A Procedure to Select Earthquake Time Histories for Deterministic Seismic Hazard Analysis from the Next Generation Attenuation (NGA) database

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Abstract: In performance-based seismic design, ground-motion time histories are needed for analyzing dynamic responses of nonlinear structural systems. However, the number of strong-motion data at design level is often limited. In order to analyze seismic performance of structures, ground-motion time histories need to be either selected from recorded strong-motion database, or numerically simulated using stochastic approaches. In this paper. a detailed procedure to select proper acceleration time histories from the Next Generation Attenuation (NGA) database for several cities in Taiwan is presented. Target response spectra are initially determined based on a local ground motion prediction equation under representative deterministic seismic hazard analyses. Then several suites of ground motions are selected for these cities using the Design Ground Motion Library (DGML), a recently proposed interactive ground-motion selection tool. The selected time histories are representatives of the regional seismic hazard, and should be beneficial to earthquake studies when comprehensive seismic hazard assessments and site investigations are yet available. Note that this method is also applicable to site-specific motion selections with the target spectra near the ground surface considering the site effect.

Keywords: Ground motion selection, Seismic hazard analysis, NGA database, DGML tool

1 Introduction

In performance-based earthquake engineering, ground-motion time histories are usually needed for analyzing the distribution of dynamic responses of nonlinear systems, such as site response or structural analysis. In such an analysis, it is one of the key aspects to use appropriate acceleration time histories, which should realistically reflect regional seismology and site conditions.

Understandably, the selected time histories should reasonably respond to seismic hazards at a given site. For example, a recent technical guideline implemented by the U.S. Nuclear Regulatory Commission (USNRC, 2007) prescribed the probabilistic seismic hazard analysis (PSHA) as the underlying approach to generate time histories for future earthquake-resistant designs. Many studies have highlighted the importance of matching a target response spectrum in the ground-motion selection and modification process (e.g., Bommer and Acevedo, 2004). The target spectrum can be obtained by deterministic seismic hazard analysis (DSHA), probabilistic seismic hazard analysis (PSHA) or seismic design codes. A classic example is SIMQKE, which generates synthetic time histories to match a target response spectrum with an iterative process using Gaussian random process and a time-varying modulating function (Gasparini and Vanmarcke, 1976).

Recently, some scholars studied that a well-selected ground motion suite should match not only the target mean, but also the variation of the target spectrum (Jayaram et al., 2011; Wang, 2011). In other words, a suite of ground motions should be selected in performance-based earthquake engineering; the resulting ground motion suite should properly capture the statistical distribution of ground motions under the given earthquake scenario, which is commonly specified by means, standard deviations, and inherent correlations (e.g., Baker and Jayaram, 2008; Wang and Du, 2012) of a target spectrum. There are several ground motion selection algorithms available in the literature (Baker, 2010; Jayaram et al., 2011; Wang, 2011). One of the recently proposed interactive tools is the Design Ground Motion Library (DGML), which allows for selecting a suite of modified ground motions (multiple by scale factors) on the basis of response spectral shape, as well as the characteristics of the recordings such as magnitude, distances, faulting types and site conditions (Wang et al., 2015).

This paper aims at presenting a detailed procedure in selecting ground-motion time histories for major cities of Taiwan using the DGML interactive tool. With deterministic seismic hazard analysis for these cities, several suites of time histories are selected from the Pacific Earthquake Engineering Research Center's Next Generation Attenuation (NGA) strong-motion database (Chiou et al., 2008). Those selected motion suites are appropriate for general seismic designs, e.g., dynamic analysis of structures in these cities.

2 Deterministic Seismic Hazard Analyses (DSHA) for Major Cities in Taiwan

2.1 Overview of DSHA

Seismic hazard analysis is an approach to describe the potential shaking intensity for future earthquakes, which can be estimated by deterministic or probabilistic approaches. The deterministic approach estimates the intensity measure amplitude (e.g., peak ground acceleration PGA as 0.2 g) under an assigned earthquake scenario, while the probabilistic approach estimates the annual rate of exceeding specific level of earthquake shaking at a site (e.g., PGA=0.2 g corresponding to 10% probability of exceedance in 50 years).

Compared to the complicated probabilistic approach, DSHA is an analysis accounting for a worst-case scenario in terms of earthquake size and location. Specifically, DSHA utilizes the maximum magnitude and shortest source-to-site distance to evaluate the ground motion intensities under such a worse-case scenario. The basic steps are listed as follows: (1) Identify all possible fault sources of earthquakes around a given site; (2) Define the maximum magnitude and closest distance for each fault; (3) Compute the ground motion intensities based on attenuation relationships; (4) Take the maximum intensity amplitudes as the final DSHA estimate. Figure 1 shows a schematic diagram illustrating the framework and the algorithm for DSHA. Seismic source models, the maximum earthquake of each source, and ground motion prediction equations (GMPEs) are key inputs for DSHA. The detailed source models and GMPEs used in this study would be introduced in this following subsection.

2.2 Seismic source model and ground-motion model

Figures 2 and 3 show the up-to-date seismic source models for Taiwan (Cheng et al., 2007), which have also been used in a few seismic hazard studies by several authors (Cheng et al., 2007). It includes 20 area sources, in addition to 49 line sources associated with each active fault on this island. Table 1 summarizes the best-estimated maximum magnitude for each source from the literature (Cheng et al., 2007). With those best estimates, the response spectra for major cities in Taiwan are also presented in this section with DSHA calculations.

Ground motion prediction equations (GMPEs) are commonly used to predict ground motion intensities (e.g., PGA) as a function of earthquake magnitude, source-to-site distance, site parameters, etc. A few regional GMPEs models have been developed based on local strong-motion data in Taiwan (Cheng et al., 2007; Lin et al., 2011). Specifically, the recent GMPE developed by Lin et al. (2011) is capable of predicting PGA and response spectra for periods ranging from 0.01 s to 5 s, and therefore it is adopted in this study, to develop the target response spectra for selecting earthquake time histories.

The function form of the adopted model (Lin et al. 2011) is expressed as follows:

$$\ln Y = c_1 + c_2 M_w + c_3 \ln(R + c_4 e^{c_5 M_w}) \qquad \sigma_{\ln Y} = \sigma^* \tag{1}$$

where Y denotes PGA or spectral accelerations in unit of g; M_w refers to moment magnitude; R is the rupture distance (closest distance from the rupture surface to site) in *km*; c_1 to c_5 are regressed coefficients. The model's coefficients are summarized in Table 2, and $\sigma_{\ln Y}$ denotes the model's standard deviation. It is noted that this model was developed using around 5,000 earthquake records, 98% of which are taken from Taiwan. Therefore, the attenuation model should provide more realistic ground motion estimates in Taiwan (Lin et al., 2011), making it appropriate to construct the target response spectra.

It is also worth noting that we only employ the local ground motion model in this study. It is understood that logic-tree analyses can be used to quantity the so-called epistemic uncertainty in PSHA. But as studied by some scholars (e.g., Krinitzsky, 2003), the weights in logic-tree analyses cannot be scientifically verified. Therefore, this study used one local model available as the best estimate. When new local models are developed, the update of seismic hazards or sensitivity analyses will be worth conducting in future.

2.3 DSHA-based response spectra for major cities in Taiwan

The aforementioned DSHA procedures can be performed for major cities in Taiwan, with the adopted seismic source models (Figures 2 and 3) and attenuation relationship introduced in previous subsections. Six major cities are chosen for such calculations, and coordinates of the study cities (i.e., the city's geographical centers) are summarized in Table 3. For each site or city, the worse-case scenario was firstly identified, and then the corresponding response spectrum was determined by using the adopted local GMPE.

Figure 4 shows the resulting response spectra from DSHA calculations for the six considered cities in Taiwan. Table 3 also summarizes the controlling seismic source for each site. For example, the DSHA seismic hazard at the center of Taipei is governed by Area Source C. In other words, the Area Source C, rather than the other line sources or active faults, contributes to the deterministic seismic hazard for the center of Taipei. The same situation is occurring to other cities with an area source being the controlling source. This is expected, since the DSHA seismic hazard from an area source could be commonly higher than a line source due to the relatively closer source-to-site distance.

It should be noted that the adopted local GMPE has been thoroughly compared with the globally NGA GMPEs (Abrahamson and Silva, 2008; Boore and Atkinson, 2008; Campbell and Bozorgnia, 2008; Chiou and Youngs, 2008). In general, the PGA amplitudes predicted by the adopted model is generally comparable to those of the NGA models, except that for scenarios with distances greater than 20 km the estimated PGAs of the local model attenuate faster. The steeper slope of the local attenuation curves could be due to the fact that the local crust is relatively weak, given that Taiwan is a very young orogeny (Lin et al., 2011). This implies that a design or target spectrum derived from local GMPEs is particularly necessary for selecting suitable ground-motion time histories for local engineering practice.

