Journal of Marine Science and Technology; Vol. 17, No. 4B; 2017: 82-95
DOI: 10.15625/1859-3097/17/4B/12996
http://www.vjs.ac.vn/index.php/jmst

SEISMIC HAZARD ASSESSMENT AND LOCAL SITE EFFECT EVALUATION IN HANOI, VIETNAM

Nguyen Anh Duong*, Pham Dinh Nguyen, Vu Minh Tuan, Bui Van Duan, Nguyen Thuy Linh

Department of Seismology, Institute of Geophysics, VAST
*E-mail: duongna@igp-vast.vn

Received: 9-11-2017

ABTRACT: In this study, we have carried out the probabilistic seismic hazard analysis in Hanoi based on the latest seismotectonic data. The seismic hazard map shows peak ground acceleration values on rock corresponding to the 10% probability of exceedance in a 50-year time period (approximately return periods of 500 years). The calculated results reveal that the maximum ground acceleration can occur on rock in Hanoi is about 0.13 g corresponding to the shaking intensity level of VIII on the MSK-64 scale. The ground motion values calculated on rock vary according to the local site conditions. We have evaluated and corrected the local site effects on ground motion in Ha Dong district, Hanoi by using microtremor and borehole data. The Nakamura's H/V spectral ratio method has been applied to establish a map of ground dominant periods in Ha Dong with a T_S range of 0.6 - 1.2 seconds. The relatively high values of periods indicate that Ha Dong has soft soil and thick Quaternary sediments. The sediment thickness in Ha Dong is calculated to vary between 30 - 75 m based on ground dominant periods and shear wave velocity V_{S30} = 171 - 254 m/s. The results of local site effect on ground motion show that the 500-year return period peak ground acceleration in Ha Dong ranges from 0.13 g to 0.17 g. It is once again asserted that the seismic hazard in Hanoi is a matter of great concern, due not only to the relatively high ground acceleration, but also to the seismic characteristics of soil (low shear wave velocity, ground dominant period of approximately 1 second).

Keywords: Probability seismic hazard analysis, Hanoi, site effect, earthquake, microtremor, fault.

INTRODUCTION

Hanoi is the capital of Vietnam; therefore, the speed of construction development is great. Many important buildings have been putting up in the city. On the seismic zoning map of Vietnam, on a scale of 1:1,000,000, the Hanoi area is crossed by the Red river fault zone (considered as an active fault zone, which can generate earthquakes with the magnitude M = 6.1) and located in the region of maximum shaking intensity of VIII corresponding to type A ground (rock) (fig. 1) [1, 2]. Actually, the majority of Hanoi area is located on thick and soft sediments; very few places can be classified into ground type A [3]. Therefore, the accurate assessment of seismic hazard on specific ground types of the city and the establishment of detailed seismic zoning map for planning and design of structures for earthquake resistance are extremely important. In this setting, the detailed seismic zoning of Hanoi has been repeatedly conducted in several stages based on available data sources, scientific and technological capacity of Vietnam as well as socio-economic development of Hanoi in each stage [1, 4, 5]. Until 2005, with the former administrative boundary of Hanoi, the database on ground motion characteristics (the distribution of peak ground acceleration corresponding to different return periods, the period of free oscillation and the response spectrum of soil) basically meets the requirement for planning and earthquake-resistant design of buildings in the city [5].

Since August 2008, the Hanoi area has been expanded more than three times. Ha Tay province (including Ha Dong), Me Linh district - Vinh Phuc province, and Dong Xuan, Tien Xuan, Yen Binh, Yen Trung communes - Luong Son district - Hoa Binh province have been merged into Hanoi. Many important industrial zones as well as satellite towns of Hanoi are located in this expanded area. To facilitate the planning and development of public space in Hanoi and to provide the information for earthquake-resistant calculation of buildings, the newly merged regions must be added to the detailed seismic zoning map of Hanoi on a scale of 1:25,000; moreover, the database on ground motion characteristics should be developed. Therefore, in this study we have carried out the probabilistic seismic hazard analysis (calculation of peak ground acceleration with return period T = 500 years on ground type A) for the entire area of Hanoi and the detailed seismic zoning (examination of local site effect) for Ha Dong to complete the former seismic zoning map of Hanoi on a scale of 1:25,000.

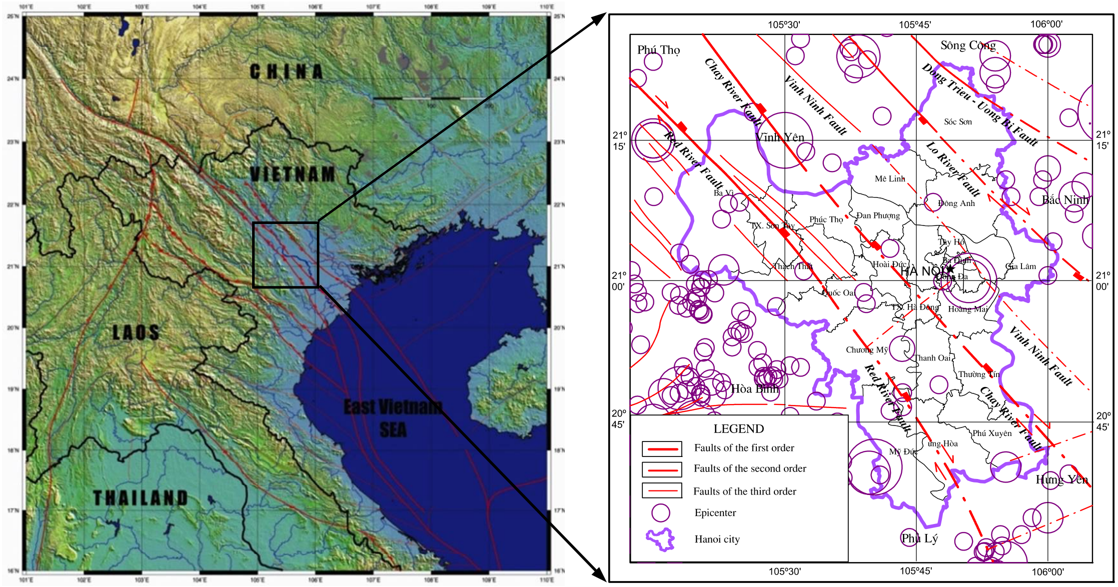

Fig. 1. Map of faults and earthquake epicenters in the Hanoi area and its vicinity (magnitude: $1.0 \leq M \leq 5.6$; period: 1277-2016)

ACTIVE FAULTS AND SEISMICITY

The study area is located in the boundary deformation zone between South China and Sunda blocks [6, 7] whose center is the Red river fault zone. In addition, many active fault zones cross or adjoin the study area such as Chay river, Dong Trieu - Uong Bi, Son La, Da River faults (fig. 1). These fault zones are likely to generate the strongest earthquakes in Vietnam, potentially endangering the buildings in the study area and its vicinity.

