Sensitivity Analysis of Parameters in Simulating the Amplification Effect of Long Period Ground Motion in Basins

Wuping Gao[1,2], Yanxiang Yu[1,*]

[1]Institute of Geophysics, China Earthquake Administration, Beijing 100081, China
[2]Tianjin Earthquake Agency, Tianjin 300201, China

*Corresponding author's e-mail:yuyx@cea-igp.ac.cn

Abstract. In the numerical simulation of the amplification effect of long-term seismic motion in basins, changes in basin parameters often have a relatively significant impact on the simulation results. Based on a simplified model of buried basin structure in North China, this paper conducted a sensitivity analysis of the impact of basin related parameters on the amplification effect of long-term seismic motion. The results showed that (1) the depth of the basin and the value of shear wave velocity at the base of the basin significantly affect the amplification effect of long-term seismic motion in the basin, they are sensitive parameters; (2) The influence of basin basement density and basement P-wave is not significant and belongs to micro sensitive parameters; (3) The Q value of the basin basement has almost no impact on the basin amplification, so it is an insensitive parameter.

Keywords: Disaster preparedness and mitigation, Risk assessment, Deep sedimentary basin, Numerical simulation, Sensitivity analysis.

1 Introduction

The amplification effect of long-period ground motion in basins has been one of the focuses of scholars' research. In the 1990s, attention was paid to the long-period ground motion in basins. Frankel A(1993) simulated the propagation of ground motion in San Bernardino Canyon with the finite-difference method, and analyzed the amplification effect in the basin in terms of the surface velocity amplitude and the time-holding dimensions in comparison[1]. Fletcher Jon B et al (2005) found that the amplification effect of long-period ground motion above 1 s is positively correlated with the thickness of the sedimentary layer in the basin, and concluded that the main factors affecting the amplification effect in the basin also include the difference in wave impedance between the layers of the medium[2]. Fu Changhua (2012) studied in detail the effect of long-period ground motion response spectra in the Beijing Basin in northern China, and defined the "equivalent sediment thickness" to measure the influence of the Tertiary and Quaternary systems on the long-period ground motion[3].

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Ye Yingchen (2014) showed that the horizontally layered sedimentary layers can also generate strong surface waves and produce significant long-period ground motion by numerical simulation of the one-dimensional wave field[4].

Although current research results have made great progress in recognizing that the basin amplification effect has a certain correlation with the sediment thickness, basin geometry, sediment physical parameters and basin-source location in the basin, there is far from agreement on which factors in the basin structure are the key factors influencing the amplification effect of ground motion, and the amplification effect is still mainly examined with the variable of sediment thickness or basin depth[5-7].

Long-period ground shaking amplification is an unavoidable problem for the Beijing-Tianjin-Hebei urban agglomeration in the North China Basin to carry out seismic disaster risk. Geologically, the North China Basin is a large-scale depression basin based on many Paleoproterozoic fault basins, which received a large number of Neoproterozoic and Quaternary sediments to form a unified large depression basin [8], which has both deep horizontal stratified sedimentary layers and submerged basin tectonics with quite a lot of fallout, and many of the submerged basins are also of very large scale, which makes the area a key area for the study of the long-period ground shaking amplification effect of the sedimentary layers and the basin tectonics. It has become a key area to study the amplification effect of long-period ground shaking on sedimentary layers and basin structures. In the absence of large earthquakes in the past few decades, ground shaking numerical simulation has been increasingly used in seismic hazard risk assessment and construction of urban seismic hazard scenarios. However, the differences in the data used by different researchers and the model parameters used have led to doubts about the reliability of the research results, and scholars have also realized that the values of the model parameters are becoming more and more critical in the numerical simulation.

Currently, the numerical simulation of earthquakes in the North China Basin is more often carried out from the perspective of "reproducing" historical earthquakes, mainly analyzing the comprehensive amplification effect of sedimentary basins, and not paying much attention to the uncertainty brought by the parameterization of the basin model. In this paper, from the perspective of evaluating the long-period ground shaking amplification effect in the sedimentary layer of the North China Basin, based on the structural pattern of the submerged basin in North China, we establish the basin tectonic model of "two concave sandwiched by a convex one", and use finite difference numerical simulation to simulate a large number of working conditions, and then analyze in detail the sensitivity of the structural parameters of the basin to the amplification effect of long-period ground shaking. The sensitivity of basin structural parameters to the amplification effect of long-period ground shaking is analyzed in detail, which provides a reference basis for the establishment of a numerical simulation model of ground shaking that is more in line with the actual situation in North China, and lays a foundation for the assessment of seismic hazard risk in the Beijing-Tianjin-Hebei urban agglomeration, and for the construction of more scientific and reasonable scenarios of seismic hazards in large cities.

