RAPID MAGNITUDE DETERMINATION FOR VRANCEA EARLY WARNING SYSTEM

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Due to the huge amount of recorded data, an automatic procedure was developed and used to test different methods to rapidly evaluate earthquake magnitude from the first seconds of the P wave. In order to test all the algorithms involved in detection and rapid earthquake magnitude estimation, several tests were performed, in order to avoid false alarms. A special detection algorithm was developed, that is based on the classical STA/LTA algorithm and tuned for early warning purpose. A method to rapidly estimate magnitude in 4 seconds from detection of P wave in the epicenter is proposed. The method was tested on al recorded data, and the magnitude error determination is acceptable taking into account that it is computed from only 3 stations in a very short time interval.

Key words: Vrancea seismic region, warning time, P wave detector, rapid magnitude determination.

1. INTRODUCTION

Earthquake early warning systems are an approach to earthquake hazard mitigation which use the rapid availability of earthquake recorded data, determine rapidly the strength of the earthquake and issue an alarm, prior to earthquake arrival at the sensitive area that has to be protected.

The Romanian territory is exposed to high seismic risk associated to earthquakes occurring in Vrancea area. Major earthquakes occurred in this area in the last century (November 10, 1940, $M_w = 7.7$, depth 140 Km; March 4, 1977, $M_w = 7.4$, depth 95 Km; August 30, 1986, $M_w = 7.1$, depth 130 Km and May 30, 1990, $M_w = 6.9$, depth 90 Km).

An early warning system consists of several different parts: a dedicated acquisition system, algorithms to rapidly detect seismic events, algorithms that eliminate false detections and alarms and methods to estimate the earthquake magnitude and to send the warning to the users. All of these parts have to work automatically, in real time, without interruption for a long period of time.

Taking into account the warning time for Bucharest, which represents the time interval between the moment of P wave detection in Vrancea epicenter and the moment when the S wave, that carries most of the earthquake energy, arrives in Bucharest, interval around 25 seconds, (Fig. 1, [1, 4–6]), this warning system was never intended to warn population and its main target is represented by critical facilities. This is one of the few operational early warning systems in the world.

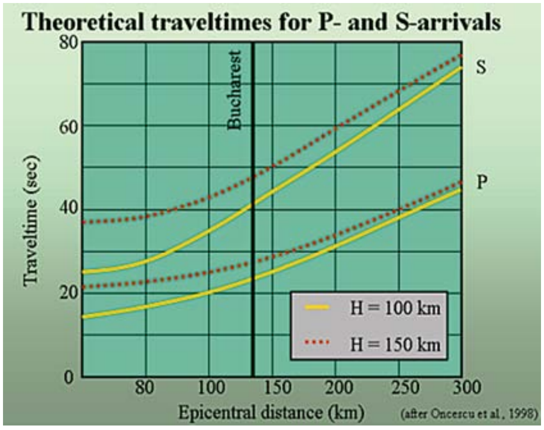

Fig. 1 – Theoretical traveltimes for P- and S-arrivals for Bucharest ([1, 4–6]).

2. METHOD AND RESULTS

Due the huge amount of recorded data, an automatic procedure was necessary to be designed in order to test different detection algorithms. A total of 2669 recorded events (over 16000 waveforms) were used in this analysis. One big problem was that these waveforms had no P wave associated to them. Also in order to convert the information from counts were necessary different calibration constants depending on different sensors. Taking into account that the events were recorded since 1996 on 3 different stations located in the epicenter area and during this period different sensors were used on each station, a set of applications were developed to make automatically necessary corrections to data.

Taking into account the seismicity of Romania (Fig. 2) and that there is no other information available prior to the detection time, the algorithms involved in the warning process (detection and magnitude estimation) need to be stable for different types of events and magnitudes. This represents the main reason why all available recorded events were used. Earthquakes location and seismic stations used are plotted in Fig. 3.

The first step in warning process consists in the detection of the earthquake. In order to rapidly detect the P wave, a modified STA/LTA detection algorithm was developed. STA/LTA stands for Short Term Averaging / Long Term Averaging (Fig. 4, [2]). In order to minimize the detection time, STA interval was chosen to be 1 second and LTA was considered 10 seconds.

