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Aspects of earthquake risk management in Slovenia

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Abstract

This article presents the collaboration of two inter-disciplinary research projects on earthquake risk management for Slovenia and its capital city Ljubljana. Seismic resistance, structural vulnerability and fundamental frequency assessments of individual buildings were made and, using data from the Real Estate and Central Population registers, scenarios for the impact of different earthquake intensities were constructed. In addition, four applications were developed: guidance on earthquake preparedness for the public; a web application for self-assessment of building vulnerability; a support system for earthquake damage inspection; and an early post-earthquake damage assessment tool for planning rescue operations.

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1. Introduction

The article presents the scientific basis and the applications of numerous research projects which lately culminated in a Slovenian national research project “Earthquake Risk in Slovenia” (Lutman et al. 2013) and Ljubljana’s municipal research project “Earthquake Risk Assessment” (Banovec et al. 2012). After many years of planned

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research on earthquake hazard, structural vulnerability and earthquake risk, conducted separately by different scientific disciplines and professions, the time was ripe to start a joint research project with practical applications. Joining civil engineering, seismology, geology, mathematic, computer science and disaster management was not an easy task. But the effort paid off with numerous project outputs enhancing knowledge on possible earthquake effects in Slovenia and producing tools to tackle some of them. With knowledge on structural vulnerability, gained by analyses of numerous buildings, backed by knowledge of general seismicity, seismic microzonation, and the fundamental frequency of buildings it was possible to extrapolate, by applying mathematical modeling and computer science, to all building stock, using data from the newly established Slovenian National Real Estate Register. When data from other national and local registers, namely the Central Population Register and the rescue personnel register was used, hitherto unknown aspects of the social effects of an earthquake became apparent. This knowledge became the basis for development of a set of tools for disaster managers. Most obvious are earthquake risk assessment with different scenarios to be used for planning and preparedness and response instructions for the public. Others are an internet based application giving information on possible structural damage of an individual building after an earthquake, an internet based application for early post-earthquake damage assessment joined with on-line data gathering from public on the earthquake effects, and a support system for after earthquake building inspection.

1. The seismic risk of Slovenia and seismic vulnerability of its buildings

Slovenia is exposed to earthquakes: more than most European countries. Earthquakes of intensity VII and VIII on the European Macroseismic Scale (EMS) (Grünthal 1998) with a 475-years return period are expected in 54% and 41% of the area of Slovenia, respectively. The most severe earthquakes are expected in the territories around the City of Ljubljana, which are also the areas of the highest population density, in the River Soča valley and in the region around the City of Brežice. Given that damage and casualties are not caused by an earthquake itself, but by buildings and other civil engineering structures, it is necessary to know the seismic resistance and vulnerability of existing buildings, as well as an estimation of damage caused by an earthquake of expected intensity.

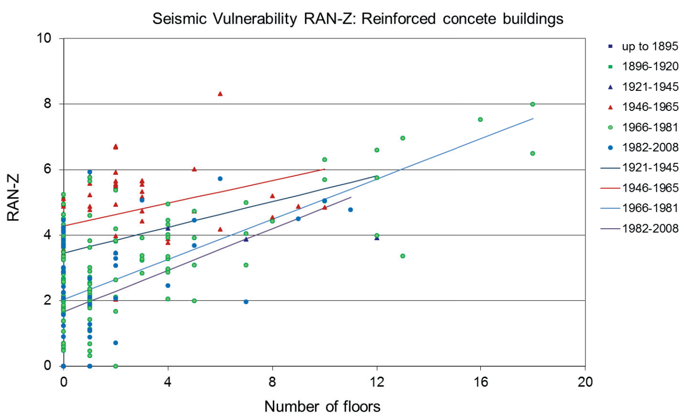
1.1. Seismic hazard - microzonation maps

Microzonation was applied to the area, where values in the design ground acceleration (ag) map of Slovenia (Lapajne et al., 2001) equal or exceed 0.225g (approximately 9% of the territory of Slovenia). The influence of local ground conditions on the seismic action was accounted for by considering the ground types and its corresponding soil factors as described in Eurocode 8 (EC8) (SIST EN 1998-1:2005, SIST EN 1998-1:2005/A101). Existing microzonation studies (Bovec valley, Breginj area, City of Ljubljana), data from the basic geological map and existing geophysical data were used. Some details were verified in the field. Two hundred lithostratigraphic units were recognised in all areas and classified into 6 ground types (A, B, C, D, E and S_1) with corresponding soil factors. The largest part of the investigated area is classified as soil type A (57 %), the least represented is soil type E. Data from the ground acceleration map of Slovenia for a return period of 475 years in rock or firm soil (Lapajne et al. 2001) was multiplied by soil factors to get the microzonation map based on EC8 ground types. The microzonation map in terms of the EMS intensity was based on the seismic intensity map of Slovenia (Šket Motnikar and Zupančič 2011). The map is made for a return period of 475 years and was based on average ground conditions of the given intensity area. In this study, the intensity increment was determined from EC8 ground types as follows: the intensity is decreased by 0.5 intensity degrees for ground type A, for ground types B and C it remains the same, for ground type D and E it is increased by 0.5 intensity degrees and for ground type S_1 it is increased by one EMS intensity degree.

