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ASSESSMENT OF THE EARTHQUAKE VULNERABILITY OF MULTI-RESIDENTIAL BUILDINGS IN SLOVENIA

OCENA POTRESNE OGROŽENOSTI VEČSTANOVANJSKIH ZGRADB V SLOVENIJI

Vojko Kilar, Domen Kušar

VOJKO KILAR

This multi-residential building was severely damaged during the earthquake in Koaceli, Turkey, in 2002.
V potresu leta 2002 poškodovana večstanovanjska hiša v kraju Koaceli v Turčiji.

Assessment of the earthquake vulnerability of multi-residential buildings in Slovenia

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ABSTRACT: The paper assesses the earthquake vulnerability of multi-residential buildings in Slovenia, although it is limited to the buildings that were built before 1981, in the time when the earthquake building codes were much less elaborated than today. In the paper, based on the building completion year, buildings are classified into different time periods, which are characterized by important historical events and bigger changes in earthquake building codes. The assessment of earthquake vulnerability is based on the data from the building completion year, number of storeys, prevailing structural material and the year of the last renovation as obtained from the last census of the population, households and apartments completed in 2002. The result is an estimation of the earthquake vulnerability of a building, also because for very similar buildings the earthquake resistance depends on the architectural design of a building, the amount and layout of its structural elements, foundations, soil profile and other influences. In the first part of the paper the multi-residential buildings are divided by age, material and number of storeys. In the second part, the assessment of the earthquake vulnerability of these buildings is divided into three classes: a) probably earthquake unsafe, b) probably earthquake less safe and c) probably earthquake safe. Additionally the earthquake vulnerability assessment is presented geographically by showing the earthquake less safe and unsafe buildings on the maps and charts for different communities in Slovenia. It has been concluded that the earthquake safety of many multi-residential buildings in Slovenia might be questionable, while we have detected also bigger differences between communities.

KEY WORDS: architecture, structural engineering, geography, earthquake safety, earthquake vulnerability, earthquake unsafe buildings, multi-residential buildings, Slovenia

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Contents

1 Introduction

In Slovenia the majority of the population, especially in cities, lives in multi-residential buildings. These buildings are mainly multi-storey apartment blocks and skyscrapers built in the previous century, especially after the end of World War II, when the erection of such structures became more popular. The results of the census of the population, households and apartments performed by Statistical Bureau of Republic of Slovenia in 2002, show that at that time there were 18,005 multi-residential buildings in Slovenia, which represented only 3.9% of all residential buildings. However, in multi-residential buildings there were 242,011 apartments, which was almost one third of all apartments in the country. The area of all apartments in multi-residential buildings amounted to 13,491,714 m^2 which is 23.2% of the total area of all apartments in Slovenia. Before 1981, there were built 14,744 multi-residential buildings with 185,994 apartments with an area of 10,253,913 m^2, which was as much as 76% of the total area in all multi-residential buildings.

The first part of the paper describes characteristic building time periods, which were characterized by important historical events and major developments in earthquake building codes. Based on the year of the erection of a building we can make a judgement about its current condition and earthquake resistance. We have limited our study to the buildings built before 1981, because after the Montenegro earthquake (1979) the new Yugoslavian earthquake building codes, which assured much better earthquake safety, were introduced in 1981. By statistical analysis, all buildings were classified by age, material and number of storeys. Considering relatively logical assumption that the builders had followed valid building codes, we can estimate the level of earthquake resistance of the existing building by comparison of the code's requirements valid at the time of erection with the requirements that are valid today. The classification in the older group does not automatically mean a lower level of earthquake resistance, since in some older periods, building of certain types of multi-residential buildings was better than in the periods that followed. For example, building quality of low-rise masonry and mixed multi-residential buildings in the first half of the 20th century taking into consideration Austrian codes and regulations were relatively good. On the contrary, building quality in the first year of the development of socialism after World War II was generally much worse and consequently most of the higher buildings from that period were probably earthquake less safe.

The main contribution of this paper is the preparation of the criteria for the assessment of the earthquake vulnerability of multi-residential buildings built before 1981 and their division into 'probably earthquake unsafe', 'probably earthquake less safe' and 'probably earthquake safe' categories.

It should be stressed, that on the basis of census data, only a general estimation of the earthquake vulnerability and the necessity for an earthquake retrofit can be given. A more accurate evaluation can only be obtained by detailed inspection and analysis of individual buildings or group of buildings in a smaller region and its generalization to the area of the whole of Slovenia. The obtained results for the state and regional level show share of probably earthquake unsafe and probably earthquake less safe building for all Slovene communities. Alas the application of higher safety standards remains problematic, since it depends mainly on financial resources, which are getting even more complicated in the new proprietorial relations recently formed in many multi-residential buildings.

2 Methodology

Earthquake resistance of buildings is normally determined by studying the building plans and performing static calculations and analyses for each individual building (Tomaževič 1987 and 1998; Fajfar et al 2000; Dujič, Žarnić 2008; Bosilkov et al 2008). This method, however accurate, might be expensive or even unworkable, if we are trying to asses earthquake vulnerability of a larger area, region or even of the whole country. Several similar earthquake vulnerability assessments have already been made for Ljubljana and some other Slovenian cities and municipalities (Orožen Adamič 1995; Orožen Adamič and Perko 1996; Kilar 2004). In our study we have used the results of the last census of the population, households and apartments (Popis … 2002), which also contains some data about the buildings within which the apartments are located (Zupančič et al 2003). Data on year of completion, number of storeys, type of structural system and prevailing material of the load bearing system of the building, as well as the year of the last renovation of the apartment, purpose of use and number of apartments in a building are available.

Assuming that the builders had followed the building code valid at the time of building, we can compare the code's demands with the demands that are valid today and estimate the number of apartments in »probably earthquake unsafe« buildings, number of apartments in »probably earthquake less safe« buildings and number of apartments in buildings which can be considered as earthquake safe (Kilar 2004). In this context the formulation »probably earthquake unsafe« building stands for a building which could have been dangerous during an earthquake and could be damaged beyond the repair limit (or could even endanger human lives), however, it is not necessary that this would actually happen since the majority of buildings have certain additional strength, which is the consequence of the amount and the disposition of load bearing elements (Tomaževič 1987; Kilar and Koren 2009), their interconnections, solid building according to sound engineering principles, fulfilment of minimal requirements, general work quality and quality of details (Žarnić 2005), as well as soil quality and other influences (Orožen Adamič and Hrvatin 2001; Slak and Kilar 2005). For these reasons buildings with the same height and age, built of the same material on similar ground, are not necessarily equally vulnerable during the same earthquake. Because of this additional strength many buildings survive an earthquake even if they are not built according to any earthquake building code. Exact determination of additional strength is only possible by structural analysis of each individual building and it cannot be included in this general assessment of earthquake vulnerability, based on a limited statistical input parameters. It is therefore necessary to interpret the results about »probably earthquake unsafe« buildings with some caution, understanding that these buildings could be dangerous during an earthquake, however, it is not certain that they would be destroyed or that they would cause danger to human lives.

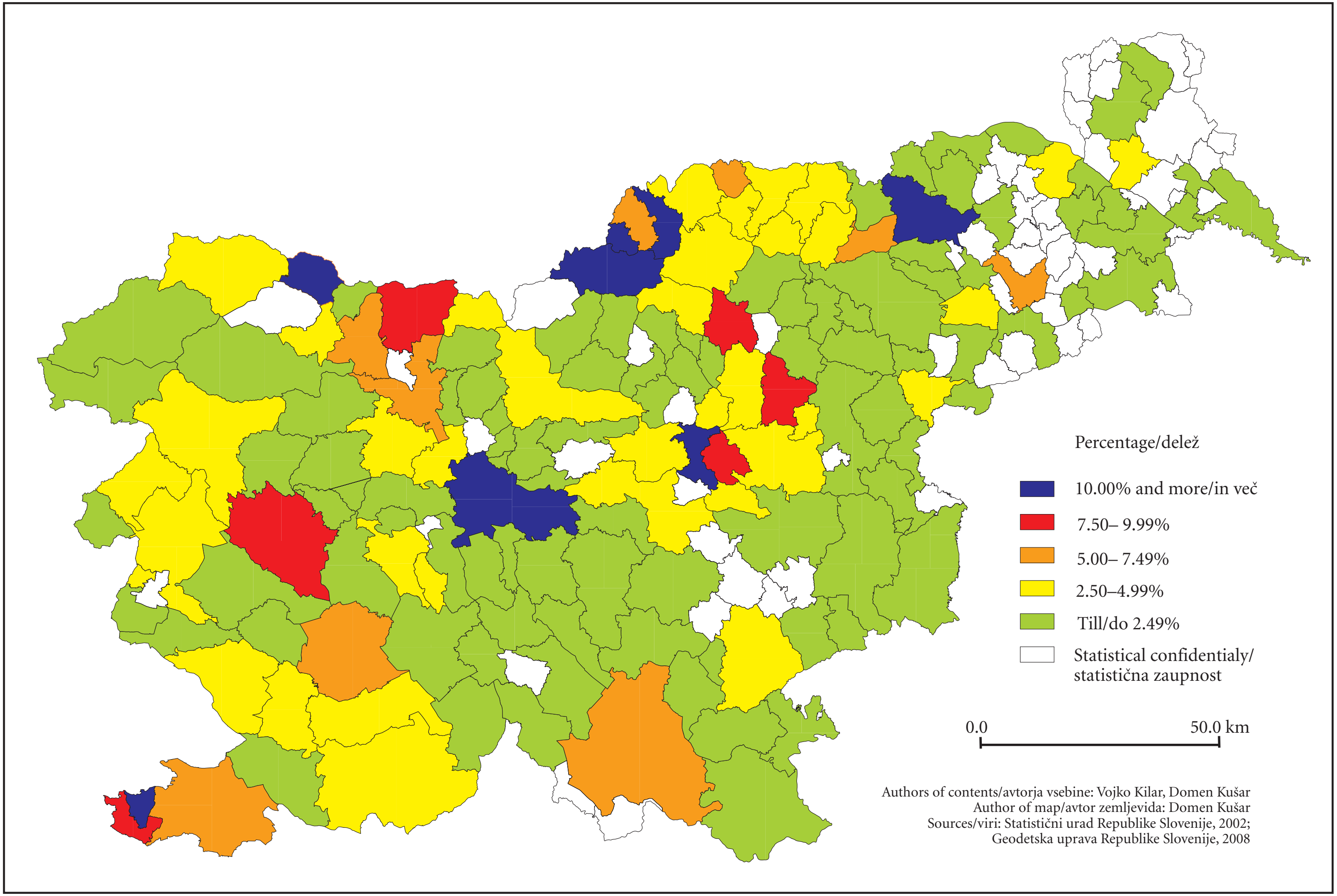
3 Characteristics of multi-residential building

The 2002 census of the population, households and apartments (Popis … 2002) classified multi-residential buildings as apartment blocks, skyscrapers or older municipal multi-storey buildings, which are built one next to another and do not look like a modern multi-residential building. All considered multi-residential buildings have certain common characteristics, mostly related to building material and plan layout. Most of the buildings are made as a combination of reinforced concrete elements and shear masonry walls. The reinforced concrete is mostly used for ceilings, staircases and beams, while shear walls are mostly made of masonry units or prefabricated concrete panels. In older buildings, ceilings are made of wooden beams, while walls are built of masonry without any concrete confinement elements. Concrete became more popular for building walls after World War II. Wood as structural material has been mainly used for roofing, while wooden multi-residential buildings were only exceptional in the considered time period. Similarly, use of steel frame structures for multi-residential buildings had not been popular until the last decade.