The studies on seismic activity in Vietnam have shown that strong seismic activity is closely related to active faults. While weak earthquakes are evenly distributed throughout the territory as well as geological structures, strong and felt earthquakes with magnitude $M \geq 4.5$ are mainly distributed on deep active fault systems and associated with these faults [2]. The seismic activity in the study area is also not beyond this pattern.

Strong earthquakes occurred quite frequently on the Dong Trieu - Uong Bi fault in the 20th century. The Mao Khe earthquake occurred in 1903, the Bac Giang earthquake occurred in 1961, and the earthquake of level VI-VII occurred in Yen The on January 6, 1987. The Bac Giang earthquake occurring on June 12, 1961 was only about 60 km from the northeast of Hanoi. The isoseismal map of this earthquake (fig. 2) was drawn according to field survey data in 1964. The shaking intensity at the epicenter, the hypocentral depth, and the magnitude were I_o = VII, h = 28 km, and M = 5.6, respectively. This strong earthquake with deep hypocenter caused the shaking intensity I ≥ IV-V in most of Northern Vietnam, while the shaking intensity in Hanoi was I = VI.

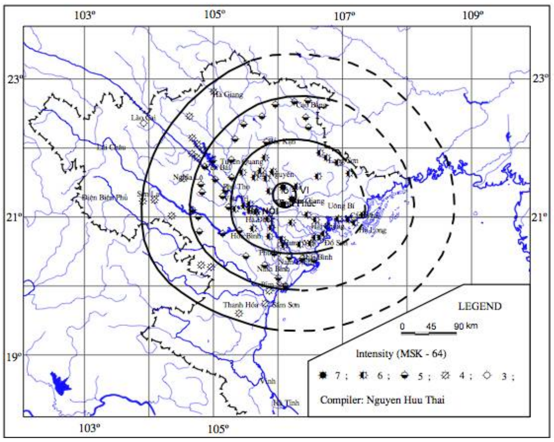

Fig. 2. Isoseismal map of Bac Giang earthquake on June 12, 1961 (M = 5.6; h = 28 km; I_o = VII on the MSK scale)

A series of earthquakes with shaking levels of VII-VIII occurred on the Chay river fault (Hanoi earthquakes in 1277, 1278, 1285). In the 20th century, earthquakes of level VII occurred continuously in Luc Yen (Yen Bai) in 1953, 1954. In 1958, on the Chay River fault, an earthquake occurred in Yen Lac. The Dien Bien earthquake with a magnitude M = 6.7 occurring in the Fu May Tun fault zone in 1935 (fig. 3) and the Tuan Giao earthquake with a magnitude M = 6.8 occurring in the Son La fault zone in 1983 (fig. 4) have been the strongest earthquakes in Vietnam. These two earthquakes brought about the strong shaking in the large area, destroyed the houses, caused the landslides and made several dozen people dead and injured [3]. The activities of Lo river, Da river and other faults are weaker; as a result, the earthquakes occur weakly and infrequently on these faults.

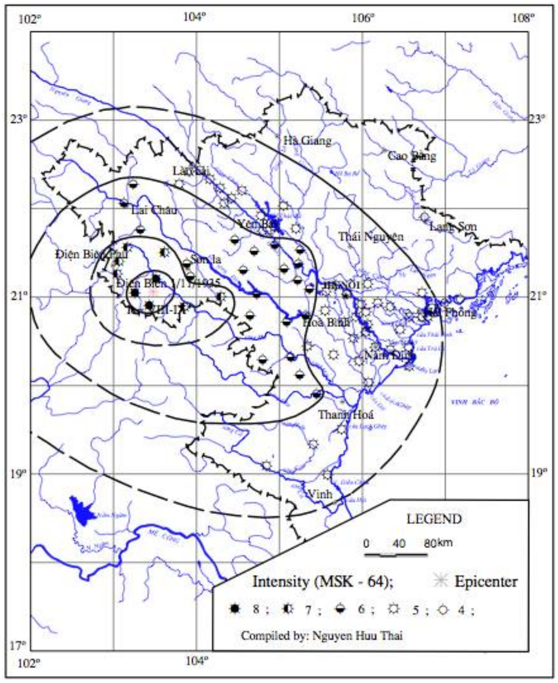

Fig. 3. Isoseismal map of Dien Bien earthquake on November 1, 1935 (M = 6.7; h = 22 km; I_o = VIII - IX on the MSK scale)

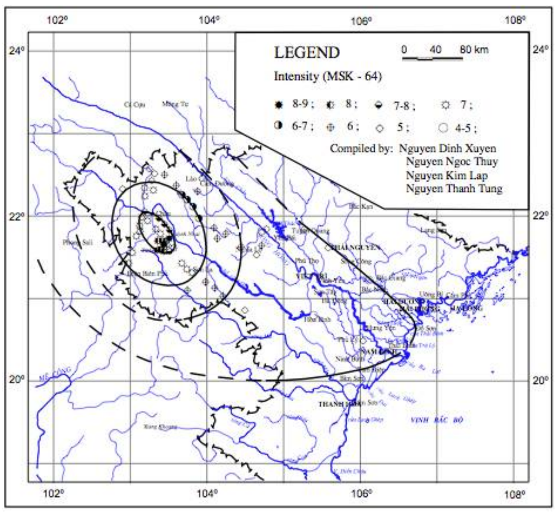

Fig. 4. Isoseismal map of Tuan Giao earthquake on June 24, 1983 (M = 6.8; h = 23 km; I_o = VIII - IX on the MSK scale)

PROBABILISTIC SEISMIC HAZARD ANALYSIS

Methodology

Probabilistic seismic hazard analysis (PSHA) refers to the possibility of occurrence of seismic shaking A (A may be displacement, velocity, peak ground acceleration, or shaking intensity) caused by the earthquake at a point in a given period of time that is equal to or exceeds the value of seismic shaking A_0 with a certain probability P [8, 9]. The theory of probabilistic seismic hazard analysis is based on the following viewpoints:

The seismogenic source zones are connected with the active fault zones, each source zone can generate maximum earthquakes with the specific magnitude M_{max}.

The propagation of shaking from the earthquakes at source zones to the surrounding regions depends on the magnitude M and the hypocentral distance R according to ground motion attenuation law.

$$I = C_1 + C_2 M + C_3 \ln(R + R_o) + \varepsilon \tag{1}$$

Where I is the level of shaking intensity; C_i, i = 1, 2, 3 are the constants; R is the hypocentral distance; R_o is the radius of the region in which the shaking intensity is not attenuated; ε is the standard deviation. Another attenuation law that is now commonly used has the general form as follows:

$$a_{max} = b_1 e^{b_2 M} R^{-b_3} \tag{2}$$

Where: a_{max} can be the peak value of acceleration, velocity, or displacement of ground motion caused by the earthquake with a magnitude M at the hypocentral distance R, b_i are the coefficients depending on seismic source and wave propagation environment.

