

DANGEROUS SEISMOTECTONIC SITUATION FOR ANCIENT AND MEDIAEVAL MONUMENTS IN SOFIA CITY (BULGARIA)

M. MATOVA¹

ABSTRACT

Sofia city with its ancient and mediaeval monuments is situated in the Sofia graben. The neotectonic evolution of the graben and its surrounding horsts is considerable. The block fragmentation and the realized horizontal and vertical block movements in the Sofia graben and the adjacent horsts are investigated geologically. The number of the seismic events in the graben and the horsts is significant. The epicenters of the earthquakes are concentrated along the main faults of the Sofia graben, the Vitosha and the Negushevo fault zones and the Chepintsi fault. The seismic and the structural characteristics show the considerable activity of the Sofia graben and the surrounding horsts. These seismotectonic conditions are dangerous for the ancient and mediaeval monuments in the city.

KEY WORDS: Sofia graben, block fragmentation, seismic movements, monuments, seismotectonic danger.

1. INTRODUCTION

Sofia city (1 128 859 inhabitants according the data of the end of 1987) has a long-term evolution. The city is attractive with its position on the crossings of important highways, with the mineral water springs, fertile lands, healthy climate and the mountain's surrounding. The old traces of the Thracians, the Hellenes, the Romans, the Huns, the Bizantines, the Slavs, the Bulgarians and the Ottomans could be found in the territory of the city. The periods of its prosperity and destruction are in often replacements.

The traces of the ancient city castle with impressive and wide walls, public and private buildings, the churches "St. George" and "St. Sofia" mark its prosperity respectively during the 4th and the 6th centuries A.D. The mediaeval monuments, like the Boyana church (14th century), the Kremikovtsi (15th century) and the Seslavtsi (17 century) monasteries mark next stages of development

2. SEISMOTECTONIC NOTES

Sofia city is placed in the middle part of the Sofia graben and partially on the peripheries of the surrounding horsts. The graben is of intensive Neogene-Quaternary development. The graben is limited by two longitudinal faults, the Negushevo (NW-SE) and the Vitosha (NW-SE) fault zones (Fig. 1). The faults with NW-SE, NE-SW, submeridional and subequatorial directions control the graben fragmentation which is remarkable.

The numerous blocks of various sizes participate in the vertical and horizontal movements. The vertical displacements are relatively more considerable than the horizontal ones.

The vertical displacements mark the maximal values in the blocks of the contacts of the Sofia graben and the surrounding horsts. The contrast block movements are relatively the most considerable in the blocks of the contact between the graben's middle part and the southern adjacent Vitosha horst.

The thermal mineral water springs are concentrated generally in the southern boundary of the graben - mainly along the Vitosha fault zone. Some other springs are localized along the inner graben fault - the Chepintsi one (NE-SW). The block displacements and the spatial distribution of the mineral water sources (Fig. 1) are among the indications for the recent fault activity in the investigated territory of the Sofia graben.

The local seismic manifestations in Sofia graben are of various characteristics. All of them are of shallow hypocenters.

