TAO, Vol.4, No.3, 257-271, September 1993

Aspects of Large Taiwan Earthquakes and Their Aftershocks

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(Manuscript received 1 May 1993, in final form 8 September 1993)

ABSTRACT

From the data of 31 large Taiwan earthquakes and their aftershocks published by Hsu (1971, 1980, and 1985) and reported in the Earthquake Data Report (EDR) by USGS, several aspects of mainshocks and their aftershocks are studied. Results show that the magnitude difference (ΔM) between mainshock and the largest aftershock increases with mainshock magnitude (M). The linear relations of ΔM vs. M are different for two data sets. The difference of original times of mainshock and the largest aftershock more or less decreases with magnitude of mainshock. The departure of the M_s-m_b scaling of the mainshock from that of aftershocks is bigger for larger mainshocks than for smaller ones. The mainshock magnitude cannot be estimated from the logN-M relation from aftershocks and is actually larger than the maximum magnitude evaluated from the relation.

1. INTRODUCTION

Excluding swarms, almost all larger earthquakes are followed up by aftershocks. There is a close relation between the mainshock and aftershocks. Numerous properties of mainshock and aftershocks have been studied for the understanding of the physical relation between mainshock and aftershock and the possible transition process from mainshock to aftershocks. Omori (1896) first proposed a power law to describe the number of aftershocks with time: $n(t)=k/t^p$. This power law is called as Omori's law. Hereafter, Richter (1958) found that the difference in the surface-wave magnitude values of larger shallow-focus earthquakes and the largest aftershocks is about 1.2, and he named the rule as "Båth's law". The difference was found to depend on mainshock magnitude, time of occurrence, region and depth, being larger for deeper events (Båth, 1965, 1977; Utsu, 1969, 1970, and 1971; Vere-Jones, 1969; Gibowicz, 1973; Olsson, 1973; Purcaru, 1974; Okada, 1979; Papazachos, 1981; Papazachos and Comninakis, 1982; Lomnitz and Nava, 1983; Singh *et al.*, 1983). It was also found that the finite magnitude difference significantly affects the shape of the recurrence curve for two earthquake populations of mainshocks and aftershocks, and the phenomenum of double

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population was demonstrated in the recurrence curves for earthquakes in the seismically active region (Båth, 1980, 1981, and 1983; Wesnousky *et al.*, 1983; Singh *et al.*, 1983). For large earthquakes ($M \geq 5.5$) within the western Cordillera of the United States, Doser (1989) found that the average value of magnitude difference between mainshocks and their largest aftershocks is 1.03 ± 0.47, and the difference somewhat decreases with increasing heat flow. The difference in time (T) between mainshock and the largest aftershock in an earthquake sequence is also a significant parameter. For 59 Fennoscandian earthquake sequences, Båth (1984) reported that the frequency of earthquake sequence with T decreases with T, and the average value is about 7.0 ± 6.3 months. It is obvious that the standard deviation is quite large.

Tucker and Brune (1977) compared the m_b and M_s values of aftershocks of the 1971 February 9 San Fernando, California earthquake, and concluded that almost all data points of m_b vs. M_s lie within 1 standard deviation of the straight line with slope of 1. This means that the source properties of aftershocks of this earthquake show unique m_b-M_s scaling. The body-wave magnitude (m_b) is determined from the amplitude of short-period (~1 sec) teleseismic P waves, and the surface wave magnitude (M_s) from the amplitude of long-period (~20 sec) Rayleigh waves. Hence, the relation of the two magnitude scales is considered to be capable of showing the source scaling (Aki, 1967, 1972; Kanamori and Anderson, 1975) and plate tectonic characteristics (Nuttli, 1983a, b), and can be used for distinguishing nuclear explosions from earthquakes (Marshall and Basham, 1972).

Gutenberg and Richter (1944) first proposed the following relation:

$$logN = a - bM \tag{1}$$

to correlate earthquake magnitude M to the cumulative number (N) of events with magnitude greater than or equal to M. This relation is commonly considered to be the typical of earthquakes in a broad region as suggested by Gutenberg and Richter (1944), and Ishimoto and Iida (1939), but also for earthquakes in a single fault or fault segment (Nur, 1978; Hanks, 1979; Andrews, 1980; von Seggern, 1980). Wesnousky *et al.* (1983) called this model the b value model. However, geological work by Allen (1968), Wallace (1970) and Matsuda (1977) shows a strongly dissimilar result that faults or fault segments generate earthquakes of a characteristic size that is a function of fault length and tectonic settings, and that those events and their foreshocks and aftershocks account for all seismic slip on a fault. Actually, numerous observations show that the maximum magnitude model holds for earthquakes occurring in a fault (Wesnousky *et al.*, 1983; Singh, 1983; Schwartz and Coppersmith, 1984; Davison and Schulz, 1985). Wesnousky *et al.* (1983) called this model the maximum magnitude model. The maximum magnitude of an earthquake in a region, or a fault or a fault segment can be predicted from observed data through Eq. (1) for the b value model but not from the maximum magnitude model.

