НАЦИОНАЛЕН ИНСТИТУТ ПО ГЕОФИЗИКА, ГЕОДЕЗИЯ И ГЕОГРАФИЯ - БАН

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COUNTRY ASSESSMENT REPORT - BULGARIA

SOFIA
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I. Introduction

Black Sea Earthquake Safety Net(work) – ESNET project deals with earthquakes and prevention of natural disaster generated by such events. The Black Sea region has a long history concerning the earthquakes. In the past, the earthquakes in the Black Sea basin have generated lots of casualties and material loses, therefore it is extremely necessary to review the seismic hazard, and existing monitoring and intervention systems. As far as northern part of the Bulgarian Black Sea region is one of the most seismically active zones in the project area, participation of the NIGGG in the ESNET project is crucial and useful for solving common problems as risk reduction and population safety. Sharing knowledge about the earthquake potential in the Black sea region is a valuable tool to obtain an accurate assessment of the general threat coming from nature and to develop a better concept for joint monitoring and intervention system. The purpose of this report is to provide detailed information about the seismicity, hazard, risk and emergency reaction in case of an earthquake in Bulgaria.

II. Seismicity

II.1. Eligible project area in Bulgaria

Bulgaria is situated in the eastern part of the Balkan Peninsula and is bounded on the east with Black sea. The Bulgarian project area (Fig.1) includes North-East and South-East regions (Severoiztochen and Yugoiztochen) of the country. These two regions consist of 8 districts (Fig. 1) – Burgas, Sliven, Yambol, Stara Zagora, Varna, Dobrich, Shumen and Targoviste. The total area of the two regions is 33678 km^2 or more of 30% of the territory of Bulgaria. The population is 2131570 or more than 25% of the population of Bulgaria.

Economy

South-East region (Yugoiztochen - districts Burgas, Sliven, Yambol, Stara Zagora) is the second richest Bulgarian region. Most important are tourism, electric power generation, and services. Burgas is the second largest Bulgarian port, big tourist centers are Sunny beach, Sozopol, Pomorie, Primorsko, Ravda and Kiten. Main industrial centers are the big cities and towns of Radnevo and Galabovo – are important units in electric power generation and mining.

One of the richest regions in Bulgaria is the North-East region (Severoiztochen - districts Varna, Dobrich, Shumen and Targoviste). It is of substantial importance for the national economy. Its economy is service-oriented and includes tourism. Severoiztochen is the second most-visited region by foreign tourists after Yugoiztochen. Notable resorts include Golden Sands, Albena, SS Constantine and Helena. Interesting places are the old towns of Balchik, Kavarna, Cape Kaliakra - at the seaside, Madara - nearby the city of Shumen; Shumen boasts the Monument to 1300 Years of Bulgaria. Dobrich Province form Southern Dobruja - the Bulgarian breadbasket. The port of Varna is the largest port in Bulgaria and the third largest on the Black Sea. The port of Balchik is a small fishing town. Varna is Bulgaria's second financial capital after Sofia; the city produces electronics, ships, food and other goods. Other important industrial centers in the region are Shumen - production and repair of trucks; Dobrich - big food-producing city, unofficial capital of Dobruja; Devnya - big chemical center (cement and nitric fertilizer).

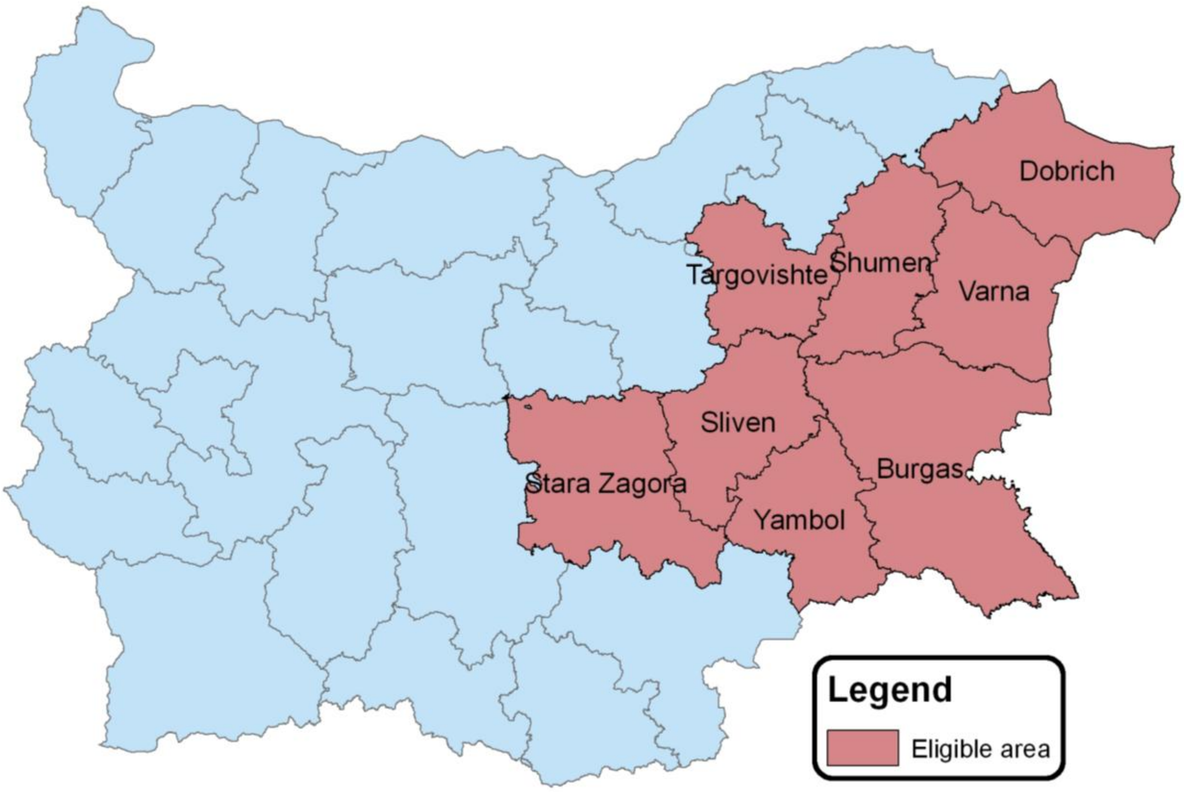


***Figure 1**. ESNET Bulgarian eligible area*

II.2 Seismic activity, strong earthquakes now and historic ones

Earthquakes are the most deadly of the natural disasters affecting the human environment, indeed catastrophic earthquakes have marked the whole human history, accounting for 60% of worldwide casualties associated with natural disasters. Earthquakes are the expression of the continuing evolution of the Earth planet and its surface. Earthquakes adversely affect large parts of the Earth. Global seismic hazard and vulnerability to earthquakes are increasing steadily as urbanization and development occupy more areas that a prone to effects of strong earthquakes; the uncontrolled growth of megacities in highly seismic areas around the world is often associated with the construction of seismically unsafe buildings and infrastructures, and undertaken with an insufficient knowledge of the regional seismicity peculiarities and seismic hazard. The assessment of seismic hazard is the first link in the prevention chain and the first step in the evaluation of the seismic risk. The implementation of the seismic hazard estimates into the policies for seismic risk reduction will allow focusing on the prevention of earthquake effects rather than on intervention following the disasters.

The territory of Bulgaria represents a typical example of high seismic risk area in the eastern part of the Balkan Peninsula. The Balkan Peninsula, from plate-tectonic point of view, is an element of the continental margin of Eurasia that is located between the stable part of the European continent to the north and ophiolitic sutures (Vardar and Izmir-Ankara) to the South. South of the satures, fragments of the passive continental margin of Africa crop out (Boyanov et al., 1989). The neotectonic movements on the Balkan Peninsula were controlled by extensional collapse of the Late Alpin orogen, and were influenced by extension behind the Aegean arc and by the complicated vertical and horizontal movements in the Pannonian region (Zagorcev, 1992).

Bulgaria contains important industrial areas that face considerable earthquake risk, though less than its neighboring countries: Greece, Turkey and Romania. Over the centuries, Bulgaria has experienced strong earthquakes. The strongest events reached magnitude 7.8 in southwestern Bulgaria; magnitude 7.5 in northeastern Bulgaria, and magnitude 7.0 in southern Bulgaria. Moreover, the seismicity of the neighboring countries, like Greece, Turkey, former Yugoslavia and Romania (especially Vrancea-

Romania intermediate earthquakes involving the non-crustal lithosphere), influences the seismic hazard in Bulgaria.

The strongest and most destructive earthquakes in Bulgarian occurred after 1900 are given in Table 1.

The thickness of the earth crust varies from 30 km close to the Black sea up to 51 km in the southwestern part of Bulgaria (Boykova, 1999). According to seismological investigation (Sokerova et al, 1992; Dachev et al, 1995; Simeonova et al 2006), major part of the regional seismic sources are located inside the crust, and only a few events are related to the lower crust. The maximum depth is about 50 km in south-western Bulgaria, outside, the foci affect only the upper 30–35 km.

The documented seismicity (historical and instrumental) is presented in Fig. 2. Before 1900 are given earthquakes with magnitudes larger than or equal to 6.0 ($M \geq 6.0$), after 1900 earthquakes with magnitudes $M \geq 4.0$, after 1980 earthquakes with magnitudes $M \geq 3.0$. The instrumental seismicity (after 1980) in and near Bulgaria is presented in Fig.3.

The spatial pattern in Fig.2 shows that seismicity in the considered region is not uniformly distributed in space. Therefore the seismicity is described in distributed geographical regions – seismic zones. In the eligible area one of the most active seismic zone is located - Shabla seismic zone.

Shabla seismic zone The eastern periphery of the Moesian platform is marked by a fault system in NNE-SSW direction, separating the platform from deep part of the West Black Sea back-arch marginal riftogenic basin. Strong earthquakes manifest the Neotectonic/Quaternary activity of this fault system. The strongest seismic events (543 earthquake with M=7.6, 1444 earthquake with M=7.5, 1901 earthquake with M=7.2) are associated with Kaliakra fault system defined by numerous seismic profiling undertaken in the Black Sea. The hypocenter distribution involves the surficial 20 km. The maximum earthquake potential M_{max} associated with Shabla seismic zone is M_{max}= 8.0 (Boncev et al., 1982).

Close to the eligible area are located two active seismic zones Gorna Orjahovitca (North Bulgaria) and Maritsa (South Bulgaria).

Gorna Orjahovitza seismic zone The main tectonic structure in this area is the E-W extended Resenski trough, which is formed during the Quaternary period. Two sublatitudinal faults, which are reactivated segments of the Fore Balkan fault, and an oblique fault in NE-SW direction marks the boundaries of the Resenski trough[5]. The strongest event here occurred in 1913 (M_s=7.0), followed by seismic quiescence until 1986 when the two moderate Strazhitza earthquakes occurred (M_S=5.3 on February 21 and M_s=5.7 on December 7). The seismicity in the zone is shallow, concentrated mainly in the surficial 15 km, with rare events down to the 25-30 km depth. The maximum 7.0 earthquake is expected in Gorna Orjahovitza seismic zone (M_{max}=7.0, Boncev et al., 1982).

Maritsa seismic zone Seismicity in the Maritsatza zone is predominantly associated with the WNW-ESE oriented Maritsatza fault zone. The Maritsatza fault with its satellites belongs to structures with a long-lasting development, which continues in the neotectonic period. The largest of its segments, which is with well-expressed Neogene-Quaternary activity, reaches the length of about 70 km (Dachev et al., 1995). The 1928 earthquakes (the Chirpan earthquake of April 14, 1928 with M_S=6.8 and the Plovdiv earthquake of April 18, 1928 with M_S=7.0) are the strongest events occurred in the zone. The hypocentre distribution involves the surficial 20 km, with sporadic events down to 45 km. The highest density of foci is observed at 5-10 km depth. The maximum 7.5 earthquake is expected in Maritsatza seismic zone (M_{max}=7.5, Boncev et al., 1982).

These zones have significant impact to the seismic hazard in the area. In these zones have been realized earthquakes with magnitudes of 7.0 at the beginning of previous century. The macroseismic intensities from these earthquakes reached VIII-IX for some parts of eligible area. The macroseismic intensity is about VII-VIII (MSK) in the western part of Targoviste district.

The Northern part of the region is strongly influenced by the intermediate Vrancea earthquakes. The Southern part is influenced by strongest earthquakes on Turkish and Greece territory.

In the region of Provadia are located a lot of earthquakes with magnitudes between 4.0 and 5.0 last 30 years with maximal macroseismic intensity up to VI-VII (MSK).

Several earthquakes with magnitudes between 5 and 6 have been realized near the town of Yambol. The maximal observed intensity from these earthquakes is VIII (MSK).

