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SEISMIC WARNING TIME FOR VRANCEA EARTHQUAKES IN THREE LARGE DAMS SITES SITUATED IN THE EASTERN PART OF ROMANIA

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Abstract. The seismic early warning system (SEWS) in Romania uses a mixed regional approach, based on the national seismic network and local sensors to obtain a fast location for recorded events and estimate the actual earthquake magnitude. In order to assess the performance of the alarm system for the 3 dams studied in this paper: Poiana Uzului – Bacău County, Râpa Albastra – Vaslui County and Izvorul Muntelui – Neamț County, there have been made offline simulations on seismic recordings for estimating the actual warning time in the three locations mentioned above. There have been chosen four representative earthquakes $M_L > 5.0$, occurred in the last years in Vrancea seismic zone, for which there are enough records, one crustal from 23rd of September 2017 ($M_L = 5.7$) and three subcrustal from: 22nd November 2016 ($M_L = 5.8$), 27th December 2016 ($M_L = 5.8$) and 2nd February 2017 ($M_L = 5.0$).

Key words: earthquakes, early warning, dams.

1. INTRODUCTION

A Seismic Early Warning System (SEWS) provides advance announcement of earthquake occurrence (time and magnitude). The early warnings are based on prompt estimation of the quake's location and magnitude using fast seismic analysis of waveforms recorded by the seismometers near the epicenter.

The warning (alarm) time is the time difference between the issuing earthquake alert moment (T1) and the dangerous transversal seismic wave S arrival moment at the interest point (TS). The moment of the earthquake occurrence (To) is before T1. It is important to remember that warning time, as defined above, is very short, and may be of seconds or tens of seconds, depending on the location of the target alarmed [1, 2]. Therefore, areas near the epicenter can not receive alerts before the arrival of the seismic wave. People or institution inside the epicentral area can only receive information on the current event. It should also be noted that the precision of the quick information about the size and location of the earthquake is limited due to the estimates short time and the small number of seismic stations located in the epicentral area that might offer helpful data.

At epicentral distances larger than 60 km, the alarm is given before the arrival of seismic waves. Scientists hope to be able to give in the near future a quick estimate of the macroseismic intensity and the expected arrival time of the seismic motion in different vital sites.

The methods for distributing alerts vary according to the legislation of each country, the level of application development, the level of education of the population or the type of objective to be alerted. In Japan, alerting is done at country level by distributing alerts through the media (radio and TV).

The Seismic Early Warning System is aimed to allow countermeasures such as: to promptly slow down trains, to prevent traffic accidents, to control elevators to avoid danger, to secure safety to workers performing hazardous tasks, to suspend work in progress to avoid mistakes, to shut down the gas distribution, to enable people to quickly protect themselves in various environments such as factories, offices, supermarkets or shops, schools or houses and so on [3].

2. THE SEISMIC EARLY WARNING SYSTEM IN ROMANIA

The seismic early warning system (SEWS) in Romania (one of the few operating systems from the world) uses a mixed regional approach, based on the national seismic network and local sensors to obtain a fast location for recorded events and estimate the actual earthquake magnitude.

In recent years, researchers in Romania have been concerned with creating SEWS that would have great potential in reducing and managing seismic risk. In Romania, such a system is operational from 2013 onwards. SEWS provides real-time information and alerts to the Romanian post-crisis intervention authorities, the emergency centers of the various ministries with responsabilities in the field, and critical nuclear infrastructures (research reactors, nuclear reactors and other related facilities).

The recent improvement of the national seismic network (Fig. 1) allows the recording of strong earthquakes at low epicentral distances (less than 20 km). This factor increases the effective alarm time for strong earthquakes.

The algorithm for estimating alert parameters uses a methodology to estimate the location of earthquakes and their magnitude from the first seconds of acceleration data. In order to obtain a location with minimal errors, the alarm system uses a minimum of 6 stations (where the first P-wave arrival was recorded) to correctly estimate the depth of the earthquakes. The previous studies show that this is the optimal number of arrivals that gives an early warning with low error [4].

