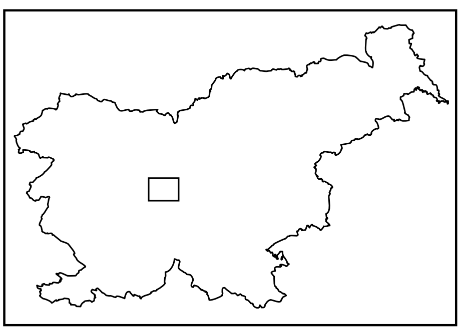
EARTHQUAKE THREAT IN LJUBLJANA
POTRESNA OGROŽENOST LJUBLJANE

Milan Orožen Adamič

Crude shelter in cabbage barrels at the time of the 1895 earthquake
(the Krakovsko suburb in Ljubljana, Helfer 1895).
Zasilna bivališča v zeljarskih sodih v času potresa leta 1895
(Krakovsko predmestje v Ljubljani, Helfer 1895).



Abstract UDC 550.34(497.12 Ljubljana)

Earthquake Threat in Ljubljana

In Slovenia, the large natural geographical units of the Alps, the Dinara Mountains, the Mediterranean, and the Pannonian basin come into contact. There have been many destructive earthquakes in this region in the past. A hundred years ago (1895), a strong earthquake with a magnitude between 8 and 9 on the MCS scale severely damaged Ljubljana. Because Ljubljana is the capital of Slovenia with the largest density of population and numerous important central functions, we consider it the zone most threatened by earthquake.
A map of the microseismic zones of Ljubljana has been formulated. With the help of statistical data and other sources, we elaborated a quite detailed data base that we included in the Geographical Information System. This is the first example of such a detailed study in Slovenia, on a city area that includes about 0.9% of Slovenia's territory and 13.4% of its population. The main aim of the study was an assessment of the possible consequences of a destructive earthquake. In the most endangered zone of 9 degrees MCS are 15.23% of all the buildings in which almost 10% of Ljubljana's residents live. The assessment of earthquake vulnerability showed that in an earthquake of magnitude 9, an earthquake stronger than the one in 1895, as much as 26.3% of all the dwellings would be destroyed, and 44.9% of the dwellings would be severely damaged. In less powerful earthquakes, the consequences would naturally be correspondingly smaller.

Izvleček UDK 550.34(497.12 Ljubljana)

Potresna ogroženost Ljubljane

V Sloveniji se stikajo velike naravnogeografske enote Alpe, Dinaridi, Sredozemlje in Panonska kotlina. V preteklosti je bilo v tem območju veliko rušilnih potresov. Pred sto leti (1895) je močan potres, ki je imel učinek med 8. in 9. stopnjo po MCS lestvici, močno poškodoval Ljubljano. Ker je Ljubljana glavno mesto Slovenije, z največjo gostoto prebivalstva in številnimi drugimi pomembnimi centralnimi funkcijami, ocenjujemo, da je zato to potresno najbolj ogroženo območje.
Za Ljubljano je izdelana karta mikroseizmične rajonizacije. S pomočjo statističnih podatkov in drugih virov smo izdelali dokaj podrobno podatkovno bazo, ki smo jo vključili v geografski informacijski sistem. To je prvi primer tako podrobnega raziskovanja v Sloveniji, na mestnem območju, ki obsega približno 0,9 % površine Slovenije in 13,4 % njenega prebivalstva. Poglavitni cilj raziskave je bil ocena možnih posledic rušilnega potresa. V najbolj ogroženem območju 9. stopnje MCS je 15,23 % vseh objektov in v njih prebiva skoraj 10 % Ljubljančanov. Ocena potresne ranljivosti je pokazala, da bi ob potresu 9. stopnje, to je ob potresu, ki bi bil močnejši kot leta 1895, bi bilo uničenih kar 26,3 % vseh stanovanj, hude poškodbe bi imelo 44,9 % stanovanj. Ob manj močnih potresih pa bi bile posledice seveda ustrezno manjše.

Address – Naslov
Dr. Milan Orožen Adamič
Geografski inštitut ZRC SAZU
Gosposka 13
1000 Ljubljana
Slovenia
Phone – telefon +386 61 1256 068/300
Fax – faks +386 61 1255 253
E-Mail milan@zrc-sazu.si

Contents – Vsebina

1. Introduction

Ljubljana experienced a destructive earthquake one hundred years ago in 1895. This is not, of course, a prediction of the imminent repetition of a similar earthquake, but the possibility of one is increasing (Lapajne 1989). Just how bad the consequences of an eventual stronger earthquake in Ljubljana might be depends on our readiness. An earthquake would be the only unbiased evaluator of anti-earthquake protection measures and a merciless judge of badly planned buildings. Therefore we are interested in danger of an earthquake or the earthquake threat to Ljubljana. The aim of our study was to discover some important elements and to illuminate what various degrees of estimated earthquake risk mean for Ljubljana.

This work is a part of an extensive and long-established program of geographical research into natural disasters in Slovenia which has been ongoing in the framework of the Geographical Institute of ZRC SAZU (Scientific Research Center of the Slovene Academy of Science and Art) since 1954. Numerous geographers and other experts have cooperated in the study of all types of natural disasters. Results of these studies have been published in numerous publications, in recent years in the journal *Ujma* ("Storm Damage"). In the methodological sense, this study was part of a wider project on the possibilities of use and development of geographical information systems, also on-going in the framework of the Geographical Institute of ZRC SAZU.

Our aim was to establish and estimate the threat to individual parts of Ljubljana by covering certain "elements" of the city and individual earthquake magnitudes which are described below. We also performed certain calculations of models and tried to find answers to certain key questions.

In the Villach earthquake of 1348 that struck Carinthia, there were about 500 victims, and landslides from the Dobrač mountain range buried seventeen villages in the Zilja valley (De Reggi 1949). In the last few decades, our country has not been struck by natural disasters that could be ranked among catastrophes of world proportions according to the extent of damage or number of victims. This is not true, however, of certain natural disasters at the edge of our ethnic territory. In the 1976 Friuli earthquake in Italy, more than a thousand people lost their lives, and this earthquake caused considerable damage in Slovenia as well, though there were no lives lost in Slovenia. In Slovenia, we must seriously consider the possibility that especially a larger earthquake could result in a large number of casualties (Godec, Vidrih 1992). We must be aware of the possibility of a catastrophic earthquake like the one in 1511 (Lapajne 1988) or the slightly weaker earthquake in 1895 (Lapajne 1989). In such a disaster there could be several thousand casualties in Slovenia. There have been no casualties during earthquakes in Slovenia in this century because luckily they have not been very strong. In the Ljubljana earthquake of 1895, there were seven or twelve casualties (according to Paulin 1985 and Hoernes 1985, respectively).

Weighing the current situation and developments gives no reason for excessive optimism. The rapid growth of population in itself increases the proportion of endangered population in many countries, and at the same time increases the settling of marginal areas with worse natural conditions and greater risk. There are many such cases in Slovenia, for example the "slum" settlements on the Ljubljana Barje moor (Orožen Adamič 1982). Changes in the ecological balance of the Slovene countryside are also an important cause of increased vulnerability. A similar thought was expressed by Gams (1983 b) in the anthology *Natural Disasters in Slovenia*: "Ever since the migration of population from higher areas substantially increased the number of population and economic capabilities on the flatland, the common threat to the population has increased."

2. Some Capacities of Seismic Zones in Slovenia

In the Official Gazette of the former Yugoslavia (No. 39, 1964), of which Slovenia was a part until 1991, there was an appendix to the Regulations regarding Norms for the Construction of High Buildings in Seismic Zones (Official Gazette of SFRY, No. 49, 1982) containing a Provisional Seismic Map in the scale of 1 : 2,500,000. The primary basis for this map was data on past earthquakes (Ribarič 1982 a), of which the two most significant were the 1511 earthquake along the Idrija fault ($l_{max.}$ = 10 MSK) and the 1895 Ljubljana earthquake ($l_{max.}$ = 8.5 MSK). On the basis of this map, on which zones of maximum observed MCS intensities are marked, the Institute for Research of Material and Constructions (Geotechnics Division) published a map in the scale 1 : 400,000. This map was the basis for the first assessment of earthquake threat in Slovenia. Our aim was to attempt to determine in detail the capacities and differences in capacities among individual MCS zones with the help of statistical data (Blejec 1976). We applied the method of overlapping the enumerated and interpreted layers on the above map. All the calculations and other operations in this part of the project were performed in the classic manner. The technique of calculation itself is basically identical or very similar to the one used in the continuation of the project with the help of the Geographical Information System. Part of this research had been previously done (Orožen Adamič 1983 b). The data on population as well as other data was from 1981 and we therefore updated the findings with new population data from 1991 (Perko 1991 b).

2.1. MCS Zones in Slovenia

Slovene regulations regarding construction in seismic zones implement the use of the 12-degree MCS (Mercalli–Cancani–Sieberg) earthquake scale that in practice is gradually being replaced in descriptions by the similar 12-degree MSK (Medvedev–Sponheuer–Karnik) scale. The latter includes certain quantity definitions not found in the MCS and other scales. The most threatened areas in which 9 degree MCS magnitude earthquakes can be expected are the Tolmin zone (9 a), the Idrija zone (9 b), the Ljubljana zone (9 c), and the Brežice zone (9 d). These zones of highest threat together comprise 863 km^2 or 4.26% of Slovenia's territory. The largest is the Tolmin zone with 398 km^2 or just above 2% of Slovenia's territory followed by the Ljubljana zone with 233 km^2 including the southern part of Ljubljana with the Ljubljana Barje moor (in other, mostly older versions of this map, all of Ljubljana right to Vodice, the epicenter of the 1895 earthquake, is classified in this zone), the Brežice zone with 121 km^2, and finally the Idrija zone, the smallest with 111 km^2.

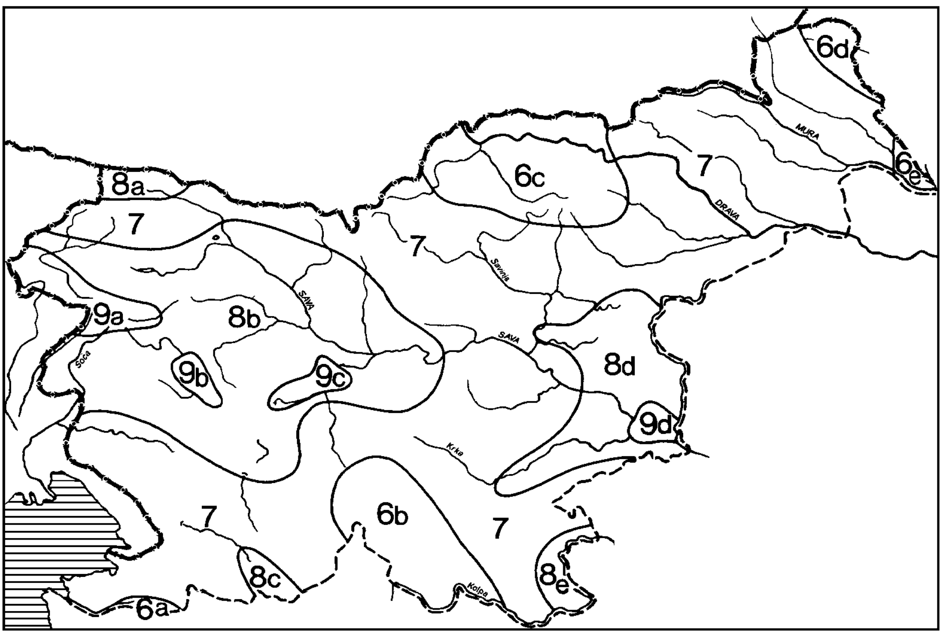


Figure 1: Provisional Seismic Map of Slovenia (1981).
Slika 1: Začasna seizmična karta Slovenije (1981).

The seismological map of Yugoslavia elaborated and published in 1987 is slightly different from the 1981 map, but in their principal outlines the individual earthquake zones are very similar. This is especially true if we consider the detailed microseismic regionalization of Ljubljana covered in the following discussion. At the moment, a completely new seismological map of Slovenia is being prepared in cooperation with other institutes by the Uprava Republike Slovenije za geofiziko (National Geophysics Administration of the Republic of Slovenia). In basic outline, there is not a great difference between the two maps. It is obvious that any such map can only give skeleton definitions. However, in our research it helped us at least answer in broad outline the questions of just what individual earthquake magnitudes mean, how much of Slovenia is threatened, how many people live in individual zones, etc.

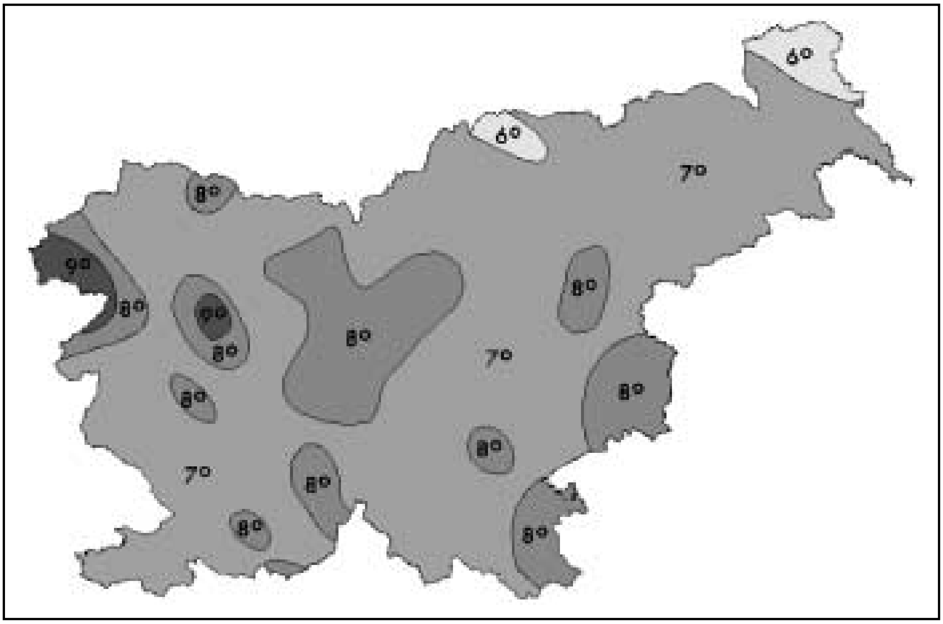


Figure 2: Section of the Seismological Map of Yugoslavia for the Return Period of 500 Years (1987).
Slika 2: Izsek iz seizmološke karte Jugoslavije za povratno dobo 500 let (1987).

The following five zones rank in the magnitude 8 degrees MCS as relatively strongly threatened parts of Slovenia: the Kranjska gora zone (8 a), the Western Alpine zone (8 b), the Ilirska Bistrica zone (8 c), the Lower Sava–Kozjansko zone (8 d), and the Bela Krajina zone (8 e). Together they comprise 5470 km^2 or 27% of Slovenia. The largest is the Western Alpine zone (8 b) with 3980 km^2 or 20% of Slovenia's territory followed by the Lower Sava–Kozjansko zone with 1029 km^2 or 5.1% of the territory of Slovenia. The remaining three zones of magnitude 8 degrees MCS are substantially smaller, the largest being the Ilirska Bistrica zone with approximately 133 km^2.
With a magnitude 7 degrees MCS threat there is only one cohesive and widely branching earthquake zone in Slovenia, extending from Primorska across central Slovenia and part of the Kamniške-Savinjske Alps all the way to Goričko and Lendava in eastern Slovenia. This is the largest earthquake zone with 11,457 km^2, more than half of Slovenia (56.55%).
With a magnitude 6 degrees MCS are five least threatened zones: the Istria zone (6 a), the Notranjska zone (6 b), the Koroška–Pohorje zone (6 c), the Eastern Goričko zone (6 d), and the Lower Lendava zone (6 e). Areas relatively safe from earthquake damage comprise 2429 km^2 or 12.19% of Slovenia. The largest of these is Koroška–Pohorje with 1304 km^2 or 6.44% of Slovenia's territory, followed by Notranjska with 927 km^2 or 4.55% of Slovenia's territory. The remaining zones of magnitude 6 degrees MCS are substantially smaller.

Earthquakes with magnitudes of 8 or 9 – and substantial material damage – can be expected over some 31.26% of the territory of Slovenia. If we add the zones with expected earthquake magnitudes of 7 degrees MCS in which there can still be substantial material damage, 87.81% of the territory of Slovenia is relatively strongly threatened.

TABLE 1: AREA AND POPULATION ACCORDING TO MCS ZONES.

MCS Zones	area km²	%	population 1981	population 1991	% of population 1991	population/ km² 1991	% in category 1991
9 a	398.33	1.96	15,240	15,531	0.79	39	9.89
9 b	111.19	0.55	10,569	10,616	0.54	95	6.76
9 c	232.72	1.15	99,563	112,454	5.72	483	71.59
9 d	120.73	0.60	17,539	18,480	0.94	153	11.76
9 together	862.97	4.26	142,911	157,081	7.99	182	100.00
8 a	130.97	0.65	5,068	5,111	0.26	39	0.72
8 b	3,979.60	19.64	546,708	567,187	28.85	143	79.78
8 c	132.64	0.65	10,771	11,010	0.56	83	1.55
8 d	1,029.47	5.08	105,441	110,095	5.60	107	15.49
8 e	197.78	0.98	16,785	17,497	0.89	88	2.46
8 together	5,470.46	27.00	684,773	710,900	36.16	130	100.00
7	11,457.18	56.55	920,160	953,503	48.50	83	100.00
6 a	43.13	0.21	987	983	0.05	23	0.68
6 b	927.08	4.58	50,309	51,902	2.64	56	35.92
6 c	1,303.97	6.44	78,638	82,178	4.18	63	56.87
6 d	152.22	0.76	6,520	6,684	0.34	44	4.63
6 e	41.46	0.20	2,569	2,752	0.14	66	1.90
6 together	2,468.86	12.19	139,068	144,499	7.35	59	100.00
total	20,259.00	100.00	1,886,912	1,965,983	100.00	97	–

2.2 Population in MCS Zones

The determined number of residents in individual MCS zones is based on the 1981 and 1991 census figures. In the period between 1981 and 1991, the population of Slovenia increased by the index 104.5. In 1981, 143,911 people or 7.57% of the population of Slovenia lived in zones of magnitude 9 degrees MCS. In 1991, there were altogether 157,081 people or 7.99% of the population of Slovenia in these zones.

In the Ljubljana zone of magnitude 9 degrees MCS there were altogether 112,454 residents (this zone includes the Ljubljana Center district, part of the population of the Ljubljana Vič-Rudnik district, and part of the population of the Vrhnika district), some 6.76% of the population of Slovenia. According to population follow the Brežice zone with 18,480 residents, the Tolmin zone with 15,531 residents, and the Idrija zone with 10,616 residents.

The density of population is the highest in the Ljubljana zone, some 483 residents/km² and in the Brežice zone with 153. The average density of population in Slovenia in 1991 was 97 residents/km². The density of the population is close to the average in the Idrija zone (95 residents/km²) and in the Tolmin zone considerably below the average (39 residents/km²). Because of Ljubljana, the average density of population in the most threatened earthquake zones (magnitude 9 degrees) is above average, and the same was true in 1981. Also due to Ljubljana, the average density of population in this seismic zone has increased from 166 to 182 residents/km².

In the zones of magnitude 8 degrees MCS live 710,900 residents or 36.16% of the population of Slovenia. Adding to these the zones of magnitude 9 degrees MCS, 44.15% of Slovenia's population is potentially strongly threatened. 567,187 residents live in the Western Alpine zone (8 b) with an average density of 143 residents/km². Also above-average in population density is the Lower Sava–Kozjansko zone with an average density of 107 residents/km^2 (110,095 residents). In the rest of the zones there are fewer residents and smaller average population densities.

In the zone of magnitude 7 degrees MCS live 953,503 people or 48.50% of the population of Slovenia with a below average density of population (83 residents/km^2). Altogether, 92.65% of the residents of Slovenia live in the zones of magnitude 9, 8, and 7 degrees MCS. Therefore, the possibility exists that more than 90% of the population of Slovenia could suffer damage in earthquakes with magnitudes of 7 or more degrees MCS.

A small number of people, only 144,499 or 7.35% of the population with an average population density of only 56 residents/km^2, live in the seismically less threatened or relatively safe seismic zones of magnitude 6 degrees MCS which cover 12.19% of Slovenia.

If we assume that in the sense of potential threat a connection exists between the highest expected seismic magnitude and density of population in an individual zone, the threat is higher in densely populated zones. The Ljubljana zone stands out strongly in this respect, followed by the Brežice and Idrija zones. To this group we can also add two zones of magnitude 8 degrees MCS with above-average population densities: the population density is highest in the Western Alpine zone (8 b) and closer to the average in the Lower Sava–Kozjansko zone (8 d).

The zones of magnitude 9 and 8 degrees MCS with below average densities of population are the Tolmin zone (9 a), the Bela krajina zone (8 e), the Ilirska Bistrica zone (8 c), and the Kranjska gora zone (8 a).

None of the zones studied ranked In the third group with relatively low highest expected seismic magnitudes of 7 and 6 degrees MCS and above-average densities of population. This shows that the zones where we do not expect extremely strong earthquakes have below average population densities. The extensive zone of magnitude 7 degrees MCS has a population density slightly below the Slovene average. In order of density of population in the magnitude 6 degrees MCS zones are the Lower Lendava zone (6 e), the Koroška–Pohorje zone (6 c), the Notranjska zone (6 b), the east Goričko zone (6 d), and the Istria zone (6 a).

If we place seismic intensity foremost and then consider population density, the zones rank in the following order: 1. the Ljubljana zone (9 c), 2. the Brežice zone (9 d), 3. the Idrija zone (9 b), 4. the Tolmin zone (9 a), 5. the Western Alpine zone (8 b), 6. the Lower Sava–Kozjansko zone (8 d), 7. the Bela krajina zone (8 e), 8. the Ilirska Bistrica zone (8 c), 9. the Kranjska gora zone (8 a), 10. the Primorska, Central, and Eastern Slovenia zone (7), 11. the Lower Lendava zone (6 e), 12. the Koroška–Pohorje zone (6 c), 13. the Notranjska zone (6 b), 14. the Eastern Goričko zone (6 d), and 15. the Istria zone (6 a). This arrangement does not give a significantly different picture from the first distribution.

According to the numbers of population threatened, Ljubljana stands out by far in both cases. The Tolmin zone is in fourth position due mostly to its relatively low population density. Equally strong earthquakes would be more dangerous in the Ljubljana zone than in the Tolmin zone of the Posočje region because of its larger population.

Studying the consequences of earthquakes in the Posočje region (Orožen Adamič 1978 b) has shown that for a complete assessment of the threat it is also important to consider other elements, for example, the GDP or the amount (mass) and value of goods produced. One such complete study of Slovenia (Orožen Adamič 1983 b) revealed that the Ljubljana zone is by far the most threatened. It indicated that in the seismically most threatened zones of magnitude 9 degrees MCS, such industries should be developed that can operate in relatively simple and inexpensive buildings and that the location here of industries with extensive, complicated, and sensitive equipment should be avoided. Seismically safe construction is more expensive in more threatened zones. This is true not only for industries but also for other construction (Bubnov 1987).

According to its capacities, the Ljubljana zone of magnitude 9 degrees MCS (9 c) stands out strongly. This is the zone with the highest concentration of population and the highest average per capita GDP. While the level of industrialization is relatively low here (although high in the absolute sense), there are other activities in the foreground and the central functions of this capital city should not be forgotten. The number of relatively old and seismically inadequate buildings is large (buildings erected before 1946). For these reasons, the Ljubljana zone is justly considered the relatively most threatened area in Slovenia.

2.3. Influence of Local Conditions on the Impact of Earthquakes

Studying the consequences of the well known Friuli earthquake that struck Posočje in 1976 (Orožen Adamič 1978 a), we determined that locally there can be great differences in damage or consequences of an earthquake. For example, the section of Kobarid built on a hard limestone bedrock was very little damaged while the southern section of town built on the sedimentary plain suffered decidedly greater damage. We found many such and similar examples while studying the consequences of this earthquake in detail, which only confirmed the older finding that microground conditions are extremely significant for the direct consequences to buildings (Ribarič 1963, 1964). In weak earthquakes these elements are negligible, but from a magnitude of 5 degrees MCS (or MSK) upward, many things can happen to buildings erected on inappropriate ground (Ribarič 181). The accurate distinction of microseismic units is therefore extremely important for detailed studies.

The Upper Posočje region struck by the 1976 Friuli earthquake belongs among the most diverse of Slovene landscapes. Height differences even over small distances are great, more than 2000 meters absolute above-sea level in 200 to 300 meters' distance. The central valley of the Soča River has none of the larger and extensive flood plains characteristic of the rest of Slovenia. Somewhat larger widenings only occur near Bovec, Kobarid, and Tolmin with the side valley along the Nadiža River. It appears that climatic, tectonic, and other characteristics unique to this area contributed greatly to the morphological structure of the Posočje region.

Figure 3: Reproduction of a copper engraving from around 1840 (Goldstein–Pajk) clearly shows the once untouched banks of the Ljubljanica River (Kopriva 1989).
Slika 3: Na reprodukciji bakroreza, nastalega okrog leta 1840 (Goldstein–Pajk), so lepo vidne nekdaj neobzidane brežine Ljubljanice (Kopriva 1989).

In the Upper Posočje region, Triassic limestone and partly dolomite prevails. From the Bovec basin downriver, mostly at lower elevations, Jurassic and Cretaceous impermeable stone hillocks with sandstone and flysch are well represented. In the valley bottoms are large quantities of Quaternary gravel sediment accompanied along the slopes by numerous fans made by regular and torrential streams and scree formations. At some places, for example at Breginjski kot, there are clearly evident remains of glaciation.

After the earthquakes that shook this region in 1976, there were visibly large differences in the amount of damage caused by the earthquakes over very small distances (Orožen Adamič 1979). The same phenomenon was discovered during a detailed study by the same author of the consequences of an earthquake in Rescia and the Torre River valley. To a large extent, this phenomenon can be explained by differences in micro and macro geological conditions. Even the initial survey of the extent of damage showed that the greatest damage had occurred in settlements built on uncompacted ground such as gravel, and especially where ground water was close to the surface. A more detailed study of the consequences of an earthquake in Podbela revealed that the higher level of the ground water in the southern and southwestern section of the settlement additionally influenced the extent of damage caused. Generally speaking, there was much less damage to settlements situated on flysch, for example, at Drežnica in the immediate vicinity of Ladra-Smast which itself suffered extremely great damage. On the whole, settlements in the Posočje region situated on carbonate stone survived the earthquake best. The northeastern section of Kobarid was less damaged than the rest of the town which is situated on Quaternary sediment. According to the effects of earthquakes in relation to the dominant geological bedrock, the Upper Posočje region can be divided into three units:

Figure 4: This photograph taken from approximately the same place as the previous figure shows the differences in the arrangement of the banks of the Ljubljanica and of the city.
Slika 4: Fotografija je posneta s približno istega mesta, kot prejšnja slika nam kažete razliko v ureditvi bregov Ljubljanice, oziroma mesta.

