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NATIONAL SEISMIC RISK ASSESSMENT FOR MONTENEGRO

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The previous seismic risk assessment for Montenegro was done after the 1979 earthquake for the purpose of developing the Spatial Plan of Montenegro. Following that catastrophic event, a robust response from relevant institutions ensued, focusing on mitigating seismic risk and regulating construction in vulnerable areas. This period witnessed significant strides in projects to revitalize and reconstruct Montenegrin society. As a result of these efforts, a study was developed, representing a valuable document on vulnerability and seismic risk based on the consequences of the 1979 earthquake. Recognizing seismic risk as a dynamic parameter, it is necessary to conduct periodic updates in risk studies. Regrettably, Montenegro's seismic risk assessment remained stagnant until 2021, when extensive research was undertaken as part of a project funded by the European Commission. The Department of Civil Protection (DCP) coordinated the project in which the National Risk Assessment (NRA), focused on nine different natural and technical-technological risks, was developed. The participation of the national DCP ensured the scientific community's involvement, including the researchers from the University of Montenegro, the Faculty of Civil Engineering and the National Seismological Institute. This collaboration, guided and coordinated by the DCP, resulted in the successful completion of a new national seismic risk assessment. The paper briefly presents results and methodology for seismic risk assessment, providing details on available and used data for exposure and vulnerability models. The discussion includes results on damages (residential buildings and road infrastructure), impact on people, economic losses and presentation of political and social impacts for two earthquake scenarios. Finally, the seismic risk level is calculated and presented in risk matrices.

Keywords: seismic risk, impact indicators, impact on people, economic losses, social and political impact, seismic risk matrix

1 INTRODUCTION

The first seismic risk assessment for Montenegro was developed in 1984, prompted by the catastrophic 1979 earthquake. This pivotal study [1] analyzed approximately 40 000 damaged structures across six coastal and two central municipalities, representing the valuable base for urban planning focused on seismic risk reduction. Due to the evolving parameters such as population exposure and vulnerabilities, the dynamic nature of seismic risk underscores the importance of permanent research towards their periodic updates. However, subsequent research on seismic risk was lacking in Montenegro. In 2021, the Department of Civil Protection (DCP) led the National Risk Assessment (NRA) development [2], responding to Montenegro's EU accession requirements. Coordinated by the DCP, with active participation from partners, the University of Montenegro, the Faculty of Civil Engineering, and the Seismological Institute, a new seismic risk assessment is developed. Aligned with EU guidelines [3], this assessment contributes to a shared understanding of disaster risks and supports coordinated actions in prevention, preparedness, and planning stages with EU member states.

According to ISO 31010, risk is the combination of hazard consequences and likelihood of certain hazard. Hazard refers to a dangerous phenomenon, and consequences quantify negative effects in terms of human, economic, environmental, political, and social impacts. In that light, the seismic risk is a convulsion of hazard probability, the vulnerability of built environment, and exposure. EU methodology recommends using quantitative impact indicators for risk measurement, categorized into human, economic/environmental, and political/social impacts. Visualizing risk employs a risk matrix, emphasizing likelihood and using colours to represent different risk levels. This approach aligns with Civil Protection needs, prioritizing the most severe outcomes.

This paper presents the results of a seismic risk assessment for Montenegro, developed according to EU guidelines. Seismic risk assessment for Montenegro is scenario-based, meaning that risk is calculated for specific earthquake events with significant impacts on society. Consequences for considered hazard scenarios are presented through quantitative impact indicators such as: damages on residential buildings expressed as the number of dwellings in 5 classes of damages; damages on road infrastructure expressed as the number of km of damaged roads; resulting consequences on people calculated as number of victims and injured; economic losses expressed as share in gross domestic product (GDP) and political and social impact expressed as much as possible through the quantitative parameters. Finally, based on these consequence magnitudes (choosing from minimal to catastrophic) and the probability of occurrence of developed hazard scenarios, the level of seismic risk is calculated and presented in seismic risk matrices.

2 METHODOLOGY USED AND DATA ON HAZARD, EXPOSURE AND VULNERABILITY

2.1 Hazard scenarios

As previously stated, seismic risk analysis in Montenegro is scenario-based risk assessment, meaning that potential earthquake events, with assigned probability of occurrence, are examined to evaluate their impact on people, economy and society. Two earthquake scenarios are considered. The first scenario (Scenario 1) aims to depict the most likely event, representing an earthquake with a return period of 95 years having magnitude M=6. The second scenario (Scenario 2) represents an event with a return period of 475 years that is considered the event with the worst possible consequences, with magnitude M=7. The scenario development process involves specifying the earthquake's location, magnitude, intensity distribution, and soil amplification factors and determining the time of occurrence and duration. These tasks are done by researchers from the Seismological Institute of Montenegro and will not be discussed in this paper. Both scenarios considered earthquakes with the exact epicentre located near municipalities Bar and Ulcinj, 13 km south of settlement Kruce at a depth of 10 km. The intensity distribution for Scenarios 1 and 2 are given in Figure 1.

