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DEFINITION OF THE EXPOSURE MODEL FOR THE CASE STUDY KARPOSH IN SKOPJE ACCORDING TO TWO URBAN SCENARIOS

Abstract

The application of seismic design codes is crucially important for the seismic safety of the built environment developed in earthquake prone regions. However, there are also buildings built before the introduction of seismic design codes. Seismic risk assessment is a useful process which can help identify the seismic safety of the urban regions with buildings belonging to different periods. Defining the components of seismic risk; hazard, exposure and vulnerability is a very important step in order to obtain reliable seismic risk assessment results. The focus of this research paper is on defining the exposure model attributes in the case study Karposh. Characteristic for the case study is the fact that it consists of buildings built in different periods, before and after the introduction of seismic design codes. There are also buildings which have been structurally modified and resulted with mixed structures. The approach in the definition of the exposure model is based on urban planning aspects as well and the exposure model is defined according to two urban scenarios, scenario 1 - the existing site and scenario 2 - the planned site.

Keywords: exposure model, urban scenarios, case study

ДЕФИНИЦИЈА МОДЕЛА ИЗЛОЖЕНОСТИ ЗА СТУДИЈУ СЛУЧАЈА КАРПОШ У СКОПЉУ ПРЕМА ДВА УРБАНА СЦЕНАРИЈА

Сажетак

Примјена кодова за сеизмичко пројектовање од кључне је важности за сеизмичку безбједност изграђеног окружења у подручјима склоним земљотресима. Међутим, постоје и зграде изграђене прије увођења кодова за сеизмичко пројектовање. Процјена сеизмичког ризика користан је процес који може помоћи у идентификацији сеизмичке безбједности урбаних подручја са зградама које припадају различитим периодима. Дефинисање компоненти сеизмичког ризика; опасности, изложености и рањивости, врло је важан корак како би се добили поуздани резултати процјене сеизмичког ризика. Фокус овог истраживачког рада је на дефинисању атрибута модела изложености у студији случаја Карпош. Оно што је карактеристично за ову студију случаја је чињеница да се састоји од зграда изграђених у различитим периодима, прије и послије увођења кодова за сеизмичко пројектовање. Постоје и зграде које су конструктивно модификоване и резултирале мјешовитим конструкцијама. Приступ дефинисању модела изложености заснован је и на урбанистичким аспектима, а модел изложености дефинисан је према два урбана сценарија, сценарио 1 - постојеће мјесто и сценарио 2 - планирано мјесто.

Кључне ријечи: модел изложености, урбани сценарији, студија случаја

INTRODUCTION

Earthquakes as natural phenomena represent a serious threat to the seismic safety of the built environment. The seismic safety of human settlements developed in earthquake prone regions in first place relies on the use of seismic design codes in the process of design and construction of the buildings. However, not all buildings are designed and built according to seismic design codes. Namely, urban tissues consist of buildings belonging to different periods, built before and after the introduction of seismic design codes. Non-seismically designed and constructed buildings pose danger to their urban environment because their seismic stability is unknown [1].

In order to identify such buildings which are vulnerable to seismic risk it is recommended to apply seismic risk assessment at urban scale [2]. Based on the definition of risk in Sendai framework for action, the seismic risk can be defined as function of interrelated components of hazard, exposure and vulnerability. The hazard component refers to the ground shaking caused by earthquake while all the entities in the area affected by the earthquake make up the exposure component. The characteristics of the exposed entities to get damaged or to endure losses during an earthquake is referred to as vulnerability. Besides the mentioned components also there is the component of resilience, the capacity of the exposed entities to overcome an adverse situation and get back to normal state [3].

As part of the doctoral dissertation research of the first author, an urban region consisting of mixture of buildings from different periods was taken as a case study to assess the seismic risk level. The case study is a residential urban region in the Municipality of Karposh in the City of Skopje. The territory of Skopje is well known for its seismicity and the greatest natural catastrophe in the history of the city was the earthquake of 1963 where 1.070 people lost their lives, 3.300 were injured and many were left homeless [4].

The focus of this research paper is the development of exposure model, the component of seismic risk with most dynamic nature. In the seismic risk assessment of the case study in Karposh, beside understanding the seismic risk level, the aim was to identify the urban planning parameters which have influence on the seismic risk. For this purpose, the exposure model of the urban region was prepared in two urban scenarios, in scenario 1 the site was treated in its existing condition, while in scenario 2 the exposure model was prepared according to Detailed Urban Plan.

1. BRIEF REVIEW OF THE SELECTED CASE STUDY KARPOSH

The Municipality of Karposh is one of the four largest municipalities in Skopje. Karposh, founded as a municipality in 1976, extends to area of 35 km^2 and has approximate population of 60.750 residents according to census data from 2021 [5]. Most of today's territory of Karposh was built after the 1963 earthquake but some areas closer to the center of the city existed also prior to this earthquake. The case study area (figure 1) is an example of urban planning and construction practice in the City of Skopje.

