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SEISMIC DAMAGE ASSESSMENT OF ELEMENTARY SCHOOL BUILDINGS IN TAIPEI, TAIWAN

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ABSTRACT

This paper presents a seismic damage assessment of all elementary school buildings in Taipei City. First, we collect pertinent data on 139 elementary schools and 559 schools buildings. In this study, we consider four scenario earthquakes on the Sanjiao fault or in the Yilan and Hualien area. At each school site, the peak ground acceleration (PGA) is estimated using an attenuation relation and a site modification factor; the occurrence of liquefaction is evaluated based on the Taipei liquefaction potential map. The seismic capacity of each school building is determined based on a fragility curve and building deficiencies identified from a school survey. We determine the damage state of each school building caused by four scenario earthquakes and then identify most vulnerable school buildings. This study may provide a useful resource for authority to make decision on seismic retrofit of elementary school buildings in Taipei City.

Introduction

In Taiwan, evaluation of possible seismic damage to school buildings is usually carried out on the basis of a single building. However, it may be very useful to decision makers if in a seismic event they have a clear picture of possible damage to all the school buildings under their jurisdiction. This paper presents a seismic damage assessment of all elementary school buildings in Taipei City. The procedure used to evaluate seismic damage to school buildings is shown in Fig. 1. The results may provide a useful resource for school authority to make decision on seismic retrofit of elementary school buildings in Taipei City.

GIS Database of Taipei Elementary School Buildings

As of 2004, Taipei City has 139 elementary schools. For each school, we collect pertinent data such as school name, address, and number of buildings, and then input this information into a GIS database. The Taipei elementary schools have a total of 559 buildings. For each school building, we also collect data such as building name, number of stories, construction type, year built, and input this information into a GIS database. In addition, The National Center for Earthquake Engineering Research (NCREE) carried out a survey of school buildings and the deficiencies of school buildings have been identified. The survey results are also included into the school building database. For the details of school building database, the reader may refer to the thesis by Wei (2005). A summary of Taipei elementary buildings is shown in Table 1.

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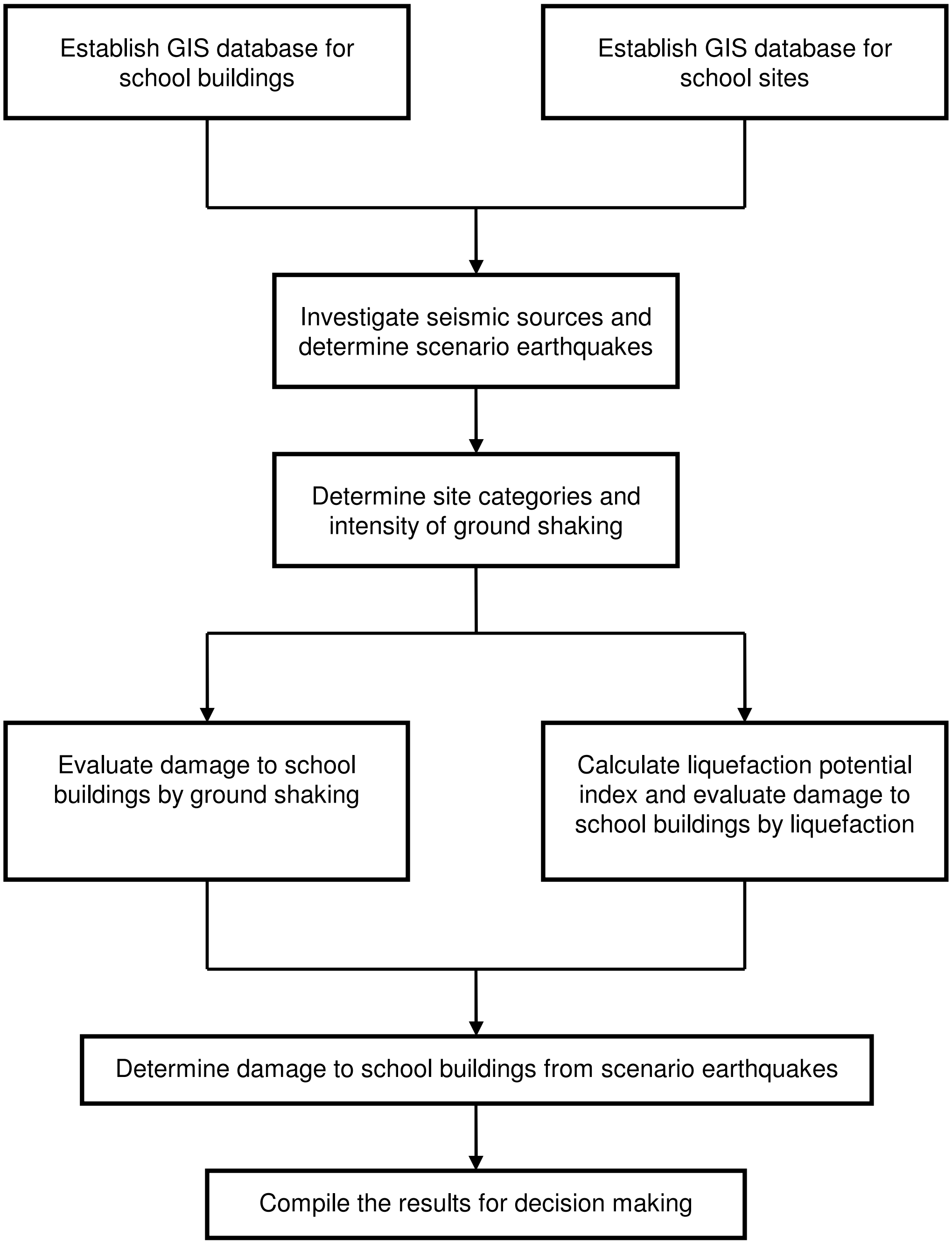

