

Chapter 2

Seismic Array Monitoring Results Analysis

Bedrock and overburden slope is a special kind of rock slope. In order to reveal the failure mechanism of it under earthquake, its seismic dynamic response must be explored first. The dynamic response of rock slope includes acceleration, velocity, displacement, stress, and strain. The research results show that the inertia force caused by acceleration is the main reason of slope deformation and failure, which could provide reference to the seismic design of slope engineering. Hence, acceleration and its distribution rules are basic materials to evaluate the seismic dynamic characteristics of slope engineering.

So far, the research method for seismic ground motion characteristics of slopes mainly include field investigation, model tests, numerical simulation, and theoretical analysis, while seismic array monitoring is an important measure which can most reliably and truly reflect the seismic ground motion characteristics of slopes, whose monitoring data could provide valuable original data for seismic response analysis. Thus, this section will adopt the monitoring data of seismic array of rock slope in the Sishan park, Zigong in “5.12 Wenchuan Earthquake,” explain the real motion characteristics of slopes under seismic effects from the macro perspective, and visually analyze the seismic ground motion characteristics of rock slope so as to provide basic reference for following shaking table test, numerical simulation, and theoretical derivation of rock slopes as well as the formation mechanism of bedrock and overburden slopes.

2.1 General Condition

Zigong City locates in southern Sichuan Basin, and its distance to the epicenter of Wenchuan earthquake is about 227 km, it is composed of hills and valleys. Elevation decreases from northwest to southeast, mainly in the range of 250–450 m, as illustrated in Fig. 2.1. The elevation of downtown area is from 280 to 400 m, ground relative elevation is small, as shown in Fig. 2.2. Seismic array