3 Selection of Ground-Motion Time Histories

3.1 The NGA database and Design Ground Motion Library (DGML)

The source for ground-motion selection in this study is the PEER-NGA strong motion database, which contains 3,551 three-component recordings from 173 earthquakes (Chiou et al., 2008). Various subsets of the database have been used to develop GMPE models for various ground motion intensities in earthquake engineering (e.g., Du and Wang, 2013; Foulser-Piggott and Stafford, 2012). Figure 5 shows the moment magnitude-rupture distance distribution of the ground motions in the NGA database. The aforementioned interactive tool, DGML, is used to search ground-motion time histories in the NGA database on the basis of similarity of a record's response spectrum to the target response spectrum over a use-defined range of period (Wang et al., 2015). The DGML has the broad capability of searching for ground-motion time histories in the library database on the basis of response spectral shape, characteristics of the recordings in terms of earthquake magnitude and type of faulting distance, site characteristics, duration, and presence of velocity pulses in near-fault time histories. These ground motions intensity measures have been found important in liquefaction and seismic assessment of a variety of geotechnical systems (Wang and Wei, 2016; Ye and Wang, 2016).

To select appropriate ground motions by DGML, it is requested to specify the seismological parameter bounds (e.g., range of considered M_w and distance *R*) as inputs, which can implicitly constrain the ground motion characteristics in addition to the explicit target spectrum. Given the fact that the target spectra from DSHA are a result of the maximum earthquake and the closest source-to-site distance, a relatively large magnitude bound ($5.5<M_w<8$) and a narrow distance range (0 km$<R_{rup}<30$ km) have been employed as the searching criteria, as shown in Fig. 6. Since all the six cities are located at soil sites, a V_{s30} (time-averaged shear-wave velocity down to 30 m) bound in the range of 0-450 m/s is also applied. Other causal parameters, such as the category of fault types or the range of duration parameters, are not particularly specified.

Scaling factor is another key input for selecting ground motions, but has been subjected to intense debate over the past decades. Previous researchers pointed out that improper scaling of a record can lead to bias estimates of structural responses (Luco and Bazzurro 2007). For example, if an excessive range of scale factors is applied, the selected ground motion suite might result in drastically biased distribution of the other ground-motion characteristics, such as duration, Arias intensity, that cannot be represented by the target response spectrum. Therefore, we follow the general practice of the Design Ground Motion Library (DGML) and assign a relative narrow range of scale factors (0.4-2.5) throughout the selection procedure in this study (Wang et al. 2015).

Figure 6 shows the interface of DGML while searching for properly matched time histories with target spectrum and magnitude and distance thresholds. The ranking of earthquake motions is tabulated after spectral matching process. The motions of interest can be downloaded from the list, as well as their descriptions such as fault types, earthquake magnitudes, rupture distances, durations, scaling factors, and V_{s30} values (V_{s30} is commonly employed site condition indicator). Note that DGML is also capable of performing weight-matching when a specific range of the motion's frequencies is of more interest in follow-up applications.

3.2 Time history recommendations for major cities of Taiwan

With the target spectra from DSHA calculations, the selection procedures in DGML are performed to select a suite of time histories from the NGA database for each city. The DGML search engine adopted in this study searches the NGA database for ground-motion waveforms that satisfy the general criteria (i.e. 5.5<M_w<8, 0<R_{rup}<30 km) and then ranks theses records in an order of an increasing (mean squared error) MSE. It means that the ground-motion waveform that matches the target RS best has the lowest MSE and will be ranked No. 1. To be more specific, the MSE is defined using the following equation (Wang et al. 2015):

$$\mathrm{MSE} = \frac{\sum_i w(T_i)\left\{\ln\left(Sa^{target}(T_i)\right) - \ln\left(f \times Sa^{record}(T_i)\right)\right\}^2}{\sum_i w(T_i)} \qquad (2)$$

where T_i denotes considered spectral periods, $w(T_i)$ denotes a weight function that allows for assigning weights to different period ranges so that the periods of more interest can be emphasized in the ground-motion selection process, f represents a scale factor to linearly scale the whole ground-motion time history. It should be also noted that the MSE does not vary too much in some cases. For example, as highlighted in the Figure 6, the MSE ranges from 0.023-0.035, indicating that the selected scaled ground motions are almost equally good and compatible with the target response spectrum. Therefore, in this study, we intentionally select some other ground-motion waveforms if some of them have been recommended in the other study cities. We expect, by doing so, more flexibility and options can be provided for time-history analyses in engineering practice. It should be also noted that although different ground motions are selected for various sites, they are statically consistent and compatible with the corresponding DSHA spectrum.

Figure 7 shows the selected response spectra for the six study cities. The median and median ± one standard deviation of the selected SA ordinates are also compared to the target spectrum in each plot. It can be seen that the selected ground motion suites can properly match the target spectra over a wide period range. Table 4 summarizes the time histories selected from the database. Figures 8-14 show the selected time histories for the six cities in Taiwan with seismic hazards calculated with DSHA calculations. Note that two sets of selections were given for Taipei, with and without the consideration of basin effect. It should also be noted that for each site the best-matching motions were selected regardless of local earthquakes or not, in addition to one or two best-matching local motion (i.e., the Chi-Chi earthquake). The multiple time histories in each suite are considered as a measure to account for the variability or natural randomness of ground motion characteristics under a considered scenario, which, for example, is considered as mandatory for probabilistic site response analyses prescribed in a technical reference (USNRC, 2007).

4 Discussions

4.1 DSHA versus PSHA

PSHA and DSHA are the two representative approaches in assessing earthquake hazards. Over the past decades, numerous seismic hazard studies have been conducted with the two methods (e.g., Joshi et al., 2007; Kolathayar and Sitharam, 2012; Moratto et al., 2007; Sitharam and Vipin, 2011; Stirling et al., 2011). The two methods have also been prescribed in various technical references. As mentioned previously, a technical reference (USNRC, 2007) prescribes PSHA as the underlying approach, in contrast to another guideline implemented by Department of California Transportation prescribing DSHA for bridge designs under earthquake loadings (Mualchin, 2011).

It is worth noting that extensive discussions over the pros and cons of the two methods have been reported in the literature (e.g., Bommer, 2003; Castanos and Lomnitz, 2002; Krinitzsky, 2003; Klugel, 2008). In general, DSHA is a simple approach that earthquake scenarios are considered logically understandably, but the uncertainties in DSHA may not be well quantified. On the other hand, PSHA is capable of quantifying the uncertainties associated with earthquake scenarios via a probabilistic approach; however, some scholars (e.g., Krinitzsky, 2003) pointed out the shortcomings in PSHA, such as the uniform assumption in the occurrences of earthquakes. It is not this paper's purpose to argue which seismic hazard method is superior. But with all that in mind, it should come to a logical understanding that both the deterministic and probabilistic analyses are needed and useful in engineering applications. The use of the DSHA approach in this paper is mainly due to its analytical simplicity and transparency. Since it has been reported that DSHA rather than PSHA is more appropriate for design of critical structures (Bommer et al., 2000), the selected ground motion suites, with a representative seismic hazard analysis and a reputable earthquake database, are then recommended for such applications.

4.2 Site-specific time histories

This paper presents an option to select earthquake time histories from the reputable NGA database. But strictly speaking, those time history recommendations are not site-specific, because the site condition is not carefully taken into account with a comprehensive site investigations and site response analyses. In other words, the site-specific motions are those from seismic hazard analyses, to site response studies (e.g., Du and Pan, 2016).

As a result, this study refers to those time-history recommendations as "tentative site-specific," because the site effect is not comprehensively characterized with a more detailed site response analysis, but with a soil-site ground motion prediction model. Therefore, the selected ground motion time-histories could be recommended for general earthquake analytical cases, where specific site investigations are not performed. Since the recommended time-histories can reasonably reflect the local seismic hazards at these cities, they should be used as basic results and then be serviceable for common engineering practice.

4.3 Basin effect

Basin effect is another important issue to estimate the seismic hazards for sites within Taipei. From analyzing the recorded time histories around Taipei (Sokolov et al., 2009; 2010), some suggestions were made to up-scale low-frequency spectral accelerations to incorporate the basin effect in Taipei. Following this suggestion, Figure 15 shows the response spectra with/without considering basin effects for Taipei by DSHA calculations. Likewise, the time histories matching the up-scaled spectra (with basin effects) as the target are selected from the database, as summarized in Table 4.

