SIMULATION OF STRONG GROUND MOTION SCENARIO IN THE GREATER BEIJING AREA CAUSED BY THE 1679 M8 SANHE-PINGGU EARTHQUAKE

K. He[1], L. Liu[2,3], W. Wang[3], Y. Tan[3], and Q. Chen[3]

[1] *Department of Physics , University of Connecticut, Storrs, CT, USA*
[2] *Dept. of Civil & Environmental Engineering , University of Connecticut, Storrs, CT, USA*
[3] *Institute of Earthquake Science, China Earthquake Administration, Beijing, China*
Email: kuang.he@uconn.edu, lanbo.liu@uconn.edu

ABSTRACT

The great Sanhe-Pinggu earthquake (M~8, with the maximum intensity of XI at the epicenter and VIII in Beijing city) occurred in September, 1679 is the largest historic event in the past 500 years within a 100-km radius from the center of Beijing. A detailed comprehension of the ground motion scenario caused by this earthquake will provide valuable information for seismic hazard reduction in the metropolitan Beijing area. Numerical simulation of seismic wave propagation and strong ground motion using high performance computational methods is a proven tool in seismic hazard zonation and local site effect assessment based on scenario earthquakes. We studied the effect of the 1679 Sanhe-Pinggu M8 earthquake in Beijing area with the staggered grid pseudospectral time domain (PSTD) method, with stretched coordinate perfectly matched layer (PML) absorption boundary conditions. The epicenter of this great event was about 60 km ENE of the center of Beijing city. The simulated seismic source is the distributed 5-m right-lateral, strike-slip rupture along the ~150 km long, NE oriented near-vertical Xiadian Fault. The seismic wave propagation is simulated for up to 1 Hz. The grid size is about 0.18 km. High resolution near-surface velocity structure obtained by the newly acquired microtremor data was incorporated in the crust model. The result suggests that numerical modeling approach is effective in seismic hazard assessment and provides valuable information for mitigating losses for possible earthquakes in the future. 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: Sanhe-Pinggu earthquake, numerical simulation, strong ground motion, pseudospectral time domain method, sediment amplification

1. INTRODUCTION

It has long been recognized that the structure and material property of the uppermost sediments is a fatally critical factor to determine the brutality of strong ground motion caused by earthquake shaking (Anderson, 1996). Thus, study of the local site effects is a critical part in seismic hazard mitigation effort, and has resulted in the concept of seismic micro-zonation.

Historic earthquake records indicate that moderate to strong earthquakes have been frequently striking the greater Beijing area. During the past 500 years (the Ming and Qing Dynasties), there have been 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. The Sanhe-Pinggu (M~8) earthquake, the largest historic event, occurred 65 km ENE of Beijing, severely damaged the city on September 2, 1679 (Institute of Geophysics, 1990).

To quantitatively assess the seismic risk of Beijing area, especially at a few critical sites associated with the 2008 Summer 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 sediment layer thickness information obtained by a microtremor measurement campaign conducted in summer 2007 (Chen et al., 2008) was incorporated into the crustal model. With more constraints on near-surface geological information, we possess the opportunity to better estimate the local site effects on strong ground motion in the greater Beijing area generated by the potential pending earthquake (the scenario event) similar to the 1679 Sanhe-Pinggu M8 event.

2. SUMMARY OF THE NUMERICAL MODEL

2.1 Modeled Area

Figure 1 shows a map view of the modeled area, with the 2nd to 5th Beijing beltways and main roads highlighted for reference. We have also highlighted the epicenter of the Sanhe-Pinggu event and four other locations we are concerned about: the Tiananmen Square, an often used national symbol which also marks the center of Beijing city; the 2008 Summer Olympics Stadium (also known for its nickname “Bird Nest”), where the 2008 Summer Olympics Games are currently being hosted when we write this paper; Wukesong Culture and Sports Center, an indoor arena for the 2008 Summer Olympics basketball preliminaries and finals; and the Beijing University of Technology (BUT), whose stadium is hosting the Olympics badminton matches. Detailed shear wave velocity profiling experiments have been done at all the 3 Olympics game-related sites (e.g., Wang et al, 2008). The thickness of the Quaternary sediment layer is also shown in Figure 1, with data taken from Jia et al. (2005), and Chen et al. (2008).

