ON THE EARTHQUAKE HAZARD AND THE MANAGEMENT OF SEISMIC RISK IN BULGARIA

Liudmil TZENOV and Emil BOTEV

Abstract: This article examines issues of assessment and management of seismic risk in Bulgaria in recent years. It presents the views of the authors also from their positions in the leadership of the former Expert Council on Assessment and Management of Seismic Risk (AMSR) of the Scientific Coordinating Council (SCC) serving the Government Commission for Population Protection against Disasters, Accidents and Catastrophes (GCPPDAC). Some basic knowledge on earthquake sources, seismicity and seismic zoning of the Bulgarian territory is given. Effects of seismic excitations on different types of structure are presented. The report is illustrated with original photographs of the destruction and damage caused by the impact of earthquakes in our country and adjacent lands over the past three decades. Considering the high level of seismicity and vulnerability of the Bulgarian territory some conclusions and recommendations on seismic risk mitigation of structures are made.

Keywords: Seismic risk, seismic risk management, earthquake hazard.

On the Earthquake Hazard in Bulgaria

Bulgarian territory is characterized by high level of earthquake hazard and this assessment is based on the large number of strong and weak earthquakes, some with significant catastrophic consequences in the recent past. At present, this earthquake hazard leads to even more significant risk of destructive consequences for stronger earthquakes because of the much higher level of urbanization of our land. Seismological research in Bulgaria proves in a very convincing way the fact that the territory of the country has been an arena of strong earthquakes since ancient times till nowadays. At least 30 earthquakes of magnitude $M > 6.0$ are known since year 347 till now according to detailed studies based on historical data.[1] At least 10 of these earthquakes were of magnitude $M > 7.0$ (Figure 1), and the strongest one is the well-known earthquake in the region of Krupnik-Kresna from the year 1904 of magnitude $M = 7.8$, considered as one of the strongest crustal (shallow) earthquakes in the whole of Europe.

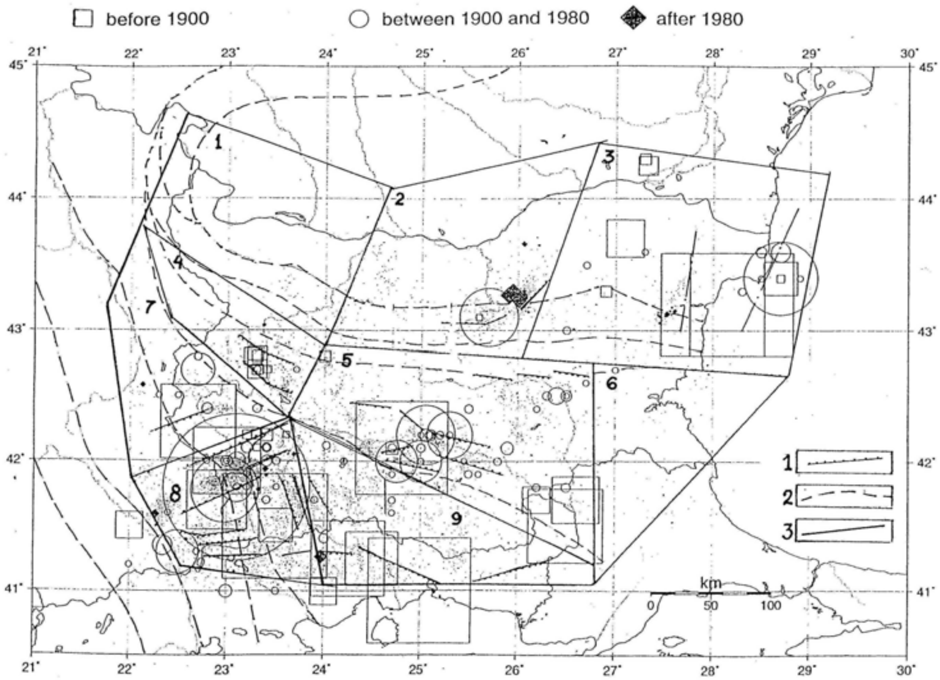

Figure 1: Epicentral Distribution of Events with Magnitude $M > 2.0$.