Table 1. Strong and destructive earthquakes in Bulgaria after 1900 year
(bold and red – earthquakes in or close to eligible area)

Date d. m. y.	Time GMT h. m. s.	Epicenter coordinates φ°N λ°E	h km	M	I_0
31.03.1901	**07 10 22**	**43.37 28.70**	**14**	**7.2**	**10**
04 04 1904	10 02 34	41.77 23.05	15	7.3	9-10
04 04 1904	10 25 55	41.85 23.08	18	7.8	10
08 10 1905	07 27 30	41.86 23.08	19	6.4	8-9
15 02 1909	**09 33 40**	**42.52 26.48**	**4-8**	**6.0**	**8**
23 02 1910	07 52 14	41.70 23.55	10	5.4	7-8
14 06 1913	**09 33 13**	**43.10 25.70**	**15**	**7.0**	**9-10**
18 10 1917	18 57 40	42.70 23.33	6	5.2	7-8
14 04 1928	**09 00 01**	**42.21 25.36**	**10**	**6.8**	**9**
18 04 1928	**19 22 48**	**42.20 25.06**	**16**	**7.1**	**9-10**
25 04 1928	**09 25 46**	**42.08 25.89**	**13**	**5.7**	**8**
23 08 1942	**15 41 25**	**43.47 26.60**	**10**	**5.1**	**7**
30 06 1956	**01 50 22**	**43.55 28.68**	**20**	**5.5**	**7**
03 11 1977	02 22 58	42.08 24.08	8	5.3	7
21 02 1986	**05 39 56**	**43.21 26.01**	**8**	**5.1**	**7-8**
07 12 1986	**14 17 09**	**43.19 26.01**	**10**	**5.7**	**8**
22 05 2012	00 00 32	42.58 23.00	9	5.8	7-8

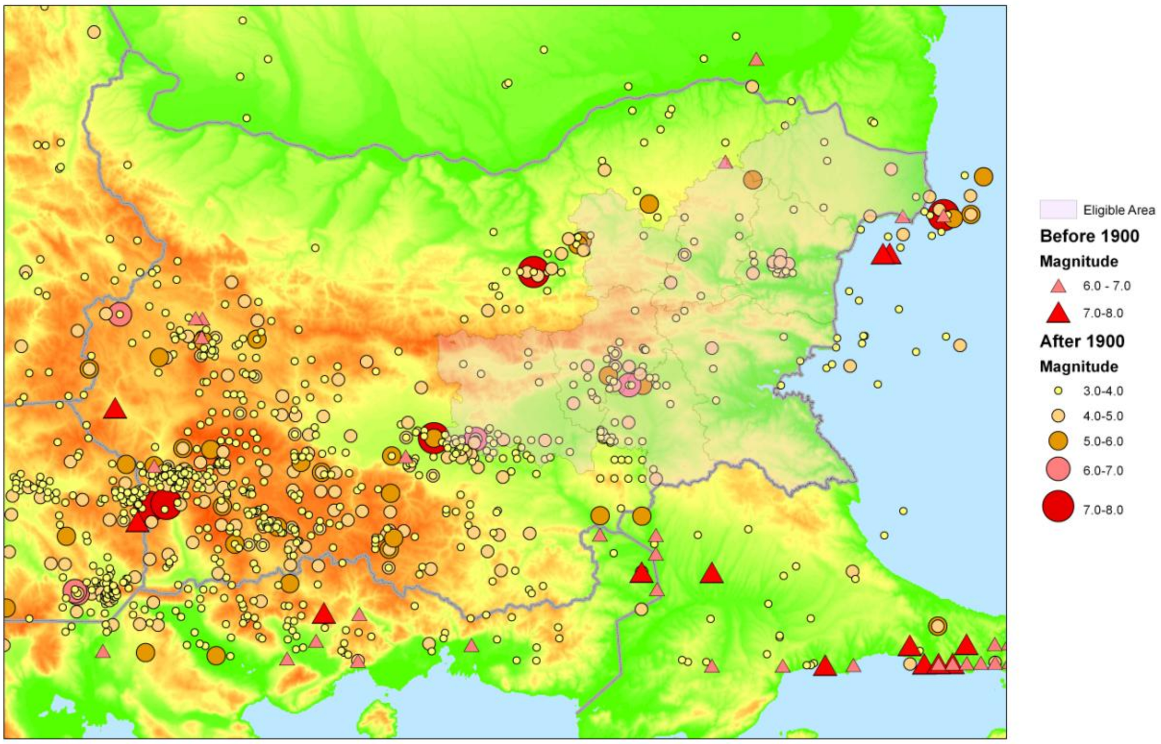
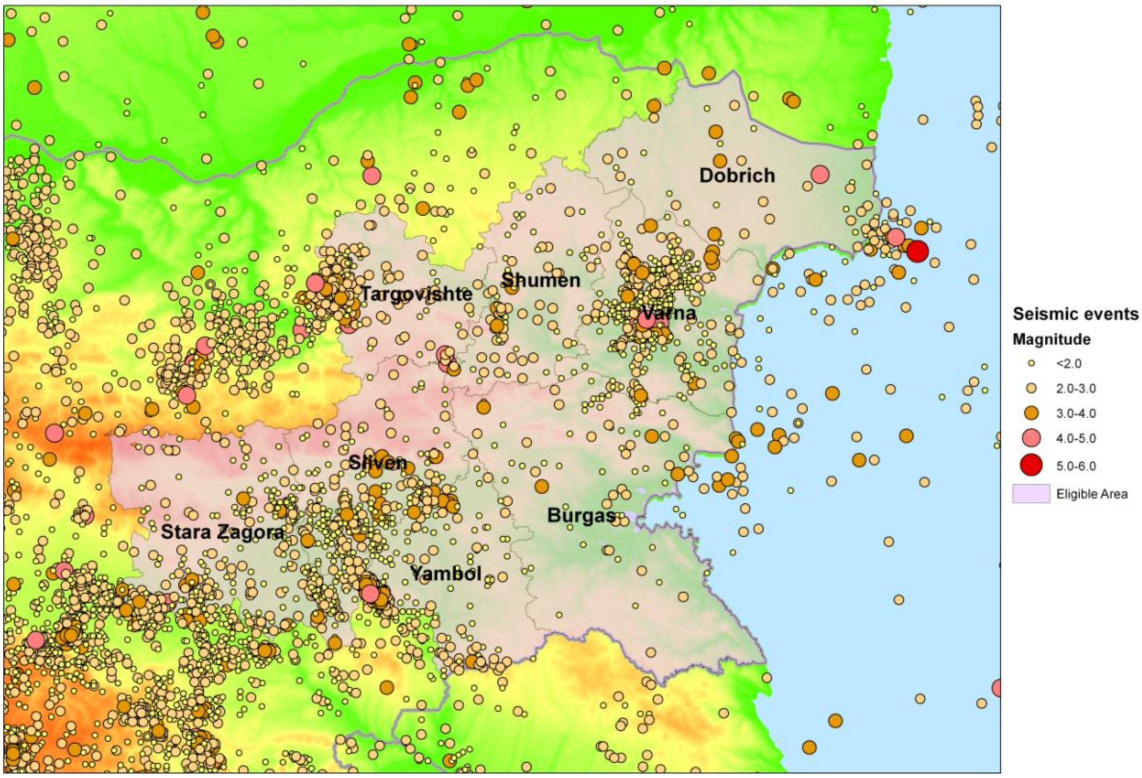


Figure 2. Epicentral map for Bulgaria and surroundings (M≥3.0)



Fgure 3. Epicentral map for Bulgaria and surroundings
(after 1980, all recorded quakes)

II.3. Seismic monitoring network

The Bulgarian seismological network-NOTSSI (National Operative Telemetric System for Seismological Information) was founded at the end of 1980. The objective of NOTSSI is continuous monitoring of seismic activity in the territory of Bulgaria and adjacent areas within the Balkan region. The network comprises today 14 permanent seismic stations spanning the entire territory of the country and two local net works (7 stations) that are deployed around the town of Provadia and Kozloduy Nuclear Power Plant. Data from all stations are transmitted in real time to the Seismic Center installed in the National Institute of Geophysics Geodesy and Geography (NIGGG). NOTSSI is the only organization in Bulgaria in charge of acquisition of seismological information and is the national information center of rapid earthquake information and seismic hazard mitigation. In the case of a felt earthquake on the territory of Bulgaria, the information is transmitted to the Council of Ministers, the Governmental Commission of Disasters, National Fire Safety and Protection of Population Service and other interested organizations, including mass media and general public. In close relationship with the National Fire Safety and Protection of Population Service and other governmental institutions, NOTSSI and respectively the National Institute of Geophysics Geodesy and Geography are responsible for earthquake disaster mitigation.

The major tasks of the Bulgarian National Seismological Network are:

- To provide reliable recording and transfer of seismological data;
- To ensure rapid notification of the governmental authorities, media and broad public in case of felt or damaging earthquakes on the territory of Bulgaria;
- To provide a modern basis for seismological studies in Bulgaria.

The modernization of NOTSSI started in 1996. First, station Vitosha (VTS, since 1979) was included in the MEDNET project and was updated with STS-1 and Quanterra 380 (Fig. 4). The VTS-MEDNET station became fully operational since May 13, 1996.

Then, in 2003, two stations: Plovdiv (PLD since 1977) and Jambol (JMB since 1982) were equipped with Quanterra 330 data loggers and Guralp CMG-40T broad-band sensors with government funding. The existing National Seismological Data Center (NSDC) in the Geophysical Institute, Sofia, was upgraded as a permanent center disseminating earthquake data in real time (near real time) to other centers within Europe and its surroundings. NSDC is equipped with COMPAQ computer and SUN workstation. The latest versions of Earthquake Explorer, Seisgram2K (for real time miniseed data visualization), SeismicViewer, SHAPE Java software (for Dataless SEED data creation), PITSA software (used for waveform data analysis) and AutoLoc software package were installed at the Data Center. Simple software is developed for conversion of Nanometrics Y files to GSE format in order to apply Seismic Handler. The data flow is presented in Fig 5.

Fig. 4 Quanterra 380 acquisition system STS – 1 very broad-band seismometer

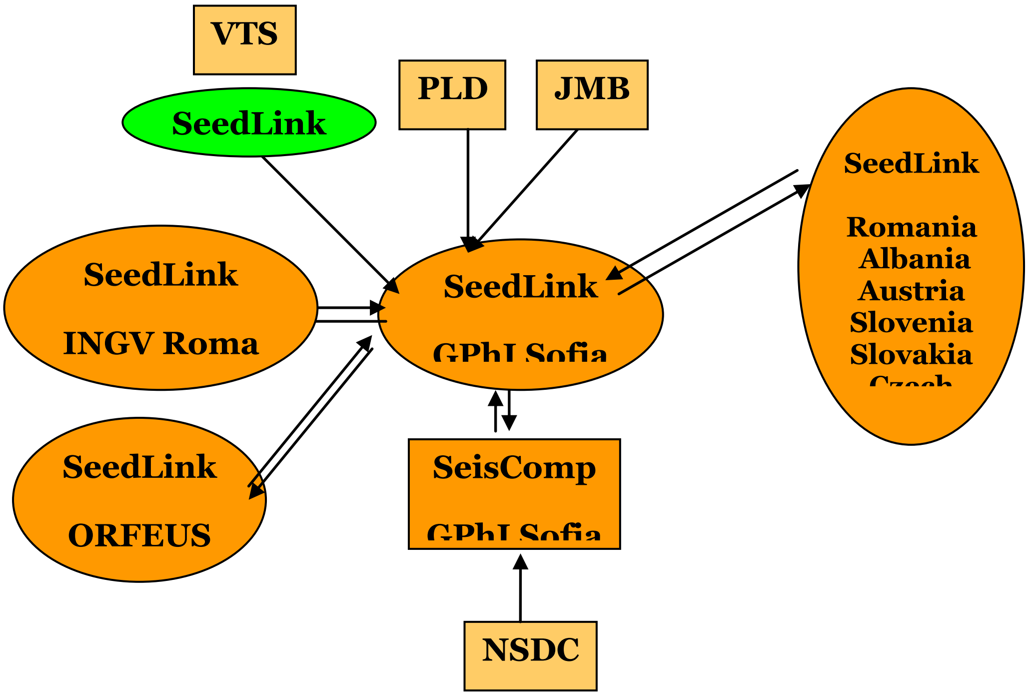


Fig. 5 Digital data flow in 2003

In 2005, the Permanent Commission for Prevention of the Population from Natural Disasters and Catastrophes supported the former Geophysical Institute for overall modernization of the seismological network. After evaluation of competitive bids, REF

TEK was awarded the contract to upgrade the existing national seismological network to a modern technology digital network. At the beginning of December 2005 all stations located around the country were installed (station equipment is presented in Fig.6) and transmitted data in real-time to the NSDC using the VPN and MAN networks of the Bulgarian Telecommunication Company.

The general scheme of up grated Bulgarian seismological network is presented in Fig.7.