1.2. Seismic resistance and vulnerability of buildings

In the framework of the recent project different methods for the assessment of seismic resistance and vulnerability were developed, suitable for different types of load-bearing structures. A parametric method "PO-ZID" has been developed for the assessment of the seismic resistance of masonry buildings (Lutman et al. 2002). The method “PO-AB” (Lutman and Peruš 2002) is suitable for assessing the seismic resistance of reinforced concrete buildings, and its results are comparable to the results of the method “PO-ZID”. An older method “RAN-Z” (Peruš et al. 1995) has been used for an evaluation of seismic vulnerability of buildings. These methods were first applied to important civil building in the City of Ljubljana: historical buildings of its old centre and other districts, health centers, fire stations, school buildings and kindergartens, buildings of different residential quarters and buildings of public services of the city. Earthquake resistance of older masonry high-rise buildings was evaluated by a nonlinear analytical method (Lutman 2012) and a computer program NASK (Lutman 1996), which uses the push-over method. During last three years, a large number of public buildings have been evaluated (Lutman et al. 2013). They are located outside the city of Ljubljana but within the areas of ag >= 0.225 g. Heritage stone buildings in Posočje region, that was hit by the two recent and most damaging earthquakes in Slovenia, were also analyzed. Since these buildings were repaired and strengthened post-earthquake, they represent a specific part of the whole database.

a)



b)

Period of construction / No. of floors	up to 1895	1896-1920	1921-1945	1946-1965	1966-1981	1982-2008
0	1	1	1	1	0	0
1	2	2	2	1	0	0
2	3	3	2	2	0	0
3	3	3	3	3	1	0
4	3	3	3	3	1	
5	4	4	4	3	1	
6	4	4	4	4	2	
7				4		
8				4		
9				4		
10				5		

Figure 1: (a) The correlation between the seismic vulnerability RAN-Z and the number of stories for reinforced concrete buildings; (b) Part of the model for the assessment of the damage grade, valid for the brick masonry buildings in the City of Ljubljana, sticken by an earthquake of EMS VIII (Lutman et al. 2013).

The estimates of seismic resistance and vulnerability have created a valuable database, from which certain correlations have been found. These findings are valid for buildings in Slovenia and reflect the influence of design codes, professional knowledge and construction practices from the period, in which a certain building has been constructed. For this reason it is expected that a building, for which higher seismic loads have been taken into account in the design project, is more resistant than a building designed to withstand lower seismic loads. Consequently, the seismic hazard maps, used in the design practice in different periods have been taken into account.

Relevant correlations have been identified within the database. Different correlations between the value of the seismic vulnerability of RAN-Z and the number of floors have been established for different types of vertical load-bearing structures and for different periods of construction. Regarding the types of the material of vertical structures there are stone masonry buildings, brick masonry buildings, reinforced concrete structures, combined structures (load-bearing walls and reinforced concrete vertical elements) and metal structures. Six periods of the construction have been selected: up to 1895, 1896-1920, 1921-1945, 1946-1965, 1966-1981 and 1982-2008. Derived correlations for reinforced concrete buildings are given in figure 1a. As expected, the newer buildings are less vulnerable and the most vulnerable reinforced concrete building in the data base were built closely after the Second World War (red line, figure 1a).

Correlations have been established for a rough assessment of the entire population of buildings in different areas of Slovenia with ag >= 0.225 g, for which reliable data for the year of construction, structural type and number of floors (the basic three characteristics) are available in the national Real Estate Register.

