第7回地震時保有耐力法に基づく橋梁等構造の
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MICROTREMOR OBSERVATIONS IN THE GREATER BANGKOK AREA FOR MICROZONATION

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1. Introduction

The characteristics of incoming seismic waves are substantially influenced by the local ground. Flat areas along the coast and rivers generally consist of thick layers of soft clay and sand. The soft soil deposits are found to amplify certain frequencies of ground motion thereby increasing earthquake damage. A well-known example is the 1985 Michoacan earthquake in Mexico City. Mexico City is built on the former bed of a drained lake over a soft soil deposition of lacustrine origin. The fault rupture in this earthquake was around 350 km away from the city; however, Mexico City sustained catastrophic damage due to the strong amplification of the ground motion by soft soil deposits [1]. The devastation caused in Mexico City due to the strong amplification of the ground motion by superficial deposits reflects the potential hazard from distant earthquakes in modern cities built over soft deposits.

Bangkok, the capital city of Thailand, is located in a low seismic hazard area. However, recent researches have shown that there is a potential hazard from distant earthquakes, due to the ability of underlying soft clay to amplify ground motions [2]. The variation in the ground motion, according to the geological site conditions, makes it necessary for big cities like Bangkok to conduct seismic microzonation. Seismic microzonation is defined as the process of subdividing an area into zones with respect to geological characteristics of the sites, so that seismic hazards at different locations within a city can correctly be identified. Microzonation provides the basis for a site-specific risk analysis, which can assist in the mitigation of earthquake damages. No studies have been carried out for the microzonation of Bangkok to date.

This study is focused on the microzonation of the greater Bangkok area using microtremor observations at different sites. The microtremor method measures ambient vibrations in the order of microns present on the ground surface. The main sources of these vibrations are traffic, and industrial and human activities. Observation of these microtremors can be used to determine the predominant period of vibration of a site [3-4]. Nakamura [3] proposed the *H/V* spectral ratio method, in which the predominant period of the ground vibration is determined by the ratio of horizontal and vertical Fourier spectra of microtremors recorded at a site. A number of experimental investigations have validated the reliability of the *H/V* method in determining the predominant period of the ground [5-6].

The conventional means for determining the soil profile is the borehole method. However, this method is costly and time consuming, and hence it is generally not suitable for microzonation. Methods based on the analysis of strong-motion records are more straightforward for determining site effects. However, the availability of ground motion records is limited to very few countries.

The strong-motion records for Thailand are very limited, and hence, are not adequate for estimating the site effects. In this context, microtremor observation becomes the most appealing approach for site effect studies.

The area of study (Figure 1) is located within latitudes 13°30'N and 14°30' N and longitudes 99°45' E and 101°30' E, including Bangkok Metropolitan Area and the areas in the vicinity. Microtremor measurements were performed at more than 150 sites in the greater Bangkok area and the *H/V* spectrum ratio technique was applied to estimate the predominant periods of the ground vibration at all the sites. A microzonation map for the city was then developed based on the results of the *H/V* analysis.

