ASSESSMENT AND MANAGEMENT ON EARTHQUAKE DISASTERS IN METROPOLITAN TAIPEI

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***ABSTRACT*:** This paper wants to suggest how to prevent and manage disasters caused by earthquake hazard in metropolitan Taipei. In front of them, we need to understand the major sources that may occur earthquakes near Taipei city. These sources include Shanchiao fault, crustal areal sources and subduction zones. Especially, Shanchiao fault has been reinvestigated recently, its length which includes inland and offshore portions approzimated 80 kilometers and could occur earthquakes with maximum moment magnitude till 7.2. In terms of the new investigating data, this paper estimated seismic hazard and finished the 475 or 2475 return period PSHA distribution map in metropolitan Taipei. Our research also did the scenario of Shanchiao fault rupturing and occurring earthquake Mw7.2.

According to the renewal parameters of Shanchiao fault, this research considered the hanging wall effect and adopted the latest ground motion attenuation formula to estimate the earthquake loss by using Taiwan Earthquake Loss Estimate System (TELES). The issues of earthquake loss include the number of casualties, building collapse and fire occurrence. This paper also compared the difference of loss result between the earlier seismic source parameters and this study. Our result shows that the hanging wall effect and the increase of earthquake magnitude obviously cause the higer damage and loss in metropolitan Taipei. The number of casualties is the most in Shihlin District, and the second in Beitou District. The number of fire occurrence is the most in Beitou and Shihlin District, and the second in Chungshan and Tatung District.

This paper also illustrated the secondary disasters after a big earthquake in metropolitan Taipei. The high potential location distribution of liquefaction and landslides were been discussed. Finally, we suggested the strategy of disaster prevention and management. The results of this paper can be an useful reference in disaster prevention plan for Taipei city.

KEYWORDS: Metropolitan Taipei, Shanchiao fault, PSHA, TELES

1. INTRODUCTION

The Metropolitan Taipei is the capital of Taiwan where several million people reside. It is located in Taipei basin that formed by extension stress of back arc spreading and the subsidence of normal faulting. Shanchiao fault, which is located at the west of Taipei basin, is considered as an active fault by Central Geological Survey (C.G.S.). If the rupture of Shanchiao fault happened, the induced earthquake must impact the Metropolitan Taipei. In addition, The Metropolitan Taipei is located upon the subduction zone system. It is worth concerning whether the subduction zone occurr earthquakes influence the Metropolitan Taipei.

In this paper, we not only introduce the two main earthquake sources that may influence the Metropolitan Taipei, but assessment the seismic hazard. We modeled the possible losses and distribution in Metropolitan Taipei when Shanchiao fault occurred big earthquake. This paper also illustrated the secondary disasters after a big earthquake in metropolitan Taipei. The high potential location distribution of liquefaction and landslides were been discussed. Finally, we suggested the strategy of disaster prevention and management.

2. The Earthquake sources

2.1 Tectonic setting

The northern Taiwan is located upon the subduction zone system between Philippine sea plate and Eurasian plate, which also collide obliquely at the east of the northern Taiwan. The arc-continent collision which made Taiwan Island uplifts rapidly, and then formed complex fold and thrust fault systems. Because the oblique collision between these two plates, the fold and thrust fault systems started to develop at northern Taiwan, and then slightly transported to central and southern Taiwan. The orogeny is still happened at central and southern Taiwan, but not at northern Taiwan now. The northern Taiwan has become an extensional state tectonic structure, and the active fault mechanism has become normal fault mechanism. The reverse fault system is inactive now.

In the following paragraph, we introduced two main earthquake sources that may occur disasters in metropolitan Taipei. The former is Shanchiao fault, the latter is subduction zone sources.

2.2 Shanchiao fault

1. fault length

According to the Central Geological Survey Special Publication NO. 19 “Active faults of Northern Taiwan”, Shanchiao Fault can be divided into two segments. The length of southern segment is 13 km, and the northern one is 21 km. But, according to the recent geophysical survey made by National Central University and Sinotech Engineering consultants, LTD., there may be a 40km extension of Shanchiao fault to offshore, and the total rupture length of Shanchiao Fault may reach to 76km. Fig. 1 shows the distribution and geometry of Shanchiao fault.

