Effects of soil sites on ground motions in the Qionghai basin in the Wenchuan great earthquake

Haiyun Wang, Lili Xie, Bingjie Chen, Xuetao Zhang, Fanyu Kong, Suyang Wang and Peng Ye
Institute of Engineering Mechanics, China Earthquake Administration, Harbin 150080, China

15 WCEE
LISBOA 2012

SUMMARY: Utilizing acceleration time histories of the Wenchuan earthquake's main shock recorded by four stations (i.e., one bedrock station and three soil stations) in the Qionghai basin, the amplification effects of soil sites on ground motions are studied by traditional spectral ratio method while the bedrock station is selected as reference station. The results are as follows. (1) The peak ground accelerations (PGA) on soil sites are far greater than ones on the bedrock, PGA of EW, NS and UD on soil sites are 3.96-6.58, 6.27-10.98, and 3.17-6.66 times as great as ones on bedrock site respectively. (2) The amplification effects of soil sites on ground motions in frequency range from 0.1Hz to 10Hz are significant. For shallow soil sites, high frequency components of ground motion are significantly amplified, and for intermediate soil sites, low and high frequency components of ground motion are significantly amplified. (3) As a result of strong heterogeneity in different directions in soil, both the amplification factors and the predominant frequencies of soil sites in EW, NS and UD are different.

Keywords: site amplification; spectral ratio method; acceleration time history; Qionghai basin; Wenchuan great earthquake

1. INTRODUCTION

The site response is an important research topic in seismology and earthquake engineering, and has important theoretical significance and practical value for studying ground motion spatial distribution, and both site selection and seismic fortification of buildings and structures. Lots of research results show that the earthquake damage of buildings and structures is closely related to geological conditions of sites under them. For instance, a flexible structure with a long natural period usually suffers serious earthquake damage in the soft soil site, while a rigid structure with a short natural period usually suffers serious earthquake damage in the hard soil site. The main reasons are as follows: (1) The pseudo-resonance caused by that natural periods of buildings and structure are close to predominant periods of sites; (2) site amplification caused by that surface wave impedance decreases. Zhou *et al*. (1991) pointed out: for large earthquake, long period components of ground motions on the far-field thick soil layer is more abundant, therefore high-rise buildings are prone to the pseudo-resonance phenomenon in some long period range, and suffer more serious earthquake damage in the corresponding period range; And rigid buildings (such as masonry *et al*.) on the near-field thin soil layer are prone to the pseudo-resonance in some short period range, and suffer more serious earthquake damage in the corresponding period range. Using traditional spectral ratio method, Wang (2011) studied and analyzed the site responses of 25 soil stations in the Weihe basin utilizing ground motions recorded in the Wenchuan great earthquake. Results show that for deep, intermediate and shallow soil sites, low frequency components, components in the vicinity of 1Hz and high frequency components of ground motions are significantly amplified, respectively. It is noteworthy that high frequency components of ground motions are also amplified to a centain extent for deep soil sites, but the amplification factors of high frequency components are far less than ones of low frequency components.

Qionghai basin is a Quaternary graben sedimentary basin located in the south by west of the epicenter of Wenchuan Earthquake, with an epicentral distance from 360km to 380km (Fig.1), and is a earthquake-prone area. The area suffered serious earthquakes damage in historical earthquakes, such as Xichang earthquakes (Ms6.75, Ms7.5 and Ms7.5) occurred in 1489, 1536 and 1850 respectively, which caused enormous economic losses and heavy casualties(Jiang, 2005). The seismic fortification intensity of the area is not less than 9, and is one of the highest fortification intensity areas in China, and the design basic acceleration is not less than 0.40 g. Based on the data collected from surface surveys and drilling, lake and alluvial sediments during middle-upper Pleistocene and Holocene were accumulated in the basin (Fig.2, 3).

