MEASURES FOR THE EARTHQUAKE RISK REDUCTION IN THE CITY OF ZAGREB, CROATIA

Josip ATALIC¹, Marta SAVOR NOVAK², Mario UROS³, Sanja HAK⁴, Domagoj DAMJANOVIC⁵, Zvonko SIGMUND⁶

ABSTRACT

The ongoing study on earthquake risk reduction conducted in collaboration with the City of Zagreb is presented in this paper. Zagreb is the capital of the Republic of Croatia, with almost 20% of the country's population. It is located in the seismically active zone. Most of the residential units were designed according to seismic loads that are significantly lower than those in currently valid seismic codes (Eurocode 8). Therefore, an earthquake poses a great hazard for the city. Zagreb building stock data have been very limited, but the new project proposal for a comprehensive study on Zagreb seismic risk, including the establishment of the building inventory, is currently awaiting approval. In the scope of the process, necessary screening forms for buildings and bridges were proposed. Faced with many unknowns regarding the building inventory, in this project phase the focus was on local specific buildings and buildings of great importance for the City, which were analyzed in detail. Preliminary vulnerability assessment was performed using proposed forms developed in the study. In the next step, performance of selected structures was evaluated, based on numerical models and experimental testing. It was found that verification and calibration of numerical models based on testing was essential for some specific buildings. Preliminary results were obtained and damage was estimated according to EMS-98, and critical structural elements for all analyzed buildings were also detected.

Keywords: earthquake risk reduction; seismic performance assessment; Zagreb building stock; damage evaluation

1. INTRODUCTION

Zagreb is the administrative, cultural, scientific and economic center of the Republic of Croatia, with almost 20% of all population living in the country and about one third of the country’s GDP according to the Croatian Bureau of Statistics (2017). It is the seat of the central government, administrative bodies and almost all government ministries, as well as the largest Croatian companies, media, many scientific and cultural institutions, hospitals, industrial facilities and historic monuments. Zagreb is also the most important center of Croatian road, rail and air networks, but also a very important European transport intersection. The Zagreb region is located in north-western Croatia, seismically the most vulnerable region in Croatia due to its economic importance. It is in the border zone between the Alps, the Dinarides and the Pannonian basin, at the “triple junction” between the Periadriatic, Balaton and Drava transcurrent faults, which may generate moderate to strong earthquakes (Herak 2009, Kuk et al. 2000). Zagreb lies in the zone bordered by more seismically active epicentral areas, of which the most important is Medvednica Mountain area. In the last few centuries Zagreb and its surroundings experienced strong seismic activity. In the great Zagreb earthquake in 1880 almost all of the buildings were damaged and many of them collapsed (Figure 1). Moreover, it is reported that liquefaction

¹Assistant professor, Faculty of Civil Engineering, University of Zagreb, Croatia, atalic@grad.hr
²Assistant professor, Faculty of Civil Engineering, University of Zagreb, Croatia, msavor@grad.hr
³Assistant professor, Faculty of Civil Engineering, University of Zagreb, Croatia, uros@grad.hr
⁴Seismic Structural Engineer, Basler & Hofmann AG, Zürich, Switzerland, sanja.hak@gmail.com
⁵Associate professor, Faculty of Civil Engineering, University of Zagreb, Croatia, ddomagoj@grad.hr
⁶Postdoctoral researcher, Faculty of Civil Engineering, University of Zagreb, Croatia, zsigmund@grad.hr
appeared in the valley of the Sava River (Herak et al. 2009).

According to the Croatian seismic hazard map (Herak 2012), the reference peak ground acceleration is approximately 0.20-0.28g on bedrock for the return period of 475 years. Seismic micro-zonation for the city is still in progress, but for the investigated city areas it is established that the stratigraphic profile corresponds mostly to ground type B and C according to Eurocode 8 (Jurak et al. 2008, Herak et al. 2013). It should be pointed out that almost one third of all Zagreb residential units were built before 1964 when the first seismic codes appeared in the region (after Skopje earthquake) and additionally, approximately half of the residential units built after 1964 were designed for the seismic loads that are less than 50 % of the seismic load according to valid Croatian seismic standard Eurocode 8.

In regard to the risk estimation at global level, in the framework of Global Assessment Report (UNISDR 2015) the probabilistic seismic hazard assessment was developed and used for risk estimation. For Croatia, considering earthquake hazard, the average annual loss is estimated to be 153 million USD, while the probable maximum loss for five mean return periods (100, 250, 500, 1000 and 1500 years) is estimated as 1.7, 3.6, 5.7, 8.4 and 10.2 billion USD. On the pan-European level, the seismic risk of 28 EU countries (Croatia included) was assessed by Corbane et al (2016). According to the study results no city in Croatia is in the top 20 cities in EU in terms of absolute or relative (to GDP) expected losses.

