

# Estimation of Seismic Ground Motions and Attendant Potential Human Fatalities from Scenario Earthquakes on the Sanchiao Fault in Taipei City, Taiwan

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**Abstract:** The purpose of this study is to estimate maximum ground motions in Taipei city in the form of ShakeMaps as well as to assess potential human fatalities from scenario earthquakes on the Sanchiao active faults in this area. Analysis of seismic hazard potential becomes necessary in Taipei City for the Central Geological Survey (CGS) announced the Sanchiao active fault as Category II. The resultant ShakeMap patterns of maximum ground motion by using ground motion prediction equation (GMPE) method in a case of Mw6.88 show the areas of PGA above 400 gals are located in the northern and western parts of Taipei. Furthermore, the areas of PGA above 500 gals are located in these regions: Beitou, Shihlin, Datong, Wanhua, Jhongheng, northern Neihu, western Jhongshan, western Daan and western Sinyi. In addition, seismic hazards in terms of PGA and PGV in the vicinity of the Sanchiao fault are not completely dominated by the Sanchiao fault. The main reason is that some areas located in the vicinity of the Sanchiao fault are marked with low site response amplification values of 0.55 and 0.67 for PGA and PGV, respectively. Finally, from estimation of potential human fatalities from scenario earthquakes on the Sanchiao active fault, it is noted that potential fatalities increase rapidly in people above age 45. Total fatalities reach a high peak in age groups of 55–64. Another to pay special attention is Taipei City has hundreds of thousands of households whose residences over 40 years old. When a strong earthquake strikes, these old houses are vulnerable to collapse. In light of the results of this study, the author urge both the municipal and central governments to take effective seismic hazard mitigation measures in the highly urbanized areas with a large number of old buildings in Taipei city. The results of this study will show which areas with higher earthquake hazard potential in Taipei City. It will help mitigate Taipei City earthquake disaster loss in the future, as well as provide critical information for emergency response plans.

**Keywords:** Sanchiao Fault, Potential Human Fatality, Ground Motion, ShakeMap, Taipei City

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## 1. Introduction

Taiwan is located along the circum-Pacific seismic belt. During the last four hundred years, 20 damaging earthquakes had occurred in Taipei area. Historically, there were three damaging earthquakes, 1986 Hualien earthquake, 1999 Chi-Chi earthquake and 2002 Hualien earthquake during the last century had resulted in heavy loss of human lives in Taipei. They occurred primarily at shallow depths, and were mostly associated with active faults that ruptured the ground surface. Accordingly, the assessment of potential seismic hazards has become increasingly important in Taipei city since the Central Geological Survey upgraded the Sanchiao active

fault from suspected fault to Category II in 2010 [1]. It poses a high potential for seismic disaster in the event of a large magnitude earthquake on the fault that most likely could cause serious damage. Hence, the governments need to put in more efforts on earthquake disaster prevention in these areas to reduce probably earthquake losses.

Earthquakes have caused great loss of lives in Taiwan. Hence, National Science Council (NSC) of Taiwan started the HAZ-Taiwan project to promote research on seismic hazard analysis [2]. Reliable assessment of seismic hazards is a fundamental requirement for effective earthquake disaster mitigation. Reliable seismic hazard assessment, in turn, requires accurate ground motion estimates. In addition, some

studies estimated potential seismic hazards in southern Taiwan in the form of ShakeMaps. Particularly, the site response factor is incorporated into their ground motion prediction models to obtain more realistic peak ground motion estimates for assessment of potential seismic hazards [3-7].

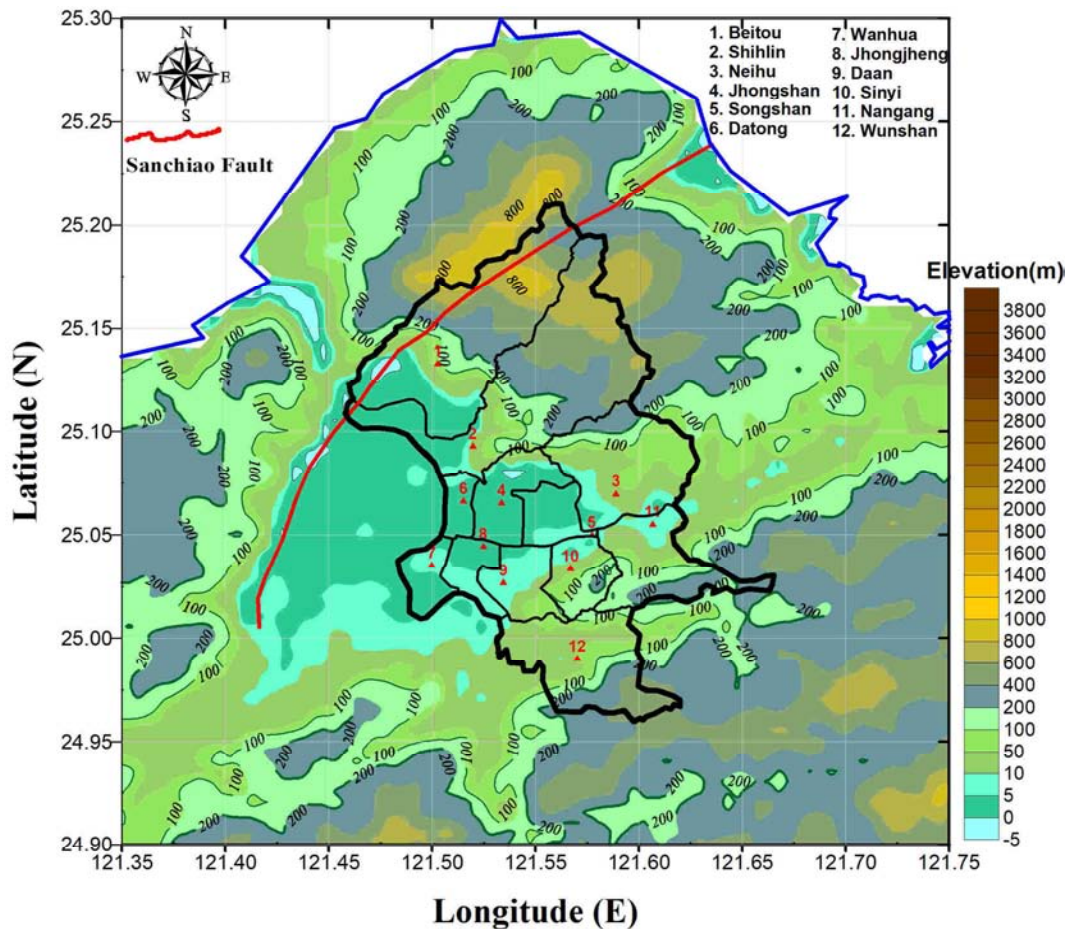
The ShakeMap developed by the United States Geological Survey (USGS) provides a means of generating not only peak ground acceleration and velocity maps, but also a Modified Mercalli Intensity (MMI) map [8]. This map makes it easier to relate the recorded ground motions to the shaking intensity and attendant damage. On the MMI intensity scale, the levels of earthquake shaking are designated as light damage (MMI VI), moderate damage (MMI VII), and heavy damage (MMI VIII). Recent ShakeMap studies based upon maximum ground motion analyses showed areas of MMI intensity greater than VIII in the Chianan plains [4]. In addition, Liu and Tsai [9] applied a formula established by Tsai et al. [10] that relates the human fatality rate with age, together with the age distribution of the population that could be affected by scenario earthquakes on Meishan, Chukou and Hsinhua active faults in Chianan area to estimate the potential death tolls due to large future earthquakes.

