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A BUILDING CLASSIFICATION SYSTEM FOR SEISMIC RISK ASSESSMENT OF GOSTIVAR, NORTH MACEDONIA

Shpresim Ibraimi [(1)], Koce Todorov [(2)], Miroslav Nastev [(3)], Stanislav Milovanovic [(4)]

[(1)] *MSc, Institute of earthquake engineering and climate change Skopje, North Macedonia, shpresim@izikp.mk*
[(2)] *Prof, Civil engineering Faculty, University Ss "Cyril and Methodius" Skopje, North Macedonia, todorov@gf.ukim.edu.mk*
[(3)] *Research scientist, Geological Survey of Canada, Québec, Canada, miroslav.nastev@nrcan-mcan.gc.ca*
[(4)] *Prof, ZIM "Skopje" AD Skopje, North Macedonia, info@zimad.com.mk*

Abstract

Seismic risk assessment is central for planning of the emergency response and short- and long-term mitigation efforts in earthquake prone areas. This paper focuses on the classification of the existing building stock as one of the input parameters. With more than 30,000 inhabitants and urban zone characterized with a large portion of older buildings built before the introduction of the first seismic code in 1964, the city of Gostivar, located about 65 km SW from the capital Skopje, was selected as the study area. The proposed classification system was developed collecting information from national census database, municipal and cadastre archives, literature review, rapid visual screening from street surveys and web services such as Google map. The ongoing detailed inventory consist already of a few thousand buildings with assigned attributes including coordinates, footprint, number of stories, structural material, load bearing system, quality of the construction (code level), and occupancy class (residential, commercial, industrial, governmental, agricultural and religious). Particular attention was paid to the inventory of the essential facilities, such as hospitals, police and fire stations, and schools. The proposed classification scheme is based mainly on roundtable discussions with experienced engineers and on existing exposure models for Skopje developed following the 1963 earthquake, EMS-98, Risk-EU project and GEM building taxonomy. It consists of eight main structural types: wooden (1), unreinforced masonry (3), confined masonry (1) and reinforced concrete (3).

Keywords: seismic risk, building classification system, existing buildings, attributes, building taxonomy

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1. Introduction

Strong earthquakes are among the most destructive natural hazards. Although relatively rare, their negative effects must be adequately addressed to allow communities to withstand, respond and recover from earthquakes. The development of building exposure model represents the first step towards community resilience to seismic events. The process of development of an exposure model at municipal or regional level requires comprehensive methodologies and relies on multi-disciplinary and multi-institutional cooperation and constant updating of the collected information. To date, in North Macedonia as well as other countries in the region, databases from the national census or other statistics do not contain data on the characteristics of the structures.

The exposure studies, as a first step in the seismic risk process are very limited in the region. The first exposure model was done following the 1963 Skopje earthquake, where expert committees collected data and statistics on occurred damage to buildings and their classification according to the structural system and the degree of damage [1]. The RISK-EU project [2] developed building taxonomies for cities in Europe, including Bitola in North Macedonia, while in Europe are developed other building taxonomies, i.e. Syner-G [3], GEM [4].

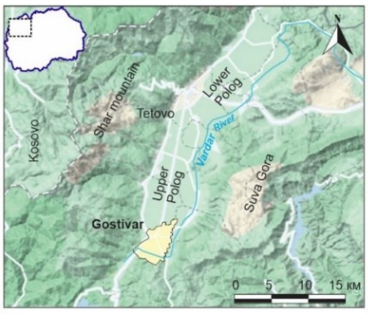
North Macedonia is one of the seismically active regions in the Balkans, south-eastern Europe. Of major importance is the NE-SW seismotectonic zone extending a few hundred kilometres from Kjustendil (Bulgaria), via the capital Skopje to Vlorë (Albania), since it affects the most densely populated areas with about 60% of the total population [5]. The city of Gostivar was selected as the study area for the present research. It is located about 65 km SW from Skopje at the edge of the Polog graben intersected by several active faults [6]. With a population of more than 30.000 inhabitants, the urban area of Gostivar is characterized with a large portion of older buildings built before the introduction of seismic codes. Most of the recent building stock consists of residential buildings built of reinforced concrete.

This paper focuses on the classification system for the existing building stock in the city of Gostivar, North Macedonia, which will consecutively be used for an urban scale risk assessment study. The proposed building classification system is based mainly on roundtable discussions with experienced engineers and on existing exposure models for Skopje following the 1963 earthquake, EMS-98, Risk-EU and GEM building taxonomies. First a brief description of the study area is provided together with seismotectonic settings. Follows the literature review of the past and present seismic codes in North Macedonia and the most important building taxonomies worldwide. The proposed building classification scheme consisting of eight major structural types is given at the end.

