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Estimation of local magnitude from signal duration records of W. W. N. S. S., Shillong

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सार –– उत्तरपूर्व भारत में शिलांग पठार के क्षेत्र के अंदर और आस-पास उत्पन्न होने वाले 1.8 से 5.9 तक के परिमाण स्पेक्ट्रा के अंतर्गत 140 भूकम्पों के संबंध में स्थानीय परिमाण (एम. एल.) वुड-एन्डरसन भूकम्प अभिलेखों से प्राप्त किए गए हैं और इनकी संगत संकेत अवधि शिलांग वेधशाला में भूकम्प स्टेशनों के भूकम्पलेखों के अल्पावधि उर्ध्वाधर विश्वव्यापी नेटवर्क के भूकम्प संबंधी रिकार्डों से निर्धारित की गई है। संकेत अवधि से स्थानीय परिमाण, (एम. एल.) क आकलन के लिए न्यूनतम वर्ग की विधि द्वारा आनुभाविक समीकरणों को प्राप्त किया गया है। इसमें देखा गया है कि परिमाण का आकलन +0.32 एककों की सीमाओं में किया जा सकता है।

आनुभाविक समीकरण एम.एल. और सतही तरंग परिमाण (राव और नाग 1981) के एम. एस. और एम. एल. और सिगनल अवधि परिमाण (दत्तात्रेयम और श्रीवास्तव 1988) के एम. डी. के बीच भी प्राप्त किये गये हैं। वर्तमान अध्ययन में संकेत अवधि से आकलित स्थानीय परिमाण (एम. एल.) की उपयुक्ता का पता लगाया गया है और इसका एम. एस. (राव और नाग 1981) और एम. डी. (दत्तात्रेयम और श्रीवास्तव के साथ सहसंबंध गुणांकों और आकलनों की मानक त्रुटियों के रूप में मूल्यांकन किया गया है।

ABSTRACT. Local magnitude (M_L) in respect of 140 earthquakes, within magnitude spectra from 1.8. to 5.9, originating from within and around Shillong plateau in the northeast India, have been obtained from Wood-Anderson seismograms and corresponding signal duration in seconds have been determined from the earthquake records of short period vertical World Wide Network of Seismological Stations (WWNSS) seismograph at Shillong Observatory. Empirical equations have been obtained by the method of least squares for estimation of local magnitude, M_L, from signal duration. It is seen that magnitude can be estimated within the limits of ± 0.32 units.

Empirical equations have also been obtained between, M_L, and surface wave magnitude, M_S, of Rao and Nag (1981) and M_L and signal duration magnitude, M_D, of Dattatrayam and Srivastava (1988). The fitness of local magnitude, M_L, as estimated from signal duriation in the present study and also with M_S (Rao and Nag 1981) and M_D (Dattatrayam and Srivastava 1988) is evaluated in terms of correlation coefficients and standard errors of estimates.

1. Introduction

With the advent of modern high gain seismographs in recent years, detection level for earthquakes of low magnitude in a seismically active region has increased considerably. While this is considered as an asset for recording large number of low magnitude earthquakes, it has also created some difficulties in measurement of amplitude and corresponding periods of seismic waves from high magnitude earthquakes. It has been observed that amplitude traces become white for higher magnitude events in case of photographic records and clip in case of recording on heat sensitive ink or smoked paper. This forbids recording of actual amplitude of waves, thus constraining determination of magnitude.

Richter (1935), proposed a method for estimating local magnitude (M_L) of earthquakes which was later extended to teleseismic events (Gutenberg and Richter 1956). This requires measurement of maximum trace amplitude of seismic waves on the Wood-Anderson seismograms. This measurement is found erroneous in case of low as well as high magnitude events as low magnitude events are not recorded well by very low magnification Wood-Anderson seismograph and traces become white for high magnitude earthquakes.

