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SEISMIC MICROZONATION OF HANOI, VIETNAM USING MICROTREMOR OBSERVATIONS

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SUMMARY

It is imperative to carry out comprehensive seismic hazard assessment for big cities in order to reduce the potential damage from earthquakes. One of the fundamental steps in seismic hazard assessment is microzonation of cities, which provides a basis for site-specific hazard analysis. This study focuses on microzonation of Hanoi, the capital city of Vietnam, using microtremor observations. Microtremor observations were carried out at 63 sites in Hanoi. The predominant period of the ground at all the sites were determined from the horizontal to vertical (H/V) spectral ratios of microtremors and a microzonation map was developed for Hanoi on the basis of the variation of the predominant period of the ground. It was observed that in Hanoi, the northern part of the city has shorter predominant period (less than 0.4 s) and the predominant period of the ground increases towards south. The areas in the Hanoi metropolitan area, especially areas located along the Red River and around the West Lake have comparatively longer predominant period (0.6-1.0 s). The western districts of Hanoi also have longer predominant period (0.6-1.2 s) and it decreases towards the eastern direction. This study shows that there is a possibility of long-period ground motion in Hanoi, especially in Hanoi metropolitan area and western and southern districts of Hanoi. The long-period ground motion may have severe effects on high-rise buildings and other long-period structures.

INTRODUCTION

Seismic hazard assessment of big cities is imperative to mitigate the potential damage and loss of life due to earthquakes. The comprehensive seismic hazard assessment involves: a) identifying the regional seismic sources and defining attenuation model for the area, b) identifying local site effects and microzonation of cities, and c) vulnerability analysis of structures. This research focuses on the second fundamental step, i.e. seismic microzonation, for Hanoi, the capital city of Vietnam.

Local ground conditions substantially affect the characteristics of incoming seismic waves during earthquakes. Soft soil deposits amplify certain frequencies of ground motion and extend the duration of the motion, thereby increasing earthquake damage. Flat areas along the coast and rivers generally consist

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of thick layers of clay, sand and silt. During earthquakes, these soft deposits tend to amplify ground motions considerably. Seismic waves are trapped in the soft soil layer and multi-reflection phenomenon occurs. As a result, the ground vibrates severely with a specific dominant period. This period is called the predominant period of the ground, and the vibration of structures on the surface is highly influenced by it.

The variation in the ground motion, according to the geological site conditions, makes it necessary for big cities to do more detailed seismic hazard assessments. Seismic zonation maps developed for the whole country might not be adequate for identifying the variation of seismic hazards at different locations within the city. It, therefore, becomes imperative for big cities to conduct microzonation. Seismic microzonation is defined as the process of subdividing an area into zones with respect to geological characteristics of the sites, so that seismic hazards at different locations within the city can correctly be identified. Microzonation provides the basis for site-specific risk analysis, which can assist in the mitigation of earthquake damage.

Microtremor observations can be used to determine the dynamic properties of a site and, hence, can be used for microzonation. Microtremor method measures ambient vibrations in the order of microns present in the ground [1]. Observation of these microtremors can be used to determine the predominant period of vibration of a site [2-5]. The area can then be classified according to the predominant period of the ground. The conventional means for determining the dynamic characteristics of soil is the borehole method. However, this method is costly, time consuming and is generally not suitable for microzonation work [6]. Methods based on analysis of strong motion data are more straightforward for determining site effects. Nevertheless, the availability of ground motion records is limited to very few countries only [7]. Hence, in the context of most of the Asian countries where ground motion records are limited, microtremor observation is an appealing method for Microzonation [8].

The area of study under consideration is Hanoi, the capital city of Vietnam. Hanoi is located in the Red River delta along the Red River and has a population of 2.7 million. The Red River fault, which runs through Hanoi, is a major cause of many ground motions in this region. The area of study is located within Latitude 20° 80’ N to 21° 90’ N and Longitude 105° 15’ E - 106° 00’ E. The study area extends 35 km in the east-west and 54 km in the north-south directions and includes Hanoi metropolitan area.