4.4 Why local earthquake's motions are not selected for all cases?

It somewhat comes to as a surprise that the motions of the local earthquake were "out-performed" by non-local motions in matching the response spectra with local ground motion models. This might be due to two reasons. First, apart from the Chi-Chi earthquake, most events used for developing the local GMPE are not included in the NGA database. The second reason is that the employed searching process does not specify more weights or preferences to local earthquakes. As discussed previously, the search criterion are only associated with the spectral shape, as well as seismological parameters such as magnitude, distance, site condition, *etc*. The search engine searches the database and ranks the records based on a quantitative measure: the mean squared error. With this in mind, as long as the size of the database is sufficient, it is not surprising that a non-local ground motion can be found better matching the target spectra.

5 Conclusions

The paper presented the procedures to select earthquake time histories with target response spectra from deterministic seismic hazard analysis (DSHA), using the recently proposed DGML selection tool. The worst-case earthquake scenarios were first defined for six major cities in Taiwan, and the response target spectra were computed by employing a regional attenuation model under these defined scenarios. Finally, a suite of time histories are selected for each city by matching the calculated target spectra. The selected suites of time histories can properly represent the regional seismic hazards, which are then recommended and used for seismic analyses in these cities. The similar ground motion selection approaches can also be applicable to selecting appropriate time histories at bedrock layers, as input motions for a more comprehensive site investigations and site response analysis.

Given the limited understandings of the earthquake process and the randomness in nature, some scholars have pointed out the importance of analytical simplicity to earthquake studies. Among several approaches to define the target spectra, the ones from DSHA calculations are logically transparent and simple, and therefore they are adopted in this study for selecting hazard-consist time histories.

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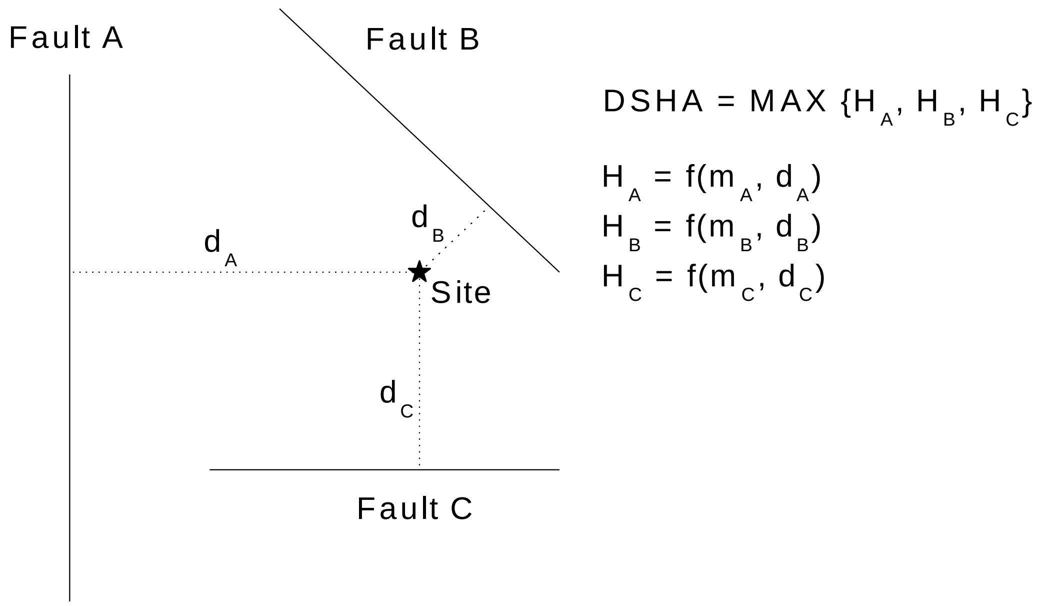

Figure 1. Schematic diagram illustrating the analytical framework of DSHA, where *H* denotes the seismic hazard induced by each source, *m* and *d* are the maximum earthquake magnitude and shortest source-to-site distance, and *f* is the function of a ground motion model

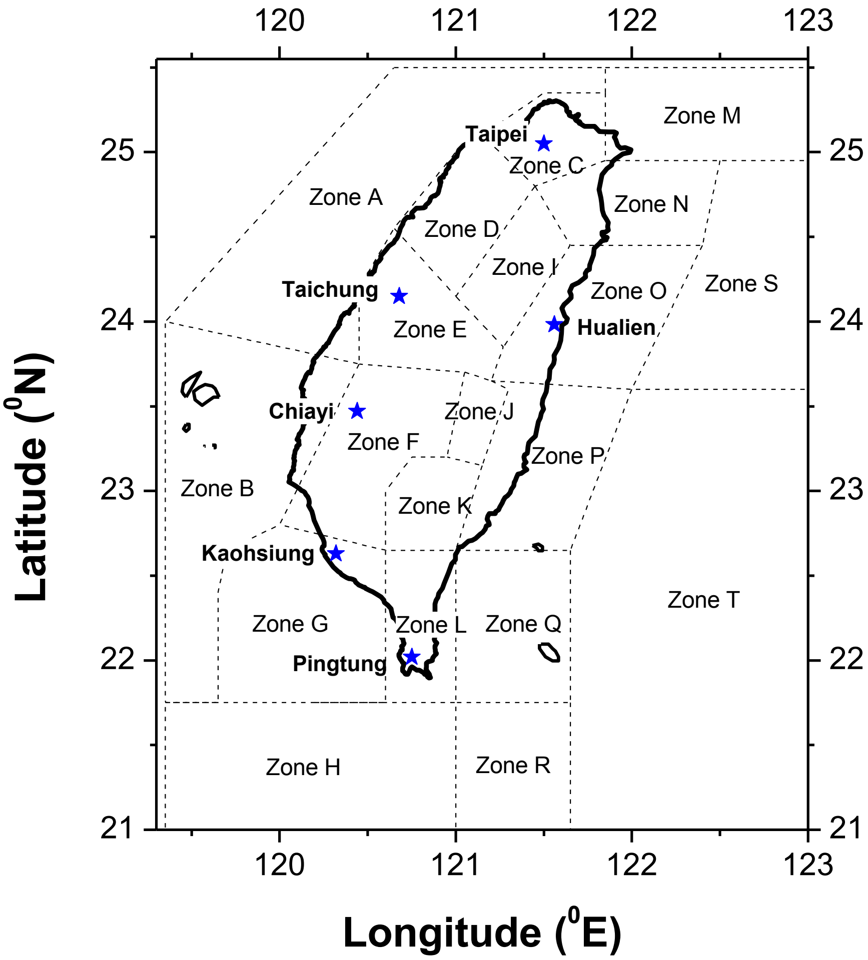

Figure 2. The area seismic source model for Taiwan (after Cheng et al., 2007)