Most Slovene multi-residential buildings have an elevated ground floor with the main entrance followed by a small entrance hall (windbreak) with letter boxes. This space is usually separated from the main communications inside the buildings. Typically the communication corridors and staircases are positioned in the centre of the building, while the apartments are arranged on the perimeter of the building. In the higher buildings, one or two elevators are positioned next to the main communication shafts. Such an arrangement enables better illumination of the apartments. Due to the rationality of communal pipelines, plan layout remains practically the same on all storeys.

Three types of multi-residential buildings are most common in Slovenia: multi-storey houses, skyscrapers and apartment blocks. Each type has its own characteristics; nevertheless the multi-storey house and apartment block seem to be structurally very similar to each other. A typical skyscraper has a rectangular or even square floor plan shape and ranges in height from 10 to 12 storeys. The apartment block is usually elongated in one direction and includes more than one communication shaft. It usually has a ground floor and three or four storeys, because for all buildings higher than four storeys the elevators were mandatory. Some apartment blocks have vertical communications in the centre, while in others they are positioned closer to the side with one wall on the perimeter of the building. In this way natural illumination of the stairs has been made possible during the daytime. Storey height in older buildings is about 3 m, respecting the standards valid at that time (Building law, 1931) which required a minimal height of

Figure 1: Share of multi-residential buildings in Slovene communities in 2002 (100% = all residential buildings in the community). ➤ p. 94


Percentage/delež
10.00% and more/in več
7.50– 9.99%
5.00– 7.49%
2.50–4.99%
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Author of map/avtor zemljevida: Domen Kušar
Sources/viri: Statistični urad Republike Slovenije, 2002;
Geodetska uprava Republike Slovenije, 2008

2.8 m. Newer buildings have lower storey height; nowadays the required height amounts to 2.5 m while the height is usually higher. We can conclude that height of older multi-residential buildings with a ground floor and four storeys is about 15 or 16 m and height of an average older skyscraper with twelve storeys around 36 m.

Usually, multi-residential buildings from the considered period do not have parking areas under the building, the basements are usually used for storage and maintenance. The garages are arranged next to the building or separately. Newer buildings have more basement floors including parking areas.

Most multi-residential buildings are in municipal communities with a developed industry. Many of such buildings can be found on the Slovenian coast and in the north part of Slovenia (Figure 1). The highest percentage was recorded in Trbovlje (14%), Maribor (13%), Ljubljana (13%) and Mežica (13%), while the largest number of such buildings can be found in Ljubljana (4291), Maribor (2094), Celje (682), Koper (569) and Kranj (528).

4 Development of earthquake building codes and building time periods

The development of earthquake building codes has been gradual; they were usually extended and made stricter after every strong earthquake. The first code that included earthquake loading as a separate loading case was the Temporary technical code (*Privremeni tehnički propisi – PTP*), which was issued in the Federative Republic of Yugoslavia back in 1948. According to the overview of the code development in Slovenia in the past one hundred years we can establish the characteristic building time periods, which significantly differ from what was at that time the valid building code and requirements for earthquake resistant design (Bubnov et al. 1982; Bubnov 1996; Kilar 2004; Slak and Kilar 2005; Žarnić 2005).

In this article we have determined four characteristic building time periods before 1981 taking into consideration the historical bench-marks and time of implementation of different building codes, Tables 1 to 4 present a review of the apartment area in buildings built from different materials. Total apartment area in the corresponding building time period is also given together with share percentages so the exact values can be calculated. The Statistical Bureau of the Republic of Slovenia strictly considers the provisions about data confidentiality required by the law, so all values smaller than 5 are not published. However, total sums of these low data values are included, so the sum of individual percentages is lower than 100%.

4.1 The period before 1894 (before the Ljubljana earthquake in 1895)

In this period, the earthquake resistance was mainly achieved by experience, such as by reducing the building height, increasing the wall thicknesses in lower storeys, lowering the mass centre of the building, etc. Some buildings that were built in this period might have already reached their life-time limit and should have probably been renovated or demolished. Historically protected buildings need a special approach in this manner.

The area of multi-residential buildings from this period amounts to 6.5% of all multi-residential buildings in Slovenia (13,491,714 m^2). They are made of masonry (41.1%), combined materials (20.6%), stone (17.9%) and concrete (16.8%). The division of multi-residential buildings based on material and number

Table 1: Division of the area of multi-residential buildings built before 1894, according to the prevailing structural material and number of storeys. Total area of reviewed buildings in this time period is 874,993 m^2.

	Single	From 1 to 3 storeys	4 storeys	From 5 to 8 storeys	9 and more storeys
Masonry	0.50	35.41	2.83	1.73	0.63
Concrete		0.48	4.82	4.75	6.77
Combination of different materials	0.46	17.41	2.00	0.50	0.22
Wood		0.25			
Stone	0.56	16.60	0.75		
Other	0.01	0.06	0.02		

of storeys is presented in Table 1. Most of the apartment area (70.2%) is in one to three-storeys buildings, while 14.6% of apartments can be found in higher buildings with five or more storeys. According to census data 66,500 m^2 of buildings with nine or more storeys were built in this period, which does not seem very likely, since such buildings from this period do not exist excluding belfries and towers. It is also possible that there were some errors or inconsistencies during the census.

4.2 The period from 1895 to 1945 (before World War I and between the World Wars)

Buildings were built according to Austrian and old Yugoslavian building codes in this period, which prescribed the thickness of the masonry walls for different storeys, width of walls between windows, procedures for fabrication of ceilings, fire walls and massive floor plates (Gradbeni zakon 1931). For horizontal loading only the wind loading was considered. Most buildings from this period are solidly built, relatively regular in plan and elevation with prescribed details and carefully selected materials. They had started to use reinforced concrete in this period to build the first higher building and sky scrapers which react to earthquake loading completely differently from rigid masonry buildings from previous centuries. The most well known example in Slovenia is the Ljubljana skyscraper from 1933.

Area of multi-residential buildings from this period amounts to 9.2% of all multi-residential buildings in Slovenia. They are mostly made of masonry (67.9%) and combined materials (18.0%). The division of multi-residential buildings based on material and number of storeys is presented in Table 2. Most of the apartment area (76.9%) is in one- to three-storey buildings, while 8.6% of apartments are in buildings with five or more storeys.

Table 2: The division of area of multi-residential buildings built from 1895 to 1945, according to the prevailing structural material and number of storeys. Total area of the reviewed buildings in this time period is 1,247,127 m^2.

	Single	From 1 to 3 storeys	4 storeys	From 5 to 8 storeys	9 and more storeys
Masonry	1.40	55.16	6.71	4.17	0.51
Concrete		2.20	2.08	1.61	1.35
Combination of different materials	0.63	14.85	1.69	0.84	0.06
Wood	0.06	0.14			
Stone	0.05	3.89			
Other		0.12			

4.3 Period from 1946 to 1963 (the period soon after the second world war)

Most of the buildings from this period were built according to the first Yugoslavian codes for imposed building loads (PTP – Privremeni tehnički propisi, 1948). Yugoslavia was divided into three earthquake zones according to this code:

- Zone a) of smaller damage,
- Zone b) of bigger damage and
- Zone c) of possible catastrophic destruction.

According to this code maximum earthquake force for Zone (c) amounted to 3% of the dead load and half of the live load. These values are up to five to ten times smaller than the forces used in modern standards. For this period of growing socialism the quality of building was generally not very high. This code was valid until 1963.

Area of multi-residential buildings from this period amounts to 22.6% of all multi-residential buildings in Slovenia. They are mostly made of masonry (62.9%), concrete (21.5%) and combined materials (13.8%). The division of multi-residential buildings based on material and number of storeys is presented in Table 3. Most of the apartment area (45.6%) is in one to three-storeys buildings, while 29.1% of apartments are in buildings with five or more storeys.

Table 3: Division of area of multi-residential buildings built from 1946 and 1963, according to the prevailing structural material and number of storeys. The total area of the reviewed buildings in this time period is 3,053,960 m^2.

	Single	From 1 to 3 storeys	4 storeys	From 5 to 8 storeys	9 and more storeys
Masonry	0.62	33.97	14.47	11.53	2.17
Concrete	0.01	4.46	5.78	6.87	4.41
Combination of different materials	0.06	6.27	3.83	2.81	0.82
Wood	0.03	0.18			
Stone	0.03	0.38	0.02		
Other		0.28	0.45	0.47	

4.4 Period from 1964 to 1981 (after the Skopje earthquake)

After the catastrophic earthquake in Skopje in 1963, a new earthquake building code was introduced in 1964. This code significantly increased earthquake forces for all types of buildings, prescribed distribution of horizontal forces over the height of a building and included influence of soil quality on the determination of horizontal forces. Also, in the same year, a new seismic hazard map of Slovenia was issued, which presented the division of earthquake prone areas in Slovenia much better. Code requirements for building masonry buildings in earthquake prone areas were completely changed. For the first time vertical reinforced concrete confinement elements at the corners and at the junctions of masonry walls were prescribed. The new code also improved building of concrete structures by prescribing the reinforcement details such as shape and distance between stirrups, overlapping of reinforcing bars, anchorage. Nevertheless, quality of the prescribed details was still much lower than in present codes. In general, earthquake resistance of buildings built in this period was higher than for older buildings. This code was again critically analyzed after the Montenegro earthquake in 1979, resulting in a new Yugoslavian earthquake building code which was issued 1981.

Table 4: The division of the area of multi-residential buildings built from 1964 and 1981, according to the prevailing structural material and number of storeys. The total area of the reviewed buildings in this time period is 5,478,708 m^2.

	Single	From 1 to 3 storeys	4 storeys	From 5 to 8 storeys	9 and more storeys
Masonry	0.09	5.50	6.16	3.80	1.17
Concrete		5.90	21.80	21.41	24.56
Combination of different materials		2.01	3.23	2.49	0.43
Wood	0.07	0.03		0.05	
Stone		0.11			
Other			0.42		

Area of the multi-residential buildings from this period amounts to 40.6% of all multi-residential buildings in Slovenia. The majority of them are built of concrete (73.7%), much less of masonry (16.7%) and of combined materials (8.2%). The division of the multi-residential buildings based on material and number of storeys is presented in Table 4. In this period approximately one third of apartments (31.6%) were built in four storey multi-residential buildings, while more than half of the apartments from this period (53.9%) are in buildings with five or more storeys.

5 Criteria for earthquake vulnerability assessment of multi-residential buildings

The data collected by the 2002 census of population, households and apartments are unfortunately not complete enough to analytically evaluate the earthquake resistance of a building. It is however possible to make a general assessment of earthquake vulnerability based on year of building completion, prevailing material of the structural system, number of storeys and year of the eventual renovation. We also wanted to include actual earthquake hazard as an influencing parameter, as it is shown on the seismic hazard map

Figure 2: Seismic hazard map of Slovene communities based on the seismic hazard map of Slovenia including the proposed weight factor (CEN (2004): Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings, EN 1998-1). ➤ p. 99

of expected ground accelerations in Slovenia (CEN (2004): Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings, EN 1998-1). The seismic hazard map divides municipalities into areas with different expected ground acceleration (Figure 2). We anticipated that the probability that a building (which was not built according to modern standards) is earthquake unsafe, is much higher in the communities with larger than expected ground acceleration. Influence of the expected ground acceleration has been considered by a weight coefficient. Its value is 1.0 for areas with the highest ground acceleration (> 0.25 g), and smaller than 1.0 in all other areas. If a specific area is not prone to earthquakes (e. g. North West of Slovenia) the coefficient amounts to 0.4. We therefore simply considered that the weight coefficient is linearly proportional to the design ground acceleration (i. e. earthquake forces) in our analysis. Actually the relation between damage and ground acceleration is a non-linear one as it also depends on dissipated energy and other parameters, such as soil quality and distance from epicentre.

