A Study on the Spectrum Shape for Performance Based Design of Taipei Basin

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ABSTRACT :

Taipei Basin located in northern Taiwan has been experienced several damaging earthquakes in the past decades, the recent of which occurred on September 21, 1999 and March 31, 2002. Although the Taipei Basin is located more than 130 km away from the epicenter of these two earthquakes, the damage level in the area was greater than others in the northern region. According to the Taiwan seismic design code, Taipei Basin is classified as a special site and particular design spectra are prepared for the basin., Due to the geotechnical properties at the site and the source parameters of earthquake, the recorded earthquake ground motions show large variation within the basin. According to the analysis of strong ground motion data recorded by the CWB, we found that if the magnitude is larger than 6.5 and PGA > 30 gal, the basin effect will be excited significantly and the associated spectral response accelerations at medium to long periods in some area inside Taipei Basin will attenuate slowly. In this paper, the site-specific shapes of response spectrum were determined on the basis of some representative earthquake events, and then compared with the shape of design spectrum. By adjusting zone map, a new seismic micro-zone map for the area of Taipei Basin can be developed.

KEYWORDS: Seismic Design Code, Response Spectrum, Basin Effect, Spectral Shapes

1. Introduction

Studies of severe earthquakes that have occurred around the world over the last few years have shown that, in many cases, local ground motion has exacerbated the damage caused in heavily-populated cities. The Taipei Basin is located at one of the areas with lowest seismicity in Taiwan, however, due to the unique topography and geology of the basin, a pronounced magnification of the impact of seismic waves will be induced by the basin effect, and hence, far-field earthquakes from Taipei may cause major damage in the city. Therefore, particular attention must be paid to the impact of basin effect on the seismic design of buildings at Taipei Basin.

2. Development of Seismic Design Codes for Taipei Basin

In Taiwan, the seismic force requirements (SFR) for building structures followed the format of US Uniform Building Codes were first implemented in 1974. In 1982, the importance factors for various building occupancy categories were further incorporated into the SFR. After the Mexico Earthquake occurred in 1985, the importance of fundamental vibration of Taipei Basin was recognized and a specific acceleration response spectrum was incorporated into the SFR in 1989. In 1997, the SFR was undergone major changes. These changes include the dynamic analysis procedures using response spectrum method, the number of seismic zones increased from 3 to 4, the zoning factor directly represents the design peak ground acceleration associated with a hazard level of 10% chance of exceedance in 50 years (10/50 event). In addition, the force reduction factors associated with any one specific structural system follow the Newmark and Hall recommendations. Hence, the force reduction factor varies depending on the fundamental vibration periods of a given structural system.

After the occurrence of 1999 Chi-Chi Earthquake, an emergency change of building codes released three months after the event temporarily reduced the number of Taiwan seismic zones from 4 to 2. For Taipei Basin,

the zoning factor Z was defined by 0.23 g, and the value at the constant acceleration and constant velocity ranges of the normalized design spectrum were defined by C=2.5 and C=3.3/T, respectively, for whole basin. without taking into consideration the variation between different sites within the basin.
The current version, a completely new version of the SFR, was released in 2005. In this version, the mapped design spectral response acceleration parameters are determined directly based on the uniform hazard analysis considering 10% probability of exceedance in 50 years (10/50 hazard or a return period of 475 years). The 5%-damped spectral response acceleration for short periods and at 1.0 second are prescribed for each municipal unit such as village, town or city. In addition, the site-adjusted spectral response acceleration parameters for short periods and 1.0 second structures can be defined by multiplying the site coefficients to incorporate the local site effects. Then, the design spectral response acceleration can be developed on the basis of the site-adjusted spectral response acceleration parameters. Thus, it can be further used to determine the design base shear. For Taipei Basin, four seismic micro-zones are defined to reflect the observed basin effects due to the varied thickness of the sedimentary soil layers in the noted region, as shown in Figure 1. The specific value of the corner period T_0 between the short and moderate period ranges of the design response spectrum is defined for each micro-zone. Thus, applying the uniform hazard analysis, the design spectral response acceleration for structures in Taipei Basin can be determined directly from the design spectral response acceleration at short periods as well as the corner period T_0 prescribed for each micro-zone.