The relationship between the frequency of earthquake occurrence $N(M \geq M_o)$ and the magnitude M of the earthquake is expressed by the Gutenberg-Richter equation [10, 11]:

$$\lg N(M \geq M_o) = a - bM \tag{3}$$

Where $N(M \geq M_o)$ is the number of earthquakes per year with the magnitude M not smaller than a certain level M_o; a and b are the coefficients depending on the seismicity of the study area.

The probability of earthquake occurrence complies with Poisson distribution.

In each source zone, the number of earthquakes that can cause ground motion with the intensity $I \geq i$ in a time unit is determined by:

$$E[n/year]_{zone} = V_{zone} \int P_{rob}[A \geq A_o / R = r] f_r(r) dr \tag{4}$$

Where $f_r(r)$ is the probability density function of earthquake occurrence according to the distance R from the earthquake hypocenter to the calculated position.

Applying the above formula for all the source zones that affect the calculated position, we have:

$$E[n/year]_{zone} = \sum_{soucre\ zone} V_{zones} \int P_{rob}[A \geq A_o / R = r] f_r(r) dr \tag{5}$$

Or it can be generally expressed by the following formula:

$$E(j) = \sum_{i=1}^{N} a_i \int_{m_o}^{m_u} \int_{r=0}^{r=\infty} f_i(m) f_i(r) P(A \geq A_o) dr dm \tag{6}$$

Where: $E(j)$ is the number of exceedances of a given level j in a period of t years; α_i is the rate of earthquake occurrence per year within the examined magnitude range (m_o, m_u are the lower and upper bounds, corresponding to the representative and maximum magnitudes) in the ith source; $f_i(m)$ is the probability density function of magnitude for the source i; $f_i(r)$ is the probability density function of the distance between the calculated position and the source i; $P(A \geq A_o)$ is the probability of exceedance of a given level A_o caused by an earthquake with the magnitude m and the distance r to the source.

Seismogenic source zone

As mentioned above, in the study area, the manifestation of seismic activity is obvious on the Red river, Chay river, Lo river, Dong Trieu - Uong Bi, Trung Luong, Tan Mai, Thai Nguyen - Bac Can - Yen Minh (TN-BC-YM), Cao Bang - Tien Yen, Nam Ninh - Thai Thuy, Da river, Son La, Ma river, Fu May Tun, Lai Chau - Dien Bien fault zones,… The seismogenic source zones that can endanger Hanoi are determined to be connected with these fault zones. The magnitude M_{max} of maximum earthquake that is likely to occur in the seismogenic source zones is assessed by the set of methods: The correlation between the magnitude M and the fault rupture length on the ground surface [12] and the Gumbel distribution [13]. By using these methods, the magnitude M_{max} of maximum earthquake in the seismogenic source zones in the study area has been determined and presented in table 1 [2, 3].

Table 1. Basic parameters of source zones used in probabilistic seismic hazard analysis in Hanoi

Seismic source zone	Magnitude		b-value	Rate (N/yr)	Depth (km)
	M_{min}	M_{max}			
Ma river, Son La, Fu May Tun	4.0	7.0	0.85	0.16	22
Da river, Muong La - Bac Yen	4.0	5.5	0.85	0.08	12
Lai Chau - Dien Bien	4.0	6.2	0.85	0.10	15
Red river, Chay river	4.0	6.1	0.93	0.22	17
Lo river	4.0	5.5	0.89	0.06	12
Dong Trieu - Uong Bi	4.0	6.2	0.89	0.06	22
Thai Nguyen - Bac Can - Yen Minh, Thuong river, Tan Mai	4.0	5.5	0.89	0.02	12
Cao Bang - Tien Yen	4.0	5.5	0.89	0.04	12

The width of each seismogenic source zone is determined by the projection of fault on the ground surface to the depth of lower boundary of seismogenic layer. This is the width of the rupture zone in which the maximum earthquakes can occur (fig. 5). According to the result of M_{max} (table 1), the source zones in Northern Vietnam can generate earthquakes with the maximum magnitude M = 7.0. Therefore, these source zones within a radius of 200 km from the center of the study area perfectly meet the requirements of seismic hazard analysis.

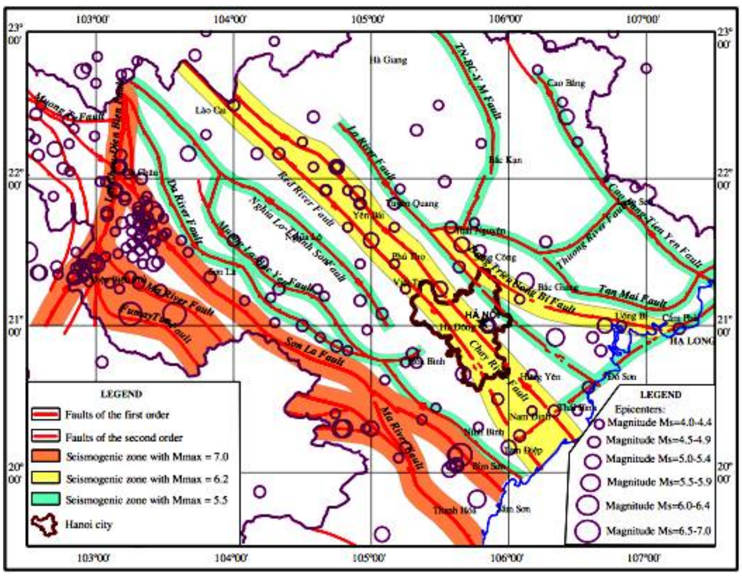

Fig. 5. Map of seismogenic source zones in Hanoi and its vicinity (period: 1277-2016)

With the updated observation data on earthquakes in the study area, we have determined the distribution pattern of earthquakes in accordance with the magnitude by using the formula (3) (Gutenberg-Richter equation) for the source zones that have the same tectonic conditions and can endanger the Hanoi area:

The Northwest region (including the Ma river, Son La, Fu May Tun, Am river, Da river, Muong La - Bac Yen, Phong Tho, Nghia Lo - Thanh Son and Than Uyen fault zones):

$$\lg(N) = 3.63 - 0.85M \quad (7)$$

The Northeast region (including the Dong Trieu - Uong Bi, Lo river, Thai Nguyen - Bac Can - Yen Ninh, Tan Mai, Thuong river, Cao Bang - Tien Yen fault zones):

$$\lg(N) = 2.95 - 0.89M \quad (8)$$

The Red river - Chay river fault zone:

$$\lg(N) = 3.27 - 0.93M \quad (9)$$

For all the source zones in this study, M_{min} is selected to be 4.0 with the supposition that there are no significant seismic hazards to the buildings that can be caused by earthquakes with the magnitude smaller than this threshold value (M_{min}) [14]. The seismic characteristics of seismogenic source zones in the study area are presented in table 1.

