DEVELOPMENT OF HAZARD DAMAGED BUILDINGS MODEL BY CHI-CHI EARTHQUAKE DATA

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Abstract

On September 9th, 1999, a violent earthquake stroke Chi-Chi located in Nantou County. It caused unprecedented damage to the buildings and nearly twenty thousand houses complete or partially collapsed. In consideration of the extensive destruction made this time, the anti-seismic ability of houses has become the most critical issue in earthquake engineering of these days. This study is basically divided into two parts; first, a database of buildings damaged by the earthquake was established. Second, a building damage assessment model was set up via the data collected from Chi-Chi Earthquake. To obtain the fragility curve of various buildings, a couple of important subjects will be discussed in this research, there are: strong motion attenuation form, strong motion correction factor, and spatial statistics (Kriging) and building damage risk analysis. Upon establishment of these relations, we can use result to evaluate the destruction level and the collapse probability of various categories of buildings. Besides, they can be served as a reference of design specifications for the buildings in the fault neighborhood as well as a simulation practice against seismic disasters in the future.

INTRODUCTION

A violent earthquake stroke Chi-Chi, a town of Nantou county in Taiwan at the 1:47 (AM), September 21, 1999 (GMT: 12.6 sec. 17:47, Sep. 20). The epicenter was located at 23.87^o NL, 120.75^o EL, which was about 12.5 KM away from the west of Sun Moon Lake. The focus depth was about 7 to 10 KM and the scale was ML = 7.3 (CWB) or MW = 7.6 (USGS). Chi-Chi earthquake was an inland shallow layer earthquake triggered by Che-Long-Pu Fault in central Taiwan. The length of the main fault resulted from the quake was about 83 KM and that extending to northeast was about 22 KM with a total length of 105 KM approximately. A total number of about 20,000 buildings were half or complete collapsed in Chi-Chi Earthquake, and its cause heavy casualties of over 2,400 dead (including missing people) and more than 8,000 injured (Huang and Jian, 1999). Thus, it can be termed as the most serious seismic motion with the biggest number of casualties in Taiwan recently.

Generally, the seismic vulnerability curve/fragility curve（hereafter called fragility curve）of a building refers to the probability of different levels of damage at various Strong Motion Index (ex: PGA, PGV, etc.). Ge and Chen (2000) express the fragility curve could be obtained in three ways, which were

“Nonlinear Static Analysis Procedure”, “Nonlinear Dynamic Analysis Procedure” and “Earthquake Damage Investigate Statistic Method”. For “Nonlinear Static Analysis Procedure”, three methods are further divided. The first method is to get the Global Damage Index through Nonlinear Static Analysis Procedure prior to drafting the fragility curve. The Capacity Curve is obtained in the second method of equivalent static analysis procedure and the Demand Spectrum is spectral transformed from the structural response. Damage status is determined by spectral displacement of the building. Combining the above three parameters and the scale of the earthquake will result in the damage chance of the building, which is the approach HAZUS 97 of the U.S.A. adopts for the fragility curve (Yeh and Chen 1999). The third method is to apply Nonlinear Static Analysis Procedure to construct the Capacity Curve (Multi-degree of Freedom) before getting the fragility curve. For “Nonlinear Dynamic Analysis Procedure”, methods consist of Finite Element Method, Shear Beam Model, Hybrid Model, Discrete Hinge Model and Single Degree of Freedom Model, etc. These types of methods are to make use of the results of nonlinear dynamic analysis to describe the global damage index of the building and use this results to estimation the fragility curve (Ge and Chen, 2000). The third method is use the “Earthquake Damage Investigate Statistic Method” procedure to estimation the fragility curve, but this method requires complete data of damaged building after earthquake (Shinozuk, 1999; Yamazaki et al., 1999; Yamazaki & Murao, 2000; Murao et al., 2000). Shinozuk (1999) applied the measurement data obtained from the Hyogoken Nanbu Earthquake of 1995 to estimate the fragility curve for the hazard of bridges. The fragility curve in his study was established by logarithmic normal function (Nonlinear Dynamic Analysis Procedure) and the double parameters inference by the Maximum Likelihood Method. Yamazaki et al. (1999) used the same measurement data and considered various factors (ex: the building structure, the year of construction, etc.) to set up fragility curves for various types of buildings. The main type of building concerned in the research was wooden and construction an assessment model of building damage risk model for the Tokyo government. Lee et al. (2001) collected household-based damage data in Nantou area after Chi-Chi earthquake and basic information of the household from the National Tax Administration (NTA) database. They transform and normalization the data format, a database based on the properties of the buildings was established, which resulted in various buildings fragility curves in Nantou County. However, the “Earthquake Damage Investigate Statistic Method” is the most reliable approach among the three methods mentioned above and its results can be served more information for risk assessments of building damage (Hsieh, 2000). The major reason of this procedure is because the results are actual facts obtained from seismic data, but this method required the complete and clear investigation on the properties of the buildings after earthquake.

In this study, we collected the Strong Motion Index of Peak Ground Acceleration (PGA) and analyzed the impact of the building damage. The GIS system was applied to collect and establish data, these data included the original information on house taxes provided by revenue service units, an inventory of name for complete or half collapsed houses after earthquake, and various town-based numeric data like the average strong motion index, etc. Finally, we can construct the database and estimation fragility curve for evaluate of building Risk analysis, and formulated of anti-seismic design laws and reduce disaster impact for the buildings in the future.

STUDY AREA AND DATA DESCRIPTION

Study Area

The epicenter of Chi-Chi earthquake was located near Chi-Chi, Nantou County and great casualties were caused in central regions of Taiwan. In order to explore the impact upon buildings imposed by strong motion of the earthquake, study areas will be decided in the central of Taiwan (Nantou county & city, Taichung county & city). The study area and location of the epicenter of Chi-Chi earthquake shows in the Figure 1.

