LIQUEFACTION POTENTIAL STUDY OF TAIWAN

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SUMMARY

The HAZ-Taiwan earthquake loss estimation program is an integrated geographical information system in estimation of potential seismic hazard and induced physical damage. Liquefaction is one of the ground failures in potential earth science hazard. Incorporating with the digital maps, the geological GIS system that contains bore hole data and ground water data has been established. In combination with some applicable liquefaction estimating criteria, the potential of liquefaction of some area in Taiwan can then be evaluated. Parametric study of liquefaction potential, including method of analysis, PGA-value and earthquake magnitude is also made in the paper.

INTRODUCTION

In the development of HAZ-Taiwan earthquake loss estimation methodology potential earth science hazards (PESH) include ground motion and ground failure. Liquefaction is one of the major types for ground failure. Liquefaction is a soil behavior phenomenon in which a saturated soil losses a substantial amount of strength due to high excess pore-water pressure generated by and accumulated during strong earthquake ground shaking. The devastating damage of liquefaction induced ground failures in the Alaska 1964 and Niigata 1964 earthquakes serve as a clear reminder of such events.

Evaluation of liquefaction potential requires two sets of parameters: parameters for the seismic loading and parameters to represent the characteristics of soil deposit. Each parameter influences the evaluation of liquefaction potential to a different degree, and there is considerable uncertainty associated with each of them. Youd and Perkins (1978) have addressed the liquefaction susceptibility of various types of soil deposits by assigning a qualitative susceptibility rating based on general deposit environment and geologic age of the deposit. The likelihood of experiencing liquefaction at a specific location is primarily influenced by the susceptibility of the soil, the amplitude and duration of ground shaking and the depth of ground water. Thus, the probability of liquefaction for a given susceptibility category can be determined by the following relationships [HAZUS97]

$$P\,[\text{Liquefaction}] = \frac{P\,[\text{Liquefaction} \mid PGA = a]}{K_M - K_W} - P_{ml} \qquad (1)$$

where $P[\text{Liquefaction} \mid \text{PGA} = a]$ is the conditional liquefaction probability for a given susceptibility category at a specified level of PGA value

K_M is the moment magnitude correction factor

K_W is the ground water correction factor

P_{ml} probability of map unit susceptible to liquefaction

It has to point out that the conditional liquefaction probability relationships shown in Eq. (1) were developed for a specific M and an assumed ground depth

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Application of Eq. (1) to Taiwan for liquefaction potential estimation is difficult because the correction factor K_M and K_W are not well established in this area. The purpose of this paper is to use a simple method for estimating liquefaction potential of Taiwan area.

ZONING FOR SOIL LIQUEFACTION

Soil liquefaction has been a major cause of damage to soil structure, lifelines and building foundation. Zoning for liquefaction, therefore, has been an important goal for seismic hazard mitigation. Various methods have been proposed for predicting liquefaction potential, these methods can be classified into Level-I and Level-II approaches. Level-I method for liquefaction assessment is based on existing data from published sources. By combing site-specific geotechnical surveys, detail zonation of liquefaction can be achieved which is defined as the Level-II method. Level-II method approaches to the assessment of liquefaction potential consist of the following steps:

1. estimation of the liquefaction resistance of soils in a deposit;
2. estimation of the maximum or equivalent cyclic shear stress likely to be induced in a soil deposit during an earthquake;
3. estimation of the liquefaction potential.

For the evaluation of liquefaction potential in HAZ-Taiwan earthquake loss estimation program Level-II method was used, Seed's simplified method incorporated with Iwasaki's weighting scheme was applied. In the first part the cyclic stress ratio, developed at a particular depth beneath a level ground surface, may be estimated using the relation developed by Seed and Idriss:

$$\frac{\tau_{av}}{\sigma'_0} = 0.65 \frac{a_{\max}}{g} \frac{\sigma_0}{\sigma'_0} r_d \tag{2}$$

where σ_{av} is the "average" cyclic shear stress during a particular time history, σ'_0 is the effective overburden stress at the depth in question, σ_0 is the total overburden stress at that depth, $a_{\max}$ is the peak horizontal ground acceleration generated by the earthquake at the ground surface, g is the acceleration of gravity, and r_d is a stress reduction factor which is a function of depth and the rigidity of the soil column.