Chapter 5 presents the criteria for the division of concrete, masonry and combined buildings in three classes with different level of earthquake vulnerability which were derived from the demands and descriptions of characteristic time periods in Chapter 4.

5.1 Probably earthquake unsafe buildings

These buildings have a higher probability to be earthquake unsafe and it is very likely that their structural system should be seismically retrofitted.

Masonry buildings:

- Buildings with five or more storeys built before 1981 (too high in respect to current codes, which for such buildings require the usage of reinforced masonry, but only in the areas with lower seismicity.
- Buildings with four or less storeys built before 1964 (there were no reinforced concrete vertical confinement elements used, probably also no horizontal confinement connections on top of the walls were built in). All newer building codes require vertical and horizontal reinforcing ties, which should be concreted at the prescribed distances after building the masonry walls. They bind the entire building in a homogenous unit and increase its strength (Tomaževič 1987; Slak and Kilar 2005).

Combined buildings:

- Buildings built before 1894 and between the years 1946 and 1963 (too small earthquake design loads, in combination with masonry it is very likely that vertical and horizontal reinforced concrete confining elements are missing).

Concrete buildings:

- Buildings with four or more storeys built before 1894 and between the years 1946 and 1963 (much smaller earthquake design loads, in some cases only concrete blocks without any reinforcement were used).

5.2 Probably earthquake less safe buildings

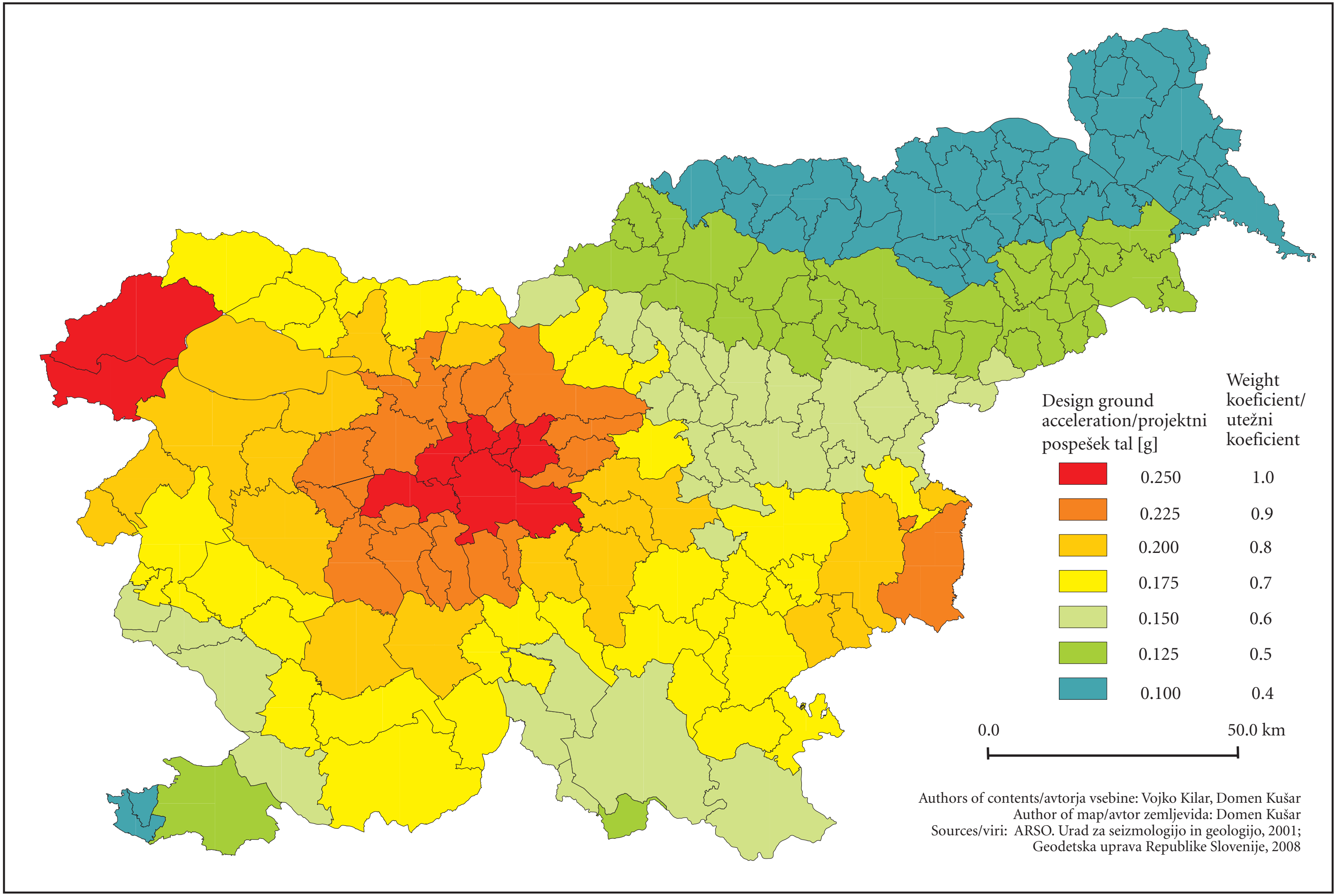
These buildings are probably earthquake less safe and it is possible that their structural resistance to horizontal loads needs some improvement.

Masonry buildings:

- Buildings with five or more storeys built between 1982 and 1999 (too high in respect to *Eurocode 8*, which requires the use of reinforced masonry in these cases). Our investigation shows that there are not many such buildings in Slovenia. Since our research is limited to buildings built before 1981, this group of buildings was not included.

Combined buildings:

- Buildings built between 1894 and 1945 (too small earthquake design forces, probably higher building quality than in the period before and after that).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Authors of contents/avtorja vsebine: Vojko Kilar, Domen Kušar
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Geodetska uprava Republike Slovenije, 2008

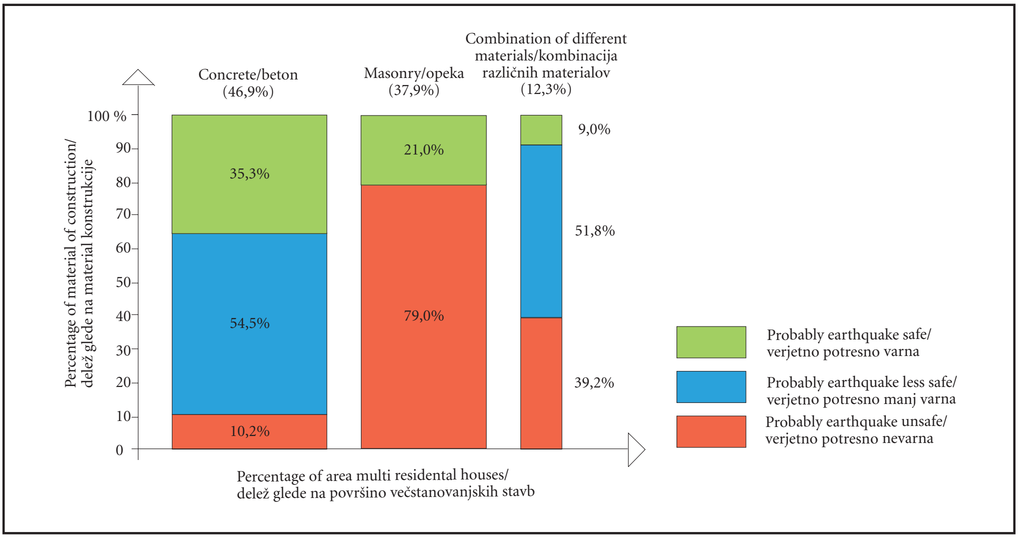


Figure 3: Earthquake vulnerability of multi-residential buildings made from different building materials (apartment area in %).

- Buildings with four or more storeys built between 1964 and 1981 (too small earthquake design forces, the details/connections/stirrups of concrete parts of these structures prescribed at that time are disputable from the modern code point of view).

Concrete buildings:

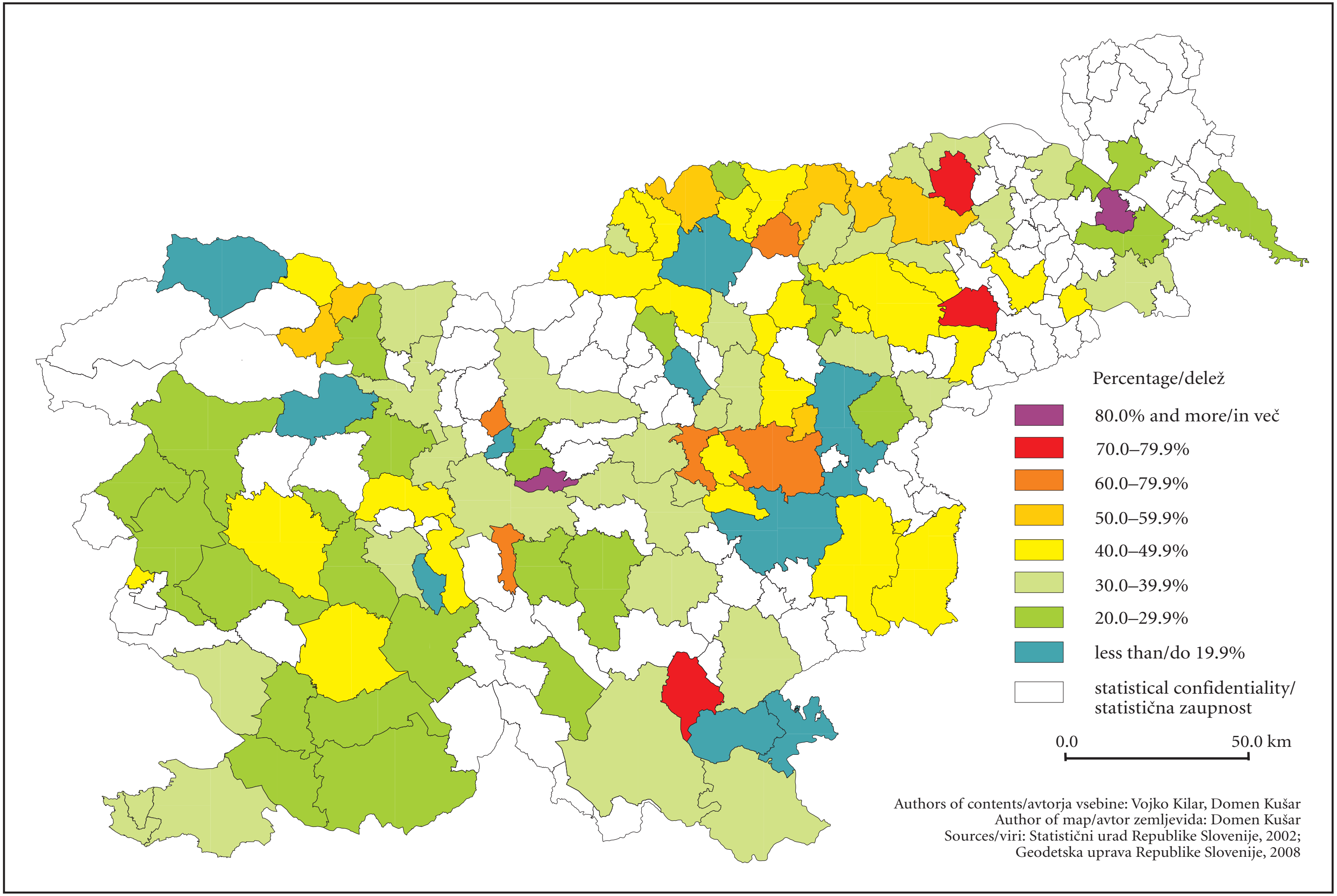
- Buildings with four or more storeys built between 1894 and 1945 (too small earthquake design forces but probably higher building quality).
- Buildings with five or more storeys built between 1964 and 1981 (too small earthquake design forces, the prescribed details/connections/stirrups for concrete structures are disputable from the modern code point of view).

