Estimation of Long Period Ground Motion Earthquake Effects to Highrise Buildings at Hanoi and Hochiminh Cities, Vietnam

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Estimation of dynamic characteristics of subsurface such as predominant period, amplification factor, shear wave velocity play an important role in researchs of the effects of long-period ground motion earthquakes on high-rise buildings in big cities. However, in Vietnam, due to the lack of observation devices, there is a shortage of dynamic ground information. Consequently, in this paper, at first, the results of applying the Nakamura Method to data processing of microtremor observations in Hanoi and HoChiMinh City of Vietnam are presented. By using this method, the predominant period of the ground at the sites could be estimated from the horizontal to vertical (H/V) spectral ratios of microtremors. The obtained results show that the grounds of the mentioned two cities have considerable possibility of resonating with long-period ground motions. Then, the spectral accelerations in bedrock of Hanoi and HoChiMinh city were estimated by attenuation relationship of Uchiyama and Midorikawa 2006 with the far-source rupture faults that were Sumatra earthquake 2004 and Tha-Khaek fault line in Thailand. Next, the accelerations on ground surface of the above two Vietnamese cities were calculated by using spectral ratio of microtremor and inverse Fourier transform. Finally, those obtained accelerations were used to do the time history analysis applied for 8 high-rise buildings in Hanoi and HoChiMinh city. The results of this final step show that far-source rupture faults have considerable possibility to generate long-period ground motions that cause certain affects to the behaviors of high-rise buildings in Vietnamese cities.

Key Words : *Acceleration attenuation relationship, microtremor, long-period ground motion, high-rise building*

1. INTRODUCTION

(1) Overview of the earthquake situation all over the World and in Vietnam

In recent years, several large earthquakes have occurred in the world, causing severe damage to people, houses and buildings as well as technical infrastructure even for countries, which have economic potential and experiences in earthquake resistance construction, such as Japan, U.S.A, New Zealand, etc… Typical examples are the 2004 Sumatra earthquake of 9.1 Richter scale in Indonesia; the 2008 Tu Xuyen earthquake of 7.8 Richter scale in China; the 2011 Christchurch earthquake in New Zealand and most recently, on 11 March, 2011, the earthquake in Japan with magnitude of 9 Richter scale, which was the largest earthquake in the history of this country.

So far, in Vietnam, earthquakes have occurred in many localities throughout the country (fig. 1), among which several significant earthquakes can be mentioned such as the 1935 earthquakes of 6.8 Richter scale in Dien Bien, causing seismic level VIII (MSK-1964 levels of intensity); the 1983 earthquake of 6.7 Richter scale, seismic level VIII in Tuan Giao – Lai Chau, causing ground cracks in large areas, large landslides on the mountains, damage to buildings within a radius of 35km; the 2006 earthquake of 4.9 Richter scale, seismic level IV in Do Luong – Nghe An. Recently, on 19 February, 2001, an earthquake of 5.3 Richter scale occurred on the mountains of Nam Oun – Laos (close to Dien Bien city) at a depth of 12 km, causing damage to some buildings in Dien Bien. Most recently, on 24 March, 2011, an earthquake of 7.0 Richter scale happened in Myanmar, near the border of Myanmar, Laos and Thailand. This earthquake caused shocks of seismic level V in Hanoi and seismic level VI (MSK-1964 levels of intensity) in some localities in the Western North of Vietnam.

In the Southern provinces of Vietnam, on 28 November, 2007, an earthquake of 5.1 Richter scale occurred, whose hypocenter was off the coast of Vung Tau City at a distance of about 30 km. This earthquake caused shocks of seismic level IV in some areas of Ho Chi Minh City. On 23 June, 2010, another earthquake of 4.7 Richter scale happened offshore Vung Tau and Phan Thiet, causing some shakings of seismic level IV in Ho Chi Minh City, Vung Tau and Dong Nai.

Consequently, with only a few earthquakes happened in the past, Vietnam was considered as a country with low seismic activity. (Fig 1)

However, in recent years, the Government of Vietnam has paid more attention to earthquake engineering, as there is increasing frequency of earthquakes in the country. Recently, the State Authority for Construction Quality Inspection, Minister of Construction of Vietnam has conducted seismic hazard assessment, which includes reviewing the current seismic resistance standards systems and inspecting the application of these standards to design and construction of high-rise buildings in big cities with high possibility of earthquakes, such as Hanoi, Ho Chi Minh City, Da Nang, Vung Tau, Dien Bien… As a result of this assessment, some necessary solutions have been proposed in order to mitigate the potential damage from earthquakes. (Source: Seismic report of State Authority for Construction Quality Inspection, Minister of Construction of Vietnam) [1)]

Table 1 Historical Earthquakes in Vietnam

No.	Year	Location	Domain Of Vietnam	Richter Scale
1	1935	DienBien	Northwest	6.8
2	1983	TuanGiao LaiChau	Northwest	6.7
3	2001	NamOun (Close to DienBien)	Northwest	5.3
4	2006	DoLuong NgheAn	Middle	4.9
5	2007	30Km Offshore VungTau City	South	5.1
6	2010	Offshore VungTau PhanThiet	South	4.7
7	2011	Myanmar	Near border of Myanmar, Laos, Thailand	7.0

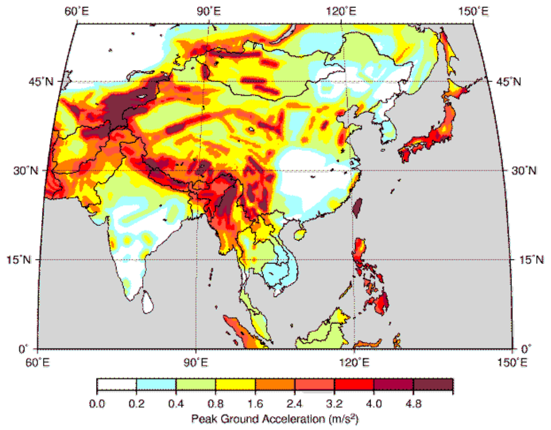


Fig.1 PGA (Peak Ground Acceleration) map of Vietnam in the world (Source: http://www.seismo.ethz.ch/static/GSHAP/eastasia/asiafin.gif)

(2) Introduction of long-period ground motion of the occurred earthquakes

Nowadays, with the increase in the number of large-scale structures, such as high-rise buildings, oil storage tanks, water reservoirs and long-span bridges, it is imperative for the designers to have knowledge of long-period ground motions, which have become an important issue in the seismic design of these large structures. Long-period ground motion is ground movement during an earthquake with a period longer than 1 second. The frequency of such waves is 1 Hz or lower, placing them in the infrasonic part of the audio spectrum. Long-period ground motions are divided into 2 types: far-source and near-fault long-period ground motions. Far-source long-period ground motion can be generated by large subduction-zone earthquakes and moderate to large crustal earthquakes in distant sedimentary basins with the help of path effects. On the other hand, the source effects of forward rupture directivity can generate near-fault long-period ground motion. Far-source long-period ground motions consist primarily of surface waves with longer durations than near-fault long-period ground motions. They were first recognized in the seismograms of the 1968 Tokachi-oki and 1966 Parkfield earthquakes, and their identification has been applied to the 1964 Niigata earthquake and earlier earthquakes. Through the investigation of tank damage by liquid sloshing, we can identify far-source long-period ground motions, even if there is no seismogram [2).]

The long-period ground motions attenuate slowly with distance because of certain path effects, and site effects amplify the long-period component of seismic ground motion generated by earthquakes in distant basins so that they can cause destruction over a much greater range beside their initial damages in near-fault regions through source effects such as the directivity effect of rupture propagation and the near-field term of body wave radiation.

In the past, most structures might only be resonant with relatively short-period (1 s or shorter) ground motions because in earthquake-prone regions, they were low-profile structures. Thus short-period ground motions were important with the past structures. Nevertheless, nowadays, with the unremitting increasing number of large structures that have long-period fundamental periods such as high-rise buildings, oil storage tanks, suspension bridges, off-shore oil drilling platforms, and recent base-isolated structures, long-period (1 to 10 s or longer) ground motions have been increasingly important (e.g., Kanamori 1979 [3)]; Fukuwa 2008 [4)]).

The worst example of destruction caused by long-period ground motion occurred in Mexico City, 400 km from the 1985 Michoacan earthquake (Mw= 8.0; e.g., Beck and Hall 1986 [5)]). Another example is the 2003 Tokachi-oki earthquake (Mw=8.3) that occurred in Hokkaido, Japan (e.g., Koketsu et al. 2005) [6)].

Return to Vietnam, this country is located in the Southeast Asia that is very near to many countries with high probability of occurring earthquakes for example China, Indonesia, Philippines, Thailand ...etc. Moreover, in Vietnam, because of the unstopping requirement of houses for the citizens and the offices for many companies, more and more high-rise buildings are being constructed in the metropolitan area of big cities such as Hanoi, Ho Chi Minh City. From the "List of tallest buildings in Vietnam", the numbers of floor in those buildings vary from 23 to 70 floors, the heights vary from 101m (331ft) to 336m (1102ft) (Source: http://en.wikipedia.org/wiki/List_of_tallest_buildings_in_Vietnam). Those high-rise buildings are categorized into long-period structures; consequently, the research of long-period ground motion in Vietnam is very necessary.

(3) Introduction of microtremor and Nakamura method [7)]

Microtremor observations are based on measurements of ground vibrations caused by natural phenomena such as wind, waves, transport, industrial plants ... etc. In the world, this kind of measurement is one of the important data in the study of seismic microzonation, the partition map of the earthquake. In Vietnam, there were several researches conducted in a few cities such as Hanoi [8)], Dien Bien ...etc and at some construction sites of important projects. The Nakamura technique is used for calculating the spectral ratio of horizontal and vertical component of seismic waves of the microtremor observation. In his theory, based on the ratio of this spectrum, the resonant frequencies and the amplification factors of the ground can be evaluated. Estimation of dynamic characteristics of subsurface such as predominant period, amplification factor, shear wave velocity play an important role in researchs of the effects of long-period ground motion earthquakes on high-rise buildings in big cities. However, in Vietnam, due to the lack of observation devices, there is a shortage of dynamic ground information. Consequently, in this paper, at first, the results of applying the Nakamura Method to data processing of microtremor observations in Hanoi and HoChiMinh City of Vietnam are presented. By using this method, the predominant period of the ground at the sites could be estimated from the horizontal to vertical (H/V) spectral ratios of microtremors.

2. MICROTREMOR OBSERVATIONS IN HANOI AND HOCHIMINH CITIES, VIETNAM

(1) Experiment sites of microtremor measurement in Hanoi and Ho Chi Minh Cities, Vietnam

Microtremor measurements were carried out twice in Ho Chi Minh City in March 2011 at 5 sites and in September 2011 with 4 sites. The local weather was sunny, sometimes it had small rain, and the temperature varied around 30^{o}C.

In March 2011, the chosen experiment sites were 5 points (results for 4 sites are shown in this paper only, because there was no reasonable result for the first site) in the central area of Ho Chi Minh City shown in Fig 2 & Table 2:

Table 2 Microtremor Experiment Sites in March 2011 - HoChiMinh City

Site 2:	Tao Dan Park (TD)
Site 3:	Ky Hoa Travel Area (KH)
Site 4:	Le Thi Rieng Park (LTR)
Site 5:	Hoang Van Thu Park (HVT)

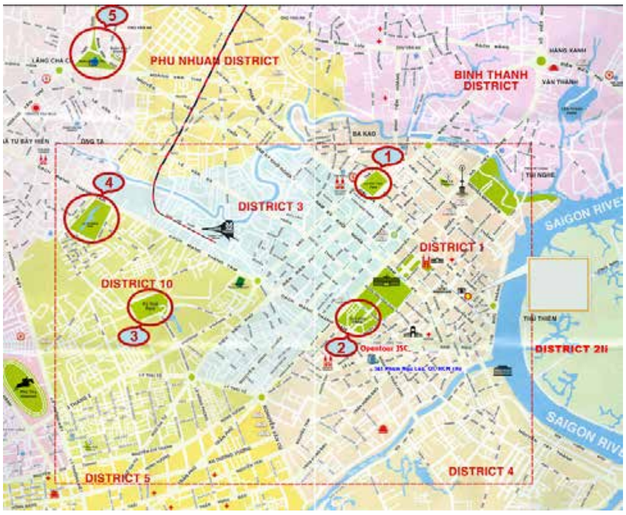


Figure 2. Microtremor Experiment Sites in March 2011 - HoChiMinh City

In September 2011, the chosen experiment sites were 4 points in the central area of Ho Chi Minh City shown in Fig 3 & Table 3. Moreover, 2 sites in Hanoi City were chosen to do the measurement of microtremor as well. (shown in Fig 4 & Table 4)

Table 3 Microtremor Experiment Sites in September 2011 - HoChiMinh City

Site 1:	Le Van Tam Park (LVT)
Site 2:	Tao Dan Park (TD)
Site 4:	Le Thi Rieng Park (LTR)
Site 5:	Hoang Van Thu Park (HVT)

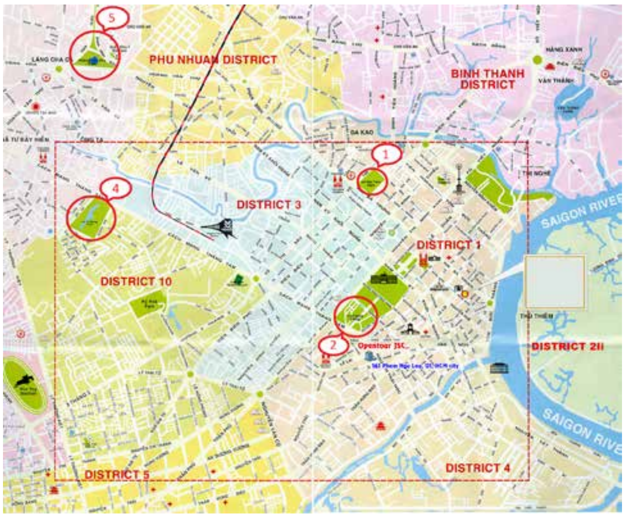


Figure 3. Microtremor Experiment Sites in September 2011 - HoChiMinh City

Table 4 Microtremor Experiment Sites in September 2011 - Hanoi City

Site 1:	NUCE (National University of Civil Engineering)
Site 2:	Youth Park (YP)

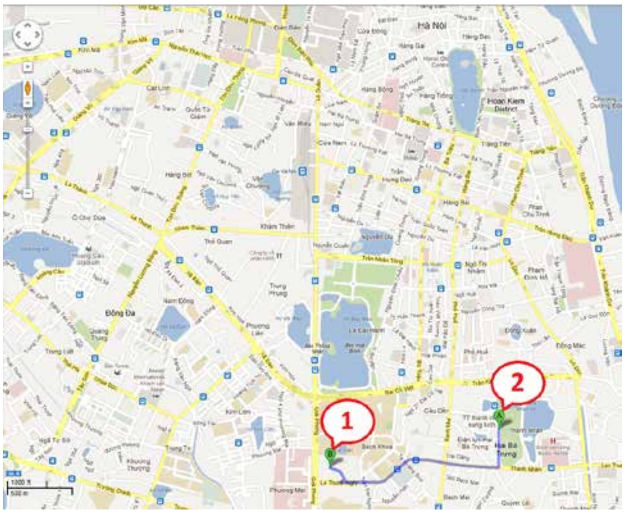


Figure 4. Microtremor Experiment Sites in September 2011 - Hanoi City

The reason for those sites selection is that, the behavior of high-rise buildings located in the central area as well as the dynamic characteristics of the soil will be examined carefully. The first step is to examine the dynamic characteristics of the ground such as predominant period, amplification factor, shear wave velocity...etc. In this paper, only the predominant period and frequency are examined and introduced.

Microtremor measurement is carried out in the center of each site. The sites of experiment are parks or natural land areas that have the minimum activities of traffic. Hanoi and HoChiMinh Cities are big cities with very high density of traffic activity. Such sites selection could reduce the noise effects on the measurement (Fig 5).

Figure 5. One Experiment Site

(2) Experiment description

Microtremor observations were carried out using portable microtremor equipment. The model microtremor device is GPL-6A3P that was manufactured by Akashi Company. For each site, microtremor measurement was done 3 times. The time duration for each measurement were 3 minutes (for measurements in March 2011) and 10 minutes (for measurements in September 2011); the directions were 3 channels (Up-Down, North-South, and East-West).

In the present study to measure the small vibration of microtremor portable data logger manufactured by Akashi GPL-6A3P (Ltd) was used.

Because analog data is obtained in the measurement, thus, to perform computer analysis, it is necessary to convert analog data into digital data values. Because the target period of the microtremor of the ground in this study is about 0.1 to about 10 seconds, the sampling frequency set to 100Hz. In other words, it will record a number of analog data every 0.01-second interval. In total, 3 minutes, 18,000 pieces of data were recorded (for measurements in March 2011) and 60,000 pieces of data (for measurements in September 2011).

