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THREE-DIMENSIONAL FINITE-DIFFERENCE MODELING OF GROUND MOTIONS IN BEIJING FROM A MW7 SCENARIO EARTHQUAKE

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SUMMARY

A three-dimensional velocity model in Beijing area is constructed. The model comprises four main velocity layers. A Mw7 scenario on the Shunyi-Qianmen-Liangxiang fault is simulated. The bi-lateral and uni-lateral slip source models are used. The ground velocities are predicted using both source models. As contrast, a flat layer velocity model is constructed by averaging the depth of each layer. By doing so, the amplification factors are calculated to examine the basin effect in Beijing. The results show that, although the source models are different, the amplification factors in the Beijing basin are as high as 1.5 to 2.0.

INTRODUCTION

Like Los Angeles and Tokyo, Beijing is an earthquake prone megacity. Many destructive earthquakes have occurred within or around Beijing [1]. An earthquake with magnitude $6\frac{3}{4}$ occurred in 1057 in the south outskirts of Beijing. Another two events with magnitude greater than 6 occurred in the east suburbs of Beijing in 1536 and 1665, respectively, and one event with magnitude 6.5 occurred in the northwest part of Beijing in 1730. The city of Beijing suffered great losses from these events. On September 2, 1679, a great earthquake occurred about 40km east of Beijing. Several ten's of thousands of people died in this disastrous earthquake. Many towns were completely ruined.

Beijing, situated on the sedimentary basin, is a city undergoing rapid growth, including the construction of moderate to high-rise buildings. The growing potential losses and casualties make the characterization of strong ground motion extremely important in the Beijing area.

The modeling of ground motions from earthquakes in Los Angeles, Kobe, Tokyo, and the Sendai basin show that the three-dimensional finite-difference method is efficient for the study of basin effects [2, 3, 4, 5]. These authors illustrate that: (1) the three-dimensional finite-difference method is reasonable for long-

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period ground motion simulation; (2) basin effects are significant for Los Angeles, Tokyo and other cities; (3) the key factors in the three-dimensional finite-difference method are the source model and local structure model.

Strong ground motion record are rare in Beijing region. The focus of our study is to establish the source model and local structure model.

There are many studies of the structure of the capital region [6, 7, 8, 9, 10, 11]. It is possible to construct the local structure model for the purpose of ground motion simulation.

Using the three-dimensional velocity structure model, we have simulated the strong ground motions from the great Sanhe-Pinggu M8 earthquake [12]. The result show that the basin effect in Beijing is significant. The amplification factor is comparable with the surface soil effects.

The 110km length Shunyi-Qianmen-Liangxiang fault lies just under the downtown of Beijing. In 1057 an earthquake of magnitude $6\frac{3}{4}$ occurred on the south segment of Shunyi-Qianmen-Liangxiang fault. In this paper a Mw7 scenario is considered to simulate ground motions in Beijing.

VELOCITY STRUCTURE MODEL

The city of Beijing locates in the northwest part of North China plain where the Yanshan Mountain is in the north and the Taihangshan Mountain in the west. The topography of Beijing area is that in the northwest it is higher and to the southeast it is lower. Figure 1 shows the contour of depth of sedimentary base. There is a deep basin which the depth exceeds 1000m near the center of Beijing. The existence of Quaternary basin in the city of Beijing will have significant effect on the long-period ground motions.

Velocity structure model is very important in the three-dimensional simulation. The simulated results will be remarkably affected by the local velocity structure. Fortunately the study of deep and shallow structure of Beijing region is relatively enough to construct a three-dimensional structure model, although it is rough.

This velocity structure model comprises four main velocity layers within the upper 20km of the crust. The first and uppermost layer is the sedimentary layer, which has the lowest velocity. The deepest sediment is near Xidan in the central Beijing and another is near Shunyi in the north (Figure 1).

The second velocity interface is the G interface [13]. The depth of G interface varies from 4km to 12km in Beijing area [14]. We digitize the depth of G interface from Zhang and Shao [13].

The third velocity interface is the C interface [13]. The depth of C interface is from 14km to 18km and varies relatively less. We also digitize the depth of C interface from Zhang and Shao [13].

The last layer will be from the C interface to the Moho. Because the depth of Moho is deeper than our model dimension, we have no need to digitize it.

Within each layer, the P wave velocity, S wave velocity, density and Q-value are set uniform. There are many works, which relate to the P and S wave velocity survey near Beijing region [11, 15, 7, 8]. By compiling these results, we construct a composite model (Table 1).