Figure 1. Procedure for assessing damage to school buildings.

Table 1. Summary of Taipei elementary school buildings.

Structural Type	Number of Stories	Year Built	Number of Buildings
Reinforced concrete (RC)	1-3	Before 1968	68
Reinforced concrete (RC)	4-7		7
Reinforced masonry (RM)	1-3		19
Reinforced masonry (RM)	4-7		2
Reinforced concrete (RC)	1-3	After 1968	154
Reinforced concrete (RC)	4-7		294
Reinforced masonry (RM)	1-3		9
Reinforced masonry (RM)	4-7		4
Steel reinforced concrete (SRC)	4-7		2

Selection of Scenario Earthquakes

Taiwan is located in the colliding area of the Philippine Sea plate and the Eurasia plate; thus the seismicity is very active around Taiwan. In this study, we use a scenario earthquake to estimate possible damage to school buildings, so that the school authority may easily understand the results and make decisions on seismic retrofit of elementary school buildings in Taipei City. We consider the locations of faults and the distribution of seismic activity and then select three seismic sources that may produce earthquakes affecting the Taipei area. These three seismic sources are the Sanjiao fault, Yilan area and Hualien area. According to the Central Geological Survey, the Sanjiao fault is a type II fault, that is, a less-active fault; thus we assign two scenario earthquakes occurring on the Sanjiao fault. One moment magnitude 6.0 earthquake represents an earthquake that is likely to occur, and the other 7.0 earthquake represents a maximum considered earthquake that may occur on the Sanjiao fault. Furthermore, we assign a magnitude 7.5 earthquake in the Yilan area, which is a shallow earthquake. Finally, we assign a magnitude 8.0 earthquake in the Hualien area, which is a subduction earthquake. The characteristics of these four scenario earthquakes are summarized in Table 2.

Table 2. Source parameters of scenario earthquakes.

