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A SURVEY OF DAMAGE CAUSED BY 1998 EARTHQUAKE IN THE SOČA VALLEY (SLOVENIA)

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SUMMARY

The 12 April 1998 earthquake in the Soča Valley in Slovenia had a magnitude of 5.8. It caused significant damage to old buildings and to the natural environment (rock falls, rock slides). The maximum intensity of the quake is estimated at VII - VIII EMS. Older buildings made of Field stone, massive and simple stone were damaged. Some 3,390 building units were inspected in the damaged area. The floors of the buildings are made of wood. Although the Friuli (Italy) earthquake in 1976 (M = 6.5) caused a lot of damage in this area, the repair and strengthening of older buildings was often poor quality or not carried out at all. Some of the more modern, well-built buildings were also damaged. The main reason for the damage caused to these buildings was that there was low quality underlying ground (alluvial ground etc.).

The article provides a statistical overview of the damaged buildings. As the influence of local ground quality on damaged buildings was high, research is being conducted within the damaged areas in order to draw up a map of seismic microzonation as the basis for regional planning. The article also includes a presentation of the locations where damage was worst and a correlation with the map of seismic microzonation is performed.

INTRODUCTION

On 12 April, 1998, the strongest earthquake with an epicentre in Slovenia in the last one hundred years shook the upper Soča valley (Posočje, NW Slovenia). Its magnitude was 5.8 and its maximum intensity was between VII and VIII EMS. The epicentre was located in the area between the Lepena valley and the Krn mountain range (Julian Alps), and the focal depth was about 10 km.

The area of NW Slovenia is one of the most seismically active parts of the country. Earthquakes may reach intensities up to IX according to the EMS scale [Ribarič, 1987]. Its seismicity is controlled mainly by the margin between the Adriatic microplate and the Eurasian plate, since it lies on the north-eastern rim of the Adriatic microplate. The epicentral area of the Posočje April 12, 1998 earthquake lies right on the contact between the thrust units of the Alps (striking EW and verging to the south) and the Dinarides' transgressive zone (striking NW-SE).

It appears that the earthquake nucleated along the Dinaric trending fault (NW-SE) running from the Rombon mountain (NE of Bovec) towards the Krn mountain (N of Tolmin) and across the village of Tolminske Ravne towards the Cerkno area. This is confirmed by the trend of observed damage elongated along a NW-SE direction and extending from Bovec, the Lepena valley, Drežniške Ravne to Krn village [Vidrih, Godec, 1998], [Godec, Vidrih, Ribičič, 1999]. The Dinaric trend is also confirmed by the pattern of relocated aftershocks that cover a 12-km long narrow strip along the damaged area and by many large rockfalls which triggered at quake.

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The April 12, 1998 earthquake was felt all over Slovenia and in nine neighbouring countries: Croatia, Bosnia and Herzegovina, Hungary, Slovakia, Austria, Germany, Switzerland and Italy. The parameters of the main event and its strongest aftershocks are given in Table 1.

The origin time according to local time was at 12:55 (10:55 UTC), right at the time people were having the traditional Easter lunch, giving rise to some panic. The Geophysical Survey of Slovenia installed in the epicentral area at first three, then five and finally six portable stations, that recorded more than 400 aftershocks during the first 20 hours and more than 7,000 in the following months [Živčić, 1998]. The strongest aftershock occurred on May 6, 1998 at 02:52 (UTC) with a magnitude 4.2. The mechanism of the main event as given by the EMS is of a strike-slip type on an essentially vertical plane.

