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ДРУШТВО НА ГРАДЕЖНИТЕ КОНСТРУКТОРИ НА МАКЕДОНИЈА

Партизански одреди 24,
П. Фах 560, 1000 Скопје
Северна Македонија

MASE
MACEDONIAN ASSOCIATION OF STRUCTURAL ENGINEERS

Partizanski odredi 24,
P. Box 560, 1000 Skopje
North Macedonia

RSC-8

mase@gf.ukim.edu.mk
http://mase.gf.ukim.edu.mk

GEOTECHNICAL ZONNING MAPS – PREREQUISITE FOR DESIGN OF RESILIENT STRUCTURES

Milorad JOVANOVSKI[1], Igor PESHEVSKI[1], Jovan Br. PAPIC[1], Andrijana ANDREEVA[2], Lidija TRPENOVSKA[2], Julijana STAVREVSKI[2]

ABSTRACT

The article treats the applied methodology in geotechnical zonation of natural hazards for the area of Macedonian capital Skopje, where their influences were very dramatic in some periods. These extracts are part of a set of analyses prepared in the frame of the Master plan of city of Skopje for the period 2022-2032.

Importance of natural and technological hazards comes from the fact that they are associated with high level of damages on natural and urban environment, sometimes even with life losses. The geotechnical zonation is necessary because the resilience of structures to such influences cannot be achieved without knowing in detail the elements of natural geological media and possible influences of all hazards. This is especially important in seismic and flood prone regions, where importance of geotechnical zoning is one of main tools for urban planners, decision makers and designers. This can also help to define the roles of all involved parties in urban planning in choosing protective systems that will ensure reducing of all damages and possible post-recovery cost.

It is underlined that the terrain suitability for urbanization and construction is related to engineering-geological conditions, slope, groundwater level, seismicity, erosion, flood hazard, landslide susceptibility, excavation conditions etc. The advantages of GIS tools in effective data analysis and the possibility of producing various thematic maps using GIS software is underlined.

As a results from detailed analyses, different maps of seismic microzonation, flooding, erosion potential and others are presented, with a suggestion that they shall be prepared using systematic interdisciplinary cooperation between all involved parties in an urbanization process.

Keywords: GIS; Hazard; Geotechnical zoning; Urban planning; Suitability maps;

[1] Faculty of Civil Engineering, University “Ss. Cyril and Methodius”, Skopje, Republic of North Macedonia
[2] Agency for Spatial Planning, Skopje

Corresponding author: Milorad JOVANOVSKI, e-mail: jovanovski@gf.ukim.edu.mk

1. INTRODUCTION

At the present moment, an imperative in the engineering practice is to apply so called “resilient design” and the development of Smart City Concepts. The idea is to find an effective way to respond on the effects from natural and man-made disasters in a proper manner, and to reduce their impact to acceptable level. In fact, in the process, the first step shall be appropriate urban planning, where: ”In the approach to the Smart Cities Mission, the objective is to promote cities that provide core infrastructure and give a decent quality of life to its citizens, a clean and sustainable environment and application of ‘Smart’ Solutions SMART cities...” [1]. The practice clearly shows that to achieve it, we must apply an approach of rational and successful development of urban areas based on detailed analyses of morphological, geological, geotechnical, seismic, hydrological, and hydrogeological factors [2]. Such factors are dominant as well for occurrences of natural hazards as for associated risks. The recent trends also incorporate the possible long-term changes resulting from climate oscillations, but also there are trends to analyze complex influences during strong earthquakes on lithosphere, atmosphere and ionosphere, coupling associated with earthquakes using GNSS and multiple satellites [3]. An appropriate attention on this subject is also given in Eurocodes, where it is recommended to choose National Determined Parameters that suits to local country specific data, e.g., seismic zone maps, snow maps, wind maps, isotherm maps, etc. [4], [5] and [6].

It seems that the importance of geotechnical zoning in urban and contact zones with rural environment is essential in different ways, and it can be one of main tools for urban planners, decision makers and designers in choosing protective systems that will ensure reducing of all damages and possible post-recovery cost, [7] and [8]. Here, urban geology methods occupy a key place in definition of parameters in planning and mapping the geological environment [9].

