Near Real-Time Seismic Damage Assessment of the Rapid Reporting System

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ABSTRACT

Having the ability of near real-time damage assessment would benefit earthquake emergency response operations in Taiwan greatly. Thus, we established an empirical method of assessing the near real-time damage using the rapid reporting system in Taiwan. Relationships between peak ground velocity and damage rates (fatality rate, total and partial household collapsing rates) during the 1999 Chi-Chi earthquake were determined in this study. The distribution of the peak ground velocity can be mapped within minutes of post-initiation of a strong earthquake by the rapid reporting system of the Taiwan Central Weather Bureau (Wu et al. 2001). By correlating peak ground velocity with damage rates gathered by the rapid reporting system, a near real-time damage assessment can be issued, in addition to the epicenter, magnitude and intensity.

(Key words: Seismic damage rate, Seismic rapid reporting system, Peak ground acceleration, Peak ground velocity)

1. INTRODUCTION

Located on the western circum-Pacific seismic belt with a plate convergence rate of 8 cm/year (Yu et al. 1999), Taiwan had experienced numerous destructive earthquakes with severe casualties and property losses. The potential earthquake hazard will continue to increase along with the population growth. Therefore, it is essential for Taiwan to seek means through scientific research to reduce future earthquake hazards.

Taiwan established several research programs actively pursing on earthquake rapid reporting system. A Taiwan Rapid Earthquake Information Release System (TREIRS) using a real-time strong-motion accelerograph network consisting 82 stations distributed around Taiwan were established by the Central Weather Bureau (CWB) (Fig. 1). Recent findings had

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shown that the rapid reporting system (RRS) is becoming a promising tool for providing reliable and critical information during an earthquake emergency, and crucial in mitigating seismic hazards (United States Geological Survey, 1998). Recent developments of the RRS of the CWB have advanced the system (Teng et al. 1997; Wu et al. 1997, 1998, 1999, 2000, 2001). Currently, the system is capable of routine broadcasting of the earthquake location and its magnitude about one minute after the occurrence, achieving the early warning capacity (Wu and Teng, 2002). The distributions of peak ground acceleration (PGA) and peak ground velocity (PGV) can also be mapped within two minutes. Thus, if empirical relationships between PGA, PGV and earthquake losses can be found, we can further the capability of near real-time damage assessment by CWB TREIRS in Taiwan.

The 1999 Chi-Chi earthquake not only caused big impact in the central Taiwan area, but also caused collapsing of high-rised buildings with large casualties in the Taipei basin, which is about 150 km away from the epicenter. The CWB collected high quality data of the strong ground motion during this earthquake, and provide an excellent opportunity to derive empirical relationships between PGA, PGV and earthquake losses with statistic evaluation by the National office of Statistics. Tsai et al. (2001) conducted the preliminary study on the relationship between peak ground motion and earthquake losses of the Chi-Chi earthquake, and pointed out positive correlation that high ground accelerations (> 400 gal) associated in high fatality
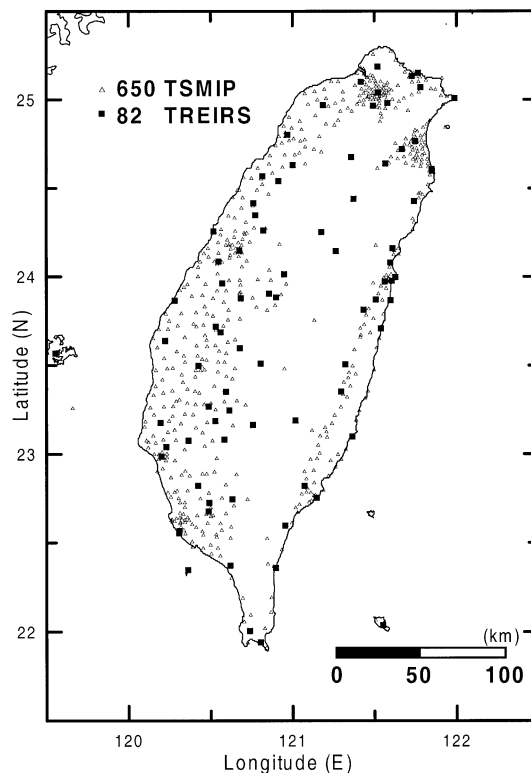