3. DATA PROCESSING AND OBTAINED RESULTS

(1) Data processing

In this section, a technique is described to process data obtained from the analysis of microtremor observations.

The output of recorded observation data is an integer value that we use to analyze acceleration (gal). Each observation in March 2011 was recorded in 3 minutes or 18000 time interval points. After converting the output data to acceleration value, each observation was divided into 8 stable part of 2048 points tremor (20.48 seconds) and processed to 8 data files. Next, these 8 time-domain data will be processed by the Fourier transform to reduce noise to obtain the 8 frequency-domain data. Then, the following formula was used for averaging to obtain further smooth data.

$$S_i = \frac{S_1 + S_2 + S_3 + S_4 + S_5 + S_6 + S_7 + S_8}{8} \quad (1)$$

Each observation in September 2011 was recorded in 10 minutes or 60000 time interval points. After converting the output data to acceleration value, each observation was divided into 28 stable part of 2048 points tremor (20.48 seconds) and processed to 28 data files. Next, these 28 time-domain data will be processed by the Fourier transform to reduce noise to obtain the 28 frequency-domain data. Then, the following formula was used for averaging to obtain further smooth data.

$$S_i = \frac{1}{28}\sum_{i=1}^{28} S_i \quad (2)$$

Here, S_i of NS, EW, and UD is the average Fourier spectral amplitude components.

Geometric mean of the amplitude Fourier spectrum of two horizontal components was obtained by the following equation, which is used for determining the average horizontal spectral amplitude (S_H).

$$S_H = \sqrt{S_{NS} \cdot S_{EW}} \quad (3)$$

Here, S_{NS}, S_{EW}, are respectively NS, EW components of the amplitude Fourier spectrum. Finally, the microtremor H / V spectral ratio ($S_{H/V}$) are defined by the following equation:

$$S_{H/V} = S_H / S_V \quad (4)$$

Here, S_V is the amplitude Fourier spectrum of vertical component.

(2) Obtained results

In this section, after processing the output data, the results of spectral ratios of 4 sites are presented.

a) Results in HoChiMinh city in March 2011

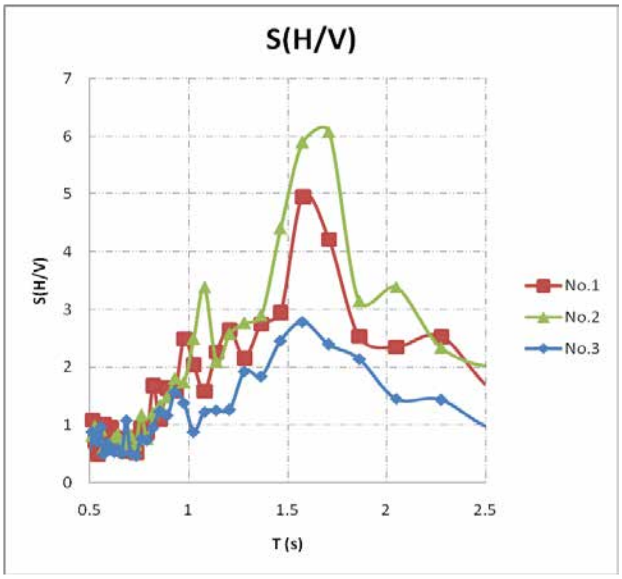


Figure 6. Spectral ratio $S_{H/V}$ of site 2 (Tao Dan Park)

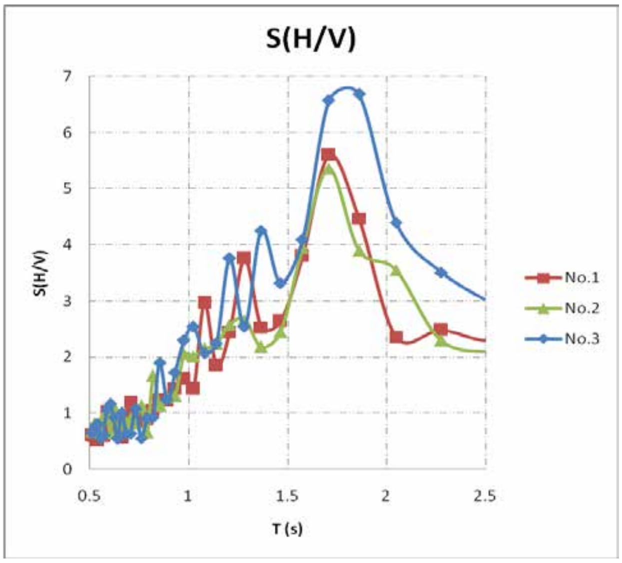


Figure 7. Spectral ratio $S_{H/V}$ of site 3 (Ky Hoa Travel Area)

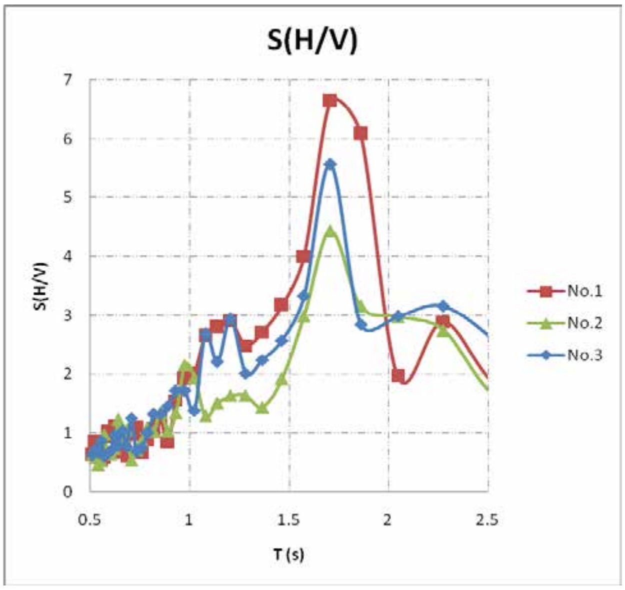


Figure 8. Spectral ratio $S_{H/V}$ of site 4 (Le Thi Rieng Park)

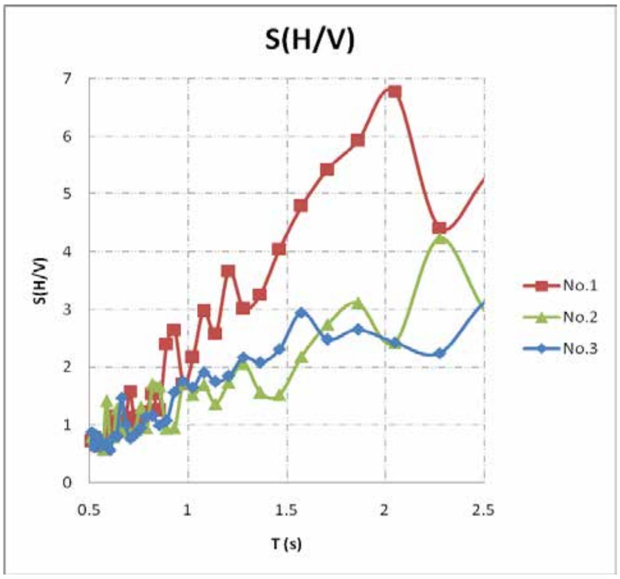


Figure 9. Spectral ratio $S_{H/V}$ of site 5 (Hoang Van Thu Park)

Figures 6 to 9 show the results of spectral ratios of 4 microtremor measurement sites in HoChiMinh City in March 2011. In the charts, the horizontal axis is the frequency with unit Hz, the vertical axis is the spectral ratio between horizontal and vertical spectral components of microtremor.

From the results, the predominant periods of 4 sites can be estimated (site 2, 3, 4, 5). The total results are summarized into the following table:

Table 5 Predominant frequencies and periods

Site	Predominant Period (s)	Predominant Frequency (Hz)
2.Tao Dan Park	1.619	0.618
3.Ky Hoa Travel Area	1.758	0.569
4.Le Thi Rieng Park	1.707	0.586
5.Hoang Van Thu Park	1.829	0.547

b) Results in HoChiMinh city in September 2011

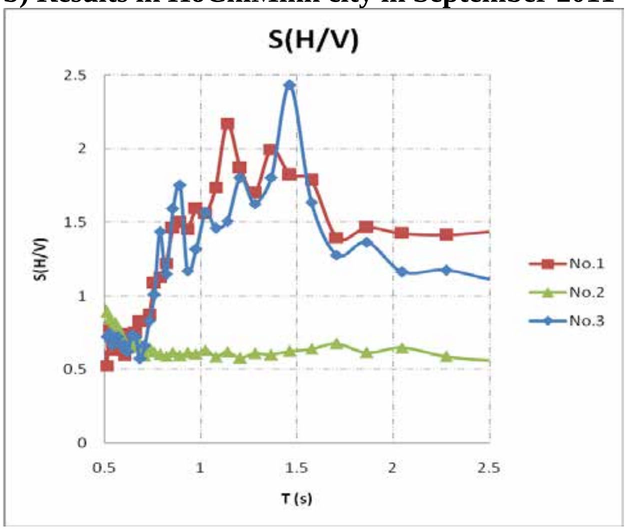


Figure 10. Spectral ratio $S_{H/V}$ of site 1 (LeVanTam Park)

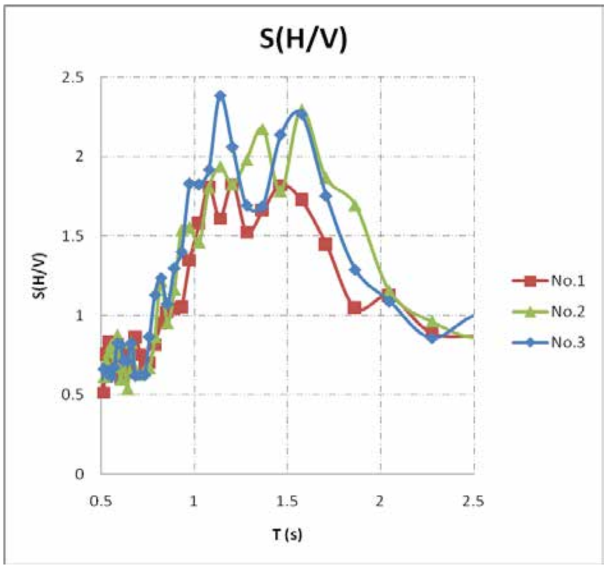


Figure 11. Spectral ratio $S_{H/V}$ of site 2 (Tao Dan Park)

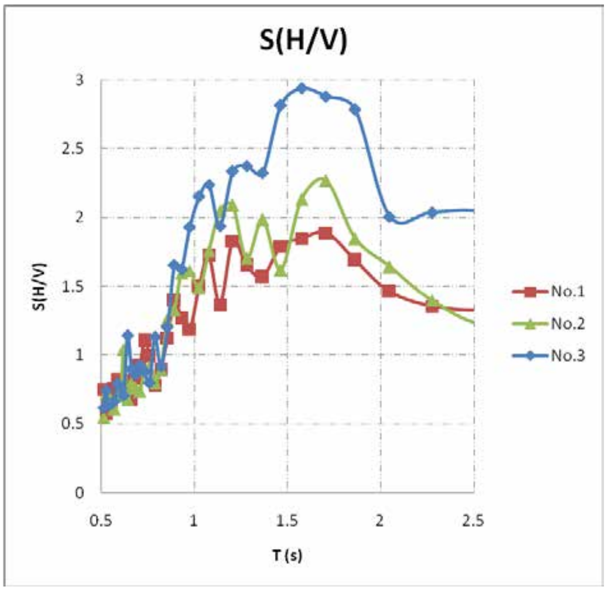


Figure 12. Spectral ratio $S_{H/V}$ of site 4 (Le Thi Rieng Park)

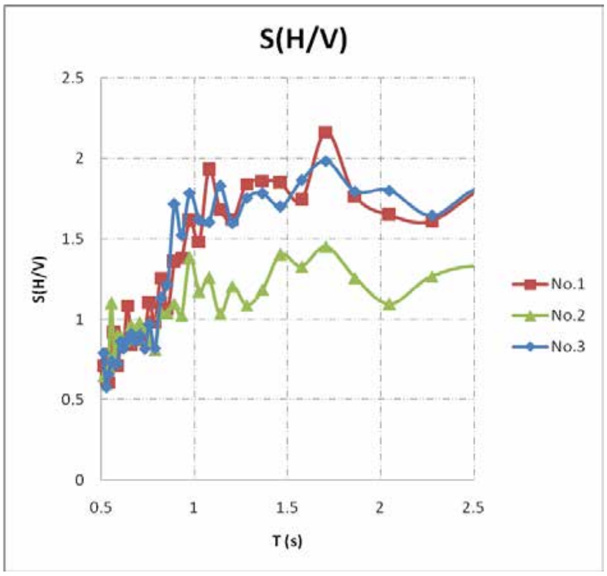


Figure 13. Spectral ratio $S_{H/V}$ of site 5 (Hoang Van Thu Park)

Figures 10 to 13 show the results of spectral ratios of 4 microtremor measurement sites in HoChiMinh City in September 2011. In the charts, the horizontal axis is the frequency with unit Hz, the vertical axis is the spectral ratio between horizontal and vertical spectral components of microtremor.

From the results, the predominant periods of 4 sites can be estimated (site 1, 2, 4, 5). The total results are summarized into the following table:

Table 6 Predominant frequencies and periods

Site	Predominant Period (s)	Predominant Frequency (Hz)
1.LeVanTam Park	1.436	0.696
2.Tao Dan Park	1.505	0.664
4.Le Thi Rieng Park	1.663	0.601
5.Hoang Van Thu Park	1.707	0.586

c) Results in Hanoi city in September 2011

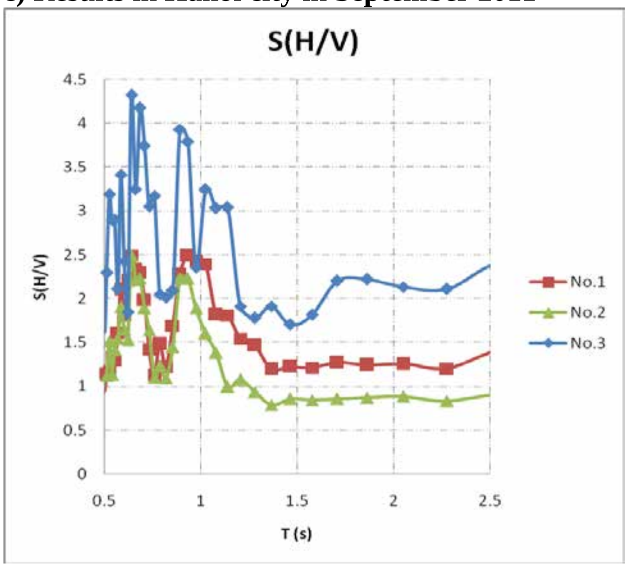


Figure 14. Spectral ratio $S_{H/V}$ of site 1 (NUCE)

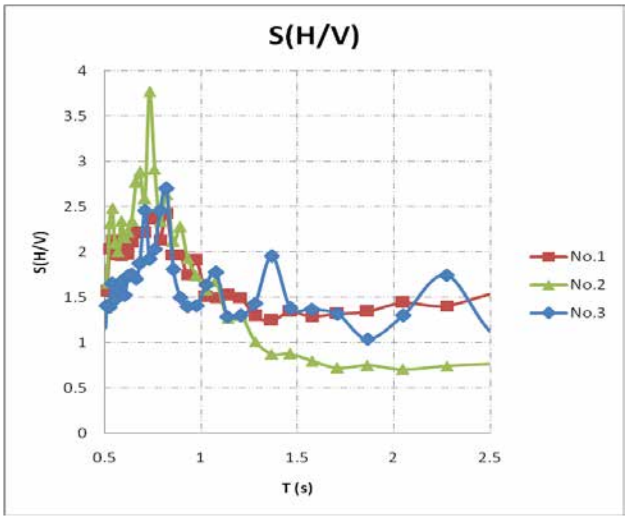


Figure 15. Spectral ratio $S_{H/V}$ of site 2 (Youth Park)

Figures 14 to 15 show the results of spectral ratios of 2 microtremor measurement sites in Hanoi City in September 2011. In the charts, the horizontal axis is the frequency with unit Hz, the vertical axis is the spectral ratio between horizontal and vertical spectral components of microtremor.

From the results, the predominant periods of 2 sites can be estimated (site 1, 2). The total results are summarized into the following table:

Table 7 Predominant frequencies and periods

Site	Predominant Period (s)	Predominant Frequency (Hz)
1.NUCE	1.707	0.586
2.Youth Park	2.062	0.485

To estimate the predominant period of each site, the long-period part of spectral raio will be considered. Each site, the microtremor observation was carried out 3 times, for each point, 1 value of period will be estimated. Then the average value of these 3 points will be the value in the above tables.