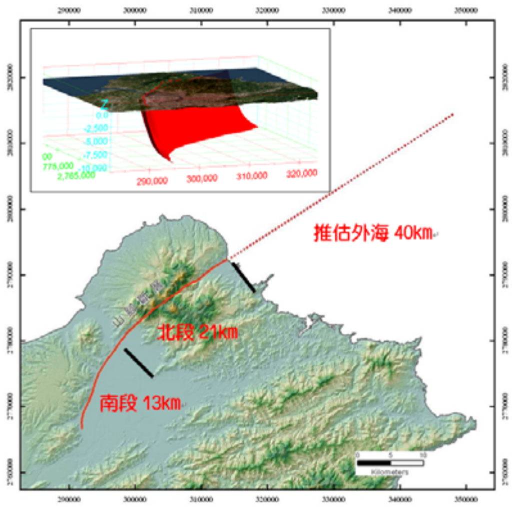


Fig. 1 The inland and offshore distribution of Shanchiao fault and the geometry of Shanchiao fault is shown at the upper left.

2. fault geometry

Shanchiao fault is a high angle dip normal fault. Shyu et al. (2005) had tried to plot the simple cross section of Taipei domain, and the geometry of Shanchao fault is shown in Fig. 2.

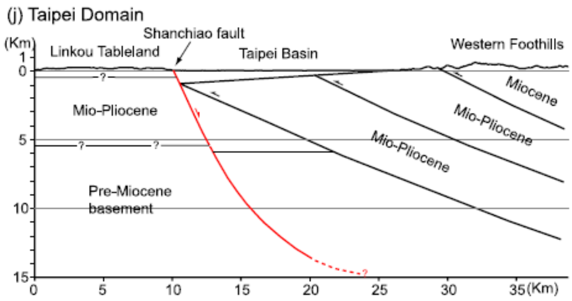


Fig. 2 Simple cross sections proposed for Taipei domains. Each crude, unbalanced cross section provides tentative geometries of the major active faults based upon geomorphic, geodetic, structural, and seismic data. Red indicates active structures; black indicates inactive structures. (Shyu et al., 2005)

3. mechanism

The Chengtzuliao profile of boreholes which crossed Shanchiao fault shows that the basement in the east of Shangchiao fault has an abrupt drop (Fig. 3). Obviously it formed by the subsidence of eastern dipping Shanchiao fault. In other boreholes' profiles, such as Taishan, Kuandu and Wuku profiles also show similar situation.

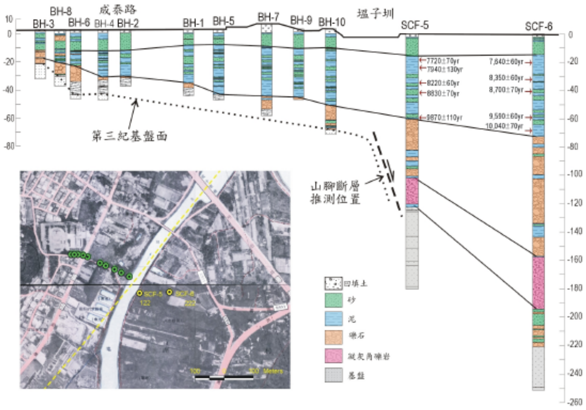


Fig. 3 The Chengtzuliao stratigraphic profile of boreholes in Taipei basin. (Liu et al., 2000; Su et al., 2003)

4. long term slip rate

The long term slip rate is an important parameter to assessment the activity and seismic hazard of active faults. Huang et al. (2007) analyzed the boreholes' core which situated in Chengtzuliao, Wuku and Shulin passed through Shangchiao fault. These cores can be recorded by logging and dating. They estimated that the subsidence rate in southern segment of Shangchiao fault is 1.8mm/yr in the past 10 thousand years, and in northern segment is 0.69mm/yr in the past 15 thousand years.

5. maximum possible magnitude

The maximum possible magnitude can be evaluated by source scaling equation, and the source scaling factors include rupture length, rupture area or displacement. In this paper, we assumed Shanchiao fault that ruptured 76km, and then adopted length – magnitude equations from Wells and Coppersmith (1994), Wu (2000) and Yen and Ma (2010). The equations are following:

$$M_W=5.08+1.16\log(L) \quad (1)$$

$$M_W=(1.32\pm0.122)\log(L)+(4.817\pm0.132) \quad (2)$$

$$\log L = (1/2) \log M_0 - 8.08 \quad (3)$$

L: rupture length, M_w: monent magnitude, M_0: seismic moment. Equation (3) need to transfer M_0 to M_w, The transfer equation can be used by Kanamori (1977) :

$$Mw = (2/3) \log M0 - 10.7$$

We evaluated the maximum possible magnitude of Shanchiao fault is about M_w=7.2~7.3.