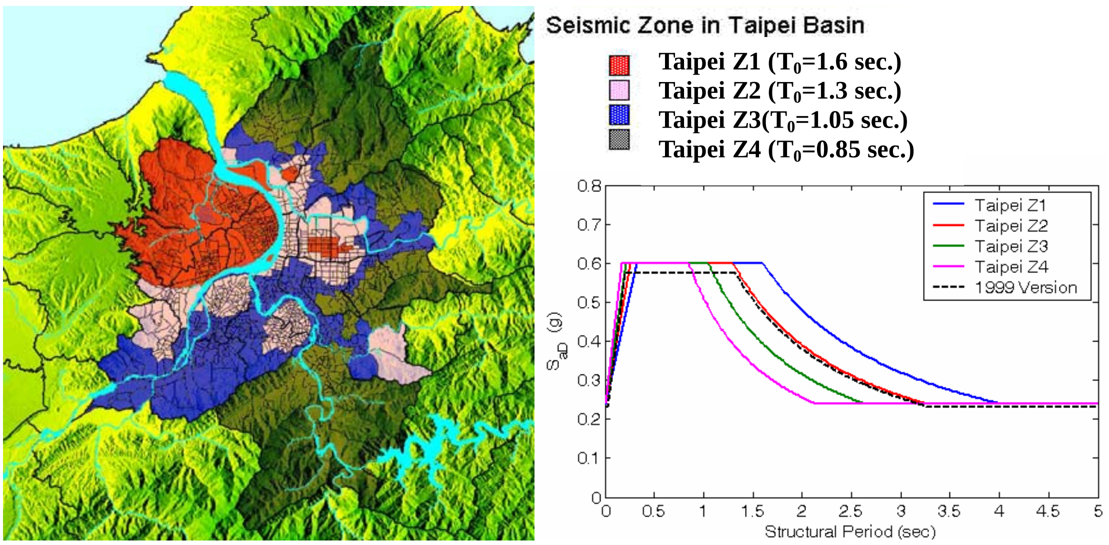


Figure 1. Distribution of the micro-zones and the design response spectrum for each micro-zone in Taipei Basin (Yeh *et al.*, 2001)

3. Earthquake Database

Most of the earthquakes that have caused significant damage in the Taipei Basin in the last few years are major earthquakes with $M_L \geq 6.8$. Consideration of design response spectra and micro-zonation should therefore be based on the major earthquakes, so that the statistical results are not distorted by minor earthquakes.

3.1. Distribution of TSMIP Stations and Earthquake Records in Taipei Basin

In 1990, the CWB began to implement the Taiwan Strong Motion Instrumentation Program (TSMIP) throughout Taiwan island, with the aim of gaining a better understanding of ground motion accompanying earthquakes, thereby reducing the amount of damage caused. Since then, around 700 free-field strong motion accelerographs have been set up in heavily populated metropolitan areas, near fault sites, and in areas with a wide range of geological characteristics. At the present day, the CWB has 67 TSMIP stations and 3

Real-time Digital (RTD) sites in Taipei Basin. The locations of observation stations within Taipei Basin are shown in Figure 2 as denoted by round dots. The current seismic design code divided Taipei Basin and the neighboring areas into four micro-zones, and the distribution of the four micro-zones is also shown in the figures. The bold line which is defined by the contour of 20m-elevation represents the boundary of the basin. The figure also shows the epicenters of earthquakes with $M_L \geq 5.0$ that occurred during the period from 1900 to July 2007. Few of these earthquakes occurred anywhere near Taipei Basin, and most of those that did were prior to 1991, before a satisfactory monitoring network was in place; as a result, there are no detailed records of earthquakes in Taipei Basin available for analysis. Since most of the earthquakes that have caused significant damage in the basin are those with epicenters far away Taipei Basin, therefore, the earthquake data induced by all of the earthquakes with $M_L \geq 6.5$ during the period from 1991 to July 2007 and recorded by the stations within Taipei Basin is adopted for the study of seismic micro-zonation.