Fig. 1. Distribution of the 82 TREIRS stations and the 650 TSMIP stations.

rates (a rapid increase of 1.112% of the involved population). Yet the amount of total and partial collapsed households remained about equal. Therefore, the relationships between PGA, PGV and earthquake damages still need further determination. In this study, we attempt to use all these data to evaluate the relationships between PGA, PGV and earthquake damage in Taiwan.

2. DATA

The Taiwan Strong Motion Instrumentation Program (TSMIP) implemented by the CWB years prior to the 1999 Chi-Chi earthquake has about 650 modern digital accelerographs installed at free-field sites (Fig. 1). In metropolitan areas the TSMIP inter-station spacing is about 5 km. Most acceleration sensor recording ranges are $\pm 2g$. It offers detailed description of ground shaking and damage assessment. The TSMIP signals are digitized at 200 samples per second or higher and at 16-bit or higher. Over 30,000 digital strong-motion records were obtained from the Chi-Chi earthquake and thousands for the aftershocks. The TSMIP recorded strong-motion by 441 stations for the mainshock (Lee et al. 2001), which is the largest data set of strong-motion from a major earthquake since begging of strong-motion recording in the 1930s. This data set is important to seismology as well as to earthquake engineering because it includes over 60 recording sites within 20 km of fault ruptures, providing a five-fold increase of near source strong-motion records from major earthquakes of the world. These mainshock strong-motion records were utilized to calculate for PGA and PGV values of individual townships in Taiwan.

The National Office of Statistics (2001) separated the 1999 Chi-Chi earthquake damages into three categories: fatalities, total-collapsed households and partial-collapsed households in individual townships. Each household represents the officially registered residence unit, and averagely there are 3.3 persons per household in Taiwan. We used households instead of the number of the buildings in this study because:

(1) The data were well collected and provided for the National Office of Statistics.

(2) Number of the households is a better index than the number of buildings, since a high-rised building may contain several tens to hundreds households, and a low-rised building may contain one or two households.

3. ANALYSIS AND RESULTS

We applied five parameters of PGA, PGV, fatality rate, total and partial collapsed household rates in individual townships, where PGA and PGV values were determined from TSMIP strong-motion records of the 1999 Chi-Chi earthquake. The fatality rate, total and partial collapsed household rates in individual townships were carefully determined during the disaster relief operations according to the population records of the 1999 demographic summary (National Office of Statistics, 2000). Figure 2 shows the townships boundary and their geometrical centers in Taiwan. Figure 3 shows the total-collapsed household rate in every township along the distribution of PGA in central and northern Taiwan. Apparently, large house-
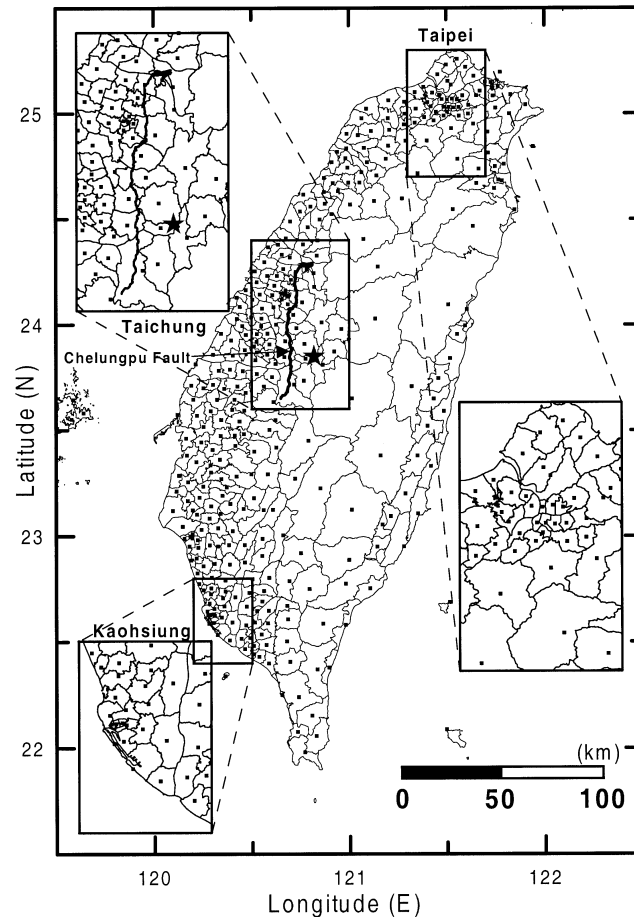
Fig. 2. Distribution of the townships boundary and their geometrical centers (solid
squares) in Taiwan region.

