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EARTH PHYSICS

NATIONAL INSTITUTE FOR EARTH PHYSICS (NIEP) PROGRESSES IN SEISMIC MONITORING, FROM THE PAST TO THE FUTURE

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Abstract. Seismic monitoring in Romania has more than 100 years of tradition. In spite of the World wars and critical periods, these activities progressed and have a good future. Presently a complex and high dynamic range real time seismic network ensures the seismic monitoring in Romania. A huge seismic database became a strong support for research and investigation in seismic field of activity. This insures a constant seismic data exchange with the global seismic monitoring systems. International collaboration is established with important scientific entities around of the world. There is a planning for a future upgrade of the National Seismic Network with more broadband seismic stations. Infrasound research project, as complementary activity for Romanian seismic monitoring, will start also.

Key words: seismic monitoring, Romania, array, infrasound.

1. MOTIVATION OF SEISMIC MONITORING IN ROMANIA

Romania is an European country having significant seismicity. The most active seismic zone is situated in Vrancea area, at the arch of the Carpathians Mountains. The seismicity of the Vrancea region in the SE-Carpathians is characterized by intermediate depth earthquakes in a narrow epicentral and hypocentral region. The epicentral area is confined to about 20 km × 60 km. Strong earthquakes occurred between 70 km and 180 km depth within an almost vertical column. Depth underestimated moment magnitude of all instrumentally recorded events are summarized in the Fig. 1 (Oncescu & Bonjer, 1996). The depth interval of the strong events is bounded by levels of low seismicity between 40 km and 60 km and beneath 180 km. The $M_W = 3.7$ event clearly represents an exception. The ruptured areas migrated from 150 km–180 km (1940) to 90 km–110 km (1977) to 130 km–150 km (1986) to 70 km–90 km (1990). The depth interval between 110 km and 130 km remained unruptured since at least 150 years. This depth is a natural candidate for the next strong Vrancea event (Fig. 1).

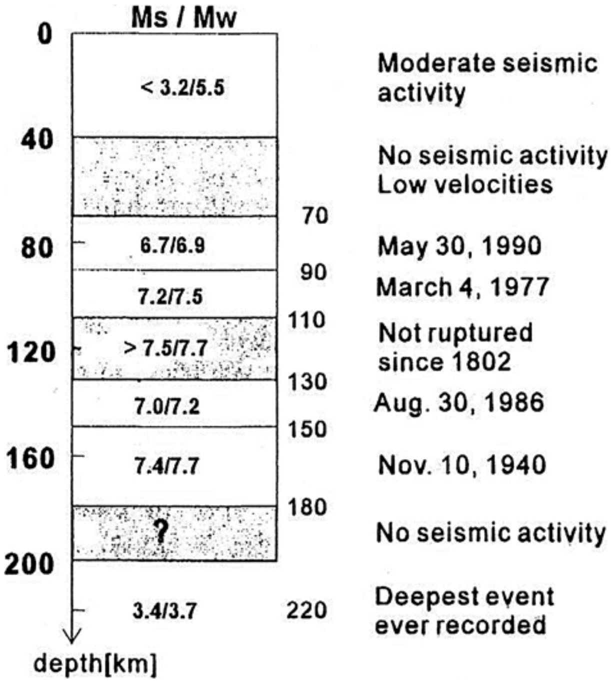

Fig. 1 – Rupture extent with depth and movement for all instrumentally recorded Vrancea earthquakes which caused major damage. It is a fair assumption that the next strong event will rupture the depth interval around 120 km.

Fagaras, Banat, Carei, Maramures, Orsova, Tulcea are other seismically active zones from Romania, characterized by crustal earthquakes at 10 km–30 km depth.

In Fig. 2 is presented the Seismicity in Romania according to Zonation Map SR 11100/ 1-1993.

In addition, the south east part of Dobrogea region is under the influence of Shabla (Fig. 3), Bulgarian seismic region (crustal earthquakes $M = 7.3$; $I_0 = \text{X}$), that hit the Romanians lands with the intensity of VIII MSK degrees in 1901 Mach 31, at 07:10 GMT [Moldoveanu, *et al.*, 2007].

