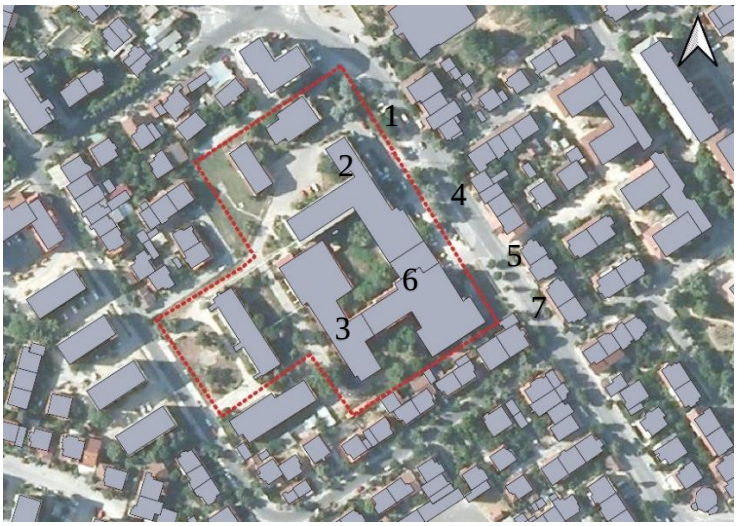

Figure 2. Schematic Layout of the Buildings within the "General Hospital" Strumica

All the listed buildings (**Figure 2**) within the complex were constructed between 1969 and 2021, in compliance with the applicable design and construction codes in our country (Министерство за транспорт и врски на РСМ, 2020).

3. Development of the Exposure Model for the Hospital Complex

The exposure model aims to collect building-level data only for certain valuable attributes associated with specific building typologies, enabling accurate risk calculations for each structure under study (Pavic, Hadzima-Nyarko, & Bulajic, 2020). To develop the exposure model for PHI "General Hospital" Strumica, the first step involved acquiring an orthophoto of the city of Strumica, captured and processed by licensed surveyors. This image included the hospital complex and was refined through photogrammetric imaging, resulting in a terrain model of the city presented as georeferenced rasters. These rasters serve as a foundational layer for mapping existing buildings within the city and the hospital complex as part of the case study (**Figure 1**). The data is applicable to all relevant public and state institutions at both the city and national levels.

All information for the seven buildings analyzed within the hospital complex (**Figure 2**) was obtained through a process of vectorization and attribution of the real estate (buildings) using two software tools: CAD and GIS (Angova-Kolevska & Vitanova, 2024). The graphical representation of the buildings was created in AutoCAD, while the attribute data for building surface areas were processed in QGIS (https://qgis.org/en/site/, n.d.). This analysis was based on data sourced from the Official Web Portal of the Real Estate Cadastre Agency of North Macedonia (https://ossp.katastar.gov.mk/OSSP/, n.d.) and the authorized local offices of the agency in Strumica.

The structural system of each building within the hospital complex was determined through on-site visual inspection conducted by the author and experts in the field, based on their prior experience in civil engineering. The number of users for each hospital building was established through interviews with hospital staff and management, as well as questionnaires distributed to patients.

The reconstruction cost of the buildings was defined using a standardized form for determining building value per square meter, as prescribed in the Methodology for determining the value of the apartment (Official Gazette of the Republic of Macedonia 13/10) (Службен весник на РМ, 2010) adopted and applied by the "Joint Stock Company for Management of State-Owned Business Permises" – Strumica (https://www.addelpro.mk/, n.d.). The financial costs were calculated individually for each analyzed building.

All this data, considered essential attributes for the exposure model, was initially recorded on paper and later transferred into an Excel file in CSV format as input data for creating the hospital complex exposure model.

3.1 Professional paper of Buildings in the Hospital Exposure Model Using the GEM Taxonomy Scheme

After establishing the primary database required for creating the exposure model of the buildings within the hospital complex, explained in **Section 3** of the study, the next step involved classifying the analyzed buildings using the taxonomy scheme developed by GEM (Brzev, et al., 2013). The existing building stock within the hospital is classified according to (4) main attributes: the primary building material, floor height, year of construction in relation to the applicable design code, and the structure's ductility. Additionally, two essential attributes - the reconstruction cost of the building and the number of users/patients at different times of the day and night - were determined and taken into account when creating the hospital's exposure model.

Information about the building structure material was obtained through on-site visual inspections involving field inspectors with prior experience and expertise.