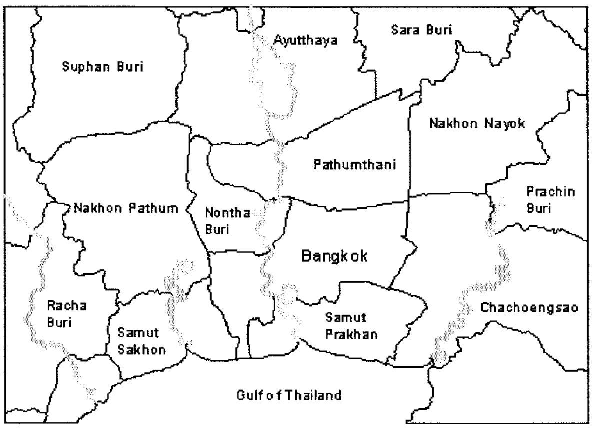


Figure 1 Area of Study

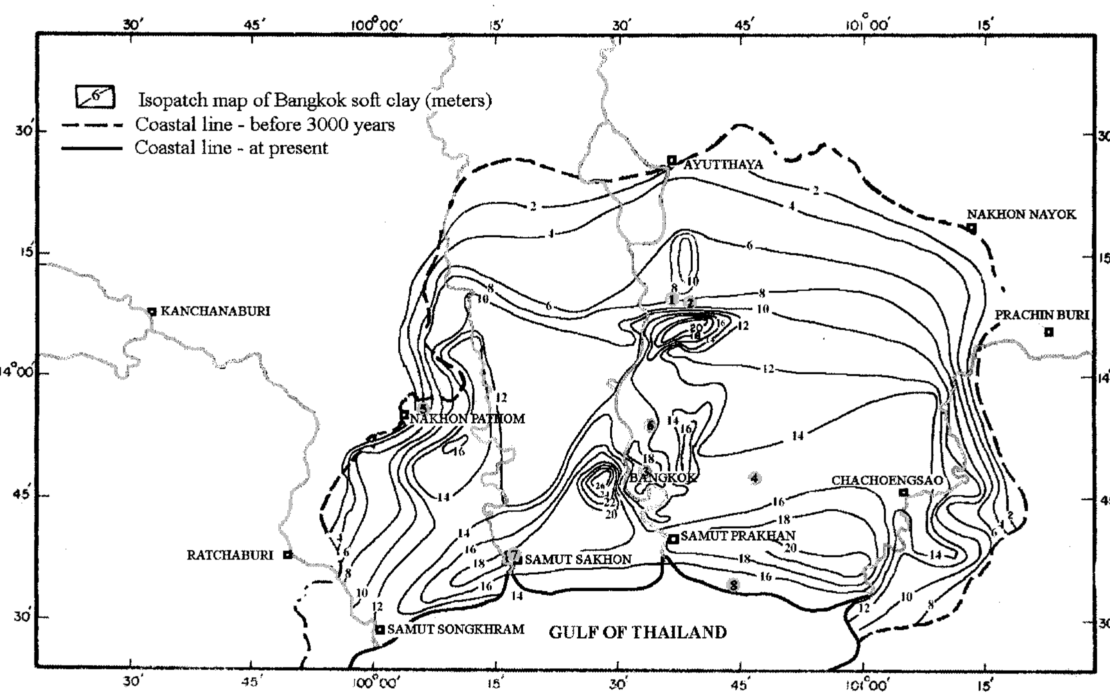
2. Seismicty of Thailand

Thailand lies in the east of the Andaman-Sumatra belt. Nutalaya et al. [7] identified twelve seismic source zones in this region after a comprehensive study on the seismo-tectonic features of the Burma-Thailand-Indochina region. The major active faults are rather far from Bangkok between 400 km and 1000 km. Some active faults are found in the western parts of Thailand at around 120 km to 300 km from Bangkok; however, their seismic activities are low in terms of recurrence interval and there are at least seven active faults in northern Thailand and five active faults in western Thailand. It was estimated from their expected rupture dimensions that a maximum earthquake of magnitude (M_W) 6.8 to 7.2 and 7.3 to 7.5 could be generated in northern and western Thailand, respectively.

Warnitchai and Lisantono [8] conducted a probabilistic seismic hazard analysis in Thailand and proposed a seismic zonation map for Thailand. According to this study, Bangkok lies in zone I ($0.025g < PGA_0 < 0.075g$), where PGA_0 is the peak ground acceleration having a 10% probability of being exceeded in a 50-year period; however, this study does not consider the site effect. Another study carried out by Warnitchai et al. [2] identified that the soil profile underlying Bangkok has the ability to amplify earthquake ground motions about 3 to 6 times for low intensity input motions (peak rock acceleration smaller than 0.02g) and about 3 to 4 times for relatively stronger input motions (peak rock accelerations larger than 0.02g).

3. Geology of Bangkok

Bangkok is situated on a large plain underlain by the thick alluvial and deltaic sediments of the Chaophraya basin. This plain, generally known as the lower central plain, is about 13,800 km^2 in area [9] (Figure 2). The plain was under a shallow sea 5000 to 3000 years ago.



* Gray circles are the location of eight sites used in SHAKE analysis

Figure 2 Isopach map showing the thickness of soft clay in Bangkok [9].