Digital acquisition system

REFTEK 130-01/3

Broad-band seismometer CMG40-T

Very broad-band seismometer KS2000

Fig 6. Seismic station equipment

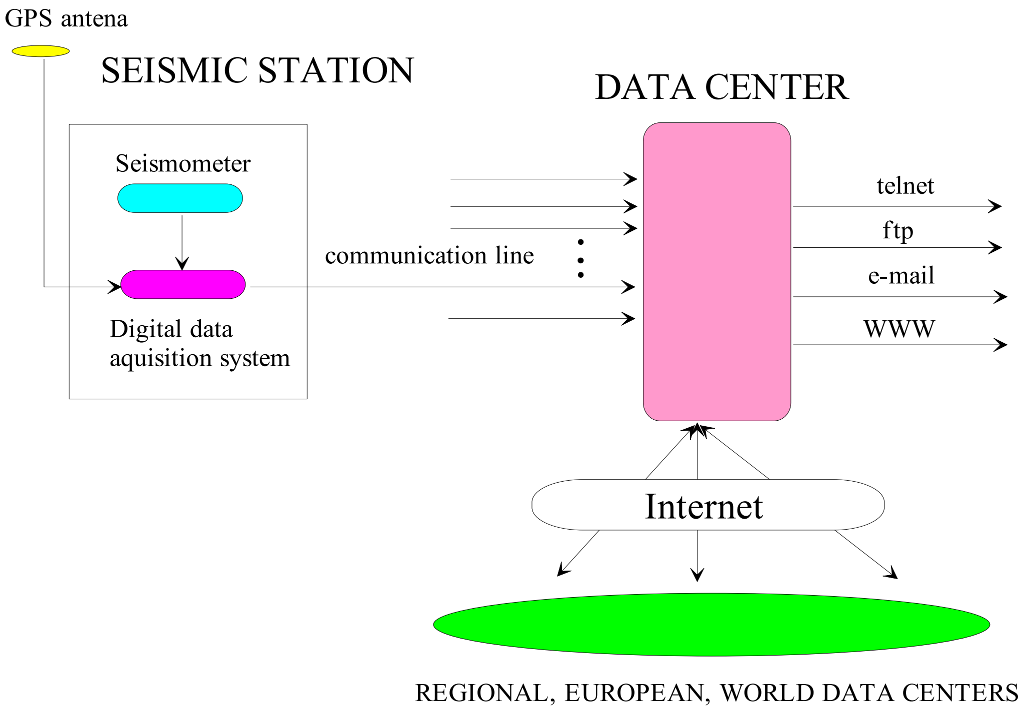


Fig. 7 Up-graded network (General Scheme)

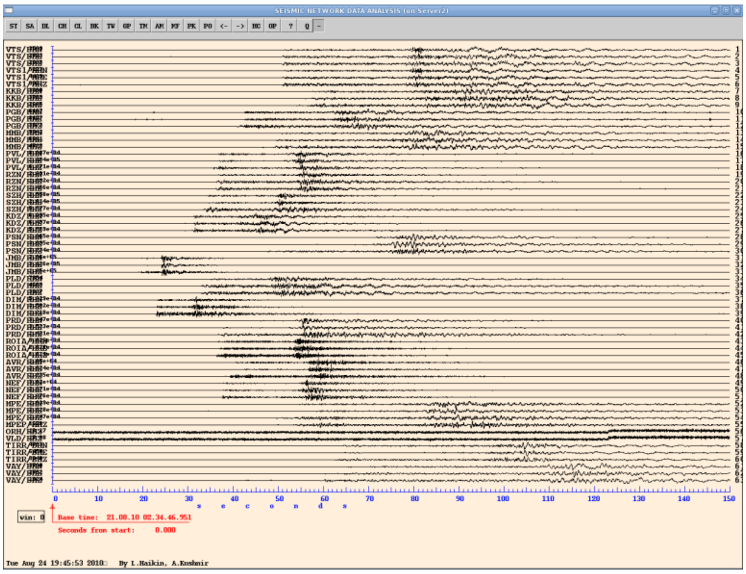
Real-time data acquisition is performed using REFTEK's full duplex error-correction protocol RTPD. Data processing is performed by the Seismic Network Data Processor (SNDP) software package running on both Servers. SNDP includes two subsystems:

- Real-time subsystem (RTS) – for signal detection; evaluation of the signal parameters; phase identification and association; source estimation.
- Seismic analysis subsystem (SNDA) – for interactive data processing.

The signal detection process is performed by traditional STA/LTA detection algorithm. The filter parameters of the detectors are defined on the base of previously evaluated ambient noise at the seismic stations.

The output of the real-time subsystem data processing is a daily bulletin with the hypocentral determinations. The event localizations are visualized on a map Fig.8 and an e-mail is sent to the list of subscribers.

The interactive processing of the seismic event parameters and magnitude determinations are performed by manual graphic analysis of the seismogram (Fig.9). An advantage of Seismic analysis subsystem is easy access to the automatic arrivals and waveforms in a disk loop for more than 365 days. Additional advantage is to operate with the waveforms in close to real-time for rapid manual relocation.



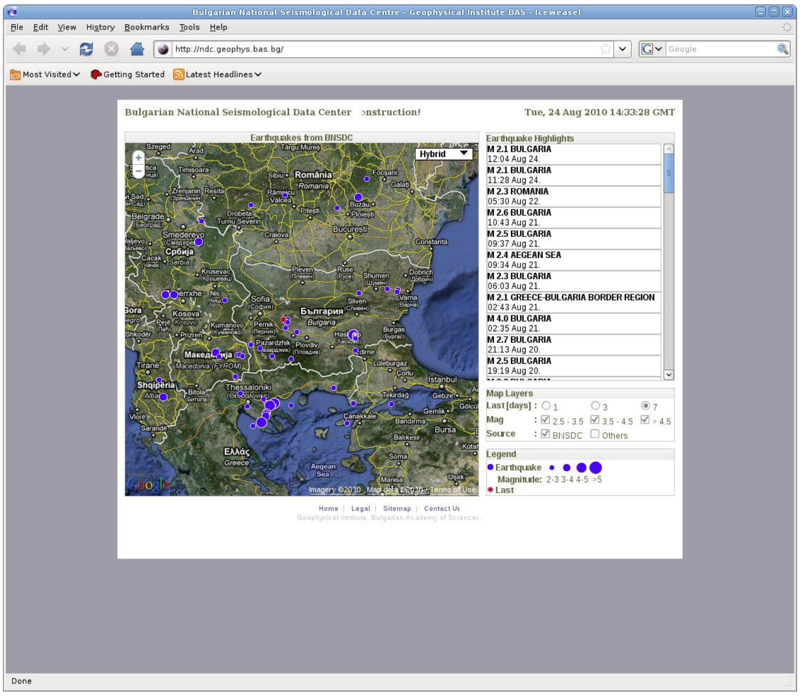


Fig.8 Real-time data flow and the map with the locations of the detected and estimated seismic events on the territory of Bulgaria and surroundings.

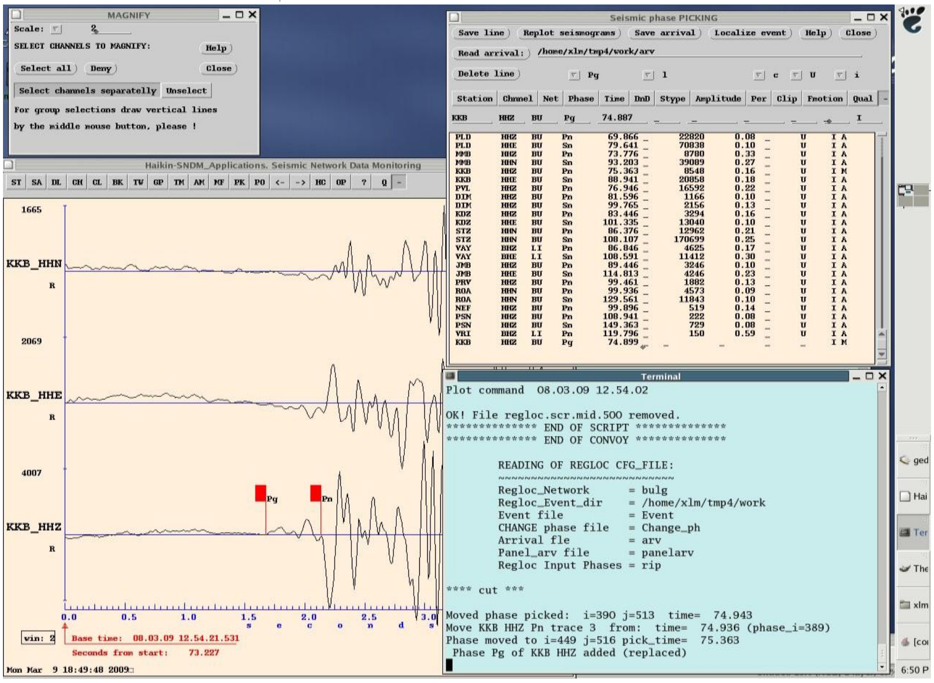


Fig. 9 Interactive data processing by means of Seismic analysis subsystem - tuning of the seismic phase parameters

The data from the Quanterra recorders are fed into RTPD in real-time via SeisComp/SeedLink protocol. Real-time and interactive data processing performed by the Seismic Network Data Processor (SNDP) software package running on two clustered SUN Fire V240 Servers. Network command/control and monitoring are performed by RTCC and RTPMonitor user interfaces which are running on two SUN Blade 1500 Workstations. Both RTCC and RTPMonitor serve up html pages that can be displayed in any standard web browser allowing the end-user to monitor the network status and control the acquisition parameters anytime and anywhere from any computer connected to the Internet (the scheme of the up grated Bulgarian network for acquisition and processing of seismological data is presented in Fig.10).

A real-time data transfer to INGV, Roma and ORFEUS Data Centers is implemented. Regional real-time data exchange between Bulgaria and Romania, FYROM, Serbia, Greece, Turkey, Slovakia, Slovenia, Austria and Czech Republic and other countries is established.

In Fig.11 is illustrated the configuration of Bulgarian seismological network. Additionally, stations from neighbouring countries that are used in data possessing are presented in the figure.

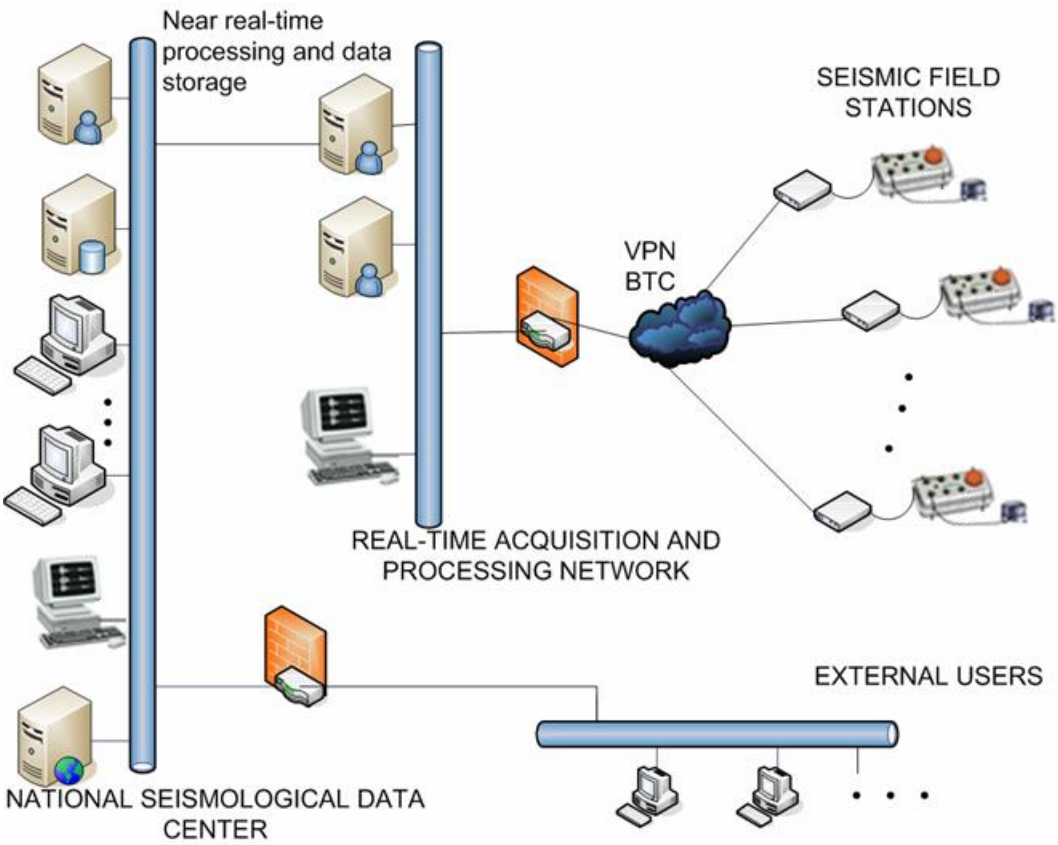


Fig. 10 Scheme of the network for acquisition and processing of seismological data

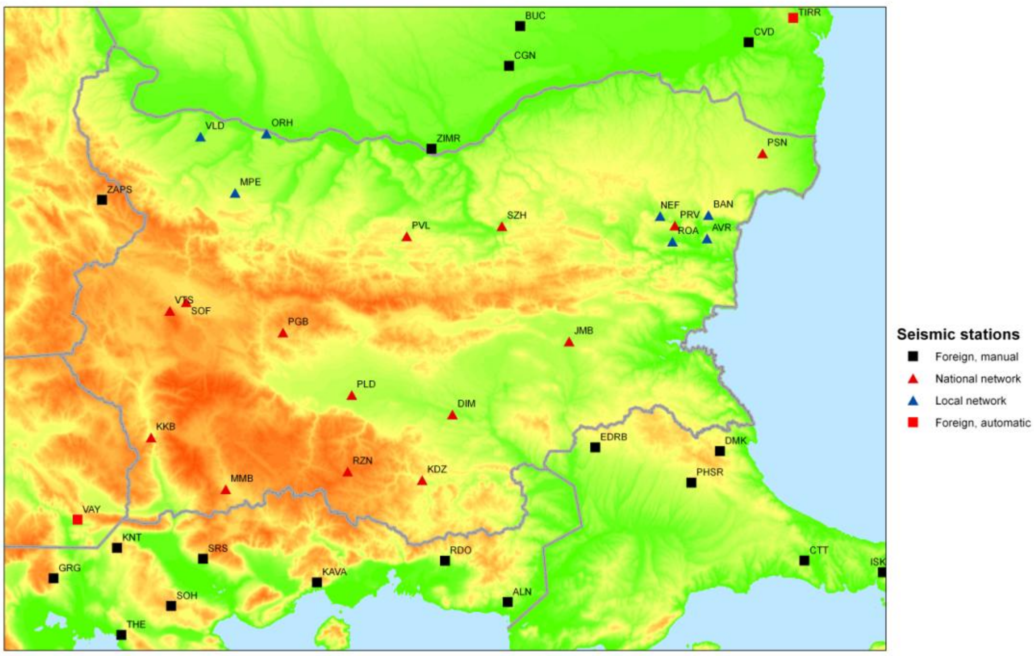


Fig.11 Bulgarian seismic network and foreign stations used in epicenter location

III. Seismic Hazard

III.1 Seismic codes

The first seismic code in Bulgaria is from 1958. It is based on seismostatistical zoning, based on observed macroseismic intensities. In 1961 and 1964 (Fig. 12) the code is reestimated and zones with VII, VIII and IX degree (MSK) are decrease. After the 1977 Vrancea earthquake some areas with VII and VIII degree (MSK) are added (Fig. 13). In 1987 a new “Standards for design of buildings and facilities in seismoactive regions” was introduced. The seismic zonation is of a hazardous type. It is based on seismic source map (Fig. 14). The shakability map for return period 1000 years is accepted as a standard for design of buildings and facilities. The 1986 seismic zoning of Bulgaria –normative map in building code is presented in Fig.15. The map is in terms of intensities (MSK). In Table 2 are presented the areas with different intensities for the different seismic zonings. The regulations from 1987 are not valid for high risk facilities as nuclear power plants, large hydro facilities etc. Spatial investigations and evaluations have to be performed for such kind of constructions.

