

Estimation of seismic moments from local magnitudes and coda durations for the Cairo earthquake aftershocks recorded at Kottamyia (KEG) Broadband station

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Abstract

The spectral analysis of fifty-five KEG VBB records from the October 12, 1992 Cairo earthquake source region was performed to obtain the seismic moment. We obtained this parameter in turn to develop empirical local magnitude (M_L), seismic moment (M_o), coda duration (D) relations for that region. In this study the data consist of L_g -waves on the vertical component seismograms for the recorded earthquakes with M_L ranging from 1.7 to 4.7. The derived empirical relation between the seismic moment (M_o) and magnitude M_L for the aftershocks sequence with $1.7 \leq M_L < 3.5$ is $\text{Log}(M_o) = (0.96 \pm 0.05) M_L + (17.88 \pm 0.13)$. We found a correlation between the coda duration (D) and Log of the moment ($\text{Log}(M_o)$) as follows: $\text{Log}(M_o) = (2.35 \pm 0.27) \text{Log}(D) + (16.33 \pm 0.48)$.

Key words aftershocks – seismic moment – scaling

1. Introduction

On 12th of October 1992 a moderate size earthquake of $M_w = 5.8$ occurred at epicentral distance of about 25 km south west of Cairo city downtown in Dahshour region (fig. 1) at a depth of 22 km. This earthquake was felt from Alexandria to Aswan. It registered a maximum observed intensity of 7+ in MSK intensity scale in Dahshour region (Maamoun *et al.*, 1993). This shock caused considerable

damage to the buildings in the eastern part of Cairo, Giza and the northern area of Fayoum. Significant damage was found mostly in adobe and old non-reinforced brick masonry buildings and non-engineering reinforced concrete buildings. In addition, extensive liquefaction of deltaic silty sand deposits (sand plumes) was observed in some cultivated fields of Giza Governorate located 19 km from the epicenter. According to eyewitnesses, sand and water continuously blew up to a height of 3 m for about 45 min (Maamoun *et al.*, 1993).

The October 12, 1992 Cairo earthquake struck a previously known low seismicity zone. The only significant earthquake reported in this region during the historical period occurred in 1847. This mainshock was followed by an aftershock sequence. Within twenty two days after the occurrence of the Cairo earth-

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quake 55 shocks with $1.7 \leq M_L \leq 4.7$ were recorded by Kottamiya (KEG) Broadband station. The event data are given in table I. Figure 1 shows the distribution of the well located aftershocks of 1992 Cairo earthquake. Aftershocks sequence was recorded by a temporary seismic network installed by National Research Institute of Astronomy and Geophysics during the first twenty days of this sequence. Details about the seismic network and the procedure for determination of the hypocenters were described by Abou El Enein *et al.* (2000). However, the pattern of the aftershocks reflects a cluster rather than a clear trend of seismicity.

Teleseismic body wave inversion of the mainshock (Hussein, 1999) suggested a normal faulting mechanism with a small strike slip component on a plane striking EW to WNW-ESE and dipping to the east (fig. 1).

The purpose of this study is to calculate the seismic moments of Cairo earthquake aftershocks recorded by the KEG Broadband station during the first three weeks after the occurrence of the mainshock using the ground displacement spectra of L_g waves and to develop empirical formulas for estimating M_0 from both M_L and coda duration.

2. Data

Fifty-five Cairo earthquake aftershock sequences recorded during the three weeks after the occurrence of the mainshock of the October 12, 1992 earthquake were used in this study. Event data are given in table I. The local magnitude (M_L) of these events varied from 1.7 to 4.7. All of these earthquakes are of crustal origin. Figure 1 shows the location of KEG station. KEG station is a part of the MEDNET project (Gardini *et al.*, 1992). The seismic records were electronically digitized at a rate of 20 samples per second by STS-1 VBB velocity type sensor. For frequencies between 0.003 and 7 Hz the velocity response is flat with a full dynamic range of 140 dB. KEG station was the only available digital recording station in Northeast Africa and Egypt in 1992.

