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Seismic Assessment of Potential Sites in Macedonia

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Abstract. For the purpose of selecting a suitable location for the construction of a Nuclear Power Plant in Macedonia, investigations of the seismicity of the specific sites in the Republic of Macedonia were carried out in the period 1976-77 and 1982-84, and a number of documents were issued. The investigations were performed for five locations: Krivolak, Ubogo, Dubrovo, Mariovo I and Mariovo II.

Recently, feasibility studies for a large power plant were reinitiated in Macedonia, and the issue of seismic acceptance was reopened in view of the internationally modified seismic requirements. The JSC Macedonian Power Plants Company contracted IZIIS (Institute of Earthquake Engineering and Engineering Seismology) to complete an update of the studies previously completed for these sites. Although still ongoing, preliminary results of this project already confirmed that the site of Mariovo can meet the modern seismic requirements. Further studies are need to fully cover the preliminary site investigation study.

This paper provides a summary of the work completed in the 70s and 80s, discusses the preliminary results obtained so far in the project with IZIIS this year, and provides some insights of recent visits to the site, where a walk-down was completed to confirm some aspects of the site adequacy to host a large power plant construction.

1 Introduction

For the purpose of selecting a suitable location for the construction of a NuclearPower Plant, investigations of the seismicity of the territory of the Republic of Macedonia were carried out in the period 1976-77 and 1982-84. The investigations were performed for five locations: Krivolak, Ubogo, Dubrovo, Mariovo I and Mariovo II.

In accordance with the instructions given by the International Agency for Atomic Energy at the time, for the purpose of definition of seismogene foci of strong earthquakes with a magnitude greater than 5 degrees ($M \geq 5.0$) in the territory of the Republic of Macedonia, in the domain of geology, the above stated locations were involved in regional geological investigations, regional seismotectonic investigations, subregional geological investigations, subregional neotectonic and seismotectonic investigations. These regions were subject of seismological investigations. The investigations were done by a number of experts from the Institute of Earthquake Engineering and Engineering Seismology within the Ss. Cyril and Methodius University, Skopje, Macedonia.

Within the frames of regional geological investigations, a synthesis review geological map of the Balkan Peninsula to the scale of 1:1000000 has been elaborated. Around the indicated locations, within a radius of 300km and area of 250000 km^2, the map covers the territory of Macedonia and parts of Bulgaria, Romania, Serbia, Montenegro, Albania and Greece.

According to this map the main geotectonic units of the Balkan Peninsula: the Mesian plate, the Carpatho-Balkanides, the Rhodopian massif, the Serbian-Macedonian massif, the Vardar zone, the Dinarides, the West Macedonian zone, the Mirdite zone, Krasta-Cukali (Debar) zone, Kruja zone, Ionic zone, Sazin plate.

Subregional geological and seismotectonic investigations were performed on the above mentioned five locations in the period 1976-77 and 1982-84. As a result of the total knowledge gained from the regional and subregional geological, tectonic, neotectonic, seismotectonic and seismological investigations, it was proposed that further investigations be done on the Mariovo I and Mariovo II locations as the most suitable for construction of a large energetic structure.

The terrains of R. Macedonia geotectonically belong to 5 main units as follows: the Serbian-Macedonian massif, the Vardar zone, the Pelagonian massif (Pelagon), the West Macedonian zone and the Debar zone (Cukali-Krasta). These were created in different geological eras. The oldest are the Serbian-Macedonian massif and the Pelagonian massif, which represent relics from the Proterozoic Earth's Crust composed of highly metamorphic gneisses, micaschists, amphibolites, granitoids, while the Pelagon also contains marbles. The West Macedonian Zone and the Vardar Zone were created in the Paleozoic whereat in the Jurassic, the Vardar Zone transformed into a rift zone, while the Debar Zone (Cukali-Krasta zone in Albania) was created in the Laramian tectonic phase of the Paleocene.

