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Discrimination between natural earthquakes and nuclear explosions using the Aswan Seismic Network

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Abstract
There are many seismological differences between earthquake and nuclear explosions, but not all of them are observable at large distances or are applicable to every earthquake and explosion. Several discriminations have been checked using the Aswan Seismic Network (ASN) data. Data of 66 earthquakes and 42 presumed underground explosions which occurred in different regions of China, the U.S.S.R., India, Iran, Turkey and recorded at ASN were collected. All data were selected from the NEIC catalogue and EDR reports. It was found that m_b: M_s as well as m_b (1 Hz): m_b (2 Hz) work well for events with m_b larger than 4.0 from data observed at ASN and obtained from the NEIC catalogue.

Key words *natural earthquake – nuclear explosion – seismic discrimination*

1. Introduction

Seismic events of different origin have been observed all over the word. A great interest in the discrimination between nuclear explosions and earthquake was simulated by its important political and military consequences. The seismological differences between earthquakes and nuclear explosions are many but not all of them are observable at large distances or are applicable to every earthquake and explosion. The basis of all discrimination criteria is the great difference between earthquake and explosions as regards their relative generation of short and long period waves. Different techniques used for discrimination between nuclear explosions and earthquake were reviewed by Bolt (1976), Dahlman and Israelson (1977), Blandford (1977, 1981, 1982), Evernden (1976, 1988), Hussein (1989, 1994) and others. From a physical point of view (Hussein, 1989), 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 countrary, for explosions, energy is concentrated at higher frequencies. For this reason, it can be expected that earthquakes have a higher M_s than that of explosions with the same m_b. This was documented is many observational studies, *e.g.*, Brune and Pomeroy (1963), Basham (1969), Evernden (1976, 1988), Tsai and Aki (1971), Landers (1972), Marshal and Basham (1972), Aki *et al.* (1974), Nuttli and Kin (1975), Stevens and Day (1985), Nowroozi (1986), Lilwall (1988) and others. Marshall and Douglas (n.d.) stated that the

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separation between explosions and earthquakes based on m_b: M_s plots 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.). Comparison of *P*-wave spectral ratio for natural earthquakes and nuclear explosions was discussed by Basham *et al.* (1970), Molnar (1971) and Wyss *et al.* (1971). This method implies the use of integrated spectral amplitudes over certain frequency bands and comparison of this quantity for natural earthquakes and nuclear explosions.

In this paper, the data of natural earthquakes and nuclear explosions recorded by the short-period seismographs at ASN were analysed. Data of these events were also collected from the NEIC catalogue and EDR. The performance of different discrimination criteria was checked.

2. Aswan Seismic Network (ASN)

On November 14, 1981 a magnitude 5.3 earthquake occurred in the Kalabsha area along the Kalabsha fault near Gebel Marawa 70 km southwest of Aswan, Egypt (Kebeasy *et al.*, 1981, 1987; Simpson *et al.*, 1982). In late June 1982 a telemetered network of eight seismograph stations was installed around the northern part of Lake Nasser.

Through 1984 and 1985 this network was expanded to 13 stations (Simpson *et al.*, 1984, 1987). The Aswan seismic stations are distributed around the northern part of Lake Nasser. Two stations were installed on the eastern bank of the lake, others were located on the western bank of the lake around the Kalabsha active fault. The geographical distri-

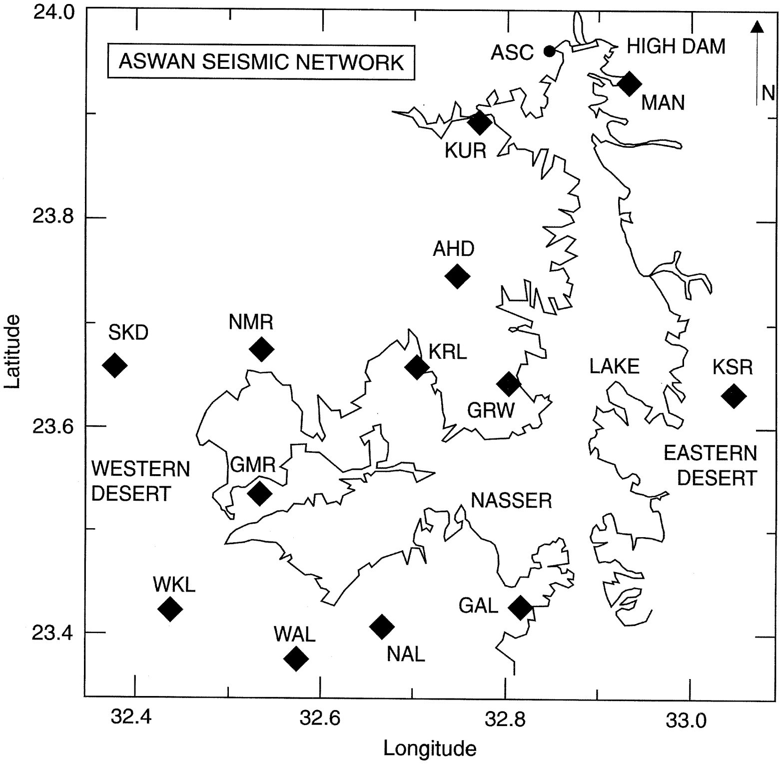

Fig. 1. Geographical distribution of the Aswan Seismic Network (ASN): • seismic field station; ◆ Aswan Seismological Center (ASC).