Table 5: Earthquake vulnerability of multi-residential buildings in Slovenia built before 1981.

	Buildings				Apartments	
	Number	Percent (%)	area (m^2)	Percent (%)	Number	Percent (%)
Probably earthquake safe	4,545	30.8	2,657,215	25.9	49,543	26.6
Probably earthquake less safe	2,287	15.5	3,383,236	33.0	61,043	32.9
Probably earthquake unsafe	7,912	53.7	4,213,462	41.1	75,408	40.5
Total	14,744	100.0	10,253,913	100.0	185,994	100.0

The results show that according to the selected criteria 41.1% of apartment's area are in probably earthquake unsafe and 33.0% in probably earthquake less safe buildings (see Table 5 and Figure 3). The results for different communities are presented in Figures 4 and 5 and in Tables 6 and 7. Figures 4 and 5 present the area of apartments in earthquake unsafe and less safe buildings geographically as a percentage of the total area in multi-residential buildings in proper municipality. The municipalities with the higher share of earthquake vulnerable apartment areas are also listed in Tables 6 and 7. It is not surprising that most municipalities stand out, even if they do not seem to be critical by share of multi-residential buildings presented in Figure 1.

Figure 4: Area of apartments in earthquake unsafe buildings as a share of total multi-residential buildings area in this community. ➤ p. 101


Percentage/delež
80.0% and more/in več
70.0–79.9%
60.0–79.9%
50.0–59.9%
40.0–49.9%
30.0–39.9%
20.0–29.9%
less than/do 19.9%
statistical confidentiality/
statistična zaupnost
0.0
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Authors of contents/avtorja vsebine: Vojko Kilar, Domen Kušar
Author of map/avtor zemljevida: Domen Kušar
Sources/viri: Statistični urad Republike Slovenije, 2002;
Geodetska uprava Republike Slovenije, 2008

Table 6: Communities with a higher percentage of probably earthquake unsafe multi-residential buildings (communities with a design ground acceleration $a_g \geq 0.175$ are marked in grey).

Municipality	Area (m^2)	Earthquake intensity weight factor
Ljubljana	1,223,045	1
Maribor	655,300	0.4
Celje	215,478	0.6
Kranj	128,537	0.9
Trbovlje	122,080	0.6
Jesenice	104,413	0.7
Koper	91,964	0.5
Velenje	91,059	0.5
Nova Gorica	69,492	0.7
Ptuj	64,928	0.5
Novo mesto	61,675	0.7
Postojna	52,875	0.8
Ravne na Koroškem	49,261	0.5
Kamnik	43,053	0.9
Piran	42,720	0.4
Hrastnik	39,555	0.6
Tržič	39,217	0.7
Krško	37,224	0.8
Kočevje	36.480	0.6
Idrija	34,649	0.8
Izola	34,169	0.4
Žalec	28,495	0.6
Domžale	28,230	1
Škofja Loka	27,372	0.9
Slovenska Bistrica	27,262	0.5

Table 7: Municipalities with a higher share of probably earthquake less safe multi-residential buildings (municipalities with a design ground acceleration $a_g \geq 0.175$ are marked in grey).

Municipality	Area (m^2)	Earthquake intensity weight factor
Ljubljana	1,223,045	1
Maribor	655,300	0.4
Celje	215,478	0.6
Kranj	128,537	0.9
Trbovlje	122,080	0.6
Jesenice	104,413	0.7
Koper	91,964	0.5
Velenje	91,059	0.5
Nova Gorica	69,492	0.7
Ptuj	64,928	0.5
Novo mesto	61,675	0.7
Postojna	52,875	0.8
Ravne na Koroškem	49,261	0.5
Kamnik	43,053	0.9
Piran	42,720	0.4
Hrastnik	39,555	0.6
Tržič	39,217	0.7
Krško	37,224	0.8
Kočevje	36,480	0.6
Idrija	34,649	0.8
Izola	34,169	0.4
Žalec	28,495	0.6
Domžale	28,230	1
Škofja Loka	27,372	0.9
Slovenska Bistrica	27,262	0.5

Figure 5: Area of apartments in earthquake less safe buildings as a percentage of the total multi-residential buildings area in this community.
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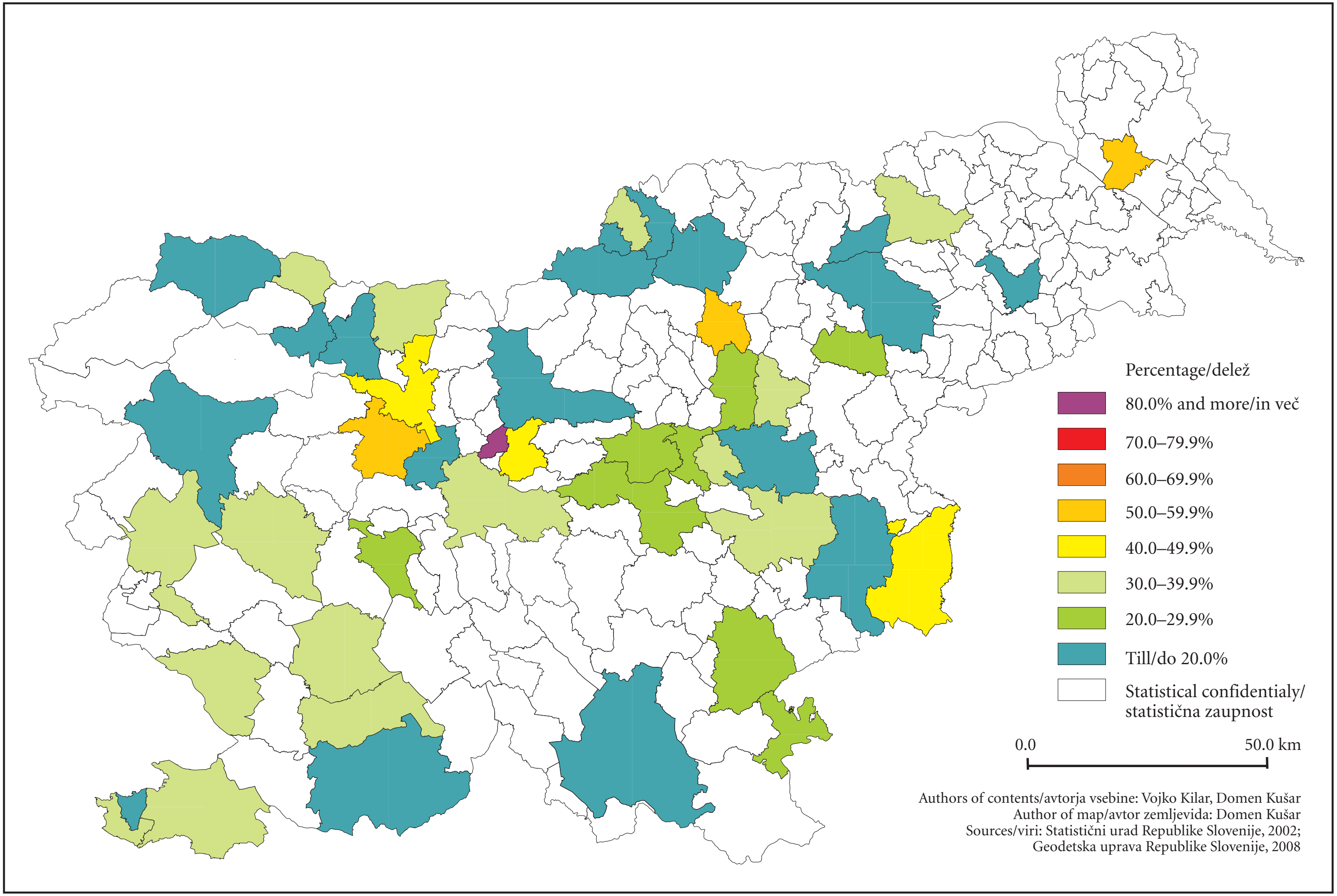
Percentage/delež
80.0% and more/in več
70.0–79.9%
60.0–69.9%
50.0–59.9%
40.0–49.9%
30.0–39.9%
20.0–29.9%
Till/do 20.0%
Statistical confidentialy/
statistična zaupnost
0.0
50.0 km
Authors of contents/avtorja vsebine: Vojko Kilar, Domen Kušar
Author of map/avtor zemljevida: Domen Kušar
Sources/viri: Statistični urad Republike Slovenije, 2002;
Geodetska uprava Republike Slovenije, 2008

It can be seen that the number of probably earthquake unsafe buildings, for which it is very likely that their structural system should be seismically retrofitted, amounts to 53.7% of the total number of all multi-residential buildings in Slovenia. The apartment area in these buildings amounts to 4,213,462 m^2 (41.1%). Most of these buildings were built of brick or other combined materials before 1963. Share of buildings which are probably earthquake less safe is smaller and amounts to 15.5%. Apartment area in these buildings is 3,383,236 m^2, which amounts to approximately to one third of all multi-residential buildings in Slovenia.

6 Conclusion

In the paper we tried to assess earthquake vulnerability of existing multi-residential buildings in Slovenia and confirm the concerns which have also been expressed by other experts for earthquake resistant design (see for example Kubelj 2009). Our research confirmed that the requirements of modern earthquake resistant codes are basically only fulfilled by less than one half of the existing multi-residential buildings. The difference from other similar studies, which were based on a rough estimation on the number and resistance of buildings, is that our study is based on statistical data collected by a census of population, households and apartments from 2002. It should be stressed that results obtained provide only an estimation of the number of probably earthquake unsafe and less safe buildings and the possible extent of retrofit measures. The earthquakes in north-western Slovenia showed that damage to buildings does not depend only on

Table 8: Five or more storey buildings are the most earthquake-vulnerable part of the Slovenian residential fund. Number of unsafe buildings, number of apartments and apartment area in these buildings are presented for each municipality (municipalities with design ground acceleration $a_g \geq 0.175$ are marked in grey).