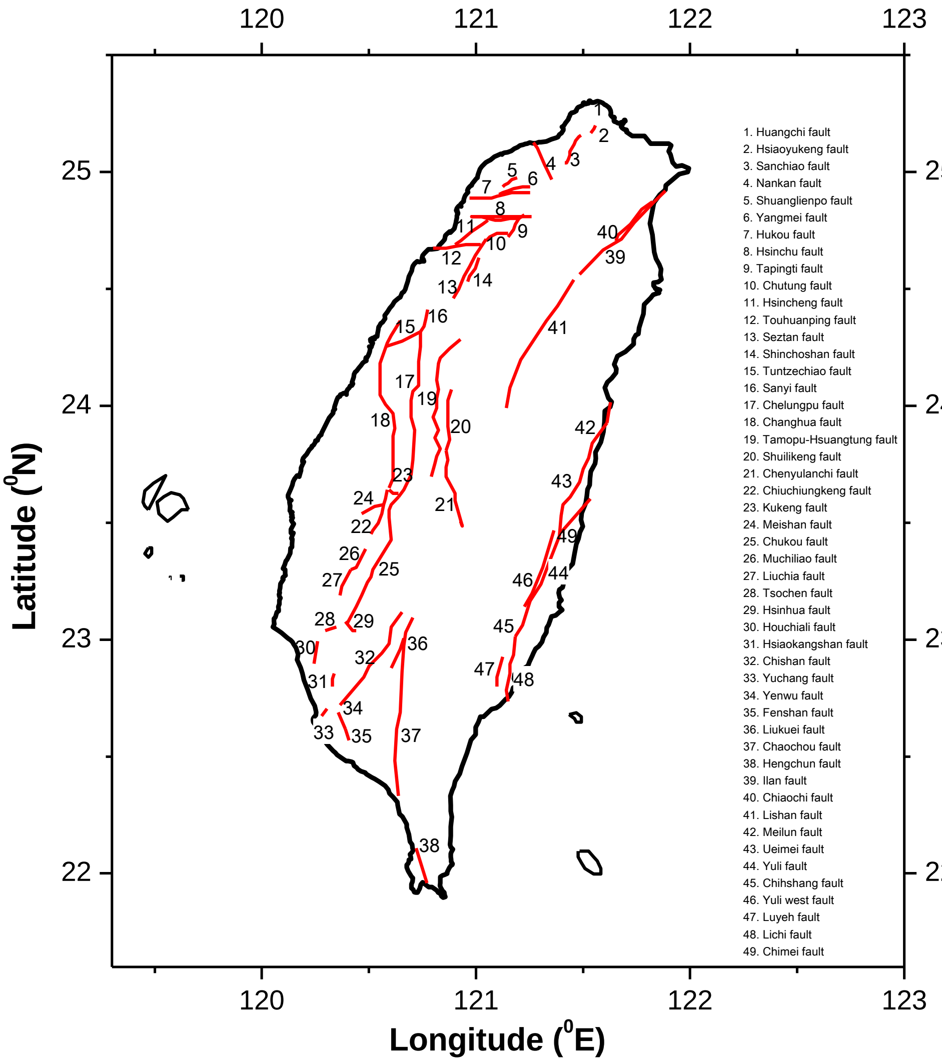

Figure 3. The line source model or the active faults in Taiwan (after Cheng et al., 2007)

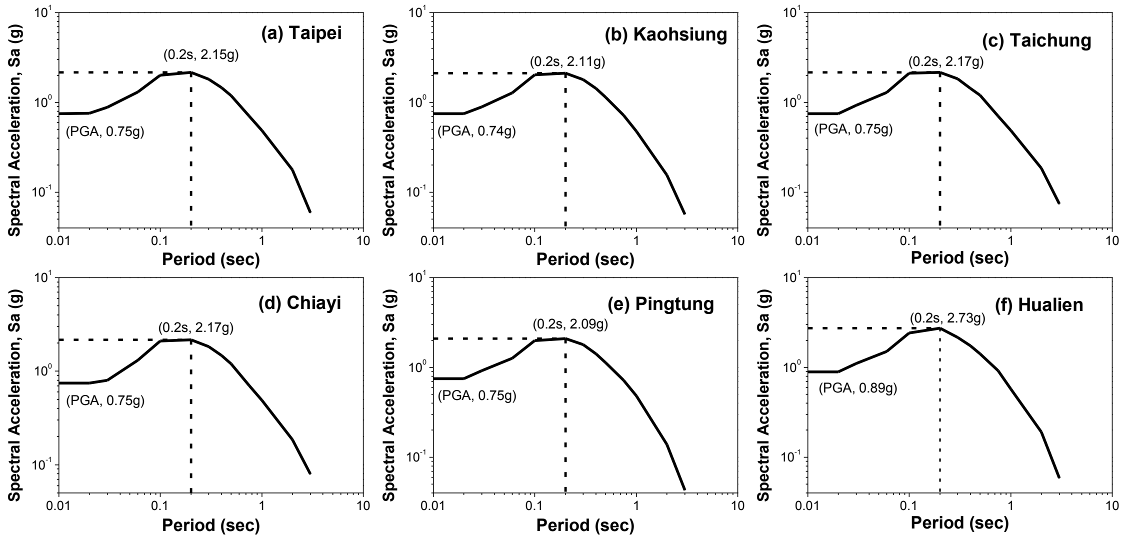

Figure 4. The response spectra for major cities in Taiwan with DSHA calculations

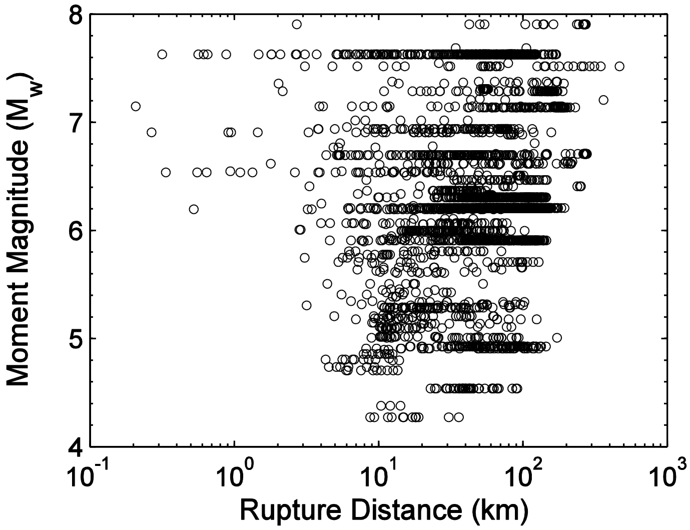

Figure 5. Moment magnitude and rupture distance distribution for PEER NGA records used in this study

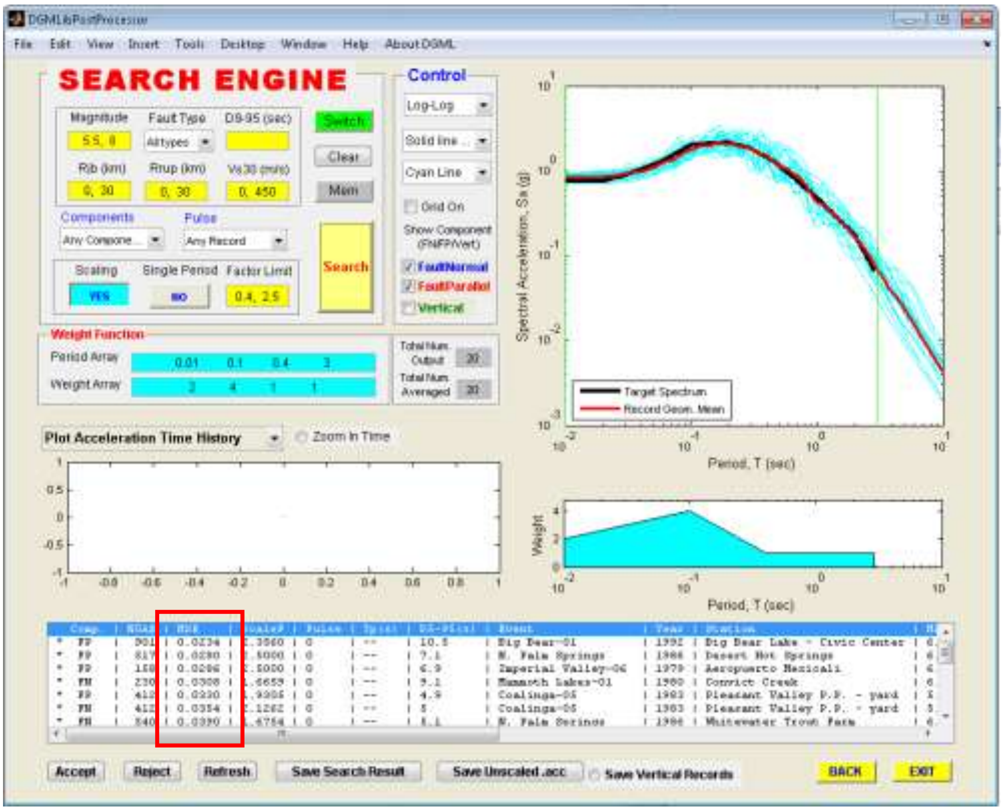

Figure 6. The screenshot of the database's interface; with searching criteria as shown in the left, the properly matching motions are tabulated (not shown), and their response spectra are plotted in a graph along with the target spectra, shown in the right