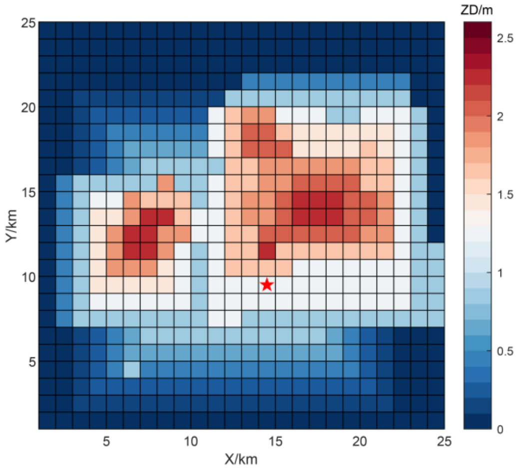
2 Method and models

Numerical simulation of seismic wave field is a method to study the propagation law of seismic wave in underground medium and synthesize ground vibration records by using theoretical calculation method with known structure and parameters of underground medium (Feng Yingjie et al, 2007)[9]. The finite difference method is a mature method in the current research of quantitative simulation of strong ground motion and earthquake damage prediction (Zhang Wei, 2006). In this work, the finite-difference computational program (FD3Dtopo software package) is used for simulation, which is capable of simulating the propagation of seismic waves excited by the kinematic rupture process of complex faults in three-dimensional arbitrary nonuniform media containing undulating topography, and the simulation accuracy is up to the fourth order in space and the second order in time. The main input parameters of the program are stratigraphic thickness, shear wave velocity, Q-value, density and physical parameters such as P-wave velocity[10].

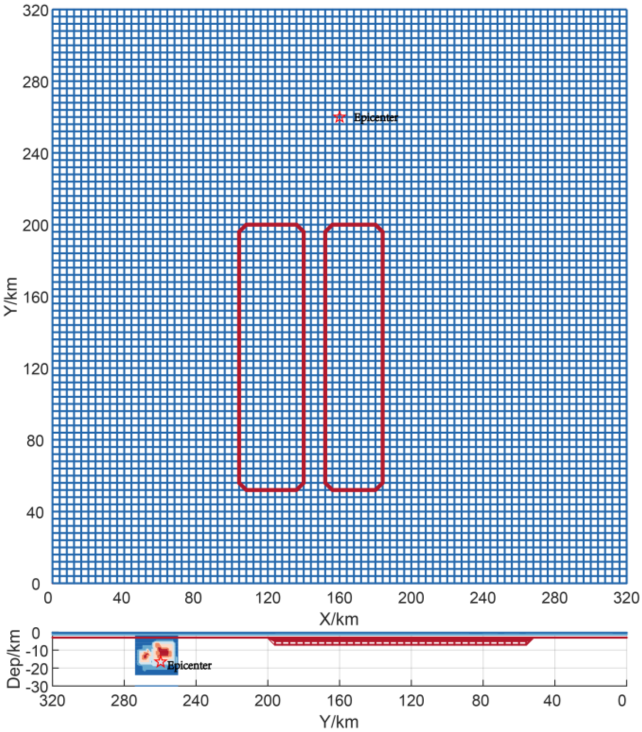
With reference to the typical submerged basin ridge tectonics and large earthquake rupture characteristics in North China, a basin model and an earthquake source rupture model are established as inputs in this numerical simulation. The source model is shown in Fig. 1(a), and the source parameters are shown in Table 1. Given that the amplification effect of ground motion along the rupture direction of the earthquake is more intense, it is set that the earthquake is outside of the basin, and the rupture direction is consistent with the direction of the basin tectonic line. Based on the stratigraphic characteristics of the North China Plain region, a "flat layer + basin tectonic" model was established at depth. In the plane, reference is made to a number of physical exploration profiles (Miao QuanYun et al, 2019), and the model of "two concave and one convex" is used to compare the Paleoproterozoic basin-ridge tectonics, and the model is set up as one deep and one shallow basin tectonics, with the basin dimensions of 160 km × 40 km, depths of 2 km and 4 km, respectively, and a bump in the middle, which is on a level with the flat-layer sedimentation. The model is schematically shown in Fig. 1(b)[11].