3. Method of analysis

In this work, a time window that started shortly before the L_g arrival, depending on the size of earthquake was obtained from the vertical component seismometer of KEG STS-1 VBB. The time window was nearly 10 s long. The digital data within the time window were corrected for the instrumental response, transformed to frequency domain using fast Fourier transformation. This spectrum was then integrated to obtain the displacement spectra. Typical spectrum examples are shown in fig. 2.

The spectrum was corrected for attenuation by multiplying it by the transfer function $e^{-\gamma r}$ where r is the distance from the source to the receiver and γ is the coefficient of anelastic attenuation which is related to the quality factor Q (Nuttli, 1986)

$$\gamma = \frac{\pi \cdot f}{U \cdot Q} \quad (3.1)$$

f is the wave frequency and U is the L_g -wave group velocity. Dessokey *et al.* (2000) obtained the γ value of 0.001497 km^{-1} for 1 Hz L_g in Dahshour region.

From the corrected spectrum, the low frequency spectral level was estimated. The low frequency level (Ω_0) was estimated visually by fitting a straight line at the low frequency spectra.

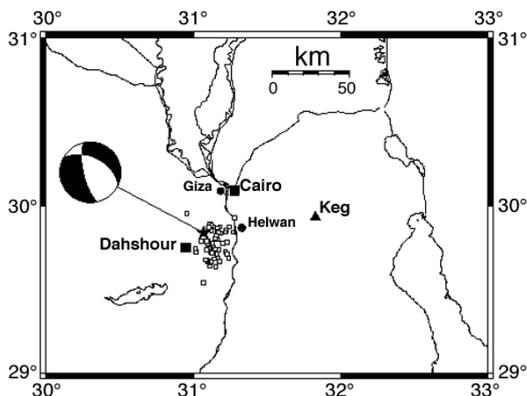


Fig. 1. Aftershocks of Dahshour earthquake of 1992 (open squares). The fault plane solution of the main shock (star) is also shown.

Table I. List of earthquakes used in this study.