Another magnitude scale called body wave magnitude (M_b) requires measurement of maximum trace amplitude and corresponding period of P-wave within a few cycles from its onset. Use of this scale also gets restricted due to traces becoming white on high gain seismograms. Such difficulties are often experienced on the seismograms of the short period vertical component seismograph at Shillong Observatory which is functioning at a gain of 200 K at 1 second ground period.

In order to overcome such difficulties, magnitude determination based on signal duration has become an important tool in the hands of seismologists. In this paper an attempt has been made to obtain an empirical equation between local magnitude (M_L) and signal duration from short period vertical component seismograph of World Wide Network of Seismological Stations (WWNSS) of United States Geological Survey (USGS) at Shillong Observatory. Results are also compared with some other similar studies on magnitude.

2. Data and Method

Local magnitude (M_L) for 140 earthquakes during the period November 1986 to September 1987 originating within and around Shillong plateau within magnitude spectra of 1.8 to 5.9 were determined from the Wood-

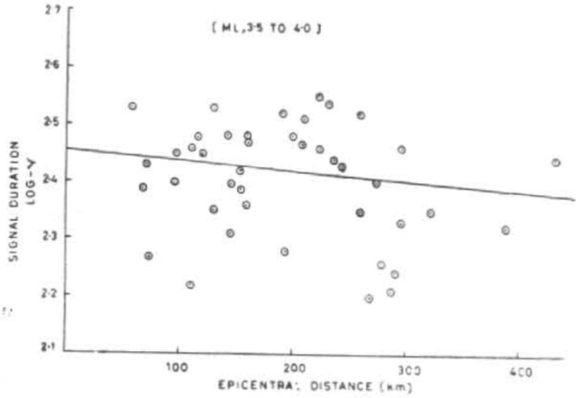

Fig. 1. Epicentral distance *versus* signal duration (log τ) for local magnitude, M_L, 4.0-4.5

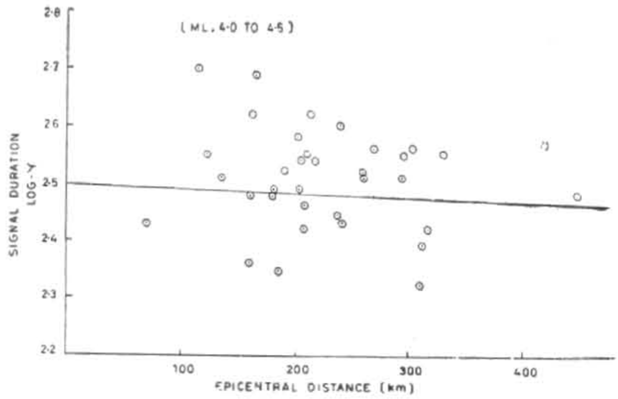

Fig. 2. Epicentral distance *versus* signal duration (log τ) for local magnitude, M_L, 3.0-3.5

Anderson seismograms of Shillong Observatory making use of the nomogram after Gutenberg and Richter (1956). The epicentral distances of these events varied between 20 and 500 km. The Wood-Anderson seismographs, both north-south and east-west components, have the following, calibration constants :

Free period of seismometer	= 0.8 sec
Damping	= Critical
Magnification	= 1000

Corresponding signal duration in seconds for all the 140 earthquakes were determined from the seismograms of the short period vertical component of the WWNSS. The seismograph has the following calibration constants:

Free period of seismometer	= 1 sec
Free period of galvanometer	= 0.75 sec
Damping	= Critical
Magnification	= 200,000 at 1sec

Several workers have defined signal duration differently for estimation of magnitude. It is, therefore, important to define the signal duration in the present study. It is defined as the duration in seconds of earthquake record on seismogram from the onset time of P-arrival till the amplitude of seismic waves merges with the background level. This is generally 1.5 mm for Shillong Observatory.

An equation given below has been used by many workers (Lee *et al.* 1972, Grosson 1972, Reel and Teng 1973, Rao and Gupta 1979, Rao and Nag 1981) to estimate local magnitude from signal duration :

$$M_L = a + b \log \tau + c \triangle \qquad (1)$$

where, M_L is the local magnitude, τ the signal duration in seconds, $\triangle$ the epicentral distance in km, a, b and c are constants. It is proposed to use the above equation in the present study and determine the values of a, b and c by the method of least squares.