Table 1. Source model parameters of the set earthquake

Parameter	Value
Magnitude (Mw)	6.7
Depth of epicenter (km)	15
Fault slip angle (°)	-15
Fault dip angle (°)	85
Fault rupture size (length km×width km)	25×25
Average sliding volume (m)	0.64
Seismic moment (N·m)	$1.28e^{19}$
Average sliding volume of the bump body(m)	1.75
Percentage share of the area of the bump body(%)	25
Bump body approximate area (along fault strike km × along fault inclination km)	2×3,7×4



(a)Distribution of the average dislocation volume of seismic rupture.



(b)Tectonic assemblage model of the Paleoproterozoic basin.

Fig. 1. Input source model and medium model in the simulation.

In Figure 1. (b),The red five stars indicate the source of the earthquake and the red rectangle indicates the basin plane projection

3 Influence of basin parameters

In order to analyze the influence of Paleoproterozoic basin parameters on the amplification effect. Based on the existing exploration data and isothermal data, the Quaternary and Neoproterozoic systems inside and outside the basin are set to be 300m and 1000m, and the Paleoproterozoic system outside the basin is set to be 1700m, and the thickness of the Paleoproterozoic system inside the basin increases with the increase of the basin depth.

3.1 Influence of basin depth

Figure 2 gives the distribution of the spectral ratio of the reaction spectra (period 3s, 5s) for a basin depth of 3 ~ 6km versus a depth of 2km. As can be seen from the figure, with the increase of the basin depth, the spectral ratio distribution characteristics do not change significantly, and the overall trend is increasing, and it can be seen that a more obvious amplification occurs in three parts of the basin, at the epicenter distance of 80 ± 10km, 140 ± 10km, and 210 ± 10km. at the same time, based on the above results, from the point of view of the risk (the closer the source of the earthquake, the higher the amplitude of the ground motion), pick up the basin range on the the first amplification significant area (80±10km) corresponding to the peak of the spectral ratio (period=3~8s), and the corresponding basin depth-amplification coefficient relationship is given by using 75th percentile regression, see Fig.3.

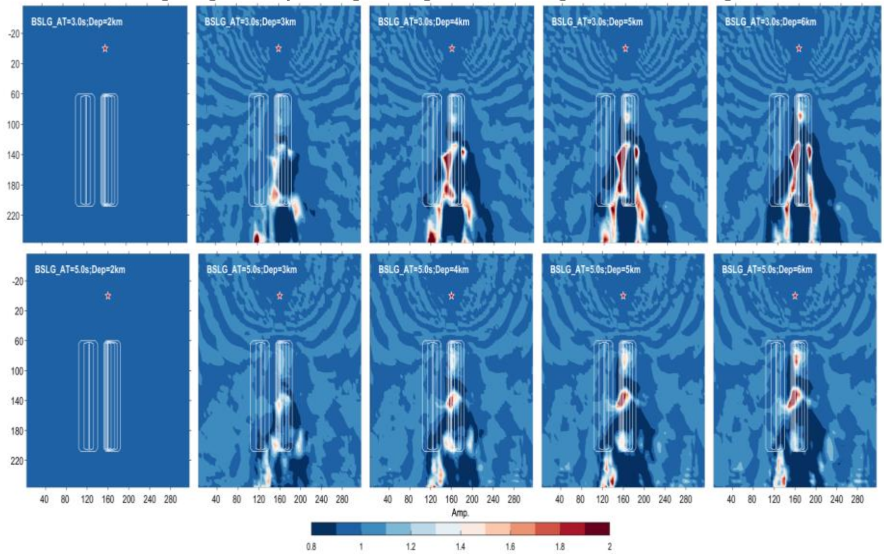


Fig. 2. Basin depth variation and its relative spectral ratio distribution.