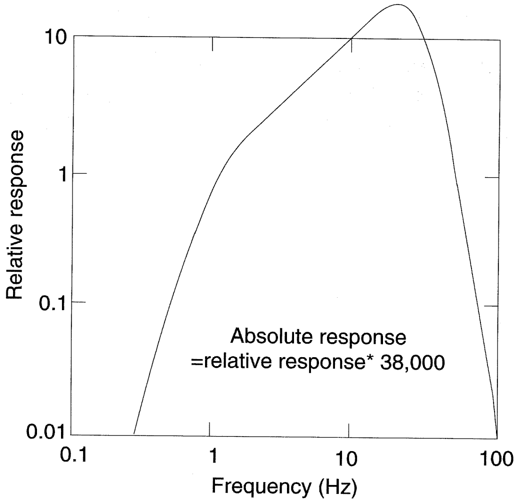

Fig. 2. A response magnification curve of GMR short period station (ASN).

bution of the stations and the recording site of the network is shown in fig. 1. Each station is equipped with a short-period vertical S-13 seismometer. Two of these 13 stations, Gebel Marawa (GMR) and Gebel Rawraw (GRW), have three component seismometers. Simpson *et al.* (1987) determined the magnification characteristics of the complete analog system and the displacement response curve is shown in fig. 2. A block diagram of field installations and the recording equipment is shown in fig. 3. Data from the field stations are transmitted via radiolink to the main recording center in Aswan. Incoming signals from five stations are discriminated in real time and recorded on five drum recorders. Signals from these are also input to an event detector system which controls the tape recorded and oscillographic recorder. Incoming FM signals from all stations are multiplexed into three channels and delayed for

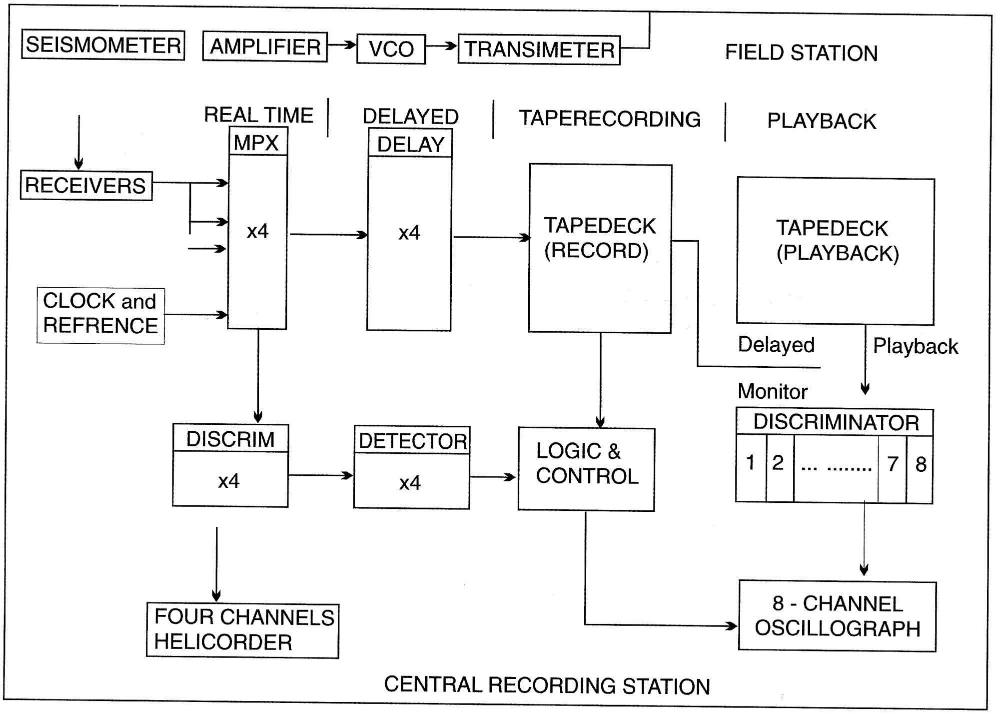

Fig. 3. Block diagram of the Aswan Telemetred Seismic Network (Simpson *et al.*, 1987).

12.3 s by an audio frequency digital delay unit. The delay allows the first seismic arrival at all stations to be recorded. The outputs of the digital delay unit are fed to both the tape recorder and a bank of 19 discriminators. These discriminators provide a continuous (but delayed) monitor of the operation of all stations. The oscillographic recorder can be controlled by the event detector to turn on with the tape recorder and provide an immediate visual record of the event. The discriminator bank and oscillographs can also be used in playback mode by driving the discriminator from an off-line tape recorder.

3. Detection capability of ASN

The detection capability (dc) of any seismic network at a given period can be calculated by using the following equation:

$$dc(\%) = \frac{Nd \times 100}{NQ}$$

where *dc* is the detection capability of the system, *Nd* is the number of detected events, *NQ* is the number of accurred events.

All events with magnitude $m_b > 5.0$ which occurred during the period from 1982 to 1990 in the U.S.S.R., China and Eastern Asia were collected from the National Earthquake Information Center (NEIC) catalogues and the Earthquake Data Report (EDR). The number of the events recorded by ASN was counted. Using the above equation the ASN capability for detecting natural and artificial events with magnitude not less that 5.0 is estimated and listed in the table I.

This table shows that all the nuclear explosions having body wave magnitude (m_b) greater than 6.0 which occurred in the U.S.S.R. and China can be recorded by ASN.

4. Data

All data in the present study were collected by ASN. Data of 66 earthquakes and 42 presumed underground nuclear explosions which occurred in different regions of the U.S.S.R., China, India, Iran and Turkey during the period from 1982 to 1990 and whose epicentre distances range from 17° to 65° were selected from the NEIC catalogue and EDR reports. Phase readings were done using seismograms recorded by ASN and the hypocentre parameters of each event were calculated.

According to the availability of the event parameters for natural earthquakes and nuclear explosions, about 71.4% of the presumed nuclear explosions events listed in table II were used for interpretation. In contrast, 54.5% of the listed natural earthquakes were used.