A perusal of Eqn. (1) indicates that local magnitude of an earthquake is primarily dependent on signal duration of earthquake record and its epicentral distance. In order to evaluate the dependence of signal duration (τ) on epicentral distance ($\triangle$), log τ has been plotted against epicentral distance in Figs. 1 and 2 for earthquakes of local magnitude 3-3.5 and 4-4.5 respectively. The choice for these two magnitude range only was made mainly because large quantity of observations were available. Although a look at Figs. 1 and 2 indicates good scatter, a straight line appears to reasonably satisfy the data. With this in view, straight line ($\log \tau = a + b\triangle$) equations, as given below, have been obtained by the method of least squares :

$$\log \tau = 2.50(\pm 0.05) - 0.000079\triangle \qquad (2)$$
$$(4.0 \leqslant M_L \leqslant 4.5)$$

$$\log \tau = 2.46(\pm 0.04) - 0.000169\triangle \qquad (3)$$
$$(3.0 \leqslant M_L \leqslant 3.5)$$

It is seen from Eqns. (2) and (3) that values of constant terms are not differing much and the variations are within the limits of errors. This suggests that dependence of log τ on epicentral distance is not much related to the magnitude of earthquakes. However, an average of the constants in Eqns. (2) and (3) has been adopted to evaluate the dependence of log τ on epicentral distance. The equation, as obtained, is given below :

$$\log \tau = 2.48 - 0.0001241\triangle \qquad (4)$$

In order to determine an empirical equation between log τ and local magnitude, it is necessary to remove the effect of epicentral distance on log τ. Since the effect is observed to be magnitude independent, Eqn. (4) was used for the purpose for all the 140 earthquakes. The values of log τ so obtained have been plotted against respective magnitude in Fig. 3. Although data shows some scatter, a linear relationship between local magnitude and signal duration appears to emerge out. Hence, a straight line equation, as given below, has been obtained by the method of least squares. It has been shown as a solid line in Fig. 3 :

$$M_L = 2.5240 \log \tau - 2.3794 \qquad (5)$$

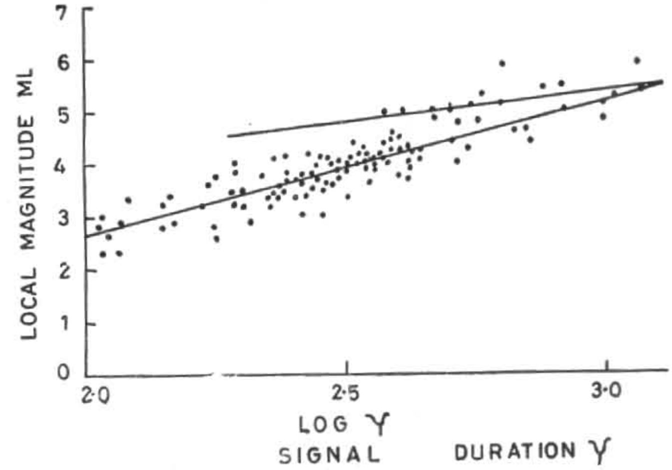

Fig. 3. Local magnitude, M_L, *versus* signal duration (log τ)