Subregional geological investigations have been done on an area within a radius of 50 km around the Mariovo locations. The area of both locations is a constituent part of

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the Pelagonian massif, whereat Mariovo I is in the vicinity of the contact between the Pelagonian massif and the Vardar zone, while Mariovo II is within the interior of the Pelagonian massif.

2 Potential Sites

Mariovo location is situated in a seismically stable area in the territory of R. Macedonia neighboring northern Greece. So far, neither slight nor strong earthquakes have been observed at a distance of about 20 km around the location.

A number of catastrophic earthquakes happened in the wider region within radius of 300 km as well as in the territory of R Macedonia in the period 1900-1982. The closest occurred strong earthquake was the earthquake in Debar of 1967 with magnitude of 6.5 of Richter scale, and the Valandovo earthquake with magnitude of 6.7 at a distance of 80 km from Mariovo I and Mariovo II location. The Skopje earthquake epicentral area with magnitude of 6.1, at a distance of 100 km (see Table 1). The effect of the observed intensity of these catastrophic earthquakes upon Mariovo locations is given in Table1. The closest occurred earthquakes are those that occurred in Debar and Valandovo.

The earthquake that occurred the closest to the Mariovo I location was Mrezhichko earthquake of 1910 with at a distance of 20 km northeast. The closest to Mariovo II location is the earthquake focus of the Bitola-Prespa region, at a distance of 40-80 km, giving rise to earthquakes of a moderate intensity.

Table 1. Distance from epicenters of occurred catastrophic earthquakes and observed effect upon Mariovo locations

Closest occurred earthquakes	Distance from Mariovo	Observed intensity I = MCS Mariovo
1904, Pehchevo M = 7.8, I = X MCS	140	VII
1921, Uroshevac M = 6.1, I = IX MCS	150	V
1931, Valandovo M = 6.7, I = X MCS	80	VI
1963, Skopje, M = 6.1, I = IX MCS	100	V
1967, Debar, M = 6.5, I = IX	75	VI
1978, Thessaloniki-Halkidiki, M=6,5, I=IX MCS	130	VI
1979, Budva, Montenegro, M=7.0, I=IX MCS	220	VI

2.1 Mariovo I

On the Mariovo I location, the area at the Rasin Bey Bridge over Crna River has been selected for the construction of a large power plant, i.e., an area within a radius of 8 km.

The location is situated in the Crna River valley which, to the west and northwest, separates Seljachka Mountain and Dren Mountain from the regions of Nidze to the east and southeast. The sedimentary mass of the Upper Miocene-Pliocene and Pleistocene lake that stretched over these terrains was eroded with the later denudation processes whereat there remained the primary abrasive-accumulative plain with minor remains of Pliocene gravel and sand.

The Mariovo area is filled with fresh water sediments represented by basal gravel-sand over which are developed sandy-clayey sediments and marly clays, marlstone, coal clays and coal layer, with fossil remains of macroflora and Diatomean micro flora of Upper Miocene age.Over the Miocene mass, there are developed Pliocene gravels and sands, diatomites and pyroclastic material of agglomerates, tuffs and volcanic breccia of isotopic age 4±0.2-1.8±0.1Ma, mostly covered with widely spread limestone plate of Pleistocene age.

In 1983, engineering geological and geophysical investigations of the wider surrounding of Mariovo I location, in the part of Crna River, from Skochovir to Stobi, were performed. The Mariovo upland is at an altitude of 500-900m. It is enclosed by mountain massifs, namely Kozjak to the east, Dren to the north, Seljachka Mountain to the west and Kajmakchalan to the south. In the Pliocene, this upland was under water. It is therefore that the upland has a plate like form, with presence of lacustrine sediments. After the flowing of the lake from the upland, a network of rivers was formed with the main artery Crna River, whose bed is deep and cuts the massif through its central part,creating a canyon within a length of 50m. The morphology of the river valley and the formations that occurred with the cutting of the Crna River have been analyzed into details. According to their lithological content, these represent Precambrian highly metamorphic rocks (gneisses and micaschists) with a final layer of marbles, in the east peripheral part of the Mariovo upland. During the Grenville orogeny, granite and magmatic masses were intruded so that the relief is characterized by expressively exotic formations.