The second part of the Seed and Idriss procedure requires the determination of the cyclic strength of the soil deposit. This is estimated based on either empirical correlations with the SPT N_m value, or cone penetration resistance, q_c , allowing for the effects of the soil fines content. Empirical charts have been prepared to determine the cyclic strength based on corrected SPT blow count, $(N_1)_{60}$, calculated as follows:

$$(N_1)_{60} = C_n \frac{ER_m}{60} N_m \tag{3}$$

where C_n is a correction coefficient for overburden pressure and ERM is the actual energy efficiency delivered to the drill rod. Based on $(N_1)_{60}$, then the cyclic stress ratio required to induce liquefaction for a magnitude 7.5 earthquake, $(\tau_{av} / \sigma'_0)_{LM}$ = 7.5 is given by several relationships. For earthquakes of other magnitudes, the appropriate cyclic strength is obtained by multiplying by a magnitude-scaling factor. The factor of safety against liquefaction, F_L, is then estimated as:

$$F_L = \frac{(\tau_{av} / \sigma'_0)_{LM=M}}{(\tau_{av} / \sigma'_0)} \tag{4}$$

The third part is to determine the liquefaction potential index. Iwasaki, et al., [1982] quantified the severity of possible liquefaction at any site by introducing a factor called the liquefaction potential index, IL, defined as follows:

$$I_L = \int_0^{20} F(z)\, w(z)\, dz \tag{5}$$

where z is the depth below the ground surface, measured in meters; $F(z)$ is a function of the liquefaction resistance factor, F_L , where $F(z) = 1 - F_L$, but, if $F_L > 1.0$. $F(z)$ =0: and $w(z) = 10 - 0.5z$. Iwasaki concluded that sites with IL values greater than 15 suffers severe liquefaction effect whereas effects are minor at sites with a value of I_L less than about 5, and $0 < I_L \leq 5$ is defined as liquefaction risk is low, $5 < I_L < 15$ is defined as liquefaction risk is high. Figure 1 shows the flow chart of the Seed and Idriss simplified method for liquefaction analysis

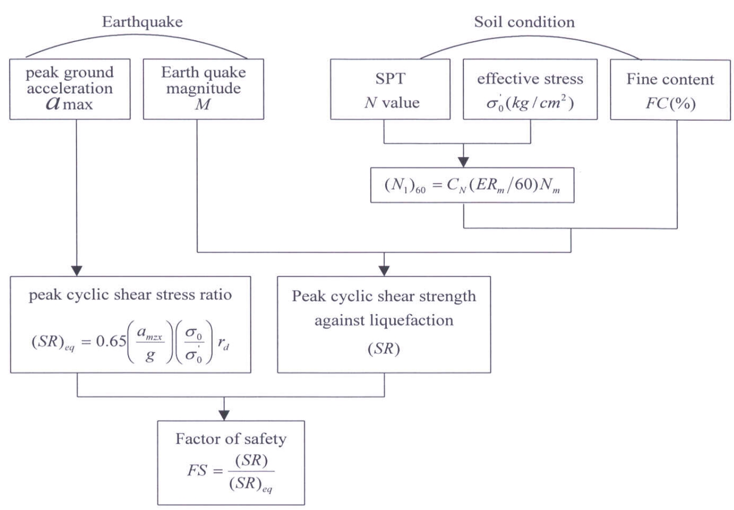

Figure 1: Flow chart of Seed's Method for liquefaction potential estimation

Different from Seed and Idriss's simplified procedure for liquefaction potential analysis. Tokimatsu and Yoshimi [1983] also proposed a modified method for liquefaction potential estimation. The cyclic stress ratio caused by earthquake loading is defined as

$$\left(\frac{\tau}{\sigma_0'}\right)_L = 0.1\times(M-1)\left(\frac{a_{\max}}{g}\right)\left(\frac{\sigma_0}{\sigma_0'}\right)\gamma_d \quad (6)$$