Based on these general principles, the applied methodology in geotechnical zonation modelling of hazards influences for the area of Macedonian capital Skopje will be presented below. It is part of a set of analyses prepared in the frame of Master plan of city of Skopje for the period 2022-2032 [10]. The steps in the preparation of the Study are based on the integrated methodology to assess the susceptibility of the area to different hazards through a multi-level approach in performing the city and the country for land and civil protection planning purposes. This is of high importance, knowing that Skopje area suffers a lot from natural hazards, as are the earthquake in 1963 (when almost 1100 people lost their life), flood events in 1962, 1979 and 2016 (when 23 people lost their life and damage cost of over 30 million EUR was estimated), and other influences.

The two key ideas underlined in the article are:

- To promote necessity of collaboration between experts from different engineering disciplines as: urban and spatial planners, architectural, geological, hydrological, geotechnical, structural engineers, in a cooperation with decision makers from national and municipality authorities.
- To promote the principle of complete access to all dataset related to natural and technogenic hazards in one system for management.

An important piece in this mosaic shall certainly be the application of principles of geotechnical zoning, where terrain suitability for urbanization and construction of resilient structures should be defined with detailed analyses of engineering-geological conditions, groundwater level, seismicity, slope, erosion, flood hazard, landslide susceptibility, excavation conditions, special needs etc. The approach can’t be achieved without collection and analysis of existing data from in situ investigations and the elaboration of thousands of related parameters. The availability of such dataset is not always on a satisfactory level, so the advantages for using of GIS tools for effective data analysis and the possibility of producing various thematic maps using GIS software must be noted [11], [12] and [13].

2. METHODOLOGY

Applied methodology is related to the fact that geotechnical zonation shall be basis for design of resilient structures. Resiliency cannot be achieved if there is no system to incorporate influences of natural hazards in all possible contexts. These aspects are explicitly or implicitly assumed in some of the main definitions related to civil engineering, where different definitions can be found.

For example, the issue of structural robustness has been recognized in structural design codes, e.g., in ISO 2394:2015 [13] and EN1991-1-7 [14], where it is defined as "the ability of a structure to withstand events like fire, explosions, impact, or the consequences of human error, without being damaged to an extent disproportionate to the original cause. "Generic, high-level definition of disaster resilience is also given by UNISDR, where the following concept is promoted: "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions." [15]. These lead us to the fact that all elements of natural environment (and city development, also) have certain temporal dimension and the time aspect must be assumed when developing resilience measures. One illustration from different sources is presented in Figure 1.

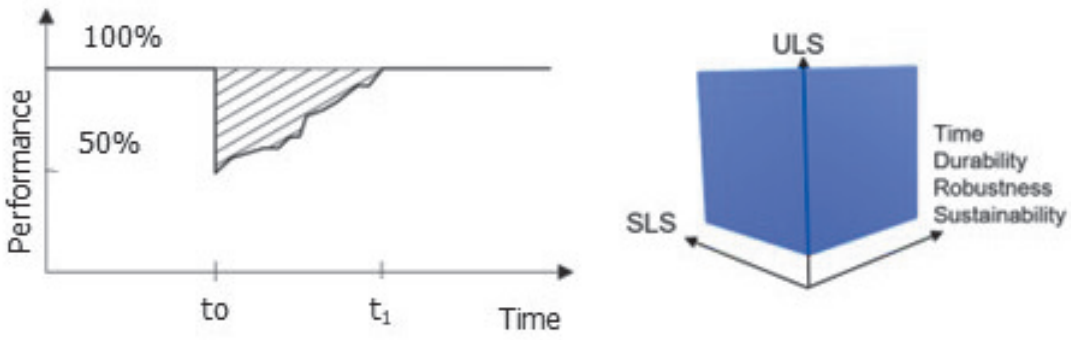

Fig. 1. Left- Diagram that illustrates the performance of some structure during time and seismic event [14]; Right- Schematic presentation of connection between Ultimate Limit State and Serviceability Limit State with Time, Durability, Robustness and Sustainability of Geotechnical structures [16]

The Fig. 1 illustrates that performance loss and the gradual recovery over time, typical for earthquakes, shall be related to larger area that is planned for urbanization, and it must be accounted in geotechnical zonation. Moreover, approach that is suggested here is based on a fact that interaction of urban area and structures shall be assumed in a wider context than usual soil-structure interaction elements (Fig. 2).