At the national scale, not many aspects aimed at the seismic risk assessment have been addressed until recently by the local civil and earthquake engineering research community (e.g. Hadzima-Nyarko et al. 2011, Galista et al. 2015, Kalman Šipoš and Hadzima-Nyarko 2017) even though Croatia includes seismically very active regions. Although for the case of all cities and counties risk assessments are prescribed by law, currently existing documents include only very general information and do not rely on sufficiently relevant data. Croatia has received the directive from the European commission to implement Risk Assessment and Mapping Guidelines for Disaster Management (Brussels, SEC (2010) 1626), with the aim to achieve the harmonization of methodologies and allow for comparison of risk assessment outcomes between member states. Based on the decision by the Croatian Government in 2013 related to the preparation of disaster risk assessment studies and the establishment of related working groups, the Faculty of Civil Engineering in Zagreb, has been nominated as one of the executive members for the assessment of risk due to earthquakes, with the aim of supporting the initiative through scientific investigations.

Therefore, a document named National Risk Assessment in the Republic of Croatia, Seismic Risk was prepared for the Ministry of Construction and Physical Planning and National Protection and Rescue Directorate of Croatia in 2014. A rough preliminary estimation of Zagreb buildings at risk for two different scenarios has been proposed, based on scientific expertise of the working group for seismic risk. It should be pointed out that this document was prepared within the restraints of specified guidelines, with predetermined earthquake scenarios and output risk matrices. During the process, it was recognized that the building inventory is far from a format usable for risk assessment procedures and that some existing data were very uncertain (e.g. because of many illegal interventions in the building stock). The need for systematic building stock database and more reliable risk assessment procedures became obvious.

Figure 1. Building damage after Zagreb earthquake 1880: a. Vlaška street, b. the Upper Town, Popov tower – observatory; c. Zrinjevac, Archaeological museum (Simović 2000)
At the local level, the only systematic study that has been carried out with the aim to estimate earthquake losses in Zagreb due to a possible earthquake scenario was published over 25 years ago (Aničić et al. 1992), so in the light of state-of-the-art expertise in the field cannot be considered appropriate any more.

Currently, the project proposal for a comprehensive study on Zagreb seismic risk, prepared by the Zagreb City Office of Emergency Management in collaboration with the Croatian Academy of Engineering and the Faculty of Civil Engineering in Zagreb, is awaiting approval. The work presented in this paper includes preliminary investigations of some specific aspects, which are important for the planned project proposal and will need sound scientific support. It covers the development of various forms (screening forms for buildings and for bridges, forms for post-earthquake investigations on buildings and bridges, forms for preliminary vulnerability assessment), first steps toward a building inventory, detailed analysis of selected buildings (with specific local features, characteristic for the city districts and important buildings representing critical City infrastructure - hospital, fire stations, an industrial building, student dorms, concert hall, national theatre, city council building, etc.), creating of numerical models database and topics linked to post-earthquake activities (Atalić et al. 2013-2017). Hence, some challenges and results of the ongoing research efforts are presented in the following paragraphs.

Recalling that seismic loss can be quantified through the convolution of four individual factors (i.e., seismic hazard, exposure, vulnerability and specific cost), it is evident that a crucial step is the formation of a building stock database with characteristic information evaluated based on local expertise. Therefore, in this preliminary phase, investigations are focused on specific building-by-building analyses, covering structures with seismic performance that cannot be captured reliably with rough estimations on the city scale, nor with common available vulnerability models.

Zagreb has moderate to high seismic hazard, high exposure (due to historical heritage, population density) and high vulnerability (due to age, poor maintenance, design for low seismic forces, poor construction quality, many buildings in aggregates without seismic joints, etc.). Therefore, a high seismic risk may be expected for the city, and consequently for the whole country because of the high impact that losses in Zagreb due to an earthquake would cause to the overall national economy.

