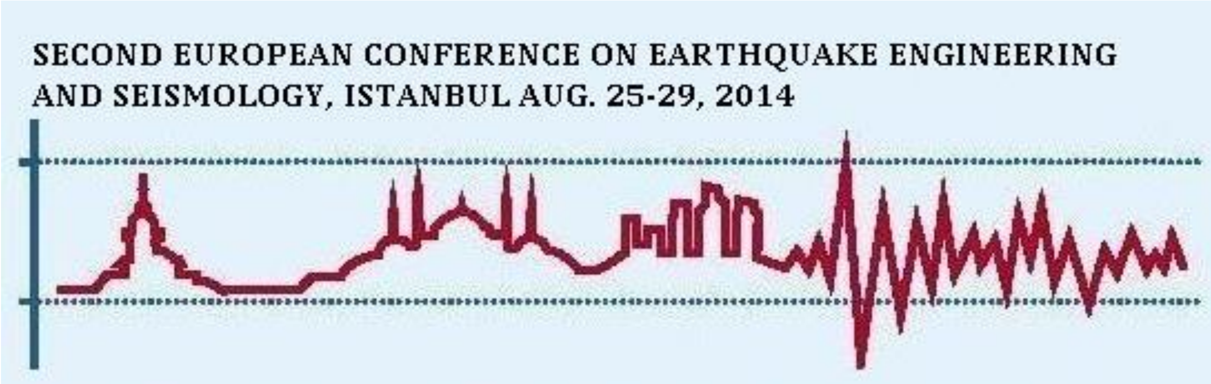

DISCRIMINATION METHODS BETWEEN MICROEARTHQUAES AND QUARRY BLASTS – A CASE STUDY IN HUNGARY

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Contamination of earthquake catalogues with artificial seismic events largely complicates the seismotectonic interpretation. It is especially true for relatively low seismicity areas, such as Hungary.

In the present study we analyze the characteristics of earthquakes and blasts of quarries occurred between 2010 and 2013 in the North Hungarian Mountains in Hungary and in the southern part of Slovakia (Fig. 1.). The natural seismic activity is significantly increased on the area at the beginning of 2013, when an M_L4.8 earthquake shocked the region of Heves, and an M_L4.2 occurred at Érsekvadkert (Gráczer et al 2012, 2013; Tóth et al. 2011, 2012, 2013). The mainshocks were followed by many aftershocks. These events were detected by the seismological station of Piszkéstető (PSZ) which also detects regularly the blasts originated from 8 different quarries.

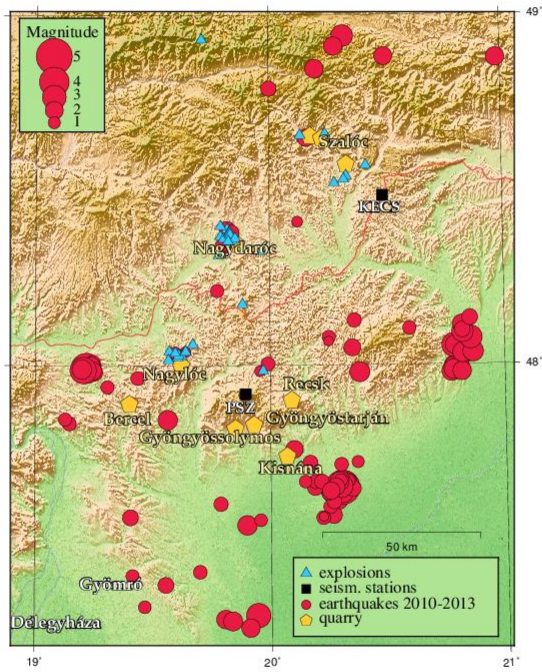

Figure 1. Epicentre map of the analyzed earthquakes and explosions (Several events used in the analysis do not have hypocenter parameters because they were detected only by the PSZ station.)

Discrimination of earthquakes and quarry blasts was very difficult, because the earthquake activity occurred in the vicinity of quarries. The problem was particularly challenging because the size of the events was usually low and the number of stations detecting them was limited. Several blasts and aftershocks were detected only by the PSZ station, so these miss the hypocenter parameters.

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Therefore discrimination based on hypocentral parameters could not be used because of the lack of coordinates and the large location errors. Studying the temporal distribution of the events, diurnal periodicity was found in both the natural and artificial events that indicates the contamination.

The goal of the study was to find the best discrimination methods and parameters. Therefore we have analysed the waveforms of the events and their Fourier amplitude spectra. Within these we examined the polarity of P wave arrivals and the amplitude ratios of different phases (Rg and high frequency P/S). Waveform similarities using cross-correlation methods were also studied, and cross-correlation matrix and dendrograms to cluster the events were determined. Furthermorespectrograms and because most of the quarry blasts were carried out by delay-fired technology, binary spectrograms were computed also. We also studied the scalloping and steepness of spectra. The parameters computed from waveforms and spectra were jointly analysed using the mathematical method of Mahalanobis distance (MD). MD is a statistical value that expresses the degree of separation and is defined as the difference between group means divided by the pooled standard deviation of the groups. As a rule of thumb, an absolute value of MD larger than 4 indicates statistically significant separation (Koch and Fäh 2002).

