Characteristics of strong shaking duration in Taiwan

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Abstract

Strong shaking duration plays an important role to affect the yield damage caused by an earthquake. In this study, we analyzed the acceleration seismograms of Taiwan Strong Motion Network to characterize the strong shaking duration with function of the earthquake magnitude and distance. We defined the duration to be the length of interval across the dissipated energy within 5%~95% of the total energy during the time interval between the first and the last amplitude which equal to or greater than a specified threshold value (here we gave the threshold value for 10gal). We calculated the strong shaking duration for 395 events with the magnitude ranged of M_L=5.0~7.0 and the depth 50*km* during 1994 to 2010. We, thus, obtained an empirical equation of strong shaking duration with magnitude and distance as $M_E(\tau,\Delta) = 2.3243 + 3.4171\log(\tau) + 0.0031\Delta$, where Δ is hypocenter distance (*km*), and τ is strong shaking duration time (*sec*). The equation can provide the characteristics of strong shaking duration preliminarily for the Taiwan earthquakes. Also we considered the site condition. The four empirical equations of different site classes are established as: $M_E(\tau) = 3.1947 + 2.8408\log(\tau) + 0.0068\Delta$ for B site (firm to hard rock), $M_E(\tau) = 2.5859 + 3.3500\log(\tau) + 0.0034\Delta$ for C site (dense soil and soft rock), $M_E(\tau) = 3.0225 + 2.4587\log(\tau) + 0.0044\Delta$ for D site (stiff soil), and $M_E(\tau) = 4.0424 + 1.6154\log(\tau) + 0.0040\Delta$ for E site (soft soil). The residual of the logarithm strong shaking duration is normally distribution. This study also validated these equations using the earthquakes with the same criteria for the year of 2011 to 2012. The result indicated that the empirical duration equations can be applicable to estimate the strong shaking duration for the criteria earthquakes (M_L5.0-7.0, depth< 50km) in Taiwan.

Definition of the Strong Shaking Duration

(1) **Bracketed duration**: the time interval between the first and last amplitude greater than a level of threshold value. (Bolt, 1973)

(2) **Significant duration** the time interval of the predetermined percentage of the total energy (Trifunac and Brady, 1975; Martin and Haresh, 1979).

(3) **This study:** the duration to be the length of interval across the dissipated energy within 5%~95% of total energy during the time interval between the first and the last amplitude which equal to or greater than 10gal (Fig. 1).

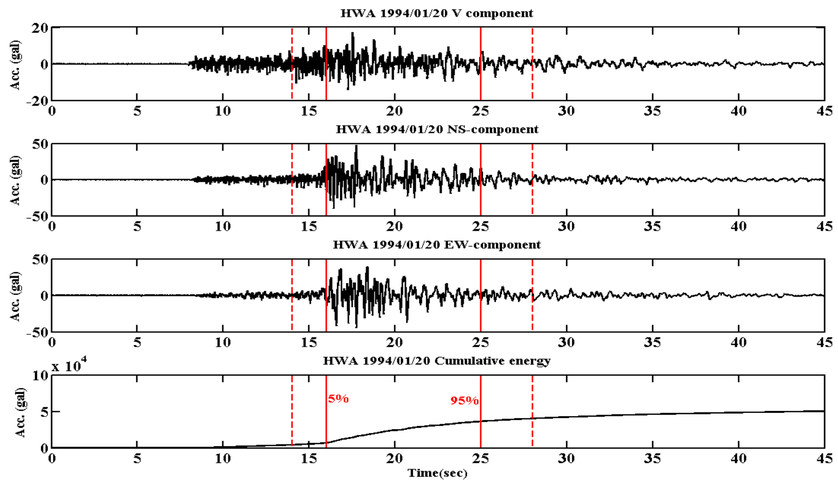

Figure 1 An example of the duration time of strong ground motion record by the acceleration seismogram of HWA station. The red dash lines show the time interval between the first and the last amplitude which equal to or greater than 10gal. The red lines show the interval across the dissipated energy within 5%~95% of the total energy of the interval of dash lines.