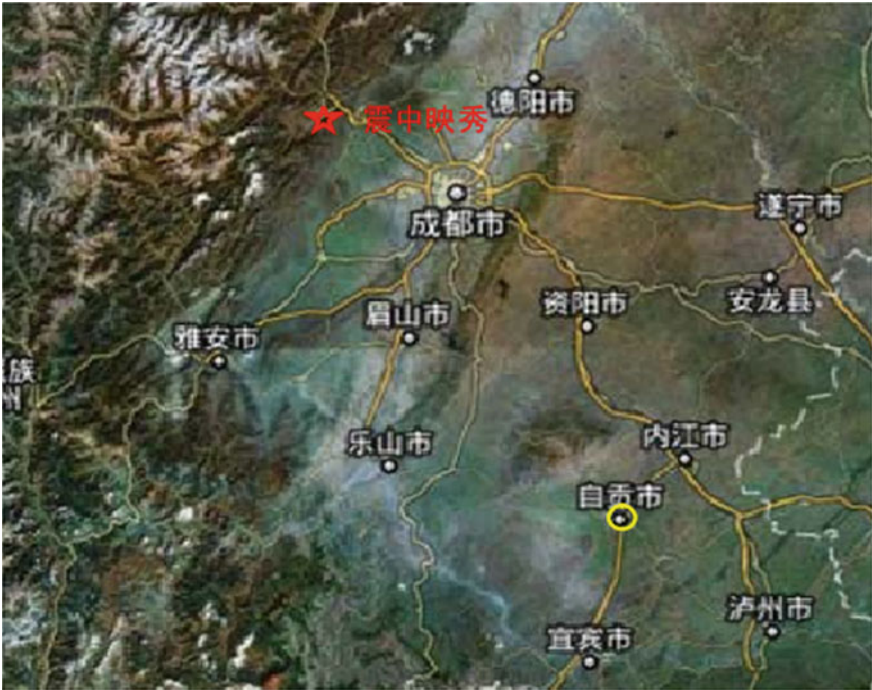


Fig. 2.1 Location of Zigong City

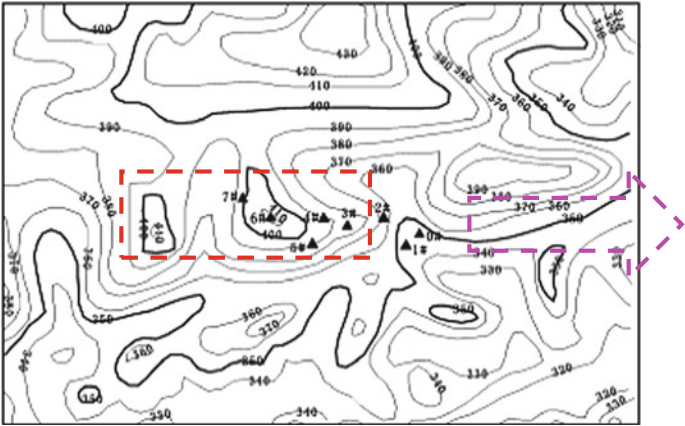


Fig. 2.2 Plane distribution map of Zigong topography monitoring points

Fig. 2.3 Distribution map of seismic array monitoring points

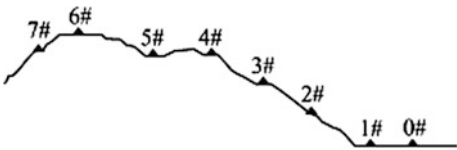


Table 2.1 Table of array parameters of Zigong topography

Station name	Elevation	Horizontal distance to reference station	Rock property
0#	345.0	51.55	Soil layer
1#	345.0	0.00	Jurassic bedrock
2#	367.0	41.64	Jurassic bedrock
3#	385.0	116.82	Jurassic bedrock
4#	392.0	171.41	Jurassic bedrock
5#	390.0	258.98	Jurassic bedrock
6#	417.0	304.55	Jurassic bedrock
7#	397.0	345.72	Jurassic bedrock

locates on a hill in Western Hills Park. The array consists of eight stations (0#–7#). Each station is equipped with digital seismograph with ETNA recorder and ES-T-type accelerometer. The maximum height difference is about 72 m between seismograph (6#) in the top of the hill and seismograph (0#, 1#) in the bottom of the hill. 0# station is located on soil site, 1# station is located on rock site, and other stations are located on rock site with different elevations (Fig. 2.3 and Table 2.1).

2.2 Monitoring Data of Seismic Array in 5.12 Wenchuan Earthquake

Wenchuan earthquake (Ms 8.0) occurred in China on May 12, 2008, and the seismogenic fault is central Longmen Shan rupture, with 230 km of surface rupture. Terrain is extremely complex, the elevation of upward plate is about 2000–3000 m, the elevation of the Chengdu Plain on the downward plate is just 500 m. The complex terrain of Longmen Shan fault zone exerts a significant effect on the Wenchuan earthquake. According to information provided by Chinese seismic array network, the seismic station in Zigong city has monitored relatively complete seismic data, which laid a solid foundation for the seismic response analysis of slope. The monitoring results are displayed in Figs. 2.4, 2.5, and 2.6.

Table 2.2 shows the peak ground accelerations of monitoring points in Xishan Park. To study the variation of PGA along elevation, so PGA in EW, NS, and UD directions are extracted, respectively, as shown in Table 2.2.

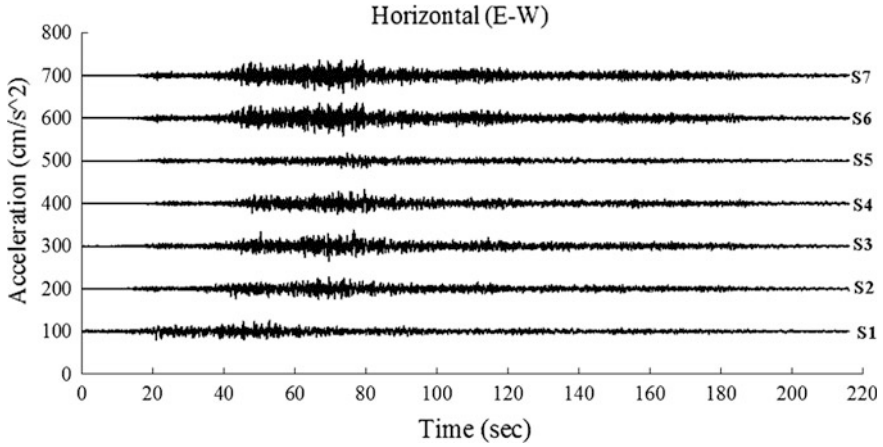


Fig. 2.4 The measured seismic ground motion time history curve in EW direction of S1–S7