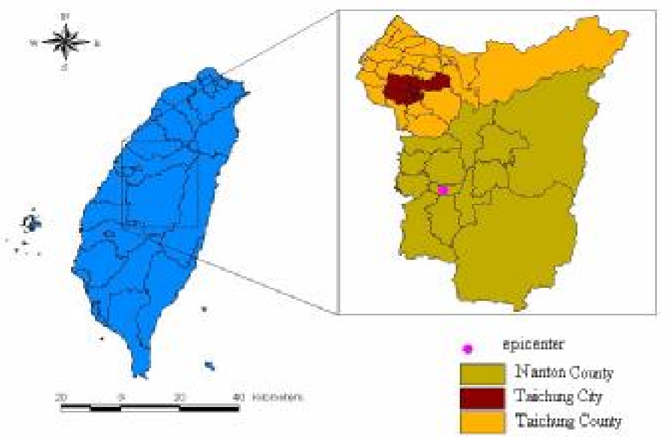


Figure 1. Location map of study areas

Building Damage Data collection

To achieve the purpose of create Chi-Chi earthquake database and evaluating building damage risk, the study collected household-based damage data in central of Taiwan area from Town Administration Office (TAO) and basic information of the house or building data from the NTA. The TAO data in the disaster region offer the complete or half collapsed building data, and this data format is a household-based unit will be applied precise statistics in this study. Besides, The NTA data offers the original information on 1.02 million house buildings in 859 townships and towns (this data include the year of construction, type of structure, area and purpose, etc.). In order to combine the two principle database, this study using GIS system to transfer data base code (financial codes to Big5) and standardization of address information, the various types of percent number of total damaged buildings in a township or town is created. Data sources of damaged buildings in Chi-Chi Earthquake are indicated in Figure 2.

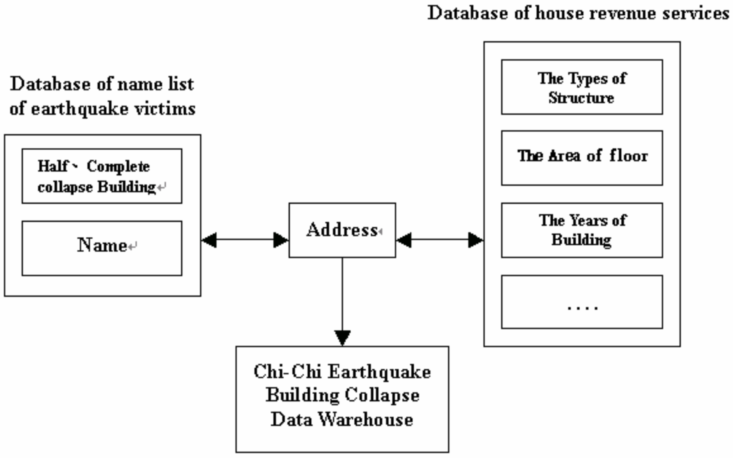


Figure 2. Establishment of Building Damage Database in Chi-Chi Earthquake

On the other hand, as the original information provided by revenue services was based on household floor area, it would be an over-statement for Reinforced Concrete (RC) buildings when the earthquake damage was concerned. Thus, the household-based "floor area" of all buildings would be transformed into the "base area" in this study; i.e., the base area of a building will become an analysis unit to solve this problem. Therefore, the building damage percentage in the research can be defined.

Strong Motion data

Data were collected from the strong motion observation stations in central regions of Taiwan, this data including Miaoli, Taichung, Nantou and Chiayi counties with a total number of 103 sites. Besides, this data have three directions (E-W, N-S and Vertical) were recorded by Central Weather Bureau (CWB). Horizontal strong motion data (E-W, N-S) were geometric average processed and converted into single force data for data interpolation. Statistic features of data collected from 103 strong motion observation stations are listed in Table 1.

Table 1. Statistic features of strong motion index in horizontal direction (gal)

	Max. Value	*Min. Value*	*Avg. Value*
PGA	**760.08**	**41.99**	**202.30**

Extract sampling data in study area

Because of strong motion effect on the site of each area decreases as the distance from the fault increases and the level of building damage reduces as well. As the purpose of this research is to analyze the ability of the building against strong motion, the fragility curve of building damage has to be obtained. Therefore, take sampling data in the study area is requirement (hereafter call empirical area). Generally, movement on the surface of the earth in fault zones is the major cause of building damage. As a result, Che-Long-Pu fault line was the center of sample segments and a range of 15 KM was extended there from for building sampling and analysis (Figure 3).

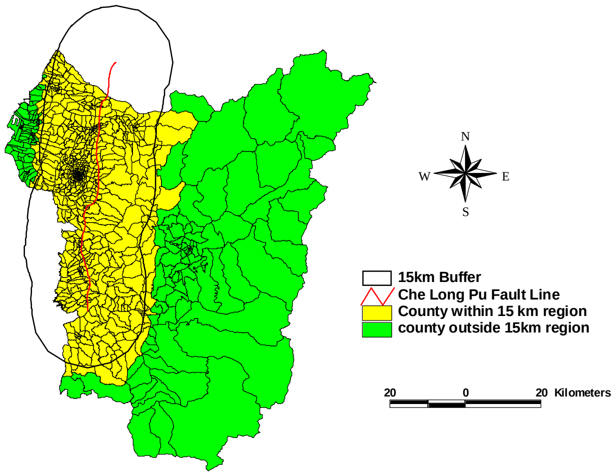


Figure 3. Empirical region

As these areas have a dense population, effect of strong motion index can be reflected effectively through the type, quantity and damage status of buildings distributed within the areas. At here the building damage is defined as a completely collapsed and structure category selection is mainly based on building materials, which can be divided into four types, there are: “RC”, “Reinforced Bricks”, “Bricks” and “Pure Clay”. Because of the RC buildings are the major structure among these four types in empirical areas, and we divided RC database again. As a result, three stages will be separated for RC buildings database. The first stage is before 1982, the second stage starts from 1983 to 1989, and the third stage is between 1990 and 1998. These stages are mainly based on the project report of “Analysis & Statistics of Building Damage from 921 Earthquake” (Hsiao, 2001).