Strong Ground Motion Data and the Strong Shaking Duration

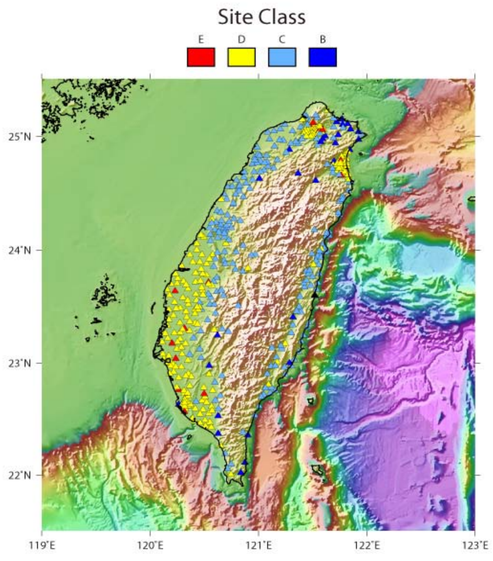

Figure 2 Distribution of strong-motion stations of Taiwan Strong Motion Instrumentation Program (TSMIP). The colors denote the site classifications as defined by Kuo et al. (2012).

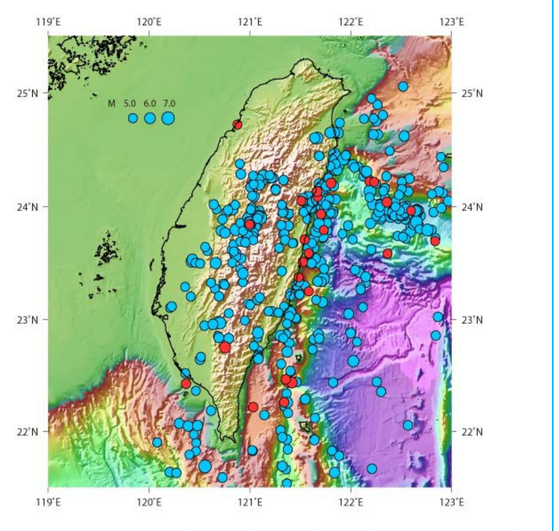

Figure 3 Earthquakes distribution of the selected events from 1994 to 2010 (blue dots) with M_L=5.0-7.0 and the depth<50 km and the selected events from 2011 to 2012 (red dots) for validation of the derived empirical equations

Development of the Empirical Equations of Strong Shaking Duration

$$\log(\tau) = \log(\tau_0) + c'\Delta \qquad M(\tau_0) = a + b(\log\tau_0)$$
$$M(\tau,\Delta) = a + b(\log\tau) - c\Delta$$

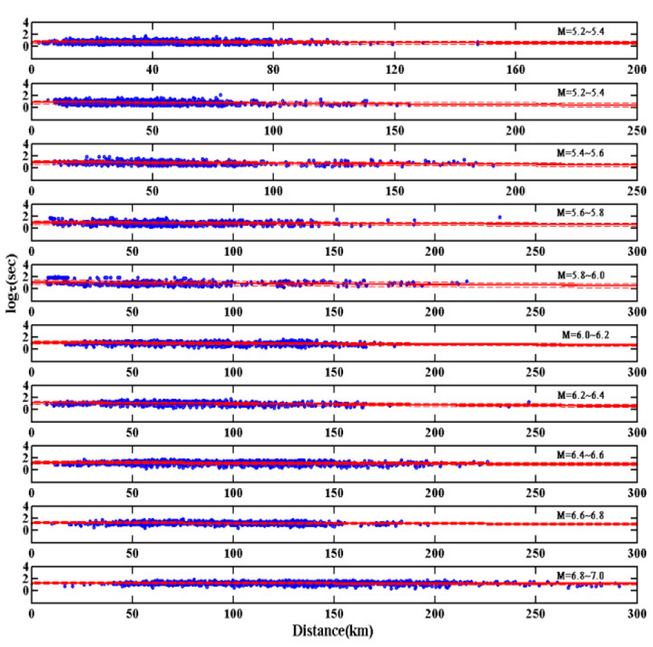

Figure 4 Logarithm of strong shaking duration time decay with distance for 0.2 magnitude interval of M=5.0-7.0. The red lines show the best regression of the data and red dash lines show the ±RMS range (68% of data in this range).

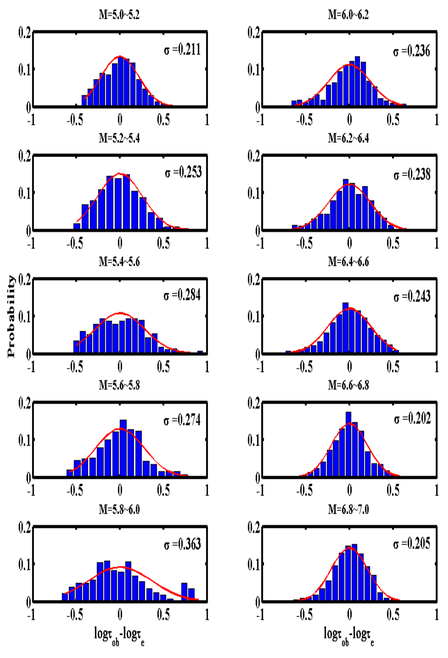

Figure 5 The probability density of the residuals of Logarithm duration time for 0.2 magnitude interval of M=5.0-7.0. The reds display the normally distribution.