Ground motion prediction model

There is a fact that the observation data on earthquakes are not sufficient to establish a ground motion attenuation model for Vietnam. Under that condition, in order to carry out seismic hazard assessment in Vietnam, the application of ground motion attenuation equation of [15] has been suggested in recent years [16]. In this paper, we use a ground motion attenuation equation of Campbell and Bozorgnia (2008) (CB08) [17], obtained based on the completion of Campbell's studies (1997) [18]. The CB08 is one of ground motion prediction equations developed for shallow crustal earthquake in Next Generation Attenuation (NGA) Project. CB08 equation was developed for the active continental region based on global earthquake data (including data at a distance of 0.1 km from seismogenic source zones), taking into account the site conditions and the types of earthquake-generating faults. The study area is considered to be located in the active continental region or in the boundary deformation zone between tectonic blocks [7, 19, 20], in which shallow crustal earthquakes occur near the seismogenic source zones. Le Quang Khoi (2015) [21] compared CB08 with the acceleration data recorded by the Vietnam seismic station network and pointed out that the ground motion attenuation in Northern Vietnam was completely consistent with the attenuation model of Campbell and Bozorgnia (2008) [17]. The use of various ground motion attenuation equations in seismic hazard assessment with different weights to overcome the disadvantages of each ground motion model is only carried out when no equation is appropriate for the study area. Moreover, Abrahamson et al., (2008) [22] made the comparisons of the NGA ground motion relations and noted that the NGA equations are all fairly similar, and all are reasonably constrained by the data. Therefore, the use of only one ground motion attenuation equation, which is appropriate for seismotectonic conditions of the study area, is adequate for seismic hazard assessment in order to avoid errors from inappropriate models.

Seismic hazard assessment results

The PSHA has produced the PGA map in Hanoi for rock condition (type A ground) with a 10% probability of exceedance in a 50-year time period (approximately return period of 500 years) (fig. 6). It can be seen that the strongest shaking can occur on rock in locations near the Red river, Chay river and Dong Trieu - Uong Bi fault zones (up to 0.13 g). Compared to the obtained results of previous studies [5, 23], this calculated value is slightly higher because the previous studies used the old ground motion attenuation equations such as Cornell et al., (1979) [24], Donovan (1973) [25]... These attenuation models were established when the observation data on near-source earthquakes were very few. Consequently, the results of extrapolation of PGA at the near distance (< 10 km) according to these equations had the low value. The use of ground motion attenuation equation of Campbell and Bozorgnia (2008) [17] has produced more reliable results at near-source distance and has been consistent with the current trend of calculation (e.g. the assessments of Japanese experts at Song Tranh 2 hydropower plant and Ninh Thuan nuclear power plant in Vietnam).

SITE EFFECTS ON GROUND MOTION IN HA DONG

In Hanoi, very few places have the rock outcrops. Most of the Hanoi area is soft soil (the relatively thick sediment overlies the rock) [5]. The calculated values of PGA on rock change in accordance with local site conditions. Under such conditions, the calculations and corrections for the Hanoi area with former administrative boundary were made in the study of Nguyen Ngoc Thuy et al., (2004) [5].

Shear wave velocity of soil layers in Ha Dong

V_{S30} is the average shear wave velocity of the first 30 meters below ground surface. The value of V_{S30} is used in building codes [23, 26, 27]. It is also an important parameter to estimate site conditions used in ground motion prediction equations and seismic hazard assessments [22, 28, 29]. In the applications of engineering seismology, site effect is estimated by using empirical correlations of V_{S30}. Those applications depend on the availability of V_{S30} measurement data at a certain point.

Shear wave velocity of a layer is calculated from the Standard Penetration Test (SPT) value (N_{SPT}) by using the Imai's formula [30]:

$$V_S = 91 * N_{SPT}^{0.337} \tag{10}$$

V_{S30} is determined from the formula of CEN [31]:

$$V_S = \frac{30}{\sum \frac{Th_i}{V_{Si}}} \tag{11}$$

Where V_{Si} and Th_i are shear wave velocity and thickness of the ith layer, respectively.

We calculate the values of V_{S30} according to the SPT data of boreholes in Ha Dong by using the formula (11). From the calculated results of shear wave velocity V_{S30}, the soil in Ha Dong is assessed as soft soil with velocity V_{S30}= 171 - 254 m/s.

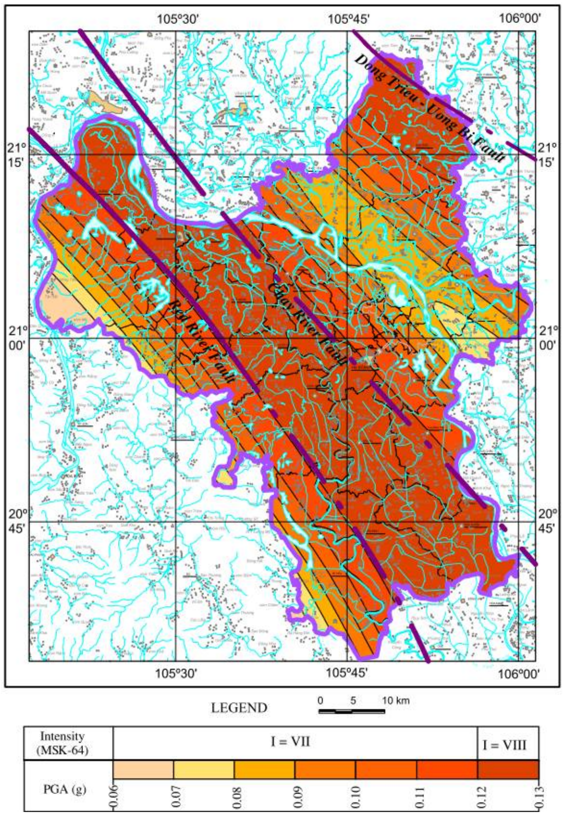

Fig. 6. PGA map corresponding to the earthquake return period T = 500 years on rock (ground type A) in Hanoi

Ground dominant periods

The method of horizontal to vertical (H/V) spectral ratio of microtremor (or Nakamura method) is usually used to determine the distribution of ground dominant periods in a study area. This method has been commonly used in the world as well as in Vietnam in the assessment of local site effects on seismic motion [5, 32-36]. The buildings are mainly damaged when the fundamental period of the building is close to the ground dominant period. The determination of ground dominant period is necessary for the earthquake-resistant design of new buildings or the reinforcement of existing buildings.

The *H/V* ratio is the Fourier spectral ratio between the horizontal and vertical components of microtremor. Nakamura suggested that the *H/V* ratio allowed the assessment of ground response to S waves [32]. His suggestion was based on interpreting microtremor as Rayleigh wave, which propagates in a single layer (loose soil) on the upper half-space of bedrock. In the frequency domain, such microtremor can be represented by four types of amplitude spectrum: the amplitude spectrum of vertical and horizontal components at the ground surface [$V_S(\omega)$, $H_S(\omega)$], and the amplitude spectrum of vertical and horizontal components at the bedrock surface [$V_b(\omega)$, $H_b(\omega)$].