Seismic Source	Epicenter		Moment Magnitude (M_w)	Focus Depth (km)
	Longitude (°)	Latitude (°)		
Sanjiao fault	121.43	25.06	6.0	8
Sanjiao fault	121.43	25.06	7.0	8
Yilan area	121.85	24.67	7.5	8.5
Hualien area	122.7	24.2	8.0	42

Evaluation of Damage to School Buildings Caused by Ground Shaking

In a seismic event, ground shaking, soil liquefaction and other seismic hazards may cause damage to buildings. In this study most elementary schools are located in the Taipei basin, where the terrain is relatively flat. Therefore, we have only consider two seismic hazards; ground shaking and soil liquefaction.

The intensity of ground shaking at a site is affected by the source characteristics of an earthquake, the attenuation of ground motion, and the local soil conditions of the site. The attenuation relations established by Chang et al. (2001) are used in this study.

For a shallow earthquake, the attenuation of the peak ground acceleration (PGA) is

$$\ln A = 2.8096 + 0.8993M_w - 0.438\ln D_p - (1.0954 - 0.0079D_p)\ln D_e \quad (1)$$

For a subduction earthquake, the attenuation of PGA is

$$\ln A = 4.7141 + 0.8468M_w - 0.1745\ln D_p - 1.2972\ln D_h \quad (2)$$

In which A is the PGA (gal, cm/sec2), D_p is the focal depth, D_e is the epicenter distance, D_h is the hypercentral distance.

In the Taipei area, local site conditions are classified into four categories (Chai et al. 2004). The site modification factors for these four categories developed by Yeh et al. (2004) are used in this study. For each school site, the PGA values resulting from four scenario earthquakes are determined using either Eqs. (1) or (2) and an appropriate site modification factor.

The city school buildings may be classified into the following categories: low-rise concrete building (CL), mid-rise concrete building (CM), low-rise reinforced masonry building (RML), mid-rise reinforced masonry building (RMM), and mid-rise steel reinforced concrete buildings (SRCM). A building may sustain various degrees of damage, from no damage to collapse during a seismic event. In this study, we consider five damage states: no damage (N), slight damage (S), moderate damage (M), extensive damage (E), and collapse (C). The seismic capacity of a building may be expressed in term of many parameters such as peak ground acceleration (PGA) and spectral acceleration (SA). When SA is used, it is required to accurately determine the fundamental period of the building. For a regional study, buildings are classified into several categories. It is difficult to determine the fundamental period for a category of buildings. Thus, we use PGA to express the seismic capacity of a building. In this study, the seismic capacity of a school building corresponding to each damage state is determined from the fragility curves developed by Liao et al. (2004). For general buildings built after 1968, the seismic capacity ranges expressed in terms of PGA are shown in Table 3.

Table 3. Seismic capacity ranges corresponding to various damage states of general buildings.

Building Type	PGA(g)				
	N	S	M	E	C
CL	<0.28	0.28-0.45	0.45-0.55	0.55-0.65	>0.65
CM	<0.28	0.28-0.5	0.5-0.6	0.6-0.68	>0.68
RML	<0.25	0.25-0.35	0.35-0.45	0.45-0.55	>0.55
RMM	<0.25	0.25-0.35	0.35-0.45	0.45-0.55	>0.55
SRCM	<0.28	0.28-0.52	0.52-0.62	0.62-0.72	>0.72

For an individual school building, some existing conditions such as short column may affect its seismic capacity. A survey of school building was carried by NCREE. For each school building, six conditions are identified as shown in Table 4. It is noted that the building irregularities is not included in the table. Most school buildings in Taiwan are low-rise with rigid diaphragm; thus such a building can be considered as a low-rise shear building and the effect of building irregularities on seismic capacity is not significant.

Table 4. Adjusting factors for various conditions.

Conditions	Yes / No	Adjusting Factor
Rusty condition of reinforced steels in beams and columns (q_1)	Yes	0.95
	No	1
Cracking conditions of beams and columns (q_2)	Yes	0.95
	No	1
Settlement or tilt of buildings (q_3)	Yes	0.95
	No	1
Existing of columns in corridor (q_4)	Yes	1.05
	No	1
Distance of adjacent buildings (q_5)	Yes	0.95
	No	1
Short columns (q_6)	Yes	0.9

On the basis of these six conditions, a total adjusting factor Q is determined as follows:

$$Q = q_1 \times q_2 \times q_3 \times q_4 \times q_5 \times q_6 \tag{3}$$

The actual seismic capacity of a school building is determined from the multiplication of the total adjusting factor Q and the capacity of a typical building shown in Table 3. From the comparison of actual seismic capacity of the building and the PGA value at a school site resulting from a scenario earthquake, the damage state of each school building can be determined.