In this study, the author first estimates the maximum

seismic ground motions in term of PGA, PGV and MMI, aiming to show high seismic hazard areas in Taipei City. Particularly, the site response factor is incorporated into the using ground motion prediction models more realistic peak ground motion estimates for assessment of potential seismic hazards. Furthermore, the potential death tolls due to large future earthquakes occurring on the Sanchiao active fault will be assessed. The results of this study will show which areas with higher earthquake hazard potential in Taipei City. It will help mitigate Taipei City earthquake disaster loss in the future, as well as provide an important database for site evaluation of critical facilities and critical information for emergency response plans.

## 2. The Study Area and Data Used

The study area, Taipei City located in Taipei Basin, northern Taiwan (Figure 1). The city and the outskirts of a typical basin, the topography of southeast hilly, northeast many mountains, northwest more flat, west of the Tamsui river. Overall, the terrain dipped from the north to the south, altitude ranged from 20 to 1100 meters. The alluvial layer is distributed in the Taipei Basin, the river channel and the littoral area [11].

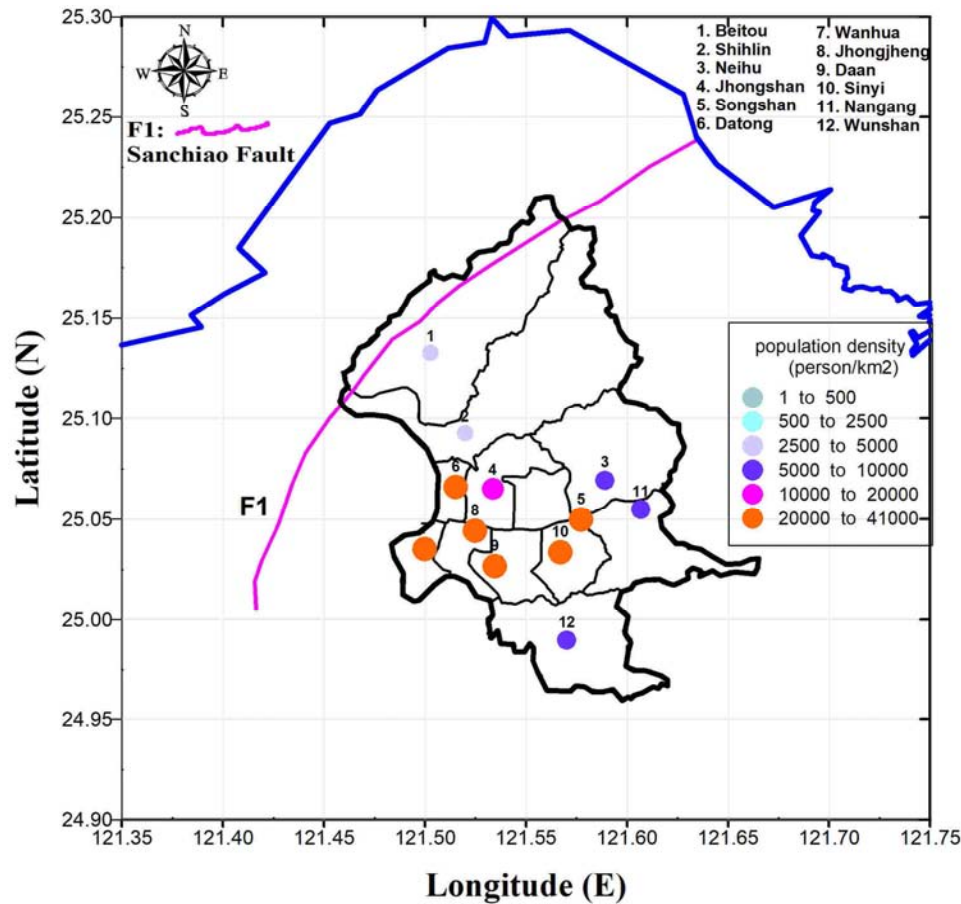


**Figure 1.** Topographic map of the Taipei City, showing the Sanchiao active fault (mapped by the Taiwan CGS) and 12 administrative districts in Taipei City.

Taipei City has 12 jurisdiction districts with a total population of 2,686,516 [12]. The population density is 9,940

people per square kilometer [11]. The numbers and names of 12 jurisdiction districts as follows: 1 Beitou, 2 Shihlin, 3 Neihu, 4 Jhongshan, 5 Songshan, 6 Datong, 7 Wanhua, 8 Jhongjheng, 9 Daan, 10 Sinyi, 11 Nangang and 12 Wunshan. Topographic map of the Taipei city and 12 administrative districts of Taipei City as well as the Sanchiao active fault (mapped by the Taiwan Central Geological Survey) [14] is

shown in Figure 1. The distribution of average population density in the area is also shown in Figure 2 and given in Table 1 [12]. Areas of high population density between 10,000 and 20,000 per km<sup>2</sup> can be seen in Jhongshan district. Furthermore, areas of high population density above 20,000 per km<sup>2</sup> can be seen in Songshan, Datong, Wanhua, Jhongjheng, Daan, and Sinyi districts.



**Figure 2.** Population density map of the Taipei City. The Sanchiao active fault and 12 administrative districts in Taipei City are also shown.

**Table 1.** Population and Population density of the administrative districts of Taipei City\*.

No.	1	2	3	4	5	6	7	8	9	10	11	12
Age	Bei-tou	Shih-lin	Nei-hu	Jhong-shan	Song-shan	Da-tong	Wan-hua	Jhong-jheng	Da-an	Sin-yi	Nan-gang	Wun-shan
0~4	13,183	14,050	14,636	11,737	10,238	6,958	9,739	8,499	15,476	11,480	6,681	13,731
5~9	10,505	11,292	12,480	8,204	9,778	4,866	6,156	8,169	14,527	8,283	4,623	11,879
10~14	13,077	13,684	15,917	9,471	12,541	6,080	6,877	10,562	18,156	9,748	5,359	15,043
15~19	14,691	16,637	18,553	11,590	11,944	7,059	9,818	9,460	17,784	12,226	6,930	17,181
20~24	15,073	16,937	18,633	12,270	10,797	7,119	10,871	8,172	15,370	12,997	7,230	15,661
25~29	16,773	19,126	19,292	13,891	11,333	8,197	12,595	8,804	15,976	14,401	8,161	16,217
30~34	22,962	25,144	24,975	19,983	15,319	11,798	18,141	12,273	21,957	19,711	11,573	22,114
35~39	21,645	23,754	23,611	19,554	16,756	11,311	16,521	13,198	23,782	19,050	11,141	22,592
40~44	20,190	21,595	22,307	17,608	17,084	9,878	14,230	13,130	24,553	17,489	9,607	22,720
45~49	19,215	21,729	23,421	18,068	16,860	9,719	14,440	12,805	24,721	17,594	9,231	22,803
50~54	19,788	22,794	24,226	18,801	16,175	9,936	15,300	12,122	24,006	18,049	9,086	21,724
55~59	19,488	23,500	22,534	18,708	15,787	9,813	15,093	11,436	23,768	17,809	8,461	19,588
60~64	16,897	20,526	16,401	16,847	14,834	8,827	13,378	10,734	23,198	16,349	7,582	16,687
65~69	9,827	11,818	7,911	10,218	9,738	5,230	8,219	6,813	15,044	10,251	4,274	9,812
70~74	8,132	9,865	6,165	7,878	7,350	4,763	7,626	5,499	11,938	8,260	3,683	7,931
75~79	5,572	7,075	4,611	5,892	5,164	3,796	5,811	4,403	8,600	5,557	2,557	5,723
80~84	4,373	5,383	3,731	4,423	4,171	2,504	4,483	3,411	6,871	4,618	1,855	4,825
85~89	2,786	3,222	2,414	2,674	2,888	1,297	2,850	2,270	4,825	3,110	1,217	3,405
90~94	1,027	1,265	832	978	1,241	503	1,035	1,041	2,153	1,158	404	1,383

