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Education of future civil engineers, civil engineers, colleagues of other professions and the public

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Abstract

Earthquakes are rather rare in Croatia. Therefore, citizens of Croatia are less motivated in understanding the earthquakes than the citizens of e.g. California or Japan. Unfortunately, this results in difficulties which civil engineers have in fulfilling the requirements of clients and even architects. Additionally, in education and lifestyle, Croatia is traditionally oriented towards Austria and Germany, northern countries where the earthquakes are not significant for the stability of the buildings. That is why the corresponding subjects were included in the civil engineering curricula in Croatia rather late. Also, this is why many of the family houses have been often built without any engineering support. Even after the March earthquake damaged a considerable number of family houses and older buildings in Zagreb and the surroundings, the citizens in general still do not understand that a stronger earthquake could be expected and they do not recognize the difference between the reparation of the cracks and improvements of the structural stability. The response of the Government showed that the community is ready to help people who lost their homes in the March earthquake, even those whose apartments or houses suffered damages. It is clear that a similar response could be expected in case other parts of the country got hit by an earthquake. It is good to bear in mind that preventing damages of this kind is several times less expensive than dealing with the damages. Therefore, it would be advisable to invest in retrofitting the older buildings and family houses. The paper suggests education for the citizens of Croatia to facilitate the understanding of the importance of the civil engineering role. The paper proposes an addition to the education of architects to ease communication with the structural and geotechnical engineers. The paper proposes elements of education for the civil engineering study programmes and the graduated civil engineers to help them deal with seismological data.

Key words: education, architects, structural engineers, earthquakes, civilians

1 Why would additional education be necessary?

The damages and phenomena following the Zagreb 22 March earthquakes, and Petrinja 28 and 29 December earthquakes had important impact on many people's lives in Croatia. Many of the persons in Zagreb or its vicinity, as well as in the Sisak-Moslavina County lost their homes or their homes got seriously damaged, and the industry and agricultural works suffered substantial losses.

How was it possible for an EU member to have this level of damages after all the standards were in place, prepared by the best experts from all around Europe? Well, like in many other areas around the world, the new standards rarely get applied to the older buildings and houses. Therefore, the older buildings and houses, built before the new standards were adopted, often suffer damages or collapse even in the areas of the world that are used to earthquakes. Sometimes we get alarmed and encouraged. The M6.9 Loma Prieta earthquake in 1989 and M6.7 Northridge in 1994, gave an important incentive to various organizations and individuals to start retrofitting bridges and buildings and preparing them for the next big one. However, for the right set of actions, we need to understand the interaction between earthquakes and buildings – which may be quite impossible without proper education.

The necessary insights are, of course, different from role to role, and it is important to have proper trust in other professions – but also to value both their competences and their limitations. It appears that without proper understanding no true improvements could be done. One of the examples was the initiative to upgrade the energy efficiency in the existing buildings in the recent years – forgetting about the certainty of new earthquakes and the necessity to improve the structures. At the same time, numerous fountains and monuments have been built in the capital of Croatia – while all the hospitals, many schools and other significant buildings, as well as bridges etc., were in need of improving their structures. A new hospital was to be built in Zagreb, but its completion was, unfortunately, stopped after the main structure was built – which is still in good condition, while the buildings of the most of the hospitals in Zagreb need retrofitting or replacement. One of the open issues is the certainty that in a foreseeable future Zagreb should expect an earthquake quite stronger than felt in the year 2020, an M6.5 or similar. Therefore, repairing the damages and returning to the previous conditions is just a temporary, maybe a too expensive solution. Zagreb needs better structures for many of its buildings. The same may be said for the vicinity of Zagreb, as well as for many other areas in Croatia.

