# Strong Ground Motion Estimation System in NCREE

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**ABSTRACT :**

Although disaster earthquakes may not happen everyday, governments of many countries need one decision support system for managing emergency response during such events. To support such a system, Center for Research on Earthquake Engineering (NCREE) is now developing a Strong Ground Motion Estimation System. This system is designed to work with the Taiwan Earthquake Loss Estimation System (TELES) which developed by NCREE, and wish to become the prototype system for Taiwan.
The Strong Ground Motion Estimation System need to get the some waveform data immediately after earthquake happen, and begin to compute the focal mechanism and to solve the earthquake rupture patterns within 30~60 minutes after earthquake. For those not monitoring remote regions and countries, this system still can fetch seismograms from global seismic network via internet after 30~60 minutes and to solve the focal mechanism and earthquake rupture patterns for additional 60 minutes. After this earthquake source resolving process, many computation techniques can be applied to make synthetic seismograms for the earthquake affected regions. Local site responses can be corrected if the site information is available. The PGA, SA contour maps can be produced for checking soil liquefactions and landslides. The response spectrums can be also produced for quickly checking the status of bridges and structures.

**KEYWORDS:** Strong Ground Motion Estimation

## 1. INTRODUCTION

In NCREE, we are going to build a "Strong Ground Motion Estimation System" for the purpose of supporting hazard mitigation, refining building codes, and obtaining better seismic-resistant designs.

Many methods are included in this system. First is setting up seismic network to monitor micro earthquakes to understand current source rupture patterns of active faults. Second is developing computation codes to deal with the near fault ground motion. Third is to study the site effects Four major methods are used in this category. Fourth is monitoring the concentration of soil Radon which is one of the earthquake precursors. Fifth is solving the earthquake rupture patterns. Final is to combine all these as a "Strong Ground Motion Estimation System". The system framework is shown as Fig.1. This proposed system can be further work with TELES (Taiwan Earthquake Loss Estimation System) which is a major project by NCREE. In the future this will be a very important tool for central and local governments.

