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ESTIMATION OF SITE EFFECTS IN BEIJING CITY

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Abstract

For the realistic modeling of the seismic ground motion in lateral heterogeneous anelastic media, the database of 3-D geophysical structures for Beijing City has been built up to model the seismic ground motion in the City, caused by the 1976 Tangshan and the 1998 Zhangbei earthquakes. The hybrid method, that combines the modal summation and the finite difference algorithms, is used in the simulation. The modeling of the seismic ground motion, for both the Tangshan and the Zhangbei earthquakes shows that the thick Quaternary sedimentary cover amplifies the peak values and increases the duration of the seismic ground motion in the northwest part of the City. Therefore the thickness of the Quaternary sediments in Beijing City is the key factor that controls the local ground effects, and four zones are defined on the base of the different thickness of the Quaternary sediments. The response spectra for each zone are computed, indicating that peak spectral values as high as 0.1g are compatible with past seismicity and can be well exceeded if an event similar to the 1697 Sanhe-Pinggu occurs.

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1. Introduction

China is one of the countries in the world exposed to the largest seismic hazard. The death caused by seismic activity exceeds the sum of victims caused by other natural hazards. Almost every province in China has historical records of destructive earthquakes.

China is located at the intersection of the Pacific Ocean seismic belt with the Euro-Asian seismic belt, and it is affected by the strongest continental seismic activity in the world. The historical records contain thousands of destructive earthquakes which occurred in China. They include eight earthquakes with magnitude greater than or equal to 8 before 1900. The 1556 ShanXi earthquake (M=8) caused 830,000 victims. After 1900, there were nine earthquakes with magnitude greater than or equal to 8, seven of which occurred in the continental area. The greatest was the 1950 Tibet earthquake with magnitude of 8.6. The 1976 Tangshan earthquake (M=7.8) caused at least 230,000 victims and destroyed a modern city in a few seconds. Based on the high level of seismic activity in China, to mitigate the loss of human life and property in seismic hazard is important and urgent, especially in the megacities and large urban areas.

Beijing, the capital city of China, has a large population (about 12 million) and hosts many important economical and political centers. The city suffered from earthquakes many times in the past. The latest great event was the 1697 Sanhe-Pinggu earthquake (M=8), at a distance of about 50km from the city. The maximum observed macroseismic intensity in Beijing was XI. The intensity was scaled on the China Seismic Intensity Table (XIE, 1957). The 1976 Tangshan earthquake (M=7.8) caused in Beijing a maximum intensity of VIII. The 1998 Zhangbei earthquake (M=6.2) is the latest strong event felt in Beijing. The spatial distribution and the physical properties of the local structures are often correlated to the seismic damage distribution.

The estimation of the seismic ground motion produced by possible strong earthquakes (earthquake scenarios) is useful to reduce the seismic damage. In a companion paper DING et al. (2002) have modeled some digital recordings of the 1998 Zhangbei earthquake. One of the stations, FHSD, is located on the thick Quaternary sediment area, at a distance of about 200 km from the epicenter. The observed seismograms show that the seismic waves are much stronger in the station FHSD than in other stations located in the mountain area, at similar epicentral distances. The modeling of DING et al. (2002) explains quite naturally the observations, i.e. the Quaternary sediments enlarge the peak values and the duration of the seismic waves at the station FHSD. Using the same modeling technique validated by DING et al. (2002) we can immediately compute the ground motion due to any scenario earthquake. In such a way we obtain the seismic response at any place for any potential strong earthquake, and we can estimate the distribution of future earthquakes effects and damages in the research area.

For such a purpose, we built the data set of the physical properties of the local 3-D underground structure in Beijing City. With this data set, the geophysical structure along arbitrary cross section can be obtained, and the latest computer codes developed at the Department of Earth Science, University of Trieste, Italy, are used for the calculation of realistic ground motion (PANZA, 1985; PANZA and SUHADOLC, 1987; FLORSCH, et al., 1991; FÄH, et al., 1993; FÄH, et al., 1994; PANZA et al. 2000).

2. *The structures database*

The research area for Beijing City is defined by the latitude from 39.8°N to 40.1°N and the longitude from 116.2°E to 116.6°E. The data from local dense drilling wells and geological survey results (GAO and MA, 1993) are used to define the distribution of the Quaternary and Tertiary sediment properties and thickness. In the research area, there is no sedimentary cover in the mountain area, while the Quaternary sediments cover the whole plain district, where the thickness increases from the northwest mountain-plain boundary to the southeastern direction. There are two abnormally thick Quaternary sediment zones near the city, one at the northwest margin of the city, the other at the northeast suburbs. In the latter the thickness reaches 800 meters.

The parameters in the database constructed to study the seismic ground motion in Beijing city, include the density, the seismic velocities of P- and S-waves, and the attenuation parameter Q values for the different sedimentary units (Quaternary, Late Tertiary and Early Tertiary). The density values are obtained from local geophysical surveys and gravity inversion results (GROUP OF RESULTS OF DEEP GEOPHYSICAL PROSPECTING, 1986). The S-wave velocity is derived from shallow seismic exploration and drilling well data.

Table 1.

Geophysical Properties of the Sediments

	Density (g/cm^3)	V_P (km/s)	V_S (km/s)	Q_s
Quaternary	1.8-2.2	1.0-3.5	0.4-2.0	40-60
Later Tertiary	2.4-2.5	4.0-4.6	2.35-2.65	100-130
Early Tertiary	2.6-2.8	5.0-5.6	2.9-3.3	150-175

Table 1 lists the available ranges of the considered parameters of the sediments. In the local geophysical data set, the thickness of the three sedimentary layers is specified on a $0.02°\times0.02°$ horizontal grid. At any point in the volume, the density, the P- and S-wave velocity and the Q value can be obtained from the data set. These parameters are then used to build up the input structural model for the calculation of synthetic seismograms in the laterally heterogeneous anelastic media.

The synthetic seismograms are calculated along the profiles by using the hybrid method, which combines the modal summation (1-D) and the finite difference (2-D) algorithms (PANZA, 1985; PANZA and SUHADOLC, 1987; FLORSCH, et al., 1991; FÄH, et al., 1993; FÄH, et al., 1994; PANZA et al. 2000). In the calculation, the seismic source, the travel path from the source to the research area, and the site structure are all taken into account. The bedrock reference 1-D structure is taken from SUN et al. (1998).

In the hybrid calculation, the finite difference method requires that there are at least ten grid points inside the shortest wavelength (FÄH, et al., 1994). In our model, the minimum S wave velocity is 0.4 km/s. If we consider an upper frequency limit of 4 Hz, the minimum wavelength is 100 meters, thus a grid size of 10 meters is appropriate to describe the structural model. The dimensions of the local laterally heterogeneous models used in Beijing City are 4 km (depth) by about 40 km (horizontal).

To account for the source finiteness, we use the scaling laws of GUSEV (1983) by properly weighting the source spectrum in the frequency domain, as reported in AKI (1987). By using the scaled signals in the frequency domain, the response spectral ratio (RSR), corresponding to the laterally varying model and to the bedrock model, versus frequency and distance along the profiles have been calculated to give an estimation of the local response.