The period of highest seismic activity in our lands has been identified around this earthquake – only for 70 years from the second half of the XIX century until 1928 about 20 earthquakes of magnitude $M > 6.0$ took place and six of them were of magnitude $M > 7.0$. As a rule all these earthquakes are felt with intensity of more than 8 degrees ($I_0 > VIII$) by MSK-64. According to the indicated sources of information the strongest earthquakes are the one in Sofia in 1858, in Dulovo in 1892, in Shabla in 1901; two earthquakes in the region of Krupnik-Kresna in 1904; in Gorna Oryahovitsa in 1913 and in the Plovdiv region in 1928. The epicenters of these earthquakes are presented in Figure 1 with symbols in accordance with the legend and big rasters corresponding to the assessment of their high magnitude. It is remarkable that after 1928 on the territory of the country only one earthquake of magnitude $M > 5.5$ took place. This is the earthquake in the region of Strazhitza (Central North Bulgaria) in 1986, and the magnitude is many times lower than the previous strong earthquakes – $M = 5.7$. However, in the surrounding areas of Central Northern Bulgaria 15,000 buildings were partially or completely destroyed and two people died. Couple of years before that, the catastrophic earthquake of magnitude $M = 7.2$ in Vrancha (Romania) (located over 200 km away from the territory of Bulgaria), led to partial or complete destruction in about 8,500 buildings and killed 125 people.

Preparation of the National Seismologic Network of high sensitivity began immediately after the earthquake of 1977, which from 1980 allows reliable registration even of the weak seismicity in the country. Since then more than 15,000 weak earthquakes are localized on the territory of the country and its immediately adjacent lands. More than 95 % of these earthquakes are micro-earthquakes – of magnitude $M < 3.0$. Preliminary information on the weak seismicity of the country is periodically presented in the related literature.[2]

Figure 1 presents the territorial distribution of earthquakes of magnitude $M \geq 2.0$; the database consists of the catalogues presented in a publication by Botev and co-authors[3] and the parameters determination and archives of the National Seismological Network.[4] In this figure, the size of the symbols corresponds to the seismic source size computed from magnitude and the different symbols indicate three time periods corresponding to different quality of location and magnitude estimation (i.e. before 1900, between 1900 and 1980, and after 1980). The seismicity prior to 1900 and that of the 20th century, show similar pattern – the Struma area in the south-western sector as well as the lower Mesta valley form the most active zone, the region of Plovdiv (Central South Bulgaria) and the Black Sea coastline in the north of Bulgaria are also seismically active, the Gorna Oryakhovitza region seems to be of a lower level of activity. More unclear is the seismicity of the Edirne area along the Greek-Turkish border, where some strong past events are documented but the information on recent seismicity is very scarce. The hypocenters of the earthquakes are concentrated in the 10-30 km depth interval from the earth surface and rarely reach down to 50 km in depth in the SW part of the country.

The pattern map of present-day weak seismicity indicates the formation of two zones within the study territory with obvious differentiation – a large active polygon spread over the south-western one-third of Bulgaria together with its neighbouring areas in Macedonia and Greece, on the one hand, and another polygon in the eastern part of Bulgaria that might be specified by sparsely distributed seismic origins where two or three clouds of epicenters (due to aftershock sequences mainly) can be distinguished, on the other hand. These weak events originate predominantly at depths of 5-20 km. The deepest seismic foci can be often met in the south and south-western parts of the country.

For the purposes of earthquake hazard assessment some seismic zoning is needed. A variant of such zoning is presented in Figure 1, where the seismic zones are outlined by counter straight lines. The ordinal number of zones is marked with big digits from 1 to 9, moving from the west to the east and from north to the south. This zoning is

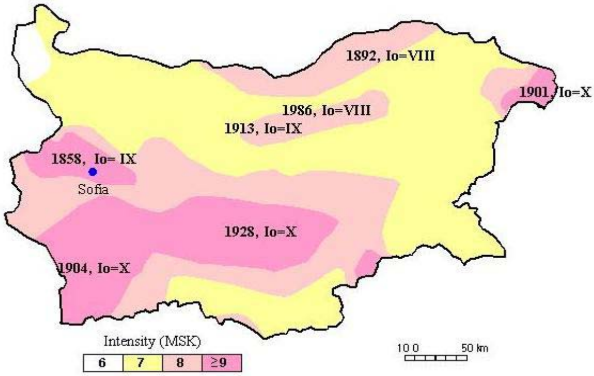

Figure 2: Map of Shakeability for a Period of One Thousand Years.

proposed by Botev and co-authors,[5] but it is derived from the complex analysis of several previous seismic zonings.[6] From scientific point of view, the earthquake hazard for a given territory is assessed by the formal methods of prognostic seismic zoning, seismic hazard and seismic risk. Prediction of earthquakes (by place, magnitude and time) is included in the broad context of activities concerning earthquake hazard assessment.