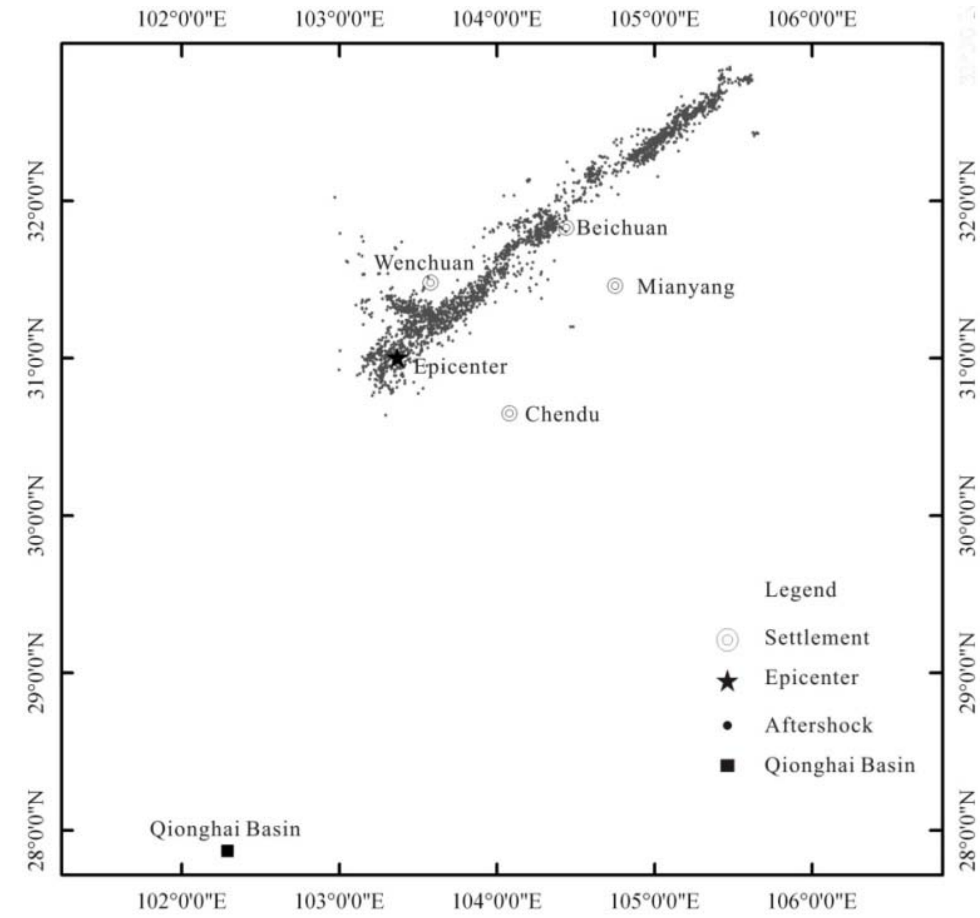


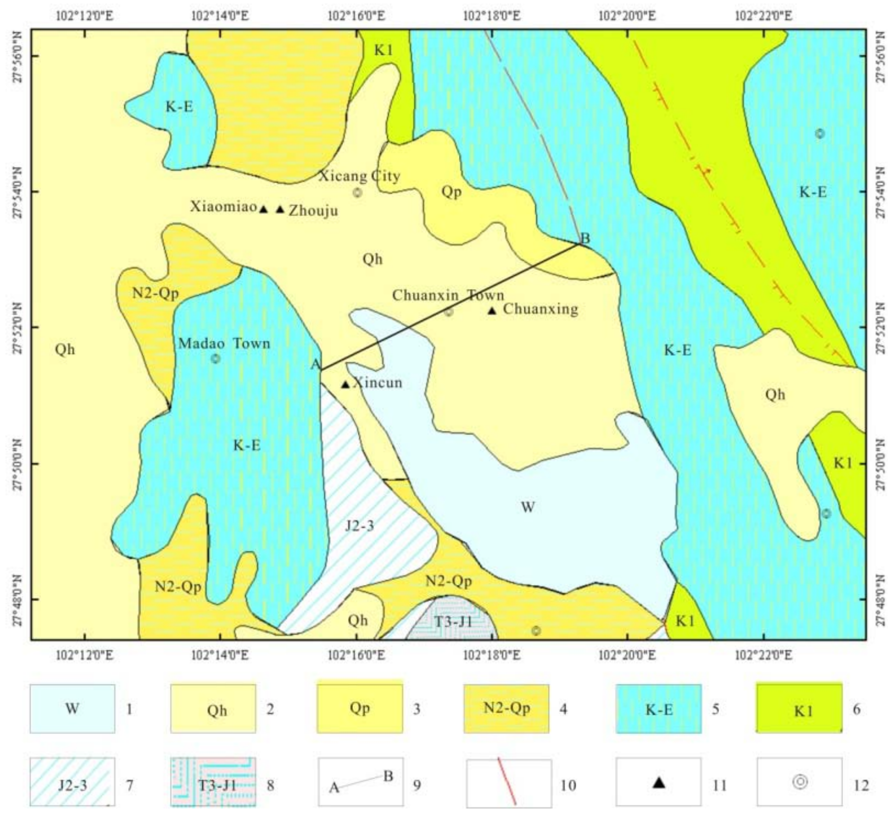
Fig.1 Location of the Qionghai basin relative to epicenter of the Wenchuan earthquake