This work is made for studies on the difference in magnitude and occurrence time of mainshocks and the largest aftershocks, the M_s-m_b relations and the logN-M relations for mainshocks and aftershocks for several large Taiwan earthquakes.

2. DATA

The data used consists of two sets: the first set is for the events, occurring in the period from 1901 to 1978, reported by Hsu (1971, 1980, 1985); and the second one is for the events, occurring from 1977 to 1991, from the Earthquake Data Report. The magnitude scale used by Hsu (1971) is the Hsu's magnitude (M_H), and the magnitude scales used in the EDR are of two types: surface-wave magnitude (M_s) and body-wave magnitude (m_b). Wang (1992) stressed that although the M_H was determined from the local seismic data, it is like the surface-wave magnitude (M_s).

From the data reported in the National Earthquake Information Service Catalogue, Tajima and Kanamori (1985) showed that the aftershock activity of a 1966 offshore Hualien, Taiwan earthquake was mainly in the 100 days after the mainshock occurrence and the linear size of the related aftershock area was about 50 km. From local seismic data published by the Central Weather Bureau, Chan (1985) reported that the aftershock activity of 1972 Juisui, Taiwan earthquake was mainly in the 100 days after the mainshock occurrence and the linear dimension of the aftershock area was about 50 km. A similar result can also be seen from the results by Chen and Wang (1984) for the 1983 Taipingshan, Taiwan earthquake. Hence, 100 days is considered to be a good interval for the selection of aftershocks. Since the uncertainty in determining the earthquake epicenter is larger from global data than from local data, the linear dimension of 50 km is also a good criterion for the choice of aftershocks. Under the two criteria, 13 mainshocks (No. 1-No. 13 in Table 1) with totally 39 aftershocks from 1906 to 1965 were selected from the first data set, and 18 mainshocks (No. 14-No. 31 in Table 1) with totally 78 aftershocks from 1977 to 1991 were selected from the second data set. The events for the first data set have M_H values greater than 5.0 and those for the second data set have M_s values larger than 4.0. For the 1951 Hualien, eastern Taiwan earthquake sequence, since two large aftershocks with the same magnitude values occurred on the same day and at nearly the same place, that earthquake sequence is not selected in this study.

The related source parameters of earthquakes used are listed in Table 1. The code "No" displays the earthquake sequence. The earthquake sequences from No. 1 to No. 13 belong to the first data set and those from No. 14 to No. 31 belong to the second one. The first event of each sequence is the mainshock. The largest aftershock is denoted by a symbol "☆" in Table 1. For sequences No. 3 and No. 4, the largest aftershocks have magnitude values very close to those of their mainshocks, and values of difference in magnitude are 0.4 and 0.0, respectively. The localities of mainshocks are shown in Figure 1: The open cycles represent the mainshocks before 1965 (the first data set), and the solid cycles denote the mainshocks after 1977 (the second data set). Out of 31 mainshocks, 4 (13%) were located in western Taiwan and 27 (87%) in eastern Taiwan. It is noted that there was no earthquake in western Taiwan for the second data set.

3. RESULTS AND DISCUSSION

The data points of the difference in magnitude values (ΔM) of the mainshock and the largest aftershock versus the magnitude (M) of the mainshock are shown in Figure 2. The data points for the first data set are shown by open circles and those for the second data set by solid circles. Essentially, the ΔM values of the first data set are smaller than those of the second data set. For the two data sets, the ΔM values increase with the magnitude of mainshock. Meanwhile, except for few data points, the data points of the two data sets are somewhat close to each other for $M < 6.5$, but separate for $M > 6.5$. It is noted that the ΔM value is not remarkably locality-dependent. The two lines shown in Figure 2 are the regression lines for the two data sets. The regression equations are:

$$\Delta M_H = (-1.377 \pm 0.910) + (0.279 \pm 0.137) M_H \qquad (2)$$

Table 1. The earthquake data used in this study. The first event is the mainshock and the event denoted by a open star is the largest aftershock.