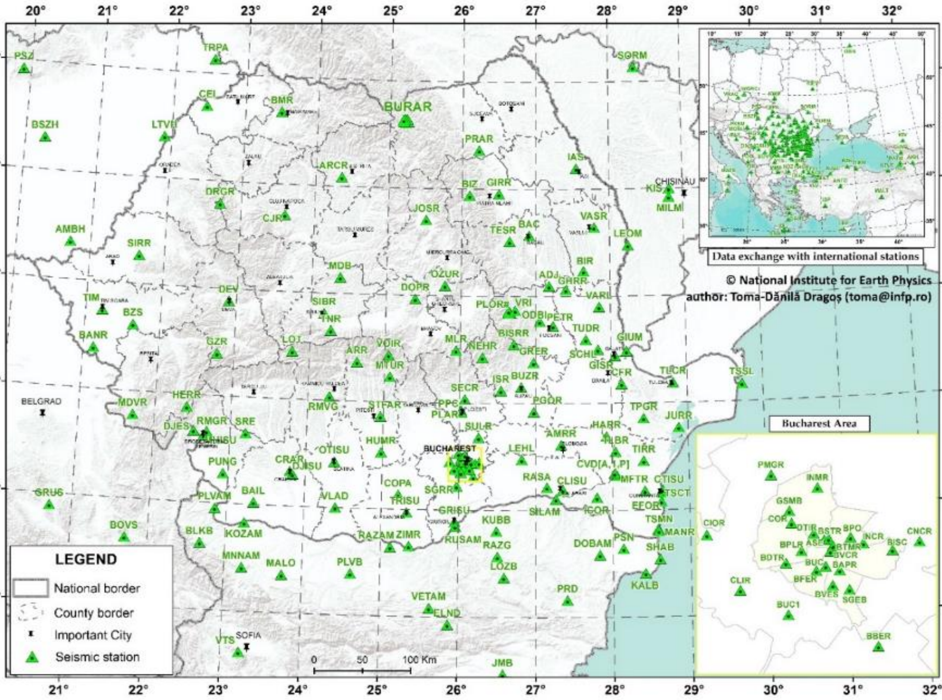


Fig. 1 – The Romanian national seismic network (February 2016), after [5] and [6].

The territory of Romania and the neighboring countries Moldova, Ukraine and Bulgaria are regularly affected by the intermediate earthquakes produced in the Vrancea seismic area, earthquakes with depths ranging from 60 km to 200 km. Geometry of seismic stations located on the territory of Romania allows the theoretical detection of 6 P waves in less than 10 seconds for an earthquake produced at a depth of 25 km and about 22 seconds for an earthquake produced at a depth of 125 km [7].

3. PERFORMANCE OF THE ROMANIAN SEISMIC EARLY WARNING SYSTEM – APPLICATION ON LARGE DAMS FROM THE EASTERN PART OF ROMANIA

In order to assess the performance of the alarm system, there have been made offline simulations on seismic recordings for estimating the actual warning time in locations of three dams situated in the Eastern Part of Romania (see Table 1, Fig. 2) [8]. For this objective, there have been chosen four representative earthquakes with $M_L > 5.0$, occurred in the last years in Vrancea seismic zone, for which there are enough records, one crustal and three subcrustal (see Table 2, Fig. 2).

Table 1

Characteristics of the studied dams from the Eastern part of Romania

No	Dam	Long	Lat	River	County	Year	*H* (m)	*L* (m)	*V* (hmc)
1	Rapa Albastra	27.6831	46.2690	Simila	Vaslui	1975	18	810	24.8
2	Poiana Uzului	26.3923	46.3359	Uz	Bacau	1973	80	500	88
3	Izvorul Muntelui	26.1030	46.9380	Bistrita	Neamt	1961	127	430	1230