Event No.	Date y.m.d	Origin time h min s	Lat. °N	Long. °E	Depth (km)	M_D (HLW)	M_L
1	1992.10.12	13 50 9.65	29-46.94	31-13.66	10.93		2.5
2	1992.10.12	14 11 8.64	29-43.33	31-9.12	18.84		2.3
3	1992.10.12	14 15 7.43	29-57.23	30-57.28	25.09		2.8
4	1992.10.12	14 58 14.73	29-52.55	31-14.55	22.32		1.8
5	1992.10.12	15 07 42.05	29-53.52	31-6.80	26.85		2.3
6	1992.10.12	15 25 24.65	29-52.48	31-6.83	29.55		4.7
7	1992.10.12	15 52 50.77	29-51.24	31-9.94	22.77		2.3
8	1992.10.12	16 55 9.79	29-50.29	31-11.01	25.59		2.4
9	1992.10.12	18 31 42.36	29-47.89	31-9.82	21.14		2.2
10	1992.10.12	19 55 59.20	29-51.15	31-13.38	19.10		2.2
11	1992.10.12	21 31 34.22	29-40.00	31-7.06	20.73		4.2
12	1992.10.12	21 46 16.02	29-43.61	31-13.10	9.83	2.9	2.5
13	1992.10.12	23 34 22.50	29-55.72	31-16.90	17.10	3.0	2.7
14	1992.10.12	23 46 24.42	29-44.40	31-10.38	21.78	2.9	2.1
15	1992.10.13	18 09 8.14	29-52.44	31-10.98	22.39	3.4	3.7
16	1992.10.13	18 34 54.26	29-50.62	31-13.15	20.72		3.2
17	1992.10.13	23 27 56.39	29-53.00	31-7.37	32.02	2.4	2.2
18	1992.10.14	02 44 23.14	29-52.16	31-9.69	30.25	3.1	2.8
19	1992.10.14	03 50 14.53	29-46.63	31-6.43	29.49	3.4	2.8
20	1992.10.14	09 40 27.04	29-43.49	31-1.28	27.64	4.0	4.2
21	1992.10.14	10 41 57.34	29-46.67	31-7.99	22.95	2.6	1.9
22	1992.10.14	12 09 15.72	29-43.34	31-5.99	20.53		3.0
23	1992.10.14	13 46 39.47	29-50.45	31-10.37	28.51	3.5	3.2
24	1992.10.14	14 23 44.67	29-41.18	31-14.42	20.22	3.1	2.4
25	1992.10.14	14 31 27.90	29-43.41	31-6.98	24.97	3.3	2.9
26	1992.10.14	20 16 11.05	29-49.25	31-9.74	20.94	2.6	2.3
27	1992.10.15	12 13 41.41	29-48.25	31-9.02	25.52	2.6	2.0
28	1992.10.16	03 28 51.46	29-47.29	31-5.79	24.12	2.5	2.0
29	1992.10.16	05 56 11.84	29-47.31	31-3.17	30.70	3.1	2.9
30	1992.10.16	09 57 46.87	29-47.50	31-5.51	26.25	3.3	3.1
31	1992.10.16	18 07 53.12	29-51.50	31-7.49	24.20	2.6	2.4
32	1992.10.17	01 35 28.51	29-45.06	31-8.25	25.44	2.6	2.0
33	1992.10.18	08 12 16.12	29-43.38	31-8.40	20.74	3.4	2.9
34	1992.10.18	13 04 28.44	29-42.75	31-13.80	18.50	3.0	2.6
35	1992.10.19	10 46 30.95	29-42.67	31-9.58	21.58	2.9	2.2
36	1992.10.19	12 30 16.44	29-44.22	31-6.30	25.20	3.2	3.0
37	1992.10.19	14 59 50.43	29-44.50	31-8.87	18.68	3.3	3.2
38	1992.10.20	06 00 30.77	29-32.36	31-4.27	22.28	2.7	1.7
39	1992.10.20	17 28 28.44	29-40.39	31-9.24	20.62	2.5	2.0
40	1992.10.20	23 14 47.46	29-43.08	31-7.65	17.20	3.1	3.1
41	1992.10.21	18 09 27.53	29-46.47	31-2.00	14.65	2.7	2.0
42	1992.10.22	08 28 58.70	29-44.83	31-6.53	21.90	3.4	3.4
43	1992.10.22	17 38 57.30	29-40.62	31-5.68	22.88	3.9	4.6
44	1992.10.23	02 40 5.43	29-44.21	31-5.46	22.85	2.6	2.2
45	1992.10.23	15 12 10.08	29-41.39	31-10.00	22.40	3.8	3.3
46	1992.10.23	16 02 4.12	29-44.78	31-7.38	21.70	2.4	1.7
47	1992.10.25	09 05 4.64	29-40.09	31-10.71	22.05	3.1	2.8
48	1992.10.25	12 26 15.06	29-39.93	31-5.95	24.12	3.1	2.7
49	1992.10.25	16 21 05.28	29-38.35	31-6.70	22.92	2.9	2.3
50	1992.10.25	19 45 34.56	29-40.97	31-8.52	23.78	2.3	3.2
51	1992.10.26	06 45 23.96	29-52.40	31-6.49	27.45	3.4	3.3
52	1992.10.26	08 43 52.01	29-40.55	31-5.75	28.25	2.8	2.4
53	1992.10.28	06 20 54.90	29-37.30	31-3.63	24.63	2.9	2.5
54	1992.10.28	18 25 56.28	29-50.64	31-16.07	19.46	2.8	2.5
55	1992.10.30	14 08 11.19	29-40.70	31-5.09	25.71	3.0	2.7