No	Date	Lat.	Long.	H(km)	M_H	m_b	M_S
01	190603162242	23.500	120.500		7.10		
	190603261129	23.500	120.500		5.00		
	190604070053	23.500	120.500		5.50		
	190604072240	23.500	120.500		5.50		
	☆190604131918	23.500	120.500		6.60		
	190604140752	23.500	120.500		5.80		
02	191701041655	23.900	120.900		5.80		
	☆191701061808	23.900	120.900		5.60		
03	192209011916	24.600	122.200		7.60		
	☆192209141931	24.600	122.300		7.20		
	192210150747	24.500	122.200		5.90		
	192212021146	24.600	122.000		6.00		
04	193012081610	23.300	120.400	05.0	6.50		
	☆193012220808	23.300	120.400		6.50		
	193012221219	23.300	120.400		5.60		
05	193101012352	23.500	122.000		6.03		
	☆193102130041	24.100	121.900		5.74		
06	193504202201	24.300	120.800	10.0	7.10		
	193504202226	24.700	120.900		6.00		
	193505042302	24.500	120.800		6.00		
	☆193507161619	24.400	120.700	30.0	6.40		
07	193712081633	23.100	121.400		7.00		
	☆193712170932	22.800	121.500		6.50		
08	195710191829	23.700	121.500	10.0	6.60		
	☆195801221829	23.600	121.300	05.0	6.00		
09	195908150857	21.700	121.300	20.0	6.80		
	195908180034	22.100	121.700	15.0	6.10		
	☆195909250237	22.100	121.200	10.0	6.50		
10	196104091535	23.800	122.300	56.0	6.50		
	196105191637	23.300	123.600	65.0	5.50		
	☆196109170842	23.700	122.200	45.0	5.90		
11	196302130850	24.400	122.100	47.0	7.20		
	☆196303041338	24.600	121.800	05.0	6.10		
	196303100253	24.500	121.800	05.0	6.00		
12	196304210438	23.900	122.200	20.0	5.50		
	196304262345	23.900	122.200	05.0	5.30		
	☆196305111749	23.900	122.000	10.0	5.40		
13	196504262215	21.200	120.700	33.0	6.10		
	☆196505280516	21.000	120.900	38.0	5.40		

for the first data set and

$$\Delta M_s = (-2.965 \pm 1.081) + (0.638 \pm 0.174) M_s \tag{3}$$

for the second data set. The slope value of Eq. (3) is larger than that of Eq. (2). The two lines display a systematic difference in magnitude between the two data sets. Although Wang (1992) stated the similarity between M_H and M_s, his conclusion might be not good enough for larger events because his data set has a small number of events with $M_s > 6.5$. Meanwhile, for the events with $M_s > 6.5$ used in his study, the M_s values are greater than

Table 1. (Continued.)

No	Date	Lat.	Long.	H(km)	M_H	m_b	M_S
14	197707150212	24.051	122.214	33.4		5.5	5.7
	☆197712252233	24.175	121.690	40.5		5.2	4.7
15	197802080015	24.146	122.663	39.9		5.5	5.7
	☆197803142032	24.072	122.638	42.7		5.5	5.4
16	197807231442	22.282	121.512	16.9		6.5	7.4
	197807240236	21.951	121.465	33.0		5.2	5.2
	☆197807241141	22.242	121.574	30.4		5.0	5.5
	197807242354	22.135	121.437	18.0		5.0	5.4
	197807250416	22.531	121.270	10.7		4.1	4.5
	197807251756	22.346	121.391	27.6		5.2	4.8
	197807260334	22.186	121.290	24.0		4.7	4.6
	197808071016	22.576	121.342	33.0		4.4	4.5
	197808130341	22.226	121.517	19.0		5.4	4.6
	197808260453	22.046	121.517	10.0		4.8	5.2
17	197812231123	23.247	122.075	33.0		6.6	7.0
	197812231503	23.050	121.873	33.0		5.0	4.9
	☆197812260749	22.907	121.700	10.0		5.1	5.3
	197812271446	23.245	122.159	33.0		4.9	4.2
18	197912020525	22.919	121.448	36.5		5.5	5.7
	☆197912230946	22.965	121.740	33.0		5.1	5.1
19	198103021213	22.894	121.453	23.5		5.5	5.9
	☆198103272241	22.981	121.662	26.0		4.6	4.6
	198109122332	22.970	121.427	33.9		4.8	4.5
20	198201231410	23.900	121.707	17.0		5.6	5.9
	☆198202171653	23.790	121.588	35.5		5.0	4.7
21	198306240906	24.176	122.402	44.1		6.1	6.7
	198306251940	24.008	122.528	34.4		5.4	5.0
	☆198309072311	24.032	122.327	33.0		5.5	5.7
	198309091701	24.094	122.373	33.0		5.3	5.1
22	198309211920	24.095	122.148	28.2		6.0	6.4
	☆198309231229	24.013	122.228	32.4		5.7	5.8
	198309250329	23.937	122.266	33.0		5.1	4.0
	198310050329	24.070	121.768	33.0		5.0	4.6
	198310072005	23.969	122.584	33.0		5.1	4.7
	198401191112	24.138	122.371	34.9		5.0	5.2
23	198506121722	24.585	122.078	27.9		5.2	5.8
	☆198507101706	24.199	121.745	35.0		4.8	4.1
24	198508051300	24.394	121.886	10.0		5.2	5.5
	☆198509201501	24.593	122.280	18.4		5.3	5.1