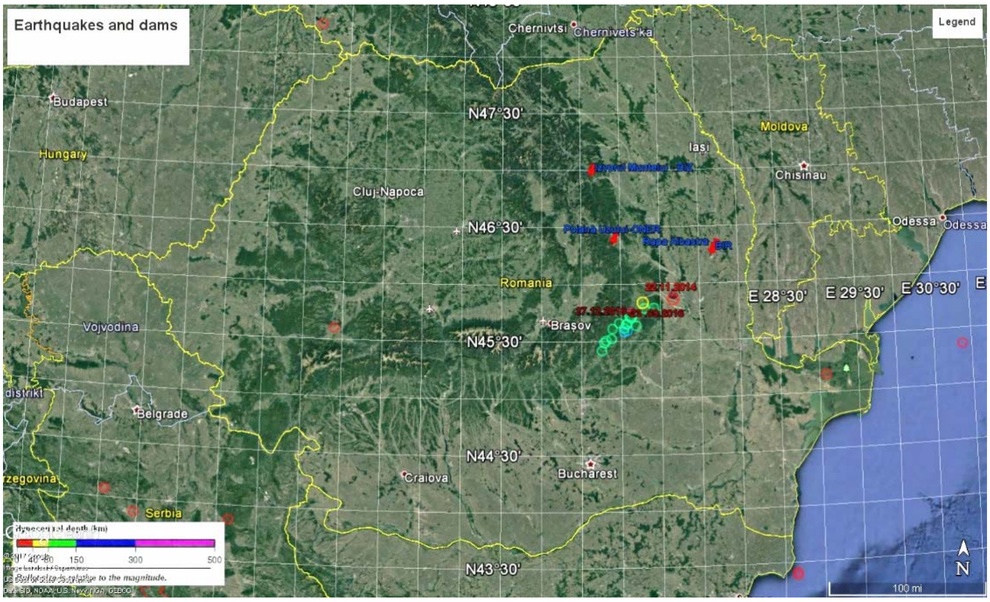


Fig. 2 – Recent seismicity and location of the studied dams [9, 10].

Table 2

Recent seismicity (M_L > 5.0) from Vrancea zone (after Romplus* and [11, 12])

No	Date	Time	Latitude	Longitude	Depth	M_L	M_w	I_0
Eq 1	2014/11/22	19:14:17.11	45.8683	27.1517	40.9	5.7	5.4	VI
Eq 2	2016/09/23	23:11:20.06	45.7148	26.6181	92.0	5.8	5.5	VI
Eq 3	2016/12/27	23:20:55.94	45.7139	26.5987	96.9	5.8	5.6	VI
Eq 4	2017/02/08	15:08:20.89	45.4874	26.2849	123.2	5.0	4.8	IV

Using the real recordings, the alert system has correctly generated the earthquakes parameters for all studied events from Table 2. In Figs. 3a–d are presented the time evolution of the number of seismic stations participating to earthquake location, the location and magnitude errors for earthquakes from Table 2.