The purpose of this study is to estimate site responses of soil sites in the Qionghai basin by using traditional spectral ratio method and utilizing ground motions recorded in the basin in Wenchuan great earthquake, and to provide basis data of soil site response for seismic fortification of buildings and structures.

2. STRONG MOTION DATA

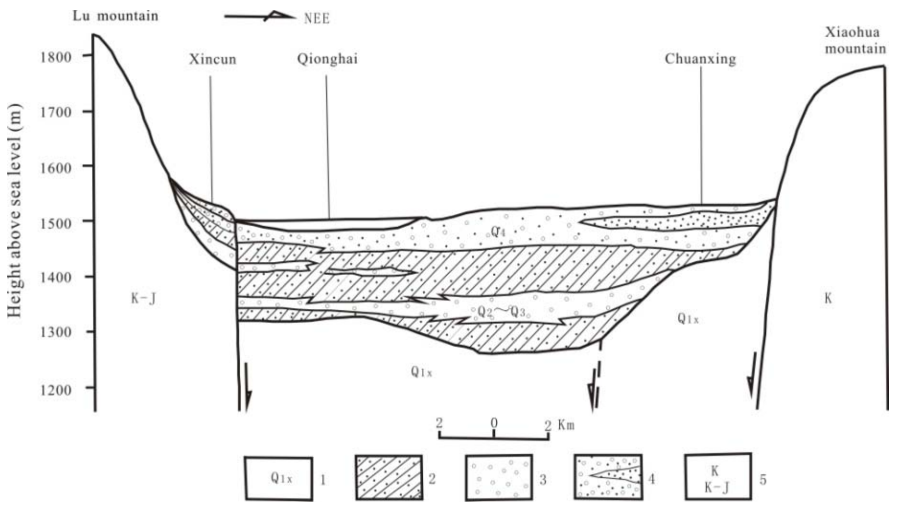
During Wenchuan great earthquake, the main-shock's acceleration time histories of four stations in the Qionghai basin were recorded (Fig.4), including a rock station (Xiaomiao Station) and three soil stations. The basic parameters of the stations are shown in Table 1.

It is seen from Figure 4 that the PGA of bedrock station (Xiaomiao) are minimal, the PGA of EW, NS and UD components are -5.868 cm/s^2, -4.006 cm/s^2 and 3.142 cm/s^2 respectively; the PGA of three soil stations are far greater than PGA of bedrock station. EW, NS and UD components' PGA of three soil stations are 3.96-6.58, 6.27-10.98, and 3.17-6.66 times as great as ones of bedrock station respectively (Table 1).