Figure 5: Demolishing of damaged buildings after the 1895 earthquake along Francovo nabrežje, now Cankarjevo nabrežje (Helfer 1895).
Slika 5: Rušenje poškodovanih hiš, po potresu leta 1895, ob Francoven, sedaj Cankarjevem nabrežju (Helfer 1895).

1. Quaternary sediments,
2. mainly impermeable stone hillocks, and
3. hard carbonate stone.

Quaternary sediments are mostly composed of more or less agglutinate fluvioglacial material, slope gravel, and the like. These are advantageous areas for settlement and agrarian exploitation. They comprise the lower parts of valleys and indent like tongues into the steeper slopes. However, due to the nature of the underlying soil itself, the large differences in elevation, and the high level of precipitation of the Posočje region, the land is quite unstable. In the bottom sections of the valleys, the ground water is often close to the surface and floods are frequent in certain places. The settlements in the Upper Posočje region are mostly situated on the margins of Quaternary sediments and at junctures with impermeable or carbonate stone. Agrarian settlements are typically located at the juncture of diverse natural geographical and geo-ecological units. Permanent reservoirs of ground water in the Upper Posočje region are not large because there are no suitable orographical conditions. The valleys are relatively narrow and there is also no possibility for larger accumulations of ground water in the Quaternary sediments. Not least important is that many settlements are situated on the slopes of fans or on screes where the structure of the soil and inclination of the terrain further increase the instability of the ground:

- Ladra is situated on gravel deposits from the Soča River and its smaller side tributaries, and the ground water is close to the surface due to the closeness of the river.
- Borjana, Potoki, Stanovišče, Homec, and many other settlements are situated on scree.
- Breginj and several other places in the Upper Posočje region are located largely on unagglutinated slope gravel and partly on the remains of glacial moraines.

Here we must point out that flysch is found at various depths under many of these settlements, covered by Quaternary sediments which additionally frustrates direct reciprocal comparisons. It appears due to this very fact that there were no major differences in the extent of damage caused.

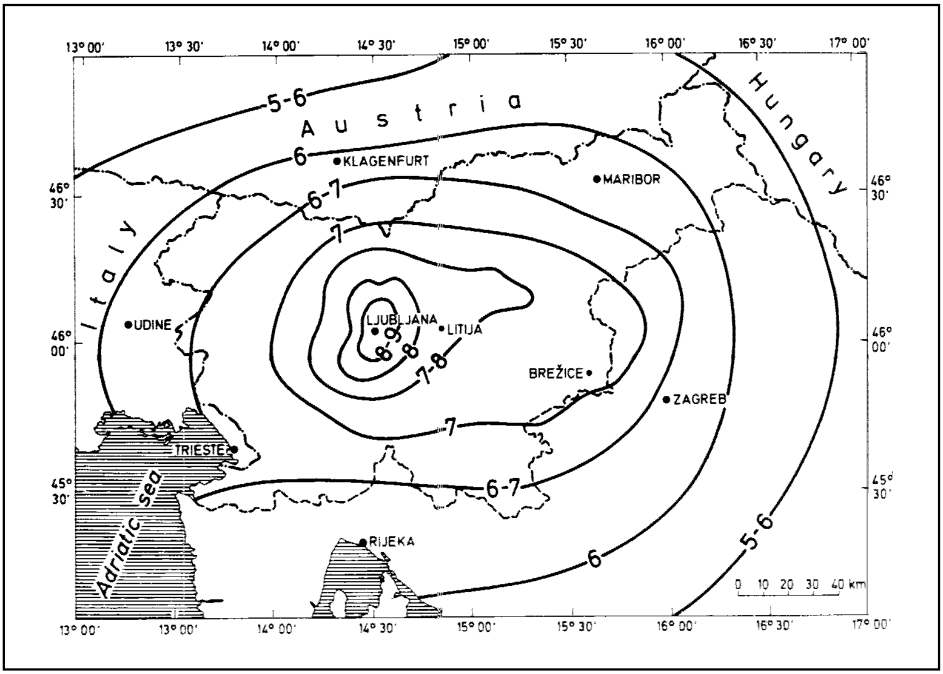


Figure 6: Field of the effects of the Ljubljana earthquake of April 14, 1895 in degrees of the MSK scale (Lapajne 1989).
Slika 6: Polje učinkov ljubljanskega potresa z dne 14.4.1895 v stopinjah MSK lestvice (Lapajne 1989).

Similar and even greater landscape diversity is characteristic of the majority of Slovene landscapes and not only of the Posočje region. The Posočje experience has taught us that this factor must be taken into serious consideration in earthquake threatened areas.

Soil and topographical influences are combined and interwoven with the basic shaking of the ground on the bedrock. In practice it is very difficult to estimate them quantitatively or assess them. In addition, certain factors, for example the depth of the ground water, are changeable and inconstant.

In urban areas, along with natural circumstances, there are many anthropogenic changes to the original ground (excavations and filled-in gravel pits, sewage systems, and the most varied construction and technical operations). With its development and growth, some sections of a city are greatly changed. One such case is the reshaping of the banks of the Ljubljanica River in Ljubljana.

At least partial answers to these questions may be found in the "microseismic regionalization" usually done for the most threatened areas such as Slovenia's Ljubljana zone. These very detailed microseismic assessments are also being done for very important buildings, for example the microseismic assessment of the Krško nuclear plant.

3. Risk of an Earthquake Occurring in Ljubljana

On the basis of now available geological, seismological, and technical construction data, a study of the risk of an earthquake occurring in Ljubljana was made for earthquakes with recurring periods from 50 to 10,000 years (Lapajne, Tomaževič 1991 a, 1991 b). The threat to the old part of the city was also studied by Godec and Vidrih (1992). In this study they pointed out that the majority of input data is still only approximate and additionally the state of construction in the city and the disposition of its residents and other users is constantly changing. Regrettably, quality data bases usable for the assessment of earthquake threat to other city districts do not yet exist. We therefore set out in our study to establish such a computerized data base and its inclusion in the Geographical Information System.

3.1. Seismogenic Zones of Ljubljana and its Surroundings

According to Lapajne and Tomaževič (1991 b) and Vidrih and Godec (1992), the entire area of Ljubljana's districts belongs to the Gorenjska–Ljubljana–Dolenjska–Bela krajina seismogenic area which consists of three systems:

- Gorenjska–Ljubljana,
- Dolenjska,
- Notranjska–Bela krajina.

These systems are divided into seismogenic zones and blocks:

- the Gorenjska–Ljubljana system
- the Gorenjska seismogenic zone
- the Gorenjska seismogenic block
- Sorško polje (plain) seismogenic block
- the Kranj polje (plain) seismogenic block

- the Ljubljana seismogenic zone
- the Ljubljana central block
- the seismogenic block of isolated areas
- the Kamniško polje (plain) seismogenic block
- the Ljubljana Barje moor seismogenic block

- the Polhov gradec Dolomites seismogenic zone
- the Tošč seismogenic block
- the Polhov gradec seismogenic block
- the Horjul seismogenic block

- the Dolenjska seismogenic system
- the Litija–Sevnica seismogenic zone
- the Litija–Sava seismogenic block
- the Miren seismogenic block
- the Mokronog seismogenic block

- the Krško seismogenic zone
- the Krško polje (plain) seismogenic block
- the Novo mesto seismogenic block
- the Notranjska–Bela krajina seismogenic system
- the Bela krajina seismogenic zone
- the Črnomelj seismogenic block

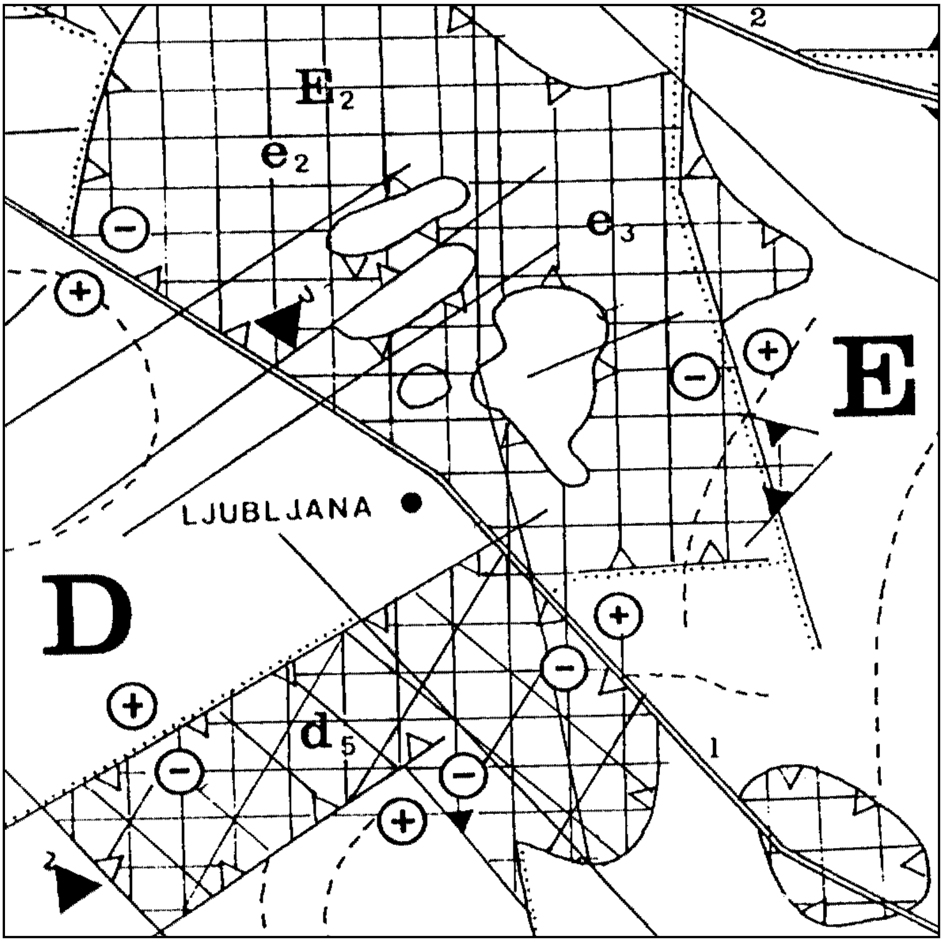
The prognostic characteristics of each seismogenic block were calculated. In the Gorenjska–Ljubljana seismogenic system, the greatest possible magnitude (M) is 6.2 and the greatest possible intensity (l_0 is 9 degrees MSK (Sikošek 1982).

3.2. Neotectonic Structure of the Ground

Ljubljana and its wider surroundings lie on the juncture of two morphostructural zones: to the northeast is the Kranjska–Dolenjska zone and to the southwest the Notranjska–Gorenjska zone. Between these lies the Toplice–Žužemberg–Dražgoše fault system.

3.3. Faults

The territory of Ljubljana and its wider surroundings is composed of neotectonic blocks. Areas south of Ljubljana proper sank in the Quaternary period (and are still sinking), while areas to the west and east have a tendency to rise. The northern parts consist of Miocene depressions with sinking in Pliocene and Quaternary periods.

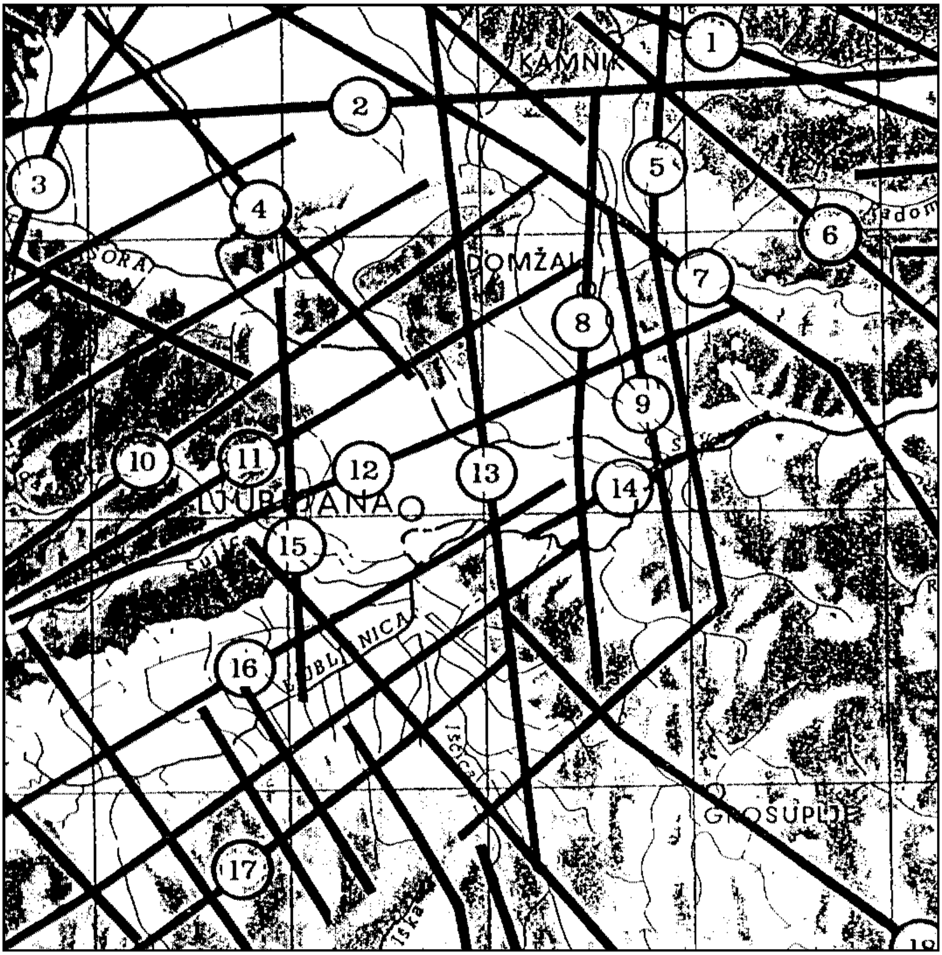


Key:
D the Notranjska–Gorenjska morphostructural zone
E the Kranjska–Dolenjska zone
d_5 The Ljubljana Barje moor
E_2 floor of the Ljubljana Basin
e_2 the Kranjska–Sorška soil
e_3 the Mengeš soil
1 the Toplice–Žužemberg–Dražgoše fault
2 the Sava–Brežice

Figure 7: Neotectonic structure of the wider Ljubljana area (Lapajne, Tomaževič 1991 b).
Slika 7: Neotektonska zgradba širše okolice Ljubljane (Lapajne, Tomaževič 1991 b).

Ljubljana and its surroundings are intersected by numerous faults that stretch in four main directions. Along with the rare oldest faults oriented east–west, the area is intersected by numerous Dinaric and cross-Dinaric faults which are mostly earthquake active. Also earthquake active are the faults that run north–south. The tectonic conditions are very complicated. The area is a constituent part of the southern branch of Alpine orogeny. Here, two large geotectonic units contact, the southern Alps and the Dinara Mountains. Typical here are the older folded and the younger (neotectonic) anticlinorium structures (Premru 1977). The folded structure was caused by two periods of folding in the Tertiary period. In the first period, between the Oligocene and Miocene periods, the Dinaric area folded from the northwest to the southwest direction. In the second period, between Miocene and Pliocene periods, the area of the south Alps folded from the north to the south. Individual sheaves of faults and fault systems mean potential earthquake zones.

The Ljubljana plain is a young tectonic depression. Two tectonic troughs run west–east (Premru 1977). The Ljubljana Barje moor is also a young tectonic depression composed of low tectonic troughs of various orientation. The strongest prevailing direction is northeast–southwest.



Key:
1 Sava fault
2 Celje fault
3 Breg fault
4 Smlednik fault
5 Radomlje fault
6 Litija fault
7 Šentvid fault
8 Domžale fault
9 Laniški fault
10 Mengeš fault
11 Horjul fault
12 Brezovica–Vič fault
13 Trzin fault
14 Žalec fault
15 Ljubljana fault
16 Matena fault
17 Ljubljanica fault
18 Žužemberk fault

Figure 8: Schematized map of faults intersecting the wider surroundings of Ljubljana (Ribarič 1982 b).
Slika 8: Shematizirana karta prelomov, ki sekajo širšo okolico mesta Ljubljane (Ribarič 1982 b).

3.4. Survey of Stronger Earthquakes with Epicenters in the Wider Surroundings of Ljubljana

In the period since 792 A. D., there have been many strong earthquakes in the Ljubljana area. According to frequency, this area ranks among the seismically most active in Slovenia. A detailed survey has been provided by Ribarič (1982 a) in his catalogue of earthquakes. The table shows all the earthquakes in the wider Ljubljana area that reached the largest intensity $I_0 > 6.5$ degrees MSK. Regarding the data on older earthquakes, the older the estimates, the less reliable they are (Ribarič 1984).

TABLE 2: SURVEY OF STRONGER EARTHQUAKES IN LJUBLJANA AND ITS SURROUNDINGS SINCE 792 A. D. SHOWN ARE ALL EARTHQUAKES THAT REACHED EFFECTS LARGER THAN 6.7 MAGNITUDE MSK.

Date	Universal Time	Region	I_0 MSK	Richter Magnitude
792 A. D.	–	Kranjska	8	
January 985	–	Kranjska	6	
January 1000	–	Ljubljana	8	
March 26, 1081	–	Ljubljana	8	
January 1508	–	Ljubljana	7	
November 17, 1575	–	Ljubljana	7	4.7
April 22, 1590	12:30	Ljubljana	7	4.7
leto 1621	–	Ljubljana	7	4.7
May 5, 1622	11:00	Ljubljana	7–8	4.9
leto 1625	–	Kranjska	7	4.7
October 21, 1684	05:30	Ljubljana	7	4.7
December 21, 1845	20:40	Ljubljana	7–8	4.9
November 9, 1856	22:17	Ljubljana	7	4.5
July 17, 1882	07:51	Vrhnika–Rovte	7	4.8
April 14, 1895	22:17	Ljubljana	8–9	6.1
April 14, 1895	23:01	Ljubljana	7	5.1
July 15, 1897	05.57	Ljubljana	7–8	4.9
May 19, 1963	10:00	Litija–Šmartno	7	4.9

The last destructive earthquake in the Ljubljana area occurred on April 14, 1895, at 22:17 p.m. The geographical coordinates of the epicenter were 46.1° N and 14.5° E. The depth of the hypocenter was approximately 16 kilometers. In the epicentral area, the effects were between 8 and 9 degrees MSK. From the field of earthquake effects, its magnitude was estimated to be around 6.1 (Lapajne 1983 b, 1989). In the area of the Posavje folds, the earthquake shock triggered landslides. The earthquake was felt from Vienna to Split and in Italian cities of Assisi and Florence (Seidl 1985). During the night many aftershocks occurred, as is usual. Of these, the aftershock at one minute past eleven is estimated to have even reached 7 degrees MCS. In the first twelve days, 109 aftershocks were registered, and by October 1896, 200 aftershocks altogether. The ground stabilized only after four years (Kajzer 1983). This earthquake, since designated the "Ljubljana earthquake," was the strongest to occur in Slovenia in the last century. It had important and, in spite of its catastrophic effects, positive consequences. The systematic study and observation of seismic activity in Slovenia began in that period (Lapajne 1989). During the post-earthquake renewal, Ljubljana acquired a new urban image, and modern city planning began to develop (Demšar 1990). Ljubljana experienced an economic, social, and political revival, and within a few years it changed from being the capital of Carniola with German provincial appearance into a modern Slovene center (Lapajne 1989). This, of course, was not just the result of the earthquake but also of general social and economic changes.

Along with local earthquakes, buildings in Ljubljana can also be affected by stronger earthquakes from more distant seismogenic areas. Here primarily the Cerknica, Idrija, Friuli, and Villach seismic zones must be considered (Lapajne 1983 a).

In the Ljubljana area, three stronger, more distant earthquakes have had major impacts in the past:

- 1348 in Villach,
- 1511 in Idrija, and
- 1976 in Friuli (Ribarič 1984).

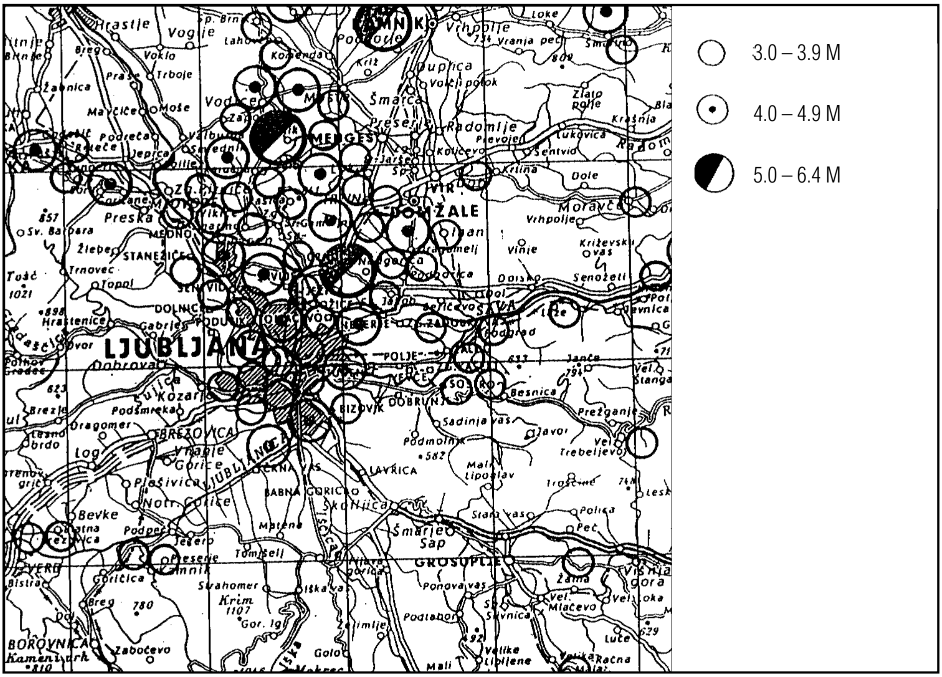


Figure 9: Magnitudes of earthquakes in the Ljubljana area since 792 A. D. (according to the Richter scale). Only earthquakes whose magnitudes exceeded 3.0 degrees on the Richter scale are shown (Ribarič 1982 b).
Slika 9: Magnitude potresov na ljubljanskem območju od leta 792 n. e. do danes (po Richterjevi lestvici). Narisani so le potresi, katerih magnituda je presegla 3.0 stopnje po Richterjevi lestvici (Ribarič 1982 b).

During the 1976 Friuli earthquake, several unstable chimneys were destroyed or badly damaged in Old Ljubljana. Less known is that smaller damage and cracks in walls were found in individual buildings (e.g., in Trnovo).

3.5. Maps of Recurrent Periods of Earthquakes for the Wider Ljubljana Area

For a better understanding of the threat to Slovenia, maps of recurrent earthquake periods have been made (Ribarič 1987). The accompanying maps are sections from maps of Slovenia published in the framework of maps of Yugoslavia (Ribarič 1987). The maps were made on the basis of numerous studies (seismological, seismogeological, seismotectonic, etc.) and show the seismic zones where seismic energy is generated. They provide an empirical basis for improving existing regulations regarding the construction of buildings in seismic areas and for the needs of the spatial and urban planning and projecting.
The value of these maps is prognostic because they show us the possibilities of recurring earthquake shocks in a defined space in the future. They have been made on the basis of epicentral zones of the earthquakes which are assessed with maximum magnitudes. From these magnitudes, maximum intensities for different areas and various recurrent periods of earthquakes were calculated according to the method of extreme values. Maximum intensities were calculated for the longest period, that is, for 10,000 years. For the construction of buildings, parameters had to be calculated and maps had be made for shorter time periods, for 50, 100, 200, 500 and 1000 years. The isoseismal lines shown on the maps were created by connecting points of equal values of individual intensity. The isoseis-

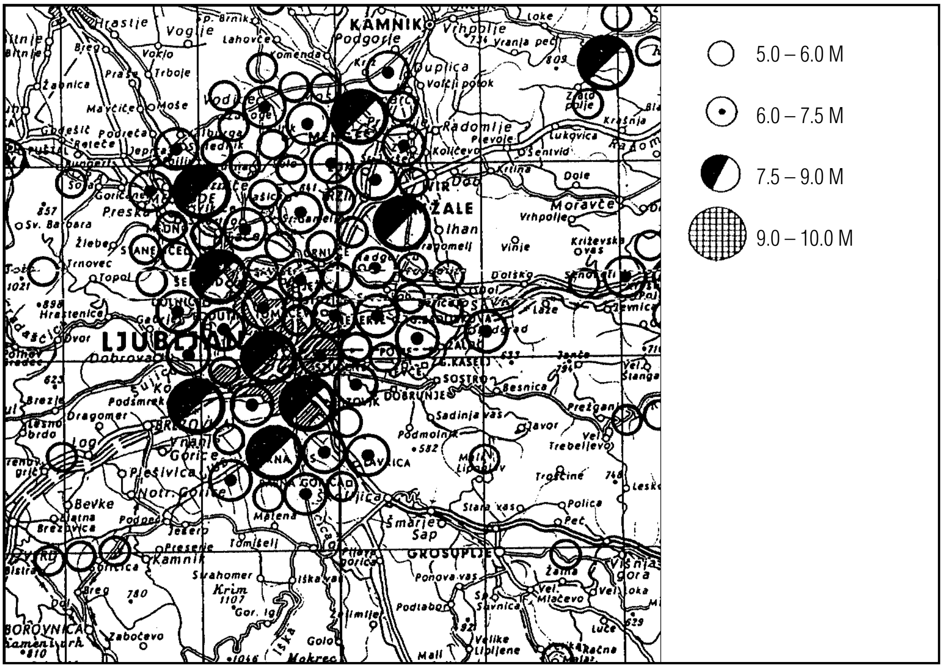


Figure 10: Intensities of earthquakes in the Ljubljana area since 792 A. D. (MSK scale). Only earthquakes whose intensity exceeded 5 degrees MSK are shown (Ribarič 1982 b).
Slika 10: Intenzitete potresov na Ljubljanskem območju od leta 792 n. e. do danes (MSK-lestvica). Narisani so le tisti potresi, katerih intenziteta je presegle 5 stopenj po MSK (Ribarič 1982 b).

mal lines delimit the areas of equal degrees of forecast earthquake intensities. Errors in isoseismal lines can be + 5 km at most. Places situated on the isoseismal lines belong among the areas of higher intensity. The probability of recurrent earthquakes in a given time period is 63% (for example, we are interested in Ljubljana). From the maps we see that there is 63% possibility that every fifty years an earthquake with a maximum intensity of 7 degrees MSK will occur, every one hundred years an earthquake with a maximum intensity of 8 degrees MSK, every two hundred years an earthquake with a maximum intensity of 8 degrees MSK, and the same for the recurrent period of five hundred years. Every one thousand years a shock can be expected in the Ljubljana area with a maximum intensity of 9 degrees MSK, and the same applies for the longest period of ten thousand years. Of course, we must perform additional studies on the seismic activity of each individual location for every intensity exceeding a magnitude of 7 degrees MSK. This must be done for all buildings ranked as category I buildings according to the regulations on the construction of high buildings in seismic zones (Official Gazette of SFRY, No. 31/81 with additions). A new augmented map that will become part of the new legislation is being prepared.

