Study on the Site Effects on Ground Motion during the Wenchun Ms8.0 Earthquake，China

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SUMMARY:
Based on mobile strong motion array observation，earth tremor observation, borehole exploration and site seismic response analysis, the site effects of mountainous topography in southeastern Gansu and the topography of loess Yuan on ground motion were investigated in details. The analysis on acceleration records of aftershocks showed that the peak ground acceleration at top of the mountain is nearly 2 times of that at the foot of it. The predominant frequency on the top of mountain is much lower than that at the foot of it. The seismic response analysis of sites shows that the loess Yuan may amplify PGA by 1.44-2.0 times. Therefore, site effects of mountains and loess topography on ground motion should been taken account into seismic design of buildings.

Keywords: Mobile strong observation; earth tremor; site effects; seismic response

1. INTRODUCTION

The 2008 Wenchuan Ms8.0 earthquake not only caused enormous buildings and houses collapsed or seriously damaged, but also triggered more than 12,000 landslides, collapses and mudflows, which dammed more than 30 quake lakes. During the huge quake, the phenomena of site effects on ground motion were very obvious both in the mountainous area of southeastern Gansu province and the Loess Plateau area within the range of 200km to 670km away from the epicentre[1]. In the mountainous areas, earthquake intensity on the top of mountains was higher than that at the foot of mountains by 1 degree. In the topography of loess Yuan, which was one of typical topographies in Loess Plateau, a flat vast expense of thick loess deposit with abrupt edge, houses and buildings on the top of loess Yuan damaged seriously, however, those at the valleys kept in good condition, even if where locates more than 600 kilometers away from the epicenter[2-3].

Figure 1. The Dazhai Loess Yuan (left) and damaged houses of Dazhai village (right) , Pingliang City

Figure 2. The Dundunliang Loess Yuan (left) and the collapsed cave dwelling at the Dundun mountain (right), Quzi Village, Qingyang City

In the mountainous area of southeast Gansu Province, a mobile strong motion array was set to obtain the aftershocks acceleration records after the main shock of the 2008 Wenchun earthquake. In Qingyang City and Pingliang City of Gansu Province, we chose two typical loess Yuan sites for earthquake damage investigation (Figure1, 2), where the houses and buildings located on the top of the Yuan were damaged seriously. The investigation methods include differential GPS, borehole drilling exploration, microtremor survey, and site amplification effects numerical simulation. The aim of this project was to study on the mechanism of the site amplification effects on ground motion induced by the earthquake at the mountainous areas and thick loess deposit sites.

2. MOBILE STRONG MOTION ARRAY OBSERVATION

2.1. Mobile strong observation site

After the huge event, we set up a mobile strong motion array at a hill near the Wenxian Town in southeastern Gansu province. Three observation stations were set at the bottom (N 32.94, E 104.70, altitude, 927 m), middle (N 32.95, E 104.67, altitude, 960 m) and top site (N 32.94, E 104.67, altitude，969 m) of the hill respectively (Figure 3). The site conditions were the same at these three sites.

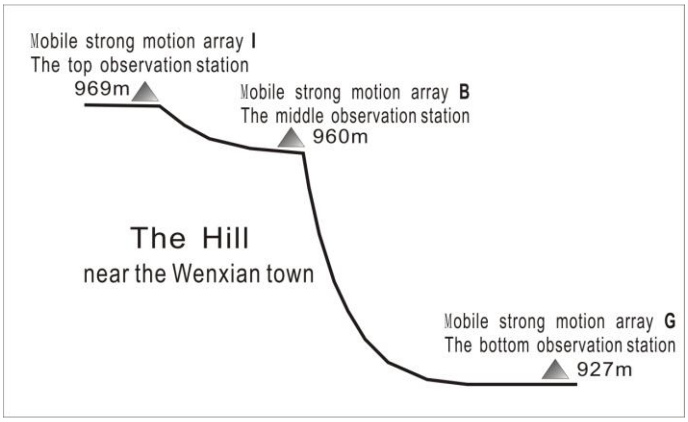


Figure 3. Mobile strong motion observation array near the Wenxian Town

2.2. Observation data

We used the ETNA strong motion accelerometer for observation, which has three direction sensors, NS, EW and UD, the sampling rate is 200 per second, frequency range is between 0.1 and 50 Hz.