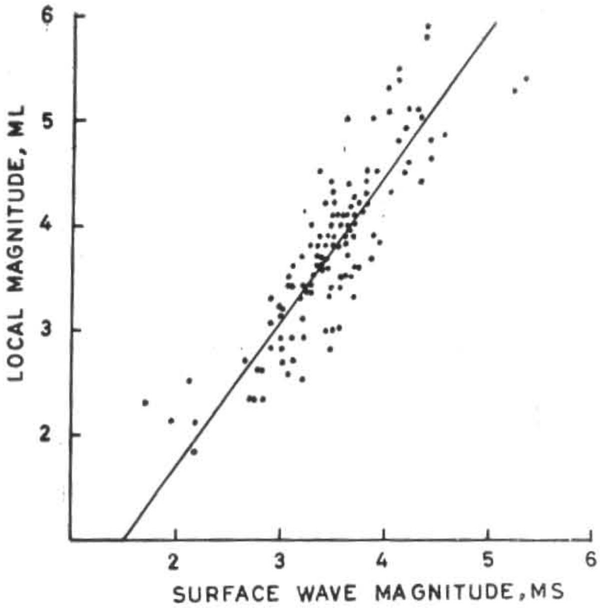

Fig. 4. Local magnitude, M_L, *versus* surface wave magnitude, M_S (Rao and Nag 1981)

It is seen from Fig. 3 that almost all the data points for magnitude equal to or greater than 4.8 lie well above the solid line. This suggests that values of logτ above this magnitude are comparatively lower. Hence, local magnitude estimate based on signal duration using Eqn. (5) will always tend to be less than expected for magnitude equal to or greater than 4.8. With this in view, two other straight line equations between signal duration and local magnitude have been obtained by the method of least squares for magnitudes 2-4.7 and 4.8-5.9 respectively. They are as given below :

$$M_L = 2.11418 \log \tau - 1.4574 \quad (6)$$
$$2.0 \leqslant M_L \leqslant 4.7$$
$$M_L = 1.13616 \log \tau + 1.9818 \quad (7)$$
$$4.8 \leqslant M_L \leqslant 5.9$$

Combining the effect of epicentral distance on log τ in Eqns. (6) and (7) we get the final equations, as given below, for local magnitude estimation. It is proposed to use these two equations for estimation of local magnitude:

$$M_L = 2.11418 \log \tau + 0.0001241 \triangle - 1.4574 \quad (8)$$
$$2.0 \leqslant M_L \leqslant 4.7$$
$$M_L = 1.13616 \log \tau + 0.0001241 \triangle + 1.9818 \quad (9)$$
$$4.8 \leqslant M_L \leqslant 5.9$$

Uncertainity in determining magnitude using above equations is estimated by :

$$\sigma = \left[\sum_{i=1}^{n} (M_L - M_T)^2 / (n-1) \right]^{\frac{1}{2}} \quad (10)$$

It is found to be $\pm$ 0.32 for magnitude between 2.0 & 4.7 and $\pm$ 0.23 for magnitude 4.8 & 5.9.

3. Comparison with other works

Rao and Nag (1981) obtained the following empirical equation for estimation of magnitude from signal duration of earthquake records on the seismogram of short period vertical component WWNSS at shillong :

$$M_S = 0.53 + 1.07 \log \tau + 0.0019 \triangle \quad (11)$$

where M_S is the surface wave magnitude estimated using the relation (Karnik *et al.* 1982). They, however, did not try to obtain any relation between this magnitude and local magnitude, M_L. In order to get one, M_S values for all the 140 earthquakes were determined using Eqn. (11). These have been plotted in Fig. 4 against local magnitude, M_L. A look at this figure clearly indicates a linear relation between M_L and M_S. Hence a straight line equation, as given below, has been obtained by the method of least squares :

$$M_L = 1.4135 \ M_S - 1.1335 \quad (12)$$

It is seen from Fig. 4 that there is good correspondence between M_L and M_S for $M_L < 5.0$, but M_L values are always above solid line for $M_L \geqslant 5.0$. It is, therefore, suggested that Eqn. (12) may be used for $M_L < 5.0$. The uncertainty in this estimation is found to be $\pm$ 0.56.