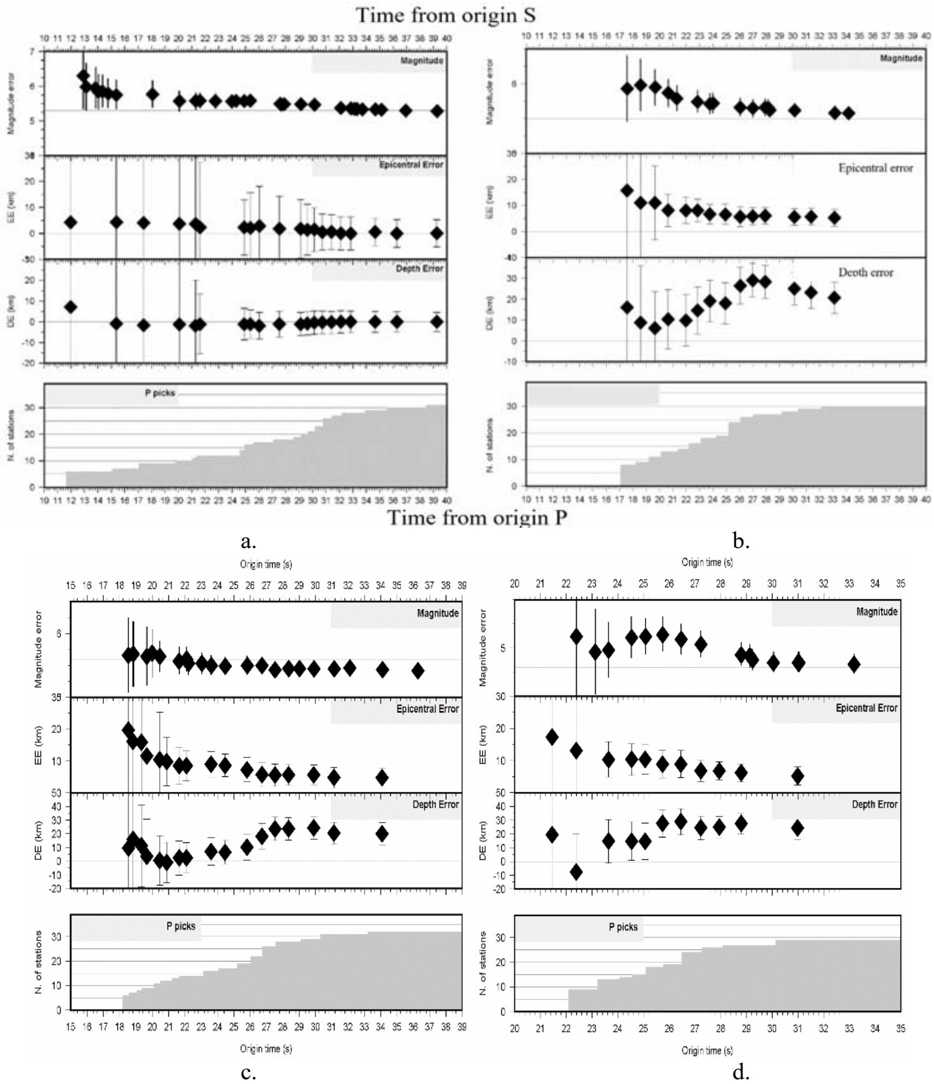
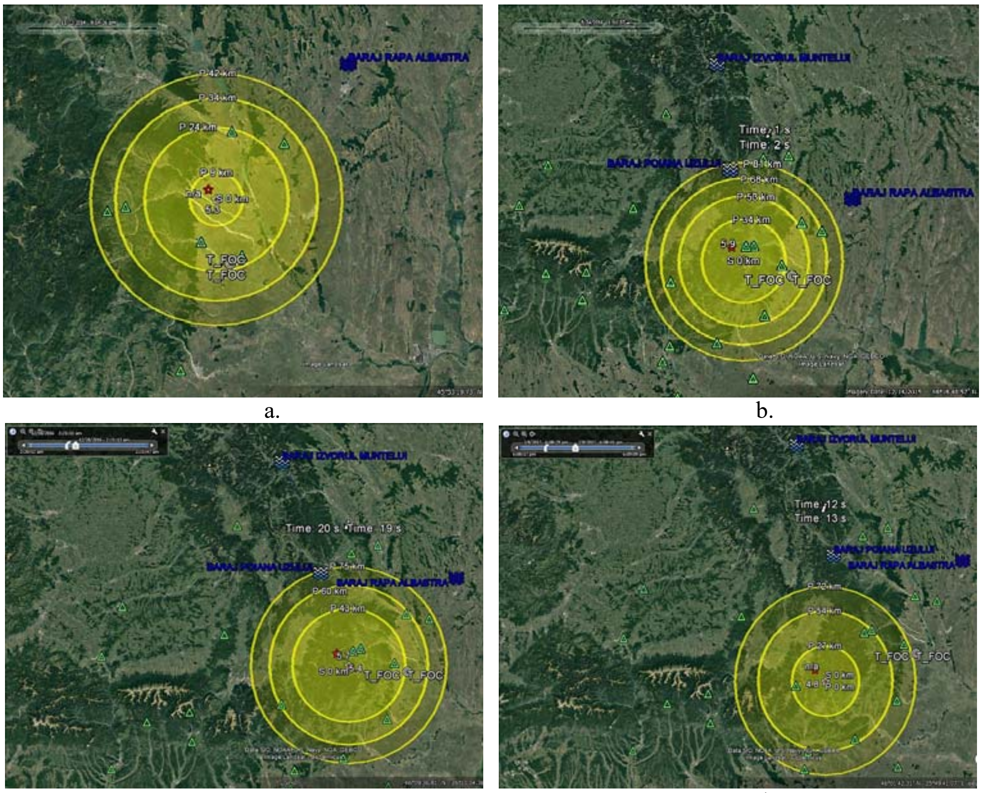


Fig. 3 – The time evolution of the number of seismic stations participating to earthquake location, the location and magnitude errors for earthquakes:
a) Eq 1; b) Eq 2; c) Eq 3; d) Eq 4 (see Table 2).