hold collapse rates occurred in the townships with high PGA (>400 gal), and mostly distrib-
uted on the hanging wall of the Chelungpu fault (east side). Both PGA and household collapse
rates decreased sharply to the foot wall (west side) of the Chelungpu fault. Figure 4 shows the
distribution of fatality rates and PGV values for every township in central and northern Taiwan.
All fatalities took place in the townships with PGV values greater than 20 cm/sec, and the
fatality rates greatly increased when PGV reached 60 cm/sec and higher.

For regression analysis, we applied Kriging method to calculate the PGA and PGV values
of the geometrical center of each township with assigned average PGA and PGV values. Table
1 and Table 2 show the averaged damage rates within different PGA and PGV ranges for
regression analysis.

Logarithm regression of the damage rate with PGA and PGV values yielded roughly
linear relation. Figures 5 and 6 illustrate the regression relations of the observed and predicted
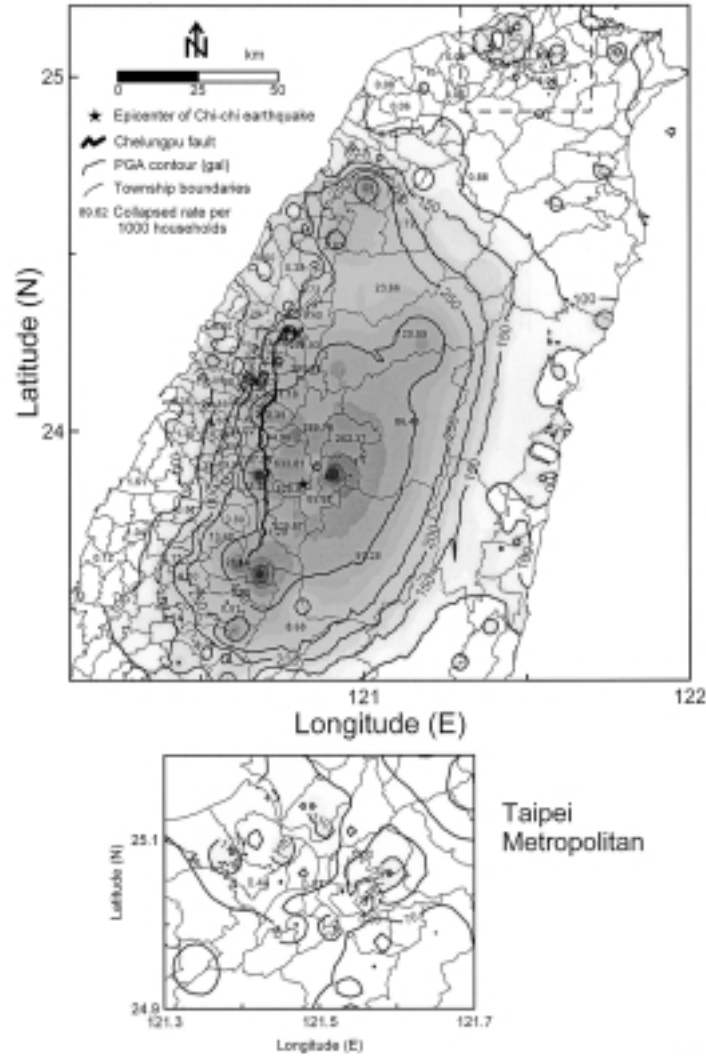damage rates (dots) with PGA and PGV values (solid lines), as the regressions were defined

