Local network deployed around the Kozloduy NPP - a useful tool for seismological monitoring

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Radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences. International safety standards provide support for states in meeting their obligations under general principles of international law, such as those relating to environmental protection. Seismic safety is a key element of the NPP safe operation. Safety and security measures have in common the aim of protecting human life and health and the environment.

Kozloduy NPP Plc. is the only nuclear power plant in Bulgaria and the main electricity generating plant main providing more than one third of the total annual electricity output of the country. Safety is the main priority at Kozloduy NPP and it is a subject to independent state surveillance by the Nuclear Regulatory Agency at the Bulgarian Council of Ministers. Kozloduy NPP safety has been highly assessed and acknowledged internationally as a result of the reviews conducted in the last years, by teams of the International Atomic Energy Agency, World Association of Nuclear Operators (WANO), Atomic Questions Group at the European Commission etc. The electricity generation of Kozloduy NPP entirely fits into the World Nuclear Association's concept of nuclear renaissance. The company meets the high environmental requirements of the Kyoto Protocol for it does not release any greenhouse gasses into the atmosphere. Environmental protection is a fundamental issue in the company's policy.

The LSN (presented in Fig.1) covers 3 seismic stations (SS: MPE, VLD and ORH) installed permanently within and close to the near 30 km region. At present NIGGG-BAS runs LSN around the Kozloduy NPP site. The operation and data processing, data interpretation, and reporting of the local micro-earthquake network are linked to the national seismic network (NOTSSI). A real-time data transfer from stations to National Data Center (in Sofia) was implemented using the VPN and MAN networks of the Bulgarian telecommunication. Real-time and interactive data processing are performed by the Seismic Network Data Processor (SNDP) software package.

The Kozloduy NPP site is located in the stable part of the Moesian platform (area of about 50000 km^2). From seismological point of view the Moesian platform is the most quitest region on the territory of Bulgaria. There are neither historical nor instrumental earthquakes with M≥4.5 occurred within the platform. The near region (area with radial extent of 30 km) of the NPP site is characterized with very low seismic activity. The strongest recorded quake is the 1987 earthquake M_S=3.6, localized 22 km northwest of the Kozloduy NPP site on the territory of Romania.

As a key element of the NPP seismic safety, a local seismological network (LSN) of sensitive seismographs which have a recording capability for micro-earthquakes has been installed around Kozloduy NPP and has operated since 1997. The main goal of the local seismological network is to supplement the available seismological data with more detailed information on small earthquakes occur in the near region of Kozloduy NPP.

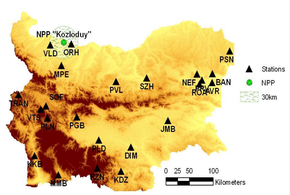


Fig.1. Bulgarian seismological network and LSN around the Kozloduy NPP (green point).

Seismological equipment of the LSN seismic stations is presented in Fig.2. At the SS MPE the following is installed: Reftek digitizer DAS 130 1/6, broad band seismometer Reftek 151 with flat response from 120 s to 50Hz and short period seismometer S13 with natural frequency of 1Hz. Additionally, digitizer Bazalt and accelerometer Epi-sensor as a part of Early Warning System (EWS) deployed in the territory of North Bulgaria and South Romania in the frame of the DACEA project are installed. Additionally EWS alert system is installed at Kozloduy NPP in the frame of the same project. Equipment in SS VLD and SS ORH consists of Reftek digitizer DAS 130 1/3 and short period seismometers S13 with natural frequency 1Hz. The seismometers are situated in a borehole at the depth with 230m at SS VLD while in SS ORH the seismometers are installed in a 5m deep pit. The equipment is periodically upgraded and calibrated to provide adequate information in line with updated international operational practice.

Fig.2. Equipment of the LSN Kozloduy Seismic Stations.

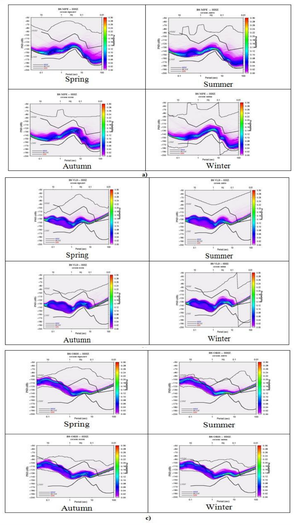


Fig.3. Seasonal distribution of the ambient noise power at the seismic stations: a) MPE; b) VLD and c) ORH.