2.2 Model Implementation

We have used the staggered grid pseudospectral time domain (PSTD) method (e.g., Witte, 1989; Liu 1997; Cormier, 2000; Liu and Arcone, 2005) to simulate the seismic wave propagation generated by a scenario earthquake based on the 1679 Sanhe-Pinggu M8 event. Our 3D model consists of a system of 512x256x64 grids, with dx=dy=dx=0.18 km. The model consists of three layers, similar to what is used in Ding et al (2004): the Quaternary sediment layer (v_p = 1.56 km/s, v_s = 0.9 km/s), the Tertiary sediment layer (v_p = 4.5 km/s, v_s = 2.6 km/s), and the bedrock (v_p = 6 km/s, v_s = 3.46 km/s). The modeled surface area has a rectangular shape, with the southwest vertex at (39.8000°N, 116.1000°E) and the northeast vertex at (40.2149°N, 117.1823°E). For simplicity, we have assumed a uniform density 2,500 kg/m^3 throughout our model domain.

PML absorption boundary conditions (Chew and Weedon, 1994; Liu and Tao, 1997) have been used in our modeling, and its thickness is 10 grid points, which is a good tradeoff for this case. The time step used is 7.5 ms, and we have calculated 11,466 time steps, equivalent to 85.995 seconds in time, which is sufficient for all the wave phases to propagate through the entire model domain.

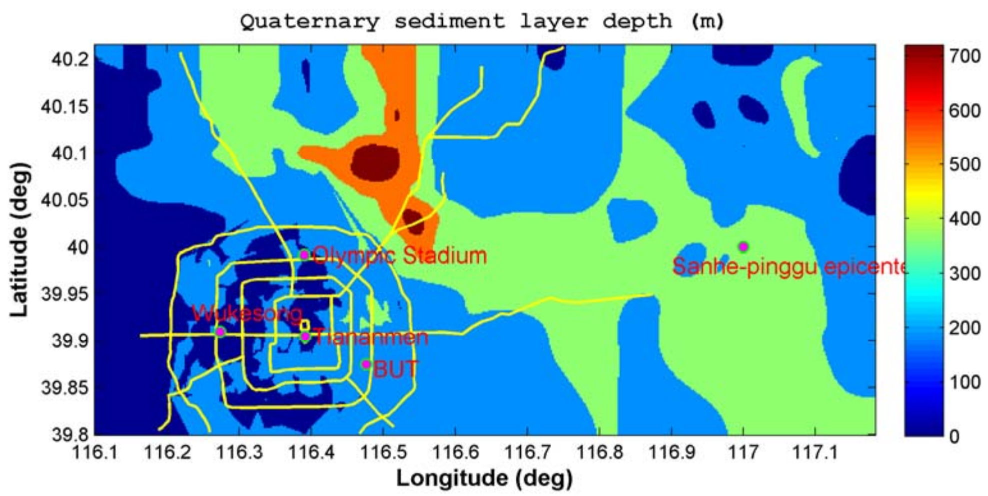


Figure 1 Thickness of the Quaternary layer of the model, with Beijing city beltways, main roads, and some specific places we are particularly interested in highlighted

3. THE SOURCE PARAMETERS

The parameters used for modeling the scenario seismic source are listed in Table 1. Most of these parameters are directly obtained, indirectly derived, or inferred based on previous studies (Xu et al., 2002; Shen et al., 2004; Biasi and Weldon, 2006; Liu et al., 2007). The length and width of the fault are 140 km and 30 km, respectively. However, due to the limited size of our model, we have only been able to construct a fault of 42.48 km in length and 11.52 km in width, with the source time window 30.20 second long. The length of the fault is in agreement with the magnitude and rupture length relation (Biasi and Weldon, 2006). We used particle velocity on the fault plane as the source, which is distributed over the modeled fault plane, and which decay in accordance with a sinusoidal relation to the surface and the lateral border of the model. The source time function that has been used is a Ricker wavelet with a central frequency of 1 Hz. We have assumed that the source mechanism has a rupture velocity 0.8 km/s, slightly less than the S-wave velocity (0.9 km/s) in the Quaternary sediment layer. The largest particle velocity used is 66.67 m/s, which is justified by the argument shown as follows.

