SEISMIC HAZARD ASSESSMENT WITH MICROTREMOR ARRAY OBSERVATION AND COMPUTATIONAL SIMULATION IN THE METROPOLITAN BEIJING AREA

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ABSTRACT :

Historic earthquake record indicates that mediate to strong earthquakes have been frequently striking the greater Beijing metropolitan area where is going to host the 2008 summer Olympic Games. During the last 500 years (the Ming and Qing Dynasties) there are at least 11 earthquakes with the maximum intensity of VI or greater occurred within a 100-km radius centered at the Tiananmen Square, the center of Beijing City. To quantitatively assess the seismic risk of Beijing at a few critical sites of the 2008 Olympic Games, we used the numerical simulation to study the strong ground motion scenarios based on historic earthquake records. To improve the modeling efficiency and accuracy, the high-resolution near-surface geologic information was studied with a microtremor array measurement campaign conducted in summer 2007. We have collected microtremor arrays data at more than 1,000 sites in the metropolitan Beijing area with 30 three-component short-period seismometers. The collected data are processed with both the horizontal to vertical spectral ratio method (H/V) to extract the resonant frequency, thickness of the sediments, and the ground motion amplification factor; and the space correlation method to extract near-surface shear wave velocity structure. As an example, the newly acquired engineering geological and seismological data were used to estimate the near-surface site effects caused by the strong ground motion in the Beijing area generated by an scenario event similar to one historic earthquake occurred in the city center. Local site effects expressed as the ground motion amplification were found in the northwest corner of Beijing area, similar to what has been observed for the 1976 Tangshan earthquake. This project is supported by the Ministry of Science and Technology of China with Project No. 2006DFA21650 and the Institute of Earthquake Science (Project No.0207690229).

KEYWORDS: Beijing, site effect, numerical simulation, strong ground motion scenarios

1. INTRODUCTION

It has long been recognized that strong ground motion and resulting damage is larger over soft sediments than on bedrock. This is important since that most of urban settlements have been located along river valleys, mountain-front alluvial fans and coastal plains where thick aquifers can be found for water supplies. Identification of abnormal ground motion amplification area is a critical task for seismologists and earthquake engineers for cities sited on soft sediments earthquake prone zones.

Historic earthquake record indicates mediate to strong earthquakes having been frequently in the greater Beijing area. During the last 500 years, which is the Ming and Qing Dynasties in Chinese history, at least eleven earthquake events with a maximum intensity of VI or greater have occurred within a 100-km radius from the city center (State Seismological Bureau, 1995). The 1679 Sanhe-Pinggu Earthquake (M~8, Maximum Intensity XI at the epicenter and Intensity VIII in Beijing city) was only 60 km ENE of the city center. The much closer 1076 City Center Earthquake (M~5, Maximum Intensity VIII in city center), which was occurred in the city center, had generated abnormal strong ground shaking in Haidian District. Contemporarily, the 1976 Tangshan earthquake (~150km east of Beijing) has also severely shaken greater Beijing area. On July 4, 2006, the Wen'an Mw 4.9 earthquake (Major CMT solutions: Lat= 38.85° Lon= 116.30°, Depth= 22.7 km, Moment Tensor: [0.147, 1.390, -1.540, 0.768, 1.020, 2.040] ×1023 dyne-cm, Mw = 4.9) caused perceptible ground shaking in the entire Beijing area, with an epicentral distance approximately 100 km south of Beijing.

This event has raised more awareness about the earthquake safety for the Beijing Olympic Games. The existence of the thick Tertiary-Quaternary sediments (maximum thickness ~ 2 km) in Beijing area plays a critical role on estimating the surface ground motion at the Olympic Games sites. Acquisition of high-resolution engineering geological and seismological data in the metropolitan area, especially for the uppermost soft quaternary layer is required for providing better constraints in estimating the near-surface site effects on potential earthquake strong ground motions.

There has been a significant paradox in high-resolution earthquake hazard assessment for Beijing metropolitan area. On one hand, there have been few microseismicity events in the direct vicinity of Beijing area; meanwhile, no active artificial seismic sources (explosives, strong vibrations, heave mass drops, etc) are permitted in the heavily populated Beijing area. This means no usable seismic sources, passive and active, to be used in seismic surveys for obtaining high-resolution subsurface images. On the other hand; city planners, emergency response officers, and infrastructure engineers are actively seeking high-resolution, high accuracy engineering and geologic information for earthquake-resistant infrastructure design, seismic damage assessment, and emergency preparation and response.