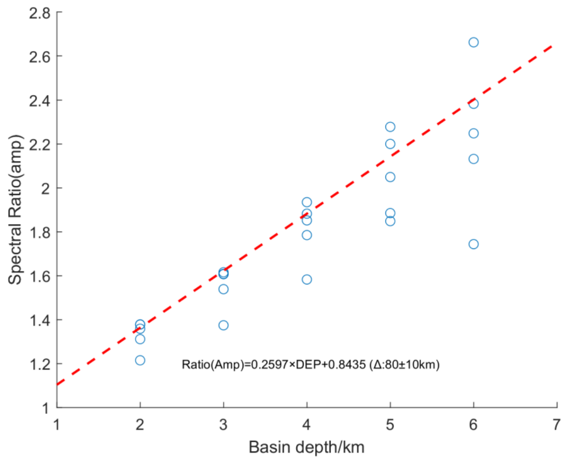
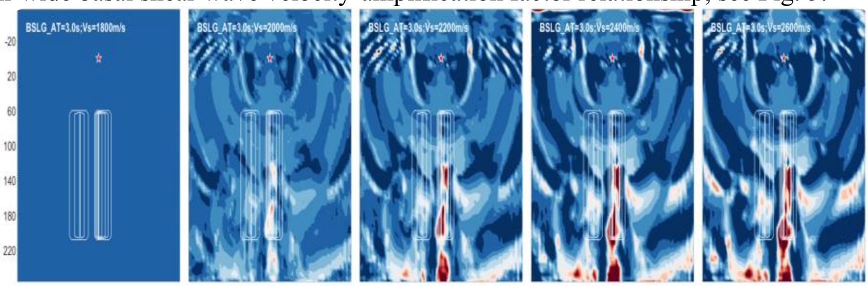


Fig. 3. 75th percentile regression curve of basin depth versus peak spectral ratio (Period=3~8s).

3.2 Influence of basin basement shear wave velocity

Taking the basin depth of 3km as the base, the simulation is carried out in the case that other parameters remain unchanged and only the change of basal shear wave velocity in the basin is changed. Figure 4 gives the distribution of the spectral ratio of the reaction spectrum (T=3, 5, 8s) with the basal shear wave speed of 1.8~2.6km/s and the basal shear wave speed of 1.8km/s. As can be seen from the figure, with the increase of the basal shear wave velocity, the characteristic pattern of the spectral ratio distribution does not change significantly, but shows an increasing trend, and there are two parts of the amplification significant area in the basin, specifically in the distance between the epicenter of the epicenter of the 140 ± 15km and 210 ± 10km. similarly, pick up the basin range of the first amplification of the first amplification of the peak spectral ratio corresponding to the first area of the significant area (140 ± 15km) (T = 3~8s), using 75th percentile regression to give the corresponding basin-wide basal shear wave velocity-amplification factor relationship, see Fig. 5.



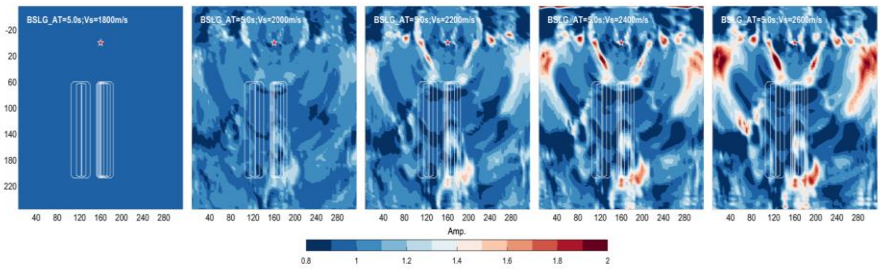


Fig. 4. Basin basement shear wave speed variation and its amplification effect.