Different from Eq. (2) the earthquake magnitude was considered in Eq. (6), and $\gamma_d = 1.0 - 0.015Z$. The cyclic strength of the soil deposit is defined as:

$$\left(\frac{\tau}{\sigma_0'}\right)_R = a\ C_r\left[\frac{16\sqrt{N_a}}{100} + \left(\frac{16\sqrt{N_a}}{C_a}\right)^n\right] \quad (7)$$

where a = 0.45, n = 14 are constant, C_r = 0.57 (from experiment). C_a is between 80 to 90, and

$$N_a = N_1 + \Delta N_f \qquad \text{where } N_1 = \frac{1.7}{\sigma_0' + 0.7}N\ ,\quad \Delta N_f = \begin{cases} 0 & \text{for } FC \le 5 \\ FC-5 & \text{for } 5 \le FC \le 10 \\ 0.1FC+4 & \text{for } 10 \le FC \end{cases} \quad (8)$$

where FC is the fine content of soil. Also, based on Eq. (4), the factor of safety can be obtained. Figure 2 shows the flow chart of the method.

CASE STUDY

Consider Chai-I county as the demonstration area for the study of liquefaction potential. Two earthquake simulations were made: one is the Ray-Li earthquake, which occurred on 1998-7-17 with magnitude 6.8. The epicenter is shown in Fig. 3, the other is the earthquake which occurred at Mai-Shan fault with magnitude 7.5 (epicenter is also shown in Fig. 3). For the estimation of liquefaction potential the soil profile is needed. Figure 4 shows the example of liquefaction on soil data for each borehole. Soil information was collected from the borehole data around Taiwan area, and there are over 4000 borehole data been used for the estimation of liquefaction potential study. Figure 5 to Fig. 8 show the liquefaction potential map of Chai-I County using both Seed and Idriss simplified method and Tokimatsu's method. Comparison on the estimation of liquefaction between two methods shows that Seed's method provides higher estimation on liquefaction potential. Figure 9 to Fig. 12 show the result from earthquake scenario. It has to point out that the PGA attenuation equation was used to predict the ground acceleration at a site and then implement to the analysis module to estimate liquefaction potential.

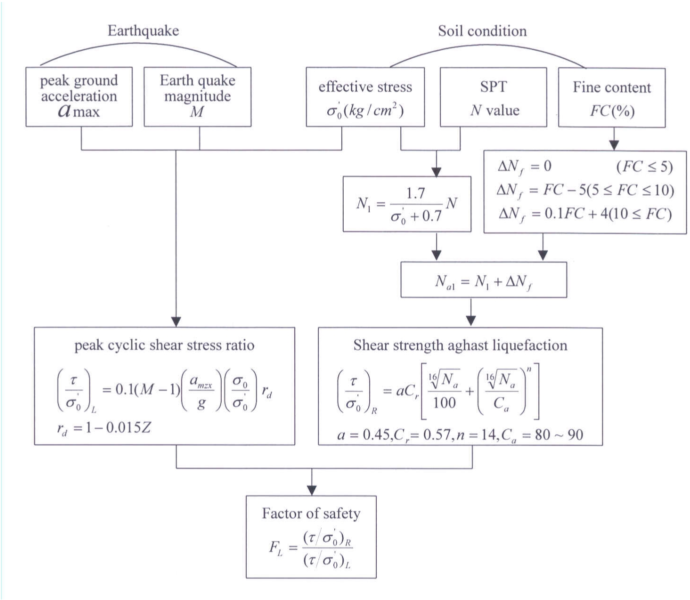

Figure 2: Flow chart of Tokimatsu and Yoshimi's Method for liquefaction potential estimation