6. the latest event

The historical earthquake catalog didn't find big earthquake about Shanchiao fault, and we didn't find paleoearthquake from any trench. Huang et al. (2007) analyzed the borehole dating and supposed that there was an earthquake event before 8,400~8,600 years. The historical literature which written by Yu-Yung-Ho recorded a "Kang-Hsi Taipei lake event" in 1694. This event may happened because of the Shanchiao fault's rupture. Actually, we don't have sufficient evidence to make sure which time the Shanchiao fault had happened big earthquake.

2.3 Subduction zone sources

The geometry of the subduction zone plate can be delineated from well located seismicity data. The top surface of the subducting PSP is shown in Fig. 4. The subducting PSP reaches a depth of about 90 km under metropolitan. The closest distance from Taipei to the top of the subducting slab is about 60 km, therefore, earthquakes occurring in this slab could contribute significantly to a seismic hazard in the Taipei region. Also, the slow rate of ground motion attenuation with distance would increase the level of hazard at a site, as well as increasing ground motion with increasing focal depth for a given earthquake magnitude. The source-to-site distance also increases the hazard (Crouse 1991; Youngs et al. 1997; Lin and Lee 2008). Utmost attention should be given to the intraslab earthquake sources in any evaluation of seismic hazard.

In PSHA, the intraslab earthquake sources were divided into 9 zones of different depths (NP1 - NP9 as shown in Fig. 4). The dependence of PGA on focal depth could be approximated by separating several segments of slab according to depth. The average depth of each segment could then be used as the nominal focal depth to predict ground motion (Cheng et al. 2007). Several earthquakes with magnitudes greater than M_W 7.0 occurred in the intraslab sources in the last century (1909/04/15, 1910/4/12, 1920/6/23). The most important intraslab source is NP3, which at its closest is, approximately 60 km from the top of the intraslab source of the PSP to Taipei. The return period of an M_W 6.0 earthquake in NP3 would be around 30 years, as calculated from the parameters of truncated-exponential model (shown in Table 2). In this study, it is assumed that the intraslab sources under the Taipei metropolis fault randomly so the spatial distribution of small to moderate earthquakes within these crustal areal sources would be uniform.

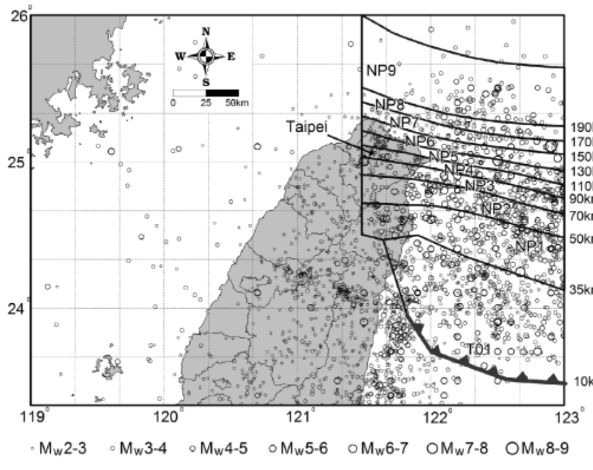


Fig. 4. Isobaths contours of the top of subducting Philippine Sea plate and spatial distribution of independent intermediate-depth and deep earthquakes (depth F 35 km) in northern Taiwan. Locations of subduction zone earthquake sources (intraslab NP1 ~ NP9, interface T01) for PSHA of this study are also shown.

3. Seismic Hazard and Potential assessment in Metropolitan Taipei

3.1 The earthquake probability of Shanchao fault

The C.G.S. had collected the parameters of Shanchiao fault (Its' length didn't include the offshore segment extension) and assessed the earthquake probability of Shanchiao fault. Their results showed that the percentage of earthquake magnitude bigger than Mw 6.7 occurred by Shanchiao fault is not more than 10% in the future 30 years, and about 15% in the future 50 years, and about 20% in the future 100 years. When the offshore segment of Shanchiao fault is included in this analysis, the magnitude would be increased, and the probability would be fallen. We tried to use Mw 7.3 as the maximum possible magnitude, and the percentage is lower than 10% in the future 100 years.