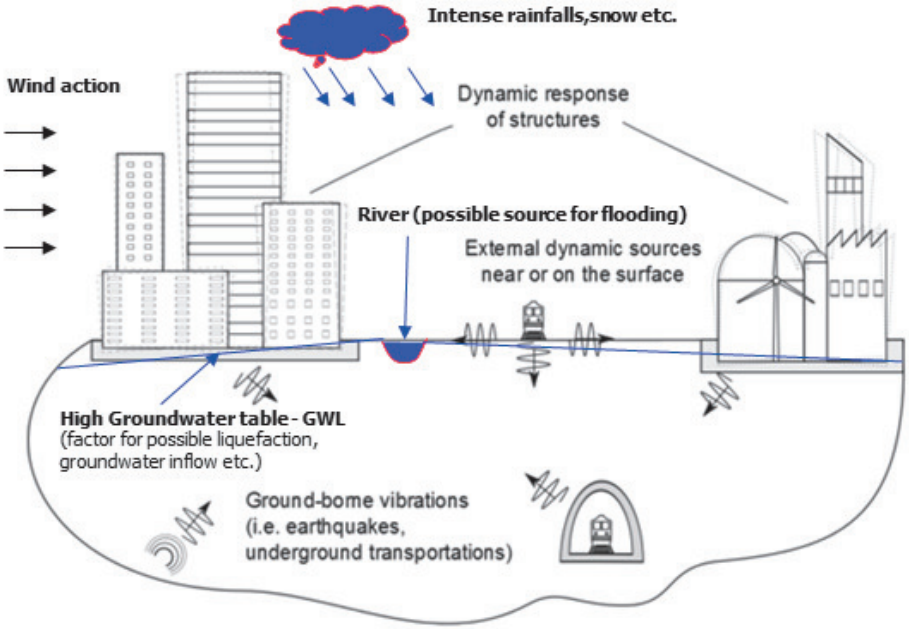

Fig. 2. Extended schematic illustrations of elements involved in soil-atmospheric-structure interactions (partially modified from [17])

One of the goals of applied methodology is to incorporate some of uncertainties in geotechnical zoning related to geological processes and spatial distributions of natural hazard elements. Here, the approach

presented in Fig.3 is suggested. The Fig.3 is extended to and modified mainly on works earlier presented by several authors as Burland, 1987; Keaton, 2013; Juang et al., 2019 [18].

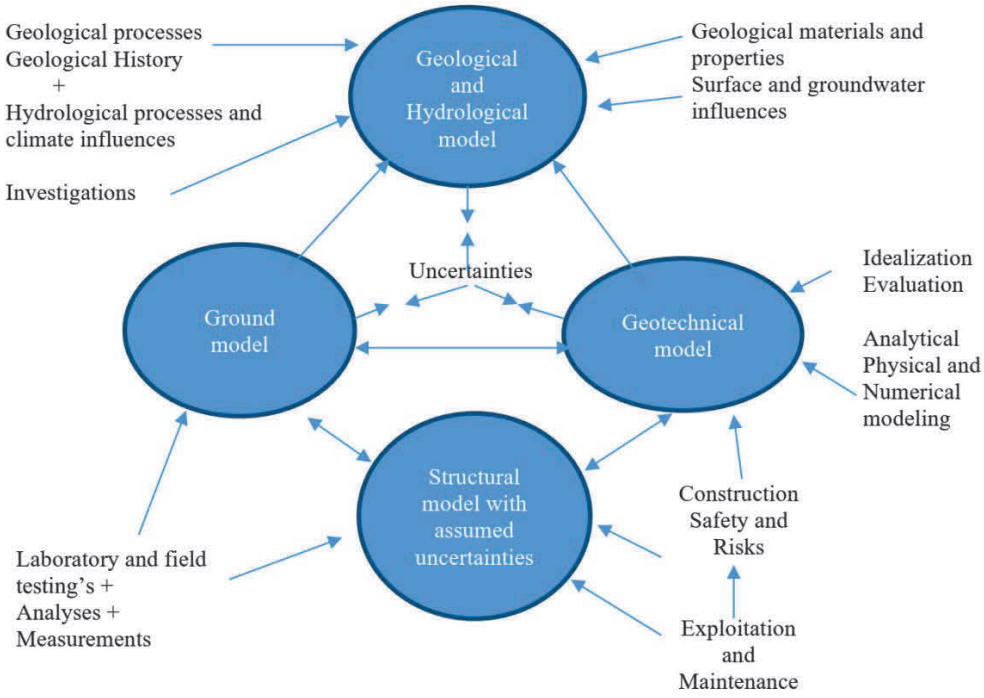

Fig. 3. Relationship between the geological and hydrological, ground, geotechnical and structural model, modified from [18]

