EARTHQUAKE-RESISTANT CITIES IN ALBANIA: SEISMIC MICROZONATION STUDIES (SM) AND LIMIT CONDITION IN EMERGENCY (LCE)INTEGRATED APPROACH

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ABSTRACT

This work aims to highlight the indispensable significance of the seismic microzonation studies (SM) and the Limit Condition in Emergency (LCE) at the level of primary decision-making in urban planning studies and to help resolve a range of problems connected to seismic risk assessment in Albania. Following the 1979 Montenegro seismic sequence, the Albanian government implemented a 'National Plan for Seismic Prevention', which funded the SM of some of the biggest cities in Albania. Unfortunately, the seismic risk prevention activities were halted after the renewal of the national codes for design in 1989. Located next to the most active fault in Albania, the main cities of the country have experienced seventeen (17) seismic events with magnitudes varying from 5.4 to 6.6 in the last 114 years. The most recent earthquakes that hit Albania on September 21st, 2019 of Mw 5.4 and November 26th, 2019 of Mw 6.2 severely damaged the cities of Durrës, Thumanë, Tirana, Vora, Shijak and the villages around. The main event of the 26th November caused the deaths of 51 persons and the damaging of hundreds of buildings. The degree of damages produced by these earthquakes has been, in some cases, significantly enhanced by the characteristics of the earthquake ground motion affected by the local subsurface soil structure of the cities. The seismic events of 2019 evidenced the crucial importance of earthquake risk reduction and mitigation. For this purpose, a multidisciplinary research activity was carried out to define the SM of two archaeological cities in Albania: Durrës and Gjirokastër. Based on the SM, the LCE were applied in both cities. In the process of creating earthquake-resistant cities, the SM and the LCE could be the best tools for a better seismic hazard mitigation and prevention in Albania.

Keywords: seismic microzonation studies, Limit Condition in Emergency, Durrës earthquakes, seismic mitigation, seismic prevention.

1. INTRODUCTION

Albania is a Balkan country charachterized by a very high seismic activity. It a rather is geologically and seismo-tectonically complicated region. The country is characterized by obvious micro-seismicity (a high number of small earthquakes), sparse medium-sized earthquakes (magnitude M from 5.5 to 5.9), and rare large earthquakes with magnitude M>6. The strongest Albanian earthquakes have occurred along three well-defined seismic belts: i) the Ionian-Adriatic coastal belt extending northwest to southeast and coinciding with the boundary between the European plate and the Adria microplate; ii) the Peshkopia-Korça belt (the so called Drini belt), extending north-south in the eastern part of the country and iii) the Elbasani-Dibra-Tetova transverse belt, extending southwest to northeast across the former two belts. During the last 114 years, along these seismic belts seventeen (17) seismic events have been occurred with magnitude from 5.4 to 6.6. These earthquakes caused 407 victims and hundreds of thousands injured. One of the most destructive earthquakes in Albania has been the seismic event of 1979 in Montenegro. Following this seismic event, the Albanian government implemented a "National Plan for the seismic prevention" funding the seismic microzonation (hereafter SM) studies of some of the biggest cities in Albania. Unfortunately, the seismic risk prevention activities were halted after the implementation of the renewed national codes for design in 1989.

Fifty one people died and hundreds of buildings were damaged in Durrës, Thumanë, Tirana, Vora, Shijak and their villages due to the earthquake of November 26, 2019. In some cases the damages caused by these earthquakes have significantly worsened by the characteristics of the earthquake ground motion affected by the local subsurface soil structure of the cities [9].

In the process of creating earthquake-resistant cities, the geophysical and engineering-geological methods, which take into account the geological and geomorphological characteristics of the local subsoil, for an effective SM, could be fundamental.

The integrated studies of the SM with the Limit Condition in Emergency (hereafter LCE) could be the best tools for a better seismic hazard mitigation and prevention in Albania.

For this purpose, a multidisciplinary research activity that integrated the existing geotechnical and geophysical data with original geophysical surveys was carried out to define the SM of two archaeological cities in Albania: Durrës and Gjirokastër. Based on the SM, the LCE were applied in both cities.

The integrated SM-LCE approach studies can help decision-makers to identify the strategic buildings, structural blocks, emergency areas and the strategic paths for a successful emergency plan at a municipality level.

1st level of SM of the Durrës and Gjirokastra municipalities

SM studies are important tools in the suitable urban planning and in the prospective of seismic hazards mitigation and prevention. The main goal of the SM is to delineate areas, within a municipality level, with homogenous seismic response in terms of stratigraphic and topographic amplification, as well as areas of earthquake-induced phenomena such as landslides, liquefaction and sinkholes.

