CALCULATION OF LONG-PERIOD GROUND MOTION RESPONSE SPECTRUM BY USING BROAD-BAND DIGITAL RECORD

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SUMMARY

In this paper, we use the digital broad-band records to study the characteristics of long-period ground motion. The record of Chinese Digital Seismograph Network (CDSN) is used as an example to demonstrate the method of recovery of the ground motion and correction procedure. We analyzed the signal and noise level in order to discuss the reliability of the calculated long-period response spectrum. The results show that, differ from the strong motion accelerographs used in engineering research, the digital broad-band records in this work can be used to obtain credible ground motion response spectra in the period of longer than 10 sec. The velocity type record have higher signal-to-noise ratio than that of the acceleration type record. The horizontal long-period response spectra of different damping ratio which the period is up to 20 second are calculated.

INTRODUCTION

The damages of large-scale structures due to earthquakes increase in the world. For example, during the southern Yellow Sea earthquake (November 9, 1996, Ms6.1), there is no building collapse in Shanghai which is about 160 kilometers away from the epicenter, but several lightning rods on the top of the TV tower which is 468 meters tall are broken off. Along with the rapid development of China economy, many long-period structures will be built. For example, for the suspension bridge which the span is 1000 to 2000 meters and high-rise building which is 80 to 100 stories the natural period will be more than 10 second. These structures belong to either life-lines or important systems. If they are damaged by earthquakes, the direct and indirect loss will be tremendous. Therefor it is a important and pressing problem to study the characteristics of long-period ground motion.

The databases that are used to study the characteristics of ground motion are mostly from the analog accelerometers. Due to the limitation of instrument response of analog accelerometer and processing procedures, the reliable frequency band is less than several seconds and therefor is not suitable for studying the characteristics of long-period ground motion. Compared with the analog accelerometer, the frequency response of the digital accelerometer improved a lot, and the long-period error introduced by digitization of analog record is avoided. So the digital data are generally considered reliable to study the long-period ground motion and some researchers hereby have calculated the long-period response spectra (*eg*., xie *et al.*, 1990). Nevertheless, some recent researches show that when the period is longer than 10 second, the record of digital accelerometer is unreliable due to background noise (Chiu, 1997; Zhou *et al*., 1997). Therefor, if we want to study the ground motion which the period is longer than 10 second, the existing strong motion data can't meet the demand. Besides the empirical method, it is also feasible to study the long-period ground motion by seismic method from the earthquake source and propagation path (Trifunac, 1993, 1995; Lu, 1995), nevertheless, the result should be checked by reliable observation data. At present there is limitation to understand the characteristics of long-period ground motion and the lack of reliable long-period ground motion observation data is the key problem.

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The digital broad-band seismometer which designed for seismic study has some excellent properties such as high dynamic range, broad band and low noise level. These properties are also needed by earthquake engineering study, and under some condition the records of the digital broad-band seismometer can be used in earthquake engineering. Therefor, we demonstrate the applicable of such records to long-period ground motion research from instrument response, recovery of ground motion, data correction and signal-to-noise ratio. The records of more than 70 earthquakes occurred after 1986 in China recorded by broad-band or very broad-band (BB or VBB) channels and low-gain short period channel (LG) of China Digital Seismograph Network (CDSN) and the very broad-band channel of Wushi seismic station of Geoscope of France are processed. The horizontal long-period response spectra of different damping ratio which the period is up to 20 second are calculated.

INTRODUCTION TO INSTRUMENT RESPONSE

The Sino-US cooperative CDSN operated since 1986. Now there are 11 stations which installed the broad-band seismometer (BB, 4-0.04Hz, 20sps). After the second-phase technical upgrade in 1995, the BB channel is changed to very broad-band channel (VBB, 8.5-0.003Hz, 20sps) (Zhou et al., 1995) and the low-gain short period channel (LG, 40-0.001Hz, 80sps) is added in some stations (Lai et al., 1994). The instrument frequency response of VBB channel of Geoscope is similar to that of CDSN. The frequency response of these 4 seismometers is shown in Figure 1. The amplitude response of BB and VBB is flat relative to velocity, whereas that of LG is flat relative to acceleration and is low-gain so it is similar to the accelerometer.

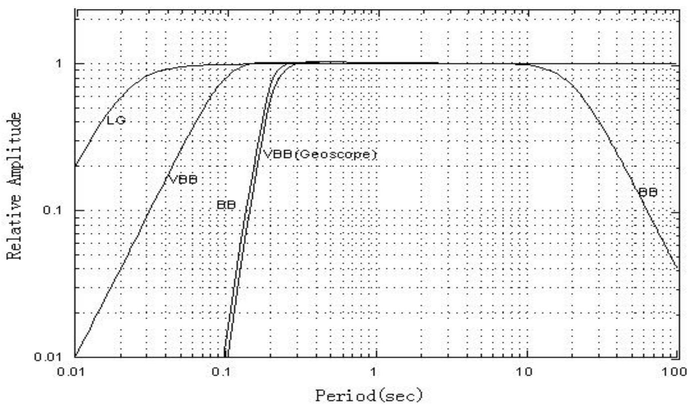

Fig. 1 The frequency response of 4 seismometers. The LG is relative to acceleration and the others are relative to velocity.