No.	1	2	3	4	5	6	7	8	9	10	11	12
Age	Bei-tou	Shih-lin	Nei-hu	Jhong-shan	Song-shan	Da-tong	Wan-hua	Jhong-jheng	Da-an	Sin-yi	Nan-gang	Wun-shan
95~99	231	282	165	232	274	122	238	254	527	285	86	279
>100	49	64	27	48	71	44	50	85	131	71	11	43
Pop.	255484	289742	282842	229075	210343	129820	193471	163140	313363	228496	119752	271341
Pop.D.	4496	4646	8957	16719	22647	22850	21857	21446	27581	20387	5483	8612

\* Note:

(1) Data source: National Statistics (2014).

(2) Pop. = Population.

(3) Pop.D. = Population Density.

According to the active fault map of Taiwan by the Central Geological Survey [1], a Sanchiao active fault was distributed in the northwestern of Taipei area. The Sanchiao active fault belongs to Type II, namely late Pleistocene active fault. The Sanchiao fault is a normal fault, showing the strike of north-north east, divided into two segments: The southern section ranged northward from the Shulin District of New Taipei City to Beitou District of Taipei City with a length of 13 km. The northern section ranged northward from Beitou District of Taipei City to Jinshan District of New Taipei City with a length of 21 km [1]. Apparently, Taipei City has high seismic hazard potential. Compounded with rapid urban growth and development, population increase, and the slow rebuilding of old buildings, any major earthquake is likely to cause severe damages. Effective earthquake disaster prevention measures in the region will be required in order to reduce future earthquake loss [13-15].

According the empirical relationships among magnitude and rupture length of fault developed by Wells and Coppersmith (1994) [16]. The reasonable magnitude value for Sanchiao fault would be  $M_w6.88$  and  $M_w6.33$  corresponding to a fault length of 34 km for all sections and 13km for southern section, respectively. In addition, the focal depth for the scenario earthquakes on Sanchiao fault was assumed to be 10km, based on the information from Taiwan Earthquake Loss Estimation System (TELES) developed by the National Center for Research on Earthquake Engineering (NCREE) [2] and CGS [1]. Hence, considering the uncertainty and possibility, two magnitude values of  $M_w6.88$  and  $M_w6.33$  will use to estimate the maximum ground motions and attendant potential human fatalities.

In this study the site effects are included in the ground motion prediction model by a site response factor at each grid point. These predictive relationships were obtained by using the Taiwan Strong Motion Instrumentation Program (TSMIP) network data operated by the CWB of Taiwan to estimate peak ground motion at all grid points [6, 17, 18]. The TSMIP network has been designed to enhance the ability to monitor strong earthquakes and to collect high-quality instrumental recordings of free-field ground shaking [4, 5, 19].

### 3. Methodology

#### 3.1. Maximum Ground Motion Parameters

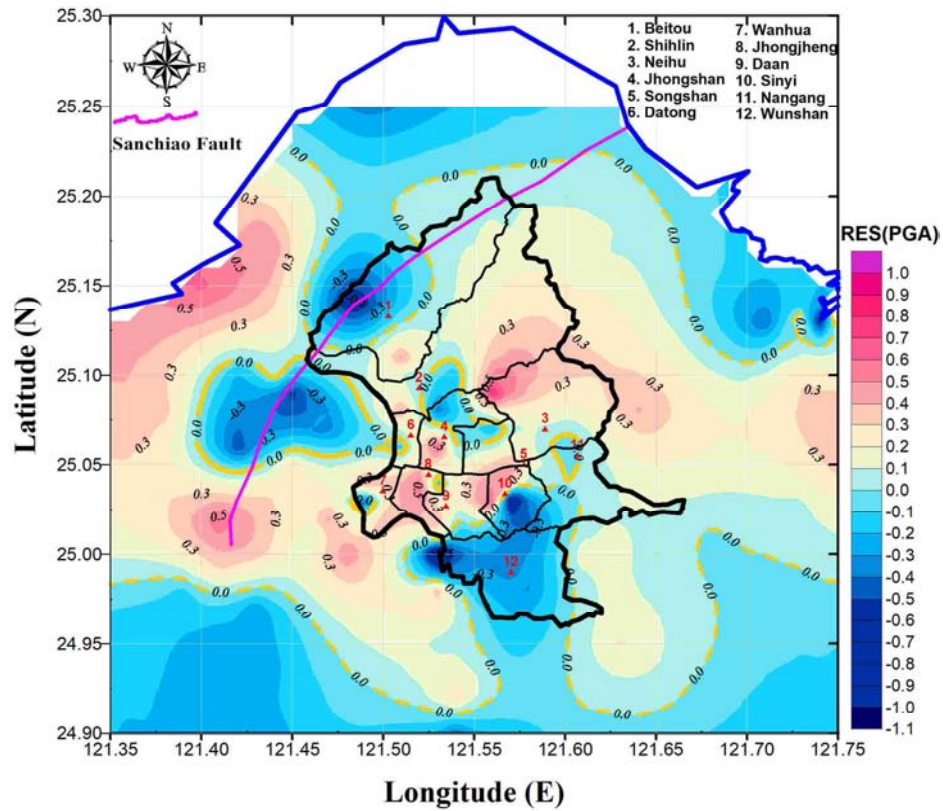
Ground motion prediction equation (GMPE) is a predictive

relationship that allows estimation of peak ground motions, in terms of either peak ground acceleration (PGA) or peak ground velocity (PGV), at a given distance for an assumed earthquake magnitude. To obtain ShakeMap, the empirical attenuation relationship provided by Liu and Tsai [18] is used for conversion from peak acceleration and velocity. In addition, a Modified Mercalli Intensity (MMI) map also has uses in combination by PGA and PGV. This MMI map makes it easier to relate the recorded ground motions to the shaking intensity and attendant damage.