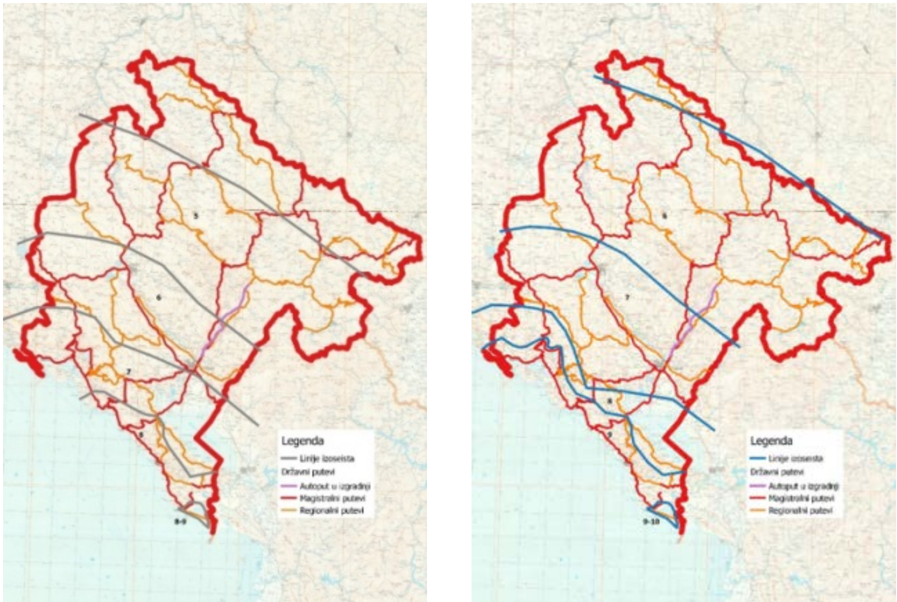

Fig. 1. Intensity distribution for Scenario 1 and Scenario 2 [2]

2.2 Exposure and vulnerability data

Examining people's exposure involves considering their geographic location and placement within specific structural typologies, easily correlated with vulnerability classes. Census data in Montenegro provides the residential population at the municipality level but lacks a systematic database for buildings, including location, structural details, material, and number of floors. This data gap, common in many countries, posed a significant challenge for the authors in this research. Given this limitation, the study for Montenegro's national seismic risk assessment relies on existing exposure models, such as the SERA model [4], based on 2011 census data.

The analysis of building vulnerability applied the methodology from the European Macroseismic Scale EMS-98 [5]. According to this methodology, structures are categorized into four construction types: 1) Masonry, 2) Reinforced Concrete, 3) Steel, and 4) Wood, with six vulnerability classes (from A to F). Class A represents the most vulnerable, while Class F is the least vulnerable. To determine the number of dwellings in each vulnerability class, it was assumed that all buildings of the same type are in the most probable vulnerability class. This is done due to the lack of data on potential reinforcements or weaknesses in the structural systems of buildings. Considering that a high level of seismic design implies the use of contemporary methods and principles (i.e., performance-based design according to EN1998-1), and given that such methods were not present in design practices in Montenegro until 2011, there are no buildings classified as vulnerability Class E or F.

As an example, the distribution of dwellings through vulnerability classes A to D for Scenario 2 will be presented here (see Table 1).

Furthermore, quantification of damage intensity and distribution for specific vulnerability classes (A, B, C, and D) outlined in [5] is done using damage probability matrices. These matrices, tailored for each vulnerability class (A to D), establish a correlation between the level of damage (D1 to D5, representing minor damage to collapsed buildings) and EMS-98 earthquake intensity. Specifically, for vulnerability class D buildings (confined masonry, reinforced concrete frame, and wall structures with moderate seismic design) located in a region with IX EMS-98 earthquake intensity, the expected outcome is damage level 2 (D2) for 'many' buildings and damage level 3 (D3) for 'few' buildings. In the seismic National Risk Assessment (NRA) for Montenegro, the quantification is carried out through expert judgment.