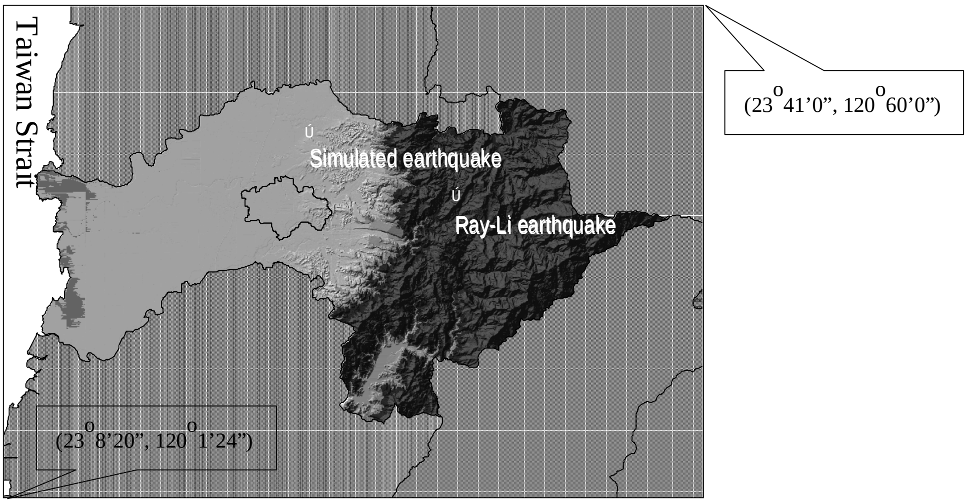

Figure 3: Digital terrain model of Chia-I area and the location of Ray-Li earthquake and simulated earthquake

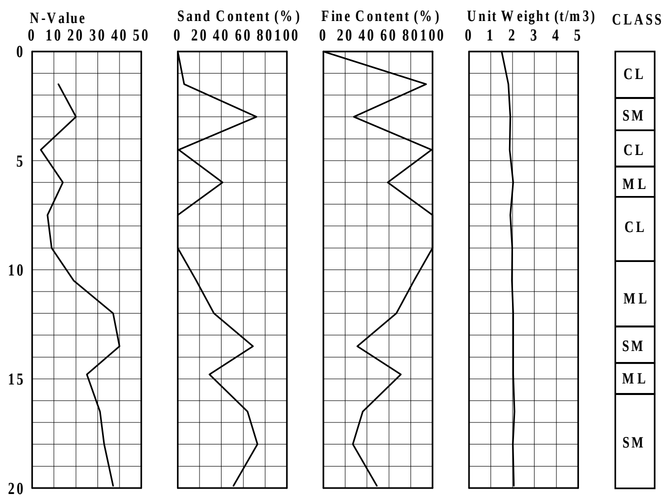

Figure 4: Soil condition at site (190726,2596975)

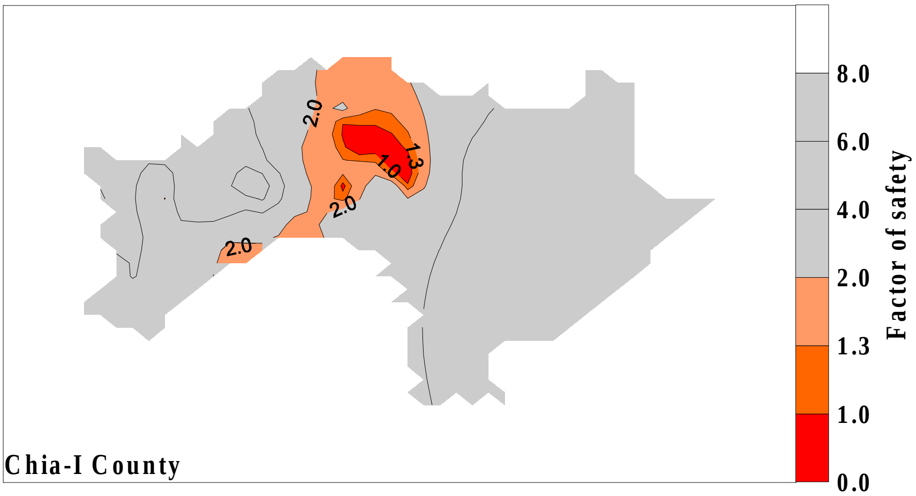

Figure 5: Distribution of minimum factor of safety using Seed's Method (Ray-Li earthquake)