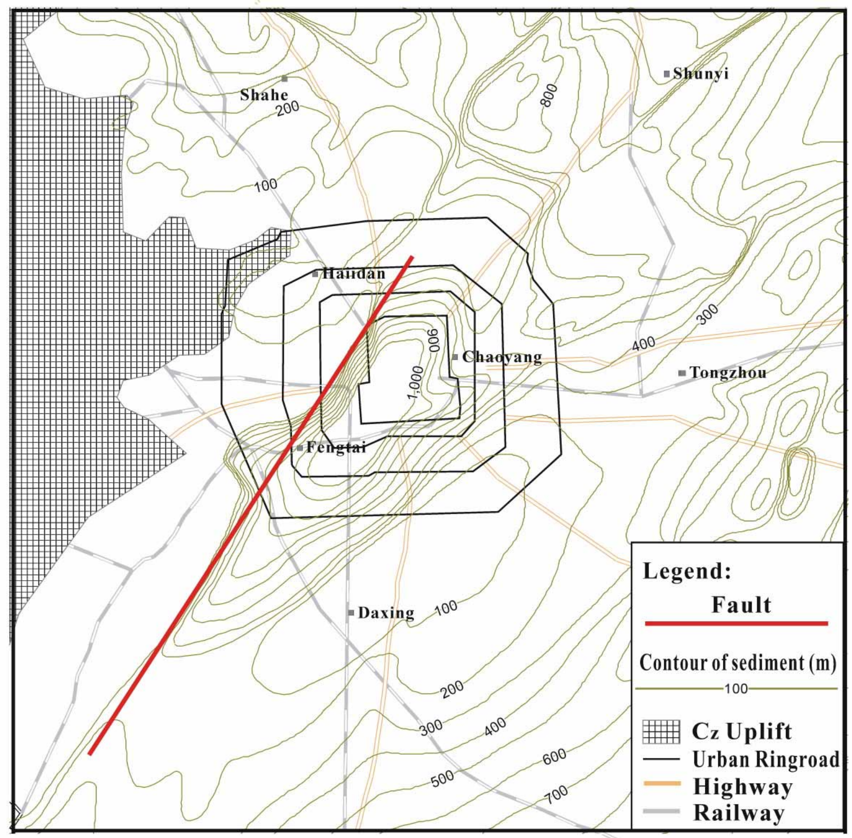

Figure 1 Contour of depth of sedimentary base

In order to estimate the basin effect, two models are used in our simulation. Besides above structure model, a flat model is used also. The flat model is constructed by averaging each interface depth to obtain flat layers. In each layer in the flat model, the velocity parameters, density and Q value are keep unchanged compared with the real structure model.

Table 1 Velocity structure model

Layer	*Vp*(km/s)	*Vs*(km/s)	Density(g/cm^3)	**Q**
1	3.5	1.6	2.40	200
2	6.0	3.4	2.76	800
3	6.2	3.5	2.82	900
4	6.6	3.7	2.90	1000

SOURCE MODELS

The 110km length Shunyi-Qianmen-Liangxiang fault lies just through the downtown of Beijing (Figure 1). The strike of the fault is about N25°E-N30°E. the dip angle is about 60°-80°. The fault can be divided into two segments, the south segment and the north segment. In 1057 an earthquake of magnitude $6\frac{3}{4}$ occurred on the south segment of Shunyi-Qianmen-Liangxiang fault. It can be concluded from the scale of the fault and seismic hazard assessment that the fault has the potential to generate a Mw7 earthquake. In this paper a Mw7 scenario is therefore considered to simulate ground motions in Beijing.

To consider the ultimate effect on the ground motion in Beijing, we take the middle part of the Shunyi-Qianmen-Liangxiang fault, a 50km long segment near the basin, as the seismogenic fault (Figure 1). The fault is set to be vertical. Two simple source models are considered, bi-lateral strike-slip rupture model and uni-lateral strike-slip rupture model. The bi-lateral model ruptures from the middle of the fault. The uni-lateral rupture model starts from the southwest and ends in the northeast point of the fault. The total moment of the scenario earthquakes for both models is 4.0×1026.

Referring to the work of Xu [17] and the statistical data of the region, the speed of rupture propagation is selected as 1.6km/s. The grid space is 0.2km, and the total number of grids is 1.225×107. Total time steps we used are 5000, and the time step is 0.01 second. It is obvious that the frequency content of the simulated ground motion depends on the spatial and temporal space and the details in the rupture process. Many scientists point out that the random details in rupture will control the high frequency content of the ground motion. So in the currently used three-dimensional finite-difference model, the high frequency content is not reliable. The maximum frequency content is our model is 1.6Hz. That means that this result only valid for the motion with period more than 0.65 second.