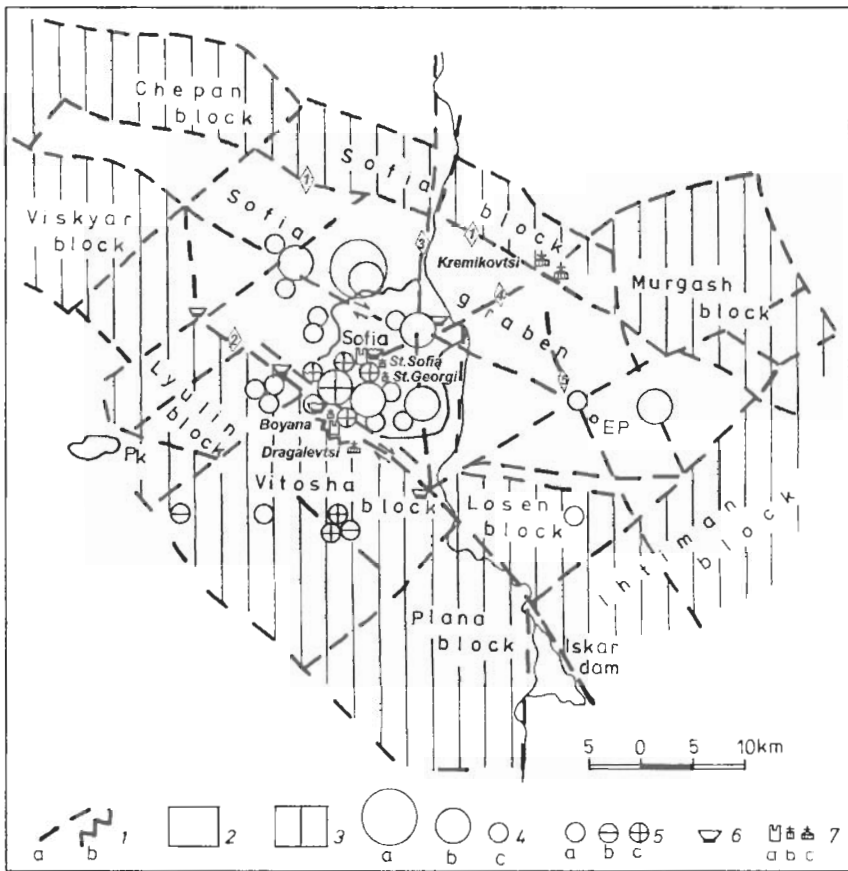


Fig. 1. Strong and moderate earthquakes in the block segmented Sofia graben and surrounding horsts, where ancient and mediaeval monuments are situated.

1 - faults: a - of the block boundaries (1 - Negushevo fault zone, 2 - Vitoshka fault zone, 3 - Iskar fault, 4 - Chepintsi fault, 5 - Elin Pelin fault), b - seismically deformed sector of the Vitoshka fault during the 1858 Sofia earthquake; 2 - block of the Sofia graben, 3 - block of the surrounding horsts, 4 - epicenters of earthquakes with magnitude M : a - $M=6.1-7.0$, b - $M=5.1-6.0$, c - $M=4.1-5.0$; 5 - depths of their hypocenters: a - up to 10 km, b - 11-20 km, c - 21-30 km; 6 - thermal mineral spring; 7 - several ancient and mediaeval monuments of Sofia city: a - castle, b - church, c - monastery. Abbreviation of town names: EP - Elin Pelin, Pk - Pernik.

The last investigations and the revision of the seismological information indicate the presence of strong earthquake in 19th century. It is a 1858 Sofia earthquake ($M=6.5-7.0$) (Solakov et al., 2001). The earthquake epicenter is situated in the center of the investigated graben. The depth of the hypocenter is no more than 10 km.

The local moderate shallow earthquakes are registered or noted in the Sofia graben and its surrounding horsts. A great part of their epicenters are localized in the crossing of the Vitoshka and the Chepintsi faults (Fig. 1). The great part of the seismic events are related to hypocenters which depth is also no more than 10 km.

The above mentioned strong and moderate earthquakes which hypocenters are in the very shallow layers of the crust permits to suppose the presence of considerable seismic effects in Sofia city, including in the ancient and mediaeval monuments (Fig. 1).

Considerable number of local weak earthquakes are registered in the Sofia graben. The distribution of their epicenters proposes an additional and significant information for the recent mobility of the graben and for its seismotectonic potential in the destruction processes (Fig. 2).

