

EARLY ESTIMATION PROCEDURE OF SEISMIC HAZARD FOR MAJOR EARTHQUAKE

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Abstract

A shakemap system providing rapid estimates of strong ground shaking could be useful for emergency response providers in a disaster earthquake. A hybrid procedure, which combines site-dependent ground motion prediction models and the limited observations of the Real-Time Digital stream output system (RTD system operated by CWB), was setup to provide a high-resolution shakemap in a near-real-time manner.

One of the main factors that affect the result of ground motion prediction analysis is the existence of site effects. The purpose of this paper is to investigate the local site effects and its influence in the ground shaking and, then, establish an early estimation procedure of natural hazard for disaster earthquakes. Based on the attenuation law, the site effects of each TSMIP site are discussed in terms of a bias function that is site and intensity-level dependent function. The standard deviation of the site-dependent ground motion prediction model can be significantly reduced. The nonlinear behavior of ground soil is automatically taken into account in the intensity-level dependent bias function. Both the PGA and the spectral acceleration are studied in this study. Based on the RTD data, event correctors are calculated and applied to precisely estimate the shakemap for disaster earthquake.

INTRODUCTION

The Seismicity in Taiwan area is very high; the government supported an extensive seismic instrumentation program, which operated by the Central Weather Bureau (CWB) for the populated areas with dense digital strong-motion networks. This instrumentation program consists two networks around Taiwan: (1) The Taiwan Rapid Earthquake Information Release System (TREIRS, also known as the Real-Time Digital stream output system, RTD), and, (2) The Taiwan Strong Motion Instrumentation Program (TSMIP). The RTD system using a real-time strong-motion accelerograph network consisting more than 80 stations is currently capable of routine broadcasting of the earthquake location and its magnitude about one minute after the occurrence (Wu *et al.*, 2002). The TSMIP system, consisting of more than 700 stations that are spaced approximately 5 km apart in populated areas, was widely deployed in Taiwan area.

The networks of RTD and TSMIP collect a large amount of high quality earthquake data and provide useful information for seismology and earthquake engineering. The wealth strong motion data

recorded at wide range of PGA due to different levels of excitation. These ground motion data offer a good opportunity to study attenuation models and the site amplification effects for a given site in response to different levels of excitation. There are several site classification schemes used in engineering practices. However, the information for site classification may be not widely available for strong motion station sites. An effective site-dependent attenuation model should be provided for better estimate of ground motions.

The seismic hazard analysis is usually to develop rock outcrop or hard soil site ground motion for seismic design and earthquake loss estimation. One of the main factors that affect the seismic risk is the existence of site effects on the attenuation relations, which are probabilistic descriptions of the level of ground motion as a function of the earthquake and site parameters. In order to make a good estimate of ground motion, many parameters are taken into consideration for attenuation relations. Many researchers proposed several attenuation relations for different source regions and site classifications (Campbell, 1981; Abrahamson and Shedlock, 1997). In these attenuation relationships there is a degree of scatter about the median value calculated by the attenuation form. An important issue is to find some measurable parameters or functions that can help to reduce the uncertainty (and/or bias) in the attenuation laws, which can be used in seismic hazard analysis and earthquake loss estimations to account for site effects.

Completing a three-phase research project performed by Southern California Earthquake Center, the phase-III report pointed out some aspects about the ground-motion and the site effects (Field *et al.*, 2000): (1) in a single earthquake the ground shaking at one site can easily be 10 times stronger than that at a neighboring site; (2) there are two important geologic factors, the softness of the rock or soil near the surface as well as the thickness of the sediments above hard bedrock, can significantly affect the level of ground shaking. A site- and intensity-level- dependent ground motion prediction model (attenuation form) is proposed in this paper. This model can be used to improve the results for seismic hazard analysis.

However, for an individual earthquake, the intensity predicted by the attenuation model may not be adequate. It is easy to find that the pattern of shaking varies from earthquake to earthquake, especially for some basin areas. This discrepancy may be come from the source effects. It is believe that a theoretical 3-D model should be developed to precisely solve this problem. Instead of such model, an empirical procedure is developed to correct the discrepancy of the ground shaking estimated from the attenuation form. The RTD system is capable of routine broadcasting of the earthquake location and its magnitude about one minute after the earthquake occurred. The ground shaking information of the RTD site can also be automatically distributed in the same time. In this study, the RTD data are used event correctors and the ground shake-map is modified for earthquake emergency response providers.

PROPOSED EMPIRICAL PROCEDURE TO ESTIMATE SHAKEMAP

An empirical procedure was setup to provide a high-resolution shakemap in a near-real-time manner for earthquake emergency response. This procedure combines site-dependent ground motion prediction models and the limited observations of the Real-Time Digital stream output system (RTD system). The flowchart, as shown in figure 1, shows the procedure to estimate the shakemap. Three considerations are described as followings:

1. Reference Attenuation Form: the ground motion attenuation form for rock site is estimated in the first step. This attenuation form is used as the reference model (artificial reference site) to

study the site effect.