Data on propagation velocities of shear and longitudinal seismic waves were obtained based on the geophysical investigations of the terrain of Mariovo I location with a total length of developed research profiles of 2500 m. The orientation of the profiles is in compliance with the structure of the investigated area and the characteristics of the relief. Crossing of the profiles was done to get an insight into the homogeneity and anisotropy conditioned by the foliation.

2.2 Mariovo II

Mariovo II location is situated in the south central parts of SeljachkaMountain, at Smagovo location which is not very far away from the Chebren gorge on Crna River. The investigations involved an area of 55 hectares. In this terrain, there were performed engineering-geological and geophysical investigations. Its wider surrounding belongs to the deeper disclosed levels of the Proterozoic crystalline mass of the Pleagonian massif and the Pelagonian neotectonic depression (graben).

According to the elaborated engineering-geological map, the geology is relatively very simple, i.e., the terrain is dominantly composed of highly metamorphic gneisses pierced with a smaller mass of granodiorites, which are a constituent part of the Pelagonian massif. Also, there occur several quartzite veins stretching NW-SE and NE-SW.

The gneisses and the granodiorites are grussed upon the surface, whereat grussed material with a thickness of 0.5–2.0 m is extensively present in the terrain.

The Pelagonian depression is situated west from the Pelagonian crystalline massif. It was formed during the neotectonic motions of subsidence of the terrains between the mountains to the east, namely, Rudina-Babuna-Seljachka Mountain and the west parts of Kajmakchalan, while to the west, the Baba (Pelister) Mountain – Krushevo Mountains (Busheva Mountain). The peleorelief of the graben belongs partially to the Pelagonian massif and partially to the West-Macedonian zone.

The graben is N-S oriented and has a length of about 100 km (including the Lerin part, Florina in Greece) and a maximum width of 25 km. It started to be formed in the second cycle (Sarmatian-Meotian) in the area between Bitola and Lerin to the South, where the sedimentary mass reaches over 800 m and gradually extends toward south, in the Prilep area where the deposits are 450-500m thick. Due to the fast uplifting of the surrounding terrains (horsts) in the longer geological period, mainly Terigene gravel and sediments were created in the formed fresh water lake. It was only during the Meotian-Pontian that untroubled shallow water to marshy sedimentation occurred when, in the west part of the basen, there were created thick deposits of coal clays and coal layers and over them, diatomite-clayey-alevrite clays. On the top, there are mainly eroded Pliocene gravels and sands as well as remains of Pleistocene alluvial-proluvial deposits.The gravitational faults toward Baba Mountain are seismically active. Earthquakes have been recorded along them, while no earthquakes have been recorded along faults toward the Seljachka Mountain.

Within the frames of the investigated Mariovo area, detailed engineering geological and seismological investigation of the Smagovo location was done additionally. These investigations provided the possibility for comparative analysis for the purpose of selection of the most suitable location for the construction of the energetic structure. Engineering-geological mapping has been performed on the pantographic plan provided by the Inveastor to the scale of 1:2500, covering an area of 55 hectares. Profiles with individual length of 100 and 150 meters and total length of 1500 meters were realized. The orientation of the profiles and their crossing were in accordance with the structure of the investigated area and the characteristics of the relief. According to age and level of diagenesis, several types of rock masses are distinguished. These are Precambrian highly metamorphic rocks (gneisses and granites) and media that represent the most recent products of their disintegration in the form of gruss and crushed stone.