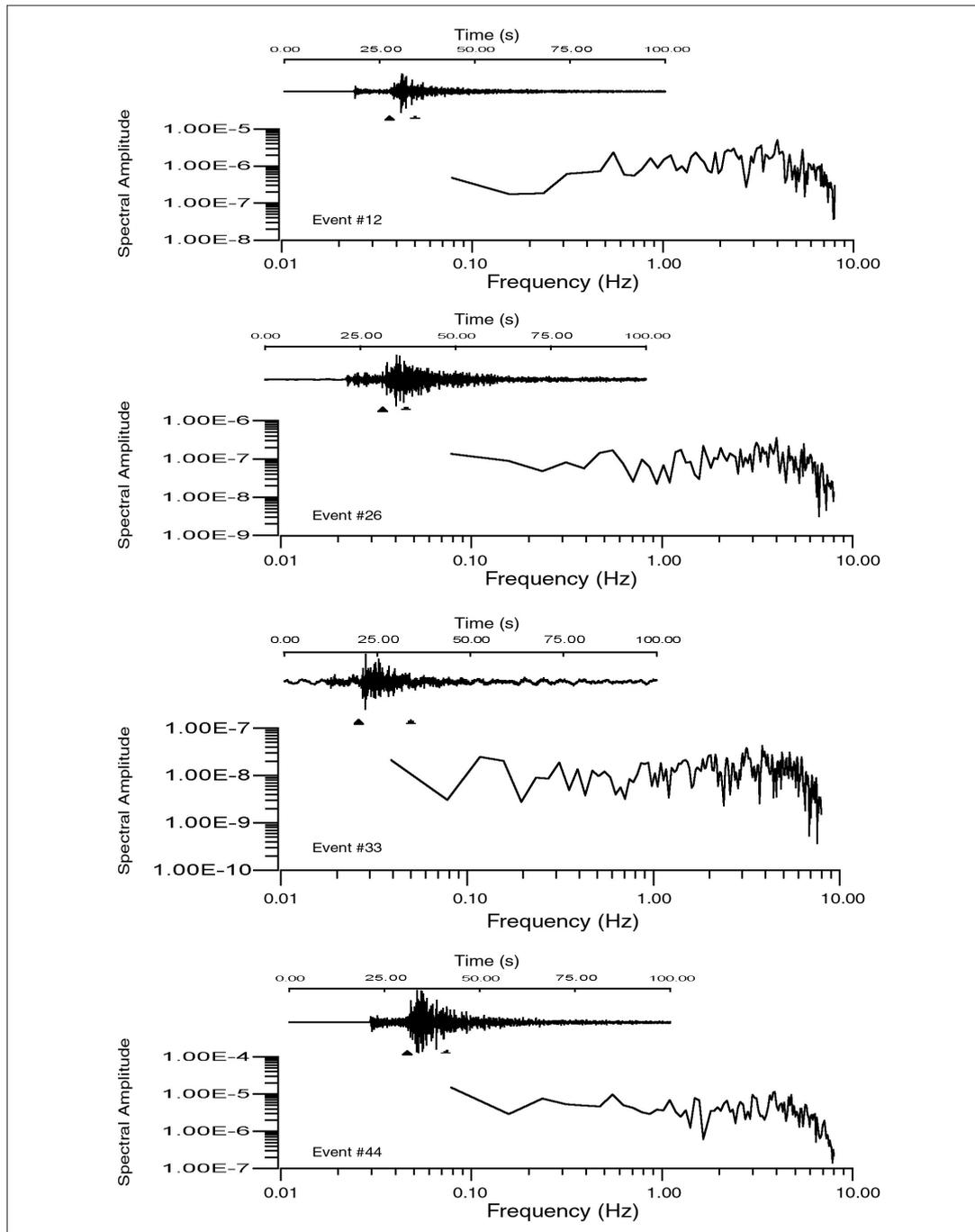


Fig. 2. Displacement spectra for L_g -waves for some selected events.