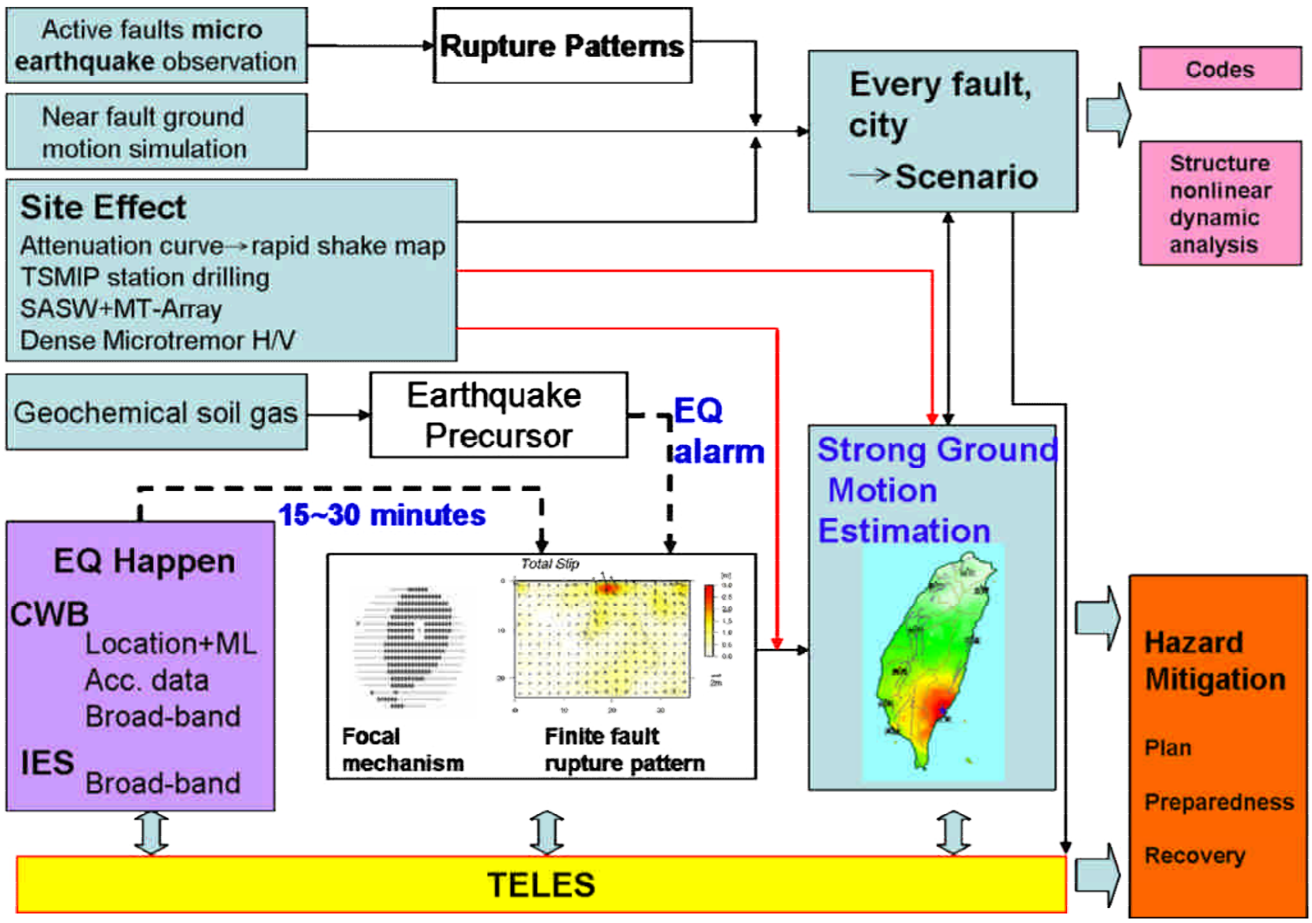


Figure 1 Framework of Strong Motion Estimation System

## 2.Micro Earthquake Monitoring Networks

Roughly about 90% people live in the western part of Taiwan. In this region, at least 30 active faults were identified. Most of them are located in the western foothill region. To fully understand the possible rupture pattern of a future disaster earthquake which related to active faults, the current source rupture patterns had to be studied. The best tool to achieve such task is to set up dense micro-earthquake monitoring networks. So far, two micro-earthquake monitoring networks was setup in Hsinchu-Miaoli area and in Tainan-Chiayi area. Another seismic network will be deployed before the end of 2008 to cover the Taichung-Nanto area. It is believed that if these micro-earthquakes have been studied carefully, some important insight about the seismic zone can be obtained. Many micro-earthquakes were observed. The number is 2~3 times than CWB S13 network. For the northern network, most of them are in the Sanyi-Puli seismic zone, the Shih-Tan fault, and in the foothill regions. For the southern network, the earthquakes are strongly related to the Chuko fault.

## 3.SITE EFFECT

In NCREE, there are several researches related to site effect. They are: (1) Using the TSMIP (Taiwan Strong Motion Instrumentation Program) data to get local amplification factors for each TSMIP acceleration station. This is useful to quickly estimate the shake-map after a strong earthquake happen. (2) Study the geological condition of TSMIP stations by drilling. The geological descriptions and STP-N values are obtained. The seismic Vp and Vs velocity profiles are obtained by PS suspension logging method. (3) Obtain deeper Vs velocity profile by using micro-tremor array method. (4) Perform micro-tremor measurements for a large area to study the site effects.

### *3.1 GEOTECHNICAL DATABASE*

To make the most use of TSMIP data, the clear site condition are indispensable. NCREE collaborate with CWB to drill each TSMIP station after the 1999 921 Earthquake. There are three major items in the Geotechnical Database in Taiwan. The first item is the general information of the station site, including latitude and longitude of the station site, ground water level, geographical/topographical conditions, and surrounding structures. The second item is the physical properties of soils. The SPT-N value, water content, unit weight, soil classification, and grain size distribution are obtained by on-site boring, sampling, and laboratory testing. After the borehole was drilled, the suspension P-S logging technique was used to measure the wave velocity of the stratum in depth for every 0.5 m. The wave velocity of the stratum is an important index
for site classification, so it is selected as the third item in the database. If the geological condition of the station site is classified to the rock outcrop, only the general environmental investigation was performed to collect the basic information of the station site.