To estimate the magnitude of the particle velocity caused by an earthquake rupturing, we assume that a substantial portion of the elastic potential energy E_p has been converted to the kinetic energy E_k:

$$Ek \sim Ep \tag{3.1}$$

As we all know, the kinetic energy of a volume element can be expressed as

$$E_k = \frac{1}{2} m\bar{v}^2 \tag{3.2}$$

And the elastic potential energy is

$$E_p = \frac{1}{2} \sum V \sigma_{ij} \varepsilon_{ij} \tag{3.3}$$

where m and V are the mass and volume of a volume element on the fault plane, respectively; σ_{ij} and ε_{ij} are stress and strain tensor components; and $\bar{v}$ is the average particle velocity over the whole fault plane. To model the strike-slip faulting, only the shear motion is involved so that we have the simplified Hooke's Law

$$\sigma_{ij} = \mu \varepsilon_{ij} \tag{3.4}$$

where μ is the shear modules, and only the shear components of stress and strain get involved in Eqn. (3.4). Moreover, the relation between seismic moment and stress tensor can be characterized as:

$$\sigma_{ij} = M_0 \frac{M_{ij}}{V} . \tag{3.5}$$

where M_0 is the scalar moment carrying the magnitude and dimension of the seismic moment caused by an earthquake rupturing, and M_{ij} is the moment tensor carrying the relativity of different motion with a maximum of unity. Then, from Eqns. (3.1)-(3.5), the average particle velocity on the fault plane can be estimated as:

$$\bar{v} = \frac{M_0}{V} \sqrt{\frac{1}{\rho\mu}} \tag{3.6}$$

From the M_0-M relation (Hanks and Kanamori, 1979; Deichmann 2006):

$$M = \frac{2}{3} \log M_0 - 6 \tag{3.7}$$

we can estimate M_0, hence the average velocity $\bar{v}$, from Eqn. (3.6) with a given density ρ and shear modulus μ.

Table 1 Source parameters of the Sanhe-Pinggu earthquake

Parameters	Value	Parameters	Value
seismic moment	$1.26\text{x}1028\text{x}10^{-7}$ N·m	source depth	10 km
stress drop	20 MPa	dip	70˚
length of the fault	140 km	strike	50˚
vertical extension	30 km	rake	18˚
epicenter location	40˚N / 117˚E		

4. RESULT DISCUSSION

4.1. Surface Peak Ground Velocity (PGV) and Peak Ground Acceleration (PGV)

PGV and PGA plots are very useful for earthquake engineering purposes. Surface PGV and PGA plots in the Beijing city area are shown in Figure 2, with the top row showing the three-component PGV, and the bottom row showing the three-component PGA. Beltways and main roads are also shown for reference. We have noticed that in the region shown in Figure 2, the most prominent PGV and PGA is in the east part. That is understandable, since the epicenter is ENE of the center of Beijing city.