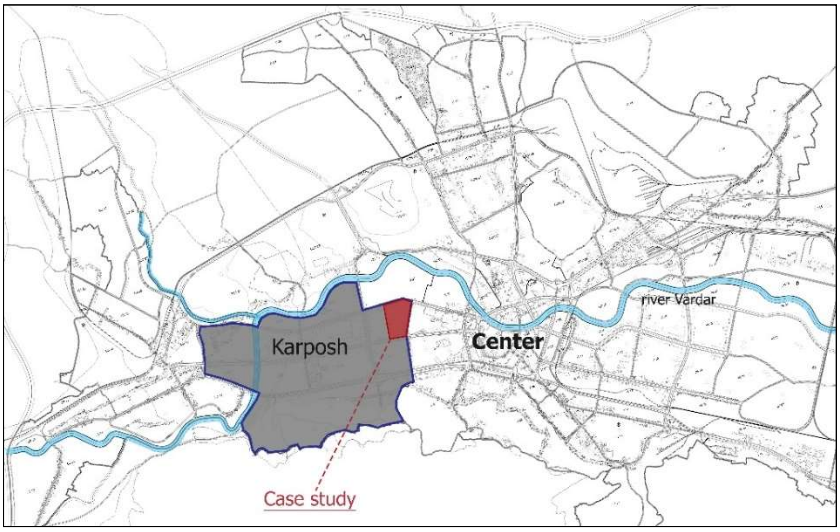

Figure 1. The urban territory of Municipality of Karposh. Map prepared by author based on the General Urban Plan of City of Skopje for plan period of 2011-2022. Source: [6]

Between 1950 and 1963 in the West side of the City of Skopje, today's territory of Karposh, to ensure the accommodation requirements triggered by the rapid urbanization due to industrial development of the country, many residential buildings with standardized typology of masonry structure with height between 3 to 5 floors were built with low to moderate construction quality. The first seismic design codes were introduced in 1964 [7] followed by more advanced seismic design code of 1981 [8] which is still in use. Buildings constructed before these seismic design codes are considered to be seismically vulnerable [9]. Expectedly, these buildings endured big damages in the aftermath of the 1963 earthquake. Masonry structures were the most heavily damaged, while reinforced concrete buildings showed less damages [10].

After the earthquake with the purpose to increase the speed of construction industry to meet the housing requirements the factory for production of concrete building blocks named "Karposh" was established in the Municipality of Karposh [10].

Starting from 1990's the trend of making structural changes to existing buildings, such as increasing living space by enclosing balconies into rooms, adding roof floors to flat roofs, became a regular practice [11;12]. This type of modifications, annexes to existing buildings, leads to creation of built environment with unknown seismic stability and safety.

Even though at the beginnings adding annexes to existing buildings was considered illegal, this practice got recognized by the building law in 2008 and since then structural interventions to existing buildings are subject to building permit approval, whereas, illegally constructed annexes prior to this law were legalized with the amendments in 2011 and 2013 [12].

The urban region selected as case study consists of buildings built in different periods, before the 1963 earthquake, according to two different seismic design codes and has examples of buildings with mixed structures as result of annexes.

2. KARPOSH CASE STUDY AND URBAN SCENARIOS

The case study building stock was subject to seismic risk assessment for two urban scenarios, scenario 1 – existing site and scenario 2 – planned site. The exposure model was prepared for both scenarios, scenario 1 based on the previous field studies by IZIIS [11; 13] and scenario 2 based on the Detailed Urban Plan [14] and estimation of buildings' structures.

The seismic risk assessment was conducted by using the Open Quake engine, developed and maintained by GEM [15]. Accordingly, all the information about the entities formulating the exposure model was analyzed and translated into GEM's classification of attributes defining the exposure model.

2.1. EXPOSURE MODEL FOR SCENARIO 1

In urban scenario 1, the existing site of the case study, the exposure model was prepared based on previous field studies by IZIIS [11; 13]. The data about the building stock in the case study area was collected with rapid visual inspection approach with use FEMA-154 methodology [16]. Based on visual inspection as well as buildings' plan and section drawings the following information was compiled in the report of IZIIS: the typology of structural system, year of construction, height of building, structural modifications made on building and damages endured by the building [11]. During the visual inspection process by IZIIS, some of the buildings were identified as seismically vulnerable and they were denoted to be analyzed in more detail [11]. The total number of buildings in the case study area is 203 while 159 were subject to visual inspection. In order to simplify the process of seismic risk assessment smaller size buildings such as garages and buildings with wooden structure were eliminated. In this way, in scenario 1 the total number of buildings is 147 while the number of structures is 173. The difference between the number of buildings and structures is due to the structural interventions applied on the existing buildings which results in buildings with mixed structures (see 4.1.1). Figure 2 (left image) shows the mapping of the buildings and annexes in QGIS [17] according to scenario 1 of the case study.