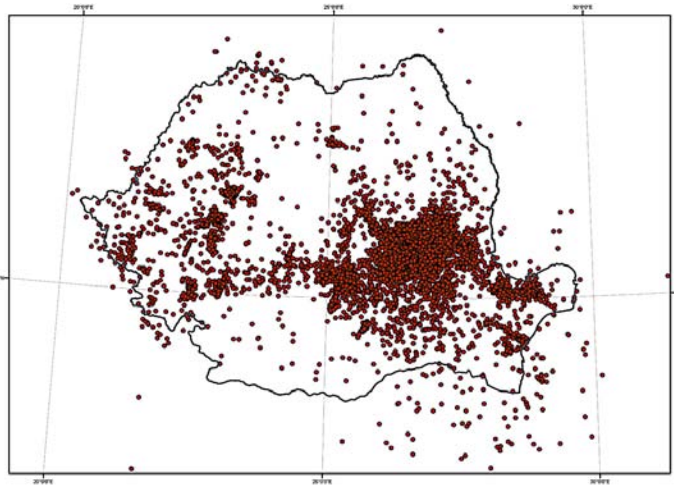

Fig. 2 – Seismicity of Romania (ROMPLUS catalogue 1996–2008).

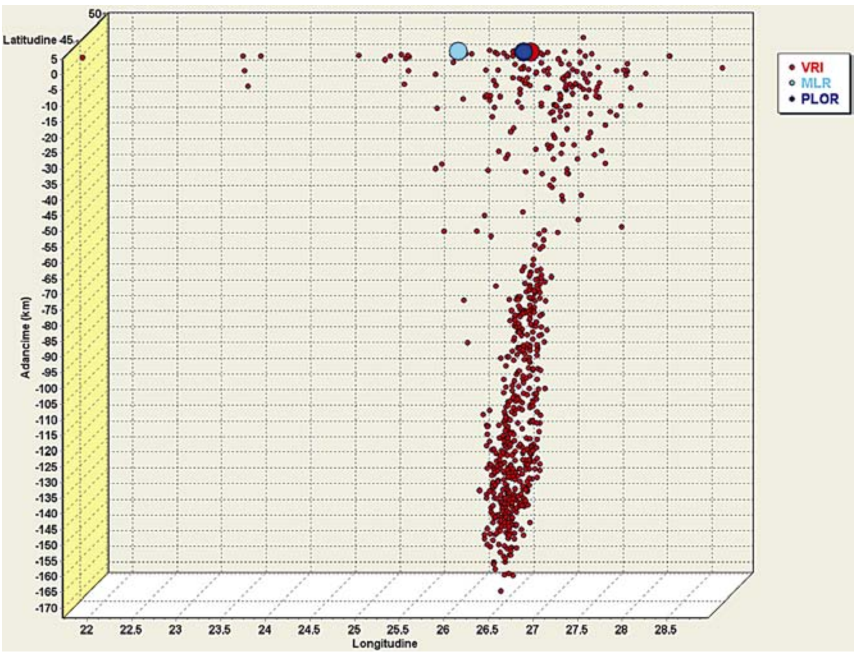

Fig. 3 – Earthquakes used in this study (all recorded events between 1996 and 2006) together with the seismic stations located in the Vrancea epicenter area: VRI – Vrâncioaia, PLOR – Ploștina and MLR – Red Mountain.

The maximum acceleration is obtained from the vertical component of the acceleration channel and is converted to cm/s^2, by using calibration constants (Fig. 5). There can be observed unusual maximum acceleration values in the

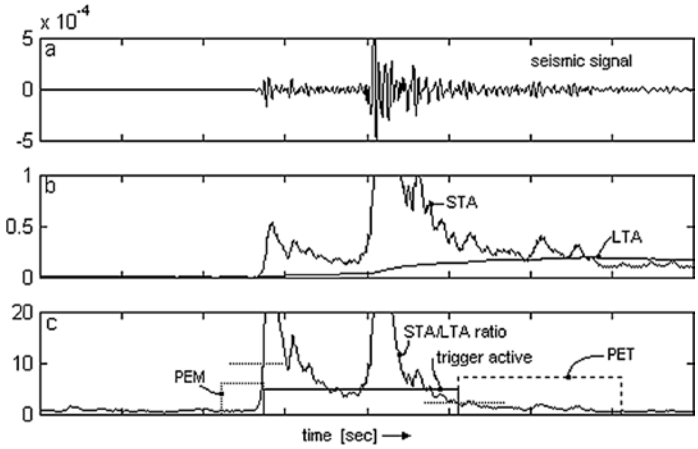

Fig. 4 – STA/LTA detection algorithm ([3], modified).