Dattatrayam and Srivastava (1988) in a similar study obtained empirical equations, as given below, for estimation of magnitude from signal duration of earthquake record of short period vertical seismograph of WWNSS at Shillong :

$$M_D = 1.6265 \log \tau + 0.0038 \triangle - 0.6066 \text{ Model II} \quad (13)$$
$$M_D = 0.3396 (\log \tau)^2 + 0.0039 \triangle + 1.2946 \text{ Model III} \quad (14)$$

M_D values of 140 earthquakes were determined using Eqns. (13) and (14) and are plotted in Figs. 5 and 6 against M_L . A look at these figures eventhough shows comparatively higher scatter in data than in Figs. 3 and

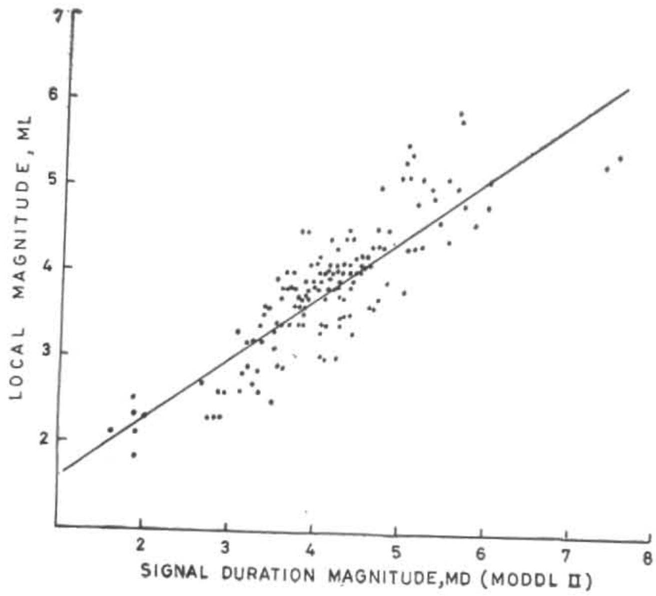

Fig. 5. Local magnitude, M_L, *versus* signal duration magnitude M_D, Model II (Dattatrayam and Srivastava 1988)

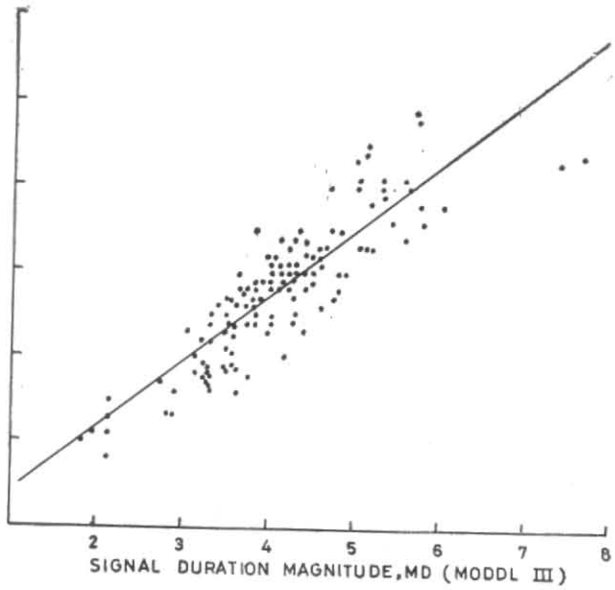

Fig. 6. Local magnitude, M_L, *versus* signal duration magnitude M_D, Model III (Dattatrayam and Srivastava 1988)

4, yet a linear relation appears to exist. Straight line equations have been obtained by the method of least squares and are given below. These straight lines have been shown as solid lines in Figs. 5 and 6 :

$$M_L = 0.71379\ M_D + 0.8424 \quad \text{Model II} \quad (15)$$

$$M_L = 0.77367\ M_D^{\bullet} + 0.6207 \quad \text{Model III} \quad (16)$$

Figs. 5 and 6 show that data points are above the solid line for $M_L \geqslant 4.8$. It is, therefore, suggested that Eqns. (15) and (16) may be used for $M_L \leqslant 4.8$. The uncertainty in the magnitude thus determined is found to be ± 0.57 and ± 0.56 respectively.