Figure 2. Case study Karposh, mapping of buildings and their annexes in scenario 1 (left image) and scenario 2 (right image).

2.2. EXPOSURE MODEL FOR SCENARIO 2

The exposure model in urban scenario 2 for the case study was prepared based on the Detailed Urban Plan (DUP) [14] developed for the region Z 08 where the case study location is situated. The structural system of each entity of the exposure model to which a certain change was foreseen with the DUP was defined taking into consideration the construction practice in the city, seismic design codes and experts' opinion. Regarding the existing buildings which are foreseen to have changes in terms of urban parameters, the DUP doesn't define if the existing building should be demolished and rebuilt or the spatial area of the existing building can be increased by annexes (structural interventions). In order to solve this dilemma each entity was analyzed from the following aspects:

- What is the difference in the gross area and number of floors between the existing and the planned version of the building?
- What is the year of construction of the existing building?
- What is the structural system of the existing building?

Considering all these aspects it was decided whether the building should be demolished and rebuild or it can be upgraded with annexes. In scenario 2 exposure model 50 buildings were decided to be demolished and rebuilt with structures in line with modern seismic design code. Changes to existing buildings were also allowed but with use of annexes with expansion joints in most of the cases. However, adding a single story to an existing building was considered as annex without use of expansion joints. Beside the changes applied to existing buildings, the DUP proposes 9 new buildings of which the structural system was decided to be best suitable for the number of floors and gross area of the buildings. By deciding about the construction status of the buildings and their structural system the exposure model in scenario 2 regarding the taxonomy of the exposed entities is improved compared to exposure model of scenario 1. There are in total 155 buildings and 204 structures in scenario 2 (figure 2, right image).

3. KARPOSH CASE STUDY EXPOSURE MODEL

The exposure model consists of taxonomy and additional attributes which define the characteristics of the exposed entities. The taxonomy is the most important part of the exposure model since it is used to correlate the exposed entity to the fragility and vulnerability functions in the calculation processes by Open Quake engine [15]. Since in the seismic risk assessment of the case study Karposh existing fragility and vulnerability curves were selected from the database of ESRM20 [18], the taxonomy attributes were defined in accordance with the attributes of these fragility and vulnerability functions. Beside the taxonomy, urban planning attributes and structural cost for replacement of buildings were included as additional attributes in the exposure model. The urban planning attributes considered in the exposure models are: plan shape of buildings, placement of buildings in urban block, occupancy type of buildings and number of occupants.

3.1. TAXONOMY

Each entity in the exposure model is defined with different attributes which formulate the taxonomy. For the building stock of the case study area in Karposh the taxonomy was constituted from the following attributes: material and structural system of the buildings, construction period, alignment with the seismic design codes and ductility level, height of the buildings (table 1). For reinforced concrete frame and infilled frame structures also the coefficient of lateral force was taken into account when defining the taxonomy.

Table 6: Description of the attributes in taxonomy of the entities from the exposure models.

Material	CR: reinforced concrete	MCF: confined brick masonry	MUR: unreinforced brick masonry
Lateral load resisting structural system	LDUAL: dual frame-wall system	LWAL: load bearing wall	LWAL: load bearing wall
	LFINF: infilled frame	/	/
	LFM: frame	/	/
Seismic design code /coefficient of lateral force (applies only for LFINF and LFM)	CDL: low code	/	/
	CDM: medium code	/	/
Ductility	DNO: no ductility	DNO: no ductility	DNO: no ductility
	DUL: low ductility	DUL: low ductility	DUL: low ductility
	DUM: moderate ductility	DUM: moderate ductility	DUM: moderate ductility
Height (number of floors)	LDUAL_H: 1-12	1-6	1-5
	LFINF_H: 1-6		
	LFM_H: 1-6		

As result of structural interventions made on existing buildings in the case study area there are also buildings with mixed structures which results in having greater number of structures compared to the number of buildings. Each structure in the exposure model is defined with the appropriate taxonomy. The simplified version of the different taxonomies and their numbers in different scenarios of the exposure model are shown in table 2. In scenario 2 the structures with taxonomies known to be more vulnerable to seismic risk were replaced with structures which have better seismic performance.

Table 7: Number of structures per taxonomy in scenario 1 and 2.