4. Earthquake Threat in Ljubljana

On the basis of the assessment of earthquake threat in Slovenia, we determined that the Ljubljana area is seismically the most endangered for two reasons:

1. according to macroseismic regionalization for a 1000-year period, this area ranks at 9 degrees MCS, and
2. its population density is above average for Slovenia and the city serves important key functions in the life of the nation.

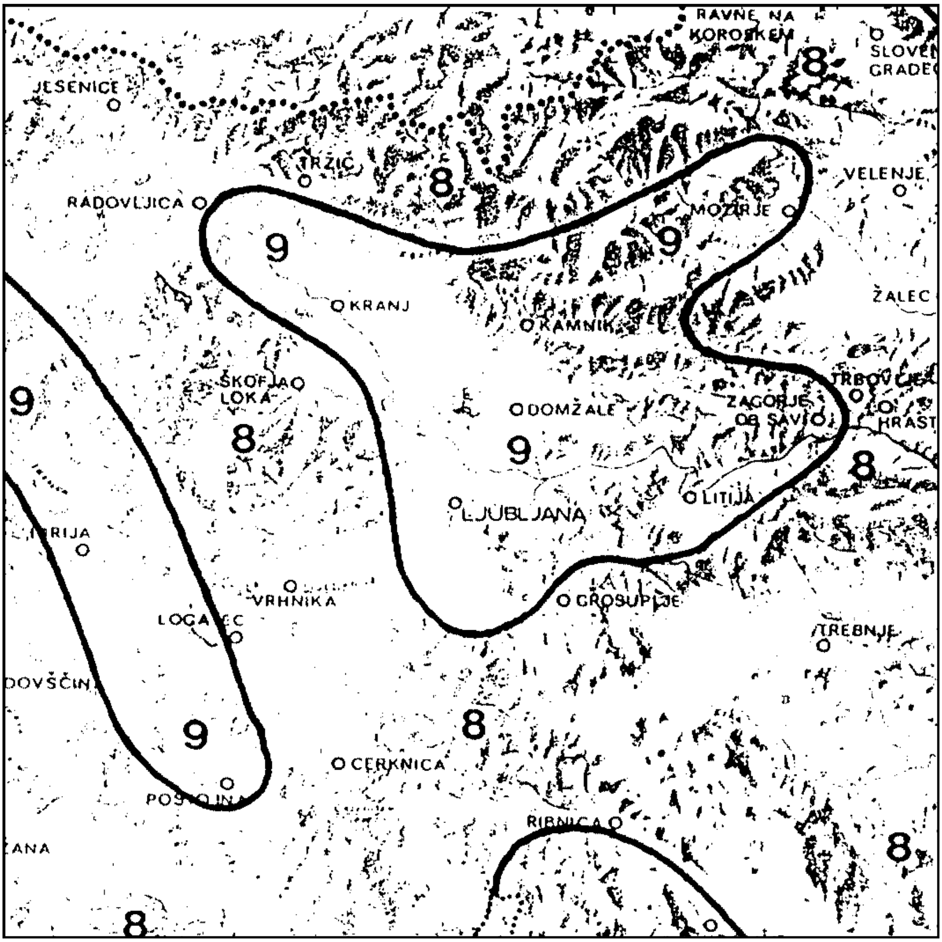


Figure 11: Seismological map of Ljubljana with its surroundings for the recurrent period of 1000 years in degrees MSK (Lapajne, Tomaževič 1990 b).
Slika 11: Seizmološka karta Ljubljane z okolico za povratno periodo 1,000 let v stopnjah MSK (Lapajne, Tomaževič 1990 b).

With this conclusion we naturally do not wish to minimize the importance of the degree of threat to other areas of Slovenia. However, we do believe that the 1976 earthquake that struck the Posočje region, a less densely populated and less developed area, would have had considerably larger consequences in the Ljubljana area. It is understandable that the impact would be different because these are two essentially different areas in the regional sense.

The earthquake threat to Ljubljana and its wider area has been long recognized, even if we mention only the 1895 earthquake and its consequences (Hoernes 1895). The long-held and indisputable assumption is that only by long-term preventive activity can we essentially mitigate the consequences of an earthquake. Years ago, this generally held belief influenced the undertaking of a very detailed study of the Ljubljana area entitled "The Earthquake Microregionalization of Ljubljana" (Ribarič 1972). This study was also one of the fundamental spatial "givens" in the draft documents for upgrading the General Urban Plan of Ljubljana (GUP, *Ljubljana 2000*, Orožen Adamič 1974 b).

The first map of microseismic regionalization was done for the central part of the city in 1972 (Ribarič). The already-mentioned wider seismic regionalization is valid for the areas outside this map. Later this map was augmented, and the last version was made to be used by the civil defense authorities (Lapajne, Tomaževič 1991 b). According to these maps, the northern part of the city is mostly in the area of 8 degrees MCS while the southern part is in the area of 9 degrees MCS. The map of microseismic regions of Ljubljana is a practical synthesis of numerous studies and shows the central part of Ljubljana divided into six different areas:

1. 8 degrees MCS – good ground with a seismic coefficient of $K_c = 0.04$
2. 8 degrees MCS – fair ground with a seismic coefficient of $K_c = 0.05$
3. 8 degrees MCS – poor ground with a seismic coefficient of $K_c = 0.06$.

Certain city areas, e.g., most of the area of the Ljubljana Barje moor, the area of the confluence of the Ljubljanica and Sava rivers, and part of the marshy area behind Rožnik Hill near Podutik have been assigned 9 degrees MCS:

4. 9 degrees MCS – good ground with a seismic coefficient of $K_c = 0.08$
5. 9 degrees MCS – fair ground with a seismic coefficient of $K_c = 0.1$
6. 9 degrees MCS – poor ground with a seismic coefficient of $K_c = 0.11$ (0.12).

The last category is limited to the markedly poor ground of the Ljubljana Barje moor with its high ground water level and other characteristics which are distinctively vulnerable to earthquakes.
Most probable effects of up to 8 degrees MCS are forecast for the Pleistocene gravel detritus and conglomerate of the Ljubljana plain, while 7 degrees MCS appears (on older versions of the map) only for Golovec, the Ljubljana Castle Hill, and Šišenski hrib where flint sandstone and clay slate dominate in the bedrock (in the newest version of the map, these areas are assigned 8 degrees MCS). The Ljubljana Barje moor and the marshy, clayey narrow pass between the Polhov gradec Dolomites and Šišenski hrib have been assigned 9 degrees MCS.
Given numerous practical examples, the conviction has developed that only "earthquake-safe" construction could guarantee relative safety, and everywhere in the world considerable attention has been paid to this technical construction problem (Mizuno 1985).
In Ljubljana we have some degree of experience. After the 1895 earthquake, a special technical construction rule book was adopted that was followed relatively consistently. Following the 1963 Skopje earthquake, the *Rule Book of Provisional Technical Regulations for Construction in Seismic Areas* was issued (1964). This was augmented several times, and norms were established in 1981 and augmented in 1982. The *Rule Book* ranks high buildings into several categories, from buildings outside categories to category 4 buildings which are temporary buildings whose destruction cannot endanger human lives. Depending on the type of building planned, it is assigned a category and must be planned and built according to detailed specific standards. This applies to new buildings, while attempts should be made to strengthen old ones in accordance with the norms in the event of renovation or reconstruction. This is a long-term and expensive process (Lapajne, Tomaževič 1991 b).

4.1. Assessment of Earthquake Threat in Ljubljana

The first attempt to assess earthquake capacities in Ljubljana was made during the upgrading of the General Urban Plan of Ljubljana in the years 1973–1974. Later this study was supplemented and partly quantitatively verified by Klemenčič (1986).
This data differs from ours given for the whole of Slovenia because this is a much more detailed analysis and the data on population is from a different time period. It is evident, however, that only the two distinctly different areas of 8 and 9 degrees MCS are considered priority for Ljubljana. These are two highest degrees of seismic threat and we can expect destructive consequences in the event of either. Each of these two degrees is further divided into three sub-degrees, marked as good, fair, bad ground. The difference between the more endangered central and southern parts of the city and the "safer" northern part of the city is apparent.
Ljubljana at the time (1986) was divided into five administrative political units (districts), and Klemenčič suggested that the practical organization of the work be divided according to districts. A fact in favour of that was that the entire range of data was gathered basically on the district level and that active city planning and action would be most suitably organized this way. Within each individual district, in the first phase it was necessary to concentrate on the most threatened areas which is already seen

in detail from the then microseismic regionalization of the city. All the city areas outside this regionalization would be studied in the later phases of the research and planning. Regarding the consequences of earthquakes, we are most shocked by the loss of human lives, and material damage comes only second, and therefore we must focus our preventive activity on buildings or areas in which the greatest number of people are concentrated.

According to census data on population and dwellings, there were 34,783 dwellings in Ljubljana in 1981. Of these still in use today, 22.59% were built before 1918, 15.41% in the period between the two World Wars (1919–1945), 37.19% between 1946 and 1970, and only 22.2% after 1971. The numbers show that we have many older dwellings in Ljubljana whose technical construction relative to anti-earthquake quality we can assume is questionable.

In the framework of the construction of dwellings we make a rough distinction between the "collective" and "individual" housing according to the density of the use of the ground and the number of residents. The fact that in collective housing the density of population per building unit or area is three to five times larger than in individual housing is reflected in a tendency to emphasize collective housing in the research (Orožen, Adamič 1974 a).

The time people spend in particular types of buildings is important. It is typical for dwellings to be occupied by many people during the night, while in the morning when people leave for work, schools fill up, etc., the number drops steeply. Dwellings, however, are never quite empty. After two, three and five p.m., dwellings start to fill up again until around eight or ten p.m. when the number of night residents is reached. A considerable amount of the time people spend in dwellings varies with the seasons, length of day, etc. We have no such detailed figures for all these factors applicable to Ljubljana.

In the 1963 Skopje earthquake, which occurred early in the morning, the majority of victims lost their lives in destroyed collective dwellings, i. e., apartment blocks.

TABLE 3: AREA AND POPULATION ACCORDING TO INDIVIDUAL MICROSEISMIC AREAS OF LJUBLJANA (KLEMENČIČ 1986).

MCS area	area in hectares	area in %	population	population in %
8/1	10,562	37	43,527	13.9
8/2	7,555	26	145,662	46.8
8/3	4,491	16	98,764	31.8
8 together	22,608	79	287,953	92.5
9/1	360	1	–	–
9/2	2,617	9	19,322	6.1
9/3	3,122	11	4,544	1.4
9 together	6,099	21	23,866	0.5
total	28,707	100	311,819	100

(1985 population figures)

It is typical of work places that they fill quickly in the morning with the arrival of people for work (between six and nine a.m.), and they tend to empty just as quickly at the end of the working day. For Slovenia and Ljubljana, this pattern is typical for a very large proportion of the working population. Therefore, special attention should be paid to this phenomenon. The seismic quality of schools, kindergartens, and other educational institutions in particular must be examined.

Typical of the widest variety of public buildings are the extremely different time periods when large numbers of people are present. In hospitals, these oscillations are considerably smaller than, for example, in cinemas, supermarkets, etc. It is typical of certain public buildings to have an extremely high number of people in a small place for a relatively short time.

We could enumerate a whole set of these and similar findings. Gradually, the view was established by 1986 (Klemenčič) that we should start from the above described assumptions for the detailed analysis of the earthquake threat to Ljubljana.

Studies oriented toward prevention should be carried out on two parallel levels. First we should catalogue buildings in which a large number of people spend time and the amount of time spent there

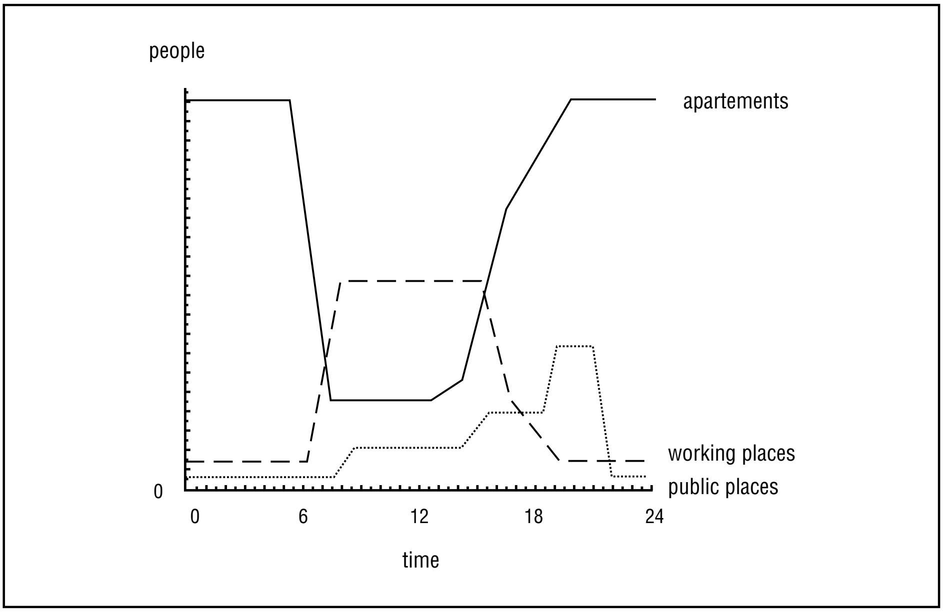


Figure 12: Assessment of locations people are concentrated according to type of building and time of earthquake (Orožen Adamič 1991).
Slika 12: Ocena zadrževanja števila ljudi glede na tip objekta in uro potresa (Orožen Adamič 1991).

and examine the technical construction elements of the buildings on the basis of this data individually. If these buildings should prove technically inadequate in construction, they should be ranked among priority buildings for investment in preventive improvements. This should be the task of detailed microseismic and technical construction examinations of concrete buildings which should become long-term and continuous. This analysis is especially urgent for older buildings erected before the Skopje earthquake. This job has been undertaken by the Institute for Research of Material and Constructions in cooperation with others. Then we should work out a new detailed microseismic regionalization and analysis of earthquake capacities in Ljubljana. A detailed microseismic regionalization and a report on the technical construction studies performed so far were made in 1991 (Lapajne, Tomaževič 1991 a, b). Through long-term and well led preventive activity we could essentially reduce the potential threat and number of victims of an eventual catastrophic earthquake. This is an expensive and long-term process, especially for the improvement of old buildings, and therefore not much has been done in this regard in Ljubljana.

4.2. Method of Work

One of the main aims of our study was to ascertain the capacities in earthquake threatened areas. As we are interested in actual earthquake threats, we want to determine specific minimum, maximum, and average earthquake magnitudes and several other important facts regarding individual parts of the city. Until January 31, 1994, Ljubljana was divided into five districts which today are united in just one joint municiplaity. These districts were divided into a larger number of smaller territorial units or local communities, and even smaller territorial units of streets, buildings, and apartment. At first, we set out to study the problem at the level of local communities, the smallest administrative unit. In the area of the city studied there are 101 local communities. However, it soon became obvious that such a classical approach to geographical research of Ljubljana and its earthquake threat was not accurate enough and inappropriate. We therefore decided to analyse the city on the level of each individual house or even individual apartment unit. This was made possible by the 1991 cen-

sus of the population and dwellings when the geographical coordinates were determined for each dwelling, a centroid for the dwelling with a degree of accuracy within one meter.
For greater clarity the results of our study are in the form of synoptic tables and on thematic maps worked out to a degree of accuracy of 0.25 hectares, that is, to an area of 50 × 50 meters. This form of work was also dictated by the Geographical Information System employed (IDRISI) which is based on rastered graphics. Our primary aim was to discover and assess the earthquake threat to individual parts of Ljubljana by covering certain "capacities" of the city and individual earthquake degrees as described below and to establish what individual areas of microseismic regionalization in Ljubljana actually signify. The basic concepts of this method were applied to city planning for the first time in 1972 (Orožen Adamič, Berdajs 1972). In this study we used the Geographical Information System and a computerized data base that contains graphic information on the one hand and textual and quantitative-numerical information on the other (Perko 1991 c).
The relationships between individual elements of the city (landscape) and the map of earthquake threat are the primary subject-matter of our study. In this way, earthquake threat or the possible effects of an earthquake are closely linked with certain elements (more with some and less with others) of the landscape. Relief, relatively unchangeable in comparison with other factors, together with its elements (inclination, height above sea level, dissection, etc.) often plays a decisive role in the formation and exterior appearance of a landscape (especially in Slovenia with its extremely diverse relief) as well as in the occurrence, course, and consequences of certain natural disasters.
To ascertain the significance of relief for individual types of natural disasters, we can use the digital relief model (DRM), which can be used as a constituent element (layer) of Geographical Information System, to perform an accurate and versatile examination of natural disasters (Perko 1991 a).
Our studies of Ljubljana are based on the detailed map of the microseismic regionalization of Ljubljana published in the paper "Danger From Earthquake in Ljubljana II" (Lapajne, Tomaževič 1991 a). This paper provides three maps of earthquakes for the recurrent periods of 50, 500, and 1000 years. The outlines of the maps are identical, and the values presented are recorded in the table for individual areas on each map (of different recurrent periods).

TABLE 4: EARTHQUAKE DEGREES IN MAPS OF EARTHQUAKE MICROREGIONALIZATION.

Earthquakes for a recurrent period	Earthquake areas				
50 years	7/1	7/2	7/3	8/2	8/3
500 years	8/1	8/2	8/3	9/2	9/3
1000 years	9/1	9/2	9/3	10/2	10/3

In the continuation of the study we named individual seismic areas according to the markings on the map for the 500-year recurrent period. For the second cartographic basis, by means of which we did the primary analysis of capacities – the land use – in individual earthquake areas, we took a 1 : 20,000 scale map of Ljubljana that was made on the basis of generalizing the 1 : 5,000 scale map which is a detailed map of the city (Geodetic Institute 1991). Because of printing and other limitations, the area of this second map is 778 × 565 mm (which is approximately A_1 format). In size it is somewhat smaller than the first, but it still encompasses all the essential parts of the city, and we therefore limited the extent of our study to the extent of this map. In the first phase we transferred the boundaries of earthquake areas from the first to the second map.
Because the extent of the second map is slightly smaller and the starting point of our information system limited to the extent of this second map, some marginal and less important areas of the city with 7/3 degrees MCS were omitted.

4.2.1. Digital Relief Model

The digital relief model (DRM) is a set of points on the earth's surface identified by three space coordinates (geographical longitude, latitude, and height above sea level) in the form of matrix fields stored in the computer media (magnetic band). For Slovenia, two digital relief models are available: the 500-

meter (DRM 500) and 100-meter (DRM 100) models (Perko 1991 a). In the framework of the functions of the Social Planning Institute of the Republic of Slovenia, the digital relief model with a regular (square) grid of 500 meters was made in the 1980's (Social Planning Institute of Slovenia 1978). Each 1 km × 1 km unit within the 10 km × 10 km sections and 100 km × 100 km regions was divided into basic 500 m × 500 m planes (hence the contraction “DRM 500”) where the coordinates of the corners were determined by the Gauss-Krüger system and the height above sea level was taken from 1 : 25,000 scale topographical maps. The reliability of the heights is calculated mathematically with possible errors of 0.5 to 5.5 meters up or down for surfaces with inclines from 0 to 45 degrees (Lipej 1991). The DRM 100 was determined for a square grid of hectares. Each 1 km × 1 km unit in the framework of 100 km^2 sections and 10,000 km^2 regions was divided into primary planes of 100 m × 100 m (1 hectare) and the three determined parameters for corner points on the basis of the basic 1 : 5,000 or 1 : 10,000 scale topographical maps. The reliability of the height above sea level of this digital model is calculated mathematically with possible errors of 0.3 to 1.5 meters up or down (National Geodetic Administration 1991, Gabrovec 1990).

To solve concrete problems in the city where the primary unit of threat is a building or land with an building on it, even the DRM 100 is not accurate enough. In studying the general characteristics of larger areas (for example, Slovenia) where primary unit of threat is a settlement, the 500 m digital relief model (DRM 500) is suitable.

Then followed the phase of specific elaboration of the 100 m × 100 m digital relief model provided by the National Geodetic Administration (1989) which is the basis of our computer information system. The dimensions of the 1 : 20,000 scale map are 156 (x – columns) × 118 (y – lines). Each cell in the grid is 100 × 100 meters or an area of 1 hectare and there are a total of 18,408 grid cells or hectares. Because in our case we are dealing with a relatively detailed study of the area of Ljubljana, we decided on a more precise, four times more detailed grid. We mathematically interpolated the 100 m × 100 m grid into a four times more detailed grid of 50 m × 50 m. This is the basic grid used by our Geographical Information System. A unit of one cell covers or represents 0.25 hectare. The studied area or size of the map (grid) of our information system contains 73,085 cells the size of 0.25 hectare. Along the × axis are 311 cells or 15.55 km and along the y axis 235 cells or 11.75 km. The area of our information system is thus 73,085 × 0.25 = 18,271.25 hectares. This equals 182.7125 km^2 or 0.9% of the territory of Slovenia.

Banovec and Lesar (1975) already pointed to the possibility of using a digital relief model, and many researchers have used it in Slovenia in the field of geography. Perko (1991) pointed out that a digital relief model could be an important basis of the Geographical Information System. The initial use of this technology reaches far back into the past when we performed the first manual experiments (with modest computer support) in 1972 (Orožen Adamič, Berdajs 1972). At the time we solved a problem in city planning of Ljubljana, in spite of the lack of computers, with a special method of applying data from the population census for allocations of densities in detailed space planning (Orožen Adamič, Kreitmajer 1973). For the needs of upgrading of General Urban Plan of Ljubljana, a special 1 : 10,000 scale map was formulated with the 100-meter Gauss–Krüger grid coordinates drawn on it that pointed to the possibility of the elaboration we undertook for the present task. We used this map, which was based on 1 : 5000 scale maps (reduced), to great advantage for certain verifications of our information system. Today, there is no doubt that for geographers and others who deal with spatial problems the digital relief model is an important technical and methodological tool for studying diverse landscape relationships, and in the majority of cases, it forms the basic layer of all geographical information systems.

At the Anton Melik Institute of Geography of ZRC SAZU, research work under the heading of “Geographical Information Systems” is in progress to resolve methodological and content issues and to perform some useful studies with the help of IDRISI, a new Geographical Information System software packet. In contrast to other research in Slovenia which aims to establish basic data bases for all of Slovenia (Perko 1991 b), in this case we decided on the reverse path, to condense information. We therefore mathematically condensed the basic 100 m × 100 m digital relief model to a 50 m × 50 m digital relief model. In his analysis of vineyards in Slovenske gorice, Žiberna (1992) used a 50 m × 50 m digital relief model, but such a detailed digital relief model has never been used before in Slovenia for such a large and urban area. Our Geographical Information System is based on the

standard of the Gauss–Krüger grid (as are many such systems, Branderberger 1988) or the kilometer coordinate system in the following framework:
On the figure above, the coordinates of the Gauss–Krüger grid are drawn to 1 meter exactness, the first number indicating the coordinates on the × axis and the second on the y axis. Our grid system of 0.25 hectare cells has the following coordinates: on the × axis from 0 to 311 and on the y axis from 0 to 235. Due to systemic reasons of data processing, we transferred the defined coordinate system marked in the figure above with the extreme points to our coordinate system on the 1 : 25,000 scale map, according to individual cells of the studied area.

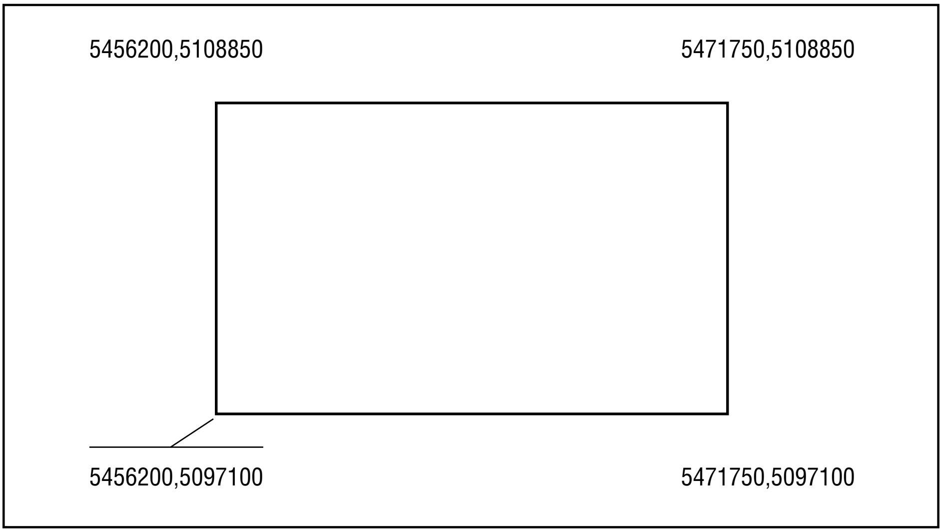


Figure 13: Framework of the specific area studied and the Geographical Information System.
Slika 13: Okvir ožjega obravnavanega območja in GIS-a.

This was followed by a phase of detailed gathering of a whole set of data, mostly by means of digitalization, and a phase of forming data collections in the Geographical Information System. In the process, we used several computer programs: STEVE (word processor, data base, graphics), AUTOCAD (digitalization), ROOTS (digitalization), DESIGN CAD (digitalization, conversion of data), IDRISI 4 (geographical information system), QUATRO PRO 4.0 (data base) and the widest variety of other software for the conversion of formats, arrangement and analysis of pictures, analysis of spatial data, etc. Equipment used in our work included an Atari computer (4 Mb), two IBM compatible 486 computers, an A_0 format digitalizer, and the Micro VAX III computer.

4.3. Survey of the Basic Data of the Geographical Information System

In this phase of work on our Geographical Information System, we gathered a set of data for the area of Ljubljana studied. The digital relief model was prepared with the help of data extracted from the National Geodetic Administration (1991). Most of the remaining data on the area was taken from our own digitalization of the basic cartographic sources (Geodetic Institute 1991). The basic data or layers were transformed into special thematic tables in the continuation of the study. In this way, for example, we analyzed all the relief inclinations according to individual classes, and from individual basic information we got whole set of auxiliary, graphic, or alphanumeric information that is not specifically cited in the survey below.

Survey of basic layers:
- 100 m × 100 m digital relief model,
- interpolated 50 m × 50 m digital relief model,
- 10 m height belts,
- 25 m height belts,
- 50 m height belts,
- inclinations of the terrain,
- hydrographic network,
- earthquake zones,
- administrative divisions by districts,
- administrative divisions by local communities,
- built-up areas,
- residential areas,
- industrial areas,
- areas intended for schools,
- areas intended for sport and recreation,
- sacral buildings and areas,
- green areas (forest),
- park areas,
- railroads,
- existing expressways,
- planned expressways.

