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Performance of the stations from the Seismological Network of Sofia University

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Summary
Currently, the Seismic Network of Sofia University consists of two stations. Station SOFSU has been operating at the Faculty of Physics since September 2023 and consists of 2 instruments: Geofon-4.5 Hz and SS02-0.2Hz. Station SRKO was installed in the village of Sredni Kolibi in August 2024 and is equipped with SS08, a broadband seismometer of SARA Electronic Instruments s.r.l. with flat response between 50 Hz and 120 sec. The data from the stations have been used in noise spectrum studies, velocity structure estimations and focal mechanism analyses. The third station is in the process of compilation: a broadband instrument SS08 will be installed at one of the holiday bases of Sofia University.

Introduction

The Virtual Seismological Network of Sofia University (VSNSU) was established in 2015 with the support of the Scientific Research Fund of Sofia University "St. Kliment Ohridski". It consisted of several seismic stations from national and international networks located on the Balkan Peninsula that provide open real-time data. Until 2021, the seismic records were analyzed and used in various scientific studies (Raykova et al. 2018; Dimova et al. 2019; Dragomirov et al. 2021), as well as during students' seismological practice.

Different difficulties related to data acquisition led to the establishment of a real seismological network of Sofia University that allows students and young scientists to work directly with seismic equipment and use the data for different scientific and educational purposes. The Bulgarian University Seismic Network (BUSN) is officially registered with code "B" through the International Federation of Digital Seismograph Networks (FDSN) and doi: 10.7914/tawk-rh33. At present, it includes two stations (SOFSU and SRKO) and the third one is in the testing period (temporary code GIUL).

Station SOFSU, located in the Faculty of Physics in Sofia, became operational on September 11th 2023. The first instrument, a Geophone seismometer (4.5 Hz), was purchased with funding from the Scientific Research Fund of Sofia University "St. Kliment Ohridski" and in October 2023 a second instrument with greater capabilities than the geophone, a SS02 seismometer (0.2 Hz), was added. According to international seismological standards, the instruments are assigned location codes "00" and "10", respectively. The second station SRKO is located in the village of Sredni Kolibi and started operating in August 2024. It is equipped with a broadband SS08 seismometer (50 Hz to 120 s). The third station (GIUL) has the same equipment as SRKO and will be installed in Giulechiza, Rila mountain.

Data from the two stations have been used for noise spectrum studies (Pandurska et al. 2023; Dimova et al. 2023), velocity structure estimations and focal mechanism analyses (Dimova and Raykova 2024; Dimova et al. 2024). The characteristics of the terrain in the region of SOFSU station were determined using the SS02 seismometer (Penev 2024).

Technical Characteristics of the Stations

Station SOFSU has coordinates 42.67304°N, 23.32938°E and an altitude of 609 m. It includes two sets of instruments. The first one consists of a 3-component 4.5 Hz Geophone seismometer with a PSN-ADC24 Webtronics digitizer, a GPS antenna for receiving accurate time and a portable computer for registering and archiving the data. Its frequency response allows the detection of local shallow earthquakes with epicentral distances up to approximately 200 km. The sampling rate of the digital data is 100 samples per second. Data received from the geophone can be visualized and archived with the WinSDR software (www.seismicnet.com). The second set is the seismic set Velbox of SARA Electronic Instruments s.r.l (www.sara.pg.it). It consists of a 3-component 0.2 Hz SS02 seismometer and a SL06 digitizer with internal memory and great capacity for data storage. The system has an internal battery and low energy consumption. A battery ensures continuous work of the equipment in the SOFSU station. While the geophone has maximum amplification at higher

frequencies (greater than 4.5 Hz), the SS02 seismometer is more sensitive to lower frequencies (at 0.2 Hz). The large range of frequencies that can be registered with the Velbox set results in a less noisy signal which makes the identification of events on the seismic records easier, especially of S- and surface waves. The instrument is easy to configure and manage remotely through a web browser interface. The necessary software SeismoNux® for connecting to the sensor is pre-installed on the SL06 digitizer. Connection can also be established through LAN. Data are registered and can be analyzed using the SEISMOWIN® software of SARA Electronic Instruments s.r.l.