From May 22 to June 28, 2008, there were 12 aftershocks records obtained, of which the event location, time, magnitude, and epicenter are listed in Table 1[4]. The distances to epicenters were between 68Km and 136Km.

Table 1. The information of recorded events

sequence numbers	Data	Time	Magnitude (Ms)	longitude	latitude	Sites	epicenter distance （km）
1	2008.5.27	16:37:53	5.7	105.6	32.8	Ningqiang	88
2	2008.5.27	21:59:34	4.9	105.16700	32.53300	Qingchuan	64
3	2008.6.05	12:41:08	5	105.00000	32.30000	Qingchuan	78
4	2008.6.07	10:18:00	3.2	104.93330	32.33330	Pingwu	72
5	2008.6.07	14:28:35	4.3	105.40000	32.50000	Qingchuan	83
6	2008.6.08	6:14:29	4.7	105.10000	32.50000	Qingchuan	72
7	2008.6.10	10:14:00	3.7	105.05000	32.40000	Qingchuan	68
8	2008.6.17	13:51:00	4.5	105.60000	32.80000	Ningqiang	87
9	2008.6.19	18:25:00	4.4	105.50000	32.80000	Qingchuan	78
10	2008.6.22	18:37:00	4.2	104.50000	32.20000	Pingwu	84
11	2008.6.23	5:38:00	4.1	105.10000	32.40000	Qingchuan	72
12	2008.6.28	5:42:13	4.8	105.90000	32.31667	Pingwu	73

Figure 4 shows the acceleration values of the Ningqiang Ms5.7 event for each component and different sites. The values difference for the EW component are greater than the others, and the PGA at the top of the hill is about 1.5 times of that at the bottom. The PGA values of 12 events at three sites are shown in Figure 5. All the PGA values at the top are greater than that at the middle of the hill, and the values at the middle are slight greater than that at the bottom, except for No.3 event. Moreover, the greater the magnitude, the sites amplification are more obvious at the top of the hill.

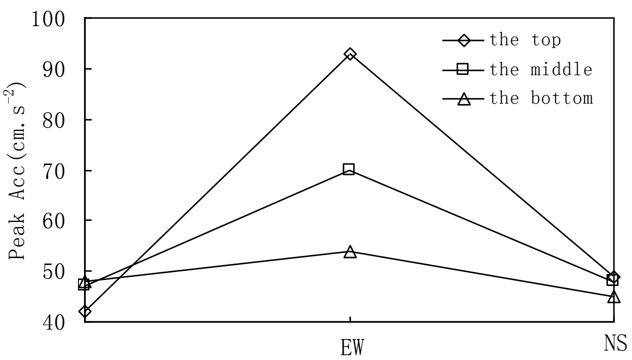


Figure 4. Comparisons on typical recorded PGAs at the foot, side, and top of the mountain.

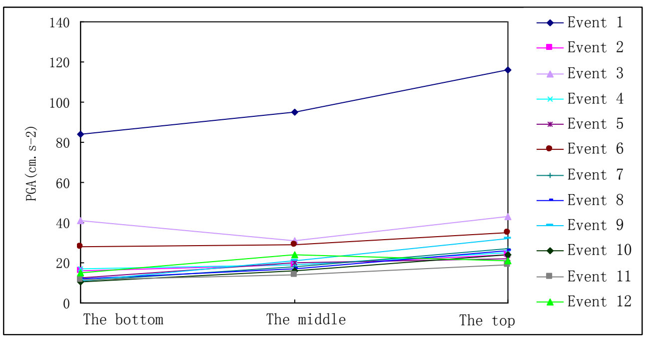


Figure 5. Comparison on PGAs of the mobile strong motion records at the Wenxian Town array（12 events）

3. DIFFERENTIAL GPS AND BOREHOLE DRILLING

3.1. Differential GPS result

The differential GPS were carried out for topography survey at the Dazai Village, Pingliang City and Quzi Village, Qingyang City respectively. Figure 6 and Figure 7 show the varied topography of the two sites accurately.