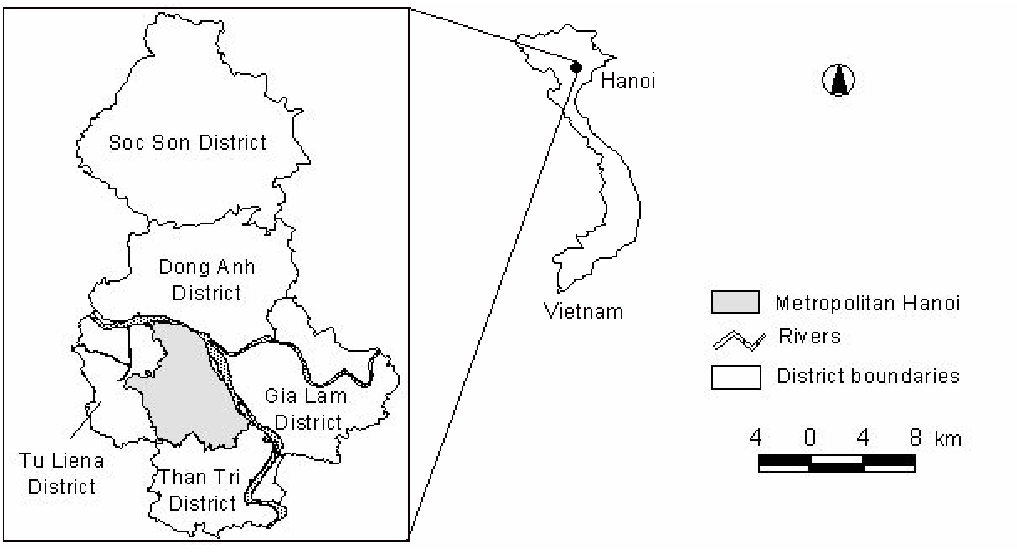

Figure 1 Area of the Study

SEISMICITY OF HANOI

Vietnam is situated between two major faults Himalayan Fault and Pacific Fault. These faults have strong effect on seismo-tectonic setting of this region. Moreover, Red River fault running through the north portion of Vietnam has caused several earthquakes in the region [9].

In Hanoi, the tectonic fault exists along the Hong (Red) River, Chay River and Lo River [10]. The seismographic survey shows that earthquakes of magnitude $M_s = 5.0$ have occurred in north Vietnam, in the north border of Hanoi depression and in the coastal zone of the central part of Vietnam. More than 1,450 events with magnitude around 7 Richter scale were reported during 1900-1999 [11]. Some of the significant earthquakes in this region are - the Dien Bien earthquake of 6.8 Richter scale; the 1961 Bac Giang earthquake of 5.3 Richter scale; the 1983 Tuan Giao earthquake of 5.3 Richter scale. The last two earthquakes caused some shakings in Hanoi. Most recently, on 19 February, 2001, an earthquake of 5.3 Richter scale occurred in Dien Bien (close to the border with Laos PDR) at a depth of 12 kilometers, causing heavy damages and losses in this mountainous region. This earthquake occurred along the Lai Chau - Dien Bien rupture, parallel with the Hong (Red) River rupture. Researches point out that the Hong (Red) River rupture has potential of causing earthquakes of 7-8 Richter scale [10].