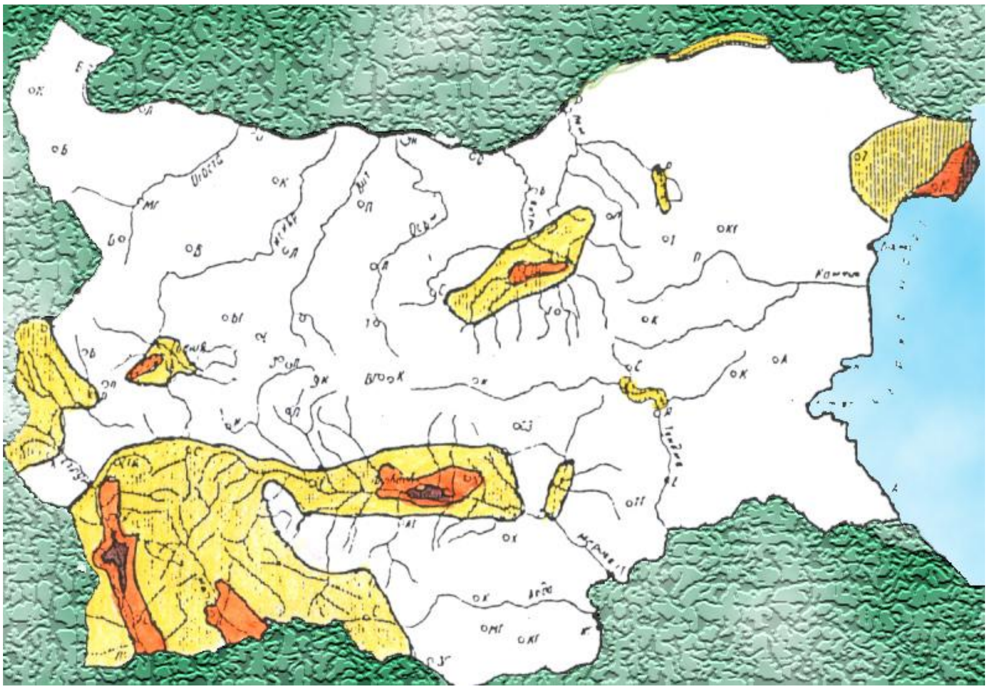


Fig. 12 Seismic zoning in Bulgaria – 1964

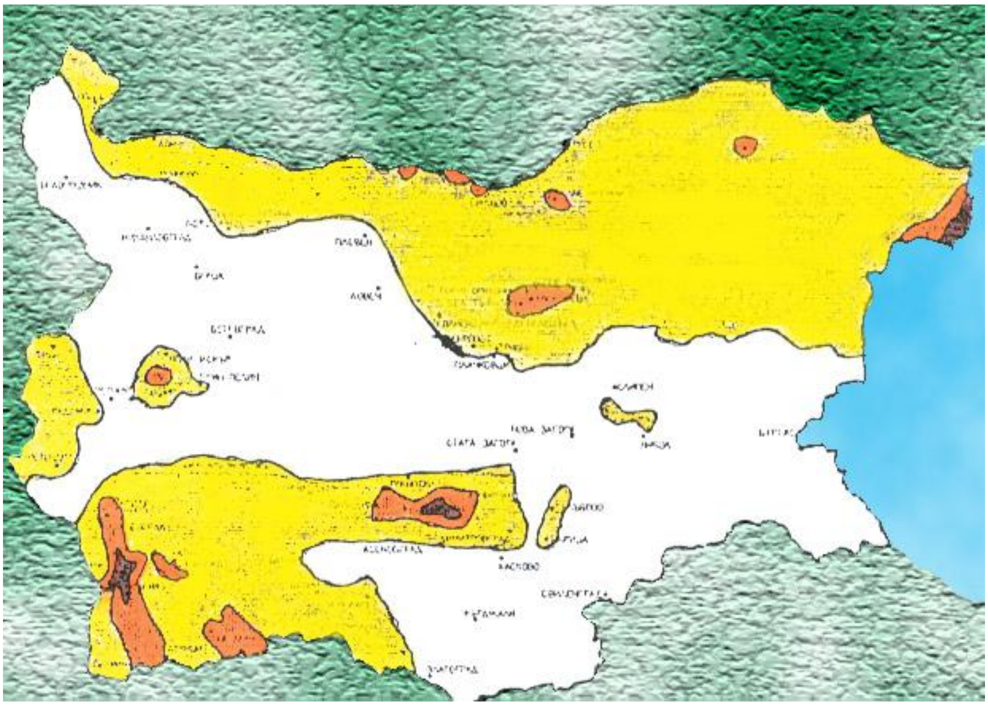


Fig. 13 Seismic zoning in Bulgaria – 1977

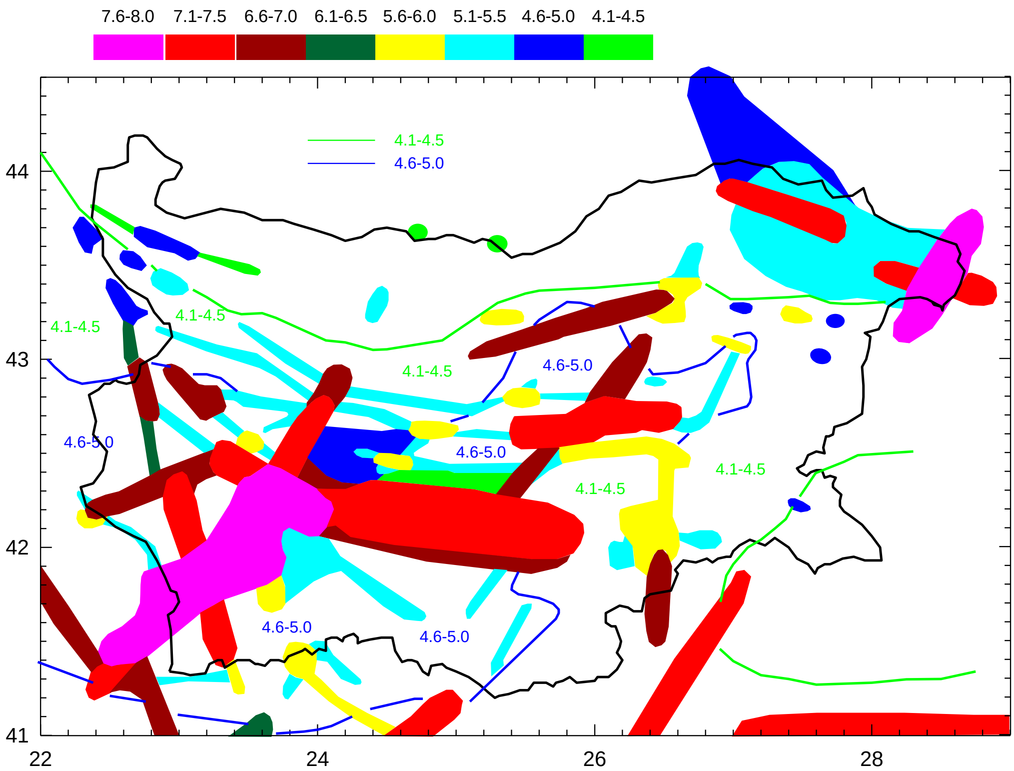


Fig. 14 Seismic source model (Bonchev et al, 1982)

Fig. 15 Seismic zoning of Bulgaria – 1986 (normative map in building code)

Table 2. Area distribution (in %) with different macroseismic degrees

Seismic zoning	Intensity (MSK)				
	VI	VII	VIII	≥IX	≥VII
1987 standards (1000 years return period)	2	51	28	19	98
1961-1964 Standards	78	17	4	1	22
Updated map in 1977	60	34	5	1	40
Maximal observed intensities	36	49	11	4	64

III.2 Probabilistic hazard assessment

A new seismic zoning was performed after 2007 in accordance with the requirements of Eurcode8 (EC8). The zoning is based on probabilistic hazard assessment in terms of peak ground acceleration. A return period of 475 years is accepted as a standard (due to EC8 recommendation).

III.2.1 Methodology

The formal procedure for probabilistic calculations taking account of spatial and temporal uncertainty in the future seismicity was presented by Esteva (1967, 1968) and Cornell (1968). The probabilistic method of seismic hazard analysis, as it is currently understood, was presented by Cornell (1971), and by Merz and Cornell (1973).

It is commonly assumed that the occurrence of individual event can be represented as a Poisson process. The probability that at a given site a ground motion parameter, Z, will exceed a specified level, z, during a given time period, t, is given by the expression:

$$P(Z \geq z \mid t) = 1 - e^{-\nu(z)t} \leq \nu(z)t \qquad (3.1)$$

where $\nu(z)$ is the average frequency during time period t at which the level of ground motion parameter Z exceeds z at the site resulting from earthquakes in all sources in the region.

The “return period” of z is defined as:

$$R_Z(z) = \frac{1}{\nu(Z \geq z)} = \frac{-t}{\ln(1 - P(Z \geq z))} \qquad (3.2)$$

The inequality at the right side of above equation (4.1) is valid regardless of the appropriate probability model for earthquake occurrence and $\nu(z)t$ provides an accurate and slightly conservative estimate for probabilities less than 0.1.

The frequency of exceedance, $\nu(z)$, is a function of the uncertainty in the time, size and location of future earthquakes and uncertainty in the level of ground motions they may produce at the site.

It is computed by expression:

$$\nu(z) = \sum_n \alpha_n(m^0) \int_{m^0}^{m^u} \int_0^{\infty} f(m) f(r \mid m) P(Z \geq z \mid m, r) dr dm \qquad (3.3)$$

where $\alpha_n(m^o)$ is the frequency of earthquakes on source n above a minimum magnitude of engineering significance m^o; f(m) is the probability density function for event size between m^o and maximal event for the source m^u; f(r|m) is the probability density function for distance to the earthquake rupture which is usually conditional on the earthquake size; and P(Z<z | m,r) is the probability that for a given magnitude m earthquake at a distance r from the site, the ground motion exceeds level z. The average frequency $\nu(z)$ is evaluated by three probability functions: magnitude distribution, conditional distance distribution and conditional exceedance probability distribution.

The constituent models of the Probabilistic Seismic Hazard Methodology are models of: 1) seismic sources; 2) earthquake recurrence frequency; 3) ground motion attenuation; and 4) ground motion occurrence probability at a site (Thenhaus and Campbell, 2003).

Seismic sources

Description of the geometry of a seismic source is necessary for evaluation of site-source distances.

Seismic sources are identified on the base of geological, seismological and geophysical data. An understanding of the regional tectonics, local Quaternary history and seismicity of an area leads to the identification of geological structures that may be seismic sources. The association of geological structure with historic or instrumental seismicity clarifies their role in the present tectonic stress regime.

The limiting size earthquake that can occur on each seismic source is a very important parameter in seismic hazard analysis, especially at low probability levels. For sources defined as faults, the maximum earthquake magnitude is related to the fault geometry and fault behavior through an assessment of the maximum dimensions of a single rupture. For area sources maximum magnitude is taken from Bonchev et al, 1982 (Fig. 14). In Fig. 16 is presented the seismic source model used for hazard estimation.