1.3. Fundamental periods of buildings

The fundamental period of a building is a parameter that influences a building's seismic load and consequently the building vulnerability and risk estimation. Microtremor measurements and their analyses (Gosar et al. 2010) were applied to estimate the fundamental period of more than 300 buildings in Slovenia. The method is cheap, fast and efficient. The ratio of amplitude spectra between the highest floor and the basement was computed for both horizontal components. The frequency, at which this floor spectral ratio reaches maximal value, is taken to be the fundamental frequency of the building. Based on a sample of 300 measured buildings, regression equations for fundamental building period as a function of height were determined for masonry, reinforced-concrete and combined type of construction, taking into account also residential or nonresidential usage. In such a way, the fundamental period of the majority of buildings that are described in the Real Estate Register, can be estimated, which allows further risk study.

Additionally, in the Ljubljana area free-field measurements were performed outside each building as well as in a 200 x 200 m^2 grid of free-field points, resulting in a map of the fundamental frequency of the sediments. By overlying this map with the fundamental frequencies of buildings, the locations of possible soil-structure resonance were identified.

1.4. Assessment of damage grade according to European Macroseismic scale

EMS gives the classification of damage to buildings, which defines five structural damage grades. Damage grade has a direct influence on the safety of buildings (ATC 1998). Buildings with no damage or with damage grade 1 are habitable (labeled: "green"), buildings with damage grades 2 or 3 have a limited use (labeled: "yellow") and buildings with damage grades 4 or 5 are not safe (labeled: "red"). The usability labels do not predict the economic eligibility for the costs of post-earthquake repair. For this purpose, further expert damage and safety evaluation is needed after the response phase.

A correlation has been established between the seismic vulnerability “RAN-Z” and the EMS. Taking into account the description of the EMS vulnerability classification, the appropriate EMS vulnerability class has been chosen for each combination of the basic three characteristics. This innovative procedure represents an important upgrade and the expected damage grade according to the EMS can be assessed. Relevant information about the population of the building stock has been used to estimate the distribution of damage among buildings of a certain area in Slovenia, hit by an earthquake of certain intensity. However, it is not suitable for the assessment of damage to individual buildings. Part of this model, which refers to the brick masonry buildings, exposed to an earthquake of intensity VIII EMS in the City of Ljubljana is shown in figure 1b.

Finally, the entire model for the assessment of seismic risk has been established by using the correlations, obtained from database of the Slovenian National Building and Civil Engineering Institute, the definitions of EMS, microzonation maps and publicly available databases, such as Real Estate Register and the Central Population Register. This model was used for the different scenarios described in the following sections.

2. Risk assessment

The City of Ljubljana is the capital city and the largest agglomeration in the Republic of Slovenia. According to the Central Population Register (March 2012) there are 299,483 permanent or temporary residents, living in the environs of the city, that is about 15% of the Slovene population.

An earthquake risk assessment model has been developed based upon the model described in 2.4., with the data input from the Real Estate Register and the Central Population Register. The outcome is information on how many people (with certain socio-demographic characteristics) will probably be directly affected by the earthquake of a certain intensity, how many people will probably need temporary shelter, and how many will probably need urban search and rescue, medical assistance, and permanent housing, how much temporary housing (tents etc.) is needed and how much land is needed to set it up, how much debris and ruble will probably need processing, how many light, medium and heavy urban search and rescue teams could be needed, how much fuel to run the equipment, etc (Banovec et al. 2012). Results are used for urban planning, contingency planning, emergency management planning, rescue operations planning and for table-top exercises (Jeraj and Lotrič 2014).

Strong earthquake with intensity VII-IX (dependent on ground type) could leave 20 % (11729) of buildings in the City of Ljubljana temporarily and 1 % (560) buildings permanently out of use. That also means 101168 (42 %) citizens temporarily without home and needing temporary housing and 14192 (6 %) citizens permanently without home and possibly needing rescue, medical care and rehousing (Banovec et al. 2012).

To further improve validity of the risk assessment, data on daily commuters from Statistical Office of the Republic of Slovenia was used and supplemented by data from the vehicle counting system and data on secondary school pupils and students. The main commuter traffic to the area of the City of Ljubljana consists of about 110,000 workers, about 50.000 other commuters (students, tourists, etc.) and about 15.000 people who are travelling to work in other municipalities. According to this data it is estimated that about 150,000 people commute to Ljubljana, which forms the basis for the evaluation of the daily earthquake scenario.

Given that even the destinations of the commuters remain largely unknown because existing registers do not contain data which could enable us to assign commuters to specific buildings, the seismic risk assessment is carried out on the basis that occupancy of buildings is increased by 50%, according to data on occupancy of buildings assumed from the Central Population Register. Thus, instead of roughly 300.000 people covered by the assessment of a night scenario, a daily scenario is based on 450,000 persons for the same buildings as in the night scenario. There is no need to provide temporary or permanent accommodation for commuting persons, but it is certainly necessary to provide search, rescue, and medical care. In the future a possible way of improving the daily scenario may be to use mobile phone occupancy.

