EARTHQUAKE SAFETY NETWORK RISK ANALYSIS BY SEISMIC FRAGILITY OF BUILDING

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ABSTRACT

The safety network is significant affair after disastrous earthquake. The purpose of this study is to develop an earthquake safety network risk analysis method base on the fragility curves. First, integrating the Chi-Chi earthquake database with seismic attenuation form of Campell, a spatial statistics procedure is employed to obtain the fragility curves by Kriging interpolating of ground motion distribution and maximum likelihood estimate. For building database, the study join the database of house tax statements and the database of relief-fund distribution lists to convert into Chi-Chi earthquake damage building database, and sort these buildings to 16 category by type, age and height of building. In the network risk analysis, the concept of joint probability density function is introduced; order statistics and story-width ratio is employed to establish every road safety stage estimate. Finally, the risk analysis procedure applies in study area such as Central District, Taichung. The result shows that the safety network risk analysis model can reasonably evaluate a safety degree for every road in study area.

Key Words: Earthquake, Safety network, Fragility curves, Risk analysis

INTRODUCTION

The Chi-Chi earthquake struck central region of Taiwan on September 21, 1999, with a local magnitude of 7.3, which is the most serious earthquake of Taiwan in recent century. After the Chi-Chi earthquake, the Architecture and Building Research Institute Ministry of The Interior (ABRI) immediately cooperate with National Center for Research on Earthquake Engineering (NCREE) mobilize architects and engineers to work for damage building inspection and statistic on the disaster area. Due to the short lead time, the preliminary building damage database only capture visible damaged building, but the building population is insufficient. Statistics result shows the earthquake caused 8,773 complete and partially collapsed building all over the Taiwan (Hsiao *et al.*,1999). However, the preliminary building damage database provides much valuable original information such as “house tax statements” and “relief-fund distribution lists”. Furthermore, the seismic building fragility curves in Taiwan region after the Chi-Chi earthquake then could build by database processing and GIS technology.

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In general, seismic risk analysis could base on two tactic as “ urban disaster prevention” and “earthquake engineering”. Urban disaster prevention analysis consider multiple factor to estimate disaster risk. Analytical Hierarchy Process (AHP) is employed to this analysis modeling than been use to develop a lot network plan study at present. However, this analysis modeling is insufficient implement for earthquake characteristic assumption and earth-spatial relation. Sub-risk factors are considered only in assessment criteria and employed in risk analysis. The problem is that this estimate result depends on subjective exposition from contriver so that actualy situation differece exists between with reality risk. Earthquake engineering analysis is developed and built base on earthquake characteristic and earth-spatial relation, and integrate earthquake engineering with statistc theory. By this objective statistic analysis, analysis results are applied more reliable and realistic in disaster prevention affairs. However, earthquake engineering analysis require accurately investigative data then construct reasonable statistic model or experiment after earthquake.

The seismic building fragility curves express probability of exceeding a damage state in specific seismic intensity such as peak ground acceleration (PGA). In generally, fragility curve can be defined as cumulative distribution with two-parameter lognormal distribution functions. Empirical fragility curves are developed bases on the building database and damage inspected after the earthquake event. Actual damage data could construct more realistic fragility curves to solve building damage problem of complex factor at the earthquake.

After the Chi-Chi earthquake, Lee *et al.* (2005) considered structure type and building age to construct seismic building fragility curves by least square method. Base on the smallest district “village”, collecting and summing building damage area up then compute building damage ratio of village at the Taichung and Nantou area. Further, Hsieh *et al.* (2007; 2008) propose improve maximum likelihood method to build seismic building fragility curves, the analysis procedure employ ordinary Kriging spatial interpolation with corrected attenuation relationship. Integrating “database of house tax statements” and “database of relief-fund distribution lists” be into database of building damage which is inspected after Chi-Chi earthquake in Taiwan.

In earthquake network risk analysis, Lee (2005) introduced implement of spatial analysis and saptial statistic to estimate network by GIS-base technique. This study integrated rating method and fragility curve study result (Lee *et al.*, 2005) to obtain the risk of road blocked. Leu (2000) proposed a road blocked estimate model to obtained objective road risk value. This model considers building damage ratio, building height and road width at every road. The advantage of this model is estimate quickly a road risk value in once earthquake event. However, all of the construction structure are indistinction at estimate model, but every road risk value should be difference cause by different structure type composition. Lead to identical results while the same building height and road width of the roads.

The aim of the study is introduce an “earthquake engineering model” to estimate earthquake safety network risk. First, integrating the Chi-Chi earthquake database with seismic attenuation form of Cambpell, and introduce fragility curves by maximum likelihood estimate (Hsieh *et al.*, 2007; 2008). The concept of joint probability density function, order statistics and harmonic ratio is employed to establish every road safety stage analysis with seismic building fragility curves. The risk analysis model emphasizes the influence of building structure type, which obtained more objective estimate results. Further, the model is implemented for an earthquake safety network planning in designated study area of Central District, Taichung.