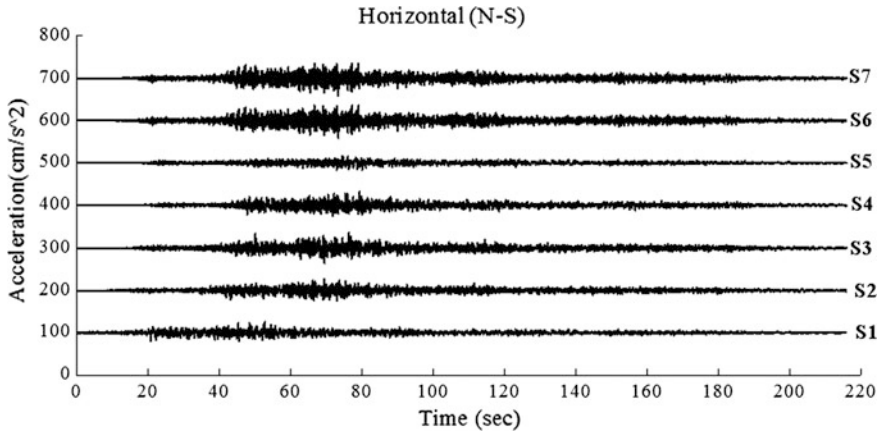


Fig. 2.5 The measured seismic ground motion time history curve in NS direction of S1–S7

2.3 Response Characteristics Analysis

According to the data from Zigong seismic array, elevation amplification effect will be discussed in this section. The #1 is chosen as reference point, PGA amplification factor is defined as the ratio of PGA at any point to that of #1, as shown in Figs. 2.7, 2.8, and 2.9. It should be pointed out that the elevation of each site is the relative elevation to #1.

From Figs. 2.7, 2.8, and 2.9, the PGA amplification factor increases with the relative elevation in three directions. The maximum value of PGA amplification factor in EW direction is 1.768 at #1, that in ES direction is 1.717 at #7, and that in

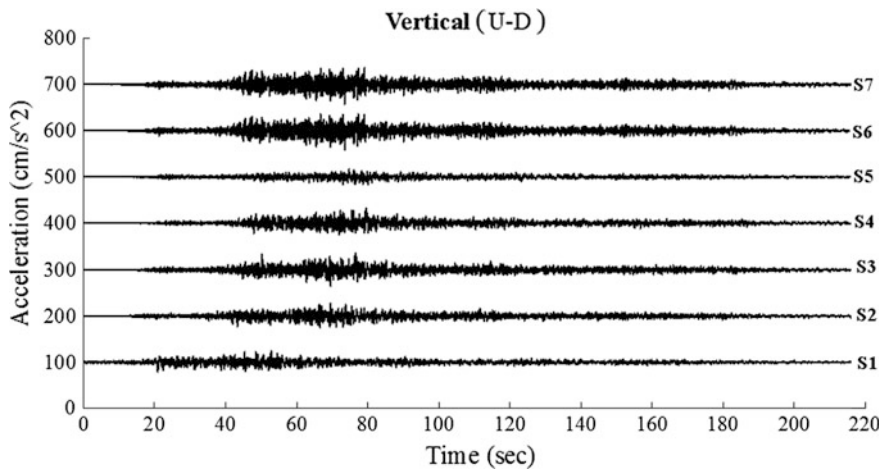


Fig. 2.6 The measured seismic ground motion time history curve in UD direction of S1–S7. *Note* all the time history curves are drew by uniform scale, and the stations are numbered S1–S7

Table 2.2 PGA response characteristics of Zigong topography monitoring array (cm/s/s)

No.	Relative elevation (m)	PGA (cm/s ²)			Acceleration amplification coefficient		
		EW component	NS component	UD component	EW component	NS component	UD component
1#	0	23.036	26.489	14.726	1	1	1
2#	22	28.078	29.952	15.953	1.219	1.131	1.083
3#	40	34.863	32.533	18.336	1.513	1.228	1.245
4#	47	32.531	32.226	19.719	1.412	1.217	1.339
5#	45	33.030	42.169	17.240	1.434	1.592	1.171
6#	72	40.735	42.244	19.742	1.768	1.595	1.341
7#	52	39.299	45.489	16.049	1.706	1.717	1.090