Suppose that microtremor is generated by local sources (ignoring deep noise sources), the microtremor at the bedrock surface is not affected. On the other hand, assuming that the vertical component of microtremor is not amplified by the surface soil, the spectral shape of microtremor source $A_S(\omega)$ can be estimated as a function of the frequency ω according to the following ratio:

$$A_S(\omega) = V_S(\omega)/V_b(\omega) \tag{12}$$

The effect of soil S_E in the engineering seismology is also estimated by the ratio between the amplitude spectrum of horizontal component at ground surface and that at bedrock:

$$S_E(\omega) = H_S(\omega)/H_b(\omega) \tag{13}$$

The spectral ratio S_M, which represents the modified local site effect compared to S_E, can be equivalently estimated when being compensated by the spectrum of microtremor source A_S:

$$S_M(\omega) = S_E(\omega)/A_S(\omega) \tag{14}$$

When empirically examining through the seismic records obtained in the boreholes, Nakamura (1989) [32] concluded that:

$$H_b(\omega)/V_b(\omega) = 1 \tag{15}$$

Thus:

$$S_M(\omega) = H_S(\omega)/V_S(\omega) \tag{16}$$

From this formula, Nakamura suggested that the local site effect could be determined by the spectral ratio between horizontal and vertical components of microtremor. Up to now, the Nakamura method has been considered one of the most inexpensive and appropriate methods for reliable calculations of dominant periods of loose sediments [33, 35].

In this work, we use Altus-K2 manufactured by KINEMETRICS of USA and SAMTAC-801H manufactured by Japan to measure ambient noise in Ha Dong. They are the digital recorders with high dynamic range, recording three velocity components of ground motion (vertical, horizontal in north-south and south-east). Measurement points are evenly distributed with a density of 3 locations/1 km^2. At each location, three components of microtremor are recorded in about 15-30 minutes. The sampling rate set for the entire process is 100 samples/second. During the recording process, we try to minimize the effect of nearby artificial sources of noise. The unavoidable cases are noted in the logbook and then are removed in the data processing. In response to this requirement, in Ha Dong, the fieldwork is carried out in the day time at locations far from residential area and industrial zones, and from 12:00 AM to 4:00 AM in the populous areas. In Ha Dong, we have conducted the survey at 162 locations in an area of 47.9 km^2.

For each component of microtremor (vertical, north-south or east-west) recorded at each location, we select segments with the amplitude corresponding to the period of 20.48 seconds in order to produce the spectrum. The Fourier spectrum corresponding to each segment is smoothed by the Hanning window (fig. 7-left). The median line of all these spectra is considered to represent the processed component of microtremor (fig. 7-right). The

H/V spectral ratio for each location is determined by the following formula:

$$H/V = \frac{\sqrt{H_{S1}(\omega) * H_{S2}(\omega)}}{V_S(\omega)} \qquad (17)$$

Where $H_{S1}(\omega)$, $H_{S2}(\omega)$ are the spectra representing the north-south and east-west components respectively, $V_S(\omega)$ is the spectrum representing the vertical component.

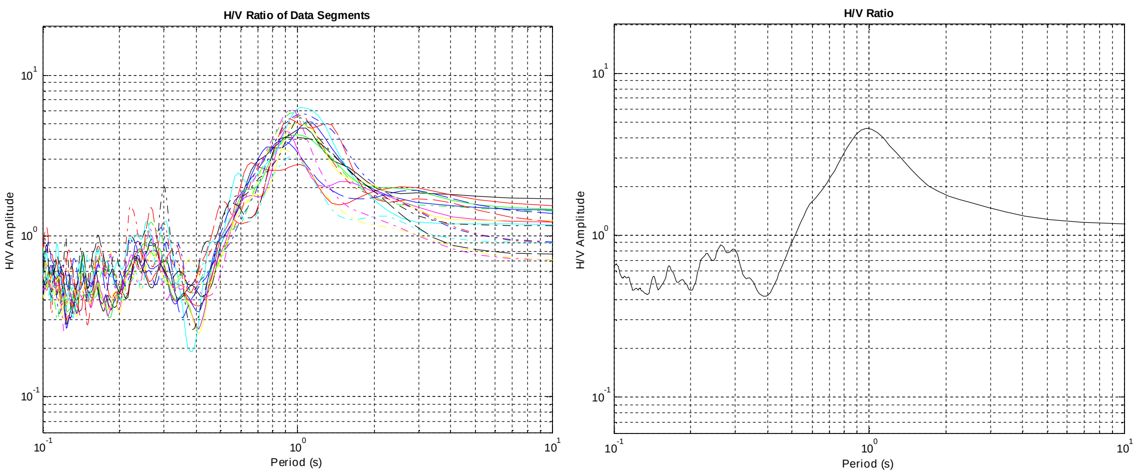

Fig. 7. Microtremor data processing in the measurement point VDC030. (left) The *H/V* ratios of data segments. (right) The representative *H/V* spectral line with ground dominant period $T_S = 1$ s