2 Immediate response and decision to help and support restoration

For people in Croatia owning a house or apartment is quite important as other solutions of living are expensive and often unpleasant. Therefore, many people engage a big portion of their income, take loans and suffer for years to allow their families, and future families of their children, to live in nice houses and have proper safety in their lives.
In the cities, apartment buildings are quite common, but in the suburbs and in villages, many people live in family houses, and in many cases, those were built or rebuilt by their owners, or with some support not-adequately educated. Family houses are rarely designed by engineers. Many of such houses suffered badly in the recent earthquakes, as well as older buildings built before appropriate standards were developed.
Volunteers from all over the country started gathering in a couple of hours after the earthquake to lower the dangerous chimneys, improve the roofs situation, help in all imaginable ways, but also to inspect the houses safety, give psychological support, cook, bring food, clothes, toys, etc., as well as to provide caravan trailers, container houses, houses. The law was passed promising financial support to those who lost their homes or those that were damaged, although there are some differences in the level of the promised restoration. It is important to note that the community, both as individuals who quickly organized themselves, and as the state, decided to compensate for the lost homes and make sure that the citizens affected by these earthquakes get decent places to live. This will mean substantial costs to the EU and Croatia, but it certainly seems proper not to abandon the victims of a natural catastrophe. It is important to notice here that the reparation may be several to many times more expensive than prevention of the earthquake damages. [1]
It is important to keep in mind that many parts of Croatia may expect strong earthquakes in the future and that there is a substantial number of buildings and houses which need retrofitting.

3 Role of civil engineers

Although civil engineering has been an almost invisible profession for decades, the structural engineers came into focus of media after the earthquakes in Croatia, as they volunteered, together with many architects – from the first hours after the events – in evaluating the safety of the damaged buildings and houses. It became clear very soon that many of the buildings built without the engineering support behaved very badly and had a lot of damages or even collapsed. Most of the citizens understood quickly that the engineers (structural engineers) were needed to give them approval to continue living in their homes, or no approval so that they have to leave them.
The Croatian Centre for Earthquake Engineering (Hrvatski centar za potresno inženjerstvo) [2] was established ad hoc by the experts in structural engineering, earthquake

engineering and in damage recognition. The education for the younger or less experienced colleagues was prepared, so more than 1,000 volunteers contributed to the wellbeing of the citizens and worked on preliminary inspection quickly and diligently.
In the Petrinja earthquakes, another series of problems appeared: numerous cases of liquefaction under houses and in the field, landslides and cover-collapse sinkholes. These events turned the spotlight on geotechnical engineers and geologists.
Geotechnical engineering should be present also to recognize the possible amplification of the earthquake effects on the buildings on soft soil. Famous are the damages in the Mexico City in 1985 event M8.0, some 400 km from the epicentre – due to the amplification on the soft deposits under the city.
Geotechnical engineering should be also present to recognize the dangers of liquefaction and landslides and to prevent those problems, or deal with them should they occur. Actually, geotechnical investigation should never be forgotten.
Hopefully, civil engineering and geotechnical engineering, with the support of geology and seismology, will retain the deserving importance after being suddenly recognized.

4 Our cities in the past, present, and in the future

Having a history connected with Austria and Hungary, many of our former engineers and architects came from those countries or studied there, where the earthquakes do not significantly influence the building safety. Therefore, many of the Downtown buildings in Zagreb and Petrinja were built without considering the earthquakes and with more or less rich decorations, and contrary to the suggestions of the great Andrija Mohorovičić, who already after the 1880 Zagreb event warned of the dangers from the falling sculptures etc. [3] as seen in Figure 1 after the 2020 event.

Figure 1. Detail of one of the buildings in Zagreb with beautiful decorations, beheaded

In the meantime, the situation of those beautiful buildings deteriorated – the material aged while various windows or doors got opened up, or walls removed, without proper care for the stability.

The 1962 Makarska M6.1 brought again the awareness of the earthquakes into our lives. The 1963 Skopje M6.1 event provoked the creation of new standards, which allowed the newer buildings to be safer and their behaviour in recent events better. However, even the 1969 Banja Luka M6.0 and 6.4 events were not sufficient to turn the understanding of the public to the downtowns built before.

Joining the European Union and adopting the Eurocodes increased the requirements on the design of buildings but, unfortunately, without much reflection on the 19th or the first half of 20th century. Many of those buildings were damaged in March 2020. Some of them are being repaired, some of them strengthened.