The regression of sea took place around 2700 years ago, leaving the soft clay deposits, which now form the lower central plain. This plain consists of thick clay known as Bangkok clay on its top layer, and its thickness is about 15 m to 20 m in the Bangkok metropolitan area (Figure 2).

The soft clay has very low shear strength, and is highly compressible, as it has never been subjected to mechanical consolidation. The thickness of soft clay increases towards the sea and decreases rapidly in the northerly direction from Bangkok. The first stiff clay layer exists below the soft clay layer. The first sand layer is found beneath 50m. At greater depths, alternate layers of the stiff clay and sand layers are found. The bedrock is found at the large depths varying from 500 m to 2000 m under the unconsolidated sediments and its structure is poorly known [9]. The in-situ *S*-wave velocity (V_S) measurement performed in Bangkok shows notably low V_S in soft Bangkok clay (about 60 to 100 m/s) [10-11]. Shear wave velocity for the first stiff clay layer was found to be in the range 150-200 m/s. Vs was found to increase to about 250 m/s in the first sand layer, and to continue to increase, although at a slower rate, in the deeper strata [10-11]. The low V_S for Bangkok soft clay and first stiff clay layer are comparable to that of Mexico City clay [2]. Moreover, the drastic increase of the V_S in the first sand layer can aggravate the amplification of ground motion.

4. Microtremor measurements and data analysis

4.1 Instrument setup

Microtremor observations were performed using portable microtremor equipment (Figure 3). The sampling frequency for all the measurements was set at 100 Hz. The low pass filter of 50 Hz was set in the data acquisition unit. The velocity sensor used can measure three components of vibration, two horizontal and one vertical; the natural period of the sensor is 2 s. The available frequency response range for the sensor is 0.5-20 Hz. A global positioning system (GPS) was used for recording the coordinates of observation sites.

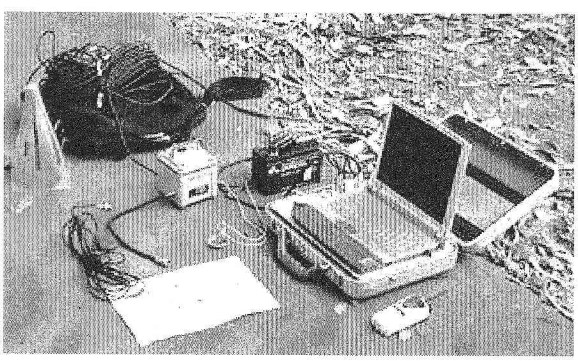


Figure 3 Portable microtremor measuring equipment

4.2 Data acquisition and processing

Microtremor observations were carried out at more than 150 sites in the greater Bangkok area. The measurements were carried out along the highways that run in the radial directions from central Bangkok, at a distance interval of approximately 10 km. The observations were conducted along the small streets at least hundred meters away from the busy highways. However, inside the Bangkok metropolitan area most of the measurements were carried out in open-public spaces, such as parks, schools, universities, temples and government offices

At each site, data was recorded for 327.68 seconds (i.e. 32768 data points at the sampling rate of 100 Hz). The recorded time series data were divided into 16 segments each of 20.48s duration. For each site, ten segments of the data were chosen from 16 segments, omitting the segments that are influenced by very near noise sources. These ten segments were used for the calculations. The Fourier spectra were calculated for the selected ten segments using the Fast Fourier Transform (FFT) algorithm and the Fourier spectra were smoothed using a Parzen window of bandwidth 0.4 Hz. The Fourier amplitude ratio of the two horizontal Fourier spectra and one vertical Fourier spectrum were obtained using Equation 1:

$$r(f) = \frac{\sqrt{F_{NS}(T) \times F_{EW}(T)}}{F_{UD}(T)} \quad (1)$$

where $r(f)$ is the horizontal to vertical *(H/V)* spectrum ratio, F_{NS}, F_{EW} and F_{UD} are the Fourier amplitude spectra in the *NS*, *EW* and *UD* directions, respectively.

After obtaining the *H/V* spectra for the ten segments, the average of the spectra were obtained as the *H/V* spectrum for a particular site. The peak period of the *H/V* spectrum plot shows the predominant period of the site.