To establish the boundaries of administrative divisions we used vector data from the ROTE register (Lipej 1991) provided by the National Geodetic Administration (1992). However, we were unable to use the centroids of settlements (National Geodetic Administration 1991) as our study is on a very detailed level (buildings) and their data is too rough.

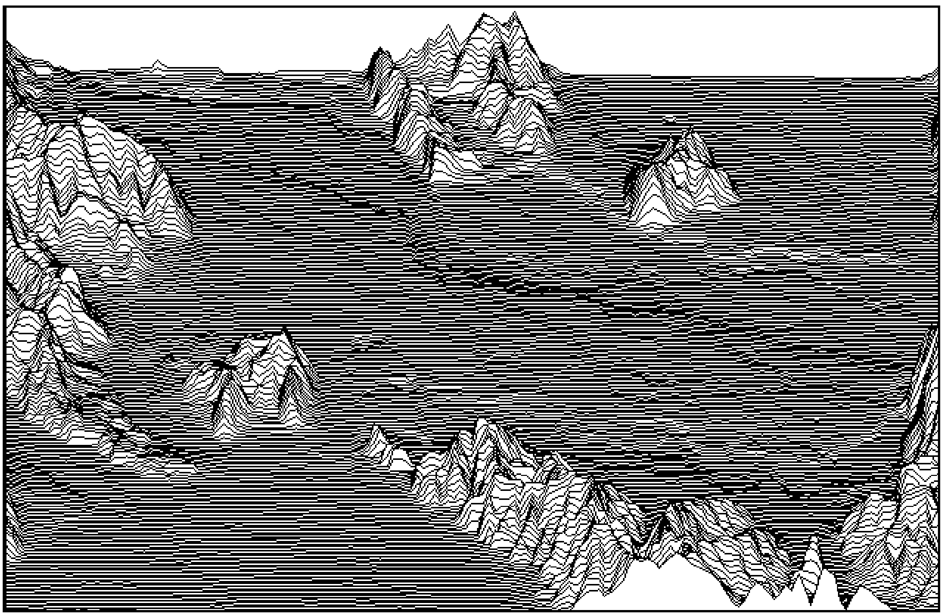


Figure 14: Orthographic view of Ljubljana and its surroundings – 50 m × 50 m digital relief model (interpolation from DRM 100, view from the south, 50 degrees above the horizon). The diversity of the studied area, its relief, is clearly evident (Ljubljana Castle Hill, Golovec, Rožnik, the Sava terraces, and the surrounding hills). The heights are deliberately presented somewhat exaggerated.
Slika 14: Perspektivni pogled na Ljubljano z okolico – digitalni model reliefa 50 m × 50 m (interpolacija iz DMR 100, pogled z juga, 50° nad obzorjem). Lepo je vidna razgibanost obravnavanega območja – reliefa (Grad, Golovec, Rožnik, savske terase in okoliško gričevje). Višine so namerno prikazane nekoliko povečane.

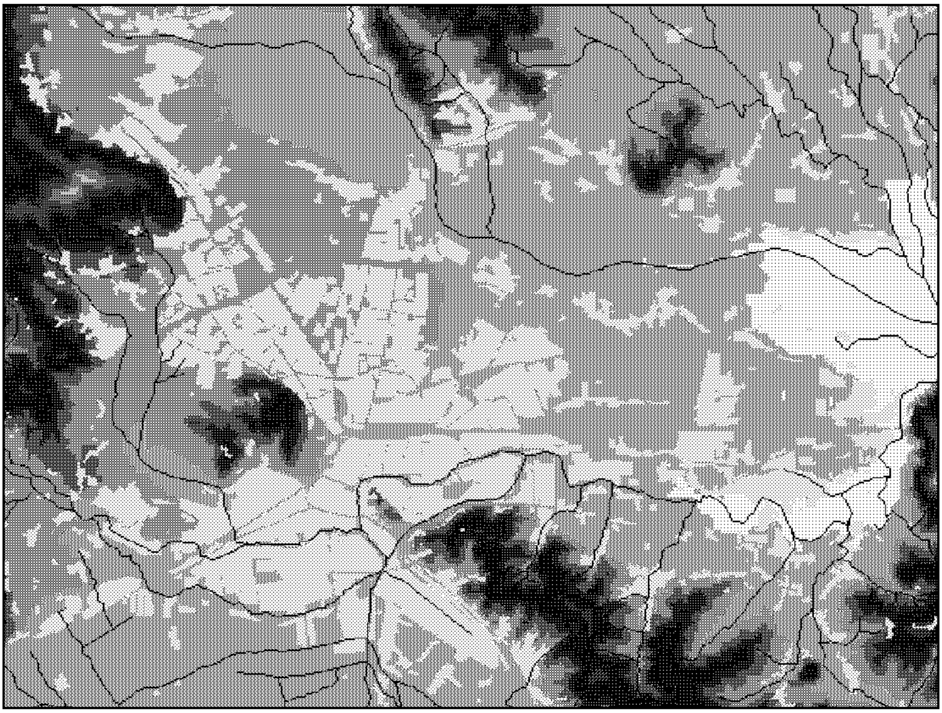


Figure 15: An example of a map from our Geographical Information System. The dark shades indicate 25-meter height belts, light shades indicate built-up areas, and the hydrographic network has been added. Together, the three layers show the 25-meter height belts, the built-up areas, and the hydrographic network. In the Geographical Information System data base each layer is, of course, archived individually, and we have the possibility of combining them as we please and of performing statistical spatial calculations.
Slika 15: Primer karte iz našega geografskega informacijskega sistema. S temnimi odtenki so odtisnjeni 25 metrski višinski pasovi, v svetlem odtenku so pozidane površine, dodana pa je tudi *hidrografska mreža. Skupaj so prikazane tri plasti: 25-metrski višinski pasovi, pozidane površine in hidrografska mreža. V podatkovni bazi GIS-a imamo seveda arhivirano vsako plast posebej in imamo možnost, da jih med seboj poljubno kombiniramo ali izvajamo prostorske statistične izračune.

It is evident from this map that we have 9 areas of the lowest degree MCS, 8/1, in our study area. These mainly include the marginal hills, and only one extends into the central area of the Ljubljana plain. These are the safest and least earthquake threatened areas. A large part of the Ljubljana plain lies in the 8/2 degrees MCS area, followed by only one large determined area of 8/3 degrees MCS where the ground water is on the surface or just beneath it. The transition of this area into the Ljubljana Barje moor is shown by the substantially higher 9/2 degrees MCS. Only the Ljubljana Barje moor and the swampy Podutik–Koseze areas, however, are marked by the highest 9/3 degrees MCS.
From the above figure we could determine the areas of individual earthquake zones in hectares and reciprocal proportions shown in the following table and figure.

TABLE 5: AREA AND PROPORTION OF INDIVIDUAL MCS AREAS.

MCS	hectares	%
8/1	4,989.50	27.31
8/2	5,366.75	29.37
8/3	5,748.00	31.46
9/2	776.00	4.25
9/3	1,391.00	7.61
total	18,271.25	100.00

Figure 16: Map of the microregionalization of the Ljubljana area according to MCS scale for 500 years (Lapajne, Tomaževič 1991 b), included in the area of our information system.
Slika 16: Karta mikrorajonizacije območja mesta Ljubljane po MCS lestvici za 500 let (Lapajne, Tomaževič 1991 b), vpeta v območje našega informacijskega sistema.

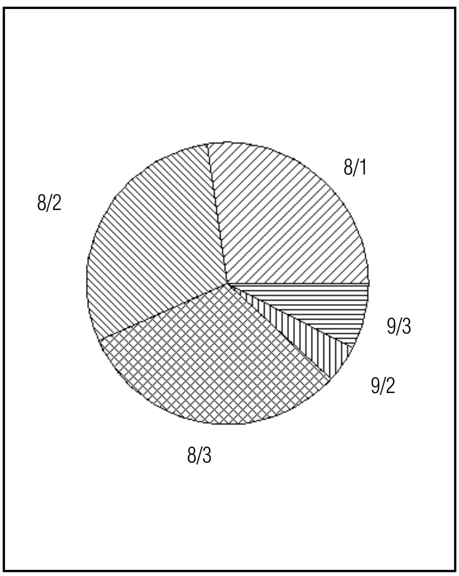


Figure 17: Proportion of area of individual seismic zones in the studied area.
Slika 17: Deleži površine posameznih seizmičnih območij na obravnavanem območju.

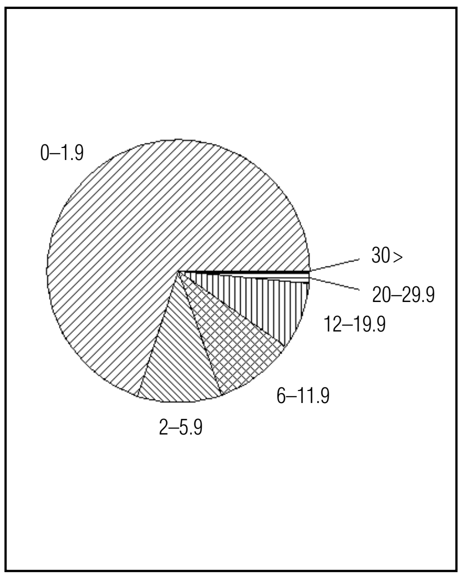


Figure 18: Proportion of classes of relief inclination in the studied area.
Slika 18: Deleži naklonskih razredov reliefa obravnavanega območja.

It is evident from the table above that zones with earthquake degrees from 8/1, 8/2, and 8/3 comprise 88.14% of the area studied and that only 11.86% of the area studied falls in zones of 9/2 and 9/3 degrees MCS. This was the first significant finding due to seismic microregionalization, since according to the basic survey map for the whole of Slovenia almost the entire Ljubljana area is ranked as 9 degrees MCS.

The highest categories of earthquake threat in Ljubljana (9/3 and 9/2) are almost exclusively limited to flatlands where the ground water is close to the surface.

TABLE 6: SURVEY OF LAND USE IN THE STUDIED AREA.

no.	land use	number of cells	hectares	%
1	built-up areas	12,178	3,044.50	16.6628
2	industrial	2,278	569.50	3.1169
3	schools	246	61.50	0.3366
4	sport facilities	203	50.75	0.2778
5	sacral areas (churches, cemeteries)	226	56.50	0.3092
6	existing expressways	863	215.75	1.1808
7	planned expressways	675	168.75	0.9236
8	railroad	918	229.50	1.2561
9	water areas	3,977	994.25	5.4416
10	other (forest, meadow, field, uncultivated)	51,521	12,880.25	70.4946
11	total communal areas (6+7+8)	2,456	614.00	3.3605
12	total built-up areas (1+2+3+4+5)	15,131	3,782.75	20.7033
13	total	73,085	18,271.25	100.0000

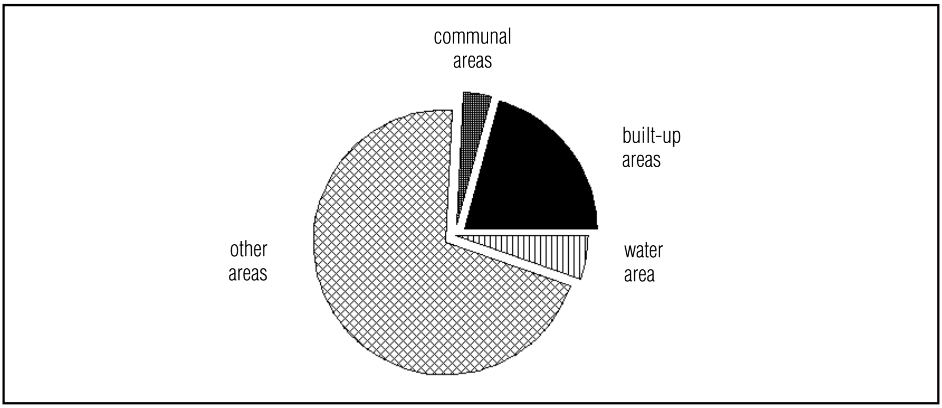


Figure 19: Proportion of land use in the studied area.
Slika 19: Deleži rabe tal na obravnavanem območju.

Predominantly residential area accounts for 16.66% of the land, while industrial areas (factories, warehouses) occupy 3.12%. Schools (mainly larger areas intended for primary and secondary schools are considered) occupy 0.34%. Relatively little area is occupied by various facilities intended for sport and recreation (0.28%). Somewhat larger areas, however, are occupied by sacral buildings, largely due to cemeteries (0.31%).

A relatively large area is occupied by the railroad and its accompanying buildings (1.26%). The same amount is occupied by existing and planned expressways.

In the studied area, built-up areas occupy 20.7% of the total. These include residential buildings, business premises, schools, sports or recreational facilities, churches, cemeteries, and other built-up areas. Communal areas occupy 3.36%, as we only to into account the areas of existing completed expressways with their direct junctions, planned expressways, and areas occupied by the railroad and its accom-

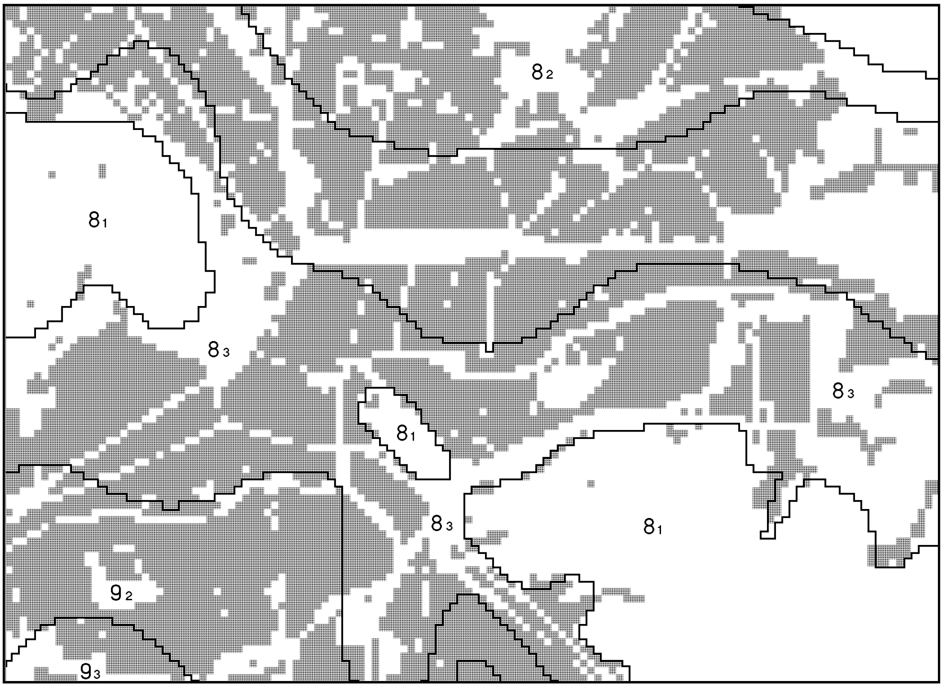


Figure 20: Microseismic earthquake regions and the built-up areas in the central part of Ljubljana. Grid units are 50 m × 50 m. This is a typical example of a map from our Geographical Information System.
Slika 20: Mikroseizmična potresna območja in pozidane površine v osrednjem delu mesta Ljubljana. Enota kvadrata – mreže je 50 m × 50 m. To je tipičen primer karte iz našega geografskega informacijskega sistema.

panying buildings. Forests, meadows, fields, and other areas threatened by earthquake to a minor degree occupy 70.49% of the area studied. Water areas such as rivers, lakes, marshes, and the like occupy 5.44% of the total area.

In this part of the study we were unable to respond to a range of details regarding dwellings, population, etc. However, we were able to establish individual elements of the city according to districts and local communities. This is not covered in this discussion as we believe that this part of the study is less interesting to the wider public. However, this part of the study already indicated the areas of largest earthquake threats that require more attention. Within these areas, similar studies should be undertaken in addition to ours, particularly a technical construction assessment of buildings of special social importance. It is reasonable that special attention (with priority on earthquake protection) be paid to schools, industrial buildings, and the like. Undoubtedly, this would be the first task, the basis for long-term preventive activities which, of course, is not a task for geography but for the official administrative services. There is relatively little built-up area, only 109.75 hectares or 2.9%, in the region of the highest degree of earthquake threat. There is considerably more built-up area, almost three times as much (11.45%), in the region of 9/2 degrees MCS. The total of Ljubljana's built-up area falling in 9 degree MCS regions is 14.35%. Within the 8 degree MCS regions, the built-up area is most dense in the 8/3 region (35.07%), somewhat smaller (34.09%) in the 8/2 degree MCS region, and substantially smaller (16.49%) in the safest 8/1 degree MCS region.

Several questions arise. Why don't we build, or why haven't we built, the greater part of Ljubljana in the 8/1 degree MCS regions? One possible answer is that these areas are the most undulating, least level and most hilly, as the tables and figures show. In addition, a large complex of the 8/1 degree MCS region in the central part of the Ljubljana plain has limited building possibilities because of the water reserve, and therefore we cannot expect to build there more intensively even in the future. Still, much could be done, and with detailed, well considered planning, the earthquake safer areas

of the city could be usefully exploited. In the United States, (e.g., in the San Francisco area), lower insurance rates apply in earthquake safer areas (Palm 1990).
The largest part of the city, almost 70%, occupies the predominantly flatland regions of 8/3 and 8/2 degrees MCS. These are mainly transitional areas with traditional cores of settlement, and the land here is the most expensive. Furthermore, most of the land here is intended for the most important central city functions, and we will not be able to avoid this in future. As a result, we must be especially concerned about earthquake safe construction.

4.4. Analysis of Earthquake Threat to Buildings and Dwellings in Ljubljana

The earthquakes in Posočje (Orožen Adamič 1983 a), Kozjansko (Turnšek 1974), and elsewhere (Orožen Adamič 1990) showed that the most difficult thing to do was to provide shelters in a very short time for the population left without safe dwellings following an earthquake. The fact is that in Slovenia we do not have an overall technical construction evaluation of the quality and seismic threat of the housing fund. Therefore, we used statistical records of the number and age of dwellings. In 1981, there were 585,780 dwellings in Slovenia. Of these, 116,255 or 19.85% were built before 1918, 61,317 or 10.47% were built between 1919 and 1945, 211,088 dwellings or 36.04% were built in the period from 1946 to 1970, and at the most only 180,947 or 30.89% were built after 1971. We have no information on the age of 16,173 or 2.76% of the dwellings. We can maintain that earthquake safer construction started to a larger extent only after the 1963 Skopje earthquake. For pre-1918 dwellings, modern building materials and construction were not much in use; a large number of these dwellings are very old and were built in the local traditional way. Such was the case in Posočje before the 1976 earthquake. During the period between the two World Wars, especially in the period of the Great Depression, construction was little better.
In the 1895 Ljubljana earthquake, numerous buildings made of brick or stone were badly damaged, but according to the available data (Stanek 1935), total physical destruction did not occur. Major damage was caused by falling chimneys, and cracks also appeared in walls and vaulted ceiling constructions, especially in those parts of the town where the structure of the ground was disadvantageous. Of 1373 damaged buildings, only 49 or some 3.5% were later demolished completely (Godec, Fajfar 1986), and some of these were demolished for city planning reasons. The remainder of the buildings were repaired, partly reconstructed, or rebuilt (Kajzer 1983). After the earthquake a law was passed demanding the suitable arrangement of walls and built-in iron fasteners in brick walls of new buildings. In this way it was possible to considerably increase the rigidity of the building to the height of the ceiling constructions (Turnšek, Terčelj, Sheppard, Tomaževič 1978).
The majority of older rural dwellings and farm buildings in Slovenia are built of stone and lime mortar. The quality of this construction is usually poorer than that of more important city buildings. The walls were normally constructed of two layers of rough or partly cut stone and the space between the two external layers filled with stony gravel, altogether with poor lime mortar. The majority of the buildings were built this way in Kozjansko where the 1974 earthquake ($l_{max} = 7.3$ MSK) caused considerable damage. In this less developed area there were many such buildings; and thus it was no coincidence that in spite of the relatively weak earthquake some 15% of all buildings surveyed were condemned for demolition since the costs of improvements and renovation were not considered economically justifiable (Turnšek 1982).
Of dwellings built in Slovenia before 1945, over 17,967 are in areas of 9 degrees MCS and 55,390 are in areas of 8 degrees MCS, altogether as many as 73,357 in 8 and 9 degree MCS areas. This represents 13.21% of the existing housing fund. There are 103,149 dwellings built between 1946 and 1970 or 17.61% in the most threatened areas of Slovenia. Dwellings built after 1970 are earthquake safer, although, of course, we cannot exclude the possibility of damage even here; while on the contrary, even some older, suitably constructed buildings might stand earthquake shocks well enough (*Rule Book of Provisional Technical Regulations for Construction in Seismic Areas* 1964).

After the earthquake in Posočje, many old buildings had to be demolished or renovated. In the Tolmin district relatively few dwellings remained that were built before 1945 (1919 or 32.59%). In the Tolmin zone only 19.33% of the dwellings had been built in the period between 1945 and 1970, the reason being the modest amount of construction activity in the period. Well above average (44.71%) is the proportion of dwellings built after 1970, a consequence of the renovation of dwellings after the earthquake. In the other areas of 9 degrees MCS, the proportion of buildings built after 1970 is considerably lower: 27.34% in the Brežice zone, 27.21% in the Idrija zone, and only 22.2% in the Ljubljana zone (Orožen Adamič 1980). In the Ljubljana zone only 37.19% of dwellings were built between 1946 and 1970, and some 38% or 13,216 dwellings were built before 1945. In an earthquake equally as strong as the one that struck Posočje in 1976, the damage would be greater because of larger capacities of the Ljubljana area.

Considerable damage to the housing fund can also be anticipated in the areas of 8 degrees MCS where there are fewer old dwellings, particularly in the largest, 8 b – Western Alpine zone (23.03% or 40,398 dwellings). All the other areas of 8 degrees MCS, with the exception of 8 d (Lower Sava–Kozjansko), are relatively smaller and so the consequences would be correspondingly smaller.

4.4.1. Territorial Units and Method of Work

For the reasons stated above, we carried out a detailed analysis of Ljubljana by individual buildings. The locations of buildings are recorded in a special register (EHIŠ) commissioned by the National Geodetic Administration of Slovenia and elaborated by the Geodetic Institute of Slovenia. Data was supplied by the National Geodetic Administration in August 1992. Because the city is a living organism, this data, like any data, demands regular updating and maintenance. In the practice of researching phenomena of Slovenia's towns and citites this data has never previously been used to such an extent. It was first used by Gabrovec in his study of the Polhov gradec Dolomites (1990).

The basis for gathering this location data is the basic 1 : 5000 scale national maps (ODK). Every building has two determined coordinates (x, y) that we transferred into the coordinate system of our Geographical Information System. In addition, each building was assigned a cipher containing data about the district, local community, street, and house number. Because of the restrictions established by the Law on the Protection of Personal Data, this information is not mentioned in the study. Thus in the following, all the results of the study are shown in various aggregated forms, that is according to individual classes or specially determined and described territorial units.

Because the frameworks of the Geographical Information System are known and precisely determined, we could transfer information from the EHIŠ register to it. This is vector point information with a range of various attributes that we drew from the basic data collection. Because the IDRISI program is a raster oriented geographical information system, a phase of transferring the vector information into raster form was required. This means that all the information was bound to uniform units of the same area across the entire studied area. This unit of 50 m × 50 m sides and area of 0.25 hectare is called a cell.

The data on buildings from the EHIŠ is exact, giving precisely defined territorial units having a specific address (district, local community, street, house number). The number of all the dwellings at this address, or other facts about dwellings, can of course be multiple, but all this information is included in this uniform territorial unit. For this study we simplified the data and analysis from the EHIŠ register and called them just buildings.

This method allows us to work out very detailed analyses, based on randomly chosen territorial units still precisely specified in the Geographical Information System. In our study these are individual MCS areas.

For planning purposes, quadrangles are also used in Ljubljana, 194 of them in the Ljubljana Center district. This is a more precise territorial unit than the local community, of which there are thirteen in the Ljubljana Center district. The bad side of the quadrangles is that like the local communities they are not uniform in area. In the Ljubljana Center district, 2,304 buildings were analyzed according to these quadrangles (Lapajne, Tomaževič 191 b). On the average, each quadrangle contains 11.88 buildings.

In simple terms, our analysis is about ten times more precise than the analysis according to quadrangles or nearly 177 times more precise than analysis according to local communities, because there are approximately 177 buildings in each local community in the Ljubljana Center district. Even more, the basic information in our analysis is based on dwellings. On average this is three times more precise a territorial unit than a building since apartment blocks in Ljubljana average slightly more than three dwellings each. This is the smallest possible, the most detailed territorial unit.

In the studied area in Ljubljana there are 31,824 buildings. Our Geographical Information System covers 95.99% of all the buildings in the city itself, while the rest of the buildings (4.01%) are in smaller settlements in the Ljubljana surroundings.

On the following maps the locations of individual buildings are clearly evident. The first shows the extent of the entire area studied with drawn locations of all the buildings. Individual buildings on the margins are clearly seen and the central, more densely built-up parts of the city are covered by numerous buildings. The map with a certain level of generalization as the actual area of buildings is not shown still shows the extent and intensity of build-up. An enlargement of a section of this map (the following figure) shows the detailed locations of individual buildings studied in the Geographical Information System, each presented as a independent territorial unit.

With suitably organized legal arrangements, software, and staff, this extremely detailed information could be usefully exploited in the event of a disaster, particularly if we consider the possibility of linking this data with EMŠO (the standard identity number of each resident of Slovenia in the population register) data. This data is organized in Slovenia and a whole range of additional information is linked to it such as tax reports that reflect the economic situation of the population, medical statistics, etc. We only wish to point out additional possibilities of the projected information system that could have very practical value, especially in larger disasters. Recently, however, misgivings regarding the encroachment of such information systems on individual privacy and security of personal information are increasingly coming to the fore in Slovenia.