In Bulgaria, the most important part of the prediction problem is reliably resolved – where and how strong (with what magnitude) earthquakes could be expected.[7] The map of the possible (or expected) source zones, however, does not give a direct idea for the intensity of the possible effects on the surface, as well as for the period of their occurrence. For that reason, the real seismic zoning of Bulgaria has also characteristics of long-term forecasting of the intensity of the possible surface effects and the probability for realization of the maximum magnitude events in the respective zone. Such probabilistic characteristics are provided by the maps of shakeability for different periods. The map covering a thousand years period (Figure 2) is normative for seismic safety building – it was used in the norm of 1987.

Despite its undisputable qualities, the last seismic zoning needs updating after almost 20 years from its creation, and it mainly needs co-ordination and harmonization with the requirements of the European standards. This approach has already been applied in the Geophysical Institute (GI) and the Central Laboratory of Seismic Mechanics and Earthquake Engineering (CLSMEE) of the Bulgarian Academy of Sciences

(BAS) through creation of a Concept for new seismic zoning and seismic parameters for building design in Bulgaria, approved and adopted by the Ministry of the Regional Development and Public Works (MRDPW). The realization of this Concept is already underway, and should be considered as a very important perspective for seismic risk mitigation or reducing the negative consequences of the expected strong earthquakes in Bulgaria.

Seismic Evaluation of Existing Building Structures – A Main Component of Seismic Risk Management

From the viewpoint of earthquake engineering[8] the building structures could roughly be divided into two groups. The first group includes the bigger part of existing buildings whose construction is not preceded by special calculations for determining the additional loading due to seismic excitation. The second group includes the buildings whose construction projects are in compliance with the building design norms (Building Code) for earthquake-prone regions.

The absence of specialized calculations for the expected seismic loading in the first group of buildings does not mean that they are all condemned. In many cases the vulnerability to earthquakes is reduced due to conscientious implementation, high-quality construction materials and engineering experience and intuition of the designer.

On the other hand, compliance with the requirements of the Building Code for earthquake-prone regions in the latter group of buildings is not a guarantee of their seismic resistance due to the following more important reasons: shortcomings in the regulations in force during the design works; gross mistakes in the design due to the lack of adequate professional training and qualification; bad implementation and use of poor quality or inappropriate construction materials.

One of the most important measures for adequate reaction with the aim of decreasing of the unfavorable effects from the future earthquakes is the critical professional assessment of the results and vulnerability of the building inventory of the earthquake disasters till present. The examples given of the consequences of earthquakes in the late 20th century in our country clearly illustrate the impact of the above mentioned negative circumstances.

In the second half of the 20th century the most serious consequences on the territory of our country were caused by the earthquakes in the Vrancha mountain (on Romanian territory, 4 March 1997) and in the region of Strazhitza (Central North Bulgaria, 7 December 1986). On March 4, 1977, in the town of Svishtov three buildings collapsed “to the ground” – the administrative building of “Rudmetal,” a block of flats at “R. Avramov” street and the youth hostel of Combinat “Sviloza” (Figure 3). Over 120 people died. All three buildings destroyed were built with a “flexible” first floor,

Figure 3: Youth Community Housing of Combinat “Sviloza” in Svishtov (1977).

i.e. with a relatively high eigentone period of vibration. This means that these buildings were in more unfavorable conditions in comparison with the low (“stiff”) buildings with “small” eigentone periods. Characteristic of the youth hostel is the lack of building beams along the cross axes of the building (Figure 3). From the viewpoint of seismic engineering this is inappropriate constructive (design) decision. Together with this earthquake, the one of 4th of March 1977 showed that the quality of construction is one of the major factors determining seismic vulnerability of the building constructions.