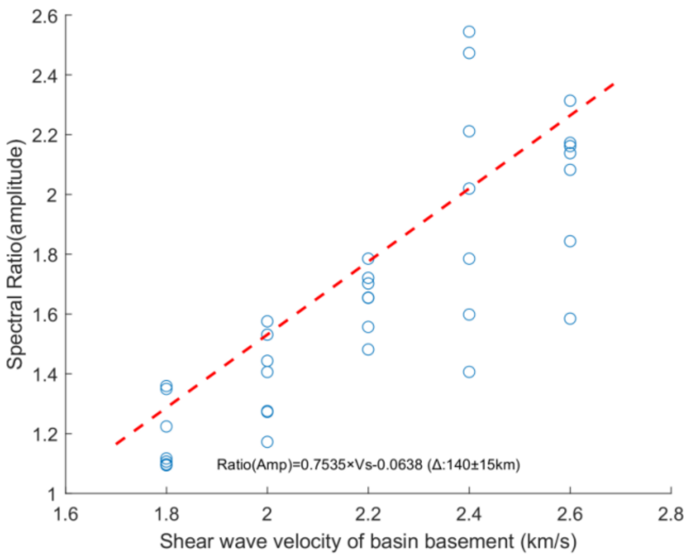


Fig. 5. Basin basement shear wave velocity versus spectral ratio peak 75th percentile regression curve (Period =3~8s).

3.3 Influence of variation of basin basement Q value

Taking the basin depth of 3km as the base, the Q value of the basin basement varies between 320~440, and other parameters are unchanged, and the simulation of multiple working conditions is carried out, and the distribution of reaction spectrum spectral ratios is given in Fig. 6. From the figure, it can be seen that the amplification tends to increase with the increase of the basin basement Q value, but it is not obvious, varying between 0.95 and 1.05.

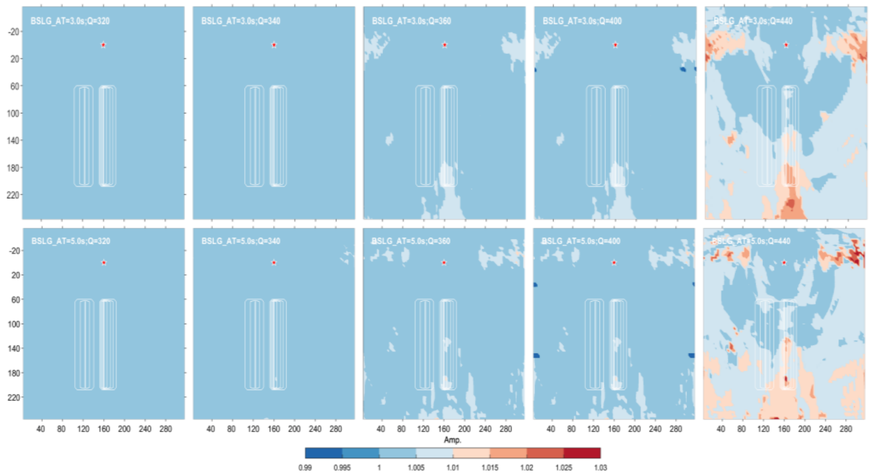


Fig. 6. Basin basement Q variation and response spectrum spectral ratio.

3.4 Influence of Basin Substrate Density Changes

Taking the basin depth of 3km as the base, the basin basement density varies from 2.63 to 2.93g/cm3, and the other parameters are constant under the condition of multi-state simulation, and the corresponding distribution of response spectrum spectral ratios is given in Fig. 7. From the figure, it can be seen that the amplification tends to increase with the increase of basin basement density, but it is not obvious and varies between 1 and 1.15.

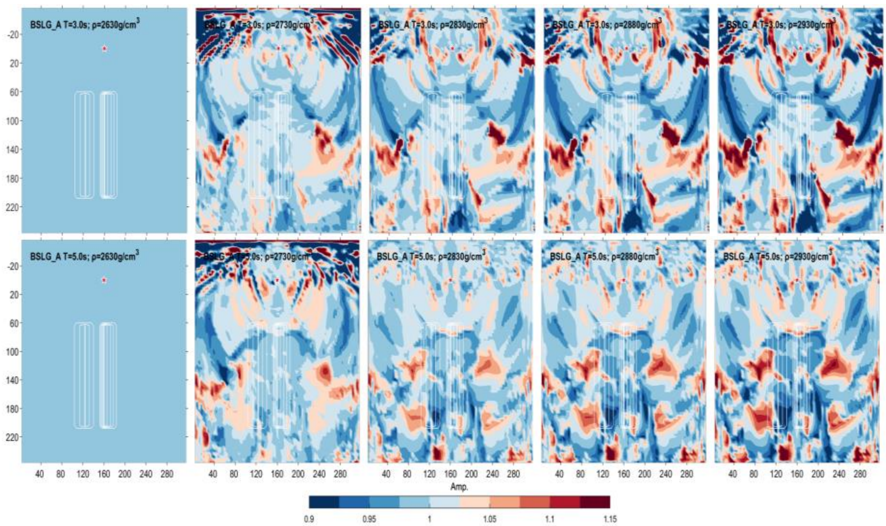


Fig. 7. Basin basement density variation and response spectrum spectral ratio.