Evaluation of Damage to School Buildings Caused by Liquefaction

Yeh (2003) developed a liquefaction potential map for Taipei City based on a moment magnitude of 7.5 and a water table level of 1.5 meters. This author also divided the Taipei area into several liquefaction sensitivity categories. For different magnitude and water table, the liquefaction potential index P_L (Iwasaki et al., 1982) for each liquefaction sensitivity category can be determined as follows:

$$P_L = \boldsymbol{\alpha}_i \cdot f(M_w) \cdot g(d_w) \cdot PGA + \boldsymbol{\beta}_i \tag{4}$$

$$f(M_w) = 0.0353M_w^{2} - 0.1855M_w + 0.4069 \tag{5}$$

$$g(d_w) = 0.000192d_w^{4} - 0.005145d_w^{3} + 0.0535\,d_w^{2} - 0.2758d_w + 1.3105 \tag{6}$$

In which **α** $_i$ and **β** $_i$ are the regression coefficients for the i-th liquefaction sensitivity category. Using these equations, the liquefaction potential index at the school sites can be determined for each scenario earthquake.

When liquefaction occurs at a site, the ground may produce uneven settlements and lateral spreads. As a consequence, the building may suffer various degrees of damage. According to Iwasaki et al. (1982), Toprak and Holzer (2003), Juang et al. (2005), the damage states of a building caused by liquefaction may be correlated to the values of the liquefaction potential index as show in Table 5. Given the P_L value at the school site determined from each scenario earthquake, the damage state of each school building caused by liquefaction can be determined.

Table 5. Damage states of school buildings induced by liquefaction.

P_L Range	Degrees of Liquefaction	Damage States of Buildings
$P_L = 0$	No liquefaction	No damage
$0 < P_L < 5$	Slight liquefaction	Slight damage
$5 < P_L < 15$	Moderate liquefaction	Moderate damage
$P_L \geq 15$	Severe liquefaction	Extensive damage

Summary of Damage to Buildings Caused by Scenario Earthquakes

In this study, we consider two kinds of seismic hazards, ground shaking and soil liquefaction, resulting from a scenario earthquake. We first evaluate the damage state of a school building caused by the individual seismic hazard; then we compare these two damage states, and take the more serious one to represent the damage state of the building caused by the scenario earthquake. The summary of damage states of school buildings resulting from four scenario earthquakes are shown in Table 6. As an example, the distribution of damage to school buildings caused by a moment magnitude 7.0 earthquake on Sanjiao fault are shown in Fig. 2.

Table 6. Summary of school buildings damaged by scenario earthquakes.

Scenario Earthquake	No Damage	Slight Damage	Moderate Damage	Extensive Damage	Collapse
Sanjiao fault ($M_w = 6.0$)	401	153	5	0	0
Sanjiao fault ($M_w = 7.0$)	46	198	149	113	53
Yilan area	451	77	31	0	0
Hualien area	460	68	31	0	0