3 Seismic Assessment Updates

According to a number of geological, tectonic and seismotectonic parameters and the spatial possibilities for construction of a large energetic structure, it is concluded that additional investigations of the Mariovo locations are necessary to be carried out in future. From geological and seismotectonic aspect, Mariovo II location appears to be more suitable. Therefore, the following geological surveys should additionally are being done for this location:

- Analysis of the seismotectonic conditions in the wider and closer surrounding. A seismotectonic map of the subregion should be elaborated, i.e., analysis of earthquakes that occurred within the Bitola, Prespa, Ohrid and Kichevo earthquake foci and the effect of the observed intensity upon Mariovo I and Mariovo II locations should be carried out.
- A geological map to the scale of 1:5000 is elaborated for an area within a radius of 5 km. In addition to detailed lithological investigations and determination of individual petrographic units, detailed measurements of structural elements (foliation, cracks, faults, cleavages and lineation) should be carried out and stereographically analyzed. Various geological profiles are elaborated.
- A geological map to the scale of 1:500 is elaborated for an area of 1 km^2. The faults and the network of cracks and other structural elements should be explored in details. The map will also serve for location of boreholes for geomechanical and other engineering-geological investigations.
- Detailed investigation is performed regarding the lithostratigraphy of the Neogene grabens: the Pelagonian massif, Prespa, Porech and Kichevo grabens that are situated west from the Pelagonian massif and are connected with faults and Mariovo graben formed at the boundary between the Vardar zone and the Pelagonian massif.
- Neotectonic surveys are being performed for the wider terrain and the inner tectonic structure of the grabens. Most of the neotectonic faults that limit the grabens are only geologically active but, in the course of time, they can turn into seismically active areas.

Additional investigations that are necessary to be done in future for the purpose of proper and complete definition of seismicity include:

1. All data on historic earthquakes that have not been obtained by instruments should be collected. Paleoseismic and archaeological data on historic and prehistoric earthquakes should also be taken into account.

2. The intensity scale that is used in the catalogue should be specified since the intensity levels may vary depending on the used scale. The evaluations of magnitude and depth of each earthquake should be based on relevant empirical relationships between instrumental data and macroseismic data that can be developed from the database directly from the data on intensity or by use of isoseismals.

3. It is necessary to collect all available instrumental data on earthquakes. To locate earthquakes, existing information on the models of the Earth crust should be obtained. The information obtained on the earthquakes should include:

- Date, time duration and beginning time,
- Coordinates of the epicenter,
- Focal depth,
- All definitions of magnitude, including those on different scales and all information on seismic moment,
- Information on observed foreshocks and aftershocks with their dimensions and geometry, where possible,
- Other information that can be useful in understanding the seismotectonic regime as are the focal mechanism, the seismic moment, the reduction of stresses and other parameters of the seismic source,
- Assessment of uncertainties in each of the mentioned parameters,
- Information on the causative fault, direction and time duration of crack,
- Records from wide band seismometers and strong motion accelerographs.

4 Mariovo Site Walkdown

In order to determine the exact location for the construction of Nuclear Power Plant (NPP hereafter), defined in the research and studies done in the 70 s and 80 s, AD ELEM on June 16, 2014 organized a site walkdownin Mariovo.

Photograps were taken and geographic coordinates were recorded by professional GPS device. Figure 1 displays the coordinates of the characteristic places that were visited. The place Rasimbegov Bridge served as an auxiliary point for orientation, while the selected site of Smagovo (see Figure 1) was defined in the previous studies.

A view of the potential sites defined in previous studies [13] prepared by the experts of the University Cyril and Methodius at Skopje is shown in Figure 2 without geo-