GEOLOGY OF HANOI

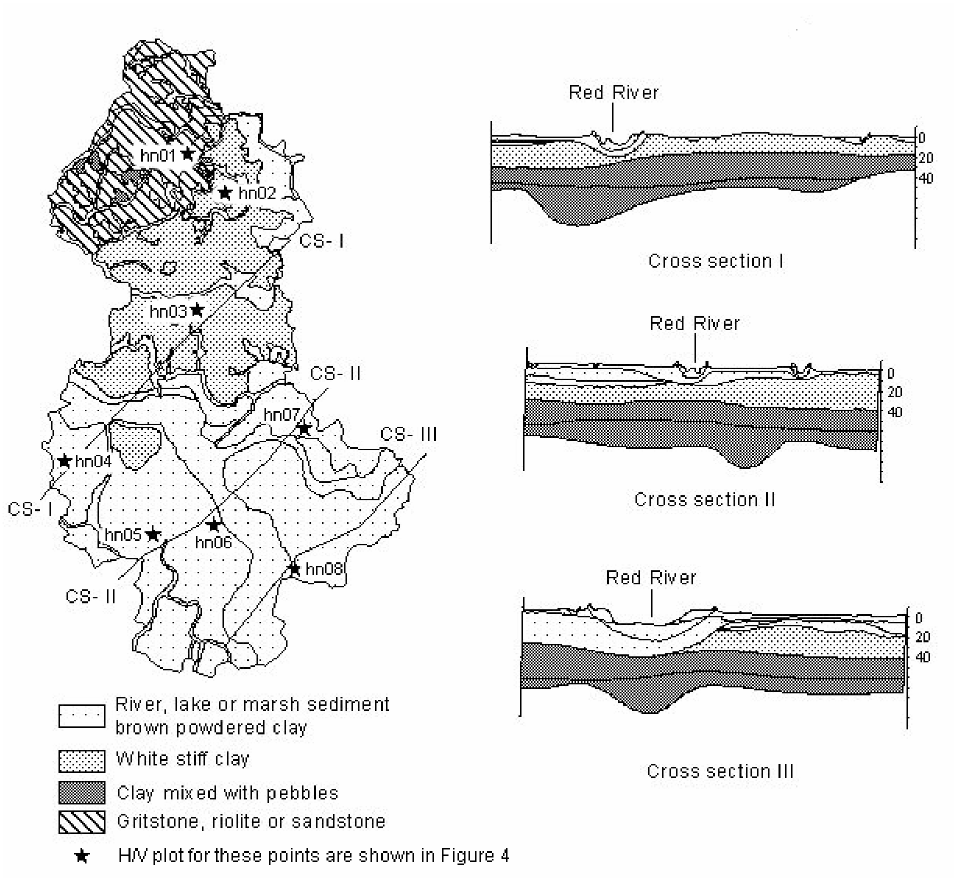

Figure 2 Geological map of Hanoi [12]

The city's topography gradually lowers from north to south [12]. Tam Dao mountain range is in the northern part. The rest of Hanoi can be divided into 3 regions: the upper region includes Soc Son district, adjacent to Tam Dao Mountain Range, has an average height of 8 - 12m; the middle region Dong Anh, Gia Lam and Tu Liem districts, and the urban area, has an average height of 5 - 10m; the lower land in Thanh Tri district has an average elevation of 3 - 4m. South Hanoi, including Hanoi metropolitan area, is located in the Red River Delta and has soft river, lake or marsh sediments on the surface. Dong Anh district and southern portion of Soc Son district have white stiff clay on the top layer and the northern areas of Soc Son district have gritstone, riolite or sandstone on the surface. Figure 2 shows the geologic map of Hanoi together with the soil strata along three cross-sections [12]. It can be seen that in the southern part of Hanoi, the thickness of soft sediments is larger and the thickness decreases towards east. This soft sediment mainly consists of river, lakes deposits and is followed by white stiff clay. Clay layer mixed with pebbles exits below the stiff clay layer.

MICROTREMOR MEASUREMENTS AND DATA ANALYSIS

Instrument Setup

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

Data Acquisition and Processing

At each site, data were recorded for 327.68 seconds (i.e. 32,768 data points at the sampling rate of 100 Hz). The recorded time series data were divided into 16 segments each of 20.48s duration. For each site, ten segments of the data were chosen from 16 segments, omitting the segments that are influenced by very near noise sources. These ten segments were used for the calculation. The Fourier spectra were calculated for the selected ten segments using the Fast Fourier Transform (FFT) algorithm and the Fourier spectra were smoothed using a Parzen window of bandwidth 0.4 Hz. The Fourier amplitude ratio of the two horizontal Fourier spectra and one vertical Fourier spectrum were obtained using Equation 1:

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

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

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

The H/V spectra were obtained for all the observation sites and the predominant periods of all the sites were identified. Observation points were then overlain on a digital map of Hanoi. Inverse distance weighing (IDW) method [13] was used for spatial interpolation for plotting the microzonation map for Hanoi metropolitan area, from the data measured at discrete locations.