On a local scale, the SM identifies the areas that manifest a homogeneous seismic behavior during an earthquake event. According to the Italian guidelines (firstly proposed from the International Society for Soil Mechanics and Geotechnical Engineering ISSMGE in 1999), a municipality territory could be characterized in accordance with three types of areas: i) stable areas, ii) stable areas susceptible to local seismic amplification and iii) areas susceptible to instability (e.g. earthquake-induced landslides, soil liquefaction and surface fractures and faulting). Three levels of SM are considered in these guidelines. The 1st level is based on the collection of the existing data and the distribution of the new surveys, in such a way as to acquire the most in-depth information possible for the municipality territory. This level identifies the areas with the same seismic behavior, based on the three typologies described above. The results are shown on the Seismically Homogeneous Microzones Map (SHMM) (in 1:5000 or 1:10000 scales) and the databases of the investigations are then uploaded into a geographic information system. The 1st level process is totally based on the detailed engineering-geological and geophysical models of the subsoil. The target of the 2nd and 3rd levels is the evaluation of the local seismic response and seismic amplification factors of the entire territory of the municipalities. The municipalities involved in the process are those with the highest values of peak ground acceleration on rocks, ag_R, corresponding to the reference probability of exceedance (PNCR) of 10% in a nominal lifespan of 50 years, equivalently to a reference return period of 475 years [11]. One and two-dimensional numerical modeling analyses based on the modification of the reference seismic signal due to the specific site conditions is needed to quantify the local amplification and to perform the dynamic analysis of slope instability and the liquefaction susceptibility [10].

Based on these criteria, two different ancient cities in Albania were chosen for the 1st level of SM, specifically, the cities of Durrës and Gjirokastra.

Located next to the most active fault in Albania, these cities have experienced several strong earthquakes in the past, sometimes exceeding the magnitude of 6. The seismic event of October 10th, 1858, destroyed many buildings in the city of Gjirokastra. Historians claim that it had a huge impact on the economic life of this archaeological city [12].

The ancient city of Dyrrachium (modern name: Durrës) is not new at seismic risk and has been severely destroyed by a series of earthquakes. The most important ones on record are: the earthquake of 177 B.C., May 1st or 2nd, then in 58 A.D., 334, 345, 506 (that almost destroyed the entire ancient city), March 1st, 1273, 1279, 1869, 1870 and December 17th, 1926 of Ms 6.2 and seismic intensity of IX (MSK-64 scale) [1].

The last earthquake sequence started in September 21st, 2019 with a ML 5.4 and a relatively deep hypocenter (around 17 km referring to cnt.rm.ingv.it). The main event occurred on November 26th, 2019 with Mw 6.2 causing 51 victims and extensive damage to hundreds of buildings in the cities of Durrës, Thumanë, Tiranë, Vorë, Shijak and many others. The earthquake sequence included 8 strong seismic events with magnitude larger than 5. The activation of the reverse faulting system produced many phenomena connected to the local soil conditions such as: seismic stratigraphic amplification, soil liquefaction, surface fractures and earthquake-induced landslides [4].

The city of Durrës is located along the Adriatic coast in the central part of Albania, in the lowland of the Periadriatic Depression.

In the process of collecting existing data, the engineering-geological map of the city of Durrës [3] was taken into account, alongside data obtained through laboratory testing regarding the geotechnical parameters of the clayey formation of Lower Pliocene at Durrës Hill, thus determining their key role in the generation of landslides [5 &6]. These results were incorporated in the geological map at the scale 1:10.000 , the previous microzonation map of the city [1], the bedrock map [2] and the private engineering-geological reports and studies conducted on the city of Durrës. All the collected data were integrated into a detailed Gis-database for the SM activities.

In order to make a better assessment of the local seismic hazard at the historical center of the city of Durrës and determine the distribution of Quaternary deposits, a series of different geophysical investigations were carried out. Twenty-two single-station noise measurements, processed through the Horizontal/Vertical Spectral Ratio technique, two (Multichannel Analysis of Surface Waves surveys and two 2D array measurements were performed to cover an area of around 3 km^2 of the historical center of Durrës (Figure1) [4]. The fundamental frequencies of resonance f0, were determined for each HVSR curve from noise measurements. Afterwards, the corresponding fundamental periods T0 as 1/f0 were computed. Four different groups of T0 ranges were obtained: i) one group shows no peak; ii) another group highlighted the presence of very thin surficial layers (i.e., top few meters) prone to amplification; iii) the third group showsa predominant peak period in the range of 0.7 - 1.1s and iv) the last group shows the presence of the highest fundamental periods T0 (higher than 1.1s) indicating a deep bedrock interface [4].