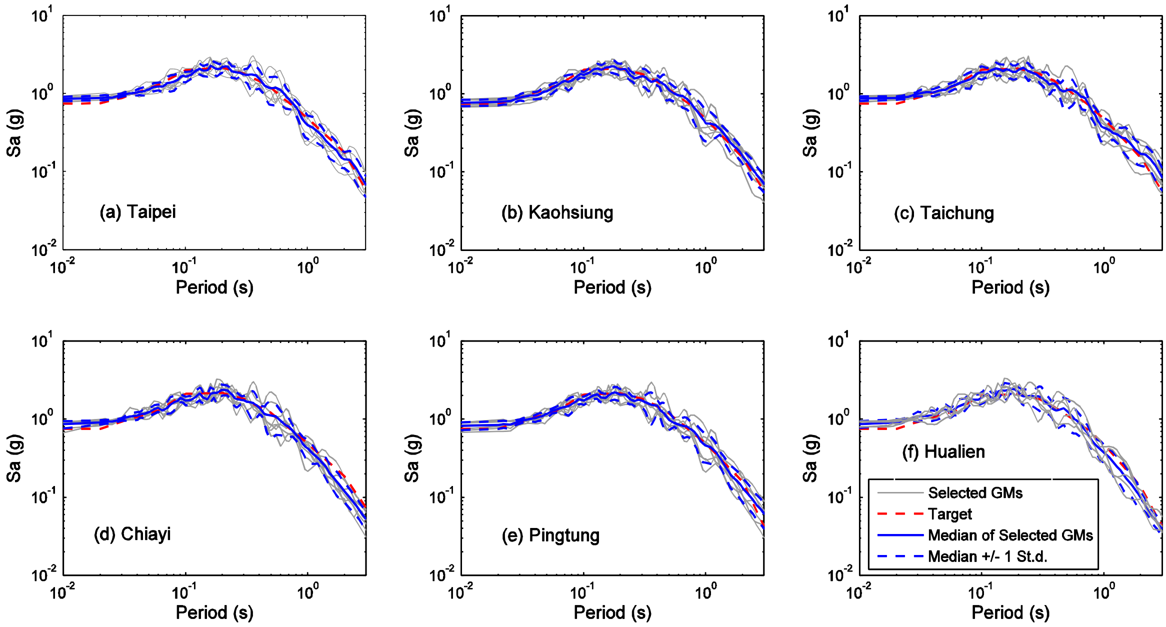

Figure 7. The target spectrum, individual and average response spectrum of selected records for six major cities in Taiwan

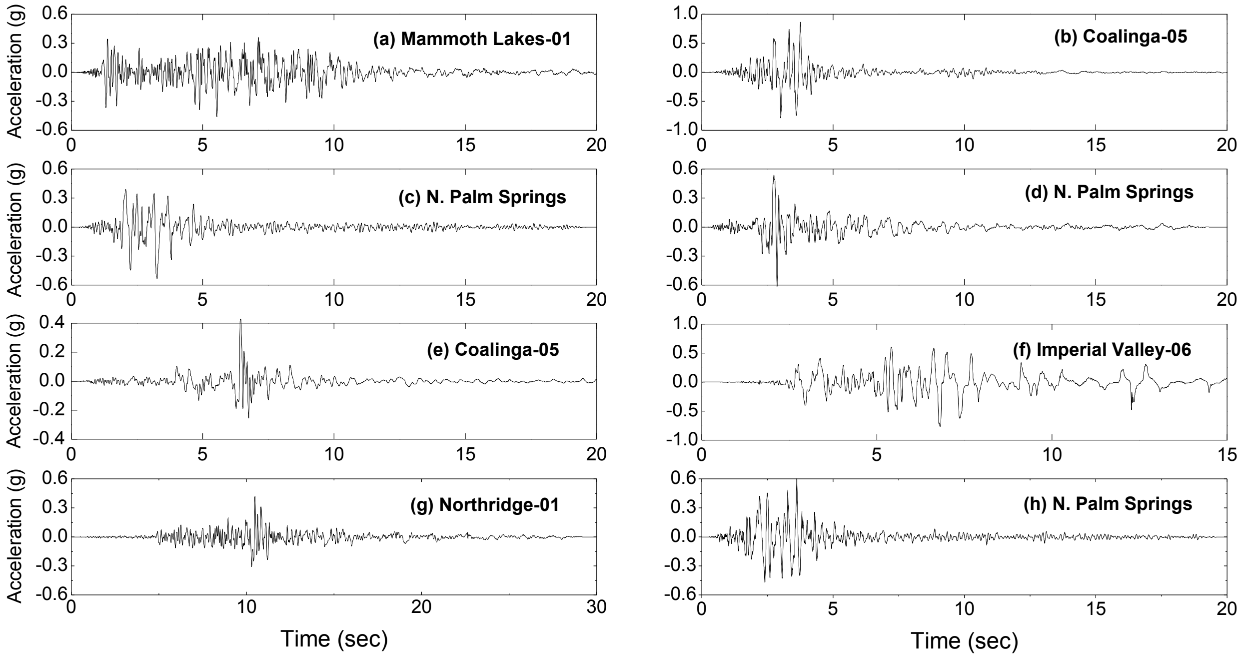

Figure 8. Eight time history recommendations for Taipei with DSHA calculations and the NGA strong-motion database

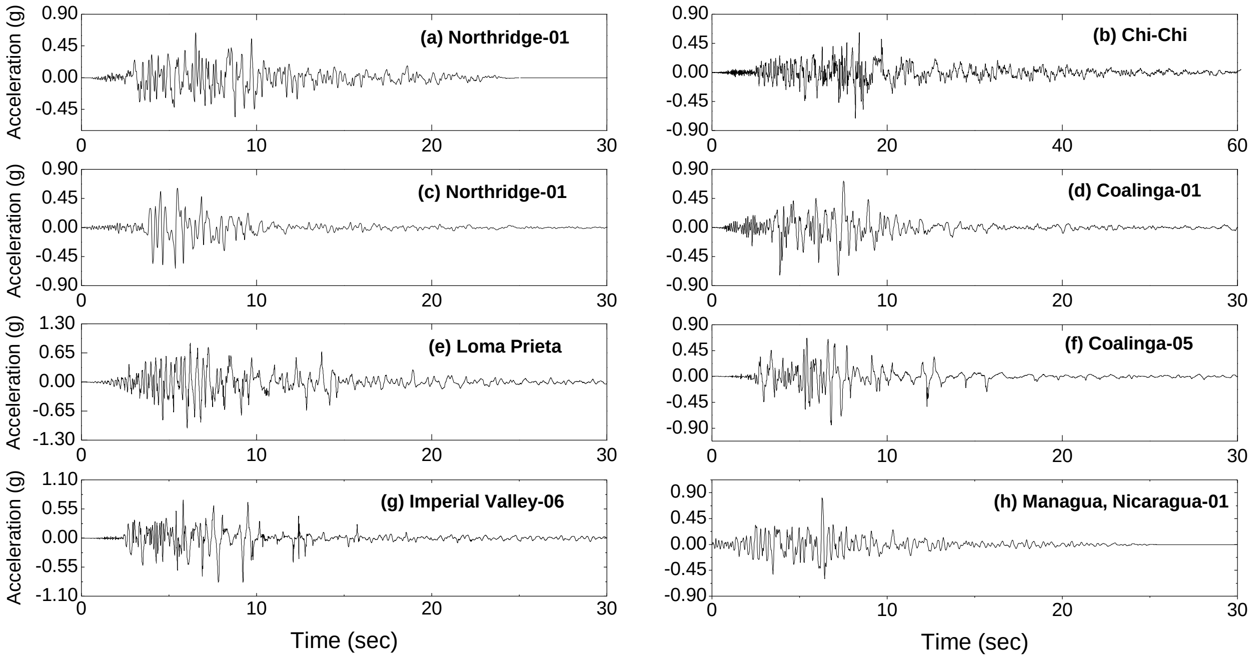

Figure 9. Another set of time history recommendations for Taipei with the basin effect taken into account