3.2 Results of PSHA and Deaggregation

The PSHA procedure used in this study mainly depends on the Taiwan seismic hazard model proposed by Campbell et al. (2002) and Cheng (2002). In this PSHA, fault-specific sources (active faults and subduction interface) are used to represent a specific geologic structure or fault. These sources are modeled as segmented planar features with their geometry represented by the fault trace, fault dip, and depth range where it is assumed that future earthquakes will occur. After earthquake source zone identification, two earthquake recurrence models are adopted to estimate the recurrence rate of each earthquake source. The first one is the truncated-exponential model developed from the mainshock catalog (in MW) from 1900 through 1999.

This is used to depict the recurrence of earthquakes triggered by crustal areal and intraslab sources. The second one is the characteristic-earthquake model estimated by the fault slip rate, which is used to describe the earthquake recurrence frequency of active fault and subduction interface sources. For the characterization of the four earthquake sources (crustal areal sources, active faults, interface, and intraslab) refers to Lee (1999), Cheng (2002), and Cheng et al. (2007). Their source parameters are shown in Cheng et al. (2010). For easy handling and access during the PSHA, the parameters and information on seismogenic sources and active faults mentioned above were incorporated and integrated into GIS (Cheng et al. 1998).

The appropriate attenuation relationships were applied to predict the peak ground motion of crustal and subduction zone earthquakes individually. The ground-motion attenuation relationships adopted in this study are shown in Cheng et al. (2010). The truncation of the predicted ground-motion distribution (at 2 σ lny) of the attenuation relationships has been recommended by the USGS for conservative engineering design in the United States (NRC 1988; Petersen et al. 2008). We adopted the same truncation method for conducting the PSHA of the Taipei area.

After setting the parameters for earthquake sources and attenuation relationships as input for this PSHA, the logic tree methodology was employed to incorporate uncertainty into the modeling. The logic tree formulation for seismic hazard analysis involves setting out the sequence of assessment that must be made in order to perform the analysis, addressing the uncertainty in each of these assessments in a sequential manner (NRC 1988; Cheng et al. 2007). This provides a convenient approach for breaking a large, complex assessment into a sequence of smaller, simpler components that can be addressed more easily. The logic tree method was thus used to address the uncertainty of source type, attenuation relationships, focal depth, earthquake recurrence model, and fault geometry was addressed in this study. The mathematical formulation and PSHA approach developed by Cornell (1968) and the NRC (1988) were adopted for calculating the PSHA for the Taipei area. For a detailed description of the utilization of the logic tree technique for addressing the uncertainty of input parameter of Taiwan PSHA model please refer to Cheng (2002) and Cheng et al. (2007).

The seismic hazard was computed and the results summarized given the size of earthquakes from minimum magnitude mo to maximum mu in each seismogenic zone. For each level of ground motion, a complete set of hazard values was computed over all end branches of the logic tree to form a discrete distribution for frequency of exceedance. The computed distributions were used to obtain the mean frequency of exceeding each level of peak ground motion (forming the mean hazard curve) as well as hazard curves representing the various percentiles of the distributions. The seismic hazard logic tree represents our best judgment of the uncertainty in defining the input parameters. Hence, the computed distributions represent our confidence interval for the estimated hazard. The total probability of seismic hazard of specific PGA level is integrated from the probability of exceedance of surrounding earthquake sources of different magnitudes, distance and epsilon (ε) intervals. In addition, the meaning of ε is the expected PGA level scaled to the number of standard deviation of ground motion relationship. In contrast, the total probability of seismic hazard could be de-aggregated into numbers of subgroup sources in different bins of magnitude, distance and epsilon (ε). Furthermore, it is easy to rank the hazard contribution of each subgroup source, and then pick out the most important for seismic hazard mitigation using deaggregation analysis (Harmsen and Frankel 2001; Cheng et al. 2007).

