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Spectral Studies of Quarry Blasts and Earthquakes in Eastern Cairo, Egypt

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Abstract: The discrimination between natural earthquakes and quarry blasts is faced by seismologists as a difficult problem, whereas the seismological differences between them are many, but not all of them are observable at short distances or are applicable to every earthquake and quarry blast. In the present study, *P*-wave spectra from 37 earthquakes and 26 quarry blasts recorded by the Egyptian National Seismic Network (ENSN) in eastern Cairo at epicentral distances of up to 275 km were computed and analyzed. Three seismic techniques were proposed for discrimination between natural earthquakes and quarry blasts. The amplitude spectra of quarry blasts have a strong peak and simple pattern for the first onset. But in case of natural earthquakes, the spectra are more complicated and appear very different from those of blasts. From the relation between body and surface wave amplitudes determined at the Egyptian National Seismic Stations as a discriminant criterion, it was possible to identify quarry blasts from natural earthquakes. In conclusion, the final result in this study showed that, waveform characteristic of seismic wave generated by earthquakes and quarry blasts can be used as a diagnostic aid in distinguishing between them.

Key words: Natural earthquakes · Quarry blasts · Spectral studies · Eastern Cairo

INTRODUCTION

The problem of distinguishing the quarry blasts from natural earthquakes using seismic data has been studied for a long time ago. Currently, the discrimination of regional data is an important research topic and a variety of the regional discriminates have been proposed by many researchers. The discrimination of small magnitude events (mb< 4), the spectral discrimination using multiple regional phases has recently received much attention [1, 3]. When the event magnitude is less than 4.0, the surface wave signal may be masked by background noise, even at distances as short as a few hundred kilometers. In this case short- period seismic discrimination must be applied. However, short period discriminations are generally less robust and their physical basis not as well understood as for the discriminations utilizing longer period surface wave energy [4].

Different approaches to discriminating automatically between natural earthquakes and man- made explosions have been developed worldwide, each one generally appropriate to a particular type of explosion. For example, high-energy explosions can be discriminated using the mb: Ms ratio [5, 6]. For events of medium and low magnitude, other discriminants are used, such as: the spectral shape of the whole wavepacket, P/S spectral ratios, ratio of peak, rms, average amplitude in low and high frequency bands for specific phase, spectral modulation caused by ripple firing waveform inversion, spectral semblance and cross- correlation statistics and measuring the coherency of smoothed spectra at different station in specific frequency bands [7-10]. Hartse *et al*. [11], for example, compared a method based on measure of the spectral content of the scattered energy contained in the seismogram codes with methods based on other kind of seismic discriminants and demonstrated that their method, called the coda method, can be successfully applied to seismograms from small energy nuclear events in a monitoring situation where data quality and quantity are limited. A number of natural earthquakes and quarry blasts were recorded in eastern Cairo using the stations of Egyptian National Seismograph Network (ENSN) to study short- period discrimination (Fig. 1). Phase identification for the first arrivals of the P-waves and S-waves as a primitive step was done to calculate the origin time, longitude and latitude, as well as to calculate the magnitude, spectral analysis and the polarity of the first arrivals of each event. DAN software was used in these identifications and calculations. By using arrival time (S-P), the classification of earthquakes into local or regional is easily done.

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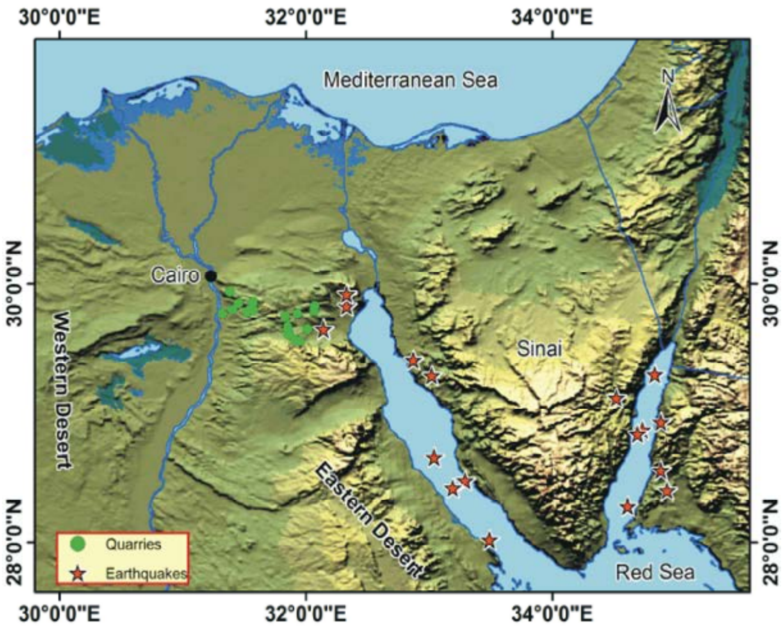