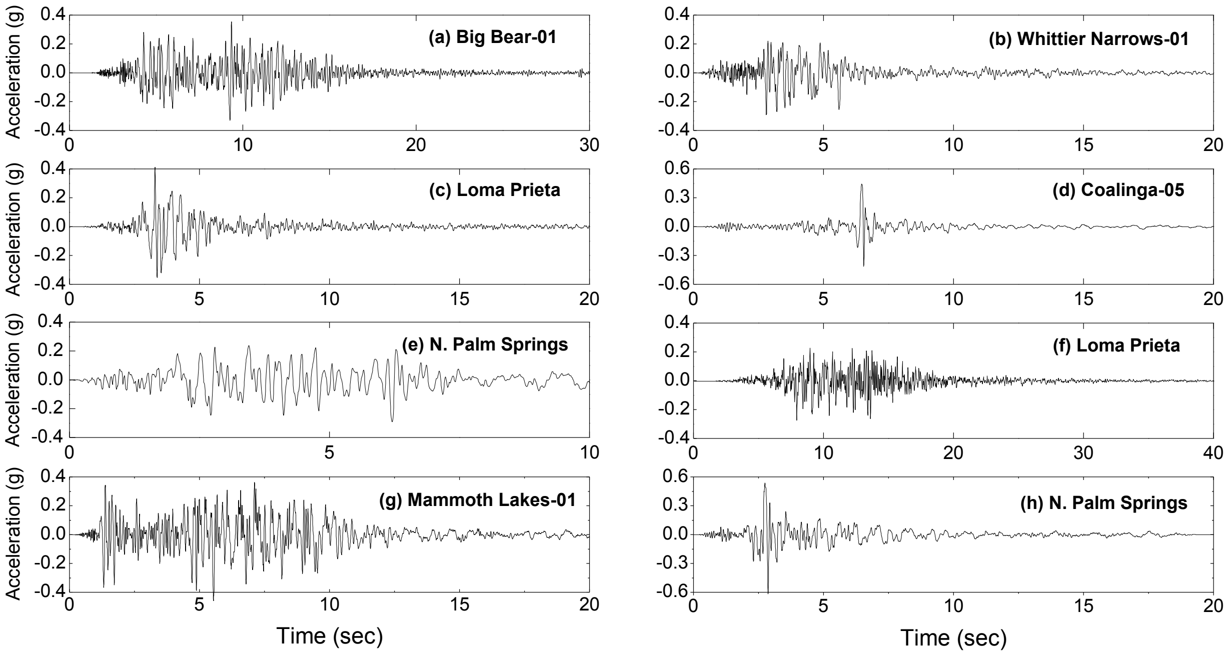

Figure 10. Eight time history recommendations for Kaohsiung with DSHA calculations and the NGA strong-motion database

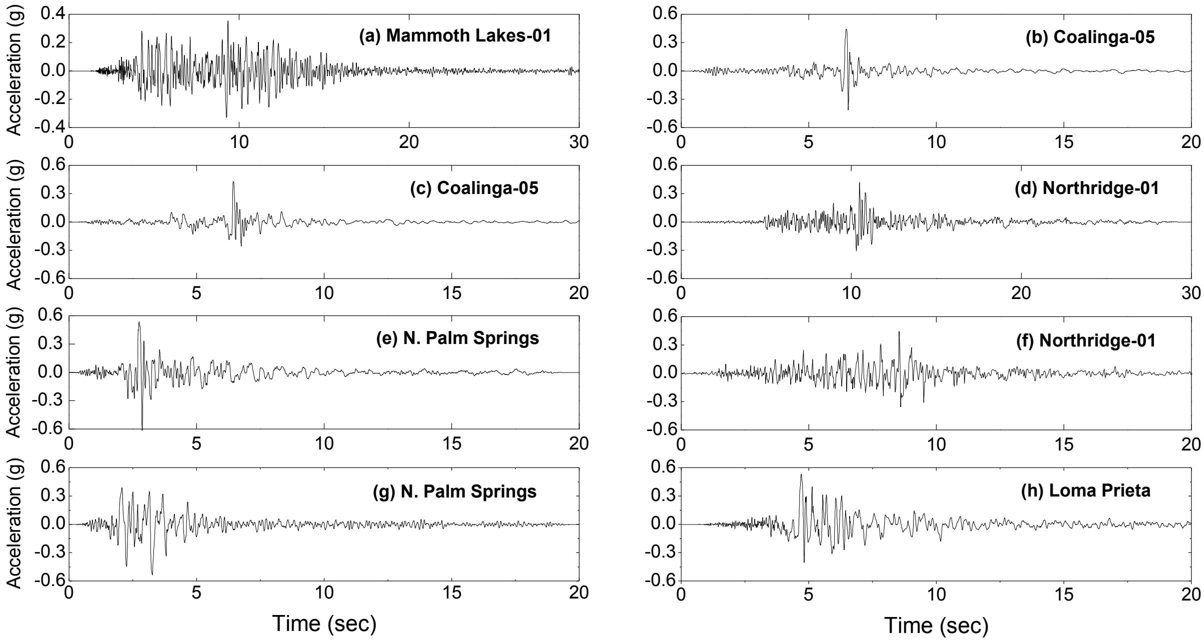

Figure 11. Eight time history recommendations for Taichung with DSHA calculations and the NGA strong-motion database

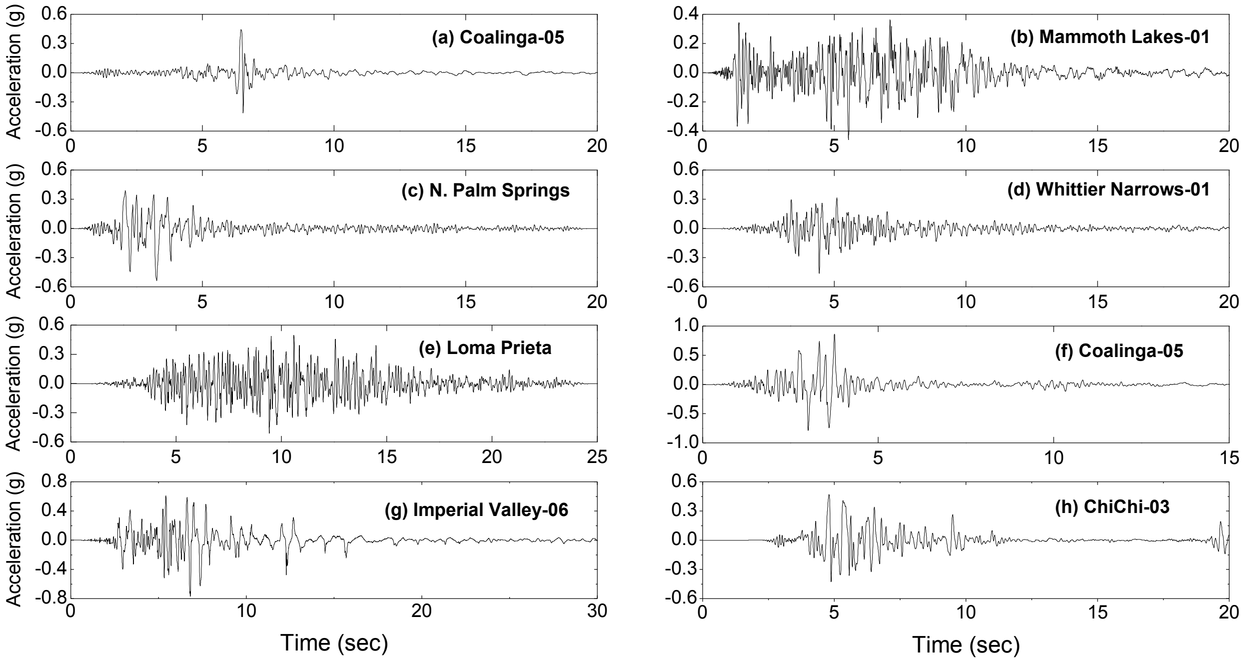

Figure 12. Eight time history recommendations for Chaiyi with DSHA calculations and the NGA strong-motion database

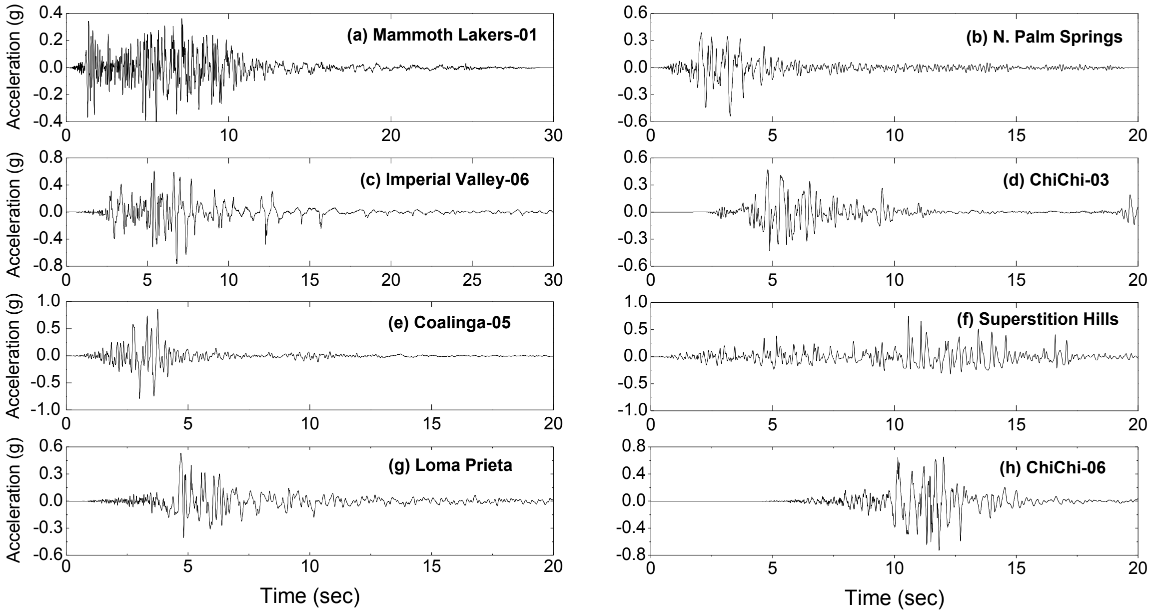

Figure 13. Eight time history recommendations for Hualien with DSHA calculations and the NGA strong-motion database