Outputs of the playback system for these events were manually digitized and body wave magnitudes at 1 and 2 Hz (m_{b1} and m_{b2}) were calculated. All of these data are listed in table II. Figure 4a,b shows examples of *SP* vertical component seismograms recorded by two different stations of ASN. There is a remarkable difference between earthquake and underground nuclear explosion seismograms which: a) have almost the same magnitude, b) are recorded by the same station and, c) have almost the same azimuth.

Table I. Detection capability of Aswan seismological network.

Body-wave magnitude	Detection capability of Aswan Seismic Network
$5.0 < m_b < 5.5$	30.7%
$5.5 < m_b < 6.0$	71.8%
$m_b < 6.0$	100%

Table II. Data used for discrimination between earthquakes and nuclear explosions.

No.	Date	O.T.	Location		h km	NEIC			ASN		Distance	Azimuth
	y m d	h min s	(N)	(E)		m_b	M_s	m_b^*	m_{b1}	m_{b2}	degrees	
1	82.07.04	011714.8	50.1	78.8	0	6.1	4.9	5.9	6.2	6.4	44.54	41.41
2	82.09.04	175958.2	69.1	81.7	0	5.2	3.4	5.7	–	–	54.27	19.35
3	82.12.05	033712.6	49.9	78.8	0	6.1	4.4	6.3	6.1	6.2	44.55	41.59
4	82.12.26	033514.1	50.0	79.0	0	5.7	–	5.7	–	–	44.70	41.45
5	83.06.12	023643.5	49.8	78.9	0	6.1	4.6	5.9	–	–	44.59	41.67
6	83.09.25	130957.7	73.3	54.5	0	6.4	5.8	6.2	6.3	6.5	51.26	07.90
7	83.10.06	014706.6	49.9	78.8	0	6.0	–	6.2	6.4	6.7	44.52	41.57
8	83.10.06	100002.7	41.5	88.7	0	5.9	–	5.7	5.9	6.6	49.78	54.53
9	83.10.26	015504.8	49.8	78.8	0	6.1	4.6	6.4	6.3	6.7	44.53	41.65
10	84.02.19	035703.4	49.9	78.8	0	5.8	4.3	6.1	–	–	44.51	41.59
11	84.03.29	051908.2	49.9	79.0	0	5.9	4.3	6.1	–	–	44.64	41.62
12	84.04.25	010903.5	49.9	78.9	0	5.9	4.7	6.1	5.8	5.7	44.60	41.58
13	84.05.26	031312.4	49.9	79.1	0	6.0	–	6.1	–	–	44.68	41.57
14	84.07.14	010910.5	49.8	78.9	0	6.2	4.6	6.5	6.2	6.3	44.59	41.64
15	84.10.25	062557.7	73.3	54.9	0	5.9	4.7	6.0	5.9	6.3	51.34	08.03
16	84.12.02	031906.3	49.9	79.0	0	5.8	4.6	6.0	–	–	44.69	41.56
17	84.12.16	035502.7	49.9	78.8	0	6.1	4.6	6.5	6.3	6.4	44.55	41.54
18	85.02.10	032707.6	49.8	78.8	0	5.9	4.4	6.4	5.9	6.0	44.50	41.67
19	85.04.25	005706.5	49.9	78.9	0	5.9	5.0	6.1	5.8	5.9	44.60	41.63
20	85.06.15	005700.7	49.8	78.8	0	6.0	4.4	6.4	6.3	6.5	44.54	41.64
21	85.06.30	023902.7	49.8	78.7	0	6.0	4.2	5.9	–	–	44.42	41.63
22	85.07.20	005314.5	49.9	78.8	0	5.9	4.3	6.2	–	–	44.17	41.46
23	87.04.03	011708.0	49.9	78.8	0	6.2	4.7	6.3	6.3	6.5	44.53	41.58
24	87.04.17	010304.8	49.8	78.6	0	6.0	4.3	6.3	–	–	44.43	41.59
25	87.06.05	045958.3	41.5	88.7	0	6.2	4.4	6.4	6.2	6.4	49.78	54.49
26	87.06.20	005304.8	49.9	78.7	0	6.1	4.2	6.0	5.8	6.2	44.46	41.58
27	87.08.02	005806.8	49.8	78.9	0	5.9	3.8	6.3	5.9	6.6	44.56	41.67
28	87.08.02	015959.8	73.3	54.6	0	5.8	3.4	6.1	–	–	51.14	07.97
29	87.11.15	033106.7	49.8	78.7	0	6.0	4.8	6.2	5.8	6.3	44.41	41.75
30	87.12.13	032104.8	49.9	78.8	0	6.1	4.5	6.4	–	–	44.46	41.68
31	87.12.27	030504.7	49.8	78.7	0	6.1	4.5	6.4	–	–	44.43	41.91
32	88.02.13	030505.9	49.9	78.9	0	6.1	4.5	6.3	6.3	6.7	44.58	41.57
33	88.04.03	013305.8	49.9	78.9	0	6.1	–	6.4	5.8	6.1	44.59	41.63
34	88.05.04	005706.8	49.9	78.7	0	6.1	–	6.4	5.8	6.2	44.49	41.56
35	88.05.07	225000.0	73.3	53.0	0	5.6	3.8	5.9	–	–	51.22	07.38
36	88.09.14	035957.4	49.8	78.8	0	6.1	4.5	6.3	–	–	44.48	41.71

Table II (*continued*).