the M_H values. Hsu's magnitude was estimated from the peak amplitude value of local seismograms recorded by the old seismographs of the Central Weather Bureau (CWB, formerly Taiwan Weather Bureau) through the formulae calibrated based on surface-wave magnitude. The predominant period of the peak amplitude values is around 1 second. From the scaling low proposed by Aki (1967, 1972), the displacement amplitude value of 1 second period and that of 20 second period cannot increase with the same rate with the earthquake magnitude and the former is usually saturated as the magnitude is greater than 3. The saturation becomes very serious as the magnitude value is greater than 7. Hence, it is suggested that the magnitude values of the mainshocks of the first data set were under-estimated. The under-estimation might increase with magnitude. On the other hand, the peak amplitude of

Table 1. (Continued.)

No	Date	Lat.	Long.	H(km)	M_H	m_b	M_S
25	198605200525	24.125	121.619	19.3		6.1	6.4
	198605221747	23.934	121.686	28.6		4.9	4.8
	☆198606041620	23.951	121.739	20.1		5.1	5.3
26	198607301131	24.611	121.782	33.0		5.6	5.6
	☆198607311136	24.829	122.761	33.0		5.1	5.2
27	198611142120	23.901	121.574	33.8		6.3	7.8
	☆198611142304	23.866	121.711	33.0		6.1	6.3
	198611150100	23.955	121.839	33.0		5.1	5.4
	198611150724	23.877	121.677	28.0		5.5	5.8
	198611151612	23.923	122.039	33.0		4.9	4.9
	198611180849	24.008	121.787	33.0		5.1	5.2
	198611260949	24.215	121.858	32.5		4.8	4.5
	198611300303	23.950	121.960	33.5		5.1	4.2
28	198908212312	24.094	122.478	42.8		5.6	6.3
	☆198908222002	23.957	122.610	37.9		4.9	5.0
	198909061216	24.048	122.562	23.8		4.2	4.5
	198909061339	23.993	122.569	32.8		5.0	4.3
29	199012131950	23.722	121.627	10.0		5.9	6.3
	199012132156	23.713	121.673	10.0		5.3	5.1
	☆199012132318	23.681	121.625	10.0		5.4	5.7
	199012132328	23.807	121.678	10.0		5.7	5.4
	199012140143	23.822	121.716	10.0		5.1	4.9
	199012140237	23.584	121.677	10.0		5.1	4.9
	199012140455	23.883	121.758	10.0		4.6	4.4
	199012180439	23.766	121.772	10.0		5.0	4.8
	199012190020	23.701	121.579	10.0		5.2	5.3
	199012192338	23.669	121.606	10.0		5.3	5.2
30	199103260358	21.704	121.789	17.7		5.8	6.3
	199103260619	21.673	121.826	19.4		5.2	5.1
	199103260637	21.633	121.714	10.0		4.4	3.9
	☆199103261024	21.867	121.610	10.0		5.3	5.5
	199103261240	21.651	121.992	10.0		4.2	3.7
	199103261343	21.607	121.871	10.0		4.3	4.8
	199103261420	22.175	121.657	10.0		4.4	4.0
	199103261830	21.870	121.722	10.0		4.6	4.8
	199104091004	21.548	121.850	10.0		4.5	4.0
31	199109300944	22.535	121.479	24.3		5.5	5.2
	☆199110120508	22.798	121.536	7.7		5.1	4.8
	199112051548	22.544	121.450	16.5		4.6	4.7

the Rayleigh waves with period of around 20 seconds in the seismograms recorded on the world-wide stations is less saturated as the magnitude value is smaller than 8. Hence, the magnitude values of the mainshocks of the second data set, which are smaller than 8, could be estimated to some extent correctly. On the other hand, the magnitude value of the largest aftershock can be correlatively determined from both the long-period and the short-period signal because its value is not so large as that of the mainshock. Therefore, the difference in magnitude between the mainshock and the largest aftershock must be smaller for M_H scale than for M_s scale. This interprets the systematic difference in Eq. (2) and Eq. (3) and the data points shown in Figure 2.