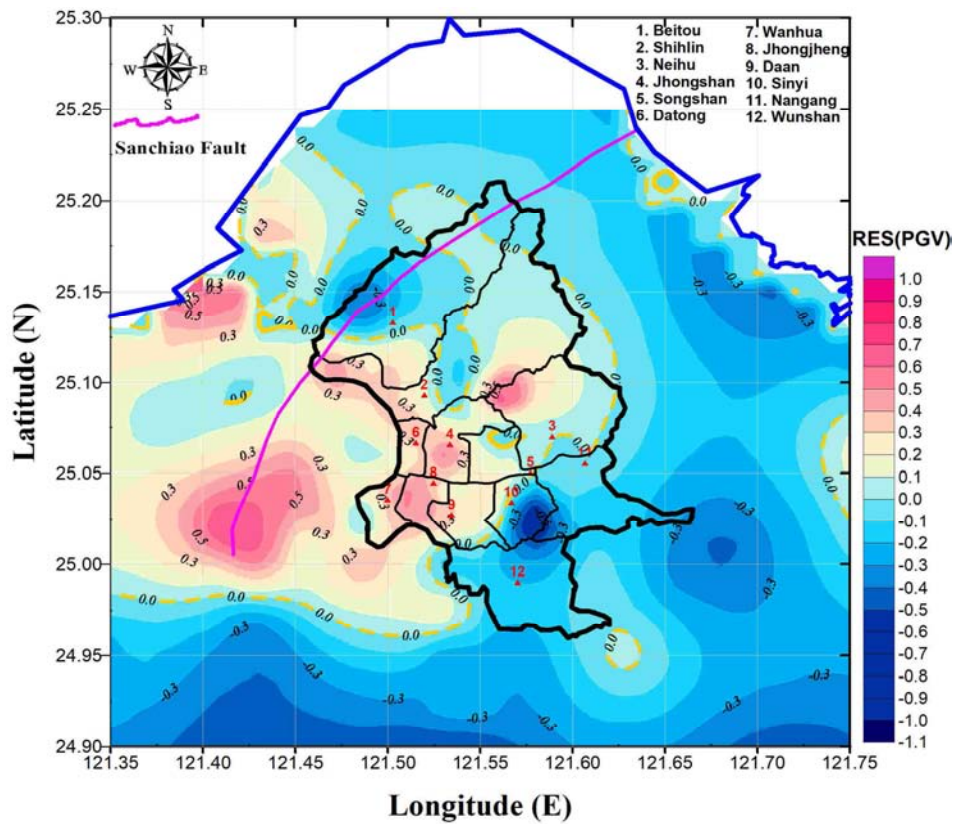
Because quantitative site description of  $V_{s30}$ , the average shear-wave velocity over the top 30 m, is not available for all strong-motion sites of CWB [18], the traditional attenuation analysis cannot include a site response factor in the ground motion attenuation relationship of Liu and Tsai [18]. Alternatively, the site effect was corrected in this study by a site response factor at each grid point. At first, these predictive relationships are used to estimate peak ground motion for each grid point, and then correct the amplitude at that location using a site response factor determined by Liu and Tsai [6, 18]. The site response factor  $r$  is defined as the difference between the logarithms of the observed and the predicted ground motion. The site amplification values can be calculated from  $\exp(r)$  [6].

In brief, a two-dimensional surface grid map with a block size of  $0.01^\circ \times 0.01^\circ$  (or roughly 1 km  $\times$  1 km) across the entire study area is advised. This is followed by a procedure to construct the Shakemaps, as follows: First, the empirical attenuation relationships obtained from Taiwan by Liu and Tsai [18] are used to calculate PGA and PGV for earthquakes in the database at each grid point. In this step, the Sanchiao active fault was used as a line source to calculate the maximum ground motion. Second, a site response factor is used to correct above PGA and PGV at all grid points, as shown in Figures 3 and 4. Finally, the above results with the estimated PGA and PGV are combined into MMI maps. The maximum ground motion parameters inside a block provide a means to assess the potential earthquake hazard in a region. In this study, ground shaking selected both for the Modified Mercalli Intensity (MMI) scale and the Taiwan intensity scale used by the Central Weather Bureau (CWB) of Taiwan is given in Tables 2 (URL <http://earthquake.usgs.gov/eqcenter/shakemap/background.php>) and 3 (URL <http://www.cwb.gov.tw/in/seismic/quake/preparedness.htm>), respectively.





**Figure 3.** Distribution of the site response factor for PGA in the Taipei City. The site response factor is defined as the residual value  $r$  that is the difference between logarithms of the observed and the predicted PGA, The amplification values of site response can be calculated from  $\exp(r)$ .



**Figure 4.** Distribution of the site response factor for PGV in the Taipei City. The site response factor is defined as the residual value  $r$  that is the difference between logarithms of the observed and the predicted PGV, The amplification values of site response can be calculated from  $\exp(r)$ .

**Table 2.** Modified Mercalli Intensity Scale (MMI).

Estimated Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X+
Peak Acc. %g	<0.17	0.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
gal	<1.7	1.7-13.7	13.7-38.2	38.2-90.2	90.2-176	176-333	333-637	637-1215	>1215
Peak Vel. (cm/s)	<0.1	0.1- 1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
Perceived Shaking	Not Felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential Damage	None	None	None	Very Light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy

**Table 3.** Central Weather Bureau Intensity Scale (CWB I) of Taiwan.

Intensity Scale	0	1	2	3	4	5	6	7
	Micro	Very minor	Minor	Light	Moderate	Strong	Very Strong	Great
Peak Acc. (cm/s <sup>2</sup> )	<0.8	0.8~2.5	2.5~8.0	8~25	25~80	80~250	250~400	>400
Effects Or Damage			Hanging lamps vibrate slightly.	Buildings shake, hanging objects shake visibly.	Buildings rock noticeably; may cause slight damage.	Walls crack; some chimneys and large archways topple over.	Damage to some buildings, doors and windows bend.	Severe damage to or collapse of some buildings; underground lines break.

### 3.2. Assessment of Human Fatality

To be effective an earthquake protection program needs to include realistic estimation of life loss in future earthquakes. Yet empirical data that document the occurrences of fatalities in earthquakes are relatively rare [10, 20]. Tsai et al. [10] made a realistic assessment of probable levels of human casualties caused by the 1999 Chi-Chi earthquake in Taiwan. The results showed clear age dependence of the human-fatality rate based on demographic data of the two hardest-hit Nantou and Taichung counties. Accordingly, a realistic estimation of total human fatalities in areas of high seismic intensity, either before a large earthquake by performing scenario studies, or shortly after a real earthquake by a system of rapid intensity mapping can be made. The age dependence of human fatality rate used in this study to calculate the number of fatalities is expressed as follows [7, 9, 10]:

$$Y\% = 0.00022 X^2 - 0.01 X + 0.16 \quad (1)$$

Where  $Y\%$  is the age-group fatality rate in percentage, and  $X$  represents age.

The above equation was conducted by Yu [21] according the total fatalities in individual townships located inside the seismic intensity greater than 250 gals in Nantou and Taichung counties. Because the Chi-Chi earthquake struck late at night (1:47am, local time), almost all residents were at home. In fact, most people in the strongly shaken rural areas were in bed. As a result, building collapse became the most dominant cause of fatalities [10]. Hence, the fatality rate model in this study should be more suitable for night time. On the other hand, the primary cause of death of the victims of the Chi-Chi earthquake was structural failure and the building types was cited as one of the most important factors affected this [22]. Due to building code revisions after 1999, better building quality is expected and corresponding fatality rate should be reduced.