The above presented approach can be useful in definition of uncertainties related to all geotechnical factors used in preparation of thematic geotechnical maps according to different methodologies. In any case, process of zoning is one of the first necessary steps because it gives general distribution of basic parameters for design of resilient systems from natural and technogenic hazards. The concept incorporates wide range of geological and hydrogeological processes necessary for modeling. Here, it is recommended to apply specific principles for site zoning and right selection of qualitative and quantitative parameters using GIS technology. In this case, GIS software is used in the preparation of more than 100 combinations of different maps for erosion protection, landslide hazard, flooding protection, geological, hydrogeological, bearing capacity maps etc., for Skopje valley area. In most of the cases, a so called Polynomial Interpolation Method (PIM) is used, which allows extrapolation of each value of selected parameters in preparation of the maps: it has been explained in more detail in [18].

3. RESULTS

The main goal of the research was to determine zones that have similar conditions for construction and to differentiate highly unfavorable zones in terms of natural hazards. By using the above mentioned PIM method, so called individual rating maps are prepared for the groundwater conditions, slope angles, lithological settings, excavation conditions, and seismic intensity maps. The combination of the individual rating maps leads to preparation of a Urbanization Suitability Map (Fig.4).

Urbanization suitability map is only the first approach in preparation of urban and spatial plans, and they should be used in a combination of geotechnical zoning maps necessary for calculations of structures stability, robustness and serviceability from seismic, flood erosion or landslide protection aspects.

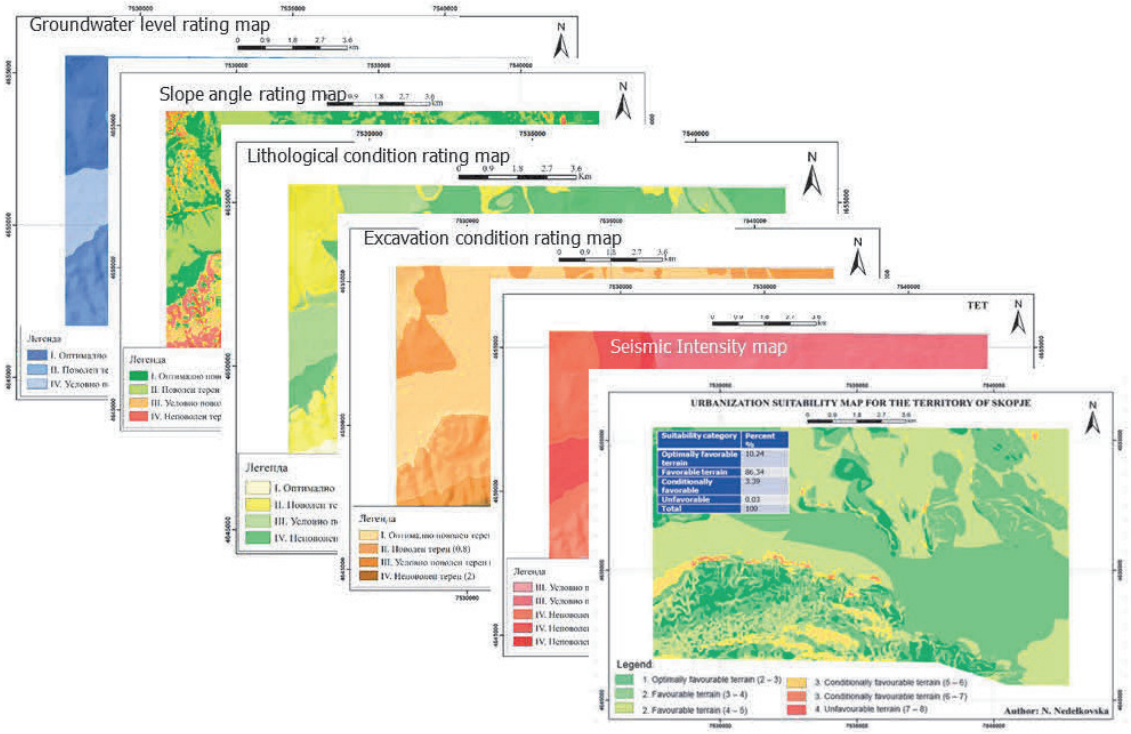

Fig 4. Urbanization suitability map for the area of City of Skopje

For these purposes, specific additional analyses and preparation of specific thematic maps is necessary. Some of them are presented in the following figures. For example, areas with known active landslides and erosion phenomena are presented in Figure 5.