Fig. 2.7 Acceleration elevation amplification effects in EW direction

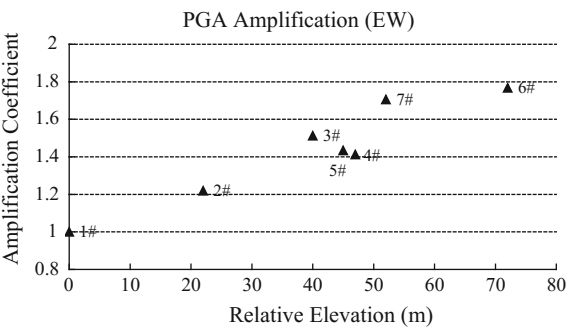


Fig. 2.8 Acceleration elevation amplification effects in NS direction

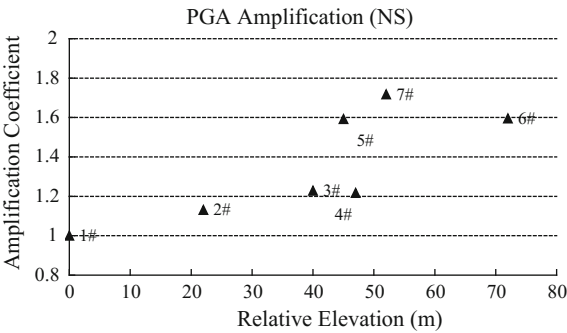
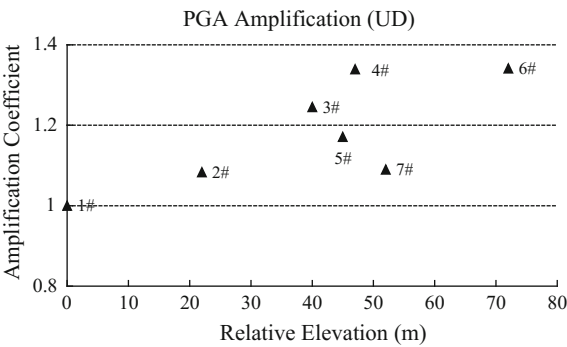


Fig. 2.9 Acceleration elevation amplification effects in UD direction



UD direction is 1.341 #6. The values of horizontal directions are very close, both are great than that in vertical direction. This may be caused by the fact that EW is close to the direction of free surface and the NS is close to the tendency of the slope. The free surface amplification effect results in a more intensive amplification in EW direction than NS direction. It is noteworthy that the PGA amplification factor of #7 is smaller that of #5 while the relative elevation of the former site is larger than the later site. This can be contributed to the fact that the #5 locates in a local canyon. The reflection, refraction, and transmission effect will be triggered while the up propagation seismic waves encounter the interface between the soil layer and underlying bedrock, which lead to a much more intense ground motion at #5. This indicates that the acceleration effect is dependent on direction, namely the direction corresponding to the free surface has the largest amplification value, the vertical direction has the smallest amplification, and the direction parallel to the slope tendency is moderate.

2.4 Frequency Spectrum Response Characteristics

Based on the monitoring results of seismic dynamic response of seismic array of Zigong topography, this section analyzes the frequency spectrum response characteristics of rock slopes from both Fourier spectrum and response spectrum.

2.4.1 Fourier Spectrum Along Elevation

Fourier spectrum is the method to change complex seismic acceleration time history $\alpha(t)$ into N frequency combinations by discrete Fourier transform technique:

$$\alpha(t) = \sum_{i=1}^N A_i(\omega) \sin[\omega_i t + \varphi_i(\omega)] \quad (2.1)$$

In the formula, $A_i(\omega)$, $\varphi_i(\omega)$ are the amplitude and phase angle of vibration component of angular frequency ω_i ;

Formula (2.1) can be rewritten into:

$$\alpha(t) = \sum_{i=1}^N A_i(i\omega) e^{i\omega_i t} \quad (2.2)$$

In the formula, $i = \sqrt{-1}$, complex function $A(i\omega)$ is Fourier spectrum, and its module $|A(i\omega)|$ is the amplitude spectrum.

Calculate the Fourier spectrum in EW, NS, and UD direction from S1 to S7 based on the monitoring results of Zigong topography seismic array, and carry out smooth effect to the Fourier spectrum, which are shown in Figs. 2.10, 2.11, 2.12, 2.13, 2.14, 2.15, and 2.16.

