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Detecting and Identifying Seismic Events Using the Egyptian National Seismic Network

Sayed A. Dahy and Gaber H. Hassib

National Research Institute of Astronomy and Geophysics, Egypt

Abstract: The detection and monitoring of underground nuclear explosions has been discussed for over 40 years in connection with verification of the comprehensive test ban treaties and identifying of seismic events is also one of the basic ways to learn about nuclear weapons development in different countries. Nuclear explosions have a number of differences from other events that lead to differences in their seismic signatures. The present study described the different kinds of seismic sources and the basis for solving the identification problem. Large natural or artificial events, with magnitudes greater than 4.8 are detected by Egyptian National Seismic Network (ENSN) and the detection capability of teleseismic events for distance range between 25° to 35° is clearly low at body wave magnitude less than 5.0. A number of identification methods have evolved. These can be identified by well-established discrimination techniques such spectral analysis of body waves and also from magnitude residuals versus body wave magnitude plots. From this study, we concluded that, explosions are characterized by more high-frequency energy than earthquakes and discrimination between teleseismic earthquakes and nuclear explosions could be achieved at high magnitude range, but for smaller events, it can be very difficult to detect and to discriminate between them. Also, separation between natural earthquakes and nuclear explosions is observed clearly using the relation between magnitude residuals with body wave magnitudes.

Key words: Detection · Identification · Nuclear explosion · Earthquakes · Spectral · Magnitude residual

INTRODUCTION

Once a seismic event has been detected, the next task is to determine if it was created by an underground nuclear explosion. Other seismic events include natural earthquakes, rockbursts in mines and chemical explosions conducted for mining, quarry blasting and construction. On a global basis, over 90% of all seismic events can be identified as earthquakes simply because they are too deep or not in a plausible location for a nuclear explosion. For seismic events that cannot be distinguished by depth and location, other methods of discrimination are used. These methods are based on physical differences between earthquakes and explosions. The aim of the detection processes is to explore differences between signals and noise in order to improve the detection capability. Detection capability of event registered at any seismological station depends mainly on the specifications of the instruments specially; their sensitivity and noise level at station site and also depends considerably on where the events occur [1]. Different techniques used for identifying of seismic events were reviewed by Kim *et al*. [2], Kebeasy *et al.* [3], Battone *et al.* [4], Fisk [5], Taylor [6] and Taylor *et al*. [7] and others. From a physical point of view [8], it is expected that the spectra of earthquakes is more complicated and appear very different from those of explosions. Also, the energy released in the case of a natural earthquake is distributed in a large frequency range. On the contrary, for explosions, energy is concentrated at higher frequencies. For this reason, it can be expected that earthquakes have a higher Ms than that of explosions with same mb. This was documented is many observational studies, e.g., Dahlman and Israelson [1], Lilwall [9], Murphy *et al*. [10], Bonner *et al.* [11], Fisk [5] and others. Marshall and Douglas [12] stated that the separation between explosions and earthquakes based on mb to Ms plot works very well for some regions in the world (e.g., U.S.S.R.) but not quite so well for all (e.g., Nevada, U.S.A.).

In this paper, the data of natural earthquakes and nuclear explosions recorded by the short-period seismographs at ENSN were analyzed. Data of these events were also collected from the NEIS catalogue and earthquake data report (EDR).

Corresponding author: Sayed A. Dahy, National Research Institute of Astronomy and Geophysics, Egypt.