2. HISTORY

Romania is one of the first countries from the world to be involved in seismic monitoring. The beginning of Romanian Seismology was connected to the activity of academician Stefan C. Hepites, who started in 1892 the observations about seismic activity in Romania using the meteorological observatories infrastructure and facilities existent at that time in the country. Two years later the first Romanian seismic station was born in Filaret-Bucharest meteorological observatory, by installing of one microseismoscop Guzzanti and one seismometrograph Tacchini, both Italian products. In 1902 another two horizontal mechanical seismographs type Bosch using smoking paper recorder were installed at Filaret [Radulescu, 2001]. Having short non-operating periods (between 1908 and 1935) this type of seismic equipment insures the seismic monitoring of Romania's capital area until 1958.

In 1935, January first, the Romanian Seismological Service was official created, having Professor Gheorghe Demetrescu as coordinator. A good period for seismic monitoring start in Romania and new seismic observatories using smoked or photographic paper recorders were set up around of the country in: Focsani (set up in 1942, July 12), Bacau (set up in 1942, December 25) Campulung-Muscel (set up in 1943 Mach first), Iasi (set up 1951 December 10), Vrancioaia (set up in 1952, July), etc.

As an evident example of the excellent management of the seismic monitoring in Romania in old times, there are even recordings performed in very dangerous and hard conditions of work, generated by the dropping of bombs in Bucharest, during the Second World War (Fig. 4a, 4b, 4c). These meant a serious and constant scientific activity for seismic monitoring during the most difficult period in Romania.

Unfortunately, in the communist period the seismic monitoring activity in Romania was not considered a priority and it was hosted in different institutions some of which having very weak connection with the geophysical world community. Good opportunities for seismic monitoring upgrading in Romania by international cooperation were lost because of the restrictive official politics concerning the relationship with the western countries. In February 1977 the Center for Earth Physics and Seismology was created, under State Committee for Nuclear Energy authority. The catastrophic earthquake from 1977 Mach 4 hit Romania as a country with very poor seismic monitoring service, in reorganization process, with old and improper seismic equipment that didn't help too much the Romanian seismologists to calculate during that hard and tragic night the parameters of this very strong seismic event ($M_w = 7.5$).

US Government and the PNUD – UNESCO shortly allocated about two million dollars to help the Romanian seismology and a new Teledyne Geotech seismic network telemetred by radio links (18 stations) and 20 pieces strong motion Kinemetrics accelerographs were bought by international bidding procedure. Romanian Government promised to support the installing cost for this new seismic equipment and to build a new facility for National Data Center (NDC), dedicated to host the analog recorders room (seismic Helicorders), a special room for real time seismic data analyzing computer PDP 11, and headquarter for Romanian seismic monitoring service, also. Unfortunately, the Romanian part didn't respect the international engagement, because of official politics and poor management. The officials in charge to decide about the installing of the new seismic equipment, received as help by Romanian seismology, found the worst solution and ordered to settle the Romanian NDC in one former meat storage facility, totally improper old building, that in short time was in evidence as lethal for most seismic equipment.

Finally, in September 1980 the installing work started, after many hesitations and discussions. Until June 1982, the first Romanian real time Seismic network, telemetred by radio links, having 18 stations with two channels gain and very good quality short period seismometers S-13 (the some type that Apollo mission installed on the Moon) was installed to full cover the Romanian territory and special Vrancea area (Fig. 5). In addition the SMA-1 Strong motion network Kinemetrics accelerometers, using industrial Kodak films, was installed to monitor the strong and moderate Vrancea earthquakes.

Unfortunately, because of official politic requirements to reduce the fuel consumption in Romania and cutting the budget for the imported spare parts, in joint with an very unproductive procedure for field work vehicles access, promoted by the central institutions that ruled Centre for Earth Physics and Seismology at that times, it was practically impossible to maintain this new and very useful seismic networks. Starting from June 1985 until December 1989 the Romanian Seismic Telemetred Network closed 9 (from 18) seismic stations situated at more than 200 km far from Bucharest and the majority of SMA-1strong motion accelerographs was out of work because of the import cutting for Kodak films and internal Cadmium-Nickel batteries.