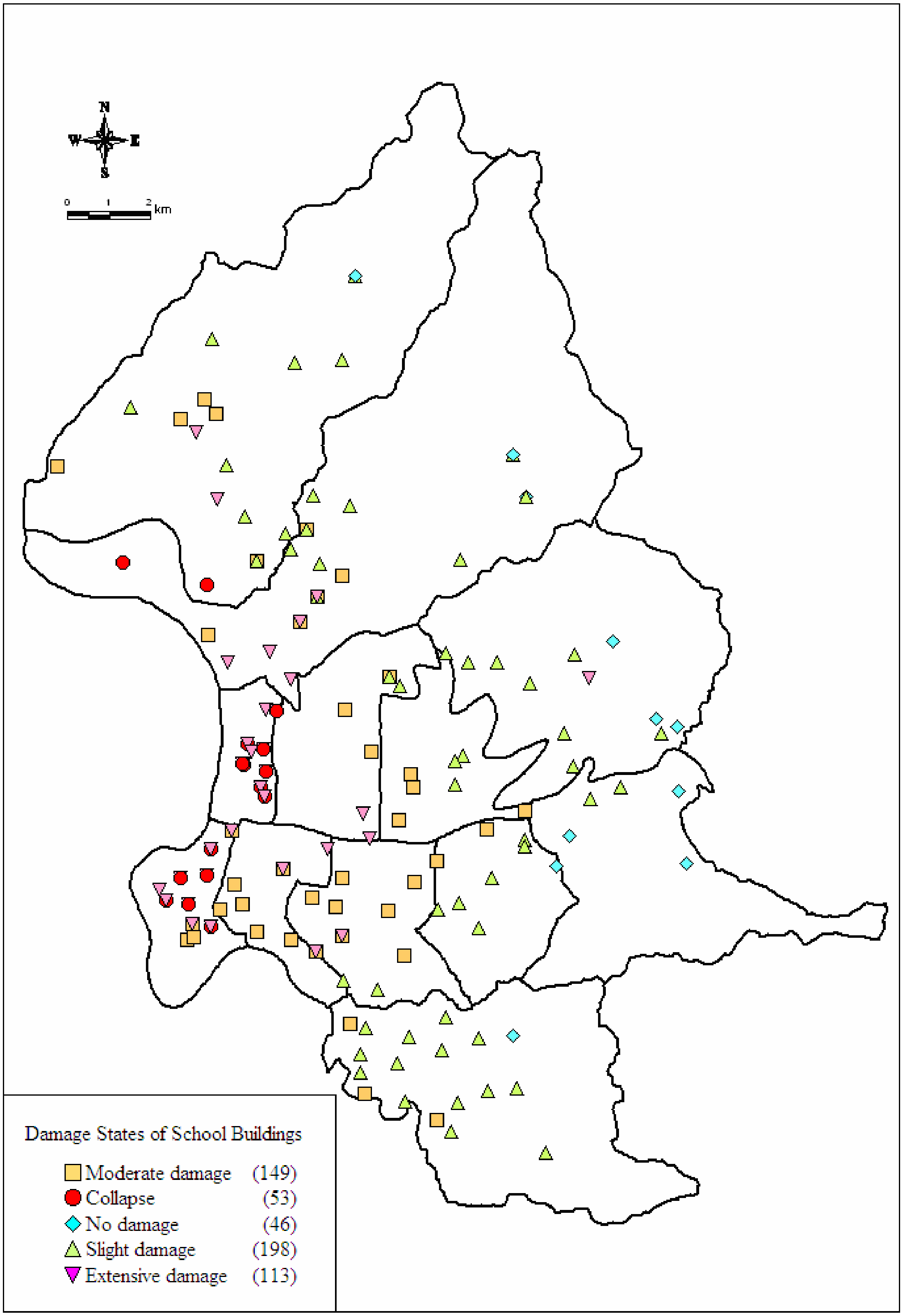

Figure 2. Seismic damage to elementary school buildings in Taipei City by a magnitude 7.0 earthquake on the Sanjiao fault.

As shown in the table, when a magnitude 7.0 earthquake occurs on the Sanjiao fault, the elementary school buildings in Taipei City will suffer significant damage. However, the chance of such an earthquake occurrence may be low. A magnitude 6.0 earthquake is more probable. If such an earthquake occurs on the Sanjiao fault, only five school buildings may suffer moderate damage, other buildings may suffer slight damage or no damage. Thus we put these five school buildings in the list of the most vulnerable school buildings as shown in Table 7.

When an earthquake occurs in the Yilan or Hualien area, the elementary school buildings in Taipei City may sustain some slight damage caused by ground shaking; however, 31 buildings in six elementary schools may suffer moderate damage resulting from soil liquefaction. Since Yilan and Hualien are seismic active area, we also include these 31 buildings in the list of the most vulnerable school buildings (Table 7).