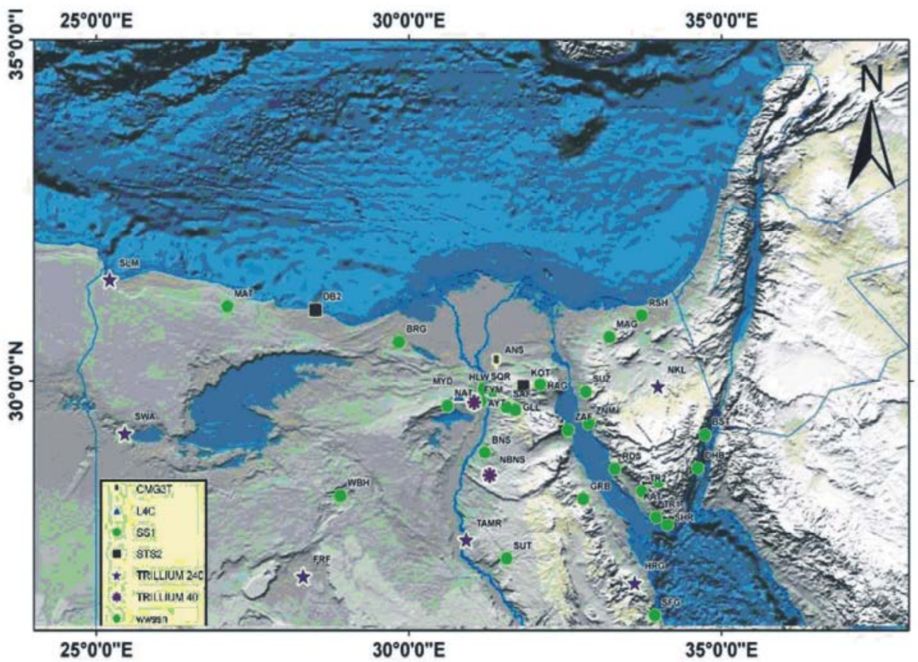

Fig. 1: The Egyptian National Seismic Network (ENSN) in the northern part of Egypt

Egyptian National Seismic Network: Recent earthquake records started in Egypt in 1899 with Helwan station. By mid 1980's the number of installed seismic stations was increased, whereas Aswan Seismic Network; 13 stations, was installed in 1981. In 1990, a very broad band Kottamia station was installed. After 3 years, in 1994, Hurghada Seismic Network; 6 stations, was installed (Fig. 1). Recently, in 2003, the Egyptian National Seismological Network (ENSN) was achieved to work in a complete system with improving the old seismic stations to include more than 66 seismic stations. All these seismic stations that cover most of Egypt land send the digital data to the main center in Helwan. In addition, ENSN has 24 mobile seismograph stations and strong motion accelerographs. By this dense array of these seismic stations, it is becoming available to record the seismic activity in Egypt.

Data Used and Magnitude Determination: The data used in the present study were obtained from the records of Egyptian National Seismological Network (ENSN). Data of 29 presumed underground nuclear explosions and 41 natural earthquakes occurred in different regions of Former Soviet Union (FSU), China, India, Iran, Turkey and Afghanistan border region during the period from 1982 to late, 2010 are used in identification process. Both earthquakes and nuclear explosions must be selected from the same area in order to obtain reliable results. If events of only one class were added from other areas, the signal differences would arise not only from nature of the source but also from the effects of different source area and propagation path. Consequently, the discrimination function is applicable only to the area covered by the original data set.

Body- wave magnitudes were determined from short-period, vertical component seismograms at teleseismic distances, using one- half the largest peak- to- peak motion found in the first 3 cycles of the P- wave at maximum amplitude.

Gutenberg and Richter [13] derived the following formula for magnitude determination using P- wave amplitude. In this study the body- wave magnitudes (mb) have been calculated by using this formula

$$mb = \log A/T + Q \tag{1}$$

whereas A is one half of P- wave amplitude reduced to ground motion in microns, T is the period in seconds and Q is calibrated distance- depth factor. Surface- wave magnitudes were determined from the amplitudes of the vertical component Raleigh waves and the standard IASPEI formula was, namely

$$Ms = \log A/T + 1.66 \log \Delta + 3.3 \tag{2}$$

Whereas Δ is the epicentral distance from the event to the station in Degrees and A/T is in microns per seconds.

Outputs of the playback system for these events were manually digitized and body wave magnitudes at 1 and 2 Hz (mb1 and mb2) were calculated.

Detection Capability of ENSN: The aim of the detection processes is to explore differences between signals and noise in order to improve the detection capability. Detection capability of event registered at any seismological station depends mainly on the specifications of the instruments specially; their sensitivity and noise level at station site and also depends considerably on where the events occur. The detection capability (D. C) of any seismic network at a given period can be calculated by using the following equation:

$$Detection\ Capability\ (D.\ C) = Nd/Nq \times 100\ \% \qquad (3)$$

whereas *Nd* is the number of detected events, *Nq* is the number of occurred events. All events with magnitude mb > 5.0 which occurred Eurasian continentals were collected from the National Earthquake Information Center (NEIC) catalogues and the Earthquake Data Report (EDR). The number of the events recorded by ENSN was counted. Using the above equation the ENSN capability for detecting natural and artificial events with magnitude not less than 5.0 is estimated and listed in table 1. This table shows that all the events having body wave magnitude greater than 5.8 which occurred in Eurasia can be recorded by ENSN.

On the other hand, if detection capability means the capability of a station to record earthquakes that occur anywhere in the world, then the detection capability of a certain period in connection with the magnitude and the epicentral distance is given in Table 2.