1-Qionghai waters; 2-gravel and sandy clay of alluvium of the Holocene Series; 3-gravel, sand and clay of alluvium and glacier deposits of the Middle-Upper Pleistocene Series; 4-yellow siltstone and clay-rock of Panxi's Xigeda formation from Pliocene Series to Pleistocene Series; 5-purple sandstone and siltstone with mudstone and argillaceous limestone of Panxi's Xiaoba and Leidashu formations from Cretaceous to Early Tertiary; 6-purple gritstone with gravel, sandstone, siltstone and mudstone of Panxi's Feitianshan formation of Lower Cretaceous Series; 7-purple shale, siltstone, sandstone and argillaceous limestone of Panxi;s Xincun and guangou formations of Middle-Upper Jurassic Series; 8-purple mudstone and siltstone with limestone of Panxi;s Baoding or Baiguowan and Yimen formations from Upper Triassic Series to Lower Jurassic Series; 9-The location of cross-section of the Qionghai Basin in Fig.3; 10-fault; 11-strong motion station; 12- settlement

Fig.2 Geological map of Qionghai basin and the location of four strong motion stations



1-mudstone of Xigeda formation of Lower Pleistocene Series; 2-sub-clay bed and sand soil of alluvium and lake sediment of Middle-Upper Pleistocene Series; 3- alluvial gravel of Middle-Upper Pleistocene Series; 4- alluvial gravel with sub-clay bed of Holocene Series; 5-sandstone of Cretaceous period or Cretaceous-Jurassic period

Fig.3 The cross-section of the Qionghai Basin (modified from Wen, 1985)

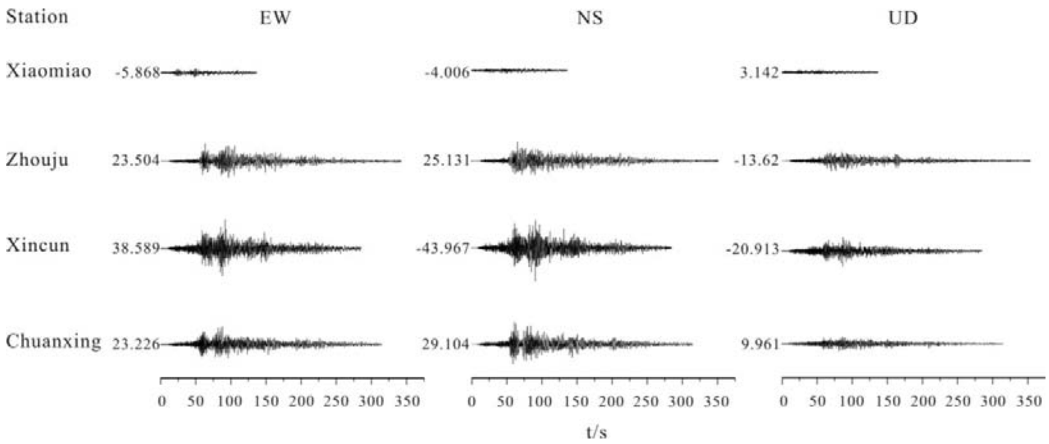


Fig.4 The main shock's acceleration time histories recorded in the Qionghai basin in the Wenchuan earthquake (acceleration unit: cm/s^2)

Table 1 The parameters of four stations in the Qionghai basin

Stations	Lon. (°)	Lat. (°)	Epicentral distance （km）	Distance from the rock site（km）	Site type	PGA ratio with bedrock site		
						EW	NS	UD
Xiaomiao	102.24	27.90	362.69	\	bedrock	1.00	1.00	1.00
Zhouju	102.25	27.90	362.57	0.39	soil	4.01	6.27	4.34
Xincun	102.26	27.85	366.69	5.18	soil	6.58	10.98	6.66
Chuanxin	102.30	27.87	363.76	6.17	soil	3.96	7.27	3.17

3. METHOD

A ground motion is the result of a complex system composed by three physical processes, including the source rupture process (source effect), wave propagation in the crust (path effect) and site response (site effect). To estimate the site response, the source and path effects need to be removed from ground motion records.

The basic idea of the traditional spectral ratio method is as followed: there is a bedrock reference site in the vicinity of the soil sites, they have the same effect of the source and almost the same path effect. Site response of soil sites can be estimated by calculating Fourier spectrum ratio of ground motions between the soil sites and the reference site (Borcherdt, 1970; Field *et al*., 1995).