2. Study area

Throughout the geological history, the territory of North Macedonia was exposed to multiple tectonic, magmatic, sedimentation and metamorphic processes. As a result, its relief is predominantly hilly to mountainous with relatively narrow valleys. One such depression is the Polog neotectonic graben, where the Gostivar study area is located in its northern (upper) part, Fig. 1a.

a)



b)

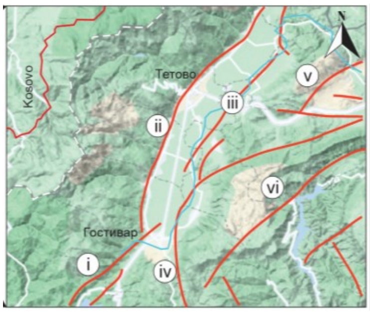


Figure 1. a) location of the Gostivar study area; b) Active fault structures: i) Mavrovo; ii) Shar mountain; iii) Zeden; iv) Suva Gora; v) Rasce; vi) Karsijaka faults. [5]

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The city is located in the Vardar River valley filled with relatively soft geological deposits at the surface with shallow groundwater level. These conditions may contribute to a significant amplification of the amplitude and modification of the frequency of the incoming seismic waves during strong earthquakes.

2.1. Tectonic characteristics

The Polog graben belongs to the Western Macedonian tectonic zone characterized with active radial (vertical) tectonics manifested by increased seismicity. In Fig. 1b are given the confirmed and presumed active faults within the wider study area, given schematically. It can be observed that the main network of approximately parallel faults on both eastern and western sides of Polog, indicated with ii) and iii), dictates the direction of the current flow of the Vardar River. The Shar mountain and Zeden faults extend in the NE-SW direction and belong to the group of normal faults, and located on the foothills of the surrounding mountain chains along the periphery of the valley. Of interest for this study are also the Mavrovo and Suva Gora faults, i) and iv), as the more important faults in the Polog group of faults.

2.2. Seismicity

As a part of the Balkan Peninsula, the territory of North Macedonia belongs to the Eurasian tectonic plate and represents an active seismic area. Therefore, in addition to the seismic hazard from local fault zones within the Polog graben (Tetovo-Gostivar) estimated with a maximum magnitude of M6.1, the potential seismic impacts from more distant and regional zones are also important for the dynamic stability of structures. The most active seismic zones at the regional scale are Skopje M6.5, Ferizaj-Vitina-Kačanik M6.5, Valandovo-Gevgelija M6.9, Mrežičko Kavadarci M6.1, Debar-Peshkopeja M6.9, Struga-Ohrid-Peshtani M6.1, the southern part of Lake Ohrid M6.9, Bitola M6.1 and the most active Pehčevo-Kresna seismic zone M7.9. Among the latest recorded local earthquakes in the Tetovo-Gostivar seismic zone, which can be assumed to be the result of the release of accumulated energy along the Mavrovo Fault, we will mention the earthquakes of: November 11, 2020 with a magnitude of M5.0 and an epicenter 8 kilometers southwest of Vrutok, near Mavrovo Lake; November 11, 2020 with M4.9, 19 kilometers southwest of Gostivar at a depth of 10 km; March 12, 2021 with M4.7 followed by a weaker earthquake M4.2, 18 kilometers southwest of Gostivar. According to the national Annex MKS EN 1998-1/NA:2020, the peak ground acceleration (PGA) and Sa0.2 values for the city of Gostivar are estimated at 0.20-0.25g and 0.55g, respectively, for a return period of 475 years.

3. Building codes, taxonomies and seismic behavior

3.1. Past and current building codes in North Macedonia

In North Macedonia, the building codes evolved gradually with time. Building codes set rules, standards and requirements related to the quality, durability, ductility and safety of structures. Their primary goal is the reduction of damage and losses to buildings from poor construction practices and manmade and natural hazards, such as earthquakes, winds and floods. The first building code on the territory of North Macedonia, then part of ex-Yugoslavia, was introduced with the "Temporary technical guidelines for loading of building structures" in 1948. This code, however, did not contain specific recommendations for reinforced concrete and masonry structures, and eventual dynamic design forces were considered as static loads. The structures were, therefore, designed to withstand the vertical gravity loads only, whereas the resistance to lateral impacts from seismic forces was generally negligible. Still, some of the structures that were designed for wind action suffered minor damage during the devastating 1963 M6.1 Skopje earthquake.