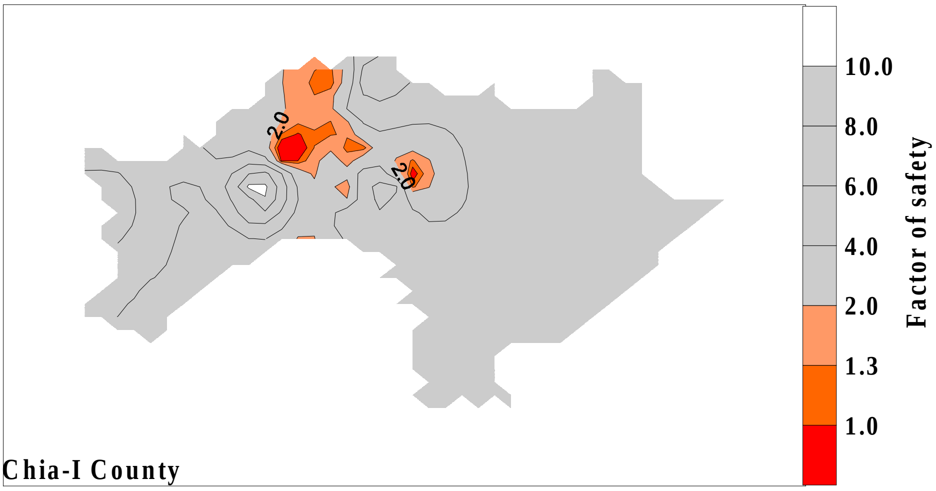

Figure 6:Distribution of minimum factor of safety using Tokimatsu and Yoshimi's Method(Ray-Li earthquake)

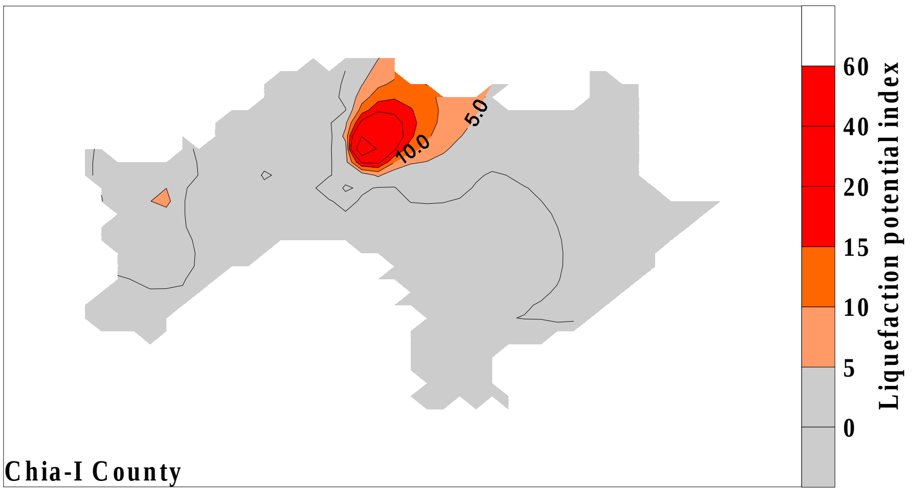

Figure 7:Liquefaction potential index using Seed's Method with Iwasaki's Weighted Method (Ray-Li earthquake)