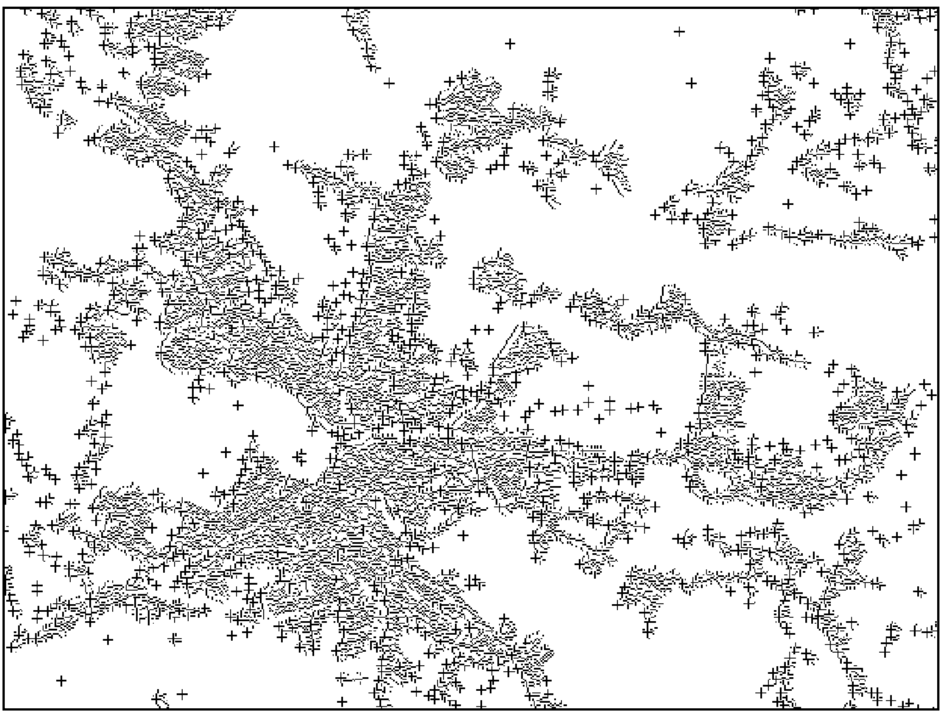


Figure 21: Buildings in the studied area.
Slika 21: Hiše na obravnavanem območju.

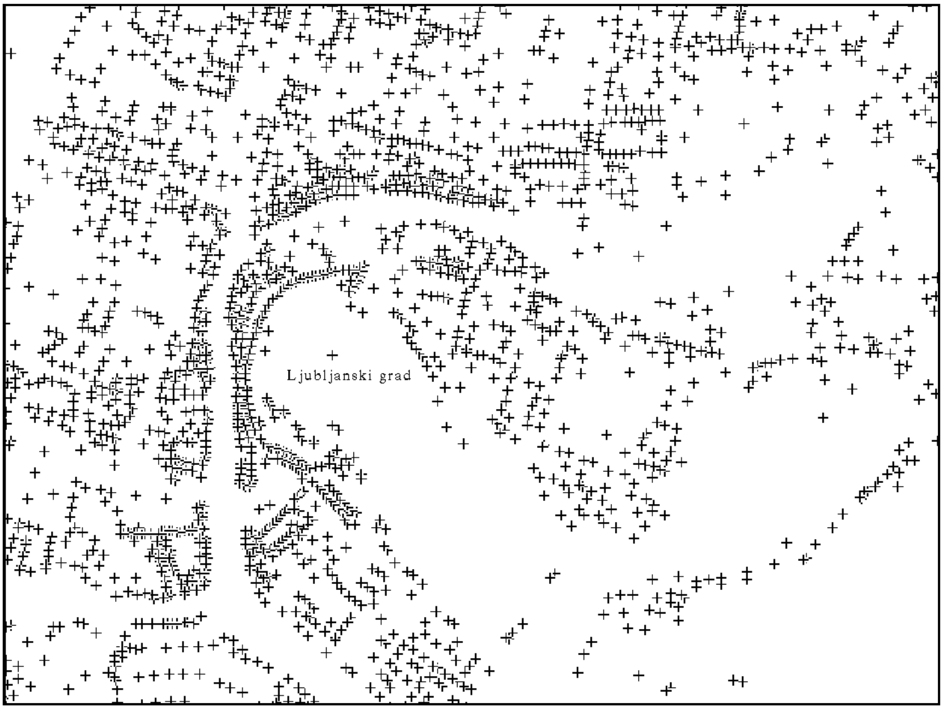


Figure 22: Enlarged section from the previous figure, locations of individual buildings clearly evident.
Slika 22: Povečava – izrez s prejšnje slike, lepo so vidne lokacije posameznih objektov.

4.4.2. Collection of Data on Dwellings

In continuing the study we decided on a detailed analysis of data from the 1991 census of dwellings and households (Statistics Office of Slovenia). In the 31,824 buildings in the studied area shown in the map, there are 95,877 dwellings. In our study we only processed basic statistical data from the Statistics Office. For this study we used only a part of the interesting information from form P-2, the questionnaire for the 1991 census of population, households, dwellings, and farm households in Slovenia. The basic data required appropriate technical processing and entering in the data base of our Geographical Information System. Each dwelling in Ljubljana has 42 items of ciphered numeric information:

1. location of dwelling, defined by coordinates.
2. information about the dwelling, household, and building contained in the questionnaire:
   1 – residence,
   2 – occupied business space,
   3 – temporarily occupied space,
3. use of dwelling:
   1 – only as residence,
   2 – for residence and work,
   3 – only for work,
   4 – temporarily vacant residence,
   5 – uninhabited (abandoned) residence,
   rest and recreation dwellings:
   6 – in a vacation house,
   7 – in a family house,

8 – in a different kind of a building,
9 – in the period of seasonal farm work.
4. Total area of dwelling in square meters.
5. Floor on which dwelling is located:
00 – ground floor,
01 – 1st floor,
02 – 2nd floor,
03, 04, 05 etc.
60 – basement,
70 – sub-ground floor,
80 – mansard,
90 – split level
6. Year of construction of building (to 1900 inclusive and then each year).
7. Material of outer walls of building:
1 – firm material,
2 – poorer material.
8. Number of surveyed households in dwelling
9. Number of surveyed persons in dwelling.

In addition to this data we also used the information described in previous chapters. In parallel with our study, we performed several analyses to clarify the geography of Ljubljana which we do not explain in detail here unless they have a direct bearing on the established aim of the study.
Among the most interesting analyses (all apply to Ljubljana in 1991):
- density of settlement,
- density of households,
- density of dwellings,
- density of area of the housing fund,
- year of construction of dwellings,
- height of buildings,

and some others.

4.4.3. Buildings

From the point data itself on the location of a building we can calculate nothing in particular if we do not have the additional information on its characteristics. The following table (7) shows that we have 31,824 buildings. The frequency distribution presented shows that 81.94% of the cells in the studied area are without buildings.
Table 7 is the result of cross comparison of data on the locations of buildings and individual earthquake (MCS) areas and shows us the number of buildings according to individual MCS areas.

TABLE 7: NUMBER OF BUILDINGS IN INDIVIDUAL MCS AREAS.

	MCS area					
	8/1	8/2	8/3	9/2	9/3	total
total buildings	4,379	10,229	12,362	3,687	1,167	31,824
%	13.76	32.14	38.84	11.59	3.67	100.0

The table above shows the number of cells located in individual MCS areas. The relationships of the actual built-on areas (floor plans) were shown in detail by a previous analyses done by the digitalization (vector input of polygons) of actual built-on areas. This table shows us the number of buildings in individual MCS areas. In Ljubljana, only 1,167 buildings or 3.67% of all buildings are situated in the most earthquake threatened (9/3) area. In the slightly less endangered area (9/2), there are 3,686 buildings or 11.59%. Altogether, 4,853 or 15.26% of the buildings are in areas of 9 degrees MCS. This is relatively few. More about these buildings follows in the detailed analysis below.
The remaining 84.74% of the buildings (26,971) are in areas of 8 degrees MCS.

4.4.4. Dwellings

Buildings are, of course, intended for the most diverse uses. Most of them are residential buildings, and we therefore decided to study these in detail in the continuing research. From the experience of the consequences of the 1976 Posočje earthquake, we know that in the first phase after an earthquake the greatest problem is how to ensure safe shelter for the stricken population. Reliable data on the intended use of non-residential buildings does not exist. A survey of the data showed that non-residential buildings have extremely diverse parameters that changed rapidly in recent times due to the major social and economic changes. A complete data processing would be necessary for each individual building, and therefore we did not use them in this study.

According to official data from the 1991 census of population and dwellings, the Ljubljana Center district had a population of 28,351. Our data on the number of residents was taken from the basic sources of the census of dwellings and according to this, there were 29,504 residents in the Ljubljana Center district. The index is 104.07, the difference small and still within the limits of statistical reliability. The reason for the difference is in the methodological basis for drawing the data and in its final analysis.

Because 95.99% of the buildings of our area are within the City of Ljubljana, we can state that 264,815 residents live in it. According to official census data, Ljubljana had 267,003 residents in 1991, which is 2,188 or 0.83% more. The difference is minimal. Our study treats the entire extent of the city and some surrounding settlements or parts of these settlements in which 11,060 people lived in 1991.

The darker areas in the figure show the concentration of dwellings. Differences between individual parts of the city where multi-story block construction prevails are clearly evident. From the histogram of the number of dwellings according to cells, the distribution of the number of dwellings is evident.

Figure 23: Illustration of density of dwellings in Ljubljana.
Slika 23: Prikaz gostote stanovanj v Ljubljani.

This map is an example of one "side product" of our Geographical Information System and is the first map to show the density of dwellings in Ljubljana.

TABLE 8: BUILDINGS, APARTMENTS, RESIDENTS, AND HOUSEHOLDS BY INDIVIDUAL MCS AREAS.

MCS area	no. of buildings	%	no. of dwellings	%	average no. of apartments per building	no. of residents	%	no. of households	%
8/1	4,379	13.760	15,686	16.361	3.58	44,326	16.07	16,088	16.33
8/2	10,229	32.142	32,468	33.864	3.17	94,673	34.32	33,600	34.11
8/3	12,362	38.845	37,283	38.886	3.16	106,715	38.68	38,235	38.82
9/2	3,687	11.586	9,140	9.533	2.48	25,858	9.37	9,251	9.39
9/3	1,167	3.667	1,300	1.356	1.11	4,306	1.56	1,330	1.35
total	31,824	100.00	95,877	100.00	3.01	275,878	100.00	98,504	100.00

4.4.5. Dwellings According to MCS Areas and Inclinations of the Ground

The larger the inclination the larger the height shown in the figure. The terraces along the Sava and the Ljubljanica are clearly evident.
Table 9 shows that in Ljubljana 88.96% of dwellings are in the lowest inclination class, that is, in areas with inclinations up to and including 1.9 degrees.

TABLE 9: DWELLINGS ACCORDING TO INDIVIDUAL INCLINATION CLASSES IN DEGREES.

inclination class	no. of dwellings	%
0–1.9	85,288	88.96
2–5.9	6,989	7.29
6–11.9	2,053	2.14
12–19.9	1,431	1.49
20–29.9	108	0.11
30–44.9	8	0.01
total	95,877	100.00

Through cross analysis of the map of earthquake areas and the inclinations of the terrain, we made a map that we gave the working name "earthquake – inclination." It illustrates that in Ljubljana we have 23 of the 30 possible combinations (classes) that are seen in detail in Table 10. This table has more detail than Table 9, showing the number of dwellings according to individual inclination classes and according to individual MCS areas. It is evident from this table that we have only a very small number of dwellings in the studied areas on larger inclinations of terrain and with higher degrees MCS. There are only 43 dwellings in the 2 to 5.9 degree inclination class in the 9 degree MCS areas. The table further shows the proportion of dwellings according to individual classes. We can state that we do not anticipate much damage in an earthquake due to additional landslides because there are relatively few dwellings in Ljubljana in areas of such threat. Here we must especially stress that inclination is just one of the important factors in dealing with problems with the liquefaction of soil during an earthquake (Ribarič 1984). More detailed geological and technical construction studies are necessary, but our study can point to these areas.

4.4.6. Population

We made an analysis of settlement in the studied area according to the already described method. In the first part, the number of people in dwellings is shown. In the second, we established the density of settling according to cells with the help of which we could ascertain the number of residents in individual MCS areas and the distribution of settling per hectare.

TABLE 10: EARTHQUAKE AREAS, INCLINATIONS OF THE TERRAIN (IN DEGREES), AND DWELLINGS.

class	MCS area	inclination of terrain	area in hectares	%	no. of dwellings	%
1.	8/1	0–1.9	1,723.50	9.43	14,599	15.23
2.	8/2	0–1.9	4,446.25	24.33	29,123	30.38
3.	8/3	0–1.9	4,469.25	24.45	31,169	32.51
4.	9/2	0–1.9	771.50	4.22	9,139	9.53
5.	9/3	0–1.9	1,367.50	7.48	1,258	1.31
6.	8/1	2–5.9	596.75	3.27	472	0.49
7.	8/2	2–5.9	513.00	2.81	2,874	3.00
8.	8/3	2–5.9	767.25	4.20	3,600	3.75
9.	9/2	2–5.9	4.25	0.02	1	0.00
10	9/3	2–5.9	20.75	0.11	42	0.04
11.	8/1	6–11.9	1,263.00	6.91	278	0.29
12.	8/2	6–11.9	227.75	1.25	405	0.42
13.	8/3	6–11.9	314.00	1.72	1,370	1.43
14.	9/3	6–11.9	2.75	0.01	0	0.00
15.	8/1	12–19.9	1,187.75	6.50	298	0.31
16.	8/2	12–19.9	159.00	0.87	66	0.07
17.	8/3	12–19.9	160.25	0.88	1,067	1.11
18.	8/1	20–29.9	202.50	1.11	36	0.04
19.	8/2	20–29.9	20.50	0.11	0	0.00
20.	8/3	20–29.9	34.25	0.19	72	0.08
21.	8/1	30–44.9	16.25	0.09	3	0.00
22.	8/2	30–44.9	0.25	0.001	0	0.00
23.	8/3	30–44.9	3.00	0.02	5	0.01
total			18,271.25	100.00	95,877	99.99

TABLE 11: DISTRIBUTION OF SETTLING PER 1 HECTARE.

*	class	cells	hectares	%	% of density
	0	61,236	15,300.00	83.79	–
1	1–9.9	803	200.75	1.10	6.78
2	10–19.9	1,631	407.75	2.23	13.76
3	20–49.9	4,447	111.75	6.08	37.53
4	50–99.9	2,575	643.75	3.52	1.73
5	100–199.9	1,139	284.75	1.56	9.61
6	200–499.9	865	216.25	1.18	7.30
7	500–999.9	302	75.5	0.41	2.55
8	1000–1999.9	79	19.75	0.11	0.67
	2000 >	8	2.00	0.01	0.07
	total	73,085	18,271.25	99.99	–
	settled	11,849	16.20	100.00	

* individual classes shown in Table 11 are also shown in Figure 25. In the 8th class we also included densities above 2000 residents/hectare.

The analysis above shows the concentration of settlement in Ljubljana. From the table above and Figure 25 it can be seen that a density of population between 20 and 49.9 residents/hectare (37.76%) prevails in Ljubljana. A density of settling between 50 and 99.99 residents/hectare (21.73%) follows, and in the rest of the classes densities are below 20 or 10 residents/hectare.

From Table 12 it is evident that at the census there were only 173 uninhabited dwellings, that only 0.22% of dwellings were inhabited by only one person, that the largest number of dwellings (24.4%) were inhabited by only 2 persons, and that three persons lived in 23.01% of the dwellings and four in 23.4% of the dwellings. These dwellings together represent 91% of all dwellings. Thereafter the number of residents in dwellings rises rapidly. The dwellings with high numbers of residents were

Figure 24: Generalized map of density of settling in Ljubljana according to classes shown in Table 11.
Slika 24: Generalizirana karta gostote poselitve v Ljubljani po razredih, ki so prikazani v preglednici 11.

examined and turned out to be individual workers' housing, pensioners' homes or school dormitories.

TABLE 12: NUMBER OF RESIDENTS IN DWELLINGS ACCORDING TO THE 1991 CENSUS.

no. of residents	no. of dwellings	%
0	173	0.000
1	19,386	20.220
2	23,396	24.402
3	22,064	23.013
4	22,429	23.394
5	5,667	5.911
6	1,813	1.891
7	554	0.578
8	163	0.170
9	78	0.081
10	37	0.039
11	17	0.018
12	9	0.009
13	7	0.007
14	7	0.007
15	4	0.004
16	4	0.004
17	4	0.004
18	2	0.002
19	2	0.002
20	1	0.001
21 or more	60	6.258
total	95,877	99.817

4.4.7. Households

The number of households in dwellings shows that there is just one household in the majority of dwellings (98.1%).

TABLE 13: NUMBER OF HOUSEHOLDS IN A DWELLING.

households	dwellings	%
0	174	0.000
1	94,022	98.065
2	1486	1,550
3	110	0,115
4	24	0,025
5	13	0,014
6	10	0,010
7	9	0,009
9	4	0,004
10	3	0,003
11 or more	22	0.205
total	95,877	100.000

A more interesting picture shows the number of households in individual MCS areas, the number of households is larger than the number of dwellings. Experience from the reconstruction following the Posočje destruction showed that after the earthquake, people wanted new, replacement dwellings according to the number of households and not according the number of former dwellings.

TABLE 14: NUMBER OF HOUSEHOLDS IN INDIVIDUAL AREAS.

MCS area	households	%
8/1	16,088	16.33
8/2	33,600	34.11
8/3	38,235	38.82
9/2	9,251	9.39
9/3	1,330	1.35
total	98,504	100.00

4.4.8. Area of Dwellings

Analysis of the area of the residential housing fund showed that altogether there is 6,121,073 m^2 of residential space in the studied area. The average dwelling area is 63.84 m^2. The individual resident of Ljubljana has on average 22.19 m^2 of residential area.

TABLE 15: AREA OF DWELLINGS ACCORDING TO CLASSES.

m^2	no. of dwellings	area of dwellings in m^2	% of residential area	% of common residential area
to 10	366	703	0.38	0.011
10–19	1,499	23,099	1.56	0.377
20–49	27,275	1,005,759	28.45	16.431
50–99	56,472	3,825,635	58.90	62.499
100–199	9,888	1,184,450	10.31	19.351
200–300	377	81,427	0.39	1.330
total	95,877	6,121,073	99.99	99.999

TABLE 16: COMMON AREA OF DWELLINGS IN M² IN INDIVIDUAL MCS AREAS.

MCS area	area of dwellings in m²	%
8/1	971,506	15.87
8/2	2,034,972	33.24
8/3	2,434,474	39.77
9/2	584,804	9.55
9/3	95,317	1.56
total	6,121,073	99.99

4.4.9. Year of Construction of Dwellings

In studying the earthquake threat to Ljubljana we can establish two important milestones and classify the buildings and dwellings into three age groups. After the earthquake that Ljubljana experienced in 1895, special construction regulations were introduced and many buildings were renovated. A that time, a decree was passed in Ljubljana to regulate construction that was safer from earthquakes. For older buildings (erected before the 1895 earthquake), worse earthquake effects can be expected in a case of an earthquake for the same degrees of intensity.
The second important milestone occurred in 1965 when after the 1963 Skopje earthquake new and stricter technical construction regulations came into effect.
Therefore we decided to divide buildings into the following groups:
- buildings erected before 1895,
- buildings erected in the period between 1896 and 1965, and
- buildings erected after 1965.

The data on the age of dwellings which we have available regrettably does not contain information on the age of buildings erected before 1900. Therefore we decided to classify all the buildings erected in 1900 and before in the first group, buildings erected in the period between 1901 and 1964 in the second group, and buildings erected after 1964 – i. e., between 1965 and 1991 – in the third group.

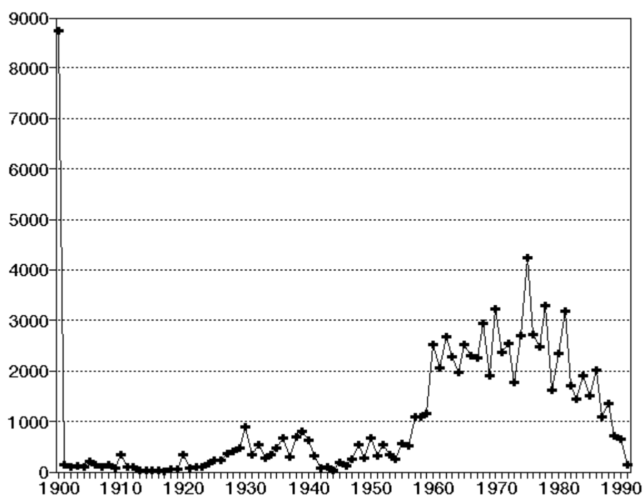


Figure 25: Year of construction of dwellings in Ljubljana. The dynamics of construction are clearly evident.
Slika 25: Leto izgradnje stanovanj v Ljubljani. Lepo je vidna dinamika izgradnje stanovanj.

As this data has been collected for dwellings, we made an analysis according to dwellings which is approximately three times more detailed as the analysis for buildings.
The age of 737 dwellings (0.77%) is not known. According to our data, 65 dwellings are uncompleted but already inhabited, 14 dwellings are in provisionally settled apartment buildings. This is a small number of dwellings that we ranked in the category of oldest dwellings for safety reasons.

TABLE 17: AGE OF DWELLINGS IN MCS AREAS.

MCS area	< 1900	%	1901–1964	%	1965 >	%	total	%
8/1	642	7.34	4,831	16.00	10,213	17.94	15,686	16.36
8/2	1,923	21.99	11,231	37.20	19,314	33.92	32,468	33.86
8/3	5,291	60.49	12,040	39.88	19,952	35.03	37,283	38.89
9/2	746	8.53	1,899	6.29	6,495	11.41	9,140	9.53
9/3	144	1.65	189	0.63	967	1.70	1,300	1.36
total	8,746	100.00	30,190	100.00	56,941	100.00	95,877	100.00
%	(9.12)		(31.49)		(59.39)		(100.00)	

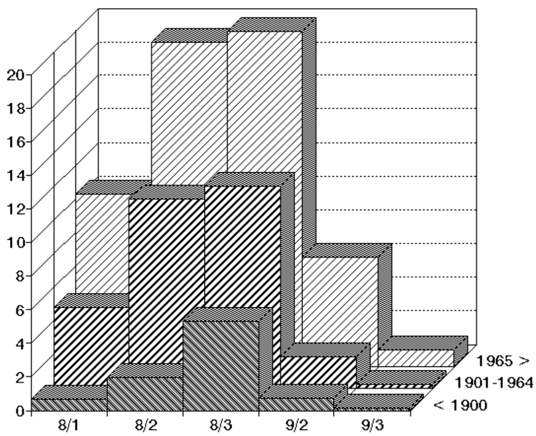


Figure 26: Age of dwellings (in thousands) by MCS areas and different time periods.
Slika 26: Starost stanovanj (v tisočih) po MCS območjih in v različnih časovnih obdobjih.

4.4.10. Material of Outer Walls of Buildings

In the 1991 census of dwellings there was a question regarding the material of the outer walls of the building in which the dwelling is situated. A detailed survey of this data showed that 95,138 (99.229%) of the buildings were made of better material than stated, and only 456 (0.476%) of the building walls were made of poorer material. There was no data for 283 (0.295%) of the buildings. From this it is clear that the criterion “better – poorer” is very loose. This data tells us little it only applies to the material of the outer walls, and we cannot make any conclusions about the earthquake firmness of a building on the basis of this data.

4.4.11. Floor on Which Dwelling is Located

From our data on dwellings we can determine the floor on which a dwelling is located. The following table presents the number of dwellings in the studied area according to individual floors. By far the largest number of dwellings are on the ground floor (32.8%), and the number falls rapidly according to the number of the floor. An interesting fact is that twelve dwellings in Ljubljana are even on the 20th floor. From this information we can approximately determine the height of apartment buildings and the areas with extremely high dwellings (skyscrapers) where special problems can be anticipated in the event of evacuation. We have 27,041 dwellings on the third or higher floors.

TABLE 18: NUMBER OF DWELLINGS ACCORDING TO FLOOR.

floor	no. of dwellings	%
basement	793	0.827
sub-ground	231	0.241
ground floor	31,481	32.835
1st floor	18,020	18.795
split level	5,946	6.202
2nd floor	10,509	10.961
3rd floor	8,874	9.256
4th	6,352	6.625
5th	2,597	2.709
6th	2,080	2.169
7th	1,847	1.926
8th	1,505	1.570
9th	1,290	1.345
10th	953	0.994
11th	627	0.654
12th	450	0.469
13th	212	0.221
14th	109	0.114
15th	32	0.033
16th	33	0.034
17th	29	0.030
18th	23	0.024
19th	16	0.017
20th	12	0.013
mansard	1,856	1.936
total	95,877	100.000

There are 7,802 or 8.1% mansard and split level dwellings. We cannot precisely determine in which class to place these dwellings. A detailed survey of split level dwellings showed that in more than 9 out of 10 cases these were single-family residential houses with a ground floor and a first floor, and we therefore placed them in the first class. In this class we also placed all the basement, sub-ground floor, and ground floor dwellings. The reverse situation was determined for mansard dwellings that we placed in the second class. Placing the 2nd, 3rd, and 4th floors in this class is logical because according to city planning standards and practice, elevators are not installed in such dwellings in Slovenia.

TABLE 19: NUMBER OF DWELLINGS ACCORDING TO FLOORS IN THE MCS AREAS.

MCS area	> 1st	%	2nd–4th	%	5th–9th	%	10th >	%
8/1	8,691	15.390	4,788	17.353	1,760	18.886	447	17.909
8/2	18,685	33.088	9,438	34.207	3,412	36.613	933	37.380
8/3	21,675	38.382	10,822	39.223	3,674	39.425	1,112	44.551
9/2	6,164	10.915	2,500	9.061	472	5.065	4	0.160
9/3	1,256	2.224	43	0.156	1	0.012	0	0.000
total	56,471	99.999	27,591	100.000	9,319	100.001	2,496	100.000

After consultation with colleagues at the National Office for Protection and Rescue (Ministry of Defence, engineer Janez Hočevar and civil defense engineer Tomaž Kučič), we decided on a slightly different arrangement of classes. The average gross construction height of dwellings in Ljubljana is estimated to be approximately three meters. From this we can approximately determine the relative height of the building in which the dwellings are. In the first group we classified dwellings up to and including the 1st floor. These are dwellings with a maximum height between three and five meters above the ground and rescue is therefore possible using simple methods. In this group of dwellings residents have many possibilities to rescue themselves without the use of special help. More than a half of Ljubljana's dwellings are of this type (56,471 or 58.9%).

In the second group we placed dwellings on the 2nd and 3rd floors that can be reached with relatively simple extension ladders. Fire brigades and ordinary maintenance services (postal service, electrical maintenance service) all have such ladders. If necessary, these ladders can reach up to twelve meters, but due to the necessary inclination of the ladder, the realistic maximum height for rescue work is nine to ten meters at most. There are 19,383 or 20.9% of all dwellings in this group. In the first and the second group together are 75,854 or 79.8% of all dwellings. Four fifths of the dwellings in Ljubljana are therefore at heights that allow rescue in extreme conditions with simple ladders and other aids, which does not present a technical or technological problem.

In the third group we placed dwellings from the 4th to the 7th floors. The relative height above the ground of these dwellings is from twelve to twenty-one meters. Rescue from these heights demands special ladders or apparatus reaching up to 23 meters high and usually found on vehicles. We have twelve to fifteen such pieces of equipment in Ljubljana and its immediate surroundings. The cost of such an apparatus is around 1,000,000 DEM. In extreme situations we could count on help from other places. In this height class there are 12,876 or 13.43% of all dwellings.