Using the ambient noise (microtremor) measurements to delineate local site effects represents a fast and low-cost way to provide high-resolution maps of the predominant resonance frequency, the thickness of the soft sediments, and the ground motion amplifications (Bodin and Horton, 1999; Drawinski et al., 1996; Okada, 2003). This paper presents these site effect results for the entire Beijing area inside the 5th Beltway based on microtremor easurements. The new results on near-surface sediemtns will provid more constraints to better understand the local site effects on strong ground motion in the Beijing metropolitan area.

2. LOCAL SITE EFFECT ON EARTHQUAKE GROUND MOTION DERIVED FROM THE HORIZONTAL TO VERTICAL SPECTRAL RATIO (H/V) METHOD

With great advances in electronic hardware and the computational software it is possible now to turn microtremors, the ambient noises in the traditional sense, into signals in order to extract useful information. The vast availability of spatial and temporal distributions of microtremors caused by man-made traffic and industrial activities, as well as the natural sources from waves of ocean and meteorological condition variations are a geophysicists' 'friend', rather than the 'enemy', as viewed a couple of decades ago.

The field observation campaign on microtremor surveys took place in June, 2007. More than 1000 sites inside Beijing's 5th Beltway were occupied with the 3-component Guralp 40T-1 feedback seismometer and Reftek 130B recorder. The spacing between 2 adjacent sites is approximately 1 km. At one particular site the minimum recording length is one hour, with a sampling rate of 50 Hz. The surveys were conducted during daylight hours in the suburban area and night in the inner city area to assure acquiring the best quality microtremor data.

In data processing, the microtremor field data were first cut into 25-second segments. Using the GEOPSY software package (see http://www.geopsy.org), the horizontal to vertical spectral ratio (H/V) analysis (Nakamura, 1989) was conducted for data acquired at each site with the anti-triggering (opposite to triggering approach of the traditional seismic records) on raw data and STA/LTA (1.0 sec for STA and 25 sec for LTA with the minimum ratio of 0.2 to maximum of 4.0) to assure that only the coherent constituent of microtremors are included and the transient are discarded. The H/V ratio was then smoothed with the Konno-Ohmachi algorithm (Konno and Ohmachi, 1998) with a smoothing constant of 50.

3. DISCUSSION OF THE H/V RESULTS

From the analyses of the H/V ratios for these 1000 plus sites we found that the predominant resonance frequency has a range of 0.5 Hz to ~8 Hz (Figure 1). The high resonance frequencies (close to 8 Hz) tightly concentrated in a small area west of central Beijing near Babaoshan (Babao Hill), a topography high with bedrock outcrops; whereas the lowest frequencies were found in a much vast area east of central Beijing that is the SW end of the Shunyi Depression.

Based on H/V peak frequency –sediment thickness relationship (Ibs-von and Wohlenberg, 1999; Parolai et al., 2002) with the local constraint of available borehole data of metropolitan Beijing, a map of thickness of soft sediments (Figure 2a) was inferred from the H/V resonance frequencies. The inferred soft sediment thickness is in the range of zero (the Babaoshan area west of the City) to ~400 meters (east of the City) with an average of about 100 meters in the city. The relative thicker sediment (about 250 meters) in the NW corner between the 4th and the 5th beltways on the map coincides with the location of the Kunming Lake in the Summer Palace, the largest surface water body inside the 5th Beltway. In the inner city, the thicker sediments seems to be following the ancient surface water system around the 2nd Beltway, the location of the ancient city wall with guardian canal filling with water.