The *H/V* spectra were obtained for all the observation sites and the predominant periods of all the sites were identified. Observation points were then overlain on a digital map of the greater Bangkok area and the inverse distance weighing (IDW) method [12] was used for spatial interpolation from the data measured at discrete locations.

5. Results of microtremor measurements

The microtremor measurements show that the sites located near the Gulf of Thailand have considerably long predominant period, around 0.8 s to 1.2 s. This matches quite well with the variation of the soft soil thickness as shown in Figure 2, which suggests that the thickness of soft clay in these areas ranges from 15 m to 20 m. The Bangkok metropolitan area also has a considerably long predominant period, longer than 0.8 s. The period decreases towards the north and the period reduces to below 0.4 s near Ayutthaya. The period also decreases towards the east and west directions.

According to the variation of the predominant period of the ground, the greater Bangkok area is classified into four zones as follows:

a) Zone I - period less than 0.4 s
b) Zone II - period ranging from 0.4 to 0.6 s
c) Zone III - period ranging from 0.6 to 0.8 s
d) Zone IV - period longer than 0.8 s

The *H/V* spectral ratios for the sites in the different zones are shown in Figure 4. The variation of the predominant period of ground in the greater Bangkok area is shown Figure 5. The proposed four period ranges were taken from the highway bridge code of Japan [13].

5.1 Variation of predominant period with thickness of soft clay

Soil profiles at eight sites viz. 1.Asian Institute of Technology; 2. Thamasart University Rangsit; 3. Chulalongkorn University; 4. Ladkrabang; 5. Nakhon Pathom; 6. Chatuchak; 7. Samut Sakhon, and 8. Ban Tamru (locations shown in Figure 2) were studied to investigate the correlation between the thickness of soft clay layer and the predominant period of the ground. These eight sites were chosen because detailed soil profiles and microtremor observation data were available.

5.2 Transfer functions of Bangkok sites using SHAKE91

The transfer functions were calculated using the computer program SHAKE91, for the eight sites where microtremor data were also available (Figure 6). Here, the transfer function is defined as the ratio of surface Fourier spectrum to the rock outcrop Fourier spectrum.

As stated earlier, the microtremor observations measure the vibration in the range of microns. At such low strains, soil basically behaves as a linear material having a constant damping ratio and a shear modulus. The transfer functions were computed assuming the damping ratio as two percent of critical.