Figure 4: Block of Flats under Construction in Housing Estate “Dunav” in Svishtov (1977).

Figure 5: The School in Dve Mogili (1977) – Absence of Steel-concrete Connections.

In the building in Figure 4, apart from the cracks in the masonry there is a bearing armature without concrete covering, and cracks in the inner washer – poor quality of construction. On 4th of March 1977 the residential buildings with between-storey floor plates, filled with hollow cylindrical panels received more damage than the "normal" adjacent buildings. The main reason is that the connection between individual floor panels does not provide solidity of between-storey plates/panels.

Poor quality of construction works mainly in the building of steel-concrete elements is the main reason for the damage in the Bulgarian National Bank building in the town of Dve Mogili – whole wall by the roof at the main entrance of the bank was demolished. Indicative for the effect of the absence of the necessary horizontal and vertical steel-concrete bindings is the example of the school in Dve Mogili (Figure 5). The earthquake "showed" where the location of the missing horizontal and vertical steel-concrete bindings should be.

Figure 6: Block of Flats in Strazhitza (1986) – "Flexible" First Floor with Elements of Destructions.

Figure 7: School in Strazhitza (1986) – Complex Configuration and Absence of Seismic Joints.

In 1986 by the "Strazhitza" earthquake the buildings with "weakened" first floor got serious damage. The "weakening" is due to the formation of "flexible" first floor because of the absence of a given number of "non-bearing" barrier walls. In result of removing walls on the first floor of the 9-story apartment block (Figure 6), the center of "stiffness" at this level is shifted (compared to the upper floors). This contributed also to the appearance of a twisting, which made additionally harder the work of the "self-dependent" columns.

The absence of seismic joints and the complex configuration of the building in the front layout as well as along its height is the major reason for damage in some of the situations shown in Figure 7. The joint reaction of the main body and the superstructure with different "stiffness" and various dominating deformations (by dynamic

Figure 8: Old and New Buildings in Strazhitza (1986) – Lack of Different Types of Connections.

loadings) are similar reason for the damage in the community cultural center in Strazhitza – the effect could have been reduced by the presence of seismic joints. The absence of horizontal and vertical bindings (bars and columns, or horizontal and vertical steel-concrete belts), "shouldering" the masonry and securing spatial reaction of the construction as a whole, is the main reason for the damages in the old building as well as in some new ones (Figure 8). The example in Figure 8 illustrates absence of connection bindings in the masonry as well as between the masonry and the main construction for the old building of the former high-school in Strazhitza built last century (brickwork masonry and metal stretchers) and for the production corpus from assembly steel-concrete elements with columns height of 15 meters.

Conclusions and Recommendations

Seismological studies in Bulgaria show that certain regions of the Bulgarian territory are seriously threatened by extreme seismic excitations. The fact that the earthquake hazard is a reality for the whole country is also confirmed by the results of the latest seismic zoning showing that 95% of the territory of the country is endangered by strong seismic excitation (minimum VII by MSK-64). On the other hand, earthquake engineering shows poor state of the buildings with respect to earthquakes – evidence is provided by the above described numerous examples of the effects of the earthquakes in the second half of the 20^{th} century in our country. The effects of these earthquakes expressively convince that poor-quality construction may compromise the most sound design from the viewpoint of seismic engineering; the absence of binding connections between elements (major and minor) of the construction reduces its deformation capacity and increases its seismic vulnerability; earthquake engineering is able to decrease many times the damage and destruction of the buildings and hence decrease the number of human victims. Notwithstanding the development of the new seismic zoning and the new regulations for design and construction of buildings, under the already existing conditions of inadequate construction status of the buildings with respect to the real danger of strong earthquakes, it is necessary to improve the quality of the various preventive measures. The basis of all activities for seismic risk mitigation is conscientious real seismic assessment of the existing buildings.