Fig. 3. The distribution of total household collapse rates and PGA values in individual townships in central and northern Taiwan.

by:

$$\log_{10}(Fr) = -12.572 + 4.282 * \log_{10}(PGA) \pm 0.657$$
$$\log_{10}(Ct) = -10.118 + 4.146 * \log_{10}(PGA) \pm 0.508$$
$$\log_{10}(Cp) = -9.941 + 4.061 * \log_{10}(PGA) \pm 0.501$$
$$\log_{10}(Fr) = -9.360 + 4.315 * \log_{10}(PGV) \pm 0.341$$
$$\log_{10}(Ct) = -8.452 + 4.825 * \log_{10}(PGV) \pm 0.483$$
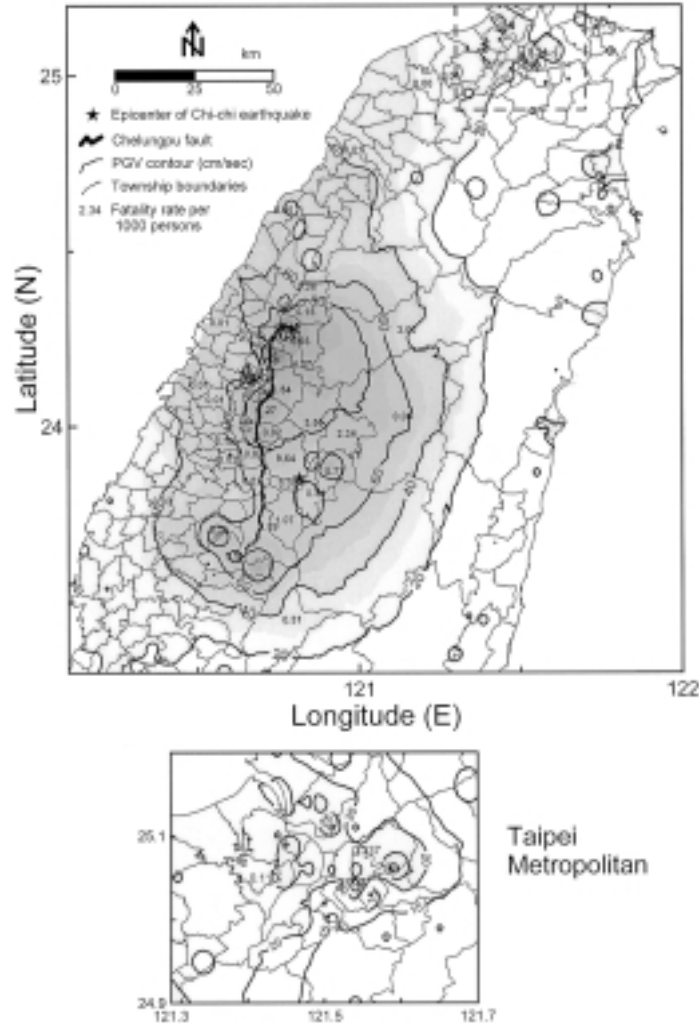$$\log_{10}(Cp) = -8.007 + 4.452 * \log_{10}(PGV) \pm 0.541 \tag{1}$$

Fig. 4. The distribution of fatality rates and PGV values in individual townships in central and northern Taiwan.

where Fr, Ct, and Cp are rate percentages of the fatality, total and partial-collapsed households, respectively. PGA is the peak ground acceleration (gal). PGV is the peak ground velocity (cm/sec).