Fig. 2.10 Fourier spectrum of three-direction acceleration of S1

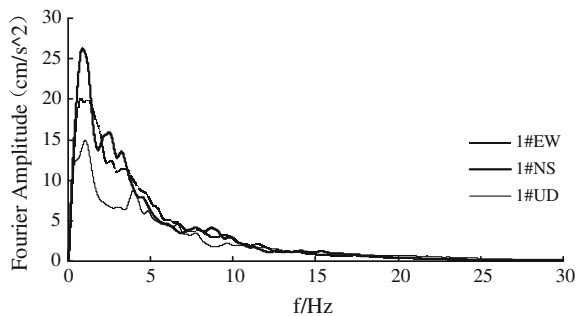


Fig. 2.11 Fourier spectrum of three-direction acceleration of S2

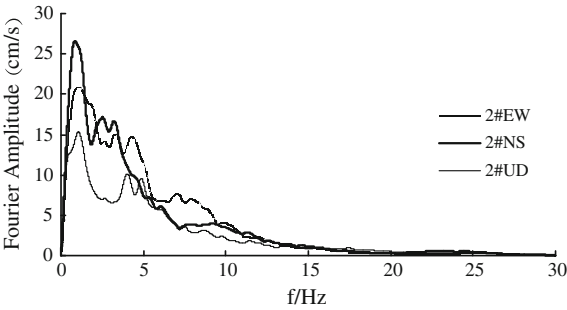


Fig. 2.12 Fourier spectrum of three-direction acceleration of S3

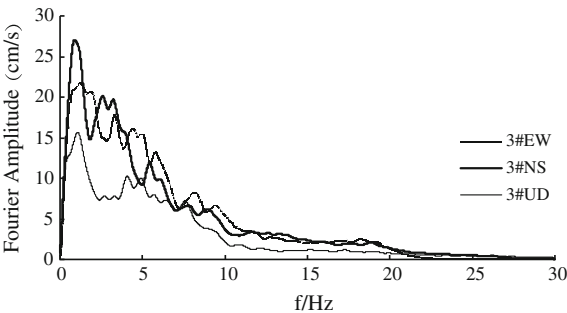


Fig. 2.13 Fourier spectrum of three-direction acceleration of S4

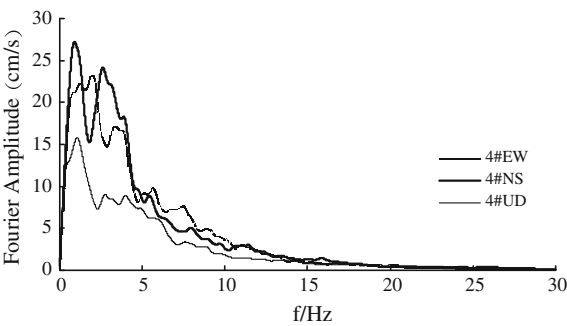


Fig. 2.14 Fourier spectrum of three-direction acceleration of S5

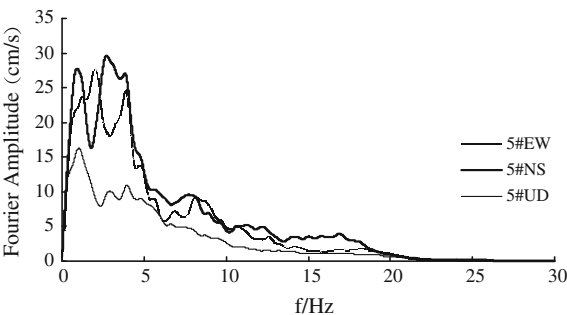


Fig. 2.15 Fourier spectrum of three-direction acceleration of S6

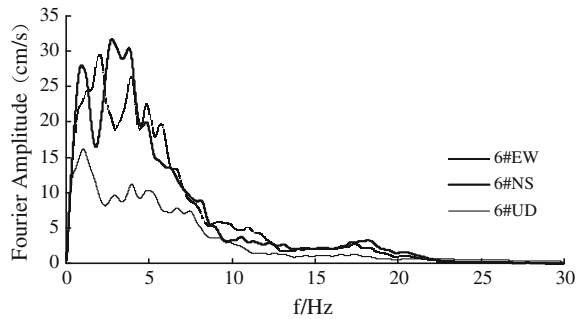
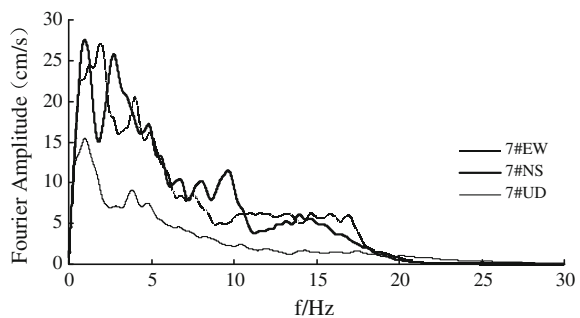