In the last group we placed dwellings on the 8th floor or higher. Those are dwellings from heights of twenty-four meters to about sixty meters on the 20th floor. In Ljubljana we only have one piece of equipment that reaches 57 meters. In an extreme situation, rescue by helicopters would come into consideration. There are 5,291 or 5.53% of dwellings in this group. This is a relatively high number. According to technical construction standards, dwellings on the 5th floor or higher are equipped with elevators. In an earthquake we can anticipate damage to the electrical systems and internal communications in high buildings. The use of elevators and staircases can be impossible or dangerous. In the event of an earthquake, even though the building is not destroyed, we must take rescue with ladders and special equipment into serious consideration.

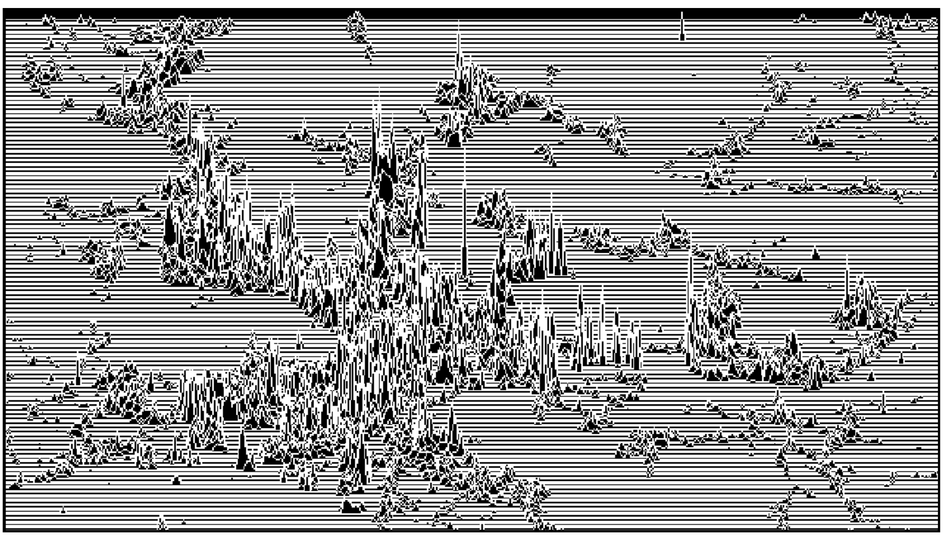


Figure 27: Dwellings in Ljubljana on and below 1st floor. Height of column represents number of dwellings.
Slika 27: Stanovanja v Ljubljani do vključno 1. nadstropja. Višina stolpca pomeni število takih stanovanj.

TABLE 20: NUMBER OF DWELLINGS ACCORDING TO FLOORS IN MCS AREAS.

MCS area	> 1st	%	2nd–3rd	%	4th–7th	%	8th >	%
8/1	8,691	15.390	3,343	17.25	2,611	20.28	878	16.59
8/2	18,685	33.088	6,816	35.16	4,409	34.24	1,954	36.93
8/3	21,675	38.382	7,499	38.69	4,887	37.95	2,354	44.49
9/2	6,164	10.915	1,711	8.83	969	7.53	104	1.97
9/3	1,256	2.224	14	0.07	0	0	1	0.02
total	56,471	999.99	19,383	100.00	12,876	100.00	5,291	100.00

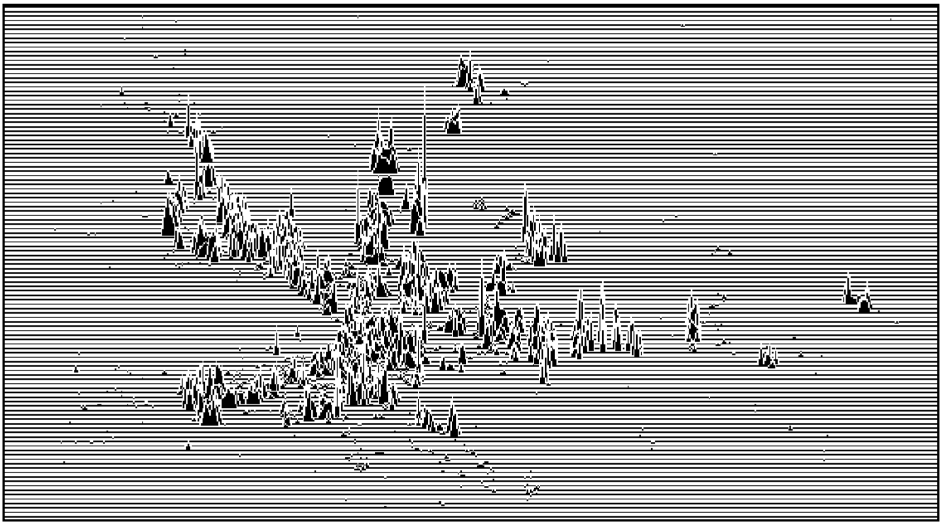


Figure 28: Dwellings in Ljubljana on 2nd and 3rd floors. Height of column represents number of dwellings.
Slika 28: Stanovanja v Ljubljani od 2. do 3. nadstropja. Višina stolpca prikazuje število stanovanj.

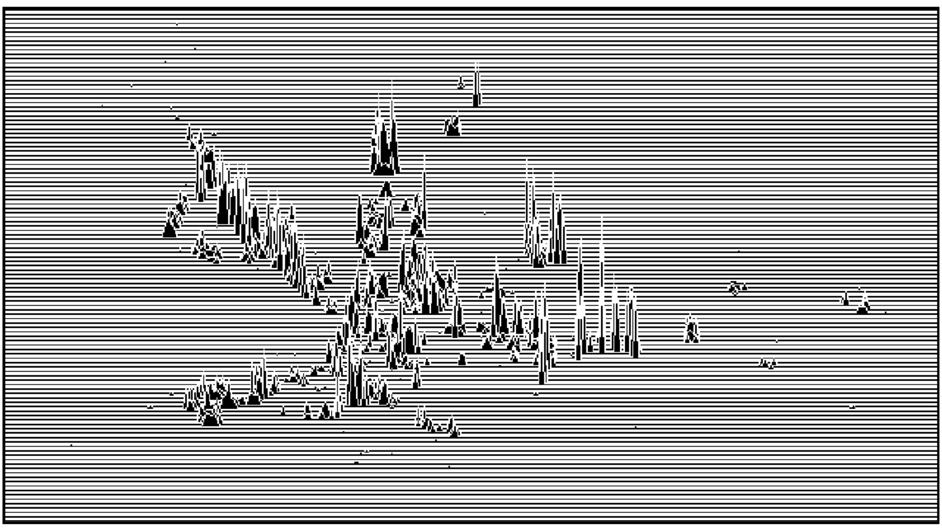


Figure 29: Dwellings in Ljubljana on 4th through 7th floors. Height of column represents number of dwellings.
Slika 29: Stanovanja v Ljubljani od 4. do 7. nadstropja. Višina stolpca prikazuje število stanovanj.

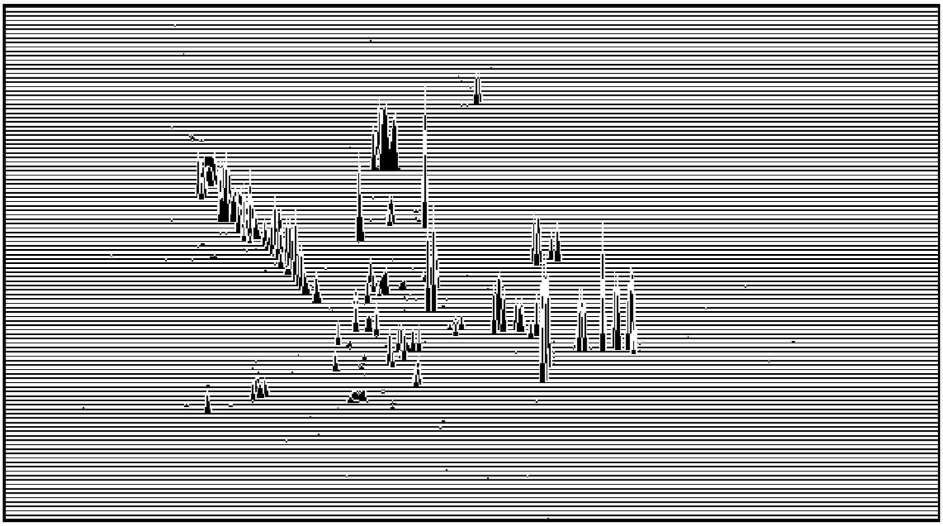


Figure 30: Number of dwellings in Ljubljana on 8th floor or higher. Height of column represents number of dwellings.
Slika 30: Stanovanja v Ljubljani v 8. ali višjem nadstropju. Višina stolpca prikazuje število stanovanj.

The four figures above (28–31) show the classification of height of dwellings in Ljubljana. The last figure shows the areas of extremely high dwellings. In such high buildings other difficulties can also be anticipated, for example, the oscillation that Ljubljana residents remember from the 1976 Friuli earthquake.

4.4.12. Use of Dwellings

From the data in the 1991 census of population and dwellings we can also establish the use of dwellings. A detailed analysis of the studied area showed that more than 9 out of 10 dwellings were being used for a primary activity. Only 1,782 or 1.86% of dwellings were being used for other activities. Only 39 dwellings in this area were used for holiday and recreation purposes. Eight dwellings were used during seasonal farm work.

TABLE 21: USE OF DWELLINGS IN THE STUDIED AREA.

intended use	number	%
residence only	93,765	97.80
residential and business purposes	1,782	1.86
holiday and recreation	39	0.04
seasonal farm work	8	0.01
unidentified	283	0.29
total	95,877	100.00

These are very small, negligible differences in use. With all this in mind it is worth noting that with the process of democratization in Slovenia and the development of private business, this category of dwellings will probably become larger and change rapidly. Because of the extremely dynamic changes related to changes in the ownership of dwellings and companies, at this moment it is practically impossible to operate with other statistically reliable data.

4.4.13. Schools

The Ljubljana Division of the Office for Schools and Sport of Slovenia provided a list of primary and secondary schools in Ljubljana and its surroundings. We found there were 49 primary and 31 secondary schools in the territory of our study, and their locations were transferred into our Geographical Information System. On May 10, 1993, we carried out our own telephone census of the number of students in primary and secondary schools.

None of the schools are in the 9/3 degrees MCS area. The largest number, 36, are in the 8/3 degrees MCS area, 21 schools are in the 8/2 degrees MCS area, 17 in the 8/1 degrees MCS area, and 6 in the 9/2 degrees MCS area. Four of the latter are primary schools and two are secondary schools.

The data on the number of schools in MCS areas says nothing about the technical construction elements of school buildings, but the survey points to the necessity of a such study.

We determined the number of students according to MCS areas. In the area of our study, there are 56,236 students in primary and secondary schools. In primary schools there are 28,625 students (50.1%) and in secondary schools, 27,611 students (49.9%). This is a very large number and represents some 20.4% of the entire population of the studied area. Another important factor is that Ljubljana is an important educational center for Slovenia. Many students come to secondary schools and the university in Ljubljana from across Slovenia. There is no doubt that the destruction of even one of the 80 schools would be a catastrophe of the first degree. The schools are of various sizes, having from a few dozen to almost 1900 students.

The great majority of primary schools (13) only operate in one shift, and the time students spend at school is six to eight hours. The remainder of the schools have extended or even two-shift schedules. In these schools, students remain for eight to ten hours and more. In secondary schools, the two-shift schedule prevails; only six secondary schools have just one shift. A detailed survey showed that on every week day, between 22,000 and 32,000 students are present in primary and secondary schools for ten hours. Happily, more than 82% of these students go to schools in relatively safer earthquake areas (8 degrees MCS). Just under half (46.2%) attend schools in the 8/3 degrees MCS areas, 22.7% go to schools in the 8/2 degrees MCS areas, and 23.9% go to schools in the safest area of 8/1 degrees MCS.

To these numbers can also be added approximately 10,000 students at university faculties that are largely in the areas of 9/3, 9/2, and 8/3 degrees MCS.

TABLE 22: SCHOOLS AND STUDENTS ACCORDING TO MCS AREAS.

Students and primary schools according to MCS areas.

MCS area	no. of schools	%	no. of schools
8/1	4,877	17.0	8
8/2	10,268	35.9	18
8/3	11,089	38.7	19
9/2	2,391	8.4	4
9/3	0	0	0
total	28,625	100.0	49

Students and secondary schools according to MCS areas.

MCS area	no. of schools	%	no. of schools
8/1	8,580	31.1	9
8/2	2,482	9.0	3
8/3	14,889	53.9	17
9/2	1,660	6.0	2
9/3	0	0	0
total	27,611	100.0	31

Total number of schools and students according to MCS areas.

MCS area	total no. of students	%	total no. of schools
8/1	13,457	23.9	17
8/2	12,750	22.7	21
8/3	25,978	46.2	36
9/2	4,051	7.2	6
9/3	0	0	0
total	56,236	100.0	80

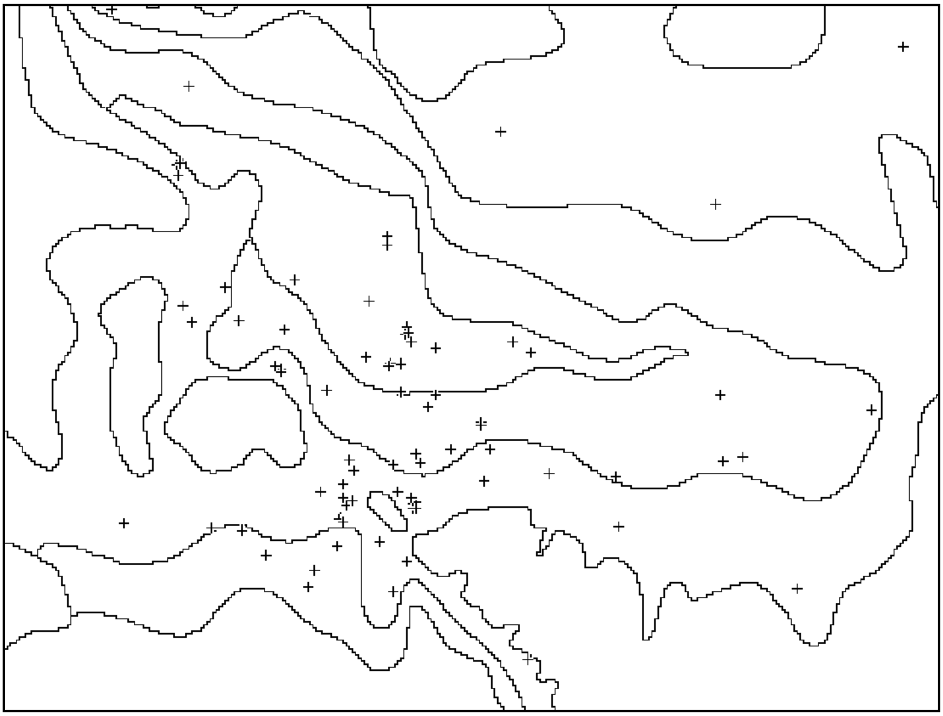


Figure 31: Locations of primary and secondary schools.
Slika 31: Lokacije osnovnih in srednjih šol po MCS območjih.

4.5. Cultural and Historical Monuments

We attempted to delineate this financially difficult to measure or only partly measurable part of the capacities of Ljubljana. We relied on the documentation in decrees regarding the protection of cultural and historical monuments issued by the Ljubljana Regional Institute for Protection of Natural and Cultural Heritage as of 1993. In this documentation all the decrees from 1945 on are taken into consideration that were issued in the Official Gazette of Slovenia, the Official Gazette of Gorenjska, the Official Gazette of Zasavje, the Dolenjska Assembly Gazette, and their predecessors; those decrees issued before the adoption of the Law on Protection of Natural and Cultural Heritage in 1981; and those issued later. We also considered temporary announcements published in the listed gazettes. A detailed survey of this documentation showed that a whole range of buildings or areas that deserve such status were not included in this list. This is not and cannot be a subject of our study, but such a study is very necessary in order to define in detail this part of earthquake threat.

Several years ago a definition was adopted that ranked all those typical or key buildings which are the highest achievements or the most typical of their type and are irreplaceable in the national geographical space among the monuments of the first category (Fister 1989). Therefore, along with national significance they also have international significance. An equally sensible decision contains the international charter on the conservation and restoration of monuments and monumental areas states in its introduction, "The historical monuments of all nations, bearers of spiritual messages of the past, are for us in modern times living witnesses to centuries and millennia of tradition. Mankind is becoming increasingly aware of the general preciousness of human values, counting them among its common heritage and recognizing that as a whole, it is responsible for their preservation for coming generations. It is our duty to pass them on in all the richness of their originality."

There are 604 first category cultural monuments in Slovenia according to decrees issued through 1993. We cannot determine which would be threatened in an earthquake or to what extent. We could only consider the physical number of first category cultural monuments. In the areas of 9 degrees MCS there are 34 such monuments or 5.7%. In the areas of 8 degrees MCS there are 245 first category monuments or 40.6%. We conclude that because of the possibility of destructive earthquakes in these two areas, less than half of our cultural monuments are threatened (Orožen Adamič 1983 b).
We transferred the above data for Ljubljana into our Geographical Information System with the determined (physical) locations of individual buildings. The protected *Footpath of Memory and Solidarity of Occupied Ljubljana* presented a special problem, and we decided to register only individual memorial markers. In the studied area. There are 340 various protected cultural and historical monuments and no protected natural areas.

TABLE 23: NUMBER AND PROPORTION OF CULTURAL AND HISTORICAL MONUMENTS PROTECTED BY DECREES ACCORDING TO MCS AREAS.

MCS area	no. of monuments	%
8/1	41	12,1
8/2	33	9,7
8/3	227	66,8
9/2	28	8,2
9/3	11	3,2
total	340	100.0

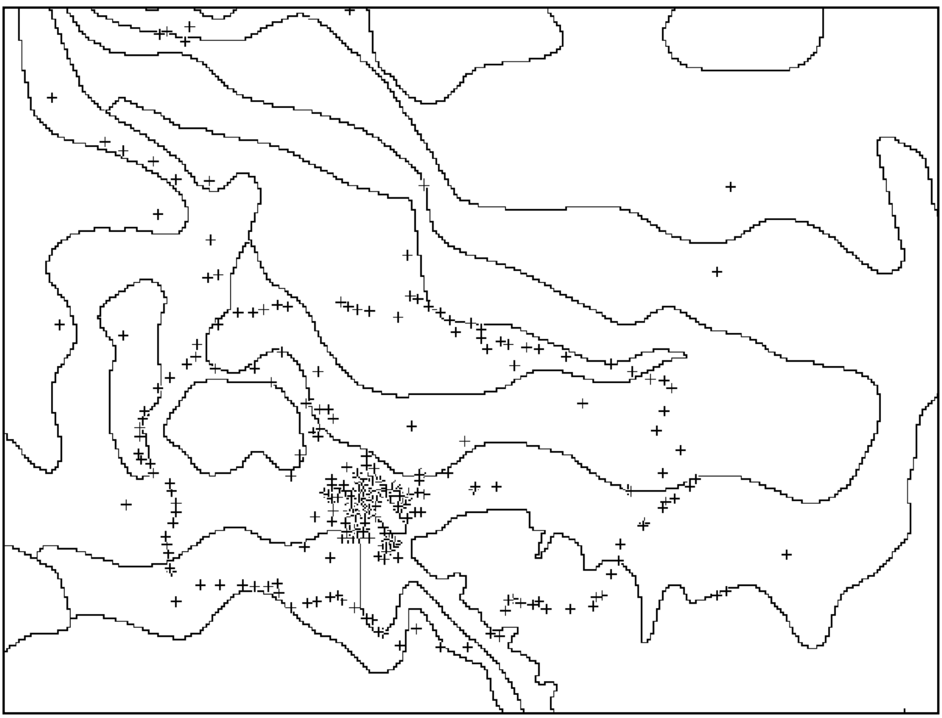


Figure 32: Locations of protected cultural and historical monuments (+) within MCS areas. Their concentration in the oldest part of the city around Ljubljana Castle is clearly evident.
Slika 32: Lokacije zavarovanih kulturnih in zgodovinskih spomenikov (+) z omejitvami na MCS območjih. Lepo je vidna koncentracija v najstarejšem delu mesta okrog Ljubljanskega gradu.

Table 23 shows that most of the monuments (66.8%) are in the 8/3 degree MCS area that includes the largest part of the old part of the city. Only 11.4% of the monuments are in areas of 9 degrees MCS and only 3.2% of these in the highest earthquake degree. A detailed survey showed that those are almost exclusively memorial markers along the *Footpath of Memory and Solidarity* which would not suffer any considerable damage.

5. Attempt to Estimate the Possible Consequences of an Earthquake

In spite of everything, we can estimate the consequences of anticipated earthquakes only very approximately. The basic problem is in the accuracy of predicting events during an earthquake. According to numerous experiences around the world, there can be great differences between one earthquake and another (depth of hypocenter, remoteness of the epicenter from the city, time of earthquake, etc.). Another problem lies in the fact that Ljubljana has no available assessment of technical construction quality. This would undoubtedly be a very important study. In the first part of this chapter we cite some known assessments and in the second we try to establish possible consequences on the basis of the research done. A third problem lies in the fact that for various reasons we are well acquainted with only part of the capacities of Ljubljana. We are therefore dealing with a large number of unknowns, and our evaluation of possible consequences of the earthquake is only an outline.
The map of earthquake microregionalization and the described effects of earthquake degrees are an important basis for assessing anticipated losses in an earthquake.
According to seismological data, there is a 63% probability of exceeding the recurrent period of 1000 years for earthquakes of 9 degrees MCS (Lapajne, Tomaževič 1991 b).

TABLE 24: RECURRENT PERIODS OF THE HIGHEST ANTICIPATED MCS DEGREE.

recurrent period	intensity
1000 years	9 degrees MCS
500 years	8 degrees MCS
50 years	7 degrees MCS

5.1. Anticipated Earthquake Consequences

5.1.1. Types of Buildings

Buildings and damage categories are divided according to MCS earthquake scale into the following types (Lapajne, Tomaževič 1991 b):

A. Buildings of uncut stone, farm buildings, buildings made of air-dried brick (adobe), dwellings made of clay. There are no such buildings in Ljubljana.
B. Ordinary brick buildings, buildings made of large concrete blocks, brick buildings with wood framework, buildings made of natural cut stone. The majority of old buildings in Ljubljana belong to this group.
C. Buildings of reinforced concrete with steel reinforcement or framework, buildings made of larger prefabricated sheets, stronger wooden buildings.

(Note: Buildings erected according to earthquake-safe construction are not included here.

5.1.2. Damage Categories

1st category – LIGHT DAMAGE: fine cracks in the plaster, small pieces of plaster falling off.
2nd category – MODERATE DAMAGE: small cracks in walls, larger pieces of plaster falling off, roofing tiles falling off, cracks in chimneys, parts of chimneys broken off.
3rd category: – MAJOR DAMAGE: large and deep cracks in walls, chimneys broken off.
4th category – PARTIAL DESTRUCTION: ruptures and fissures in walls, parts of buildings collapsed, weakened links between individual parts of buildings, inner walls and fillings in framework collapsed.
5th category – TOTAL DESTRUCTION: buildings collapsed.

5.1.3. Assessment of Earthquake Vulnerability

In spite of the range of factors already mentioned, our assessment can only be approximate. However, we still believe it is useful because it defines certain concrete quantities. The macroseismic intensity scale does not address physical or geophysical quantities. Macroseismic intensity is a statistical quantity, definable for a specific area (not just for one location) and for a population of elements (not just for one element). As such, it is a semi-quantitative measure of the effects of an earthquake and has proven suitable for the analysis of earthquake threat (Lapajne 1984). This definition encouraged us to decide on this trial calculation for the assessment of earthquake consequences.

TABLE 25: PROPORTION OF DAMAGE TO ALL BUILDINGS ACCORDING TO THE MCS SCALE.

MCS degrees	light	moderate	major	partial destruction	total destruction
7/1	42	12	3		
7/2	55	20	5		
7/3	50	30	8		
8/1		42	12	3	
8/2		55	20	5	
8/3		50	30	8	
9/1			42	12	3
9/2			55	20	5
9/3			50	30	8

In the previous analysis we determined the type of quantities according to individual MCS areas. In our study, we have five such areas: 8/1, 8/2, 8/3, 9/2, and 9/3.
The information on the year of construction allows an approximate but not reliable determination of the type of building. In Ljubljana, there are three significant construction periods.
The tables below show more detailed and slightly differently defined proportions than the table above. They were done on the basis of a detailed technical construction evaluation of the earthquake vulnerability of 113 dwellings in Ljubljana. This model was a starting point for forming a slightly modified damage proportion from the basic table which is standard in the MCS scale. It was made only for the stated age of the buildings (Lapajne, Tomaževič 1991 b).

TABLE 26: PROPORTION OF DAMAGE AT DIFFERENT DEGREES OF EARTHQUAKE INTENSITY FOR BUILDINGS ERECTED BEFORE 1895.

MCS degrees	light	moderate	major	partial destruction	total destruction
7/1	34	17	4		
7/2	45	29	6		
7/3	40	42	10	1	
8/1		34	17	4	
8/2		45	29	6	
8/3		40	42	10	1
9/1			34	17	4
9/2			45	29	6
9/3			40	42	10

*Because the year of construction of buildings is not known for the period before 1900 in Ljubljana, we placed only buildings erected before 1900 in this group. This is a statistical approximation which is still acceptable (Bajec 1976).

TABLE 27: PROPORTION OF DAMAGE AT DIFFERENT DEGREES OF EARTHQUAKE INTENSITY FOR BUILDINGS ERECTED BETWEEN 1895 AND 1965.

MCS degrees	light	moderate	major	partial destruction	total destruction
7/1	42	11	2		
7/2	55	19	3		
7/3	50	28	5	0.5	
8/1		42	11	2	
8/2		55	19	3	
8/3		50	28	5	0.5
9/1			42	11	2
9/2			55	19	3
9/3			50	28	5

*Because the year construction of buildings is not known for the period before 1900 in Ljubljana, only buildings erected between 1901 and 1965 have been placed in the second group. In this case as well, the approximation is statistically acceptable.

Because we are interested in the picture of the entire area with a statistically significant population (Gregory 1968) and because deviations from the basic scale are not great, we decided that in the continuation we would place our calculations only in the basic scale. Tables 26 and 27 point to possible deviations from the basic model of anticipated damage.

5.1.4. Anticipated Earthquake Effects

We marked individual areas as if an earthquake of 8 degrees MCS had occurred. In the event of an earthquake of 7 degrees MCS, all the values are lower by one degree and in the event of 9 degrees MCS, one degree higher.

TABLE 28: EFFECTS OF AN EARTHQUAKE IN DIFFERENT MCS DEGREE IN OUR STUDIED AREAS.

area	7 degrees	8 degrees*	9 degrees
1	7/1	8/1	9/1
2	7/2	8/2	9/2
3	7/3	8/3	9/3
4	8/2	9/2	10/2
5	8/3	9/3	10/3

*With these marks we designated individual studied areas.

We decided to show only some elements of the city in the conclusive evaluation: number of dwellings, area of dwellings, and number of residents in them. We must be aware that especially regarding the numbers of residents there are large differences according to the time of an earthquake. Our assessment is for the most unfortunate time, at night when the majority of the people are in their dwellings. In the following table, the most important quantities are summed up according to individual MCS areas.