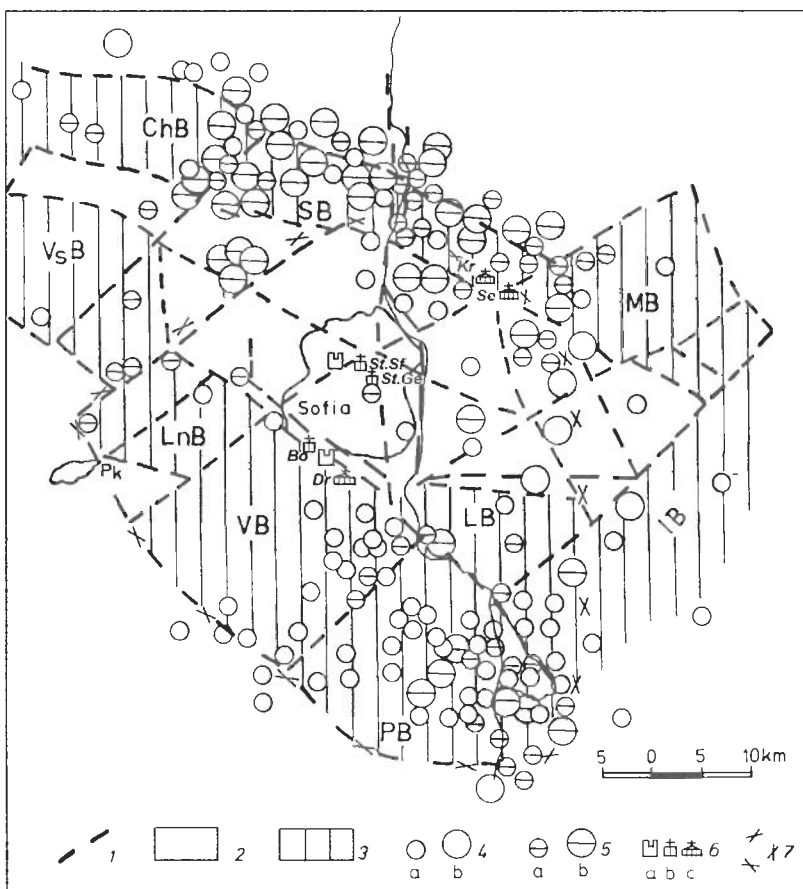


Fig. 2. Weak earthquakes during 1966-1979 (summary of seismic data in the publications of the Geophysical Institute after Matova, 1998) in the block segmented Sofia graben and surrounding horsts.

1-fault of the block boundaries, 2 - block of the Sofia graben, 3 - block of the surrounding horsts, 4 - epicenters of earthquakes (1966-1976) with magnitude M : a - $M < 1.5$, b - $M \geq 1.5$; 5 - epicenters of earthquakes (1976-1979): a - only recorded, b - felt by the population; 6 - several ancient and mediaeval monuments of Sofia city: a - castle, b - church, c - monastery, 7 - Sofia city hinterland. Abbreviations: ChB - Chepan block, SB - Sofia block, MB - Murgash block, IB - Ihtiman block, Lb - Lozen block, VB - Vitosha block, PB - Plana block, LnB - Lyulin block, VsB - Viskyar block, Kr - Kremikovtzi monastery, SE - Seslavtzi monastery; St.Sf - St. Sofia church, St.Ge - St. Georgue church; Bo - Boyana church, Dr - Dragalevtzi monastery; Pk - Pernik, EP - Elin Pelin.

The influence of the regional strong earthquakes is also of great importance for the studied territory. The strong shallow earthquakes, like the 1904 Krupnik one ($M=7.8$), provoke seismic effects of $I_0=VII$ in Sofia city, including building destruction and liquefaction. The numerous, long-term manifested and periodically repeated strong Vrancea intermediate earthquakes provoke also small destruction effects in certain localities of the city.

The summary impact of the above cited local and regional seismic events could be of great importance for the stability of the city buildings. The summary seismic influence over the historical monuments was very continuous.

The seismotectonic situation in the Sofia graben and the surrounding horsts creates serious problems for the city. The problems are related mainly to the protection of the old city and its monuments as well as to the development of the new city.

3. SEVERAL ANCIENT AND MEDIAEVAL MONUMENTS IN SOFIA CITY

Numerous traces of the Thracian, Hellenic, Roman, Byzantine, Bulgarian and Ottoman periods could be observed in the center and the peripheries of the city. The town was attractive for the population of the Balkan

Peninsula and for the participants in the Great migration of the peoples.

Several important ancient (1st - 8th centuries) and mediaeval cultural monuments (9th -17th A.D.) are the subject of the study. They are placed in different quarters of Sofia city. They mark the long evolution of the city during the millenniums.

Constructions of the Roman period (1st -4th centuries A.D.) could be observed in the center of the city and its southern periphery. They are represented mainly by the partially saved city castle, some public and private buildings. The traces of the castle, of the buildings and inner streets are marked in the center of the city. Very bad saved traces of outer walls of the city castle and of the water-supply system are established in the southern periphery of the city - the Boyana quarter.

The ancient churches "St. Sofia" and "St. George" are among the relicts of the Byzantine period. The churches are situated in the center of the city. The first of them, "St. Sofia" church, was so remarkable, that the name of the city is related to it during Middle Age.

The biggest part of the mediaeval monuments are represented by churches and monasteries. The Boyana church (11th-13th centuries A.D.), also the Dragalevtsi (14th century), the Kremikovtsi (15th century) and the Seslavtsi (17th century) monasteries are among the most representative monuments (Fig. 1). Their building and painting represent an expression of the economic possibilities and the cultural needs of the population in the city and its surrounding.

The Boyana church (Fig. 3) was constructed during three stages - the 11th, the 13th and the 19th centuries, but only the first two of them are of historical value. The second stage of the Boyana church was the most important for the cultural history of the country and the world. The Boyana church is included in the UNESCO List of the World Cultural Heritage.

The painting of the Boyana church during the 13th century is remarkable. The murals of the church include 89 scenes with 240 human faces.

The portraits of the local Sevastokrator Kaloyan and his wife Desislava are of exceptional value for the Bulgarian art history. They represent indications for the development of the Bulgarian Renaissance. The other portraits of the Bulgarian Tsar Constantin Asen and his wife Irina, also of the military saints are also among the significant ones. The presence of wall painting compositions with several elements of the Bulgarian life is one of the very impressive church characteristics.