3.5 Influence of P-wave velocity variation in the basin basement

Taking the basin depth of 3 km as the base, the P-wave velocity varies from 3.8 to 4.4 km/s, and other parameters are unchanged, and the multi-case simulation is carried out, and the distribution of the spectral ratio of the corresponding response spectra is given in Fig. 8. From the figure, it can be seen that the amplification effect tends to increase with the increase of P-wave velocity at the basin base, but it is not obvious, and the amplification coefficient varies between 1 and 1.1 in the basin range.

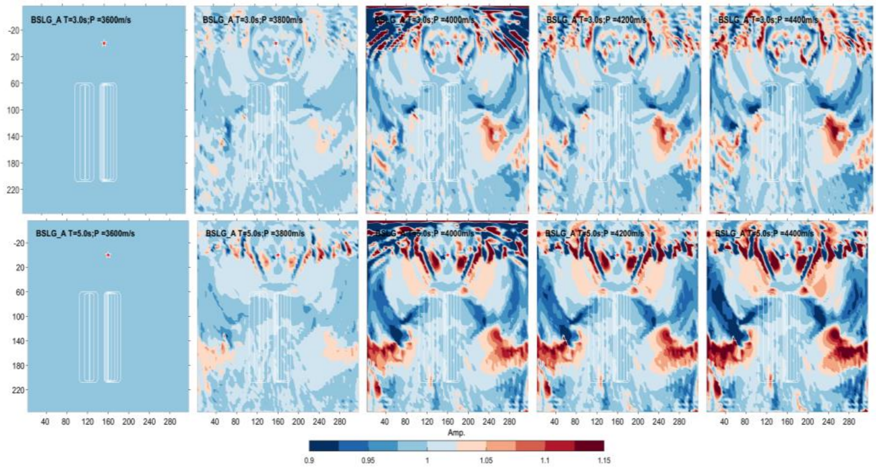


Fig. 8. Basin basement P-wave velocity variation and response spectrum spectral ratio.

It can be seen that basin depth and basin basement shear wave velocity are the basin parameters that have a greater effect on long-period ground motion, basement density and P-wave wave velocity do not have a significant effect on basin amplification, and the basin basement Q value is insensitive to the amplification of the basin.

4 Conclusion

The sensitivity analysis of basin-related parameters in the simulation of long-period ground motion in this paper shows that: the depth of the basin, the change of the basin basement shear wave speed will have a significant effect on the basin long-period ground motion, which is a sensitive parameter; (2) the basin basement density, the change of the basement P-wave has an effect on the basin long-period ground motion, but not significant, which is a microsensitive parameter; (3) the change of the basin basement Q-value on the amplification of the basin is very weak, which is an insensitive parameter.

Since the model parameters are the problems that must be faced in the numerical simulation of ground vibration, and the influence of some parameters on the simulation results is more significant, it is crucial to find out the influence of these parameters to obtain scientific and reasonable results. Therefore, in the numerical simulation of ground vibration, those sensitive parameters should be taken with great caution, and the uncertainty of the results caused by the sensitive parameters should be fully evaluated, so as to prevent the weak change of the parameters from bringing about the drastic oscillation of the results.

In addition, this also brings important insights for the geophysical exploration practice of seismic hazard risk assessment in North China. At present, it has become a consensus that only refined geophysical exploration can obtain numerical simulation results that are more in line with the real situation. However, under the objective conditions of funding and resources, it is obvious that if we take the lead in realizing refinement in the two aspects of basin basement and shear wave velocity, we will achieve more outstanding results. This means that in the tectonic detection work in North China, firstly, the detection of stratigraphic interface should be deeper, which should change the current status quo that only 1~2km of shallow surface is detected; secondly, the detection of shear wave velocity structure should be more accurate, and the more sensitive detection means of shear wave velocity should be selected; thirdly, from the viewpoint of seismic disaster risk assessment, not only the active faults detection should be carried out in the Beijing-Tianjin-Hebei urban agglomeration, but the detection of the velocity structure of the urban subsurface should be put in the same position.

Acknowledgments

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