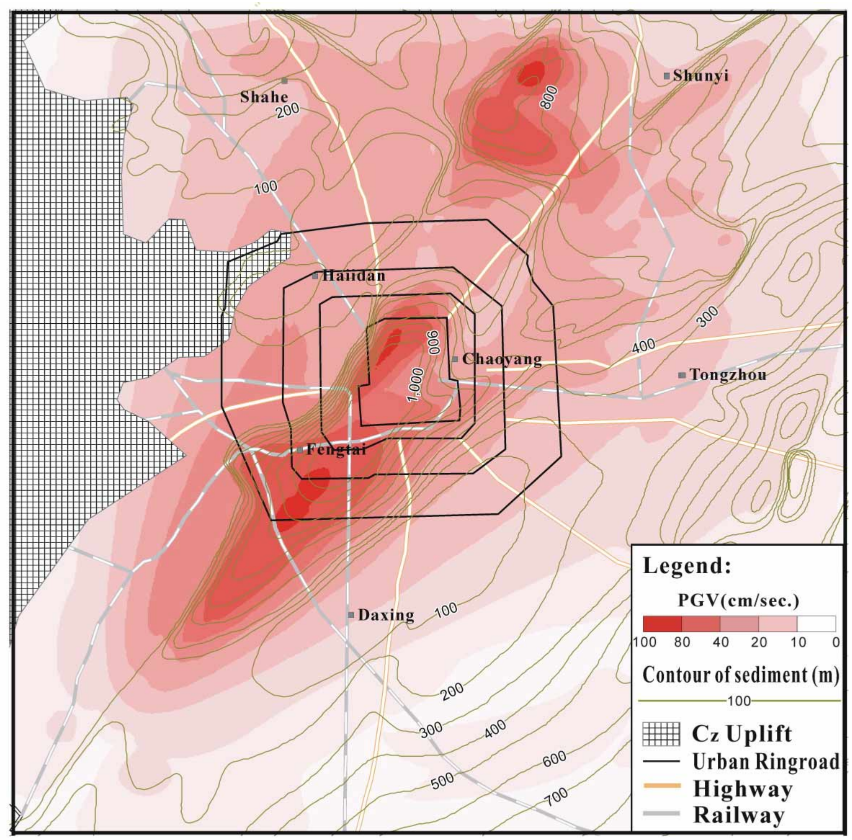

Figure 2 PGV distribution for uni-lateral rupture model

Some results of strong ground motion simulation show that the rise time is also sensitive to the results [18]. We chose this function from Somerville et al. [19]:

$$T_r = 1.72 \times 10^{-9} \cdot M_0^{1/3} \tag{1}$$

From equation (1), the rise time Tr is 1.27s.

Our model dimension is 70km×70km×20km. The fault is about 50km long and 18km deep and the strike is N33°E. The model parameters are shown in Table 2

Table 2 Model Parameters

Model dimen. (nx×ny×nz)	350×350×100
Total time steps	5000
Grid spacing(km)	0.2
Time step (sec)	0.01
Min. Velocity (km/sec)	1.6
Max. Frequency (Hz)	1.6
Model size (total grid points)	1.225×10^7

RESULTS

The ground motions are simulated using the three-dimensional finite-difference method [20]. This numerical approach, with a memory optimization procedure, allows large-scale three-dimensional finite-difference problems to be computed on a conventional computer.