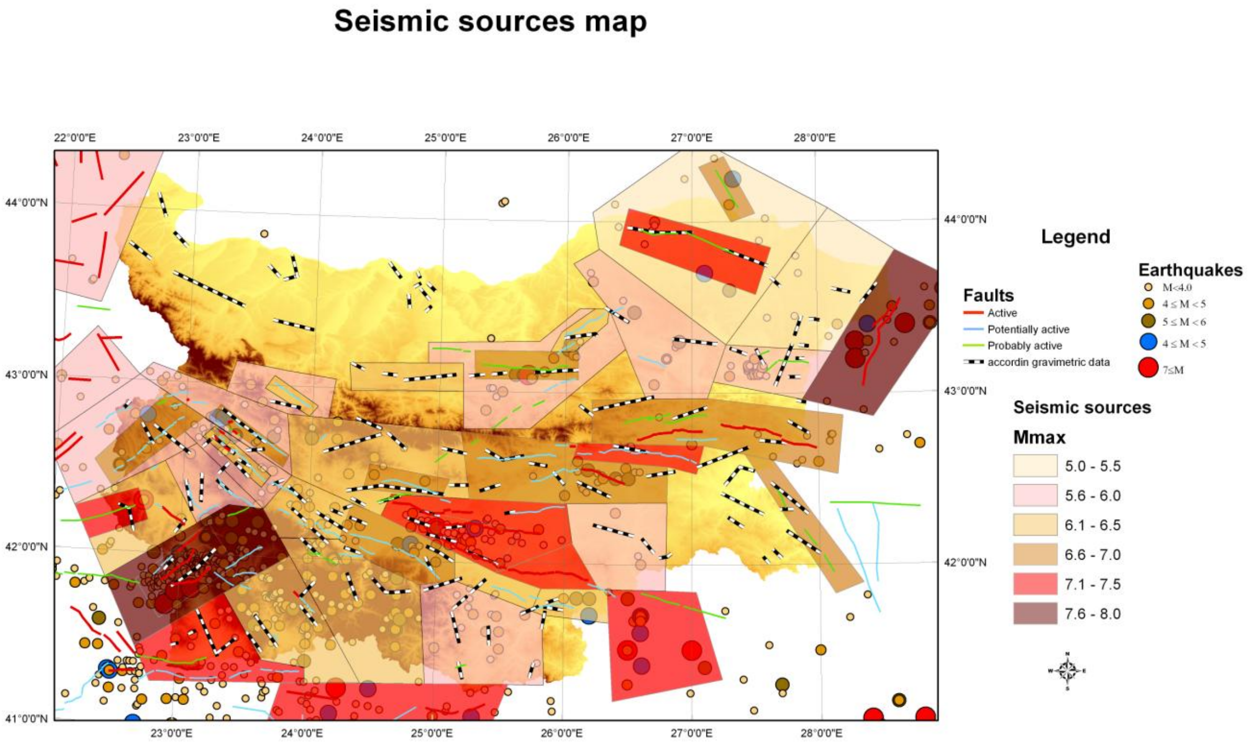


Fig.16 Map of seismic sources used for seismic hazard assessment

Ground motion attenuation

Ground motion attenuation relationships define the values of a ground motion parameter, such as peak ground acceleration or response spectral values, as a function of earthquake size (magnitude M) and the distance in terms of both the expected values and the dispersion of the expected values. Attenuation relationships are developed usually from statistical analysis of strong motion data or from peak ground motion parameters inferred from reported shaking intensity. The ground motion attenuation relationships and their uncertainties are of substantial importance in hazard analysis. Estimates of parameters (coefficients and standard deviation) of an attenuation equation depend on quantity and quality of input data (magnitude range, homogeneity of the available data sample etc.). The ground motion attenuation relationship presented in Ambraseys et al. (1996) is used for hazard assessment.

Ground motion probability

The probability model widely used in hazard analysis is that earthquakes occur as a Poisson process in a time. The probabilistic methodology quantifies the hazard at a site from all earthquakes of all possible magnitudes, at all distances from the site as probability of exceeding some amplitudes of shaking at a site in periods of interest (Thenhaus and Campbell, 2003).

III.2.2 Results

The seismic hazard for the country in different return periods have been evaluated applying the above described methodology, the compiled seismic source model and selected attenuation model. In Fig. 17 are presented the obtained results for the eligible area.

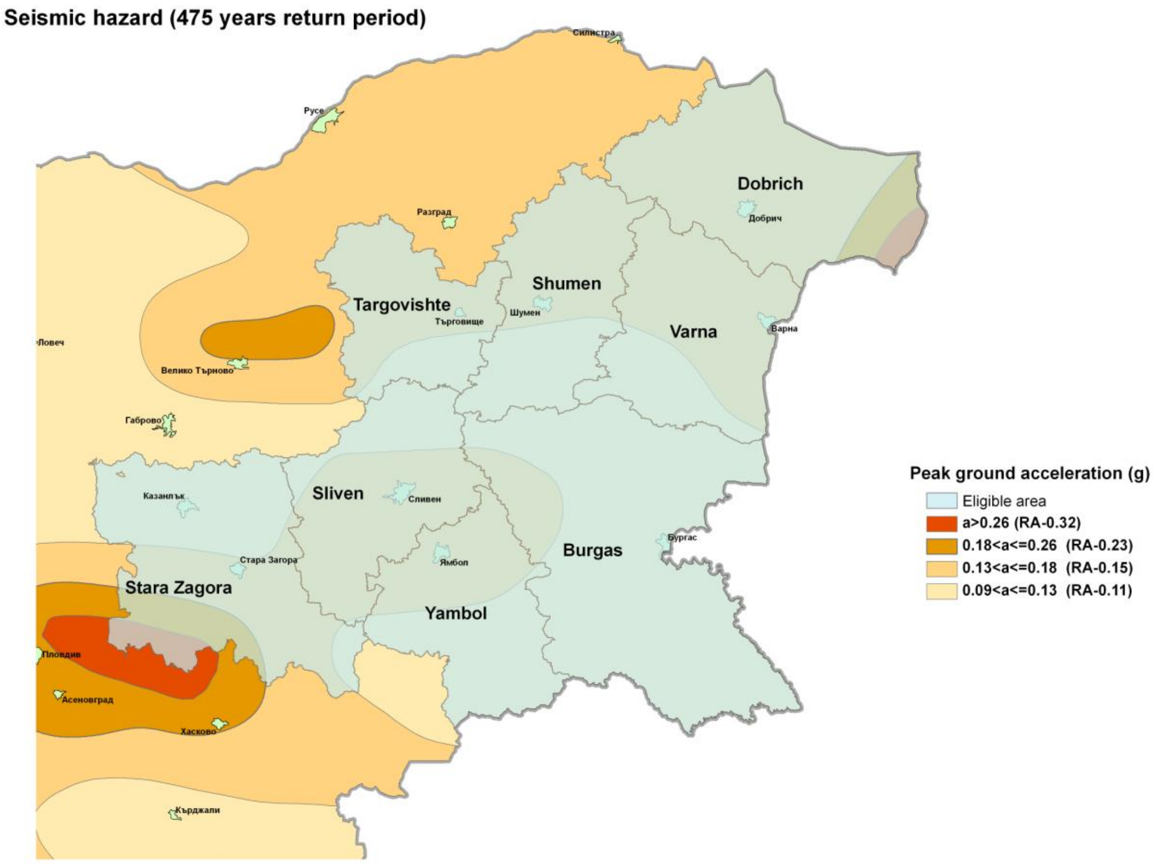


Fig.17 Proposed map for seismic code (eligible area)

Large parts of the area are with expected acceleration between 0.09 and 0.13 and between 0.13 and 0.18 g (proposed reference accelerations 0.11 and 0.15

correspondingly). Small parts (North-East and South-West) fall in territories with expected acceleration between 0.18 and 0.26 and larger than 0.26 (proposed reference accelerations 0.23 and 0.32 correspondingly).

In Fig. 18 is presented the influence of the intermediate Vrancea earthquakes on the seismic hazard. As seen in the figure almost all Northern part of the eligible area is strongly (more than 50 %) influenced by Vrancea earthquakes.

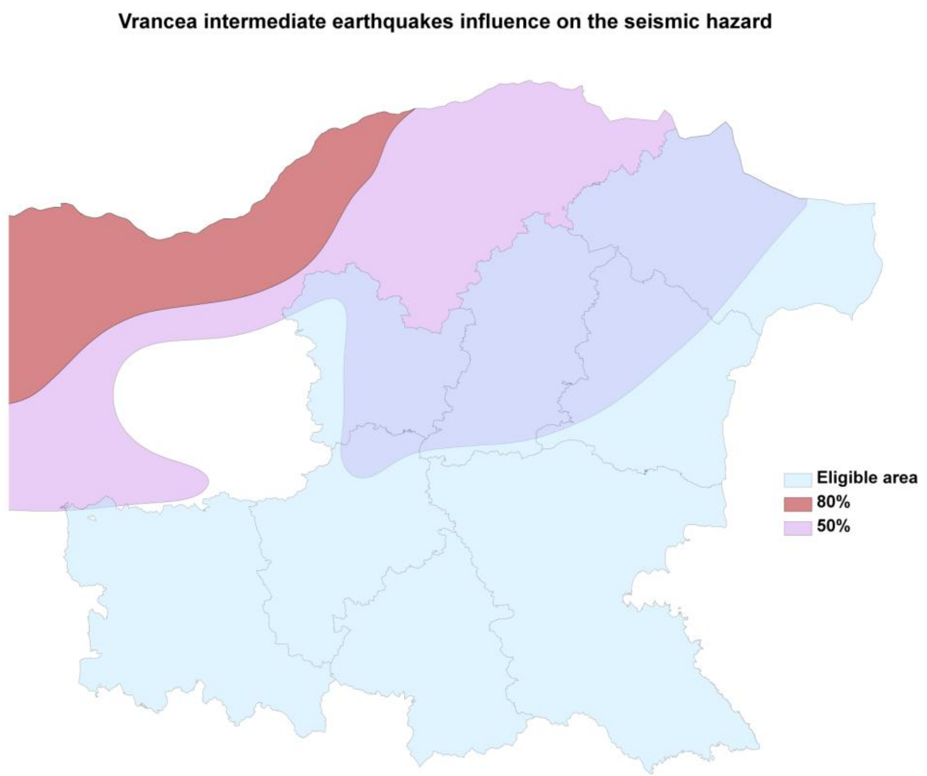


Fig. 18 Influence of the intermediate Vrancea earthquakes on the seismic hazard

III.3 De-aggregation of Probabilistic Seismic Hazard Assessment for ESNET Bulgarian eligible area

The probabilistic seismic hazard analysis (PSHA) carries out integration over the total expected seismicity during a given exposure period to provide the estimate of a strong-motion parameter of interest with a specified confidence level. Modern PSHA considers multiple hypotheses on input assumptions and thereby reflect the relative credibility of competing scientific hypotheses. Thus the PSHA allow the ground motion hazard to be expressed at multiple sites consistently in terms of earthquake sizes, frequency of occurrence, attenuation and associated ground motion.

However, the physical image of an earthquake in terms of magnitude and source-to-site distance (the concept of a “design earthquake”) is lost in the PSHA analysis (McGuire, 1995). This disadvantage (first recognized by Aki committee, National Research Council, 1988) results directly from the integrative nature of PSHA. For design, analysis, retrofit, or other seismic risk decisions a single “design earthquake” is often desired wherein the earthquake threat is characterised by a single magnitude, distance, and other parameters. The advantages of developing one or a few “design earthquakes” that can be used for detail analysis and decision making can be summarized as follows (McGuire, 1995): the earthquakes dominating the hazard at chosen probability level are defined; these earthquakes can be associated with a fault or a seismic zone and additional specific characteristics can be ascribed (such as a magnitude, stress drop, azimuth, depth and distance); more detailed analyses can be performed (e.g., the generation of durations and time histories of motion for nonlinear structural analysis).

For physical interpretation of the PSHA results and to take certain engineering decisions, it is desirable to have a representative earthquake which is compatible with the results of the PSHA method. This could be achieved through the de-aggregation of the probabilistic seismic hazard (McGuire, 1995). A procedure called de-aggregation (or disaggregation) has been developed to examine the spatial and magnitude dependence of PSHA results. The aim is to determine the magnitudes and distances that contribute to the calculated exceedance frequencies at a given return period and at a structural period of engineering interest (Thenhaus and Campbell, 2003). De-aggregating PSHA results two important goals are achieved (McGuire, 1995): 1) a relation between the calculated hazard and the specified seismic sources; 2) the loop between scientists performing hazard assessment and users of hazard studies is closed. As a result the seismic hazard philosophy is better understood and more reliable decisions on seismic design, analysis, and retrofit are undertaken.

De-aggregation of the seismic hazard for a recurrence period of 475 years (probability of exceedance of 10% in 50 years) for PGA was performed for 8 cities (administrative centres) on the territory of ESNET Bulgarian eligible area

The de-aggregation results show existence of both unimodal and bimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency for PGA.

PSHA de-aggregation plots for PGA show the following peculiarities:

1. Unimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency for PGA is observed. The mode of the distribution is for magnitude 5.0-7.5 earthquake at a distance of 5 to 20 km from the city of Yambol. The strongest contributor to the hazard is the near regional seismicity (Fig.19).

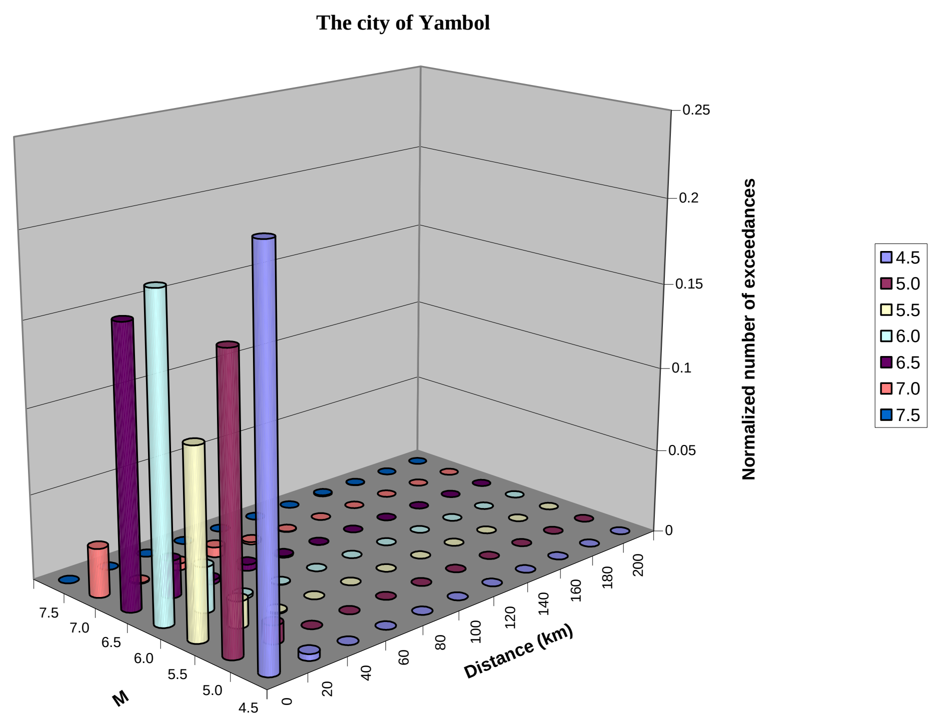


Fig.19 Unimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency - the strongest contributor to the hazard for the cities is the near regional seismicity

2. PSHA disaggregation plots show a slight bimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency is observed for PGA (Fig.20). The primary mode in Fig.20 (well expressed) is a magnitude 5.0 to 6.0 earthquake at 10 to 20 km from the cities of Sliven and Stara Zagora (effect of the near regional seismicity). The secondary mode (not well expressed) is for magnitude greater or equal to 7.5 earthquakes at a distance of more than 220 from the city (effect of Vrancea intermediate

earthquakes). The strongest contributor to the hazard for the cities of Sliven and Stara Zagora is the near regional seismicity.