TABLE 29: DWELLINGS, AREA OF DWELLINGS, AND RESIDENTS ACCORDING TO INDIVIDUAL MCS AREAS.

MCS area	no. of dwellings	area of dwellings	residents
1 (8/1)	15,686	971,506	44,326
2 (8/2)	32,468	2,034,972	94,673
3 (8/3)	37,283	2,434,474	106,715
4 (9/2)	9,140	584,804	25,858
5 (9/3)	1,300	95,317	4,306
total	95,877	6,121,073	275,878

5.1.5. Dwellings

From the previous analysis and summary data in the table above and the established model, we estimated the anticipated damage to dwellings in the event of an earthquake of 7, 8, and 9 degrees MCS, as shown in the following tables.

TABLE 30: ANTICIPATED DAMAGE BY NUMBER OF DWELLINGS IN AN EARTHQUAKE WITH THE EFFECTS OF 7 DEGREES MCS.

MCS degrees	light	moderate	major	partial destruction	total destruction
7/1	6,588	1,882	471		
7/2	17,857	6,494	1,623		
7/3	18,641	11,185	2,983		
8/2		5,027	1,828	457	
8/3		650	390	104	
total	43,086	25,238	7,295	561	

19,697 dwellings will presumably remain unharmed. In such an earthquake we do not anticipate completely destroyed dwellings.

TABLE 31: ANTICIPATED DAMAGE BY NUMBER OF DWELLINGS IN AN EARTHQUAKE WITH THE EFFECTS OF 8 DEGREES MCS.

MCS degrees	light	moderate	major	partial destruction	total destruction
8/1		6,588	1,882	471	
8/2		17,857	6,494	1,623	
8/3		18,641	11,185	2,983	
9/2			5,027	1,828	457
9/3			650	390	104
total	(19697)	43,086	25,238	7,295	561

TABLE 32: ANTICIPATED DAMAGE BY NUMBER OF DWELLINGS IN AN EARTHQUAKE OF 9 DEGREES MCS.

MCS degrees	light	moderate	major	partial destruction	total destruction
9/1			6,588	1,882	471
9/2			17,857	6,494	1,623
9/3			18,641	11,185	2,983
10/2				5,027	1,828
10/3				650	390
total		(20,258)	43,086	25,238	7,295

20,258 dwellings will not be damaged or will have light, moderate, and major damage.

From the three tables above, the number of damaged dwellings in the anticipated earthquake degrees according to MCS areas in Ljubljana is clear. In an earthquake of 9 degrees MCS, as many as 7,295 or 7.6% of dwellings would be totally destroyed. 25,238 or 26.3% would suffer partial destruction, and 43,086 or 44.9% would suffer major damage. In weaker earthquakes the damage would be proportionally smaller. In an earthquake of 8 degrees MCS, only 0.58% of dwellings would be completely destroyed, and in an earthquake of 7 degrees MCS there would be no such damage to dwellings.

5.1.6. Area of Dwellings

We decided to analyze the area of dwellings in the same way. Those calculations enable an approximate evaluation of damage in dwellings that can be expressed in money.

TABLE 33: ANTICIPATED DAMAGE TO DWELLING AREAS IN M^2 IN AN EARTHQUAKE OF 7 DEGREES MCS.

MCS degrees	light	moderate	major	partial destruction	total destruction
7/1	408,033	116,581	29,145		
7/2	1,119,235	406,994	101,749		
7/3	1,217,237	730,342	194,758		
8/2		32,164	11,696	29,240	
8/3		47,658	28,593	7,625	
total	2,744,505	1,333,739	365,941	36,865	

1,640,023 m^2 of area of dwellings will have no or little damage.

TABLE 34: ANTICIPATED DAMAGE TO DWELLING AREAS IN M^2 IN AN EARTHQUAKE OF 8 DEGREES MCS.

MCS degrees	light	moderate	major	partial destruction	total destruction
8/1		408,033	116,581	29,145	
8/2		1,119,235	406,994	101,749	
8/3		1,217,237	730,342	194,758	
9/2			32,164	11,696	29,240
9/3			47,658	28,593	7,625
total	(1,640,023)	2,744,505	1,333,739	365,941	36,865

TABLE 35: ANTICIPATED DAMAGE TO DWELLING AREAS IN M^2 IN AN EARTHQUAKE OF 9 DEGREES MCS.

MCS degrees	light	moderate	major	partial destruction	total destruction
9/1			408,033	116,581	29,145
9/2			1,119,235	406,994	101,749
9/3			1,217,237	730,342	194,758
10/2				32,164	11,696
10/3				47,658	28,593
total	(1,676,888)	2,744,505	1,333,739	365,941	

In Ljubljana, one square meter of dwelling area costs between 1,300 and 2,400 DEM. Differences in the price depend, of course, on the age of the dwelling, its location, and a range of other factors. If the destroyed dwellings and buildings have to be rebuilt completely, the cost per square meter of a dwelling could be set at about 2,000 DEM. The cost of thoroughly repairing badly damaged buildings would be 1,000 DEM per m^2. The cost of repairing moderately damaged dwellings would be 500 DEM per m^2, and for lightly damaged dwellings, 250 DEM per m^2. Of course, there are other expenses to be taken into consideration: the demolition of buildings, renewal of communications and the communal infrastructure, loss of income, expenses for temporary residence, etc. This part of the costs is very difficult to estimate. On the other hand, the greatest possible reduction to the costs would certainly be applied (Markov 1987). In addition, damage can be anticipated to industrial, business, sacral, and other buildings that is hard or impossible to estimate objectively. In spite of all objections and unknowns, some framework values appear that we cite in the following table.

TABLE 36: APPROXIMATE ESTIMATE OF DAMAGE TO DWELLINGS IN DEM

earthquake effect	light damage (250 DEM/m^2)	moderate damage (500 DEM/m^2)	major damage (1000 DEM/m^2)	partial and total destruction (2000 DEM/m^2)	total in DEM
7 degrees MCS	686,126,250	666,869,500	365,941,000	73,730,000	1,792,666,750
8 degrees MCS	?	1,372,252,500	1,333,739,000	805,612,000	3,511,603,500
9 degrees MCS	?	?	2,744,505,000	3,399,360,000	6,143,865,000

? denotes unknown quantity of damage.

These are large numbers, calculated according to the described suppositions. The experience of the consequences of earthquakes across the world and in Slovenia show that they are quite realistic (Knez 1981). In 1990, Slovenia's GDP was 164,942,591,000 dinars. At the exchange rate at that time of 7 dinars to the German mark, this represented 23,563,227,268 DEM (Statistics Office of Slovenia, 1991). According to the decades long established methodology (Knez 1981) of calculating damage according to the GDP of the previous year, we can approximately calculate the proportion of damage. In an earthquake of 7 degrees MCS, the damage to dwellings alone would amount to 8% of Slovenia's GDP for the previous year, 15% in an earthquake of 8 degrees MCS, and 26% in an earthquake of 9 degrees MCS.

In an earthquake of 8 or 9 degrees MCS, the unknown amount of light and moderate damage to dwellings is marked in the table with a question mark. To this we must add other damage that cannot be anticipated, and therefore the final sum would be considerably higher. Numerous concrete assessments following various natural disasters in Slovenia suggest that the proportion of damage could be higher by 100% or more. The reality of this assessment can be compared to the assessment of the damage caused in Slovenia by the 1976 Friuli earthquake. The total proportion of the damage in the GDP was estimated to be around 7%. A similar comparison can be made with the proportion of damage in the floods that struck Slovenia in 1991 which totaled about 20% of the GDP. Analysis of the consequences of the earthquake that struck Posočje in 1976 showed that the proportion of the damage to dwellings alone amounted to about 40% of the total damage (Orožen Adamič 1979). With this we must be aware of local factors, namely that there were no significant secondary and tertiary activities in Posočje. The total anticipated damage can therefore be increased by at least 150%. On this assumption, in an earthquake of 7 degrees MCS in Ljubljana the total damage would be about 20% of the annual GDP, in an earthquake of 8 degrees MCS close to 40%, and in an earthquake of 9 degrees MCS even more than 75%. With all this a range of questions and objections arise, but the

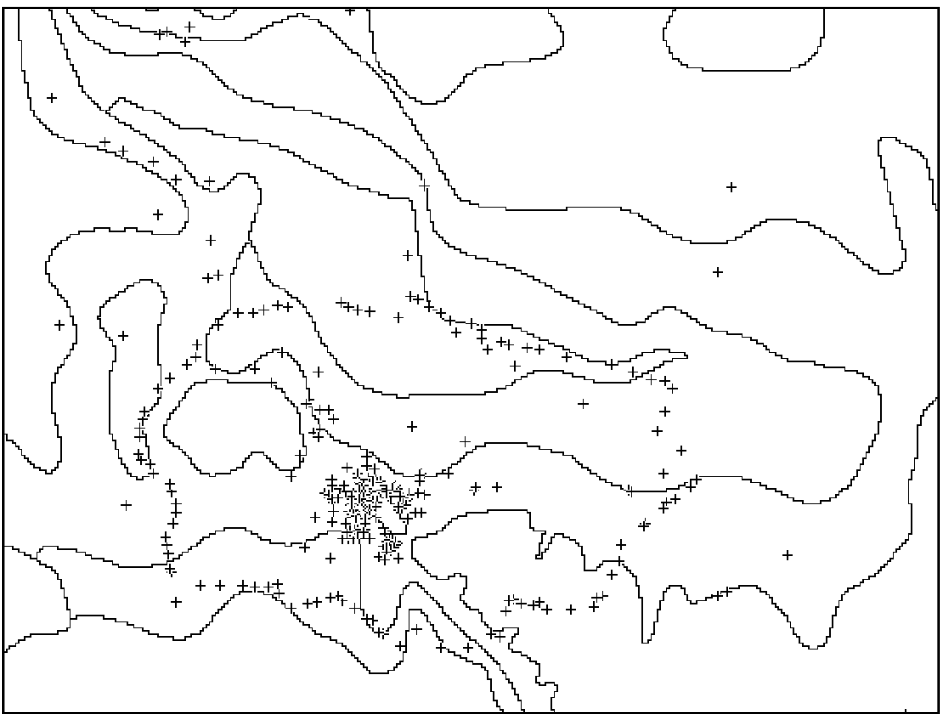


Figure 33: Proportion of dead in earthquake according to residence in different types of buildings (Coburn 1989).
Slika 33: Delež umrlih pri potresu glede na bivanje v različnih tipih objektov (Coburn 1989).

fact remains that earthquakes of 7, 8, and especially 9 degrees MCS would cause immense material damage. Therefore we must try to do everything possible to lessen the possible effects of a destructive earthquake.

5.1.7. **Residents**

In the same manner we can determine the number of people in an individual type of damaged building. The results of this analysis can only be approximate, of course. Here we must be aware that the quality of the housing fund is constantly changing along with the number and arrangement of residents and other users. In addition, this assessment is based only on dwellings and not on business and other premises which many people occupy daily.

TABLE 37: NUMBER OF PEOPLE ACCORDING TO THE TYPE OF DAMAGED DWELLINGS IN AN EARTHQUAKE WITH THE EFFECTS OF 7 DEGREES MCS.

MCS degrees	light	moderate	major	partial destruction	total destruction
7/1	18,617	5,319	1,330		
7/2	52,070	18,935	4,734		
7/3	53,357	32,014	8,537		
8/2		14,222	7,757	1,293	
8/3		2,153	1,292	344	
total	124,044	72,643	23,650	1,637	

53,904 people live in dwellings where there would be no damage or damage would be slight.

TABLE 38: NUMBER OF PEOPLE ACCORDING TO THE TYPE OF DAMAGED DWELLINGS IN AN EARTHQUAKE WITH THE EFFECTS OF 8 DEGREES MCS.

MCS degrees	light	moderate	major	partial destruction	total destruction
8/1		18,617	5,319	1,330	
8/2		52,070	18,935	4,734	
8/3		53,357	32,014	8,537	
9/2			14,222	7,757	1,293
9/3			2,153	1,292	344
total	(53,904)	124,044	72,643	23,650	1,637

53,904 people would be in dwellings that would experience light to moderate damage or no damage.

TABLE 39: NUMBER OF PEOPLE ACCORDING TO THE TYPE OF DAMAGED DWELLINGS IN AN EARTHQUAKE WITH THE EFFECTS OF 9 DEGREES MCS.

MCS degrees	light	moderate	major	partial destruction	total destruction
9/1			18,617	5,319	1,330
9/2			52,070	18,935	4,734
9/3			53,357	32,014	8,537
10/2				14,222	7,757
10/3				2,153	1,292
total	(55,541)		124,044	72,643	23,650

TABLE 40: ESTIMATED NUMBER OF PEOPLE BURIED BENEATH RUINS FOR EARTHQUAKES OF VARIOUS DEGREES IN LJUBLJANA.

degrees MCS	partially destroyed dwellings	totally destroyed dwellings	number buried*
9	72,643	23,650	20,575
7	1,673	–	–
8	23,650	1,637	1,425

According to the different types of buildings there are considerable variations in the number of dead for different degrees of earthquakes. The abbreviation “AB” means “reinforced concrete buildings.” Since a categorization of buildings and dwellings in Ljubljana does not exist and therefore the above graph can only provide an orientation, we based our calculations on the average degree of damage to buildings.

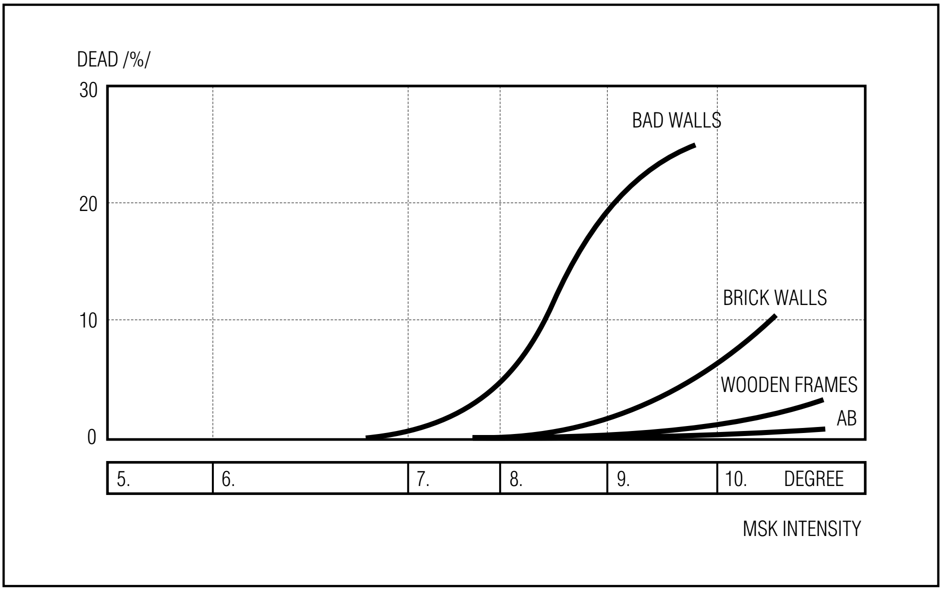


Figure 34: Proportion of residents buried under ruined buildings (Sakai 1990).
Slika 34: Delež zasutih stanovalcev pri porušenem objektu (Sakai 1990).

According to the empirical graph (Sakai 1990), we can estimate approximately the proportion of buried people and calculate it for the entire studied area. According to one estimate (Lapajne, Tomaževič 1991 b), this number is a little more than ten times smaller just for the area of the former district of Ljubljana Center (the central part of Ljubljana). In an 8 degree MCS earthquake, about 130 people would be buried and in an earthquake of 9 degrees MCS, about 1700. Here we must know that the southern part of the city has considerably higher anticipated earthquake degrees (even 10/2 and 10/3) than the Ljubljana Center district. There are a number of conspicuously old and poor buildings in the old part of the city. Almost 1,500 buried in the event of and 8 degree MCS earthquake and some 20,000 in the event of a 9 degree MCS earthquake are frighteningly high numbers. We again emphasize that this is only a calculated value (supposition). There is no particularly firm link between the degree of damage to a building and the number of people buried.

We can only hope that this calculated value is highly exaggerated and that an earthquake in which these numbers would perhaps even triple never occurs.

From practical experience and the analysis of the consequences of the 1976 Posočje earthquake (Orožen Adamič 1979), we should point out that at the time, 9.31% of the population in the stricken area were temporarily or for a longer period without safe shelter. In Slovenia, the consequences of this earthquake were estimated from an average of 7 degrees MCS for the area of the districts of Tolmin, Nova Gorica, and Idrija to 8 degrees MCS in the small area of Breginjski kot. This study showed that in the event of an earthquake in Ljubljana of 7 degrees MCS, there would be 25,287 people in badly damaged and destroyed buildings. This is 9.2% of the population which is remarkably similar to the situation in Posočje. In a stronger earthquake of 8 degrees MCS, the proportion of the population temporarily or for a longer time without safe shelter rises to about 35% and even to 80% in case of an earthquake of 9 degrees MCS. These are very high numbers and mean that just as in Posočje, many temporary shelters would have to be provided and the intensive repair of damaged dwellings and the construction of new dwellings begun in a very short time.

In the case of the Friuli earthquake, a foreshock almost one minute before the main destructive shock warned and frightened the population (Geipel 1982). Many people therefore had the chance to exit buildings and the number of casualties was definitely smaller than if the "warning" foreshock had not occurred. A series of aftershocks following the main destructive earthquake and the extremely strong recurrence of seismic activity in September 1976 contributed considerably to the final damage. From all this we conclude that there is no clear clink between the degree of damage to buildings and the number of casualties. Therefore, this part of the assessment is the most questionable, most variable, and the least valid.

6. Natural Disasters in Combination

Frequently during natural disasters, several different natural disasters occur at the same time, an event that cannot be foreseen. The most frequent combination of different types of natural disasters are thunderstorms with hail, usually accompanied by strong destructive winds. We could enumerate many more such examples and combinations. Destructive natural phenomena often have a close reciprocal relationship. During natural disasters we are not usually dealing with the effects of just one phenomena, even though in practice the concrete disaster is denoted according to the dominant phenomenon.

The first attempt at an integral evaluation of the threat to Slovenia from natural disasters was made by Perko (1992). A special layer (map) was made for several types of natural disasters and placed in a framework of a geographical information system that contains the widest variety of characteristics of natural disasters (extent, duration, frequency of occurrence, damage, etc.).

The values from each layer were then divided by the largest value of the layer. The absolute values were thus changed into relative values with an interval from 0 to 1 which, among other things, allowed the mutual comparison of all the layers.

Values were weighted according to the type of natural disaster and the subject of the threat. The layers were then overlapped, and the values divided by the number of layers were totaled. The values received or "indexes of threat" have values between 0 and 1 that express the degree of threat. The highest possible value of 1 is attributed to areas that are ranked with the highest degree of threat in all the individual layers.

Three types of natural disasters were selected: earthquakes, floods, and landslides. With the help of basic maps (Grimšičar 1983, Orožen Adamič 1984, Šifrer 1983), three layers were formed. The first layer denotes the threat from earthquakes. Four degrees of threat were determined that match the degrees of the MCS earthquake scale. The second layer denotes the threat from landslides that was defined on the basis of relief and lithological conditions to which soils and ground conditions in general are linked. Three degrees of threat were defined: a value of 0 for areas where the danger of landslides is small according to the inclination and the bedrock, a value of 1 for areas where the danger of landslides exists because of one of these two factors, and a value of 2 for areas where both factors accelerate landslides. The third layer denotes the threat from floods. Only two degrees were defined: flood plains with the value of 1 and non-flood plains with the value of 0.

Of the total 20,256 km^2 surface area of Slovenia, only 50 km^2 (0.3%) occurs in the lowest degree of threat, and almost 1,200 km^2 or not quite 6% occurs in the second degree. A good 2,500 km^2 or 12% occurs in the third degree, and the largest part, 6,442 km^2 or 32% occurs in the fourth degree. Altogether, almost half of Slovenia lies in the first four degrees of threat. 3,657 km^2 or 18.1% occurs in the fifth degree, and 5,092 km^2 or 25% in the sixth. Much less area occurs in the next two degrees: 1236 km^2 or 6% in the seventh and only 103 km^2 or less than 1% in the eighth degree. Nowhere in Slovenia does the index of threat exceed the value of 0.8, so we do not have ninth or tenth degrees of threat in Slovenia.

Of the 5,918 settlements officially recorded in the statistics (1991), there are only 15 or 0.3% in the area of first degree threat, which corresponds with the proportion of area in this degree. In the area of second degree threat are some 425 or 7% of all settlements, which is above the proportion of area. In both lowest degrees, one settlement on average occupies about 3 km^2. In the area of third degree threat there are 545 or 9% of the settlements with 4% of the area per settlement. A similar density occurs in the area of fourth degree threat where there are 1,574 or 26% of the settlements and in the area of fifth degree threat where there are 987 or 16% of the settlements. The majority of settlements are in the area of sixth degree threat, 1,934 or 33%, and this means 30% more than the share of area in the same degree. In the area of seventh degree threat there are only 422 or 7%, and in the area of eighth degree threat, only 49 or less than 1% of the settlements. An interesting point is that the density of settlements is greatest in the eighth degree threat area, half of a settlement per km^2 or, in other words, one settlement occupies only two km^2. As many as 80% of the settlements with more than 10,000 residents and only 42% of the settlements with fewer than 100 residents occupy areas of third and fourth degree threat. In the area of seventh and eighth degree threat there are no large settlements.

Just under 6,000 residents lived in the area of first degree threat in 1991, a density of population 28% higher than the average for Slovenia, which is 93 people per km^2. In the area of second degree threat there are a good 300,000 people and a density amounting to 260 people per km^2, 180% higher than the Slovene average and by far the most densely populated of all the degrees. In the area of third degree threat, where almost 400,000 residents lived, the density was also above average, while in the fourth, fifth, and sixth degrees it was below average. As in the area of fourth degree threat, in the area of sixth degree threat there were good 400,000 residents. In the area of seventh degree threat were only 100,000 residents or 5% of the population, and in the eighth only 16,000 or 1% of the population. However, the density here was two thirds higher than the average density for Slovenia. Altogether, almost two thirds of the population live in areas of first, second, third, and fourth degree threat, while in areas of seventh and eighth degree threat, only 6%, which still means more than 100,000 people.

From the point of view of landscape, the least threatened area are the flatlands above the flood plains (part of the Pomurje plain, part of the Celje basin), while the most threatened areas are Haloze, Posotelje, the Bizeljsko area, the Idrija area, and the western part of Slovenia. These are areas where floods and landslides occur and the level of threat due to earthquakes is relatively high. At the same time, these are the areas that need particularly thorough research.

6.1. Areas in Ljubljana Threatened by Earthquakes and Floods

For our narrow study area of Ljubljana, we made a joint map of earthquake areas and floods. By overlaying the map of earthquake areas and the map of floods we determined ten areas: five earthquake areas that are not threatened by floods and five earthquake areas that are.

TABLE 41: SURVEY OF EARTHQUAKE AREAS THREATENED BY FLOODS.

No. of area	MCS degrees	floods
1	8/1	no
2	8/2	no
3	8/3	no
4	9/2	no
5	9/3	no
6	8/1	yes
7	8/2	yes
8	8/3	yes
9	9/2	yes
10	9/3	yes

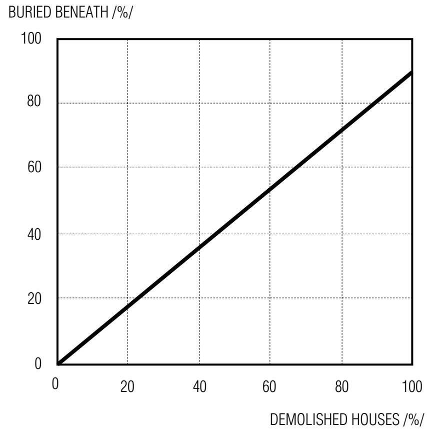


Figure 35: MCS areas and areas threatened by floods (key in Table 41).
Slika 35: MCS območja in območja, ki jih ogrožajo poplave (legenda je v preglednici 41).

With the help of data in our Geographical Information System, we determined the area (in hectares), the number of buildings, the number of dwellings, the number of residents, and the density of settlement per km^2.

TABLE 41: AREA, BUILDINGS, DWELLINGS, AND RESIDENTS ACCORDING TO EARTHQUAKE AREAS AND AREAS THREATENED BY FLOODS.

MCS area*	area in hectares	%	no. of buildings	no. of dwellings	no. of residents	density of settlement /km^2
1 (8/1; no)	4,978.50	27.2	4,374	15,682	44,315	890
2 (8/2; no)	4,945.75	27.1	10,059	32,269	93,868	1,898
3 (8/3; no)	3,938.00	21.6	10,698	33,112	94,466	2,399
4 (9/2; no)	426.75	2.3	1,967	4,448	12,372	2,899
5 (9/3; no)	994.25	5.4	869	928	3061	308
6 (8/1; yes)	11.25	0.1	5	4	11	98
7 (8/2; yes)	421.00	2.3	170	199	805	191
8 (8/3; yes)	1,810.00	9.9	1,664	4,171	12,246	677
9 (9/2; yes)	349.00	1.9	1,720	4,692	13,486	3,864
10 (9/3; yes)	396.75	2.2	298	372	1,245	314
total	18,271.25	100.0	31,824	95,877	275,875	1,510

*Areas are described in detail in the previous table and text.

Table 41 shows clearly the size, number of buildings (EHIŠ), dwellings, residents and density of settling per km^2 according to individual areas. Mainly interesting is the second part of the table (areas 6–10) because it warns us of floods according to individual earthquake areas. In the highest MCS area (9/3), a danger from floods exists in the Ljubljana Barje moor (extent of large floods). In the area of our study, this area (10) covers 396.75 hectares or 2.2% of the studied area. It is encouraging that there are only 298 buildings and 372 dwellings here. This area is divided into two parts: the larger in the Ljubljana Barje moor includes Rakova Jelša and Ilovica, while the smaller along the Glinščica stream is uninhabited. It is expedient that the area along the Glinščica remain without housing in future.