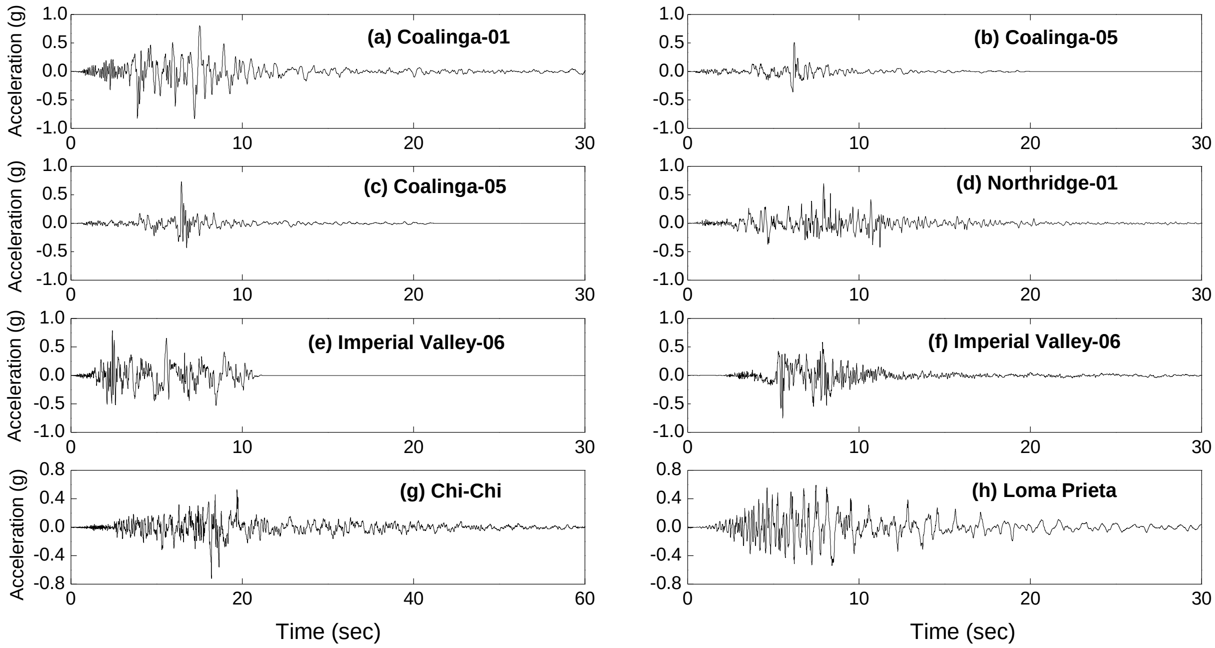

Figure 14. Eight time history recommendations for Pingtung with DSHA calculations and the NGA strong-motion database

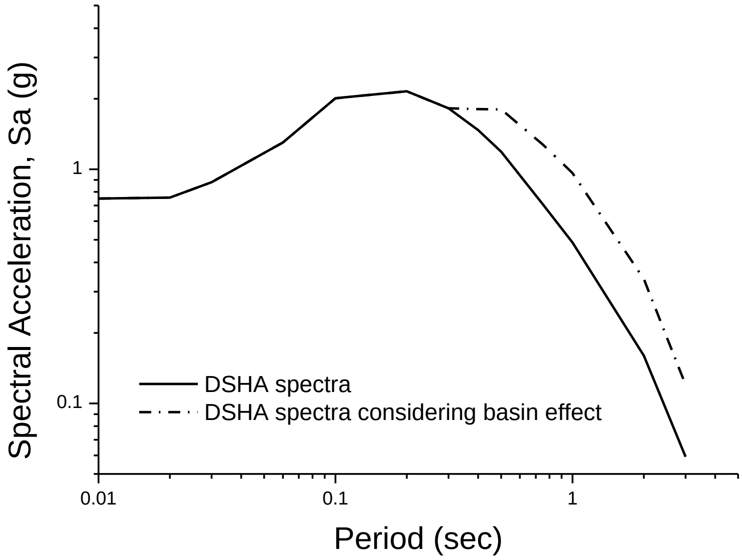

Figure 15. The basin effect in Taipei on response spectra; the spectra scaling follows the suggestions of Solokov et al. (2009, 2010)

Table 1. Summary of Maximum Earthquake Magnitudes (in M_w) of Each Seismic Source around Taiwan

Area source	Max. magnitude	Line source (active fault)	Max. magnitude	Fault Mechanism
Zone A	6.5	Huangchi	7.0	Norma & Sinistral
Zone B	6.5	Hsiaoyukeng	7.0	Norma & Sinistral
Zone C	7.1	Sanchiao	7.0	Norma & Sinistral
Zone D	7.3	Nankan	6.5	Normal & Dextral
Zone E	7.3	Shuanglienpo	6.2	Reverse
Zone F	7.3	Yangmei	6.6	Reverse
Zone G	6.5	Hukou	6.9	Thrust
Zone H	7.3	Hsinchu	6.8	Thrust
Zone I	6.5	Tapingti	6.5	Thrust
Zone J	6.5	Chutung	6.5	Reverse
Zone K	6.5	Hsincheng	6.7	Thrust
Zone L	7.3	Touhuanping	6.7	Dextral
Zone M	6.5	Seztan	6.8	Reverse
Zone N	8.0	Shinchoshan	6.5	Reverse
Zone O	8.3	Tuntzechiao	6.5	Dextral
Zone P	7.8	Sanyi	6.9	Thrust
Zone Q	7.8	Chelungpu	7.7	Thrust
Zone R	7.8	Changhua	7.6	Thrust
Zone S	8.0	Tamopu-Hsuangtung	7.4	Thrust
Zone T	7.8	Shuilikeng	7.0	Thrust

Table 1. Summary of Maximum Earthquake Magnitudes (in M_w) of Each Seismic Source around Taiwan (Continued)

Line source (active fault)	Max. magnitude	Fault Mechanism	Line source (active fault)	Max. magnitude	Fault Mechanism
Chenyulanchi	7.0	Thrust	Lishan	6.9	Normal
Chiuchiungkeng	7.0	Thrust	Meilun	7.3	Norma & Sinistral
Kukeng	6.3	Sinistral	Ueimei	7.5	Norma & Sinistral
Meishan	6.5	Dextral	Yuli	7.5	Norma & Sinistral
Chukou	7.5	Thrust	Chihshang	7.3	Norma & Sinistral
Muchiliao	7.1	Thrust	Yuli west	7.3	Norma & Sinistral
Liuchia	7.1	Thrust	Luyeh	6.9	Reverse
Tsochen	6.4	Sinistral	Lichi	7.1	Norma & Sinistral
Hsinhua	6.4	Dextral	Chimei	7.2	Norma & Sinistral
Houchiali	6.4	Thrust			
Hsiaokangshan	6.5	Reverse			
Chishan	7.3	Thrust			
Yuchang	6.4	Reverse			
Yenwu	6.7	Reverse			
Fenshan	6.7	Reverse			
Liukuei	6.7	Reverse			
Chaochou	7.3	Reverse			
Hengchun	7.2	Reverse			
Ilan	6.9	Normal			
Chiaochi	6.8	Normal			

Table 2. Summary of the Coefficients of the Local Ground Motion Models used in This Study (Lin et al. 2011)

Periods (s)	c_1	c_2	c_3	c_4	c_5	$\sigma_{\ln Y}$
PGA	-3.279	1.035	-1.651	0.152	0.623	0.651
0.01	-3.253	1.018	-1.629	0.159	0.612	0.647
0.06	-1.738	0.908	-1.769	0.327	0.502	0.702
0.09	-1.237	0.841	-1.750	0.478	0.402	0.748
0.1	-1.103	0.841	-1.765	0.455	0.417	0.750
0.2	-2.767	0.980	-1.522	0.097	0.627	0.697
0.3	-4.440	1.186	-1.438	0.027	0.823	0.685
0.4	-5.630	1.335	-1.414	0.014	0.932	0.683
0.5	-6.746	1.456	-1.365	0.006	1.057	0.678
0.6	-7.637	1.557	-1.348	0.0033	1.147	0.666
0.75	-8.641	1.653	-1.313	0.0015	1.257	0.652
1	-9.978	1.800	-1.286	0.0008	1.377	0.671
2	-12.611	2.058	-1.261	0.0005	1.497	0.706
3	-13.303	2.036	-1.234	0.0013	1.302	0.702