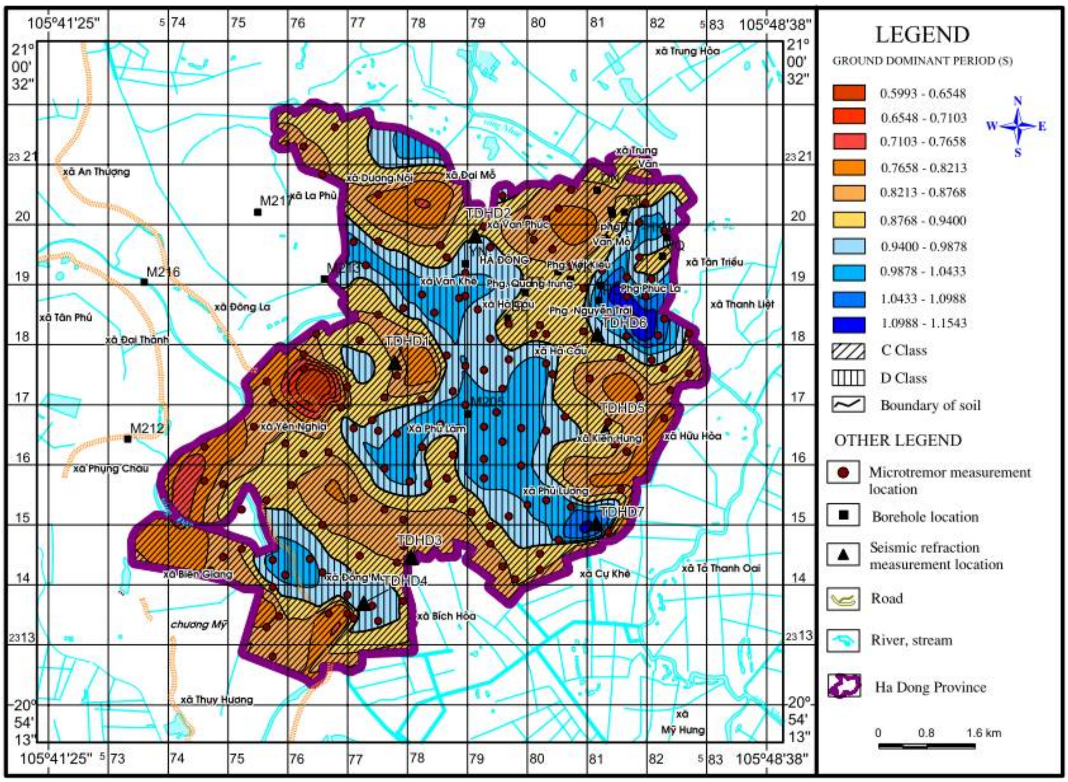

Fig. 8. Distribution map of ground dominant periods in Ha Dong

The ground dominant period at the survey site is determined to correspond to the position of maximum spectral amplitude. The processing results at 162 locations in Ha Dong show that the values of ground dominant periods range from 0.6 to 1.2 seconds. The change of dominant period is usually closely related to the sediment thickness. The thick sediment is characterized by the high value of dominant period and vice versa. The results of assessment of dominant periods in Ha Dong show that the sediment layer is relatively thick. With the supposition that the average shear wave velocity of sediment layer above the rock is 171 - 254 m/s, the sediment thickness in Ha Dong is calculated to vary from 30 m to 75 m.

We apply the geostatistical method of Kriging regression to plot the map of ground dominant periods for Ha Dong from 162 sites of microtremor survey (fig. 8). Kriging interpolation algorithm trending to the ground dominant period distribution is used to smooth the resulting map at the locations with the dense coverage of microtremor survey points [37].

Ground motion in Ha Dong

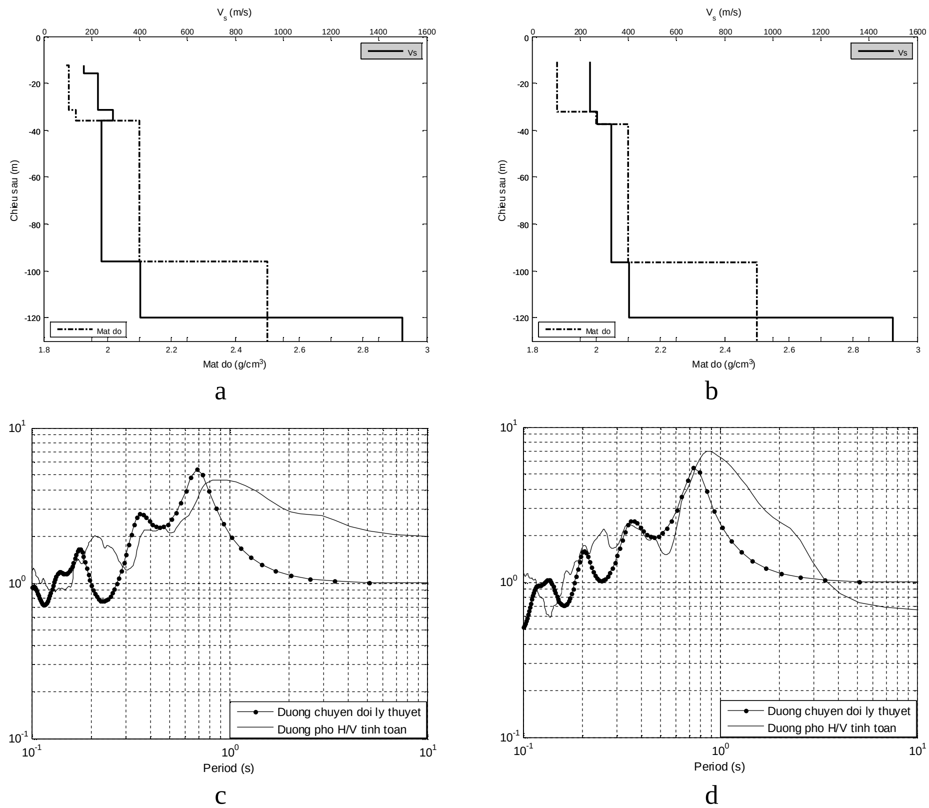

Fig. 9. Distribution of *S* wave velocity and density of soil layers in the survey sites in Hanoi (a and b) and comparison of theoretical transform function in these sites with *H/V* spectrum obtained in the corresponding locations (c and d) [36]

At the same location but on different types of ground, the PGA value can change by a corrective increment ΔA in comparison with that on rock calculated and presented in the section 3.4. In order to establish the detailed PGA map for the study area, it is necessary to determine the corrective increment ΔA for each soil type with reference to PGA on rock. To solve this problem, we carry out the soil classification for Ha Dong according to Vietnam Building Code TCXDVN 375-2006 [23] based on the information about ground dominant periods, shear wave velocity and engineering geological characteristics. The objective is to determine the PGA amplification coefficient *S* at the survey sites. The corrective increment Δ*A* with reference to the peak ground acceleration on rock *A* is defined by the formula:

$$\Delta A = A * (S - 1)$$

It can be seen that in Ha Dong all the soil types have dominant periods of > 0.6 seconds. According to the soil classification of Japan [38], the soil with dominant period of > 0.6 seconds is classified as loose soil, including two types C and D in TCXDVN 375-2006. To distinguish between C and D types in Ha Dong, we use the information about ground dominant periods obtained from the microtremor method. When comparing the *H/V* spectrum obtained from the microtremor data with the theoretical transform function obtained from wave propagation model (fig. 9), it can be seen that the two spectral lines are quite consistent with each other. This suggests that the value of dominant period obtained from the microtremor method can provide information about the average shear wave velocity of the top 30 m depth (V_{S30}). By comparing the characteristics of ground dominant period and V_{S30}, the engineering geological characteristics in locations with adequate information, we conduct the soil classification in Ha Dong as follows: Locations with dominant periods of over 1 second are classified as type D, locations with dominant periods of 0.6 - 1.0 second are classified as type C. Arcording to TCXDVN 375-2006, the coefficients S for soil types C and D are 1.15 and 1.35, respectively. By combining the results presented in fig. 6 and in fig. 9, we determine the coefficient Δ*A* as well as the PGA distribution in Ha Dong. The peak ground acceleration corresponding to the 500-year return period in Ha Dong is calculated in the range of 0.13 - 0.17 g, corresponding to shaking intensity level VIII on the MSK-64 scale (fig. 10).