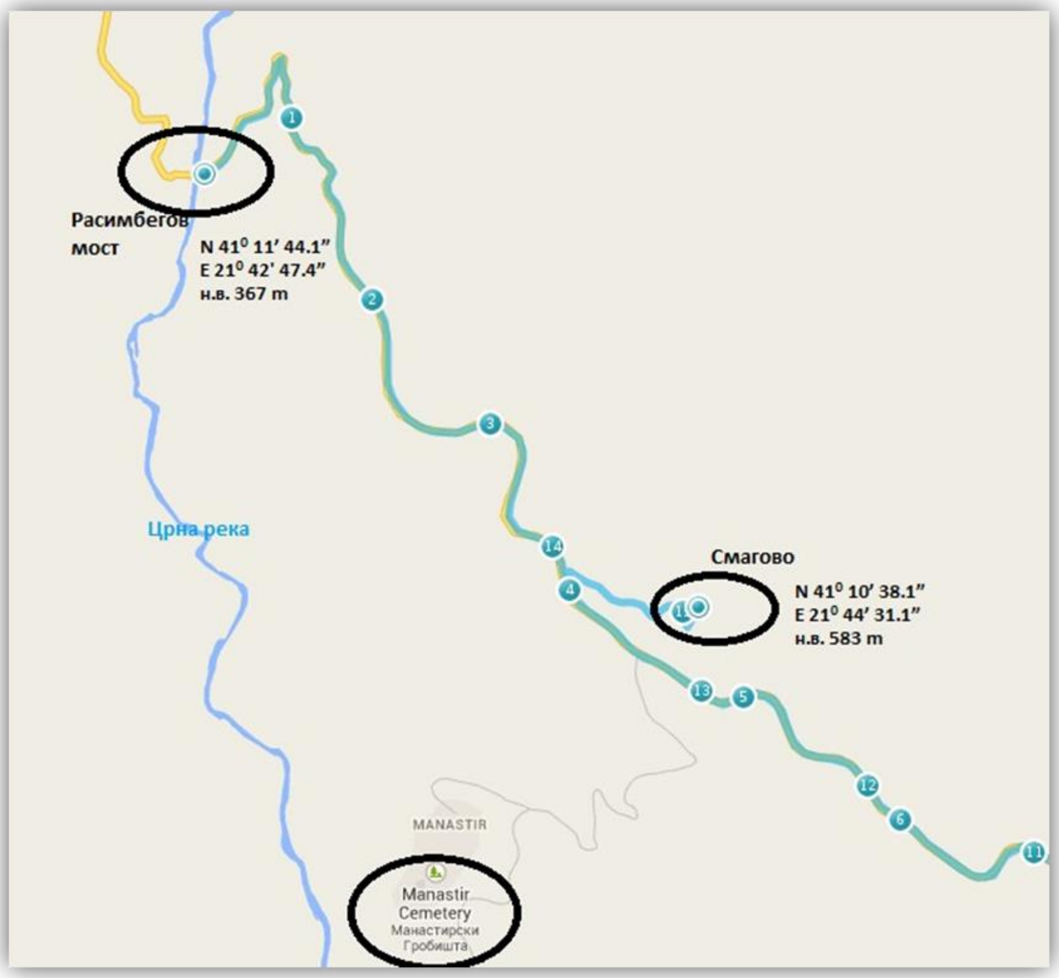

Figure 1. Coordinates of Smagovo NPP potential site.