No.	Date	O.T.	Location		h km	NEIC			ASN		Distance	Azimuth
	y m d	h min s	(N)	(E)		m_b	M_s	m_b^*	m_{b1}	m_{b2}	degrees	
37	88.11.12	033011.0	50.0	78.9	0	5.3	–	5.6	–	–	44.52	41.68
38	88.12.04	051953.0	72.9	55.6	0	–	–	5.9	6.3	6.4	51.01	08.52
39	88.12.17	041004.0	49.6	79.6	0	–	–	6.4	–	–	44.89	42.24
40	89.01.22	035707.0	49.8	79.0	0	–	–	6.0	6.1	6.2	44.58	41.80
41	89.02.12	041508.0	49.8	78.7	0	–	–	6.0	6.3	6.5	44.40	41.71
42	89.07.08	034654.0	49.4	79.5	0	–	–	5.6	–	–	44.77	42.48
43	82.07.04	012006.8	27.9	136.9	536	6.3	–	6.5	–	–	90.99	63.49
44	82.07.05	085655.6	30.9	130.4	116	5.7	–	5.9	–	–	84.55	57.03
45	82.07.11	131950.9	27.8	56.2	46	5.3	4.4	5.9	–	–	21.79	49.71
46	82.09.02	100348.4	36.5	70.6	210	4.9	–	–	–	–	35.18	59.26
47	82.09.06	014702.7	29.3	140.3	176	6.5	–	6.8	–	–	92.96	56.60
48	82.12.16	004048.7	36.1	69.0	36	6.2	6.6	6.7	6.5	6.1	33.84	59.86
49	82.12.17	024303.6	24.6	122.5	87	6.1	6.2	6.3	6.5	6.3	80.55	68.32
50	82.12.19	194053.1	30.5	57.5	40	5.0	5.9	5.3	–	–	23.30	66.13
51	83.02.07	150627.5	26.8	57.5	33	5.5	5.7	5.6	5.2	4.9	22.87	65.81
52	83.03.24	105556.9	37.1	29.3	10	4.5	4.8	–	–	–	13.82	02.69
53	83.03.26	040719.5	35.9	52.2	33	5.4	4.7	5.5	5.6	5.1	21.06	49.38
54	83.04.05	065033.4	40.0	75.2	33	5.5	5.6	5.6	5.9	5.4	39.45	54.84
55	83.04.15	145159.1	53.3	160.3	65	5.8	–	6.7	–	–	91.03	28.13
56	83.04.18	105851.2	27.7	62.0	64	6.5	–	6.7	–	–	26.90	74.40
57	83.04.21	161853.0	39.3	33.1	11	4.8	4.1	4.8	5.0	4.9	15.73	01.75
58	83.05.01	181040.3	46.3	153.4	24	6.1	6.0	6.0	6.4	5.6	92.27	36.35
59	83.05.28	113551.9	32.5	48.5	18	5.6	5.1	5.3	5.8	5.4	16.77	53.81
60	83.06.09	124903.8	40.2	139.0	31	6.3	6.6	6.6	6.7	6.4	86.76	47.15
61	83.06.09	130400.5	40.3	139.0	28	6.3	5.6	6.4	6.2	5.9	86.46	47.21
62	83.06.21	170651.4	29.7	129.4	158	5.9	6.1	6.5	6.1	5.2	84.22	60.07
63	83.06.24	071822.1	21.7	103.2	18	6.1	6.6	6.7	–	–	64.68	75.98
64	83.07.15	120127.3	40.3	40.2	17	5.7	5.9	5.7	6.1	5.6	17.97	19.45
65	83.07.22	024100.8	36.9	49.1	41	5.6	5.0	5.2	5.8	5.4	19.59	43.05
66	83.09.12	154208.5	36.5	71.0	209	6.1	–	6.8	–	–	35.55	59.49
67	83.10.21	203449.1	40.1	29.3	14	5.1	5.0	5.6	5.8	5.2	16.76	01.73
68	83.10.30	041227.1	40.3	42.2	12	6.1	6.9	6.2	6.3	6.0	18.62	23.60
69	83.12.30	235239.9	36.3	70.7	215	6.6	–	6.8	–	–	35.26	59.39
70	84.01.05	203441.0	36.4	70.5	213	4.9	–	5.6	5.1	4.5	37.40	59.47
71	84.01.27	130140.2	36.4	71.0	172	5.8	5.6	6.3	5.8	5.4	35.49	59.66
72	84.02.01	072828.7	49.0	146.6	573	5.9	5.8	6.1	6.0	5.8	86.94	31.27

Table II (*continued*).