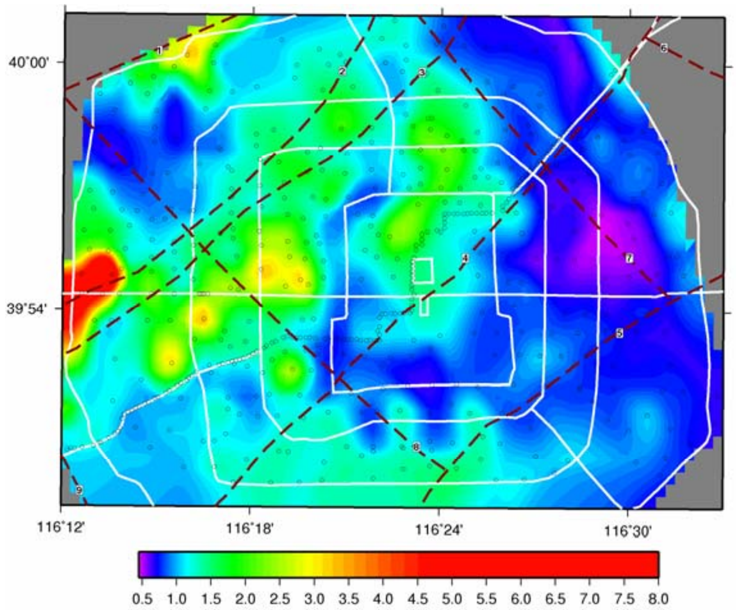

Figure 1. The map of predominant resonance frequency (in Hz) distribution. The open circles are the location of microtremor measurements. The white curves are the major highways, and the red broken curves are the major fault lines. The faults are: 1. Qinghe Fault, 2. Babaoshan Fault, 3. Huangzhuang-Gaoliying Fault, 4. Shunyi-Liangxiang Fault, 5. Nanyuan-Tongxian Fault, 6. Nankou-Sunhe Fault, 7. Nanhuqu-Daludian Fault, and 9. Qiyuan-Xiangshan Fault.

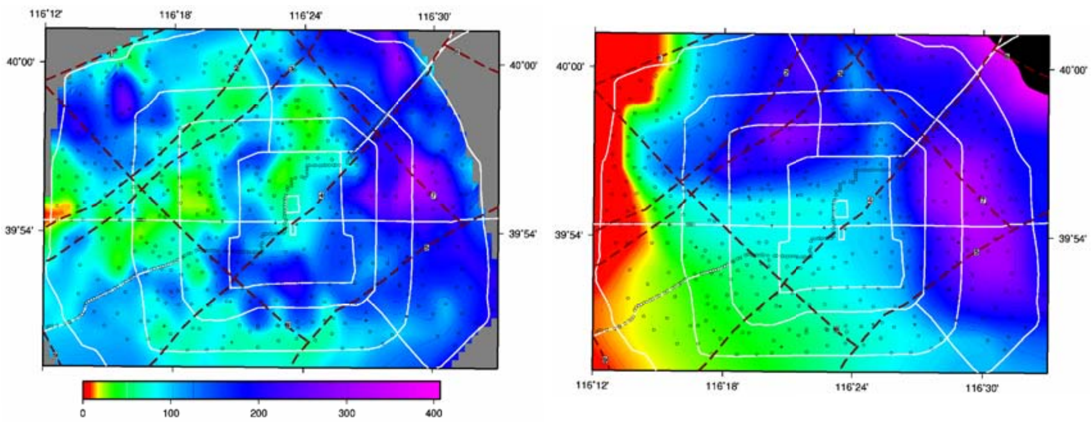

Figure 2. (a) Thickness (in meters) of the soft sedimentary layer derived from the H/V resonance frequency. (b) Thickness (in meters) of the Quaternary sediment layer modified from Figure 4 of Ding et al (2004)

Ding et al. (2004) compiled a Quaternary thickness map (Figure 2b) for Beijing area based on much sparser borehole data existing before late 1980s. The H/V derived sediment thickness presented in this paper (Figure 2a) coincides with Ding's Quaternary thickness map at the largest wavelength, i.e., the Quaternary sediments is much thinner at the west side, and much thicker at the east side of the City. Moreover, the new sediments thickness map (Figure 2a) provided more details with much shorter wavelength undulations over the entire area. These short-wavelength features appear to be reasonably in agreement with surface morphology and subsurface geology in this area.

Figure 3 presents the H/V ratio magnitudes at 0.5, 1.0, 2.0 Hz and at the peak resonance frequency. It is clearly noticeable that the high amplitudes are mostly concentrated on the north side of the City for all frequencies of 0.5, 1.0, and 2.0 Hz. The southeast corner of the City is another area with concentrated high H/V amplitudes. It is worthy to point out that during the 1976 Tangshan Earthquake abnormal high amplitude ground motion were reported in the Haidian District (the NW corner between the 4th and the 5th Beltways), and the area southeast of Beijing area (Ding et al 2004).