STUDY METHODS AND PROCESS

Methods of Estimating Strong Motion Index

1. Equation of horizontal attenuation relationship

Attenuation relationship plays an important rule while estimating the hazard of buildings. According to the observations of seismologists in the past, especially the data obtained around the near-fault rupture surface, vibration on the surface of the earth attenuates along with the increase in the distance from the fault. Thus, the distance between the building and the fault is an important parameter (Yeh and Hong, 1999). The Bao (1992) point out that better results might be using Campbell Form for was strong motion PGA index in Taiwan. Therefore, Campbell form is used in this research as the source of horizontal attenuation relationship (Campbell, 1997).

2. Correction factor for strong motion index

The attenuation relationship model of Campbell Form was the outcome of various seismic measurement records collected by seismic scholars after earthquake, which is not exactly the same as the data collected from Chi-Chi Earthquake. To be consistent with the measurements of the Chi-Chi Earthquake by applying the equation of horizontal attenuation relationship, correction factor is required as follows

$$\min \Delta = \sum_{i=1}^{n} \left| PGA_T - aPGA_E \right| \qquad (1)$$

Where a is correction factor; the number of observation stations is n. In Eq. (1), PGA_T represents the data collected from each observation station during Chi-Chi earthquake (103 sites) and PGA_E express for the result calculated by Campbell Form.

Geostatistical Theory

1. Basic theory of regionalization variable

A group data in the space or phenomenon have specific spatial structure, its called regionalization problem. On the other hand, because of strong motion problems resulted from earthquakes, strong motion data are characterized with random variable features and can apply to the following equation:

$$Z(x) = M(x) + Y(x) \qquad (2)$$

The variable $Z(x)$ expresses a Regionalized Variable (RV) at x. The variable $M(x)$ expresses the regular and continuous variation of the Random Fields (RF); i.e. the called trend or drift effect (deterministic function). Its value equals to the expectation of Z at x ($M(x)=E[Z(x)]$). The variable $Y(x)$ means erratic fluctuations in space and its expectation value equal to zero. For seismic analysis, trend effect as horizontal attenuation relationship (e.g. Campbell Form). Subtract regional trend effect of $M(x)$ from strong motion observation data $Z(x)$, and we have the result consistent with the hypothesis of the regionalized variable theory (2^{nd} order stationary hypothesis). Consequently, interpolations data in space can be using Kriging Method. Finally, we can add regional trend effect data and estimation data in the whole space and get the finally result. The relationship between regional trend (or drift) and erratic fluctuations is shown in Figure 4.

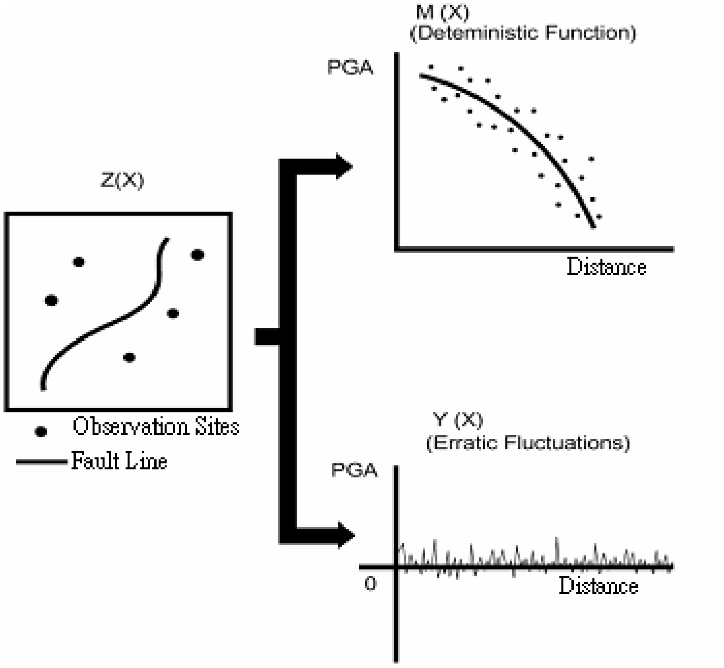


Figure 4. Relationship of trend effect and erratic fluctuations in strong motion data

2. Semivariogram

Semivariogram represents spatial variation in the observation data and is the kernel of Kriging estimation theory. In the Ordinary Kriging (OK) method as assume to $E[Z(x)]=E[Z(x+h)]$, and calculation of experimental semivariogram may be conducted through equations (3) and (4) (Isaaks and Srivastava, 1989; Journal and Huijbregts, 1991).

If $Z(x)$ is stationary, then:

$$g(h)=\frac{1}{n}\sum_{i=1}^{n}\left[\frac{1}{2}[Z(x)-Z(x+h)]^2\right] \quad (3)$$

The $Z(x)$, $Z(x+h)$ expresses two random observation values in space; n is the number of observation data. The h expresses the relative distance between observation values.