A significant knowledge gain on the potential seismic impacts was acquired following the 1963 Skopje earthquake. Expert committees were formed to collect statistics on occurred damage to buildings and their classification according to the structural system and the degree of damage. This documentation, together with the experiences and regulations of other countries, was used as the basis for the preparation of the new building guidelines, "Temporary regulations for construction in seismic regions" of 1964 (Official Gazette of SFRY No. 39/64). This time the design seismic forces were determined

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based on the assumed seismic shaking intensity, importance of the building, dynamic characteristics of the structure and the soil category. Respective seismic coefficients were recommended according to the seismic zoning map for a return period of 500 years, i.e. zones VII, VIII and IX according to MCS, soil category (weak, moderate and stiff) and the building occupancy. These guidelines contained only basic provisions for reinforced concrete and masonry structures. For example, recommendations and precise guidance were missing for reinforced concrete structures on the reinforcement, anchoring, placement of stirrups and ties in the elements, as well as the use of materials with lower strength was allowed. On the other hand, for masonry structures, no provisions for detailing were prescribed at all, there were only restrictions on the number of storeys depending on the shaking intensity.

Currently, the "Technical regulations for construction of buildings in seismic regions" from 1981 are still in place (Official Gazette of SFRY No. 31/81). According to this code, the equivalent static analysis is mandatory for most of the structures, whereas the dynamic analysis is required for special structures, high-rise buildings over 25 floors and irregular structures. The recommended intensity of seismic shaking is according to the probabilistic seismic hazard analyses (PSHA) for return periods of 50, 100, 200, 500, 1000 and 10000 years through the degree of macro-seismic intensity. A coefficient is introduced that takes into account the importance of the structure, soil category, intensity of seismic shaking, ductility and damping. The ratio of the total lateral force and weight of the structure for buildings of II importance category, built on a medium soil category in a zone with seismic intensity IX varies from 5% for flexible structure, 10% for structures with flexible ground floors, to 13% for rigid masonry structures. Provided are also precise design provisions, details of structural ductility with inclusion of "weak beam-strong columns" failure mechanism, with plastic joints formed at the ends of the elements, details of the reinforcement guidance in all reinforced concrete elements, as well as recommendations for the use of lightweight materials for reinforced concrete frames. These provisions, however, are still descriptive, without specific design guidelines. For masonry structures, provisions are given regarding their spacing, size of openings, thickness and type of element, and mechanical properties. The height of confined masonry structures is limited to 3 floors for zones with seismic intensity IX, to 4 floors for intensity VIII and 5 floors for intensity VII. The allowed height of unreinforced masonry structures is limited to 2 floors for zone VIII and 3 floors for zone VII, whereas this type of structure is not allowed in zones with intensity IX.

New seismic hazard maps were issued with the introduction of the national Annex MKS EN 1998-1/NA: 2020, Fig. 2a and b. These maps were compiled based on the PSHA approach, with the seismic hazard defined with PGA values for return period of 475 yrs ("no-collapse" requirement) and 95 yrs ("damage limitation" requirement). The maps show PGA values for the ground type A, defined as "rock formations", and five and three zones respectively for 475 and 95-year return period. In the calculation of the base-shear force, the PGA value is multiplied by the respective value of the soil factor (S) at the given location, which depends on the spectrum type (1 or 2) and ground type (A to E). Even though MKS EN 1998-1/NA:2020 is in parallel use with current regulations from 1981, almost all designs are done according to the existing code. The next generation probabilistic seismic hazard map with spatial distribution of the spectral acceleration Sa0.2s is given in Fig. 2c [11].

a) b) c)

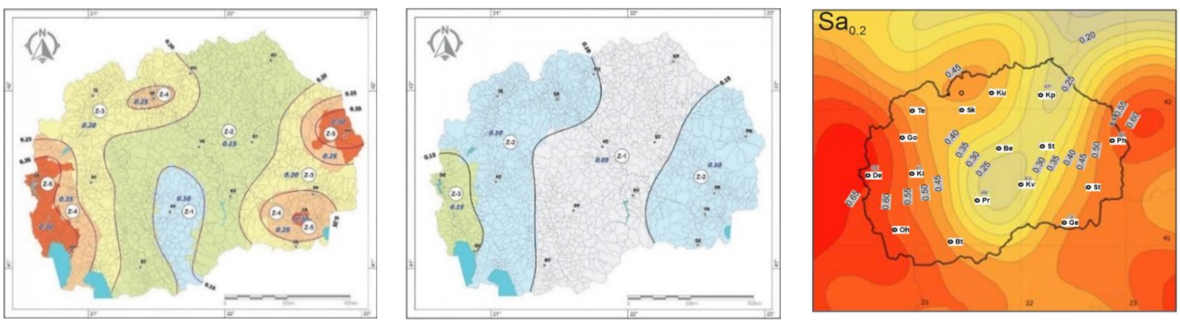

Figure 2. Seizmic hazard maps for PGA for 1/475yrs (a), 95-year return period (b), for soil type A (hard rock) [MKS EN 1998-1/NA: 2020; 11], and (c) for spectral acceleration Sa0.2s for a return period of 475 yrs

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3.2. Existing global and site-specific taxonomies

Creation of a representative exposure model represents the fundamental step in any seismic risk assessment. The most important is the classification of buildings (taxonomy) with respect to their structural system and dynamic behavior during strong seismic motion. Each building class is provided an adequate description with various attributes that cover different characteristics. Depending on the required accuracy and scale of the study area, the exposure model can be based on data collected in-situ with street survey, from municipal databases, from web services such as Google map, and data from national censuses or other statistics. Different taxonomies are currently existing for use at the global and regional levels, which are briefly presented herein.