2. BUILDING INVENTORY

Development of a seismic risk model depends significantly on the exposure data, with the building stock data being the most important of it. In the recent years significant efforts towards the development of a European building inventory database have been undertaken (Crowley et al. 2012, 2014), with the aim to describe the number and area of different European building typologies. Within the scope of the European FP7-funded project NERA (Network of European Research for Earthquake Risk Assessment and Mitigation) building stock information has been collected for each country taking into account national building or dwelling censuses and national records on construction practices performed by statistical or financial services of the country. Available data for Croatia is to some extent limited with respect to some other earthquake-prone countries, since despite the recent census in 2011 (Croatian Bureau of Statistics, 2011) only the date of construction, the occupancy class, the number of dwellings and the average number of people per dwelling could be extracted from statistical information. Other details needed for the more precise description of the building exposure (e.g. number of buildings, material, number of stories, structural type, etc.) were not available through statistical data. Therefore, building classification and number of dwelling in each building class for urban areas in Croatia was obtained using Google Street View application and forms filled out by the local experts.

The database structure of the Global Exposure Database (Gamba et al. 2012), an initiative of the Global Earthquake Model (Pinho, 2012), is being used to store the European building inventory data, available at different levels of resolution and characterization across Europe. The results of the validation of the proposed uniform European building database using a set of so-called test-bed sites in Europe in which detailed local building-by-building surveys have been made, demonstrated the need for further studies to identify the regional and local variations in building stock as a basis for loss
estimation, rather than relying on estimates made on a national basis, which may be seriously misleading (Spence et al. 2012).

The planned project for the comprehensive study on Zagreb seismic risk (City Office of Emergency Management with Croatian Academy of Engineering in collaboration with the Faculty of Civil Engineering) is aimed to contribute to forming a systematic database of the characteristic building stock in Zagreb. In the scope of research for the project preparation (Aničić et al. 2014) it is very roughly estimated that in Zagreb the most common building structural type are masonry buildings (approx. two thirds of all buildings), followed by reinforced concrete buildings (less than 30 %). Since the project proposal is still awaiting approval, preliminary steps towards a building stock database have been undertaken within the scope of this study. Zagreb is divided into different areas taking into account specific building types (e.g. monolithic RC structures, RC prefabricated structures, masonry buildings with RC floors, masonry buildings with timber floors, etc.) and the time of construction (Figure 2).

![Figure 2. Map of Zagreb with labeled regions comprising characteristic types of buildings; photo of the region 7](image)

These specific areas are investigated in detail and comprise collection of building data from existing documentation, including statistical datasets, national registers, samples of drawings, technical specifications and photographs taken during the construction. Additionally, field surveys are conducted in these regions.

For example, region marked with number 7 covers city districts Zapruđe and Utrine, with occupancy of approximately 13,000 inhabitants. Building were constructed in 1960’s and consist of reinforced concrete prefabricated elements, specific for construction in the region (Jugomont JU-61 system). Three types of residential buildings in the region are: the lower type, consisting of ground floor and 4 storeys (GF+4S), of medium height (GF+8S) and higher buildings (B+HGF+16S). Totally, there are 7 buildings of lower type, 58 buildings of the medium height type and 8 towers. A typical medium height building with layout and characteristic detail of prefabricated element connection is given in Figure 3. The process of collecting documentation for further specific areas is still ongoing. Additionally, some other sources for filling in the database are currently being explored.

Furthermore, the link between the construction period and seismic codes is established. That way, it can be assumed what seismic loading a building of interest was designed for and roughly get an insight to its seismic resistance. From Table 1 it is evident that very few dwellings were designed according to modern seismic codes.
Following challenges have been encountered during the preliminary building data collection:

- Many buildings (especially old ones) are of unknown structural and material parameters (non-existing architectural plans and design documentation);
- In some cases, when documentation exists, real structural state differs a lot from the designed one because of:
  - many structural interventions (reconstructions, adaptations, enlargements) made after the construction (very often illegally and without any expertise),
  - large deviations from the designed parameters during construction of many recently constructed buildings designed according to modern codes (urban villas built for fast profit of the investors);
- Many completely illegal buildings (without any design or documentation).

The government recognized the problem of illegally built structures, so the Act on Proceeding with Illegally Built Buildings entered into force in 2012 with the basic purpose to legalize as many as possible of illegally built buildings and thus making order in the state physical planning. For example, more than 90,000 applications to legalize buildings were submitted in the Zagreb region from 2012 and the period for submission of applications is still opened (until end of June 2018).

Therefore, great care should be taken in creating the building database, because documentation/visual screening conducted outside of the building/aerial snapshots/google street view may give incorrect/incomplete information, as has been confirmed during this study.

In the scope of this study, screening forms for buildings and bridges were proposed, taking into account local-specific features, necessary for future building-by-building field surveys. Furthermore, the applicability of these forms for implementation to Global Earthquake Model database is currently being investigated.