## 4. Results and Discussion

### 4.1. Maximum Ground Motion Parameters

The studies of ground motion characteristics in Taiwan require ground-motion attenuation models. Attenuation relationships, or "Ground Motion Prediction Equations (GMPEs)", provides an efficient means for predicting the level of ground shaking and its associated uncertainty at any given site or location, as well as for use in seismic hazard analyses [23]. The value of the maximum ground motion parameters is calculated at each grid point of the study area to contour the ShakeMap. As explained earlier, two magnitude values of  $M_w 6.88$  and  $6.33$  are used for case 1 and 2, respectively to estimate the maximum ground motions.

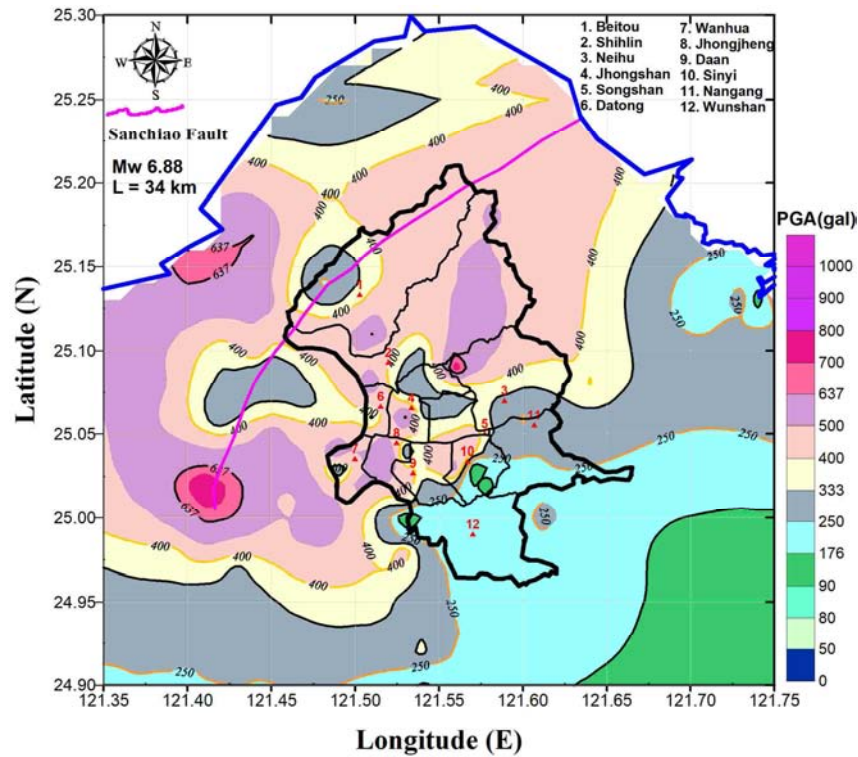
#### 4.1.1. Case 1 for $M_w 6.88$

The maximum PGA ShakeMap for an  $M_w 6.88$  scenario earthquake on the Sanchiao active fault in Taipei City is shown in Figure 5. Locations of the 12 administrative districts and Sanchiao fault are also shown. The results reveal that high PGA areas greater than 400 gals, corresponding to CWB intensity greater than VII, are located in the northern and western parts of Taipei, as shown in the regions inside the yellow lines in Figure 5. Furthermore, the areas of PGA above 500 gals are located in these regions: Beitou, Shihlin, Datong, Wanhua, Zhongjheng, northern Neihu, western Jhongshan, western Daan and western Sinyi. The high PGA areas greater than 637 gal, corresponding to MMI intensity greater than IX, are located in the border area of Shihlin and Neihu. Likewise, Figure 6 is shown the maximum PGV ShakeMap. It can be seen that the areal patterns of high PGV greater than 31 cm/s, corresponding to MMI intensity greater than VIII, are similar to that of the PGA. In addition, the high PGV area greater than 60 cm/s, corresponding to MMI intensity greater than IX, is located in northwestern Shihlin.

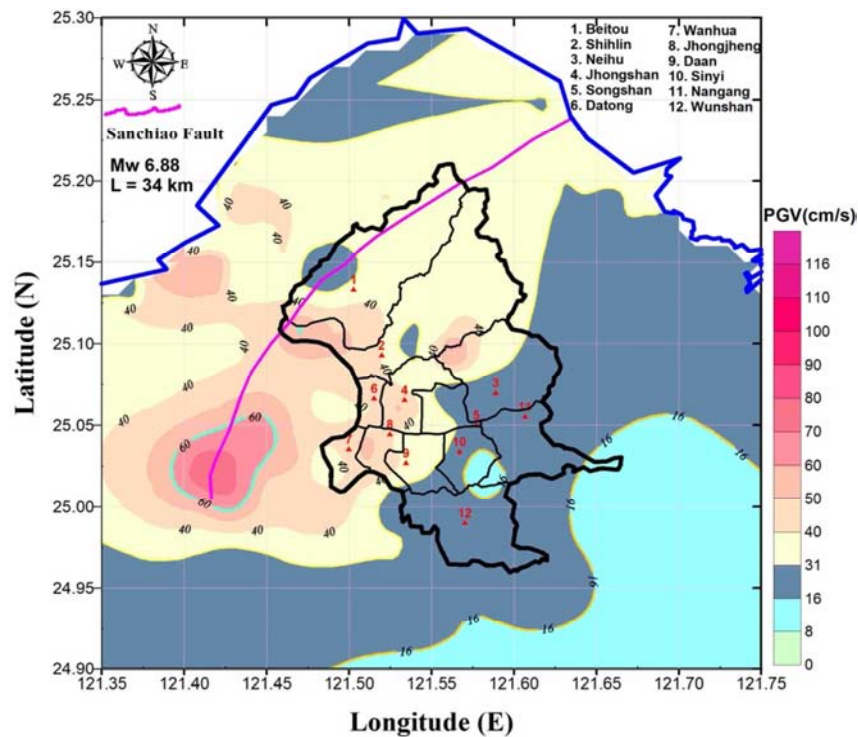
Seismic intensity, especially for that of the MMI is widely

used to represent the level of ground shaking following a damaging earthquake [8]. Accordingly, an MMI intensity map, based on a combination of estimated maximum PGA and PGV is obtained and shown in Figure 7. It can be seen that the patterns of high MMI greater than VIII, are similar to the

contour pattern of the PGV greater than 31 cm/s. In summary, the ShapeMaps shown in Figures 5-7 can provide critical information to assess potential earthquake hazards in Taipei City.