The seismic moments (M_o) were derived for the 55 recorded events from the low spectral level (Ω_o) using Street *et al.* (1975)'s formula that was subsequently derived by means of theoretical model by Herrmann and Kijko (1983)

$$M_o = 4\pi\rho\beta^3 R_o(R/R_o)\Omega_o \quad R < R_o$$

$$M_o = 4\pi\rho\beta^3 R_o(R/R_o)^{1/2}\Omega_o \quad R \geq R_o \quad (3.2)$$

where ρ is the density of the medium, β is the shear wave velocity, R is the epicentral distance and R_o is the reference distance. The reference distance R_o is related to different kinds of L_g -waves geometric spreading.

4. Results

4.1. Seismic moment coda duration and local magnitude

The seismic moment M_o is a measure of an earthquake strength defined in terms of parameters of double couple shear dislocation source model (Aki, 1966). It provides a better description of the real size of an earthquake.

On the basis of previous empirical results, the seismic moments of the events under study were estimated using eq. (3.2). Constant values corresponding to Cairo earthquake source region in eq. (3.2) were selected as follows: $\rho = 2.7 \text{ gm/cm}^3$, $\beta = 3.5 \text{ km/s}$ and $R_o = 100 \text{ km}$. The seismic moment estimated was found to range from 3.5×10^{19} to 2.5×10^{22} dyne-cm. The calculated seismic moments using eq. (3.2) are listed in table II.

The scatter for the events having a duration longer than 108 s (fig. 3) is due to the small number of longer duration shocks. To obtain a more appropriate relation between the moment and the duration, a mathematical regression between the reported seismic moments and the corresponding coda durations D was made for $30 \leq D \leq 108$ s. The coda duration in seconds used in this study was obtained from the available analog seismographic stations installed at the time of the earthquake. It was taken from the P arrival to the point in the coda where the seismic amplitude is nearly twice the back-

Table II. Seismic moment of the events under study.

Event No.	Duration (s)	M_L	M_o (dyne · cm)
1		2.5	1.942783E + 20
2		2.3	2.267175E + 20
3		2.8	2.836813E + 20
4		1.8	5.468023E + 19
5		2.3	7.922314E + 19
6	279	4.7	2.267175E + 22
7		2.3	8.386375E + 19
8		2.4	1.225617E + 20
9		2.2	1.28611E + 20
10		2.2	1.520192E + 20
11	169	4.2	7.825914E + 21
12	57	2.5	1.021348E + 20
13	65	2.7	7.1504E + 20
14		2.1	8.689964E + 19
15	161	3.7	2.028367E + 21
16	1992	3.2	7.671786E + 20
17	37	2.2	6.70293E + 19
18	56	2.8	3.1557E + 20
29		2.8	4.717935E + 20
20	237	4.2	5.429151E + 21
21		1.9	5.667937E + 19
22	34	3.0	3.666106E + 20
23		3.2	4.157197E + 20
24		2.4	4.071058E + 20
25	69	2.9	4.769604E + 20
26	45	2.3	6.387174E + 19
27	35	2.0	6.550127E + 19
28		2.0	3.571662E + 19
29	108	2.9	5.07458E + 20
30	62	3.1	7.187676E + 20
31		2.4	2.237957E + 20
32	35	2.0	6.845436E + 19
33	78	2.9	4.614945E + 20
34	63	2.6	3.037181E + 20
35	39	2.2	9.024836E + 19
36	85	3.0	7.510935E + 20
37	79	3.2	6.659202E + 20
38		1.7	2.856025E + 19
39	30	2.0	5.832978E + 19
40	87	3.1	9.421127E + 20
41		2.0	6.235795E + 19
42	94	3.4	1.637872E + 21
43		4.6	2.522325E + 22
44	34	2.2	1.227609E + 20
45		3.3	1.490997E + 21
46		1.7	3.499786E + 19
47	55	2.8	4.527036E + 20
48	68	2.7	5.052129E + 20
49	38	2.3	1.011922E + 20
50		3.2	7.076904E + 20
51	99	3.3	1.602396E + 21
52	34	2.4	1.00893E + 20
53	59	2.5	2.729787E + 20
54	50	2.5	1.03903E + 20
55		2.7	3.834036E + 20