Taxonomy	**Number of structures**	
	Scenario 1	**Scenario 2**
CR_LDUAL_DUL	10	7
CR_LDUAL_DUM	18	26
CR_LFINF-CDL-10	3	3
CR_LFINF-CDM-10	30	53
CR_LFM-CDL-10	1	1
CR_LFM-CDM-10	15	64
MCF_LWAL-DUL	27	17
MCF_LWAL-DUM	4	4
MUR-CL_LWAL-DNO	65	29
Total number of structures	**173**	**204**

3.1.1. MATERIAL AND STRUCTURAL SYSTEM OF BUILDINGS (DUCTILITY, COEFFICIENT OF LATERAL FORCE)

The material and structural system of the buildings present in the case study area can be defined in three groups: unreinforced brick masonry load bearing wall structures (MUR_LWAL), confined brick masonry load bearing wall structures (MCF_LWAL) and reinforced concrete structures (CR). Within the category of reinforced concrete structures there are moment frame structures (CR_LFM), infilled moment frame structures (CR_LFINF) and dual structures consisting of frame and load bearing wall (CR_LDUAL).

The mapping of the different structures on the case study for scenario 1 and 2 is shown in the figures 3 and 4 respectively.

Figure 3. Mapping of structural system of buildings and annexes in scenario 1.

Figure 4. Mapping of structural system of buildings and annexes in scenario 2.

Within the exposure model there are also buildings with mixed structures which is result of structural interventions made on existing buildings. Buildings which were subject to structural interventions were defined as two categories. In the first category, structural interventions were directly constructed on the existing structure without use of expansion joints (figure 5). Whereas, in the second category, structural modifications were applied by using expansion joints (figure 6). In the ERSM20 model there are no fragility or vulnerability functions which correlate to buildings with mixed structures. In order to define the taxonomies of such buildings in more reliable way the following criteria was applied; if the structural modification was done with use of expansion joints the taxonomy was defined separately, for the original (existing) structure and for new built ones, whereas if the structural modification was done without use of expansion joints then the taxonomy was defined as one structure based on the properties of the existing building (more conservative solution).

Figure 5. Buildings with mixed structure without use of expansion joints. Sources: photos by K. Edip.

Figure 6. Buildings with mixed structure with use of expansion joints. Source: photos by K. Edip.

3.1.2. CONSTRUCTION PERIOD AND ALIGNMENT WITH SEISMIC DESIGN CODES

According to the year of construction the buildings in the case study area, with respect to the application of seismic design codes, can be grouped in the following three categories:

- Buildings constructed before 1964
- Buildings constructed between 1964-1981
- Buildings constructed after 1981

Until 1964 buildings were constructed without taking into consideration the seismic forces because there was no seismic design code. Structures of the buildings constructed before 1964 in their taxonomy are defined as CDN (no seismic design) or DNO (no ductility). In 1964 the first seismic design codes were introduced which required structures to be designed and constructed according to method of allowable stress design. In 1981 the modern seismic design codes were adopted and the design of the structures was according to the method of modern limit state design and partially applying the method of capacity design [19].

The presence of structures belonging to different periods of construction in scenario 1 and 2 are shown in the figures 7 and 8 respectively.

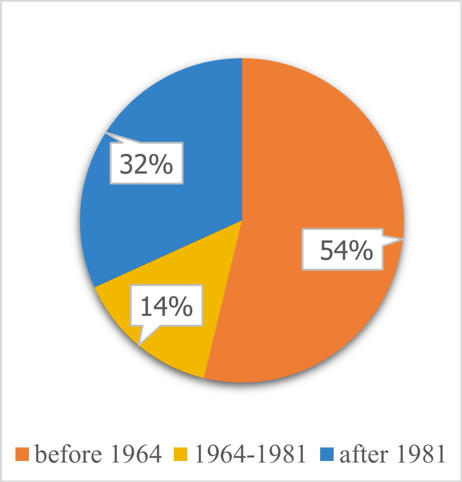

Figure 7. Scenario 1 – construction period of structures

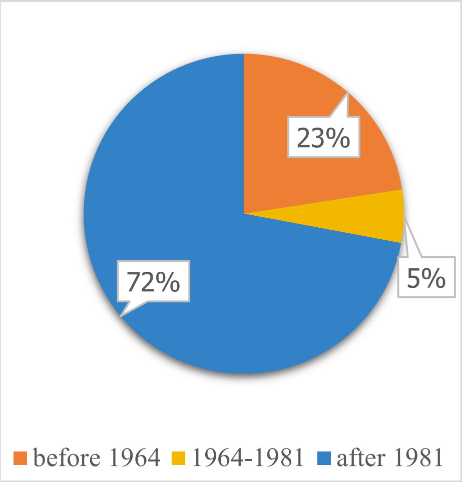

Figure 8. Scenario 2 – construction period of structures

In scenario 2 the number of structures designed and built according to the modern seismic design codes of 1981 is increased compared to scenario 1 where most dominant are the structures built prior to the introduction of the seismic design codes of 1964. Distribution of building entities per structural system and period of construction, in both scenarios, is shown in figures 9 and 10 respectively.

