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40 years after Montenegrin earthquake: lessons learned and future challenges

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Abstract

The territory of Montenegro is characterised with very high seismicity, where seismic hazard decrease from the coast to mainland. The last devastating earthquake occurred in April 1979 when a lot of modern facilities were destroyed, as well cultural and historical monuments, roads and railways. The directed damages were approximately in value of 15 billion of US dollars in today's value. This paper presents the overview of characteristics structural damages observed in facilities caused by this earthquake. The known circumstances and human errors that led to collapse of structures are also discussed. The paper briefly presents most common structural measures taken in Montenegrin engineering practice in order to repair the the earthquake induced damages or to retrofit existing facilities. 40 years after an earthquake, Montenegrin society is facing new challenges in earthquake engineering, both from practise and science point of view. 4 % in total losses from natural disaster events in past 15 years is induced by earthquakes, which is a lot considering that no significant earthquakes were registered during the period. An overview of measures taken (or planned to be taken in future period) in order to decrease seismic risk on territory of Montenegro are presented: from implementation of modern codes, developing and implementation of innovative solutions for retrofitting of structures to conducting national seismic risk assessment.

Key words: past earthquake events, earthquake damages, decreasing seismic risk

1 Introduction

On April 15, 1979, at 7 hours and 19 minutes, Montenegro experienced a catastrophic earthquake, a devastating catastrophe that was more severe than any other in this region, many centuries back. The time of the earthquake occurrence was fortunate circumstance in the disaster that hit Montenegrin society and economy. The consequences of such an earthquake if it had happen on a working day or during the tourist season can hardly be imagined. The earthquake epicentre was in the Adriatic Sea, between Ulcinj and Bar, at a distance of 14 kilometres from the coast, at a depth of 15 km with the magnitude of M = 7. Seismological research has shown that the preparation of this earthquake lasted longer than two years, with pronounced seismic activity at the ends of known seismic faults [1, 2]. As of March 31, 15 days before the earthquake, activity intensified in the vicinity of future epicentres - the city of Ulcinj. The main foreshock of the earthquake took place on April 9 with a magnitude of 5.1. After the main impact on 15th of April, seismic activity continued on the Montenegrin coast, so only in 1979 in Montenegro there were 60 strong earthquakes with a magnitude greater than or equal to 4 and more than 100 earthquakes with a magnitude in the range of 3.4 to 4. Results of analyses [3] showed that in the period of 40 days after the main earthquake, about 40 % of the total energy of aftershocks was released, and remaining 60 % in the following period, which lasted longer than a year.

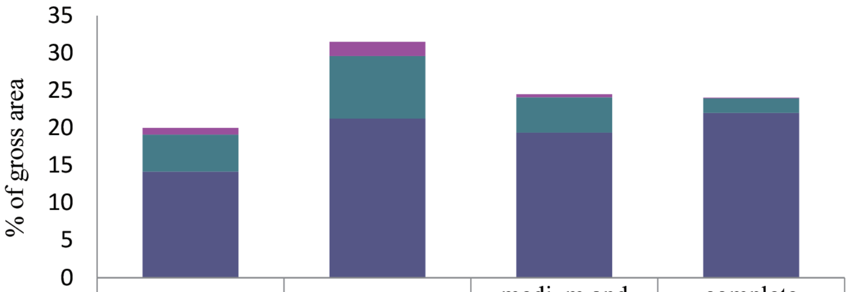
From this time distance, it is fair to say that Montenegro was not prepared for such a strong earthquake. It did not have the adequate organization, nor was it able to respond adequately in terms of personnel and institution capacity immediately after the earthquake. In the folowing days, months and years after the earthquake, Montenegro had great support coming to eliminate the consequences from the former Republics of SFRY, as well as in international organizations such as UNDP, UNDRO, UNESCO.

2 Montenegro earthquake effects

It is estimated that around 58 000 facilities was damaged with minor or major damage occurrence in Montenegro earthquake. The study [4], covered 40 000 facilities in six coastal and two central municipalities. 92.9 % of buildings investigated were masonry structures, 4.91 % reinforced concrete (RC) and 2.18 % steel and wooden structures. According to the gross area of the surveyed buildings, masonry structures occupied 76.76 %, reinforced concrete 19.96 % and wooden and steel structures 3.27 % of total investigated area. By their occupancy 82.3 % were residential facilities, and the rest were cultural, tourism or education facilities.