In spite of the technical and political problems from ’80, the operations of these seismic networks generated a productive period for Romanian seismologists and insured the first Romanian digital seismic database. It was also a good study opportunity for many young researchers in this field of activity that shortly after the opening of the Romanian society towards the World from 1990, established direct connections with the western seismologist community and started to run in different projects.

3. NIEP AGE AND NEW OPORTUNITIES

In 2004, February 24, the Centre for Earth Physics and Seismology, that hosted the research activities related to earthquakes in Romania, become, finally, an independent entity as The National Institute for Earth Physics (NIEP). This new institution was additionally renamed in October 26, 2006 as National Institute of Research and Development for Earth Physics (INCDFP), coordinated by the Romanian Ministry for Education and Research. As main task, NIEP carries out the seismic survey of Romania and operates the national seismic network. It has a wide background in earth sciences research, with focus on seismic source and seismotectonics, seismic hazard assessment, site effects and microzonation, lithosphere structure and dynamics, earthquake prediction, assessment and mitigation of seismic risk. The result of this new reorganization was very benefic for seismic monitoring in Romania. A lot of collaborations, with very important institutions around of the world, very soon started.

Since 1994, in cooperation with the German government, one of NIEP seismic station (Muntele Roşu) was provided with high performance seismological instruments and became part of the GEOFON network. NIEP data center start to use an automated and networked seismological system for the on-line digital acquisition and processing of the seismic data, providing rapid earthquake location and magnitude determination (Oncescu *et al.*, 1996). The results are rapidly distributed, via Internet, to several seismological services around the world, including the European-Mediterranean Seismological Centre, to be used in the association/ confirmation procedures and for contributing to unified seismic bulletins.

In 1995–1997 a new strong motion network using Kinemetrics K2-digital accelorographs has been installed in Romania, in the framework of the Romanian-German cooperation, within the project "Strong Earthquakes: A Challenge for Geosciences and Civil Engineering" of the University of Karlsruhe, Germany (Bonjer *et al.*, 2000). All these equipments, having 24 bits dynamic range analog/digital convertors, synchronized by GPS time receivers and saving of the seismic data on the flash card memory, were centered around the Vrancea seismic zone and covering an area with a diameter of up to 500 km.

Romania has more than 25 years of experience in global seismological monitoring in support of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). It is participating to the international verification activities with the seismic station Muntele Rosu, which was included in the auxiliary seismic network of the International Monitoring System, and with the operation of the Romania's National Data Centre (NDC). In order to ensure Romania's technical contribution to CTBTO at the operational standards required by the Treaty, since 1999 an important upgrade has been under development both at the seismic station Muntele Roşu and at the NDC Bucharest, involving technical cooperation with the Government of Japan and technical assistance from the CTBTO. In the fall of 2001 a new seismic monitoring system was installed and is now fully operational, by recording continuous earth motion data at Muntele Rosu site and transmitting these data in real-time to the facilities in Bucharest in the framework of the Japan International Cooperation Agency project "Technical Cooperation for Seismic Monitoring System in Romania". Also, during 2001–2002, the CTBT Organization had supported the site preparation works at the seismic station Muntele Roşu and supplied equipment for establishing reliable data communications links between the seismic station, the NDC Bucharest and the International Data Centre from Vienna (Rizescu *et al.*, 2002).

3.1. BUCOVINA SEISMIC ARRAY

A new age in the Romanian seismic monitoring activity started in 2002 when a very professional seismic monitoring station, the Bucovina Seismic Array (BURAR), has been established in the northern part of Romania, in a joint effort of the Air Force Technical Applications Center, USA, and the NIEP. BURAR consists of 10 seismic stations located in boreholes and distributed on a 5 km × 5 km area (see Fig. 6).

Nine (9) stations are equipped with short-period (SP) vertical sensors (GS-21) and one station is equipped with broad-band (BB) three component sensor (KS 54000). The broad-band station is located in the same site with the element number 8.