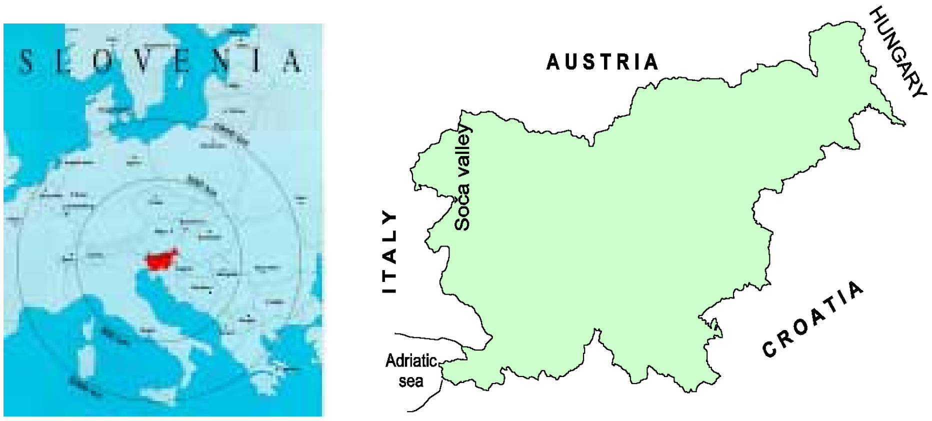

Fig. 1. Slovenia’s position in Europe and position of Soča Valley in Slovenia.

Table 1. The main shock on Sunday, April 12, 1998 at 10:55 (UTC) and its strongest aftershocks (M ≥ 3).

Date	Origin time (UTC)	Deg N	Deg E	M
12.04.1998	10:55	46.320	13.663	5.8
12.04.1998	13:35	46.262	13.557	3.2
12.04.1998	16:15	46.314	13.594	3.0
12.04.1998	22:13	46.317	13.628	3.2
15.04.1996	19:40	46.284	13.720	3.4
15.05.1998	22:42	46.320	13.467	3.1
06.05.1998	02:52	46.299	13.705	4.2
11.05.1998	23:30	46.294	13.723	3.2
13.05.1998	01:58	46.294	13.720	3.1
10.06.1998	23:32	46.318	13.638	3.2
30.08.1998	01:18	46.251	13.684	3.1
24.11.1998	13:49	46.235	13.664	3.4

DAMAGE OBSERVED IN THE EPICENTRAL AREA

The broader epicentral area of the Posočje April 12, 1998 earthquake is a mountainous region formed by carbonate rocks, mainly limestones and dolomites. The valleys are filled with alluvium of fluvial and glacial origins. The Soča river and its affluents from alluvial terraces are made of gravel, sand and, more rarely, conglomerates [Vidrih et al., 1991].

It is well known that the local geology can have large effects on the amplification of seismic waves leading to intensity increments of the order of one or two degrees. The areal extent of the observed damage fully confirms these findings [Ribičič, Vidrih, 1998], [Vidrih, Ribičič, 1999]. The strongest damage was observed in Mala vas (Bovec), and the villages of Spodnje Drežniške Ravne, Magozd, Lepena and on the Polog alp. The estimated intensity in these places was between VII and VIII degrees on the EMS scale. Damage of degree VII EMS was estimated for the localities Kal-Koritnica, Zgornje Drežniške Ravne, Jezerca, Krn, Tolminske Ravne.

BUILDINGS IN GENERAL

What are the general characteristics of the buildings that were damaged? In total, we assessed the data collected on 3,390 buildings (as at August 1998). We used the information gathered by employees of the Geophysical Survey and that collected by municipality committees to assess the damage, with expert help being offered by the Ministry of Environment and Physical Planning. We harmonised the assessing of damage levels of both groups so that they are in accordance with the instructions of the European Macroseismic Scale [Grünthal, 1998].

General characteristics of the inspected buildings:

- Foundations: there were 301 buildings without or with very poor foundations, 2,095 buildings had stone and 569 had concrete foundations. Other types of foundations were found with 82 buildings, while no data is available for 343 buildings.

- Walls: 1,931 buildings have stone walls, 367 have walls made from mixed materials, 493 have brick walls, while 37 have concrete walls. Other materials were used for 213 buildings, while no data is available on wall composition for 349 buildings.

- Floors: 1,545 buildings have wooden floors, 81 have brick floors, while 1,024 have concrete floors. The floors of 366 buildings are made from materials different to those mentioned above, while no data is available on the floor materials of 367 buildings.

- Roof frame: Wooden roof trusses prevail, found on 2,919 buildings.

- Roof cover: 406 buildings are covered by curved tiles, 677 by flat roof tiles, 952 by asbestos ‘Salonit’ brand tiles, and 930 in some other way. There is no information available for 416 buildings.

- Year of construction: 805 buildings were built before 1914, 1,687 of the inspected buildings were constructed in the period between the two World Wars (between 1914 and 1945), 249 buildings were made between 1945 and 1964, while 291 buildings were made between 1964 and 1981. After 1981, 158 buildings were constructed. There is no information regarding the year of construction of 200 buildings. The periods of construction were selected with regard to major turning points, namely renovation after the First and the Second World Wars, introduction of regulations on earthquake-resistant construction in the region in question (in 1964 and 1981).