The seismic ground motion in Beijing City is simulated for two selected large earthquakes: the 1976 Tangshan and the 1998 Zhangbei earthquakes, which lie to the southeast and northwest of the City, respectively. These events can be considered representative of the most dangerous seismogenic areas around Beijing. The three component broadband synthetic seismograms along 5 profiles crossing the city area have been calculated, with the maximum frequency of 4 Hz. The ground motion in this frequency band is effective for various buildings existing inside the research area. Three profiles, TS02, TS03, TS04, point towards to epicenter of the 1976 Tangshan earthquake, two profiles, ZB05 and ZB06, point towards to epicenter of the 1998 Zhangbei earthquake.

3. Synthetic results

The 1976 Tangshan earthquake caused damages in Beijing City. The observed macroseismic intensity is VI in most of Beijing City. But an abnormal intensity was observed in the northwest part of the city with the value of VII. The source parameters of the earthquake can be referred to DING et al. (2002). The seismic ground motion for the 1976 Tangshan earthquake is modeled along the three profiles, TS02, TS03 and TS04, shown in Fig. 1. The ends of the profiles in Beijing City for profiles TS02, TS03 and TS04 are at (39.9°N, 116.2°E), (39.95°N, 116.2°E), and (40.0°N, 116.2°E), respectively. The distance along the profile is measured from the epicenter of the 1976 Tangshan earthquake.

The profile TS02 passes through the south of the town. The Quaternary sediment is thinner westward (toward the mountain area) with increasing epicenter distance. The Tertiary Beijing depression is located between a distance of 160 and 172 km (Fig. 2). The synthetic seismograms show that the thick Tertiary sediments amplify only the seismic ground motion of Rayleigh and P-SV-waves. The Love and SH-waves, due to the source orientation with respect to the considered profiles in the city, are the strongest waves in this case and do not show any significant unusual phenomena.

The profile TS03 penetrates the center of the city. The seismic waves are mainly controlled by the thickness of the Quaternary sediments (Fig. 3). The acceleration amplitudes are enlarged at a distance of 148-160 km and 175 km, where thicker Quaternary sediments are present.

The profile TS04 penetrates the northern part of the City. The cross section cuts across the Tertiary depression zone between the distance of 157 and 168 km, and the thickness of the Tertiary sediments along TS04 is not as large as along TS02 and TS03. Two thick Quaternary sediment areas are situated around 153-163 km and 170 km (see Fig. 4). The synthetic acceleration seismograms of profile TS04 are shown in Fig. 4. The amplitude of the transverse component is 10 times larger than the radial and vertical components, and the waveforms of all three components along the profile are mainly controlled by the thickness of the Quaternary sediment. Enlarged amplitudes and longer durations of seismic ground motion characterize the northwest part of the city, at a distance of 170km. This is the district of

Beijing where, during the 1976 Tangshan earthquake, abnormally high - one degree higher than the value in the surrounding area.- macroseismic intensity has been observed.

In figure 5 the RSR versus epicentral distance and frequency reaches the larges values in correspondence of the thick Quaternary sediment at about 170km and at the frequency of 1-2 Hz, that is the fundamental resonant frequency for the stack of the Quaternary sediment there. For the transverse component, which is the dominant one, the RSR for a set of selected sites is shown in Fig. 6, to illustrate the variation of the dominant frequency along the profile.

In January 10, 1998, an earthquake occurred in Zhangbei County, which is located to the northwest of Beijing City, at a distance of about 200. The source parameters of the earthquake can be referred to DING et al. (2002). The profiles ZB05 and ZB06 (Figure 7) are oriented from the epicenter to the points (39.8°N, 116.535°E) and (39.8°N, 116.6°E), respectively. The scale of the profiles is the distance from the epicenter.

The profile ZB05 passes through the northwest and southeast corners of the City. There are thick Quaternary sediments between 212km and 217km, while the Tertiary depression zone is located between 217km and 231km. Fig. 8 shows the local structure and the synthetic seismograms along the profile. The seismic waves are obviously amplified at about 215 km, where the thick Quaternary sediments are located. Figure 9 shows the maximum acceleration (AMAX) and the ratios AMAX(2D)/AMAX(1D) and W(2D)/W(1D) versus epicenter distance. Here (2D) represents the local lateral inhomogeneous structure, (1D) the reference bedrock structure and W is the so-called relative Arias intensity (ARIAS, 1970) defined as:

$$W = \frac{\pi}{2g} \lim_{t} \int_0^t [\ddot{x}(\tau)]^2 d\tau$$

where x is the ground displacement and g in gravity. All these parameters reach peak values around 215 km, where the thick Quaternary sediments are located.

From the RSR versus frequency and distance along this profile (Fig. 10), the amplitude peak at 215 km is mainly at high frequency, from 1.7 to 3 Hz. This is the fundamental resonant frequency for the thick Quaternary sediment there. For other places with thinner Quaternary sediments, the dominant frequency is greater than 2.5 Hz.

Profile ZB06 crosses the north and east suburbs and the northeastern part of the City. Two thick Quaternary sediment zones lie on the profile at about 215km and 232km. Fig. 11 shows the synthetic 3-component seismograms along the profile: the amplification of the seismic waves is controlled by the thickness of the Quaternary sediments.

4. Site effects in Beijing City

From the synthetic seismograms used to model the ground motion due to the 1976 Tangshan and the 1998 Zhangbei earthquakes, it can be concluded that mainly the thickness of the Quaternary sediments controls the seismic ground motion variations in Beijing City. The two earthquakes are at different azimuths, therefore it is reasonable to extend such a conclusion to the whole research area (PANZA et al., 2000). Four zones can be defined accordingly to the thickness of the Quaternary sediments. Zone 1 includes the areas with the thickness of Quaternary sediments less than 50m, Zone 2 between 50m and 100m, Zone 3 between 100m and 200m, and Zone 4 greater than 200m. The distribution of the four zones is shown in Fig. 12.

For the Tangshan earthquake, the RSR have been computed for all sites located in each of the four zones along the profiles TS02, TS03 and TS04. From these values, the average and the maximum RSR, for 0% and 5% damping of the oscillator, are determined and they are shown in Fig. 13. Such spectral properties can be considered representative of the four zones shown in Fig. 12.

Figure 14 displays, for each of zone, the absolute response spectra . As in the case for EC8 design spectrum, the DGA can be obtained by dividing the largest spectral value by 2.5 in each zone. Therefore, the DGA in Beijing City for the 1976 Tangshan earthquake could be obtained as 0.03g, 0.04g, 0.07g and 0.1g for Zone 1, Zone2, Zone3 and Zone4, respectively.

5. Conclusions

3-D geological and geophysical models have been built up for Beijing City. With this database, realistic three component broadband synthetic seismograms have been calculated with a cutoff frequency of 4 Hz. The synthetic seismograms are computed along five selected profiles.

Along all the profiles the thick Quaternary sediments cause large amplitude and long duration of the ground motion, due to resonance effects and to the excitation of local surface waves.

Four zones are defined accordingly with the thickness of the Quaternary sediments in the area of Beijing City, each characterized by different spectral responses. The response spectra indicate that peak spectral values as high as 0.1g are compatible with the past seismicity and can be well exceeded if an event similar to the 1697 Sanhe-Pinggu occurs.