4. DISCUSSIONS

According to the relationships of PGA and PGV with damage rates (Table 1 and 2), no seismic damages occurred for PGA and PGV values lower than 50 gal and 10 cm/sec during the Chi-Chi earthquake, and these two thresholds can be used for future seismic damage analysis.

Comparing the damage rate regression results from the PGA and PGV (equation 1; Figs 5

Table 1. The distributions of fatality rate, total and partial household collapse rates within different PGA (Peak Ground Acceleration) ranges of the 1999 Chi-Chi earthquake.

PGA Ranges (gal)	Fatality Rate (%)	Total Household Collapse Rate (%)	Partial Household Collapse Rate (%)
50 – 75	4.549E-06	3.785E-03	2.208E-03
75 – 100	7.637E-04	4.816E-03	4.492E-03
100 – 125	1.204E-04	5.861E-03	7.273E-03
125 – 150	1.678E-04	1.943E-02	1.910E-02
150 – 175	2.618E-04	9.421E-02	0.1212
175 – 200	1.385E-04	0.2459	0.4274
200 – 250	2.303E-03	2.350	4.236
250 – 300	2.091E-02	2.219	1.480
300 – 350	8.912E-02	4.337	3.545
350 – 400	0.2092	9.976	5.436
400 – 500	9.623E-02	11.91	13.57
500 – 600	0.3980	37.68	24.76
600 – 700	0.1149	2.116	2.522
700 – 800	7.734E-02	48.32	30.03

Table 2. The distributions of fatality rate, total and partial household collapse rates within different PGV (Peak Ground Velocity) ranges of the 1999 Chi-Chi earthquake.

| PGV Ranges (cm/sec)	Fatality Rate (%)	Total Household Collapse Rate (%)	Partial Household Collapse Rate (%)
10 – 20	2.740E-05	9.297E-04	1.547E-03
20 – 30	7.876E-04	8.507E-03	6.515E-03
30 – 40	1.597E-03	5.258E-02	2.681E-02
40 – 50	9.164E-03	0.8719	1.122
50 – 60	3.995E-03	0.5996	0.9571
60 – 70	6.601E-02	13.90	13.64
70 – 80	0.2096	12.45	8.963
80 – 90	0.2165	38.65	29.18
90 – 100	8.005E-02	7.255	8.926
100 – 125	0.1519	16.53	8.423
125 – 150	0.5929	29.09	23.69
150 – 175	1.127	44.27	21.32
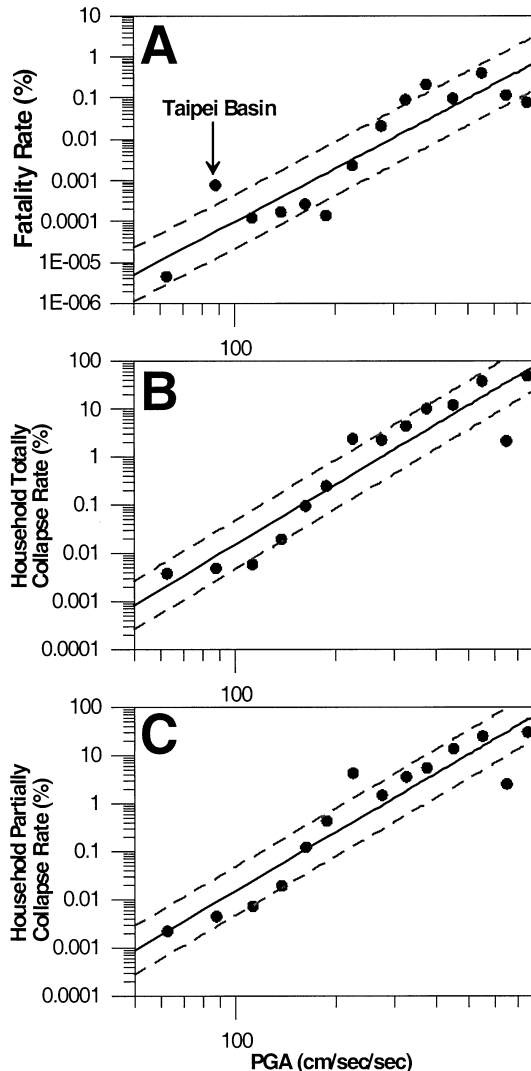
Fig. 5. (A) Relationship between fatality rate and PGA; (B) Relationship between total household collapse rate and PGA; (C) Relationship between partial household collapse rate and PGA.