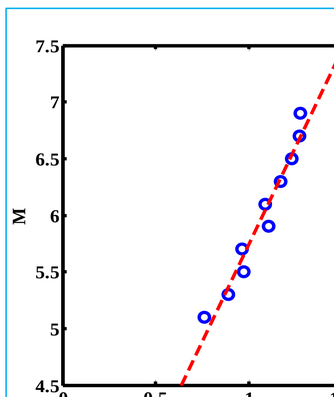

Figure 6 The regressed relationship between the strong shaking duration at 0 km distance(τ_0) and magnitude(M).

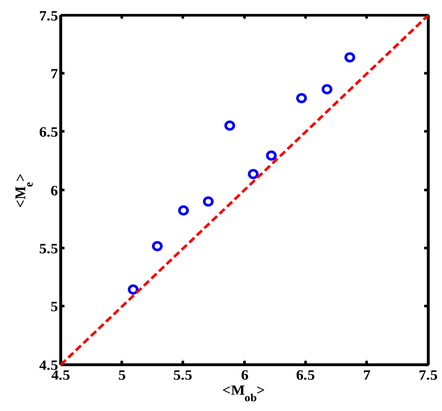

Figure 7 The comparison of the estimated magnitudes <Me> and the observed magnitudes <Mob> for every 0.2 magnitude interval with c=-0.0009.

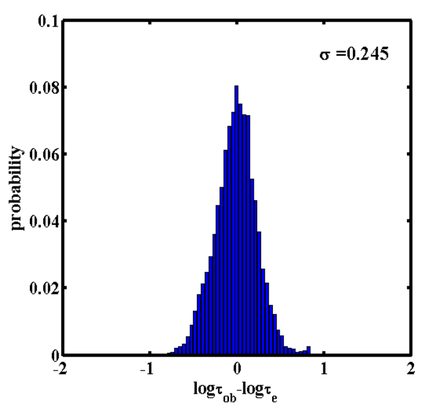

Figure 8 The probability density of the residuals of Logarithm duration time

Empirical Equation of Duration in Different Site Conditions

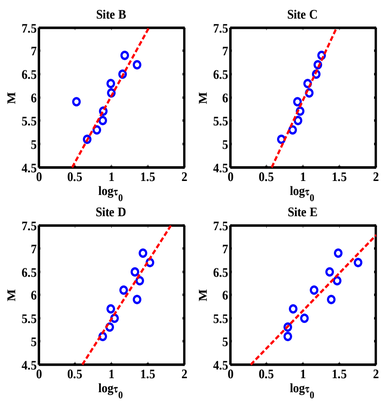

Figure 9 The regression relationship of strong shaking duration at zero distance (τ_0) and magnitude(M) for different site classes.

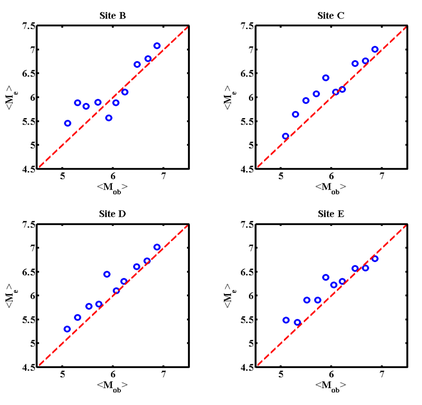

Figure 10 The comparison of the average of the estimated magnitude <Me> to the observed magnitudes <Mob>for magnitude in 0.2 interval for site classes B, C, D, and E.

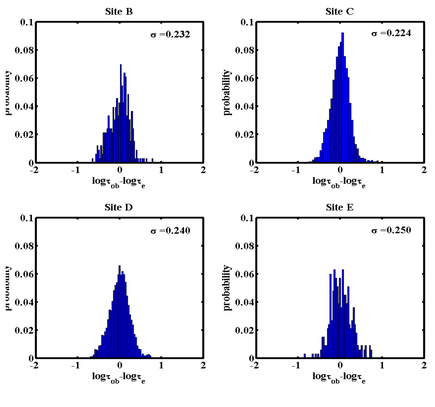

Figure 11 The probability density of the residuals of Logarithm duration time for site classes B, C, D, and E.