PAGER-STR is a worldwide taxonomy that classifies buildings into a total of 101 classes based on the construction material, structural system, height, etc [7]. The taxonomy was created by merging existing taxonomies and later supplemented with building typologies collected from a number of countries. This taxonomy is global and is mainly used for real-time first-hand earthquake damage assessment and earthquake risk analysis.

World Housing Encyclopedia (WHE) is a collection of resources related to building practices in seismically active regions. Its mission is to share experience with different construction typologies and to encourage the use of seismically resistant structures. WHE includes more than 170 different building typologies from more than 45 countries.

HAZUS taxonomy is introduced by the DHS Federal Emergency Management Agency [8] to assess the impact of natural disasters, i.e. earthquakes, floods, tsunamis and hurricanes, on buildings in the USA. The taxonomy is characteristic for North American construction practices based on building typologies proposed by a rapid visual inspection in order to assess their occupancy class and safety. It contains 36 building typologies defined based on the structural system, number of stories (low, medium, high) and damage state (five classes).

Several building taxonomies have been developed for the European construction practices. According to the EMS98 - Macroseismic Scale [9] buildings are classified into 15 classes (7 masonry structures, 6 reinforced concrete structures and one steel and one wood structure) based on material and various structural characteristics. Each building class is characterized by an expected vulnerability (six classes). The RISK-EU project proposed building taxonomies for seven selected cities in Europe, including Bitola in North Macedonia. The structures are classified into 23 building classes depending on the structural system, construction material (masonry, reinforced concrete, steel, wood), number of stories (1-2, 3-5, 6+) and quality of construction defined with seismic code level (high, moderate, low and pre code), for a total of 65 building classes [2]. SYNER-G taxonomy includes 15 attributes and is used to classify buildings in a flexible non-hierarchical manner [3]. GEM building taxonomy [4] describes buildings through 13 attributes which are associated with building characteristics that can potentially affect seismic performance.

Although it is a common practice to use taxonomies developed in other regions, this can cause important epistemic uncertainties in the damage model. In addition to this type of uncertainties, it is important to keep in mind that the process of direct classification of buildings into pre-determined classes can be partially biased with respect to the expert experience. In addition, by assigning a given class, some of the information on the structural and non-structural elements is lost. In the phase of data collection, a large number of attributes can be observed and recorded. However, most often only a part of these attributes is used for the actual classification of buildings. Namely, at the application stage, most of this data can be rejected (not used) by using simplified taxonomies that may not fully capture the properties of a building stock. Therefore, it is suggested that the building taxonomy must be sufficiently flexible to allow a classification of the buildings present in the respective study areas that captures the basic characteristic and features that may be used to validate the selected category.

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3.3.Seismic behavior of buildings during the 1963 M6.1 Skopje earthquake

Although it occurred more than 80 years ago, the 1963 M6.1 Skopje earthquake is still the most destructive recent earthquake in North Macedonia. It caused significant human casualties and physical and social damage. It is estimated that a total of 1.500 people died and more than 4.000 were injured. There are unfortunately no seismic records of the earthquake, and according to a few data from seismological stations, the epicenter was located in the northern part of the city, with an estimated depth of 2 - 5 km, and a moment magnitude 9° according to the MCS scale, which corresponds to a moment magnitude M6.1. According to recent analyses [10], the magnitude of the earthquake was estimated at M5.9, the activated fault zone had dimensions of 15x8 km, depth of 2 km, dip of 79°, and strike in the northwest-southeast (NW-SE) direction.

The main reason for the collapse of most of the buildings was that they were designed to withstand vertical gravitational loads only, whereas the resistance to impacts from lateral seismic forces was generally negligible, Fig. 3. Some of the buildings that were designed for wind action suffered minor damage. The most common high damage and collapse states were observed in the older unreinforced masonry buildings (mainly sun-dried bricks), in buildings with weak horizontal and vertical connections between load-bearing elements, in RC buildings with shear walls and infills with poorly reinforced concrete columns and small cross-sectional dimensions. The poor quality of the built-in materials and the poor quality of the construction and maintenance of the buildings contributed to additional weakening of the load-bearing capacity of the structural systems.