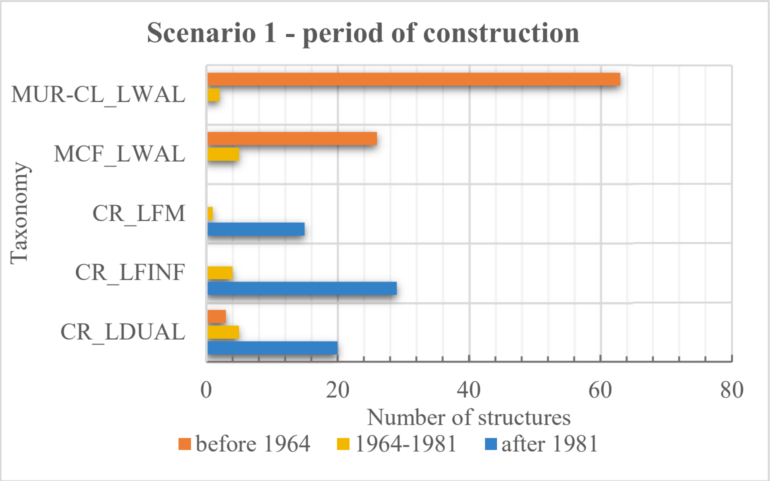

Figure 9. Structural system and period of construction in scenario 1.

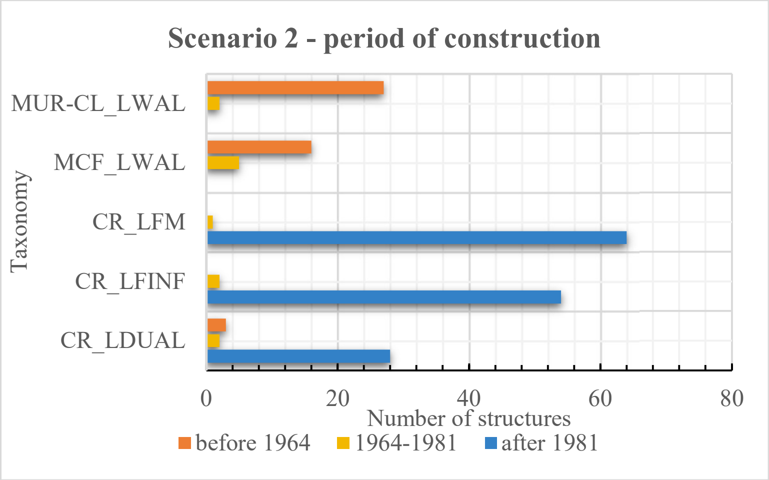

Figure 10. Structural system and period of construction in scenario 2

3.1.3. HEIGHT OF BUILDINGS

According to the height of the building, the entities in the exposure model are divided in three categories: low rise buildings with height up to 3 floors above ground, midrise buildings with 4 to 7 floors and high rise buildings with more than 8 floors height. In both scenarios there are just a few high rise buildings, there are 6 structures in scenario 1 and 12 structures in scenario 2 considered as high rise buildings, while the maximum height is 18 floors. As shown in figure 11, in scenario 1 mostly dominate the low rise structures, while in scenario 2 these are replaced by midrise structures.

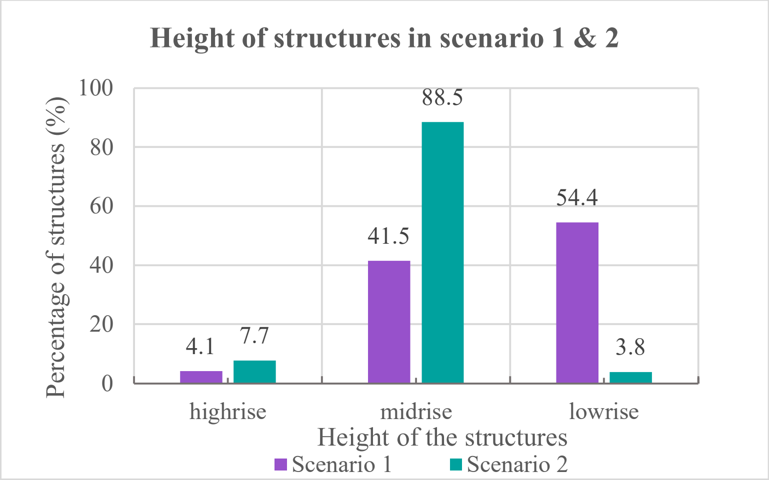

Figure 11. Height of structures in scenario 1 and 2.