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REFERENCES

AKI, K., *Strong Motion Seismology.* In *Strong Ground Motion Seismology* (eds. Erdik, M. Ö. And Toksöz, M. N.) (NATO Advanced Study Institute Series, Series C: Mathematical and Physical Sciences, D. Reidel Publishing Company. The Netherlands 1987), **204**, pp. 3-39.

Arias, A. (1970), A measure of earthquake intensity. In Seismic Design for Nuclear Power Plants, (ed. R. Hansen), Cambridge, Massachusets.

DING, Z., ROMANELLI, F., CHEN, Y., PANZA, G. F. (this issue), *Realistic modeling of seismic strounг ground motion in Beijing area.*

FÄH, D., IODICE, C., SUHADOLC, P., PANZA, G. F. (1993), *A new method for the realistic estimation of seismic ground motion in megacities: the case of Rome*, Earthquake Spectra, **9**(4), 643-668.

FÄH, D., SUHADOLC, P., MUELLER, St., PANZA, G. F. (1994), *A hybrid method for the estimation of ground motion in sedimentary basin: Quantitative modelling for Mexico City*, Bull. Seism. Soc. Am., **84**, 383-399.

FLORSCH, N., FÄH, D., SUHADOLC, P., PANZA, G. F. (1991), *Complete synthetic seismograms for high-frequency multimode SH-waves*, PAGEOPH, **136**, 529-560.

GAO, W., MA, J., *Seismo-geological surroundings and seismic hazards in Capital area* (Seismological Press, Beijing, 1993).

GROUP OF RESULTS OF DEEP GEOPHYSICAL PROSPECTING, State Seismological Bureau, Results of Deep Exploration of the Crust and Upper Mantle of China (Seismological Press, Beijing, 1986).

GUSEV, A. A. (1983), *Descriptive statistical model of earthquake source radiation and its application to an estimation of short-period strong motion*, Geophys. J. R. Astr. Soc., **74**, 787-800.

PANZA, G. F. (1985), *Synthetic seismograms: the Rayleigh waves modal summation,* J. Geophysics, **58**, 125-145.

PANZA, G. F., and SUHADOLC, P., *Complete strong motion synthetics*, In *Seismic Strong Motion Synthetics*, (ed. B. A. Bolt) (Academic Press, Orlando, 1987), *Computational Techniques,* **4**, 153-204.

PANZA, G. F., ROMANELLI, F., VACCARI, F. (2000), *Seismic wave propagation in laterally heterogeneous anelastic media: theory and applications to seismic zonation,* Advances in Geophysics, **43**, 1-95.

SUN, R., VACCARI, F., MARRARA, F., and PANZA, G. F. (1998), *The main features of the local geological conditions can explain the macroseismic intensity caused in Xiji-Langfu (Beijing) by the Tangshan 1976 earthquake*, PAGEOPH, **152**, 507-522.

WESSEL, P., and SMITH, W. H. F. (1995a), *New version of the generic mapping tools released*, EOS Trans. AGU, 76, 329.

WESSEL, P., and SMITH, W. H. F. (1995b), *The Generic Mapping Tools (GMT) Version 3.0 Technical Reference & Cookbook*, SOEST/NOAA.

XIE, Y. (1957), *A new scale of seismic intensity adapted to the conditions in Chinese territories,* Acta Geophysica Sinica, 6, 35-48.

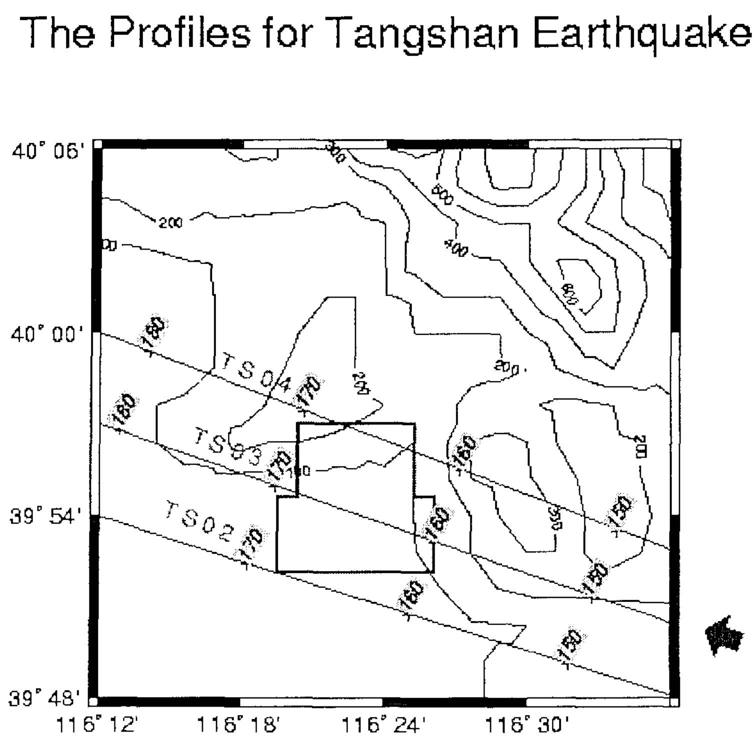


Figure 1: Profiles for the 1976 Tangshan Earthquake

The background contours represent the Quaternary sediment depth in meters. The polygon represents the city of Beijing. Three profiles, TS02, TS03 and TS04 are shown in the figure. The profiles point towards the epicenter of the 1976 Tangshan earthquake, which is located in the southeast. The numbers along the profiles are the distances from the epicenter, in km.