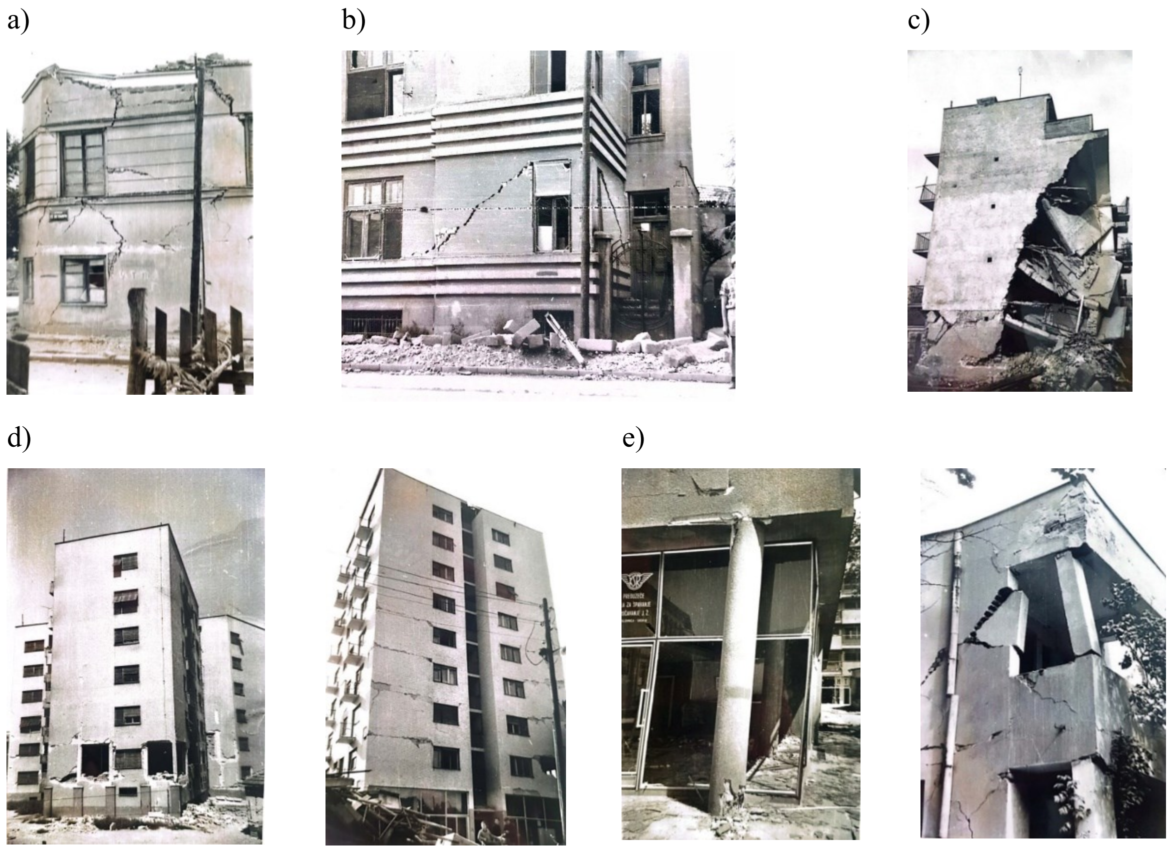

Figure 3. Typical damage during the 1963 Skopje earthquake: a) lack of horizontal/vertical connections, b) diagonal cracks in masonry at ground level; c) collapse of corners and walls due to lack of horizontal/vertical connections; d) separation of walls from the floor structure and partial damage to columns and beams, e) damage to columns due to low stiffness, sparsely placed stirrups and poor horizontal/vertical connections [1].

Buildings with a wooden frame (W) behaved relatively well under seismic loading and large transient deformations. They suffered small permanent deformations and loss of the infill and insignificant displacements of the frame.

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Buildings of unreinforced masonry with flexible diaphragms (URM2) did not behave favorably and, due to the insufficient stiffness along the height, they were partially collapsed or shaken, which posed a problem for reconstruction. The appearance of cracks due to exceeding the in-plane load-bearing capacity of the walls was a common occurrence, Fig. 3a. In the interior, there were partition walls with a smaller thickness, which contributed poorly to the global building stiffness.

Most of the damage to the unreinforced masonry buildings with rigid diaphragms (URM3) occurred in the ground floor. Diagonal cracks were common due to exceedance of the shear strength under alternating horizontal cyclic loading. This type of failure mechanism was often accompanied by cracks along the joints, due to poor mortar quality. In walls with poor stiffness, a tendency for collapse was observed for the corner joints and the joints of the partition walls. There was also frequent damage and separation of the stairs which were supported by the floor structure and the surrounding relatively solid core of thick masonry. At the similar typology (mid-rise), due to the high initial stiffness and low shear resistance, diagonal cracks appeared on the weakened load-bearing walls, corner joints, horizontal cracks at the level of the floor structures, as well as cracks in the partition walls, Fig. 3b and c.