Data on the number of above-ground floors for each individual building was collected online through the official web portal of the Real Estate Cadastre Agency of North Macedonia (https://ossp.katastar.gov.mk/OSSP/, n.d.).
The year or period of construction of each building within the complex was determined through conducted interviews and distributed questionnaires among the local population in the city of Strumica.
The seismic design code of the existing building stock in Strumica was established by considering the evolution of seismic design codes and construction practices in the Republic of North Macedonia based on (Paz, 1994) were it was confirmed that three out of four seismic design code categories are present in our country currently: Absence of Seismic Design (CDN) for structures designed before 1948, Low Code Level (CDL) for structures designed between 1948 and 1964, and Moderate Code Level (CDM) for structures designed from 1964 up to today (Angova-Kolevska & Vitanova, 2024).
Regarding structural ductility, following the experiences from European and global exposure models described in (Yepes-Estrada, и др., 2023), it was determined that the level of ductility for each structure analyzed in this study is directly related to the year of construction and the development of applicable seismic codes and standards in the country, region, or city under investigation (Angova-Kolevska & Vitanova, 2024).
The reconstruction cost of the building as an additional attribute was defined using standardized form for determining building value per square meter (Службен весник на РМ, 2010) explained in **Section 3** of the paper, while the number of users/patients at different building within the hospital complex at various times of the day and night - was determined on-site, through conversations and interviews with the hospital staff and management.
According to the established methodologies and sources described above throughout this paper, the determined attribute data necessary for creating the exposure model for each individual building at PHI "General Hospital" Strumica are presented in **Table 1 and Figure 3**, where the defined building taxonomies and all required attributes for creating the exposure model are shown.

Table 1. Mandatory attributes of buildings at PHI "General Hospital" Strumica, applied in the creation of the exposure (Exposure Modelling Input Data)

nb	id	lon	lat	taxonomy	num	structural	day	night
1	1533	22.649339	41.439702	CR_LFINF-CDM-0_H2	1	527100	20	9
2	3093	22.651305	41.441407	CR_LFINF-CDM-0_H2	1	222156	16	/
3	1421	22.649028	41.438739	CR_LFINF-CDM-0_H2	1	838842	50	1
4	4232	22.649734	41.4393	CR_LFINF-CDM-0_H5	1	5489370	109	57
5	3091	22.650067	41.439052	CR_LFINF-CDM-0_H1	1	184485	2	/
6	3092	22.649556	41.438849	CR_LFINF-CDM-0_H1	1	394471	13	/
7	3881	22.650142	41.438827	CR_LDUAL-DUM_H5	1	5417835	60	/

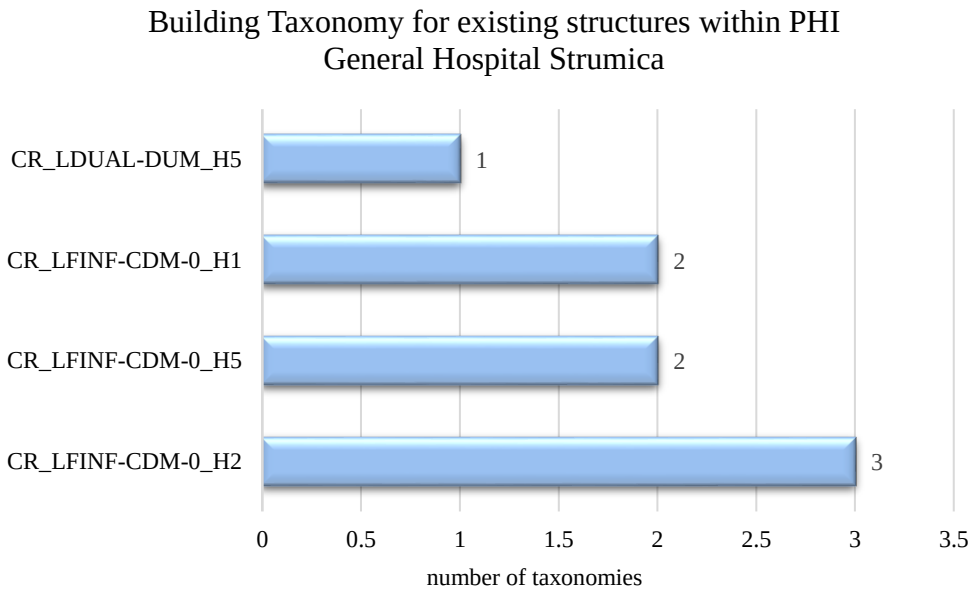

Figure 3. Building taxonomies for existing building structures within PHI General Hospital Strumica

After defining the dominant building classes within the analyzed structures of the hospital complex, and their presentation in the form of taxonomic strings according to the building taxonomy scheme developed by GEM (Brzev, et al., 2013) (**Table 1**), a visual inspection of the site was conducted by the author to verify the actual condition of each building in the hospital complex. **Table 2** shows photographs of all buildings in the complex along with their typology.