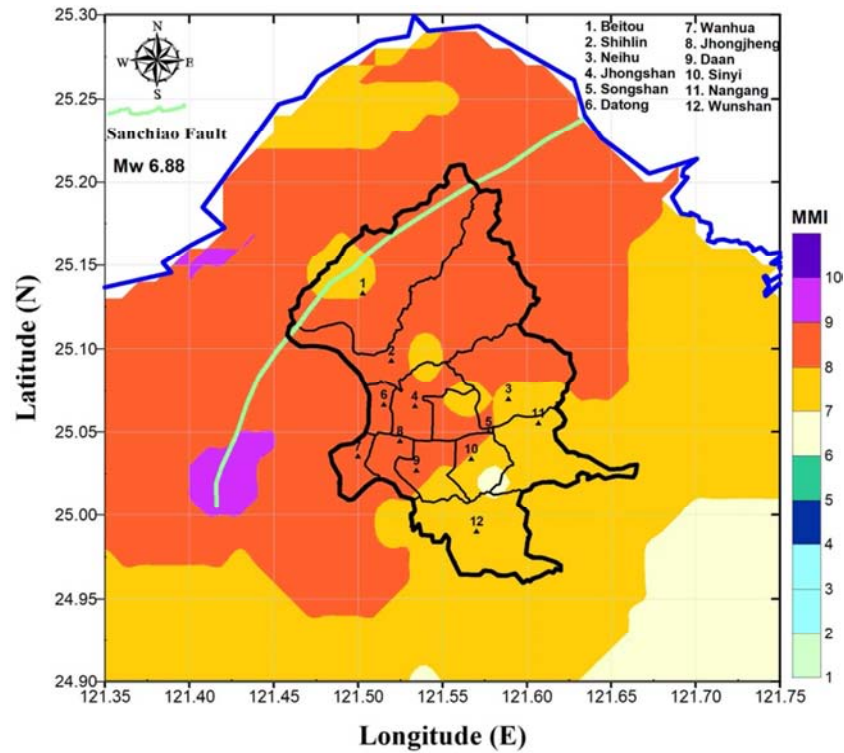


**Figure 5.** The maximum PGA ShakeMap for Mw6.88 scenario earthquake on the Sanchiao active fault in Taipei City. Locations of the 12 administrative districts of Taipei City and Sanchiao fault are also shown.

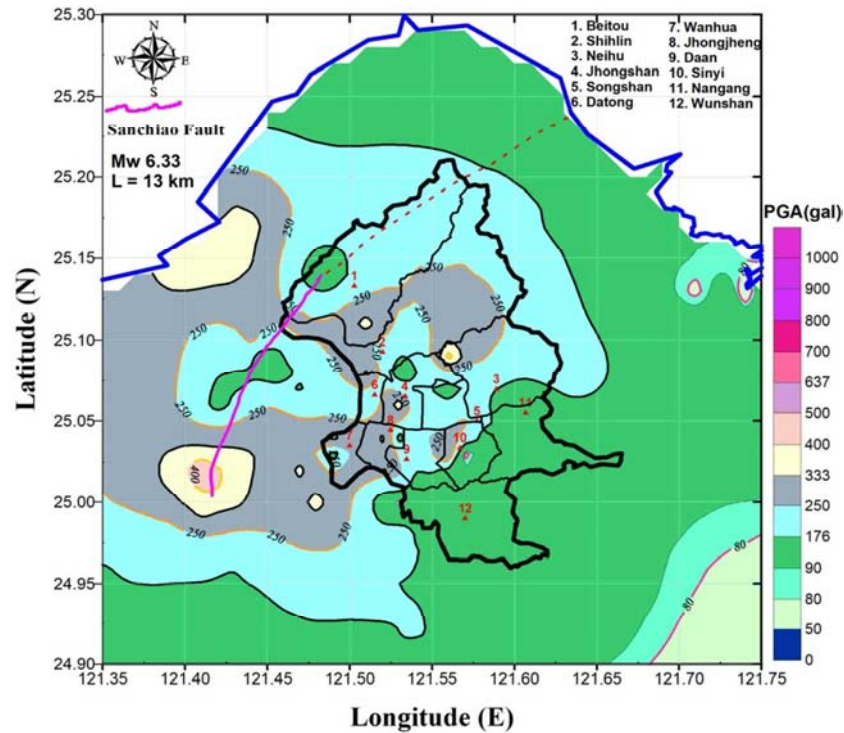


**Figure 6.** The maximum PGV ShakeMap for Mw6.88 scenario earthquake on the Sanchiao active fault in Taipei City. Locations of the 12 administrative districts of Taipei City and Sanchiao fault are also shown.





**Figure 7.** The maximum MMI ShakeMap for Mw6.88 scenario earthquake on the Sanchiao active fault in Taipei City. Locations of the 12 administrative districts of Taipei City and Sanchiao fault are also shown.



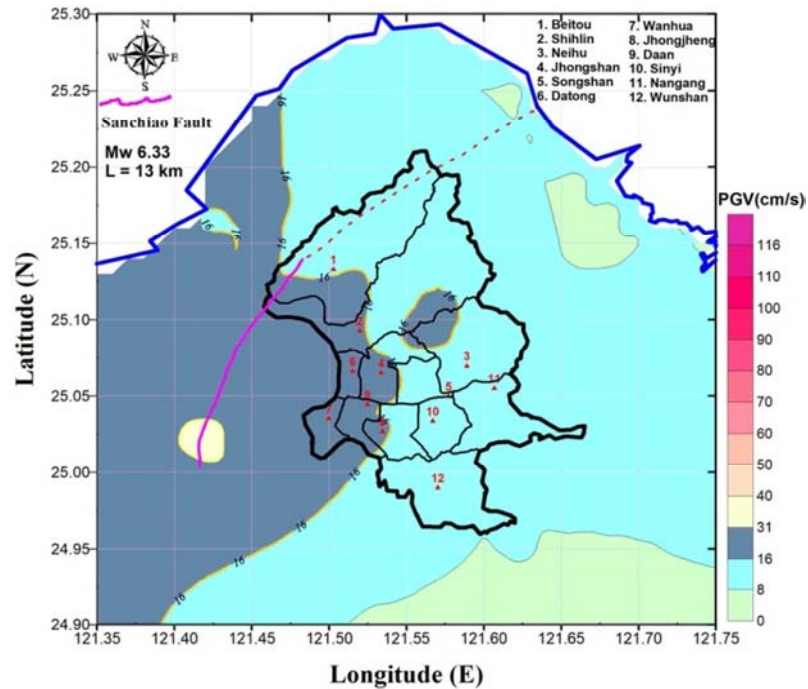
**Figure 8.** The maximum PGA ShakeMap for Mw6.33 scenario earthquake on the southern part of Sanchiao active fault in Taipei City. Locations of the 12 administrative districts of Taipei City and Sanchiao fault are also shown.

#### 4.1.2. Case 2 for Mw 6.33

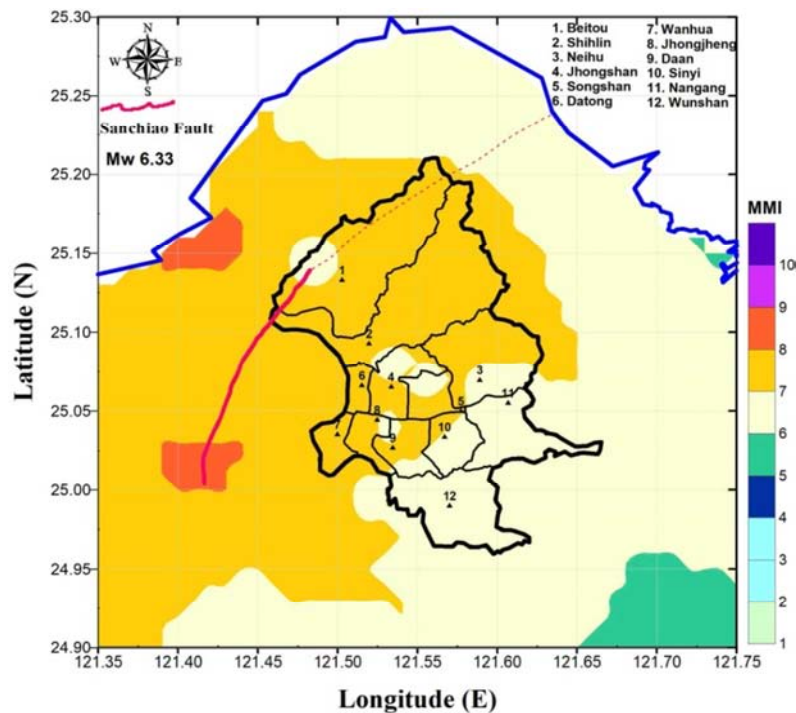
The maximum PGA ShakeMap for an Mw6.33 scenario earthquake on the Sanchiao active fault in Taipei City is shown in Figure 8. Locations of the 12 administrative districts and Sanchiao fault are also shown. The results reveal that high PGA areas greater than 250 gals, corresponding to CWB intensity greater than VI, as shown in the regions inside the orange lines in Figure 8, are located as follows: southern Beitou, western and southeastern Shihlin, northwestern Neihu, southwestern Jhongshan,