However, even some newer buildings got damaged and many might be seriously damaged in the stronger earthquake that may be expected. Unfortunately, still in the recent years structural engineers have difficulties in persuading some of their colleagues architects, and various investors to allow for better structures, as the behaviour of a building depends decidedly on the design, not only on the calculations.

5 Behaviour of structures in earthquakes and their design

Almost each big earthquake gives new insights and allows the design rules to be improved. However, the importance of the structural simplicity has been recognized a long time ago, together with the importance of regular stiffness distribution, uniformity, symmetry and redundancy, regularity in elevation and in plan, minimizing weights, etc. The behaviour of buildings may be regulated by pendulums, dampers, isolators, etc. [4]. Less fortunate buildings – with irregular plans and without proper reinforced concrete elements – suffered serious damages or collapsed. Two examples shown in Figure 2 witness our need to close the walls and to highlight the edges – but it was done only as a decoration, not structurally.

Figure 2. Unfortunate houses in Petrinja illustrate the need to hem the walls – which was done only visually, not structurally

6 Education of civil engineering before, now and in the immediate future

Quick education prepared by the Croatian Centre for Earthquake Engineering [2] was sufficient for the young colleagues to inspect the damaged houses and categorize them. Nowadays, the retrofitting of many buildings is starting and new experts are going to be necessary. Many engineers with appropriate experiences and competences never stopped working, but the need in demanding structural design got high.

It would be recommendable for all the institutions teaching civil engineering to revise and expand their programs with earthquake engineering. The same is valid for the programs offered to the chartered engineers. Geotechnical earthquake engineering should not be forgotten on both levels with additional geology and seismology, earthquake effects, basic soil mechanics if necessary, appropriate field investigation and laboratory testing, stress-strain models, liquefaction, slope stability problems, bearing capacity and settlement of structures, retaining walls and seismic zonation. Some elements of seismology to better understand the uncertainties would be valuable addition.

One of the weaknesses of civil engineering designers is low assertiveness and adding subjects on communication skills as a welcome addition to the curricula. Many of the communication problems, however, that structural engineers have with architects, might be attributed to the too small overlapping in education.

7 Does the education of architects need to be expanded?

Japanese architects are at the same time structural engineers. Architects in Croatia, on the other hand, in spite of the rich program about structures in their curricula, often lack the understanding of the intentions and requirements given by structural engineers. Encouraged to be imaginative and original and artistic, some architects forget about the importance of stability, and especially of the stability in an earthquake and long series of aftershocks. The rules for the design in seismic conditions are simple, but very important. One of the most important recommendations is to keep the distribution of stiffness wide enough and the plan simple and symmetrical.

To cope with insisting on symmetry, colours, for example, may be used to give the necessary visual individual qualities, as obvious on the famous "Vitić" building designed by the architect Ivan Vitić and shown in Figure 3.

Additionally, very important are many details which are usually to be decided by architects, but are crucial for the behaviour of structures. For example, parapet walls, as in Figure 4, may shorten the column in between making it stiffer and loading it with bigger force. If not designed appropriately, the structure does not correspond to the calculations of the civil engineer. This is why it is vital that architects take part in the communication with the colleagues while designing a building.

In the Petrinja earthquake the wooden houses– light and flexible – behaved very nicely, like the one in Figure 5, however old it is.

Figure 3. Building designed by architect Ivan Vitić in Zagreb, Laginjina 9 photo by Borko Vukosav [5]

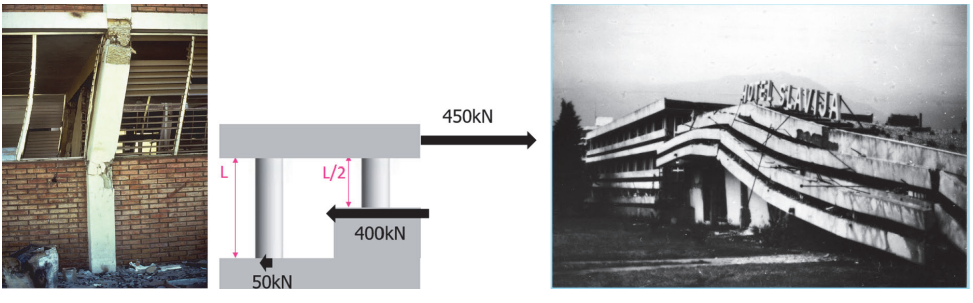

Figure 4. An example of short column [6], an explanation, and an example of soft storeys [7] illustrating the need to coordinate closely the work of architects and structural engineers