The seismic energy E relates to surface-wave magnitude (M_s) in the following form:

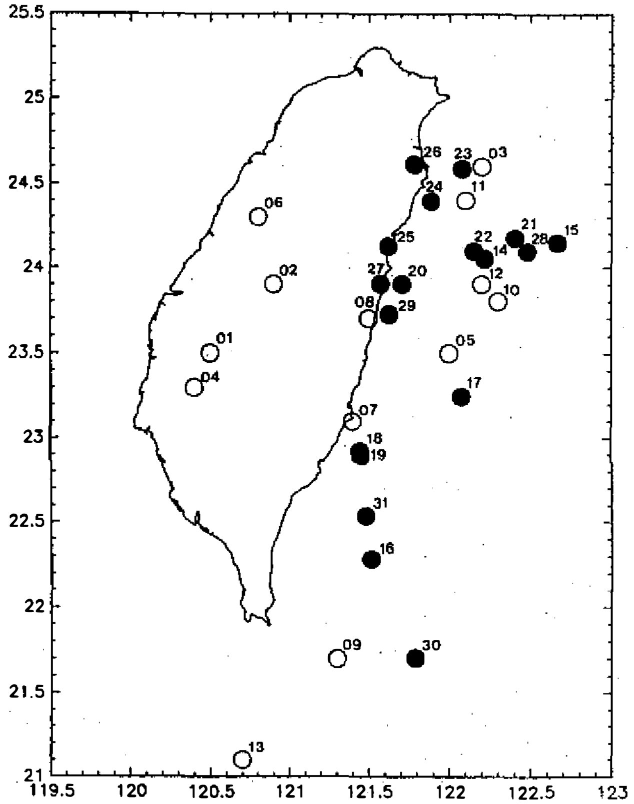

Fig. 1. Figure shows the localities of mainshocks listed in Table 1. The open circles represent the events of the first data set and the solid circles denote the events of the second one as described in the text. The number near the circles is the number of event listed in Table 1.

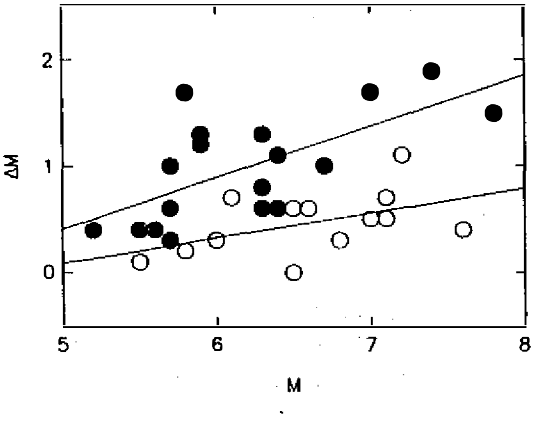

Fig. 2. Figure shows the data points of ΔM vs. M: the open circles for events of the first data set and the solid circles for events of the second data set. The two solid lines represent the regression lines of the two data, respectively.

$$logE = 11.8 + 1.5M_s \qquad (4)$$

by Gutenberg and Richter (1956). Let E_0 and E_a be the seismic energy of mainshock and the largest aftershock, respectively. Hence, $\log(E_0/E_a) = 1.5\Delta M_s$. From Eq. (3), the ΔM_s-M_s relation approximately has the form $\Delta M_s \sim 2/3 M_s$. Thus $\log(E_0/E_a) \sim \Delta M_s$ or $E_a/E_0 \sim 10^{1/M_s}$. This leads to the fact that the E_a/E_0 value decreases exponentially with the mainshock magnitude. The larger the mainshock magnitude is, the bigger the energy releases during the mainshock occurrence. Therefore, for large Taiwan earthquakes, the seismic energy of an earthquake sequence is mainly released from the mainshock. It is noted that for earthquakes within the western Cordillera of the United States, Doser (1989) reported a similar result.

The distributions of number of events versus magnitude difference for the two data sets are shown in Figure 3, in which the upper diagram is made for the first data set and the lower one for the second data set. From the upper diagram, it can be seen that the number of events is quite uniform for $\Delta M_H < 1.2$, and from the lower diagram, the number of events distributes in a wider range of ΔM value. In order to compare the two variations quantitatively, the mean values, standard deviations and their ratio are computed. For the first data set, the mean value (m_1) is 0.46 and the standard deviation (δ_1) is about 0.29. Their ratio, i.e. $C_{v1} = \delta_1/m_1$, is 0.63. For the second data set, the mean value (m_2), standard deviation (δ_2) and the C_{v2} value are 0.99, 0.51, and 0.52, respectively. The mean value of the first data set is smaller than that of the second data set. The two C_v values (0.63 and 0.52) are smaller than 1, and thus the distributions of number vs. magnitude difference are not considered to be the Poisson distribution. In order to test the hypothesis H_o: $m_1 = m_2$ vs. H_1: $m_1 < m_2$, we must employ the test statistic

$$t = (m_1 - m_2)/S\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}, \qquad (5)$$