From the obtained results, HoChiMinh city has the predominant periods could reach the value of 1.4 to 1.8 seconds. Besides that, in Hanoi city, the predominant periods in some locations could reach the value of 1.7 to 2.0 seconds. Those predominant periods are belonged to the long period part, thus, the researchs of long period ground motion effects to high-rise buildings in these 2 cities are very necessary.

4. VERIFICATION OF THE RESULTS OF MICROTREMOR MEASUREMENT BY BOREHOLE DATA

In this section, the results of predominant periods estimated in part 3 will be verified by using the collected borehole data.

The period of the soil was estimated using the soil strata properties and utilizing the unidimentional wave propagation theory for shear waves in viscoelastic medium (Bowles, 1977) [9]. According with this method the natural period is:

$$T = 4 \ \Sigma H_i / \beta_i \qquad (5)$$

Where:

H = i-stratum wide (m)

β = Shear wave velocity

Shear wave velocity can be estimated by these following formulas:

$$\beta = (G_i / \tau_i)^{1/2} \qquad (6)$$

$$\beta = 89.8 \times N^{\alpha} \qquad (7)$$

$$\beta = 80 \times N^{1/3} \qquad (8)$$

$$\beta = 1000 \times N^{1/3} \qquad (9)$$

Where:

G = Shear Module

τ = Material Density

Several borehole data have been collected from many big constructional projects that belonged to 8 buildings in HoChiMinh city and 4 buildings in Hanoi city. All of borehole data have N-SPT value, however, some of them do not have enough information of G (Shear Module). Consequently, empirical formulas (6) and (7) will be used to estimate the shear wave velocity for the ground in Hanoi and Ho Chi Minh City. Then the period of the soil in those two cities will be estimated.

(3) is used for sand (clayey sand is considered as sand).

(4) is used for clay (sandy clay is considered as clay)

The obtained results are displayed as follows.

(1) Borehole Data in HoChiMinh City

Table 8 PhuocBinh Apartment Building

Borehole	Period (s)	Depth (m)
1	0.877	66.00
2	0.916	66.00
3	0.827	66.00

Table 9 PhuHoangAnh Apartment Building

Borehole	Period (s)	Depth (m)
1	0.909	70.00
2	0.919	70.00
3	0.972	70.00
4	0.893	70.00
5	1.254	70.00
6	1.161	70.00
7	0.915	70.00
8	0.957	70.00
9	0.756	70.00
10	0.916	70.00
11	0.921	70.00
12	0.894	70.00
13	0.897	70.00

Table 10 18th Floor Apartment Building

Borehole	Period (s)	Depth (m)
1	1.005	90.00
2	0.872	70.00
3	0.934	90.00
4	0.851	70.00

Table 11 High Building for Rent

Borehole	Period (s)	Depth (m)
1	1.425	80.00
2	1.154	70.00
3	1.160	70.00
4	1.131	80.00

Table 12 Appartment of HoangAnhGiaLai

Borehole	Period (s)	Depth (m)
1	0.977	70.00
2	0.951	70.00
3	1.005	70.00
4	0.986	70.00
5	0.922	70.00
6	0.916	70.00
7	0.847	70.00
8	0.894	70.00

Table 13 PullMan Saigon Centre

Borehole	Period (s)	Depth (m)
3	1.261	80.00
4	1.350	80.00

Table 14 Extension of Continental Hotel

Borehole	Period (s)	Depth (m)
1	0.989	60.00
2	0.999	60.00
3	1.029	60.00

Table 15 Savico Twin Towers

Borehole	Period (s)	Depth (m)
1	1.017	60.00
2	1.116	60.00
3	1.006	60.00
4	1.004	60.00
5	1.108	60.00

The results show that the predominant period of those construction sites in HoChiMinh city vary from 0.756 to 1.425 seconds. Besides that the results from microtremor observation were 1.4 to 1.8 seconds. Consequently, the assumption that the ground in HoChiMinh city have the potential to resonate with long-period ground motion is reasonable.

(2) Borehole Data in Hanoi City

Table 16 Mandarin Garden Residential

Borehole	Period (s)	Depth (m)
4	0.902	69.80
5	0.909	70.15
13	0.934	69.50
14	0.924	70.05

Table 17 Golden Palace

Borehole	Period (s)	Depth (m)
1	0.699	55.00
2	0.704	55.00
3	0.713	70.00
4	0.685	55.00
5	0.686	55.00
6	0.746	55.00
7	0.712	70.00
8	0.655	55.00
9	0.700	55.00

Table 18 VinhTuy Complex

Borehole	Period (s)	Depth (m)
2	0.952	55.00
3	0.879	55.00
4	0.813	55.00
5	0.859	55.00

Table 19 Crystal Tower

Borehole	Period (s)	Depth (m)
1	0.840	60.00
2	0.842	60.00
3	0.826	60.00

The results show that the predominant period of those construction sites in Hanoi city vary from 0.655 to 0.952 seconds. Besides that the results from microtremor observation were 1.7 to 2.0 seconds. However, the collected borehole data in this city are very few, thus, in the future, more data should be considered to fit with the results of microtremor measurements.

5. ESTIMATION OF LONG-PERIOD GROUND MOTION IN HANOI AND HOCHIMINH CITIES

In this section, the spectral accelerations in bedrock of Hanoi and HoChiMinh city were estimated by attenuation relationship of Uchiyama and Midorikawa 2006 [10)] with the far-source rupture faults that were Sumatra earthquake 2004 and Tha-Khaek fault line in Thailand. Next, the accelerations on ground surface of the above two Vietnamese cities were calculated by using spectral ratio of microtremor and inverse Fourier transform.

(1) Attenuation relationship (AR)

Attenuation relationship is the relationship between the magnitude of an earthquake and the distance away from the fault rupture for a particular ground motion parameter.
These parameters include PGA, PGV, PGD, duration of shaking, predominant period, response spectra.
With AR, far-source strong Eqs can generate ground motion in the surface of distant cities (Fig 16).

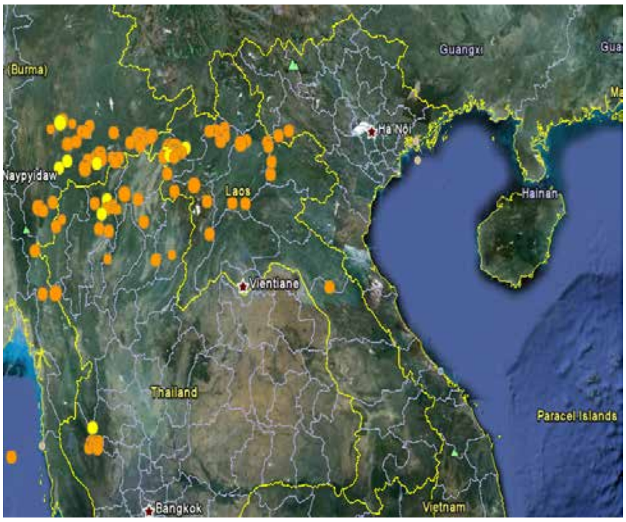


Figure 16. Far-source rupture faults

(Uchiyama-Midorikawa 2006) [10)] attenuation relationship for acceleration spectra has been used. This relationship was developed from 3198 strong motion data from 52 earthquakes happened in and around Japan from 1978 to 2003 with moment magnitude 5.5 to 8.3. The following equation expresses this relationship:

$$\log SA(T) = a(T)M_w + b(T)X + g + d(T)D + c(T) + \sigma(T) \quad (10)$$

Where:
SA: spectral acceleration (cm/s^2)
T: period (s)
a(T) ~ d(T): regression factors
σ(T): logarithm of standard deviation
Mw: moment magnitude
X: closest distance fault (km)
D: depth of epicenter (km)
g = -log(X+e) D ≤ 30km
g = 0.4log(1.7D+e) - 1.4log(X+e) D > 30km
e = 0.006 . 100.5Mw

(2) Regression Factors

a(T) ~ d(T) were determined by regression analysis. (3198 strong motions from 52 earthquakes).

After that, a(T) ~ d(T) can be estimated by x(T):

$$x(T) = x_0 + \sum_{i=1}^{4} x_i.(\log T)^i \quad (11)$$

Where x_0 ~ x_4 are looked up from this table:

Table 20 Regression Factors

Factors	x_0	x_1	x_2	x_3	x_4
a(T)	0.6692	0.3140	0.1199	-0.1135	-0.0541
b(T)	-0.0018	0.0029	-0.0010	-0.0006	0.0003
c(T)	-0.8028	-3.4501	-1.3750	1.0960	0.5136
d(T)	0.0025	-0.0054	-0.004	0.0012	0.0001

The value of logarithm of standard deviation σ(T) is traced directly from the chart result of Uchiyama - Midorikawa paper 2006. (by the free software: Engauge Digitizer 4.1)

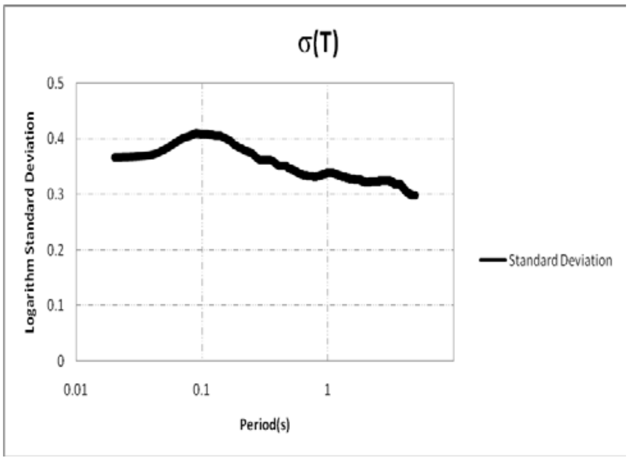


Figure 17. Logarithm of standard deviation

(3) Far sources rupture faults

This section describes the rupture faults that were used to estimated ground motion in Hanoi and HoChiMinh cities.

a) Sumatra earthquake 2004

This earthquake was used to estimated ground motion in HoChiMinh city with attenuation relationship.
It happened on 2004 December 26 00:58:53 UTC. (from USGS report)
Mw = 9.3 (Moment magnitude = (logMo/1.5)-10.73
where Mo = 10^{30} is seismic moment = [fault rigidity] x [fault area] x [fault slip distance]) [11)]
Nearest Distance Fault to HoChiMinh City: 1174 km. The depth: D = 30 km.

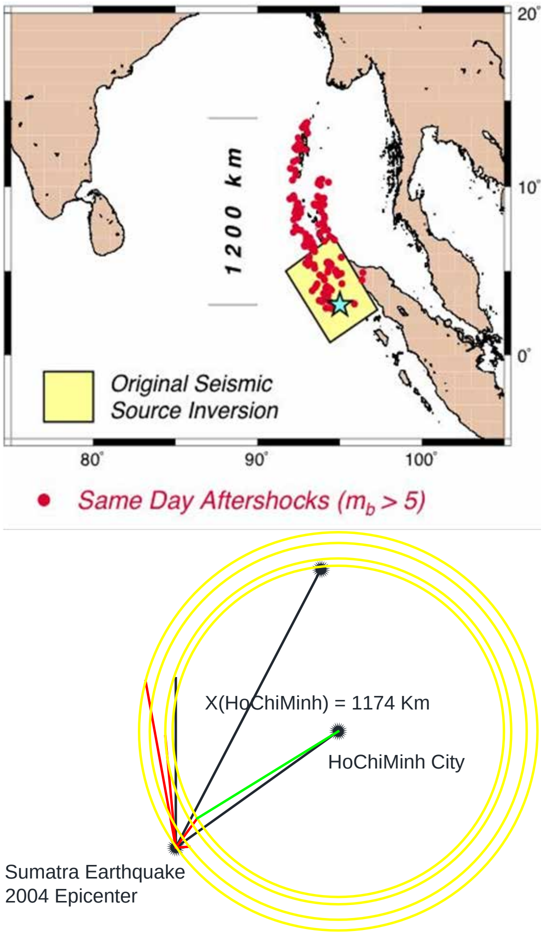


Figure 18. Sumatra 2004 location and nearest distance fault to HoChiMinh city (the green line)

b) THA KHAEK fault line in Thailand

This fault line was used to estimate the ground motion in Hanoi city.

From Matsuda 1975 research [12], moment magnitude of a rupture fault could be estimated by the fault length as follows:

$M_w = 0.88*(\log L+2.9)/0.6+0.54$ (12)

Where L is the fault length = 140 km

$\rightarrow M_w = 7.94$

Nearest Distance Fault to Hanoi City: 357 km

The assumed depth: D = 30 km

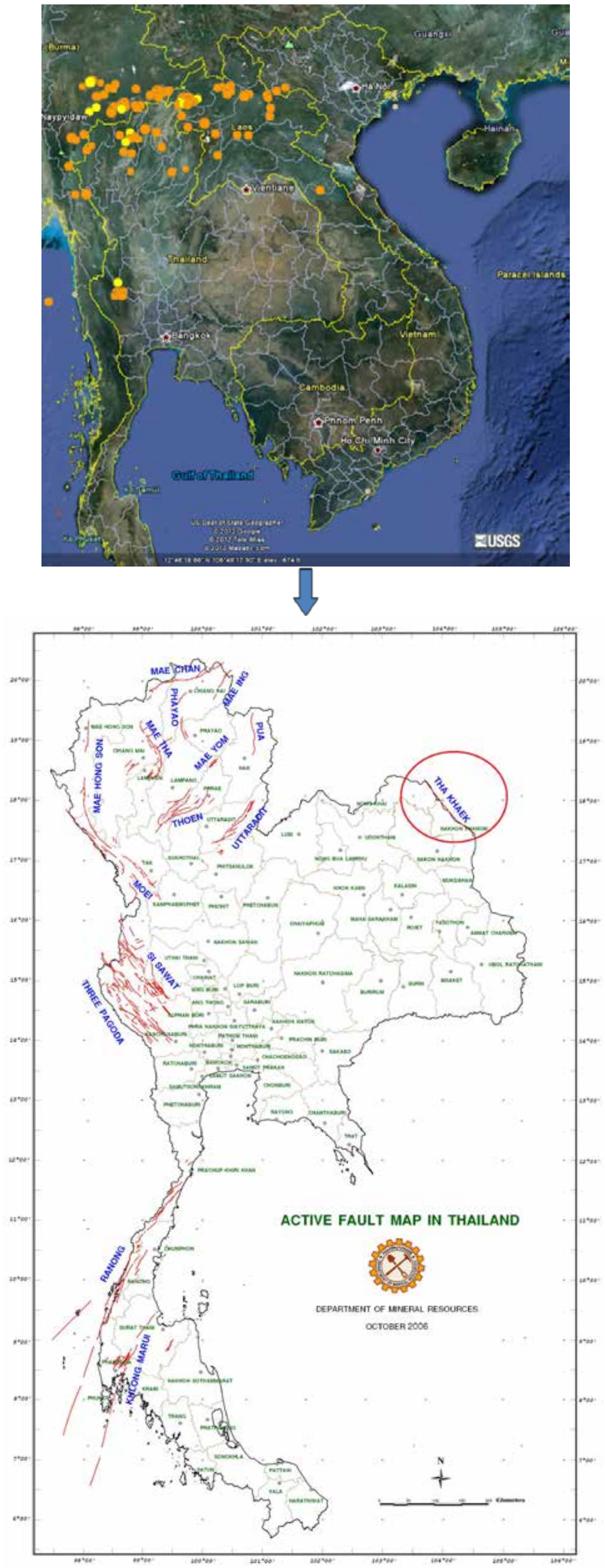


Figure 19. THA-KHAEK fault line in Thailand (the red circled)

(4) Spectral acceleration in bedrock and on ground surface of Hanoi and HoChiMinh cities

a) Spectral acceleration in bedrock

Apply attenuation relationship (Uchiyama and Midorikawa 2006) for acceleration spectra, we have the following results:

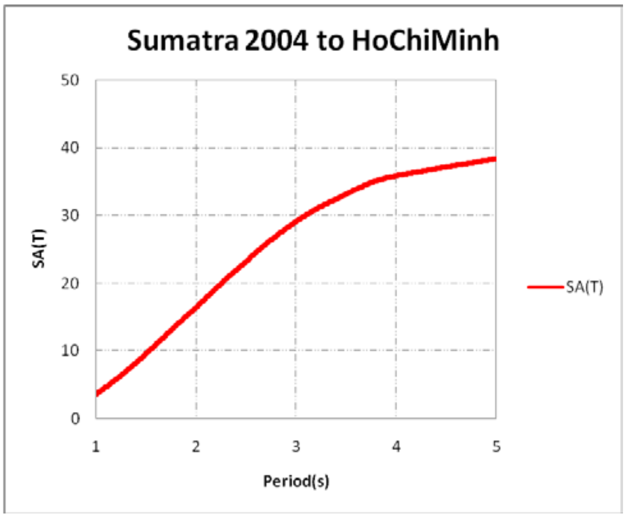


Figure 20. Spectral acceleration in HoChiMinh city bedrock

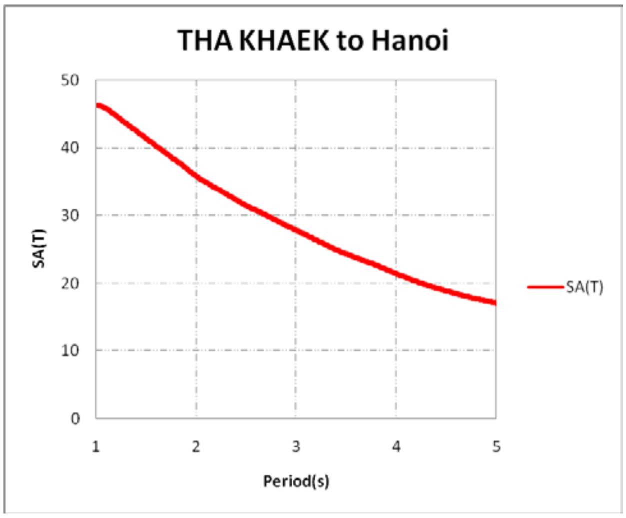


Figure 21. Spectral acceleration in Hanoi city bedrock

b) Spectral acceleration on ground surface

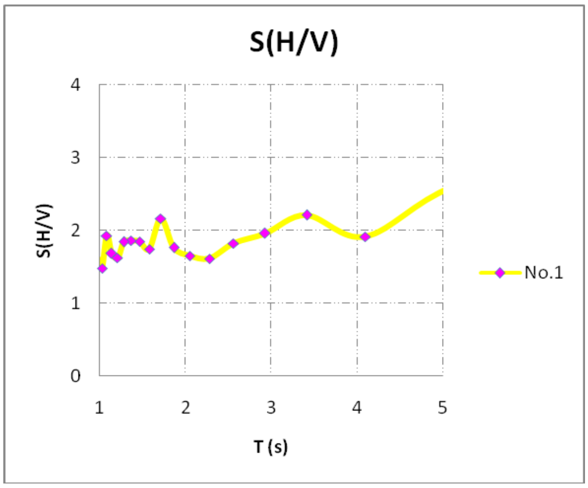
From many researches for instance 上半　文昭: 常時微動による地盤・構造物の評価法 (Evaluation methods and structures of the ground by Microtremor), RRR 2009.9

Spectral acceleration in ground surface could be estimated by:

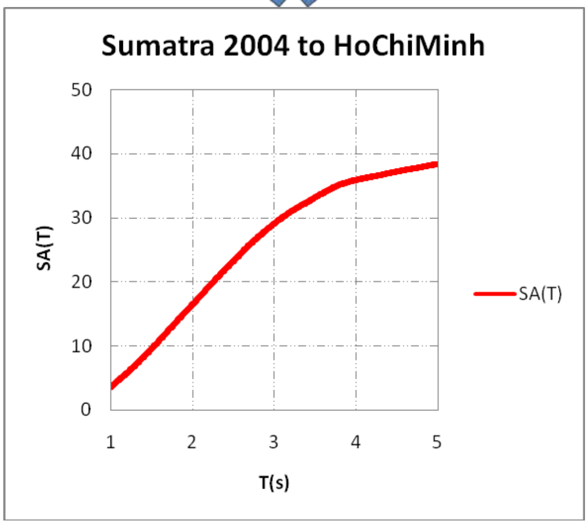
$Sa_{(surface)} = Sa_{(bed\ rock)} \times (H/V)_{Sa}$

Where $(H/V)_{Sa}$ is acceleration spectral ratio of Microtremor - that were estimated in March and September 2011.

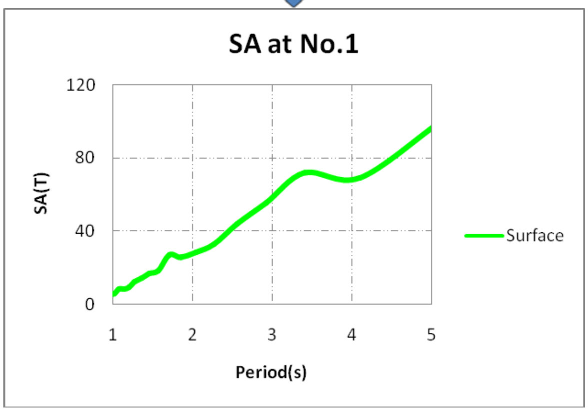
We have the result as follows:



Spectral ratio for HoangVanThu park - point 1 (HoChiMinh city - September 2011)

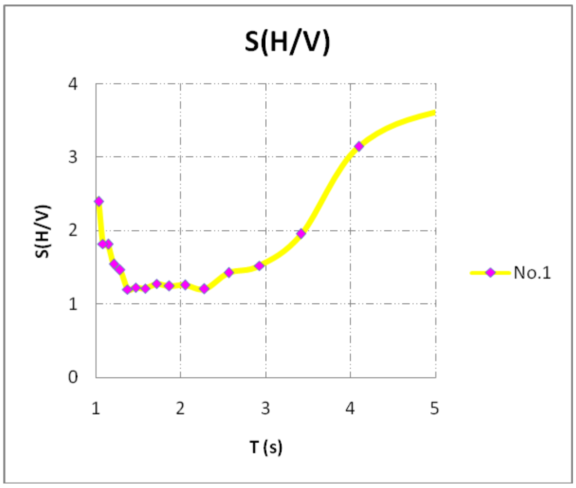


Sa in HoChiMinh city bedrock



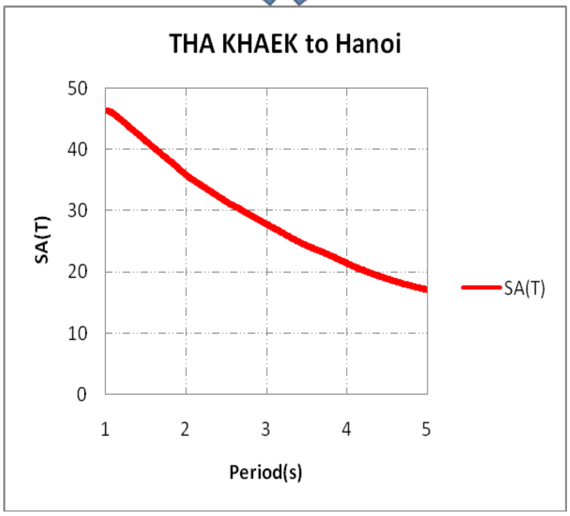
Sa on surface of HoangVanThu park - point 1 (HoChiMinh city - September 2011)

Figure 22. Estimation of Sa on surface of 1 site in HoChi-Minh city

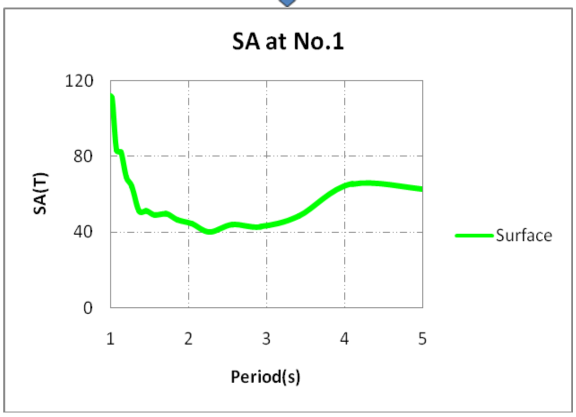


Spectral ratio for NUCE - point 1

(Hanoi city - September 2011)



Sa in Hanoi city bedrock



Sa on surface of NUCE - point 1

(Hanoi city - September 2011)

Figure 23. Estimation of Sa on surface of 1 site in Hanoi city

We only show 2 sites for illustration in the 2 cites, the results of other sites would be summarized in to the appendix.

(5) Acceleration on ground surface of Hanoi and HoChiMinh cities

Next, using the Fortran code to do the inverse Fourier transform of the spectral acceleration on ground surface in the previous step, the accelerations on ground surface of the above two Vietnamese cities are obtained and showed as follows:

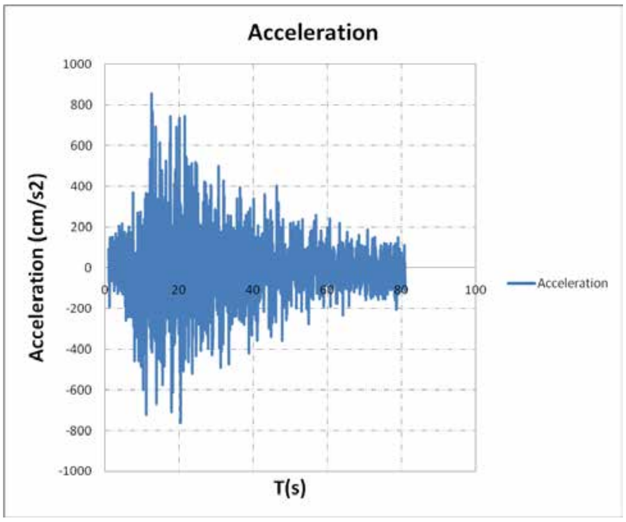


Figure 24. Acceleration on ground surface of 1 site in HoChiMinh city - HoangVanThu park - point 1 (HoChiMinh city - September 2011)

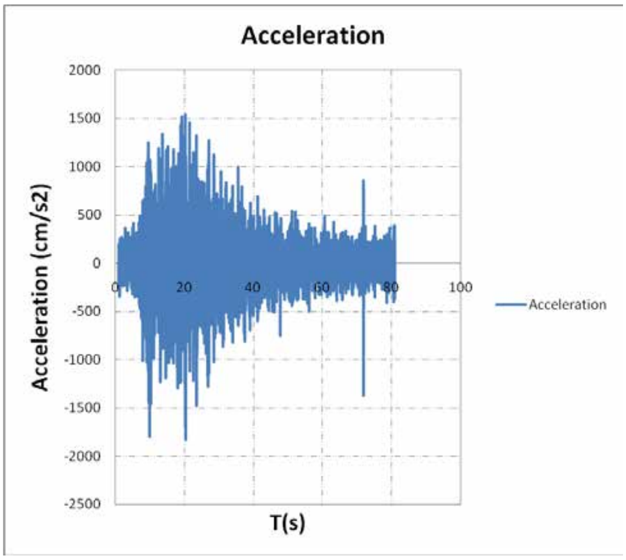


Figure 25. Acceleration on ground surface of 1 site in Hanoi city - NUCE - point 1 (Hanoi city - September 2011)

We only show 2 sites for illustration in the 2 cites, the results of other sites would be summarized in to the appendix.

The following tables show the PGA results of sites in Hanoi and HoChiMinh cities.

Table 21 PGA of sites in HoChiMinh city - March 2011

Site	HVT1	HVT2	HVT3	KH1	KH2	KH3
PGA(g)	2.69	1.29	1.30	1.24	1.18	1.50
Site	LTR1	LTR2	LTR3	TD1	TD2	TD3
PGA(g)	1.19	0.95	1.04	0.96	1.19	0.65

Table 22 PGA of sites in HoChiMinh city - September 2011

Site	HVT1	HVT2	HVT3	LVT1	LVT2	LVT3
PGA(g)	0.88	0.56	0.76	0.65	0.26	0.56
Site	LTR1	LTR2	LTR3	TD1	TD2	TD3
PGA(g)	0.64	0.66	0.92	0.46	0.54	0.49

Table 23 PGA of sites in Hanoi city - September 2011

Site	NUCE1	NUCE2	NUCE3	YP1	YP2	YP3
PGA(g)	1.85	1.42	2.88	1.68	1.74	1.70

Some comments could be drawn from those above results:

Far-source large earthquakes like Sumatra 2004 could attenuately genenerate long-period ground motions in HoChiMinh city with significant PGA bigger than 1.0g or even up to 2.69g.

Moreover, long-period ground motions with big PGA (exceeded 1.0g or even up to 2.88g) in Hanoi city could be atenually generated by far-source rupture faults like THA-KHAEK fault line in Thailand.

6. TIME HISTORY ANALYSIS OF THE SELECTED BUILDINGS IN HANOI AND HOCHIMINH CITIES

In this section, the obtained accelerations in the previous step were used to do the time history analysis applied for 8 high-rise buildings in Hanoi and HoChiMinh city.

(1) Overview the information of the 8 selected high-rise buildings

I. Southern Cross Sky View
Zone A, south Saigon, belonged to District 7, HoChiMinh City, 18 floors, 1 basement 3.3m, 1 roof, building height: 66.35m. Usage plan 35m x 35m, constructed on weak ground.

II. Highrise XuanLa
19 floors, 1 basement, 1 roof, building height: 72.5m
Area: 45m x 22.5m
Level: Multistorey building type II (H<75m)
Address: New urban area XuanLa, TayHo district, Hanoi City.

III. Vietcombank Tower
Adress: Tran Quang Khai street, Hanoi City.
22 floors, 2 basements, 1 roof, 1 technical floor, building height: 78.5m, area: 27m x 54m
Level: Multistorey building type I (H>=75m)

IV. Highrise BMC
Address: 258 Ben Chuong Duong, phuong CoGiang, District 1, HoChiMinh City
20 floors, 2 basements, building height: 74.35m.

V. Highrise Office A&B Tower
Address: 76 LeLai street, District 1, HochiMinh City
25 floors, 3 basements, building height: 98m, area: 35.2m x 37.7m.

VI. The LICOGI 13 Condominiums (from Ngo Viet Dung's Bachelor Thesis)
Address: KhuatDuyTien Street, ThanhXuan district, Hanoi City
18 floors, 1 basement, 1 roof, 1 technical floor, Multi Storey Building Type II, Building height: 62.3m.

VII. Industrial and Comercial Bank
Adress: GiangVanMinh street, BaDinh district, Hanoi City
18 floors, 1 basement, 1 roof, 1 technical floor, building height: 61.2m.

VIII. CT CIPUTRA Apartment - D, E
Address: New Urban Area - South ThangLong - TuLiem District, Hanoi City
23 floors, 2 technical floors, 1 roof, building height: 85.5m.

(2) Time history analysis

The 8 buildings were modelled in the program ETABS Nonliniear V9.4.7. The accelerations obtained in the previous step were inputed into time history function, after that, the time history cases were defined (fig 25, 26 for instance).

After running the time history analysis, the roof displacement (Ur(max), Ur(min)) and the maximum storey drift (Dmax) of each building will be received in the output table.

The duration of time history analysis was 80 seconds, that was 8000 steps for 0.01s time interval

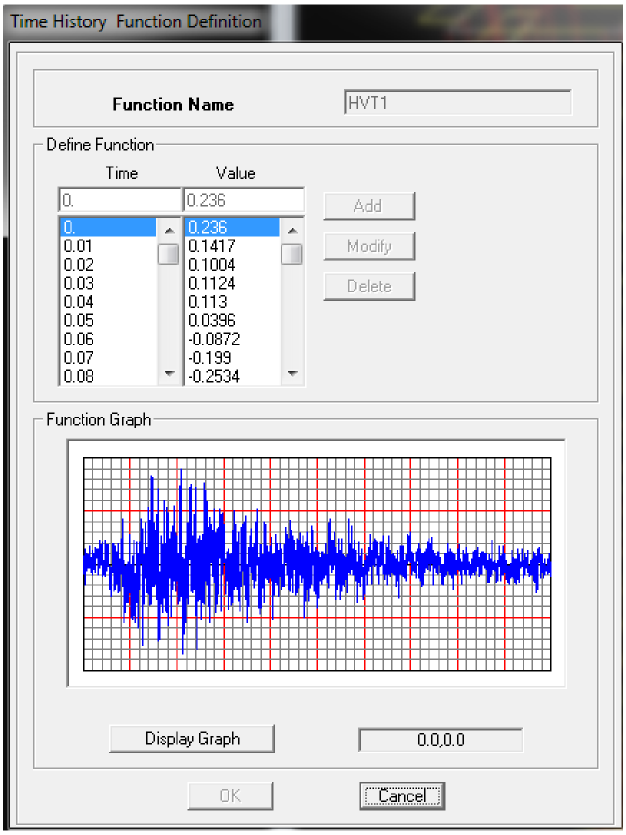


Figure 26. Time history function definition

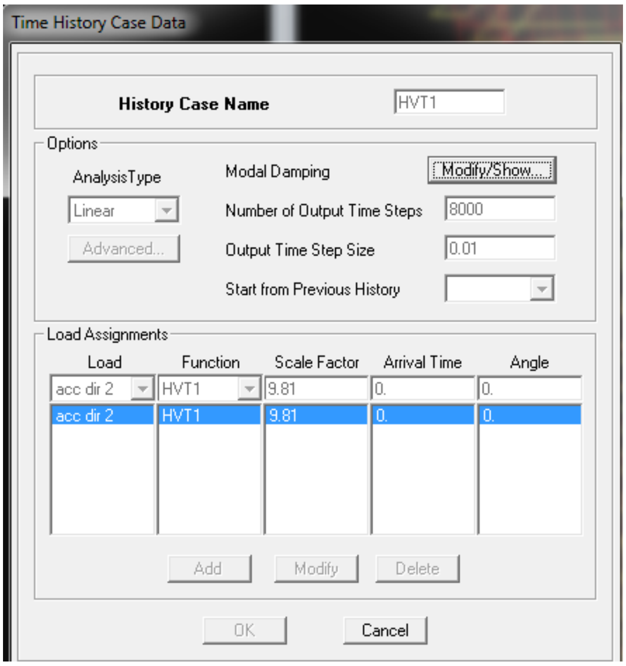


Figure 27. Time history case data

We have the results as follows:

a) Time history analysis (THA) for accelerations obtained in HoChiMinh city in March 2011