For the proper emergency management planning and implementation of the rescue operations after the earthquake, a risk assessment of the rescue services is also necessary. Assessment of seismic vulnerability of their premises (mainly fire stations and health care facilities) was performed and indicated that some of those building could not be safe to use after an earthquake. Further hypothesis is that emergency and life-line services personnel will not be fully available also because they will be affected by the earthquake on their home - personally or their families. According to the analysis of their homes half of the City’s rescue personnel will be available after a strong earthquake (VIII EMS).

3. Web application for citizens for rough assessment of earthquake caused damage to their building

This questionnaire, prepared and available as a stand-alone internet application is a very important tool for general public. It allows an individual to estimate the expected damage of his or her building in case of an earthquake. Besides, it can significantly raise public earthquake awareness and understanding of the impact that quality of building maintenance and reconstructions have on its seismic vulnerability.

For the building under consideration basic characteristics have to be given first (year of construction, number of floors, the material of vertical load-bearing structure) and some complementary characteristics are taken into account as well (the slope of the terrain, the regularity in layout and in elevation, structural reconstructions, existing structural decay or damage). Basic and complementary characteristics are illustrated for a better understanding. Finally, the EMS intensity degree for the area of the building has to be chosen, assisted with the hazard map of Slovenia. The application gives estimates of the probability of damage −for each EMS grade− that could be caused to the building by an earthquake of the given intensity.

Due to the specificities and the limited number of reference buildings in ZAG database we should be aware that these estimates can be used as initial information only which can raise awareness and stimulate further action. They may not replace the proper analysis of the structure, made by an expert. Possible damage to a specific building can significantly deviate from the estimate due to the microlocation and configuration of the building, its condition, previous structural interventions and other parameters which require a proper on-site evaluation.

4. Early Post-Earthquake Damage Assessment Tool

The utilization of loss estimation techniques in the immediate post-earthquake context is a key development and marks a significant departure from conventional loss estimation applications (Eguchi et al. 1997). Within the project a comprehensive system for rapid earthquake damage assessment was for the first time developed for Slovenia as an easy to use web application and can be used by civil protection authorities for assessing general damage either immediately after an earthquake or can be used as a tool for training and planning purposes.

The components are complex mathematical models in combination with large publicly available databases, expert knowledge of building earthquake resistance and on-line data from seismograph sensors. The inputs to the Early Post-Earthquake Damage Assessment Tool are multiple databases that (1) describe the building's age, dimensions and construction parameters, (2) location according to seismic microzonation, (3) registered inhabitants of each individual building and (4) earthquake intensity at the epicenter. The tool calculates the impact of the earthquake for each individual building using the described mathematical models and intensity attenuation model as shown on the figure 2a (Šket Motnikar and Zupančič 2011).

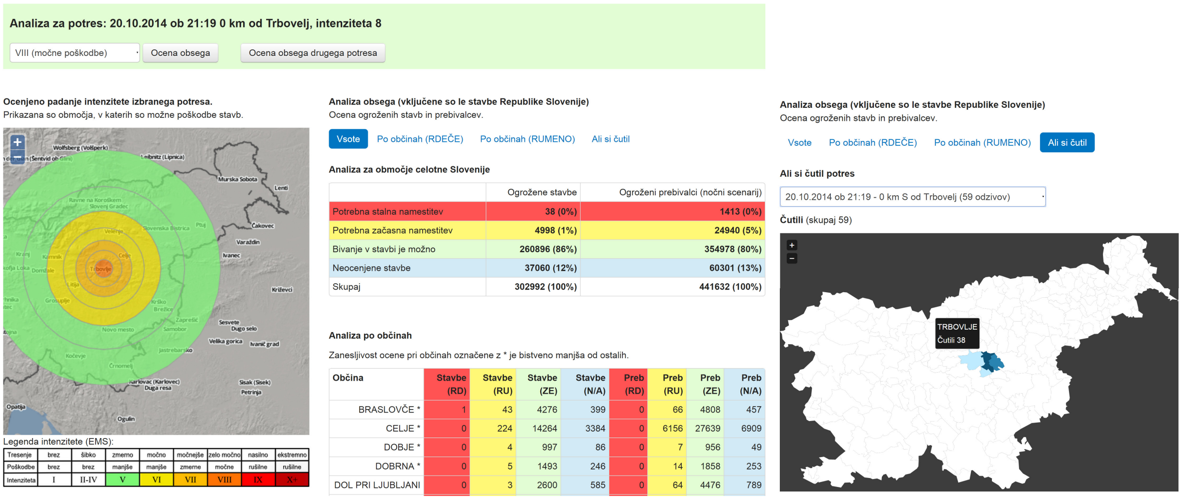


Figure 2: Web window system of Early Post-Earthquake Damage Assessment Tool. a) calculated impact (left); b) reported effects (right)