Fig. 1: The spatial distribution of natural earthquakes and quarry blasts in Eastern Cairo

Discrimination Methods: The seismic waves that propagated from the source to seismic station are influenced by three factors: the first is the properties of the source and the second is the structure in the vicinity of the source and between the source and stations, while the third is the recording conditions at the station. It is not simple to study the properties of the seismic source independently of the other factors, especially if the structure in the source region and between the source and receivers is not known. It is clear that, the mechanism of the natural earthquakes is rather different from the mechanism of explosions. So, the seismic waves propagated from natural earthquakes and explosions are considerably influenced the generation mechanism [12]. From this point of view, it seems, it would be simple to find some discrimination criteria between the natural earthquakes and explosions, based on the seismic records. On reality, these differences may be overlapped by other factors, mainly by the local structure close to the source and by the structure between the source and receiver. For this reason, any discrimination criterion based on some theoretical assumption must be fully investigated empirically. To exclude the effects of the structure of the earth's surface, we shall consider only the sources that situated in an unbounded, homogeneous isotropic and perfectly elastic medium. Then, we could summarize some basic differences between the natural earthquakes and explosions.

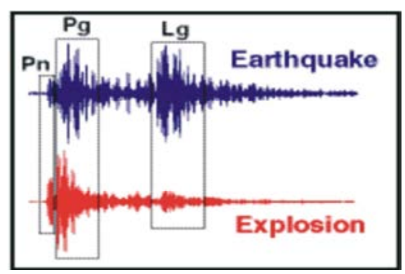

Fig. 2: Example of earthquake and explosion seismograms [13]

Waveform and Mechanism of Natural Earthquakes and Explosions: The differences between earthquakes and quarry blasts turned out most clearly from their waveforms. Figure (2) shows a natural earthquake with a Quarry explosion of approximately the same size. Both events were recorded by the same Seismic station with the same type of equipment and the distance between the explosion and recording station is approximately same as the distance between the earthquake and recording station. The explosion waveform is dominated by the P wave (the first arrival) and haven't love wave while the earthquake has much large S waves (and surface waves). Also, the duration of explosion source processes is shorter and the oscillations are of impulse character. This peculiarity and the increasing high frequency component absorption cause the more rapid attenuation of the explosion- generated oscillations with distance.

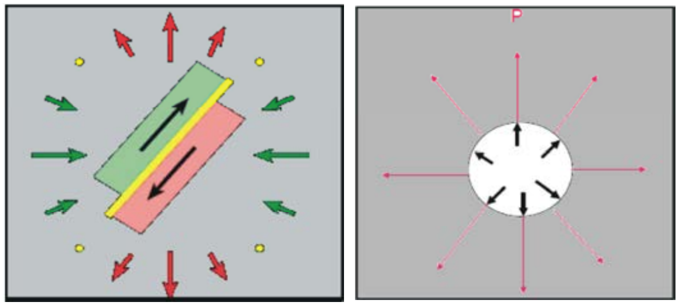

Fig. 3: Seismic source mechanism for natural earthquakes and explosions

The mechanism of an explosion is spherically symmetric, at least theoretically, radiating longitudinal waves of equal amplitude in all directions. This corresponds to the ideal case. However, this does not happen in practice, because of the inhomogeneous structure of the Earth's crust. Therefore, explosions also exhibit a certain lack of symmetry, even though this is not as pronounced as in the case of earthquakes. The observed fact that, explosions also generate transverse waves even though such waves would not be expected in the ideal case is another expression of the asymmetry [14]. According to Hussein [12], for any earthquake, the double couple character with quadripolar radiation pattern of the generated P-waves depends upon the fault geometry and ray direction (both for body and surface waves). But for the explosions, the radiation pattern is isotropic i.e. compressional in all directions, homogeneous amplitude, if delta is the same and the shear and love waves are not generated (Fig. 3).