Table 24 Building I: Southern Cross Sky View

THA cases	Ur(max) (m)	Ur(min) (m)	Dmax (%)
HVT1	2.876	-2.640	5.564
HVT2	1.003	-0.913	1.960
HVT3	1.101	-1.024	2.157
KH1	0.874	-0.802	1.708
KH2	0.846	-0.769	1.653
KH3	0.972	-0.902	1.895
LTR1	0.495	-0.455	0.976
LTR2	0.485	-0.445	0.954
LTR3	0.487	-0.449	0.961
TD1	0.422	-0.380	0.837
TD2	0.630	-0.582	1.227
TD3	0.380	-0.348	0.749

Table 25 Building IV: Highrise Apartment BMC

THA cases	Ur(max) (m)	Ur(min) (m)	Dmax (%)
HVT1	3.415	-3.590	6.255
HVT2	1.157	-1.235	2.191
HVT3	1.362	-1.415	2.451
KH1	1.037	-1.095	1.918
KH2	0.982	-1.043	1.847
KH3	1.187	-1.237	2.149
LTR1	0.588	-0.622	1.099
LTR2	0.578	-0.611	1.079
LTR3	0.583	-0.614	1.092
TD1	0.475	-0.513	0.933
TD2	0.758	-0.796	1.388
TD3	0.452	-0.477	0.844

Table 26 Building V: Highrise Office A&B Tower

THA cases	Ur(max) (m)	Ur(min) (m)	Dmax (%)
HVT1	6.059	-0.4860	7.321
HVT2	2.038	-1.647	2.488
HVT3	2.451	-1.960	2.911
KH1	1.844	-1.483	2.225
KH2	1.730	-1.394	2.104
KH3	2.130	-1.704	2.549
LTR1	1.049	-0.845	1.267
LTR2	1.030	-0.830	1.243
LTR3	1.041	-0.838	1.258
TD1	0.828	-0.674	1.020
TD2	1.358	-1.090	1.633
TD3	0.802	-0.646	0.967

b) Time history analysis (THA) for accelerations obtained in HoChiMinh city in September 2011

Table 27 Building I: Southern Cross Sky View

THA cases	Ur(max) (m)	Ur(min) (m)	Dmax (%)
HVT1	0.671	-0.618	1.316
HVT2	0.408	-0.377	0.800
HVT3	0.598	-0.549	1.169
LTR1	0.453	-0.417	0.886
LTR2	0.442	-0.406	0.863

LTR3	0.666	-0.611	1.304
LVT1	0.433	-0.397	0.852
LVT2	0.174	-0.160	0.342
LVT3	0.351	-0.319	0.694
TD1	0.247	-0.223	0.488
TD2	0.246	-0.224	0.487
TD3	0.196	-0.179	0.386

Table 28 Building IV: Highrise Apartment BMC

THA cases	Ur(max) (m)	Ur(min) (m)	Dmax (%)
HVT1	0.810	-0.850	1.487
HVT2	0.495	-0.518	0.906
HVT3	0.708	-0.748	1.315
LTR1	0.543	-0.571	1.000
LTR2	0.528	-0.556	0.972
LTR3	0.789	-0.834	1.467
LVT1	0.495	-0.518	0.906
LVT2	0.207	-0.219	0.386
LVT3	0.407	-0.434	0.777
TD1	0.280	-0.301	0.544
TD2	0.284	-0.304	0.544
TD3	0.231	-0.245	0.436

Table 29 Building V: Highrise Office A&B Tower

THA cases	Ur(max) (m)	Ur(min) (m)	Dmax (%)
HVT1	1.447	-1.162	1.733
HVT2	0.885	-0.711	1.060
HVT3	1.258	-1.012	1.520
LTR1	0.969	-0.779	1.165
LTR2	0.941	-0.756	1.134
LTR3	1.402	-1.128	1.694
LVT1	0.912	-0.735	1.101
LVT2	0.367	-0.296	0.443
LVT3	0.716	-0.579	0.871
TD1	0.490	-0.397	0.600
TD2	0.500	-0.405	0.609
TD3	0.411	-0.332	0.498

c) Time history analysis (THA) for accelerations obtained in Hanoi city in September 2011

Table 30 Building VI: The LICOGI 13 Condominiums

THA cases	Ur(max) (m)	Ur(min) (m)	Dmax (%)
NUCE1	0.838	-1.003	1.980
NUCE2	0.427	-0.505	1.015
NUCE3	0.798	-0.944	1.948
YP1	0.838	-1.003	1.980
YP2	0.242	-0.275	0.573
YP3	0.583	-0.693	1.408

Table 31 Building VII: Industrial and Comercial Bank

THA cases	Ur(max) (m)	Ur(min) (m)	Dmax (%)
NUCE1	0.530	-0.520	1.104
NUCE2	0.270	-0.262	0.565
NUCE3	0.508	-0.507	1.086
YP1	0.320	-0.310	0.674
YP2	0.154	-0.141	0.324
YP3	0.372	-0.373	0.794

Table 32 Building VIII: CT CIPUTRA Apartment - D, E

THA cases	Ur(max) (m)	Ur(min) (m)	Dmax (%)
NUCE1	0.763	-0.771	1.184
NUCE2	0.388	-0.387	0.605
NUCE3	0.734	-0.717	1.148
YP1	0.457	-0.457	0.718
YP2	0.220	-0.210	0.344
YP3	0.537	-0.528	0.840

Table 33 Building II: High-rise XuanLa

THA cases	Ur(max) (m)	Ur(min) (m)	Dmax (%)
NUCE1	0.773	-0.876	1.748
NUCE2	0.396	-0.437	0.874
NUCE3	0.723	-0.770	1.619
YP1	0.469	-0.517	1.041
YP2	0.230	-0.234	0.506
YP3	0.529	-0.570	1.173

Table 34 Building III: Vietcombank Tower

THA cases	Ur(max) (m)	Ur(min) (m)	Dmax (%)
NUCE1	0.844	-0.849	1.831
NUCE2	0.431	-0.424	0.931
NUCE3	0.792	-0.771	1.702
YP1	0.509	-0.500	1.100
YP2	0.246	-0.226	0.529
YP3	0.579	-0.570	1.242

d) Discussion of the results of time history analysis

In Hanoi city, some roof displacements were very big (up to 6 meters) when these buildings were impacted by large acceleration excitation. People who work or live in top floors might feel uncomfortable with the vibration or shaking of the building that might affect to their health . Moreover, the maximum storey drift nearcould reach 7.3% that could influence the seismic performance of building. Large inter-story drifts may lead to extensive non-structural damage, for instance, the devices, machines, furniture or lifeline system located inside the building.

In HoChiMinh city, the results showed smaller values of storey drift and roof displacement when comparing with buildings in Hanoi city. However, the maximum drift might reach 1.98% would cause certain unwanted affects to the behavior of furniture inside building.

7. CONCLUSIONS

In this research, the brief overviews of the earthquake situation in the world and in Vietnam were introduced. With the unremitting increase of high-rise buildings and large-scale structures in big cities in Vietnam, the researches of long-period ground motion effects on them are necessary. This paper is only the first attempt to estimate the long period ground motion in Hanoi and HoChiMinh cites, Vietnam.

By using the microtremor observations (first time in HoChiMinh city in March, 2011; and second time in Hanoi and HoChiMinh cities in September, 2011) and the attenuation relationship for spectral acceleration, the predominant periods of the ground in Hanoi and HoChiMinh cities were estimated. Furthermore, the attenuated accelerations on ground surface of those two cites were determined as well. Those obtained accelerations were used to do the time history analysis applied for 8 high-rise buildings in Hanoi and HoChiMinh city to examine their behaviors.

The obtained results show that the ground of HoChiMinh city has considerable possibility of resonating with long-period ground motions, especially, with the ground motions that have the period of around 1.4 to 1.8 seconds. Besides, the ground of Hanoi city might resonant with long-period ground motions that have the period of around 1.7 to 2.0 seconds.

Moreover, the high-rise buildings with typical natural periods approximated to the predominant periods of the ground could be resonating with those long-period ground motions as well.

The verification of borehole data in determining the long-period ground motion show better corresponding in the case of HoChiMinh city than in the case of Hanoi city.

Estimation of accelerations in the two cities showed that: Far-source large earthquakes like Sumatra 2004 could genenerate attenuately long-period ground motions in HoChiMinh city with significant PGA bigger than 1.0g or even up to 2.69g. Moreover, long-period ground motions with big PGA (exceeded 1.0g or even up to 2.88g) in Hanoi city could be generated atenually by far-source rupture faults like THA-KHAEK fault line in Thailand.

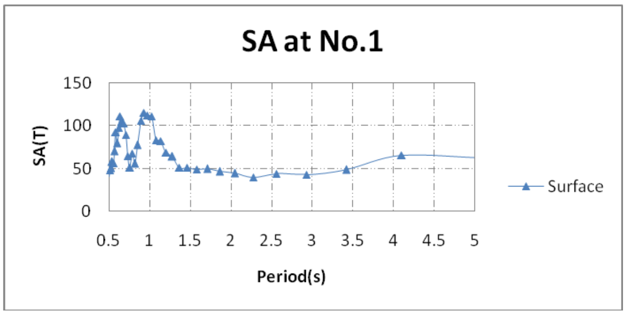
The results of time history analysis implied that far-source rupture faults have considerable possibility to generate long-period ground motions that cause certain affects to the behaviors of high-rise buildings in Vietnamese cities.

In the future researches, more observation of microtremor and borehole data in other cities should be collected. Other far-source such as Taiwanese, Chinese rupture faults or large earthquakes should be considered to examine the behaviors of high-rise buildings with the impact of their attenuated long-period ground motion that might be generated on the ground surface of Vietnamese cities.

ACKNOWLEDGMENT

This study was funded by Kanazawa University and the "322-Project" Scholarship of Vietnamese Government. My special thanks to Prof. Mijajima Masakatsu and Dr. Akira Murata in Earthquake Engineering Lab of Kanazawa University for the kind instruction of the theories for the author to understand and process the output data. We also thank Prof. Idkemoto for useful advices and the review of the microtremor observation results.

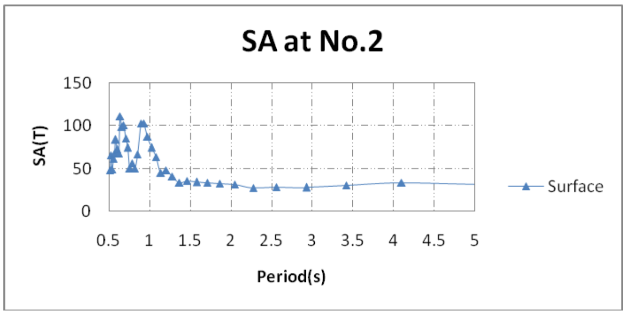
APPENDIX



Sa on surface of NUCE - point 1

(Hanoi city - September 2011)

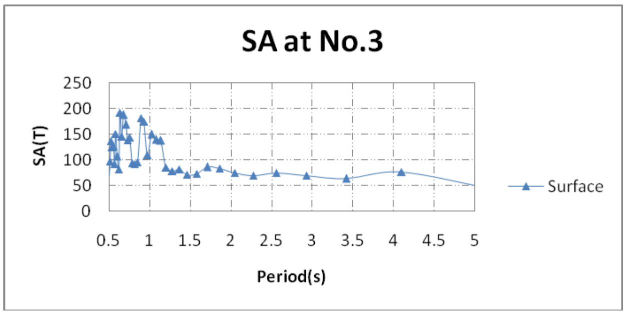
Figure A1. Estimation of Sa on surface of 1 site in Hanoi city



Sa on surface of NUCE - point 2

(Hanoi city - September 2011)

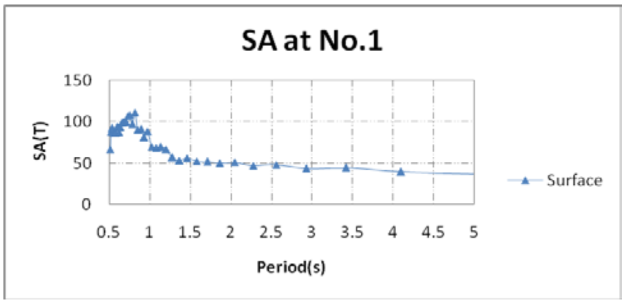
Figure A2. Estimation of Sa on surface of 1 site in Hanoi city



Sa on surface of NUCE - point 3

(Hanoi city - September 2011)

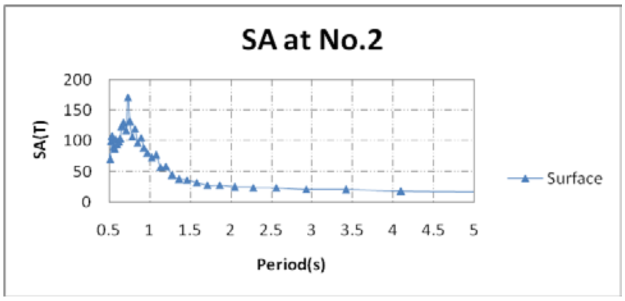
Figure A3. Estimation of Sa on surface of 1 site in Hanoi city



Sa on surface of YP - point 1

(Hanoi city - September 2011)

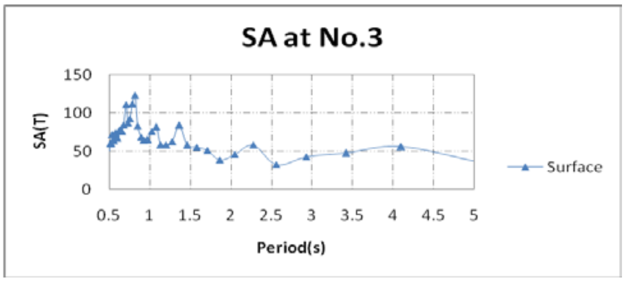
Figure A4. Estimation of Sa on surface of 1 site in Hanoi city



Sa on surface of YP - point 2

(Hanoi city - September 2011)

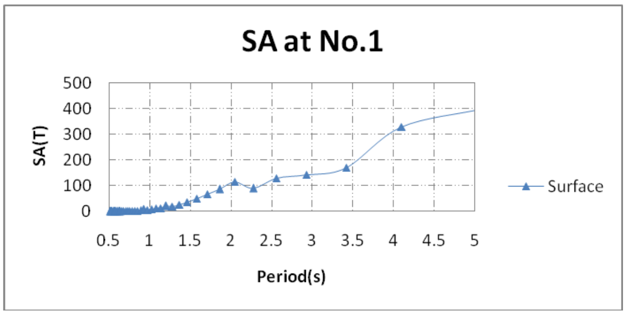
Figure A5. Estimation of Sa on surface of 1 site in Hanoi city



Sa on surface of YP - point 3

(Hanoi city - September 2011)

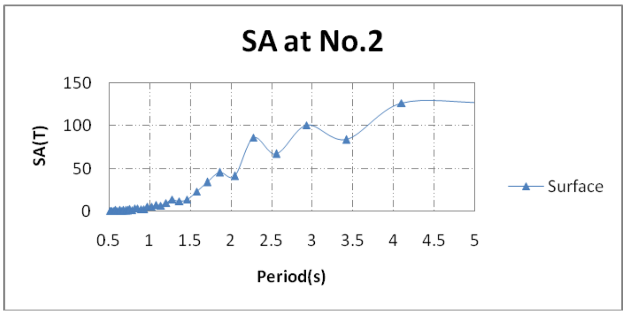
Figure A6. Estimation of Sa on surface of 1 site in Hanoi city



Sa on surface of HVT - point 1

(HoChiMinh (HCM) city - March 2011)

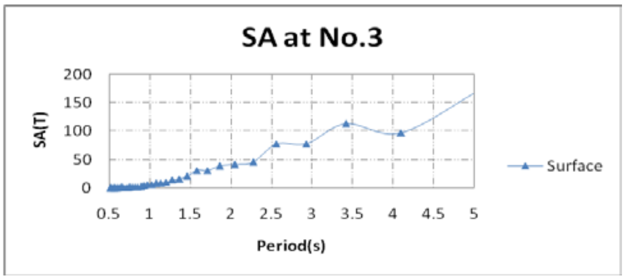
Figure A7. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of HVT - point 2

(HoChiMinh city - March 2011)

