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USE OF STRONG-MOTION ACCELEROGRAMS TO EVALUATE THE MAGNITUDES OF SOME SIGNIFICANT EARTHQUAKES IN THE KOYNA DAM AREA, INDIA

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ABSTRACT

The conventional Wood-Anderson Seismograph normally goes out of scale for strong local earthquakes. Also, the magnitude values determined from distant recordings may sometimes be in great error due to inaccuracies in the attenuation law used. Thus the Wood-Anderson Seismograms synthesized from strong-motion accelerograms recorded at close distances provide a useful basis for getting accurate and reliable values of local magnitudes. Using strong-motion data, local magnitudes for nineteen significant earthquakes in the Koyna dam area have been computed in the present study. The merits of the method used for computing the magnitudes from strong motion accelerograms in this study has been also discussed vis-a-vis the magnitude determinations based on Wood-Anderson records or the total coda durations as in the past.

INTRODUCTION

The local magnitude, M_L, of an earthquake is defined as (Richter, 1935),

$$M_L = \log A - \log A_o(R) \qquad \ldots (1)$$

where A is the maximum amplitude in mm recorded on the standard Wood-Anderson torsional seismograph (natural period T_n = 0.8 sec, fraction of critical damping $\xi = 0.8$, and static magnification V_s = 2800) and log $A_o(R)$ is a correction factor for the attenuation of seismic waves with epicentral distance R km. Originally, Richter defined the local magnitude for $R > 25$ km, where the Wood-Anderson seismograph goes out of scale for magnitudes around 4.5. But, it was later extended upto zero distance by Gutenberg and Richter (1942) using torsional seismograph with T_n = 10 sec, $\xi = 1.0$ and static magnification equal to 4.0.

Because the standard Wood-Anderson instrument goes out of scale for $M_L \geq 4.5$ and $R \leq 25$ km, it cannot be used to estimate the magnitude of even small earthquakes at very close distances. Therefore, several investigators (e.g.; Trifunac and Brune, 1970; Kanamori and Jennings,

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1978; Uhrhammer and Bolt, 1991; Jain et al., 1992; Trifunac, 1991a, b, 1993; Lee, 1991; etc.) have proposed the use of strong-motion accelerograms to synthesize the response of Wood-Anderson seismometer to evaluate the local magnitudes. In the present study, local magnitudes of several important earthquakes in the Koyna dam area have been estimated from strong-motion accelerograms. Most of the Koyna dam earthquakes have epicentral distances less than about 25 km and hence the present values of the magnitude can be considered more accurate and reliable than those reported in the past. The present estimates of the local magnitudes have been compared with the past estimates and the causes of difference between the two have been discussed in the paper.

METHOD FOR COMPUTING STRONG-MOTION LOCAL MAGNITUDE

To compute the local magnitude, M_L^{SM}, using strong-motion accelerograms, it is necessary to synthesize the standard Wood-Anderson seismogram from a given accelerogram. Kanamori and Jennings (1978) used time-domain convolution to generate Wood-Anderson seismograms for calculating local magnitudes. Uhrhammer and Collins (1990) and Uhrhammer and Bolt (1991) applied frequency-domain convolution to synthesize the Wood-Anderson seismograms. Jain et al. (1992) used fourth order Runge-Kutta method to integrate the Wood-Anderson seismograph equation directly. In the present study, Wood-Anderson seismograph equation has been integrated very efficiently using the algorithm by Nigam and Jennings (1968), as used to compute the design response spectra. Figure 1 shows two typical examples of the synthesized Wood-Anderson records using this method.

If $A_{synthetic}$ is the computed peak amplitude of the response of Wood-Anderson seismometer, the local magnitude in several past studies (e.g. Jain et al., 1992; Kanamori and Jennings, 1980; etc.) has been defined as