Fig. 2.16 Fourier spectrum of three-direction acceleration of S7



Figures 2.10, 2.11, 2.12, 2.13, 2.14, 2.15, and 2.16, show that as for the acceleration Fourier spectrum in EW direction, the dominant frequency of 1#–4# is in the range of 1–2 Hz, these of 5# and 6# present a double peak pattern, dominant frequency is in the range of 1–2 Hz and 4–5 Hz, its amplitudes increase with the elevation. In terms of the acceleration Fourier spectrum in ES direction, the dominant frequency of 1# and 2# is in the range of 1–2 Hz, these of 3#–6# present a double peak pattern, and dominant frequency is in the range of 1–2 Hz and 3–5 Hz, its amplitudes increase with the elevation. In UD direction, the dominant frequency is in the range of 1–2 Hz, its amplitude stays unchanged and is independent of elevation. According to the evaluation method to natural frequency proposed by J.Y. Xu et al. the natural frequency of this slope is 4.02 Hz, hence, the components within 3.0–5.0 Hz are amplified.

Generally, dominant frequency band of horizontal acceleration is in the range of 1.0–2.0 Hz and 3.0–5.0 Hz. The frequency components are close to the natural frequency of the slope 3.0–5.0 Hz, so acceleration amplifies dramatically, and the Fourier amplitude spectrum transform form single mode to double peak pattern. The dominant frequency band of vertical acceleration is 1.0–2.0 Hz, which is independent of elevation.

2.4.2 Seismic Ground Motion Response Spectrum Along Elevation

In essence, seismic response spectrum is the characteristics of seismic intensity and spectrum. The response spectrum is composed of maximum responses of numerous single degree of freedom systems. The response spectra are illustrated in Ging Figs. 2.17, 2.18, 2.19, 2.20, 2.21, and 2.22 with damping ratio 5 %.