If $Z(x)$ is non-stationary, then:

$$g(h)=\frac{1}{n}\sum_{i=1}^{n}\left[\frac{1}{2}[Y(x)-Y(x+h)]^2\right]$$
$$Y(x)=Z(x)-M(x) \qquad (4)$$

After removing trend function out of strong motion data, strong motion data can be deemed stationary and experimental semivariogram can be calculated by equation (4). On the other hand, after getting experimental semivariogram and model need fitting by the theoretical semivariogram. There are four major fitting models that are commonly used and there are: (1) *Model in* h^r, (2) *Spherical Model*, (3) *Exponential Model* and (4) *Gaussian Model.*

3. Ordainary Kriging system

When we estimated the $g(h)$ by semivariogram function, the random variables of space structure will be revealed. The optimum estimation of spatial data can be conducted by the Kriging System equation. The Ordinary Kriging Method was used in this study for estimation of the Strong Motion data. The forms of Ordinary Kriging system equations are as follows:

$$\sum_{j=1}^{n} l_j g(x_i-x_j)+m=g(x_0-x_i) \quad (i=1,2...,n)$$
$$\sum_{i=1}^{n} l_i=1.0 \qquad (5)$$

Its presented in a matrix from, then:

$$\begin{bmatrix} g_{11} & g_{12} & g_{13} & \cdot & \cdot & \cdot & g_{1n} & 1 \\ g_{21} & g_{22} & g_{23} & \cdot & \cdot & \cdot & g_{2n} & 1 \\ g_{31} & g_{32} & g_{33} & \cdot & \cdot & \cdot & g_{3n} & 1 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ g_{n1} & g_{n2} & g_{n3} & \cdot & \cdot & \cdot & g_{nn} & 1 \\ 1 & 1 & 1 & \cdot & \cdot & \cdot & 1 & 0 \end{bmatrix} \begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ \cdot \\ \cdot \\ \cdot \\ l_n \\ m \end{bmatrix} = \begin{bmatrix} g_{10} \\ g_{20} \\ g_{30} \\ \cdot \\ \cdot \\ \cdot \\ g_{n0} \\ 1 \end{bmatrix} \qquad (6)$$

with $g_{ij}=g(|x_i-x_j|)=\frac{1}{2}E\{[Z(x_i)-Z(x_i)]^2\},(i,j=1,2,...,n)$.

The matrix $\lfloor g_{ij} \rfloor$ in Kriging system represents correlated characteristics among observation data and $[g_{i0}]$ means correlated features between observation point and estimation point. When the semivariogram function is estimation, weighted factor $[l_i]$ determined directly by the relative distance of the Kriging system and the variogram result will instead of observation data from observation points.

Probability density function of building damage

In the nature, the Normal distribution is almost assumed population of phenomena. The probability distribution is determined by two parameters (there are: mean m and standard deviation s). But not all natural phenomena are characterized with normal distribution. Therefore, properties of the data have to be converted for better statistic distribution. As for seismic problems, a lot of seismologists hypothesize lognormal distribution between strong motion and building damage (Shinozuka, 1999; Yamaguchi & Yamazaki, 1999; Murao, 1999). Finally, the probability density function $f_X(x)$ is shown as equation (7) as follows:

$$f_X(x) = \frac{1}{\sqrt{2p}\, sx} \exp^{-\frac{1}{2}(\frac{\ln x - m}{s})^2} \qquad -\infty < x < \infty \tag{7}$$

Risk analysis of building damage

The "Risk of Building Damage" in this study is defined as the analysis of damage rate of the building resulted from strong motion index. In other words, risk probability of building damage P_f refers to the probability when resistance of the building against strong motion index (R) is smaller than significance of strong motion (S), shown as the follows:

$$P_f = P\left(\frac{R}{S} < 1\right) \tag{8}$$

Since building damage is related to building properties (e.g. type of building, age of building and geological conditions, etc.), joint probability distribution under several conditions needs to be taken into consideration for a comprehensive understanding of the seismic problems. Therefore, joint probability distributions for different types (building strength) under different topographic conditions (various terrains impact for building by strong motion) are explored in this research. The probability of building damage can be defined as follows:

$$P_f = \int_0^1 f_Z(z)dZ \tag{9}$$

As statistics of resistance of the building against strong motion index (R) and significance of strong motion (S) are conducted independently, a natural logarithm of performance variable Z (Let $Z = R/S$) has to be obtained and converted to $LnZ = LnR - LnS$. The LnZ expresses to the building damage probability in lognormal distribution and the mean and the standard deviation are $m_Z = m_R - m_S$ and $s_Z = \sqrt{s_R^2 + s_S^2}$ respectively. Thus, the joint probability density function P_f is shown in equation (10) as follows:

$$f_Z(z) = \frac{1}{\sqrt{2p}\, s_Z} \int_0^1 \exp^{-\frac{1}{2}\left(\frac{LnZ - m_Z}{s_Z}\right)^2} dZ \tag{10}$$

If $y = \frac{LnZ - m_Z}{s_Z}$, equation (11) can be converted to the following:

$$f_Z(z) = \frac{1}{\sqrt{2p}} \int_{-\infty}^{\frac{m_Z}{s_Z}} \exp^{-\frac{1}{2}y^2} dy = 1 - \Phi\left(\frac{m_Z}{s_Z}\right) \tag{11}$$

Equation (11) represents the risk probability of building damage. The $\Phi(b)$ stands for the cumulative probability distribution and b is also called reliability index.

When the difference types of building damage ratio under estimation, the risk probability of complete collapsed buildings of all types can be evaluated. Apply the estimated strong motion index and the investigation results. The risk value of buildings in each region can be estimation through Eq. (12).

$$P_i = \sum_k (N_k \times w_{kl}) \qquad (12)$$

Where is suffix k represents "the type of building " and l represents "geology condition"; P_i: Risk rate of building collapse; N_k: Percentage of k type building; w_{kl}: risk weight.