The reinforced concrete frame buildings (RC1) with lightweight partition walls suffered relatively minor damage, while buildings with solid brick infill walls were quite damaged due to the higher mass. In buildings with central core of unreinforced concrete or reinforced concrete supporting the staircase, the seismic forces were absorbed by the rigid cores, which resulted in high damage, whereas the lighter frame structures were less damaged. In the symmetrical buildings, appeared the separation of the walls from the in-plane axe and their collapse, due to the poor structural connections and poor quality of the material, Fig. 3d. In buildings with reinforced concrete frames and shear walls (RC2), failures in columns occurred due to the low stiffness and low number of stirrups. Other reasons for collapse include weak horizontal and vertical connections and asymmetry of the buildings, Fig. 3e.

4. Simplified taxonomy for the existing buildings

According to the 2021 Census data from the State Statistical Office, the total population in the country was 1.836.716 inhabitants. In the city of Gostivar, the total population was 59.770 thousand inhabitants, with a total of 20.054 households. According to the number of households, 9.777 families (32.814 inhabitants) live in urban and 8.145 families (26.956 inhabitants) are in rural areas. According to this data, the approximate number of buildings in urban areas is 10.000, making it one of the larger cities in the country. Unfortunately, these databases do not contain data on the characteristics of the structures.

The proposed simplified taxonomy for the existing buildings in Gostivar, which covers most of the existing building types in North Macedonia, is based on roundtable discussions with experienced engineers and on existing exposure models for Skopje following the 1963 earthquake, EMS-98, Risk-EU project and GEM building taxonomy. The classification was performed based on the following attributes: material of the load-bearing structural system (wood, masonry, reinforced concrete), structural system (masonry, bearing wall system, frame system), type of floor structure (flexible, rigid), height of the structure, year of construction (related to seismic codes), occupancy, building position within a block and building irregularities. Accordingly, 8 main building typologies are proposed for the city of Gostivar: 1 wooden structure, 4 masonry structures and 3 reinforced concrete structures.

4.1. Wooden frame with infill (W) over brick or stone masonry ground floor

Until the beginning of the 20th century, in addition to stone, wood was used as a traditional material for the structural system and architectural design of individual residential buildings, especially in rural settlements. The structural solutions were dictated by the geographical and climatic conditions and the local traditional construction practices. According to the construction technique, the most commonly used were the mixed construction system, i.e., a combination of stone masonry and light wooden construction, so-called bondruk system, Fig. 4. Depending on the type of the used material, there are several types of buildings:

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- Houses where the bearing stone masonry walls are present in most of the ground floor, first and second floors, while the wooden bondruk construction is present in part of the first and second floor, with an open loggia.
- Houses built entirely of stone masonry, where only the cantilever-shaped front part (doxate, chardak) is of the bondruk construction.
- Tower houses are built entirely of stone masonry walls across three levels with wooden floors.

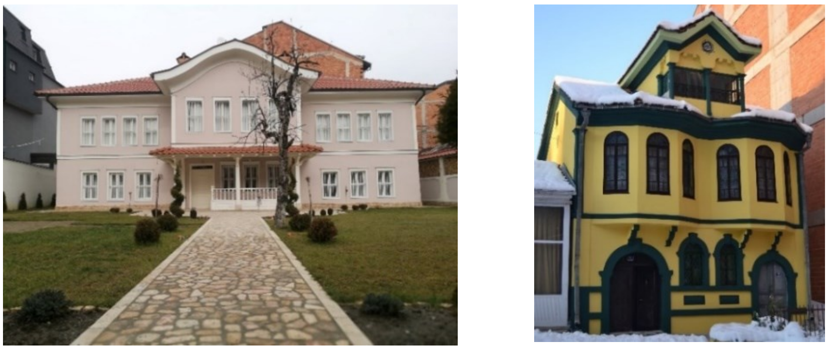

Figure 4. Houses with stone walls on the ground floor and bondruk system on the upper floors, Gostivar (W).