Spectral Analysis Method: Numerous studies on discrimination between quarry blasts and natural earthquakes at local or regional distances during the last decade have been based on variations of spectral characteristics of direct wave phases like (Pn, Pg, Lg, Rg, etc.) or on spectral ratios at different frequencies. Blasts and earthquakes have yielded different spectral amplitudes for the same direct wave phase at regional distances in many instances [1, 15], which can be used to discriminate underground explosions from earthquakes. In this study, a quarry blast- earthquake discrimination methods based on the analysis of body and S-waves in an area encompassing the eastern Cairo was presented. A total of 37 earthquakes and 26 quarry blasts distributed in an area encompassing the eastern Cairo were collected for this study. These events were recorded from 1998 to the end of 2010 by the Egyptian National Seismograph Network (ENSN). The quarries are operated by the national Portland Cement Company and Tourha Cement Company. The event focal depths range from 0 to 18 km. The magnitudes of earthquakes range from 2.2 to 4.3, while for quarry blasts they range from 2.0 to 3.6. This magnitude range was chosen to ensure that there were well developed code waves in the records with minimal signal saturation and noise contamination. For the spectral analysis a time- window length was chosen individually for every seismogram in order to embrace the whole body wave. The amplitude of these events was calculated from vertical component seismograms at seismological records of the ENSN.

Figures (4 and 5) show the spectral analysis of two earthquakes and two quarry blasts and recorded by HAG and GLL seismic stations respectively. Before, a conclusion that the difference is attributable to the difference in the source spectra between earthquakes and quarry blasts, we should also check carefully for any other possibilities that could cause these power spectrum differences. Since the recording site effect and the body waves influence are already excluded.

In Figures (4 and 5) the spectra of a earthquake and of a quarry blast both, recorded at two seismic stations of the ENSN are compared. A significant difference was found by comparing the spectra between earthquakes and quarry blasts. The curves of power spectra verses frequencey for blasts decrease more sharply than earthquakes at high frequencies. The observed difference in spectral shape between blasts and earthquakes should be due to the difference between the two sources. Also, the spectra of these events increase sharply with increasing frequency, indicating that the quarry blast source generates less high frequency energy than earthquakes. The differences between earthquakes and quarry blasts turned out most clearly from their spectra. Even reducing the signal preprocessing to a level which could be reached also by an automatic treatment, we find dominating frequencies of earthquakes being significantly

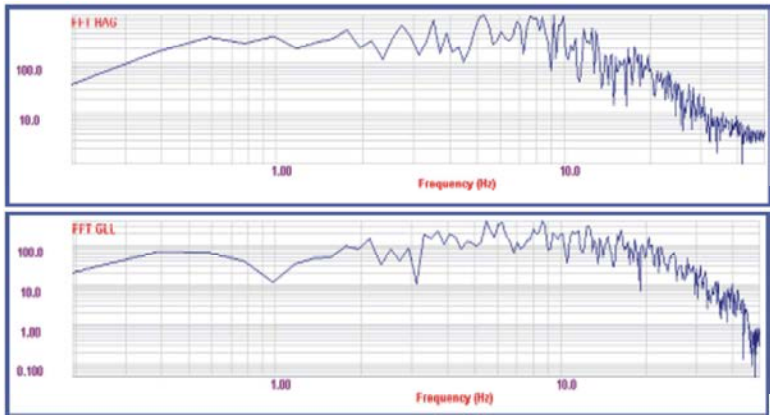

Fig. 4: Spectral analysis of two natural earthquakes from the records of HAG and GLL stations respectively

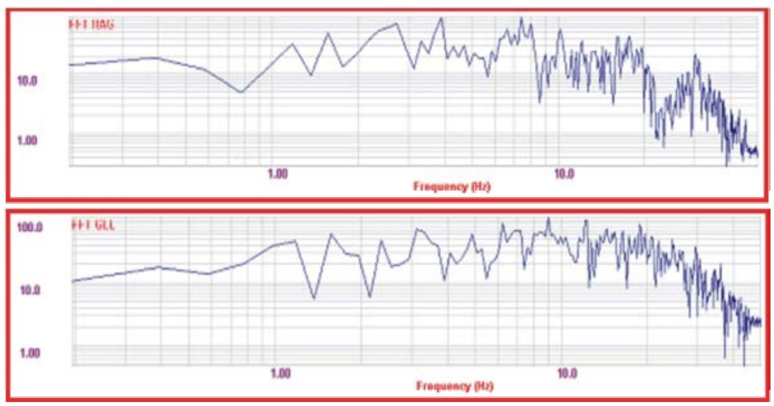

Fig. 5: Spectral analysis of quarry blasts from the records of HAG and GLL seismic stations and dated on 1- 07- 2007 and 1- 11- 2007, respectively

higher than those of quarry blasts. The amplitude spectra computed in this study was carried to establish a simple criterion for the discrimination between quarry blasts and earthquakes, which might be applied also by an automatic discrimination. The quarry blast seismograms spectra are poorer in high frequencies than seismograms of earthquakes with comparable magnitudes.