Fourier spectrum (O) of a ground motion can be expressed as the product of the source effect (E), path effect (P) and site effect (S).

$$O(r,f) = E(f)P(r,f)S(f) \qquad (1)$$

In which, r is hypocentral distance, f is frequency.

$P(r,f)$ can be express as follow:

$$P(r,f) = \frac{1}{R} e^{-\frac{\pi r f}{\beta Q(f)}} \qquad (2)$$

in which, β is shear wave velocity, and $Q(f)$ is quality factor.

Soil site response can be estimated by follow formula:

$$S^{SR}(f) = \frac{O_s(r_s,f)}{O_r(r_r,f)} \frac{r_s}{r_r} e^{\frac{\pi (r_s - r_r) f}{\beta Q(f)}} \qquad (3)$$

In which, subscript *s* and *r* express soil site and reference sire respectively.

Zhang *et al*. (2007) gave the quality factor of Sichuan basin as follow:

$$Q(f) = 217.8 f^{0.816} \quad (4)$$

The relationship was used to this study.

4. RESULTS

The site responses of three soil site are studied and analyzed using above method and ground motion data, while Xiaomiao station is selected as reference station. Fourier spectra of ground motion are smoothed by 0.4Hz Parzen window in calculation. The results are shown in Figure 5.

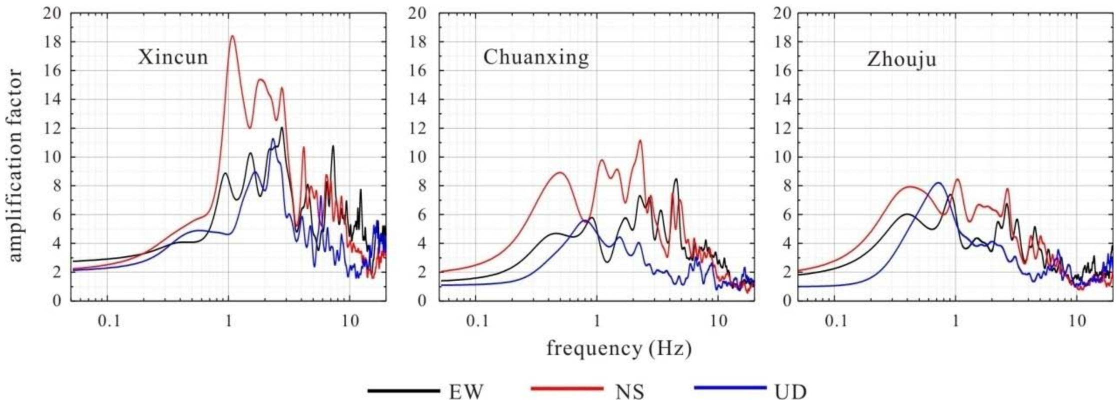


Fig.5 The site responses of three soil stations in the Qionghai basin

The amplification effects of the three soil sites on ground motions in frequency-band range from 0.1Hz to 10Hz are significant. The amplification factors of the Xincun station are maximal, maximal amplification factors of EW, NS and UD components are 12.05,18.40 and 11.26 respectively, and the corresponding predominant frequencies are 2.76Hz, 1.08Hz and 2.33Hz respectively; the amplification factors of the Chuanxing station are less than ones of Xincun station, maximal amplification factors of EW, NS and UD components are 8.47,11.12 and 5.60 respectively, and the corresponding predominant frequencies are 4.52Hz, 2.28Hz and 0.80Hz respectively; the amplification factors of the Zhouju station are minimal, maximal amplification factors of EW, NS and UD components are 7.39, 8.45 and 8.21 respectively, and the corresponding predominant frequencies are 0.91Hz, 1.04Hz and 0.72Hz respectively.

Relationship between the predominant frequency of soil site and soil thickness is $f=V_s/4H$, in which, V_s is average shear wave velocity, H is soil thickness. The relationship shows that the predominant frequency of soil site will shift to low frequency as soil thickness increases.