where n_1 and n_2 are the numbers of events of the two data sets and S is the pooled sample variance and calculated by the following formula:

$$S = [\Sigma(X_i - m_1)^2 + \Sigma(Y_i - m_2)^2]/(n_1 + n_2 - 2). \qquad (6)$$

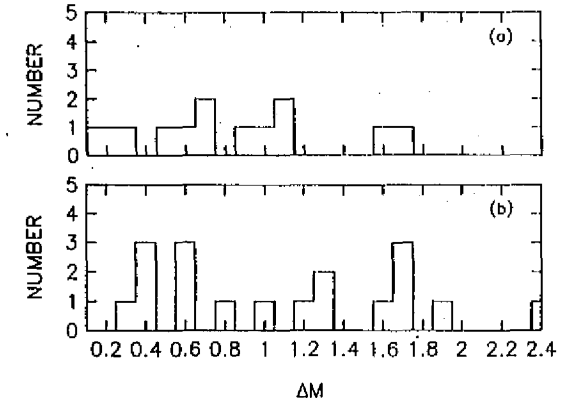

Fig. 3. The number of earthquakes with a ΔM value: (a) for the first data set and (b) for the second data set.

In Eq. (6), X_i and Y_i are the i-th values of the first and the second data sets, respectively. The t-value with risky coefficient α=0.05 is 3.36, which is greater than the theoretical t value (1.699) for the degree of freedom = 29. Hence, the H_1 hypothesis is held, i.e. the fact that the mean value (0.46) of the first data set is smaller than that (0.99) of the second data set is statistically reasonable and not due to the uncertainty of given data. The reason for this distinction is unclear.

Figure 4 shows the data points of logT, where T indicates the difference in occurrence times of mainshock and its largest aftershock in hours, versus the magnitude (M) of mainshock. In this figure, the data points of the first data set (denoted by open circles) depart from those of the second data set (denoted by solid circles). For a certain M, the T values of the first data set are in general larger than those of the second one. In about 23% of the earthquake sequences, the values of difference in time are less than one day. For earthquake sequence No. 6 with mainshock magnitude of 7.1, the difference in time is less than one hour. Generally speaking, the distribution of the data points is quite dispersive. Nevertheless, the logT value decreases somewhat with magnitude. It means that on the average, the largest aftershock occurs earlier after a bigger mainshock than after a smaller one.

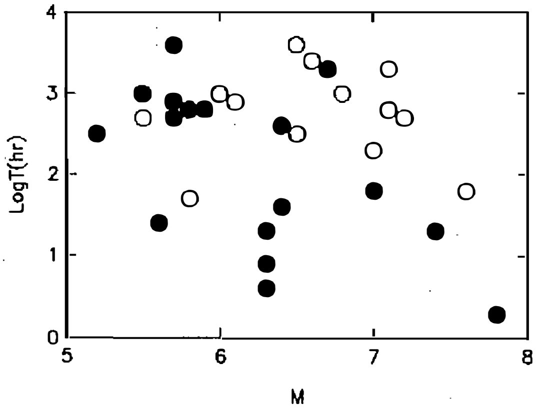

Fig. 4. Figure shows the data points of logT vs. M: the open circles for first data set and the solid circles for the second data set.

To understand the correlation of the long-period magnitude M_s to the short-period magnitude m_b for an earthquake sequence, the data points of M_s vs. m_b for four earthquake sequences Nos. 16, 27, 29 and 30, whose numbers of data are greater than 8, are shown in Figure 5. The data points for aftershocks are denoted by small open circles and those for mainshocks by large open circles. The solid lines for the four cases are the regression lines obtained from the data points of aftershocks through the least-squared method. The data points of earthquake sequences Nos. 27, 29 and 30 show linear distribution, while those of earthquake sequence No. 16 somewhat form a cluster. Hence, the regression lines of the former three sequences are more reliable than those of the latter one. The slope values of the three regression lines of the three earthquake sequences are very similar. This seems to demonstrate a very similar M_s-m_b scaling law for aftershocks of the three sequences. The relation of M_s-m_b scaling for 16 moderate Taiwan earthquakes deduced by Wang (1985) is also shown in Figure 5 with a dashed line. Except for the solid line of the No. 16 sequence, the other three solid lines are very consistent with the dashed line obtained by Wang (1985). Essentially, the source scaling based on the M_s-m_b relation for aftershocks of the three mainshocks is the same as that of moderate Taiwan earthquakes. For earthquake sequence No. 27, the data point of mainshock departs from the regression line to some extent. This implies that the scaling of source property of the mainshock might be different from that of aftershocks. Since the data points of the mainshocks is beyond the regression line, the long-period waves generated by the mainshock must be stronger than those from aftershocks and the short-period waves produced by the mainshock are comparable with those from aftershocks. Through synthetic seismogram analysis, Wu *et al.* (1989) reported that the source process of the mainshock of this earthquake sequence consisted mainly of three subevents. Hence, the deviation of the data point of mainshock from the regression line is physically reasonable.

