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RELATION AMONG MAGNITUDE SCALES RELEVANT TO STRONG GROUND MOTION

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SUMMARY

The present study obtains values of local magnitude, M_L and newly-defined magnitude M_{PZ} (M_{PH}) from Benioff seismograph in WWSSN, for earthquakes mainly in Japan. Both of them are based on the magnitude determined from the short period motion of around 1 sec. To calculate values of M_L, horizontal accelerogram records are used as an input to the Wood-Anderson seismograph and Richter's scaling curve for distance correction is replaced by a curve that fits the data.

The magnitudes M_{PZ} and M_{PH} are defined as peak vertical and horizontal response, respectively in Benioff seismograph (WWSSN) (natural period = 1 sec) in conjunction with Gutenberg's distance correction. An empirical relation between M_{PZ} (M_{PH}) and M_L is also obtained. Finally, it is found that M_L of some of the large earthquakes exceeds 7.25.

INTRODUCTION

Magnitude scale has been widely used to quantify an earthquake size, which is defined in terms of a particular seismic phase observed on a particular seismograph at a particular frequency. Though there are many magnitude scales in use, none of them are well equipped to meet the engineering needs.

Among the existing scales, 'local magnitude' defined for Southern California (Ref. 1) seems to be the most representative in ground motion in the period range of engineering interest (typically 0.2 to 3 sec).

In Japan, the magnitude scale, M_J determined on a routine basis by the Japan Meteorological Agency has been used. This magnitude is a logarithmic scale of peak response in the seismographs with the natural period of 5 sec and may not be suitable as a measure of ground motion of which the frequency range is less than 1 Hz.

Recently, a new magnitude scale m_b^* has been proposed by Takemura and Koyama (Ref. 2). This is based on the P-wave vertical response in Benioff seimographs in the World-Wide Standardized Seismograph Network (WWSSN). The Benioff seismograph has a natural period of 1 sec, and m_b^* is a measure which represents the short-period ground motion, as similar to M_L. Extending the basic idea of m_b^*, we define the magnitude scales M_{PZ} and M_{PH} based on Benioff seismograph. M_{PZ} is the same to m_b^* and M_{PH} is based on the horizontal seismogram.

In this study, values of M_L, M_{PZ} and M_{PH} are calculated mainly for earthquakes in around Japan and relations among them including M_J are obtained.

Kanamori and Jennings (Refs. 3 and 4) indicated that M_L of California earthquakes may have a saturation value of 7.25 (Fig. 1). This saturation value will be finally discussed on the basis of M_L values obtained in this study.

M_L OF EARTHQUAKES IN JAPAN

Kanamori and Jennings (Ref. 3) proposed a method to calculate M_L using accelerograms; accelerograms are used as an input excitation for the Wood-Anderson seismograph and its response is calculated. The local magnitude, M_L is calculated from the peak response using the Richter's distance correction.

We used this technique to compute M_L of earthquakes in Japan, but Richter's distance correction is replaced by a new curve to fit the data since the mechanism of many earthquakes in Japan (mainly deep dip-slip type) is different from those in Southern California (mainly shallow strike-slip type) and surface ground condition is also different from each other.

DATA BASE In Japan there is a good network of Strong Motion Accelerographs, spread all over the country and run by Port and Harbour Research Institute (PHRI), Public Works Research Institute (PWRI) and other organizations. Accelerograms have been recorded for the earthquakes which have occurred since 1962. Most of the accelerograms recorded by PHRI and some by PWRI are made available in digitized form on the magnetic tape. They have been processed for the base line correction and instrumental correction and represent uniform amplification between 0.15 Hz - 10 Hz. These accelerograms can be treated as to represent the actual ground motion acceleration. This data base has been used for the analysis in this work.

SCALING RELATION FOR LOCAL MAGNITUDE Two different closed form equations have been chosen for the new attenuation relations using the epicentral distance (case 1) and the hypocentral distance (case 2) as distance measures, respectively. They are as follows:

CASE 1 $$M_L = \mathrm{Log}_{10}A(\Delta)+a_1\mathrm{Log}_{10}(\Delta+30)+b_1 \quad (1)$$

CASE 2 $$M_L = \mathrm{Log}_{10}A(R)+a_2\mathrm{Log}_{10}(R)+b_2R+c_2 \quad (2)$$

where Δ is the epicentral distance, R is the hypocentral distance, M_L in Eq.(1) and (2) are the local magnitudes being calculated using epicentral and hypocentral distances respectively and a_1, b_1, a_2, b_2 and c_2 are the constants to be determined.