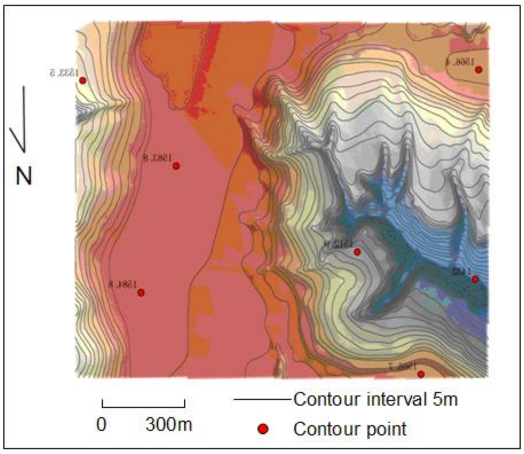


Figure 6. The varied topography of Dazai Village, Pingliang City.

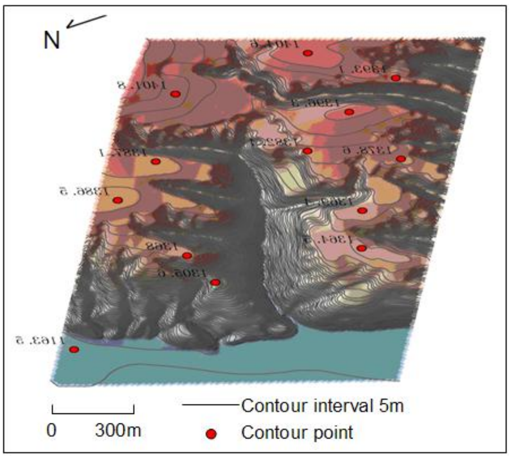


Figure 7. The varied topography of Quzi Village, Qingyang sites

3.2. Borehole drilling exploration

There are two boreholes (95-meter-deep, and 245-meter-deep respectively) to be drilled at site-one (Dazhai Village, Pingliang City) and site-two (Dundun mountain, Quzi Village, Qingyang City) . The borehole geologic records and Vs data were obtained at the two sites.(Figure 8 and Figure 9).

The topography and borehole survey data were adopted for site amplification effects numerical simulation.