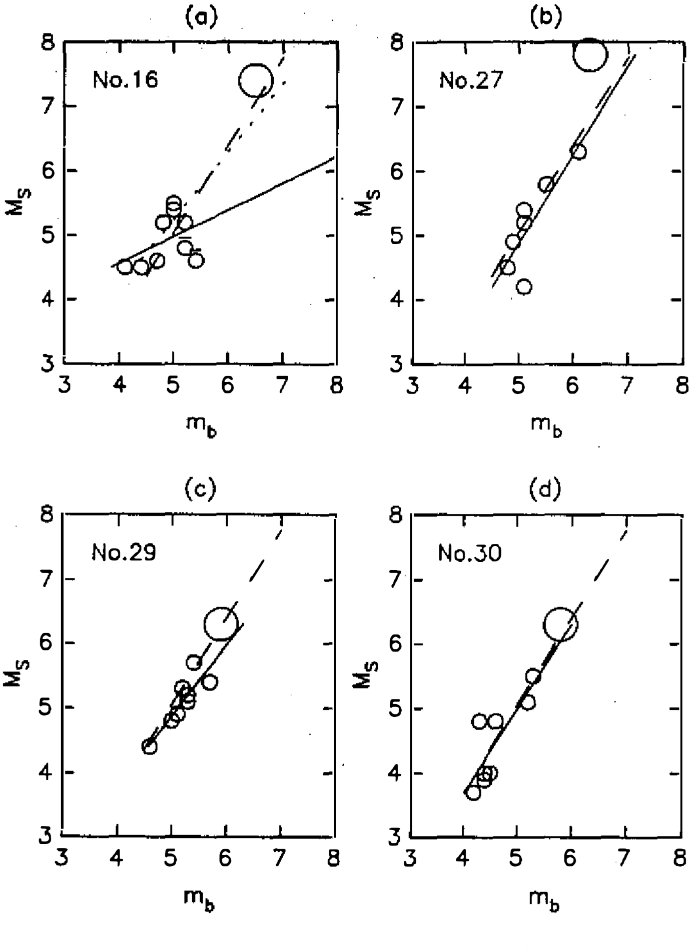

Fig. 5. Figure shows the data points of M_s vs. m_b for four earthquake sequences: (a) for No. 16, (b) for No. 27, (c) for No. 29 and (d) for No. 30. (Large open circles for mainshocks and small ones for aftershocks). The solid lines represent the regression lines from the four data points of aftershocks. The dotted line of (a) is explained in the text. The dashed line represents the M_s-m_b relation obtained by Wang (1985).

For earthquake sequence No. 16, the data point of mainshock deviates very much from the solid line, since the data points are not distributed along the regression line very well. As discarding two data points as shown by open circles with a small bar, whose M_s and m_b values were estimated from few earthquake data, a new regression line is quite different from the old one and displayed with a dotted line. It is obvious that the data points of mainshock are close to the new regression line. The new line coincides with the dashed line obtained by Wang (1985) and, of course, is consistent with the solid lines of the other three sequences. Hence, according to the similarity of the M_s-m_b scaling of aftershocks as mentioned in the above, the new line seems to be acceptable. However, from the limited data, it is actually quite difficult to determine which line is correct. Based on the source rupture process from the teleseismic long-period P waves, Chou and Wang (1992) concluded that the mainshock of July 23, 1978 Lanhsu, earthquake sequence, i.e. the present one, consisted of at least two large subevents with a time difference of about 23 sec. This difference in time could appear in the teleseismic P waves, which accounts for m_b value, but not in the teleseismic Rayleigh waves, which are used for the determination of M_s value. The first-arriving P waves must be generated by the first subevent, and thus the m_b value of mainshock concerned the first subevent. The M_s value was estimated from the teleseismic Rayleigh waves, which were formed by the superposition of P waves and S waves generated from the two subevents and some others, and thus the M_s value was associated with the total behavor of the subevents. Hence, the deviation of the data points of mainshock from the regression line must be reasonable. The old line rather than the new line can show the deviation. This means that the present data can not lead to a substantial conclusion.

On the other hand, for earthquake sequence No. 29 and No. 30, the data point of mainshock is very close to the individual regression line estimated from aftershocks. This means that the source scaling is the same for mainshock and aftershocks. Unlike earthquake sequences No. 16 and No. 27, both M_s and m_b values of the mainshocks of the two present earthquake sequences are small. The source rupture properties of the two mainshocks might be not so complicated as those of the former. It is proposed that the mainshocks and their aftershocks of the present two earthquake sequences must have similar source scaling.