$$M_L = \log A_{synthetic} - \log A_o(R) \qquad \ldots (2)$$

where $\log A_o(R)$ is the Richter's attenuation function. However, Luco (1982) found that the magnitudes evaluated from eqn.(2) are overestimated for small R, and particularly for R near 20 km. He interpreted this as resulting from the inability of $\log A_o(R)$ to describe attenuation of strong motion amplitudes in the near field and proposed a modification in the Richter's attenuation function for smaller distances. Similar modification was also suggested by Jennings and Kanamori (1983). But depending upon the source-to-site distance, magnitude, and the geological condition at a site, the peak value of the response of Wood-Anderson seismograph may occur at different wave periods. Therefore, using the frequency dependent attenuation function for strong ground motion (Trifunac and Lee, 1990) and the knowledge of the period where most energy is concentrated in the strong-motion as filtered by the Wood-Anderson seismograph, Trifunac (1991a) defined an attenuation function Att (Δ_o) in place of Richter's function $\log A_o(R)$, where $\Delta_o = \sqrt{R^2 + H^2}$ is the hypocentral distance. This new attenuation function represents faster decay of strong ground motion with distance than the Richter's function. The two functions have quite large differences for distances from about 5 to 35 km. Values of these functions for distances upto 100 km are listed in Table 1, beyond which they are almost identical. Using this new attenuation function, the local magnitude from strong-motion data can be defined as

$$M_L^{SM} = \log A_{synthetic} - Att\ (\Delta_o) \qquad \ldots (3)$$

The local magnitudes obtained from this relation are found to be larger than the corresponding Richter's magnitudes estimated by Wood-Anderson seismograph records at longer distances. This is because at longer distances the seismic waves recorded by Wood-Anderson seismograph have suffered significant decay due to anelastic attenuation. Thus to match the magnitude estimates based on strong-motion data recorded at near distances with the Richter's magnitude at longer distances, Trifunac (1991a) proposed an empirical correction function D (M_L^{SM}) as listed in Table 2. Thus the local magnitude M_L^{SM} can be finally defined as

$$M_L^{SM} = \log A_{synthetic} - Att\ (\Delta_o) - D\ (M_L^{SM}) \qquad \ldots (4)$$

This new definition of M_L^{SM} has been used to estimate the local magnitudes of Koyna earthquakes. This considers not only the distance dependent correction, but also the magnitude dependent correction, which has been shown to be very significant for local small earthquakes by Trifunac (1991a).

RESULTS AND DISCUSSION

Using the foregoing procedure, local magnitudes have been computed from strong-motion accelerograms for nineteen important earthquakes in the Koyna dam area. These accelerograms have been digitized and processed to apply instrument and base-line corrections (Gupta et al. 1989, 1992). List of the accelerograms along with the maximum amplitude of the synthesized Wood-Anderson seismograms and the computed strong-motion magnitudes M_L^{SM} for both longitudinal (L) and Transverse (T) components are given in Table 3.

Figure-2 plots the average M_L^{SM} of two components versus the Richter's magnitude reported in the past. It is seen that though both the magnitude values are generally in quite good agreement, most of the past values are slightly or higher side. The past magnitude estimates for the Koyna earthquakes are based on the records of local Wood-Anderson seismographs with static magnification $V_s = 1000$ or the empirical correlation between magnitude and total coda duration (Guha et al., 1974). But, as pointed out by Uhrhammer and Collins (1990), due to the erroneous assumption that the taught-wire suspension in a Wood-Anderson seismograph does not distort significantly, the actual magnification may be smaller than 1000, leading to somewhat higher estimates of the Richter's magnitude. The discrepancy between the present and the past magnitude values may also be due to error in the attenuation function used. The empirical relations used to determine the magnitudes from total coda duration are calibrated in terms of magnitudes from Wood-Anderson records and hence suffer from all the drawbacks associated with the use of such records. In addition, the total coda duration depends on the type of recording instrument and its estimates may be highly biased by personal judgement, because there is no standard or analytical definition of the total duration. The large uncertainty and biases which may be present in the estimation of magnitude are illustrated by the main earthquake of 10 December 1967, which has been assigned magnitude value ranging from 6.25 to 7.5 by different agencies.

The above mentioned errors can be minimised by using near distance strong-motion records for the estimation of magnitude. This is because, due to small dynamic range, the Wood-Anderson instrument is not able to faithfully record the high-frequency near source ground motion, whereas the Wood-Anderson records synthesized from strong-motion accelerograms are able to represent all the wave frequencies with equal effectiveness. Also, the Richter's attenuation function has been replaced by an improved attenuation function Att (Δ_o), which takes into consideration the frequency dependent nature of the seismic wave attenuation. The errors due to error in the attenuation function are further reduced by the use of small propagation paths. Thus the present magnitude values for the selected nineteen significant earthquakes in the Koyna dam area can be considered unbiased and more reliable estimates compared to the past values.