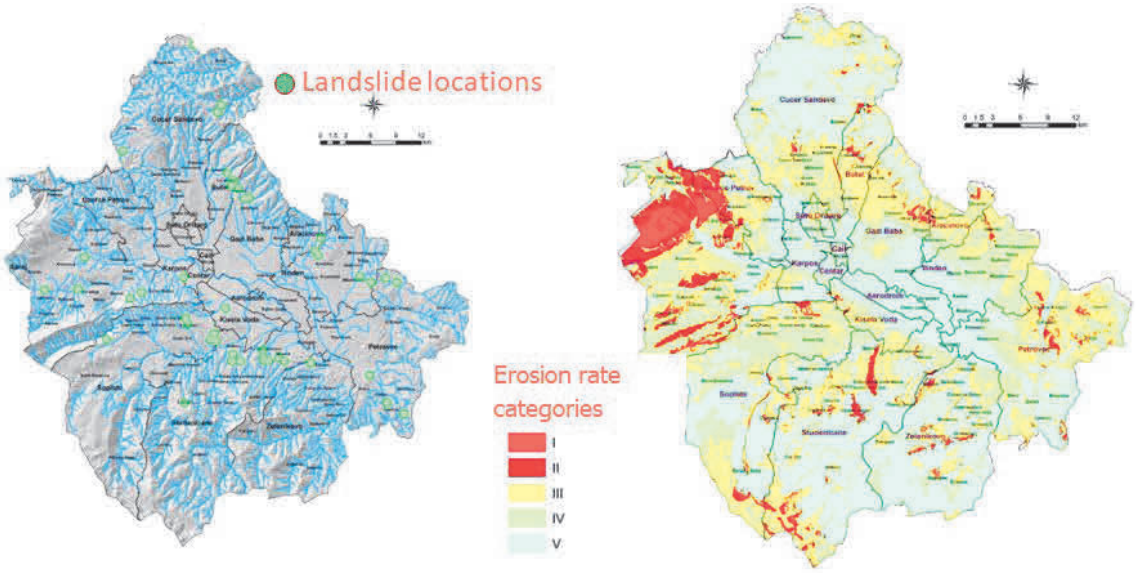

Fig.5. Landslide locations (left) and erosion rate categories (right) for the territory of Skopje valley

Floods are among the natural hazards with the highest risk for the Skopje valley, so an adequate attention must be given to these phenomena. Some data and scenarios are presented in Figure 6.