Seismic hazard curves for soil site condition at downtown Taipei City are illustrated in Fig. 5. The PSHA seismic hazard curves show the total hazard in the 5th, 50th (median), and 95th percentiles of uncertainty. The 90 percent confident interval of total hazard would be the interval bounded by the 5th and 95th percentiles in the figure. The hazard contribution from various sources around Taipei to total hazard is also indicated in Fig. 5. This reveals that the intraslab earthquake source contributes a much greater probability to total seismic hazard. The high rate of recurrence of large-magnitude intraslab earthquake and the large peak ground motion experienced in soil sites from intraslab earthquakes can be explained and understood (Cheng 2002). The minor contribution of areal crustal sources to the overall seismic hazard lies in the regions of S14B and S14A. In this region, even though the Shanchiao fault dominates the seismic hazard for the long return period (such as 2475-year), it makes minor contributions for the short return period (the less than 475-year return period). The total seismic hazards in Taipei City are deaggregated in bins of magnitude, distance and epsilon (ε), as shown in Fig. 6. The deaggregated hazard results of PGA hazard analysis indicate that the hazard contributions come primarily from subduction zone sources at 60 km, for events with a magnitude close to 7.8 in a 50-year return period. In a 475-year return period, the hazard is affected by nearby areal crustal sources, fault sources and subduction zone sources. On the other hand, in a 2475-year return period, the seismic hazard contribution comes totally from the closest fault (Shanchiao fault).

Overall, the distance of the dominating earthquake hazard increases in the northern part in the 50-year period. The seismic hazard in the northeastern part is higher for events with magnitudes of about 7 to 8. In the 2475-year period, the seismic hazard is associated with the adjacent Shanchiao fault. This type of deaggregation can assist engineers to quickly and clearly distinguish any possible earthquake hazard and its potential characteristics for different return periods.

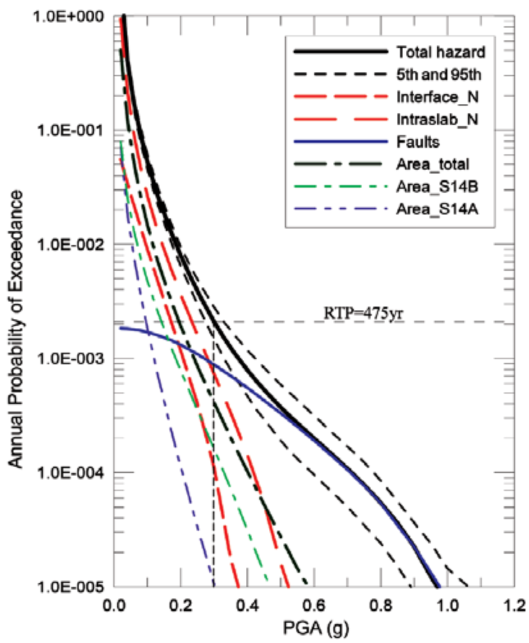


Fig. 5. Seismic hazard curves of PGA for Taipei city in soil site condition. The hazard curves of PGA present the total hazard in 5th, 50th (median), and 95th percentiles uncertainty in PSHA. In addition, the hazard contribution from the sources around Taipei to total hazard(s) is also shown in the figure in different line styles. The horizontal dashed line indicates the annual probability of exceedance in 1/475 representing 475-year return period, and the horizontal dashed line crosses over the total hazard curve at PGA 0.3 g is referred by a vertical dashed line.