Table 3. Summary of the Site's Coordinates, along with Respective Controlling Seismic Sources for Each Site in DSHA Computations

City	Latitude (° N)	Longitude (° E)	Controlling source	Maximum magnitude	Closest source-to-site distance (km)
Taipei	25.05	121.50	Zone C	7.1	2
Kaohsiung	22.63	120.32	Zone G	6.5	2
Taichung	24.15	120.68	Zone E	7.3	2
Chiayi	23.47	120.44	Zone F	7.3	2
Hualien	23.98	121.56	Zone O	8.3	2
Pingtung	22.02	120.75	Zone L	7.3	2

Table 4. Summary of the Earthquake Time History Recommendations from the NGA Database with DSHA Calculations

City	Earthquake motion	Year	Magnitude	Rupture Distance (km)	Station	Fault Mechanism	$D_{5\text{-}95}$ (s)	V_{s30} (m/s)	Scale Factor
Taipei	Mammoth Lakes-01	1980	6.06	4.0	Convict Creek	N-O***	9.1	338	1.67
	Coalinga-05	1983	5.77	16.1	Pleasant Valley P.P.-FP	Reverse	5.0	257	1.93
	N. Palm Springs	1986	6.06	6.0	Whitewater Trout Farm	R-O**	5.1	345	1.67
	N. Palm Springs	1986	6.06	11.2	North Palm Springs	R-O**	5.6	345	1.48
	Coalinga-05	1983	5.77	16.1	Pleasant Valley P.P.-FN	Reverse	5.0	257	2.00
	Imperial Valley-06	1979	6.53	2.7	Bonds Corner	Reverse	9.7	223	1.05
	Northridge-01	1994	6.69	28.3	LA – Centinela St.	Reverse	13.0	235	0.98
	N. Palm Springs	1986	6.06	6.0	Whitewater Trout Farm	R-O**	5.1	345	1.52
Taipei (with basin effect)	Northridge-01	1994	6.69	14.7	Canoga Park	Reverse	11.1	268	0.50
	Chi-Chi	1999	7.62	10.0	CHY101	R-O**	29.0	259	1.16
	Northridge-01	1994	6.69	28.3	LA – Centinela St.	Reverse	13.0	235	0.98
	Coalinga-01	1983	6.36	8.4	Pleasant Valley P.P.	Reverse	8.0	257	1.32
	Loma Prieta	1989	6.93	15.2	Capitola	R-O**	14.7	289	1.50
	Coalinga-05	1983	5.77	16.1	Pleasant Valley P.P.	Reverse	5.0	257	1.22
	Imperial Valley-06	1979	6.53	2.7	Bonds Corner	Strike-Slip	9.7	223	1.35
	M. - N.* -01	1972	6.24	4.1	Managua- ESSO	Strike-Slip	9.0	289	2.00
Kaohsiung	Big Bear-01	1992	6.46	9.4	Big Bear Lake	Strike-Slip	10.5	338	2.32
	Whittier Narrows-01	1987	5.99	14.5	Garvey Res	R-O**	5.9	468	2.49
	Loma Prieta	1989	6.93	10	Gilroy-Gavilan Coll	R-O**	4.7	729	2.04
	Coalinga-05	1983	5.77	16.1	Pleasant Valley P.P.	Reverse	4.9	257	1.90
	N. Palm Springs	1986	6.06	6.8	Desert Hot Springs	R-O**	7.1	345	2.50
	Loma Prieta	1989	6.93	14.7	Santa Teresa Hills	R-O**	10	271	2.50
	Mammoth Lakes-01	1980	6.06	4	Convict Creek	N-O***	9.1	338	1.60
	N. Palm Springs	1986	6.06	11.2	North Palm Springs	R-O**	5.6	345	1.46

Table 4. Summary of the Earthquake Time History Recommendations from the NGA Database with DSHA Calculations (Continued-I)

City	Earthquake motion	Year	Magnitude	Rupture Distance (km)	Station	Fault Mechanism	D_{5-95} (s)	V_{s30} (m/s)	Scale Factor
Taichung	Mammoth Lakes-01	1980	6.06	6.6	Convict Creek	N-O**	9.1	338	1.69
	Coalinga-05	1983	5.77	16.1	Pleasant Valley P.P.-FP	Reverse	4.9	257	1.96
	Coalinga-05	1983	5.77	16.1	Pleasant Valley P.P.-FN	Reverse	5.0	257	1.99
	Northridge-01	1994	6.69	28.3	LA – Centinela St.	Reverse	11.9	235	1.99
	N. Palm Springs	1986	6.06	16.1	North Palm Springs	R-O**	5.6	345	1.51
	Northridge-01	1994	6.69	22.5	LA-UCLA	Reverse	9.4	398	2.00
	N. Palm Springs	1986	6.06	6.0	Whitewater Trout Farm	R-O**	25.8	345	1.70
	Loma Prieta***	1989	6.93	12.8	Gilroy Array #3	R-O**	7.7	349	1.63
Chiayi	Coalinga-05	1983	5.77	2.7	Pleasant Valley P.P	Reverse	4.9	257	1.92
	Mammoth Lakes-01	1980	6.06	6.6	Convict Creek	N-O**	9.1	338	1.66
	N. Palm Springs	1986	6.06	6.0	Whitewater Trout Farm	R-O**	5.1	345	1.67
	Whittier Narrows-01	1994	6.69	28.3	LA – Obregon Park	R-O**	7.8	349	2.00
	Loma Prieta	1989	6.93	17.5	WAHO	R-O**	11.1	376	1.30
	Coalinga-05***	1983	5.77	8.5	Oil City	Reverse	2.8	376	1.03
	Imperial Valley-06	1979	6.53	2.7	Bonds Corner	Reverse	9.7	223	1.04
	Chi-Chi-03	1989	6.2	7.6	TCU078	Reverse	6.7	443	1.66
Hualien	Mammoth Lakes-01	1980	6.06	6.6	Convict Creek	N-O**	9.1	338	2.01
	N. Palm Springs	1986	6.06	6.0	Whitewater Trout Farm	R-O**	5.1	345	2.00
	Imperial Valley-06	1979	6.53	2.7	Bonds Corner	Reverse	9.7	223	1.26
	Chi-Chi-03	1989	6.2	7.6	TCU078	Reverse	6.7	443	2.00
	Coalinga-05***	1983	5.77	8.5	Oil City	Reverse	2.8	376	1.24
	Superstition Hills-02	1987	6.54	5.6	Superstition Camera	Strike-Slip	12.1	362	1.53
	Loma Prieta***	1989	6.93	12.8	Gilroy Array #3	R-O**	7.7	349	1.92
	Chi-Chi-06	1989	6.3	10.1	TCU079	Reverse	4.0	443	1.28

Table 4. Summary of the Earthquake Time History Recommendations from the NGA Database with DSHA Calculations (Continued-II)

City	Earthquake motion	Year	Magnitude	Rupture Distance (km)	Station	Fault Mechanism	D_{5-95} (s)	V_{s30} (m/s)	Scale Factor
Pingtung	Imperial Valley-06	1979	6.53	0.3	Aeropuerto Mexicali	Strike-Slip	7.1	274	2.02
	Imperial Valley-06	1979	6.53	3.9	EL Centro Array #8	Strike-Slip	5.8	206	1.38
	Coalinga-01	1983	6.36	8.4	Pleasant Valley P.P.	Reverse	8.0	257	1.30
	Coalinga-05	1983	5.77	16.1	Pleasant Valley P.P.	Reverse	5.0	257	1.50
	Coalinga-05	1983	5.77	23.5	Bonds Corner	Reverse	5.0	257	1.26
	Northridge-01	1994	6.69	15.6	Tarzana-Cedar Hill A	Reverse	10.3	257	2.00
	Chi-Chi	1999	7.62	10.0	CHY101	R-O**	29.0	258	1.59
	Loma Prieta	1989	6.93	15.2	Capitola	R-O**	14.7	288	1.43

1. * M. - N. = Managua – Nicaragua
2. R-O** = Reverse – oblique
3. N-O** = Normal – oblique
4. *** refers to pulse-like record