No.	Date y m d	O.T. h min s	Location		h km	NEIC			ASN		Distance degrees	Azimuth
			(N)	(E)		m_b	M_s	m_b^*	m_{b1}	m_{b2}		
73	84.02.16	171841.6	36.4	70.8	208	6.1	–	6.7	6.2	5.7	35.10	35.52
74	84.04.15	073412.0	42.9	131.0	538	5.0	–	5.3	–	–	80.24	47.29
75	84.04.19	025312.7	36.4	70.9	202	5.7	–	6.4	6.2	5.6	35.38	59.56
76	84.04.23	212639.2	36.4	70.7	209	5.3	5.4	5.8	–	–	35.27	59.52
77	84.05.06	151911.4	24.2	93.5	33	5.7	5.6	6.2	6.2	5.6	55.37	75.73
78	84.05.21	153858.7	32.7	121.5	18	5.7	6.0	6.3	5.8	5.2	76.86	51.88
79	84.07.19	232512.8	28.1	129.5	47	6.1	5.6	6.5	–	–	84.97	61.51
80	84.08.06	111437.6	30.8	57.1	33	5.7	5.3	5.8	6.0	5.7	22.78	66.38
81	84.08.15	020058.2	30.9	57.1	33	5.1	4.9	5.3	–	–	22.99	65.91
82	84.08.22	180054.0	36.2	70.5	137	5.4	–	5.8	–	–	36.32	59.86
83	84.10.18	094624.6	40.4	42.4	60	5.3	–	5.5	5.6	5.2	18.89	23.68
84	84.10.26	20222.0	39.2	71.3	33	6.0	–	6.3	–	–	36.32	55.12
85	85.02.02	205234.2	28.4	52.9	37	5.2	5.3	5.3	5.4	5.1	19.01	65.48
86	85.04.24	181756.7	36.3	70.7	212	4.9	–	5.6	–	–	35.21	59.62
87	85.07.29	075444.0	36.2	70.9	99	6.6	–	6.7	–	–	35.36	59.67
88	86.01.14	030337.4	36.3	71.0	245	5.2	–	–	–	–	35.46	59.43
89	86.01.27	163552.8	38.9	48.6	71	5.3	–	5.4	5.6	5.2	20.53	37.95
90	86.04.26	141507.6	36.5	71.1	187	5.6	–	6.3	–	–	35.57	59.49
91	87.01.14	110348.7	42.5	142.8	102	6.5	–	6.3	–	–	88.07	67.98
92	87.03.18	033630.3	32.0	131.8	54	6.4	–	6.8	–	–	85.19	57.10
93	87.04.02	184542.3	36.1	71.1	103	5.7	5.8	5.5	5.3	4.9	35.55	69.48
94	87.10.03	110005.2	36.4	71.4	95	5.9	5.7	6.3	6.1	5.8	35.82	59.66
95	88.02.29	053141.4	55.1	167.4	33	6.1	6.8	6.4	–	–	92.64	62.37
96	88.09.25	212804.8	36.4	70.7	212	5.6	–	6.2	5.8	5.2	35.23	59.51
97	88.09.26	071700.2	36.3	71.3	107	5.6	–	6.0	5.7	5.4	35.74	59.81
98	89.01.03	044112.0	29.5	131.4	40	5.8	5.6	6.4	6.6	6.5	85.93	59.56
99	90.03.15	001242.6	31.6	60.2	16	4.8	4.5	5.1	–	–	25.72	65.46
100	90.03.20	012711.0	35.8	52.9	33	5.5	5.6	5.7	–	–	21.43	58.92
101	90.04.26	093718.5	35.9	100.2	33	6.6	6.9	6.6	–	–	58.96	56.83
102	90.04.26	093749.5	36.4	100.1	33	6.2	–	6.5	–	–	58.79	57.04
103	90.04.30	015547.4	26.8	91.5	33	5.2	–	5.4	–	–	53.03	69.42
104	90.05.15	142520.7	35.9	70.4	117	6.0	–	6.3	6.4	6.1	34.89	59.95
105	90.05.17	132107.3	38.3	74.3	115	5.4	–	5.5	–	–	38.41	56.32
106	90.05.17	232800.9	26.6	127.8	39	6.1	5.9	6.3	6.2	6.1	84.12	58.96
107	90.03.21	224217.4	33.3	54.4	33	4.9	–	5.1	–	–	21.52	47.77
108	90.05.25	141718.6	37.0	72.9	32	6.0	6.7	6.4	6.5	6.3	37.07	57.97

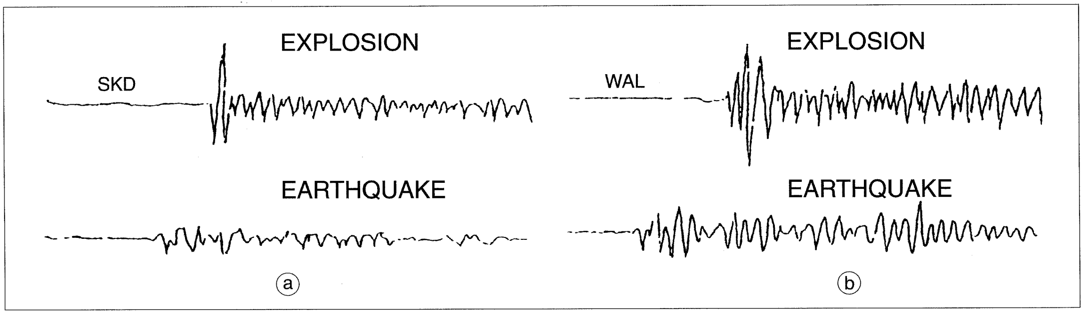

Fig. 4a,b. Example of *S-P* vertical component for two nuclear explosions and two earthquakes recorded by two stations (a = SKD and b = WAL) of ASN with the following source according to NEIC:

	Date	*O.T.*	*Epicentre*		*Depth*	m_b
a)	84.04.25	010903.5	49.9N	78.9E	0	5.3
	84.01.27	130140.2	36.3N	71.0E	172	5.8
b)	84.05.26	031312.4	49.9N	79.0E	0	6.0
	84.10.26	202222.0	39.1N	71.3E	33	6.0

5. Magnitude determination

The well known Gutenberg and Richter (1956) magnitude formula which is applied by NEIC is used at ASN taking into account the calibrated distance depth factor (*Q*). *P*-wave amplitudes for computing body wave magnitude m_b^* are measured from records of ASN. m_b^* were calculated for 105 events. Using the playback for these events, body wave magnitudes at 1 Hz and 2 Hz were calculated for each event. Out of 108 events only 58 events could be used for m_{b1} and m_{b2} determination. m_b and M_s are taken from the NEIC catalogue and EDR. The relationship between m_b (NEIC) and those determined at ASN m_b^* is shown in fig. 5. There is in general a good agreement between them especially at higher magnitude range. The scatter at the higher magnitude range can be attributed to the fact that NEIC magnitudes are average station magnitudes while ASN magnitude is affected by local structures around the network. This may also be attributed to the difference in the nature of the source and/or azimuthal difference in the ray path from the U.S.S.R. or China to ASN. All magnitude data are listed in table II.