MICROTREMOR MEASUREMENT RESULTS

Microtremor measurements were carried out at 63 sites. After digital signal processing and H/V analysis of microtremor data, a H/V spectrum ratio plot was constructed for each site. The predominant periods of ground were then determined from the H/V spectral ratio plots.

The variation of the predominant period in Hanoi is shown in Figure 3. It can be observed that the predominant period of ground increases from the north-to-south direction in Hanoi. In Soc Son district, in the northern part of Hanoi, the predominant period is less than 0.4 s. The sites located in the southern part of the city and, moreover, the areas along the Red River and areas around West Lake have a longer predominant period. It ranges from 0.6 to 1.0 s. The predominant period is longer in the southern district - Thanh Tri District - and ranges from 0.8 - 1.2 s. The period is also longer in western district (ranging from 0.6 to 1.0 s) and decreases in the eastern direction.

Figure 4 shows the H/V spectral ratio plots for eight sites marked in Figure 2. These eight sites, along the cross section I, II and III and in the Soc Son District, are picked from the 63 microtremor measurement points to show the variation in the H/V spectral ratio along these cross-sections where the geologic cross-section is available. The variation in the H/V spectral ratio correlates well with the geologic cross-section map shown in Figure 2.

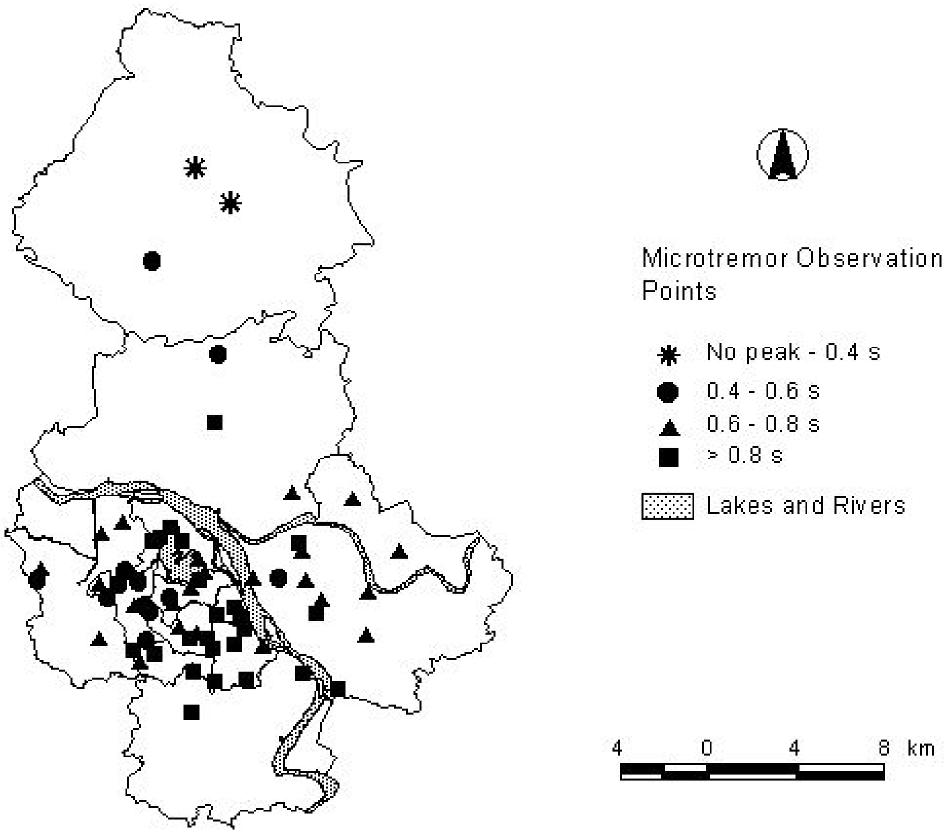

Figure 3 Microtremor observation points in Hanoi

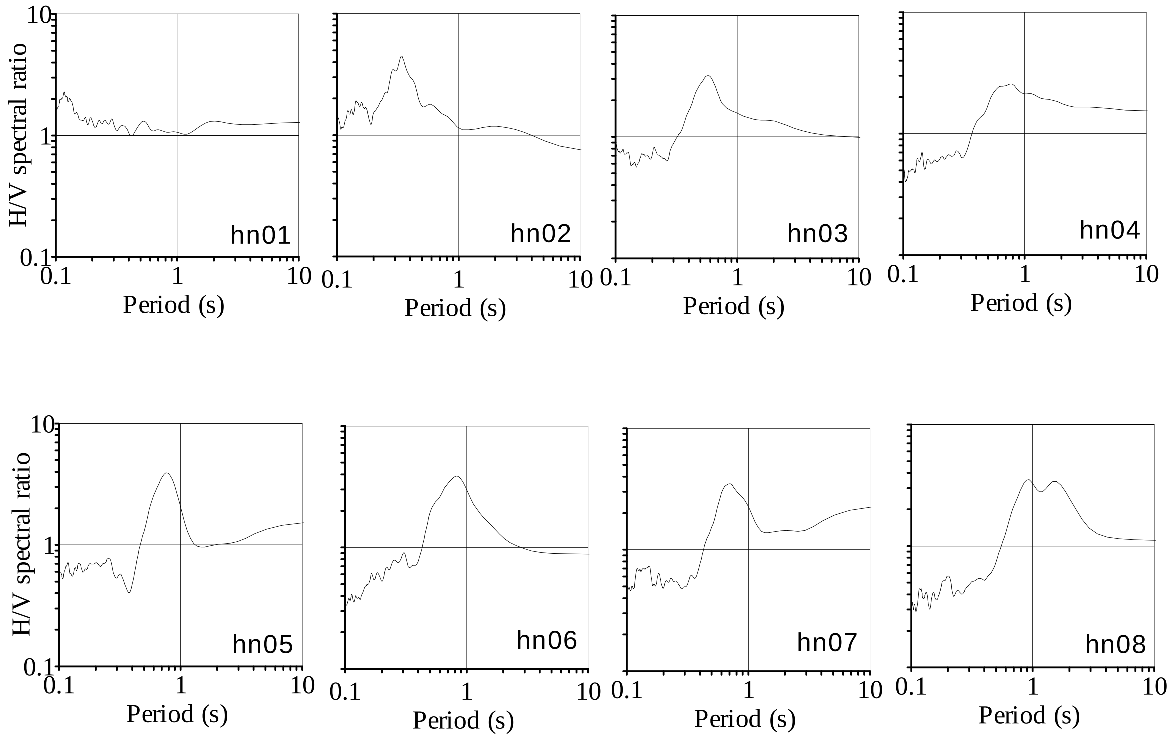

Figure 4 H/V spectral ratios for the sites marked in Figure 2

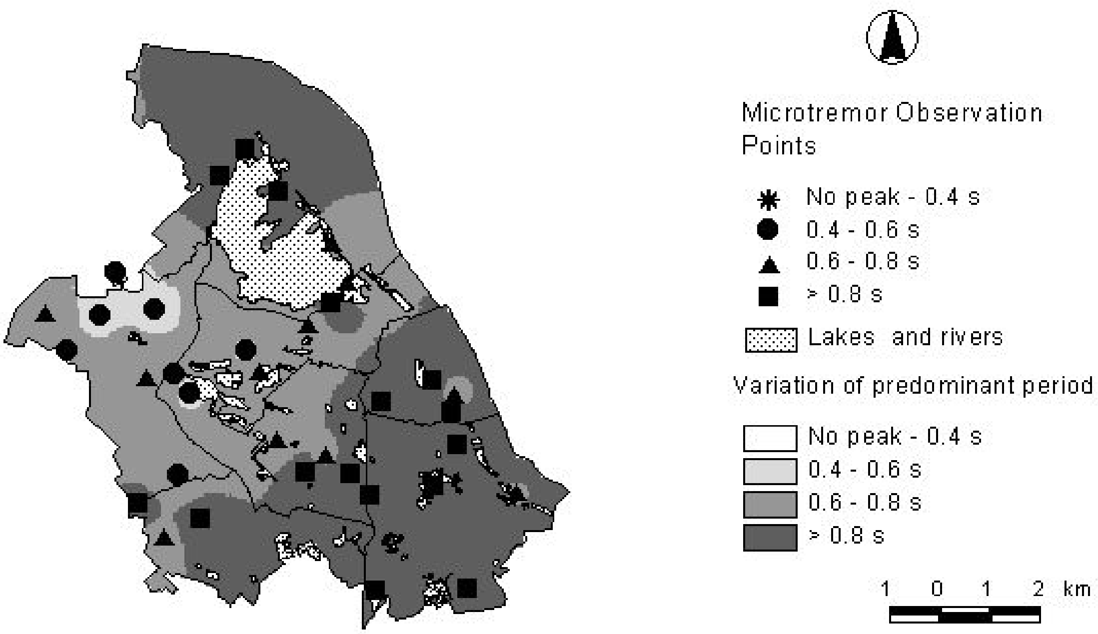

Figure 5 Microzonation map of Hanoi metropolitan area