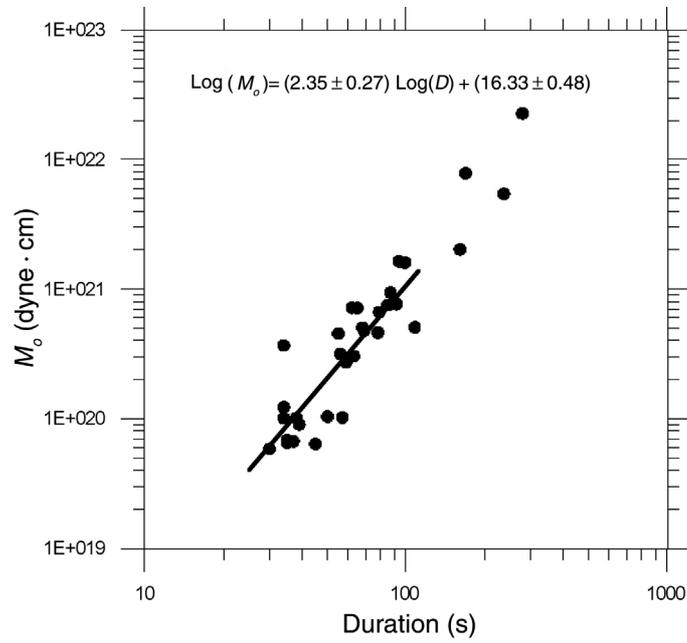


Fig. 3. Seismic moment (M_o)-coda duration relation of Dahshour aftershocks.

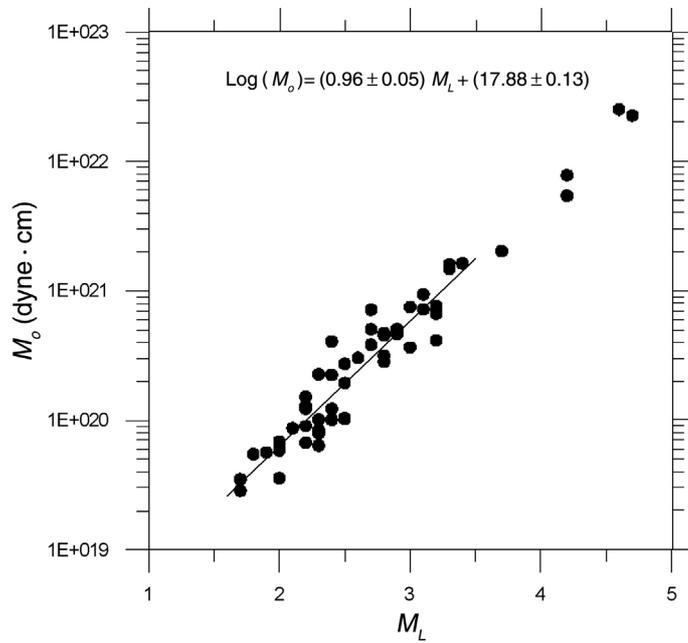


Fig. 4. Plot of seismic moment *versus* local magnitude.

ground noise amplitude. The linear regression fitting of the data as shown in fig. 3 indicates the following relation:

$$\text{Log}(M_o) = (2.35 \pm 0.27) \text{Log}(D) + (16.33 \pm 0.48) \quad (30 \leq D \leq 108). \quad (4.1)$$

Estimation of seismic moment from a simple parameter such as coda duration is very useful, as it allows the estimation of the source size of local earthquakes for the moment range 3.5×10^{19} to 1.6×10^{21} dyne · cm. Our linear moment magnitude relation over the available duration range results in mean root square error of 0.05 in $\text{Log}(M_o)$. The obtained relation for all the available moment range is insufficient for meaningful comparison with the published $\text{Log}(M_o)$ - $\text{Log}(D)$ relations in different tectonic provinces.