southeastern Datong, northern and southeastern Wanhua, Jhongjheng, western Daan and western Sinyi. Likewise, Figure 9 is shown the maximum PGV ShakeMap. It can be seen that the areal patterns of high PGV greater than 16 cm/s, corresponding to MMI intensity greater than VII, are similar to that of the PGA. Next, an MMI intensity map, based on a combination of estimated maximum PGA and PGV is obtained and shown in Figure 10. It can be seen that the patterns of high MMI greater than VII, are similar to the contour pattern of the PGA greater than 176 gals.



**Figure 9.** The maximum PGV ShakeMap for Mw6.33 scenario earthquake on the southern part of Sanchiao active fault in Taipei City. Locations of the 12 administrative districts of Taipei City and Sanchiao fault are also shown.



**Figure 10.** The maximum MMI ShakeMap for Mw6.33 scenario earthquake on the southern part of Sanchiao active fault in Taipei City. Locations of the 12 administrative districts of Taipei City and Sanchiao fault are also shown.

From Figures 2 to 10 mentioned above, the following features are found: (1) the higher magnitude for a scenario

earthquake on the Sanchiao fault, the more land coverage and population affected in areas with PGA greater than 250 gals,

corresponding to CWB intensity VI. For example, the population in areas affected PGA greater than 250 gals in Taipei City from Mw 6.88, 6.33 earthquakes are 2,238,028 and 776,384, respectively. (2) The above-mentioned areas with high PGA and PGV are due to the combined effects of the Sanchiao fault and large site response factors. For example, the high site amplification factors of 2.01 and 1.82 for PGA and PGV, respectively, in the border area of Shihlin and Neihu as can be found in Figures 3 and 4. On the other hand, the PGA not always the highest values along the fault rupture area. Such a pattern is due to the effects of low site response factors. For example, the low site response amplification values of 0.55 and 0.67 for PGA and PGV, respectively, can be found in northwestern Beitou from Figures 3 and 4. Accordingly, seismic hazard in term of PGA and PGV respectively in Figures 5 and 6 shown in the vicinity of the Sanchiao fault is not entirely dominated by the fault. The results of mentioned above show the site amplification factor plays an important role in seismic hazard assessment results. (3) Seismic intensity, especially the MMI, is widely used to represent the level of ground shaking following a damaging earthquake [8]. Accordingly, an MMI intensity map, based on a combination of estimated maximum PGA and PGV is obtained and shown in Figure 7. It can be seen that the patterns of high MMI greater than VIII, are similar to that of the PGV. In summary, the ShapeMaps shown in Figures 5-10 can provide critical information to assess potential earthquake hazards in Taipei City.

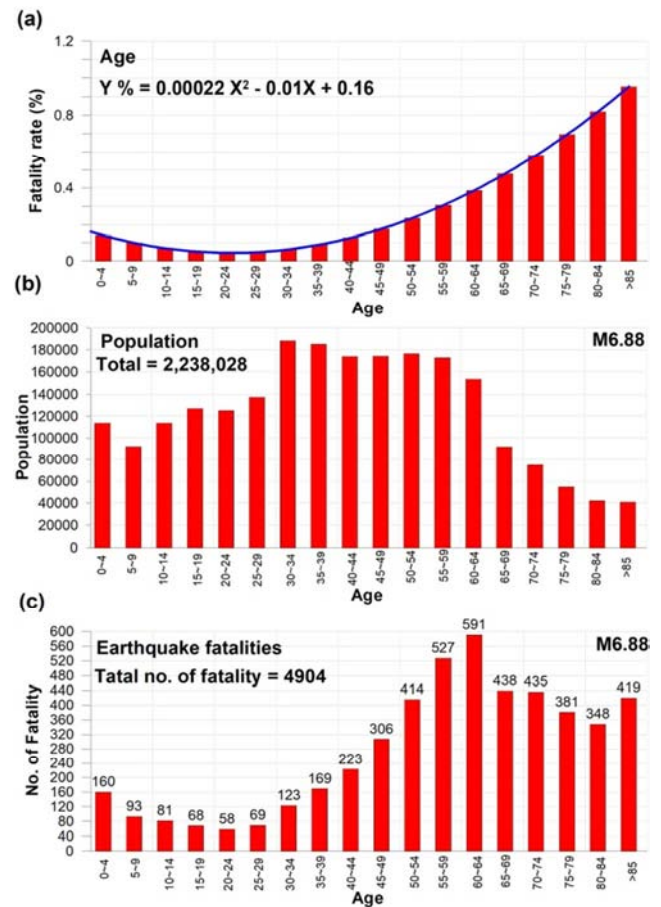
#### 4.2. Estimation of Potential Human Fatalities from Scenario Earthquakes

Next, the estimation of potential human fatalities is performed from large scenario earthquakes in Taipei City by using the empirical function for the age dependence of human fatality rate obtained by Tsai et al. [10]. For this purpose, two scenario earthquakes with Mw 6.88 6.33 on the Sanchiao fault are used.

For Case 1, a ground motion PGA ShakeMap is calculated for an Mw 6.88 earthquake on the Sanchiao active fault by using the empirical attenuation relationships by Liu and Tsai [18] with the incorporation of the site response factor in the predictive model as shown in Figure 5. Next, the age dependent fatality rate in equation 4 with impacted population data from the demographic summary [12] is combined to calculate the number of potential fatalities, as shown in Figure 11.

In Figure 11, the top panels show the fatality rates of

individual age groups. The middle panels of Figure 11 show the age distributions of a total population of 2,238,028 in the towns with estimated seismic intensity PGA greater than 250 gals of Taipei City as shown in Figure 5. The figure indicates that the numbers of the population start to decrease steadily above age 55. Finally, the bottom panel in Figure 11 shows the age distributions of 4904 fatalities in Taipei City also given in Table 4. For Taipei City as shown in Figure 11 (c), it is noted that the numbers of fatalities stay flat at an average of 93 for people below age 35. The fatalities then increase rapidly for those above age 45 and reach a high peak of 591 in the age group of 60–64. Then the number of fatalities drops rapidly back to 419 for those above age 85.