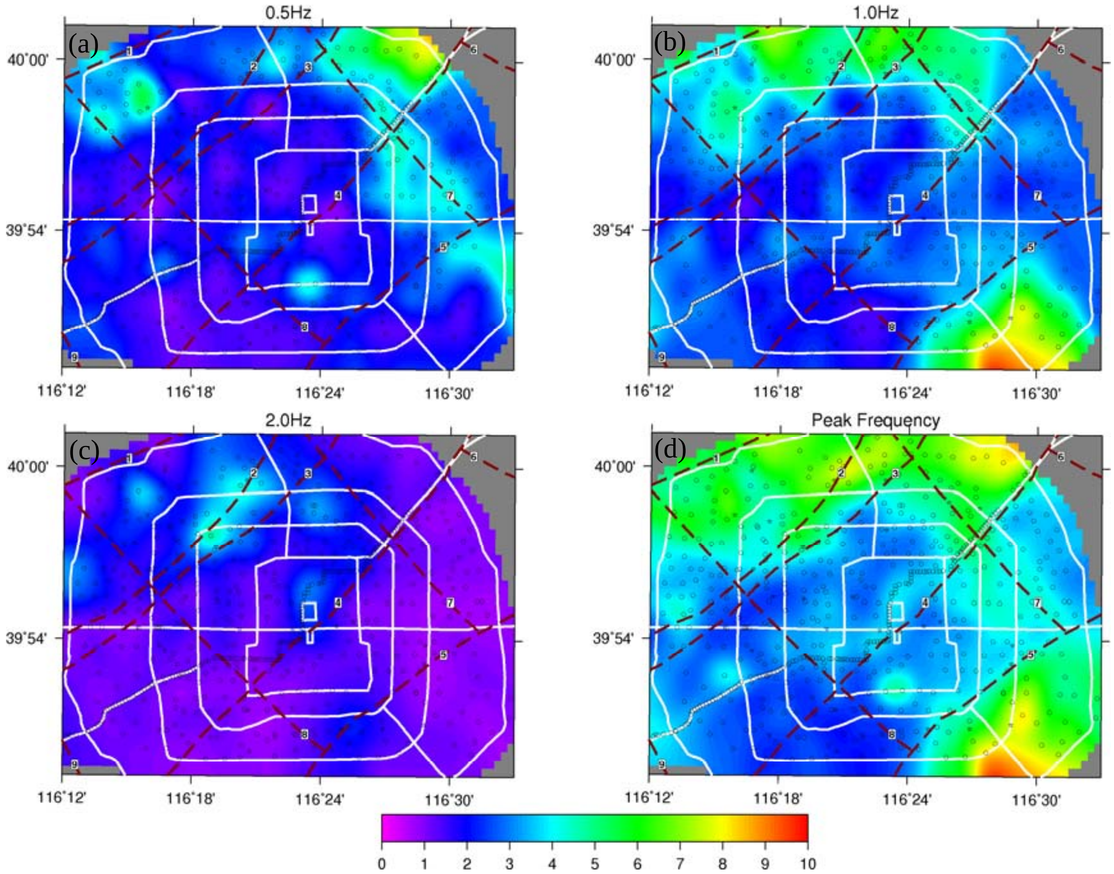

Figure 3. The amplification factor of the horizontal to vertical spectral ratio H/V at 0.5 Hz (upper left panel), 1.0 Hz (upper right panel), 2.0 Hz (lower left panel) and at the predominant resonance frequency of each site (lower right panel).

4. SIMULATION OF THE SITE EFFECT IN GREATER BEIJING AREA CAUSED BY THE 1076 M~5 CITY CENTER EARTHQUAKE

The 1076 City Center Earthquake (M~5, with the Maximum Intensity of VIII in city center) was estimated to occur epicenter directed beneath the city center, possibly on the NE oriented Fengtai-Liangxiang fault . The exist of the thick Tertiary-Quaternary sediments (maximum thickness ~ 2 km) in Beijing area plays a critical role on estimating the surface ground motion at the Olympic Games sites. With the sediment thickness estimation based on the H/V results from our microtremor measurents, local site effects on strong ground motion in Beijing area was conducted by numerical simulation of seismic wave propagations.