In Fig. 4a–d are presented the moments when was issued the first magnitude estimation and the earthquake location by the alert system for the four studied earthquakes. From Fig. 4b one can see that the P wave at Poiana Uzului Dam arrived before the alert. In Fig. 5a–d are presented the moments when the S wave arrives at Izvorul Muntelui Dam for all studied earthquakes. Izvorul Muntelui Dam was chosen because the epicentral distance is the largest and shows best the benefits of an early warning system.

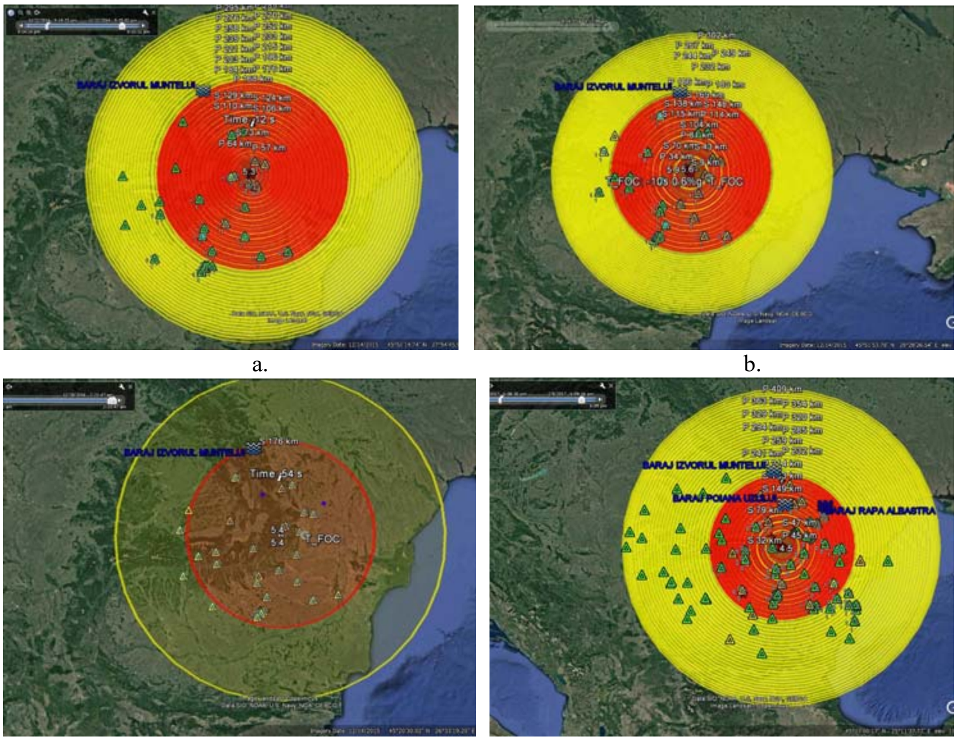


a. b.

c. d.

Fig. 4 – The moment when was issued the first magnitude estimation and the earthquake location by the alert system for: a) Eq 1-19:14:27.11; b) Eq 2-23:11:37; c) Eq 3-23:21:14; d) Eq 4-15:08:42.40.

For Eq 1 the S wave arrives at Izvorul Muntelui Dam at 19:15:02, giving an alert time of 35 seconds between the moment when the alert was issued and the S wave arrival. Because S – P = 20 s we obtain a 15 seconds period between the moment when the alert was issued and the arrival of the first wave (see Table 3). For Eq 2 the S wave arrives at 23:12:09, giving an alert time of 31 seconds between the moment when the alert was issued and the S wave arrival. Because S – P = 23 s we obtain a 9 seconds period between the moment when the alert was issued and the arrival of the first wave (see Table 3). For Eq 3 the S wave arrives at 23:21:47, giving an alert time of 33 seconds between the moment when the alert was issued and the S wave arrival. Because S – P = 25 s we obtain a 8 seconds period between the moment when the alert was issued and the arrival of the first wave (see Table 3). For Eq 4 the S wave arrives at 15:09:16, giving an alert time of 34 seconds between the moment when the alert was issued and the S wave arrival. Because S – P = 25 s we obtain a 9 seconds period between the moment when the alert was issued and the arrival of the first wave (see Table 3).



a. b.

c. d.

Fig. 5– P wave (yellow circles) and S wave (red circles) propagation and arrival at Izvorul Muntelui Dam for a) Eq 1; b) Eq 2; c) Eq 3; d) Eq 4.