The seismic moment-local magnitude relation of the form $\text{Log}(M_o) = cM_L + D$ should be carried out carefully (Shapira and Hofstetter, 1993). Bakum (1984) and Hanks and Boore (1984) detected a change in c value in this relation at $M_L \approx 3.5$, usually undetected due to a large number of $M_L < 5.0$ and relatively small number of $M_L > 5.0$ earthquakes. Using these recommendations, the moment magnitude relation is obtained for the selected 50 earthquakes in the range $1.7 \leq M_L < 3.5$. In this work, a change in the moment magnitude relation at $M_L \approx 3.5$ could not be observed due to small number of larger events. Figure 4 shows the seismic moment *versus* local magnitude M_L . The least square fitting gives the following equation:

$$\text{Log}(M_o) = (0.96 \pm 0.05) M_L + (17.88 \pm 0.13) \quad (1.7 \leq M_L < 3.5). \quad (4.2)$$

This relation is valid for earthquakes with $1.7 \leq M_L < 3.5$ and seismic moment in the range 3.5×10^{19} to 1.6×10^{21} dyne·cm. The average root mean square difference in the estimated $\text{Log}(M_o)$ is 0.028. The relation is in a fair agreement with $\text{Log} M_o = 1.1 M_L + 17.9$ for $M_L \leq 4.1$, this relation was obtained by Fletcher *et al.* (1984) for aftershocks of

Orville, California earthquake. Performing a least square fitting of $\text{Log} M_o$ *versus* M_L for $M_L \leq 4.1$ yields almost identical values to eq. (4.2) $\text{Log}(M_o) = (0.95 \pm 0.05)M_L + (17.90 \pm 0.13)$. The slope of the least square fitting between $\text{Log}(M_o)$ and M_L is near one. A slope of about 1.0 for the moment-magnitude relationship seems to be similar to those obtained in many proposed moment magnitude relations for Mammoth lakes, California (Archuleta *et al.*, 1982), Oroville, California (Fletcher *et al.*, 1984), Hawaii (Savage and Mayer, 1985), California (Chen and Chen, 1989), Baltic shield (Kim *et al.*, 1989) and Petlan, Mexico (Valdes *et al.*, 1996). Randall (1973), Archuleta *et al.* (1982), and Fletcher *et al.* (1984) demonstrated that the slope of 1.0 for moment magnitude relations can be explained by the response of the Wood-Anderson instrument since the corner frequency of small events is greater than the cutoff frequency of 1.2 Hz Wood-Anderson instrument.

5. Conclusions

Seismic moment M_o , logarithm of the coda duration and the local magnitude empirical relations were derived for the aftershocks of 1992 Cairo earthquake source area, providing a simple and straightforward way to quantify the source strength M_o through such relationships, which is superior to any magnitude scale. The resulting estimate of seismic moment, from local magnitudes and coda duration imply the following:

- Seismic moment and local magnitude data are consistent with $\text{Log}(M_o) = (0.96 \pm 0.05) M_L + (17.88 \pm 0.13)$. The rms precision in $\text{Log}(M_o)$ is 0.028.

- Coda durations are related to seismic moment by the following linear relation: $\text{Log}(M_o) = (2.35 \pm 0.27) \text{Log}(D) + (16.33 \pm 0.48)$ with a rms precision of 0.05 in $\text{Log}(M_o)$.

The derived empirical relationships are valid only for Cairo earthquake source region (Dahshour) as recorded at KEG broadband station. Their significance is only available in the 3.5×10^{19} to 1.6×10^{21} dyne·cm moment range and 1.7 to 3.4 local magnitude range.

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(received January 15, 2003;
accepted November 4, 2003)