The level of safety and comfort of life in the city significantly depends on the city's infrastructure, so it is of the great importance to enable its functioning even after an earthquake. It is important to mention that Zagreb is divided in two parts by the Sava River: the Old (north) Zagreb and the New (south) Zagreb. There are 9 road bridges in Zagreb and surroundings which connect these parts. These bridges are of strategic importance and besides traffic, they conduct many lifelines. Moreover, almost all hospitals are located in the northern part of the city, so that proper functioning of Sava bridges is of vital importance for the citizens living in the southern part. Only three of these bridges are designed according to up-to-date seismic regulations, so that significant damages and even collapse of some of them may be expected in case of strong earthquakes. It should be pointed out that their maintenance is rather poor and their design service life is well exceeded. Although some bridges databases are available in Croatia (e.g. SGG – concessionaire Croatian Motorways), there is no seismic bridge inventory, a database which would comprise all data of importance for bridge seismic performance. No systematic vulnerability assessment has so far been made for any of these bridges (only a
preliminary damage assessment of the central Sava bridge, the Liberty Arch Bridge, built in 1959, was made using calibrated numerical model), although from the available data and observed condition, some of them are in need of urgent seismic retrofit. In the scope of this study a form for seismic inspection of the bridges is developed which can be used to create the bridge seismic inventory.

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<tr>
<td>Valid seismic code</td>
<td>No code</td>
<td>Temporary technical code for building loads</td>
<td>Ordinance on Technical Standards for Construction of Building in Seismic Areas.</td>
<td></td>
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<td>European Standards EN (Eurocode 8)</td>
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<td>Motivation for code modification</td>
<td>Skopje earthquake 1963</td>
<td>Montenegro earthquake 1979</td>
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<td>Number of dwellings</td>
<td>app. 40 000 (app. 12%)</td>
<td>app. 75 000 (app. 24%)</td>
<td>app. 87 000 (app. 29%)</td>
<td>app. 70 000 (app. 22%)</td>
<td>40 000 (app. 12%)</td>
<td>Few</td>
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<td>Building seismic resistance (rough classification by structural type and analysis method)</td>
<td>buildings with an initial level of earthquake resistance (mostly masonry buildings with wooden floors, since 1920 the introduction of RC floor)</td>
<td>buildings with minimal level of earthquake resistance (RC floors: partly prefabricated or constructed in-situ, masonry buildings without confining elements, etc.)</td>
<td>buildings with a low level of earthquake resistance (masonry buildings with horiz. and vert. confining elements, RC residential buildings etc.)</td>
<td>buildings with a medium level of earthquake resistance (masonry buildings with horiz. and vert. confining elements, RC frames, RC etc.)</td>
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<tr>
<td>Structural analysis (horizontal load)</td>
<td>earthquake was not accounted for as an action, but the horizontal wind load was defined</td>
<td>earthquake was accounted for by utilizing simplified methods (e.g. concentrated force at the building top)</td>
<td>first codes for design of seismic resistance, (seismic map of 1964)</td>
<td>regulations, modifications and amendments to codes for design of structures for seismic resistance (simple rules, preliminary seismic maps, 1981 and 1988)</td>
<td>development and gradual introduction of modern codes for design of structures for earthquake resistance, increase of the seismic design loads</td>
<td>European standards for design of structures for earthquake resistance Seismic hazard map, 2013</td>
</tr>
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<td>Seismic load</td>
<td>up to 5% of the design load according to EC8</td>
<td>up to 10% of the design load according to EC8</td>
<td>30-50% of the design load according to EC8</td>
<td>30-50% of the design load according to EC8</td>
<td>75-100% of the design load according to EC8</td>
<td>100% of the design load according to EC8</td>
</tr>
<tr>
<td>Causes of building vulnerability</td>
<td>aging of materials, events through history (earthquakes, fires, etc.), insufficient initial resistance, exceeded design service life of 50 years, poor maintenance, particularly endangered cultural heritage</td>
<td>poor lateral resistance, poor construction quality, poor structural details, questionable designs</td>
<td>designed for lower seismic loads – expected damage much larger than anticipated in design (possible collapse), poor quality of materials, poor details, incomplete designs, etc.</td>
<td>designed for lower seismic loads - expected damage much larger than anticipated in design (possible collapse), illegally constructed buildings, adaptations, improper upgrading and reconstruction (additional floors), poor details etc.</td>
<td>mainly designed for seismic loads, expected damage larger than anticipated in design, illegally constructed buildings</td>
<td>Complex, poorly designed buildings; buildings with large deviations from the designed parameters during construction (urban villas built for fast profit of the investors); buildings (mostly in northern city region) built on steep grounds (landslides)</td>
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3. PRELIMINARY VULNERABILITY ASSESSMENT

The most important parts of this study are schematically shown in Figure 4.