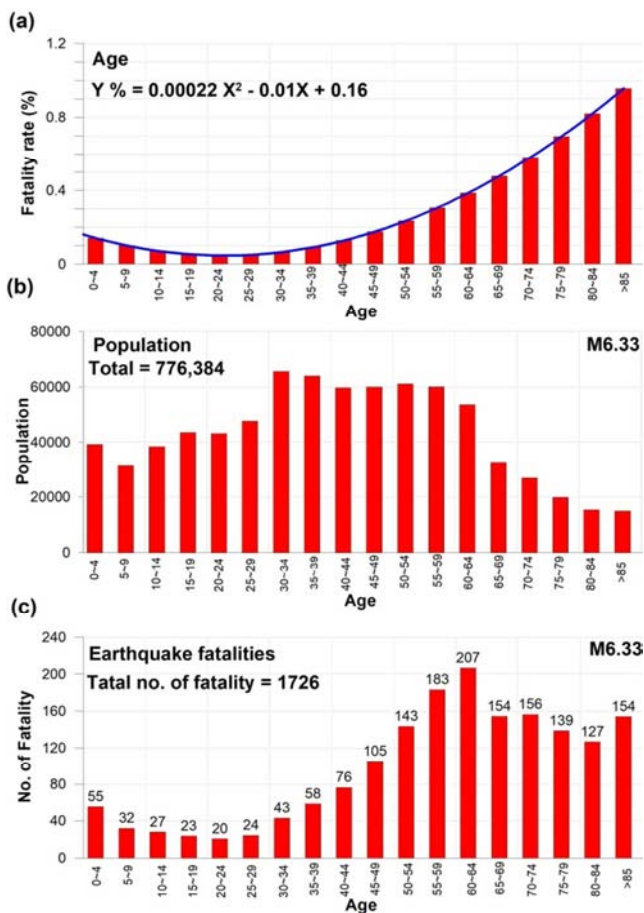


**Figure 11.** Earthquake fatality rates (top), population (middle), and the number of fatality (bottom) in the Taipei City estimated for an Mw 6.88 scenario earthquake on the Sanchiao active fault. A regression equation and corresponding curve on age dependence of the fatality rate is also shown in the top plot.

**Table 4.** The number of fatality for different age groups in Taipei City estimated for Mw 6.88 and 6.33 scenario earthquakes on the Sanchiao active fault.

Taipei City										
Age	0~4	5~9	10~14	15~19	20~24	25~29	30~34	35~39	40~44	45~49
Mw6.88	160	93	81	68	58	69	123	169	223	306
Mw6.33	55	32	27	23	20	24	43	58	76	105
Age	50~54	55~59	60~64	65~69	70~74	75~79	80~84	>85	Total	
Mw6.88	414	527	591	438	435	381	348	419	4904	
Mw6.33	143	183	207	154	156	139	127	154	1726	

Likewise, for Case 2 the ground motion PGA ShakeMap calculated for Mw 6.33 earthquake on the Sanchiao active fault is shown in Figure 8. The corresponding numbers of fatality in Taipei City are shown in Figure 12. The top panel in Figure 12 shows the age distributions of a total population of 776,384 in towns with estimated seismic intensity PGA greater than 250 gals of Taipei City as shown in Figure 8. The figure indicates that the numbers of the population start to decrease steadily above age 55. Finally, the bottom panel in Figure 12 shows the age distributions of 1726 fatalities in Taipei City for Mw 6.33. It is noted that the number of fatalities stayed flat at an average of 32 for people in Taipei City below age 35. For Taipei City as shown in Figure 12 (c), it is noted that the fatalities increase rapidly for those above age 45 and reach a high peak of 207 in the age group of 60–64. Then the number of fatalities drops rapidly back to 154 for those above age 85.



**Figure 12.** Earthquake fatality rates (top), population (middle), and the number of fatality (bottom) in the Taipei City estimated for an Mw 6.33 scenario earthquake on the southern part of Sanchiao active fault. A regression equation and corresponding curve on age dependence of the fatality rate is also shown in the top plot.

In summary, two scenario earthquakes with Mw 6.88 6.33 on the Sanchiao fault are assumed to estimate potential human casualties. As a result, the fatalities in Taipei City are 4904 and 1726, respectively for Mw 6.88 and 6.33. From the study of Pai et al. [22] showed the primary cause of death for the

victims of the Chi-Chi earthquake was structural failure and the building types was cited as one of the most important factors affected this. The human-fatality rates were found to be less in masonry and RC buildings as opposed mud-brick. The main cause lies in the difference was the capacity of the different building types to resist strong shaking. In spite of building code revisions after 1999, better building quality is expected and corresponding fatality rate should be reduced. However, the author concern and worry about the capacity of old buildings to resist strong shaking, especially has hundreds of thousands of households whose residences over 40 years old, including bungalows and 2-3 stories houses in Taipei City. Many of them are still in use in the city center where the population is highly concentrated. In case of an earthquake, the consequences would be unthinkable. When a strong earthquake strikes, these old houses are vulnerable to collapse. Hence, the results of this study can provide a valuable database for site evaluation of critical facilities in relatively high potential earthquake hazard regions. They also will be useful for land planning. Furthermore, the results will enable both local and central governments in Taiwan to take notice of potential earthquake threat in these areas, as well as to improve decision making with respect to emergency preparedness, response, and recovery activities for earthquakes.

## 5. Conclusions

According to above results and discussion, some findings are summarized as follows: From the maximum PGA ShakeMap for an Mw6.88 scenario earthquake on the Sanchiao active fault in Taipei City, the results reveal that high PGA areas greater than 400 gals are located in the northern and western parts of Taipei. Furthermore, the high PGA areas greater than 637 gal are located in the border area of Shihlin and Neihu. In addition, it can be seen that the areal patterns of high PGV greater than 31 cm/s, are similar to that of the PGA. The high PGV area greater than 60 cm/s are located in northwestern Shihlin. In summary, the ShapeMaps shown in Figures 5-7 can provide critical information to assess potential earthquake hazards in Taipei City. The above-mentioned areas with high PGA and PGV are due to the combined effects of the Sanchiao fault and large site amplification factors of 2.01 and 1.82 for PGA and PGV, respectively, in in the border area of Shihlin and Neihu. On the other hand, the PGA not always the highest values along the fault rupture area. Such a pattern is due to the effects of low site response amplification values of 0.55 and 0.67 for PGA and PGV, respectively, in northwestern Beitou. It also support that the site amplification factor plays an important role in seismic hazard assessment results.

Furthermore, the maximum ground motions and potential human fatalities by assuming two scenario earthquakes with Mw 6.88 6.33 on the Sanchiao fault have been estimated in Taipei City. It is noted that the higher magnitude for a scenario earthquake on Sanchiao fault, the greater land coverage and population in areas with that PGA above 250 gals, corresponding to CWB intensity VI. The population in

Taipei City affected PGA greater than 250 gals from Mw 6.88, 6.33 earthquakes are 2,238,028 and 776,384, respectively. As a result, the fatalities in Taipei City are 4904 and 1726, respectively for Mw 6.88 and 6.33. Moreover, the numbers of fatalities tend to increase rapidly for people above age 45. The fatalities reached a high peak in age groups of 55–64 from these scenario earthquakes on the Sanchiao fault. Finally, from the past study, the primary cause of death for the victims of the Chi-Chi earthquake was structural failure. Hence, the author concern and worry about the capacity of old buildings to resist strong shaking, especially has hundreds of thousands of households whose residences over 40 years old in the city center where population is highly concentrated. The results of this study will enable both local and central governments to take notice of potential earthquake threat in these areas, as well as to improve decision making with respect to emergency preparedness, response, and recovery activities for earthquakes in Taipei City.

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