Seismic evaluation of existing building inventory is extremely urgent in Bulgaria taking into consideration the real seismic risk, the fact that it has long been ignored in our country, as well as because of the increased vulnerability of the buildings in result of occasional reconstruction and low construction control. Seismic assessment of the existing buildings could be determined based on: the classification of buildings in terms of their age, constructive system, configuration in plan and height and other specific characteristics; updated cadastre, including reliable information on the building types and number of inhabitants; determination of the priority types of buildings and concrete representatives to assess their seismic vulnerability. For its part, seismic assessment of a given building includes engineering expertise and analysis; architectural and engineering photographing; determining the actual strength of the materials applied; in situ dynamic experimentation to establish the basic parameters which determine the reaction of the building to seismic effects; „express" determination of the computing seismic loading and verification of bearing capacity of the endangered sections of the "main" elements of the construction. Regardless of adverse circumstance and high resource-use, seismic assessment of the existing buildings should be performed because it represents the main information about the management of seismic risk as well as for the development of specific scenarios for protection of the population from strong earthquakes – to which unfortunately our country will be exposed.

In recent years, as a rule there is no requirement for opinion and viewpoint statements from recognized in the country and abroad professionals on seismic mechanics and earthquake engineering, even in the development of specific requirements related to construction in seismic zones. To obtain a more significant practical effect of applying research results it is necessary to strengthen the control of the authorized bodies on local and national level. Widespread are the signals for non-observance not only of the recommendations made by ordered research studies and scenarios, but also of the requirements of already approved regulations – such as the creation of cadastres. As a striking example of poor quality control note that even in the Directorate of National Construction Control (DNCC), there are no appointed engineers specialists in seismic engineering. Therefore, immediate reaction is needed against the increase of seismic vulnerability of buildings by approving projects and control and monitoring during construction works by authorized specialists and conducting professional training for authorized specialists.

As a whole, the *main recommendations* concerning the management of seismic risk in Bulgaria are: development of an obligatory course on earthquake engineering in the respective universities and schools; improving the qualification of engineers and technicians in the field of earthquake engineering; organizing professional training for the decision makers who give permission for construction at all levels (municipalities, regional, and others); the DNCC to establish a department for a specialized control in earthquake engineering; starting all kind of activities for seismic assessment of building inventory (classification of buildings, updated cadastres, analysis of representative buildings of each type).

Increase of the common seismic culture of the local population and authorities is highly necessary as well as is the increase of their interest to perform economic activities in compliance with the scientific evaluation of the objective seismic conditions and risk that could result from them. There are many signals for non-compliance with requirements and provisions arising from inadequate evaluation of the importance of affected personal and departmental interests. "Departmental" patriotism excludes recognition of the competence of persons outside the respective department/administration – institute, laboratory, company, etc. In the conditions of our "market economy" in the award of projects or contracts professional competence is being ignored on the account of departmental or personal financial interests.

In conclusion, it should be noted that preventive construction and other activities in the endangered regions may reduce the risk of earthquakes, but not completely prevent their effects. Therefore, these activities should be economically feasible and should involve various insurance practices.

Notes:

1 E. Grigorova, D. Sokerova, Ludmil Christoskov, and Sn. Rizhikova, *Catalogue of the Earthquakes in the Territory of Bulgaria for the Period 1900-1977* (Sofia: Bulgarian Academy of Sciences, Archives of the Geophysical Institute of BAS, 1979); Ludmil Christoskov, D. Sokerova, and Sn. Rizhikova, *New Catalogue of the Earthquakes in the Territory of Bulgaria and Adjacent Region for the Period V century BC to XIX century* (Sofia: Bulgarian Academy of Sciences, Archives of the Geophysical Institute of BAS, 1979).

2 Emil Botev *et al.*, "Preliminary Data on the Seismic Events Recorded by NOTSSI in January-June 1991," *Bulgarian Geophysical Journal* 16(1991), …, Emil Botev et al., "Preliminary Data on the Seismic Events Recorded by NOTSSI in July-December 2006," *Bulgarian Geophysical Journal* 31 (2006).

3 Botev et al., "Preliminary Data on the Seismic Events Recorded by NOTSSI in …"

4 Emil Botev, D. Slejko, G. Bressan, and P. Bragato, "Stress and Strain Modeling of the Bulgarian Area from the Focal Mechanisms" (paper presented at the 3rd Balkan Geophysical Congress and Exhibition, Sofia, 24-28 June), 329 330.