In order to have a comparative picture with regard to goodness in relationship between M_L and magnitude estimated from signal duration records in the present study as well as those in the studies of Rao and Nag (1981) and Dattatrayam and Srivastava (1988) correlation coefficients (R) have been calculated and are presented in terms of percentage in Table 1 along with standard errors. It is seen that the values of the correlation coefficient and standard errors are comparatively better in the present study than that in Dattatrayam and Srivastava (1988).

Magnitudes of 11 earthquakes outside the period considered in the present study have been determined using the empirical equations obtained in the present work and also from Models II and III of Dattatrayam and Srivastava (1988). These have been presented in Table 2 for comparison. Magnitude estimate from NEIS wherever available have also been presented in the same table. A perusal of this table reveals that a fair agreement within the limits of error, exists between the estimated local magnitude from empirical equation in the present study and M_L obtained from Wood-Anderson seismograms for all the earthquakes between magnitude 2.0 & 5.0; even M_b from NEIS agrees fairly well. It is, however, noted that a fair agreement between the values of M_D (Dattatrayam and Srivastava 1988) and M_L exists only for magnitudes less than 4.

TABLE 1

Correlation coefficients between local magnitude, M_L and estimated magnitudes from signal duration

Authors		Correlation coefficient	Standard error
Rao and Nag (1981)		87.25	0.55
Dattatrayam and Srivastava (1988)	Model II	74.19	0.57
	Model III	81.39	0.56
Present study		86.66	0.32

4. Discussion

Central Seismological Observatory, Shillong, located at Lat. 25.57° N, Long. 91.99° E and commissioned under the national network of the seismological observatories of the India Meteorological Department became a part of the World Wide Network of Seismological Station (WWNSS) of United States Geological Survey (USGS) in 1963. The station is situated in a seismically very active region. A map showing tectonics of the area is presented in Fig. 7. It is seen from this figure that there exists Frontal Himalayan thrust in the north, Himalayan Syntaxial bend in the northeast, Dhubri and many other faults in the west and Dawki fault in the south of Shillong. Towards east and southeast are located the Haflong Naga thrusts and Arakan Yoma tectonic belts. All these tectonic units are seismically potential but comprise different geologic setting. Thus, propagation paths of seismic waves towards Shillong meet with complexity which appears to be responsible for variations in signal durations leading to scatter in data.

TABLE 2

Comparison of local magnitude (M_L) with estimated magnitude from signal duration and M_b from NEIS

Date	Epicentral distance (km)	M_b (NEIS)	M_L (Richter scale)	M_S (Estimated)	M_D Model* II	M_D Model* II'
15 Nov 1987	154.0	4.2	4.5	4.23	4.34	4.34
28 Nov 1987	682.0	4.6	5.0	5.13	6.36	6.42
1 Dec 1987	153.0	4.8	5.0	5.03	4.32	4.32
3 Dec 1987	20.0	—	2.2	2.17	2.27	2.37
8 Dec 1987	319.0	—	4.3	4.15	4.88	4.49
10 Dec 1987	252.0	—	4.0	3.85	4.40	4.38
11 Dec 1987	110.0	—	4.3	4.14	4.10	4.09
12 Dec 1987	506.0	—	4.8	5.19	5.82	5.87
15 Dec 1987	55.0	—	3.3	3.1	3.04	3.02
24 Dec 1987	78.0	—	2.8	2.55	2.64	2.68
1 Jan 1988	536.0	4.4	4.5	4.2	5.71	5.74