2. Site Corrector: the second step is to estimate the site-dependent ground-motion prediction model for each CWB site. Based on residue analysis, the site effect modification function is generated to modify the attenuation obtained from step 1.
3. Event Corrector: when an earthquake occurred the earthquake parameters (magnitude and hypocenter) can be determined by the CWB RTD system within one minute. The ground-motion prediction models will, then, be applied to generate the shakemap that can take the site effects into consideration. In general, however, there still exists a bias in the shakemap for individual earthquake. This bias may be contributed from the event characteristics, and be corrected by the observations from the CWB RTD array data.

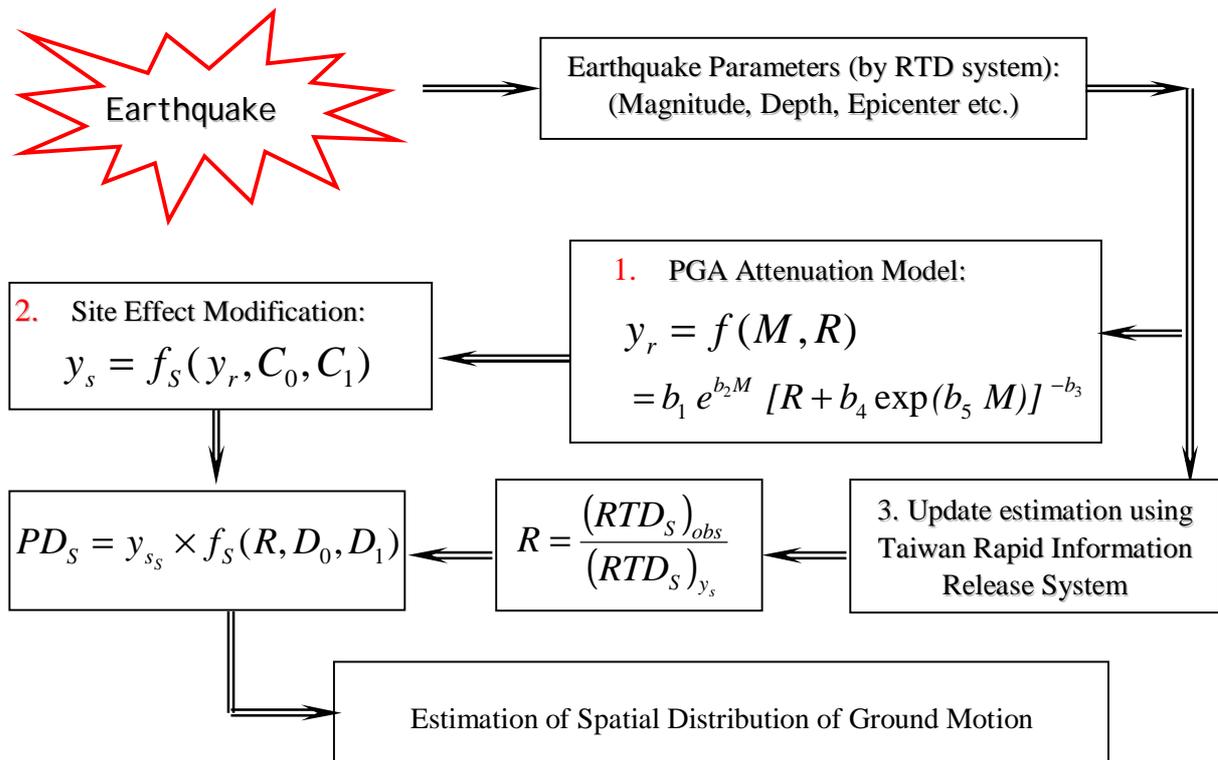


Fig. 1. Procedure to estimate the shakemap of a disaster earthquake for emergency response

Earthquake Database

One of the purposes of this paper is to investigate the classification criterion of local site effects and its influence in the seismic risk estimation. Earthquake data collected from RTD and TSMIP system were used in the first two steps to develop the rock-site empirical attenuation form and to study the site amplification factors. The database collects 242 events of magnitude $M_L \geq 4.0$ from 1993 to 2002. Fifty-nine events of magnitude $M_L \geq 5.0$ are used to develop the rock-site attenuation form. Considering the distribution of hypo-central distance, only the RTD data and the TSMIP data that with distance less than 25.0 km was used in step 1. On the step two, the whole database was used to estimate the site effects for each instrumental site. The 1999 Taiwan earthquake main-shock and its aftershock are also included in the database.