Analysis of the information on damage to buildings was made in accordance with the instructions of the EMS, where damage is divided into five grades.

Members of the municipality committees for damage inventory assessed damage according to their inventory lists. These damage categories are well harmonised with the instructions of the EMS. We compared the assessment of damage at selected locations, so that we could use as much as possible information available in analysing assessment according to the EMS. Here, there are also five grades of damage and grade 0 where the condition of a building remained undamaged.

Grade 1 - SLIGHT DAMAGE: Partial disclosure of roof, fine cracks in the structure (walls, floors up to 2 mm), broken glass elements, slight damage to utility installations (water, electricity, sewage system). Buildings are usable; level of damage – up to 15%.

Grade 2 - MODERATE DAMAGE: Prevailingly loss of roofing, cracks in the structure (walls, floors from 2 to 10 mm), moved windows and doors, broken glass elements, damage to water utility installations – useless, slight damage to electricity supply system. Buildings are usable; level of damage – from 15% to 30%.

Grade 3 - HEAVY DAMAGE: Disclosed roof and moved or damaged roofing, larger cracks in the structure (walls, floors – more than 10 mm), moved windows and doors, damage to utility installations preventing their use. Buildings are temporarily unusable; level of damage – from 30% to 50%.

Grade 4 - VERY HEAVY DAMAGE: Partial collapse of the support structure (roof, walls, floors, staircases), destruction of utility installations – to establish the appropriateness and rationality of repair. Buildings are temporarily useless; level of damage – up to 70%.

Grade 5 - DESTRUCTION: Destruction of the structure to the extent where repair is not justified. Buildings are unusable; level of damage – more than 70%.

Most of the inspected buildings were constructed before 1945 (a total of 2,492 buildings). As much as 6% of these older buildings were assessed as being unusable (damage of grade 5). This represents a total of 160 buildings. In general, this is most of such heavily damaged buildings. Only 13 of the buildings constructed after World War II suffered damage of grade 5. This is somewhat over one percent of the inspected buildings constructed after World War II.

Of all buildings with damage of grade 5, as much as 93% were constructed before 1945; they also represent the majority with other damages. Thus, of all the damaged buildings with damage of grade 4 - 91% of them are from the period before 1945 and, also among buildings with damage of grade 3 - 87% are from that period. The total share of the inspected buildings from that period in the relevant area is only 73%.

What are the major deficiencies of older buildings that put human lives and the material goods kept in them more in jeopardy? In inspecting the main characteristics of buildings whose damage was assessed as grade 5, it was found that more than one-fifth was without or with very bad foundations. As a comparison we can mention that, among buildings with grade 1 damage, three times fewer buildings had no foundations or had very bad foundations. The share of buildings with stone walls and wooden ceilings is also considerably higher with buildings with damage of grade 5. However, the roof frames for all assessed damage grades are mostly (over 90%) wooden.

What about the inhabitants in the buildings? In buildings with damage of grade 5, 158 people lived in 67 households. Most of them (92%) lived in buildings constructed before 1945. In buildings with damage of grade 4, 157 people lived in 61 households. Here also, most people (87%) lived in buildings constructed before 1945.

It is interesting that among buildings suffering damage of grade 5 there were only 33% such with permanent inhabitants. Other buildings served other purposes or were deserted. In buildings with damage of maximum grade 1, 60% of the buildings were inhabited.

Table 2. Distribution and proportions of residents, households and buildings regarding damage levels to buildings and number of damaged buildings previously renovated or strengthened in any way – the period after the Friulian earthquake is particularly stressed (1976).

Damage categories	Residents	Households	Buildings	All bldgs renovated in any	Buildings renovated after
0	797	396	462		
1	3806	1904	1810		
2	803	316	509		
3	497	188	304	182	124
4	157	61	132	61	50
5	158	67	173	76	53
Total	6218	2932	3390		

Older buildings had undergone several periods of repair. However, the post-earthquake inspection showed that not all renovation works had served to strengthen buildings to achieve aseismic safety. For the inspection of the damaged buildings showed that 76 (48%) of the buildings with damage of grade 5 had been renovated, of which 53 were renovated after 1976, the year of the Friulian earthquake. Among the buildings with damage of grade 4, there were also 61 (38%) renovated buildings. Most of them (53) were also renovated after 1976. Even such an overview gives an impression that insufficient attention was paid to strengthening buildings during renovation works.