*Models by Dattatrayam and Srivastava

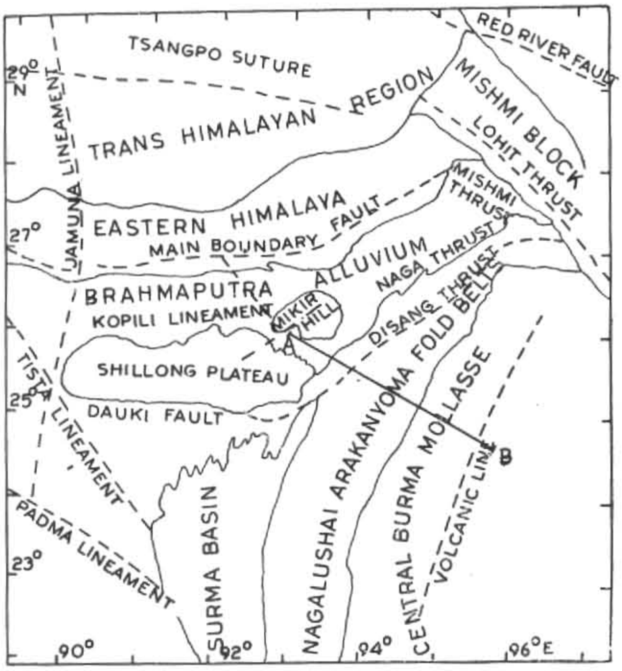

Fig. 7. Tectonic map of northeast India

As mentioned in section 3, plot of M_L against signal duration in Figs. 3 shows scatter. So is the case for M_L against M_S and M_D in Figs. 4-6. Some of the important factors on which signal duration depends are (*i*) instrumental response, (*ii*) geology of the seismological observatory, (*iii*) depth of focus of earthquakes & (*iv*) azimuth of the station from location of epicentre. While facters (*i*) and (*ii*) remained constant for all the earthquakes considered, there were variations in factors (*iii*) and (*iv*). It is mentioned that corrections for factors (*iii*) and (*iv*) were not carried out to evaluate the relation between magnitude and signal duration because exact location of epicentre and depth of focus are not available for most of the earthquakes. It is mentioned here that northeastern India is well known for its complex geology and earthquakes of varying depths of focus from shallow focus to intermidiate depths. It is felt that scatter in data can be minimised after applying such corrections. It is, therefore, suggested that this aspect may have to be looked into in subsequent studies on the subject. Nevertheless, the linear empirical relations in Eqns. (8) and (9) appear to satisfy the data reasonably well with uncertainity in determination being ± 0.32 for $2.0 \leqslant M_L \leqslant 4.7$ and ± 0.23 for $4.8 \leqslant M_L \leqslant 5.9$.

TABLE 3

The coefficients in Eqn. (1) $M_L = a + b \log \tau + c \triangle$ as obtained by different workers

Investigators	Calib. magn.	a	b	c	Uncertainty
Lee *et al.* (1972)	M_L	—0.37	2.00	0.0035	0.22
Crosson (1972)	M_L	—2.45	2.82	—	0.21
Reel and Teng (1975)	M_L	—1.01	1.89	0.0009	0.16
	M_L	1.03	0.45	0.0009	0.15
Present study	M_L (2.0-4.7)	—1.46	2.11	0.00012	0.32
	M_L (4.8-5.9)	1.98	1.14	0.00012	0.23

Results of earlier workers along with the results of the present study are presented in Table 3 for comparison. It is seen that there are differences in the values of the coefficients in Eqn. (1). These may be due to difference in instrumental response and geologic locations.

5 Conclusions

From what has been described in the foregoing sections following conclusions are drawn :

(*i*) Based on the data of local magnitude, M_L and signal duration of earthquake record on short period vertical component WWNSS seismogram at Shillong the empirical relations given by Eqns. (8) & (9) have been obtained.

Uncertainty in the estimation of magnitude using Eqns. (8) & (9) are $\pm$ 0.32 and $\pm$ 0.23 respectively.

(*ii*) The empirical relations given in Eqns. (2) (15) & (16) have been obtained between local magnitude, M_L and surface wave magnitude, M_S (Rao and Nag 1981) and M_L and magnitude estimated from signal duration of earthquake record on short period vertical component WWNSS seismogram at Shillong, M_D (Dattatrayam and Srivastava 1988). Uncertainty in the magnitude estimation using Eqns. (12), (16) & (17) are $\pm$ 0.56, $\pm$ 0.57 and $\pm$ 0.56 respectively.

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