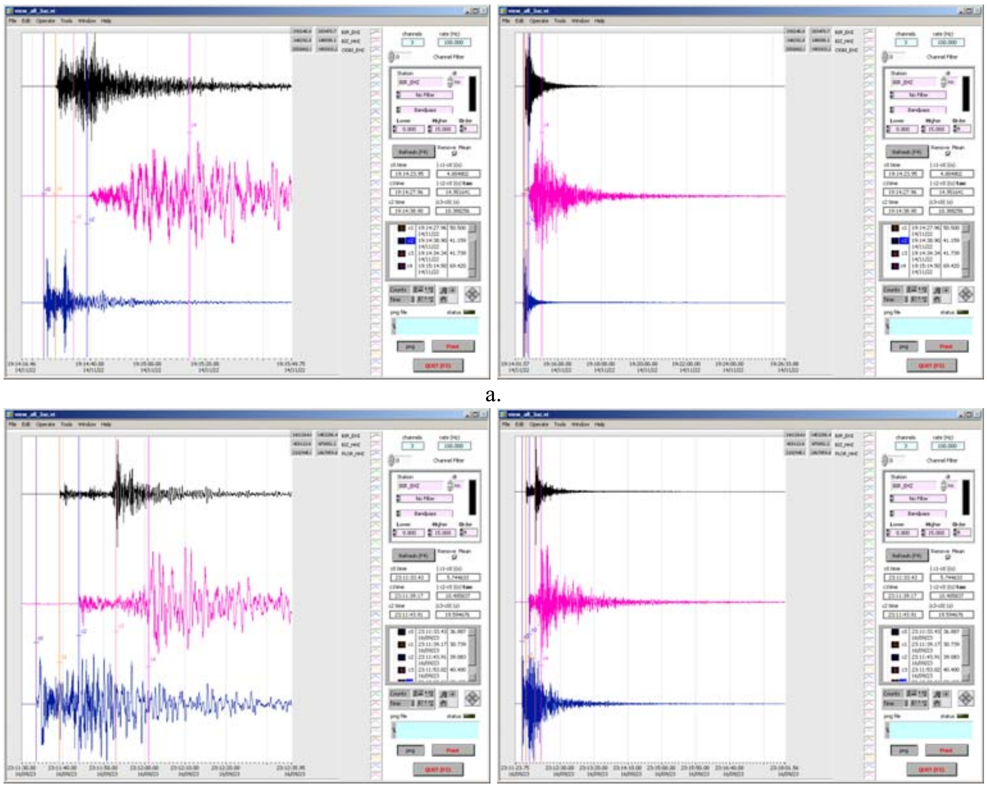
Table 3

Alert times for Rapa Albastra (1), Poiana Uzului (2) and Izvorul Muntelui (3). Dams for the studied earthquakes: Eq 1–Nov. 2014, Eq 2–Sept. 2016, Eq 3–Dec. 2016 and Eq 4–Feb. 2017

Eq no.	**Dam no.**	**Dam coordinates**		**Eq coordinates**		***D* epic (km)**	***D* hypo (km)**	**Eq mom**	**Alert mom.**	**P arrival min:s**	**S arrival min:s**	**S-P**	**Alert time (s)**
		Lat	**Long**	**Lat**	**Long**								
Eq 1	1	46.26	27.68	45.868	27.151	60.8	76.9	19:14:17.11	19:14:27	14:29	14:40	11	13
	2	46.34	26.41			71.9	86.0			14:31	14:44	13	17
	3	46.93	26.10			137.7	145.6			14:42	15:02	20	35
Eq 2	1	46.26	27.68	45.714	26.618	103.0	137.8	23:11:20.06	23:11:37	11:39	11:56	17	19
	2	46.34	26.41			72.5	116.8			**11:37**	11:53	16	16
	3	46.93	26.10			142.2	169.1			11:46	12:09	23	32
Eq 3	1	46.26	27.68	45.713	26.598	103.3	141.6	23:20:55.94	23:21:14	21:16	21:34	18	20
	2	46.34	26.41			71.1	120.2			**21:14**	21:29	15	15
	3	46.93	26.10			140.5	170.7			21:22	21:47	25	33
Eq 4	1	46.26	27.68	45.487	26.285	138.0	184.9	15:08:20.89	15:08:42	08:47	09:10	23	28
	2	46.34	26.41			95.3	155.6			08:43	09:03	20	21
	3	46.93	26.10			161.0	202.6			08:51	09:16	25	34

In Table 3 are presented the alert times and seismic P and S waves arrivals at all studied dams for earthquakes Eq 1 to Eq 4, together with information about earthquake location, epicentral and hypocentral distances, and timing like: occurrence moment, waves arrivals and alert moment.