Attenuation Model For Rock Site

The attenuation relations are probabilistic descriptions of the level of ground motion as a function of the earthquake and site parameters. The Campbell's attenuation form (Campbell, 1981) can reasonably predict the characterization of ground motion attenuation for TSMIP array data, and is applied in this study. The Campbell's form is expressed as

$$Y_r (g) = f (M, R) = b_1 e^{b_2 M} [R + b_4 \exp(b_5 M)]^{-b_3} \quad (1)$$

where Y_r is peak ground acceleration (or the spectral acceleration), M is magnitude, and R is source-site distance. The significant feature of the Campbell form is the term, $b_4 e^{b_5 M}$, which describes a magnitude dependence of the transition from near-field to far-field attenuation and it reflects a distance saturation that depends on the extent of fault rupture. The source-site distance R for the present study is taken as the hypocenter distance, however, for the earthquake data collected from 1999 Taiwan earthquake the closest distances to the surface fault rupture were used.

Site Effects

Based on the attenuation law, site effects are discussed in terms of a bias function that is site and intensity-level dependent function. The non-linear behavior of ground soil is automatically taken into account in the intensity-level dependent bias function. More than 3000 seismic records from more than 242 earthquake events are used to study the site effects.

A systematic bias of the data scattering in the attenuation law is found from the earthquake data. It is believed that the systematic bias mainly comes from the site effects. It is necessary to reduce the data scattering in the attenuation law by removing the systematic bias. For this purpose, a residual is defined as the difference between the observed and predicted values of the natural logarithm of PGA (or other ground motion parameters). Comparison on the PGA and Sa-value between observed data and those calculated from the reference attenuation form (Eq. 1) is constructed. An example of this comparison is shown in Figure 2; it shows that this site has large amplification effect (for PGA the amplification factor is about 3.0). For the case that the data points fall onto the dashed line, it means that the reference attenuation form can predict well for this site (no significant site effects).

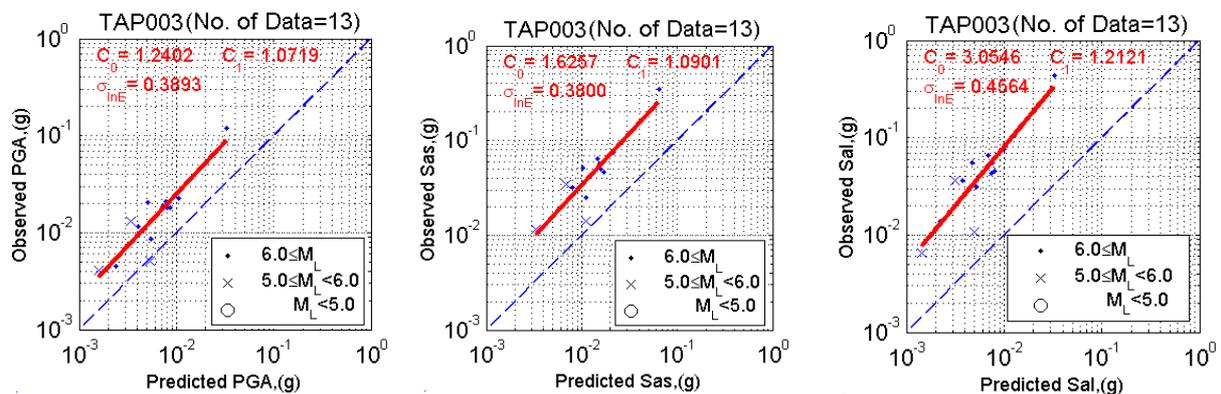


Fig. 2: Comparison between the predicted and observed PGA, and Spectral acceleration to indicate the site amplification

Based on the intensity dependent residual model, a modified intensity prediction model is found for each site. A regression form is determined for each site

$$Y_s(\textit{estimated}) = f_s(Y_r, C_0, C_1) = \exp[C_0 + C_1 \cdot \ln Y_r(M, R)] \quad (2)$$

where $Y_r(M, R)$ is obtained from equation (1), and then the site amplification factor can be calculated from the above equation. These models (Eq. 2) are used in seismic hazard analysis to account for site effects.

Event Correctors

The RTD system is capable of calculating the earthquake location and its magnitude about one minute after the earthquake occurred. The ground shaking information of the RTD site can also be automatically distributed in the same time. A predicted shakemap can then be generated from Eq. (2) to take site amplifications into consideration. Comparing the difference between the observed ground-motion and that predicted by Eq. (2), an event corrector (indicated in Figure 1) is used to modify the predicted shakemap to complete the early estimation of shakemap for earthquake emergency response providers.