Body and Surface Wave Amplitudes Method (Ap and As): Underground explosions like industrial explosions in quarries generate signals, which tend to have surface or S-wave amplitude (As) and body amplitude (Ap) that differ from those of natural earthquake signals. This is basically a result of explosions emitting more energy in the form of body waves (high- frequency seismic radiation) and earthquakes emitting more energy in the form of surface waves (low- frequency seismic radiation). Because a relative lack of radiation is an often- used explosion discriminant, we compate P- and S-wave amplitudes for earthquakes and quarry blasts using the peak amplitudes in the seismograms, band- pass filtered between 1 to 10 Hz, from the vertical component. The underlying idea for this comparison is the preferential excitation of P energy relative to S energy for explosive source. To use this method, both Ap and As values (maximum tace amplitude of P and S-waves in mm) are required in this study. The relationship between the maximum trace amplitude on seismogram of P-wave (Ap) and S-wave (As) for earthquakes and quarry blasts which occurred east of Great Cairo and recorded at SUZ and FYD seismic stations are shown in Figure 6. Also Figure 7 shows the relation between body and S-wave amplitudes calculated from the average values of five seismic stations from ENSN. From these figures, we can seen that, the best discriminant performance is given by combining phase and spectral amplitude ratios. Generally it is observed that, P-wave amplitude for quarry blasts are greater than those of earthquakes. Also S-wave amplitude for blasts are less than those of earthquakes. This can be explained that, in case of quarry blasts most of the

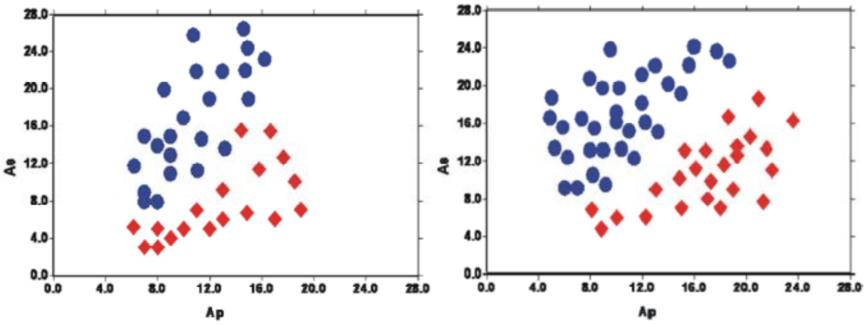

Fig. 6: Relation between P-wave and S-wave amplitude (Ap: As) for natural earthquakes (blue circle) and quarry blasts (red cube) at SUZ and FYD stations

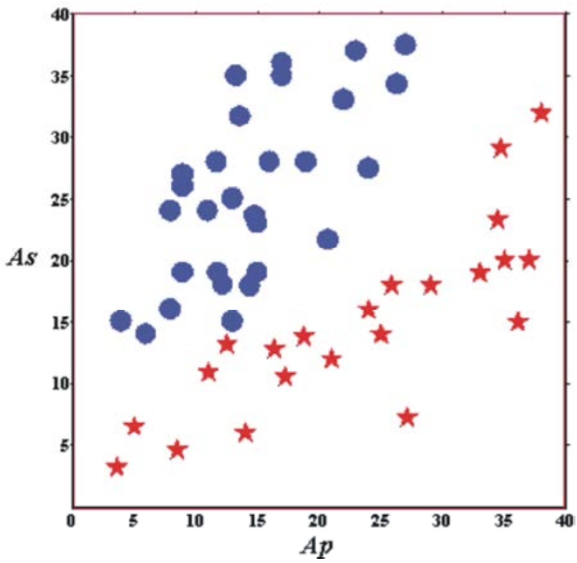

Fig. 7: Relation between P-wave and S-wave amplitude (Ap: As) for natural earthquakes (blue circle) and quarry blasts (red star) at the average values of five stations from the Egyptian national seismograph network (ENSN)