The city of Sliven

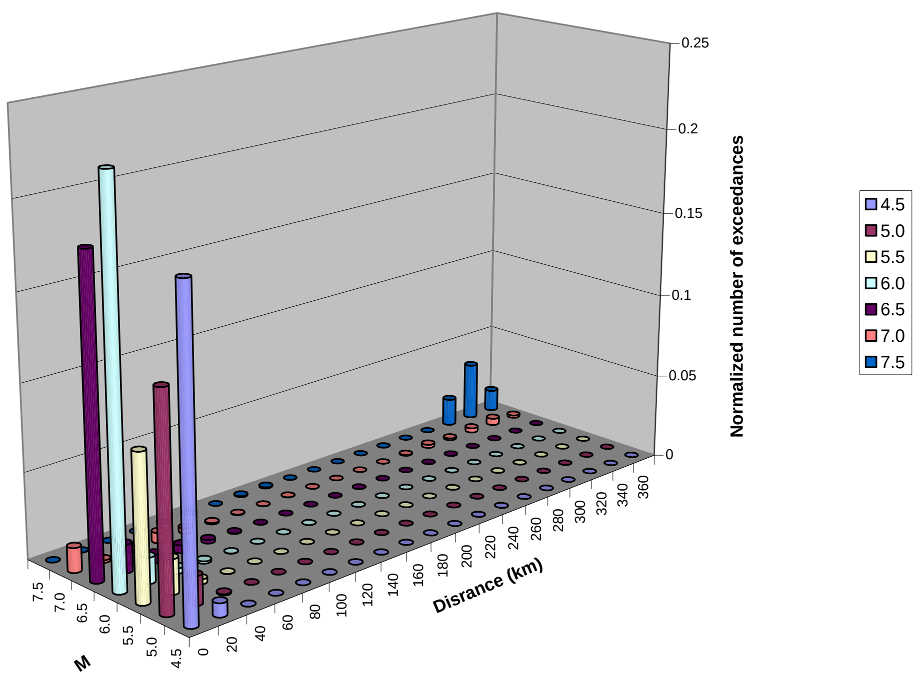


Fig.20 Slight bimodal distribution of earthquake magnitude and distance - stronger contributor to the hazard for the cities is the near regional seismicity

The city of Stara Zagora

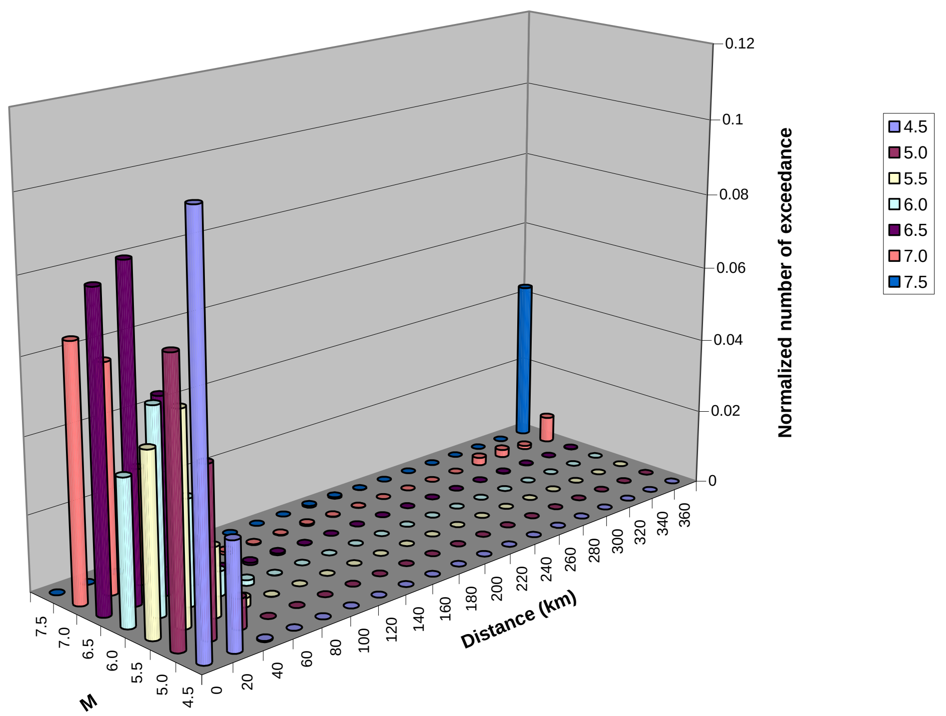
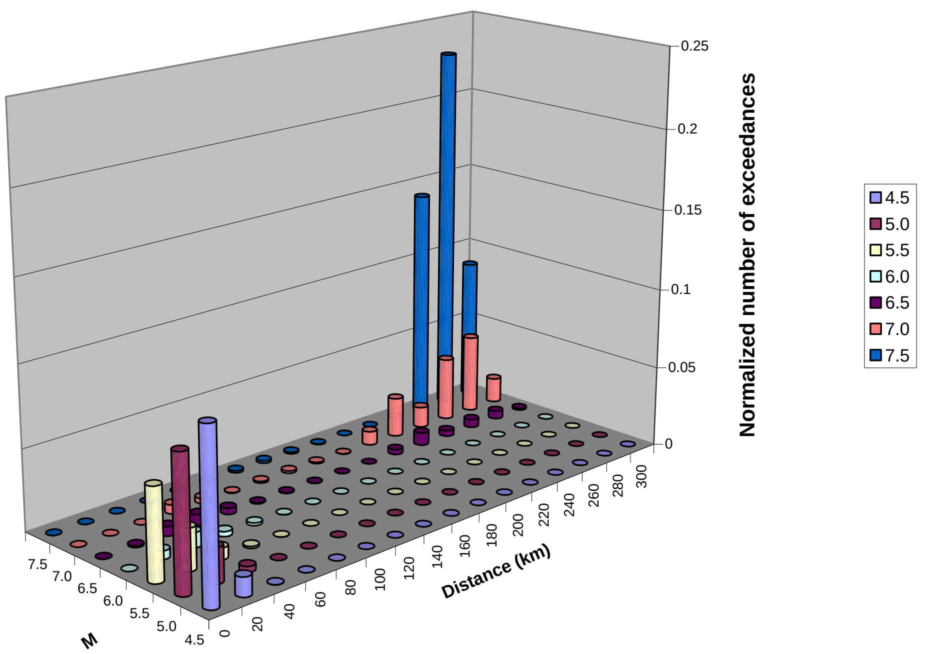


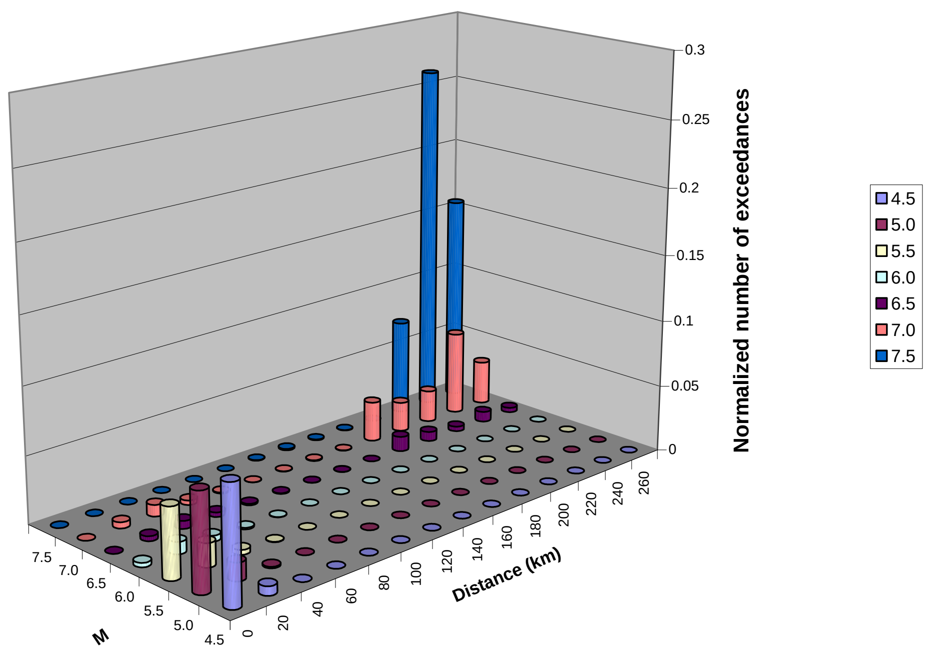
Fig.21 Slight bimodal distribution of earthquake magnitude and distance - stronger contributor to the hazard for the cities is the Vrancea intermediate source

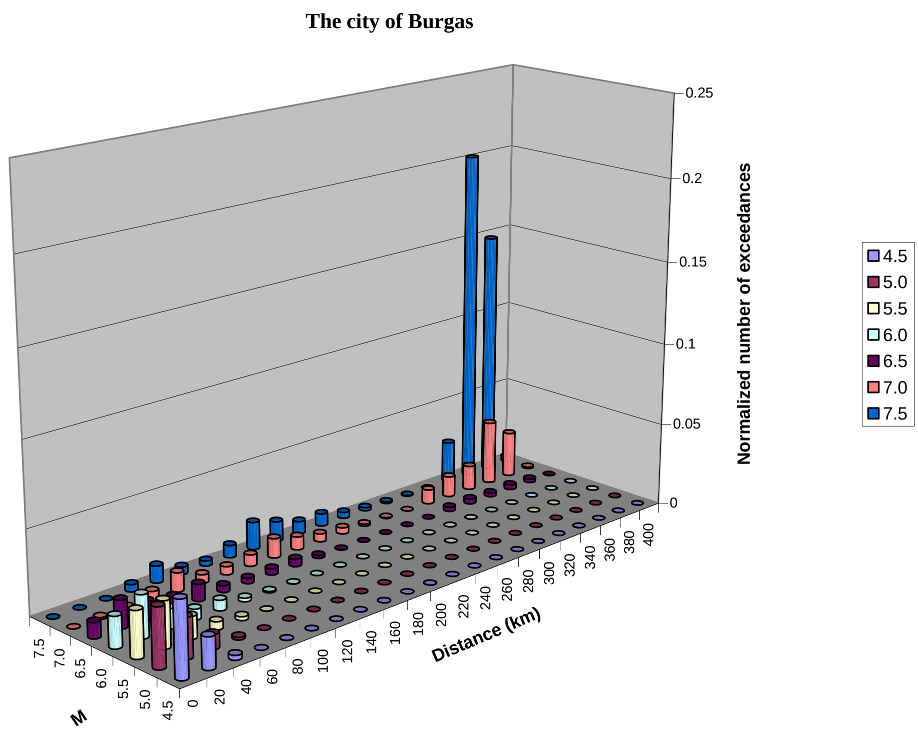
3. PSHA disaggregation plots show a slight bimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency is observed for PGA (Fig.21). The primary mode in Fig.21 is for magnitude greater or equal to 7.5 earthquakes at a distance of more than 200 km from the cities of Targovishte, Shumen, Dobrich and Burgas (effect of Vrancea intermediate earthquakes). The secondary mode is a magnitude 5.0 to 6.0 earthquake at 10 to 20 km from the cities (effect of the near regional seismicity). The strongest contributor to the hazard is the Vrancea intermediate source.