The data points of logN vs. M_s for four earthquake sequences Nos. 16, 27, 29 and 30 are shown in Figure 6. Although the data set is very small, an interesting result can still be obtained. The regression line is shown in Figure 6 with a solid line but the related regression equation is not given. Generally speaking, the data point of mainshock is somewhat away from the trend of the data points for aftershocks. The values of difference in magnitude of mainshock and the maximum magnitude estimated from the regression line are 0.9, 1.6, 0.6, and 0.9 for earthquake sequences No. 16-No. 30. In other words, the mainshock magnitude cannot be predicted from the logN-M relation of aftershocks. The difference in magnitude between the mainshock and the maximum event estimated from the regression equation increases somewhat with the magnitude of the mainshock. Results of this study are similar to those obtained by Wesnousky *et al.* (1983) and Davison and Scholz (1985). Hence, the maximum magnitude model proposed by Wesnousky *et al.* (1983) seems to be more appropriate to describe the behavior of Taiwan earthquake sequences than the b-value model.

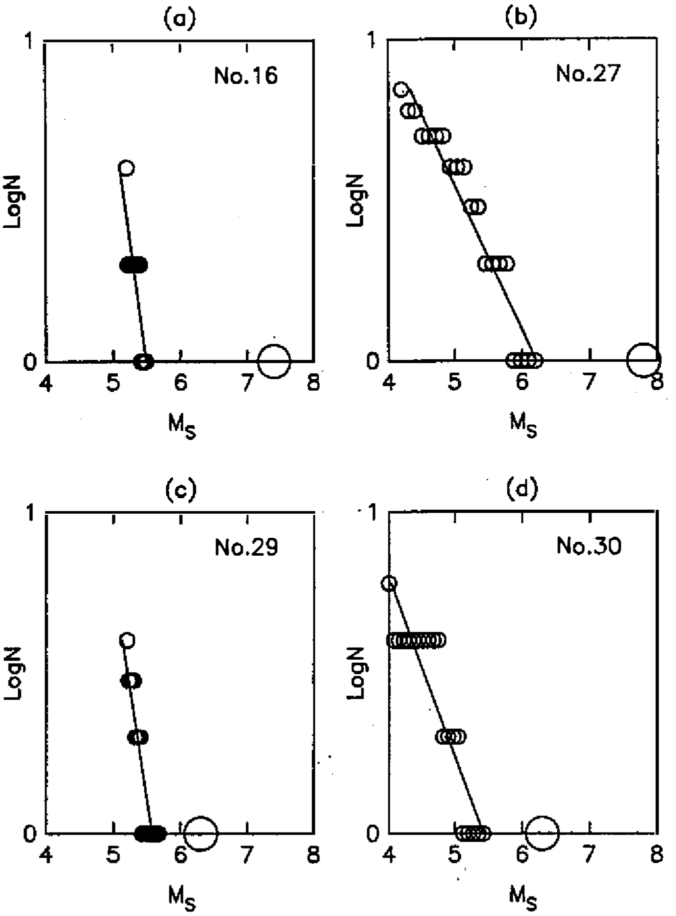

Fig. 6. The four diagrams show the data points of logN vs. M_s for four earthquake sequences: (a) for No. 16, (b) for No. 27, (c) for No. 29 and (d) for No. 30 (Large open circles for mainshocks and the small open circles for aftershocks). The solid lines represent the regression lines of the data points of aftershocks.

4. CONCLUSION

From the given data, several points can be concluded as follows:

(1.) The difference (ΔM) in the magnitude of mainshock and the largest aftershock increases with the mainshock magnitude (M). The variations of ΔM vs. M are different for Hsu's data set and the EDR data set. The difference might be due to the difference in the use of the peak amplitudes of magnitude scales in the two catalogues: a 1-second signal for the former and a 20-second one for the latter.

(2.) The data points of the difference value (T) in the original times of mainshocks and the largest aftershocks versus the magnitude of the mainshocks (M) are quite scattered. Nevertheless, the T value somewhat decreases with the increases of the M value.

(3.) From the data of four earthquakes, the departure of M_s-m_b scaling of the mainshock from that of aftershocks seems to be bigger for larger mainshocks than for smaller ones.

(4.) The mainshock magnitude is larger than the maximum magnitude estimated from the logN-M obtained from aftershock data. The value of difference is bigger for larger mainshocks than for smaller mainshocks.

Acknowledgements The authors would like to express their thanks to our colleague Mr. S. N. Cheng for providing some seismic data for earthquakes after 1978. This study was financially supported by Academia Sinica, R.O.C..

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