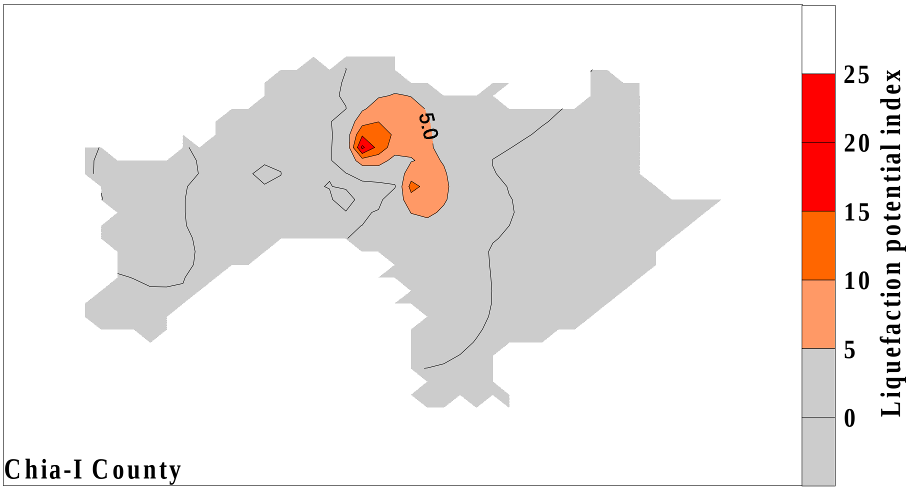

Figure 8:Liquefaction potential index using Tokimatsu and Yoshimi's Method with Iwasaki's Weighted Method (Ray-Li earthquake)

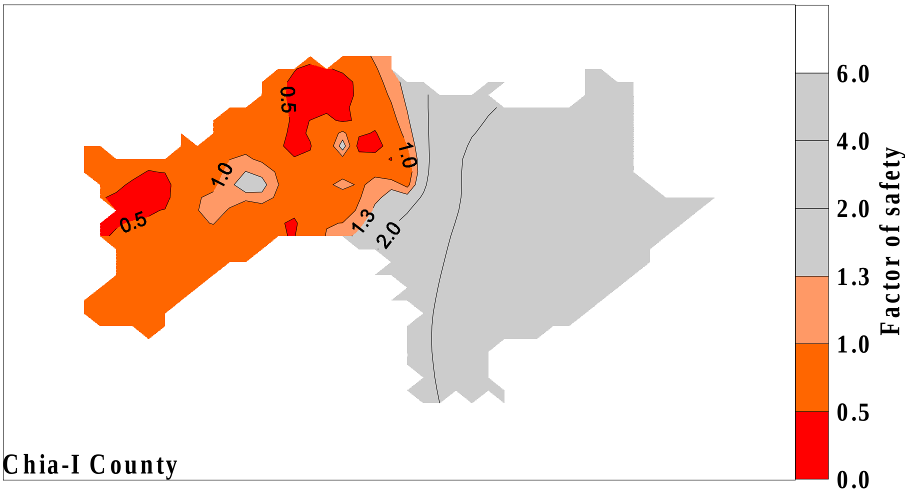

Figure 9: Distribution of minimum factor of safety using Seed's Method (simulated earthquake)

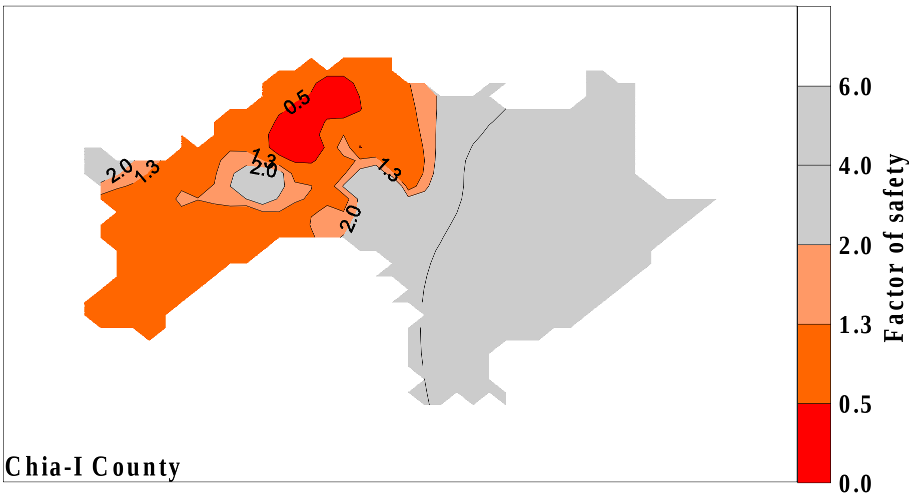

Figure 10:Distribution of minimum factor of safety using Tokimatsu and Yoshimi's Method (simulated earthquake)