RESULTS AND DISCUSSION

Processing of strong motion data

Campbell Form model after correcting the factor and observation points (PGA) during Chi-Chi earthquake are integrated in Figure 5. Its express that strong motion data reduce is about the distance of faults. On the other hands, the corrected Campbell Form model is converted to spatial data through GIS technology. The above data are further transformed into a raster format and $1\,Km \times 1\,Km$ is defined as one grid for integration of the trend effect model and other spatial estimation data.

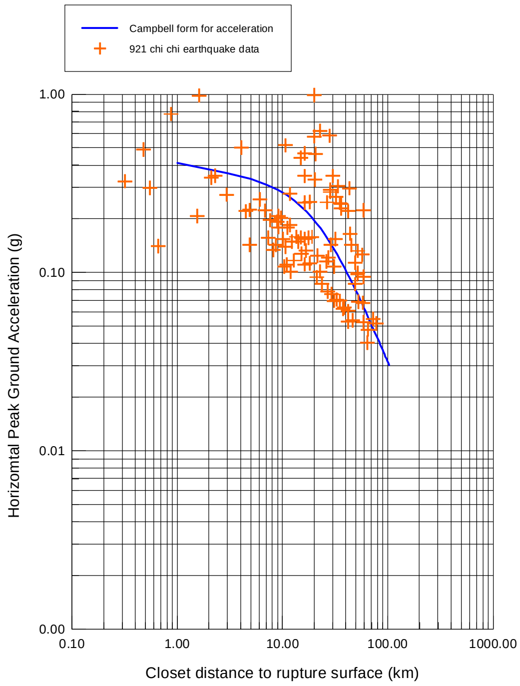


Figure 5. Deterministic function model for PGA

Spatial estimation of strong motion index

1. Fitting model of semivariogram

It is important to analyze the spatial structural characteristics of the data while estimating spatial problems with Kriging methods. If the data have spatial structural characteristics, the parameters obtained can be served as a reference for spatial estimation. The analysis of spatial structure here refers to semivariogram analysis. Semivariogram analysis for PGA is shown in Figure 6. The fitting parameters of semivariograms are show in Table 2.

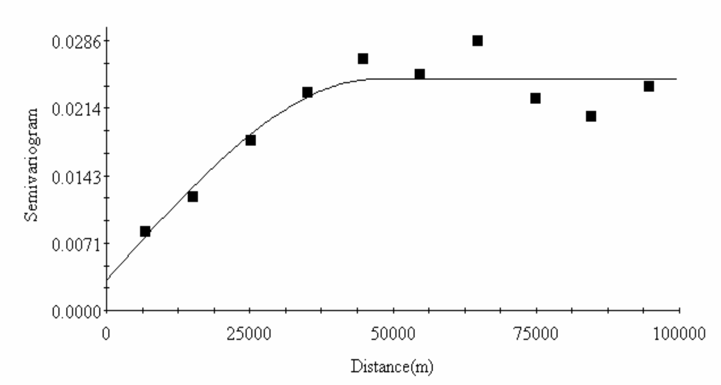


Figure 6. Semivariograms for PGA

Table 2. The model fitted parameters

C_0	$C_0 + C$	a	R^2	**Fit Model**
0.0032	0.0245	47100	0.883	Spherical

2. Estimation spatial data for PGA

The Ordinary Kriging method is applied for data estimation and comprehensive spatial data of strong motion index (Figure 7). It is apparent that enormously strong motion effect triggered by earthquakes concentrates at Che-Long-Pu and decreases gradually towards both sides of the fault. On the other hand, there is an area with a higher value (the square area in the figure), which is verified to be Pu-li basin. The region in the Pu-li town has the “basin effect” occurs in this study when an earthquake strikes.

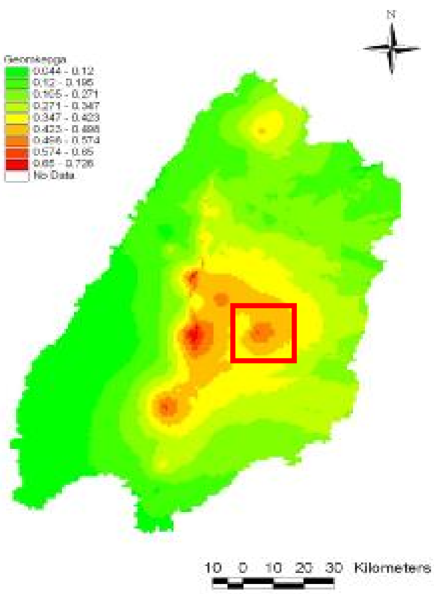


Figure 7. Spatial data interpolation of PGA (g)

Building Damage Databases of Chi-Chi Earthquake

The general structure of building damage databases of Chi-Chi earthquakes applied in this research is shown as Figure 8. It is mainly divided into building database (denominator) and building collapse database (numerator). For building database, information on original properties is focused, including name of the owner, household register address, year of construction, building structure, number of floor and floor area of the building, etc. Different conditions are further specified for information on year of construction, building structure and number of floor as data sources of fragility curves. Furthermore, household-based floor area is converted to site area to eliminate magnified measurement.