	Number of buildings	Percent (%)	Number of apartments	Percent (%)	Area (m^2)	Percent (%)	Earthquake intensity weight factor
SLOVENIA	1,188	8.1	23,721	12.8	1,263,921	12.0	–
Ljubljana	393	11.0	7,992	14.3	429,555	14.0	1.0
Maribor	164	9.4	3,205	13.8	177,728	14.0	0.4
Celje	71	12.5	1,376	16.5	67,779	15.0	0.6
Velenje	65	24.2	1,162	23.0	63,325	22.0	0.5
Kranj	51	12.1	896	15.0	47,774	14.0	0.9
Koper	40	9.4	785	16.7	40,564	15.0	0.5
Trbovlje	41	13.0	692	18.0	39,691	20.0	0.6
Jesenice	17	6.5	619	14.3	31.450	14.0	0.7
Piran	20	6.2	417	19.3	25,281	20.0	0.4
Izola	22	9.9	410	23.2	22,482	22.0	0.4
Ravne na Koroškem	17	12.1	398	20,8	21,134	20.0	0.5
Novo mesto	17	7.6	389	13.2	20,476	13.0	0.7
Nova Gorica	15	6.0	305	7.4	17,337	7.0	0.7
Postojna	11	6.7	242	12.2	13,895	12.0	0.8
Kamnik	12	7.4	260	12.2	13,639	12.0	0.9
Sežana	12	12.9	197	16,8	10,980	17.0	0.6
Laško	7	8.6	188	26.4	9,337	26.0	0.6
Idrija	12	6.8	178	11.3	9,185	11.0	0.8
Zagorje ob Savi	12	9.7	169	11.1	8,176	10.0	0.7
Murska Sobota	7	7.1	146	8.1	7,772	8.2	0.4
Škofja Loka	6	5.6	120	6.2	7,158	6.8	0.9
Domžale	5	4.3	163	8.3	7,091	6.7	1.0
Bled	5	5.8	124	20.2	6,947	21.0	0,7
Kočevje	5	2.9	145	8.0	6,582	6.9	0.6
Litija	7	7.5	118	9.1	6,209	9.2	0.8
Slovenska Bistrica	5	3.5	121	9.6	5,184	8.1	0.5
Hrastnik	5	4.6	99	6.3	4,969	6.3	0.6
Krško	5	3.8	87	5.6	4,380	5.0	0.8
Vrhnika	5	6.0	66	8.4	3,966	9.0	0.9
Ptuj	5	2.0	45	1.8	2,633	1.8	0.5

their age, height and material, but also on the amount, interconnectivity and layout of walls. The listed factors can strengthen the building during a strong earthquake. The exact determination of additional strength is only possible by structural analysis of each individual building which can not be included in this general assessment of earthquake vulnerability, based on a limited number of statistical input parameters. One should also consider the fact that effects of earthquakes also depend on local conditions (Orožen Adamič, Hrvatin 2001; Gosar 2007), such as soil and ground quality, water ground level and other influences.

The results show unexpected large numbers of earthquake unsafe buildings in north-eastern Slovenia, especially in the vicinity of the Drava river. The percentage of probably earthquake unsafe buildings in this region is more than 50% which is a consequence of early industrialization already in 19th century and the need for more apartments at that time. These buildings were built in the time where other less elaborate measures for earthquake resistance design were being used. Fortunately, this region is less exposed to earthquakes than other Slovenian regions according to recent earthquake seismic hazard maps.

Nevertheless, we should point out the group of buildings which would be possibly the most dangerous during an earthquake. These are buildings with five or more storeys built before 1981. They should be retrofitted first. There are 1,188 such buildings in Slovenia. There are 23,721 apartments in these buildings with total area 1,263,921 m^2. Area and the number of such buildings for each community are presented in Table 8.

The concern for an improvement in earthquake safety should probably be transferred to the government. New proprietorial relations recently formed in many multi-residential buildings additionally complicate the efficiency of seismic retrofit. The law on apartments requires that each owner contributes a minimal financial amount to a reserve fund for all buildings older than ten years. These funds are intended for maintenance and renewal of the building. Since the seismic retrofit is usually a high cost, such projects could only be performed with appropriate legislation measures and stimulations to the owners. Another option would be to change the ownership relations and increase the property share of the community which is ready to participate in seismic retrofit. All such measures are opening complicated legislation and economical issues that should be solved before entering into the building process itself.

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Ocena potresne ogroženosti večstanovanjskih zgradb v Sloveniji

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IZVLEČEK: Članek ocenjuje potresno ogroženost večstanovanjskih stavb v Sloveniji, pri čemer se omejuje na stavbe, zgrajene pred letom 1981, ko so veljali blažji protipotresni predpisi kot danes. Članek leto izgradnje posamezne stavbe razčleni na značilna časovna razdobja izgradnje stavb, za katera so značilni pomembni zgodovinski dogodki in razvoj predpisov za potresno varno gradnjo. Ocena ogroženosti posamezne stavbe izhaja iz podatka o letu izgradnje, številu etaž, materialu nosilne konstrukcije in letu zadnje prenove po zadnjem popisu prebivalstva, gospodinjstev in stanovanj leta 2002. Dobljena ocena je seveda približna, saj je tudi pri zelo podobnih objektih potresna odpornost odvisna še od arhitekturne zasnove konstrukcije, količine in tlorisne razporeditve nosilnih elementov, vplivov temeljnih tal in drugih dejavnikov. Večstanovanjske stavbe v Sloveniji so razčlenjene glede na starost, material in število etaž. Jedro članka predstavljajo ocene potresne ogroženosti večstanovanjskih stavb, ki so združene v tri razrede: a) potresno verjetno nevarne stavbe, b) potresno verjetno manj varne stavbe in c) potresno verjetno varne stavbe. Pri tem poskušamo opredeliti potresno ogroženost tudi v geografskem smislu, saj so podatki za prva dva razreda po posameznih slovenskih občinah prikazani tudi na zemljevidih in v preglednicah. Ugotavljamo, da je potresna varnost mnogih večstanovanjskih stavb v Sloveniji vprašljiva, pokazale pa so se tudi razlike med občinami.

KLJUČNE BESEDE: arhitektura, gradbeništvo, geografija, potresna varnost, potresna ogroženost, potresno nevarne stavbe, večstanovanjske stavbe, Slovenija

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Vsebina

1 Uvod

V Sloveniji v večstanovanjskih zgradbah živi velik del prebivalstva, zlasti mestnega. Te stavbe so predvsem bloki in stolpnice, ki so bili narejeni v prejšnjem stoletju, posebej po koncu druge svetovne vojne, ko je bila gradnja tega tipa stanovanj najbolj razširjena. Rezultati popisa Statističnega urada Republike Slovenije v letu 2002 kažejo, da je bilo takrat v Sloveniji 18.005 večstanovanjskih zgradb, kar je predstavljalo le 3,9 % vseh stanovanjskih zgradb, vendar je bilo v njih 242.011 stanovanj oziroma skoraj tretjina stanovanj v državi. Stanovanja v večstanovanjskih stavbah obsegajo 13.491.714 m^2 oziroma 23,2 % od celotne površine slovenskih stanovanj. Pred letom 1981 je bilo zgrajenih 14.744 večstanovanjskih stavb s 185.994 stanovanji s skupno površino 10.253.913 m^2, kar je kar 76,0 % stanovanjske površine v večstanovanjskih stavbah.

V prvem delu članka je prikazan kratek opis značilnih časovnih obdobij izgradnje večstanovanjskih stavb, ki so jih zaznamovali prelomni zgodovinski dogodki in razvoj predpisov za potresno varno gradnjo. Iz njih lahko sklepamo na sedanje stanje in potresno odpornost posamezne stavbe. Omejili smo se na stavbe, zgrajene pred letom 1981. Po potresu v črnogorskem primorju leta 1979 so bili namreč leta 1981 sprejeti novi jugoslovanski predpisi za protipotresno gradnjo, ki so zagotavljali precej večjo potresno varnost. V nadaljevanju je za vse večstanovanjske stavbe v Sloveniji prikazana natančna razdelitev stavb po starosti, materialu in številu etaž. Ob razmeroma logični predpostavki, da so se pri gradnji stavb upoštevali takrat veljavni predpisi, lahko s primerjavo zahtev takratnih in sodobnih predpisov ocenimo stopnjo potresne ogroženosti. Uvrstitev v starejši razred izgradnje avtomatično še ne pomeni slabše ravni potresne odpornosti, saj je bila v nekaterih starejših obdobjih gradnja določene vrste večstanovanjskih stavb bolj kakovostna kot v obdobjih, ki so jim sledila. Tako je bila na primer gradnja nižjih opečnih in mešanih večstanovanjskih stavb v prvi polovici 20. stoletja ob upoštevanju avstrijskih predpisov in smernic razmeroma dobra. Nasprotno pa je bila gradnja v prvih letih socializma po drugi svetovni vojni precej slabša, zato je večina višjih stavb iz tega obdobja verjetno potresno manj varna.

Jedro članka obravnava pripravo kriterijev za oceno potresne ogroženosti večstanovanjskih stavb in razdelitev večstanovanjskih objektov, zgrajenih pred letom 1981 na »potresno verjetno nevarne«, »potresno verjetno manj varne« in »potresno verjetno varne«. Poudariti je treba, da lahko na podlagi podatkov, zbranih s popisom, podamo le splošne ocene o potresni ogroženosti in potrebah po prenovi nosilnih konstrukcij stavb iz različnega materiala. Točnejše ocene za posamezne stavbe je mogoče dobiti le s podrobnejšimi raziskavami stanja posameznih stavb ali pa morda z raziskavo posameznih manjših območij in njeno posplošitvijo za območje celotne Slovenije. Rezultati, prikazani na državni in občinski ravni, kažejo, kakšen je v posameznih občinah delež potresno nevarnih in potresno manj varnih večstanovanjskih stavb. Žal je uveljavitev varnostnih načel tudi danes problematična, saj je odvisna predvsem od finančnih sredstev, ob tem pa je zaradi novih lastniških razmerij celoten postopek izvedbe bistveno bolj zapleten.

2 Metodologija

Varnost večstanovanjskih stavb se praviloma določa na podlagi podrobnega pregleda načrtov ter na podlagi izračunov in analiz za vsako posamezno stavbo (Tomaževič 1987 in 1998; Fajfar in ostali 2000; Dujič, Žarnić 2008; Bosilkov in ostali 2008). Način je seveda zamuden in drag ali celo neizvedljiv, če gre za oceno potresne ogroženosti stavb za večja območja ali pa kar za celotno Slovenijo. Nekaj podobnih ocen za Ljubljano, nekatera druga naselja in občine v Sloveniji pa je vendarle že bilo izvedenih (Orožen Adamič 1995; Orožen Adamič in Perko 1996; Kilar 2004).