Figure 5 shows the variation of the predominant period of ground in Hanoi metropolitan area. Dense microtremor measurement was carried out inside the Hanoi metropolitan area as most of the structures are concentrated in the metropolitan area. Inverse Distance Weighting (IDW) method [13] is used for spatial interpolation. It can be observed that the southern portion of Hanoi metropolitan area and the areas near the west lake have longer predominant periods. The areas around the west lake has the predominant period ranging from 0.6 - 1.0 s, whereas the predominant period in the southern part of Hanoi Metropolitan area ranges from 0.8 - 1.2 s.

According to the variation of the predominant period of ground, the city can be divided into four zones as explained earlier. Northern portion of Hanoi, which includes Soc Son District falls into zone I, whereas most of the areas in the Hanoi metropolitan area and southern part of Hanoi fall in zone III and zone IV.

Based on the predominant period of ground, Hanoi can be classified into four zones as follows:

zone I: predominant period shorter than 0.4 s
zone II: predominant period ranging from 0.4 to 0.6 s
zone III: predominant period ranging from 0.6 to 0.8 s
zone IV: predominant period longer than 0.8 s

The proposed four period ranges were taken from the highway bridge code of Japan [14].

CONCLUSIONS

Microtremor observations were carried out at 63 sites in Hanoi. The H/V spectral analysis was carried out for all the sites. The results show that the northern portion of the city has a shorter predominant period (less than 0.4 s). This matchs quite well with the topographical setting of the region. In the northern part of Hanoi, where Tam Dao mountain range exists, the subsoil mostly consists of riolite, sandstone and gritstone. Since the subsoil strata is stiff in this region, the predominant period is shorter.

In Dong Anh district, the subsoil strata consist of relatively stiff white clay on the surface. The predominant period in this region ranges from 0.4 - 0.6 s. In Hanoi metropolitan area, the predominant period of ground is longer along the Red River and areas around West Lake. It ranges from 0.6 - 1.0 s. The predominant period is longer in the southern districts and ranges from 0.8 - 1.2 s. The subsoil strata in these areas mostly consist of river, lake or marsh sediments. The thickness of the soft sediments decreases in the east direction. Microtremor observations also exhibit longer periods in western district (ranging from 0.6 - 1.1 s) and relatively shorter periods in the eastern direction (0.6 - 0.8 s).

According to the variation of the predominant period of ground, the city was divided in to four zones. The northern portion of the city falls into zone I, whereas most of the areas in the Hanoi metropolitan area and southern part of Hanoi fall in zone III and zone IV.

This observation shows that in Hanoi, the areas in the southern part of the city and along the Red River and West Lake have longer predominant periods. In Hanoi Metropolitan areas, there are many lakes and some of them have been filled up to build housing complexes. Most of these reclaimed areas exhibit longer predominant periods. These areas might sustain long period ground vibration during an earthquake, and there is possibility of large amplification of ground motion in these areas.

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