BUILDING SEISMIC FRAGILITY

Shinozuka *et al.* (2000; 2001) estimated the two parameters (median and log-standard deviation) of lognormal distribution with the aid of the maximum likelihood estimate. The fragility curve for the j^{th} damage state, distribution function F_j takes the following form:

$$F_j\left(a;c_j,\zeta_j\right)=\Phi\left[\frac{\ln\left(a/c_j\right)}{\zeta_j}\right] \tag{1}$$

In Eq. (1), a is peak ground acceleration (PGA), $\Phi(\cdot)$ is the standard normal distribution function, c_j and ζ_j are the median and log-standard deviation values of the fragility curve for j^{th} damage state, respectively. The empirical fragility curves can be built from this distribution function. Hsieh *et al.* (2007; 2008) propose the two parameters estimation by multinomial distribution. The likelihood functions for the j^{th} damage state $L(a_i)$ then can be express as follows:

$$L(a_i)=\prod_{k=1}^{K} MB(n_k;P_j) \tag{2}$$

In Eq. (2), K is total number of the units, n_k is total number of the buildings in the k^{th} unit, and P_j is the interval probability of the j^{th} between $j+1^{th}$ damage under peak ground acceleration a_i. The two parameters estimate are computed by maximizing the log of likelihood function as follows in general:

$$\frac{\partial \ln L}{\partial c_j}=\frac{\partial \ln L}{\partial \zeta_j}=0,\quad j=1,2,\ldots,J_{state} \tag{3}$$

The study collected accredited strong motion records from 445 TSMIP (Taiwan Strong Motion Instrumentation Program) stations on the Taiwan region, which was successfully implemented by the CWB (Central Weather Bureau) before the Chi-Chi earthquake. For PGA analysis, Kriging interpolating is employed to estimate every unit PGA value at study area base on deterministic seismic attenuation form of Cambpell. The spatial distribution of PGA at every pixel are obtained by GIS-base technique, and shown in Fig. 1.

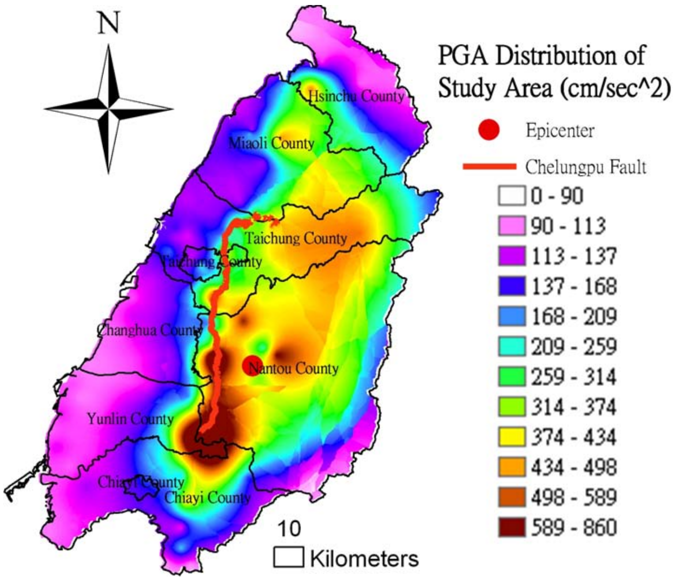

Fig. 1 PGA spatial distribute by GIS-base

On the other hand, the study inspected building damage data which focal mechanism due to the rupture of the Chelungpu fault causes severe building damage at the neighborhood along the fault zone, including Nantou County, Taichung County and City. Base on building damage data provided from Construction and Planning Agency Ministry of the Interior, Taiwan (CPAMI), the study join the database of house tax statements and the database of relief-fund distribution lists to get the Chi-Chi earthquake damage building database, and sort 767,666 buildings to 16 category by type, age and height of building, and are estimated for ‘no’, ‘moderate’ and ‘complete’ damage states. By above fragility analysis, the two parameters of specific seismic building fragility curves are obtained and shown in Table 1.

Table 1 The Two Parameters of Seismic Building Fragility Curves

	least moderate			complete			log-standard		
	Bf.1982	1983~1989	Af.1990	Bf.1982	1983~1989	Af.1990	Bf.1982	1983~1989	Af.1990
Wood Construction	-	0.700	-	-	0.850	-	-	0.496	-
Mud Construction	-	0.664	-	-	0.784	-	-	0.610	-
General Masonry	-	0.816	-	-	1.036	-	-	0.617	-
Reinforced Masonry (F1~F3)	-	0.935	-	-	1.289	-	-	0.573	-
Reinforced Masonry (F4~)	-	0.661	-	-	0.912	-	-	0.459	-
Steel (F1~F3)	-	1.339	-	-	1.682	-	-	0.687	-
Steel (F4~)	-	1.080	-	-	1.509	-	-	0.671	-
RC (F1~F3)	0.895	0.871	1.346	1.170	1.317	2.123	0.573	0.505	0.795
RC (F4~F7)	0.693	0.713	0.977	0.861	0.928	1.425	0.431	0.431	0.736

NETWORK RISK ANALYSIS MODELING

Most of the earthquake network risk study limited in semi-quantitative analysis. For safety network estimate after earthquake, the main factors of subjective judgments are considered as follow:

1. The building is damaged
2. The network is failure suffer from ground fracturing
3. The substructure is damaged such as streetlamp, signboard and underground pipeline.