Form of equation (1) has been chosen so because of it's popularity in the engineering uses. In equation (2), the second and the third terms of the right hand side can be interpreted as to represent the geometrical spread and the viscous damping of the seismic waves with distance, respectively. Maximum trace amplitude A has been obtained by simulating Wood-Anderson seismogram from strong motion accelerograph records.

REGRESSION ANALYSIS Coefficients a_1, a_2 and b_2 are obtained by minimizing the average of average squared scatters of earthquake magnitudes for individual events. Constants b_1 and c_2 are evaluated by constraining the scaling relations to conform to Richter's original definition at the distance of 100 km.

Regression analysis have been performed with 208 event-station pairs from 56 earthquakes in the magnitude range $3.7<M_J<7.8$ $(4.4<M_L<7.7)$ and epicentral distance range $9<\Delta<460$ km occurring from 1965 through 1983.

RESULTS AND DISCUSSION Regression analysis gave the following scaling relations.

CASE 1 $$M_L = \mathrm{Log}_{10}A(\Delta)+1.22\mathrm{Log}_{10}(\Delta+30)+0.41 \quad (3)$$

CASE 2 $$M_L = \mathrm{Log}_{10}A(R)+1.10\mathrm{Log}_{10}(R)+0.0003R+0.77 \quad (4)$$

Use of the above two scaling relations to calculate the magnitude of 56 earthquakes gave the average scatter in the magnitude values of 0.2491 and 0.2486 respectively, which are not so large and almost the same. The result thus leaves the better choice of distance still unresolved.

Magnitude for the same events were also calculated using the Richter's standard attenuation relation and it was found that it leads to larger scatter in the magnitude values, of the order of 0.2982.

Hence it can be concluded that the new proposed attenuation relations are the better candidates for the local magnitude calculation of earthquakes in and around Japan.

The same procedure, as used above, were also applied to calculate the local magnitude for some Southern California earthquakes. The accelerograms recorded at distances up to 200 kms were only used. It gave almost the same values of local magnitudes as published by other sources. This testifies the validity of the procedure used in this paper.

Figure 2 shows the plot of the new proposed attenuation relations and the Richter's attenuation relation. Comparison shows that the Richter's attenuation relation at large distances indicates relatively rapid decay of amplitude and hence it overestimates the magnitude. Whereas in the near source zone the Richter's relation slightly underestimates the magnitude. Though apparently unrelated, the same trend is reported even for Southern California earthquakes in the recent findings of Luco (Ref. 5), Jennings and Kanamori (Ref. 6), and Hutton and Boore (Ref. 7).

Table 1 lists local magnitudes (calculated by using the new proposed scaling relations (Eq. 3)) for major earthquakes in and around Japan along with their reported M_J and M_S values.

Figure 3 shows the plot of M_L and M_J values of the earthquakes. Regression of M_L and M_J gives the following relation:

$$M_L = 0.48M_J+3.57 \tag{5}$$

It is found that around M_J=7 event both M_J and M_L give the same values. For larger events M_J predicts slightly on the higher side whereas for smaller events it underestimates the magnitude very much.

In Japan, the saturation of local magnitude scale, with increase in the event size, doesn't seem to occur around 7.25 event as is the case in Southern California. If the saturation at all takes place the event size must be more than 7.8. The difference in the event size in the two regions may be attributed to the dip-slip type of fault in Japan compared to the strike slip type in California.

CALCULATION OF M_{PZ} AND M_{PH}

Takemura and Koyama (Ref. 2) proposed a new magnitude scale, m_b^* which is determined from the peak amplitude on the vertical response at Benioff seismograph in WWSSN.

The magnitude M_{PZ} is the same to m_b^*, while M_{PH} is determined from horizontal peak response at Benioff seismograph and this can be an extended definition.

$$M_{PZ} = \mathrm{Log}_{10}(A_{PZ}/T)+Q_{PZ}(\Delta,h) \tag{6}$$

$$M_{PH} = \mathrm{Log}_{10}(A_{PH}/T)+Q_{PH}(\Delta,h) \tag{7}$$

where A_{PZ} (A_{PH}) is peak vertical (horizontal) ground displacement (peak response is divided by the amplification of the Benioff seismograph), and A_{PH} is sum of square in two horizontal directions. Note that A_{PZ} and A_{PH} are micron in dimension. Q_{PZ} and Q_{PH} are distance correction terms and we used the value given by Gutenberg (Ref. 8). "T" is the dominant period in the seismogram.