The Local Structural Model and the Synthetic Seismograms along Profile TS02

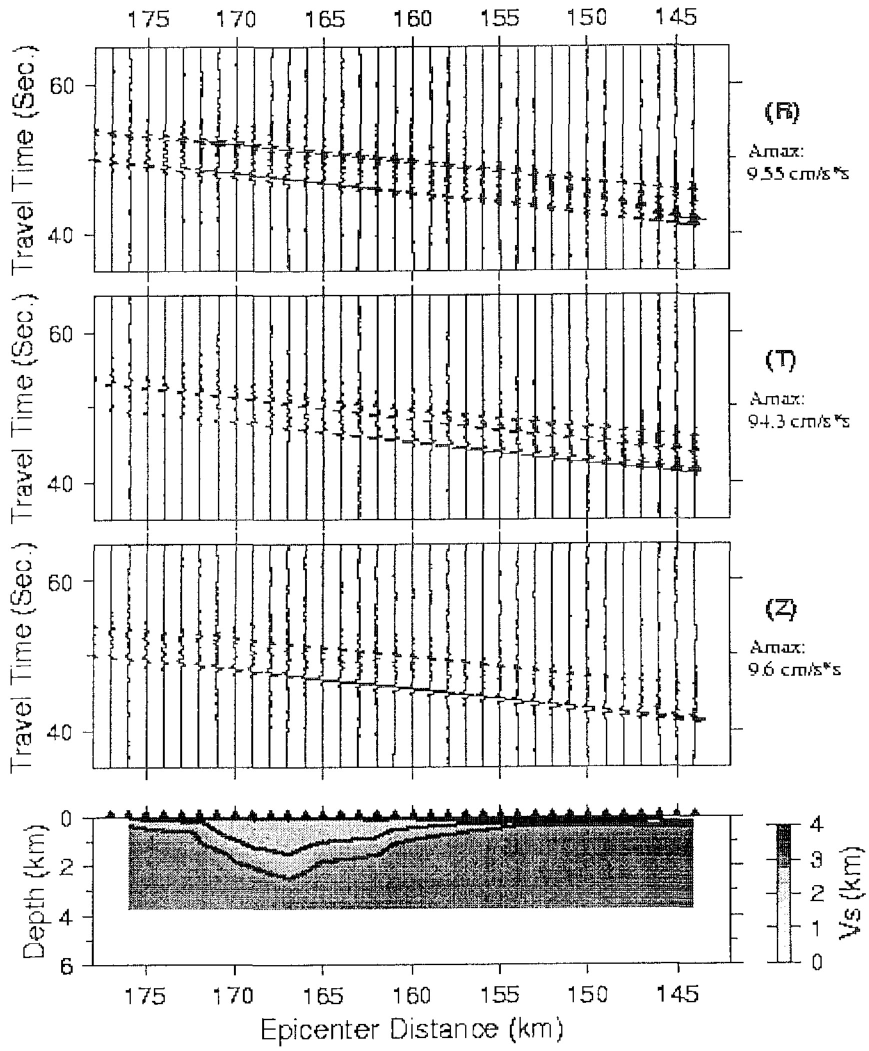


Figure 2: The local structural model and the synthetic seismograms along the profile TS02

The lines in the bottom figure outline the three sediment layers. Radial, transverse and vertical components of the synthetic ground acceleration.

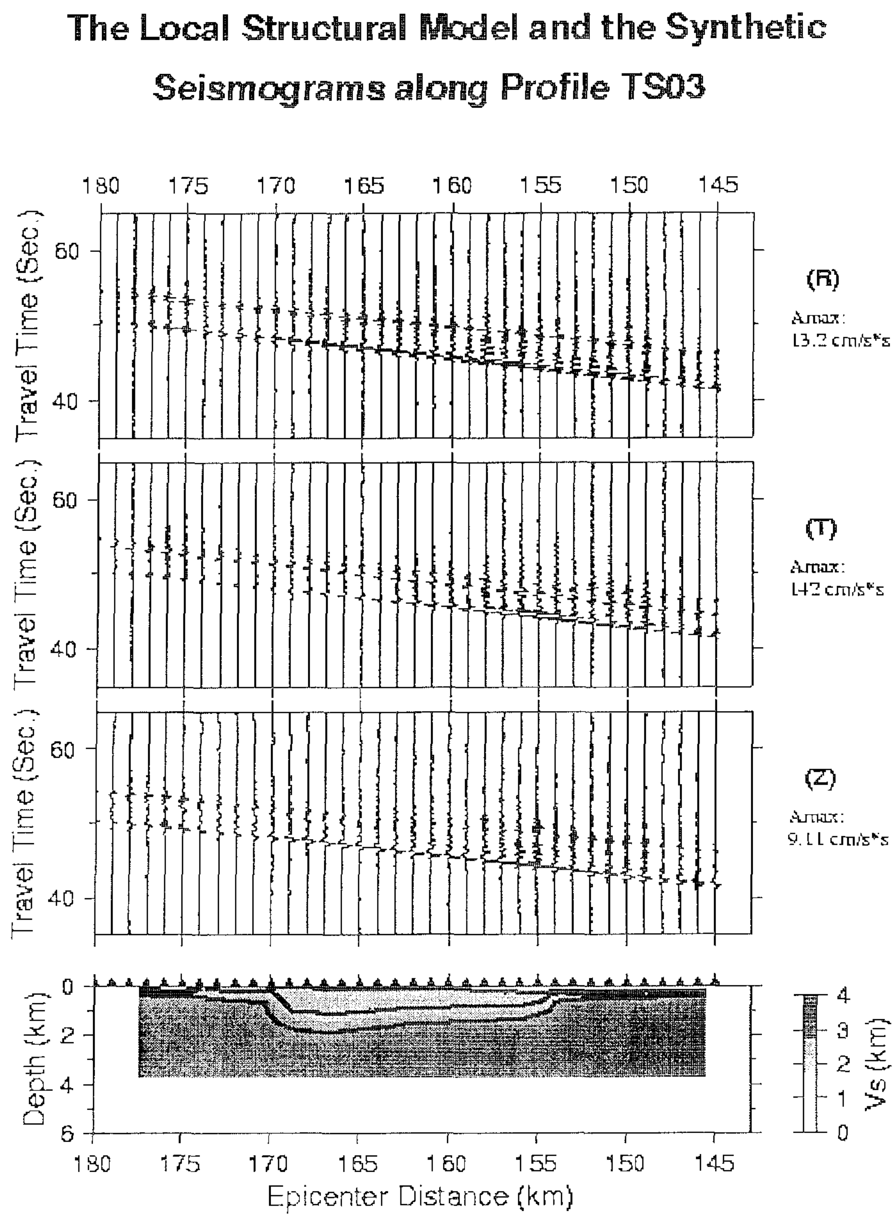


Figure 3: The local structural model and the synthetic seismograms along the profile TS03

The lines in the bottom figure outline the three sediment layers. Radial, transverse and vertical components of the synthetic ground acceleration.