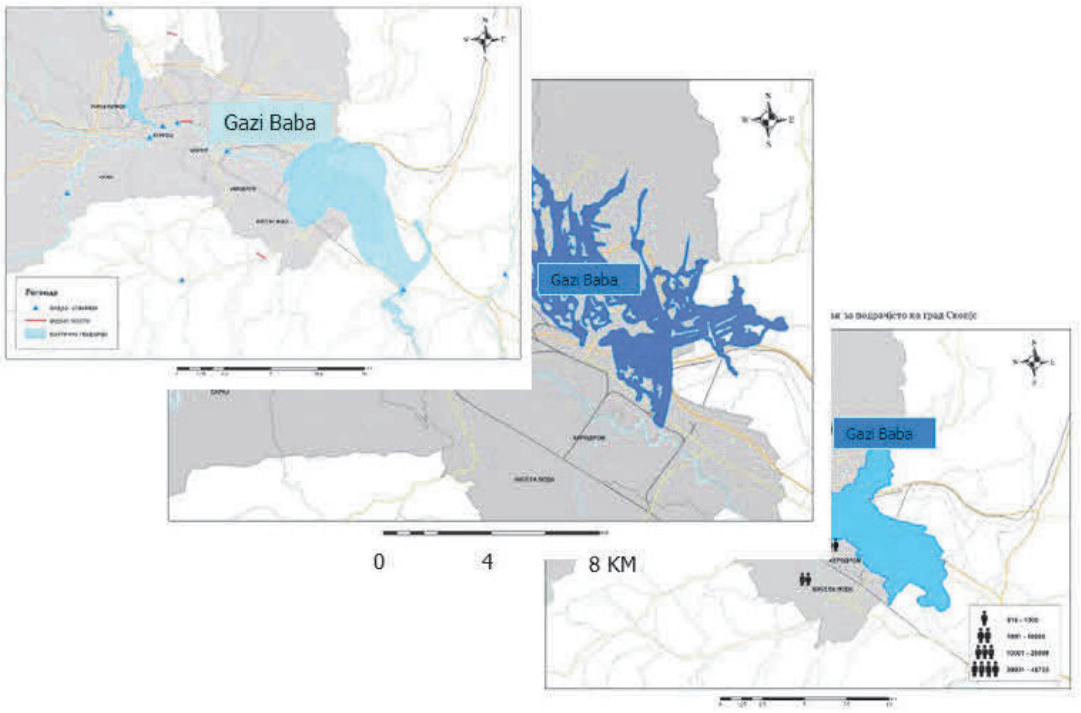

Fig.6. Some examples of flooding map of the Skopje area (upper-left corner: areas where flooding occurs frequently; in the middle: area of flood from 2016: down-right corner: scenario for flood with return period of 10 000 years including failure of dam Matka)

Another limiting factor is the seismicity of the area. Using approaches from Eurocode 8, Mirakovski et al., 2011, prepared a series of maps with expected accelerations for different damping factor return periods of 95, 145, 475, 975 and 2475 years respectively [19]. One example is presented in Figure 7.

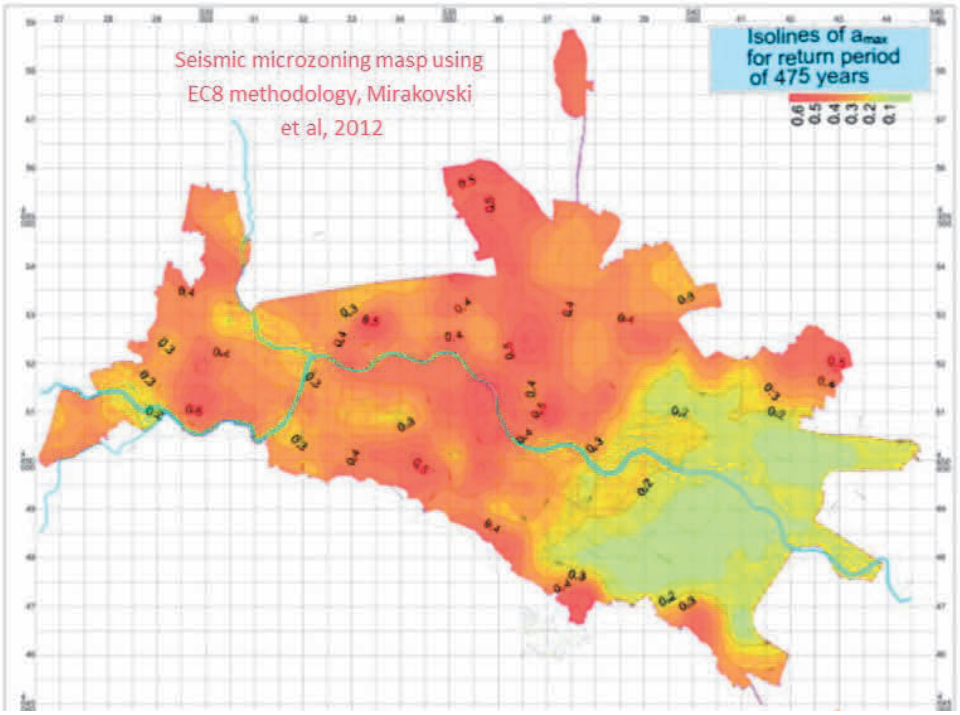

Fig.7. Isolines of peak ground acceleration amax for a return period of 475 years [19]

Another important steps are:

- to find an approach to define overall susceptibility to natural hazards in a certain area,
- to combine data from Urbanization Suitability Maps with protected areas and “hot-spots” where the urbanization shall be done with some specific protective measures and environmentally friendly structure solutions.

Due to the highest frequency of floods, followed by seismic hazards and soil erosion, one “simple” multi-hazard map is presented in Figure 8, while protected zones are presented in Figure 9.