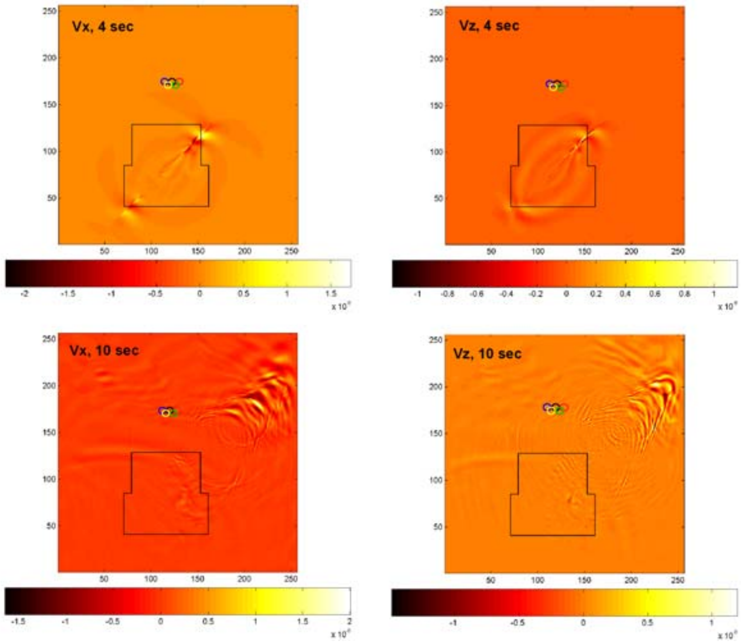

Figure 4. The snapshots of the horizontal and vertical components (Vx, left column and Vz, right column, respectively) of the particle velocity on surface at 4 and 10 seconds after the rupture of a vertical fault.

The numerical simulation technique employs the staggered grid pseudospectral time-domain (PSTD) method, with a stretched coordinate perfectly matched layer (PML) absorption boundary condition (Liu and Arcone, 2005). The simulated seismic source is the distributed right-lateral, strike-slip on the NE oriented near-vertical hidden Fengtai-Liangxiang Fault. The seismic wave propagation is simulated for up to 10 second. The grid size is about 0.1 km. High resolution near-surface velocity structure obtained by the newly acquired microtremor data was incorporated in the crust model. The synthetic seismograms are compared with the one using a model with previous Tertiary-Quaternary sediments model compiled by Ding et al (2004). The difference in the maximum surface motion velocity is shown as Figure 5. The differential surface motion clearly shows thatquite a few spots northwest of the city appears to be in high amplification. Again, it is worthy to point out that this feature is in a good agreement with observed intensity anomaly in the Haidian District caused by the 1976 Tangshan Earthquake.

4.CONCLUSIONS

The wide availability of microtremors provides an economical geophysical exploration tool to solve the significant paradox of seismic sources in earthquake hazard preparation in metropolitan city as Beijing. Using the microtremor array measurements from over 1000 sites inside Beijing's 5th Beltway a map of predominant resonance frequency was obtained and a refined map of the thickness of soft sediments was inferred. The sediment thickness map is controlled by borehole data at numerous locations in this area. The new results provided timely improved constraints for estimating local site effects on earthquake strong ground motion predications in this politically, economically, and culturally critical area. Numerical simulation of a scenario earthquake is in agreement with the observations made during the 1976 Tangshan earthquake.

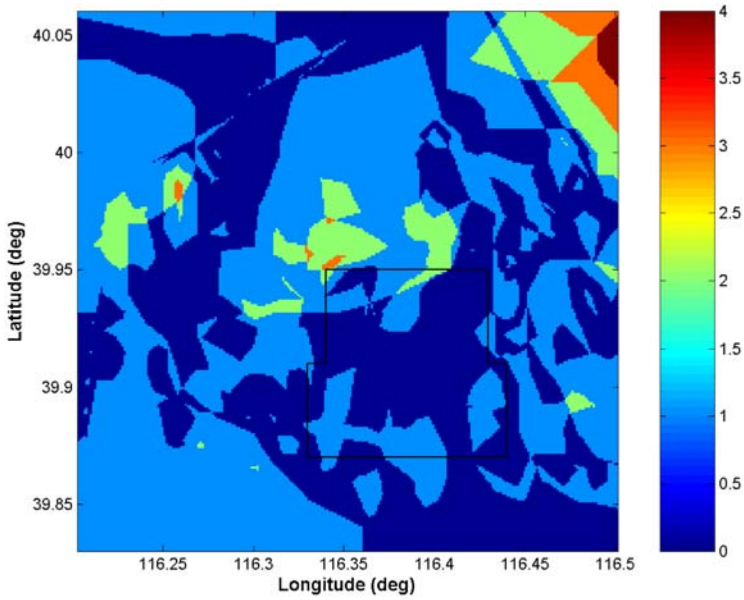

Figure 5. The difference of the surface ground motion velocity amplification with the use of the new results of quarternary thickness with the previous one obetained by Ding et al (2004)

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