In scenario 1 the low rise buildings are mostly unreinforced masonry (MUR) and confined masonry (MCF) structures. Also, there are midrise buildings with MUR and MCF structures in scenario 1. The number of midrise structures increases in scenario 2 where most of the buildings are with reinforced concrete structures (CR_LFM, CR_LFINF). High rise buildings in both scenarios are with reinforced concrete dual structures consisting of frame and wall (CR_LDUAL).

3.2. URBAN PLANNING ATTRIBUTES

Beside the attributes defining the taxonomy of the entities other attributes considered to be important in the overall seismic risk assessment were added into the exposure models of scenario 1 and 2. Attributes important from urban planning point of view are the plan shape of the buildings, placement of the buildings in urban block and the occupancy type of the buildings. The urban planning parameters were considered together with the taxonomy in order to have more comprehensive overview of the exposure model.

3.2.1. PLAN SHAPE OF THE BUILDINGS

According to the type of plan shape in the case study there are rectangular solid, rectangular with opening, square solid, polygonal solid and "L" shapes of plans. The presence of different types of plan shapes in scenarios 1 & 2 are shown in figures 12 and 13 respectively.

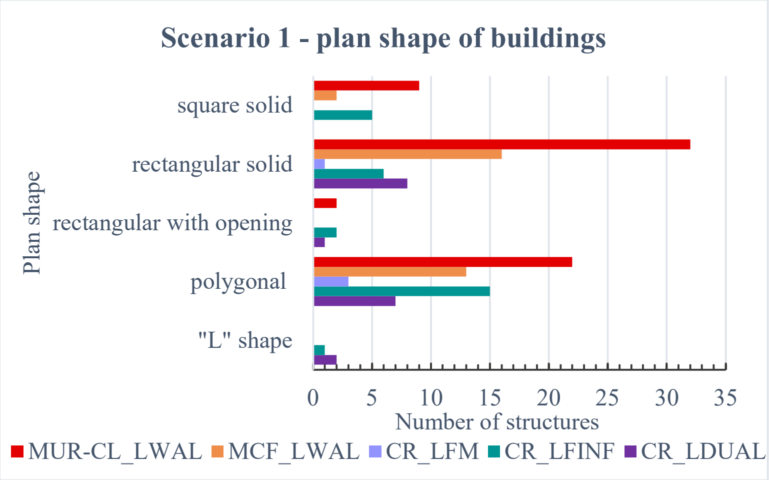

Figure 12. Taxonomy and plan shape in scenario 1.

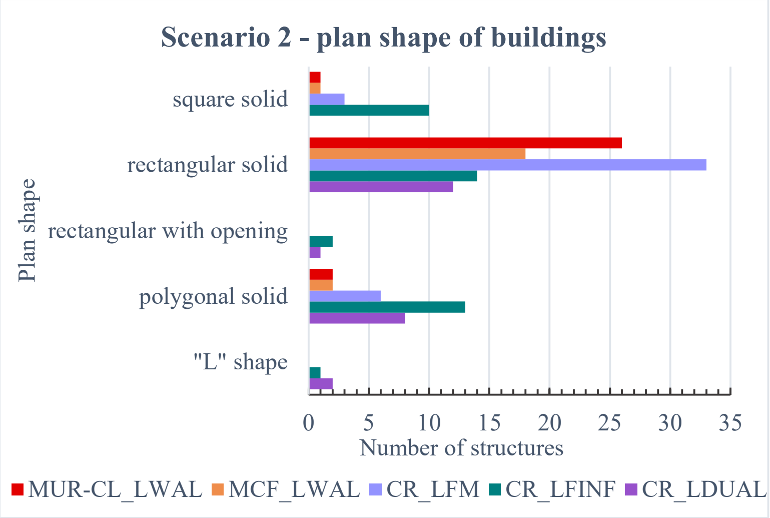

Figure 13. Taxonomy and plan shape in scenario 2.

While in scenario 1 most dominant are the rectangular solid and polygonal solid shapes with all taxonomy types, in scenario 2 the number of polygonal solid plan shape for masonry structures (MUR and MCF) is decreased. The rectangular solid and square solid plan shapes are more preferable for the seismic stability of the structures; however, the plan shape should be considered together with the taxonomy of the exposed entity.

3.2.2. PLACEMENT OF BUILDINGS IN URBAN BLOCK

In the case study area buildings are mainly placed adjacent with one building, adjacent with two buildings and there are alone standing buildings. The number of buildings adjacent on one side in scenario 1 is 45.8% and increases to 53.5% in scenario 2. The number of detached buildings decreases from 41.9% (scenario 1) to 32.9% (scenario 2). There are a few buildings which are adjacent on both sides and their percentage in scenario 1 and 2 are 7.1% and 13.5% respectively.