Fig. 2.17 Acceleration response spectrum of all stations in EW direction

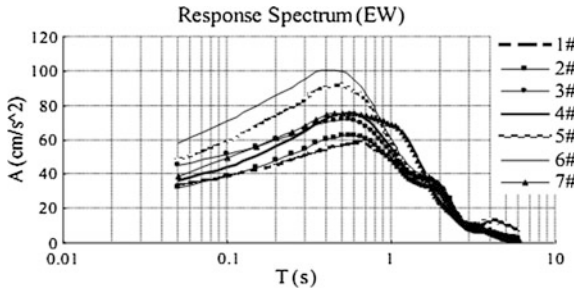


Fig. 2.18 Acceleration response spectrum of all stations in EW direction

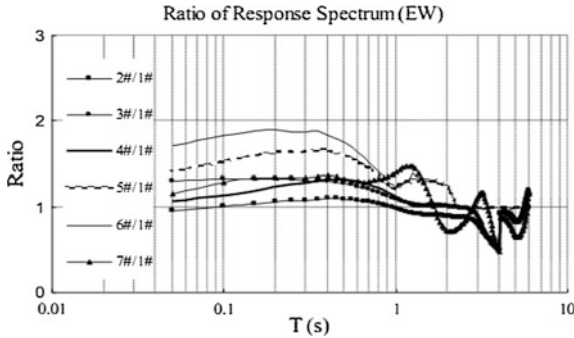


Fig. 2.19 Acceleration response spectrum of all stations in NS direction

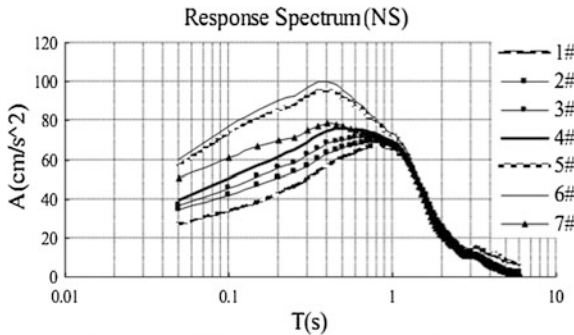


Fig. 2.20 Acceleration response spectrum of all stations in NS direction

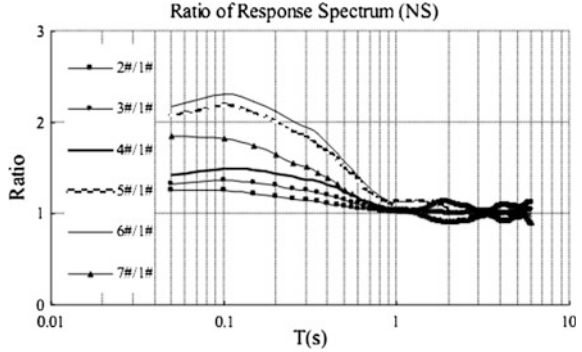


Fig. 2.21 Acceleration response spectrum of all stations in UD direction

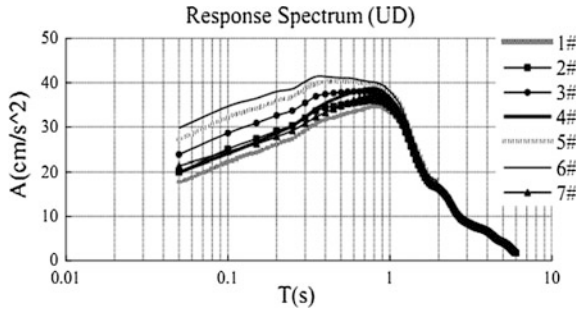
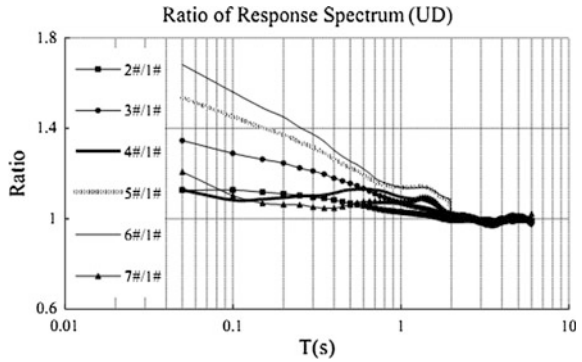


Fig. 2.22 Acceleration response spectrum of all stations in UD direction



Figures 2.17, 2.18, 2.19, 2.20, 2.21, and 2.22 show that the dominant periods of response spectrum in both EW and NS directions are in the range of 0.3–0.7 s, and the amplitudes increase with the elevation for $T \leq 1$ s, while $T > 1$ s, the response spectrum of each point are almost the same. In terms of the vertical direction, the dominant periods of response spectra are in the range of 0.6–1.0, and the amplitudes increase with the elevation for $T \leq 1$ s, while $T > 1$ s, the response spectrum of each point are almost the same, the amplitude are about one-third to half of that of

horizontal direction, and the amplitudes of 2#, 4#, and 7# have little difference. It is noteworthy that the 5# is located in a local canyon. Even though the elevation of 5# is smaller than 7#, the amplitude of 5# is greater than that of 7#, which indicates that the local site condition has a significant effect on ground amplification.

In general, the amplification coefficient of acceleration response spectrum increases with the elevation, and the amplification value in horizontal direction is greater than in vertical direction.

2.5 Brief Summary

Through the analysis of the seismic array of Xishan Park, its PGA, Fourier spectrum, and response spectrum are obtained, and the following conclusions can be drawn:

- (1) The PGA in three directions increase nonlinearly with the increase of elevation, the amplification factor is 1–1.768, 1–1.717, and 1–1.341 for three directions, respectively. The EW direction has the largest amplification value, the vertical direction has the smallest amplification, and the NS direction is moderate.
- (2) dominant frequency band of horizontal acceleration is 1.0–2.0 Hz and 3.0–5.0 Hz, these frequency components close to the natural frequency of the slope 3.0–5.0 Hz are amplified dramatically, and the Fourier amplitude spectrum transform form single peak mode to double peak pattern. The dominant frequency band of vertical acceleration is 1.0–2.0 Hz, which is independent of elevation.
- (3) The amplification factor of acceleration response spectrum increases with the elevation, and the amplification value in horizontal direction is greater than in vertical direction.

Slope Earthquake Stability

Changwei, Y.; Jingyu, Z.; Jing, L.; Wenying, Y.; Jianjing, Z.
2017, X, 218 p. 255 illus., 219 illus. in color., Hardcover
ISBN: 978-981-10-2379-8