The period are from January, 2002 to December 2006 for the events occurred in Former Soviet Union, China, India, Iran, Turkey and Afghanistan border region and reported in the summary report of NEIC and detected by ENSN. From table 2, there are three boundaries of epicentral distance to change the detection capability extremely. Almost all earthquakes of magnitude of more than 5.8 were recorded at seismic station of ENSN and the detection capability for magnitude of 4.6 < mb < 5.3 at epicentral distance from 10° to 30° is about 58.3% of that for magnitude of more than 5.8. The detection capability for epicentral distance from 31° to 45° is 81.6 % at the same period.

Table 1: Detection capability of ENSN

Body wave magnitude (mb)	Detection capability of ENSN
4.6 < mb< 5.3	47.3%
5.3< mb< 5.8	88.4%
mb> 5.8	100%

Table 2: Epicentral distances versus detection capability at different magnitudes

Epicentral distance (Δ°)	10° ~ 30°	31° ~ 45°	45° ~ 65°
Magnitude (mb)	4.6 < mb < 5.3	5.3 < mb < 5.8	5.8 < mb < 6.5
Detection capability (%)	58.3 %	81.6 %	100.0 %

Methods of Identification: The problem of distinguishing between earthquakes and underground nuclear explosions is important not only because of its strategic implications but also because of the new insight into the mechanism of earthquakes its solution could provide. Over the years, a number of identification methods have been shown to be fairly robust. Some of these methods perform the identification process by identifying certain earthquakes as being earthquakes (but not identifying explosions as being explosions). Other identification methods identify certain earthquakes as being earthquakes and certain explosions as being explosions. The identification process is therefore a winnowing process [14]. Several diagnostic techniques are examined for identifying earthquakes as events distinct from possible underground nuclear explosions. It was found that the typical or mean earthquake differs in a statistically significant way from the mean explosion for most of the techniques. Because of the variability of earthquake signatures, many earthquake parameters fall within the range observed for explosions. In this study, three various methods were used for the identification between earthquakes and nuclear explosions by using the records of Egyptian National Seismological Network (ENSN), these methods are:

- spectral analysis of body- waves
- the relation between body- wave magnitude and magnitude residuals
- the differences between body- wave magnitudes at two different frequencies (mb1- mb2)

RESULTS AND DISCUSSIONS

Spectral Analysis of P- Waves: many studies have been made by Edoardo, *et al.* [15], Bettina *et al.* [16] and Dahy *et al,* [17], they found that earthquake waves contain slightly lower frequency than the waves generated by nuclear shots (NTS), i.e., they produce seismic waves of different frequency content. Also, they studied the spectral estimation on many widely distributed events. It has been found that explosions and earthquakes can be separated by splitting Rayleigh- wave energy between 10 and 50 seconds into two period bands and calculating their ratio. Explosion ratios are confined to be narrow range. Earthquakes ratios have large scatter because they depend on depth and source mechanism parameters. Wyss *et al.* [18] illustrated that at high frequencies, the amplitude spectra of both earthquakes and underground explosions tend to vary inversely as the square of the frequency. At low frequencies the amplitude spectra of explosions tend to decrease as frequency decreases. It has a peak in the frequency range from 0.5 - 2.0 Hz. The spectra discriminant do not depend only on the nature of the seismic event (natural or artificial), but also on several other factors. Both for explosions and earthquakes, the frequency- domain discriminants usually are functions of the source strength. The larger the source the smaller the proportion of energy radiated at high frequencies. This effect, which is about the same for explosions and earthquakes, can be correct for in many cases [1]. In the present study, for investigation of the spectral characteristics of the seismic waves which are radiated from both types of sources 2 earthquakes of magnitude 6.0 & 5.9, respectively recorded by Egyptian National Seismological Network (ENSN) in digital form and two nuclear explosions of the same magnitude and the same region have been examined. After applying the corrections for the effects of the path of propagation and the recording instrument must of course be made, discrimination plots were made at each station by analysis of amplitude spectra of P- wave from earthquakes and nuclear explosions. The spectra are constant from zero frequency up to the so-called corner frequency, above which the amplitude drops with frequency *F as* $1/F^2$ *or* $1/F^3$. At teleseismic distances the corner frequency can be estimated from the amplitude spectra of short-period P-wave signals. Figures 2 and 3 observed differences between P-wave spectra of earthquakes and nuclear explosions, all events being from essentially the same source area.