For a better understanding of the meaning of alert time, the recorded waveforms at the seismic stations situated in the close vicinity of the dams are represented in Fig. 6, for Eq 1 and 2, together with the stations that have recorded the first arrival of the seismic wave.



a.

b.

Fig. 6 – Waveforms and arrival times for a) Eq 1 (November 2014);
b) Eq 2 (September 2016), 5.5 M_w.

The seismic stations near the dams are Barlad (BIR – with black on Fig. 6) and Izvorul Muntelui (BIZ – with magenta on Fig. 6) (see Fig. 2), and those situated in the epicentral area are Odobesti (ODBI) for the Eq 1 and Plostina (PLOR) for Eq 2 (with blue on Fig. 6). On the figures are marked the the P and S waves arrivals at the three stations, and their values can be visualized in the right panel. For Eq 1, the time difference between the first arrival at OBDI and the P wave arrival for BIZ seismic station is 10.38 s and for Eq 2 it is 19.59 s. This values differ from those presented before, because the alert system needs 6 arrivals for being able to issue an alert, containing a reliable earthquake location and magnitude.

4. CONCLUSIONS

As one can see from Table 3, for Eq 1, the alert time was 13 s for Rapa Albastra Dam (Barlad, Vaslui County), 17 s for Poiana Uzului Dam (Darmansesti, Bacau County) and 35 s for Izvorul Muntelui Dam (Bicaz, Neamt County). For Eq 2, the alert time was 19 s for Rapa Albastra Dam, 16 s for Poiana Uzului Dam and 32 s for Izvorul Muntelui Dam. For Eq 3 the alert time was 20 s for Rapa Albastra Dam, 15 s for Poiana Uzului Dam and 33 s for Izvorul Muntelui Dam. For Eq 4 the alert time was 28 s for Rapa Albastra Dam, 21 s for Poiana Uzului Dam and 34 s for Izvorul Muntelui Dam. It is obvious that the alert time is increasing with the epicentral and hypocentral distance. The largest alert time in this study was obtained for Izvorul Muntelui Dam, in the case of the crustal earthquake, Eq 1, *i.e.* 35 s, even if the epicentral/hypocentral distance was not the largest.

We specify that until the arrival of the first seismic movement (P wave), there have been only 2 s for Rapa Albastra Dam, 4 s for Poiana Uzului Dam, and 15 s for Izvorul Muntelui Dam, for Eq 1. For Eq 2 the time differences between the P wave arrival and the alert moment are as follows: 2 s for dam 1, zero seconds for dam 2 and 9 seconds for dam 3. For Eq 3 the time differences between the P wave arrival and the alert moment are as follows: 2 s for dam 1, zero seconds for dam 2 and 8 seconds for dam 3. For Eq 4 the time differences between the P wave arrival and the alert moment are as follows: 5 s for dam 1, 1 second for dam 2 and 9 seconds for dam 3. The largest time in this study, between the alert time and P wave arrival was obtained for Izvorul Muntelui Dam, in the case of Eq 1, *i.e.* 15 s.

As we can see in Table 3, in the case of Eq 2, and Eq 3 (similar earthquakes both on depth and location) for Poiana Uzului Dam, the alert arrived in the same time with the P wave, which triggered an alarm signal and led to the need to modify the Vrancea Intermediate depth Earthquake alert system for the special case of this dam and the use of recordings from less than 6 stations, even if this can lead to lower precision in localization. In the case of a very high earthquake, the 2 or 3 seconds can be vital, especially for Poiana Uzului Dam personnel, who might leave the barracks, could drop off the vertical stairs on the dam and could move away from the base of the dam and head for secure places.

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* *Romplus catalogue*, Updated 2017 by the Department of Data Acquisition of the National Institute for Earth Physics (NIEP), Bucharest, 2017.