Because of the different focal mechanisms, waveforms and amplitudes of arriving phases of earthquakes and quarry blasts are different. The most typical parameter, which is often used for separation, is the P and S amplitude ratio. Another key parameter is the presence of Rg waves, which is typical in case of surface events. After performing some experiments with different components and band filtering, we have used the unfiltered radial component to determine the amplitude of S and the vertical one to read off the P phase. The Rg amplitudes were read off from the filtered (0,5–1.5 Hz) vertical component. We have computed the Mahalanobis distances to look for the best parameter combination for separation. It was found that the Rg/SHR ratio performed better as discrimination parameter than the Rg/P ratio. Using more parameters, the MD distances – the degree of separation – have increased. The Mahalanobis distances were the largest when the combinations of four parameters (log(Rg/P) + log(SHR/P) + log(Rg/SHR) + log(Rg)) were taken into account. In this case 62% of the blasts and 88% of the earthquakes separated clearly from the other class. Several blasts were found that were classified earlier incorrectly as earthquake.

The power spectra of blasts and earthquakes have also shown fundamental differences. The steepness of power spectra was calculated between 1-4 Hz, and the ratio of average spectral values and maximum values between 1-10 Hz. The earthquakes were richer in high frequencies and the steepness of power spectra were smaller compared to the spectra of blasts. Delay-fired technology modulates the spectra of blasts (Gitterman et al 1993); we have observed increased performance at low frequencies. Computation of binary spectra is also a useful visualization method to recognize the delay-fired explosions, because it emphasizes the long-duration modulations of spectra. These are made from the original spectra by the application of filters that replaces the spectral amplitudes with a binary code, which simply reflects the local spectral highs and lows. The modulations were present in most of the spectra of blasts, but their strength and spacing was highly variable. In contrast to the earthquakes, the modulations were observable until the end of the spectrogram. The success of separation was determined using Mahalanobis distances, with the help of them, 84% of the blasts and 89% of the earthquakes separated clearly from the other class by combining four amplitude and spectral parameters.

Waveform similarities have been studied by cross-correlation methods. We used the GISMO Matlab toolbox for the analysis (Reyes and West, 2011) and analysed 25 sec long seismograms. The critical correlation coefficient was chosen to be 0.6. Above this value the seismograms were handled as ‘similar’ and it was found that 76% of the events were similar to any other. Seismograms of explosions originating from the same quarry and recorded at a given station tend to be similar from event-to-event. Waveforms of aftershocks were very similar that originated from hypocentres very close to each other. Geller and Mueller (1980) have found that hypocentres of earthquakes with similar focal mechanisms and recorded at a station lye within one quarter of the shortest wavelength.

Typical seismograms of the four largest clusters are shown in Fig. 2. The #1 and #2 clusters were blasts originated from two different quarries, and the #3 and #4 were aftershock sequences. Based on our experience we can say that explosions and aftershocks have never mixed in the same cluster. The clusters consisted of different magnitude events. The time span of the largest aftershock cluster (#3) was about 1 month, and contained events with magnitude between M_L1.5 and M_L3.5.

The waveform similarity analysis has resulted, that several events, which have not had hypocentre coordinates because of the limited detection capability, were included in one of the clusters. So these events can be connected to corresponding series of aftershocks (Deichmann and Garcia-Fernandez, 1996). Using the waveform cross correlation method, several misclassified events were also filtered out from the catalogue.

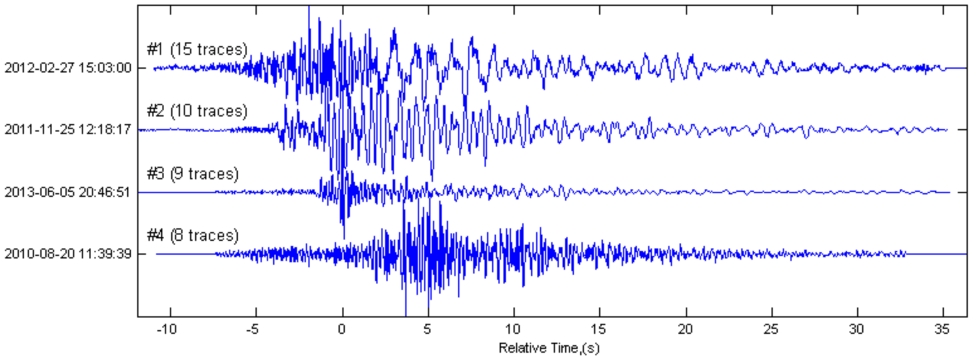

Figure 2. The typical seismograms of the four largest clusters (critical correlation coefficient was 0.6). The seismograms of #1 and #2 clusters originated from quarry blasts, and the members of #3 and #4 clusters belonged to different aftershock sequences

Overall, classes of eathquakes and quarry blasts have separated well from each other by the joint applications of the amplitude ratio, waveform similarity and the different spectral methods. The catalogue has been cleaned up from several explosions.

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