39 earthquakes in and around Japan and 5 earthquakes in North America were analysed. Fig. 4 shows an example of seismogram of Benioff seismograph at Berkeley during of the 1978 Miyagi-ken-oki earthquake. For each earthquake, more than ten seismographs were collected and we read the peak amplitudes, A_{PZ} and A_{PH}

and the dominant period, T, obtaining magnitudes M_{PZ} and M_{PH}. Finally the magnitude values calculated from those records were averaged.

The values of M_{PZ} and M_{PH} calculated are presented in Table 1.

DISCUSSION Both M_L and M_{PZ} (M_{PH}) are determined from the body-wave-induced ground motion of around 1 sec, which is within an important period range from an engineering viewpoint. The relation between M_L and M_{PZ} and the relation between M_L and M_{PH} are presented in Figs. 5 and 6, respectively. Regression lines obtained are

$$M_{PZ} = 1.02M_L - 0.73 \qquad (8)$$

$$M_{PH} = 0.93M_L + 0.04 \qquad (9)$$

The slopes in both are close to 1.0, indicating that M_{PZ} (M_{PH}) and M_L are highly correlated.

The local magnitude M_L can be calculated from M_{PZ} using Eq. 8; values of M_L are

7.7 (1968 Tokachi-Oki earthq.)
7.4 (1978 Miyagiken-Oki earthq.)
7.9 (1964 Alaska earthq.)

Values of M_L calculated from the accelerograms are

7.7 (1968 Tokachi-Oki earthq.)
7.3 (1978 Miyagiken-Oki earthq.)

M_L of the 1964 Alaska earthquake is not available because no Wood-Andersoon seismographs and accelerographs were not installed in the epicentral region. Close agreement confirms the validity of this analysis and further confirms that M_L of some of the earthquakes indeed exceed 7.25. It should be noted that all these three earthquakes are of dip-slip type.

SUMMARY

This study can be briefly summarized:

(1) The local magnitude, M_L is calculated for earthquakes in and around Japan.
(2) New magnitudes, M_{PZ} and M_{PH} are defined and calculated for 39 earthquakes in and around Japan and 5 earthquakes in North America.
(3) High correlation is observed between M_L and M_{PZ} (M_{PH}). M_L can be also computed from the empirical M_L-M_{PZ}(M_{PH}) relation obtained.
(4) It is shown that some of the great earthquakes of dip-slip type have M_L greater than 7.25. The value of M_L could exceed 7.25.

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Table 1 Magnitudes M_L , M_{PZ} and M_{PH} of Major 39 Earthquakes in Japan and 5 Earthquakes in North America