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TABLE 1

Comparision of the Wood-Anderson's attenuation function, log $A_o(R)$, with the attenuation function, Att (Δ_o), based on Trifunac and Lee's (1990) frequency-dependent attenuation function.

Δ_o, km.	-Att (Δ_o)	-log $A_o(R)$	Δ_o, km.	-Att (Δ_o)	-log $A_o(R)$
1	1.62	1.400	40	2.71	2.314
5	2.08	1.500	45	2.75	2.421
10	2.30	1.605	50	2.78	2.517
15	2.42	1.716	60	2.83	2.679
20	2.51	1.833	70	2.88	2.805
25	2.58	1.955	80	2.93	2.920
30	2.63	2.078	90	2.98	2.989
35	2.68	2.199	100	3.03	3.044

TABLE 2

Empirical function D (M_L^{SM}) versus M_L^{SM}

M_L^{SM}	D (M_L^{SM})	M_L^{SM}	D (M_L^{SM})
4.6	1.60	6.6	0.58
4.8	1.53	6.8	0.38
5.0	1.45	7.0	0.18
5.5	1.27	7.1	0.08
6.0	1.07	7.2	-0.02
6.2	0.94	7.3	-0.12
6.4	0.78		

TABLE 3

Details of accelerograms and the computed strong-motion magnitudes M_L^{SM} for the selected Koyna dam earthquakes.

Sr #	Rec #	Recording Site	R (km)	Δ_o (km)	M_L	$A_{synthetic}$, mm		M_L^{SM}	
						COMP:L	COMP:T	COMP:L	COMP:T
01	04	Shear Zone Gallery	12.0	14.0	3.5	313	395	3.40	3.54
02	05	1A Gallery	12.0	17.0	6.5	29915	30369	6.65	6.66
03	08	Shear Zone Gallery	14.1	19.0	4.7	1296	2153	4.37	4.68
04	09	1A Gallery	11.7	19.0	4.6	1957	525	4.63	3.83
05	10	1A Gallery	09.8	25.0	3.8	607	902	4.02	4.27
06	11	1A Gallery	10.7	16.0	4.1	853	558	4.06	3.81
07	14	Shear Zone Gallery	06.9	21.0	5.0	945	651	4.23	4.00
08	15	1A Gallery	06.9	21.0	5.0	754	663	4.10	4.04
09	16	Shear Zone Gallery	01.5	04.0	4.1	1241	899	3.61	3.43
10	17	1A Gallery	01.5	04.0	4.1	1424	902	3.70	3.43
11	18	Shear Zone Gallery	08.9	18.0	3.6	714	556	3.99	3.84
12	46	1A Gallery	06.0	09.0	5.2	3682	1379	4.67	4.09
13	47	Shear Zone Gallery	06.0	09.0	5.2	3328	2930	4.63	4.53
14	48	Down Stream	06.0	09.0	5.2	2782	2673	4.51	4.49
15	49	1A Gallery	01.1	03.0	4.7	3511	1401	4.09	3.55
16	26	1A Gallery	11.0	17.0	4.4	2470	1043	4.74	4.20
17	36	Kirnos Observatory	17.5	19.0	4.3	671	1119	3.98	4.27
18	37	Operation Gallery	17.5	19.0	4.3	1260	1683	4.36	4.53
19	38	Kirnos Observatory	21.0	22.0	4.7	1124	1481	4.36	4.52