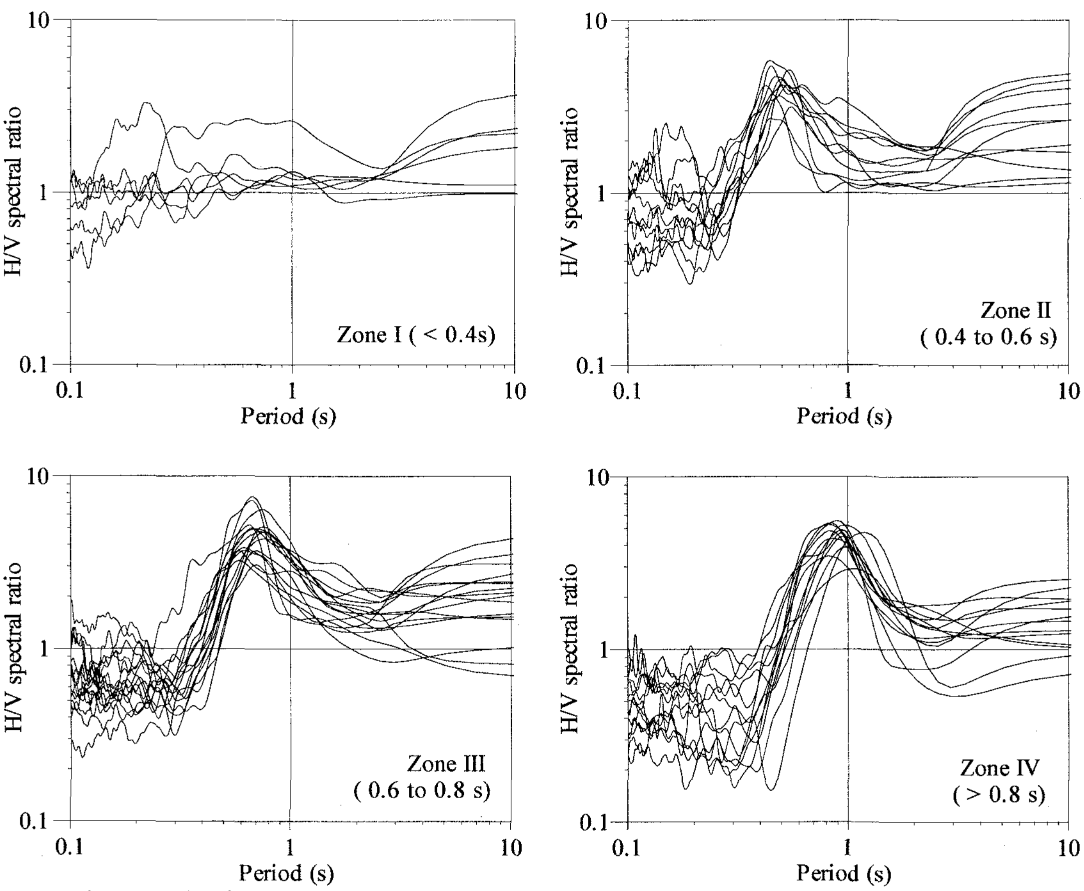


Figure 4 *H/V* spectral ratio of microtremor for sites in the four zones, based on the predominant period

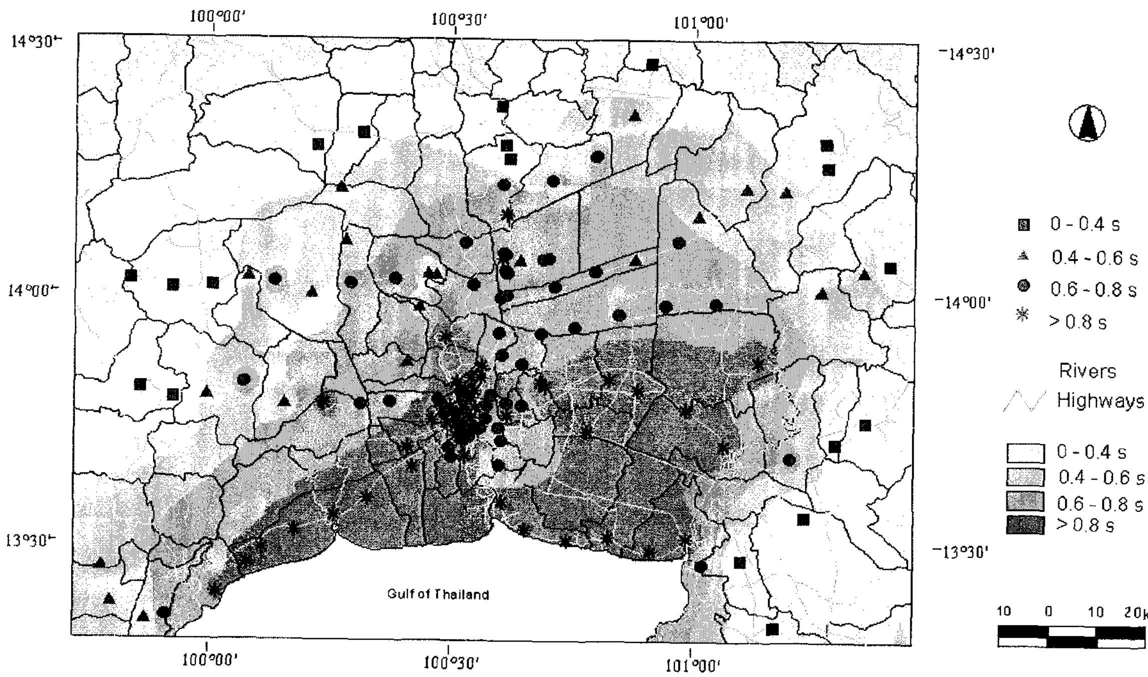


Figure 5 Microzonation of the greater Bangkok area on the basis of variation of the predominant period.