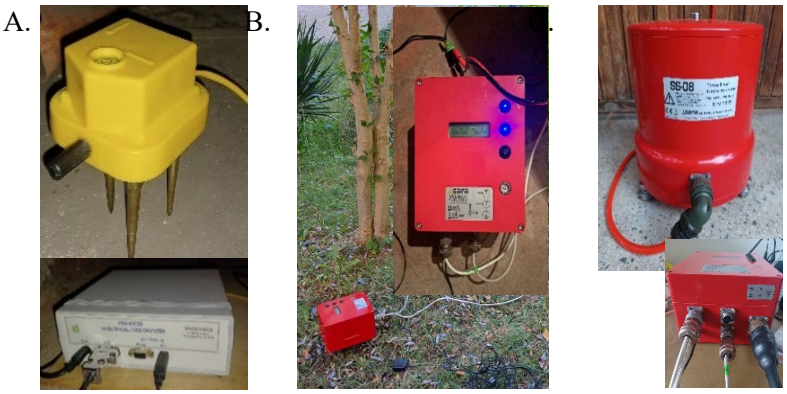


Figure 1. Instrumentation of the Bulgarian University Seismic Network (BUSN). A. Geophone in SOFSU_00 station; B. Seismometer SS02 in SOFSU_10 station – as a permanent station (top) and outdoor use (bottom); C. Seismometer SS08 in SRKO station.

Station SRKO has coordinates 42.91834°N, 25.73967°E and an altitude of 424 m. Its instrumentation consists of a portable broadband triaxial SS08 seismometer of SARA Electronic Instruments s.r.l. with flat response between 50 Hz and 120 s and a SL06 digitizer and recorder with three channels. The work of the SL06 digitizer can be automated which makes it suitable for remote permanent monitoring. The seismometer employs a symmetric architecture to recover the Z, Y, X velocity signals from U, V, W homogeneous transducers. The high sensitivity and ultra-low noise design allow the recording of a wide range of seismic signals from continuous records of seismic noise, local and regional earthquakes to teleseismic events. Low power consumption enables installation of SS08 at remote sites with limited energy sources.
At present, data from all instruments are stored on a hard disk in the MiniSEED format with each file containing one hour of continuous data for each channel.

Seismic data analysis
At the beginning, several regional earthquakes recorded by the geophone were analyzed using the WinQuake software (www.psn.quake.net/software.html). Arrival phases and spectra of different components were determined and the seismograms, the location maps of the events, FFT and DFT spectra were saved in event folders. In contrast to S- and LQ-waves, P-waves cannot be clearly identified on the records from the geophone as their amplitudes and frequencies are comparable to those of the registered seismic noise.
Data from the geophone was also used for calibration of the magnitude-amplitude relation for calculating local magnitude at SOFSU station. Due to the high noise levels at the station, only earthquakes with magnitude Ml > 2.0 are clearly recorded. Several of the registered earthquakes were used to define coefficient C3 which was calculated from the relation: C3 = Ml – logAH – logR, where Ml is the local magnitude taken from www.emsc-csem.org, AH is the averaged horizontal amplitude, R is the hypocentral distance. The values of C3 are between -1.4 and -1.7 which corresponds to a maximum deviation of 0.3 for the values of the magnitude. (Dimova et al. 2024)
The average velocities of seismic waves in the upper crust between the epicenters of the events and SOFSU station were determined by taking the arrival times of P- and/or S-waves. The S-wave velocity Vs varies between 3.0 and 3.4 km/s, while the P-wave velocity Vp is between 5.4 and 5.7 km/s. The calculated values of the Vp/Vs ratio were in the range 1.65-1.69. The observed velocities indicate the presence of high-velocity granites south to Sofia since most of the registered events are in south-western Bulgaria.

Data from SOFSU station were used for seismic noise analysis and various studies. Spectral characteristics of seismic noise at both SOFSU and SRKO stations were analyzed. The spectra from the geophone and the SS02 seismometer are similar with the maximum amplitude corresponding to the frequency with maximum amplification – 4.5 Hz and 0.2 Hz, respectively. The spectrum of the SS08 seismometer includes lower frequencies in accordance to its better frequency response. Averaged spectra were compared for different periods – night, day, working and non-working days. The noise amplitudes during the day are around 5 times larger than those during the night and the amplitudes during working days are around 2 times larger than those during non-working days. Moreover, vertical components are less noisy than horizontal ones with noise amplitudes being around 1.2 times smaller. This is a common quality of all types of seismometers. (Dimova et al. 2023) Comparing the daytime spectra for the SS02 and SS08 seismometers, it can be seen that the amplitudes for the latter are much higher (Fig. 2). Although there is greater noise in Sofia during the day, its frequency range is such that it does not disrupt the operation of the station.