V naši študiji smo za oceno potresne ogroženosti uporabili rezultate zadnjega popisa prebivalcev, gospodinjstev in stanovanj (Popis … 2002), ki vsebujejo tudi nekatere podatke o stavbah, v katerih so posamezna stanovanja (Zupančič in ostali 2003). Na razpolago so bili podatki o letu izgradnje, številu etaž, vrsti konstrukcijskega sistema, uporabljenih materialih nosilne konstrukcije, letu zadnje prenove stanovanja, namenu uporabe in številu stanovanj v stavbi. Ob predpostavki, da so pri gradnji stavb upoštevali takrat veljavne predpise, lahko primerjamo zahteve takratnih predpisov s predpisi, ki veljajo zdaj, in iz tega ocenimo, koliko je stanovanj, ki so v »potresno verjetno nevarnih« stavbah, koliko v »potresno verjetno manj varnih« stavbah in koliko je zgrajenih skladno s sodobni predpisi (Kilar 2004). Pri tem izraz »verjetno potresno nevarna stavba« pomeni stavbo, ki bi lahko bila potresno nevarna in bi lahko utrpela nepopravljive poškodbe (oziroma celo ogrozila človeška življenja), vendar pa ni nujno, da to tudi dejansko je ali bo. Dejstvo je, da ima večina stavb neko svojo dodatno nosilnost, ki izhaja iz količine in tlorisne razporeditve nosilnih elementov (Tomaževič 1987; Kilar ni Koren 2009), njihove medsebojne povezanosti, »solidne« gradnje po inženirskem občutku, izpolnjevanju minimalnih zahtev, kakovosti izvedbe in detajlov (Žarnić 2005) ter kakovosti tal in drugih dejavnikov (Orožen Adamič in Hrvatin 2001; Slak in Kilar 2005). Zato objekti enake višine iz enakega materiala in enake starosti na enakih tleh niso vedno enako potresno ogroženi. Mnoge stavbe preživijo potres tudi, če sploh niso grajene po nobenih potresnih predpisih, saj preživetje zagotavlja omenjena dodatna nosilnost. Točna določitev dodatne nosilnosti je možna le s potresno analizo vsake posamezne stavbe in je pri prikazani pavšalni oceni na podlagi omejenega števila statističnih vhodnih podatkov seveda ni bilo mogoče upoštevati. Pri interpretaciji rezultatov o potresni ogroženosti tako imenovanih »verjetno potresno nevarnih stavb«, ki je podana v članku, je torej potrebno razumeti, da gre tu za stavbe, ki so lahko potencialno nevarne, ni pa nujno, da bo v njih res prišlo do porušitev s smrtnimi žrtvami.

3 Značilnosti večstanovanjske stavbe

V popisu prebivalcev, gospodinjstev in stanovanj (Popis … 2002) so kot večstanovanjske zgradbe opredeljeni bloki, stolpnice ali starejše meščanske večstanovanjske stavbe, na primer stavbe v mestnih središčih, ki so zgrajene strnjeno druga ob drugi in po svojem videzu ne spominjajo na sodobne večstanovanjske stavbe. Zato imajo obravnavane zgradbe določene skupne značilnosti, predvsem glede gradbenega materiala in zasnove. Večstanovanjski objekti so bili v veliki meri zgrajeni v kombinaciji armiranega betona in opečne gradnje. Armiran beton prevladuje pri stropih, stopniščih in prekladah, medtem ko so nosilne stene iz opeke in betona ali pa so prefabricirani betonski elementi. V starejših večstanovanjskih zgradbah so pri stropovih uporabljeni tudi leseni tramovi – stropniki. Zidovi starejših večstanovanjskih zgradb so grajeni iz opeke, medtem ko je po drugi svetovni vojni naraščala uporaba betona tudi za gradnjo zidov. Na povečano rabo betona so vplivali modnost in uporabnost, zlasti pa dejstvo, da je tovrstnega gradbenega materiala pri nas dovolj. Les kot gradbeni material se je uporabljal le še za izdelavo ostrešij, medtem ko se večjih lesenih večstanovanjskih zgradb pri nas ni zgradilo. Prav tako se v slovenski večstanovanjski gradnji ni uveljavila jeklena skeletna gradnja. Večje spremembe v uporabi gradiv so značilne šele v zadnjih nekaj letih.

Večina večstanovanjskih stavb v Sloveniji ima dvignjeno pritličje, kjer je vhod v objekt. Za vhodnimi vrati je predprostor (vetrolov) s poštnimi nabiralniki. Ta prostor je običajno ločen od glavne komunikacije znotraj objekta, ki jo sestavljajo hodniki in stopnišča, v stolpnicah pa sta v hodnikih še eno ali dve dvigali. Značilnost komunikacij je, da so v sredini zgradbe. Po obodu so razvrščeni različni tipi stanovanj. Tak razpored omogoča večjo osvetljenost stanovanj. Organiziranost prostora (tlorisi) je zaradi racionalne zasnove komunalnih vodov v vseh etažah istega objekta praktično enaka.

V Sloveniji prevladujejo trije tipi večstanovanjskih zgradb: večstanovanjska hiša, stolpnica in blok. Vsak ima nekatere značilnosti, čeprav lahko za večstanovanjsko hišo in blok trdimo, da sta si podobna, oziroma, da gre za isto zvrst zgradbe. Tipična stolpnica ima pravokotno ali celo kvadratno tlorisno obliko in običajno 12 nadstropij. Na vrhu je ravna streha in strojnica za dvigalo. Blok je običajno podolgovate oblike in ima zato več komunikacijskih jeder. Običajna višina bloka je pritličje in še štiri nadstropja (P + 4). To višino je pogojeval star predpis, ki je za višje stavbe zahteval vgradnjo dvigala. Drugače kot pri stolpnicah imajo nekateri bloki vertikalne komunikacije v sredini, drugi pa blizu sredine, vendar tako, da imajo eno steno ob zunanji strani objekta, s čimer je čez dan dosežena naravna osvetlitev stopnišča. Etaže v starejših zgradbah so visoke okrog 3 m, kar ustreza starejšim normativom (Gradbeni zakon, 1931), ki so za višino prostorov zahtevali najmanj 2,8 m. Novejši objekti imajo nekoliko nižjo etažno višino, saj je zdaj predpisana višina prostorov vsaj 2,5 m. Pritlični prostori so običajno višji. Na podlagi tega je mogoče sklepati, da je višina starejšega večstanovanjskega objekta s pritličjem in štirimi nadstropji od 15 do 16 m, višina stolpnic z 12 etažami pa okrog 36 m.

Skupna značilnost obravnavane skupine stavb je tudi ta, da v kletnih prostorih ni garaž, pač pa so parkirišča ob samem objektu na tleh ali pa v posebnih garažnih hišah. Novejši večstanovanjski objekti imajo garaže v kletnih etažah.

Največ večstanovanjskih stavb je v občinah z velikimi mestnimi naselji, kjer je bil oziroma je pomemben razvojni dejavnik industrija. Zanimivo je, da je zelo velik delež teh stavb v priobalnih občinah in na Koroškem (slika 1). Največje deleže dosegajo v občinah Trbovlje (14 %), Maribor (13 %), Ljubljana (13 %)

in Mežica (13 %), največje število tovrstnih objektov pa je v mestnih občinah Ljubljana (4291), Maribor (2094), Celje (682), Koper (569) in Kranj (528).

Slika 1: Delež večstanovanjskih stavb od vseh stanovanjskih stavb po občinah leta 2002.
Glej angleški del prispevka.

4 Razvoj potresnih predpisov in obdobja izgradnje stavb

Razvoj predpisov za potresno varno gradnjo je bil postopen, po vsakem močnejšem potresu pa so se pravila za protipotresno gradnjo dodatno razširila in zaostrila. Prvi predpisi, ki so na naših tleh sploh vključevali potresno obtežbo kot posebno obtežno prvino, so bili Privremeni tehnički propisi (PTP), ki so bili leta 1948 sprejeti v takratni Federativni ljudski republiki Jugoslaviji. Potresno varnost stavb lahko torej na grobo presojamo tudi po letu njihove izgradnje (v kombinaciji s podatki o vrsti konstrukcijskega sistema, materialu in številu etaž). Ob pregledu predpisov o potresno varni gradnji, ki so se uporabljali na področju Slovenije v zadnjih sto letih, lahko opredelimo različna časovna obdobja izgradnje stavb, ki se razlikujejo glede na takrat veljavne predpise in zahteve za potresno varno gradnjo (Bubnov in ostali 1982; Bubnov 1996; Kilar 2004; Slak, Kilar 2005; Žarnić 2005).

Glede na zgodovinske mejnike in datume sprejema posameznih predpisov o potresnovarni gradnji smo določili štiri značilna obdobja izgradnje stavb pred letom 1981. Celovit prikaz uporabe različnih materialov nosilne konstrukcije po teh časovnih obdobjih za celotno Slovenijo je zbran v preglednicah od 1 do 4. Poleg deležev so prikazane tudi absolutne vrednosti in skupno število površin stanovanj, tako da je mogoč natančen izračun površin. Na Statističnem uradu Republike Slovenije strogo upoštevajo določila o zaupnosti podatkov, ki jih določajo Zakon o popisu prebivalstva, gospodinjstev in stanovanj v RS v letu 2002 (Ur. l. RS 66/2000 in 26/2001), Zakon o državni statistiki (Ur. l. RS 45/1995 in 09/2001) in Zakon o varstvu osebnih podatkov (Ur. l. RS 59/1999), zato smo morali za objavo zakriti vse nizke vrednosti. V skupnem seštevku so ti podatki sicer vključeni, v posameznih občinah pa jih zaradi premajhnega števila ni mogoče prikazati. Zaradi tega so tudi seštevki posameznih deležev manjši od celote 100 %.

4.1 Obdobje pred letom 1894 (pred ljubljanskim potresom leta 1895)

V tem času so se pravila potresno varne gradnje upoštevala v glavnem izkustveno, kot na primer z omejitvijo višine stavb, povečevanjem debeline zidov v spodnjih etažah, znižanjem težišča stavbe ipd. Nekaterim takšnim stavbam se obdobje življenjske dobe konstrukcije morda že izteka, zato bi jih bilo treba bodisi celovito prenoviti bodisi odstraniti. Ker so nekatere takšne stavbe spomeniško zavarovane, je zanje potrebna posebna obravnava. Delež površine večstanovanjskih stavb iz tega obdobja je 6,5 % od celotne površine vseh večstanovanjskih stavb v Sloveniji (13.491.714 m^2). Od tega jih je največ v opečnih (41,1 %), kombiniranih (20,6 %), kamnitih (17,9 %) in betonskih (16,8 %) stavbah. Členitev po materialu in številu etaž je prikazana v preglednici 1. Največji delež stanovanjske površine (70,2 %) je v eno- do trietažnih večstanovanjskih stavbah, kar 14,6 % površin pa je v stavbah s petimi ali več nadstropji. Po rezultatih popisa je bilo v tem obdobju zgrajenih 66.500 m^2 stavb visokih 9 ali več etaž, kar se zdi malo verjetno, saj razen zvonikov in stolpov gradov tako visokih večstanovanjskih stavb iz tega obdobja praktično ni. Možno je seveda tudi, da gre za napake ali nedoslednosti pri izvedbi popisa.

Preglednica 1: Členitev deleža površin večstanovanjskih stavb, zgrajenih pred letom 1894, po gradbenem materialu in številu etaž. Skupna površina obravnavanih objektov v tem obdobju je 874.993 m^2.

	pritlična	od 1 do 3 nadstropja	4 nadstropja	od 5 do 8 nadstropij	9 in več nadstropij
opeka	0,50	35,41	2,83	1,73	0,63
beton		0,48	4,82	4,75	6,77
kombinacija različnih materialov	0,46	17,41	2,00	0,50	0,22
les		0,25			
kamen	0,56	16,60	0,75		
drugo	0,01	0,06	0,02		

4.2 Obdobje od leta 1895 do leta 1945 (pred prvo svetovno vojno in med svetovnima vojnama)

Gradnja je potekala po takrat veljavnih avstrijskih in starih jugoslovanskih gradbenih predpisih, ki so določali debelino opečnih zidov v posameznih etažah stavbe, širino medokenskih sklopov, izdelavo stropov, požarnih zidov in masivnih stopov (Gradbeni zakon 1931). Kot horizontalno obtežbo so upoštevali zlasti obtežbo zaradi vetra. Za to obdobje je značilna dovolj solidna regularna gradnja, tako po zasnovi kot po izvedbi detajlov in izbiri materialov. V tem času so začeli uporabljati armiran beton, pojavijo pa se prve visoke stavbe, ki na potresno obremenitev reagirajo povsem drugače kot toge opečne stavbe iz prejšnjih stoletij. Najbolj znan primer je ljubljanski Nebotičnik iz leta 1933.