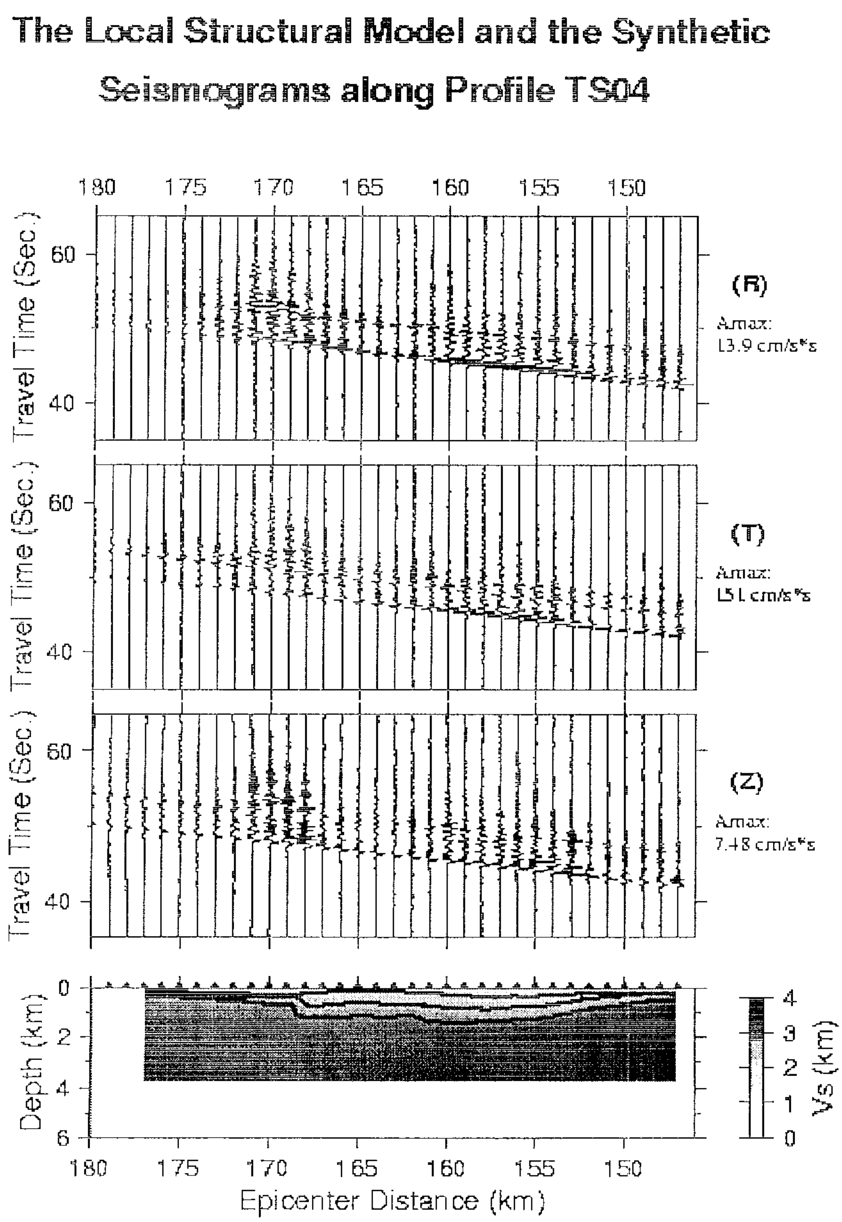


Figure 4: The local structural model and the synthetic seismograms along the profile TS04

The lines in the bottom figure outline the three sediment layers. Radial, transverse and vertical components of the synthetic ground acceleration.