and 6), PGV regression with smaller standard deviations generally provide better results than PGA regression, and is especially true for fatality rate correlations. Although the standard deviation of Cp for PGV regression is larger than PGA, Cp is not as an important factor than Ct or Fr for damage assessment. Abnormal high fatality rates were recorded for PGA within the range of 75 to 100 gal, but the same response did not occur in household collapse rates (Fig. 5). This phenomenon can be explained by the collapsing of few high-rised buildings that caused high fatality in the Taipei basin. Therefore, even the Taipei basin has rather low PGA range, it experienced a relatively higher PGV values than other places. This abnormal phenomenon does not occur in the PGV regression (Fig. 6). The Ct and Cp for PGA at the range of 600 to 700 gal is abnormally low (Fig. 5). This phenomenon may be explained by at least three events occurred at about Maioli and Chiayi region within one minute after the mainshock (Shin, 2000). These events caused high frequency acceleration signals due to mixing with the
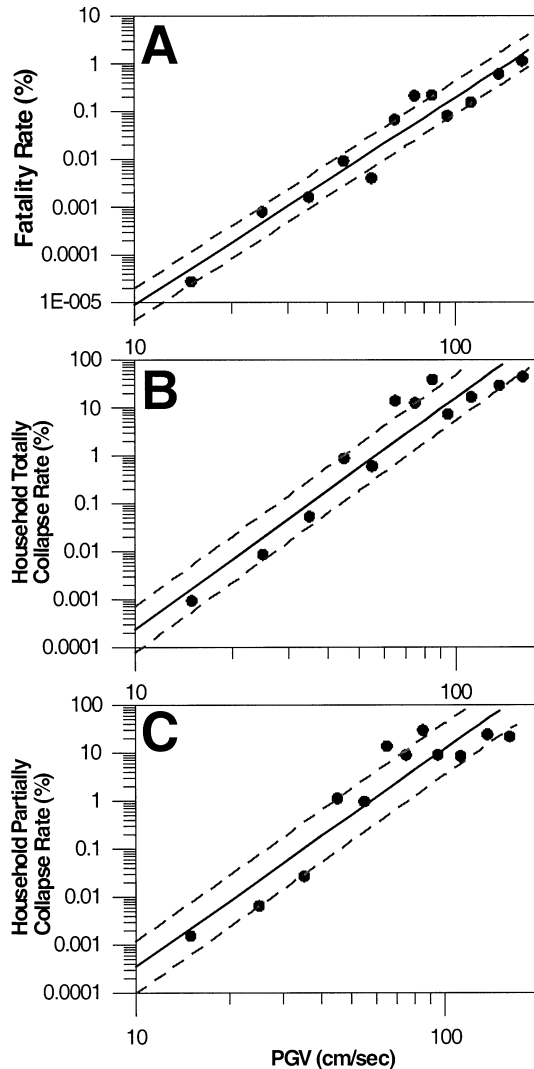
Fig. 6. (A) Relationship between fatality rate and PGV; (B) Relationship between total household collapse rate and PGV; (C) Relationship between partial household collapse rate and PGV.

mainshock, but did not cause higher PGV and significant damages. Another important phenomenon during the Chi-Chi earthquake, observed is that dramatic increasing (10%) of the household collapse rates occurred for PGV higher than 60 cm/sec.