Although horizontal predominant frequencies of soil site of Chuanxing station are greater than ones of Xincun station, but, for Xincun station, amplification effects of soil site on high frequency components of ground motions are more significant than on low frequency components; for Chuanxing station, amplification effects of soil site on low and high frequency components of ground motions are significant, although amplification factors in the high frequency are slightly greater than ones in the low frequency; thus, soil thickness of Chuanxing station is greater than one of Xincun station. For Zhouju station, the predominant frequency of soil site are minimal in three soil stations; and in the low frequency, the predominant frequency of Zhouju station is less than ones of Chuanxing station; thus, soil thickness of Zhouju station should be greater than one of Chuanxing station. And soil site of Xincun station is shallow soil; soil sites of Chuanxing and Zhouju stations are intermediate soil, because amplification factors of deep soil on low frequency components are far greater than on high frequency components (Wang, 2011).

The amplification effects of soil sites on different components of ground motions are different, which shows that there are strong heterogeneities in different direction in soil.

5. CONCLUSIONS

The ground motions recorded by four stations in Qionghai basin during Wenchuan great earthquake are weak ground motions. Utilizing the ground motion records and the traditional spectral ratio method, the amplification effects of soil sites on ground motions are studied while the bedrock station is selected as reference station. The results are as follows.

(1) PGA on the soil sites are far greater than ones on the bedrock site. EW, NS and UD components' PGA of three soil stations are 3.96-6.58, 6.27-10.98, and 3.17-6.66 times as great as ones of the bedrock station respectively.

(2) The amplification effects of soil sites on ground motion in frequency ranges from 0.1Hz to10Hz are significant. For shallow soil sites, high frequency components of ground motion are significantly amplified, and for intermediate soil sites, low and high frequency components of ground motion are significantly amplified.

(3) The Qionghai basin is a Quaternary graben sedimentary basin, During Middle-Upper Pleistocene Series and Holocene Series, different thick unconsolidated sediments (included gravel, sand and gravel, and arenaceous clay, *et al*.) were deposited in the basin. As a result of strong heterogeneity in different directions in soil, both the amplification factors and the predominant frequencies of soil sites in EW, NS and UD are different.

Amplification effects of soil sites on ground motions in future earthquake occurred in the vicinity of the Qionghai basin will possibly aggravate earthquake damage of buildings and structures in the basin, and must be considered in seismic fortification of buildings and structures to prevent or mitigate seismic hazard of them.

AKCNOWLEDGEMENT

This research work is supported by National Natural Science Foundation of China Under Grant No. 50878199, and National Basic Research Program of China Under Grant No. 2007CB714201. We thank the China Strong Motion Network Center (CSMNC) for providing the ground motion recordings used in this study.

REFERENCES

Borcherdt R.D. (1970). Effects of local geology on ground motion near San Francisco Bay. *Bull. Seism. Soc. Am.* **60 :1**, 29-61.

Field E.H., Jacob K.H. (1995). A comparison and test of various site-response estimation techniques, including three that are not reference-site dependent. *Bull. Seism. Soc. Am.* **85:4**, 1127-1143.

Jiang Z.X. (2005). Urgent measures and its social effect for three earthquakes in Ming and Qing Dynasty. *Earthquake Research in Sichuan* (in Chinese with English abstract) **2**, 6－12.

Wang H.Y. (2011). Amplification effects of soil sites on ground motions in the Weihe basin. *Chinese J. Geophys*. (in Chinese with English abstract) **54:1**, 137-150.

Wen X.Z., Wu D.Z. (1985). Origin of the Quaternary Qionghai basin, Xichang, Sichuan province. *Geological Review* (in Chinese with English abstract) **31:4**, 360-366.

Zhang Y.J., Qiao H.Z., Cheng W.Z., *et al*. (2007). Attenuation characteristics of the media in Sichuan basin region. *Journal of Seismological Research* (in Chinese with English abstract) **30:1**, 43～48.

Zhou X.Y., Wang G.J., and Su J.Y. (1991). Site, foundation, design earthquake. Earthquake Publishing House (in Chinese), Beijing, China.