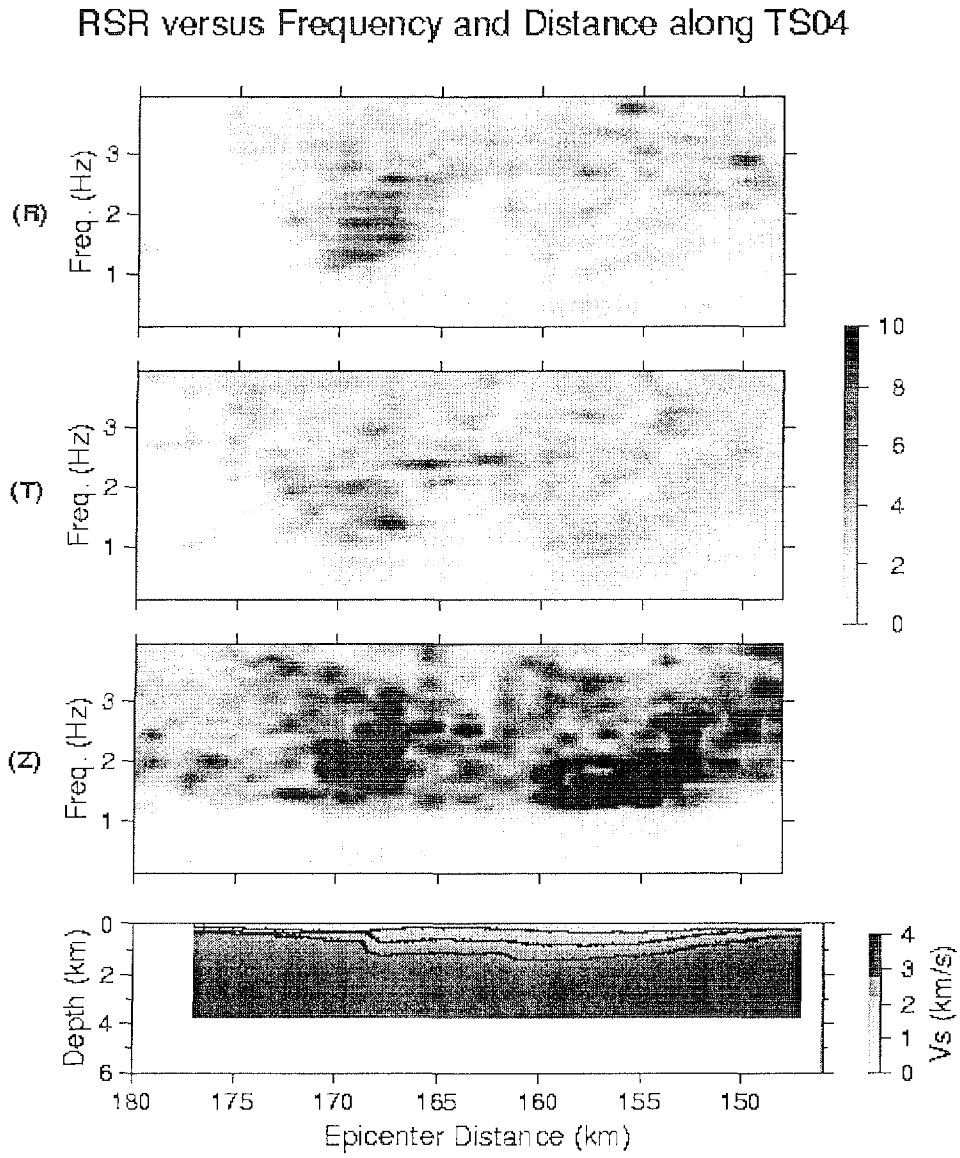


Figure 5: RSR versus frequency and distance along Profile TS04

RSR of SH-waves at Selected Sites along Profile TS04

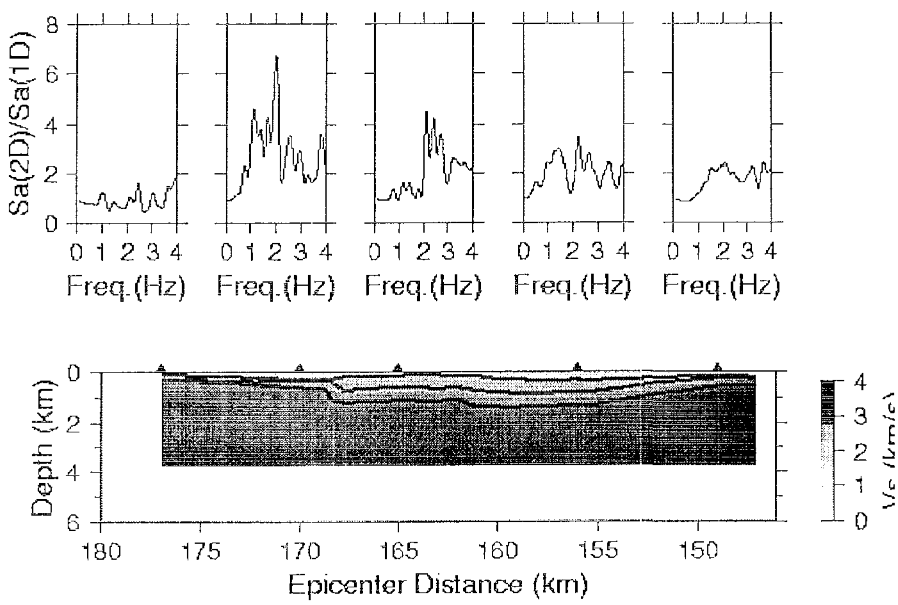


Figure 6: RSR of SH-waves at selected sites along Profile TS04

The Profiles for Zhangbei Earthquake

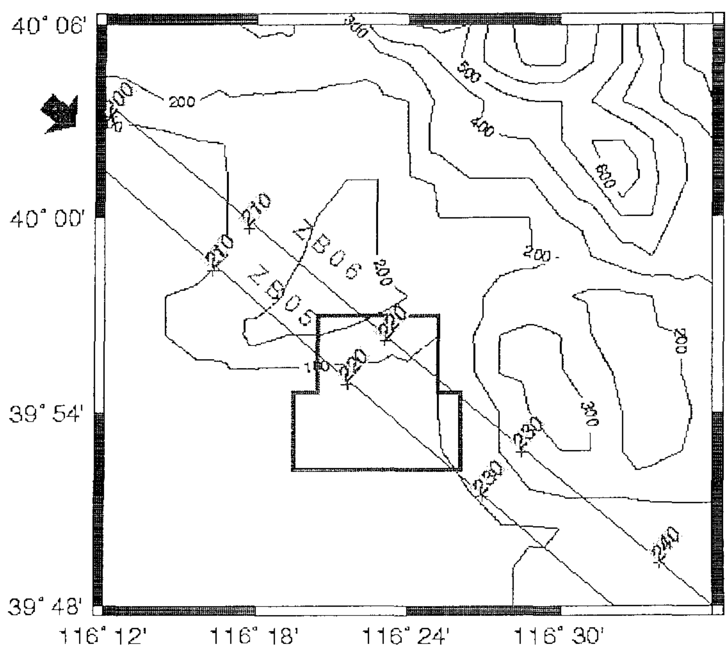


Figure 7: Profiles for Zhangbei Earthquake

The background contours represent the Quaternary sediment depth in meters. The polygon represents the city of Beijing. Two profiles, ZB05 and ZB06 are shown in the figure. The profiles point towards the epicenter of the 1998 Zhangbei earthquake, which is located in the northwest. The numbers along the profiles are the distances from the epicenter, in km.

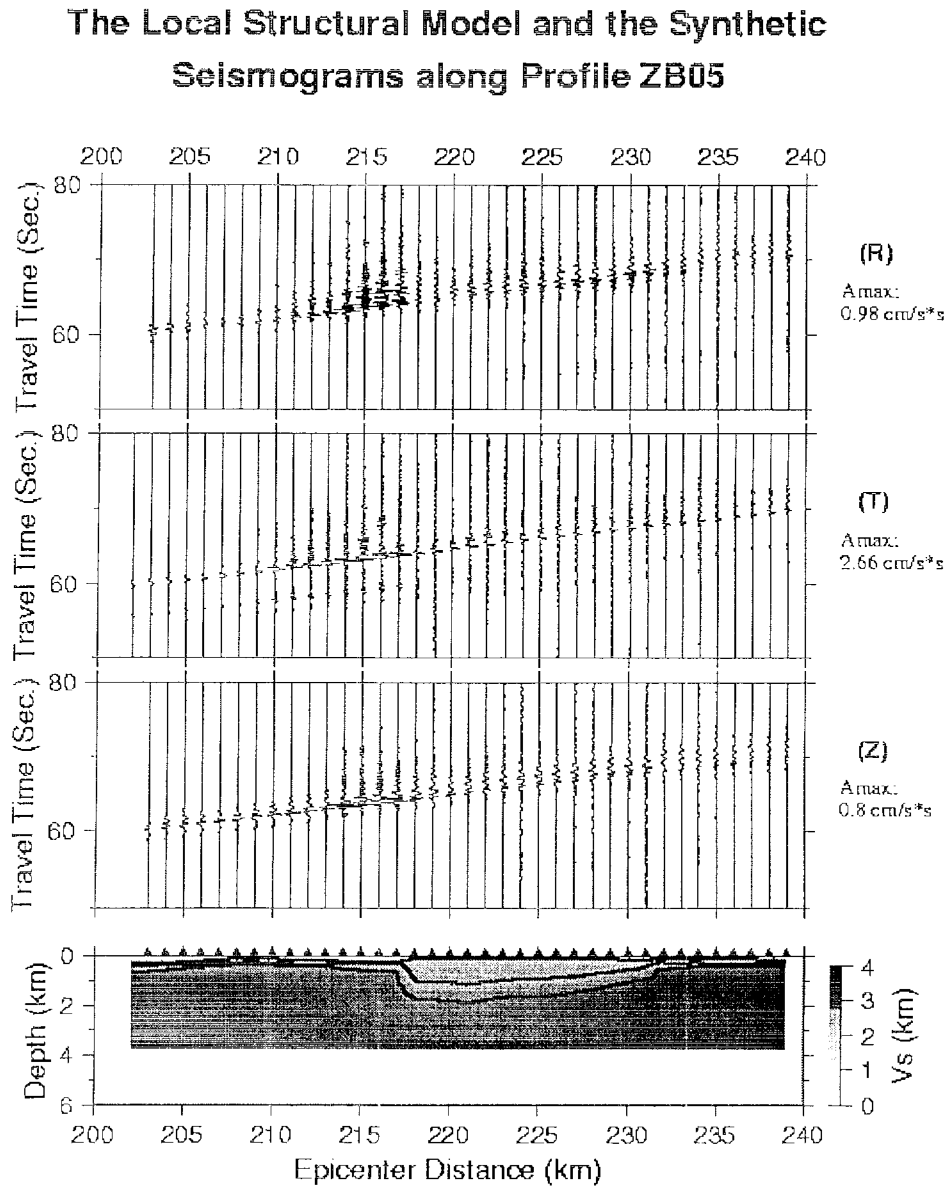


Figure 8: The local structural model and the synthetic seismograms along the profile ZB05

The lines in the bottom figure outline the three sediment layers. Radial, transverse and vertical components of the synthetic ground acceleration.