6. Results and discussion

We investigated the nature of interrelations among m_b-M_s, m_b^*-M_s and m_{b1}-m_{b2} for natural earthquakes which occurred in Asia and nuclear explosions fired in the U.S.S.R. and China. This was obtained using the Least Square technique (Bassiouni, 1997). Linear fit was applied to the whole data set first. Then only data having a deviation within twice the Root Mean Square (2σ) were accepted and the process was repeated to obtain the best fit. This was followed in three different cases, given below and shown in figs. 6, 7 and 8. Most of the rejected events were found not to have so clear a wave form which led to a misreading of wave amplitude.

Case 1 – The relation between m_b and M_s was constructed using all the data sets of 37 natural earthquakes. It was found that data did not correlate well (LCC = 0.793 and $\sigma = 0.427$). The results have been improved using 34 events with 8.7% of LCC and 17.4% of σ. The result are shown in fig. 6 and the fol-

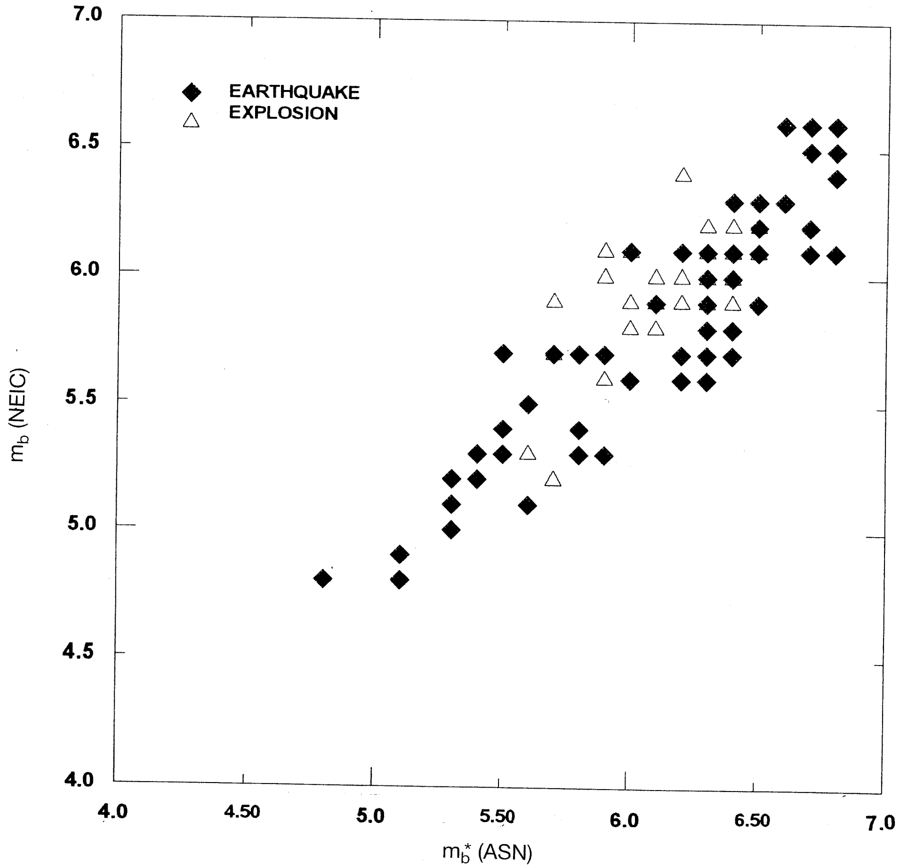

Fig. 5. Relation between m_b^* calculated at ASN and m_b of NEIC.

lowing empirical relation was obtained:

Earthquakes

$$M_s = 1.3052\ (\pm 0.1355)\ m_b - 1.7251\ (\pm 0.7739) \qquad (6.1)$$

$$\text{LCC} = 0.86222 \quad \sigma = 0.35255 \quad n = 34.$$

For nuclear explosions, the whole data set of 30 events gives LCC = 0.6944 and $\sigma = 0.3227$. The best fit was obtained when only 27 events were used. While LCC improved by 3.2% the improvement of RMS (σ) reached 20%. This can be represented by

Explosions

$$M_s = 1.1163\ (\pm 0.2270)\ m_b - 2.2638\ (\pm 1.3279) \qquad (6.2)$$

$$\text{LCC} = 0.71598 \quad \sigma = 0.2270 \quad n = 27.$$

Case 2 – Also the relation m_b^* and M_s was investigated for natural earthquakes and nuclear explosions. In the case of earthquakes, the best fit was obtained when 30 events were selected through the above mentioned criterion. The fit