The load-bearing stone masonry walls are usually made of crushed, semi-finished and rarely of finished stone. Hewn stone blocks, in the form of vertical structural elements, are found in the massive ground floors. In stone walls, horizontal wooden strips called "kusacs", visible or built into the thickness of the wall are placed with the function of leveling the stone masonry. Mud is used as a binder for stone walls in older types of buildings, while lime mortar is used in houses from the end of the 19th and first half of the 20th centuries. The frame structure-bondruk consists of a wooden frame made up of columns, horizontal and inclined girders. The filling can be different: wicker, carved planks nailed to both sides of the columns, mud and unbaked bricks. The walls are plastered, and the total thickness varies 18-22 cm. The floor structure consists of a wooden beam system. There are houses without overhang, houses with overhang only on the first or only on the second level, or they can be applied along the entire height. Overhangs are formed by extended beams from the floor structure, supported by a truss, which remain visible or are covered with planks and plastered. The roof structure is in most cases hipped, with a slight slope. The covering is made with slate stone slabs, or with clay tiles (the so-called Turkish type). Mixed structures with wood and stone masonry also belong to this typology. Therefore, the typology could further be break down in subtypes.

4.2. Unreinforced adobe or stone masonry with flexible diaphragms (URM1)

In this typology of structures, several subtypes can be identified. The majority of buildings is built with walls filled with mud or sun-dried bricks, so-called adobe. These buildings are built with a ground floor and an upper floor, with shallow foundations of stone masonry in mud mortar, and a wooden floor structures.

As a representative of the traditional construction of the 19th century is the so-called slamenica (hatched) house, which is characterized mainly as ground-floor buildings with stone walls (60 cm thick) with a mud binder, covered with reeds or straw.

Stone masonry with lime mortar has traditionally been used for the construction of older public buildings, fortresses and religious buildings, such as mosques, churches, monasteries, etc. The vulnerability assessment of these types of structures is usually done on case-by-case basis.

4.3. Unreinforced masonry with flexible diaphragms (URM2)

Constructions of this type were built until the beginning of the 20th century. The buildings were built with a ground floor and two floors, where solid firebricks were used as the structural material for the load bearing walls, Fig. 5. For the construction of the load-bearing walls, “Austrian” type of bricks were

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used with dimensions 14x29 cm with wall thickness 45-60 cm. When smaller brick dimensions were used, the wall thickness was 25-38-51 cm. In the beginning, lime mortar was used as binder, while since 1950, cement/lime mortar was introduced. Similar construction variant was built with stone masonry at the ground floor. The wooden floor structure is composed of a wooden beams with a board formwork. The foundation was made of stone masonry. The roof structure is gable or hipped, covered with tiles.

Figure 5. Unreinforced masonry with solid firebricks and wooden flexible floor, Gostivar (URM2).

4.4. Unreinforced masonry with rigid diaphragms (URM3)

Constructions of this typology can be divided into subtypes depending on the materials used, the period of construction, and the type of floor system, Fig. 6.

Buildings with bearing walls made of baked solid bricks with reinforced concrete floor structure mainly with a ground floor and first floor. The load-bearing walls are 25cm or 38cm thick, while the partition walls are 12cm thick. The floor structures are of semi-prefabricated, type of ribbed RC slab with formed horizontal beams-rings (weakly reinforced) of reinforced concrete on the load-bearing walls. This type was common in the period between the two world wars. The foundations are of unreinforced concrete or stone masonry in cement/lime or cement mortar. The buildings are made of baked brick masonry in lime mortar.

After WW2 are built typical multi-dwelling buildings in urban areas consisted of a ground floor and four floors without an elevator. These structures are with regular and symmetrical footprint. The load-bearing walls are built in two orthogonal directions with solid firebrick with lime or cement/lime mortar. The thickness of the bearing walls is 25 or 38 cm with 12 cm thick partition walls. The foundations are made of unreinforced concrete. The floor structures are of semi-prefabricated ribbed RC slabs with formed horizontal beams-rings (weakly reinforced) of reinforced concrete on the load-bearing walls.

Single-family houses have been built in urban and rural areas after WW2, with a ground floor and one floor on top. The load-bearing walls are built of modular (perforated) bricks or solid bricks in cement/lime mortar. The thickness of the walls varies from 19 to 25 cm. The foundation of these buildings is made of strip foundations made of unreinforced concrete or reinforced strip foundations. In all these types of structures, the concrete strength in the foundations is lower than the above-ground reinforced concrete structure.

Various types of reinforced concrete ribbed floor structures were used. The Herbst system consists of reinforced concrete ribs and a slab of cast concrete with a thickness of 4-5 cm. Another type of semi-prefabricated floor structure is the Avramenko type, with characteristics similar to the Herbst system. In the mid-1960s, a system of semi-prefabricated concrete and brick was used. The "Monta" system consists of hollow brick blocks that constitute the formwork, reinforcement in the ribs (in the space between the blocks) and casting of ribs and a concrete slab with a thickness of 4-5 cm. Another variant is the "Fert" system used since 1980. This system consists of reinforced concrete beams in brick molds with built-in reinforcement, placement of hollow brick blocks between the beams, additional reinforcement and concreting of a rib and a slab with a thickness of 4-5 cm. Following the 1963 Skopje earthquake, the floor structures are most often made as monolith reinforced concrete slabs in both directions. These types of floor structures are used for both masonry and reinforced concrete structures.