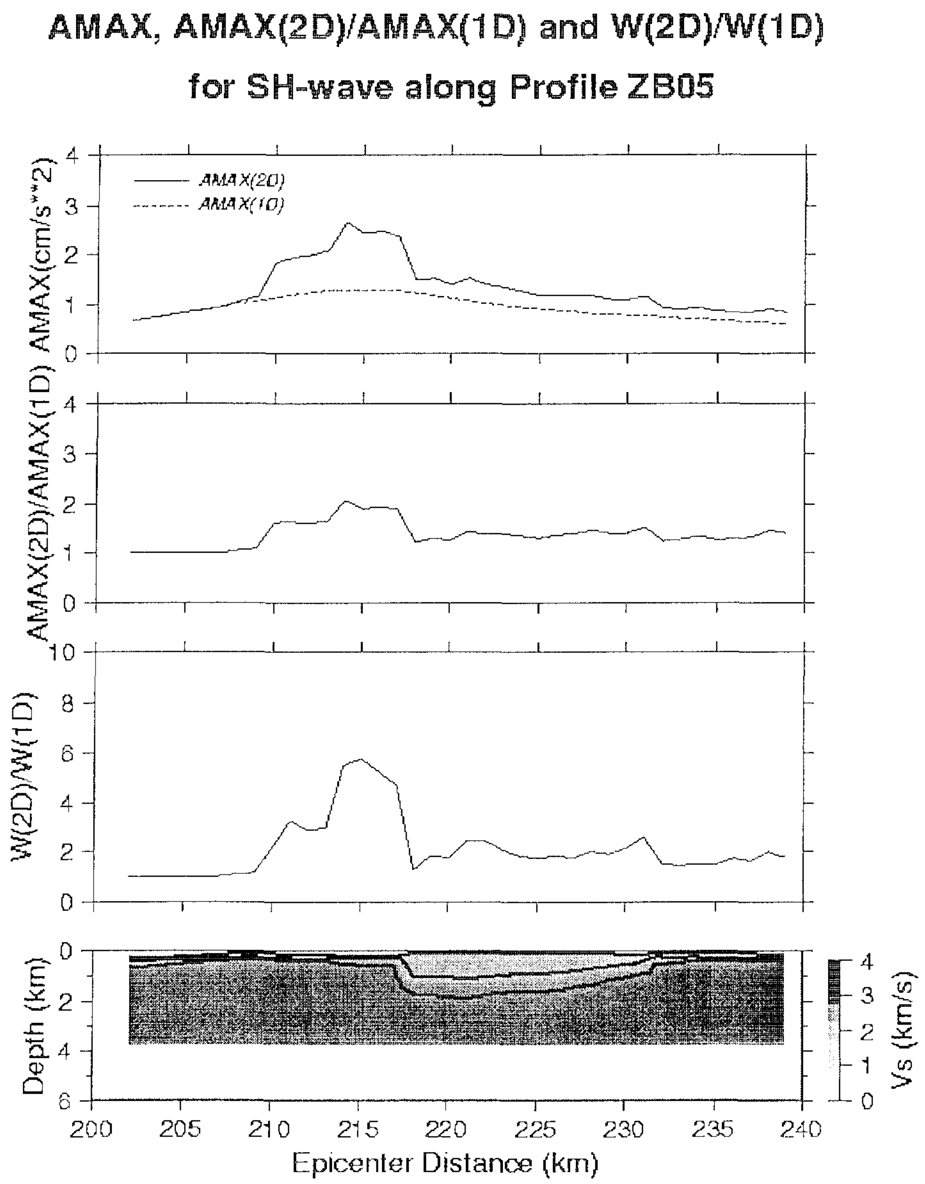


Figure 9: AMAX, AMAX(2D)/AMAX(1D) and W(2D)/W(1D) along the profile ZB05

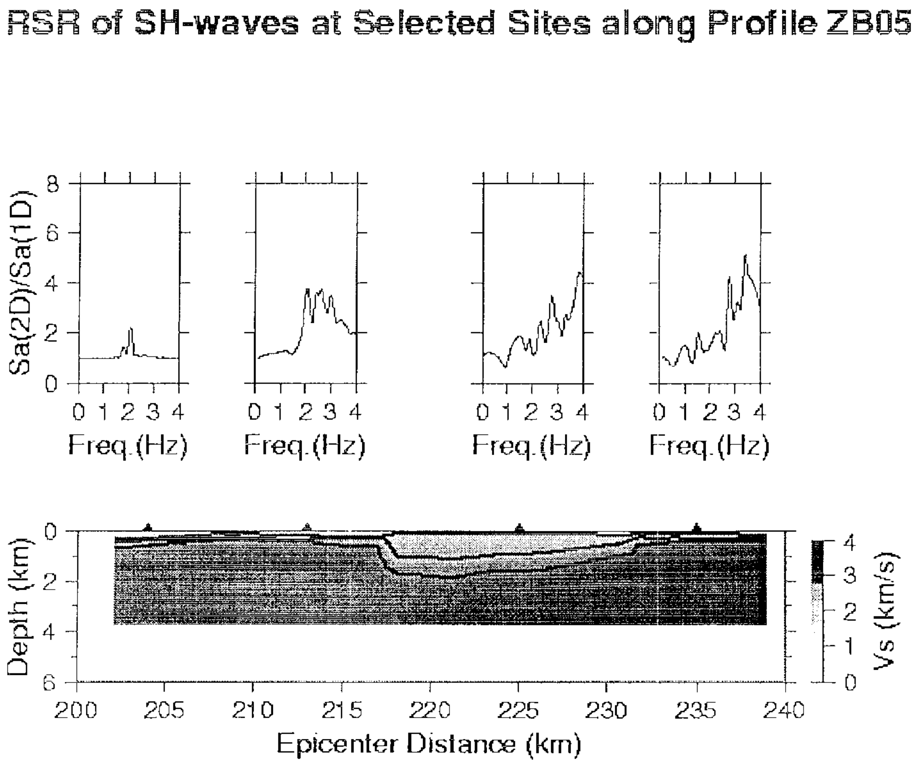


Figure 10: RSR of SH-waves at selected sites along the profile ZB05

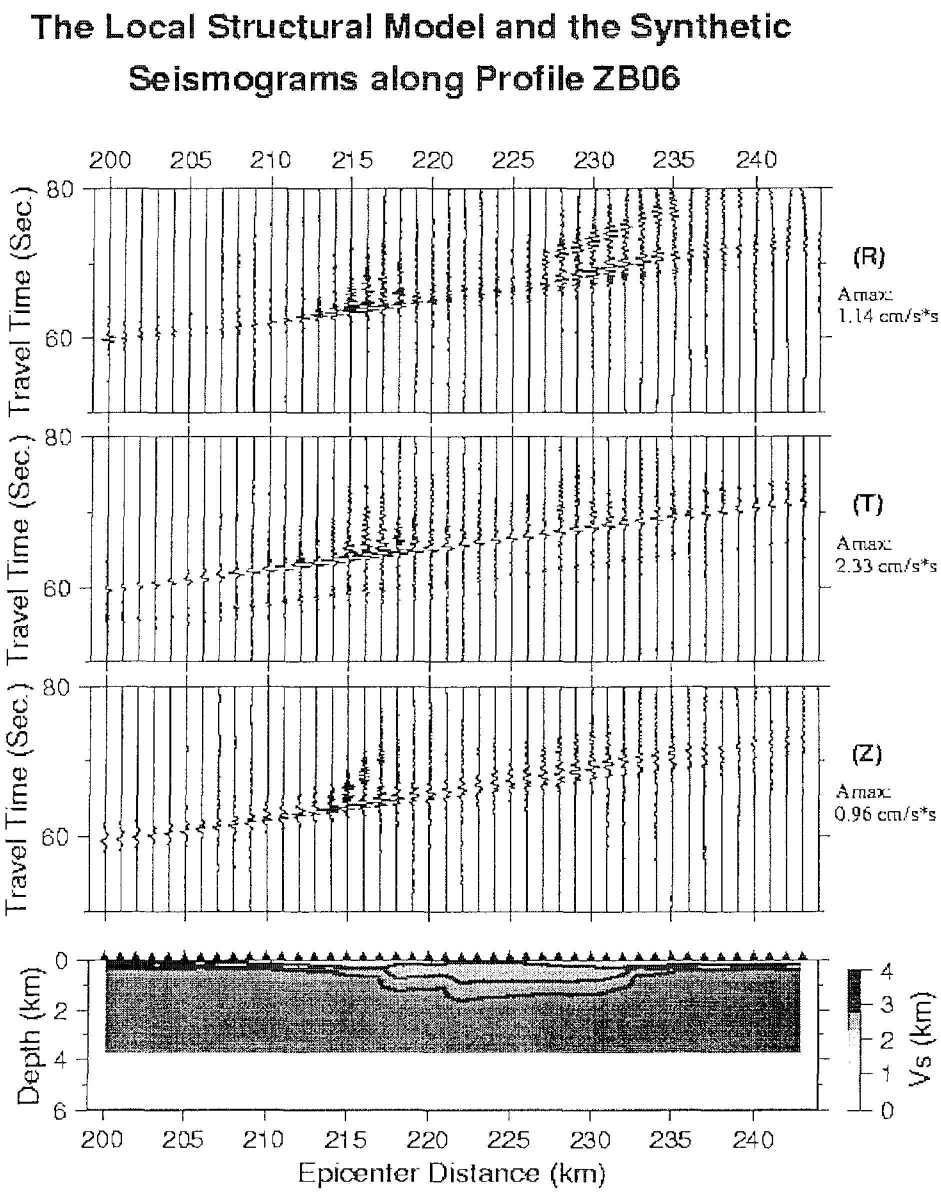


Figure 11: The structural model and the synthetic seismograms along the profile ZB06

Different Site Effect Zones in Beijing City

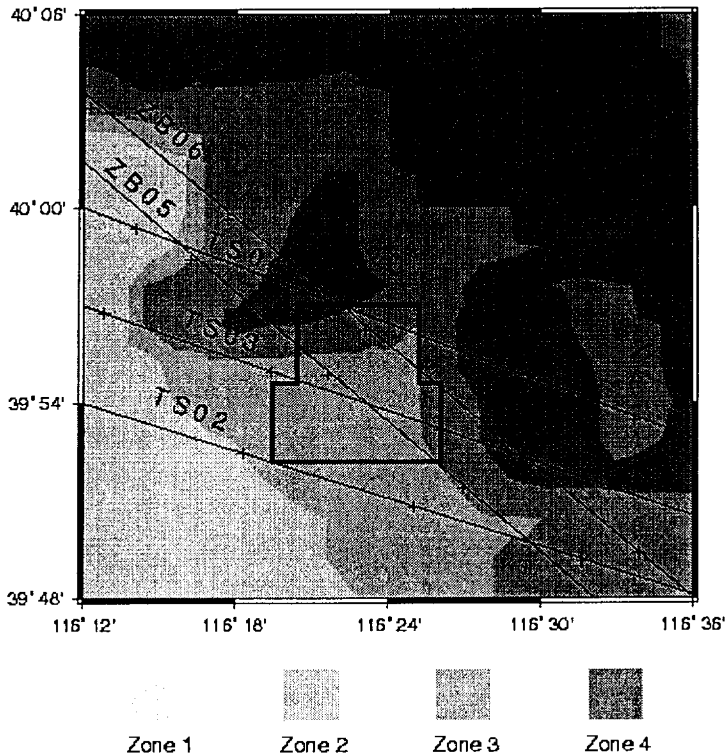