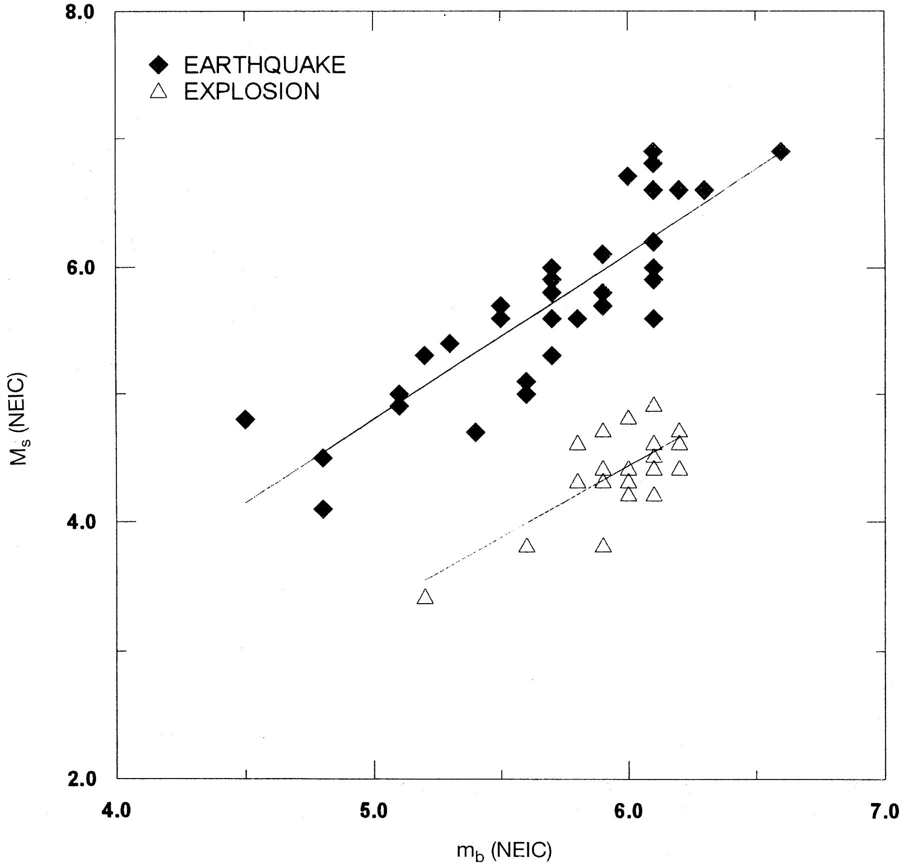

Fig. 6. Relation between m_b (NEIC) and M_s (NEIC) for earthquakes and explosions.

was improved by 9.863% for LCC and 23.839% for RMS. These results are represented by the following equation and illustrated by fig. 7:

Earthquakes

$$M_s = 0.9832\ (\pm 0.1268)\, m_b^* - 0.2071\ (\pm 0.7531) \tag{6.3}$$

LCC = 0.82598 $\sigma = 0.34911$ $n = 31$.

On the other hand, improvement reaches 70.58% for LCC and 84.785% for RMS in the case of 17 nuclear explosions. This led to the following empirical relation which is shown in fig. 7:

Explosions

$$M_s = 0.6539\ (\pm 0.1012)\, m_b^* - 0.2996\ (\pm 0.6366) \tag{6.4}$$

LCC = 0.8600 $\sigma = 0.0657$ $n = 17$.

From fig. 7 and eqs. (6.3)-(6.4) errors associated with the constant are relatively large (≈ 3 times the values). This may be due to the limited coverage of data.

From figs. 6 and 7 it can be seen that nuclear explosions are clearly distinguished from natural earthquakes especially in the large

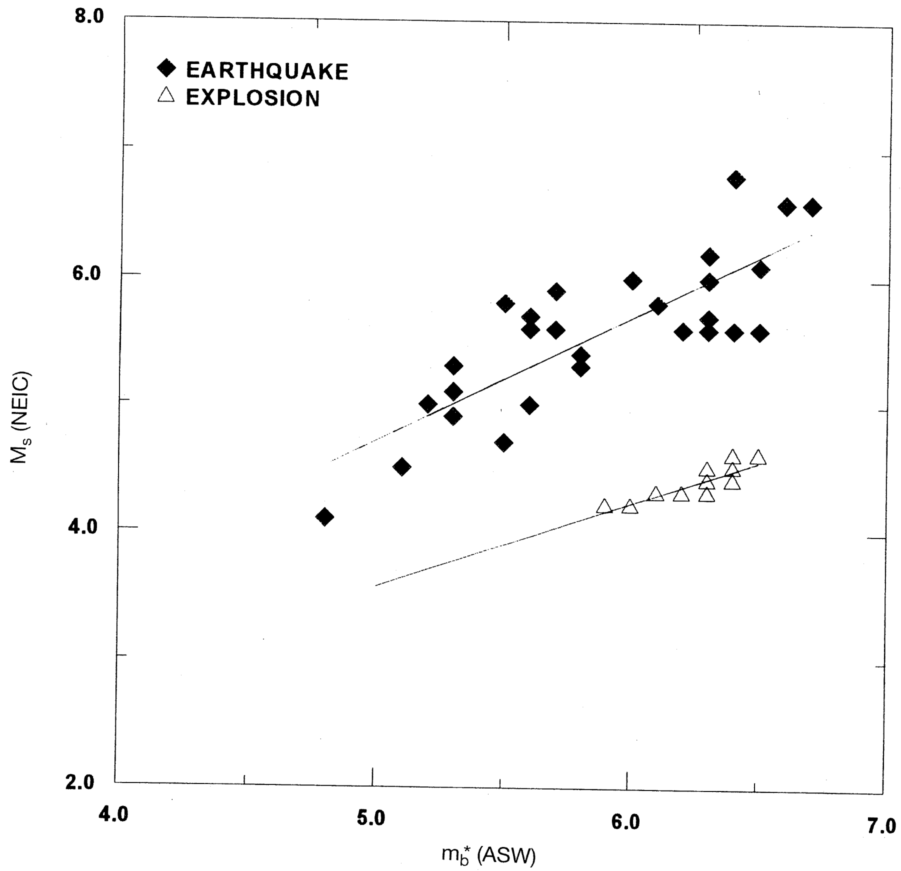

Fig. 7. Relation between m_b^* and M_s for earthquakes and explosions.

magnitude range where the local effect on the magnitude determination is considered to be minor. Since these events have almost the same magnitude, and lie almost at the same azimuth, the separation can mainly be attributed to the difference in the source nature. From these two figures, it can be seen that:

– M_s for explosions is smaller than that of the earthquakes with the same m_b.