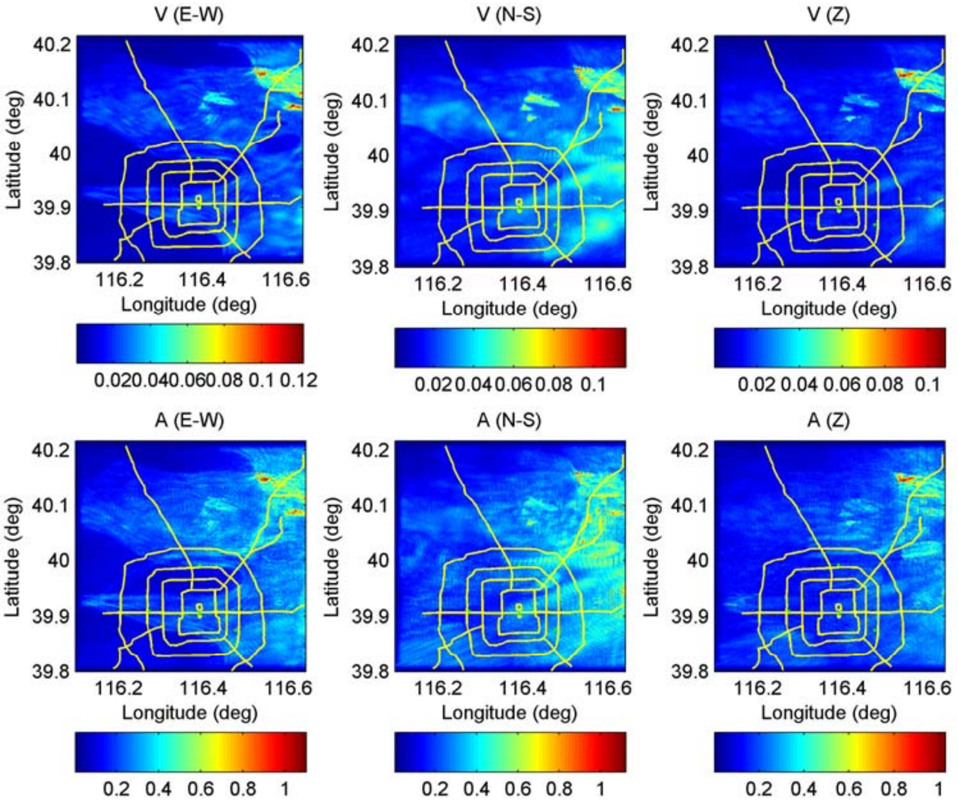


Figure 2 Top row: three component surface PGV (from left to right: East-West component, North-South component, and vertical component). Bottom row: three component surface PGA (from left to right: East-West component, North-South component, and vertical component)

In order to count for geometric spreading and to show seismic wave amplitude amplification effects which are possibly due to the sediment layers more clearly, we performed a horizontal versus vertical (H/V) PGV calculation. The result is shown in Figure 3, and we can see clearly from the rightmost plot in Figure 3 that there are strong amplitude amplification effects to the north of the city and in the southeastern corner of the Beijing city. It is worthy to point out that during the 1976 Tangshan Earthquake, abnormally high amplitude ground motion were reported in the Haidian District (the NW corner between the 4th and the 5th Beltway), and the southeast of Beijing area **(**Ding et al., 2004**)**, which has also been confirmed by observations in a recent microtremor study (Figure 4).

4.2. Synthetic Seismograms at Specific Sites

Shown in Figure 5 are the three-component synthetic seismograms recorded at four sites: the 2008 Summer Olympic Stadium, Beijing Wukesong Culture and Sports Center, Tiananmen Square, and Beijing University of Technology (BUT). The sampling rate of these seismograms is 75 ms.

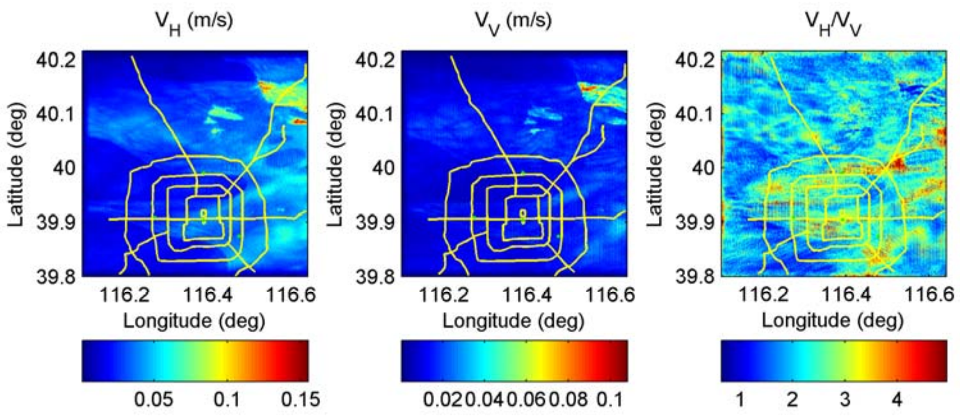
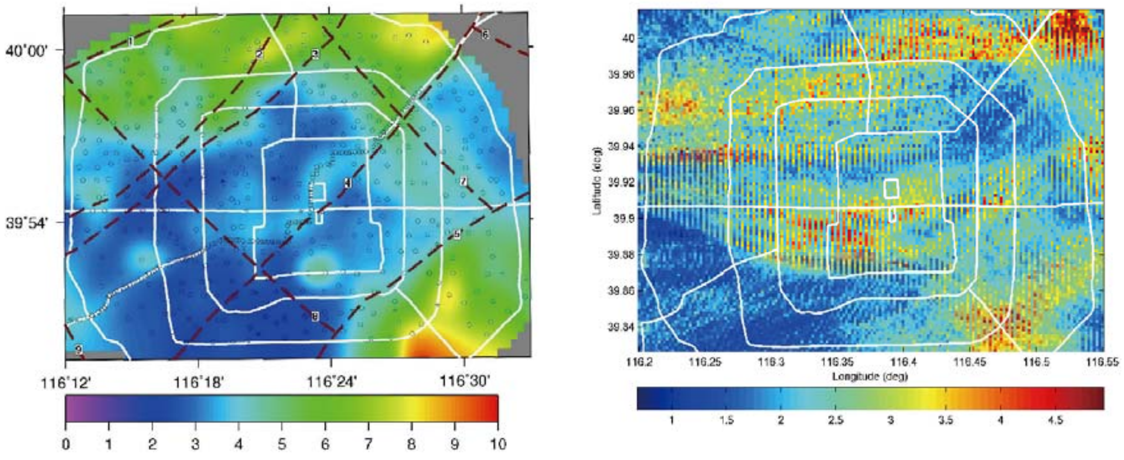