Table 3. Total number of residents in buildings constructed in different periods with regard to different damage grades and number of unoccupied buildings suffering damage of grades 4 and 5.

Construction period	Residents in buildings							Unoccupied bldg	
	Damage grades							Damage grades	
	5	**4**	**3**	**2**	**1**	**0**	**Total**	**5**	**4**
1500-1913	40	18	106	234	769	91	1258	37	18
1914-1945	106	118	286	445	1553	277	2785	69	55
1946-1964	0	0	31	103	228	112	474	6	3
1965-1980	12	15	61	21	1002	137	1248	2	1
1981-1998	0	0	10	0	207	31	248	0	2
No data	0	6	3	0	47	149	205	2	0
Total	158	157	497	803	3806	797	6218	116	79

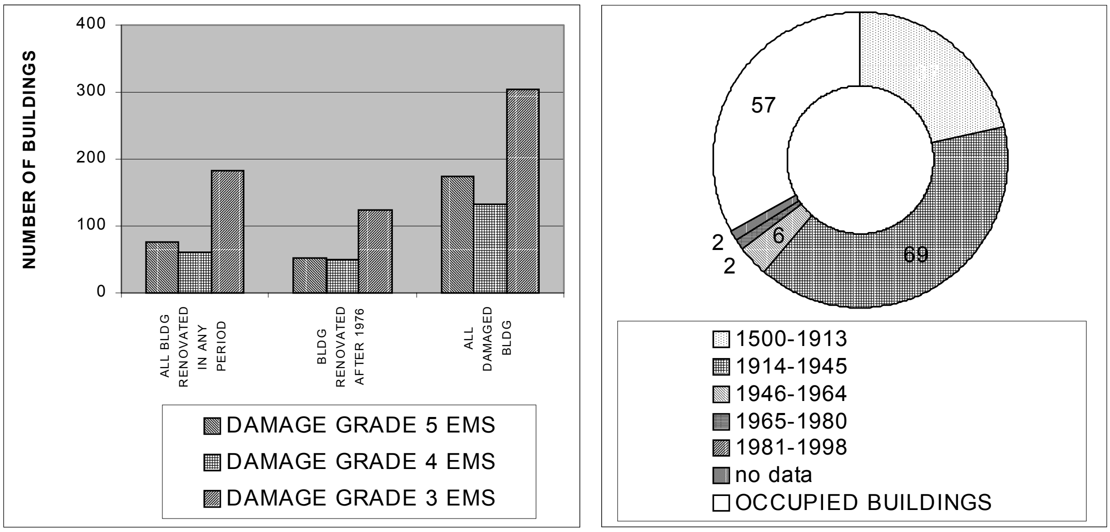

Fig. 2. Number of bldg. renovated at any time and number of occupied or unoccupied bldg with grade 5 damage.

Table 4. Number of households in buildings constructed in different periods with regard to the grades of damage to buildings.

Construction period	Damage grades						Total
	5	**4**	**3**	**2**	**1**	**0**	
1500-1913	19	9	40	93	310	40	511
1914-1945	43	46	113	182	633	87	1104
1946-1964	0	0	12	32	285	65	394
1965-1980	5	5	20	8	561	123	722
1981-1998	0	0	2	0	92	9	103
No data	0	1	1	1	23	72	98
Total	67	61	188	316	1904	396	

What is the lesson of the analysed results? Knowledge in the area of earthquake-resistant construction is constantly improving. Thus, regulations in this area are also improving around the world. Special attention and activities must be focused on increasing the seismic safety of older buildings. In inspecting buildings after the Posočje earthquake, 4/5 of the inspected buildings were constructed before 1964, when the regulation on earthquake-resistant construction was adopted. This does not mean that all older buildings are not earthquake resistant. Many have solid underlying concepts and quality construction. However, it is necessary to constantly improve the seismic safety of buildings. Additional earthquake threats result from extensions and superstructures to old buildings without the prior strengthening of the basic structure. The consequence is constant surprise during earth movements. Many are not aware that stronger earthquakes are possible several times in the life span of a building in a seismically active area. Unfortunately, often the fact is that a strong earthquake is followed by campaigns for long-term repairs and improvement of regulations in the area of earthquake-resistant construction while, later all this changes into people's falling interest and, after that (usually 10 years after an earthquake until the next earthquake), even into rejecting expenses and avoiding regulations regarding earthquake-resistant construction.