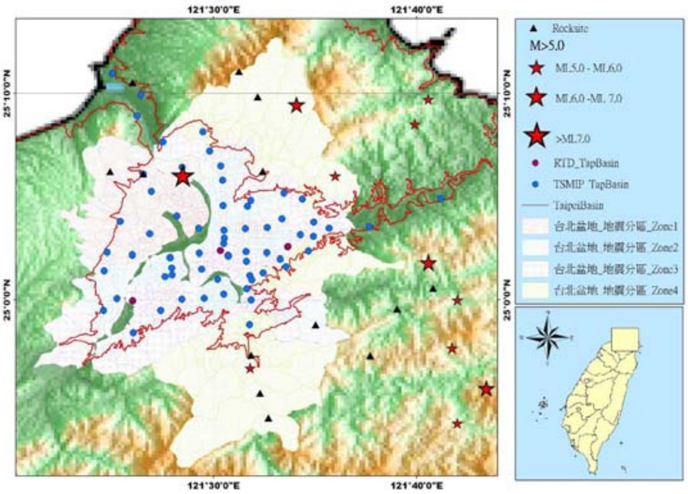
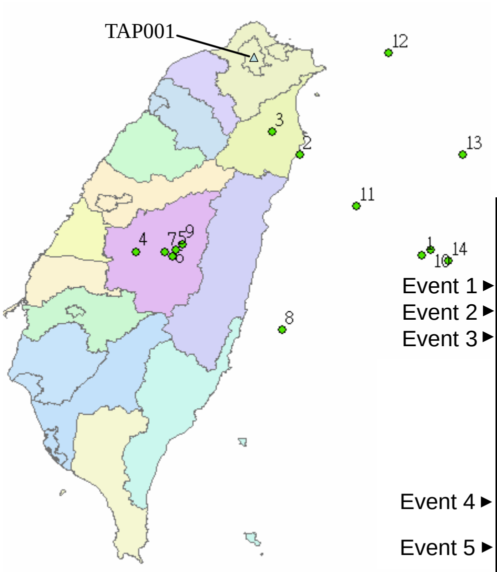


Figure 2. The distribution of CWB observation stations in Taipei Basin

3.2. Earthquake Data Selection

In this study, the earthquakes taking place since 1990 with magnitude $M_L \geq 6.5$ and for which the induced peak ground acceleration (PGA) at Taipei Basin is larger than 30 gal were selected from the CWB database, giving a total of 14 earthquake events. The distribution of the epicenters of these earthquakes is shown in Figure 3. Basic data for the earthquake events is given in the table accompanying Figure 3. The PGA value is either the east-west or north-south horizontal PGA value, whichever is larger. However, when undertaking further analysis the geo-mean of the two values is used. The two horizontal V/A values are also shown. The V/A value (the ratio of the PGV to the PGA) is normally closely related to the shape of design response spectrum; the higher the V/A value, the larger the content ratio of long-period waves, and the more pronounced the impact of basin effect. This means that, the greater the long-period spectral acceleration, the longer the corner period.

As the present study covers all of the micro-zones within Taipei Basin, it was important that there should be a sufficient quantity of records for each earthquake event. After eliminating those events for which the number of suitable records from individual observation station was inadequate, the original total of 14 events was reduced to 5 relatively large earthquake events that occurred in Taiwan in 1994, 1995, 1999, 2002 and 2004 respectively. These are the earthquakes shown in Figure 3 with a yellow background. The 1999 event was the major earthquake (the “Chi-chi Earthquake”) that occurred on September 21, 1999 (921 Earthquake); the 2002 event was the slightly less severe earthquake that occurred on March 31, 2002 (331 Earthquake); both of these earthquakes caused a significant amount of damage in the Taipei Basin. These five earthquake events were designated Events 1~5, and analysis was undertaken of their response spectrum characteristics. The distribution of the observation station for which records were available for each event is shown in Figure 4.