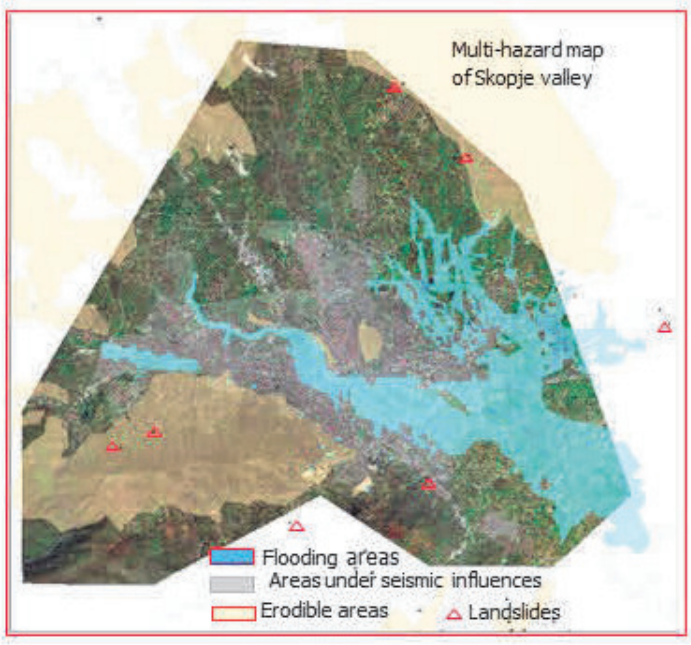

Fig.8. Multi-hazard map of Skopje valley

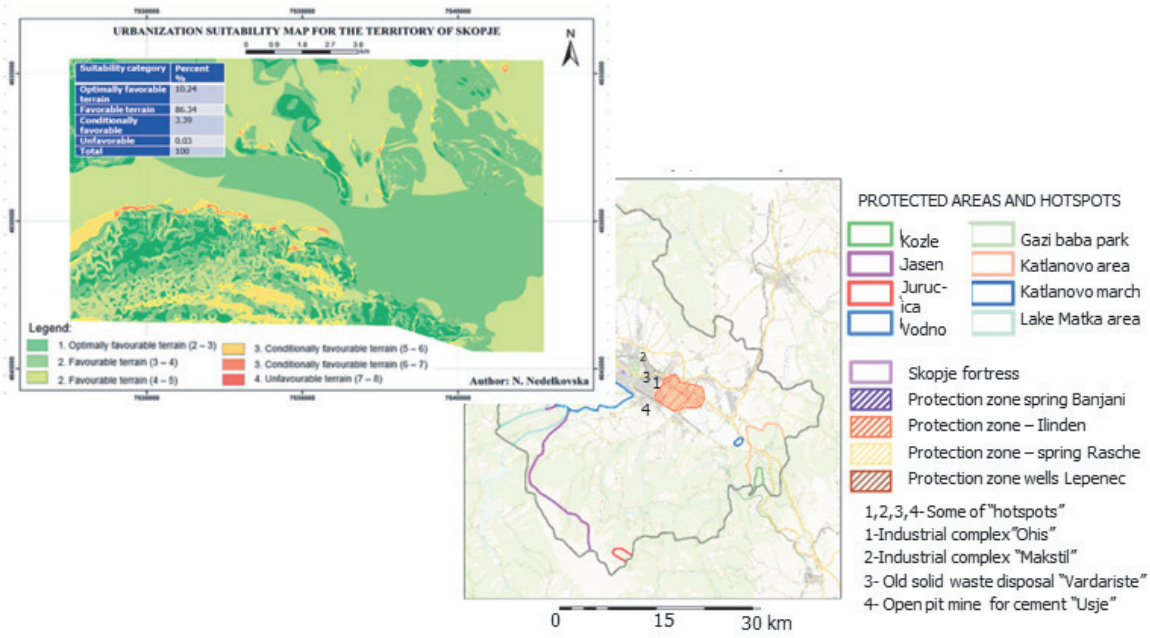

Fig.9. Position of protected areas and hotspots in Skopje valley

4. DISCUSSION

Presented results indicate that geotechnical zonation is a complex multidisciplinary process where data from different sources and past experiences shall be incorporated in a user-friendly form. Here, application of GIS-based analysis has a lot of advantages, because various hazard and risk scenarios can be developed. This is of a great importance for the local community and all institutions dealing with environmental protection and emergency management. But, all of this cannot be achieved if there is absence of good coordination among different stakeholders in the process of urban and spatial planning!

On the other side, geotechnical zoning maps shall serve as a general guide in urban planning, and for each separate structure detailed geotechnical investigations are necessary. To illustrate this, an interesting presentation of older and newer data is presented for a specific zone of Skopje City in Fig.10.