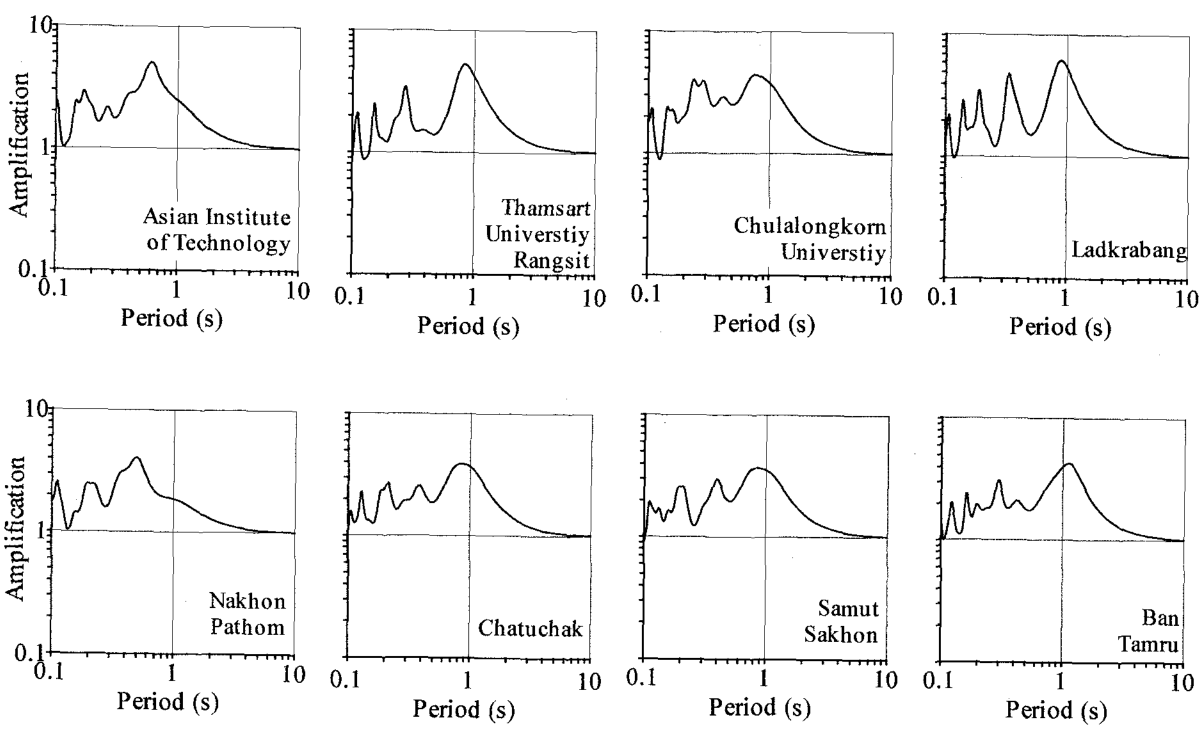


Figure 6 Transfer function calculated for eight sites in the greater Bangkok area using SHAKE91.