Table 1. Distribution of dwellings for Scenario 2

Seismic intensity EMS-98	Vulnerability classless			
	A	B	C	D
X	87	635	1155	6989
IX	662	4850	9265	50289
VIII	439	810	1752	6680
VII	4114	7591	17326	67945
VI	3724	6871	13873	42297
Total	9025	20757	43372	174200

Regarding the infrastructure, only main state roads are considered: highways and regional roads. Structures, like bridges or tunnels, on considered roads were not analyzed since a reliable registry of details for structures does not exist. Local roads, managed by local communities, are not considered because there is no consolidated data on these roads. The lengths of the state roads in regions with seismic intensities VIII and higher are approximately 212 km and 441 km for Scenario 1 and Scenario 2, respectively.

3 SEISMIC RISK ASSESSMENT RESULTS

3.1 Damages on residential buildings and impact on people

Certain assumptions have been introduced to assess the damage distribution, such as the number of dwellings and the people residing in these dwellings. The first assentation was made because available databases and relevant studies lack data on the percentage representation of specific masonry structures based on the applied construction material (stone, solid stone, brick masonry). Categorization of dwellings in vulnerability classes is done based on the year of construction, so it is assumed that the vulnerability class A include the category of unreinforced masonry structures built until 1945 for the coastal region and until 1960 for the central and northern regions. Class B comprises structures built between 1946 and 1980 for the coastal region and between 1961 and 1980 for the central and northern regions. Buildings built after 1981 for all regions are classified in vulnerability class C. The distribution of damages for two considered earthquake scenarios is given in Table 2.

Table 2. Distribution of damages for Scenario 1 and Scenario 2: number of residents, dwellings and area of dwellings for certain damage levels D1-D5

Scenario 1	Damage level					
	No damage	D1	D2	D3	D4	D5
Number of residents	545070	32438	29746	9892	2486	397
Number of dwellings	215320	12672	13588	4464	1128	181
Area of dwellings [m^2]	15530082	661394	1028152	348738	89195	15681
Scenario 2	Damage level					
	No damage	D1	D2	D3	D4	D5
Number of residents	457177	44640	63580	37836	12628	4168
Number of dwellings	176683	16511	29043	17416	5754	1947
Area of dwellings [m^2]	12825584	1162971	1917184	1209143	412073	146287

Note that 0.46% of Montenegro's population and 0.53% of all dwellings in Montenegro are distributed in most severe damage levels D4 and D5 (significant damage and collapsed buildings) in Scenario 1. For Scenario 2, 2.7% of residents and 3.11% of dwellings in Montenegro are associated with damage levels D4 and D5.

Based on the distribution of damages, the impact on people is calculated in terms of victims and injured people. In order to estimate this impact, two methodologies are used [6, 7]. According to the HAZUS methodology for Scenario 1, it is estimated that there will be 40 deaths, 20 severe injuries and 149 minor injuries requiring a certain higher level of medical care. A total of 209 residents were affected, excluding the injured that require basic medical assistance. According to the IRMA methodology for scenario 1 there will be 65 deaths and 243 injuries, which give a total number of 308 affected residents (see Figure 2). For both scenarios considered, the final judgment on consequences on people is catastrophic.

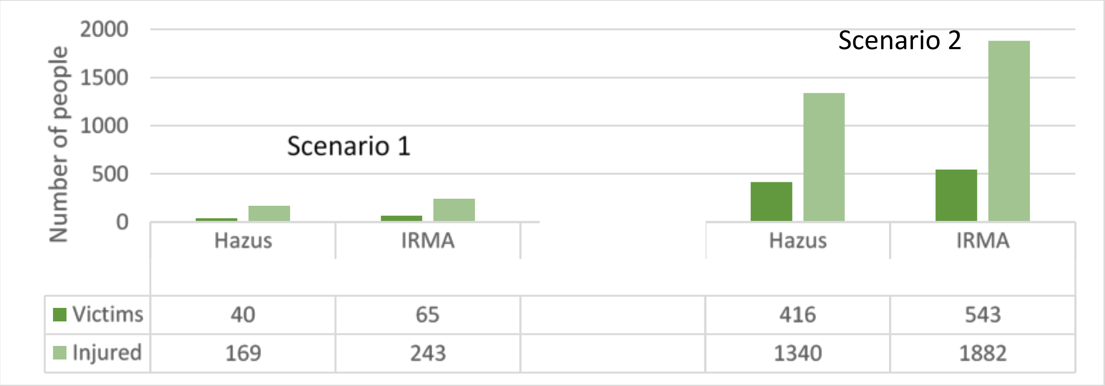

Fig. 2. Impact on people according to two methodologies

3.2 Economic impact

The economic impact is calculated based on the economic losses expressed as a percentage of GDP (taken from 2019). Economic losses take into account: the costs of repair/replacements of damaged/collapsed residential buildings, the costs of health care for injured people and road infrastructure repair costs. Losses are calculated based on the damages and impact on people as well as official data on construction and repair costs in Montenegro, the average cost of a day of hospital treatment, and the average length of hospital treatment for Montenegro (8.9 days).