In scenario 1, dominant is unreinforced masonry structures (MUR) adjacent on one side with other structures (figure 14). Having this kind of seismically vulnerable structures adjacent to other structures represents a threat for the seismic safety of the urban block. Considering this aspect, in scenario 2 the number of adjacent standing MUR structures is decreased (figure 15). Though the number of adjacent on one side and adjacent on both sides in scenario 2 increases compared to scenario 1, having structures with better taxonomy can help increase the seismic safety at urban scale.

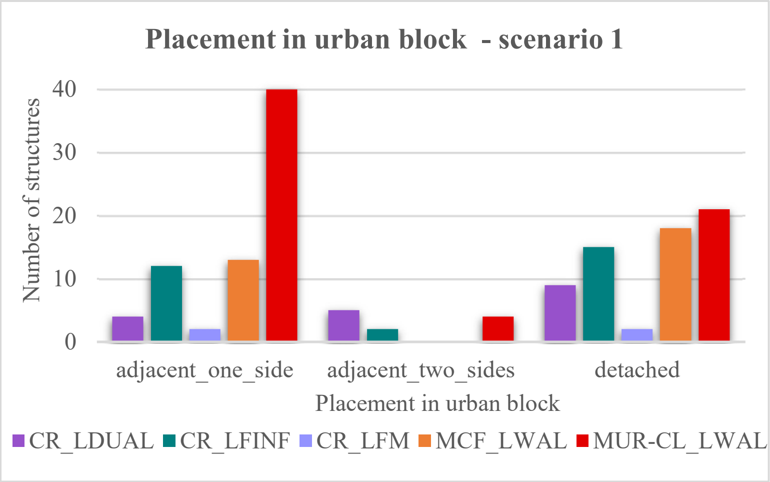

Figure 14. Placement in urban block and structural system in scenario 1

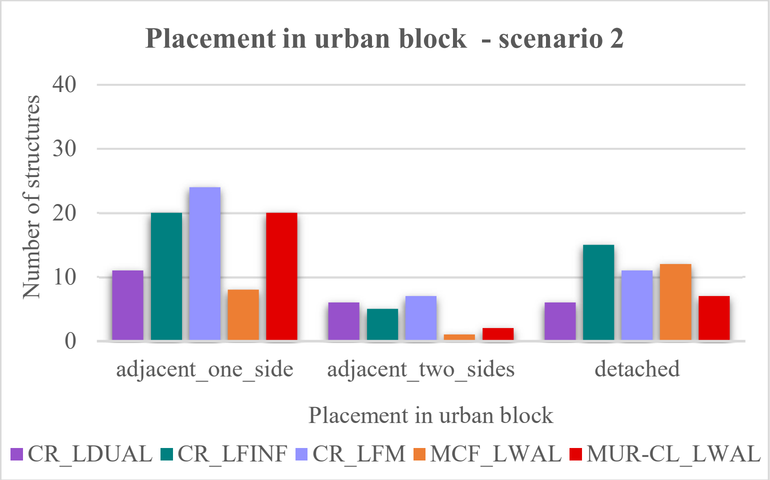

Figure 15. Placement in urban block and structural system in scenario 2.

3.2.3. OCCUPANCY TYPE OF BUILDINGS AND NUMBER OF OCCUPANTS

The case study location is mainly residential urban area consisting of multilevel apartment buildings and houses. In scenario 1 the percentage of residential occupancy type is 82.3 % and increases to 85% in scenario 2. There are also buildings with mixed occupancy type usually consisting of residential areas at upper floors and commercial use in ground floor. The presence of mixed occupancy buildings is very similar in both scenarios, approximately 11%. As standalone buildings with commercial occupancy type there are just a few in scenario 1 (6.1%), while in scenario 2 their number decreases to 3.9%.

In order to determine the number of occupants in different scenarios of case study the following steps were taken. First, the total residential area in m^2 of the buildings was calculated for both scenarios. The overall residential area in scenario 1 is equal to 181.687m^2 and in scenario 2 is 256.462m^2.

Second, to define the average living space of flats was calculated according to census data from 2021 [20]. In the Municipality of Karposh the average size of a flat is 80m^2. According to this data there are 2.271 flats in scenario 1 and 3.205 flats in scenario 2. Third, the average number of occupants per flat was defined based on data in General Urban Plan (GUP) of City of Skopje [21]. Referring to GUP the required standard living area for one occupant should be between 20 to 25m^2 [21].

Based on this data the average number of occupants per flat is equal to 3 persons. Calculated in line with the described steps, the total number of occupants in scenario 1 is equal to 6.816 while in scenario 2 is 9678. The distribution of number of occupants in taxonomies present in exposure models of scenario 1 and 2 is shown in figure 16.