Figure 3 (Left) Horizontal PGV; (Middle) Vertical PGV; (Right) Horizontal PGV divided by vertical PGV (the H/V ratio)



(a) (b)

Figure 4 (a) The amplification factor of the horizontal to vertical spectral ratio at the predominant resonance frequency for Beijing area from microtremor measurements (Chen et al., 2008) (b) the horizontal to vertical ratio of PGA generated from the synthetic simulation of the 1679 M8 Sanhe-Pinggu scenario earthquake

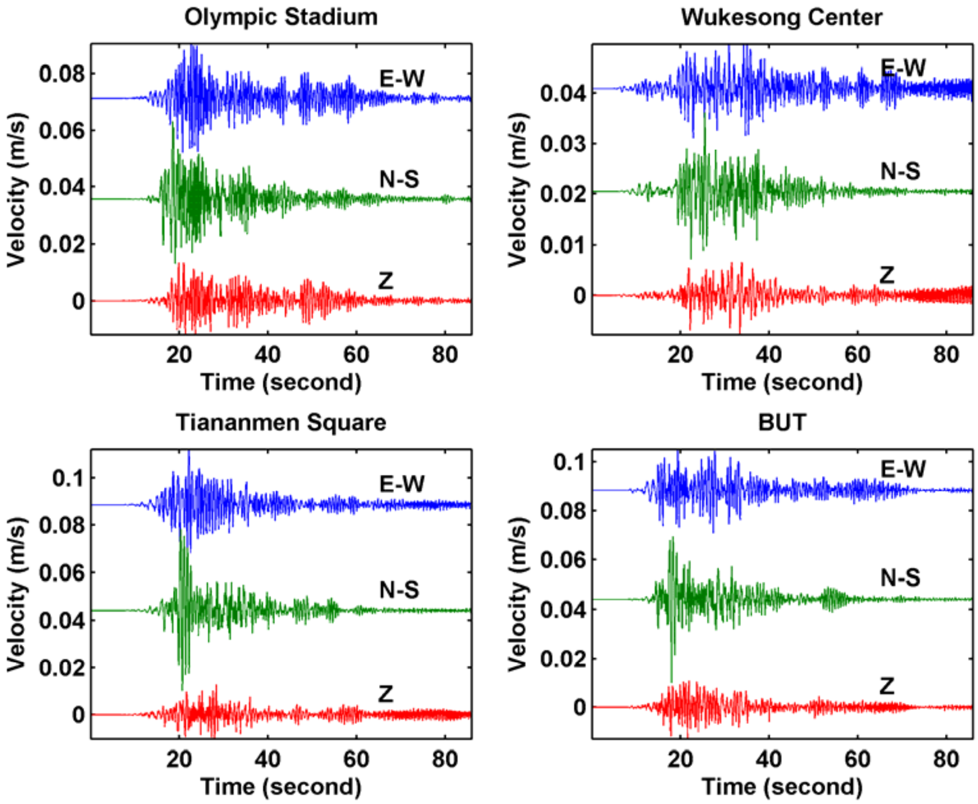


Figure 5 Three-component synthetic seismograms recorded at four sites (the 2008 Summer Olympic Stadium, Beijing Wukesong Culture and Sports Center, Tiananmen Square, and BUT), with a sampling rate of 75 ms

5. CONCLUSIONS

We have used staggered grid PSTD method to simulate the 1679 M8 Sanhe-Pinggu earthquake in the Beijing area, using a crust model with high-resolution sediment thickness information obtained from microtremor measurements in this area. Three-component synthetic seismograms of four important sites including the 2008 Summer Olympic Stadium are shown. From the surface PGV and PGA studies, together with H/V calculations, we have observed ground motion amplification effects possibly associated with local site effect in the north part and the southeast corner of Beijing area, which have also been confirmed by other studies. Our result suggests that numerical modeling approach is effective in seismic hazard assessment and provides valuable information for mitigating losses for possible pending earthquakes in the future.

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