The fundamental frequencies of resonance f0 were used to estimate the thickness (h) of the Quaternary deposits overlaying the Messinian-Pliocene bedrock [4].

The Figure 2 depicts the city of Gjirokastra located in the southern part of Albania. The first stage of the SM of the city of Gjirokastra consisted in the reconstruction of the engineering-geological model of the subsoil, with the aim of defining the geometrical setting of soil deposits and their geotechnical and geophysical properties. For this purpose, the available geological, geotechnical, and geophysical data, together with engineering-geological reports and studies from private subjects were collected and analyzed. All the collected data were integrated into a detailed Gis-database for the SM activities. Based on the geological survey and the previous data, it was possible to reproduce the Engineering-Geological Map at the scale 1:10.000, the Slope Map (at the scale 1:10.000) and the Digital Elevation ModelMap (at the scale 1:10.000 scale) for the city of Gjirokastra.

In order to define the stable areas, the stable areas susceptible to local seismic amplification and the areas susceptible to instability for the entire territory of the city of Gjirokastra, a research approach that integrated differentgeophysical methods were performed. To this purpose, 25 ambient vibration measurements were carried out for the most important buildings and across the historical center of the city and recent settlements (Figure 2). Six 2D array and six MASW measurements were performed to provide useful elements for a geophysical subsoil characterization [9].

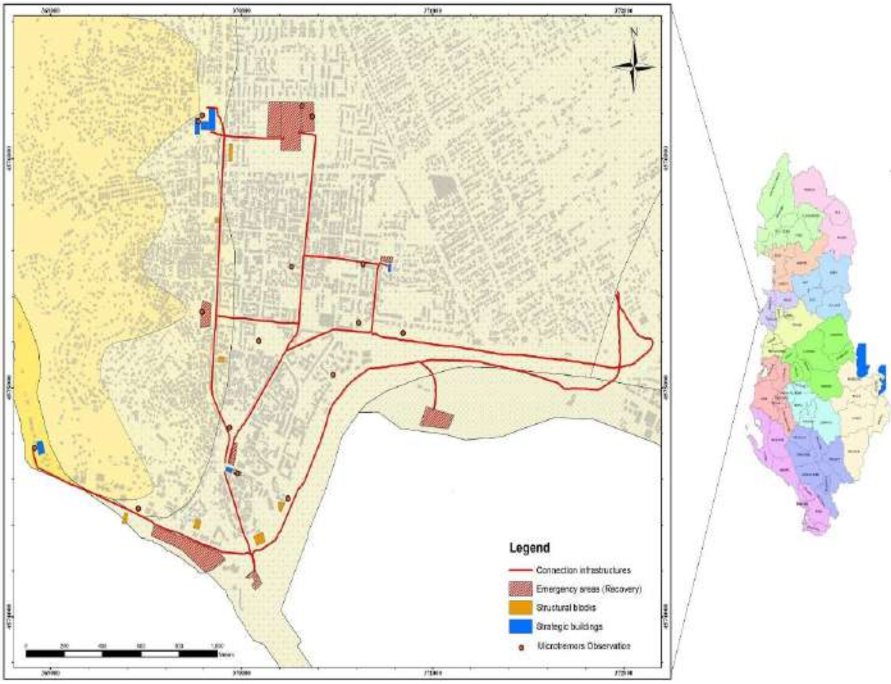

Fig. 10. Shows the integrated approach of the SM [4&9]and the LCE for the center of the city of Durrës.

Based on the data obtained, the municipality of Gjirokastra was divided into six zones of susceptibility to local ground amplification and two zones of geological instability. Due to the different geological, engineering-geological, geophysical and geomorphological settings that characterize the subsoil of the city, the earthquake-induced phenomena that could be manifested during the seismic events might vary significantly. The city of Gjirokastra is subject to extensive landslides and earthquake-induced landslides on the fractured calcareous and siliciclastic rocks and on the turbidity units. Due to the presence of the buried narrow valleys and isolated narrow ridges, this area is prone to a stratigraphic and topographic amplification of the seismic motion [9].