The city of Targovishte



The city of Shumen





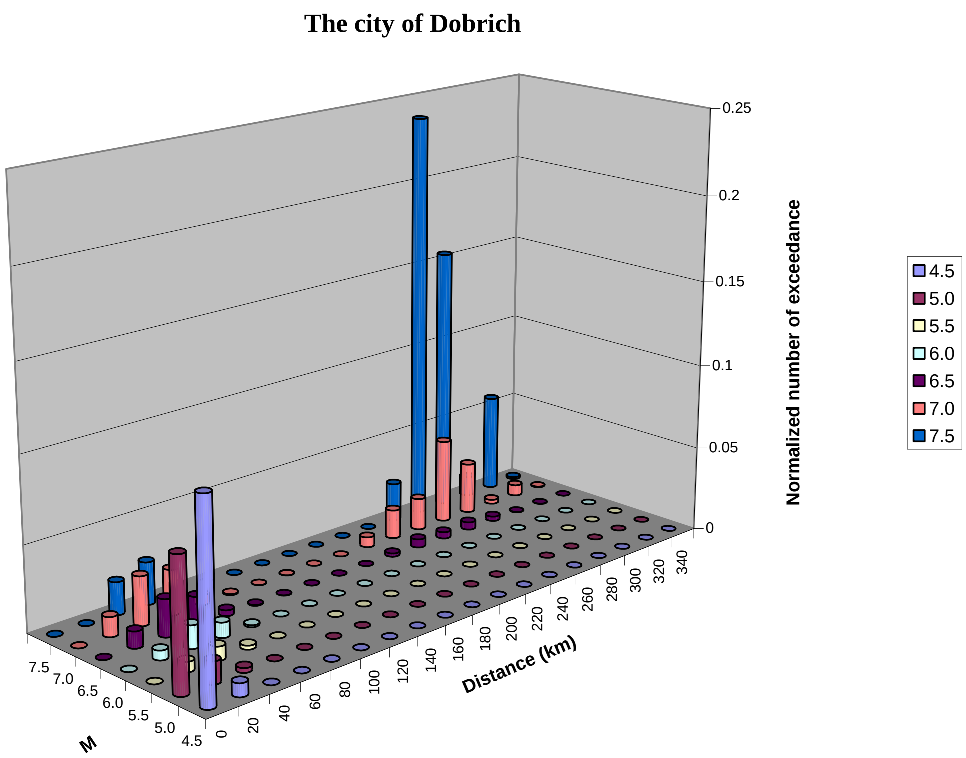


Fig.21 Slight bimodal distribution of earthquake magnitude and distance - stronger contributor to the hazard for the cities is the Vrancea intermediate source

4. PSHA disaggregation plots show a bimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency (Fig.22). The primary mode of the distribution is for magnitude greater or equal to 7.0 earthquakes at a distance 10 to 20 km from the city of Varna (effect of the near regional seismicity). The secondary mode is a magnitude 7.5 or larger earthquake at a distance of more than 250 km from the city of Varna (effect of Vrancea intermediate earthquakes).

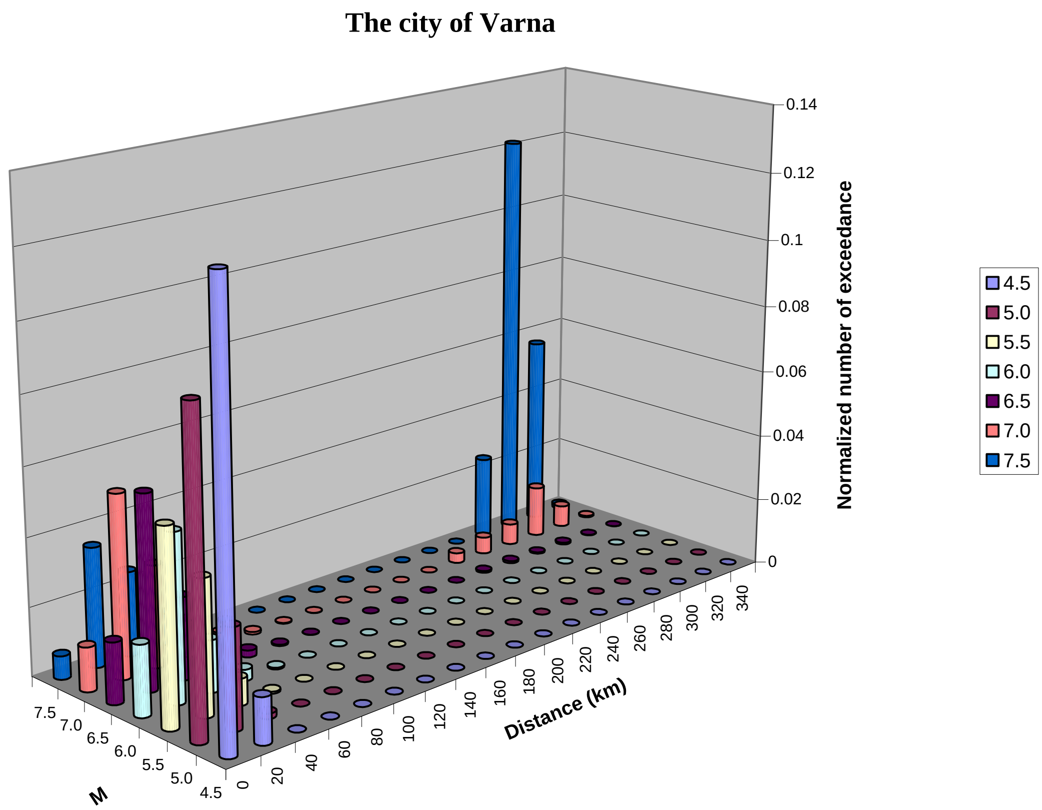


Fig.22 A bimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency

IV. Seismic risk

Consequences from strong earthquake

Automated System for Earthquake Consequences assessment (called ASEC) was proposed by Christoskov and Solakov (1992, 1995). The system was developed to answer the main disaster mitigation problems: 1) organization of immediate post-event activities and 2) pre-event prevention measures as long-term disaster mitigation plan.

The ASEC integrates geological, seismological, building, inventory and demographic information available for Bulgaria. The earthquake magnitude and its hypocentral parameters are ASEC input parameters. The output of the program is possible distribution of intensity, human casualties and buildings damages. Bellow, are briefly described the methods considered suitable for tacking the different tasks involved in ASEC.

Intensity field

The intensity field is estimated using the generalized macroseismic model for earthquakes on the territory of Bulgaria developed by Glavcheva et al. (1982, 1983). The intensity attenuation presented in Glavcheva et al. (1982, 1983) approximates the isoseismal shape by an ellipse model using the following equations:

$$Lg\ Q(I, M) = c(I)*M + d(I)$$

$$Lg(a*b^2) = c_1(I)*M + d_1(I) \qquad (4.1)$$

$$Lg(b^2/a) = c_2(I)*M + d_2(I)$$

where M-earthquake magnitude; I- macroseismic intensity; Q-size of an ellipse at a fixed I; *a* and *b*- semi-axes of an ellipse at a fixed I; c, c_i, d, d_i – empirical coefficients. The coefficients were determined on the based of historical data for earthquakes in and near Bulgaria by using the least square method.

Evaluation of human casualties

The estimate of the total number of causalities, namely the life losses (N_L) and wounded (N_W) is based on the approach initially described by Christoskov and Samardjieva (1984) and later improved and adapted for the purposes of the ASEC Christoskov and Solakov (1992, 1995). The empirical relations are given by equations:

$$\log N_L = k_1 + k_2M \qquad (4.2)$$

$$\log(N_W/N_L) = k_3 + k_4 M \, , \tag{4.3}$$

which are valid for the average population density $D \pm \partial D = const$ for affected area by earthquake of magnitude M. The coefficients k_1, k_2, k_3 and k_4 are normalized for density $D \pm \partial D$ in the intervals 0-25, 26-50, 51-75, 76-100, 101-200, 201-400 and for more than 400 pr./km^2. For the ASEC purposes a substantiation of N_L and N_W values is implemented by separation of their determinations for the areas of different intensity I (I=7, 8, ≥9 by MSK or MM scale). The mean radii r_I of areas of intensity I can be estimated by the generalized macroseismic models (Glavcheva et al., 1982, 1983).. In that case, the values N_L and N_W depend on the intensity I and on the population density D. The number of life losses within the area of intensity I, are estimated using the following relation:

$$N_L^{(I)} = w_I N_L \, , \tag{4.4}$$

where the weighting coefficients w_I for intensities I=7, 8, ≥9 are

$$w_I = 1/[r_I^2 (r_7^{-2} + r_8^{-2} + r_9^{-2})] \tag{4.5}$$

and the value of N_L is determined for the corresponding average population density D of the area of intensity I. Then, the total number of life losses is a simple sum of values $N_L^{(I)}$, so that

$$N_L = \sum_{I=7}^{9} w_I N_L = \sum_{I=7}^{9} N_L^{(I)} \tag{4.6}$$

Analogous approach could be applied for assessment of the total number of the wounded people, and therefore we have

$$\bar{N}_W = \bar{N}_L \exp(k_3 + k_4 M) \tag{4.7}$$

Evaluation of building damages

In general, the damages of the buildings, structures, different factories and installations could be divided in three major categories: architectural, constructional and destructive. The architectural damages are relatively light and do not affect the basic construction elements- they are manifested in the cracks and plaster fall off, cracking in the filling walls, fall down of chimneys and ornaments, etc. The constructional damages affect and destroy some of the basic construction elements as columns. Destructive damages mean a partial or entire destruction of the buildings.

The damages in the buildings and structures could be assessed by the destructive potential P that is the ratio between the actual horizontal force at the building foundation and the design force for the same building. The destructive potential P is defined by the following relation (presented in Tzenov, 1970, Bonceva and Tzenov, 1978):

$$P= S_a/(\kappa\ \beta\ K_c\ g)\ , \qquad (4.8)$$

where S_a is the spectral acceleration for the fundamental period of the building, κ is a coefficient, β and K_c are the dynamic and seismic coefficients and g is the Earth's acceleration. The coefficient κ might vary between 0.75 and 1 and by rough estimation it is as follows: κ=1 for masonry buildings, κ=0.8 for large panel buildings and κ=0.75 for all other buildings. The dynamic coefficient β ($2.5\geq\beta\geq0.8$) is depending on the natural period T of the building and can be determined numerically or graphically for different subsoil condition. The period T can be measured experimentally or evaluated approximately for different type of structures.

To provide an illustration through practical application to Bulgaria we estimated using ASEC possible consequences from strong earthquakes occurred in the main seismic zones (Shabla, Gorna Orjahovitca, Maritsa). The maximum 7.0 earthquakes (M_S=7.0) in Maritsa, Shabla and Gorna Orjahovitca zones are considered in modeling. The results are presented in Table 3 and illustrated in Figs.23-25. In Table 3 are given the expected mean humane causalities, building damages (slight, moderate, heavy and total). A comparison indicates that the largest consequences are to be expected from earthquake in the Maritsa zone.

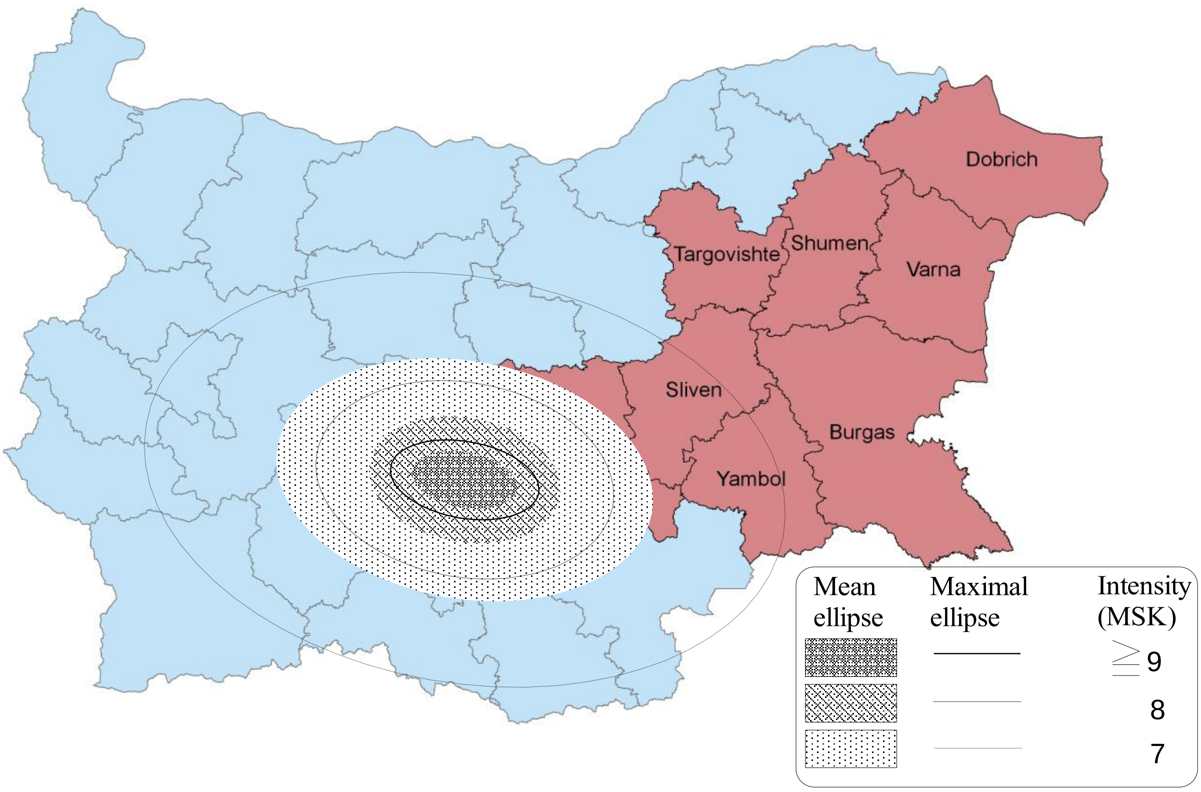


Fig. 23 Macroseismic field (Maritsa zone, M=7.0)