Geophysical and geological studies determined the best site for installing the seismic array near Benia Village, in Suceava County. The geographical position of the Bucovina Seismic Array (BURAR) is: 47.6148N latitude, 25.2168E longitude and 1150 m altitude. Site geology consists of massive pre-Cambrian and lower paleozoic epimetamorphic schists of green schist grade; in some areas limestone overlies the schists. All borehole locations are in the crystalline schist. Noise survey carried out for the site mentioned above showed a low noise level of site: the mean Power Spectral Density (PSD) values at 1 Hz are – 8.6 dB relative to 1 nm^2/Hz and – 38.4 dB at 6 Hz (see Fig. 7). The noise spectra obtained for this site were the lowest obtained for any area surveyed in Romania. Noted that 8 sites were investigated for noise survey.

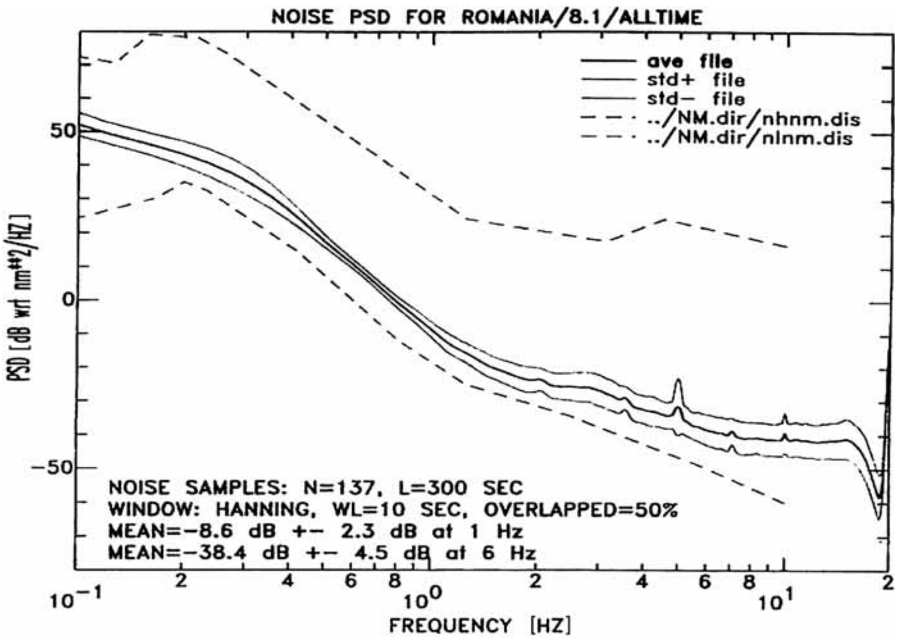

Fig. 7 – Noise power spectral density for Bucovina Array.

Starting from July 24, 2002, the new seismic monitoring system BURAR become fully operational by continuous recording and transmitting data in real-time, via satellite, to the National Data Center of Romania (RNDC) in Bucharest and National Data Center of USA (US NDC), in Florida (Grigore *et al.*, 2004).

This local seismic network has a very good detection capability and using the data processing specific Array techniques (beam forming and f-k analysis) insure the monitoring for all the seismic events around of the world. As example, BURAR Array recorded on 9 October 2006 signals from the reported underground nuclear test in North Korea (Fig. 8). The seismic waves arrived in BURAR area at 01:46:10 after about 6 500 Km traveling along the Earth, in 10 minutes and 43 seconds time interval (Fig. 9).