This project has been conducted for eight years. Till now, the site investigations at 295 station sites were completed, including 60 stations in 2000, 65 stations in 2001, 50 stations in 2002, 54 stations in 2003, 37 stations in 2004, and 29 stations in 2005. The stations are located on the alluvial deposit, gravel or even rock sites. All the results are summarized on a web page.

Most studies of site effect for earthquake ground motion are based on the soil properties in the upper 30 m. In the 1997 UBC and 1997 NEHRP provisions in the USA, the average of the shear wave velocity for the top 30 m of soils is used as an index for the site classification. In the site classification of Taiwan free-field strong-motion stations, the site conditions are classified as class B (rock), class C (soft rock or very dense soil), class D (stiff soil), and class E (soft soil) according to the geological age, rock type, and the average of SPT-N values for the upper 30 m of the stratum. With detailed subsurface soil profile and quantitative soil properties (SPT-N values and wave velocities) on a station site, the site effect of ground motions could be thoughtfully analyzed for a certain class of site conditions. Engineers may evaluate appropriate peak ground acceleration for the earthquake-resistant design of structures.

### *3.2 Dense Microtremor Measurements*

For the last five years, we have measured more than 4000 microtremor data in Taiwan. The measured regions include most populated cities and plains where people live. The average spacing for these data is roughly 2 kilometers for most plains; 1 kilometers for Ilan plain; 700 meters for Taipei and Kaohsiung cities. For some special regions such as Science Parks, the microtremor measurements will be very dense.

The science parks of Taiwan have become the centers for catering many different types of industries and produced 16% GDP of Taiwan. But for these locations, earthquakes caused by active faults will be a potential threat due to Taiwan's tectonic activities. To possibly reduce possibly the losses during the shaking of strong earthquakes, it is therefore necessary to a have a sound and reliable hazard mitigation plan. So far, such a plan is not completely conceived because of lack in some critical and relevant factors. In this project, two factors are aimed to be produced for that purpose. First, is to estimate the status of active faults near these Science parks. Second, is to measure the site effect on these Science parks.

Up to now, we have performed dense microtremor measurements for most Science Parks. The measurement is very dense spatially wherein the average distance between every two measurements is about 150~200 meters inside the science parks, and about 300~400 meters in the surrounding area. The microtremor data has been processed using the spectrum H/V ratio method. For example, the dominant frequency map of the Taichung

Science Parks can be identified. The Taichung Science Park is located at the east flank of Dadu mountain. From the dominant frequency map, it is concluded that the thickness of top loose sediment layer is thickening along the west to east direction. This phenomenon is consistent with the nearby topography.

Microtremor, also called as earth noise, is the summation of many seismic signals which caused by various sources including the nature and man-made vibration energy. The vibration sources include, for example, biology activities, traffic, wind, ocean tides and etc. Short period microtremor is consisting of Rayleigh waves induced by local traffic vibrations from many directions. The major advantage of microtremor survey is the less cost, fast, convenient, and easy to analyze. The microtremor data is very easy to obtain than the traditional strong ground motion data which require installing acceleration seismometers for many years. Microtremor survey is very efficient, especially in the urban area where the seismic reflection survey and drilling wells are not easy to be done.

Using microtremor data to study the underground geological structures, Professor Kanai (1962) of Tokyo University did a lot pioneer works. One of his conclusions is that the amplitudes of certain period waves exist in the alluvium or weathered sediment sites are larger than those at rock sites. This is because the multiple reflections and resonance of seismic signals in the sediment layers. After that, Kanai and Tanaka (1962) discuss the relation between predominant period and geological layer structures using the distribution curves of seismic wave periods. Katz (1976) did similar research using power spectrums of microtremor. Microtremor can be applied for different purposes, such as investigation on structure vibrations, characteristics of geological structures, site selection for important facilities, sediment thickness, velocity structures of sediments, amplification effect of soft soils.