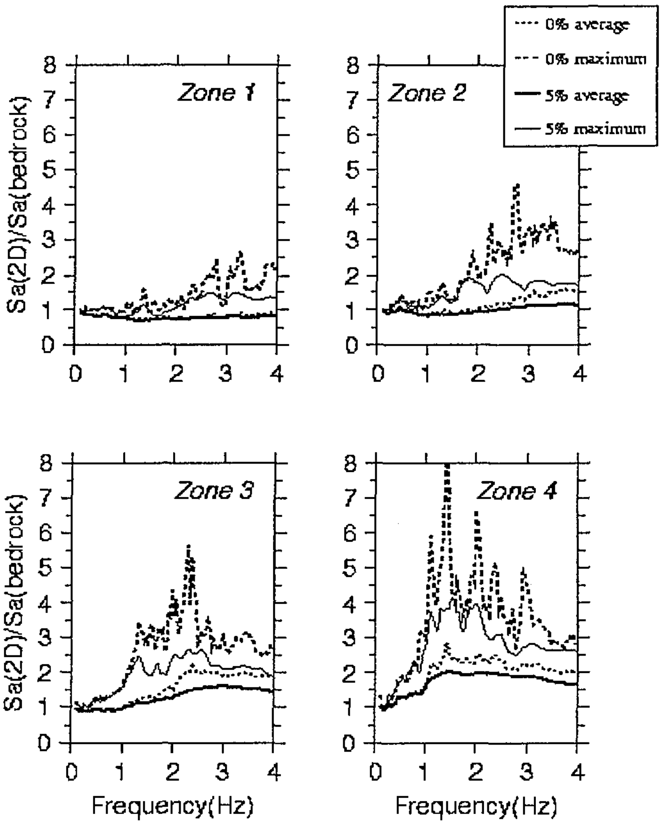
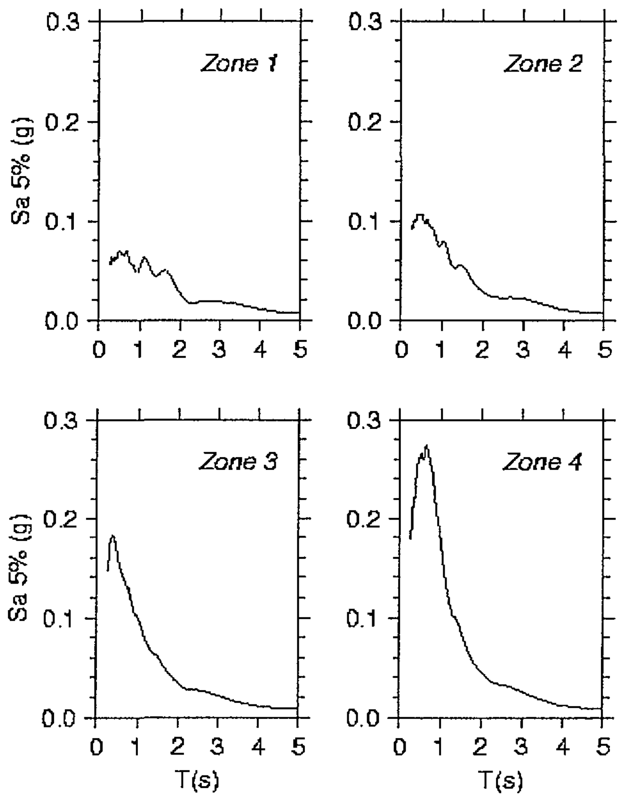


Figure 12: Different site effect zones in Beijing City



Maxmum and average RSR for 4 zones for zero damping and 5% damping.

Figure 13: Maximum and Average RSR for the four zones (for 0% and 5% damping)



Spectral acceleration (5% damping) for the 4 zones

Figure 14: Absolute Spectral Acceleration (5% damping) for the four zones