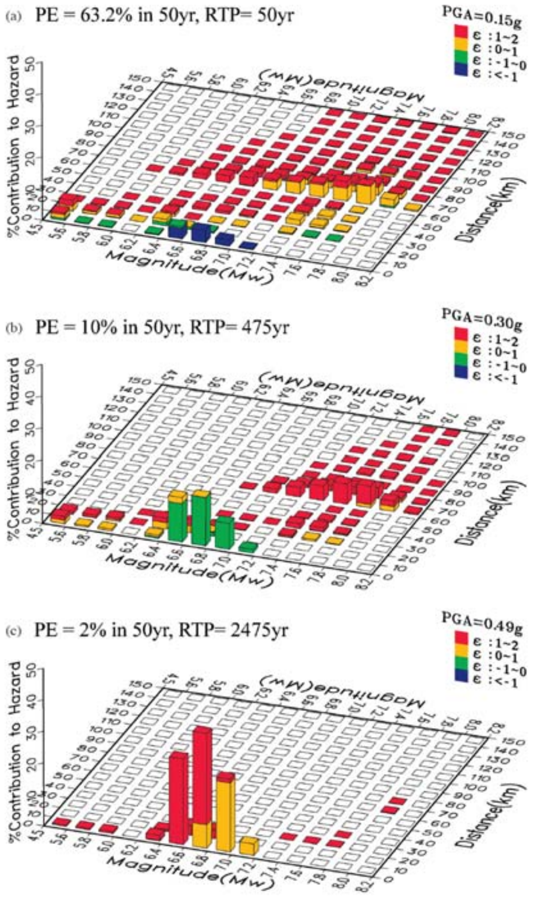


Fig. 6. Deaggregation of the total seismic hazard of Taipei in different Probability of exceedance (PE) and return period (RTP). (a) 50 yr return period; (b) 475 yr return period; (c) 2475 yr return period. The total seismic hazard is discrete in magnitude bins, distance bins and epsilon (ε). The meaning of ε is the expected PGA level scaled to number of standard deviation of ground motion relationship.

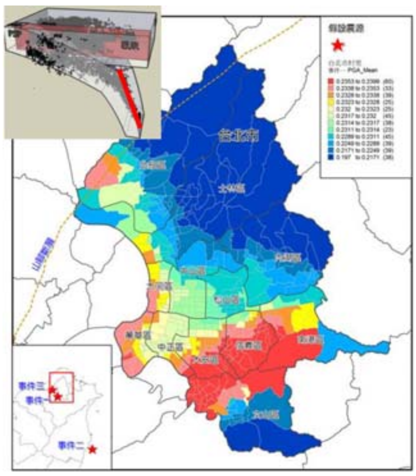
3.3 Seismic Hazard distribution in Metropolitan Taipei

Because the site design horizontal acceleration of Taipei basin is 0.23g according to the Seismic Design Codes of Buildings, this paper suggested 0.23g as horizontal acceleration that Taipei basin could bear. The earthquake sources include Subduction zone intraslab, Subduction zone interface and Shanchiao fault. The parameters of these sources are shown in table 1, and the PGA distribution map of the three sources are shown in Fig. 7.

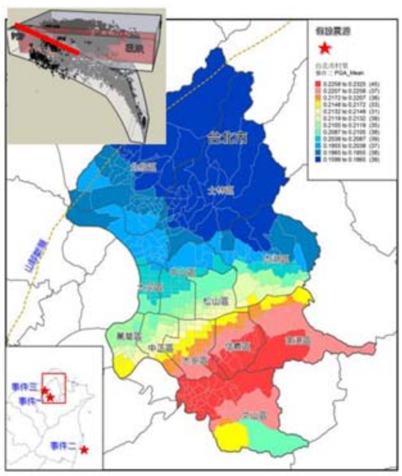
Table 1. The parameters of the most three possible earthquake sources in 475 year return period(Peak Ground Acceleration PGA=0.23g) in Taipei city.

Source type	Historical earthquake source	Magnitude M_W	Depth km	Distance km	attenuation relationships
Beneath Taipei Basin (Subduction zone intraslab)	4/15/1909	7.3	60	60	Lin et al., 2008
Ilan and Hualien offshore (Subduction zone interface)	6/5/1920	7.8	20	85	Lin et al., 2008
Taipei Basin (Shanchiao fault)	1694(?)	6.8	15	15	Lin et al., 2011

(a)



(b)



(c)

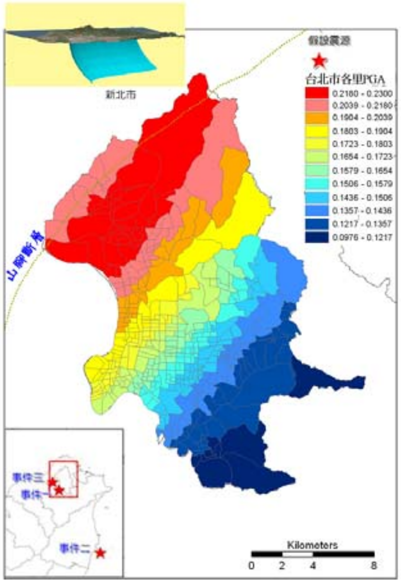


Fig. 7. The PGA distribution map of the three possible earthquake sources in 475 year return period (Peak Ground Acceleration PGA=0.23g) in Taipei city. (a) Subduction zone interface at Ilan and Hualien offshore, (b) Subduction zone intraslab beneath Taipei Basin and (c) Shanchiao fault at Taipei basin.