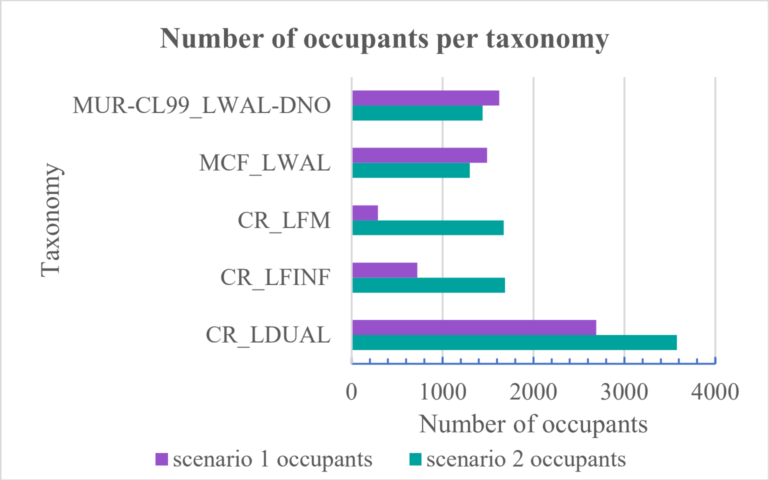

Figure 16. Number of occupants per taxonomy in scenario 1 and 2.

3.3. REPLACEMENT COST OF BUILDINGS

Defining the replacement cost of the buildings for the case study Karposh was based on the ESRM20 data [18]. In ESRM20 the average replacement cost of the buildings, which covers the structural system, non-structural elements and contents, was defined according to the following criteria:

- The country of interest
- The positioning of the building in urban context, i.e. big city, urban or rural areas
- The occupancy type of the building
- The structural material of the building

Based on the stated criteria the average replacement cost of buildings in case study area equals to 520€/m2 and it is multiplied with different indices according to the structural material. Namely, buildings with reinforced concrete structure (CR) and confined masonry structure (MCF) have the average replacement cost of 546€/m2, while the unreinforced masonry (MUR) costs 494€/m2. The average replacement costs per taxonomy in scenario 1 and 2 are shown in figure 17.

The replacement costs of buildings calculated and presented in this research are of approximate relevance. To define relevant replacement costs of the buildings in N. Macedonia additional comprehensive researches should be pursued to obtain all the required information.

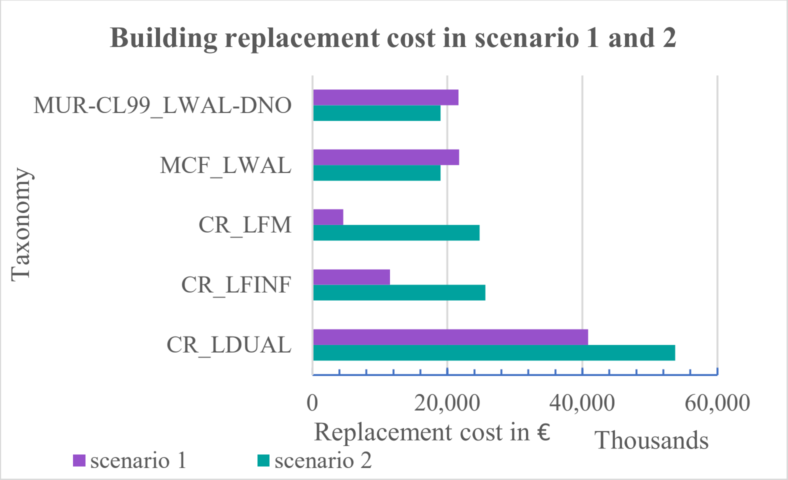

Figure 17. Replacement cost per taxonomy in scenario 1 and 2.

4. CONCLUSION

For a comprehensive seismic risk assessment, it is crucially important to have reliable data about the components of risk; hazard, exposure and vulnerability. The components of exposure and vulnerability can be influenced and can be altered in order to have less damage and losses when an earthquake hits.

In this paper the focus is on defining the exposure model. The taxonomy defined in exposure model can serve for development of site specific fragility and vulnerability functions. However, in the case study Karposh the fragility and vulnerability functions were selected from existing data base of ESRM20 created for the European building stock [18]. Consequently, the taxonomy of the exposure model for scenario 1 and 2 was defined in a way to be correlated with these fragility and vulnerability functions of ESRM20.

Beside the taxonomy, attention was paid also to urban planning parameters such as: plan shape of buildings, position in urban block, occupancy type and number of occupants. In order to calculate the economic losses, the average replacement cost was defined for each taxonomy based on data for structural losses available in ESRM20.

The defined exposure models for both scenarios were used in the seismic risk assessment of the case study area with use of Open Quake Engine and the results from two scenarios were compared in order to define the role and importance of urban planning in reducing seismic risk [1].

The exposure component in urban environments has a very dynamic character, usually more emphasized when pressurized by urbanization. Due to its dynamic character the exposure model requires to be established in a system which will continuously keep track of the changes that happen in urban environment and update the exposure model attribute information.

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