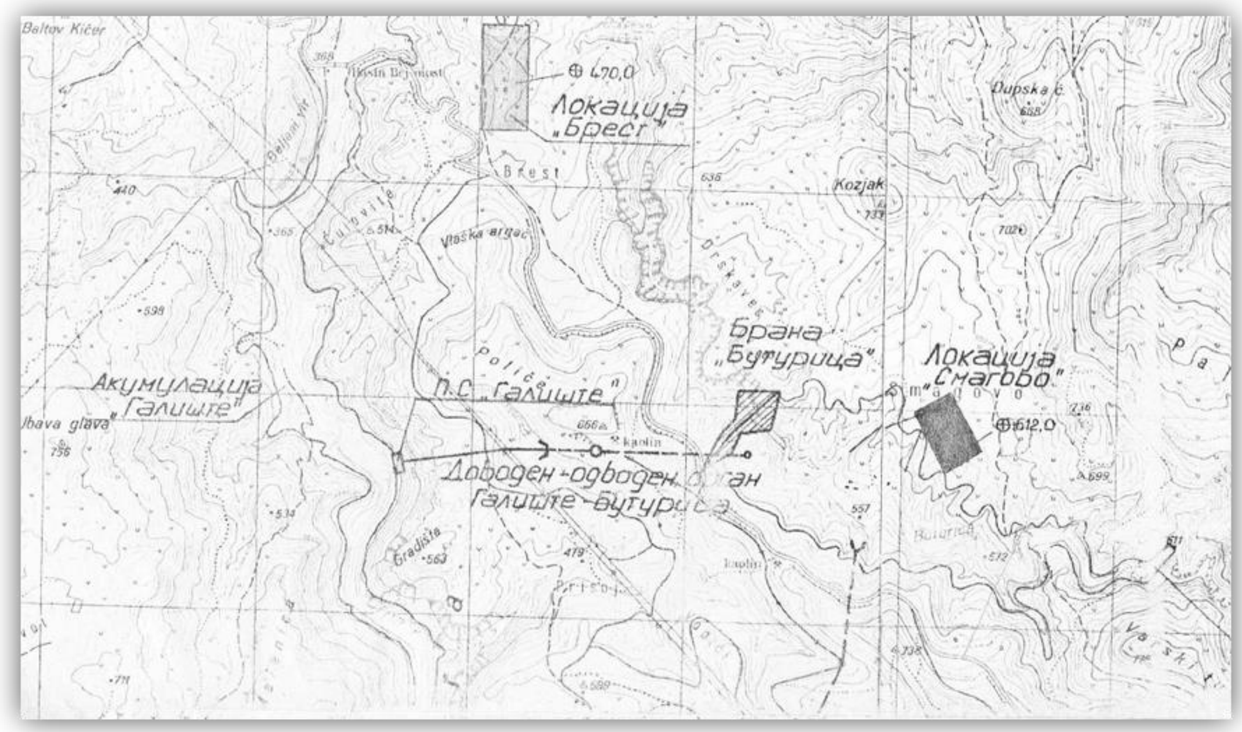

Figure 2. Map of the NPP potential sites at the Mariovo location [13].

graphical coordinates. It may be noted that in the immediate vicinity of Smagovo, construction of a dam "Buturica" was planned on the Buturica River. This small accumulation was estimated to be sufficient to supply cooling waterto the NPP cooling towers in an average year. The Butirica Lake was also connected to the much larger accumulation Cebrenandthe accumulation Galiste through an intake water channel, as shown in Figure 2. The purpose of this connection was to ensure reliable supply of cooling water to the NPP cooling towers in the case when Buturica River would not have a sufficientwater supply.

After site visit of the location area in Mariovo, it was concluded that this location meets basic requirements. The following benefits are obvious at this location:

1. Relatively isolated area from major population areas, and industrial and agricultural centers;
2. Appropriate geographical position (surrounded with mountains of medium height);
3. Proximity of 400 kV high-voltage transmission line;
4. Plan to build a large artificial lakes (Cebren and Galiste), and a small lake intake (Buturica), which should satisfy all requirements for water supply to the cooling towers. Also, this site is located at a height above the lake Cebren (planned in the near future), which satisfies the NPP flooding requirements;
5. Seismically stable area.

5 Conclusion

Regarding the Mariovo I location, the most suitable place for the construction of a large power plant is the place called Orlov Kamen, above the Rasim BegBridge. This location is surrounded by the estuary of Crna River from north-west, and by the motorway to the south, and up to the left valley of Buturica River to the east. The geological conditions at this site present a quite homogeneous Precambrian complex of gneisses with granite intrusions, with very favorable characteristics from the aspect of seismic effects. It is generally concluded that two lithological media are suitable for the foundation of the NPPIsland.

At the Mariovo II location, shown as Smagovo location on Figure 2, surface loose deluvial material, i.e., surface disintegrated gneisses occur over the entire area of the location with a thickness of 1.5–2.5 meters, at some places with a thickness of 10m. Geomechanically weakened gneisses are present at depth of 5–12 meters. Relatively compact gneisses occur over the entire region, while in the southern part of the region, these are characterized by somewhat more extensive geological damage.

The Smagovo site at the Mariovo macro location has been shown to have the most favourable seismic and geomechanical characteristics to host a new-build NPP in Macedonia. Based on the investigations in 70 s and 80 s, and the current investigations in progress, this site is the best suited for the future NPP construction. However, further studies and assessments need to be completed to ensure all relevant legal requirements and international guidance by the IAEA is adhered to.

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