No	Date	Name of Earthq.	Epicenter (deg.)		Depth (km)	Ms	ML	Mpz	MpH
			lat.(N)	long.(E)					
1	1968.04.01	Hyuganada	32.5	132.3	37	7.7 (MOS)	7.3	6.4	6.6
2	1968.05.16	Tokachi-Oki	40.9	143.4	9	7.9 (USCGS), 8.2 (MOS)	7.7	7.1	7.4
3	1968.05.16	Tokachi-Oki (Aftershock)	41.5	142.8	26	7.5 (MOS)	7.2	6.9	7.1
4	1968.06.12	Iwateken-Oki	39.5	142.9	31	7.0 (USCGS)	7.2	6.6	6.7
5	1968.07.01	Saitama Center	36.0	139.3	68	—	6.7	6.1	6.3
6	1968.08.05	Ehime West Coast	33.3	132.3	48	6.5 (MOS)	7.0	6.2	6.3
7	1968.10.08	Chiba Center	35.6	140.1	73	—	6.2	5.5	5.7
8	1969.09.09	Gifu Middle	35.8	137.1	29	6.8 (MOS), 6.0 (USCGS)	6.8	5.9	6.0
9	1970.01.20	Hokkaido South	42.5	143.0	25	6.4 (USCGS), 6.7 (MOS)	6.9	6.5	6.7
10	1970.04.01	Iwate Coast	39.8	141.9	75	—	6.2	5.8	6.0
11	1971.01.04	Aichi Offshore	34.5	137.1	44	5.8 (MOS)	6.9	5.4	5.6
12	1971.07.22	Yamanashi East	35.6	139.0	48	—	6.3	5.4	5.5
13	1971.08.02	Erimomisaki Offshore	41.4	143.4	45	7.1 (MOS)	7.1	6.6	6.8
14	1972.02.29	Hachijojima	33.4	141.0	50	7.3 (MOS)	7.1	6.7	6.9
15	1972.03.19	Aomori East	40.8	142.0	72	5.9 (MOS)	6.5	6.1	6.3
16	1972.12.04	Hachijojima	33.3	140.8	62	7.4 (MOS)	7.0	6.6	6.8
17	1973.03.27	Tokyo bay	35.5	140.0	65	—	5.9	5.6	5.9
18	1973.06.17	Nemuro Penn Offshore	43.1	145.7	41	7.7 (NEIS), 7.8 (MOS)	7.4	6.7	7.0
19	1973.11.19	Miyagi Offshore	39.0	141.9	56	6.5 (MOS)	6.6	6.2	6.4
20	*1974.05.08*	*Izuhantoo-Oki*	*34.6*	*138.8*	*20*	*6.5 (NEIS), 7.0 (MOS)*	*6.6*	*6.1*	6.2
21	1974.08.03	Saitama East	36.0	140.0	57	5.8 (MOS)	6.2	5.8	6.0
22	1975.03.14	Aichi Gifu	35.3	136.8	60	5.0 (MOS)	6.2	5.4	5.6
23	1976.06.15	East Yamanashi	35.5	139.1	47	5.1 (MOS)	6.3	5.4	5.7
24	1977.06.08	Miyagi Offshore	38.6	141.6	74	5.2 (MOS)	6.4	5.7	5.7
25	1977.12.16	Ibaraki Offshore	36.7	141.1	53	5.4 (NEIS), 5.2 (MOS)	6.4	5.6	5.9
26	1978.01.14	Izu-Ohshima-Oki	34.8	139.3	0	6.7	6.3	6.4	6.5
27	1978.02.20	Miyagi Offshore	38.8	142.3	60	6.4	6.9	6.2	6.5
28	1978.03.07	Chiba Offshore	32.0	137.6	441	6.5	7.2	6.3	6.4
29	1978.05.16	Aomori East Coast	41.1	141.1	41	5.5	6.2	6.0	6.3
30	1978.05.23	Tanegashima	31.1	130.1	160	6.2	6.5	6.3	6.4
31	1978.06.12	Miyagiken - Oki	38.2	142.0	48	7.5	7.3	6.8	7.0
32	1978.07.04	Miyagi North	32.7	131.2	125	5.3	6.8	5.9	6.0
33	1978.08.13	Tokyo Bay North	36.0	140.1	57	—	5.8	5.3	5.8
34	1978.12.06	Kunashiri Island	44.6	146.7	118	7.1	7.1	6.9	7.2
35	1979.07.13	Setonaikai West	33.9	131.9	74	5.7	6.9	5.7	5.9
36	1980.06.29	Izu-Hantoo-Oki	34.8	139.3	19	6.4	6.6	5.9	6.1
37	1980.09.23	Ibarakiken Nanseibu	36.0	139.8	88	4.8	6.2	5.4	5.6
38	1980.09.24	Chibaken Nanbu	35.5	140.2	69	5.5	6.6	5.9	6.2
39	1981.01.23	Hokkaido South	42.5	142.2	110	6.4	6.9	6.3	6.5
40	1966.06.28	Parkfield	35.9	−120.4	16	—	5.9	5.7	6.1
41	1971.02.09	San Fernando	34.4	−118.4	9	6.5 (NEIS)	6.4	6.4	6.5
42	1979.10.15	Inperial Valley	32.9	−115.5	0	6.9	6.4	5.9	6.3
43	1976.02.04	Guatemala	15.3	− 89.2	5	7.5 (Abe)	6.9	6.5	6.7
44	1964.03.28	Alaska	61.1	−147.5	23	8.4 (Abe)	—	7.3	7.5

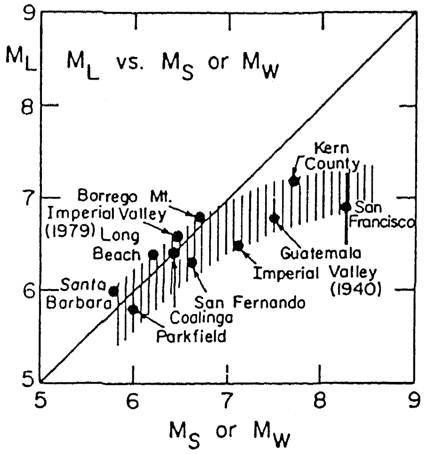

Fig. 1. Relation between local magnitude, M_L, and moment magnitude, M_W, showing saturation of M_L. (M_S is used for M_W for 2 cases where M_W is not available) (Ref. 6)