Delež površine večstanovanjskih stavb iz tega obdobja je 9,2 % od celotne površine vseh večstanovanjskih stavb v Sloveniji. Največ od tega jih je v opečnih (67,9 %) in kombiniranih (18,0 %) stavbah. Členitev po materialu in številu etaž je prikazana v preglednici 2. Največji delež stanovanjske površine (76,9 %) je v eno- do trietažnih večstanovanjskih stavbah, 8,6 % površin je v stavbah s petimi ali več nadstropji.

Preglednica 2: Členitev deleža površin večstanovanjskih stavb, zgrajenih med letoma 1895 in 1945, po gradbenem materialu in številu etaž. Skupna površina obravnavanih objektov v tem obdobju je 1.247.127 m^2.

	pritlična	od 1 do 3 nadstropja	4 nadstropja	od 5 do 8 nadstropij	9 in več nadstropij
opeka	1,40	55,16	6,71	4,17	0,51
beton		2,20	2,08	1,61	1,35
kombinacija različnih materialov	0,63	14,85	1,69	0,84	0,06
les	0,06	0,14			
kamen	0,05	3,89			
drugo		0,12			

4.3 Obdobje od leta 1946 do leta 1963 (zgodnje povojno obdobje)

Večina stavb iz tega obdobja je grajena skladno s prvimi jugoslovanskimi predpisi za obtežbo zgradb (PTP 1948), po katerih je bila Jugoslavija razdeljena na tri potresne cone:
a) cono manjših poškodb,
b) cono velikih poškodb in
c) cono katastrofalnih rušenj.

Maksimalna potresna sila za cono c je znašala največ 3 % stalne in polovico koristne obtežbe, kar je na posameznih potresno ogroženih področjih tudi od pet- do desetkrat manj od zahtev sodobnih predpisov. Za to obdobje je značilen socialistični način gradnje, kakovost teh stavb je na splošno najslabša. Predpis PTP je veljal do leta 1963.

Delež površine večstanovanjskih stavb iz tega obdobja je 22,6 % od celotne površine vseh večstanovanjskih stavb v Sloveniji. Največ od tega jih je v opečnih (62,9 %), betonskih (21,5 %) in kombiniranih (13,8 %) stavbah. Členitev po materialu in številu etaž je prikazana v preglednici 3. Največji delež stanovanjske površine (45,6 %) je v eno do trietažnih večstanovanjskih stavbah, kar 29,1 % površin pa je v stavbah s petimi ali več nadstropji.

Preglednica 3: Členitev deleža površin večstanovanjskih stavb, zgrajenih med letoma 1945 in 1963, po gradbenem materialu in številu etaž. Skupna površina obravnavanih objektov v tem obdobju je 3.053.960 m^2.

	pritlična	od 1 do 3 nadstropja	4 nadstropja	od 5 do 8 nadstropij	9 in več nadstropij
opeka	0,62	33,97	14,47	11,53	2,17
beton	0,01	4,46	5,78	6,87	4,41
kombinacija različnih materialov	0,06	6,27	3,83	2,81	0,82
les	0,03	0,18			
kamen	0,03	0,38	0,02		
drugo		0,28	0,45	0,47	

4.4 Obdobje od leta 1964 do leta 1981 (po potresu v Skopju)

Po katastrofalnem potresu v Skopju leta 1963 so bili za potresno varno gradnjo sprejeti novi predpisi, v katerih so bile močno povečane potresne sile za vse vrste stavb, predpisana je bila razporeditev horizontalnih sil po višini stavbe, zajet vpliv nosilnih tal in drugo. V tem letu je bila sprejeta tudi nova seizmološka karta Slovenije, ki je bolj realno prikazovala območja različnih intenzitet potresov. Povsem so bili spremenjeni predpisi za gradnjo zidanih konstrukcij na potresnih območjih, kjer so prvič predpisane tudi vertikalne AB vezi na vogalih stavbe ter stikih zunanjih in notranjih nosilnih zidov. Novi predpisi so izboljšali tudi gradnjo betonskih stavb, pri čemer pa so bili predpisani detajli (stremena, preklopi, sidranje …) še vedno bistveno manj kvalitetni kot v kasnejših predpisih. Na splošno so stavbe, zgrajene v tem obdobju, potresno precej bolj odporne od zgradb, zgrajenih v starejših obdobjih. Obstoječi predpisi so bili kritično analizirani po potresu v črnogorskem primorju leta 1979; začela se je priprava novih jugoslovanskih predpisov za protipotresno gradnjo, ki so izšli leta 1981.

Preglednica 4: Členitev deleža površin večstanovanjskih stavb, zgrajenih med letoma 1964 in 1981, po gradbenem materialu in številu etaž. Skupna površina obravnavanih objektov v tem obdobju je 5.478.708 m^2.

	pritlična	od 1 do 3 nadstropja	4 nadstropja	od 5 do 8 nadstropij	9 in več nadstropij
opeka	0,09	5,50	6,16	3,80	1,17
beton		5,90	21,80	21,41	24,56
kombinacija različnih materialov		2,01	3,23	2,49	0,43
les	0,07	0,03		0,05	
kamen		0,11			
drugo			0,42		

Delež površine večstanovanjskih stavb iz tega obdobja je 40,6 % od celotne površine vseh večstanovanjskih stavb v Sloveniji. Daleč največ od tega jih je v betonskih (73,7 %), bistveno manj pa v opečnih (16,7 %) in kombiniranih (8,2 %) stavbah. Členitev po materialu in številu etaž je prikazana v preglednici 4. V tem obdobju je v štirietažnih večstanovanjskih stavbah slaba tretjina (31,6 %) površine vseh takrat zgrajenih stanovanj, v stavbah s petimi ali več nadstropji pa jih je dobra polovica.

5 Kriteriji za oceno potresne ogroženosti večstanovanjskih stavb

Popisni podatki žal ne omogočajo neposredne ocene potresne ogroženosti stavb. Možna je le posredna ocena, izvedena na podlagi splošnih podatkov, kot so leto izgradnje, gradbeni material, število etaž in leto morebitne prenove. Kot kriterij smo želeli vključiti tudi dejansko potresno ogroženost, kakršno prikazuje veljavna potresna karta Slovenije (CEN (2004): Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings, EN 1998-1), ki občine deli na območja z različnim maksimalnim pričakovanim pospeškom temeljnih tal (slika 2). Pri tem je verjetnost, da je stavba, ki ni zgrajena po novejših predpisih, potresno nevarna, precej večja v občinah na potresno ogroženih območjih. Različne pričakovane vrednosti pospeška tal smo ovrednotili z utežnim koeficientom, ki je enak 1,0 le na območjih z največjo pričakovano intenziteto, povsod drugod pa je manjši od 1,0. Na območjih, ki po pričakovanjih niso potresno ogrožena (severovzhod države), ima utežnostni koeficient dokaj majhno vrednost (0,4). Poenostavljeno smo upoštevali, da je utežnostni koeficient linearno odvisen od projektnega pospeška tal (t. j. od velikosti sil), čeprav je v splošnem zveza med poškodbami in pospeškom tal nelinearna in odvisna od energijskih količin.

V nadaljevanju so podani kriteriji za razvrstitev opečnih, kombiniranih in betonskih stavb v tri razrede glede na verjetno stopnjo potresne ogroženosti, ki so bili izpeljani iz zahtev in opisov, predstavljenih v četrtem poglavju.

Slika 2: Potresni zemljevid slovenskih občin, nastal na podlagi seizmološkega zemljevida (CEN (2004): Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings, EN 1998-1), ob upoštevanju utežnostnih koeficientov.
Glej angleški del prispevka.

5.1 Potresno verjetno nevarne stavbe

Stavbe, za katere obstaja velika verjetnost, da niso potresno varne, zato je verjetno potrebna ojačitev njihove nosilne konstrukcije:

Opečne konstrukcije:

- Stavbe, visoke pet ali več etaž, zgrajene pred letom 1981 (prevelika višina glede na zahteve sodobnih predpisov, ki za opečne stavbe takšne višine dovoljujejo le v primeru uporabe armirane zidovine, pa še to le na potresno manj ogroženih območjih).
- Stavbe, visoke štiri ali manj etaž, zgrajene pred letom 1964 (ni vertikalnih vezi, verjetno manjkajo tudi horizontalne vezi – venci). Novejši predpisi za gradnjo na potresnih območjih namreč predpisujejo uporabo vertikalnih in horizontalnih armiranobetonskih vezi, ki jih je na ustreznih medsebojnih razmikih treba betonirati po končanem zidanju zidov in imajo nalogo, da povezujejo stavbo v celoto in povečujejo njeno nosilnost (Tomaževič 1987; Slak, Kilar 2005).

Kombinirane konstrukcije:

- Stavbe, zgrajene pred letom 1894 ter med letoma 1946 in 1963 (premajhne potresne sile, v kombinaciji z opeko zelo verjetno manjkajo horizontalne in vertikalne vezi).

Betonske konstrukcije:

- Stavbe, visoke štiri ali več etaž, zgrajene pred letom 1894 ter med letoma 1946 in 1963 (bistveno premajhne potresne sile, v nekaterih primerih so bili za gradnjo uporabljeni celo betonski zidaki brez ustrezne armature).

5.2 Potresno verjetno manj varne stavbe

Stavbe, ki so verjetno potresno manj varne, zato je verjetno priporočljiva ojačitev njihove nosilne konstrukcije:

Opečne konstrukcije:

- Stavbe, visoke pet ali več etaž, zgrajene med letoma 1982 in 1999 (v nasprotju z zahtevami predpisa Eurocode 8, ki opečne stavbe takšne višine dovoljuje le v primeru uporabe armirane zidovine). Rezultati so pokazali, da je takšnih stavb izredno malo. Ker se raziskava omejuje na stavbe, zgrajene pred letom 1981, te skupine v njej nismo upoštevali.

Kombinirane konstrukcije:

- Stavbe, zgrajene med letoma 1894 in 1945 (premajhne potresne sile, verjetno kvalitetnejša gradnja).
- Stavbe, visoke štiri ali več etaž, zgrajene med letoma 1964 in 1981 (premajhne potresne sile, predpisani detajli/stikovanja/stremena betonskih konstrukcij so s stališča modernih predpisov sporni).

Betonske konstrukcije:

- Stavbe, visoke štiri ali več etaž, zgrajene med letoma 1894 in 1945 (premajhne potresne sile, verjetno kvalitetnejša gradnja).
- Stavbe, visoke pet ali več etaž, zgrajene med letoma 1964 in 1981 (premajhne potresne sile, predpisani detajli/stikovanja/stremena so s stališča modernih predpisov sporni).