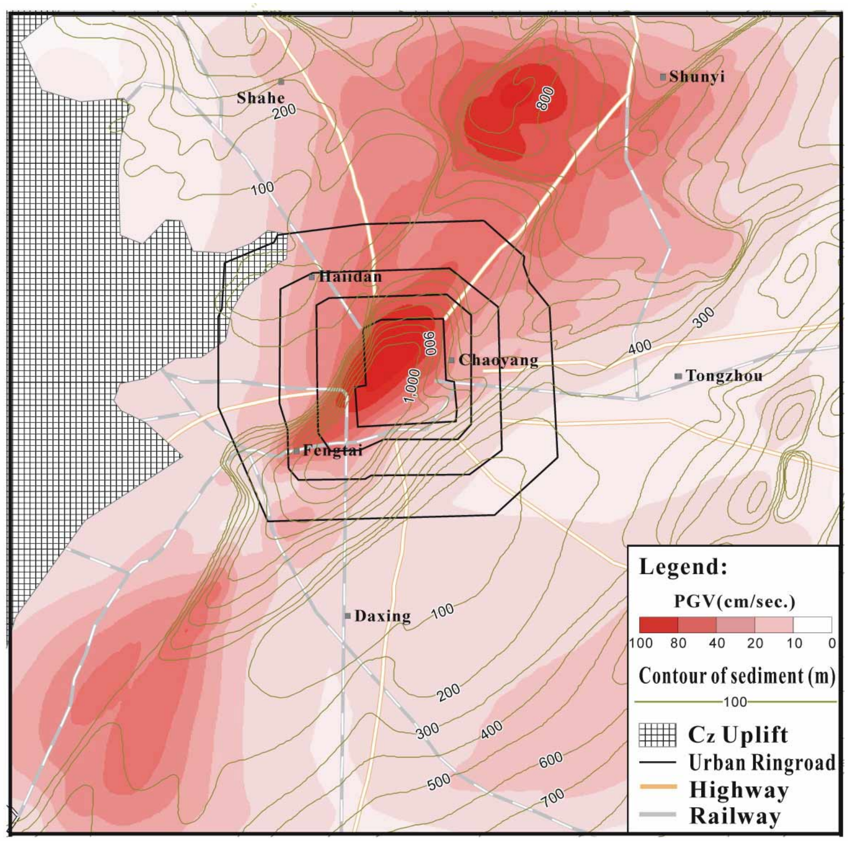

Figure 3 PGV distribution for bi-lateral rupture model

The distribution of simulated horizontal peak ground velocities in the research area for the uni-lateral rupture model is shown in Figure 2. There are several remarkable areas of strong shaking. Besides the near-fault region, the basin areas near Fengtai in the center and Shunyi in the north also have high peak ground velocity. The directivity can be clearly seen from the PGV distribution pattern.

For the bi-lateral rupture model the PGV distribution displays similar characteristics (Figure 3). The basin effect can also be seen in the basin areas. The directivity in the south direction appears compared with Figure 2.