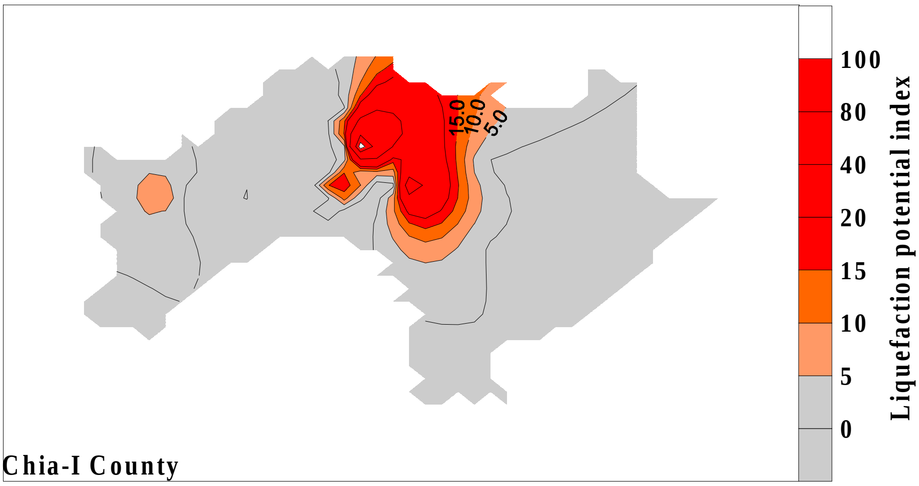

Figure 11:Liquefaction potential index using Seed's Method with Iwasaki's Weighted Method (simulated earthquake)

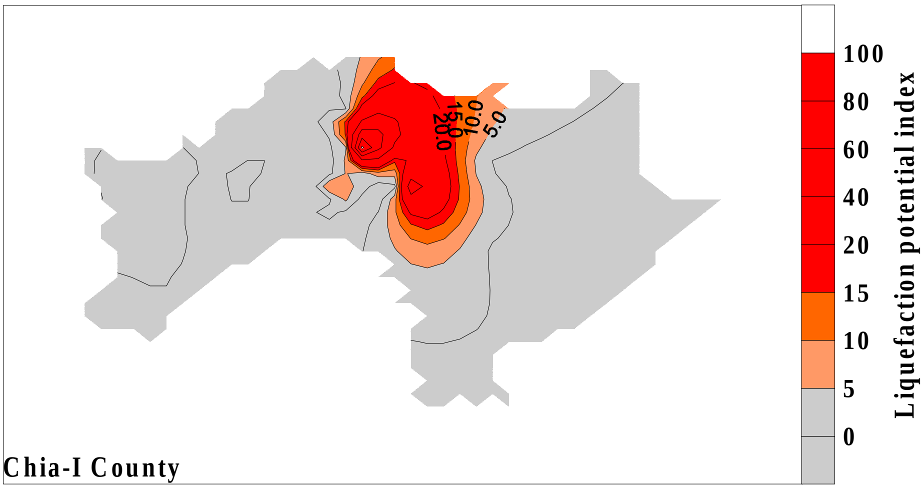

Figure 12Liquefaction potential index using Tokimatsu and Yoshimi's Method with Iwasaki's Weighted Method (simulated earthquake)

CONCLUSIONS

Liquefaction is one of the potential earth science hazards. In the development of HAZ-Taiwan earthquake loss estimation methodology liquefaction potential analysis must be implemented in the program. Based on the Seed and Idriss's simplified method as well as Tokimatsu's method for the estimation of liquefaction potential the zonation for liquefaction was generated. Liquefaction potential was estimated from analysis of the maximum horizontal surface accelerations, the duration of ground motion, the depth of water table, and the depth and standard penetration resistance of clay-free granular sediments. The results were averaged to provide an estimation of liquefaction potential to provide information for the potential earth science hazard.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to the National Science Council of Taiwan for the support under Grants No. NSC 88-2711-3-319-200.

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