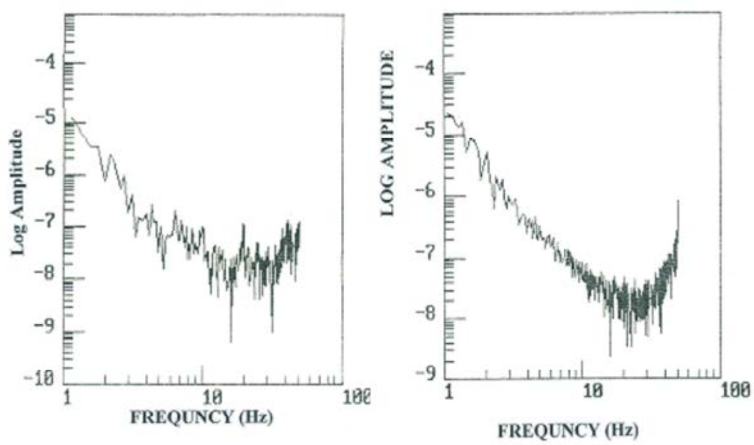

Fig. 2: P-wave spectra at AHD and GMR seismic stations for two natural earthquakes.

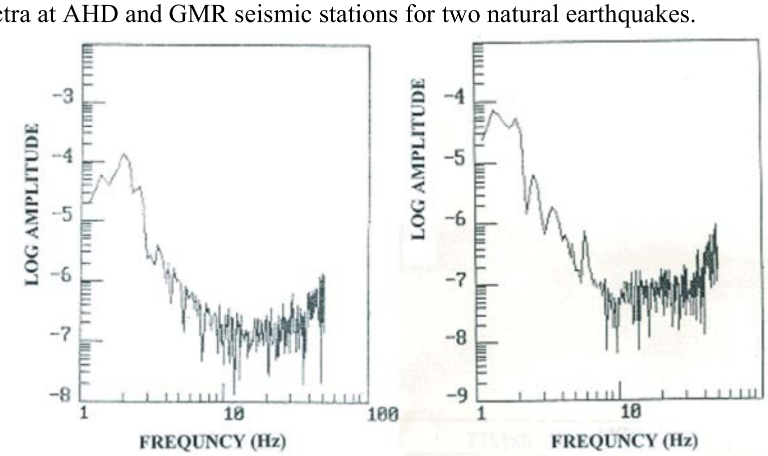

Fig. 3: P-wave spectra at AHD and GMR seismic stations for two nuclear explosions.

The important features of the explosion spectra of figures 2 and 3 are high corner frequencies relative to earthquakes with the same low- frequency spectral level and $1/F^2$ rate of decrease of spectral amplitude with increasing frequency above the corner frequency. The rate of amplitude decrease with increasing frequency appears less for explosions than for the earthquakes shown, while the precise values of the mean spectral slopes for the explosions are dependent upon corrections for propagation, they cannot much different from the $1/F^2$ variation indicated for reasonable values of parameters in the propagation corrections. Also we note that the differences between earthquakes and nuclear explosions are due to differences in focal depth and mechanism rather than in source time functions or source size. The effect of focal depth appears to have more influence than the effect of source parameters on the peak frequency F0 in the spectra of earthquakes, whereas the source function is the important parameter for shallow underground nuclear explosions.

Relation Between Body- Wave Magnitude and Magnitude Residuals: This method is used when investigating teleseismic earthquakes and nuclear explosions. A small part of the energy released by any events is converted to elastic energy and transmitted to distant part of the Earth as seismic waves. From the amplitudes of these waves, Seismologists can determine a Seismic Magnitude for the explosion using magnitude scales devised to measure the relative size of earthquakes. Some earlier studies have illustrated a significant difference in mb and Ms Relationships. The differences were first investigated by Press *et.al* [19] and Romney [20]. Thirlaway [21]; gave an explanation of the body-wave to surface- wave method based on the records of the WWSSS network in 1966. He was confident that the separation was sufficiently distinct to say that discrimination was very high for magnitude 4.75. Other similar studies were made by Lilwall [9], Kebeasy *et al.* [3] and others. All of these studies included events whose surface-wave traveled inter continental distance involving oceanic paths. In all of these studies there was a good separation between earthquakes and explosions. One of the fundamental technical problems in our study is the discrimination of earthquakes and nuclear explosions by using magnitude residuals. Measurements can be taken from seismograms that are based on the expected differences between two sources (natural or artificial).