GEOLOGICAL STRUCTURE OF BOVEC BASIN AND SEISMIC MICROZONATION

In the whole wider area of the town of Bovec, the main earth structure of the upper layers are composed of morainic glacial sediments comprising gravel alluvia. Gravel morainic sediments are covered by a layer of more of less thick clay, which appeared during the washing off of small fractions in the earliest Quaternary period. Only the ground of the south-easternmost part of Mala vas is composed of fluvial gravel alluvia of the Soča, which otherwise covers the whole Soča Valley. Therefore, the whole Bovec region is located in the same geological unit – morainic glacial and slope gravel alluvia [Vidrih, Ribičič, Lapajne, 1999].

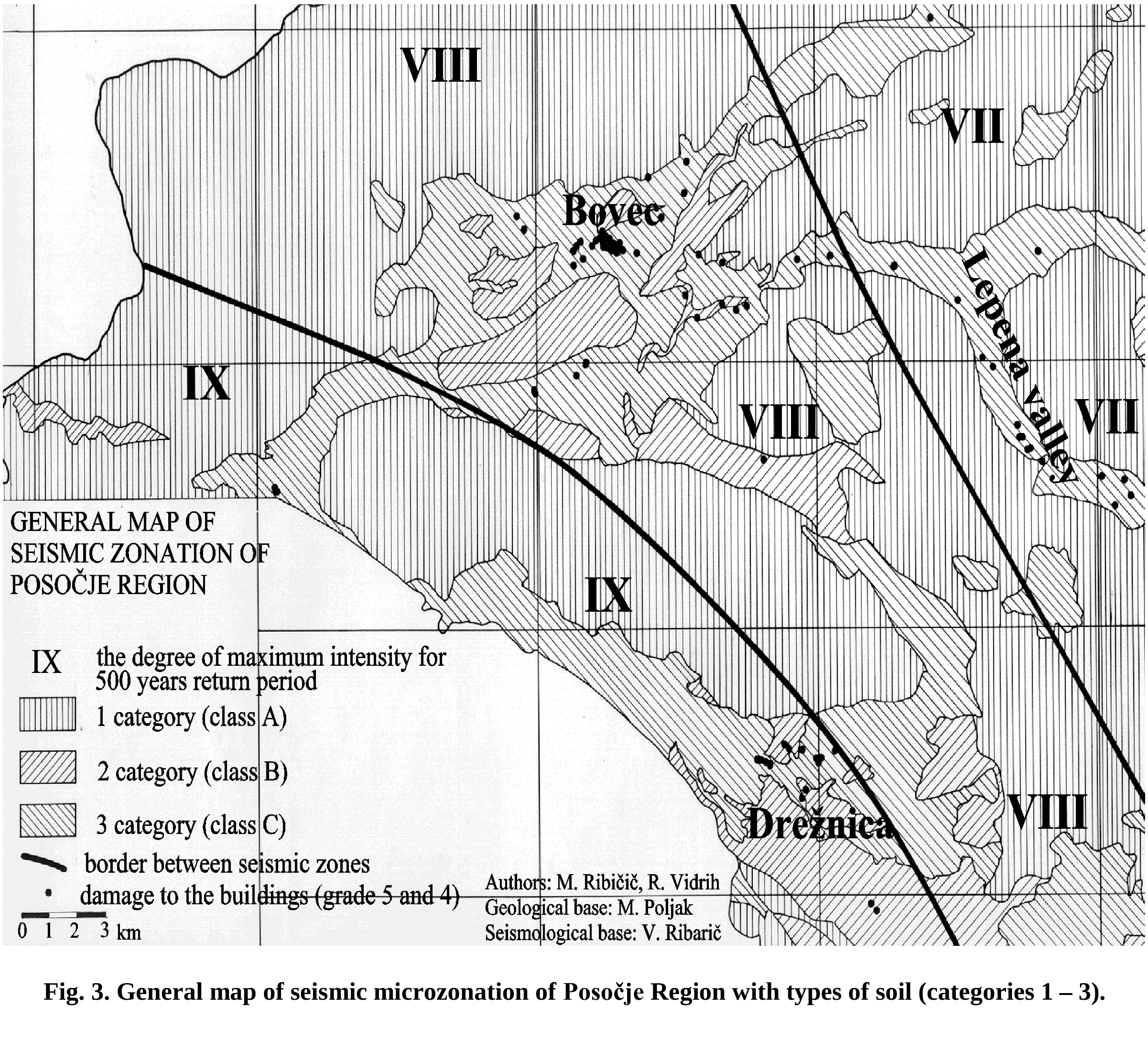

Fig. 3. General map of seismic microzonation of Posočje Region with types of soil (categories 1 – 3).

For the needs of repairs after the earthquake, we formed an overview map of seismic microzonation (Fig 3). To prepare the map of seismic microzonation, we used as the basis the official map of seismic hazard, presenting the levels of maximum seismic intensity for the return period of 500 years in Slovenia. This map is valid for planning buildings in seismically active areas. Apart from the map of seismic hazard, we also used the Geological Map of Posočje and much data from geotechnical and geo-physical studies of the area [Vidrih, Ribičič, 1994]. On the map we produced, we separated zones of different seismic intensities with thick lines. The terrain is classified into three different levels, namely levels VII, VII and IX according to the EMS-98. (It is necessary to mention that the accuracy of defining borders between zones of different intensities is estimated to involve an error of around 5 km, therefore the delineations should be taken as an approximate spatial estimate and areas in the 5-km strip should be classified into higher EMS levels.)

Slovenia's regulations enable us to divide the terrain within individual zones of seismic intensity into 3 ground categories on the basis of the seismic sensitivity of the ground. The ground category influences the earthquake-resistant design of buildings through the coefficient of seismic intensity and coefficient of dynamics, which vary for different types of ground.

The first category on the map of seismic microzonation is rock, the second category is compact and medium-compact soil deposited in thick layers and the third category is softer and less-compact soil. This division largely corresponds to the division applied in EUROCODE 8 (classes A, B and C).