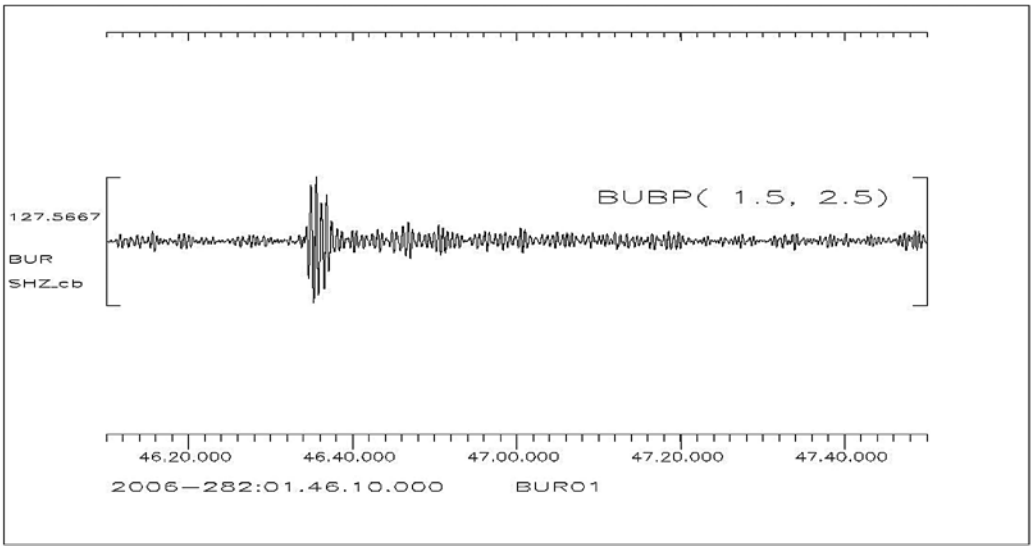

Fig. 9 – BURAR Array recording of the nuclear explosion in North Korea at October 9, 2006, 01:46:10 GMT (Origin time 01:35:27 GMT).

Presently, a complex group of high dynamic range seismic networks, installed around the country and operated by different institutions, performs the seismic monitoring in Romania for different scientific and economic results. NIEP insures the real time seismic monitoring by operating the National Seismic Network (Fig. 10), that includes the following:

– a real-time seismic network consisting of 14 short-period analog stations (*orange triangle*), 10 located in the Eastern and Southern Carpathians and telemetered by radio links to Bucharest, 3 stations sited in the Western part of Romania and telemetered to a regional recording center Timisoara, one in Southern Transilvania telemetred to Sibiu local center.

– a real-time digital seismic network consisting of 20 station having 24 bits digitizer connected, six channels (ch.1 to 3 for weak motion velocity broad band sensors and ch. 4-6 for strong motion accelerometers) connected to Bucharest NDC by satellite links or by internet (*red stars*).

– a free-field "of line" digital strong motion network consisting of 36 K2 seismic stations having 24 bits dynamic range analog/digital converters, synchronized by GPS time receivers and saving of the seismic data on the flash card memory (*yellow square*).

– BURAR- Bucovina Array consists of 10 digital seismic stations located in boreholes and distributed on a 5 km × 5 km area.

– Vrancioaia–Plostina Array consists of 4 digital seismic stations for seismic early warning purpose.

These seismic networks are permanently under upgrading process. Recently, NIEP set up in Magurele, Ilfov county, a new headquarter building (Fig. 11 – left) having a backup power system and redundant communication facilities. The seismic data from all the stations are concentrated by redundant communications links in Romanian NDC (Fig.11 – right), for processing and analysis purpose using dedicated software.

At present, a new earthquake database for Romania is being constructed, comprising complete earthquake information and being up-to-date, user-friendly and rapidly accessible. The main component of the database is the catalog of earthquakes occurred in Romania since 984 up to present, including information related to locations and other source parameters, as well as links to waveforms of strong earthquakes (Oncescu *et al.*, 1999). Seismicity analysis is continuously performed implying updating of the earthquake catalogue, spatial-temporal-magnitude patterns in different seismic regions of Romania, earthquake sequences. Interpretation and reconsidering of historical data constitutes an important issue for the seismic hazard investigation.

3.2. EARLY WARNING SYSTEM

Step by step, seismic monitoring in Romania gets a high level of activity. As result of this, many applications were set up. For example, a group of civil engineers and seismologists from the National Institute of Earth Physics (NIEP) in Romania and Karlsruhe University in Germany accomplished an earthquake Early Warning System (EWS) for the capital city of Bucharest and for industrial facilities around Vrancea area (Marmureanu *et al.*, 2006).

The Romanian capital Bucharest faces a significant earthquake hazard with a 50% chance for an event in excess of 7.6 moment magnitude every 50 years. Within the last 70 years Romania experienced 4 strong Vrancea earthquakes:

- Nov. 10, 1940 (M_w =7.7, 160 km deep);
- March 4, 1977 (M_w =7.5, 100 km deep);
- Aug. 30, 1986 (M_w =7.2, 140 km deep);
- May 30, 1990 (M_w =6.9, 80 km deep).