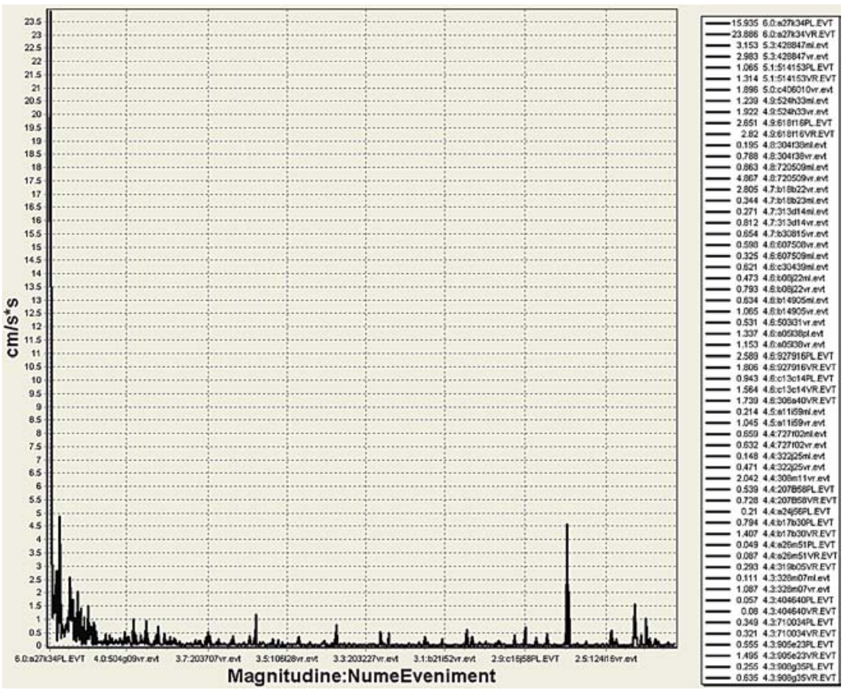

Fig. 5 – Plot of vertical acceleration (unfiltered, amplitude in cm/s^2) from the first 4 seconds of the P wave as a function of magnitude M_w on a descending scale from $M_w = 6.0$ down to $M_w = 2.0$ for all recorded events at the three considered stations.

right part of the graph, caused by shallow events with small magnitudes ($M_w = 2.7$, peak of the P wave of around 5 cm/s^2, earthquake depth 8 Km). These earthquakes can cause false alarms. Taking into account that since 1996, have been recorded around 20 events of this type, the necessity to avoid false alarms caused by them is obvious. These events were not included in any previous study due to their small magnitude, this being the first study that uses so many records. False alarms can be avoided by filtering the seismic waveforms up to 1 Hz using a Butterworth low-pass filter with 4 poles (Fig. 6).

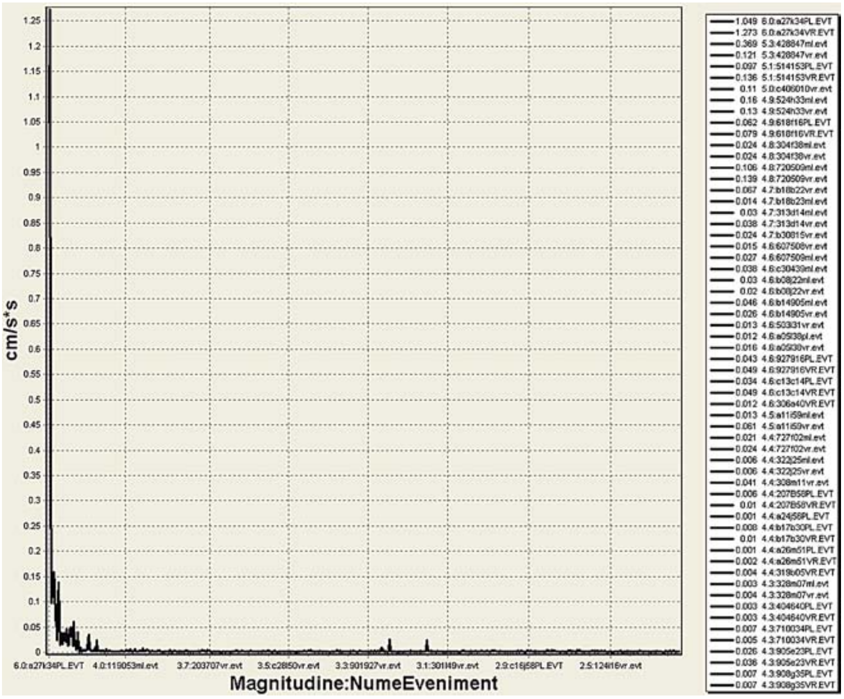

Fig. 6 – Plot of vertical acceleration (low-pass filtered 1Hz, amplitude in cm/s^2) from the first 4 seconds of the P wave as a function of magnitude M_w on a descending scale from $M_w = 6.0$ down to $M_w = 2.0$ for all recorded events at the three considered stations.