On the overview map of seismic microzonation, we classified valley alluvial and slope (glacial) deposits into the 3rd ground category. We included in the 2nd category the terrain composed of clastic rock (flysch) or obstructing gravel of the Soča river, deposited in a layer of more than 50 m. The characteristic of clastic rock is that they are covered by a relatively thick weathering layer with poor seismic characteristics. We included in the 1st category the carbonate rock (bedded limestones and dolomites) composing the Alpine region. Analysis of the damage in both quakes (1976, 1998) helped us in construction of the map.

CONCLUSION

For the Posočje region, were already, especially after the 1976 earthquake, defined the construction and seismic conditions which we can also apply to the last earthquake on 12 April, 1998. During this earthquake and the elimination of its consequences, we obtained a considerable amount of new information on the basis of field research and analyses of damage to buildings and nature. Thus, we were able to form new useful engineering-geological, geotechnical and seismic maps [Ribičič, Vidrih, 1999]. One of them is shown in the article.

In addressing the consequences of the Posočje earthquake, it was revealed that special attention must be paid to increasing the seismic safety of older buildings. In inspecting the buildings in Posočje, 4/5 of the inspected buildings were constructed before 1964, when the regulation on earthquake-resistant construction was introduced. However, this does not mean that all older buildings are not earthquake resistant. Many have solid underlying concepts and quality construction. However, it is necessary to constantly improve the resistance of buildings.

In repairing older damaged buildings, special attention must be paid to their foundations. For digging along the side of buildings showed that the foundations of most older (and also some newer) buildings are not deep enough (mostly between 0.4 and 0.6m under the surface). The foundations are also poor quality, as they are put together or made from several-decimetre large pieces of limestone (sometimes also from other types of rock) or from concrete that has become very weak over years.

Much work will be needed to avoid earthquakes constantly surprising us in the seismically active Slovenia. The best protection, with good knowledge of seismo-geological conditions, is earthquake-resistant construction of new buildings and seismic strengthening of older ones. All of this requires systematic and long work, even though there has not been a strong earthquake in individual areas for decades. In all of this, one must take into account the local situation of a given terrain, itself significantly influencing the amount of damage.

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