The results of studies on seasonal variations in the noise levels at the three LSN stations are illustrated in Fig.3. Increased level of seismic noise during the autumn-winter months in comparison to the spring-summer period is well observed at the 3 stations. That effect is related to the unstable and turbulent atmospheric processes during these seasons. VLD and ORH stations are situated in populated areas where the human activity on and near the Earth surface increases the noise level – it is seen in the frequency range below 1s. No human activity effects are observed at SS MPE and the curve of the power spectral density of the noise lies close to the curve of the Low Noise Model. It is worth to mention that the MPE station is one of the quietest stations of Bulgarian Seismological Network.

The results of more than 17 years of operation of LSN "Kozloduy" are presented in the figures Fig.4(a) – all events (more than 80% of them are industrial explosions) localized in 150 km region surrounding Kozloduy NPP; and Fig.4(b) – earthquakes occurred in 150 km region surrounding Kozloduy NPP from 1997 through 2014. Impressive seismic activity developed in the SW margin of the region after the earthquake of moment magnitude 5.6 occurred on 22, May, 2012. The earthquake is localized at about 25 km south west of the city of Sofia.

The multiple studies carried out indicate that LSN jointly with NOTSSI provide reliable registration of weak seismicity in the near (30 km) region of NPP site. Earthquakes recorded within and near the network are carefully analyzed in connection with seismotectonic studies of the near region. The seismological database acquired is homogeneous for the entire region to the extent possible or, at a minimum, is sufficiently complete for characterizing, from a seismotectonic point of view, features relevant to the site.

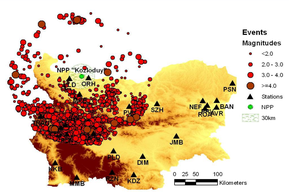


Fig. 4a). Seismicity in the 150 km region on the Kozloduy NPP (all events).

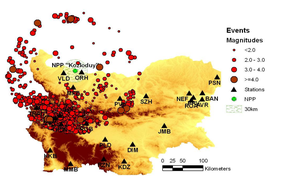


Fig. 4b). Earthquakes occur in the 150 km region on the Kozloduy NPP .

Digital records at the 3 seismic station of the Kozlduy LSN and P-wave Fourier spectra of the 2012 earthquake with magnitude Mw=5.6 occurred on 22 of May 2012 at 0^h 0^{min} GMT in south-western margin of the 150 km region surrounding Kozloduy NPP are presented in Fig.5.

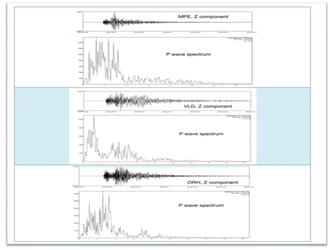


Fig.5. Digital records from the Kozlduy LSN stations and P-wave Fourier spectra of the 2012 earthquake with magnitude Mw=5.6.

Fig.7 illustrates a typical record (at SS MPE) and S - wave spectrum of industrial blast.

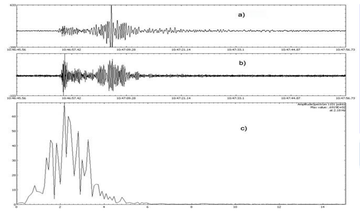


Fig.7. Digital record of industrial blast at a distance of 47km from NPP site: a) Digital record at SS MPE; b) filtered record with high pass filter (with frequency of 3.5 Hz); c) S-wave spectrum.

For the monitoring period of more than 17 years only one earthquake (with magnitude M=2.3) has been localized in the near region (within a radius of 30 km) surrounding the Kozloduy NPP. The earthquake occurred on 3 August 2013 at 00^h 14^{min} (GMT) at a distance of 21 km northeast from the NPP site. Digital records from the three Kozlduy LSN stations and P - wave and S - wave spectra of the 2013 earthquake with magnitude M=2.3 are presented In Figs.6(a) and 6(b).