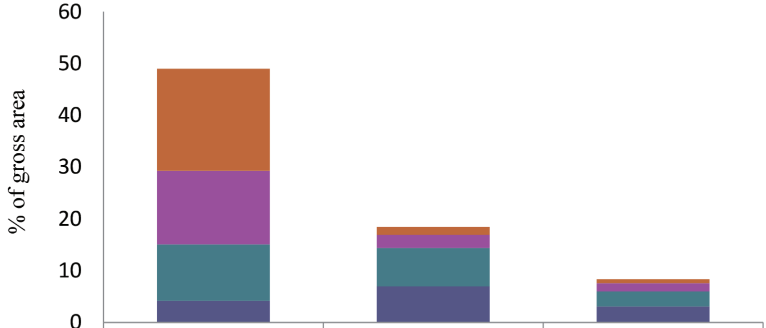
Damage in buildings of wooden and steel structures, considered both in total number and in percentage in the total gross area ofthe building is negligible. Only 0.09 % of the total area (0.04 % of the number of buildings) that suffered complete damage were classified as wooden or steel structures. The largest number of damaged buildings, in terms of both percentage in number and gross area, were masonry structures. Fig. 1. shows the distribution of damage in percent of the total area of all investigated facilities depending on the type of structure. As much as 22 % of the area declared as complete damage is accompanied to masonry structures, while approximately 2 % were RC structures. Fig 2. shows the distribution of damage among the types of masonry structures, where it is observed that the largest damages occurred in stone masonry structures, i.e. 19.6 % of the total gross area investigated that was declared as complete damage were stone masonry structures, while as expected, much better behaviour was observed in confined masonry buildings. Among RC structures, RC frame systems proved to be the most vulnerable, see Fig 3.

Totally 8 large hotel facilities collapsed, 53 hospitals and other health facilities were heavily damaged or collapsed, 570 social and child care facilities and 240 school facilities were damaged. Cultural and historical monuments (monasteries, churches, museums) were particularly affected. Major damage was observed on the road network - about 350 km of long-distance and 200 km of regional roads were damaged. Port Bar was heavily damaged, shipyard in Bijela partially sunk. The damage zone covered around 600 square kilometres, 101 people lost their lives.



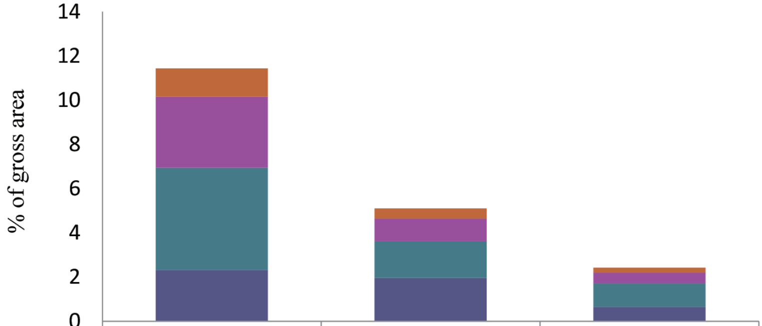
	undamaged	small damages	medium and large damages	complete damage
■ Timber and steel	0,9	1,9	0,41	0,09
■ RC structures	4,93	8,36	4,71	1,96
■ masonry	14,17	21,23	19,37	21,99

Figure 1. Damage classification according to structural type in percentage of gross area of all inspected facilities after Montenegro earthquake



	stone masonry	clay brick masonry	confined masonry
🟧 complete damages	19,67	1,52	0,78
🟪 medium and large damages	14,24	2,55	1,58
🟩 small damages	10,89	7,41	2,92
🟦 undamaged	4,16	6,95	3,06

Figure 2. Distribution of damages among masonry structural systems



	RC frame	RC wall	RC dual
🟧 complete damages	1,28	0,45	0,22
🟪 medium and large damages	3,21	1,03	0,48
🟩 small damages	4,62	1,66	1,07
🟦 undamaged	2,32	1,96	0,65

Figure 3. Distribution of damages among RC structural systems

It was obvious that most vulnerable structures were stone masonry structures, that were heavily damaged and and the large number of this type of structures suffered complete damage. In next period of time, even for structures that have not been damaged, or had small damages, the technical condition for obtaining building permits included necessary strengthening and upgrading of this type of structures, especially for old urban settlements.

Regard the significant number of modern reinforced concrete structures that had collapsed, mostly hotels situated on sea cost, it was concluded that most vulnerable among them were RC frame structures. Even if those structures have not been seismically designed, it was noticed that dual or I-wall systems from same construction period, suffered less damage. The combination of soft soil characteristic and flexible RC frame structures led to resonant behaviour and sever displacements and damages.