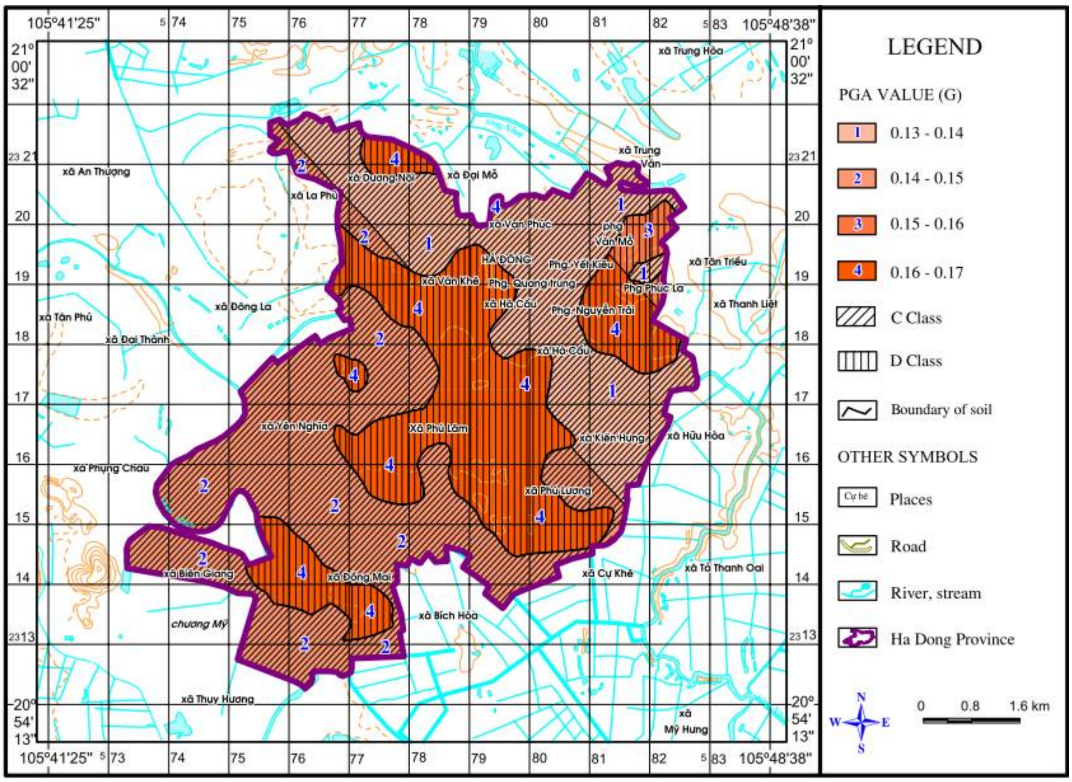

Fig. 10. PGA distribution map corresponding to the 500-year return period on different soil types in Ha Dong

CONCLUSION

The seismic hazard analysis shows that the strongest shaking corresponding to the 10% probability of exceedance in 50 years (approximately return periods of 500 years), which can occur on rock in Hanoi, is 0.13 g, corresponding to shaking intensity level VIII on the MSK-64 scale. However, very few places in Hanoi have the rock outcrops. The Hanoi area is mainly located on soft soil with relatively thick sediments overlying rock that can amplify the amplitude of seismic wave, endangering the buildings.

Ha Dong district of Hanoi city is a typical area of Quaternary sediments with the shear wave velocity of V_{S30} = 171 - 254 m/s. We have conducted the microtremor survey at 162 locations in Ha Dong and analyzed the data to determine the ground dominant periods by using the Nakamura's *H/V* spectral ratio method. The results show that the ground dominant periods in Ha Dong are relatively high, ranging from 0.6 to 1.2 seconds. It indicates that the sediment layer is relatively thick. The sediment thickness is calculated in the range of 30 - 75 m based on ground dominant periods and shear wave velocity. The results of soil classification in Ha Dong show that there are two types of soft soil C and D with ground dominant periods of 0.6 - 1.0 second and over 1 second, respectively.

From the results of assessment of local site effect on seismic motion, the PGA value corresponding to the 500-year return period in Ha Dong is determined in the range of 0.13 - 0.17 g, corresponding to shaking intensity level VIII on the MSK-64 scale. The results of detailed seismic zoning in Ha Dong basically meet the requirements for planning and designing earthquake-resistant buildings in Hanoi because they provide the information about peak ground acceleration corresponding to 500-year return period, soil types and ground dominant periods at different locations in the study area.

Acknowledgements: We are grateful to all colleagues of the Institute of Geophysics, Vietnam Academy of Science and Technology who participated in the microtremor survey campaigns to collect data for this work. This study has been supported by scientific research funding program of Hanoi city government (ID: 01C-04/04-2011-2).

REFERENCES

1. Nguyen Dinh Xuyen and Nguyen Ngoc Thuy et al., 1996. Database of solutions for seismic hazard mitigation in Vietnam- Part II: Earthquake zoning for Vietnam. *Final report of the national project KT-DT*92-07, 1992-1996. *Institute of Geophysics, Hanoi* (in Vietnamese).
2. Nguyen Dinh Xuyen et al., 2004. Study on earthquake prediction and ground motion in Vietnam. *Final report of the national project* 2000-2004. *Institute of Geophysics, Hanoi*.
3. Nguyen Ngoc Thuy et al., 2005. Detailed earthquake zoning for northwestern Vietnam. *National project on science and technology, KC*08-10, *Period* 2001-2005, *Institute of Geophysics, Hanoi, Vietnam* (in Vietnamese).
4. Nguyen Hong Phuong et al., 2002. Study on the seismic risk assessment for Hanoi. *Final report of scientific research funding program supported by Hanoi city government,* ID: 01C-04, *Institute of Geophysics, Hanoi*.
5. Nguyen Ngoc Thuy et al., 2004. Study on complement of the detailed seismic hazard map for expanded Hanoi city on the scale 1:25,000, building of database of ground motion features according to the above maps. *Final report of scientific research funding program supported by Hanoi city government,* ID: 01C-04/05-2003-2, *Institute of Geophysics, Hanoi* (in Vietnamese).
6. Simons, W. J. F., Socquet, A., Vigny, C., Ambrosius, B. A. C., Haji Abu, S., Promthong, C., Subarya, C., Sarsito, D., A., Matheussen, S., Morgan, P., and Spakman, W., 2007. A decade of GPS in Southeast Asia: Resolving Sundaland motion and boundaries. *Journal of Geophysical Research: Solid Earth*, **112**(B6).