4. Earthquake Loss Estimate

We assumed Shanchiao fault that may rupture 80 kilometers and occur a Mw=7.3 earthquake. The earthquake losses of all districts in Taipei city are estimated by Taiwan Earthquake Loss Estimate System (TELES).

The results are shown in Fig.9. The Fig. 9(a), (b) and (c) show the number of casualties in Shihlin District that is the most regardless day, night or rush hours. The second most number of casualties is in Beitou District and Taipei main station. Fig. 9(d) shows the estimation of fire occurrences in all districts in Taipei city. The number of fire occurrences in Beitou and Shihlin District is the most, and the second most number is in Chunshan and Daan District.

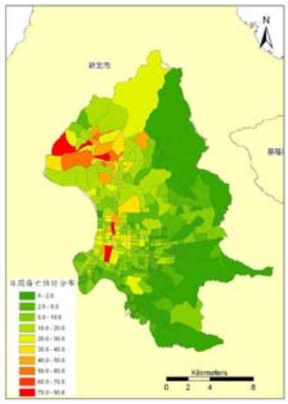
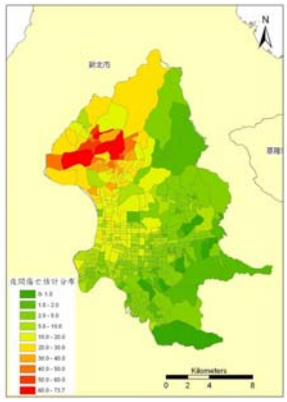
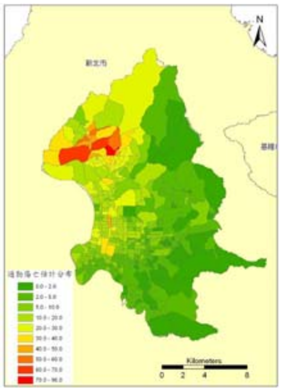
	
(a) The estimation of casualty distribution in the day time.	(b) The estimation of casualty distribution at night.
	
(c) The estimation of casualty distribution in rush hours.	(d) The estimation of fire occurrences distribution in all districts of Taipei city.

Fig. 8. We assumed that Shanchiao fault (dip angle 60E) rupturs 80km and occurs Mw 7.3 earthquake, and then considered the hanging wall effect and adopted the latest ground motion attenuation formula to estimate the earthquake loss in all districts of Taipei.

5. Discussion

5.1 Secondary Disasters of Earthquake

According to the Chi-Chi earthquake and other countries' big earthquake experiences, the potential of secondary disasters also became high. This paper suggested some secondary disasters that we need to notice and evaluate in Metropolitan Taipei.

1. Landslide and debris flow: Big earthquake will change the geological strength and topography of hill slopes, and it will heighten the potential of landslide and debris flow.
2. Liquefaction: the liquefaction on the ground makes artificial concretes or buildings differential settlement. It usually occur the decline of houses and the dislocating break of lifelines.
3. Permanent land subsidence: The west side of Taipei basin will has been subsided by Shanchiao fault' s normal faulting. The water conservancy facilities of gravity drainage will have lost their effect, and the ability of flood control and surge prevention will have lowed. Moreover, it may occur Seawater encroachment in Metropolitan Taipei.

5.2 Disaster Prevention and Management

The earthquake disasters prevention work near Shanchiao fault in Metropolitan Taipei should focus on the following points:

1. To make the secondary disasters potential map through earthquake scenario simulation: If Shanchiao fault occurred big earthquake, we need to understand all kinds of secondary disasters induced by the rupture of Shanchiao fault in Metropolitan Taipei. These secondary disasters include landslide, debris flow, liquefaction and permanent land subsidence.
2. To improve the refuge plan: By considering the above-mentioned disasters potential map, we need to strengthen the artificial concretes and lifelines. The equipments and capacity of shelters should be investigated for enhancing self supporting ability after disasters. The plan and research for earthquake prevention should be done early.
3. To improve residents' knowledge about earthquake prevention, especially those who live near the fault trace.

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