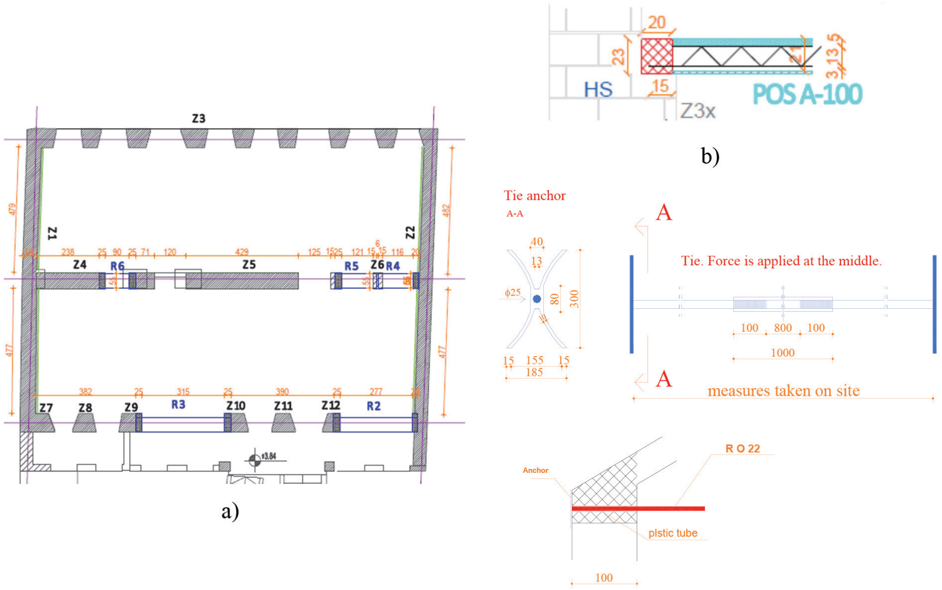
3 Measures taken after earthquake event

Immediately after the earthquake, a series of measures were adopted aimed at mitigating the consequences of the earthquake. Teams of experts for the damage classification and buildings usability have been formed at the national and municipal level. As many as 147 working groups and 26 specialized teams for cultural facilities composed of domestic and foreign experts have been employed [5]. In next months and years, with the technical assistance of UNDP, several crucial projects were implemented such as: "Spatial Plan of the Republic and general urban plans of urban settlements of Montenegro", "Reduction of seismic risk in the Balkan region", "Seismic micro-regionalization of urban areas of the Republic of Montenegro". Domestic enterprise RZUP (Republic Institute for Urbanism and Design) actively participated and managed the implementation of mentioned projects as well as many others. It should be noted here, without going into the elaboration socio-economic occasions characteristic for that period that activities of RZUP (a company that operated exclusively on market principles) were of immeasurable importance for the recovery of the whole society. The existence of such an institution, which was able to provide professional, technical and even financial support to the Government, is difficult to imagine at the present time.

In the short term, the earthquake highlighted the importance of organization and readiness to carry out all activities immediately after the earthquake: clearing roads and establishing communications, housing, providing financial support to vulnerable populations, forming and activating team experts to inspect facilities, redlines for planned and systematic data archiving [5]. The activities and measures carried out in the extended period of time after the earthquake are best illustrated by their results: Spatial Plan of Montenegro, map of the epicentre and seismic micro-zoning, map of the suitability of the terrain for urbanization, innovated design regulations (1981 and 1985), completed and the adopted method of seismic risk management "*from urban planning to expert supervision*".

In the following years, a period of renovation of damaged buildings began. Most of the damaged buildings were masonry structures, historical buildings and monuments. The priority in repair and strengthening were old rural and urban settlements followed by individual cultural monuments. Criteria for selecting priorities were [6, 7]: 1) cultural-historical significance of a building or group objects; 2) the diversity of its former functions and the possibility of valorisation of its purpose; 3) condition and degree of damage; 4) danger from further decay and 5) rationality and efficiency of possible recovery solutions for fast recovery.

All repairing measures designed for masonry structures aimed at providing structural integrity at the story level in order to ensure adequate distribution of seismic forces and to avoid individual vibration of structural components. Whenever it was possible, RC slabs with RC belt course (detail on Fig. 4b.) were designed. In case of monuments were such interventions were not possible, horizontal steel ties were incorporated at the top of the wall (see Fig. 4c)



a)

b)

c)

Figure 4. a) Floor plan of a masonry structure with interventions (measures in cm) [8] b) detail of new RC floor slab and confiment belt (measures in cm) [9] c) Steel ties at the top of the church wall (measures in mm)[10]

Improvement of bearing capacity mostly consisted of: injection of masonry with cement emulsion, jacketing of walls on both surfaces were possible, incorporating new vertical RC columns and walls. Fig. 4a. shows one typical design of strengthening masonry residential building using internal jacketing of Z1 and Z2 walls and incorporating vertical RC members (designated as Ri).