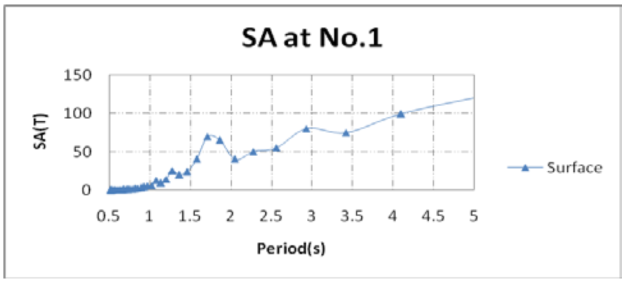
Figure A8. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of HVT - point 3

(HoChiMinh city - March 2011)

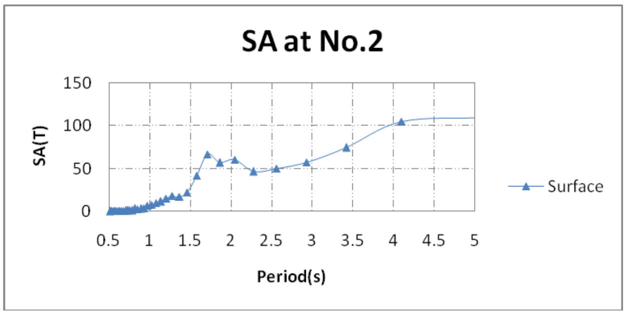
Figure A9. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of KH - point 1

(HoChiMinh city - March 2011)

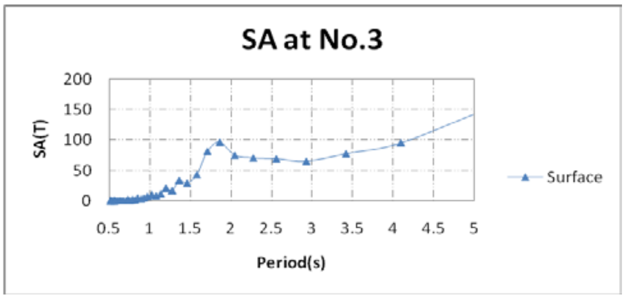
Figure A10. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of KH - point 2

(HoChiMinh city - March 2011)

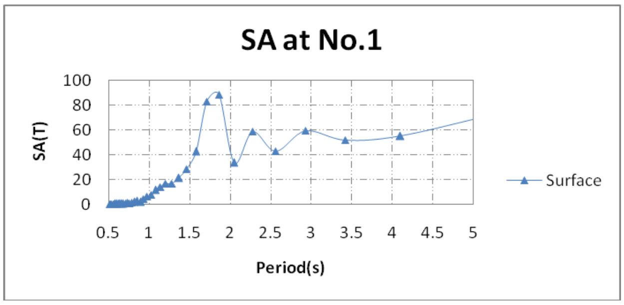
Figure A11. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of KH - point 3

(HoChiMinh city - March 2011)

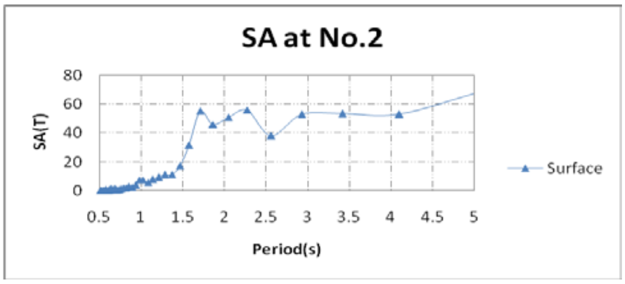
Figure A12. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of LTR - point 1

(HoChiMinh city - March 2011)

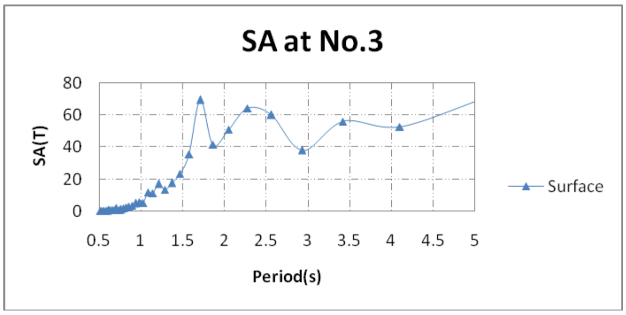
Figure A13. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of LTR - point 2

(HoChiMinh city - March 2011)

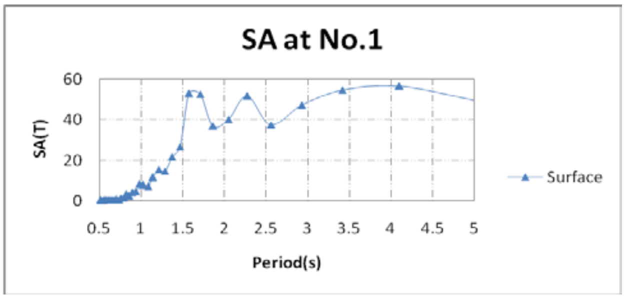
Figure A14. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of LTR - point 3

(HoChiMinh city - March 2011)

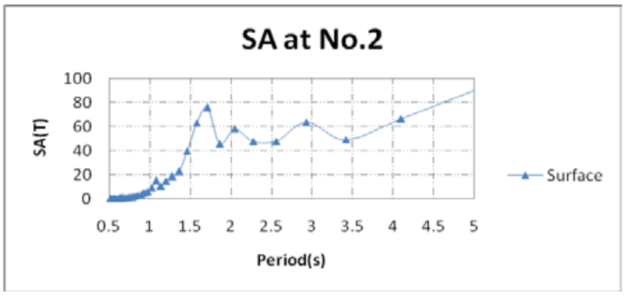
Figure A15. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of TD - point 1

(HoChiMinh city - March 2011)

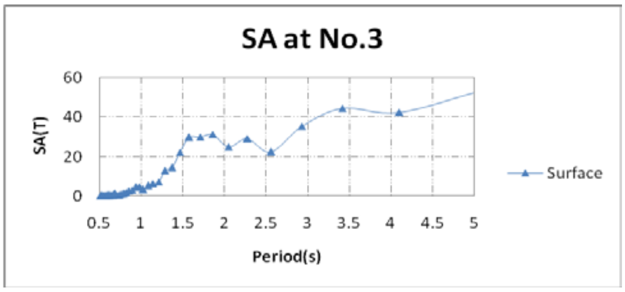
Figure A16. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of TD - point 2

(HoChiMinh city - March 2011)

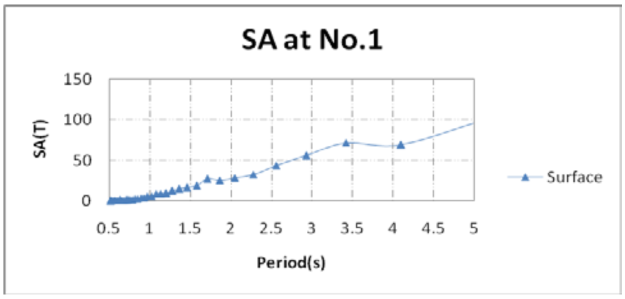
Figure A17. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of TD - point 3

(HoChiMinh city - March 2011)

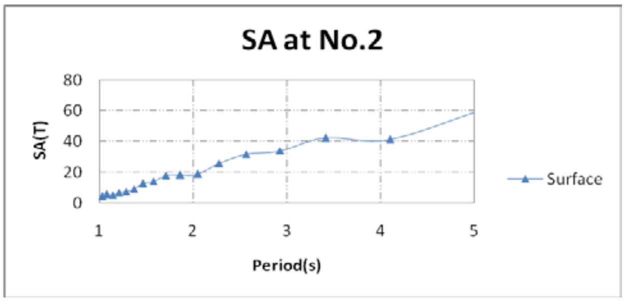
Figure A18. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of HVT - point 1

(HoChiMinh city - September 2011)

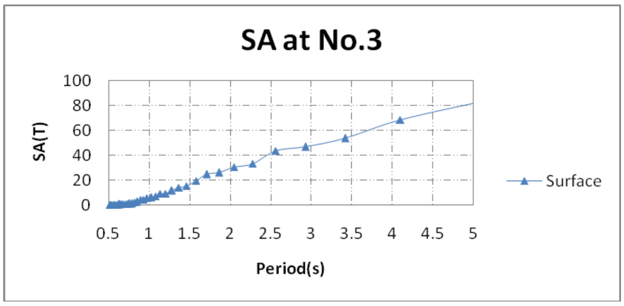
Figure A19. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of HVT - point 2

(HoChiMinh city - September 2011)

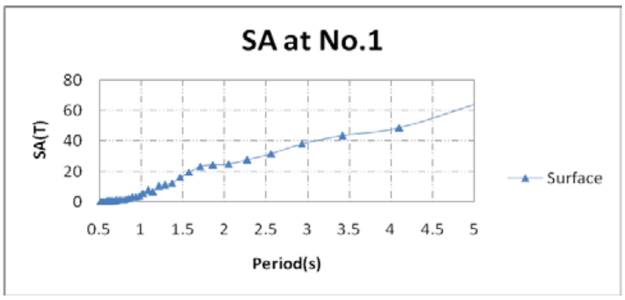
Figure A20. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of HVT - point 3

(HoChiMinh city - September 2011)

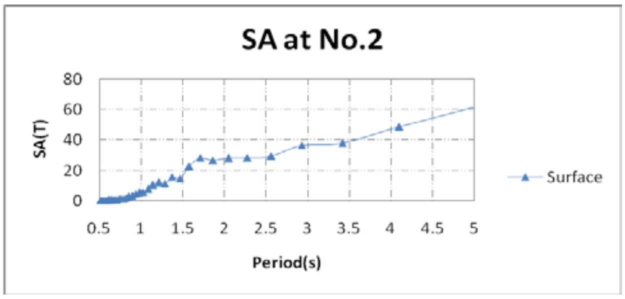
Figure A21. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of LTR - point 1

(HoChiMinh city - September 2011)

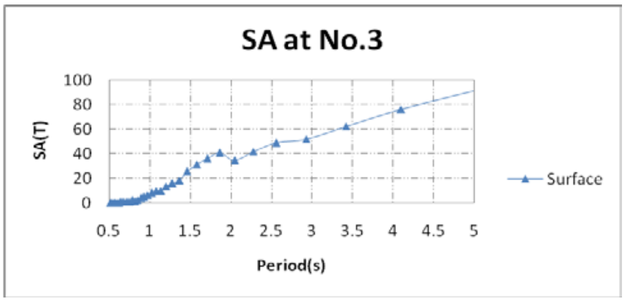
Figure A22. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of LTR - point 2

(HoChiMinh city - September 2011)

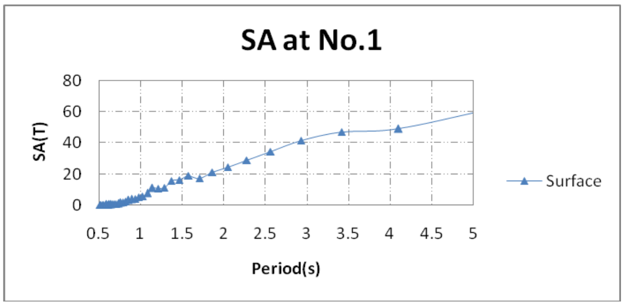
Figure A23. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of LTR - point 3

(HoChiMinh city - September 2011)

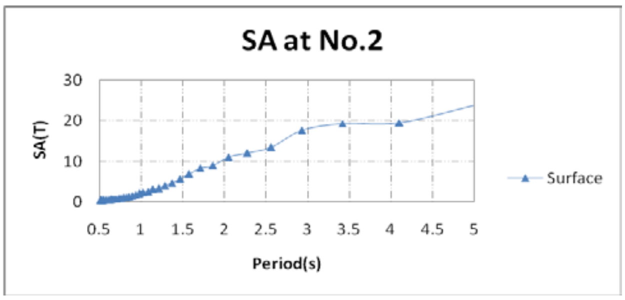
Figure A24. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of LVT - point 1

(HoChiMinh city - September 2011)

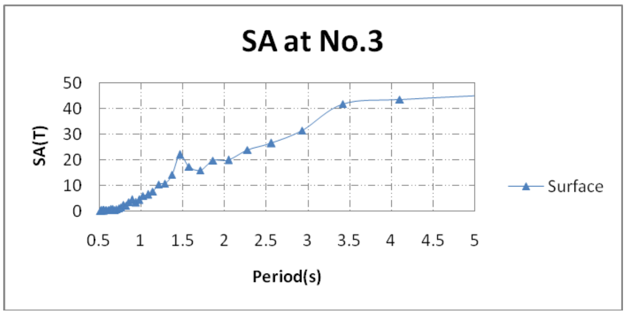
Figure A25. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of LVT - point 2

(HoChiMinh city - September 2011)

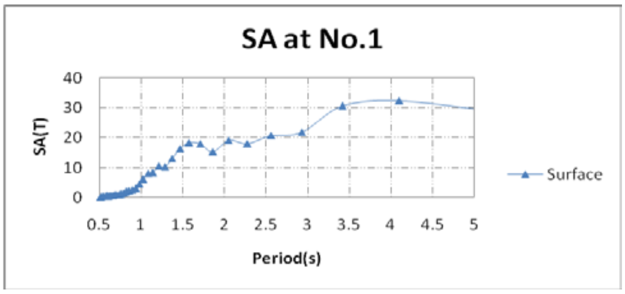
Figure A26. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of LVT - point 3

(HoChiMinh city - September 2011)

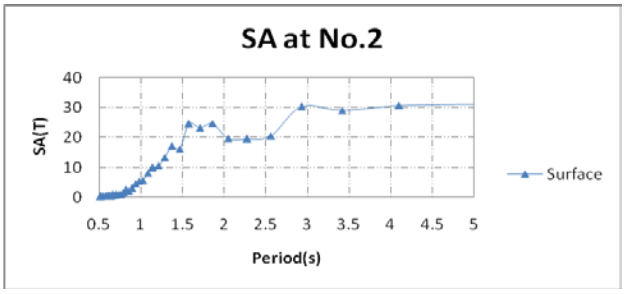
Figure A27. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of TD - point 1

(HoChiMinh city - September 2011)

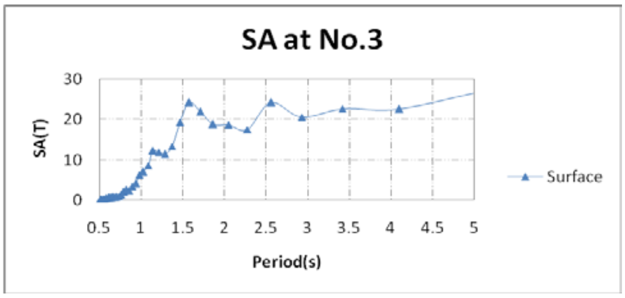
Figure A28. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of TD - point 2

(HoChiMinh city - September 2011)

Figure A29. Estimation of Sa on surface of 1 site in HCM city



Sa on surface of TD - point 3

(HoChiMinh city - September 2011)

Figure A30. Estimation of Sa on surface of 1 site in HCM city

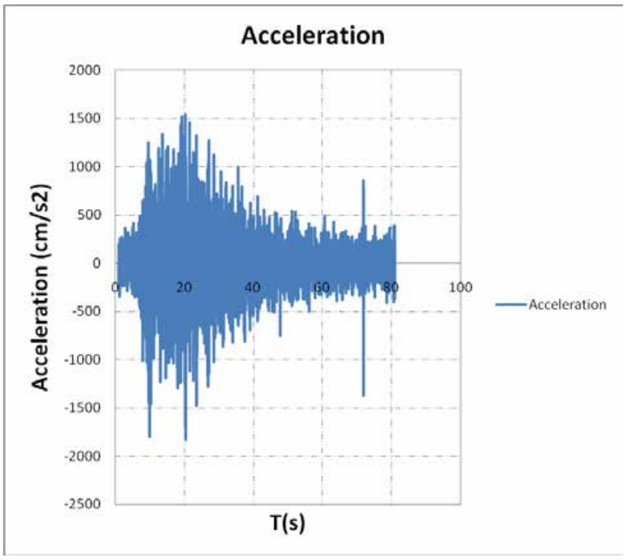


Figure B1. Acceleration on ground surface of 1 site in Hanoi city - NUCE - point 1 (Hanoi city - September 2011)

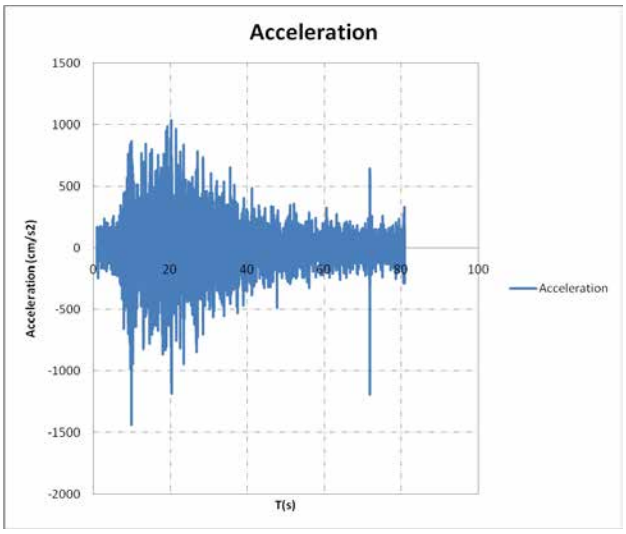


Figure B2. Acceleration on ground surface of 1 site in Hanoi city - NUCE - point 2 (Hanoi city - September 2011)