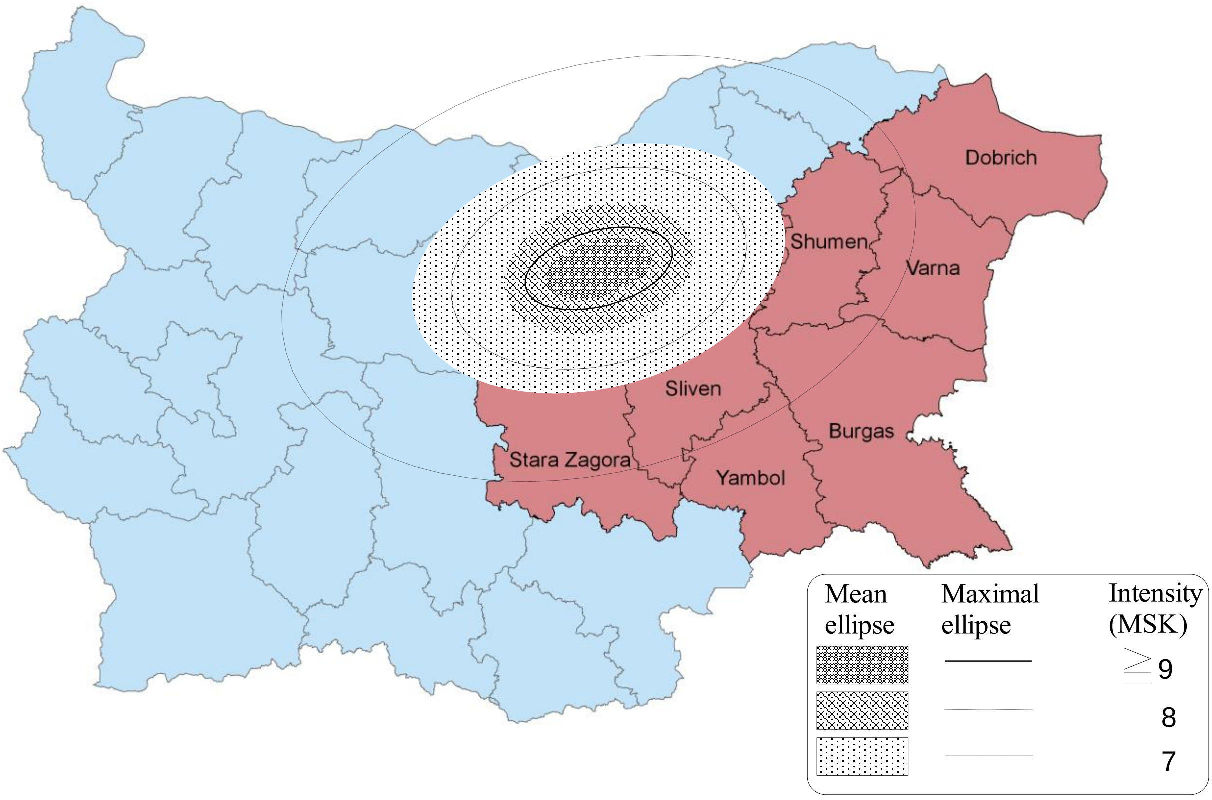


Fig. 24 Macroseismic field (Gorna Orjahovitca zone, M=7.0)

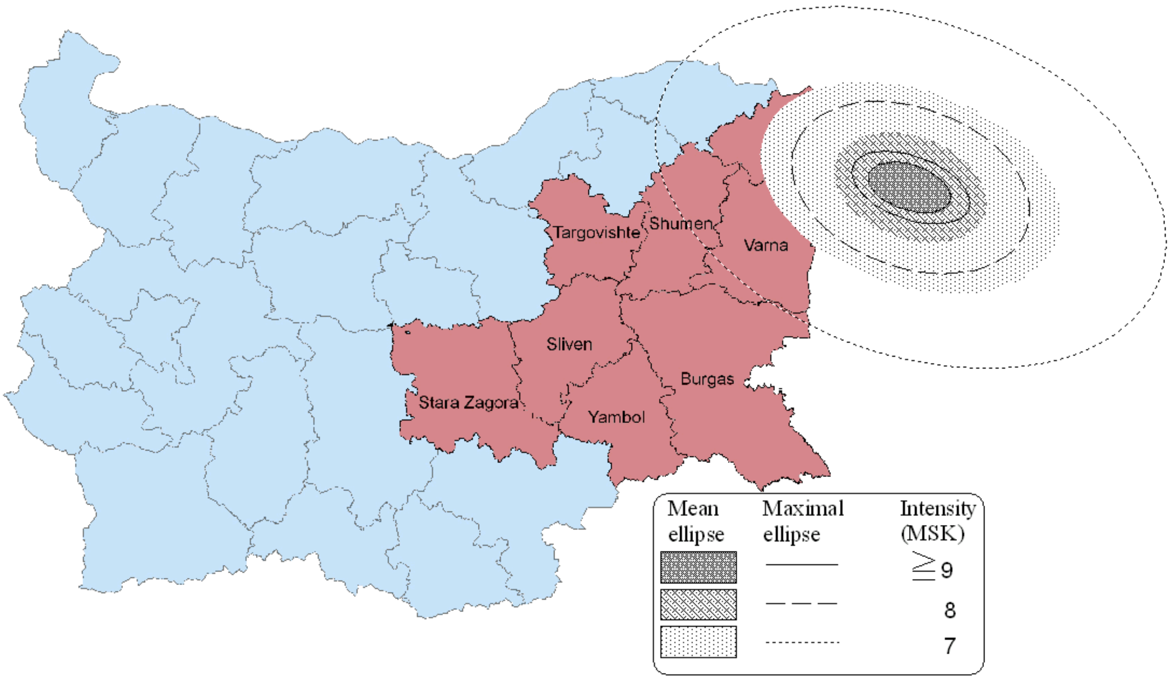


Fig. 25 Macroseismic field (Shabla zone, M=7.0)

Table 3. Consequences from strong earthquakes in Bulgaria

Seismic zone	S*	Population	D*	Life Losses	Wounded	Number of buildings	Slight damages	Moderate and heavy damages	Total damages
Maritsa M=7.0	15594	1657298	106	1141	4829	224215	117305	73661	33249
Shabla M=7.0	3611	385520	107	29	119	44720	20684	12081	4509
Gorna Orjahovitca M=7.0	14 214	1031526	73	3496	14808	197301	102686	63963	30652

S*- Size of affected area (km^2)

D* - average density of population per km^2

The ASEC estimates should be considered as statistical mean values and a comparatively large scatter (up to several times less or more) of the observed consequences are to be expected. In spite of these uncertainties the estimations can be used in mitigation policy, for developing and testing emergency response plans, urban planning and risk analysis. On the other hand the ASEC estimates are a useful tool for management and controlling the urgent interventions following the strong earthquake in Bulgaria.

IV.1 *Main strategy for risk reduction*

The main strategy for risk reduction is based on the concepts that:

- seismic risk is expressed by expected losses (causalities, injures, destructions, etc) for a given time period due to seismic hazard;
- there is no risk, even in territories with high seismic hazard, without population, infrastructure, installations et;.
- the seismic risk could be reduced

The strategy for risk reduction includes the following activities:

- Seismic hazard maps generation;
- State regulations for all aspects connected with seismic hazard – seismic monitoring, seismic hazard evaluation, seismic risk evaluation, building codes, etc;
- Building in accordance with seismic hazard and building codes;
- Development of risk scenarios for large cities, recognition of hot points on the territory of the urban areas and additional activities if necessary;
- High preparedness for earthquake risk mitigation – prevention, training of population, planning of the emergency activities etc;
- Early warning system;
- Generation of near real-time shaking maps;
- Operative urban area planning;
- Effective insurance;
- Coordination among science, insurance, governmental and other administrative units.

V. Emergency reaction and intervention related to earthquakes :

Fire Safety and Civil Protection Directorate-General, Ministry of Interior is responsible for emergency reaction and intervention in the case of strong earthquake. With the amendments of the Ministry of Interior Law (Promulg. Official Gazette, 9 November 2010) Civil Protection Directorate-General and Fire Safety and Rescue Directorate-General were united in one Directorate-General.

In Article 52g of the Ministry of Interior Law are defined the tasks of the united Directorate-General:

(1) Fire Safety and Civil Protection DG is a national specialized structure of the Ministry of Interior for ensuring fire safety, rescue and protection in the case of disasters according to the terms and regulations of this law and the Disaster Protection Law.

The Disaster Protection Law and the Ministry of Interior Law - 2006 set up an Integrated Rescue system and regulate:

- Establishment of an Integrated Rescue System;
- Participation of population, institutions and companies;
- Declaring of "state of disaster", support and recreation;
- Functions of the bodies of the Executive authorities and their basic functions;
- Relief and reconstruction.

According to Art. 5 from the Disaster Protection Law (DPL), the disaster protection is achieved by:

- conducting preventive activities;
- carrying out protection activities;
- coordination of the actions of the Integrated Rescue System;
- support and disaster recovery;
- resource provision;
- acceptance of aid

According to Art. 9 from the DPL:

(1) planning of disaster protection is carried out at municipal, regional and national level.

(2) For the activity under par.1 executive authorities draw up plans for disaster protection.

The main institutions connected with reaction in case of large disaster are:

- Ministry of Defense;

- Ministry of Environment and Water;
- Ministry of Transport, Communications and Information Technology ;
- Ministry of Foreign Affairs;
- Ministry of Agriculture and Food;
- Ministry of Economy, Energy and Tourism;
- Ministry of Regional Development and Public Works;
- Bulgarian Academy of Science

The council of Ministers forms the disaster public protection policy and adopts a National Plan for Disaster Protection (art. 62 from the Disaster Protection Law).

Contents of National Plan for Disaster Protection (art. 9, para. 4 from DPL)

- Analysis of possible disasters and weather consequences;
- Measures to prevent or mitigate the effects of disasters;
- Measures to protect the population;
- Allocation of duties and authorities and persons to implement the measures;
- Tools and resources provided for the eradication of the consequences of disasters;
- Mode of interaction between the executive authorities;
- Order early notification of the executive authorities and the population threat or occurrence of disasters.

National Institute of Geophysics, Geodesy and Geography (NIGGG) is responsible for scientific information (earthquake alerts, scientific information etc.).

The National plan for Disaster Protection is put in operation by the prime minister in case disasters (Fig. 26) affected more than one district or if the resources of the affected district are not enough to manage the disaster. In case of strong earthquake the plan is put in operation after earthquake alert from NIGGG.

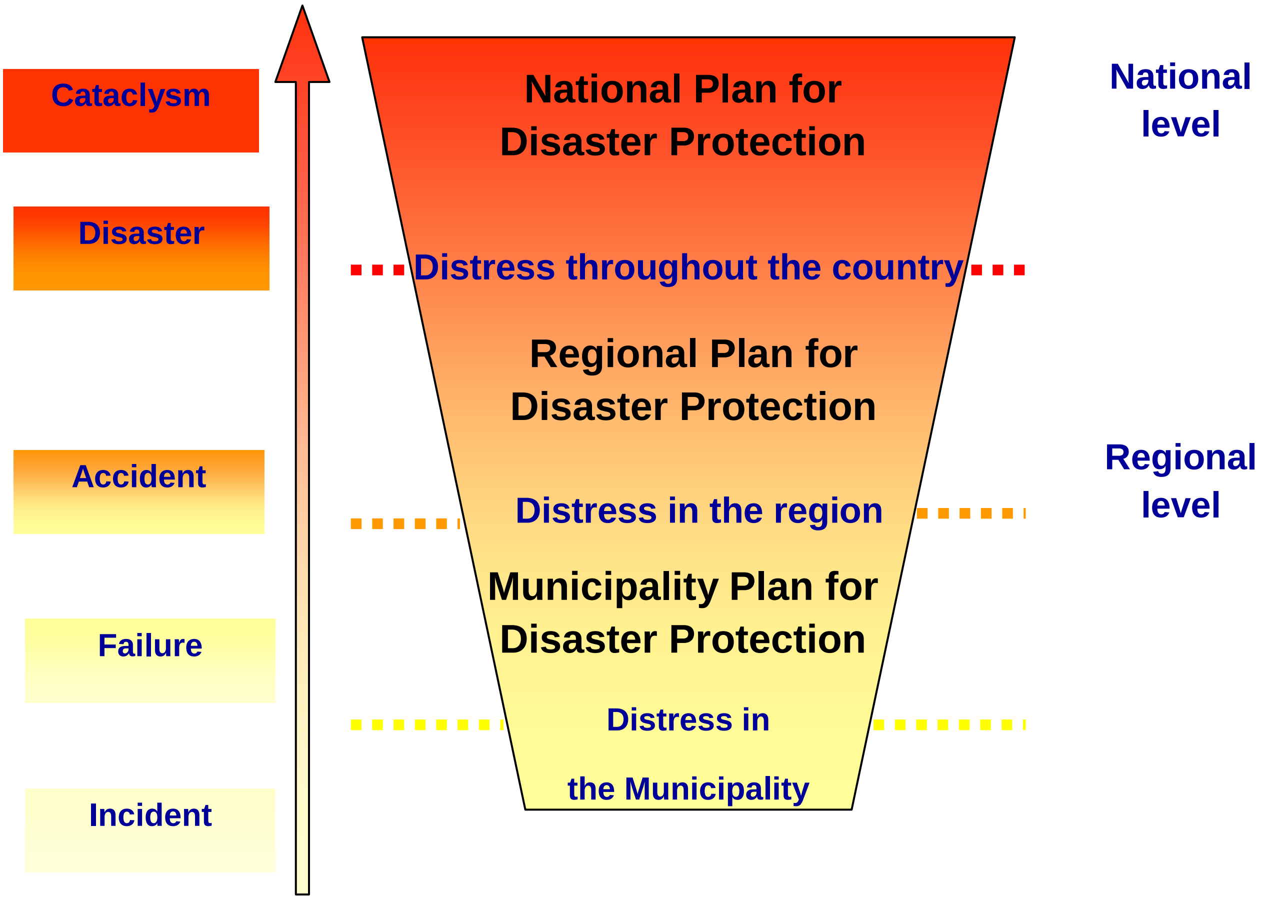


Fig. 26. Hierarchy of the Plans for disaster protection

The National Plan for Disaster Protection recommends also measures for seismic risk reduction:

- study, analyses and evaluation of the seismic risk for the territory of the country;
- updating of the seismic zoning and microseismic studies where necessary;
- buildings inspection including cultural and historical heritages;
- development of scenarious for consequences from strong earthquakes for large urban areas;
- training of central and local authorities and population etc.

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