7. Duong, N. A., Sagiya, T., Kimata, F., To, T. D., Hai, V. Q., Cong, D. C., Binh, N. X., and Xuyen, N. D., 2013. Contemporary horizontal crustal movement estimation for northwestern Vietnam inferred from repeated GPS measurements. *Earth, Planets and Space*, **65**(12), 1399-1410.
8. Cornell, C. A., 1968. Engineering seismic risk analysis. *Bulletin of the seismological society of America*, **58**(5), 1583-1606.
9. McGuire, R. K., 1976. FORTRAN computer program for seismic risk analysis (Pp. 67-76). *US Geological Survey*.
10. Gutenberg, B. and Richter, C. F., 1954. Seismicity of the Earth and Associated Phenomena. *Princeton University Press, Princeton, NJ, USA*.
11. Richter, C. F., 1958. Elementaty seismology. Freeman, San Francisco. 768 pp.
12. Wells, D. L., and Coppersmith, K. J., 1994. New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. *Bulletin of the seismological Society of America*, **84**(4), 974-1002.
13. Gumbel, E. J., 1958. Statistics of Extremes. *Columbia University Press*, *New York*.
14. Kramer, S. L., 1996. Earthquake geotechnical engineering. *Prentice Hall, Inc., Upper Saddle River, New Jersey*.
15. Campbell, K. W., 1997. Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra. *Seismological Research Letters*, **68**(1), 154-179.
16. Nguyen Dinh Xuyen and Le Tu Son, 2008. Seismic zoning map of Vietnam in the Vietnamese building standard TCXDVN 375-2006: earthquake-resistant design of constructions. Vietnam Journal of Earth Sciences, **30**(4PC), 503-513. (in Vietnamese).
17. Campbell, K. W., and Bozorgnia, Y., 2008. NGA ground motion model for the geometric mean horizontal component of PGA, PGV, PGD and 5% damped linear elastic response spectra for periods ranging from 0.01 to 10 s. *Earthquake Spectra*, **24**(1), 139-171.
18. Campbell, K. W., 1997. Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra. *Seismological Research Letters*, **68**(1), 154-179.
19. Kanter, L. R., 1994. Tectonic interpretation of stable continental crust. *Chapter 2 in The Earthquakes of Stable Continental Regions, ed. A. C. Johnston, K. J. Coppersmith, L. R. Kanter, and C. A. Cornell*, **1**, 1-98. Report for Electric Power Research Institute (EPRI), Palo Alto, CA, EPRI TR 102261.
20. Bird, P., 2003. An updated digital model of plate boundaries. *Geochemistry, Geophysics, Geosystems*, **4**(3). doi:10.1029/2001GC000252.
21. Le Quang Khoi, 2015. Checking of the consistency of ground motion attenuation model in North Vietnam. *Master's thesis, Faculty of Physics, Hanoi University of Science, Hanoi*.
22. Abrahamson, N., Atkinson, G., Boore, D., Bozorgnia, Y., Campbell, K., Chiou, B., Idriss, I. M., Silva, W., and Youngs, R., 2008. Comparisons of the NGA ground-motion relations. *Earthquake Spectra*, **24**(1), 45-66.
23. Vietnam Building Code, 2006. TCXDVN 375-2006, *Design of structure for earthquake resistance, Hanoi*.
24. Cornell, C. A., Banon, H., and Shakal, A. F., 1979. Seismic motion and response prediction alternatives. *Earthquake Engineering & Structural Dynamics*, **7**(4), 295-315.
25. Donovan, N. (1973). A statistical evaluation of strong motion data including the Feb. 9 1971, San Fernando earthquake. In *Proc. 5th World Conf. on Earthq. Eng., Rome* (Vol. 2).

26. International Code Council, 2009. 2009 IBC International Building Code, *Country Club Hills, Illinois*, 730 pp.
27. Building Seismic Safety Council, 2015. Recommended Seismic Provisions for New Buildings and Other Structures, *Part 1: Provisions, Part 2: Commentary. Report No. FEMA P-1050-1, Federal Emergency Management Agency, Washington, D.C.*, 515 pp.
28. Borcherdt, R. D., 1994. Estimates of site-dependent response spectra for design (methodology and justification). *Earthquake spectra*, **10**(4), 617-653.
29. Yousef Bozorgnia, Norman A. Abrahamson, Linda Al Atik, Timothy D. Ancheta, Gail M. Atkinson, Jack W. Baker, Annemarie Baltay, David M. Boore, Kenneth W. Campbell, Brian S.-J. Chiou, Robert Darragh, Steve Day, Jennifer Donahue, Robert W. Graves, Nick Gregor, Thomas Hanks, I. M. Idriss, Ronnie Kamai, Tadahiro Kishida, Albert Kottke, Stephen A. Mahin, Sanaz Rezaeian, Badie Rowshandel, Emel Seyhan, Shrey Shahi, Tom Shantz, Walter Silva, Paul Spudich, Jonathan P. Stewart, Jennie Watson-Lamprey, Kathryn Wooddell, and Robert Youngs, 2014. NGA-West2 research project. *Earthquake Spectra*, **30**(3), 973-987.
30. Imai, T., 1977. P-and S-wave velocities of the ground in Japan. In *Proceedings of the 9th International Conference on Soil Mechanics and Foundation Engineering,* **2**, 257-260.
31. CEN, 2004. EN 1998-1:2004, Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings. *European Committee for Standardization, Brussels, Belgium*.
32. Nakamura, Y., 1989. A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. *QR Railway Tech. Res. Inst.*, **30**(1), 25-33.
33. Bard, P. Y., 1999. Local effects on strong ground motion: physical basis and estimation methods in view of microzoning studies. *Proceedings of the Advances Study Course "Seismotectonic and Microzonation techniques in Earthquake Engineering: Integrated Training in Earthquake risk reduction practices*, 75-124.
34. Duval, A. M., Vidal, S., Meneroud, J. P., Singer, A., De Santis, F., Ramos, C., Romero, G., Rodriguez, R., Pernia, A., Reyes, N., and Griman, C., 2001. Caracas, Venezuela, Site Effect Determination with Microtremors. *Pure and Applied Geophysics*, **158**(12), 2513-2523.
35. Pham Dinh Nguyen, 2002. *Evaluation of site effect on strong ground motion. Master's thesis, Faculty of Physics, Hanoi University of Science, Hanoi.*
36. Vu Minh Tuan, Nguyen Duc Vinh, Nguyen Anh Duong, Nguyen Sinh Minh, Nguyen Cong Thang, Pham Dinh Nguyen, 2012. The H/V ratio method and its abilities in estimation of the site effects on strong ground motions in Hanoi. *Vietnam Journal of Earth Sciences*, **34**(1), 70-75. (in Vietnamese).
37. Nguyen Thuy Linh, Bui Van Duan, Nguyen Anh Duong, 2016. Methods for constructing V_{S30} maps from geology, borehole and topography data. *Vietnam Journal of Earth Sciences*, **38**(4), 356-371.
38. Campbell K. W., 2003. A Contemporary Guide to Strong-Motion Attenuation Relations. *In International Handbook of Earthquake and Engineering Seismology (W.H.K. Lee, H. Kanamori, P.C. Jennings, and C. Kisslinger, Eds.), Supplement to Chapter 60, Vol. 2, Part B, Handbook CD, Academic Press, London.*