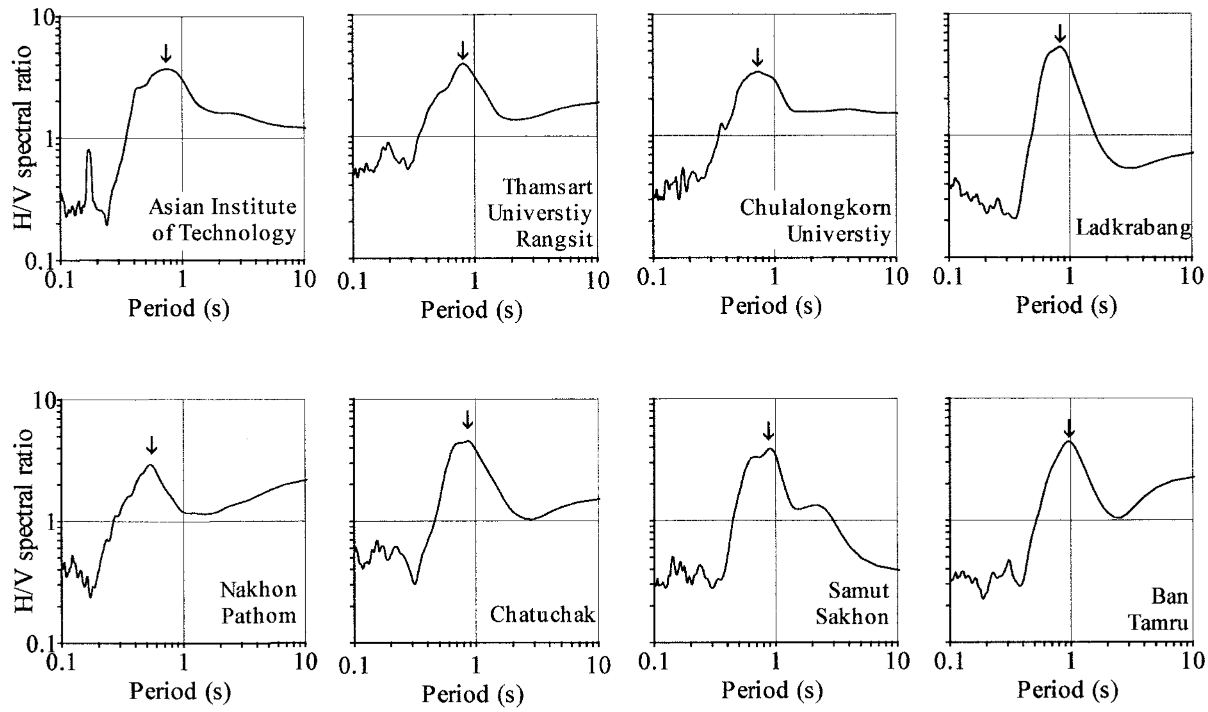


Figure 7 H/V spectral ratio for the eight sites from microtremor measurements.

The *H/V* spectral ratios from microtremor observations for the eight sites are shown in Figure 7. The predominant periods obtained from the transfer functions of the subsoil at the eight sites are analogues to the predominant periods obtained from the microtremor observation at the respective sites (Figure 8).

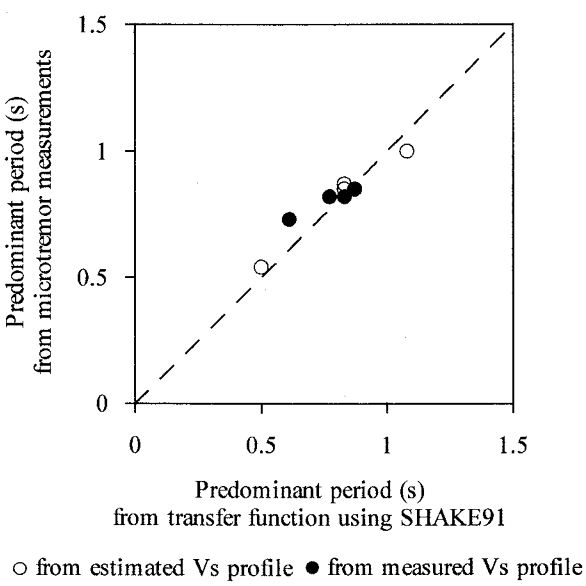


Figure 8 Predominant period from microtremor observation and SHAKE91

6. Conclusions

In this study, microtremor measurements were carried out at more than 150 sites in the greater Bangkok area. The predominant periods of the sites were obtained using the horizontal-to-vertical spectral ratio (*H/V*) method. The study showed that the predominant period varied from considerably high values, ranging from 0.8 s to 1.2 s, near the Gulf of Thailand, to low values, less than 0.4 s at the boundary of the plain. On the basis of variation of the predominant period, the greater Bangkok area was classified into four zones. Moreover, the transfer functions were calculated for the eight sites using SHAKE91. Good correlation of the predominant periods obtained from the microtremor analysis and the results from SHAKE91 validated the reliability of the *H/V* method. The predominant periods obtained from the microtremor observations are also found to correlate well with the soft soil thickness in the greater Bangkok area.

This study shows that there is a possibility of long-period ground vibration in Bangkok, especially in the areas near the Gulf of Thailand. This could cause severe damage to the long-period structures such as high-rise buildings and long-span bridges. Hence, special attention should be given towards the seismically resistant design of such structures.

7. References

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