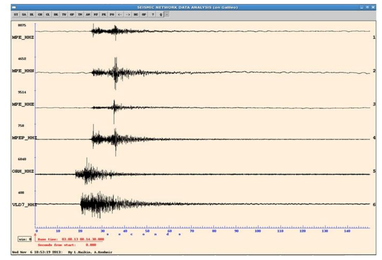


Fig.6a). Digital records at the Kozlduy LSN stations of 03.08.2013 earthquake with magnitude M=2.3.

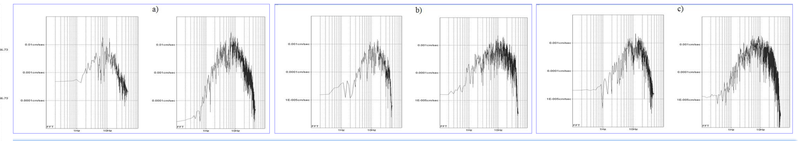
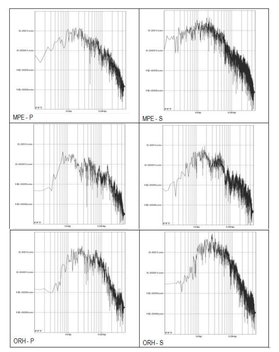


Fig. 6b). P - wave (left) and S - wave (right) spectra of the 2013 earthquake based on records at station: a) ORH; b) VLD; and c) MPE.



The Kozloduy NPP near region is affected by intermediate-depth earthquakes occurred in the Vrancea seismic source (in Romania). The Vrancea seismogenic zone in Romania represents a specific for our region seismic source, which is a major concern for the most of the northern part of Bulgaria as well.

Situated at distance of more than 280 km away from the Vrancea zone, the Kozloduy NPP site may suffer damages due to high energy Vrancea intermediate-depth earthquakes. Digital records from the Kozlduy LSN stations and P - wave and S - wave spectra of the Vrancea intermediate earthquake with magnitude M_W=5.6 occurred on 22.11.2014 at 19^h 14^{min} (GMT) are presented in Figs. 8(a) and 8(b).

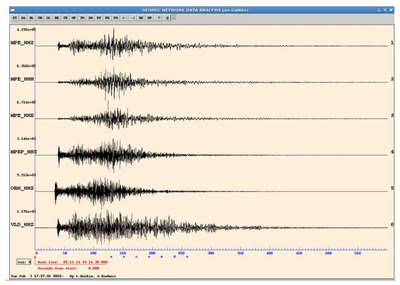


Fig.8a). Digital records at the Kozlduy LSN stations of the Vrancea intermediate earthquake with magnitude M_W=5.6 occurred on 22.11.2014 at 19^h 14^{min} GMT.

Fig.8b). P - wave (left) and S - wave (right) spectra of the 2014 intermediate earthquake (M_W=5.6) based on records at station: MPE; VLD; and ORH.

The geodynamic network in Bulgaria and the estimated horizontal velocities are presented in Fig.9. The velocity field shows predominant motion in South - Southwest to Southeast direction relative to stable Eurasia and increasing velocities from North to South confirming the extensional regime in Southwest Bulgaria and Northern Greece.

Time series (at 3 components) from ORH station observations for time period of five years are presented in Fig.10. Secular trend and annual variations are excluded.

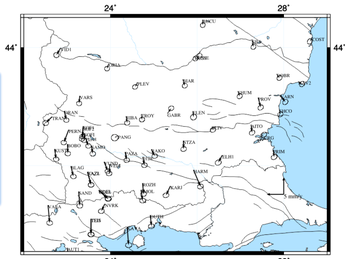


Fig.9. The velocity field in Bulgaria.

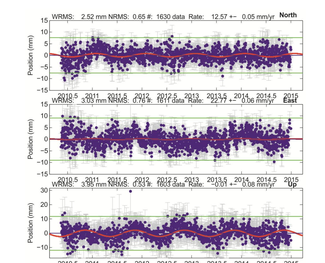


Fig.10. Time series for ORH station.

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