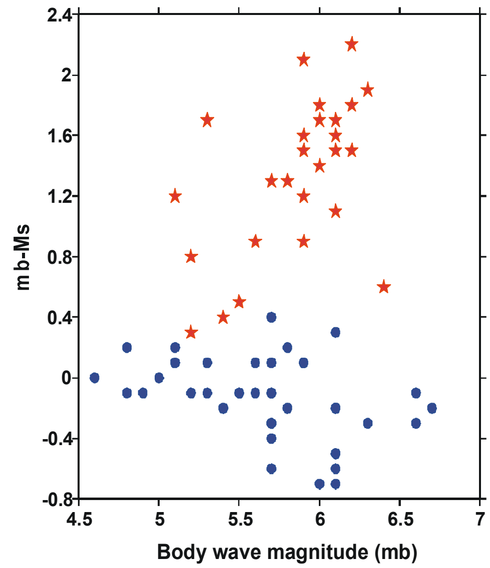

Fig. 4: Relation between body wave magnitude and magnitude residuals (mb- Ms) for earthquakes (blue circle) and nuclear explosions (red star).

The earthquake was characterized by much more late arriving shear energy in the form of low-frequency surface waves than the explosion. In contrast, the early arriving P waves from the explosion are enhanced relative to the surface waves. This is the basis of the mb- Ms discriminant (difference between body wave and surface wave magnitude), as illustrated in figure 4. In general, the performance of the short-period discriminants was quite good.

The Differences Between mb1- mb2 as Discriminant Criteria: Besides the spectral analysis and magnitude residual methods discussed above, a variety of other discriminants have been proposed and tested over the years. Most of these discriminants are generally applicable to large events only. In the present method, many trail have been made by Miyamura *et al.* [22], Kebeasy *et al.* [3], they defined two types of P-wave magnitudes as mb1 and mb2 determined from amplitudes of 1.0 Hz and 2.0 Hz respectively. Using these determined magnitudes they made sure that, the frequency-filtered seismograms are a powerful identifier for the Kazakh and Novaya Zemlya. A correlation of the magnitudes identified for body waves at two different frequencies is a more reliable way to differentiate explosions from earthquakes. In this trail, body wave magnitude was calculated using ENSN data for both earthquakes and nuclear explosions at 1 Hz (mb1) and 2 Hz (mb2). The relationship between mb1- mb2 with mb determined

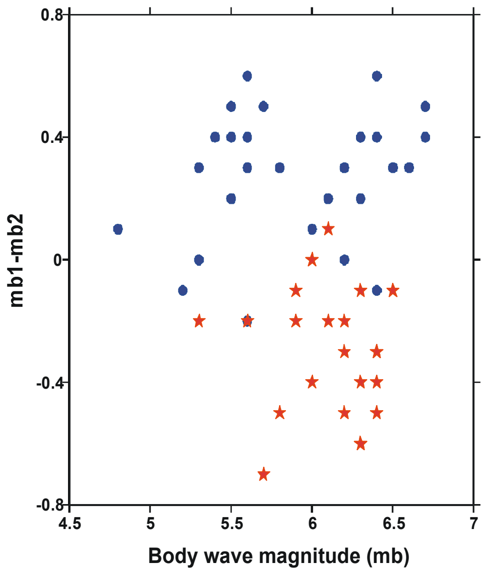

Fig. 5: Relation between mb and (mb1- Mb2) for earthquakes and nuclear explosions.

by NEIS as given in figure 5 shows that, there is acceptable agreement between NEIS body wave magnitudes (mb) and mb1 and mb2 of ENSN seismic stations, although some scatter exist in the figure and this scatter shown in this figure can be attributed to the large variation in focal depths. This investigation show that the two populations of earthquakes and explosions are separated all along the high magnitude range studied. In the magnitude range from 5.5 to 6.6, it is obvious that mb1- mb2 for natural earthquakes are greater than those of nuclear explosions.

CONCLUSIONS

The worked out investigations concern the problem of detection and identification of earthquakes and nuclear explosions. The following results of the present study show that:

The Egyptian National Seismological Network (ENSN) was found to be capable to detect and identify all of teleseismic earthquakes and nuclear explosions having body- wave magnitudes greater than 5.8 at epicentral distance less than 65° and we found that, the detection capability in connection with the magnitude and the epicentral distance. The detection capability for distance range from 10° to 30° is clearly low but more than 81 % of the events with body- wave magnitudes not greater than 5.8 at epicentral distance between 31° to 45° were detected and recorded by ENSN seismic stations.

Applying the spectral analysis technique on the P- waves recorded at digital recording of ENSN, it shows that the energy released in case of explosions is concentrated in the higher frequency range of seismic waves, while it is attributed in a large frequency range in case of natural earthquakes and the corner frequencies of earthquakes should be lower than of explosions.

Separation between earthquakes and explosions is observed clearly using the relations between mb- Ms and mb1- mb2 with magnitude of body waves.

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