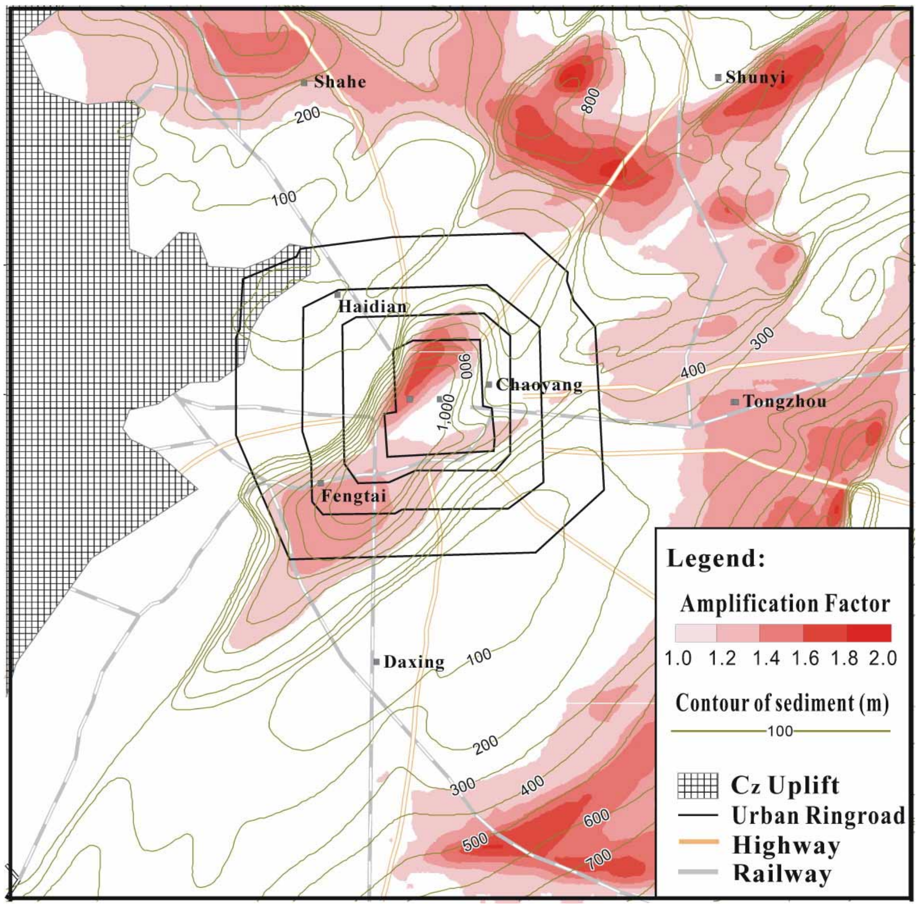

Figure 4 Amplification factor distribution for uni-lateral rupture model

In order to display the basin effect more clearly, the amplification factor map for horizontal PGV is made by comparing the PGV distribution of real structure model with the PGV distribution of flat layer model. Figure 4 is the amplification factor map in the case of uni-lateral rupture model and Figure 5 is that in the case of bi-lateral rupture model. The basin effect can be seen clearly in Figure 4 and Figure 5. In basin areas in the center, in the north and in the southeast, the amplification factor can reach as high as 2.0. The amplification by surface soil effect in Beijing is usually 1.18-1.63 [12]. In basin areas, the basin effects are comparable with the surface soil layer effects. There are possibilities that strong earthquakes occurred near downtown of Beijing. For these cases the amplification effect due to the basin structure would be much stronger. These results mean that in the moderate- to high-rise building design and risk management the basin effects must be considered. We also can find out that the combination of basin effects and surface soil effects for most sites in the downtown region of Beijing will significantly amplify the ground motions.

CONCLUSIONS

The simulation of strong ground motion due to a scenario earthquake by three-dimensional finite-difference model in the capital region of China shows that crustal structure, especially the basin structure, is significant compared with the surface soil effects. It has strong engineering meanings. The combination of basin effects and surface soil effects for many sites in the downtown region of Beijing will significantly amplify the ground motions.

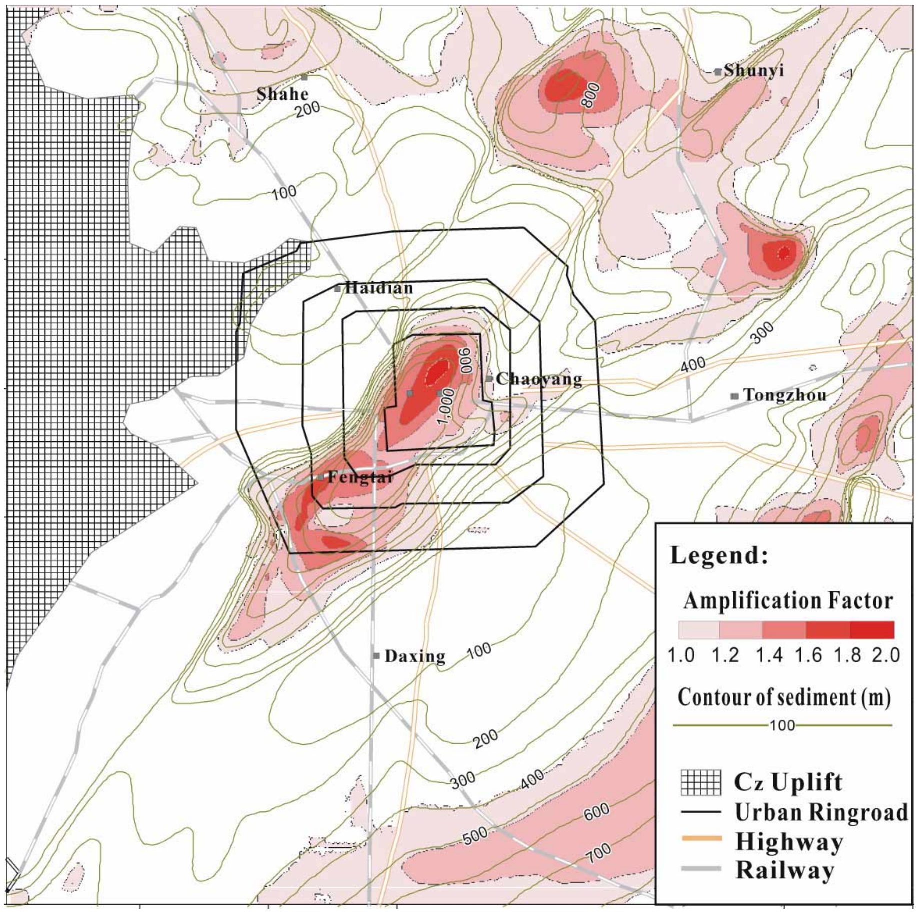

Figure 5 Amplification factor distribution for bi-lateral rupture model

There are many faults near the downtown region of Beijing. The overall basin effects with engineering purpose should be analyzed by using more scenario earthquakes.

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