Table 2. Photodocumentation of the Existing Buildings within the Hospital Complex (Current State)

 **CR_LFINF-CDM-0_H2**	**Infectious Diseases Department** built as a reinforced concrete structure with infilled walls made of hollow brick (LFINF). With G+1 (2 storeys above the ground). It was built in 1981, within the period from 1964 to the present (CDM), in accordance with the current seismic design codes.

Administrative Building built as a reinforced concrete structure with infilled walls made of hollow brick (LFINF). With G+1 (2 storeys above the ground). It was built in 1981, within the period from 1964 to the present (CDM), in accordance with the current seismic design codes.

CR_LFINF-CDM-0_H2

Dermatology Clinic built as a reinforced concrete structure with infilled walls made of hollow brick (LFINF). With G+1 (2 storeys above the ground). It was built in 1969, within the period from 1964 to the present (CDM), in accordance with the current seismic design codes.

CR_LFINF-CDM-0_H2

Main Building (4 departments, 6 clinics, X-ray service) built as a reinforced concrete frame structure with infill made of reinforced concrete (LFINF). With G+4 (5 storeys above the ground). It was built in 1970, within the period from 1964 to the present (CDM), in accordance with the current seismic design codes.

CR_LFINF-CDM-0_H5

Admissions and Discharges building built as a reinforced concrete structure with infilled walls made of hollow brick (LFINF). Built as a single-storey building (G). It was built in 1970, within the period from 1964 to the present (CDM), in accordance with the current seismic design codes.

CR_LFINF-CDM-0_H1

CR_LFINF-CDM-0_H1

Physical Therapy and Rehabilitation; Pathology Laboratory; Radiology building built as a reinforced concrete frame structure with infill made of hollow brick (LFINF). Built as a single-storey building (G). The building was built in 1981, within the period from 1964 to the present (CDM), in accordance with the current seismic design codes.

CR_LDUAL-DUM_H5

New Hospital Wing built as reinforced concrete structure with dual frame wall (LDUAL). With G+4 (5 storey above the ground). It was built in 2021, and has not yet been put into use. It demonstrates medium ductility (DUM).

What can be concluded from the research and the site inspection made by the author of this paper is that all the buildings within the hospital complex as presented and shown above in the paper are built as reinforced concrete structures with infill made of reinforced concrete or hollow brick (LFINF), built between 1969 and 2021. The only exception is the New Hospital Wing, which is built as a reinforced concrete structure with dual frame wall (LDUAL) (**Table 2**).

4. Conclusions

The creation of relevant exposure models for the constructed building stock at the local and/or regional level is of great importance, as they enable the prediction and assessment of expected damages and losses. This, in turn, raises public awareness of natural disasters and enhances the system's preparedness to respond in the event of a natural disaster and/or emergency, or immediately after it is increased.

The process of collecting data for the existing building stock goes through several stages: starting with direct cooperation with local authorities and the Real Estate Cadastre Agency of North Macedonia (https://ossp.katastar.gov.mk/OSSP/, n.d.) in order to collect available data for what has already been built, through collaboration with authorized surveyors to obtain geodetic bases on which the real estates in question are processed, until the final Professional paper of the constructed building stock as building attributes that form the so-called taxonomy

strings, according to the building taxonomy developed by GEM (Brzev, et al., 2013). Previous practice has shown that, when developing exposure models, a smaller number of attribute data are used, which provide accurate descriptions of the structures and possess the ability to classify them in accordance with the proposed building taxonomies.

Bearing in mind the enormous importance of hospitals as essential institutions in the process of dealing with crisis situations and disasters, which are required to remain fully operational and functional in the event of a natural disaster or immediately after it, throughout the pages of this paper a detailed analysis of the buildings within the hospital complex is provided. This study represents the author's technical assessment, offering a sufficient degree of accuracy, further validated through a field inspection. This assessment aimed to create a usable exposure model for the hospital complex within the PHI "General Hospital" Strumica. This micro-study can be considered as a promising basis for conducting future assessments and analyses of seismic risk in the analyzed area. The proposed exposure model of the buildings within the hospital complex can serve as a relevant basis for future research, with the potential for ongoing updates and improvements. This, in turn, will support the development of new long-term preventive strategies aimed at mitigating damages and losses caused by events that cannot be prevented or avoided.

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