Usually the most used method in studying the effect of site response or the amplification effect of soft soil layer is the two station spectrum ratio method (Borcherdt , 1970; Chávez-Gracía et al., 1990; Field et al., 1992) which is a simple and effective way to eliminate the source and propagating path effects for the regions with many earthquakes happen in the vicinity (Lermo and Chávez-García, 1993; Field and Jacob, 1995; Bonilla et al., 1997; Riepl et al., 1998). The critical point for using two-station spectrum ratio method is that a good reference site can be identified with respect to the soil site which will be studied. Usually the reference site is the site on the outcrop of bedrock which is not too far away from the soil site, therefore the spectrum ratio can really eliminate the source and path effects for the strong motion data from the same earthquake. However it is really difficult to find a good reference site, and this limit the use of this method. To overcome the difficulty in searching a good reference site, Nakamura(1989) proposed an empirical single station horizontal/vertical spectrum ratio (H/V Ratio) method which utilizing the micotremor data measured on site to study the site effect. In the beginning, the H/V ratio method is applied in studying site response for using microtremor data. After that, Lermo and Chávez-Gracía(1993) applied the same technique to strong motion data of Mexico and suggested similar site response results were obtained from S wave of strong motion data and microtremor data for four Mexican cities.

Field *et* al.(1990) pointed out that microtremor data can be used in site response and micro-zonation studies. Lermo and Chávez-Gracía(1994) analyzed the weak motion, strong motion, and microtremor data of Mexico city, and found the microtremor data can be used in estimating the predominant frequency and amplification factor of sediment layers. Most microtremor researches confirm that the dominant frequency of soft sediments can be perfectly identified using Nakamura H/V ratio method. Nakano *et al*. (2000) shown a detail dominant frequency distribution map which is created using 341 microtremor measurements, strong ground motion data and local geology, and proposed for future seismic micro-zonation and seismic design standards.

### *3.3 Velocity Profile Measurement using Micro-Tremor Array Method*

As mentioned above, usually the drilling of TSMIP station will stop at 30 meters in depth. However, the western coastal plain are much thick than 100 meters. Therefore deeper Vs profiles are required for sometimes. In NCREE, we use Micro-Tremor Array Method to estimate the Vs velocity profile in such condition. The field setup of the micro-tremor array method utilizes ten seismometers which were arranged in an array with three concentric circles of maximum radius of 32 or 64 m. In each circle, three recorders were arranged in an angle of 120 degree. Each concentric circle has a radius in an order of 2. The total time for measurement at one station must be at least one hour. After the frequency-wave number analysis of data, a dispersion curve for the site will be obtained. By using an inversion process of the genetic algorithm search method, the velocity structure can be obtained as depicted in Fig. 2. The result of CHY015 shows small difference between different methods. So far, NCREE have performed Micro-Tremor Array Method for more than 130 TSMIP stations.