The painting of the churches in the Dragalevtsi, the Kremikovtsi and the Seslavtsi monasteries is of importance for the next stages of the Bulgarian history. The murals of the cited churches propose information for the economic and cultural life of the people in the country. The decoration of the churches is realized according to the Orthodox laws, but a great number of the details give expression of the Bulgarian existence during the different periods of the Ottoman domination.

The murals of the Seslavtsi monastery church and some other churches in the region of Sofia city are attributed to the well-known Bulgarian painter Pimen Zographski and its famous painting school.

Seismotectonic information based on cultural monument's periods of construction and deconstruction

All of the mediaeval churches were built and reconstructed several times. The definition of the periods of reconstruction includes very important indirect information for the previous periods of their destruction. The destruction of the monasteries embraces data for the natural and the human impact during their long history. The human impact is of various types. One of them is of technogenic type. The last one includes the wars, the revolutions, the various peacetime industrial and transport activities etc. It is of significance in the Sofia region. The technogenically induced seismic events are not the subject of the proposed investigation.

The earthquakes are among the most significant natural impacts in the recent active territory of Sofia city. The seismically provoked deformation and destruction of the monuments are interesting for the seismotectonic interpretations. The established seismic effects permit to receive information for:

- the intensity of the earthquake in sites of monuments,
- the seismically active faults,
- the local co-seismic phenomena.

4. SEISMOTECTONIC DEFORMATIONS OF THE HISTORICAL MONUMENTS

The seismotectonic conditions are complicated in the Sofia graben and the surrounding horsts. The recent activity of the inner graben blocks creates some dangerous conditions for the city. The seismic influence in the central part of the Sofia city and graben is particularly high and reaches, in many places, up to II-VIII degree.



Fig. 3. The Boyana church (11th - 13th century A.D.)

The quality of the monument constructions is of significance for seismic effects. There are constructions that do not permit considerable deformation. The inner city castle, constructed mainly in the 4th and the 6th centuries, has exceptionally stable and large walls. The basements of this ancient castle are saved up our days. The seismic effects are not considerable.

Some other monuments represent higher constructions without so stable walls. The ancient church "St.Sofia" was transformed into mosque during the Ottoman domination. The mosque construction was partially destroyed during the moderate and strong 1553-1558 Sofia earthquakes. Its minaret was cut and fallen. The cited seismic effects of VII-VIII degree had have positive consequences for the Bulgarian population: the mosque was transformed again into church after the earthquakes.

The seismic effects in the Sofia graben boundaries are more significant, up to VIII-IX degree. The Boyana outer walls of the ancient city castle, also of the Boyana ancient water-supply system, the Boyana mediaeval church and the Dragalevtsi monastery are placed in the southern boundary of the Sofia graben. The Boyana outer walls and the water-supply system are considerably deformed. They are only partially marked now. The often deformations are the cause of numerous reconstructions of the Boyana church. The reconstruction works in the Dragalevtsi monastery are also numerous. The documented reconstruction works in the Dragalevtsi monastery are during the 15th, 16th and 19th centuries. They are related to Sofia earthquakes. The Boyana and the Dragalevtsi quarters are placed on a sector of the Vitoshka fault zone where the tectonic processes (including the seismic one) and the slope movements are very intensive. They are in the southern boundary of the Sofia graben near its contact with the Vitoshka horst. The seismic effects are up to VIII or VIII-IX degrees.

The northern boundary of the graben is of relatively limited, no considerable recent activity. The Negushevo fault zone, the Chepintsi and the Elin Pelin faults are represented in the locality of the investigated monuments. The Seslavtsi and the Kremikovtsi monasteries are in the northern graben boundary. The reconstruction works in the Kremikovtsi (16th and 19th c.) and the Seslavtsi (19th c.) monasteries could be related also to the Sofia earthquake effects. Perhaps the maximal seismic effects reach up to VII or VIII degrees.

The moderate Sofia earthquakes of 1450, 1553-8, 1818 and the strong one of 1858 caused certain deformation of the region of Sofia city. Its influence into the city historical monuments is considerable. The Balkan catalog of the earthquakes (Shebalin et al., 1974) includes data for monument's destruction in the region of Sofia city. It was noted that twelve Sofia churches were destroyed in different degrees during the mentioned 1553-8 Sofia earthquakes.