The largest share of economic losses comprises repair costs of residential buildings. These costs were calculated based on the average price per square meter of a dwelling in 2020 and the area of dwellings associated with a certain level of damage. The methodologies defined in [6,7] were used to determine the percentages of repair or replacement costs (Ct), see Table 3. Minor differences exist between the costs calculated using different methodologies in the case of Scenario 1, with a maximal value of 10% of GDP. When considering the earthquake with the most severe consequences (Scenario 2), costs range from 25.9 to 40.2 % of GDP, depending on the methodology used. Regarding the cost of health care for injured people, they are not overcoming the 0.05% of GDP in case of an earthquake with the most severe consequence.

The economic losses arising from road infrastructure repair are calculated based on the estimation of the lengths of damaged roads from the literature [8]. I.e. 4% of the length of roads located in regions with IX intensity level is considered as damaged. The repair costs were obtained based on the average costs of road reconstruction projects in Montenegro in 2016. In total, for both considered scenarios, these costs do not exceed 0.2% of GDP.

Furthermore, economic losses should also include costs of interruption of economic activities (industry, interruption of water supply, interruption of electricity supply, trade, and tourism), costs of disruption of public transport and infrastructure, costs of immediate or long-term emergency measures, costs of ecological restoration, total material damage to institutions/buildings of public social importance and cultural and historical monuments. This second group of costs is estimated as 6.8 % and 24.2% of GDP for Scenario 1 and 2 respectively, based on available official documents and literature [9].

Ultimately, as the total economic losses for Scenario 1 earthquake fall 10 to 15% (per the criteria set by the NRA) and surpass 15% for Scenario 2, the economic consequences are deemed significant and catastrophic for the respective scenarios.

Table 3. The repair costs for residential buildings

Dwelling area [m2]	Damage level	Ct (%) [6]	Repair costs [6] (Euros)	Ct (%) [7]	Repair costs [7] (Euros)
661394	D1	2	10748177	2	10748177
1028152	D2	10	125850859	10	125850859
348738	D3	60	260606483	30	130303242
89195	D4	100	112310018	60	67386011
15681	D5	100	21137423	100	21137423
Costs: Scenario 1		Total	530652960		355425711
		GDP (%)	10.7		7.2
Dwelling area [m2]	Damage level	Ct (%) [6]	Repair costs [6] (Euros)	Ct (%) [7]	Repair costs [7] (Euros)

1162971	D1	2	18602325	2	18602325
1917184	D2	10	242642987	10	242642987
1209143	D3	60	966373460	30	483186730
412073	D4	100	555595948	60	333357569
146287	D5	100	206165559	100	206165559
Costs: Scenario 2		Total (Euros)	1989380280		1283955170
		GDP (%)	40.2		25.9

3.3 Social and political impact and overall seismic risk

In this paper, the social and political impact of the considered earthquakes will be briefly discussed. Consequences for social and political stability can include categories such as the impact on public institutions, non-functioning critical infrastructure affecting daily life, psychosocial effects, internal political stability, public order, and external politics, as well as the international position of the state [3]. These consequences are assessed on a scale: 1 - Minimal; 2 - Small; 3 - Moderate; 4 - Significant; 5 – Catastrophic.