Figure 4. Schematic layout of the study

As the first step, buildings to be analyzed were selected from the preliminary database:

- Buildings with specific local features (semi-prefabricated RC structures called “cans” with characteristic connection details; structures constructed using tunnel formwork; array of buildings comprising structural walls in only one direction, constructed without seismic joints; building aggregates; etc.),
- Buildings characteristic for specific city areas defined in Figure 2 (especially, for the areas in the new part of the city, but also buildings characteristic to the old city centre, family houses, etc.),
- Important buildings (public buildings, critical infrastructure, historic monuments, e.g. hospital, fire stations, industrial buildings, student dorms, concert hall, national theatre, city council building, etc.).

Most of the selected buildings could not be assessed with common available vulnerability models.

In the scope of the study, forms for preliminary vulnerability assessment of buildings were proposed. They are constantly being updated and calibrated according to numerical model and testing results. The building vulnerability relative ranking may be established by comparing values of two proposed factors, VR and RIZ. Thus, these values may be used as preliminary indicators of the building performance during an earthquake. Factor VR represents an estimation of probability of building collapse and it depends on period of construction, reference PGA, ground type, structural system, number of floors, ratio between area of structural walls and total area of ground floor, pounding effects, etc. The other factor, RIZ, represents estimated probabilistic value of a building’s risk, which is a function of the factor VR and maximum damage to be expected in case of a total building collapse.

Abovementioned selected buildings were analyzed using proposed preliminary assessment forms and building ranking was established by comparing values of proposed factors VR and RIZ for all analyzed buildings. Following form-based vulnerability assessment, the performance of selected buildings was evaluated using numerical models calibrated with experimental measurements (almost all buildings were tested using ambient vibrations). After the ambient vibrations measurement, operational modal analysis was used to determine natural periods, mode shapes and damping of tested buildings. Although these parameters were obtained for small amplitude excitation, they were...
extremely important for verification and calibration of initial numerical models, e.g. to verify the current structural condition in comparison to the designed one (possibly very different because of interventions), to determine influence of joints between buildings in an array, etc. During this study, examples have repeatedly shown that without detail visual inspection and numerical analysis, it is very difficult to reliably predict the performance of specific existing buildings. For example, the hospital “Sveti Duh” was originally built at the beginning of the 20th century, but in the recent thirty years it was reconstructed and enlarged many times, so that today it is a complex of many buildings without seismic joints, comprising different structural systems, constructed of different materials, etc. (Figure 5a). These interventions were not documented. Therefore, the detailed visual inspection, the appropriate numerical analysis and ambient vibration measurements were crucial.

Another interesting example is Firefighting Unit (FU) Center of Zagreb Fire Department (Figure 5b), which represents critical infrastructure in every earthquake scenario in Zagreb. The location of the Unit, in the vicinity of the historic Zagreb center, is very important, because majority of casualties are expected here. The block, where the FU Center is located, comprises 8 buildings, mostly built at the beginning of the 20th century (with later reconstructions and annexes). All of them were investigated, and the most important ones (taking into account its purpose and consequences of potential collapse) were analyzed in detail. Numerical analysis results of the very important Connection Center Building indicate that the building could experience substantial to heavy damage due to design seismic load. Moreover, it is essential to ensure that a potential building collapse inside the Unit does not prevent fast exit of firefighting vehicles for intervention, but also passes towards main streets. Therefore, collapses of the buildings that could block the main exit: building of the City Housing and Municipal Services Company (GSKG) and Firefighting Tower, the oldest building and protected cultural heritage structure, are analyzed in more detail. Results show that the first building is constructed very solidly, and local collapses of the passage are not expected (only in the case of major earthquake), while the tower may experience very heavy damage due to design seismic load. Moreover, one type of reinforced concrete buildings, usually with 10 storeys (Figure 5c), which was found to have very unfavorable layout of walls in the ground floor (only in one direction and softened at many locations), showed to be much weaker than expected, even weaker than some unreinforced masonry buildings.