The 1977 event had catastrophic character with 35 high-risk buildings collapsed and 1500 casualties, the majority of them in Bucharest.

The epicenters of the instrumentally well-located intermediate depth seismicity are confined to a region of 30×70 km with an average epicentral distance to Bucharest of about 130 km. This geometric relationship between hypocenters being confined to a small source volume and at a fixed distance to the capital allows the design of a EWS with a warning time of about 25 seconds for all potential intermediate deep earthquakes. Peculiarities of the Romanian intermediate depth seismicity, such as the stationary epicenters and the stability of radiation patterns, and a line-of-sight connection between the epicentral area and the capital allow designing a simple and robust EWS (Fig. 12 a, b).

A Romanian EWS would thus be similar to the Mexican case, where the site of strong earthquakes is constrained to the plate boundary at significant distance from Mexico City. For both sites a fairly constant warning time can be made available, although Bucharest has only one third of the time available to Mexico City.

EWS uses the time interval (that is about 25 seconds for Bucharest) between the moment of the seismic waves detection at the surface in the epicenter (Vrancea) and the moment of arrival in the protected sites. This time interval depends on the depths and propagation conditions of the earthquake (Fig. 13).

EWS works in the following steps:

A. detection of the P waves and first arrivals analysis (power spectra, fast Fourier analysis and coincidence on more than one accelerometer);

B. alarm generation;

C. distribution of the alarm to the users (including also SMS and email).

For the detection of the P waves in epicenter, the triaxial strong motion accelerometers are monitoring the ground motion in two different locations situated in Vrancea. The distance between these two measuring points is about 8 km. The first site is situated at Vrancioaia Seismic Observatory (VRI) and use a triaxial accelerometer (EpiSensor) installed in a vault. In the second location, at Plostina site (PLOR), there are installed two accelerometers: one in a 50 m depth borehole and one on the surface on a vault (Fig. 14 – left). These three strong motion sensors work as a small seismic network. The goal of this configuration is to reduce the false alarms generated by any accidental high noise (sonic bangs, explosions or dropping of heavy objects near accelerometers).

The data provided by accelerometers from both locations is stored locally. The data stream is sent to Vrancioaia Observatory, where a dedicated software performs the real time analysis. Fig. 14 – right shows the typical result of the early warning software analysis.

In the present the EWS is in the testing phase. A nuclear installation from “Horia Hulubei” National Institute of Physics and Nuclear Engineering (http://www.nipne.ro/) use EWS at the moment (Fig. 15) in order to remove the nuclear source in a safe position before arrival of dangerous waves from Vrancea area[Ionescu *et al.*, 2007]. In the near future, NIEP will insure the EWS at the users as: nuclear facility, chemical factories, railway companies, etc, for shutdown purpose.

EWS can be interpreted narrowly as a technological instrument for detecting and forecasting impending hazard events and for issuing alerts. The Romanian EWS is one of the 20 Nominees for **THE EUROPEAN IST PRIZE** in **2005** (http://www.ist-prize.org)

3.3. INFRASOUND MONITORING

The experience demonstrated that infrasound monitoring is an important complementary activity of seismic monitoring. The infrasound are sounds of low frequency, situated under the human audible spectra (16–17 Hz) and go down to 0.001 Hz, covering practically the field used by the seismographers for the monitoring of the seismic movements. Unlike the seismic waves, which are propagating through the ground, the infrasonics are propagated through the atmosphere, up to very large distances and they avoid obstacles. As an example, the eruption of Krakatoa volcano in 1883 generated infrasonic waves which have surrounded the terrestrial globe several times (seven times according to the observations), being detected by the barometers from the entire world. The volcanic eruptions, the earthquakes, the massive earth slides, the avalanches, the waterfalls, the tsunami waves, the floods, the extreme meteo phenomena (violent storms, hurricanes), the meteorites penetrated in the terrestrial atmosphere, etc., produce noise of low frequency with a predominant spectral structure in the infrasound range. At the same time, there are also a multitude of technological sources which generate infrasound in the terrestrial atmosphere (planes, turbines, equipments with Diesel engines, etc.). The acoustic shocks produced by the fire weapons and by the chemical or nuclear explosions, which are most of the time associated with the local, regional and global crisis situations, are among the strongest sources of infrasound.