Figure 5. Wooden house in Mečenčani, on the fault of the December earthquake, without any damage. Wooden houses in the area suffered occasional plaster peeling, but generally no structural damages

Urbanists are too often not interested in the ground conditions. However, the widespread liquefaction in the Sisak-Moslavina County, and numerous sinkholes that suddenly opened in and around Mečenčani, show that the urbanists should get involved with geotechnical engineers, who are to work with geologists and geophysicists before deciding on the future plans for new settlements.

Figure 6. Two of the cover-collapse sinkholes in Mečenčani. Widespread liquefaction in the December earthquake [8]

In a similar way, architects should be aware of the requirements that actual ground conditions, as well as landslides etc. could pose to the foundations.

Figure 7. Three photos from Petrinja: a manhole filled with sand due to liquefaction, ejecta on the other side of the house and the consequent cracking; cracks around the balcony due to settlement caused by liquefaction across the street. Two photos from Brest Pokupski: a cracked house and thick layer of ejecta after liquefaction – the crack spread through several yards and filled several houses with up to 50 cm of sand

Figure 6 shows two sinkholes of the kind known in the area, but not in such a number as after the earthquake – obviously facilitated by many aftershocks and wet weather, occasional snow which contributed to the high water content of the soil after rapid temperature rise. Figure 7 shows two houses in Petrinja and one in Brest Pokupski after the dramatic liquefaction in the area followed by settlements and cracks in hundreds of places in the area. Having all this in mind, it is proposed to expand the curricula for future urbanists and architects with the following (foreseeable required time suggested in the parentheses):

- Appropriate earthquake engineering:
  - earthquake nature, causes, and variability in foreshock and aftershock series, (2 hours);
  - Gutenberg-Richter's frequency-magnitude relation showing uncertainty of the maximal magnitude, (1 hour);
  - magnitude and intensity in several scales with comparisons, (2 hours);
  - the main rules of aseismic design, including importance of proper detailing, (9 hours);
  - dealing with furniture etc. [9] [10], (2 hours);
  - basic assumptions of calculations, (4 hours);

- Basics of soil mechanics and geotechnical engineering:
  - problems which could be encountered (landslides, excessive settlements including soil failure, liquefaction, amplification), (2 hours);
  - the necessary main contents, methods and possibilities of geotechnical investigation, explaining the variability in the ground and its importance, (2 hours);
  - the main properties of soil and rock, with emphasis on the uncertainties, (4 hours);
  - ways to avoid various geotechnical problems, in comparison with the costs of dealing with the possible damages, (2 hours);
- Seismic zoning and geology for urbanists:
  - importance of faults recognition, irregularities i.e. periodic occurrence of earthquakes, (2 hours);
  - problems caused by building on the faults, and solutions, (2 hours);
  - roads, railways, lifelines crossing faults in earthquakes, (2 hours);
  - seismic zoning and codes, (2 hours);
  - landslide prediction limitations and current solutions, (2 hours).

The suggested time necessary for these contents is estimated on the experiences in teaching of Earthquake Geotechnical Engineering at TUAS in Finland (first author), and Earthquake Engineering at the Zagreb University of Applied Sciences (second author).

8 What should citizens know on earthquakes and earthquake engineering?

Just after the 2020 earthquakes in Croatia, television and newspapers were full of statements and explanations given by seismologists, geologists, geotechnical engineers, civil engineers, as well as reporters, to satisfy the need for explanations, to calm the weary citizens.

However, some of the given accounts got misinterpreted, and the sum of the stories does not cover the full picture. At the same time, the citizens of Croatia deserve a program which will teach the irregularities and uncertainties of earthquakes, and the meanings of the most frequently used terms – so that the reports on earthquakes would become familiar like weather reports.

The second aim of the program should be to convince of the utmost importance of the proper design and proper construction. The benefits of the involvement of architects and civil engineers should be emphasised.