As a fit between maximum 1 Hz low-pass filtered vertical acceleration and M_w magnitude, the following relation was assumed:

$$y = A_1 e^{-\frac{x}{t_1}} + y_0 , \tag{1}$$

where $A_1 = 3.97902\text{e-}7$, $t_1 = -0.4029$, $y_0 = -9.69317\text{e-}4$. This can be used to approximate very well earthquake magnitude in the first seconds after detection (Fig. 7). The average absolute error is 0.271 magnitude degrees using all existing recorded data. This error is satisfactory, taking into account that the magnitude is computed on 4 seconds after P wave is detected in the epicenter area (Fig. 8).

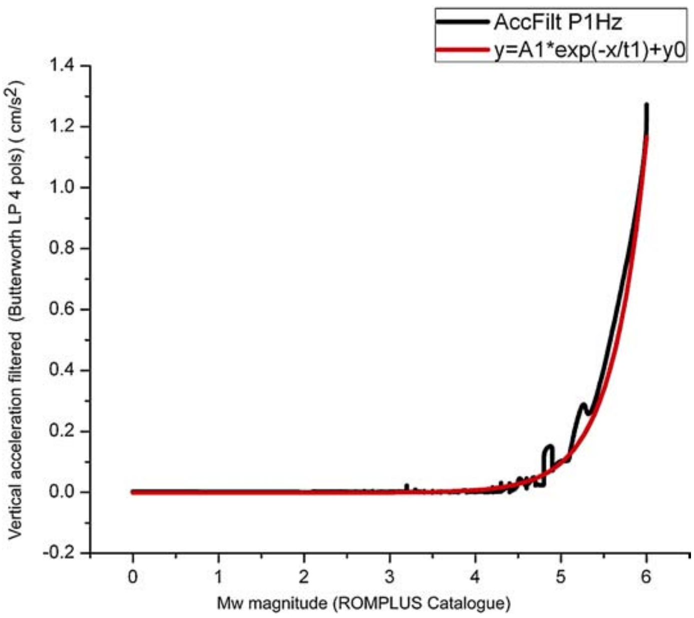

Fig. 7 – Fit between maximum 1 Hz LP filtered acceleration and M_w magnitude.

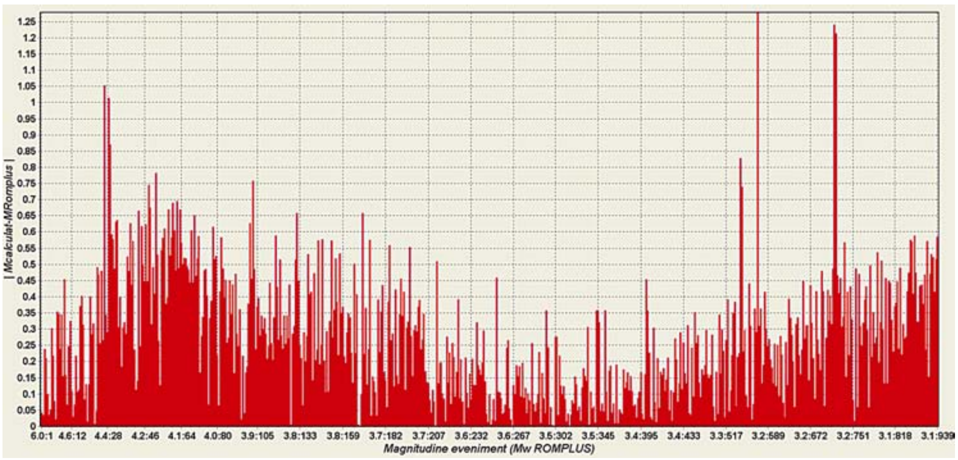

Fig. 8 – Absolute error in magnitude estimation ($|M_{computed} - M_{ROMPLUS}|$) for all recorded events at the three stations (MLR, VRI, PLOR).

4. CONCLUSIONS

The main result of this study evidences the possibility to rapidly estimate magnitude of earthquake in the first 4 seconds after detection of the P wave in the epicenter.

By filtering data, the high values of acceleration recorded during small shallow events are significantly reduced. By this, a simple and robust procedure to estimate magnitude can be developed.

The ability to rapidly estimate the earthquake magnitude combined with powerful real-time software, as parts of an early warning system, could reduce the seismic risk.

Due to the relatively small amount of warning time, this system was never intended for population, but only to critical industrial facilities.

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