5 Botev, Slejko, Bressan, and Bragato, "Stress and Strain Modeling of the Bulgarian Area from the Focal Mechanisms."

6 E. Bonchev, I. Bune, Ludmil Christoskov, J. Karagyuleva, V. Kostadinov, G.J. Reisner, S. Rizhikova, N.V. Shebalin, V.N. Sholpo, D. Sokerova, "A Method for Compilation of Seismic Zoning Prognostic Maps for the Territory of Bulgaria," *Geologica Balcanica* 12, no. 2 (1982): 3–48; Ludmil Christoskov, *Earthquakes – Hazard and Contrameasures* (Sofia, 2000), 62.

[7] Bonchev *et al.*, "A Method for Compilation of Seismic Zoning Prognostic Maps for the Territory of Bulgaria."

[8] Liudmil Tzenov, *Basics of Earthquake Engineering* (Sofia: Bulgarian Academy of Sciences, 2007), 360.

LIUDMIL TZENOV is Professor at the Central Laboratory of Seismic Mechanics and Earthquake Engineering (CLSMEE) of the Bulgarian Academy of Sciences (BAS). He is a worldwide-recognized specialist in the area of earthquake engineering. He graduated from the Sofia Civil Engineering Institute in 1960, and then he received a PhD degree in 1968 and a Doctor of Science degree in 1983. He has published nine books (some co-authored), more than 150 scientific papers, and many reports at international meetings. At present, he is Chairman of the National Committee on Earthquake Engineering and Chairman of the Expert Council on Assessment and Management of Seismic Risk (AMSR) of the Scientific Coordinating Council (SCC) serving the Government Commission for Population Protection against Disasters, Accidents and Catastrophes (GCPPDAC). He is or has been national representative of Bulgaria or leader of working groups in many international projects, for instance: Unification of European Building Code (working group of EAEE), Vulnerability and Seismic Hazard – Project "Risk Reduction in the Balkan Region Earthquake" (RER 014 UNDP/UNESCO), Project "Building Construction under Seismic Condition in the Balkan Region" (RER 015 UNDP/UNIDO), Project "Earthquake Risk Reduction in the Balkan Region" (RER 004 UNESCO). From 1995 till 2003 he was Director of CLSMEE – BAS, which is the organization in Bulgaria that leads the research on seismic risk mitigation. *Address for Correspondence:* Geophysical Institute of the Bulgarian Academy of Sciences, "Akad. G. Bonchev" Str., Block 3, Sofia 1113, Bulgaria; *Phone:* (+359 2) 979 3338.

EMIL BOTEV is Associated Professor at the Geophysical Institute of the Bulgarian Academy of Sciences (BAS). In 1979, he received Master of Science degree in Geophysics from the Sofia University. Then he was employed as a research-seismologist at the Geophysical Institute of the Bulgarian Academy of Sciences (BAS) – study of local and regional seismicity. He received a PhD degree from the Institute of Physics of the Earth, Moscow, in 1985: velocity structure modelling, seismic tomography. From 1995 till now he is the scientific leader of the Project "Monitoring of the seismicity and analysis of the seismic processes in the active zones in Bulgaria." He has published more than 100 scientific papers in the areas of seismicity and analysis of the seismic processes in Bulgaria, structure of the crust and upper mantle beneath the Bulgarian territory, geomagnetic field anomalies and correlation with the earthquake activity. At present, Dr. Botev is Head of the Department of Seismology of the Geophysical Institute of BAS. He is Scientific Secretary of the Expert Council on AMSR of the SCC serving the GCPPDAC. He is also national representative in the European-Mediterranean Seismological Centre (EMSC) and takes part in many international projects, aiming to improve the quality of real-time earthquake disaster information and rapid international exchange of data between European countries. From 2002 till 2004 he was Deputy Director of the Geophysical Institute of BAS, which is the leading organization in Bulgaria in the fields of seismic monitoring of earthquakes and seismic risk assessment. *Address for Correspondence:* Geophysical Institute of the Bulgarian Academy of Sciences, "Akad. G. Bonchev" Str., Block 3, Sofia 1113, Bulgaria; *Phone:* (+359 2) 979 3356; (+359) 896 197 099; *E-mail:* ebotev@geophys.bas.bg.