The third step should be giving the main rules for the construction of small houses. The rules should not stop with the seismic effects, but take care of the rules everyone could follow to avoid landslides, problems with foundations and retaining walls, openings and closing cracks on high plasticity clays, and similar. Such program could be prepared through television, but in a systematic way, prepared by people who are devoted to and experienced in education.

The program could be given in the way the great Dr. Andrija Štampar [11] organized his School of Public Health, but with contemporary means and dealing with the importance of house stability (including foundations and ground) and the means to achieve it, proper plumbing to avoid foundation problems and proper fixing of the furniture [9]. The details are too numerous and exceed the contents of this paper.

9 How to obtain appropriate quality of the whole system?

The response of the citizens-volunteers through their help, of the state through the new laws and organization of financial support, of the EU through the financial support, show the importance of being loyal to the victims of natural disasters.
As the prevention of damages in earthquakes is many times less expensive than the reparations [1], all the country should be engaged in the new levels of organized education to avoid future unnecessary expenses.
The citizens should be prepared to turn to the engineering support or the support from architects.
Architects should be prepared to understand the seismic and geotechnical problems and to accept the cooperation with civil engineers.
Civil and geotechnical engineers – designers – should be prepared to understand the seismological vagueness and architectural liberties.
Public administration should be prepared – by appropriate programs, or by employing the graduated civil engineers – for the inspection of the designs which passed without stricter revision.
Contractors and supervising engineers should be prepared to recognize vital details in the designs and in the construction.
All parts of the system should be involved in the safety of buildings with full responsibility for their respective part of work and cooperation.
Laws and standards should be followed strictly.
All steps should be transparent and return the faith in the community and engineering.
Most of the mentioned undesired phenomena can be prevented, which is multiple times less expensive than repairing the damages and losing the population.

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References

[1] Multi-Hazard Mitigation Council, "Natural Hazard Mitigation Saves: 2019 Report," National Institute of Building Sciences. , Washington, 2019.

[2] Hrvatski centar za potresno inženjerstvo, 2020. [Online]. Available: https://www.hcpi.hr/. [Accessed 14 02 2021].

[3] M. Herak, Personal communication, 2021.

[4] Zlatović, S., Gukov, I. (2020): "Kako smanjiti rizik od šteta uslijed potresa," Polytechnic & Design, vol. 8, no. 3, pp. 193-203.

[5] B. Vukosav, "Fotografije," Telegram [Online]. Available: https://www.telegram.hr/kultura/obnova-cuvenog-viticevog-nebodera-skoro-je-gotova-otisli-smo-vidjeti-kako-izgleda/. [Accessed 14 02 2021].

[6] Meehan, J.F. (1972): Managua, Nicaragua earthquake of December 23, The Earthquake Engineering Online Archive NISEE e-Library [Online].

[7] R. McGuire, Hotel Slavija, 1979 Yugoslavia Earthquake.jpg, U.S. Geological Survey.

[8] USGS, "M 6.4 - 2 km WSW of Petrinja, Croatia, Liquefaction Estimated," 29 12 2020. [Online]. Available: https://earthquake.usgs.gov/earthquakes/eventpage/us6000d3zh/map?bounds=45.30008111428633,15.714080672521536&bounds=45.81671702515404,16.864054051534943&shakeMapIntensity=false&ground-failure-liquefaction=true. [Accessed 29 12 2020].

[9] FEMA, "Earthquake Safety at Home," 03 2020. [Online]. Available: https://www.fema.gov/sites/default/files/2020-08/fema_earthquakes_fema-p-530-earthquake-safety-at-home-march-2020.pdf. [Accessed 15 02 2021].

[10] FEMA, "Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds," 06 2007. [Online]. Available: https://www.fema.gov/sites/default/files/2020-08/fema577_design_guide_improving_hospital_safety_2007.pdf. [Accessed 04 03 2021].

[11] The Croatian Museum of Medicine and Pharmacy, "Andrija Štampar," [Online]. Available: https://hmmf.hazu.hr/andrija-stampar-1888-1958/?lang=en. [Accessed 03 03 2021].