Preglednica 5: Potresna varnost večstanovanjskih stavb v Sloveniji, zgrajenih pred letom 1981.

	stavbe				stanovanja	
	število	delež (%)	površina (m^2)	delež (%)	število	delež
potresno verjetno varne	4545	30,8	2.657.215	25,9	49.543	26,6
potresno verjetno manj varne	2287	15,5	3.383.236	33,0	61.043	32,9
potresno verjetno nevarne	7912	53,7	4.213.462	41,1	75.408	40,5
skupaj	14.744	100,0	10.253.913	100,0	185.994	100,0

Slika 3: Delež površin večstanovanjskih zgradb glede na material konstrukcije ter potresno varnost.

Glej angleški del prispevka.

Rezultati analiz kažejo (preglednica 5 in slika 3), da je po izbranih kriterijih 41,1 % vseh površin stanovanj v potresno verjetno nevarnih in 33,0 % v potresno verjetno manj varnih stavbah. Rezultati za

Preglednica 6: Občine z največjo površino potresno verjetno nevarnih večstanovanjskih stavb (potresno bolj ogrožene občine ($a_g \geq 0,175$) so posebej označene).

občina	površina (m²)	faktor izpostavljenosti občine
Ljubljana	1.223.045	1
Maribor	655.300	0,4
Celje	215.478	0,6
Kranj	128.537	0,9
Trbovlje	122.080	0,6
Jesenice	104.413	0,7
Koper	91.964	0,5
Velenje	91.059	0,5
Nova Gorica	69.492	0,7
Ptuj	64.928	0,5
Novo mesto	61.675	0,7
Postojna	52.875	0,8
Ravne na Koroškem	49.261	0,5
Kamnik	43.053	0,9
Piran	42.720	0,4
Hrastnik	39.555	0,6
Tržič	39.217	0,7
Krško	37.224	0,8
Kočevje	36.480	0,6
Idrija	34.649	0,8
Izola	34.169	0,4
Žalec	28.495	0,6
Domžale	28.230	1
Škofja Loka	27.372	0,9
Slovenska Bistrica	27.262	0,5

Preglednica 7: Občine z največjo površino potresno verjetno manj varnih večstanovanjskih stavb (potresno bolj ogrožene občine ($a_g \geq 0,175$) so posebej označene).

občina	površina (m²)	faktor izpostavljenosti občine
Ljubljana	1.223.045	1
Maribor	655.300	0,4
Celje	215.478	0,6
Kranj	128.537	0,9
Trbovlje	122.080	0,6
Jesenice	104.413	0,7
Koper	91.964	0,5
Velenje	91.059	0,5
Nova Gorica	69.492	0,7
Ptuj	64.928	0,5
Novo mesto	61.675	0,7
Postojna	52.875	0,8
Ravne na Koroškem	49.261	0,5
Kamnik	43.053	0,9
Piran	42.720	0,4
Hrastnik	39.555	0,6
Tržič	39.217	0,7
Krško	37.224	0,8
Kočevje	36.480	0,6
Idrija	34.649	0,8
Izola	34.169	0,4
Žalec	28.495	0,6
Domžale	28.230	1
Škofja Loka	27.372	0,9
Slovenska Bistrica	27.262	0,5

posamezne občine so prikazani tudi na slikah 4 in 5 ter v preglednicah 6 in 7 (gre za stanovanjsko površino). Sliki 4 in 5 prikazujeta delež površin ogroženih stavb glede na površine vseh večstanovanjskih stavb v določeni občini. Občine z največjo površino ogroženih stanovanj so navedene v preglednicah 6 in 7. Izstopajo seveda večje mestne občine, v katerih je največ večstanovanjskih stavb, čeprav se morda na zemljevidu Delež večstanovanjskih stavb po občinah od vseh stanovanjskih stavb leta 2002 (slika 1) niso zdele kritične.

Vidimo lahko, da je delež potresno verjetno nevarnih večstanovanjskih stavb, pri katerih bi bilo verjetno potrebno ojačiti nosilno konstrukcijo, kar 53,7 % od vseh večstanovanjskih stavb. Njihova skupna površina je 4.213.462 m^2 (41,1 %). Večina teh stanovanj je v stavbah iz opeke ali iz različnih gradbenih materialov, zgrajenih pred letom 1963. Delež večstanovanjskih stavb, ki so potresno verjetno manj varne, je manjši, 15,5 %. Njihova skupna površina je 3.383.236 m^2, kar je tretjina površin stanovanj v večstanovanjskih stavbah.

Slika 4: Delež površin potresno verjetno nevarnih večstanovanjskih stavb po občinah od celotne površine večstanovanjskih stavb v občini.
Glej angleški del prispevka.

Slika 5: Delež površin potresno verjetno manj varnih večstanovanjskih zgradb po občinah od celotne površine večstanovanjskih stavb v občini.
Glej angleški del prispevka.

6 Sklep

Članek ocenjuje potresno ogroženost obstoječih večstanovanjskih zgradb v Sloveni in potrjuje zaskrbljenost, ki so jo izrazili tudi drugi strokovnjaki za potresno gradnjo (glej npr. Kubelj 2009). Naša raziskava je potrdila zaskrbljujočo potresno varnost večstanovanjskih stavb, saj sodobnim zahtevam ustreza le nekaj manj kot polovica obstoječih večstanovanjskih stavb. Za razliko od drugih tovrstnih študij predstavljena raziskava ne temelji na ocenah o številu stavb in njihovih površinah, temveč na statističnih podatkih iz popisa prebivalstva, gospodinjstev in stanovanj leta 2002. Vendar je treba še enkrat poudariti, da gre za zelo splošne ocene, temelječe na dostopnih statističnih podatkih, ki za natančnejšo oceno ne zadostujejo, omogočajo pa statistično oceno in prikaz grobe slike stanja ter obsega verjetno potrebnih potresnih sanacij. Potresi v Posočju so pokazali tudi, da poškodbe na stavbah niso odvisne le od leta njihove izgradnje, višine in materiala nosilne konstrukcije, ampak tudi od količine, povezanosti in tlorisne razporeditve sten, ki lahko daje stavbi pri potresu še kako zaželeno dodatno nosilnost. Posledice potresa so odvisne tudi od lokalnih razmer (Orožen Adamič, Hrvatin 2001; Gosar 2007), kvalitete temeljnih tal in podobnega. Bolj natančno sliko bi bilo mogoče dobiti z analizo vsake stavbe posebej, ki bi omogočala račun dejanske dodatne nosilnosti in s tem točno oceno dejanske ogroženosti, kar pa je zamudno in predvsem drago opravilo.

Rezultati po občinah so razkrili presenetljivo veliko potresno problematičnih objektov v severovzhodnem delu države, v pasu, ki se začne na Koroškem in se nadaljuje na obeh straneh Drave. Delež potresno verjetno nevarnih večstanovanjskih objektov tu presega 50 %, kar je praviloma posledica dokaj zgodnje industrializacije in potreb po večjem številu stanovanj na tem območju. Stavbe so bile grajene v času, ko so veljala drugačna – manj zahtevna varnostna načela. Na srečo je to območje po sedanjih seizmičnih zemljevidih potresno manj ogroženo.

Treba pa je izpostaviti skupino zgradb, ki so najbolj nevarne za bivanje. To so stavbe s petimi ali več etažami, ki so bile zgrajene pred letom 1981 in bi jih bilo treba najprej sanirati. Teh stavb je v Sloveniji 1188. V njih je 23.721 stanovanj s skupno površino 1.263.921 m^2. Po površini tovrstnih stavb in deležu glede na celotno površino večstanovanjskih stavb najbolj ogrožene občine so predstavljene v preglednici 8.

Skrb za izboljšanje tovrstne varnosti oziroma statično sanacijo zgradb bo verjetno morala prevzeti država. Učinkovito sanacijo zelo otežujejo zapletena lastninska razmerja v večstanovanjskih stavbah, čeprav Pravilnik o merilih za določitev prispevka etažnega lastnika v rezervni sklad in najnižji vrednosti prispevka (Ur. l. RS 11/2004) predvideva zbiranje mesečnih prispevkov vseh lastnikov stanovanj v stavbah, starejših od 10 let za tako imenovani »rezervni sklad« za izvajanje potrebnih vzdrževalnih in obnovitvenih del. Glede na to, da gre pri protipotresni sanaciji za velike denarne zneske, bo tako zahteven projekt možno izvesti le z ustrezno zakonodajo in stimulacijami lastnikov oziroma olajšavami zanje. Druga možnost bi bila sofinanciranje občin v zameno za povečanje deleža lastništva v tovrstnih zgradbah. Na kakršenkoli način se bo to stanje v prihodnosti urejalo, bo poleg gradbenih del odprlo še zelo zahtevno pravno in ekonomsko problematiko.

Preglednica 8: Občine po številu stavb, številom stanovanj v njih in njihovo površino v večstanovanjskih stavbah, višjih od štiri etaže, ki so potresno verjetno najbolj ogroženi del slovenskega večstanovanjskega fonda. Poleg absolutnih vrednosti so navedeni tudi odstotni deleži glede na vse večstanovanjske objekte v občini (potresno bolj ogrožene občine ($a_g \geq 0{,}175$) so posebej označene).

	število stavb	delež (%)	število stanovanj	delež (%)	površina (m²)	delež (%)	faktor izpostavljenosti občine
SLOVENIJA	1188	8,1	23.721	12,8	1.263.921	12,0	–
Ljubljana	393	11,0	7992	14,3	429.555	14,0	1,0
Maribor	164	9,4	3205	13,8	177.728	14,0	0,4
Celje	71	12,5	1376	16,5	67.779	15,0	0,6
Velenje	65	24,2	1162	23,0	63.325	22,0	0,5
Kranj	51	12,1	896	15,0	47.774	14,0	0,9
Koper	40	9,4	785	16,7	40.564	15,0	0,5
Trbovlje	41	13,0	692	18,0	39.691	20,0	0,6
Jesenice	17	6,5	619	14,3	31.450	14,0	0,7
Piran	20	6,2	417	19,3	25.281	20,0	0,4
Izola	22	9,9	410	23,2	22.482	22,0	0,4
Ravne na Koroškem	17	12,1	398	20,8	21.134	20,0	0,5
Novo mesto	17	7,6	389	13,2	20.476	13,0	0,7
Nova Gorica	15	6,0	305	7,4	17.337	7,0	0,7
Postojna	11	6,7	242	12,2	13.895	12,0	0,8
Kamnik	12	7,4	260	12,2	13.639	12,0	0,9
Sežana	12	12,9	197	16,8	10.980	17,0	0,6
Laško	7	8,6	188	26,4	9337	26,0	0,6
Idrija	12	6,8	178	11,3	9185	11,0	0,8
Zagorje ob Savi	12	9,7	169	11,1	8176	10,0	0,7
Murska Sobota	7	7,1	146	8,1	7772	8,2	0,4
Škofja Loka	6	5,6	120	6,2	7158	6,8	0,9
Domžale	5	4,3	163	8,3	7091	6,7	1,0
Bled	5	5,8	124	20,2	6947	21,0	0,7
Kočevje	5	2,9	145	8,0	6582	6,9	0,6
Litija	7	7,5	118	9,1	6209	9,2	0,8
Slovenska Bistrica	5	3,5	121	9,6	5184	8,1	0,5
Hrastnik	5	4,6	99	6,3	4969	6,3	0,6
Krško	5	3,8	87	5,6	4380	5,0	0,8
Vrhnika	5	6,0	66	8,4	3966	9,0	0,9
Ptuj	5	2,0	45	1,8	2633	1,8	0,5

7 Literatura

Glej angleški del prispevka.