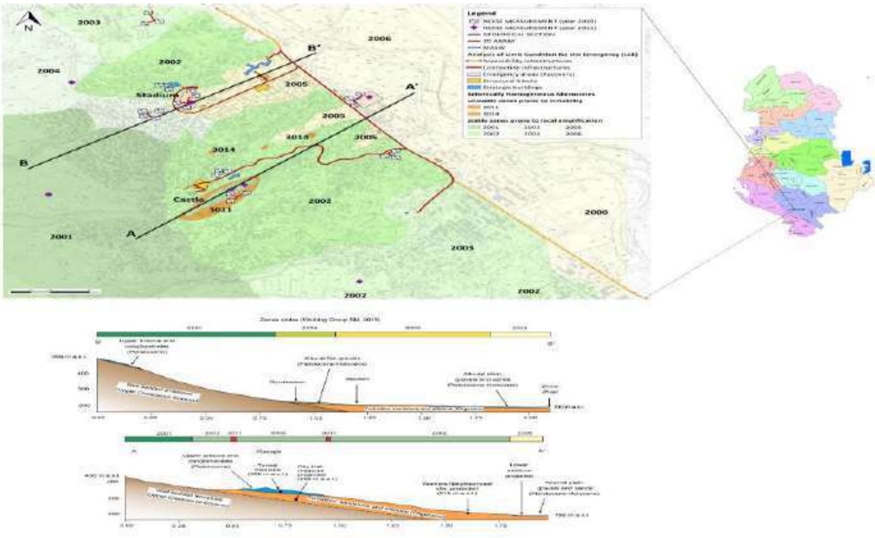

Fig. 2. The conjugate approach of the SM and the LCE of the city of Gjirokastra, allows the systematic association of strictly geological information with the strategic elements functional to emergency management [9].

The Limit Condition in Emergency - LCE

The LCE - Limit Condition in Emergency, is the condition whereby, following a seismic event, the urban settlement as a whole suffers physical and functional damage resulting in the interruption of almost all urban functions, including residency. However, the urban settlement preserves the functionality of most of the strategic functions for the emergency and their accessibility and connection to the territorial context.

The analysis involves: i) the identification of the buildings and areas that guarantee strategic functions for the emergency; ii) the identification of the infrastructures for accessibility and connection with the territorial context and, iii) the identification of structural elements and individual structural units that may interfere with accessibility infrastructures and connection with the territorial context.

By spatially superimposing the elements of LCE on the microzones identified by the SM studies, criteria and guidelines can be defined that are more targeted to the choices of ordinary planning of the territory: i) orienting the choices for the new settlements; ii) defining the eligible interventions in a given area; iii) establishing methods and priorities for intervention in urbanized areas.

An absolute ranking of seismic hazard should include the regional seismic hazard and the amplification due to the geologicaland geophysical setting [7].

Realizing these kinds of studies before an earthquake occurscan help decision-makers to highlight priority intervention areas and to define the best practice for existing structures where higher overall seismic hazard values are expected.

For both cities, the LCE was conducted in conjunction with SM (Figure 1 and 2).

2. CONCLUSIONS

This work aims to highlight the indispensable significance of the SM and the LCE at the level of primarydecision-making at urban planning studies and to help resolving arange of problems connected to seismic risk assessment.

The first level of SM in Durrës is still in process, but considering the high seismic activity of the region, the Peak Ground Acceleration value of 0.268 corresponding to the reference probability of exceedance PNCR=.10% in TL=50 years or equivalently to a reference return period of TNCR≈ 475years. [1], the high seismic vulnerability of the buildings and the many uncertainties about the thickness of the Quaternary deposits and the geometry of the depression, the authors strongly recommend the beginning, as soon as possible, of the third level of the SM for the entire municipality of Durrës. Furthermore, the studies of the local seismic response for all the important and strategic buildings of the city of Durrës must be obligatory.

Preliminary results from 2D arrays fixed the maximum depth that could be investigated and fully described the site effects in the city of Durrës. Detailed engineering-geological and geophysical investigations are needed for the third level of SM. In order to determine the distribution and the thickness of the Quaternary deposits, and to provide an image of the buried morphology for a 3D bedrock modelingforthe entire municipality, an accurate array of the gravity survey together with further noise measurements could be the most economic and strategic choice [8].

The authors of this paper emphasize that the studies for the first level of the seismic microzonation for all the cities in Albania are long overdue. They would provide the basis for the third level of SM in the cities with higher values of peak ground acceleration, ag_R, such as Durrës, Tirana, Shkodra, Vlora, Saranda, Berat, Gjirokastra, Korça, Pogradeci etc., before the next earthquake hits.

The following step would have to be an analysis of the Emergency Limit Condition – ELC for civil protection planning.

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