$M_L \geq 6.5$, PGA ≥ 30 gal

Event	Date	Magnitude	Depth (km)	Distance to TAP001(km)	Records	PGA_max (gal)	PGA_min (gal)	PGV/PGA _Max(sec)	PGV/PGA_ Max(sec)
1	05/24/1994	6.6	4.45	174.04	1	39.42	39.42	0.06	0.06
2	06/05/1994	6.5	5.3	71.828	29	97.38	32.06	0.21	0.06
3	06/25/1995	6.5	39.88	50.436	44	179.92	35.24	0.13	0.03
4	09/20/1999	7.1	8	149.53	28	138.24	42.28	0.37	0.16
5	09/20/1999	6.7	12.49	138.01	6	56.82	34.28	0.14	0.04
6	09/22/1999	6.8	15.59	142.74	3	51.68	30.32	0.11	0.07
7	09/25/1999	6.8	12.06	141.4	2	34.52	32.18	0.12	0.06
8	11/01/1999	6.9	31.33	187.56	9	54.56	31.64	0.16	0.04
9	06/14/2001	6.7	16.21	132.85	3	39.42	30.5	0.09	0.07
10	12/18/2001	6.7	12	173.81	1	37.32	37.32	0.14	0.14
11	03/31/2002	6.8	13.81	121.07	45	378.14	35.36	0.43	0.11
12	09/16/2002	6.8	175.67	88.276	1	53.96	53.96	0.08	0.08
13	10/15/2004	7.1	91.03	149.46	24	190.2	30.14	0.16	0.04
14	11/08/2004	6.58	10	187.13	4	88.46	31.28	0.12	0.03

Figure 3. The epicenters of earthquakes with $M_L \geq 6.5$ and PGA(in Taipei Basin)≥30 gal

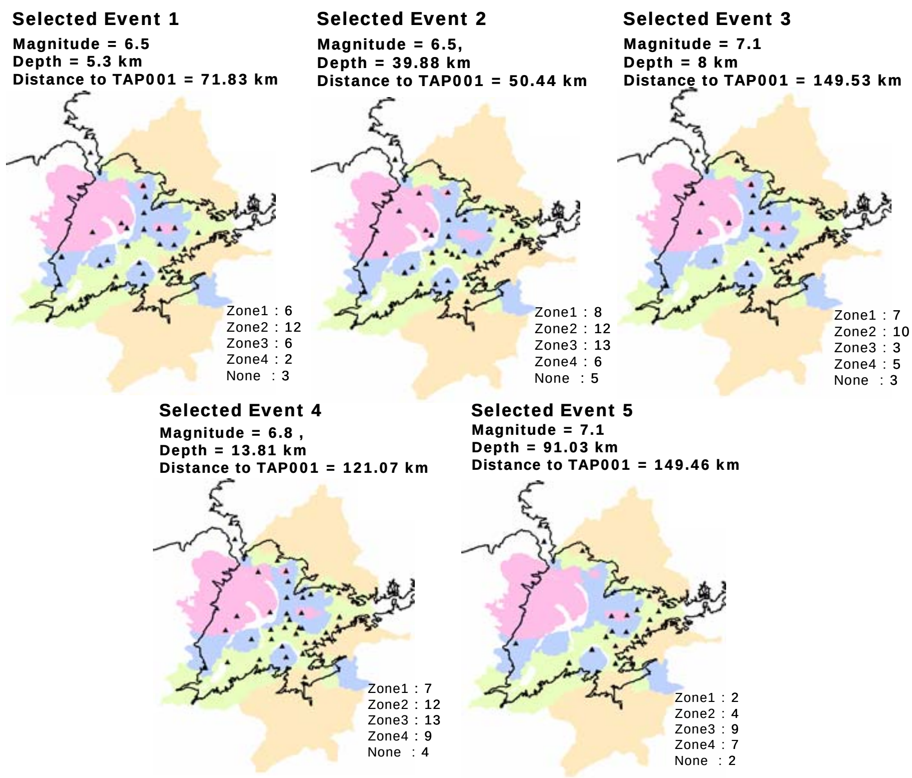


Figure 4. The distribution of the observation stations for which records were available for each selected event in Taipei Basin

4. Analysis of Corner Period of Response Spectrum

Based on the recorded data corresponding to the selected earthquake events, the associated acceleration response spectra were determined for each observation station in Taipei Basin. The results were used to evaluate whether the micro-zonation in Taipei Basin as specified by the current seismic design code can reflect the actual seismic response of Taipei Basin.