Figure 5. a) hospital “Sveti Duh” b) Firefighting Unit Center c) RC building

In the scope of the process, critical structural elements in every analyzed building were identified and described, based on the results of numerical models and testing. This is very important for future seismic retrofit and could help in an earthquake reconnaissance. Moreover, local engineering judgement was used to determine the influence of building location in relation to identified faults and potential landslides (more than 800 in the area of Medvednica Mountain). The results of the preliminary vulnerability assessment (factors VR and RIZ) were compared to the results of damage assessment based on numerical models, so that the forms could be properly calibrated.

All numerical models are saved in the database of models. Extrapolation to similar buildings is currently being investigated (number of buildings and occupancy). Results are summarized in the forms (called Building ID). The example of building ID is given in Figure 6 for a characteristic building for region number 7 (ZA) (according to Figure 2).
It is planned that all forms are incorporated to GIS (e.g. web service City Zagreb spatial data infrastructure).

Given that the creation of an earthquake risk model depends crucially on the quality of the exposure data, before the complete building stock database is formed, no reliable seismic risk assessment for Zagreb can be performed. Furthermore, only after the risk is estimated, the seismic retrofit process could be initiated. Just to mention, the process of energy renovation of public buildings and housing in Croatia, financed by European Structural and Investment Funds has already started, but the thematic priority 5 related to prevention and monitoring of the natural risks is not yet prepared on the national level, although it is in the funding priority according to the description of Competitiveness and Cohesion OP in Croatia.
4. OTHER ACTIVITIES FOR EARTHQUAKE RISK REDUCTION

In the scope of this study some other activities intended for earthquake risk mitigation are conducted. In particular, the organization of the responsibility with systematically defined communication channels is proposed for the City to be better prepared for an earthquake emergency. Forms for different levels of post-earthquake visual inspection of buildings and bridges are developed (with detailed descriptions and explanations) and they are continuously being updated according to specific local building features. Identification of critical structural elements in characteristic structures, obtained using numerical models, besides for seismic retrofit process, may also be very useful for rescue teams and for post-earthquake assessment of damages in buildings. The rescue team staff needs to be educated about different buildings’ vulnerability and especially about expected weak structural elements for specific building types. Therefore, in collaboration with the City, the training of firefighters and engineers is currently being prepared, using experiences gained through EU project Matilda (MultinATIonaL module on Damage Assessment and countermeasures). Additionally, the Faculty of Civil Engineering in collaboration with the National Protection and Rescue Directorate (firefighters, USAR teams, etc.), organizes joint exercises for various post-earthquake activities.

5. CONCLUSION

This paper briefly describes most important parts of the preliminary study, covering wide topics related to the measures for the earthquake risk mitigation in Zagreb, including seismic risk assessment, which will be the focus of the future comprehensive project currently awaiting approval. The first barrier in the development of the seismic risk model is the missing building inventory database. Therefore, all available efforts are put to constructing it from the scratches, as many useful data are missing from the national census data conducted in 2011. Many challenges have been met in this process, because physical state of the city is very “messy”, with many illegal interventions to the built environment. Various forms were proposed for the detailed visual inspection surveys, comprising additionally specific local building features. Forms for preliminary vulnerability assessment are proposed with the basic aim of identifying critical buildings, in urgent need of detailed seismic analysis and possibly a retrofit. Numerical models were developed for selected buildings that are specific for large city districts and for buildings of great importance for proper functioning of the city, for which no vulnerability models are available. Almost all selected buildings were also tested using ambient vibrations in order to capture their real condition and thus calibrate initial numerical models. The database of different numerical models is currently being prepared. After the building classification is completed, existing results of detailed analyses of individual buildings will be used for sets of buildings (results extrapolated to the all similar structures). It has to be pointed out that critical elements of every analyzed building are detected from the numerical models that might greatly contribute to process of seismic retrofit. Additionally, knowing the potentially dangerous spots in the buildings may facilitate post-earthquake inspection of buildings if needed and work of the firefighters who will participate in post-earthquake rescue teams. Although Zagreb lies in the seismically very active zone, there were no stronger earthquakes in the area since the 19th century, so that there is no public consciousness about potential catastrophic consequences. Therefore, in the scope of the study in addition to seismic risk topics, activities related to preparedness for an earthquake also needed to be covered (education and organization of the staff for post-earthquake reconnaissance, joint exercises with firefighters, National Protection and Rescue Directorate, etc.).

In conclusion, there are still many steps needed to be taken for the development of the accurate seismic risk model of Zagreb, but the process has started and hopefully, the national authorities and the public community will recognize the urgent need for systematic risk estimation and its mitigation.

6. ACKNOWLEDGMENTS

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