6.2. Most Threatened Areas in Ljubljana

We decided on a detailed inspection of the terrain of the most threatened area in the southern part of Ljubljana which already extends into the Ljubljana Barje moor (10, 9/3 degrees MCS, and floods). On the right bank of the Ljubljanica in Ilovica the area includes the following city or suburban streets: Ižanska cesta (part), Lahova pot, Uršičev štradon (part) Mihov štradon, Peruzzijeva ulica, Volarjev štradon, Na požaru (part), and Rudniška pot. On the left bank of the Ljubljanica it includes part of Rakova Jelša with Razdevškova, Preserska, and Borovniška ulica streets.
Across this area runs the newly constructed expressway of the southern Ljubljana bypass. To the south of the expressway there are not yet many buildings, though in recent times a shanty town or slum settlement has been spreading here.
In the immediate vicinity of the expressway where it crosses the Ljubljanica is the confluence of the Ižica and Ljubljanica rivers. On the right bank of the Ižica are Prošca and Krakovski graben. On the left bank of the Ljubljanica are two canal systems around Kansov graben and the very important Curnovec canal. All these canal systems that drain water off the Ljubljana Barje moor flow into the Ljubljanica a little to the north. In the hydrographic sense, this is an important complex whose task is to efficiently drain high water off Ljubljana Barje moor. North of here, in Špica, the Mali graben and Veliki Galjevec canals flow into the Ljubljanica from the right. During floods the Mali graben discharges high water flowing from the Gradaščica stream into the Glinščica stream in Vič as well as high water already in the city in Krakovo or Trnovo into the Ljubljanica. When the Gradaščica and the Mali graben have high water, they are restrained because they raise the water height of the Ljubljanica and hinder the flow of water from the Ljubljana Barje moor. Most common are one-day floods while those longer than eight days are relatively rare (Kolbezen 1985). With all this, this is also the area with the highest anticipated earthquake degree.

7. Conclusions

A responsible relationship with the environment and prevention and protection measures against disasters of all kinds also pose an important economic question, the question of survival, development, and the future.
The damage caused in Slovenia by widest variety of natural disasters changes from year to year. The consequences of the 1976 Friuli earthquake caused damage that exceeded 7% of Slovenia's annual GDP, and an equally strong earthquake in Ljubljana would cause considerably more damage. One thunderstorm with flooding in 1990 took nearly 20% of Slovenia's GDP.
1. Research into natural disasters in Slovenia has shown that we do not have adequate assessments of threat for a number of natural disasters. Many natural phenomena (disasters) and their consequences we do not know well enough or our knowledge is too unsystematic and not integrated enough. Expanding our knowledge of natural disasters should be one of our primary tasks, because only through a greater knowledge of natural disasters will it be possible to make qualitative assessments of threats.
2. Many natural disasters cannot be prevented, but with solid knowledge and organization, we can strongly mitigate their consequences. We must better organize and staff the services which observe natural phenomena and inform the public of danger. We must unite those responsible for safety measures and equip and qualify them for the job.
3. Every long-term mitigation of the consequences of natural disasters will have to take into account past experience and established regulations.
4. The most threatened areas in which we can expect earthquakes of 9 degrees MCS are the Tolmin area, the Idrija area, the Ljubljana area, and the Brežice area. Altogether they comprise 863 km^2 or 4.26% of the territory of Slovenia. The density of population is greatest in the Ljubljana area with 483 residents/km^2.
According to capacities, the Ljubljana areas stands out strongly. This is the area with the highest average GDP per capita. While the degree of industrialization here is relatively small (though large in the absolute sense), other activities are in the forefront and we must not forget the central functions

of this area. The proportion of relatively old and earthquake unsuitable dwellings is relatively high. Therefore we maintain that the Ljubljana area is the most earthquake threatened area in Slovenia.

5. From the analysis of the map of microseismic regionalization it is evident in the narrow territory of the study that areas threatened by earthquakes of 8/1, 8/2, and 8/3 degrees MCS cover 88.14% of the studied area of Ljubljana and that 11.86% of the territory lies in areas of 9/2 and 9/3 degrees MCS. This is an important finding because on the present survey map of all Slovenia almost the entire area of Ljubljana is considered a 9 degrees MCS area.

6. From our analysis of earthquake threat we determined that only seven local communities (the smallest administrative unit) of the 102 in Ljubljana can be considered relatively safe from earthquakes.

7. In the narrow area of Ljubljana studied, built-up areas comprise 20.7%, indicating a relatively low level of building. These areas include residential buildings, business premises, schools, sports or recreation facilities, churches and cemeteries, and other building areas. Communal areas cover 3.36%. Forests, meadows, fields, and other areas (70.49%) are only threatened to a smaller degree. Water surfaces such as rivers, lakes, ponds, and the like comprise 5.44%.

8. In the area of the highest level of earthquake threat in Ljubljana, only 2.9% of the area is built up. Considerably more is built up, actually three times as much (11.45%), in the area of 9/2 degrees MCS. 14.35% of all the built-up area of Ljubljana lies in 9 degree MCS areas. The highest density of build-up (35.07%) is in the 8/3 degree MCS area, a little lower, 34.09% is in 8/2 degree MCS area, and a substantially lower amount, 16.49%, is in the safest area of 8/1 degrees MCS.

9. Why have we not built a larger part of Ljubljana in areas of 8/1 degrees MCS? One possible answer is that these areas have the most varied, least level, and most hilly relief. Furthermore, a large complex of 8/1 degree MCS area in the central part of the Ljubljana plain has limited construction possibilities because it is an important water reserve. For the same reason we cannot expect to build more intensively in this area in the future. Still, many things could be done, and detailed, well considered planning could appropriately exploit the earthquake safer areas of the city. Earthquake safe construction in these areas is also cheaper, and the same will very soon be true of insurance.

10. In the studied area of Ljubljana there are 31,824 buildings (EHIŠ). With suitably organized software, legal regulations, and appropriate staff, we could make good use of this vitally important information in the event of a disaster, especially if we consider the possibility exists of linking this data with EMŠO numbers (the standard identity number of each resident of Slovenia in the population register).

11. Today, almost 10% of the residents of Ljubljana live in the most threatened areas (9/2, 9/3 degrees MCS) where 15.23% of all the buildings are located.

12. Our analysis of dwellings showed that the average area of dwellings in Ljubljana is 63.84 m^2, an average of 22.19 m^2 of dwelling area per resident. This is a relatively high standard that will not be possible to guarantee in an eventual post-earthquake renewal.

13. We also established the floor on which dwellings are located: well over 5% of dwellings are on the 8th floor or higher. Rescue from these heights demands very specialized equipment.

14. Every week day, between 22,000 and 32,000 students are present in Ljubljana's primary and secondary schools for ten hours or more. An encouraging fact here is that more than 82% of the students attend schools in earthquake safer areas (8 degrees MCS). These numbers, however, remind us that a large concentration of the population is found in a relatively small number of buildings and is therefore in great potential danger.

15. In the studied area of Ljubljana, 340 various cultural and historical monuments are protected by law. It is our duty to preserve them for future generations in all the richness of their originality.

16. Estimates of earthquake vulnerability showed that in an earthquake of 9 degrees MCS, 7,295 or 7.6% of all dwellings could be totally destroyed. 25,238 or 26.3% of all dwellings could be partially destroyed, and 43,086 or 44.9% of dwellings could suffer major damage. In weaker earthquakes the damage would be correspondingly smaller. In an earthquake of 8 degrees MCS only 0.58% of dwellings would be totally destroyed, and in an earthquake of 7 degrees MCS there would be no major damage to dwellings. There are in any case very high numbers that indicate the possible dimensions of earthquake consequences in Ljubljana. With this in mind, we must be aware that this is only part of the damage. Here a range of questions and objections arises regarding the calculations, but the fact

remains that an earthquake of 7, 8, and especially 9 degrees MCS would cause extremely large material damage. Therefore we should try to do everything possible to lessen the possible consequences of a destructive earthquake.

17. According to different types of buildings and different degrees of earthquakes, there are substantial variations in the number of dead in an earthquake. Almost 1,500 buried under rubble in the event of an 8 degree MCS earthquake and some 20,000 buried in the event of a 9 degree MCS earthquake are frighteningly high numbers. Again we stress that this is only a calculated supposition. There is no particularly firm link between the degree of damage to a building and the number of people buried, at least none that we know of. We can only hope that this calculated value is highly exaggerated and that an earthquake that would confirm these numbers never occurs.

18. Floods threaten over 300,000 hectares (14.8%) of the territory of Slovenia. Some 2,988 hectares (16.4%) of the Ljubljana area are threatened. In the area studied, altogether 12.1% of the buildings, 9.8% of dwellings, and 10.1% of the residents are potentially threatened by flooding. These are surprisingly high numbers.

19. Most dangerous of all is the possibility of the combined destructive activity of different natural disasters. In the area most threatened by earthquake (9/3 degrees MCS), the Ljubljana Barje moor, a serious threat of flooding also exists. Our study showed that the majority of the population in the Ljubljana Barje moor area are not aware of the danger of destructive earthquake and floods. Their ideas regarding the threat were quite varied and vague. While 71% of those surveyed responded that they were prepared to do more for their safety, only 18% had concrete suggestions or ideas.

In our study we employed the Geographical Information System and computer technology that enabled us to process an extremely large amount of data. We based the most detailed part of the study on dwellings or buildings (EHIŠ), the smallest possible spatial unit. This is the first example of such an extensive and detailed study and covered approximately 0.9% of the territory of Slovenia and 13.4% of its population. This is a statistically large and representative population.

The weaker side of our study is the fact that for objective reasons and in spite of all our endeavours we could not include certain information important for our goals. Primarily, this was information regarding places of work, industrial production, the value of cultural monuments, and so forth. A second problem was the fact that detailed evaluations of earthquake quality exist for only 112 buildings (0.35%) in Ljubljana, a far too small number. As a result, the suppositions used in models can only be in outline and approximate. In spite of everything, however, they do provide a definite assessment which is worth consideration in spite of any doubts.

Along with our work we also carried out a number of parallel studies. The new maps of Ljubljana showing the density of population, density of households, density of dwellings, heights of buildings, etc., are a fine example.

In recent years as the Yugoslav system of solidarity (universal salary deductions for reconstruction and compensation) following natural and other disasters was gradually abandoned in Slovenia, a larger swing toward individual insurance occurred. Our study could be used as a basis for insurance coverage calculations and the assessment of insurance premiums. Practical experiences from California where this system is well developed (Palm 1990) point to this possibility. According to the level of development and economic processes that are occurring, this will become reality in this decade.

Finally, a special information system should be created that would be operationally useful in extreme cases such as a catastrophic earthquake as accurate information is vital in the rescue phase. Part of this system already exists at Slovenia's Ministry of the Interior, but it has not been adapted to the requirements of natural disaster situations. In closing, we can only hope that a large destructive earthquake, flood, or worse, both together, never happen.

8. Bibliography

Banovec, T., Lesar, A., 1975, Digitalni model reliefa Slovenije, Prostorski informacijski sistem, 2. faza., str. 118, Ljubljana.

Blejec, M., 1976, Statistične metode za ekonomiste. Str. 868, Ljubljana.

Branderberger, C., 1988, Elektronische Datenverarbeitung – Einsatz in der Atlaskartographie. Digitale Technologie in der Kartographie. Str. 105–121, Wien.
Bubnov, S., 1987, Zaščita obstoječih stavb pred potresom. Elementarne nepogode i katastrofe. Prvo Jugoslovensko savetovanje, Budva 1986, str. 176–179, Beograd.
Coburn, A., Pomonis, A., Sakai, S., 1989, Assessing Strategies to Reduce Fatalities in Earthquakes. International Workshop on Earthquake Injury Epidemiology for Mitigation and Response, Baltimore.
De Reggi, M., 1949, Pred 600 leti se je podsul Dobrač. Planinski vestnik, št. 49, str. 159–160, Ljubljana.
Demšar, U., 1990, Potresi v Ljubljani. Str. 41, Ljubljana.
Fister, P., 1989, Popotresna obnova arhitekturnih spomenikov I. Ujma, št. 3, str. 67–69, Ljubljana.
Gabrovec, M., 1990, Pomen reliefa za geografsko podobo Polhograjskega hribovja, Geografski zbornik, št. 30, str. 7–68, Ljubljana.
Geipel, R., 1982, Disaster and Reconstruction. George Allen & Unwin, str. 202, London.
Geodetski zavod 1991, Karta Ljubljane 1 : 20.000. Ljubljana.
Godec, M., Fajfar, P., 1986, Študija potresne ogroženosti stanovanjskih in poslovnih stavb mesta Ljubljane I. del. Mestana raziskovalna skupnost, Ljubljana.
Godec, M., Vidrih, R., 1992, Potresna ogroženost v občini Ljubljana Center. Ujma št. 6, str. 82–85, Ljubljana.
Gregory, S., 1963, Statistical methods and the geographer. str. 240, London.
Grimšičar, A., 1983, Zemeljski plazovi v Sloveniji. Naravne nesreče v Sloveniji, str. 59–66, Ljubljana.
Grimšičar, A., 1988, Zemeljski plazovi v Sloveniji: I. zgodovina. Ujma, 2, str. 63–69, Ljubljana.
Helfer, W., 1895, Fotografije. Arhiv Narodne in univerzitetne knjižnice v Ljubljani.
Hoernes, R., 1895, Das Erdbeben von Laibach und seine Ursachen. Gradec.
Izpiski iz časopisov 1870–1943, arhiv GIAM ZRC SAZU, Ljubljana.
Kajzer, J., 1983, S tramovi podprto mesto. S tramovi podprto mesto, str. 84–164, Ljubljana.
Klemenčič, I., 1986, Seizmička ugroženost Ljubljane. 4. kongresu Saveza društava za seizmičko gradjevinarstvo Jugoslavije, Cavtat.
Knez, M., 1981, Ocenjevanje škode. Zbornik seminarja o izvajanju enotne metodologije za ocenjevanje škode in poškodovanuh objektov ob naravnih in drugih nesrečah. Republiški sekretariat za LO, Poljče.
Kolbezen, M., 1985, Hidrografske značilnosti poplav na Ljubljanskem barju. Geografski zbornik 24, str. 11–32, Ljubljana.
Kopriva, S., 1989, Ljubljana skozi čas. Str. 287, Ljubljana.
Lapajne, J., 1983 a, Ocenjevanje potresne ogroženosti. Prirodne nepogode u Jugoslaviji, str. 41–56, Ljubljana.
Lapajne, J., 1983 b, Potres v Ljubljani. Seizmološki zavod SR Slovenije, str. 42, Ljubljana.
Lapajne, J., 1984, The MSK-78 Intensity Scale and Seismic Risk. Engineering Geology, št. 20, Amsterdam.
Lapajne, J., 1988, Veliki potresi na Slovenskem – II.: leto 1511. Ujma, št. 2. str. 70–74, Ljubljana.
Lapajne, J., 1989, Veliki potresi na Slovenskem – III.: potres v Ljubljani leta 1895. Ujma, št. 3, str. 55–61, Ljubljana.
Lapajne, J., Tomaževič, M., 1991 a, Potresna ogroženost mesta Ljubljane 1. del. Elaborat, str. 245, Ljubljana.
Lapajne, J., Tomaževič, M., 1991 b, Potresna ogroženost mesta Ljubljane 2. del. Elaborat, str. 102, Ljubljana.
Lipej, B., 1991, Lociranje podatkov s pomočjo ROTE, EHIŠ in DMR. Geografski obzornik 38/1, str. 15–18, Ljubljana.
Markov, P., 1987, Ugradjivanje mera zaštite od elementarnih nepogoda u prostorne i urbanistiške planove. Elementarne nepogode i katastrofe. Prvo Jugoslovensko savetovanje, Budva 1986, str. 41–45, Beograd.
Mizuno, H., 1985, Earthquake Provisions in Japanese Building Code. Technology for Disaster Prevention, vol. 9, str. 81–102, Tsukuba.
Orožen Adamič, M., 1974 a, Problemi zbiranja in obdelave podatkov v urbanističnem planiranju. Geografski obzornik, Ljubljana.

Orožen Adamič, M., 1974 b, Tehnologija generalnega plana. Dopolnitev in uskladitev urbanističnega programa in načrta Ljubljane – novelacija GUP Ljubljana 2000. Ljubljana, Ljubljanski urbanistični zavod, metodologija Ljubljana.

Orožen Adamič, M., 1978 a, Geografsko proučevanje naravnih katastrof, predvsem glede na posledice nedavnega potresa v Posočju. Geografski obzornik, št. 1–2, str. 6–13, Ljubljana.

Orožen Adamič, M., 1978 b, Posledice potresov leta 1976 v SR Sloveniji. Geografski zbornik, št. 18, str. 93–168, Ljubljana.

Orožen Adamič, M., 1979, Posledice potresov leta 1976 v SR Sloveniji. Geografski zbornik, št. 18, str. 97–169. Ljubljana.

Orožen Adamič, M., 1980, Učinki potresa leta 1976 v Posočju. Potresni zbornik, str. 81–120. Tolmin.

Orožen Adamič, M., 1982, Poskus oblikovanja modela poselitve na izvenmestnih območjih (na primeru Ljubljanskega barja). Gradivo za posvetovanje geografov ob 60-letnici GDS. 119–125. Ljubljana, Geografsko društvo Slovenije.

Orožen Adamič, M., 1983 a, Geografsko proučevanje naravnih katastrof s posebnim ozirom na posledice potresa v Posočju. Geografski obzornik, Ljubljana.

Orožen Adamič, M., 1983 b, Nekatere kapacitete seizmičnih območij Slovenije. Naravne nesreče v Sloveniji, str. 27–40. Ljubljana.

Orožen Adamič, M., 1984, Classification of earthquake prone areas on the basis of potential damage in Slovenia, Yugoslavia. Natural Hazards and Human Settlements Disasters – II, Research and Management, urednik Havlik S., Ekistics, Vol. 51, Athens.

Orožen Adamič, M., 1990, Potres in preoblikovanje naselij v Reziji. Ujma, št. 4, str. 76–78, Ljubljana.

Orožen Adamič, M., 1991, Potresna ogroženost Ljubljane, analiza po krajevnih skupnostih. Elaborat, ZRMK, str. 38, Ljubljana.

Orožen Adamič, M., Berdajs, J., 1972, Cerknica–Dolenje jezero–Otok. Projekt gornji Jadran. Paris–Ljubljana.

Orožen Adamič, M., Kreitmajer, K., 1973, Metoda uporabe podatkov popisa prebivalstva za alokacijo gostot v detaljnem prostorskem planiranju. Informativni bilten RPP. 7. 34. Ljubljana.

Palm, R., 1990, Natural Hazards. The John Hopkins University Press, str. 184, Baltimore, London.

Paulin, J., 1895, Velikonedeljski potres v Ljubljani dne 14. aprila 1895 l. in cesarjev obisk. Ljubljana.

Perko, D., 1991 a, Digitalni model reliefa Slovenije. Geografski obzornik 38/1. Ljubljana, str. 19–23.

Perko, D., 1991 b, Relief in prebivalstvo. Baza podatkov na GIAM ZRC SAZU. Ljubljana.

Perko, D., 1991 c, Uporabnost digitalnega modela reliefa za določanje morfoloških enot. Geodetski vestnik 35/2. Ljubljana, str. 66–71.

Perko, D., 1992, Poplave kot sestavina splošne ogroženosti Slovenije zaradi naravnih nesreč. Poplave v Sloveniji, str. 11–20, Ljubljana.

Popis prebivalstva, gospodinjstev in stanovanj v SR Sloveniji 31.3.1981, 1982, št. 282, str. 150, Ljubljana.

Popisa prebivalstva, gospodinjstev, stanovanj in kmečkih gospodinjstev v Sloveniji v letu 1991. Ljubljana.

Pravilnik o začasnih tehničnih predpisih za graditev v seizmičnih območjih, 1964, Uradni list SFRJ, št. 39, Ljubljana.

Pravilnik o spremembah pravilnika o tehničnih normativih za graditev objektov visoke gradnje na seizmičnih območjih. Uradni list SFRJ, št 49, 1982, Ljubljana.

Pravilnik o normativih za graditev objektov visoke gradnje na seizmičnih območjih, 1981, Uradni list SFRJ št. 31, Ljubljana.

Premru, U., 1977, Geološka zgradba Ljubljane. Študija o ogroženosti mesta Ljubljane v primeru katastrofalnega potresa, FNT, str. 2, Ljubljana.

Republiška geodetska uprava 1989, Digitalni model reliefa 100 m. Baza podatkov. Ljubljana.

Republiška geodetska uprava 1991, Centroidi naselij. Baza podatkov. Ljubljana.

Republiška geodetska uprava 1992, ROTE. Baza podatkov. Ljubljana.

Ribarič, V., 1963, Študija seizmičnosti ozemlja SR Slovenije s posebnim ozirom na dinamične vplive potresov na gradbene objekte. 1. del. rokopis, str. 85, Ljubljana.

Ribarič, V., 1964, Zemlja se je tresla. Ljubljana.

Ribarič, V., 1972, Potresna mikrorajonizacija Ljubljane. Elaborat, Ljubljana.

Ribarič, V., 1981, Verjetnost metode v potresnem inženirstvu. 1. del. IKPIR 55, Ljubljana.

Ribarič, V., 1982 a, Seizmičnost Slovenije – katalog potresov (792. n. e. – 1981). Seizmološki zavod SRS, Ser. A, 1, str. 650, Ljubljana.
Ribarič, V., 1982 b, Seizmičnost, verjetnostne metode v seizmologiji in seizmično tveganje v SR Sloveniji. 2. del. IKPIR 1–43, Ljubljana.
Ribarič, V., 1984, Potresi. Cankarjeva založba, str. 271, Ljubljana.
Ribarič, V., 1987, Pojave potresa, uzroci i posljedice. Elementarne nepogode i katastrofe. Prvo Jugoslovensko savetovanje, Budva 1986, str. 117–122, Beograd.
Sakai, S., Coburn, A., Spence, R., 1990, Human Casualities in Building Colapse – Literature review. Martin Centre for Architectural and Urban Studies, Cambridge.
Seidl, F., 1895, Potresi na Kranjskem in Primorskem. Ljubljanski zvon, št.; 354, 417, 485, 545, 600, 674, 745, Ljubljana.
Stanek, L., 1935, Kako so si razlagali potres v Ljubljani leta 1895. Kronika slovenskih mest. str. 81. Ljubljana.
Šifrer, M., 1983, Vzroki in učinki poplav na Slovenskem. Naravne nesreče v Sloveniji, str. 41–49, Ljubljana.
Turnšek, V., 1974, Poročilo o oceni škode, povzročene s potresom 20.6.1974 na področju občin Šmarje pri pri Jelšah, Šentjur pri Celju, Celje in Slovenske Konjice. Ljubljana.
Turnšek, V., 1982, Eatrhquakes as a Social Problem. Social and Economic Aspects of Eartquakes, Ljubljana, str. 133–144, Ljubljana
Turnšek, V., Terčelj, S., Sheppard, P., Tomaževič, M., 1978, The seismic resistance of stone-masonry walls and buildings. 6. ECEE, zvezek 3, str. 255–262, Dubrovnik.
Z odloki zavarovani kulturni in zgodovinski spomeniki ter naravne znamenitosti na območju, ki ga pokriva Ljubljanski regionalni zavod za varstvo naravne in kulturne dediščine. 1993. Str. 27, Ljubljana.
Zavod SR Slovenije za statistiko 1972 do 1991, Statistični letopisi SR Slovenije. Ljubljana.
Zavod SR Slovenije za družbeno planiranje, 1978, Digitalni model reliefa SRS 500 m.
Žiberna, I., 1992, Vpliv klime na lego in razširjenost vinogradov na primeru Srednjih Slovenskih goric. Geografski zbornik št. 32, str. 50–139, Ljubljana.

9. Povzetek – Summary

Potresna ogroženost Ljubljane

Milan Orožen Adamič

Odgovoren odnos do okolja, preprečevanje in varstvo pred nesrečami vseh vrst je pomembno ekonomsko vprašanje, vprašanje preživetja, razvoja in prihodnosti.
Škoda, ki jo povzročajo najrazličnejše naravne nesreče v Sloveniji, se iz leta v leto spreminja. Posledice furlanskega potresa (1976) so samo v Sloveniji povzročile škodo, ki je presegla 7 % enoletnega skupnega družbenega proizvoda Slovenije. Enako močan potres bi v Ljubljani predvidoma povzročil znatno večjo škodo. Neurje s poplavo v letu 1990 nam je odneslo približno 20 % enoletnega družbenega proizvoda Slovenije.
Raziskovanje naravnih nesreč v Sloveniji je pokazalo, da za celo vrsto naravnih nesreč še nimamo dovolj podrobnih in celovitih ocen ogroženosti. Mnogih pojavov (naravnih nesreč) in njihovih posledic ne poznamo dovolj, ali pa je naše znanje o njih še vse preveč nesistematično. Morda vemo največ o potresih in najrazličnejših vrstah poplav. Poglobitev znanja o naravnih nesrečah vseh vrst, je gotovo ena od prvenstvenih nalog, kajti le z večjim znanjem o naravnih nesrečah je možno izdelati kakovostne ocene ogroženosti, varovati življenja in zmanjšati škodo, ki jo te povzročajo.
Pri raziskovanju seizmičnih območij Slovenije smo ugotovili, da močno izstopa ljubljansko območje (9. stopnje po MCS). Tu sta največja koncentracija prebivalstva in največji družbeni proizvod na prebivalca. Stopnja industrializacije je sicer razmeroma majhna (v absolutnem smislu je velika), v os-

predju pa so druge dejavnosti, pri čemer ne gre pozabiti za Slovenijo pomembnih, centralnih funkcij tega območja. Zato imamo ljubljansko območje (9 c) upravičeno za potresno najbolj ogroženo območje v Sloveniji. To je bil glavni razlog, da smo se odločili, da bomo prav temu vprašanju namenili največ pozornosti. S prekrivanjem nekaterih za potres važnih "elementov" mesta po posameznih potresnih območjih smo ugotovili in ocenili potresno nevarnost posameznih delov mesta. Poskušali smo ugotoviti, kaj posamezna območja mikroseizmične rajonizacije v Ljubljani dejansko pomenijo. V zaključku raziskave smo opravili tudi nekatere celovite izračune modelov in poizkusili za Ljubljano poiskati odgovor na vprašanje, kakšne bi bile posledice potresa 7., 8. ali 9. stopnje po MSC oziroma MSK lestvici.

V Ljubljani je še vedno živ spomin na potres iz leta 1895, to je pred 100 leti. Posledice tega potresa so bile za Ljubljano zelo dalekosežne. Po obnovi je mesto dobilo povsem novo podobo. Takratna Ljubljana je imela okrog 32.000 prebivalcev, danes jih ima približno 9-krat več. Takrat je bila Ljubljana manjše provincialno središče, danes je glavno mesto samostojne države.

Pri raziskovanju problema smo uporabili geografski informacijski sistem (GIS), ki je oprt na digitalni model reliefa. Z računalniki podprta tehnologija nam je omogočila obdelavo izjemno velikega števila podatkov. V najbolj podrobnem delu raziskave smo se oprli na enoto stanovanja oziroma hiše, ki je gotovo najmanjša možna raziskovalna prostorska enota. To je prvi primer tako podrobnega raziskovanja v Sloveniji, na mestnem območju, ki obsega približno 0,9 % površine Slovenije in 13,4 % njenega prebivalstva.

Opravili smo tudi vrsto vzporednih raziskav. Lep primer so novi zemljevidi gostote poselitve, gostote gospodinjstev, gostote stanovanj, višine stavb v mestu ipd. Nazadnje lahko le upamo, da ne bo prišlo do velikega rušilnega potresa, poplave ali celo obojega hkrati. Sicer pa bi v primeru take nesreče našo podatkovno bazo dopolnjeno z drugimi podatki lahko zelo koristno uporabili.