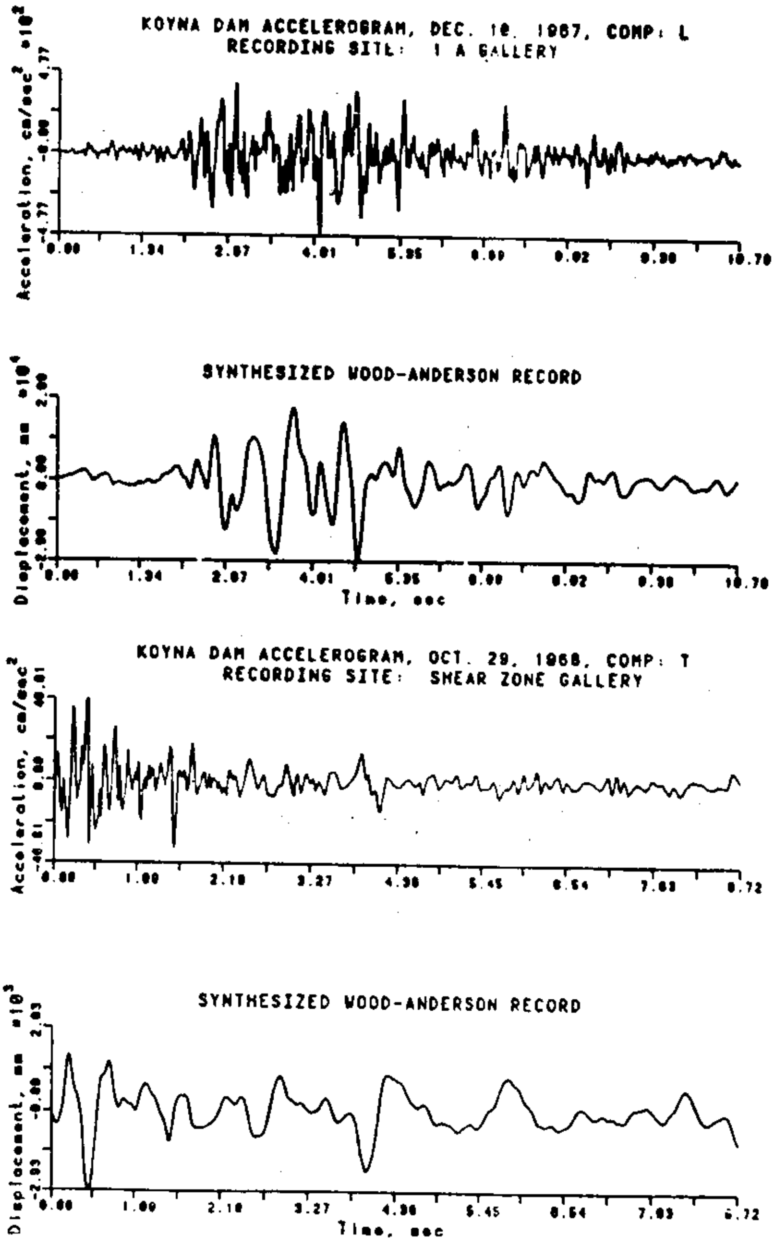

Fig. 1. Typical example of Wood-Anderson records synthesized from strong-motion accelerograms.

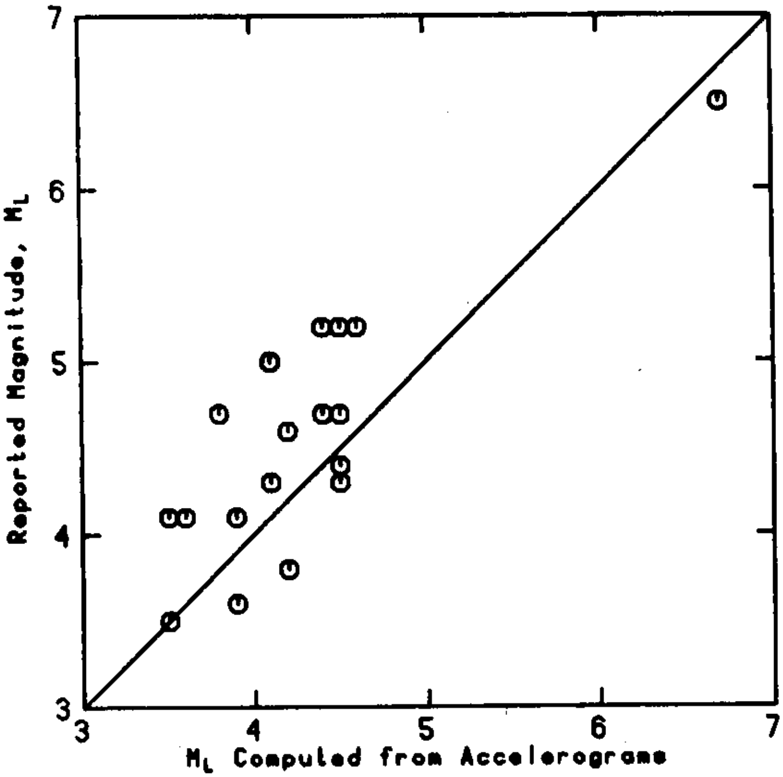

Fig. 2. Plot of strong-motion local magnitudes versus the corresponding reported Richter's local magnitudes.