The earthquakes provoke relatively large distribution of the seismic effects of VII and of VII-VIII degrees along the sectors of the Negushevo, Vitoshka, Chepintsi, Elin Pelin, Seslavtsi, Kremikovtsi, Dragalevtsi, Boyana, Sofia and the Chepintsi faults. The

seismic influence was relatively more representative in the surrounding of the crossings of the seismic active faults. The three mediaeval monasteries and the Boyana church are located near the crossing-points of active faults.

The slope processes at the foot of the high Vitosha mountain provoke the increase of the deformation effects. The seismogenic and aseismogenic landslides and rock falls are very well represented in the locality of Boyana quarter. They are of moderate distribution in the Kremikovtsi and Seslavtsi quarters of the city. The liquefaction and the land subsidence manifestations are of limited significance in the investigated region.

The above mentioned data show that the seismotectonic danger is considerable in the Sofia graben and its surrounding horsts. The seismic effects increase along the Vitosha and Negushevo faults and in their crossing points with the Chepintsi fault. The southern half of Sofia city is in close vicinity with the crossing of the Vitosha and the Chepintsi faults. The Boyana castle walls, the Boyana ancient water-supply system, the Boyana churches, the Dragalevtsi monastery, are in the surrounding of the mentioned crossing of the southern graben boundary. The inner Sofia castle, the churches "St. George" and "St. Sofia" are in the middle part of the block fragmented Sofia graben, but not far away from the mentioned fault crossing. The Kremikovtsi and the Seslavtsi monasteries are placed in the northern graben boundary closely the crossing of the Negushevo, Chepintsi and Elin Pelin faults. The position of the monuments is not favorable for their protection.

The synthesis of the research permit to go to the following information:

- The local weak, moderate and strong seismic events (Fig. 1,2) and the regional strong ones ($M \geq 7$) prepare or create the deformation of different degrees (up to $I_0=IX$) in the investigated natural and man-made structures.

- The seismic activity of the faults, generally of the Vitosha and the Chepintsi ones, is of a great significance for the locality. The activity of the Negushevo faults is of moderate importance.
- The co-seismic phenomena are also developed. There are relatively limited data for seismically-induced landslides, rockfalls, liquefaction, land subsidence and other geological phenomena.

5. CONCLUSION

The ancient and mediaeval monuments of Sofia city are numerous. Only a part of them is a subject of seismotectonic investigation.

The above mentioned ancient and mediaeval monuments of Sofia city are situated closely to recent active faults. They are also at the peripheries of the numerous blocks of the Sofia graben and the surrounding horsts.

The territory of the Sofia graben and the surrounding horsts is mobile one. The most significant recent movements are related to the contacts of the Sofia graben with the surrounding horsts, generally in the southern and northern graben boundaries. The mobility increases in the crossing-points of the active faults.

The epicenters of a considerable number of moderate and weak earthquakes, as well as the epicenter of the strong Sofia earthquake ($M = 6.7-7.0$) are distributed along the active faults, also along the block and the Sofia graben boundaries. The strong and the biggest part of the moderate Sofia earthquakes have the hypocenters at depth no more than 10 km. The seismic effects of the cited very shallow earthquakes are very dangerous for the earth surface and the monuments.

The co-seismic phenomena in the sites of the monuments are relatively well represented in the southern graben boundary, followed by the same in the northern one. The manifestations of these phenomena are more limited in the central part of the Sofia graben.

The tectonic situation of the monuments, the seismicity and the co-seismic phenomena in the sites of monuments are of significance to the explain the destruction of different degrees in the investigated monuments. The seismotectonic research helps the next works for the protection of the ancient and the mediaeval monuments.

The considerably seismically deformed Boyana outer city castle walls, Boyana water-supply system, Boyana church and Dragalevtsi monastery are situated in the southern part of Sofia graben, where is the crossing of the Vitosha and the Chepintsi active faults.

The Kremikovtsi and the Seslavtsi monasteries are placed in the northern graben boundary and in close vicinity with the fault crossing of the Negushevo, the Chepintsi and the Elin Pelin faults. The values of the seismic effects in this graben boundary are smaller than the same of the southern boundary.

The ancient monuments of the city center, the walls of the inner castle, the churches "St. Sofia" and "St. George" are in relatively less dangerous seismotectonic conditions. The seismic influence is of moderate values in the central territory of the block fragmented Sofia graben.

The impact of the long-term manifested seismicity to the Sofia graben and the historic monuments is also of

significance. The considerable quantity of seismic events provokes the numerous reconstruction periods of the investigated monuments.

Now the protection of the monuments which are deformed in different degree represents a very responsible obligation of the people and governments. The country respects his cultural heritage and tries to organize their reconstruction and conservation.

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