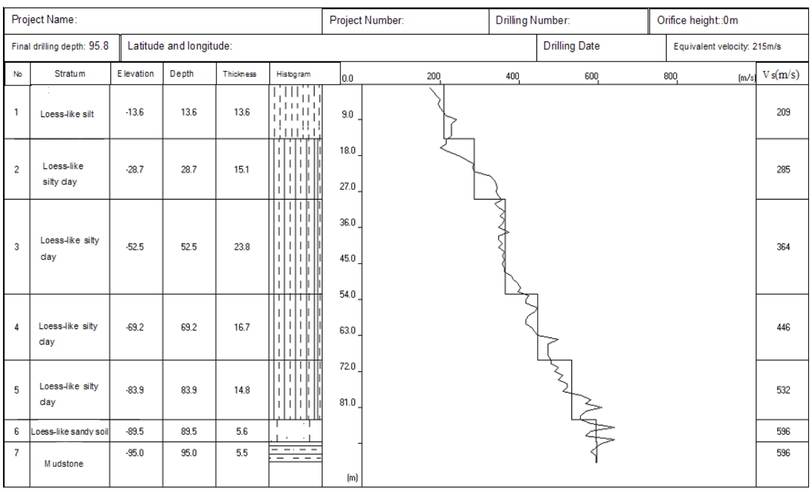


Figure 8. The borehole geologic records and Vs data of Pingliang city

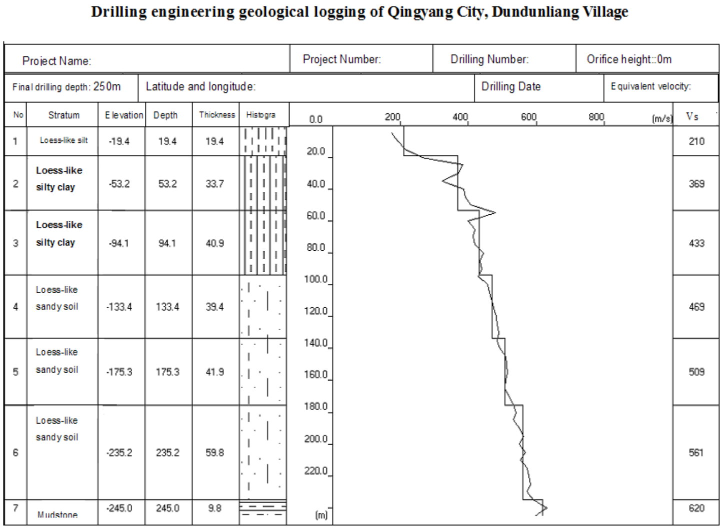


Figure 9. The borehole geologic records and Vs data of Qingyang city

4. MICRO TREMOR OBSERVATION

Based on high-density microtremor survey and borehole data respectively at these sites, the space distributions of microtremor data were studied. An inversion analysis method, which obtains predominant period and overlying soil thickness of underground loess layer, was presented using H/V frequency spectrum of microtremor.

4.1. Micro tremor observation instrument

There were two kinds of micro tremor measurement instruments, one is SPC-35 system and the other one is OYO data collector and velocity system, applied at these sites (Figure 10). The frequency ranges of SPC-35 and OYO are 0.2-70Hz and 0.1-70Hz respectively.

Figure 10. Micro tremor observation instrument. OYO system(left), SPC-35 system (right)

4.2. Predominant frequency

The predominant frequencies of these two sites are shown in Table 2. The predominant frequencies at the top of loess Yuan are lower than those at the bottom obviously. The preliminary reason may be that the top sites are mainly relatively loose and accumulative soil layer, which may enlarge the earthquake effect obviously [5].

Table 2. Predominant frequency and altitude at Dazai and Quzi Village

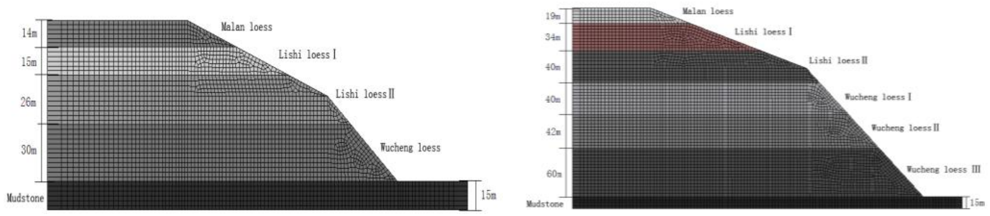
Site	Predominant frequency at top/Hz	Top altitude/m	Predominant frequency at bottom/Hz	Bottom altitude/m
Dazhai	1.20 Hz	1583 m	3.11 Hz	1432 m
Quzi	0.90 Hz	1383 m	2.50 Hz	1225 m

5. SEISMIC RESPONSE ANALYSIS

By applying the finite-element method, the two-dimension equivalent linear time history dynamic analysis was used for numerical simulation of seismic response of these two typical Loess Yuan at the Qingyang City and Pingliang City. The acceleration response, the velocity response and the displacement response of the loess Yuan were obtained, and acceleration spectral characteristics of different height were analyzed as well.