4.1. The Impact of the Earthquake Events on the Seismic Response Spectrum

Having calculated the normalized response spectra for each observation station, all the response spectra were plotted in the same figure to facilitate examination of the spectra for that site. Figure 5 presents examples of the records for four sites, one from each of the four micro-zones. The graph at top left shows the data for TAP013 (Taipei zone 1); the graph at top right shows the data for TAP020 (Taipei zone 2); the graph at bottom left shows the data for TAP032 (Taipei zone 3); the graph at bottom right shows the data for TAP094 (Taipei zone 4). From these graphs, the substantial differences between the response spectra of the different micro-zones can be seen. It can be found that the response spectra for Events 1, 2 and 5 are significantly smaller than those for Events 3(921 Earthquake) and 4(331 Earthquake); the response spectra for Events 1, 2 and 5 all fall below the average, particularly with respect to mid-period and long-period response. Events 3 and 4 both display significant mid-period and long-period response, indicating a pronounced basin effect.. For Events 1, 2 and 5, although the PGA value was relatively large, the spectral acceleration fell off dramatically as the period increased, indicating that these earthquakes failed to induce the basin effect significantly.

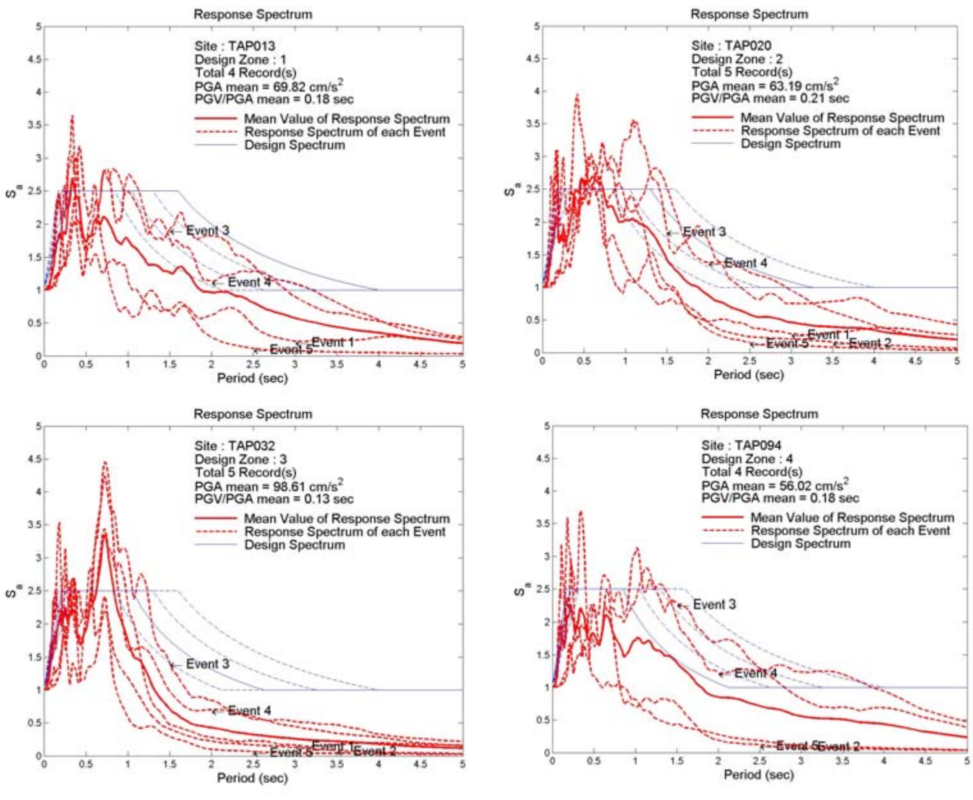


Figure 5. Examples of the response spectra for four micro-zones in Taipei Basin

It can be seen from the above analysis that, in Taipei Basin, both response spectrum shape and the corner period are noticeably affected by the characteristics of the earthquake source. For shallow earthquakes with $M_L \geq 6.8$, seismic waves with long-period contents are more likely to occur and propagate, because the surface waves may be generated due to the larger incident angle and the seismic energy have not been sufficiently attenuated. In addition, based on the seismic hazard analysis and the de-aggregation analysis, it can be observed that the control earthquakes with