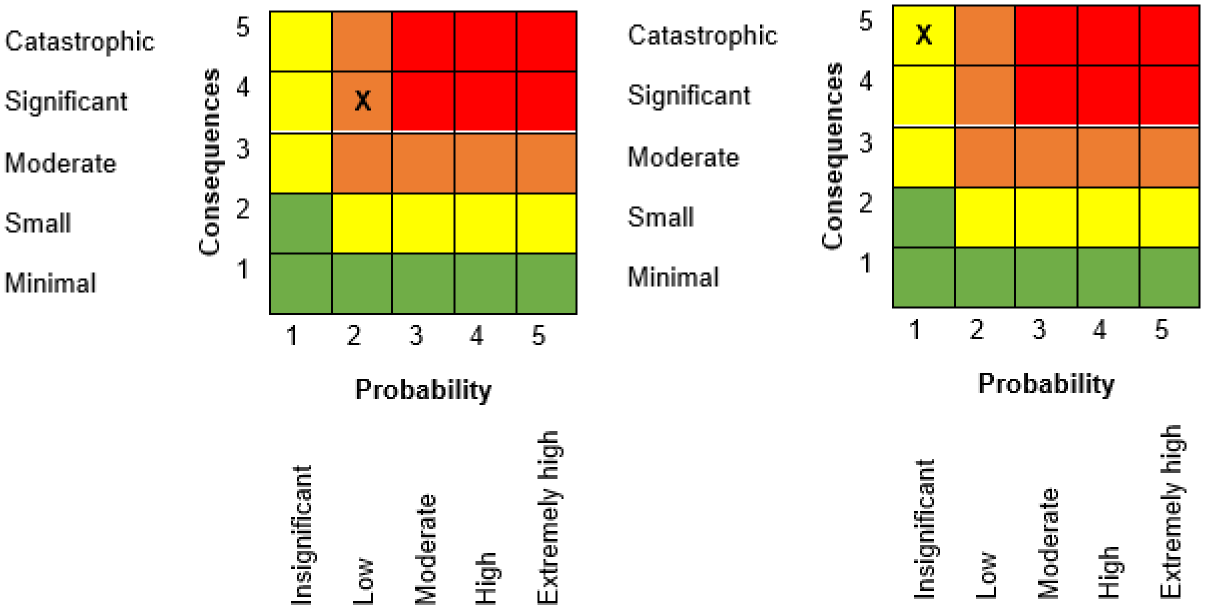

Fig. 3. The seismic risk presented in matrices: Scenario 1 and Scenario 2, respectively

For specific categories, such as the impact on internal political stability and psychosocial effects, grades are assigned using expert judgment, while other categories are estimated quantitatively. An example of the second group of consequences is the assessment of non-functioning critical infrastructure's impact on daily life. This assessment follows the methodology in [6], analyzing damage to electricity and water supply facilities and telecommunications systems. The assessment results indicate that it would take 1.6 and 3.5 days to restore regular electricity supply and 1.7 and 2.4 days to supply drinking water for Scenarios 1 and 2, respectively. Assuming the entire coastal region population is exposed (148,683 inhabitants), this corresponds to consequence categories 2 and 3, representing small and moderate consequences for Scenarios 1 and 2, respectively. Based on the average grades for the considered consequences (2.75 and 3.63), the social and political impact is judged as moderate and significant for Scenarios 1 and 2, respectively.

Finally, the overall seismic risk is calculated based on the impact on people, economic impact and social and political impacts of considered earthquake scenarios. For Scenario 1, the final overall seismic risk is graded as significant and insignificant for the Scenario 2 earthquake despite the severe consequences of this scenario (see Figure 3). It must be noted that these conclusions are driven by the fact that the used matrix is giving extra weight to likelihood, i.e. that event with a higher probability of occurrence will more easily produce risks that will be assessed as catastrophic or high risks regardless of the lower level of consequences (impacts). This approach may seem illogical, but it is in line with Civil Protection needs.

4 CONCLUSIONS

The seismic risk assessment for Montenegro has evolved significantly since its inception in 1984, prompted by the devastating 1979 earthquake. While the initial study served as a crucial foundation for urban planning, a substantial gap in subsequent seismic risk research existed until 2021, when the National Risk Assessment, led by the Department of Civil Protection, was developed. The study is done with partners including the University of Montenegro, the Faculty of Civil Engineering and the Seismological Institute. Employing a scenario-based approach, two earthquake scenarios, Scenario 1-most probable and Scenario 2-with worst consequences, were considered. The study evaluated the exposure and vulnerability of the population, relying on the SERA exposure model and the EMS-98 methodology. Despite data limitations, the analysis provided insights into building vulnerability and the distribution of damages across vulnerability classes. The impact on people in both scenarios is considered catastrophic.

Moreover, the economic impact assessment revealed that Scenario 2 poses catastrophic consequences, with losses exceeding 25% of GDP, emphasizing the severity of potential economic disruptions. The average grades for social and political impact indicate a moderate and significant risk for Scenarios 1 and 2, respectively. In calculating the overall seismic risk, integrating impacts on people, economic factors, and social and political stability, Scenario 1 produces significant seismic risk, and Scenario 2 earthquake, due to the risk matrix composition, introduces an insignificant seismic risk despite its severe consequences. This research contributes to disaster risk understanding and reduction and aids in coordinated actions with EU member states, enhancing Montenegro's resilience to seismic events.

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