5.1. Analysis Methods

The dynamic response characteristics of free-field soil and its nonlinear property are taken into account, when the two-dimension finite element dynamic analysis method is employed [6]. The values of the dynamic shear modulus and damping ratio, obtained while the maximum displacement occurred during elasticity calculation according to its dependence in strain, are applied during the dynamic analysis proceeding. According to the differential GPS measurements in the two sites, based on borehole drilling exploration and high-density microtremor survey, the finite element model is determined. The analysis models are as shown in Figure 11, where the thickness of overlying loess layer of Pingliang city is set as 85m, while the thickness of overlying loess layer of Qingyang city is set as 235m. The soil parameters at these two loess Yuan are as shown in table3,4.



(a) The analysis model of Pingliang city (b) The analysis model of Qingyang city

Figure 11. The analysis models of typical loess Yuan

The loess Yuan is set into plane strain element (linearly equivalent) and the boundary condition uses the infinite element boundary while the bottom condition uses artificial boundaries. The earthquake load is the far-field earthquake accelerogram recorded at bedrock of the Wuquan mountain in Lanzhou city, which is inputted in the horizontal direction at the bottom of the model (Figure 12).

Table 3. Soil parameters at the loess plateau of Pingliang city

Soil Layer	Density /kN/m3	Modulus of elasticity /MPa	Damping Ratio	Poisson Ratio	Angle of internal friction	Cohesion value/KPa
Malan loess	15.00	52	0.13	0.28	24°	22
Lishi loess Ⅰ	16.32	64	0.14	0.25	18°	50
Lishi loess Ⅱ	17.26	78	0.13	0.26	14°	54
Wucheng loess	18.00	93	0.12	0.27	16°	62
Mudstone	22.00	200	0.10	0.20	/	/

Table 4. Soil parameters at the loess plateau of Qingyang city

Soil Layer	Density /kN/m3	Modulus of elasticity /MPa	Damping Ratio	Poisson Ratio	Angle of internal friction	Cohension value/KPa
Malan loess	15.20	61	0.12	0.33	24°	25
Lishi loess Ⅰ	16.30	75	0.15	0.34	22°	48
Lishi loess Ⅱ	17.20	94	0.14	0.35	23°	52
Wucheng loess Ⅰ	17.80	110	0.14	0.37	21°	58
Wucheng loess Ⅱ	19.00	126	0.13	0.37	19°	64
Wucheng loess Ⅲ	19.50	140	0.12	0.38	18°	72
Mudstone	22.00	200	0.10	0.20	/	/

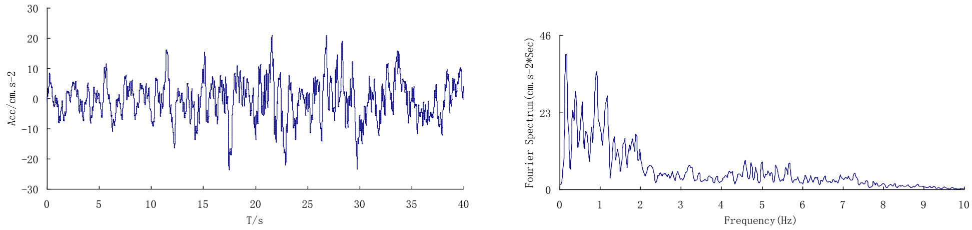
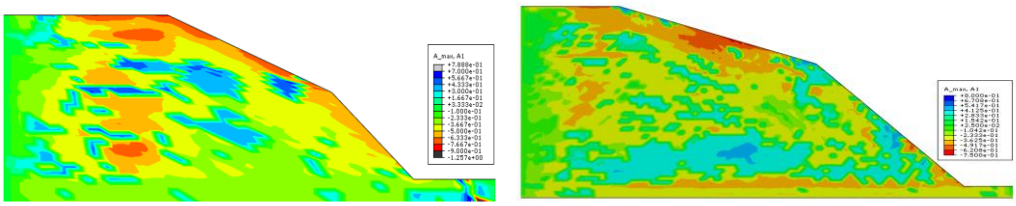


Figure 12. The far-field earthquake accelerogram and the FFT spectrum of the Wu Quanshan bedrock