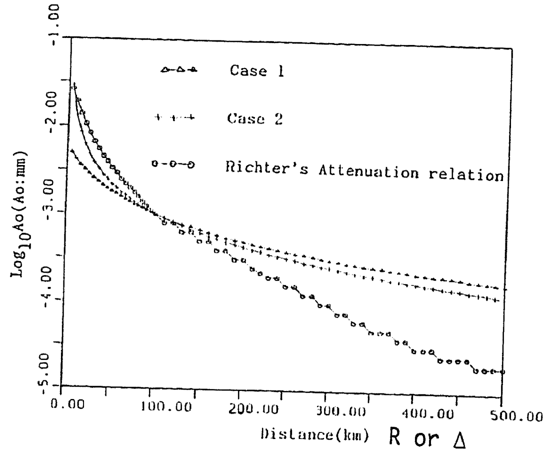

Fig. 2. Plot of proposed attenuation relations, using the epicentral distance (case 1) and the hypocentral distance (case 2) respectively, and the Richter's attenuation

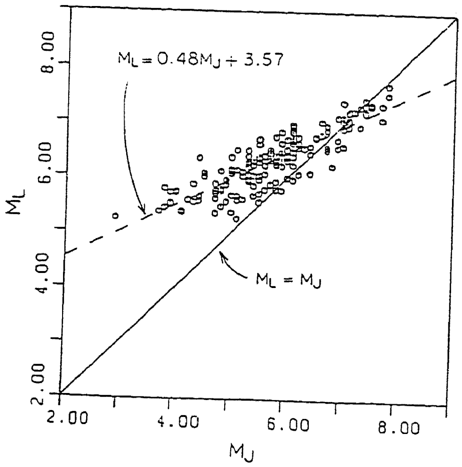

Fig. 3. Plot of M_L and M_J (160 Earthqs. in and around Japan)

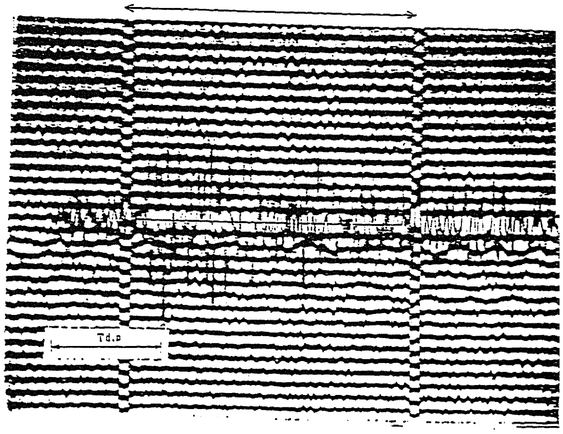

Fig. 4. Response of Benioff Seismograph at Berkeley, California during the 1978-6-12, Miyagiken-Oki Earthquake (Amplification: 37,UD component)

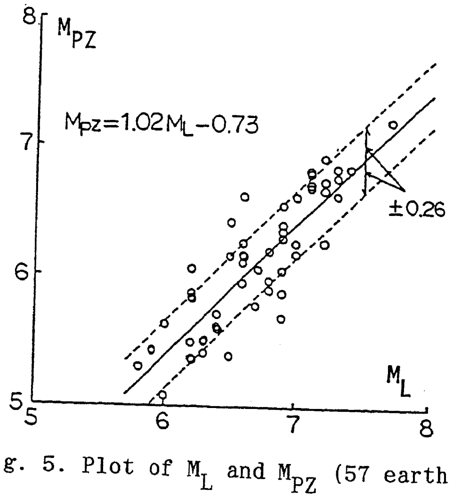

Fig. 5. Plot of M_L and M_{PZ} (57 earthqs.)

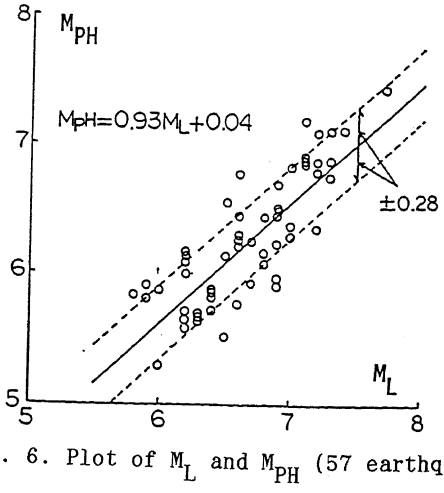

Fig. 6. Plot of M_L and M_{PH} (57 earthqs.)