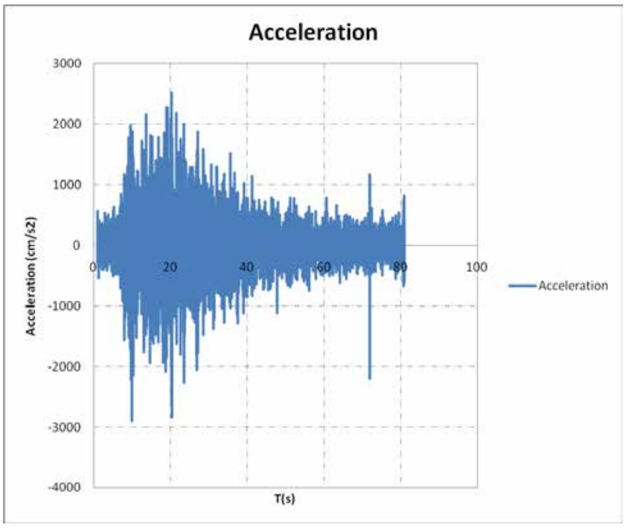


Figure B3. Acceleration on ground surface of 1 site in Hanoi city - NUCE - point 3 (Hanoi city - September 2011)

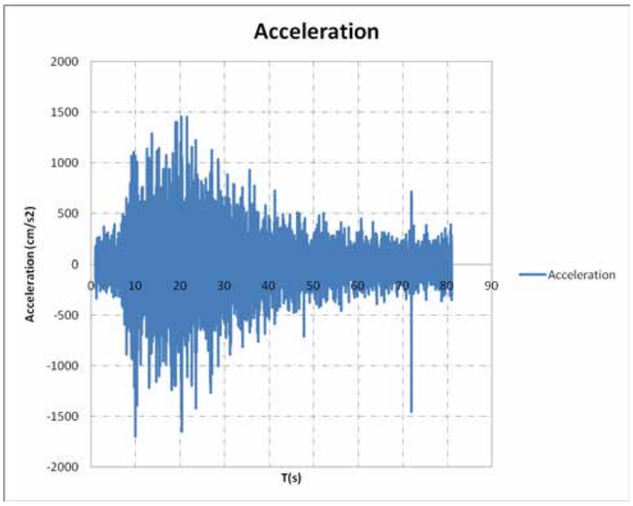


Figure B4. Acceleration on ground surface of 1 site in Hanoi city - YP - point 1 (Hanoi city - September 2011)

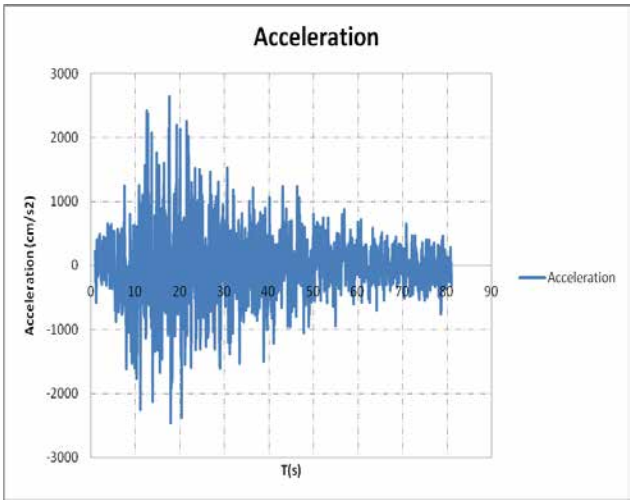


Figure B7. Acceleration on ground surface of 1 site in HoChi-Minh city - HVT - point 1 (HoChiMinh city - March 2011)

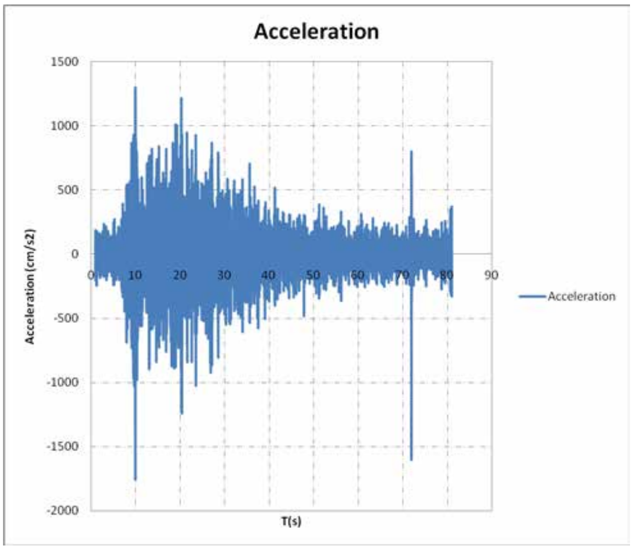


Figure B5. Acceleration on ground surface of 1 site in Hanoi city - YP - point 2 (Hanoi city - September 2011)

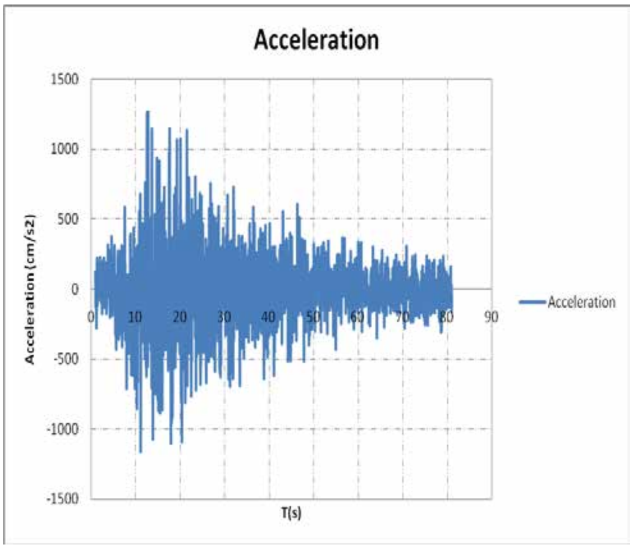


Figure B8. Acceleration on ground surface of 1 site in HoChi-Minh city - HVT - point 2 (HoChiMinh city - March 2011)

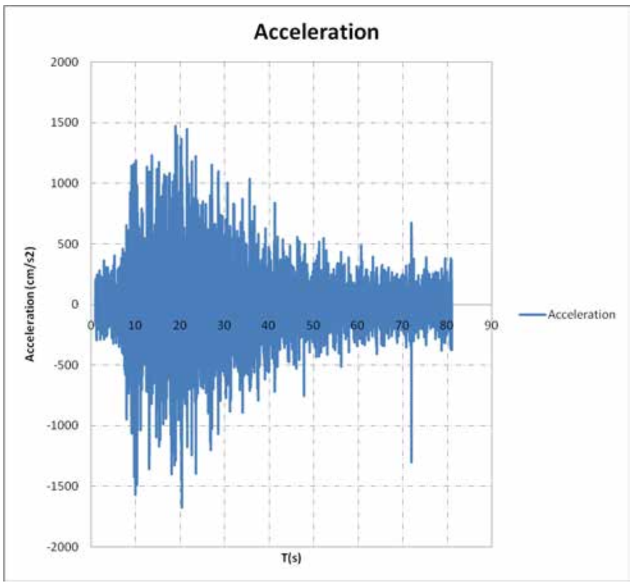


Figure B6. Acceleration on ground surface of 1 site in Hanoi city - YP - point 3 (Hanoi city - September 2011)

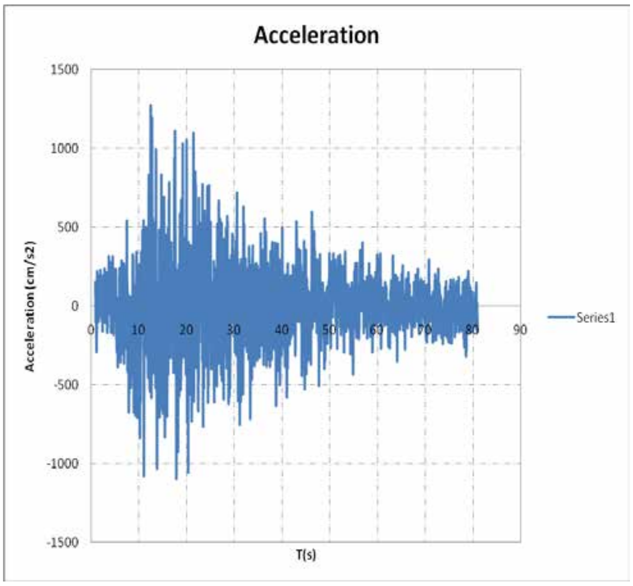


Figure B9. Acceleration on ground surface of 1 site in HoChi-Minh city - HVT - point 3 (HoChiMinh city - March 2011)

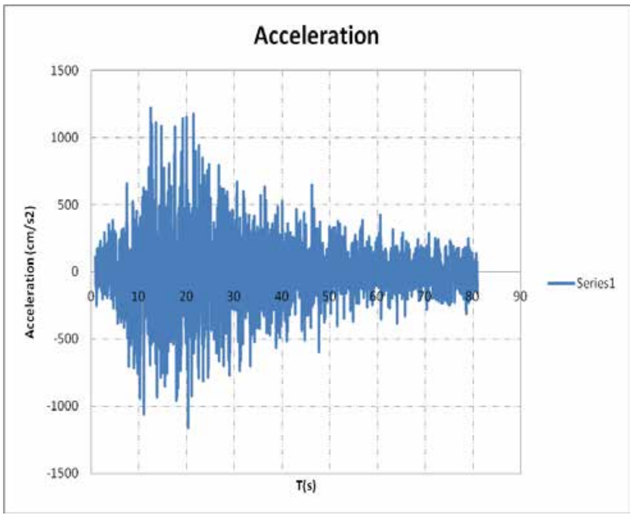


Figure B10. Acceleration on ground surface of 1 site in Ho-ChiMinh city - KH - point 1 (HoChiMinh city - March 2011)

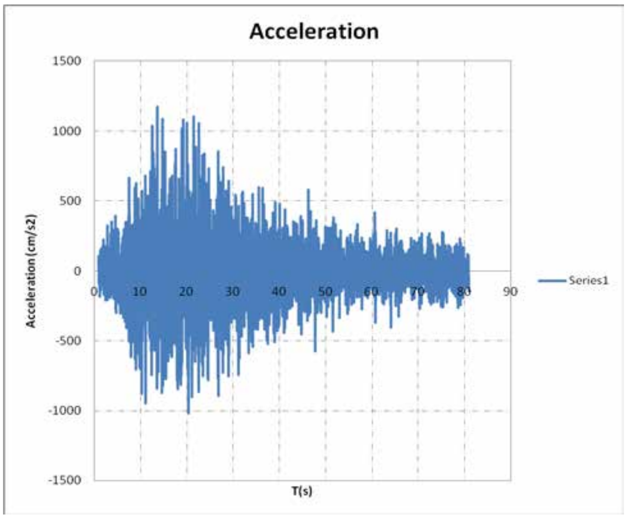


Figure B13. Acceleration on ground surface of 1 site in Ho-ChiMinh city - LTR - point 1 (HoChiMinh city - March 2011)

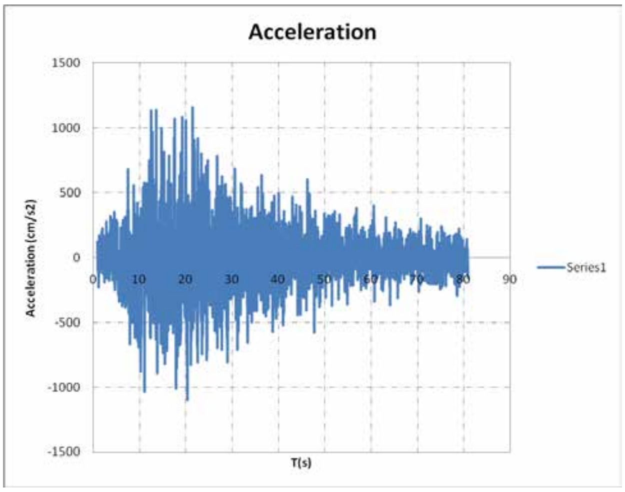


Figure B11. Acceleration on ground surface of 1 site in Ho-ChiMinh city - KH - point 2 (HoChiMinh city - March 2011)

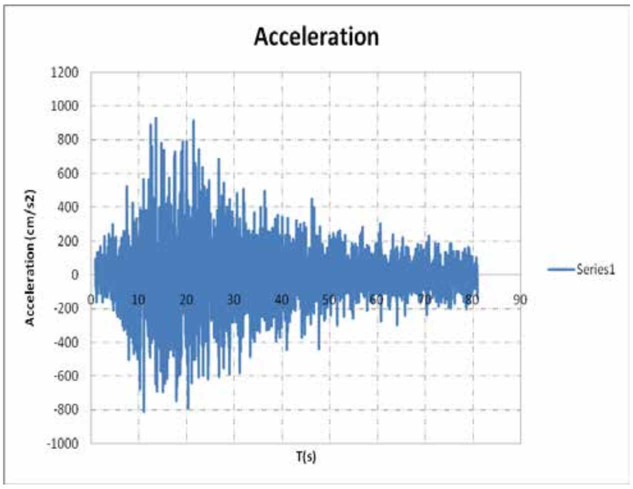


Figure B14. Acceleration on ground surface of 1 site in Ho-ChiMinh city - LTR - point 2 (HoChiMinh city - March 2011)

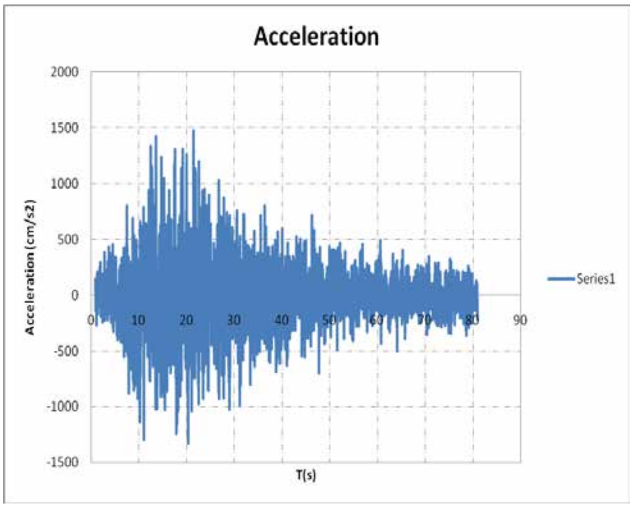


Figure B12. Acceleration on ground surface of 1 site in Ho-ChiMinh city - KH - point 3 (HoChiMinh city - March 2011)

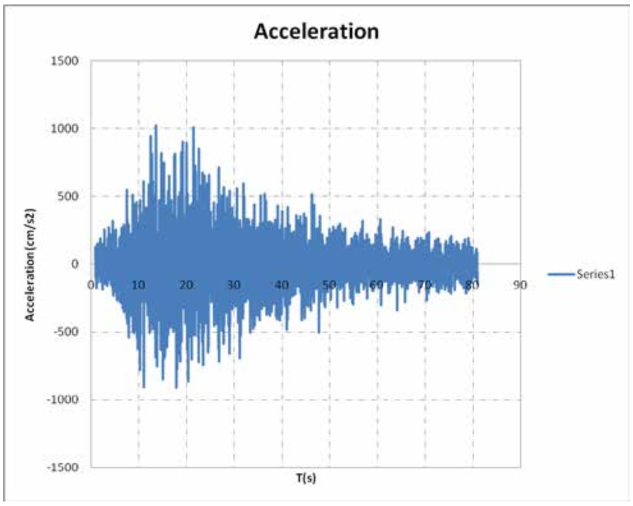


Figure B15. Acceleration on ground surface of 1 site in Ho-ChiMinh city - LTR - point 3 (HoChiMinh city - March 2011)

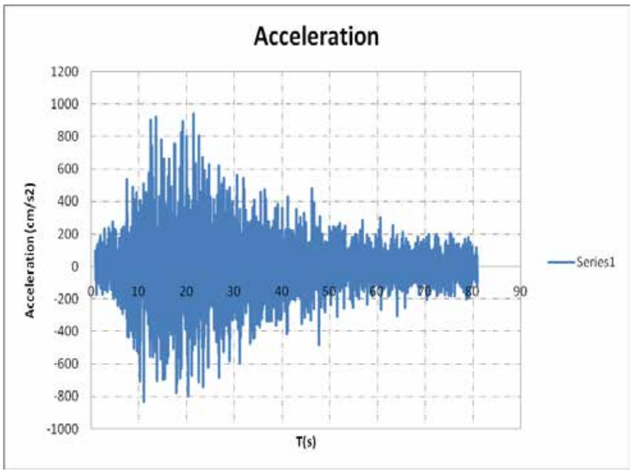


Figure B16. Acceleration on ground surface of 1 site in Ho-ChiMinh city - TD - point 1 (HoChiMinh city - March 2011)