5.2. Results of numerical analysis

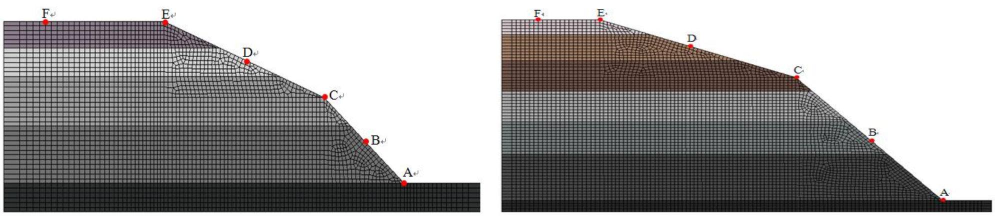
The acceleration distribution characteristics of the two loess Yuan is obtained. As shown in Figure 13, the acceleration response appeared amplification effect with the increase in slope height; moreover, the maximum acceleration values appear at the top and the slope leading edge. The acceleration values show the decreasing trend with the increasing distance from the peak plateau edge.



(a) The acceleration contours of Pingliang site (b) The acceleration contours of Qingyang site

Figure 13. The acceleration contours of different models

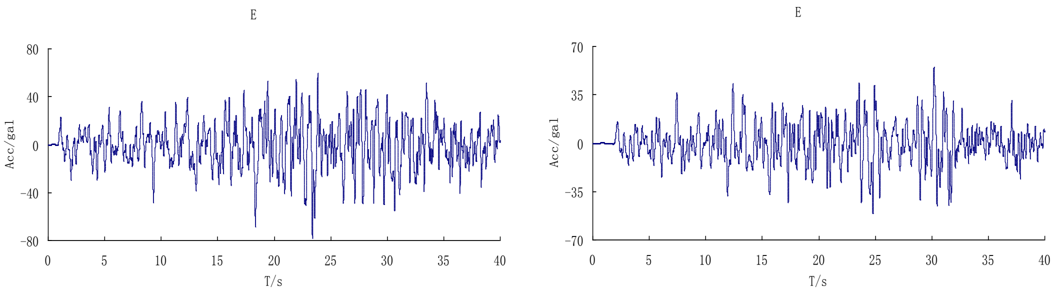
In order to analyze the acceleration amplification effect of different height accurately, six points, A-F, at different height are chosen and the acceleration-time curve of which are analyzed as well. The location of these points is marked at Figure 14.



(a) The loess Yuan of Pingliang site (b) The loess Yuan of Qingyang site

Figure 14. The analysis locations of FEM models

Take the point at the top of the hill as an example, the acceleration-time curve of point E of Pingliang site is as shown in Figure 15(a), while the acceleration-time curve of Qingyang site is as shown in Figure 15(b). Both of the two numerical analysis results indicate that the amplification of peak acceleration at the top and the slope of the loess Yuan obviously. Compared the peak acceleration of different points, combining the relative maximum velocity and displacement at different height to the foot of the slope (As shown in Table 5, 6), it could be seen that the acceleration, the velocity and the displacement all appear the amplification effects with the increase of the height. Contrasted with the peak acceleration at the base of the loess Yuan, the peak acceleration at the top of the loess Yuan at Pingliang city increases by 2 times, and the loess Yuan at Pingliang city increases by 1.44 times.



(a) The Pingliang site (b) The Qingyang site

Figure 15. The acceleration-time curve of the point at the top of the loess Yuan

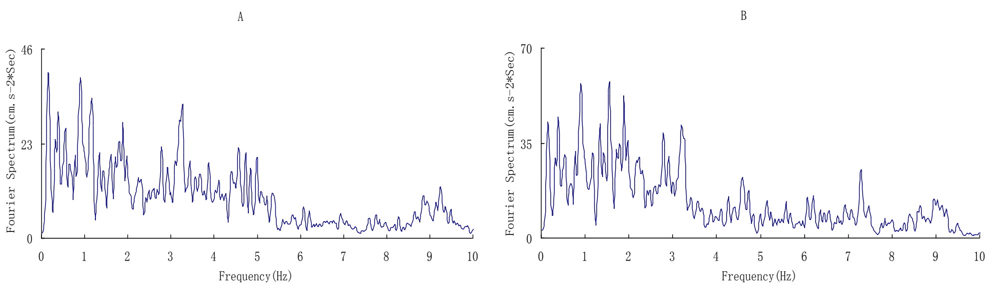
Table 5. The relative maximum velocity and displacement at different heights at Pingliang city