The researches in the infrasound field have developed rapidly, especially due to the military applications, but also to the necessities of global monitoring. Unfortunately, in Romania the researches in this field have lagged behind. The preoccupations and the results in this field exist first of all at NIEP, which through the seismic network detects the sonic bangs afferent to some explosions or to other extreme events. It must be stated that the infrasound are not detected in this case by specialized acoustic sensors, but indirectly, due to the local seismic effect induced by the acoustic waves in the seismic sensors. A relevant example in this sense was the registration by several seismic stations of the explosion signal of a truck with chemical fertilizer produced near Mihailesti, Buzau county (N 44 54.796; E 26 41.256) in the morning (03:47:33 GMT) of May 24, 2004. The seismic station from national network detected and localized the explosion. Minutes behind seismic waves, a sonic bang of the explosion arrived and hit the seismometers producing recordable waves (Table 1; Fig. 16 – left) Using the seismic and acoustic recordings, the mechanism of the explosion was determinate by Toader Victorin, FOTON (Fig. 16 – right).

In 2006 January 26, at 03:26 30 GMT, another explosion at Craiova city (Southern of Romania) made a strong sonic bang that was received. These tow unexpected events started at NIEP the researches in the infrasound field, as complementary activity for seismic monitoring.

Table 1

Seismic and acoustic recordings at nearby seismic stations: T_s – arrival time for seismic waves; T_a – arrival time for acoustic waves; D – distance from the explosion location

Istrita (INCDFP)	T_s = 05:47:42;	T_a = 05:48:50;	D = 25.46 km
Lopatari(FOTON)	T_s = 05:47:51;	T_a = 05:50:35;	D = 62.97 km
Bucuresti (FOTON)	T_s = 05:48:07;	T_a = 05:50:38;	D = 63.86 km
Harsova (INCDFP)		T_a = 05:52:28;	D = 101.10 km
Carcaliu (INCDFP)		T_a = 05:53:18;	D = 117.45 km

4. NIEP FUTURE PLAN

The future plans for NIEP are to improve the capability for seismic and infrasound monitoring in Romania. The National Seismic Network operated by NIEP will be soon in upgrade process by installing of new additionally Seismic Broad Band stations using high dynamic range Quanterra 330 Digitizers. In joint efforts with American and European partners an infrasound monitoring research project coming up. One complex infrasound array with four short period elements (Fig. 17 – left) and four long period elements (Fig. 17 – right) will be installed in selected sites (Fig. 18).

Other specific NIEP actions (Marmureanu *et al.*, 2008) to mitigate the seismic risks given by strong deep Vrancea earthquakes should be considered for future:

1. Early warning system for industrial facilities and other installations of national interest at strong Vrancea earthquakes (Government Law nr. 372/2004–Objective nr. **8**);

2. Seismic microzonation of large populated cities as part of mitigation of the impact of strong earthquakes to large populated areas (Gov. Law nr. 372/2004–Objective nr. **10b**).

3. New seismic hazard map of Romania (Government Law nr. 372/2004–Objective nr. **11b**);

4. Seismic tomography of dams for avoiding catastrophes;

5. Seismic Map of Earthquake Real Time Developing-Shake/Quake Map (Government Law nr. 372/2004–Objective nr. **17b**).

5. CONCLUSIONS

Seismic monitoring in Romania can be considerate an uninterrupted scientific activity (except for short periods), having more than 100 years of tradition. Presently a complex group of high dynamic range seismic networks installed around the country performs the seismic monitoring in Romania for different scientific and economic results. NIEP insures the real time seismic monitoring by operating the National Romanian Seismic Network. The huge database from NIEP includes historical earthquakes from 984 until the first instrumental measurements in 1894 and instrumental data from seismographs updated in the last period by high dynamic range seismic digital data. The future plan is to upgrade the National Seismic Network by installing new digital broadband stations and to develop infrasound measurements as complementary activity for seismic monitoring in Romania.

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