a return period of 475 years for the Taipei Basin are all major earthquakes with a remote epicenter; comparison with actual earthquake records confirms the significance of this type of earthquake. When considering 475-year or 2,500-year return period control earthquakes, it is important that this phenomenon should be taken into consideration by omitting the data for smaller earthquakes, so as to prevent these smaller earthquakes from distorting the averages. The above analysis also points up the significance of earthquake depth with respect to response spectra. To be able to accurately reflect the impact of earthquake source characteristics, the analysis of design response spectrum shape and corner period in the present study focused mainly on shallow earthquakes with a magnitude of M_L6.8 or larger, i.e. the records for the September 21, 1999 and March 31, 2002 earthquakes.

4.2. Adjustment of the Seismic Micro-zonation in Taipei Basin

In general, the recorded earthquake data with larger PGA are selected to develop the design response spectrum, however, as shown in the present study, focusing only on seismic intensity while ignoring the earthquake source effect and including the data for all five earthquake events (Events 1-5), the adoption of this approach would result in significantly underestimating the seismic demand.

If only the records for Event 3 (921 earthquake) and Event 4 (331 earthquake) are used, the response spectrum averaged for each of the four micro-zones are shown in Figure. 6. These data present a more accurate picture of the level of earthquake risk. A comparison of the design response spectrum and the average response spectrum for Events 3 and 4 shows that the design response spectra specified by the seismic design code are more or less in conformity with the average response spectra from actual earthquake records. The design spectrum, including the corner period and the spectral acceleration at long periods, as specified by the current seismic design code for all micro-zones in Taipei Basin can thus be considered to be acceptable.