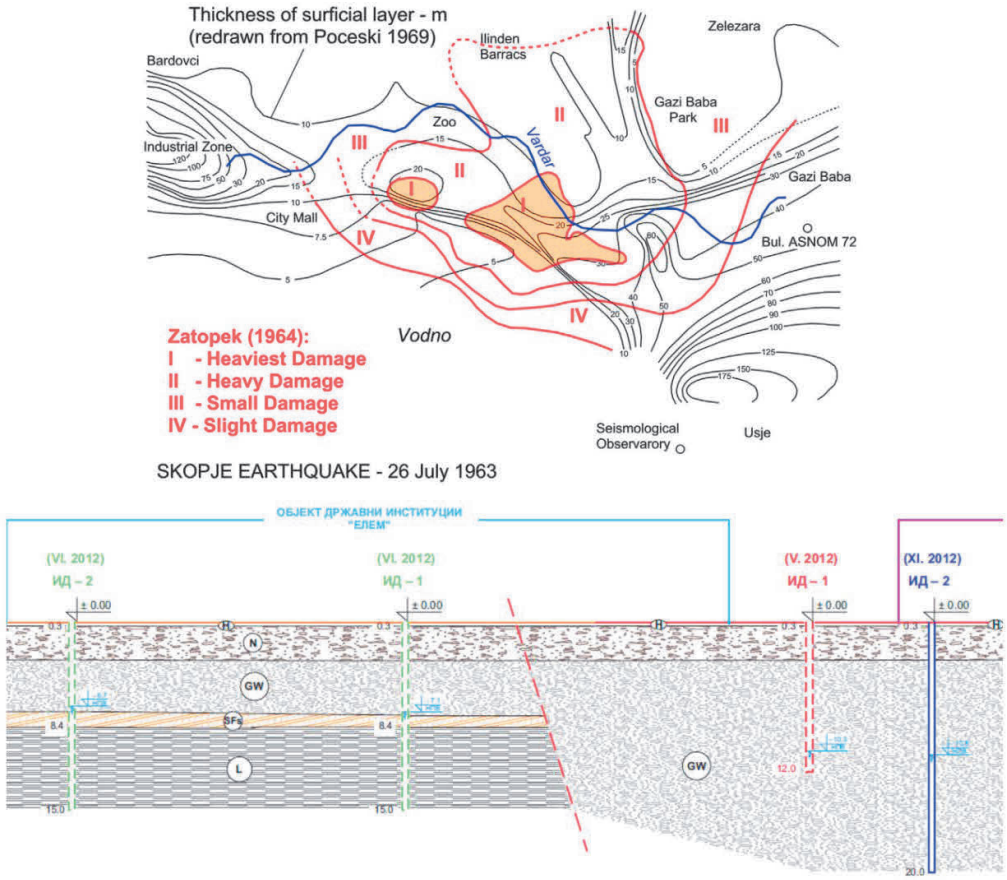

Fig.10. Upper picture: presentation of zones with different damages during Skopje earthquake according to Pocevski (data from [20]): Lower picture: detailed geotechnical profile for a new building of Public Enterprise for Electricity Production (data from [21])

Figure 10 clearly indicates that the largest damages in 1963 are, in fact, zones where local ground conditions, active faults and possible changes in the flow of Vardar River play an important role in drastic differences in foundation conditions. In such areas, the resiliency of the structures is hard to be insured, if an adequate geotechnical design is not prepared.

The good cooperation and data sharing among different engineering disciplines is a key element in such cases, to obtain long time resiliency of structures, applying measures that will minimize all main natural hazard influences. This requires systematic approach in design and construction based on the consistent application of design codes, systematic maintenance of buildings, forming of databases, and, if necessary, remediation actions. Detailed analyses of mutual influence between each factors overcomes the frame of the article.

5. CONCLUSION

Process of geotechnical zoning is one of the corner stones in definition of terrain suitability for urbanization and construction of resilient structures. The zoning must be based on collection and analysis of the all available data from field investigations and the elaboration of thousands of mutually correlated parameters, where using of GIS tools must be underlined.

The analyses clearly show that successful spatial and urban planning is not possible without an adequate methodological approach, completely adapted to the characteristics of the natural environment at hand, with a goal to insure best economic, social, environmentally friendly, and safe structures.

State and public enterprises dealing with spatial and urban planning, nature protection agencies, municipality institutions, non-government associations should be involved in a process of standardization and implementation of the multi-hazard methodologies, in monitoring, and in identification of natural disasters at a local and regional scale.

A main conclusion can be that philosophy for solving of complex urban planning and engineering problems must be based on interdisciplinary approaches, because geotechnical zoning is dynamic process, where all new data must be incorporated and used in improving of knowledge for the natural media. The authors believe that this concept can be useful in order to establish a way for defining all influential factors, with an idea to achieve the main goal: living in a resilient structures and safe environment.

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