In this study, we include 36 buildings in the list of the most vulnerable school buildings (Table 7). The government authority may hire an engineer to perform a detailed evaluation of the vulnerability of these buildings due to ground shaking and soil liquefaction and then suggest appropriate seismic retrofit, if necessary. If the resource is available, the detailed seismic evaluation may extend to other buildings that may suffer significant damage resulting from a magnitude 7.0 earthquake on the Sanjiao fault.

Table 7. Most seismic vulnerable elementary school buildings in Taipei City.

School Name	Building Name
Shuanglian Elementary School	All six buildings
Datong Elementary School	All four buildings
Dalong Elementary School	All five buildings
Minglun Elementary School	All six buildings
Zhongzheng Elementary School	All seven buildings
Kangning Elementary School	All three buildings
Yongle Elementary School	A、B、C Buildings
Shezi Elementary School	Minzu Building
Fuan Elementary School	Xinyi Building

Conclusions

In this study, we have considered four scenario earthquakes that may affect the Taipei area. For these four scenario earthquakes, we evaluated the intensity of ground shaking and the potential for liquefaction at the elementary school sites and then determined the possible damage to school buildings. We included 36 school buildings in a list of the most vulnerable school buildings and we recommend that the government authority carry out a project to perform a detailed seismic evaluation of these buildings to suggest appropriate seismic retrofit, if necessary.

Currently, the evaluation of possible seismic damage to school buildings in Taiwan is usually carried out on the basis of a single building. However, it may be very useful to decision makers if in a seismic event they have a clear picture of possible damage to all the school buildings under their jurisdiction. Furthermore, the evaluation is carried out only for ground shaking hazard, damage to buildings by liquefaction is not considered. Since soil liquefaction may cause severe damage to buildings, we recommend that the liquefaction hazard needs to be considered in the evaluation of buildings for seismic retrofit.

The Sanjiao fault is located in the vicinity of the Taipei area. If an earthquake occurs on this fault, it may cause significant damage to buildings in Taipei area. Thus, we need to include the Sanjiao fault as one of the possible seismic source, when we evaluate the seismic vulnerability of buildings in the Taipei area.

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References

Chai, J. F., T. J. Teng and C. S. Yeh, 2004. Microzonation of Taipei basin and corresponding design response spectra, *Proceedings of 7th Structural Engineering Conference*, (on CD-ROM), (in Chinese).

Chang, T. Y., F. Cotton and J. Angelier, 2001. Seismic attenuation and peak ground acceleration in Taiwan, *Bulletin of Seismological Society of America*, 91(5), 1229-1246.

Iwasaki, T., T. Arakawa and K. Tokida, 1982. Simplified procedures for assessing soil liquefaction during earthquakes, *Proceedings of the Conference on Soil Dynamics and Earthquake Engineering Conference*, Southampton, 925-939.

Juang, C. H., H. Yuan, D. K. Li, S. H. Yang, and R. A. Christopher, 2005. Estimating severity of liquefaction–induced damage near foundation, *Soil Dynamics and Earthquake Engineering*, Vol. 25, 403-411.

Liao, W. I., W. H. Lee, C. H. Yeh and C. L. Lin., 2004. Models for assessing damage to buildings and bridges, *Proceedings of 2004 Taiwan Earthquake Loss Estimation System Seminar*, National Center for Research on Earthquake Engineering, 75-92, (in Chinese).

Toprak, S. and T. L. Holzer, 2003. Liquefaction potential index: field assessment, *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, Vol. 129, No. 4, pp. 315-322.

Wei, H. L., 2005. Seismic damage assessment of Taipei elementary school buildings, *M.S. Thesis*, National Taiwan University of Science and Technology, Taipei, Taiwan (in Chinese).

Yeh, C. H., 2003. Taiwan Earthquake Loss Estimation System – TELES, *Report NCREE-03-002*, National Center for Research on Earthquake Engineering, Taipei, Taiwan (in Chinese).