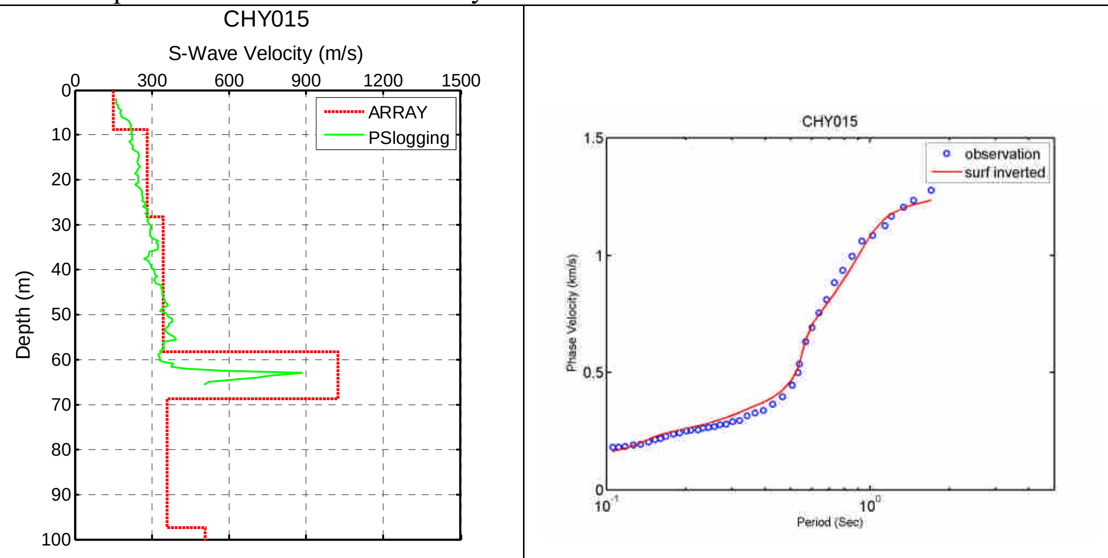


Fig. 2 The shear velocity profiles comparison of suspension P-S logger (green) vs. Micro-Tremor array method (red). The measured dispersion curve of CHY015 using Micro-Tremor array method.

## 4. Determine Source Rupture Pattern

Before we can estimate the strong ground motion of an earthquake, the detail source rupture pattern is needed. There are many methods can be used to obtain such information, we use the generalized ray method to generate the tele-seismic P-wave waveforms, and wave-number integration method to generate the local seismograms (usually integrated from the acceleration data). The multi station waveforms will be fitted by a Genetic Algorithm search method. The best searched result is described as many subevents which have its own locations, magnitude, time delays and source time functions. This information is useful for estimating strong ground motions.

## 5. Ground Motion Estimation

Recently the computer technology has tremendous progress, some complicated and difficult tasks which can not be done ten years ago are now affordable for individual researcher by using PC-clusters. In this study, we use wave-number integration method to compute the synthetic seismograms. We will briefly discuss the source, propagation path effect, velocity mode.

Since 1950s, Thomson (1950) used the matrix method to deal with the wave propagation in 1-D layered media, and Haskell (1953) promoted it into computing seismic wave propagation, the modern seismology step into its fast growing stage. Nowadays seismologists are very familiar with the synthetic seismograms computation method for 1-D layer model. Wave-number integration is one of these methods. The advantage of this method is that many type waves, such as body wave and surface waves can be calculated simultaneously, and it can deal with the elastic and inelastic attenuation properties of media. Comparing with other 3-D wave propagation techniques, wave-number integration method needs very few memory spaces and can generate high frequency seismic signals but fail to deal with the scattered waves. But when we wish to know the near-field seismic vibrations from a moderate to big earthquake, the source (rupture fault plane) become a plane source instead of a point source. Under such situation, the synthetic seismograms computed using wave-number integration are all right to use because the seismograms are now sensitive to source rupture patterns instead of scattered waves. The disaster regions are very close to the epicenter, therefore the wave-number integration method with the plane source is a proper way to study the strong ground motion patterns. To generate high frequency seismic signals from a plane source, the fault plane need to be divided into many subfaults and thus the finite subfault area will have shorter source time functions which mean the high frequency seismic signals.

In some cases, we will do the strong ground motion numerical simulations in the following manner. First of all, we will construct the rupture plane using the source parameters published by Harvard University and USGS.

Second of all, the rupture fault plane will be divided into many subfaults. The size of each subfault is 1km by 1km.. Third of all, the source rupture parameters will be set as follow. The earthquake depth will be different for different scenarios. When the earthquake began to rupture, the rupture front will propagate outward using roughly 0.85Vs and the maximum fault displacement will be decreased exponentially outward from the earthquake focus. The rupture velocity, source time function, slip length, slip direction, the initial rupture time for each subfault will be randomly changed slighly.

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