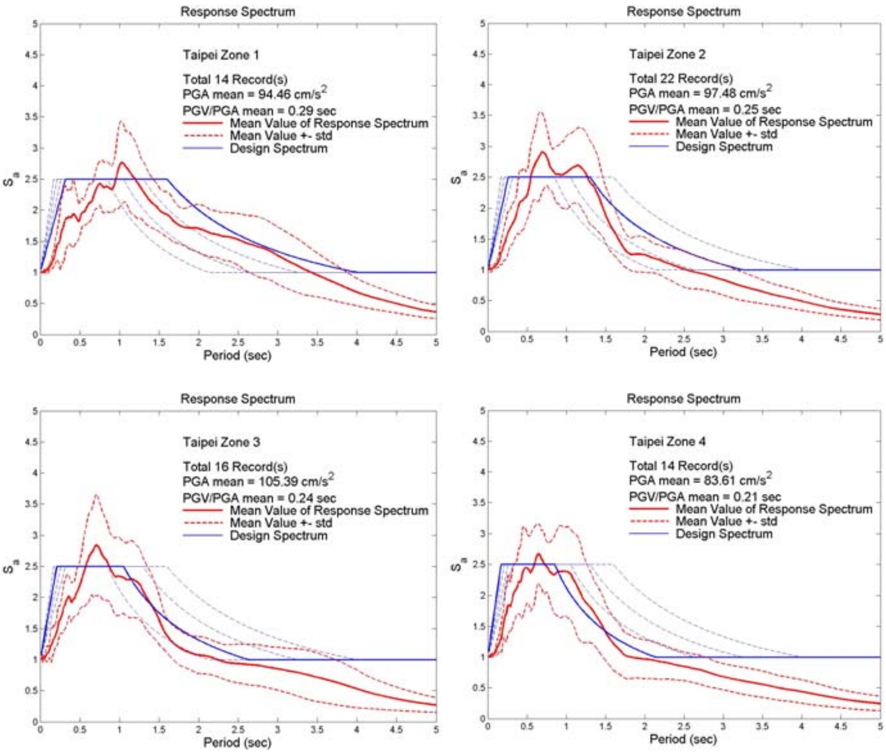


Figure 6. Averaged response spectra for 921 and 331 earthquake events

The overall averaged response spectra for 921 and 331 earthquakes and the design spectrum for the micro-zones specified by the current seismic design code display a reasonable degree of conformity with one another. However, for individual observation station, some adjustments still need to be made. Taking TAP008 as an example, based on the analysis of actual earthquake data it is suggested that, from the point of view of seismic design requirements, this site should be reclassified from Taipei zone 2 to Zone 1, as shown in Figure 7. In all, 30 sites within Taipei Basin require adjustment; the distribution of these sites, and the adjustments needed, are shown in Figure 8. The sites with the same classification as specified by the current seismic design code are denoted by blue dots. The sites marked by numbers indicate the adjustment is needed, if the number is marked in red, this indicates that the seismic demand shall be increased (e.g. from Zone 2 to Zone 1); if marked in blue, this indicates that the seismic demand may be reduced (e.g. from Zone 3 to Zone 4). The suggested adjustments are also shown in the table accompanying Figure 8.

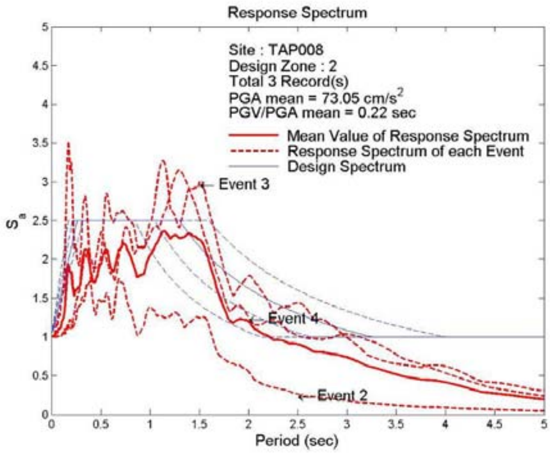


Figure 7. Adjustment of site classification for TAP008 (Taipei Zone2 to Taipei Zone 1)

Site	Origin	New
TAP001	3	2
TAP005	1	2
TAP008	2	1
TAP009	4	3
TAP011	1	2
TAP013	1	2
TAP015	3	2
TAP022	3	2
TAP025	3	2
TAP026	2	3
TAP028	2	1
TAP029	3	4
TAP030	3	4
TAP031	4	3
TAP040	None	1
TAP041	None	1
TAP042	None	4
TAP043	2	3
TAP049	None	1
TAP051	1	3
TAP054	3	2
TAP055	None	1
TAP094	4	2
TAP095	4	3
TAP096	3	2
TAP097	4	2
TAP100	3	2
TAP109	4	3
TAP110	2	1
TRB001	3	1