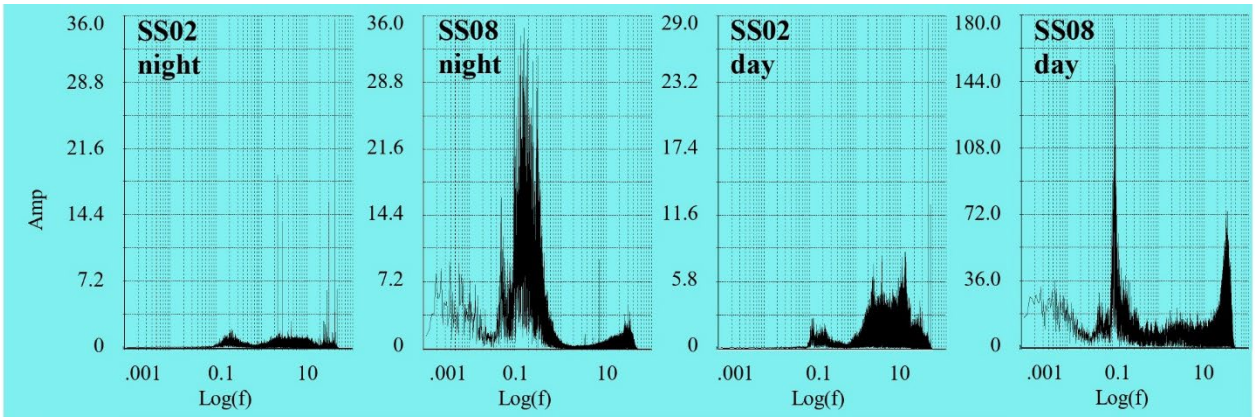


Figure 2. Comparison of 1-hour averaged seismic noise spectra during the night and during the day for the vertical Z component of SOFSU_10 (SS02) and SRKO (SS08) stations for March 1st, 2025.

Using the averaged seismic noise spectra and the HVSR method, the thickness of the sedimentary layer beneath SOFSU station was determined. After taking the ratio of the spectra of the horizontal and vertical components, the resulting signal has a maximum at around f = 0.25 Hz which is the resonance frequency of the medium beneath the station. Using the equation for the fundamental mode of surface waves f = Vs/4h and values for Vs for the uppermost sedimentary layer between 175 and 400 m/s (Ilieva et al. 2003), the shallow layer was estimated to extend to a depth between 175 and 400 m (Dimova et al. 2023).

The mobility of SOFSU_10 enables the short-time measurements of seismic noise at different sites and the study of resonance frequencies and thickness of sedimentary layers. Measurements were carried out at five points in the area of the Faculty of Physics, the Faculty of Mathematics and Informatics and the Faculty of Chemistry and Pharmacy at Sofia University. A methodology was developed for using the HVSR method with the available instrumentation and software. Three resonance frequencies were determined: 0.29 Hz, 0.4-0.45 Hz, and 0.66 Hz. They correspond to three resonance boundaries at depths 540-830 m, 350-600 m, and 240-370 m. A decrease of the thickness of the main resonance layer was also observed in direction from the Faculty of Physics to the Faculty of Chemistry and Pharmacy (Penev 2024).

The velocity structure of the granite layer between stations SOFSU and VTS1 was also studied. Four earthquakes were chosen with epicenters around Simitli so that the seismic waves propagate in an almost northward direction passing through VTS1 first before arriving at SOFSU. Differential propagation time and differential epicentral distances were calculated. For station VTS1 arrival times of P-waves were taken from the EMSC (www.emsc-csem.org) and the approximate arrival times of S-waves were calculated using the theoretical ratio Vp/Vs = 1.73. The estimated S-wave velocities between the epicenters and VTS1 station are between 3.36 and 3.58 km/s. These values are significantly larger than the values for the S-wave velocities between the epicenters and SOFSU station owing to the fact that Vitosha mountain is an extinct volcano and the upper granite layer of the crust contains a large percentage of denser basalt rocks that are characterized with higher seismic waves velocities.

Data from SRKO station have been used to study focal mechanisms of earthquakes in Bulgaria and its surroundings by applying the INPAR method for non-linear inversion which minimizes the difference between observed and synthetic seismograms. Earthquakes with magnitudes between 4.0 and 5.0 were chosen. Seismograms were retrieved from several seismic data centers including SAGE, GEOFON and EIDA. Seismic moments, moment rates of the full moment tensor components and deviatoric components and source time functions for the total moment tensors were computed and beachball diagrams were created. The robustness of the solution for each event was assessed by evaluating its consistency (Dimova and Raykova 2024).

Conclusions

At present, BUSN consists of 2 stations and one is in the process of installation. The variety of instruments allows different problems in seismology to be solved: from velocity structure to the geodynamics of the Bulgarian region.

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Competing interests

The authors have declared that no competing interests exist.

Acknowledgments

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