Comparing the relationships between PGA, PGV and seismic damage rates determined in this study, we recommend that the PGV is a much better index for seismic damage assessment. It is also commonly observed that damageless small earthquakes can produce high PGA values near source regions, but high PGV values are only observed for large earthquakes. Figure 7 shows the predicted PGA and PGV curves for Mw 4.0, 5.0, 6.0 and 7.0 from Wu et al. (2001). According to the predicted PGV curves, earthquakes with Mw < 5.0 almost never produce PGV large than 10 cm/sec. However, earthquakes of Mw < 5.0 can produce PGA as large as 200 gal. Therefore, PGV is a more reliable index than PGA for damage assessment.

According to the predicted PGV curves, it also gives us information that Mw < 5.0 earth-
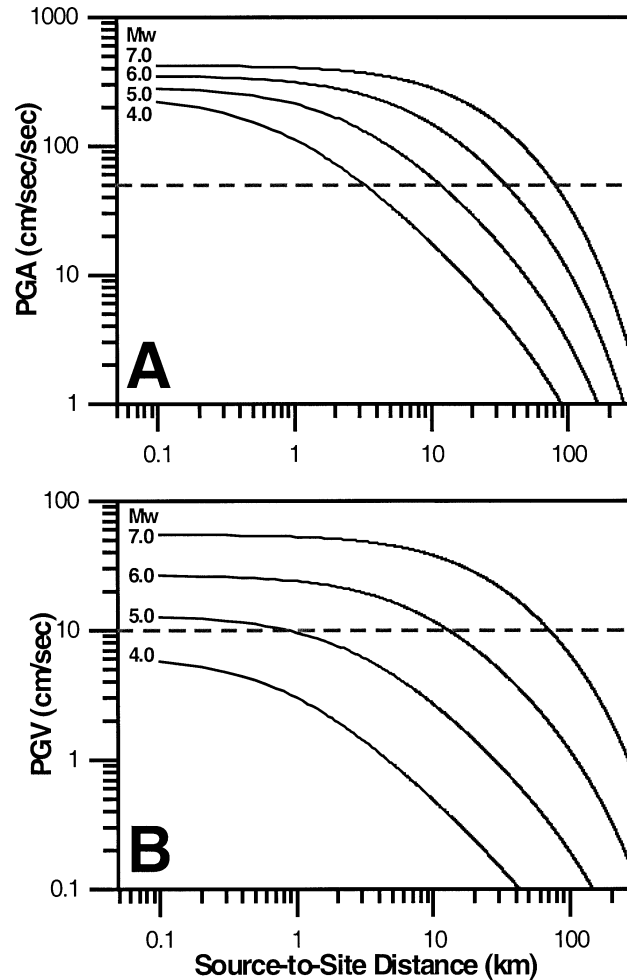
Fig. 7. (A) PGA attenuation curves for Mw 4.0, 5.0, 6.0 and 7.0 (solid lines), the
dashed line shows PGA = 50 gal; (B) PGV attenuation curves for Mw 4.
0, 5.0, 6.0 and 7.0 (solid lines), the dashed line shows PGV = 10 cm/sec.

quakes are generally undamaging in Taiwan. Thus, Mw 5.0 can be defined as the lower limit
for damaging earthquakes in Taiwan, where early warning work of earthquake should be
focused.

5. CONCLUSIONS

In this study, we investigated the relationships between the damage rates (fatality rate,
total and partial household collapse rates in individual townships) with PGA and PGV, and
determined a total of six related relationships. According to our analysis, we conclude that
PGV, rather than PGA, should be used as an index for the damage assessment as it gives a

much better indication of damage potential.

The CWB rapid reporting system can provide a near real-time damage assessments by applying the existing database on buildings and population with distribution of PGV, which is critically useful for earthquake emergency response operations.

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