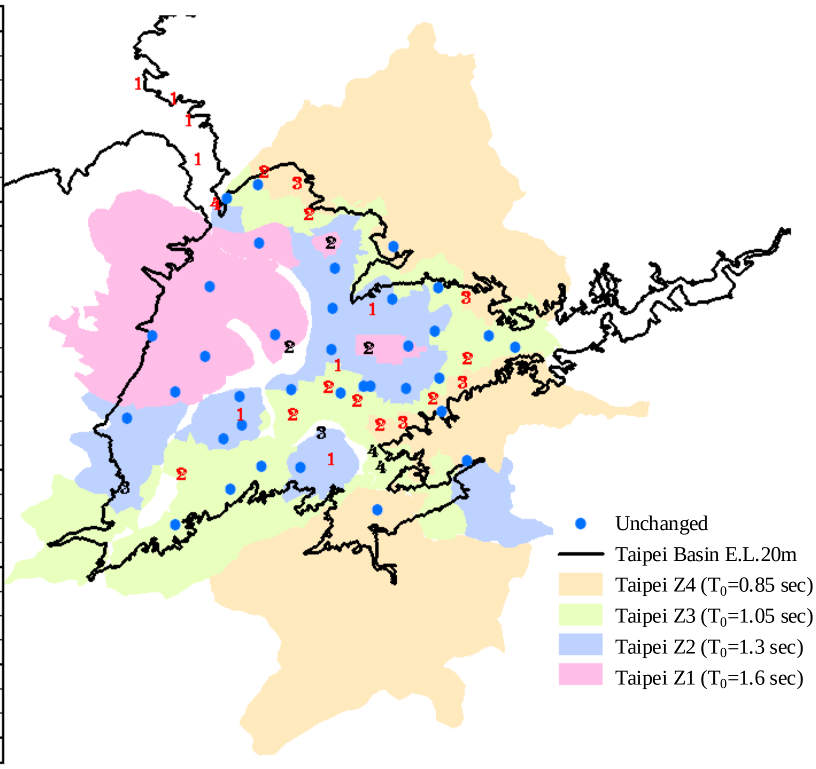


Figure 8. The adjustment of the site classification

After adjustment for the individual observation station, the averaged normalized response spectrum for Events 3 and 4 can be determined again for each micro-zone. As shown in Figure 9, the resulted response spectra conform better to the current seismic design code; the average PGV/PGA ratio for each micro-zone falls as the spectral acceleration at intermediate to long periods falls.

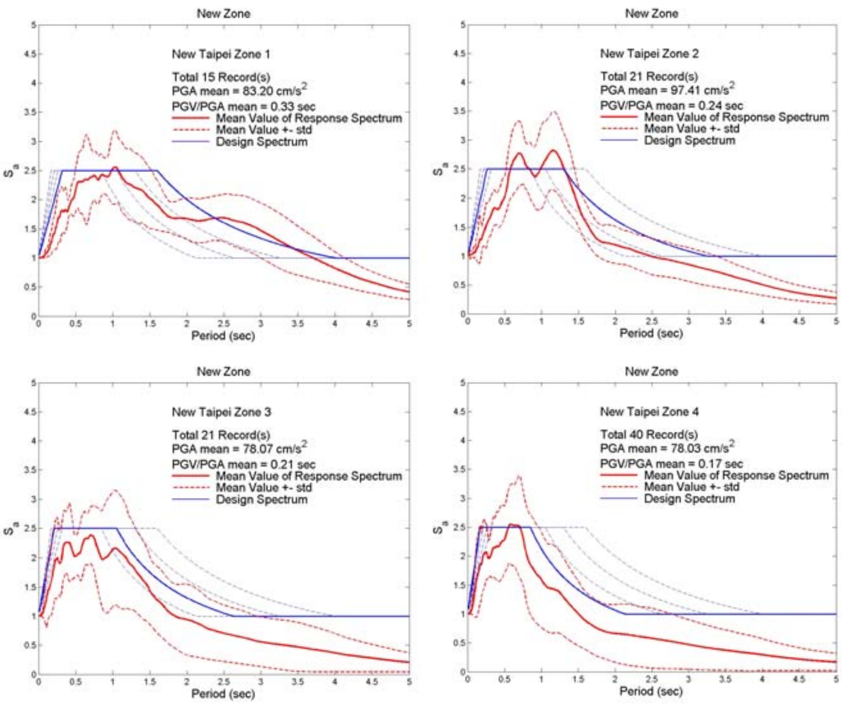


Figure 9. Averaged response spectra for 921 and 331 earthquake events for each micro-zone after adjustment of the individual observation station

5. Conclusions

Response spectra in the Taipei Basin are clearly affected by earthquake source characteristics. In the case of shallow earthquakes with a magnitude of M_L6.8 or greater, there is a pronounced basin effect. The present study uses earthquake data capable of reflecting the 475-year return period controlling earthquake – specifically, data from the major earthquakes of September 21, 1999 and March 31, 2002, both of which were shallow earthquakes with significant ground movement – to examine the seismic micro-zonation of Taipei Basin. The analysis results reveal a high degree of conformity between the averaged normalized response spectra and the ones specified by the current seismic design code. Nevertheless, adjustments are needed for some individual sites; further study could be undertaken in this regard using C_v value analysis as well as the consideration of the distribution of administrative districts.

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