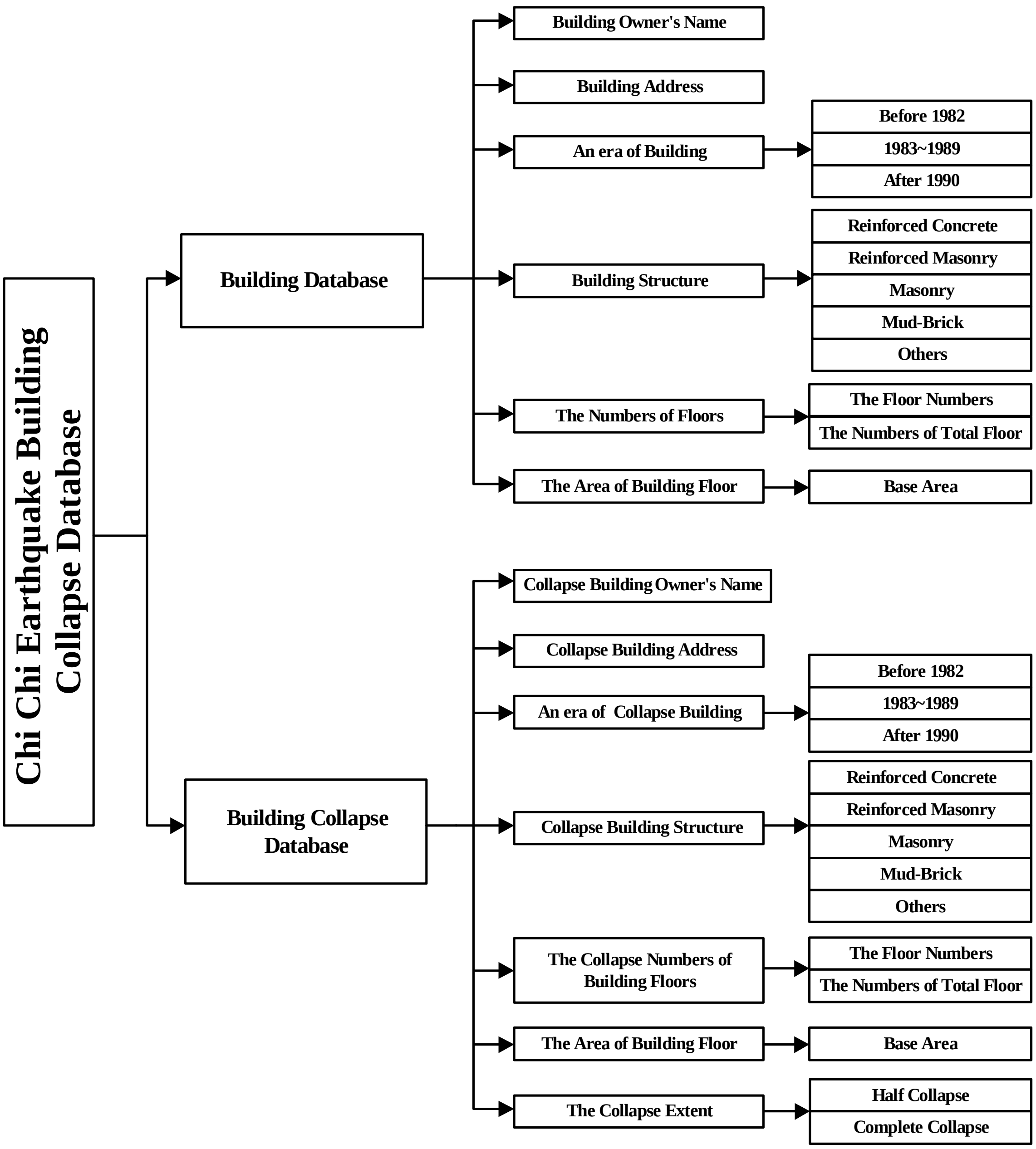


Figure 8. Building Damage Databases of Chi-Chi Earthquake

Fragility curve for building damage

In order to understand the effect of strong motion index on building damage, two fragility curves for "Complete Collapsed RC Buildings Constructed in Different Years" and "Complete Collapsed Buildings of All Types of Structure" are explored in this study. The principle purpose of age classification for RC buildings is to explore the effect of time factor on building materials and changes of regulations. On the other hand, analysis of fragility curve for complete collapsed buildings of all structural types, the main goal is to probe resistance capability of buildings against strong motion index in Chi-Chi earthquake. Results are shown in Figures 9 and 10 and Table 3. Figure 9 express clearly that earlier buildings (before 1982) have weaker anti-seismic capability. Buildings with medium anti-seismic capability range from 1983 to 1989 and the best anti-seismic buildings were constructed after 1990, which also explains that changes of time indeed result in substantial changes of the anti-seismic capability of the buildings.

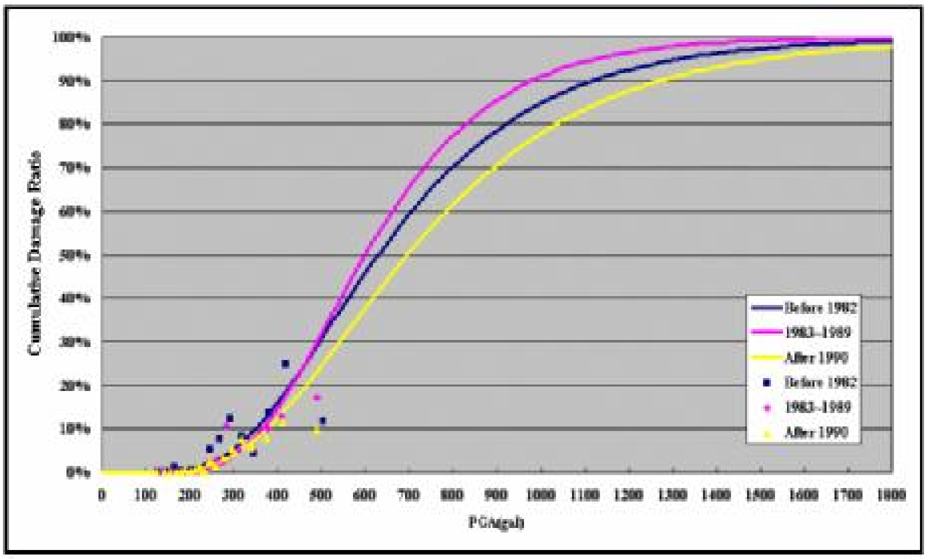


Figure 9. Fragility curves of complete collapsed RC buildings built in different years