4 Implementation of the results achieved after 1979. Earthquake in past 40 years

It is not easy to point out all relevant evaluations of archived results in seismic risk reduction in past 40 years in only one paper. Regard of original idea of urban planning driven by geoseimic conditions implemented in Montenegro spatial plan valid until 2000 (year of first implementation 1986), all further documents (spatial plans from 1997. and latest from 2008.) fully considered globally established concept. Also it can be said that all relevant supportive legislative in the domain of construction of objects continuously improved during the time. In the domain of the design today we are implementing the latest findings from European regulations: EUROCODES are valid regulations in Montenegro. Also, starting from year 2008 up today, legal solutions governing the design, execution, project documentation revision as well as supervision over the construction have become stricter and more demanding over time, aiming at establishing order in the area of planning and design. Also it is worth to mention that many strategic national documents are created and implemented in period of 2006 to 2019 i.e. *The strategy for disaster risk reduction with dynamic action plan for implementation of the strategy for the period (2018 – 2023)*, *National plan for the protection and rescue in earthquake (2018)* etc. which represent valuable contribution to future activities.

Still, it is evident that not all planed is also executed in practise. Main omissions are most obvious at the local level. Often inadequately altered detailed urban plans of settlements or their disrespecting in practise, as well as during time developed tolerance to mass illegal construction (see Fig. 5), led to significant increase in density of population and concentration of construction in urban areas. It is easy to conclude that consequently all above led to increase of seismic risk. Perhaps the best description of the situation on site can provide the term “investor urbanism” (a term used by the domestic professionals and public), which indicates the concept policy applied in urbanism in which the financial interests of investors are often at the expense of the public interest. As the example here will be stated only several ongoing cases in Montenegro: rapid and uncontrolled development in the most attractive locations right next to the coast (see Fig. 5), urbanization of national parks, etc.

Figure 5. Uncontrolled urbanisation and construction at the Montenegrin cost, illegal construction (photo source: Montenegro news portals)

It can be said that there are several challenges for Montenegrin society regard to seismic risk management at the present and in the future:

- Uncompromising implementation of existing legislation and transition to design exclusively according to European regulations;
- Monitoring and implementing further developments in modern regulations;
- Vulnerability assessment of existing buildings in Montenegro (clearly stated as necessary to be conducted in all relevant strategic documents);
- Development of innovative systems for structural upgrading adapted to local conditions, economically justified, technically viable and technologically feasible with minimal invasiveness;
- Use and application of new advanced materials for structural upgrading (i.e. composite materials, FRP materials - the fibre-reinforced polymer);
- Developing national seismic risk assessment (ongoing project started from December 2020 coordinated and guided by Ministry of internal affairs)
- Improving the scientific basis for spatial and urban planning and seismic risk mitigation as well as incorporating into European and world scientific community in order to monitor but also actively participate into relevant researches (ongoing several research international programs exists in University of Montenegro).

5 Conclusions

40 years ago Montenegro economy and its citizens suffered a catastrophic earthquake event that caused both great economic and human loses. Many urban historical settlements were heavily damaged. Mostly masonry structures collapsed or suffered the level of damaged that was considered economically or technically unjustified to repair. RC frame structures founded in soft soil in coastal area, suffered severe damages. The combination of soft soil and flexible structures led to resonant behaviour introducing large displacements and consequently in most case collapse. Recovery period lasted almost a decade. From time distance it is fair to say that Montenegro was not prepared or organized to act immediately after disaster. With the help of international community and organisation, domestic experts accomplished some great results in period of few years after the event. Some very important strategic projects were implemented all aiming to reduce seismic risk introducing geoseismic aspects in all phases of construction process: from urban planning to construction supervision. Also, it is very clear, based on the situation on site, that as the time from the earthquake passed mostly good existing legislative was not always thoroughly implemented especially on the level of local municipalities. This led to over-urbanisation of seismically very vulnerable cost, increase of population density and consequently increase of seismic risk over the years. Also, to be fair it must be highlighted that Montenegrin institutions done some very important steps in past time in order to slow down the harmful process: transition to European provisions, developing strategy in case of disaster, realisation of plans defined in strategy (i.e. ongoing national risk assessment for disasters including earthquakes), encouraging scientific community to take participation in relevant international project, etc. Still, many challenges are present and steps that need to be done in order to be able to declare full commitment to systematic problem solving in area of seismic risk reduction and mitigation i.e.: uncompromising implementation of existing legislation, monitoring and implementing further developments in modern regulations, vulnerability assessment of existing buildings in Montenegro; development of innovative systems for structural upgrading adapted to local conditions, economically justified, technically viable and technologically feasible with minimal invasiveness; use and application of new advanced materials for structural upgrading etc.

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