Results are then aggregated to larger areas (e.g. municipalities) and presented in of buildings and inhabitants who do not need tabular form and on a map as shown on figure 2a. They contain the number of damaged buildings for each aggregated area (left side) with the number of inhabitants (right side) within four different categories: (red) number of buildings and inhabitants who have to be permanently relocated and housed and potentially rescued and provided with medical care; (yellow) number of buildings and inhabitants who have to be temporary relocated and housed; (green) number to be relocated; (blue) number of buildings and inhabitants that cannot be estimated due to lack of data or estimation uncertainty.

The important part of the Early Post-Earthquake Damage Assessment Tool development was the optimization of the mathematical models and algorithms with the goal that complete assessment is done in less than 30 seconds for any earthquake affecting Slovenia. The tool is further equipped with on-line data gathering from public on the earthquake effects, and results are analyzed and visually presented (figure 2b). Comparing pictures from both, calculated and reported consequences can give civil protection authorities as fast and good as possible assessment of the earthquake effects. The Early Post-Earthquake Damage Assessment Tool was designed to serve as a useful tool in most parts of the accident life cycle: response, mitigation, planning and preparedness. The system rapidly calculates of the size of the affected area and makes an assessment of number of damaged buildings and the population at risk, which is the basis for response planning including the rapid activation of the European Civil

Protection Mechanism. It serves also as risk assessment tool for producing earthquake scenarios as an input to the emergency management planning and exercising. The tool was extensively used in the "Earthquake 2012" national exercise with a scenario of a large earthquake (Jeraj and Lotrič 2014).

5. Support system for post-earthquake building safety evaluation

One of project goals was to renew existing Slovenian form for post-earthquake building safety evaluation. Form was shortened in order to decrease the time necessary for single building assessment and adapted for the EMS. Within the revised form a new software tool for supporting post-earthquake building safety evaluation process was developed (Banovec et. al. 2014). The tool can be run on any computer without internet connection which is vital after an earthquake. The whole application is available on a single USB memory stick.

The main goal of the tool is to provide the support for populating and printing the questionnaires with up to date data from the several national public registers and to ease data collection, aggregation, dissemination and visualization.

The application is an extensive upgrade and enables civil protection authorities to quickly use the data collected on the field by providing the following features: (1) area maps including borders of inspection areas; (2) preprinted forms for each building in the affected area with data on buildings from the Real Estate Register so that experts only fill out that part of the form that refers to the building's damage; (3) quick processing of the data from the returned forms which can be done by a barcode reader or by manually with only basic data relevant for first analysis (building available for unlimited further use, lightly damaged load bearing structure – temporarily unavailable for use and partially or totally collapsed) on the needs for temporary accommodation and debris removal; (4) form processing can be done on many locations and the exported data can be sent via an email or transferred by a USB memory stick to support data import/export and allow national authorities to collect and analyze all the data in one central place; (5) quick analysis of the data can be performed directly within the tool and because of the data export feature it is possible to make more detailed analysis with other statistical applications; (5) The tool supports a "training mode" and a "real world mode" where the former mode includes only test building data which is depersonalised and slightly modified and the latter mode is password protected and includes access to the complete dataset for the whole country, which is securely encrypted and stored on a USB memory stick due to security; (6) publicly available datasets can be easily renewed when outdated; (7) implementation of standardised classifications (Real Estate Register), standardized procedures (EMS) and the option for data export/import allows that the data collected by the evaluation forms can be further used in other systems (e.g. integration with the Slovenian National System for registering damage − AJDA).

6. Conclusion

The results of two research projects on earthquake risk management for Slovenia and its capital city Ljubljana are presented. Multidisciplinary research, stimulated by the needs of emergency management professionals, provided many practical outputs that could potentially save lives. The design of the models allows for future upgrades in accordance with improvements to the quality of the data in the national registers. As more buildings are analyzed and as better data on people's whereabouts during a given period is acquired, future re-running of the models described here could give even more valid results. With adjustments for local conditions the models have wider international applications, outside of Slovenia.

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