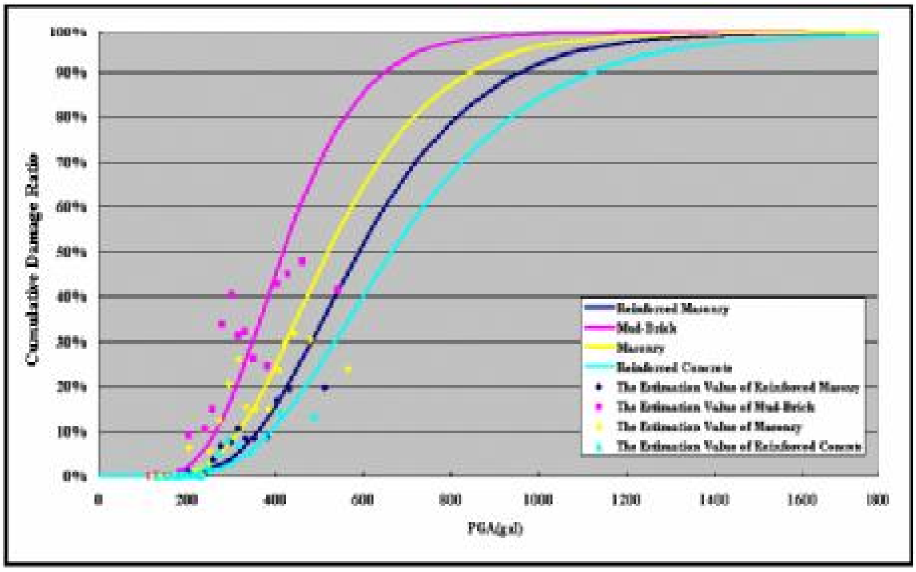


Figure 10. Fragility curves of complete collapsed buildings of all structures

Table 3. Statistical characteristics of fragility curves for all types of buildings

Building Category		***Mean***	***Standard Deviation***	R^2
RC	**Before 1982**	6.76	0.48	0.76
	1983~1989	6.87	0.45	0.79
	After 1990	7.06	0.56	0.80
Reinforced Bricks		6.72	0.45	0.86
Pure Clay		6.19	0.33	0.79
Bricks		6.48	0.40	0.79
RC		6.92	0.51	0.89

On the other hand, the damage probability for four types of structures is physically reasonable (Figure 10). The order is as follows: “Pure Clay”, “Bricks”, “Reinforced Bricks” and “RC” construction. Buildings constructed by “Pure Clay” are the weak structure because and they begin to have damage at about 150gal; however, “RC” buildings with the most excellent resistance structure and start to be damaged at about 280gal. Statistical characteristics of all types are shown in Table 3. All buildings types have high correlation of PGA and damage ratio. Thus, its results will be used for a reference of building collapse risk assessment in the future.

Building Damage Risk analysis

1. Building damage PDF curve under various geological conditions

Because of different geological conditions cause different levels of damage on the buildings, geological conditions in the database will be categorized. Three geological regions divided in the empirical areas, first, the villages and towns passing through Che-Long-Pu fault will be defined as the near-fault areas, second, the footwall refer to places on the left side of Che-Long-Pu fault, third, the locations on the right side of Che-Long-Pu fault will be specified as hanging wall. After getting the mean and standard deviation of PGA, the probability density function (PDF) figure under certain geological conditions can be plotted (Figure 11).

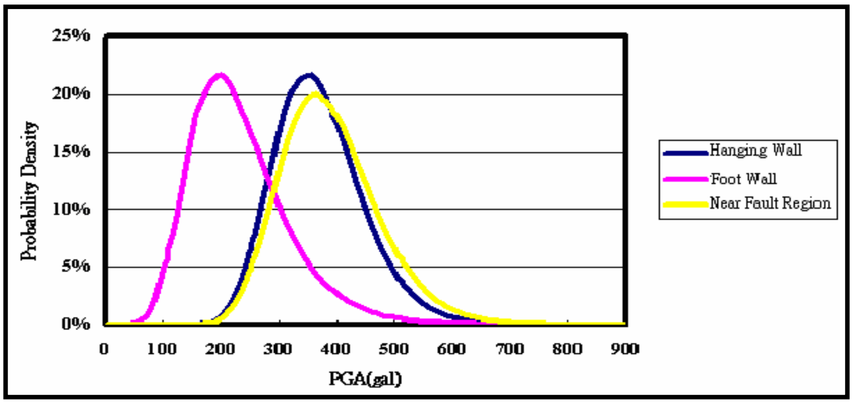


Figure 11. Building damage PDF curves under different geological conditions

2. Assessment of weighted risk

Building damage can be evaluated by the weighted risk under this process (c. f. equation 12). For example, the damage probability of “RC” buildings built before 1982 with the geological conditions of the hang wall region is 4.94% and other results under other conditions are listed in Table 4. Table 4 expresses that buildings of “Pure Clay” have the highest damage ratio, it has 25.39% damage ratio in near-fault region. The “RC” buildings built in footwall region in 1980’s have the lowest damage ratio (0.49%.). However, the results of Table 4 show the weighted risk process is available the buildings damage problem of the empirical areas.