The study considers significant building damage factor to estimate relationship between network risks with strong ground motion. The seismic building fragility curve is considered to express network risk probability which means a concept of joint probability density function can be defined the network risk degree.

1. Network failure seriousness

The influence factors of network failure seriousness include probability of building damage, building height and network width. Leu (2000) define harmonic ratio S_i to express the probable of network failure seriousness. In seismic network analysis, harmonic ratio could be explained the network is blocked or passed, and probability of building damage could be able to increase the unreasonable seismic network risk analysis results. The harmonic ratio is defined as follows:

$$S_i = \frac{H_i}{D_i} \tag{4}$$

In Eq. (4), H_i is average building height of every road i, D_i is effective width of every road i.

2. Building damage probability of network

The building damage probability density function of network $f_{X_{(k)}}$ can be obtained by joint probability density function with continuous variables by order statistics theory in statistic, which is defined as follows:

$$f_{X_{(k)}}(x) = \frac{n!}{(k-1)!(n-k)!} f(x)\left(F(x)\right)^{k-1}\left(1-F(x)\right)^{n-k}, \quad -\infty < x < \infty \tag{5}$$

In Eq. (5), n is an independent continuous variable which has the same distribution function, $X_{(k)}$ is called k^{th} order statistic, and $F(x)$ is probability of building damage.

3. Risk value of network failure

The risk value R_i of network failure can be obtained from Eq. (4) and Eq. (5), which is defined as follows:

$$R_i = f_{X_{(k)}} \times S_i \tag{6}$$

RESULTS AND CONCLUSIONS

In order to explore the network risk influence by PGA of the earthquake, the network map and shelter location are collected in the Central District, Taichung. The illustration of study area with shelter location shown in Fig. 2. The study simulates network risk value on different peak ground acceleration by 300gal, 500gal, 700gal and 900gal, respectively, which shown in Fig. 3. For the model of network risk analysis, Fig. 3 expresses every road have different risk value, and these result shows that the road risk have high relevance with building number and type. Different from the past experiences, especially, but a widly road or fewer buildings cannot ensure a secure network. The building fragility curves are more significance in safety network. The result shows that the safety network risk analysis procedure can reasonably evaluate the safety degree of every road. Furthermore, the model can provide a reliable estimate to plan safety network in the district before earthquake disaster.

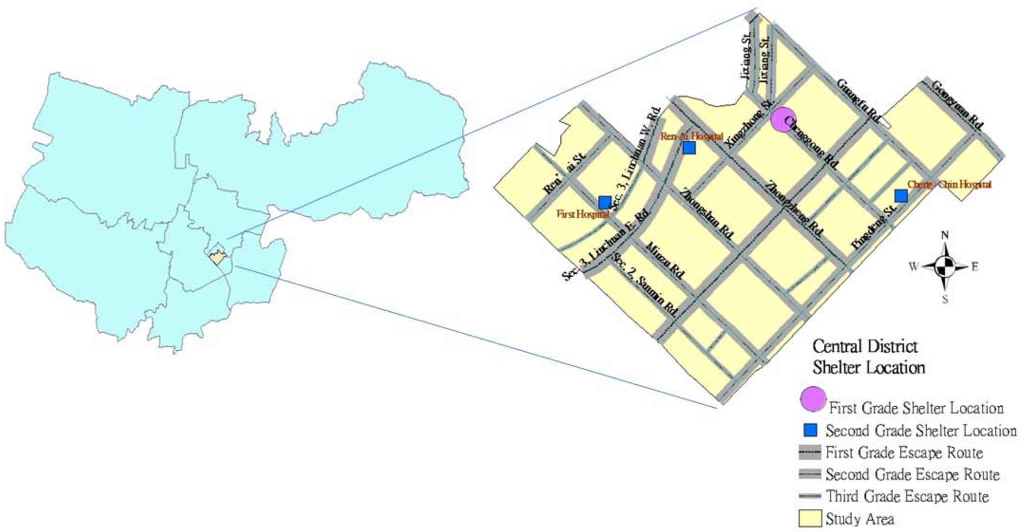

Fig. 2 The study area in Central District, Taichung

Fig. 3 Network risk value under different PGA

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