Number	A	B	C	D	E	F
Acc(cm.s-2)	39	58.3	62.4	69.6	78.5	46.7
Vel(cm.s-1)	0	5.60	8.00	9.89	10.62	/
Dis(cm)	0	1.69	4.07	7.69	13.54	/

Table 6. The relative maximum velocity and displacement at different heights at Qingyang city

Number	A	B	C	D	E	F
Acc(cm.s-2)	39.49	43.00	46.39	54.61	56.70	34.63
Vel(cm.s-1)	0	10.17	11.43	14.20	15.24	/
Dis(cm)	0	44.74	66.49	76.40	84.53	/

For further analyze of the spectrum characteristics of different points at different heights, the FFT spectral analysis of the acceleration-time curve at different heights of two site models are carried out. The FFT spectrums are shown in Figure 16, while the analysis results of loess Yuan at Qingyang city are shown in Figure 17. It indicated that the low frequency component is more abundant with the increase of the height and the high-frequency components are absorbed. Moreover, the maximum FFT spectrum is gradually increasing with increase of height; the values at the top of the loess Yuan are obvious and gradually decrease in the internal regions.



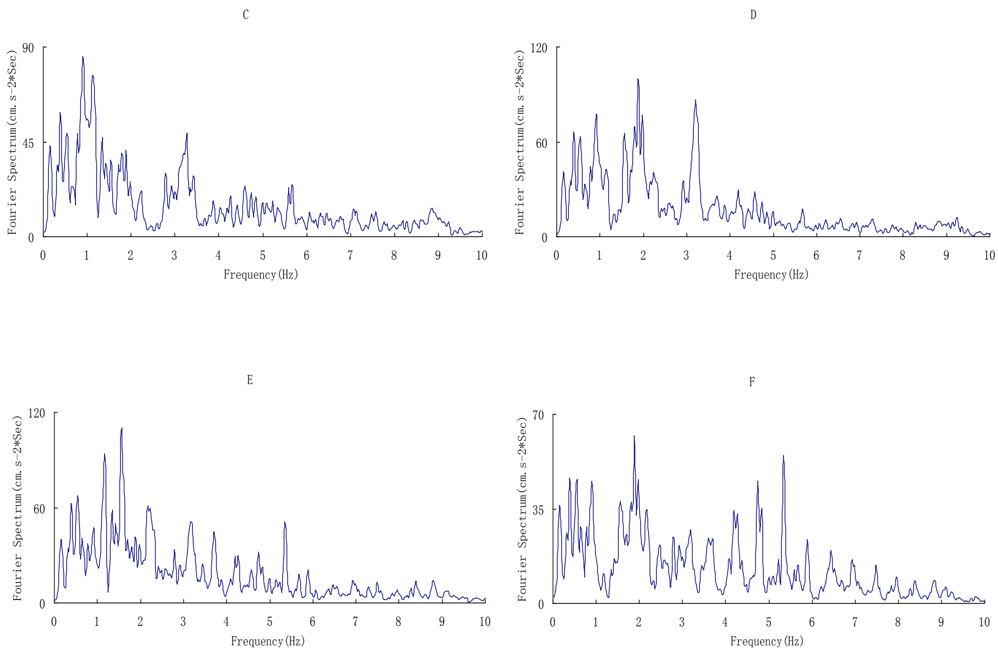


Figure 16. The FFT spectrum (A-F) of loess Yuan at Pingliang City

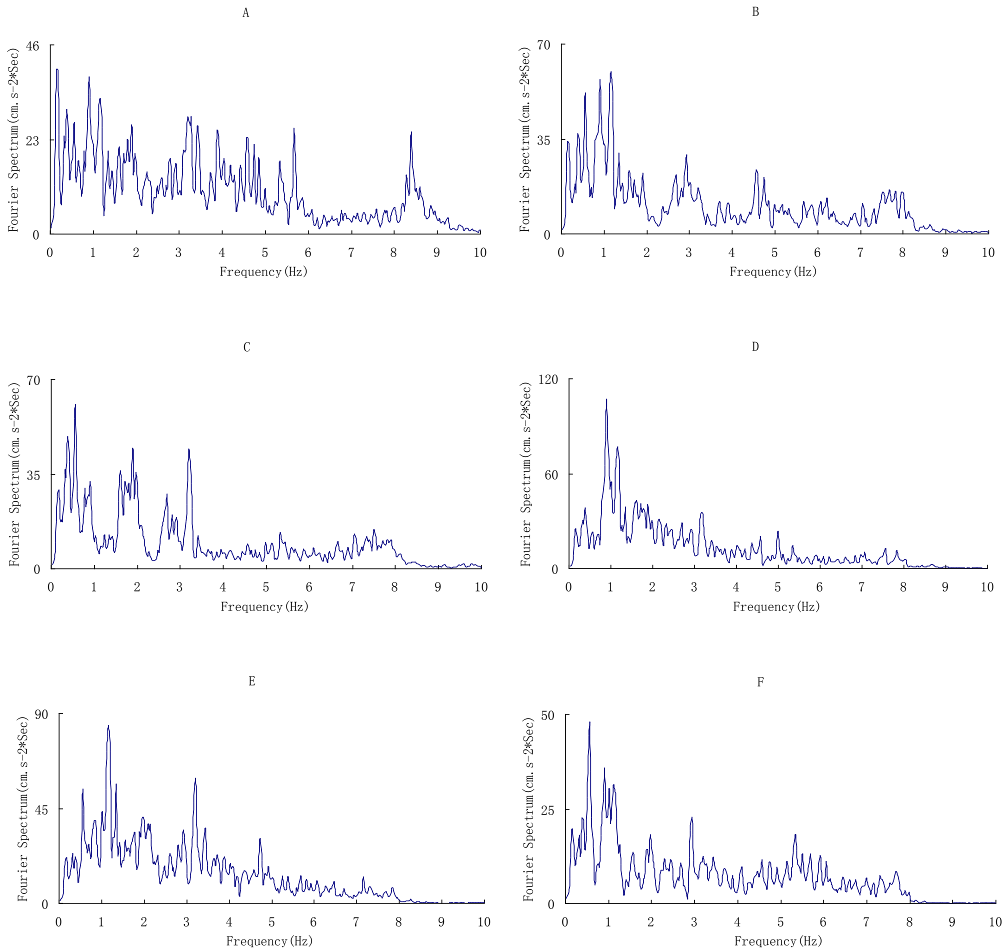


Figure 17. The FFT spectrum of loess Yuan(A-F) at Qingyang City

6. CONCLUSION

For the soil deposit of the loess Yuan at the Qingyang City and Pingliang City, the soil layers appear two-lever distribution, and the overlying loess layers present uniform and horizontal bedded deposit. The maximum thickness of loess layer is greater than 250 meters through this field investigation.

The ground motion records of aftershocks on the hill near Wenxian County show that the PGA values at the top are greater than that at the middle of the hill, and the values at the middle are slight greater than that at the bottom. Moreover, the greater the earthquake magnitude, the more obvious sites amplification appear at the top of the hill.

The predominant frequencies at the top of loess Yuan are greater than those at the bottom obviously, which may enlarge the earthquake effects obviously.

The amplification effect of the loess Yuan is to be confirmed and the acceleration magnification is gradually increasing with increase of height; the amplification effect at the top of the Yuan is obvious and gradually decreases to the internal regions. Along the slope of the loess Yuan, when the height increases, the long-period component of acceleration response spectrum increased significantly.

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