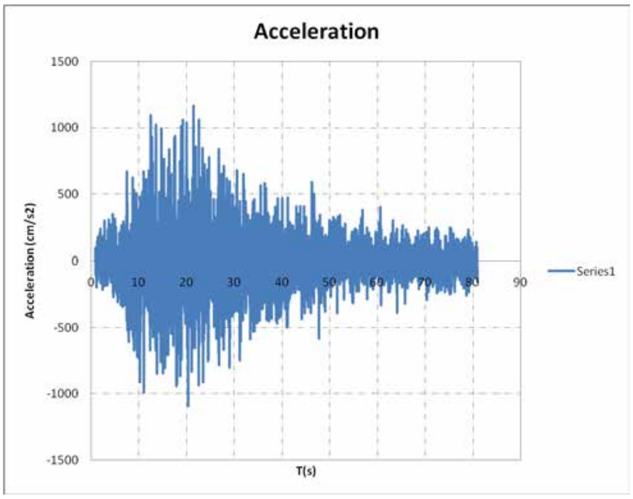


Figure B17. Acceleration on ground surface of 1 site in Ho-ChiMinh city - TD - point 2 (HoChiMinh city - March 2011)

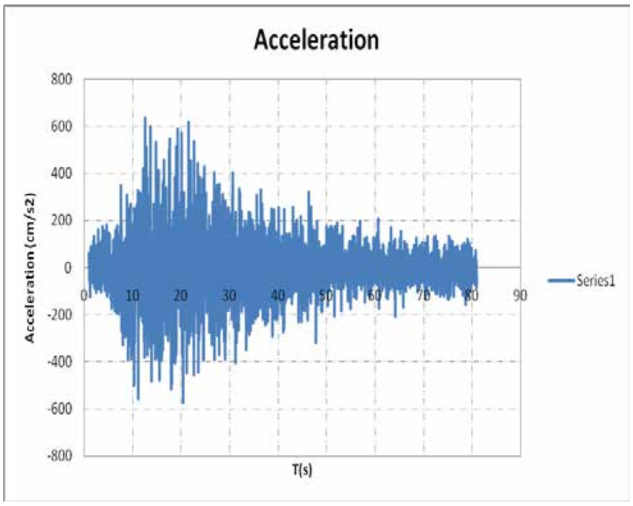


Figure B18. Acceleration on ground surface of 1 site in Ho-ChiMinh city - TD - point 3 (HoChiMinh city - March 2011)

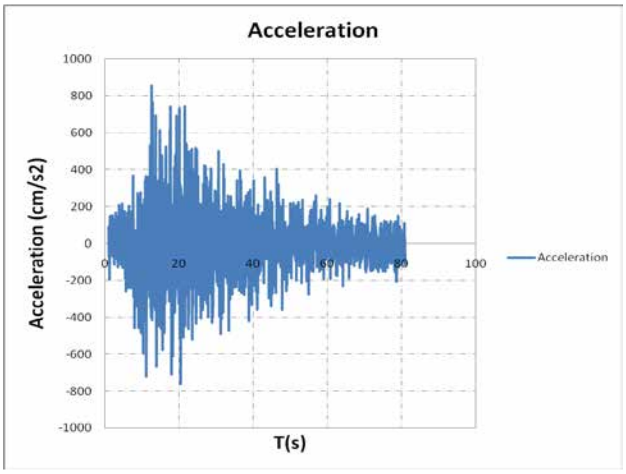


Figure B19. Acceleration on ground surface of 1 site in Ho-ChiMinh city - HVT - point 1 (September 2011)

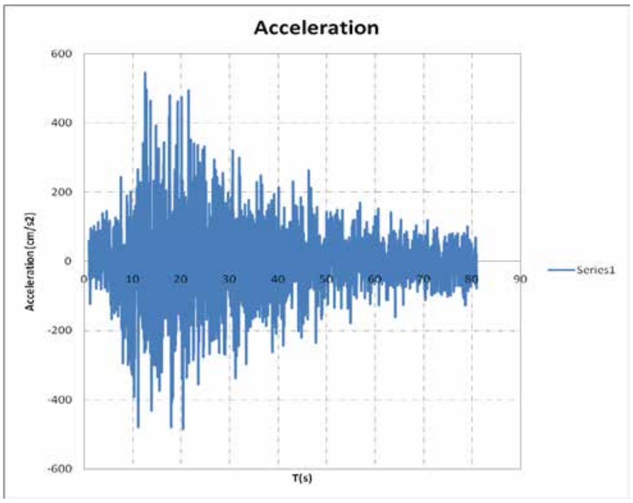


Figure B20. Acceleration on ground surface of 1 site in Ho-ChiMinh city - HVT - point 2 (September 2011)

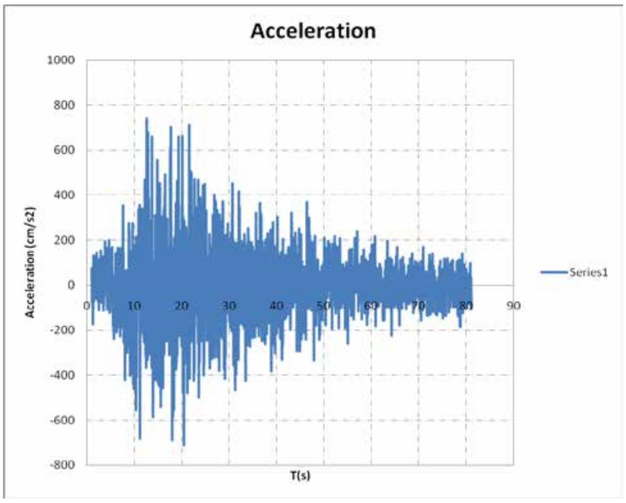


Figure B21. Acceleration on ground surface of 1 site in Ho-ChiMinh city - HVT - point 3 (September 2011)

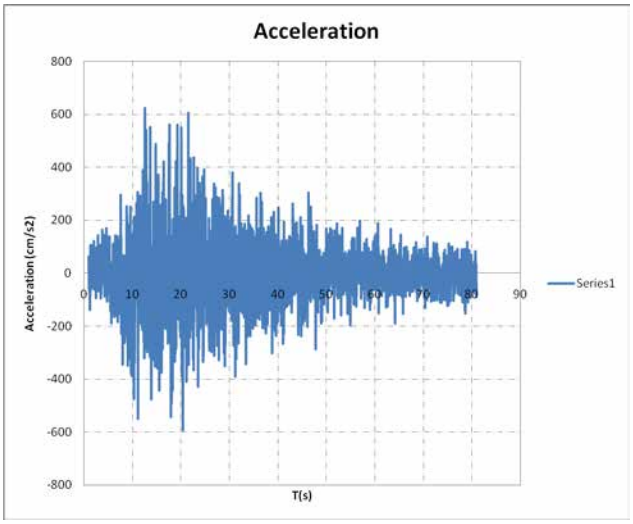


Figure B22. Acceleration on ground surface of 1 site in Ho-ChiMinh city - LTR - point 1 (September 2011)

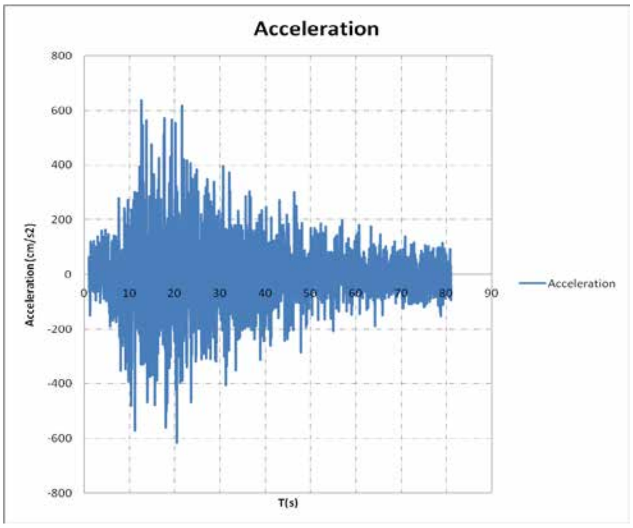


Figure B25. Acceleration on ground surface of 1 site in Ho-ChiMinh city - LVT - point 1 (September 2011)

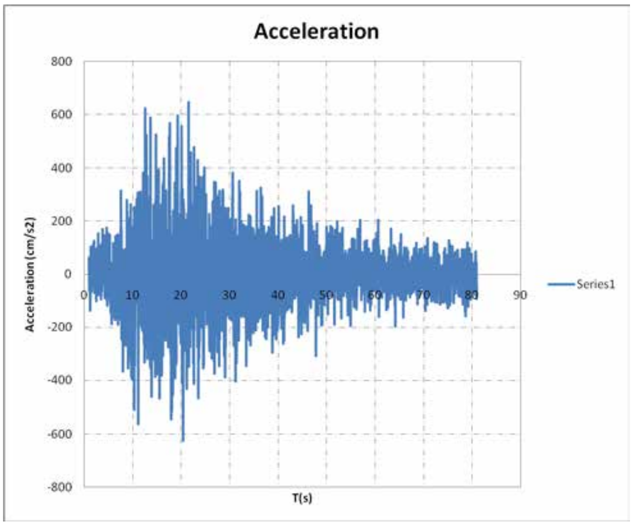


Figure B23. Acceleration on ground surface of 1 site in Ho-ChiMinh city - LTR - point 2 (September 2011)

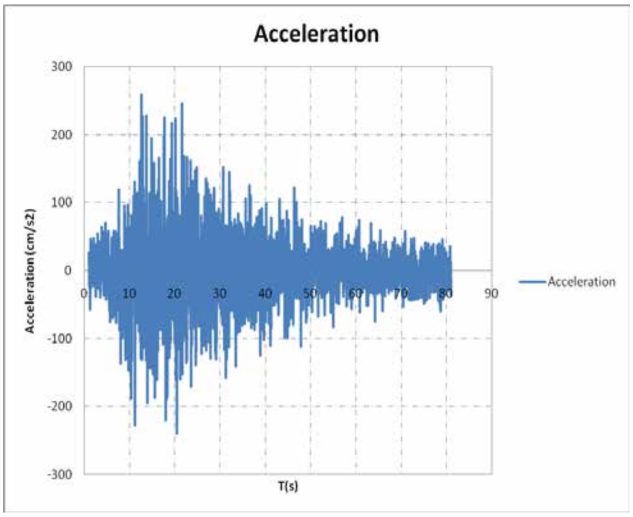


Figure B26. Acceleration on ground surface of 1 site in Ho-ChiMinh city - LVT - point 2 (September 2011)

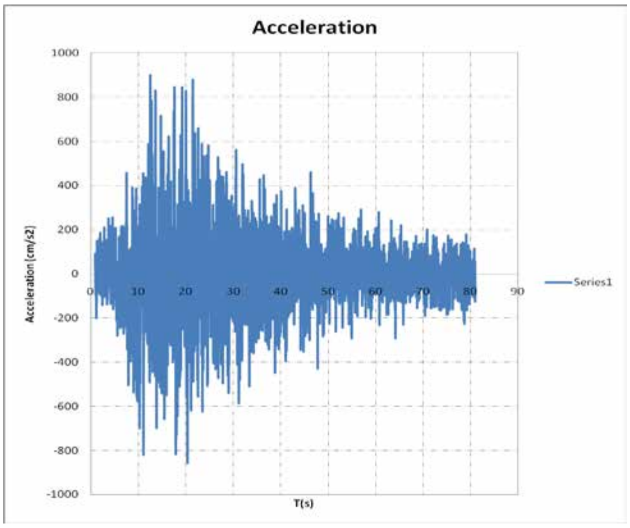


Figure B24. Acceleration on ground surface of 1 site in Ho-ChiMinh city - LTR - point 3 (September 2011)

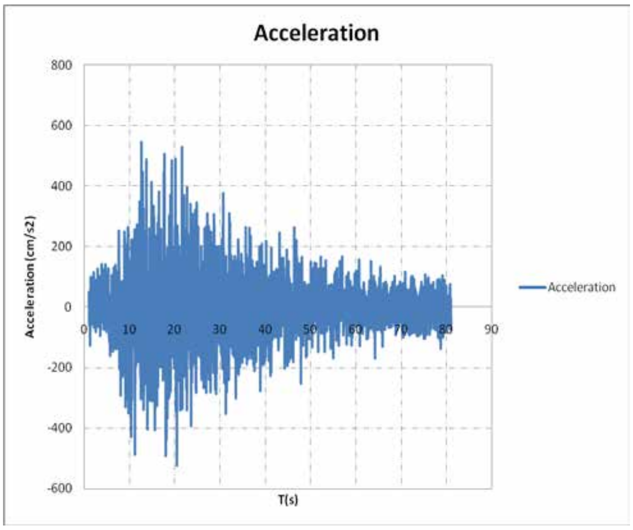


Figure B27. Acceleration on ground surface of 1 site in Ho-ChiMinh city - LVT - point 3 (September 2011)

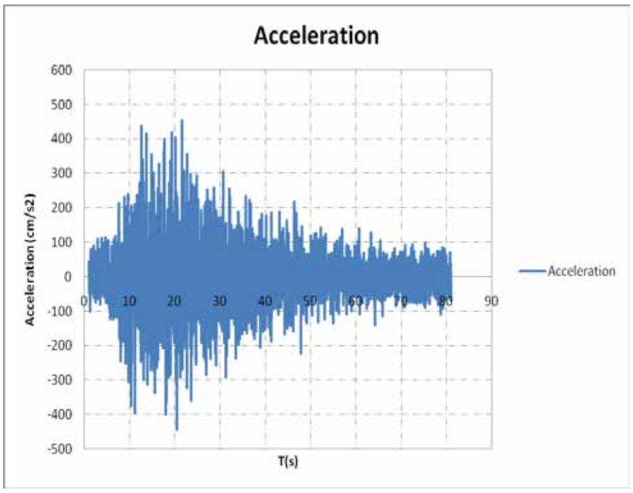


Figure B28. Acceleration on ground surface of 1 site in Ho-ChiMinh city - TD - point 1 (September 2011)

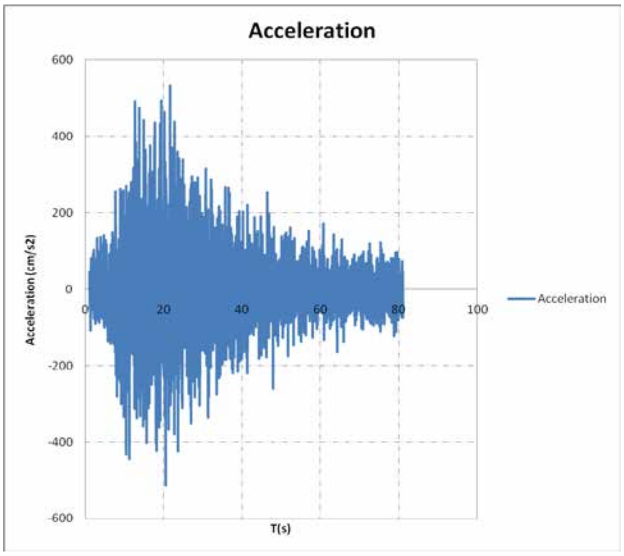


Figure B29. Acceleration on ground surface of 1 site in Ho-ChiMinh city - TD - point 2 (September 2011)

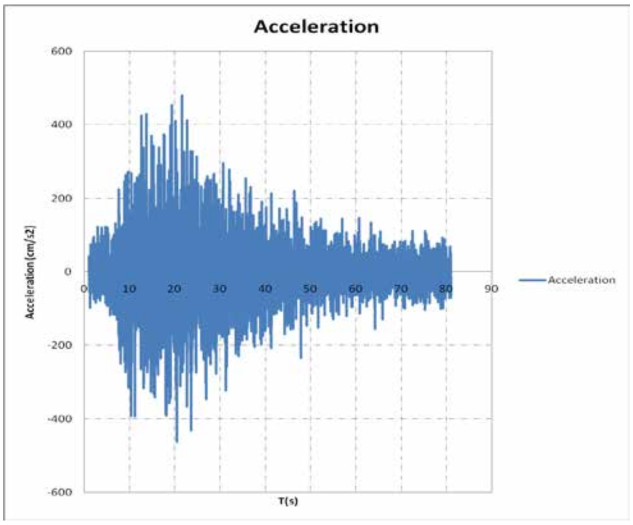


Figure B30. Acceleration on ground surface of 1 site in Ho-ChiMinh city - TD - point 3 (September 2011)

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