CASE STUDY

Taipei City is the capital of Taiwan and it is located on a sediment-filled basin. The area experienced several damaging earthquakes, the most recent of which occurred on March 31, 2002. Even the earthquake located more than 80-100 km away; a large earthquake can still cause severe damage in Taipei basin. In this study, Taipei basin was taken for case study. The ML7.3 1999 Taiwan earthquake caused severe damage in central region of Taiwan. Many buildings totally collapsed. The damaged buildings' locations are indicated in Fig. 3 and compared with the early estimated shakemap. The shakemap estimated by this study and that directly observed from the TSMIP, which could be collected more than one week later and is too late for emergency response, are in good agreement in the ground motion intensity as well as the pattern.

CONCLUSIONS

The hybrid procedure, which combines site-dependent ground motion prediction models and the limited observations of the Real-Time Digital stream output system (RTD system operated by CWB), was setup to provide a high-resolution shakemap in a near-real-time manner. The site-dependent ground-motion prediction models are setup and ready for use. If a disaster earthquake occurred, the earthquake magnitude and its location can be determined within one minute. A predicted shakemap will be calculated by Eq. (2). Comparing the difference between the observed ground-motion and that predicted by Eq. (2), an event corrector is, then, used to modify the predicted shakemap to complete the early estimation of shakemap. Testing with many observations of large earthquakes, it is concluded that this empirical procedure is able to provide very good estimation of shakemap in a near-real-time manner for earthquake emergency response providers.

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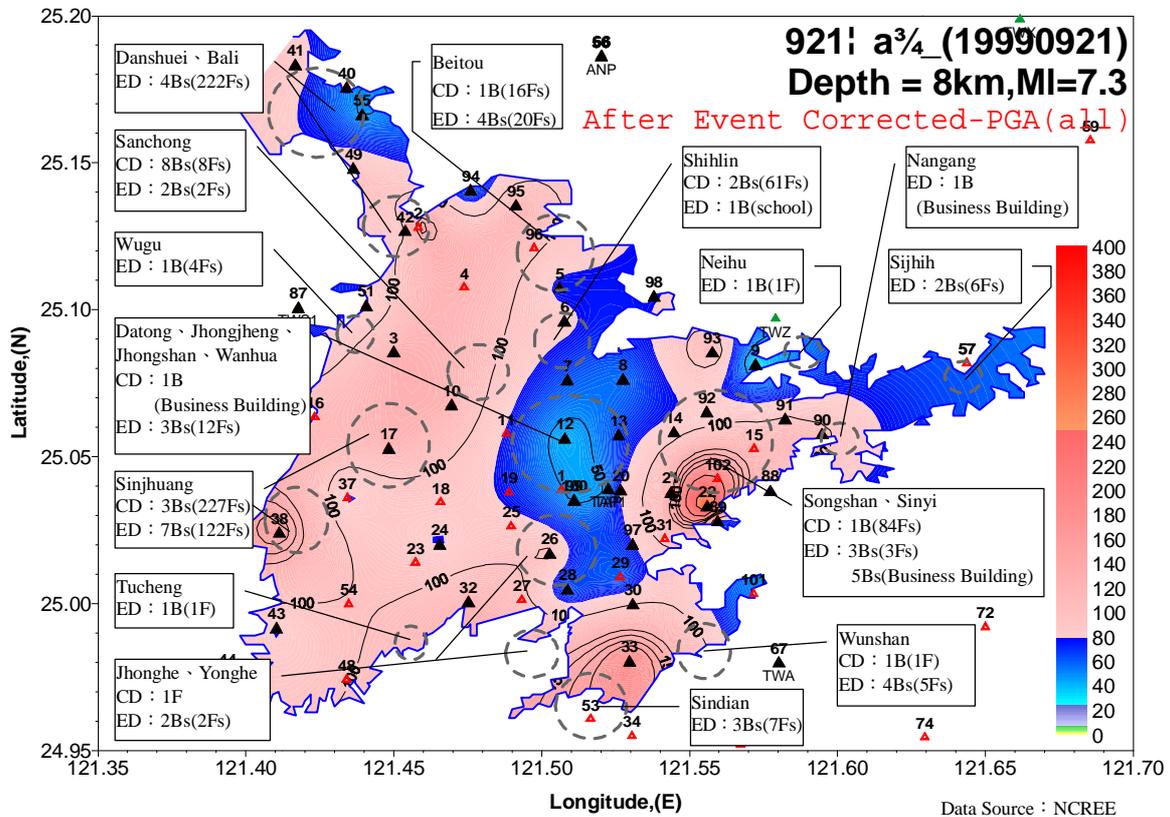


Fig. 3. Comparison of estimated shakemap (PGA) and the distribution of damage statistics in Taipei basin for 1999 Taiwan earthquake

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