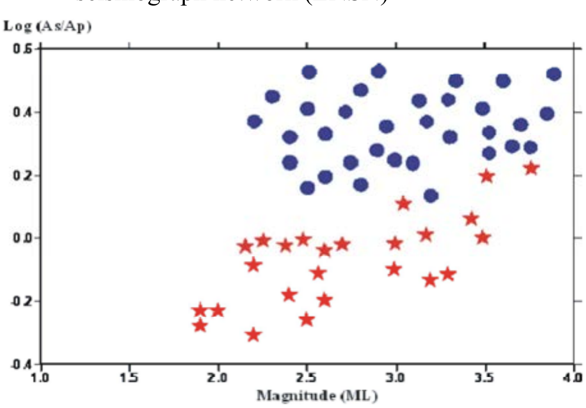

Fig. 8: Relation between local magnitude (ML) and logarithm of peak amplitude ratio (As/Ap) observed at KOT seismic station

released energy is confined in the range of high frequency waves. On the contrary, for earthquakes the released energy is distributed in the large range of frequency. In addition, quarry explosions do not, generally, generate large S-waves as they are fired near the earth's surface.

A key to the As/ Ap spectral ratio is the correction of regional signals for their source to receiver path effects since the frequency contents of P and S waves depend on specific propagation paths and local structure. Examination of As/ Ap ratios at high frequencies has now been done all over the world. the characteristic pattern of explosions have large relative P-wave amplitude than S-wave amplitudes appears to hold everywhere, provided that we filter the data at a high enough frequency and that we compare events with very similar paths.

The vertical- component log *As/Ap* ratios of 37 earthquake records and 26 quarry blast records are plotted against magnitude in Figure 8. The results indicate that for quarry explosions, the ratios are mostly minus when maximum trace amplitude of P-wave is greater than maximum trace amplitude of S-wave. Earthquakes in both regions show the values of amplitude for S-wave are greater than those of amplitude of P-wave. These amplitude ratios are probably due to the response of the employed short- period seismograph and the spectra of underground explosions have a strong peak at a higher frequency and a relatively simple pattern as easily suspected from the analogue records. The application of this method to our data set gave a success of about 90%.

DISCUSSION AND CONCLUSIONS

The seismological difference between earthquakes and underground explosions are many, but not all of them are observable at near or large distances or are applicable to every earthquake and explosion [16]. The worked out investigations concern the problem of identification of quarry blasts and natural earthquakes. The results of the previous studies showed that: waveform characteristics of seismic waves generated by local earthquakes and quarry blasts can be used as a diagnostic aid in distinguishing between two types of events [6, 13]. As a general rule it was found that the quarry blasts are richer in high body- wave amplitudes than natural earthquakes and S-wave amplitudes were generally larger for the earthquakes than the blasts. On the basis of the analysis of quarry blast and a shallow earthquake it appears that the duration as determined from the seismogram is almost two times smaller for an explosion than it is for a comparable earthquake. The earthquakes are observed to have more high- frequency energy than the explosions for all three phases. This observation may be due to actual source differences or to depth-dependent effects of attenuation on the shallow explosions and deeper earthquakes. Marshal [17], while examining the spectral differences between earthquakes and underground explosions, has studied all seismic events from the Sino -Soviet area for 1966 and found that on a Ap versus As plot, all of the events which were believed to be explosions are clearly separated from earthquakes populations. In this study the data of WWSSS network were used and the seismic paths involved oceanic segments.

It Was Concluded That: The quarry blasts waveform is dominated by the P-wave while the earthquakes has much large S-waves and surface waves. In case of blasts most of the released energy is confined in the range of high frequency waves. On the contrary, for earthquakes the released energy is distributed in the large range of frequency. In addition, quarry blasts do not, generally, generate large S-waves as they are fired near the earth's surface. In this study, all events identified as quarry blasts have occurred during daytimes and on weekdays from Saturday to Thursday. The explosions are spherically symmetric centers of energy, so the explosion generated P-wave are recorded in all seismic stations as waves of compression. At the natural earthquakes in the region under investigation, the first motion can be either compression phase or dilatation phase, which is due to the specific mechanism of earthquake source. Separation between natural earthquakes and underground quarry blasts is observed clearly in the relation between S-wave to P-wave amplitude (As: Ap) calculated from the records of the Egyptian National Seismic Network (ENSN). Natural earthquakes and quarry blasts in eastern Cairo exhibited significant differences in their average P-wave spectral properties. Quarry blast spectra are not well-fit by standard source models and typically have lower corner frequencies and anomalously steep falloffs at high frequencies compared to natural earthquakes of the same estimated magnitude and the final results from analysis of P-wave spectra may provide additional discriminates. On the other hand, the relation between log amplitude ratios As/Ap with magnitudes were generally larger for earthquakes than the blasts, but observations showed considerable scatter and intermingling which made the distinction unreliable. Many artificial events like quarry blasts produced strong short-period Rayleigh waves, but this was not the case for all blasts.

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