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The floor structures in these buildings are treated as rigid horizontal diaphragms, although the behavior of ribbed structures and reinforced concrete monolith slabs is not identical. These structures are covered with gable or hipped wooden roofs made of tiles or as flat terraces.

a) b)

Figure 6. Unreinforced masonry with rigid diaphragms a) single residential house; b) multi-dwelling building, Gostivar (URM3).

4.5. Confined masonry (CM)

This building system dates from 1970. The structure is composed of framed masonry with horizontal and vertical reinforced concrete elements, Fig. 7. These buildings are single or multi-residential built with 1 to 4 floors. The masonry is composed of modular (perforated) or solid clay blocks. The thickness of the walls varies from 19 to 25 cm in cement/lime mortar. The floor structures are executed as reinforced concrete slabs or semi-prefabricated systems (described in the previous section). The roof structures are built as flat reinforced concrete slabs or as sloping wooden roofs. The load-bearing walls are placed above reinforced concrete strip foundation.

Figure 7. Confined masonry with solid bricks or hollow blocks, Gostivar (CM).

4.6. Reinforced concrete frames with masonry infill (RC1)

The first reinforced concrete structures were built only in the 1950s, with a full expansion for residential buildings observed after the 1963 Skopje earthquake. These structures are with rectangular footprint with ground floor usually used for commercial purposes. The number of floors ranges from 6 to 10 floors, whereas it increased to more than 10 floors after 1963, Fig. 8. To increase the rigidity of the structure, reinforced concrete cores is introduced around the staircase and elevator area. The masonry infill was initially made of solid brick and hollow brick after 1963. Characteristic for these buildings is the ground floor with a increased height representing an open space for commercial premises. The foundation is made on single foundations connected with foundation beams or a foundation slab, with concrete of lower strength. The floor structures are constructed with reinforced concrete slabs. For buildings with larger spans, such as business buildings and shopping centers, the construction of floor structures of reinforced concrete cassette slabs is practiced. Following the introduction of the new regulations, "PIOVS 1981", modern reinforced concrete frame structures are being built, with building materials with stronger strength characteristics.

Figure 8. Reinforced concrete structures built before and after the 1963 Skopje earthquake, Skopje (photo no.1) and Gostivar (photo no.2, 3) (RC1).

4.7. Reinforced concrete frames with shear walls (RC2)

The application of reinforced concrete shear-walls as a vertical load-bearing system began after 1950. These systems were built with a central core of reinforced concrete walls that were mainly concentrated around the staircase, Fig. 9. The other vertical structural elements consist of reinforced concrete columns or a combination of reinforced concrete columns and walls. The floor structure is of reinforced concrete massive slab, whereas the facade walls are built of non-load-bearing masonry. The main difference between these systems is in the introduction of reinforced concrete core and additional reinforced concrete walls, which contributed to the construction of high-rise structures with more favorable behavior under seismic action. The foundation is most often constructed with a reinforced concrete slab.

Figure 9. Reinforced concrete frames with shear walls, Gostivar (RC2).

4.8. Prefabricated reinforced concrete structures (RC3)

The application of prefabricated reinforced concrete structures began after 1963. There were several different prefabricated systems, mostly the large-panel building system of “Karposh” system, Fig.10.

Figure 10. Prefabricated reinforced concrete structures of the “Karposh” system, Skopje (RC3)

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A large number of residential and industrial buildings have been built in this way due to the shorter construction time and lower costs. The large-panel system consists of reinforced concrete walls and prefabricated floor panels, assembled at the construction site with construction of special connections with steel anchors. The large-panel prefabricated buildings of the "Karposh" type are built usually with 5 to 10 floors, but also for individual residential and industrial buildings.

5. Conclusions

The exposure model is important since it represents the first step in the risk assessment process. It helps to predict and estimate the damage to buildings, social and economic losses. The present study focused on the seismic hazard setting in the study area of the city of Gostivar, North Macedonia, overview of the developed global and regional taxonomies and development of the exposure model for the existing building stock. The building classification system was developed using multiple sources defining attributes that accurately describe the structures. Only buildings of various occupancy categories were taken into account for the classification model. Eight main building categories have been retained: wooden frame with infill (W), unreinforced adobe or stone masonry with flexible diaphragms (URM1), unreinforced masonry with flexible diaphragms (URM2), unreinforced masonry with rigid diaphragms (URM3), confined masonry (CM), reinforced concrete frames with masonry infill (RC1), reinforced concrete frames with shear walls (RC2), prefabricated reinforced concrete structures (RC3). To be included in the risk assessment model under development, each of these categories needs to be further broken down into subtypes with respect to their seismic response and vulnerability.

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