$M_E(\tau) = 3.1947 + 2.8408\log(\tau) + 0.0068\Delta$ for site class B with σ=0.2324;
$M_E(\tau) = 2.5859 + 3.3500\log(\tau) + 0.0034\Delta$ for site class C with σ=0.2239;
$M_E(\tau) = 3.0225 + 2.4587\log(\tau) + 0.0044\Delta$ for site class D with σ=0.2396;
$M_E(\tau) = 4.0424 + 1.6154\log(\tau) + 0.0040\Delta$ for site class E with σ=0.2497;

Validation of the Empirical Strong Shaking Duration Equations

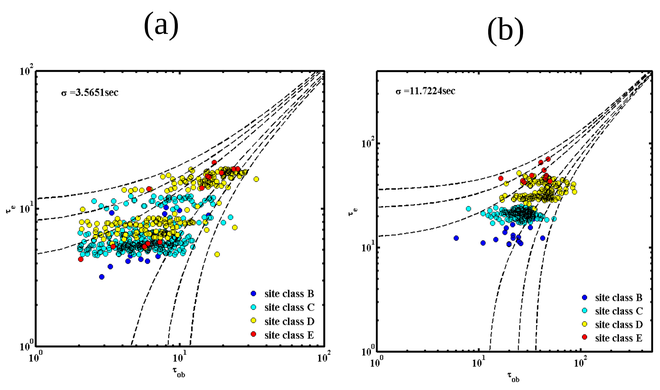

Figure 12 The comparison of the estimated duration to the observed duration for the earthquakes within M_L=5.0~7.0 from 2011 to 2012. The dash lines show the range within the standard deviation σ, 2σ, and 3σ of the estimated strong shaking duration (the 68% of strong shaking duration data within $\tau_e \pm \sigma$ sec, 95% within $\tau e \pm 2\sigma$ sec, and 99.7% within $\tau_e \pm 3\sigma$). The colors of the strong shaking duration (circles) denote the site classes of the recording data. (a) for the earthquakes within M_L=5.0~7.0 from 2011 to 2012 (b) for Chi-Chi earhtquake

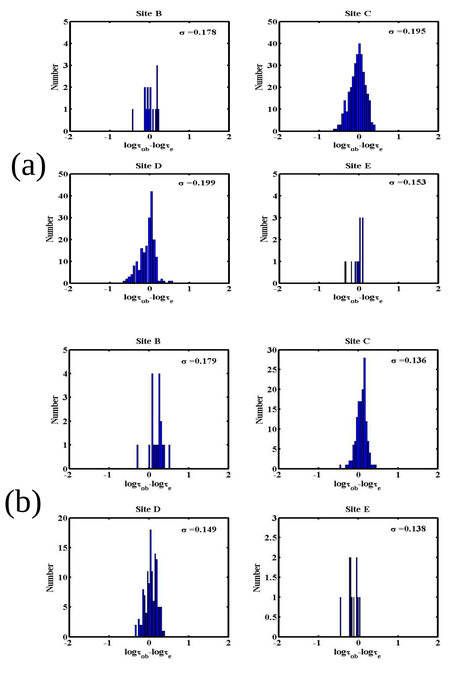

Figure 13 Histogram of the residual of the logarithm duration for site classes B, C, D, and E. The σ are standard deviation values. (a) for the earthquakes within M_L=5.0~7.0 from 2011 to 2012 (b) for Chi-Chi earhtquake

Couclusion

The major objective of this study is to establish the empirical strong shaking duration equations for Taiwan earthquakes. This study made a new definition for the strong shaking duration which is in consideration of the amplitude and energy factors. We analyzed the strong ground motion of acceleration from TSMIP network and obtained the empirical equations for different site classes B, C, D, and E individually. We also validated the equations using the earthquakes with ML5.0-7.0 and the depth < 50km for the years of 2011 to 2012. The validation result of the empirical equations shows that most of the τ_e values are comparable with the τ_{ob} values, that indicated the empirical duration equations can be applicable to estimate the strong shaking duration for the criteria earthquakes (ML5.0-7.0, depth< 50km). These empirical equations could provide the characteristics of strong shaking duration preliminarily for Taiwan earthquakes. We also found that some extreme data (τ >50 seconds) are on soil alluvium sites (plains and basin areas) in site class D and E. The site effect could efficiently cause longer strong shaking duration (Fig. 9).