– m_b for explosions is larger than that of earthquakes with the same M_s.

– Most of the released energy from explosions is confined in the range of the higher frequencies while it is distributed in the large frequency range in the case of earthquakes.

Case 3 – Body wave magnitude was calculated using ASN data for both earthquakes (34 events) and nuclear explosions (24 events) at 1 Hz (m_{b1}) and 2 Hz (m_{b2}). The best fit was obtained for earthquakes when 31 events were used. Improvement reaches 4.086% for LCC while RMS was improved by 36.834%. These results can be seen in fig. 8 and are represented by the following relation:

Earthquakes

$$m_{b2} = 1.3541\ (\pm 0.6163)\ m_{b1} + 1.918\ (\pm 0.3685) \qquad (6.5)$$

$$\mathrm{LCC} = 0.9598 \qquad \sigma = 0.1353 \qquad n = 31.$$

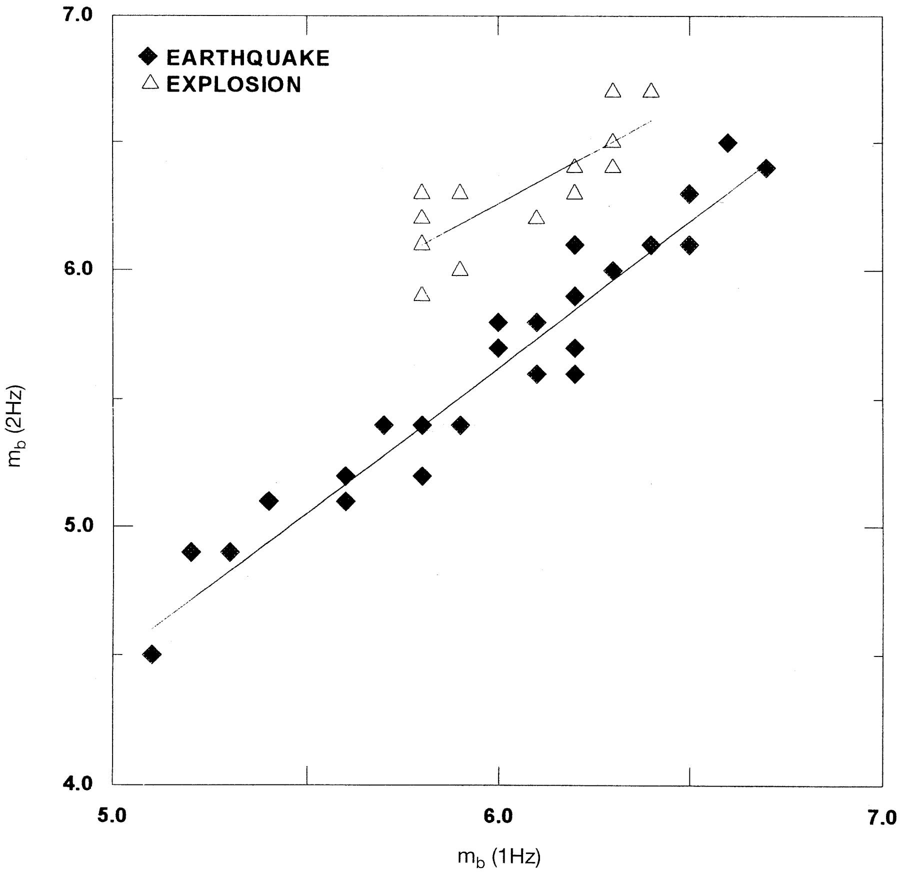

Fig. 8. Relation between m_{b1} at 1 Hz and m_{b2} at 2 Hz measured from ASN data for earthquakes and explosions.

In the case of nuclear explosions, rejection of the scattered data (events) enhanced the fit with improvement of 21.381% for LCC and 33.628% for RMS. The relation between m_{b1} and m_{b2} found is represented by the following equation:

Explosions

$$m_{b2} = 0.8121\,(\pm 0.1311)\, m_{b1} + 1.3867\ (\pm 0.8022) \tag{6.6}$$

$$\text{LCC} = 0.8178 \qquad \sigma = 0.1226 \qquad n = 21.$$

Figure 8 shows the relationship between m_{b1} (ASN) and m_{b2} (ASN) for natural earthquakes and nuclear explosions having almost the same magnitude and azimuth ranges from ASN and recorded by ASN. It can be seen that explosions have a higher m_{b2} than earthquakes having the same m_{b1}. This is due to the fact that most of the released energy from explosions is confined in the range of higher frequencies while it is distributed in a large frequency range in the case of earthquakes.

7. Conclusions

Records of 66 natural earthquakes and 42 nuclear explosions which occurred in the

U.S.S.R., China, India and Turkey regions wer analyzed. These events were recorded at ASN. Trials were done to check the validity of $m_b : M_s$ and $m_{b1} : m_{b2}$ criteria in order to discriminate between natural earthquakes and nuclear explosions for ASN data. One can conclude that the relative excitation of surface and body waves due to explosions are compared to those of earthquakes provides a reliable method of discrimination. The $m_b : M_s$ criterion is applicable to discriminate between underground nuclear explosions and natural earthquakes.

In addition, comparison of *P*-wave magnitude for natural earthquakes and nuclear explosions at a certain frequency band gives us a good criterion for discrimination.

Specifically, $m_{b1} : m_{b2}$ proved to be a reliable method to discriminate between underground nuclear explosions and natural earthquakes. Nevertheless, the derived $m_b : M_s$ and $m_{b1} : m_{b2}$ relations cannot be applied under all circumstances. Its validity has geographical dependence.

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