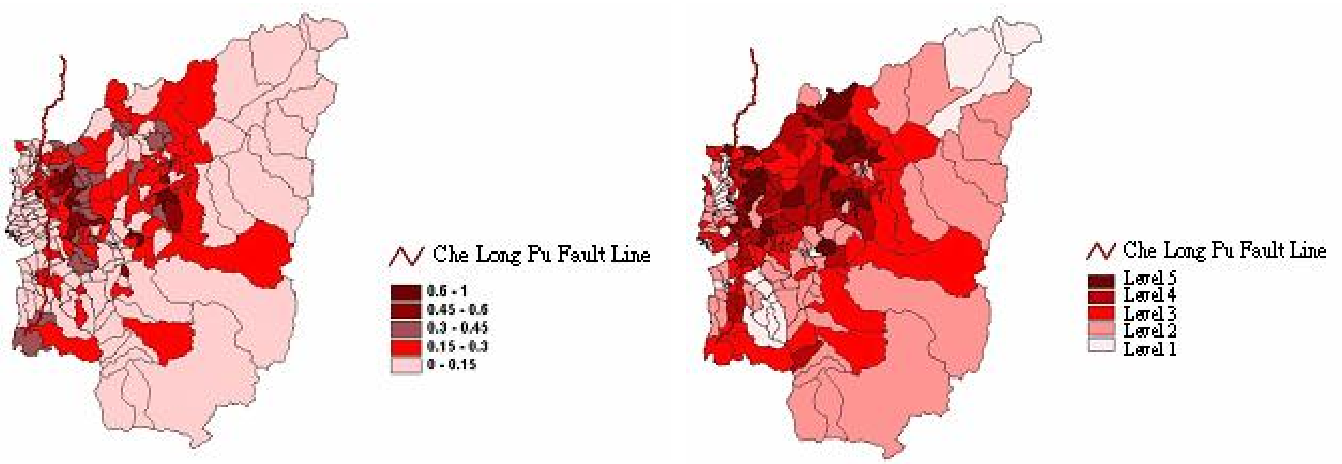
Table 4 Building damage represented under two conditions（%）

		m_R	s_R	***Geology condition***		
		-	-	**Hang wall**	**Footwall**	**Near-fault**
m_S		-	-	5.89	5.39	5.92
s_S		-	-	0.20	0.35	0.24
RC	**Before1982**	6.76	0.48	4.94%	1.11%	6.06%
	1983~1989	6.87	0.45	2.40%	0.49%	3.15%
	After 1990	7.06	0.55	2.37%	0.54%	2.94%
Reinforced Bricks		6.72	0.44	4.43%	0.93%	5.60%
Pure Clay		6.19	0.33	21.83%	4.76%	25.39%
Bricks		6.48	0.40	9.32%	1.98%	11.39

Where m_R and s_R refer to the mean and the standard deviation of building damage fragility curve respectively; m_S and s_R stand for the mean and the standard deviation with geological conditions in the empirical region.

Building damage risk evaluation- a case study of Nantou County

The actual rates of collapsed buildings in Nantou County can be extracted from the “Chi-Chi earthquake building damage database”. In this study the actual rates of building damage will be divided into five levels and darker color regions mean a higher collapse rate (Figure 12-a). On the



(a) Actual data collapse rate (%) (b) Estimation risk collapse map

Figure 12. Risk analysis of buildings in Nantou County

other hand, the results of using the building damage risk assessment process in this study are shown as Figure 12-b. After comparing these two figures, it is found that they have a similar collapse rates in Nantou County. For process applied in this research, near-fault region will have a higher damage rate and effect of earthquake damage also varies as the distance between the site and the fault changes. On the other hand, the damage ratio in hang wall region is supposed to be higher that in footwall areas and surrounding villages and towns will have lower damage levels (Ren-Ai Village & Hsin-Yi Village, etc.). Finally, the above analysis process should be able to reflect building damage estimations resulted from earthquakes. Therefore, the analysis results in this research can be served as an important reference for analysis of earthquake damages in metropolitan areas in the future.

CONCLUSION

Conclusions and suggestions of this research are listed as follows:

1. As the destruction and damage imposed by earthquakes are extremely enormous and hard to prevent, it is critically important to conduct building damage investigations after the disaster since damage consequences will affect the anti-seismic analysis operation in the future (e.g. drafting of fragility curves). According to the research, there are still a lot of shortcomings in the building damage investigation this time. For instance, standards of building damage identification are not consistent, professional personnel are not sufficient and there seems no spatial information on the buildings in villages and towns established by county and city governments and disaster statistical investigation forms are not complete (GIS data). Establishment of the above disaster prevention potential information is indispensable if we want to face the calamity brought by earthquakes seriously. Only when the aforementioned databases are set up and resistance capability of the buildings against earthquakes is reinforced, we can rest assured to meet the attacks of earthquakes bravely next time.
2. Semivariogram analysis is conducted to explore the spatial structure of strong motion index. The results indicate that PGA fitting works quite well. Therefore, such data can be applied for spatial estimation model of strong motion index.
3. Based on the results of building weighted risk assessment, the risk weight of near-fault region "Pure Clay" buildings have the highest damage risk and "RC" buildings built in 1980's in the lower areas have the lowest weighted risk. As such assessment is consistent with the status quo, it is applicable for building risk evaluation. On the other hand, the significance of applying weighted risk assessment is to conduct simulation and evaluation of building damage due to earthquakes in potentially hazardous areas prior to disasters. As long as the geological or geographical conditions of that area are controlled in advance, impact on buildings imposed by earthquakes can be analyzed and evaluated quickly once disasters really happen. So that, resources can be allocated opportunely and urgent steps may be taken to solve disaster problems.
4. As for building risk estimation, Nantou County and City are selected as the empirical areas in this research and verification results show that true building collapse rate is similar to spatial distribution through the simulation assessment method. Consequently, the above analysis flow can truly reflect the estimation of building damage imposed by earthquakes, which can be applied to be an importance reference for earthquake damage analysis in metropolitan regions in the future.

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