We can see from Figure 1 that if from the point of view of the frequency response only, these seismometers can record the long-period ground motion which we concern.

DATA PROCESSING

Recovery of ground motion

In order to recover the ground motion, the instrument correction must be made. The instrument response can be expressed as transfer function. After converted by the transfer function of the instrument system, the digital counts can be transformed into the ground displacement $x(t)$, velocity $\dot{x}(t)$ and acceleration $\ddot{x}(t)$, respectively, where t is time (Wang *et al*., 1998).

Correction

Before calculation of response spectrum, the baseline correction, rotation correction and high-pass filtering are necessary. Unfortunately, after these correction procedures the long-period information is lost simultaneously. The cut-off frequency of the high-pass filter is the key factor. If the cut-off frequency is low there will be a large baseline deviation in integrated displacement; if the cut-off frequency is high the long-period ground motion information may be filtered also. So when we are interested in the long-period ground motion, an appropriate cut-off frequency is very important.

The digital seismograph records the digital counts. If there is no baseline drift, when no ground motion the digital counts ought to fluctuate around zero. But in fact this count fluctuates around a fixed number. To deduct the constant drift a simple procedure is applied. The mean value of the pre-event record is taken as the constant drift. By deducting the constant drift from the whole record, we can get the record whose constant drift has been eliminated. It is obvious that the longer the pre-event record the more accurate the baseline correction. Most of the pre-event records we used are longer than 20 seconds, so the baseline drift can be eliminated thoroughly.

Another correction procedure we take is the high-pass filtering. When the data are corrected for the instrument response a high-pass filter which the cut-off period is 40 second is applied. Besides of above procedures, no other correction is applied.

Figure 2 is the recovered ground acceleration, velocity and displacement of E-W component of VBB and LG of BJI station for the Zhangbei earthquake of January 10, 1998, M6.2. When drawing the figure the sampling rate of the LG is resampled from 80 sps to 20 sps in order to consistent with that of the VBB. We can see from Figure 2 that the ground displacement and velocity recovered from LG record are acceptable and no significant baseline errors. And also, the ground motions recovered from VBB and LG are coincident. This consistency may indicate that the two seismometers are reliable and the true ground motion can be recorded and recovered.

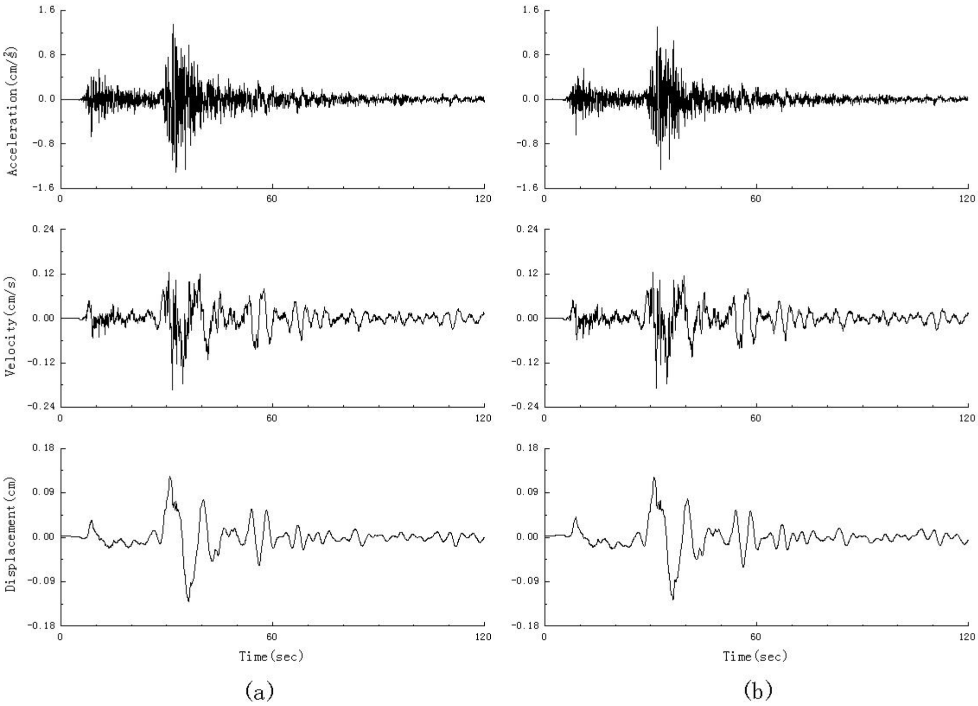

Fig. 2 Recovered ground acceleration, velocity and displacement (from top to bottom, respectively) from VBB and LG of BJI station (a) VBB (b) LG

FOURIER AMPLITUDE ANALYSIS OF SIGNAL AND NOISE

In order to verify if the digital broad-band record can be used to study the long-period ground motion, the signal-to-noise ratio is checked. The record of Zhangbei earthquake by BJI station is also as an example to analyze the Fourier spectra of the signal and noise.

The records of N-S component of VBB and LG are recovered to ground acceleration by above method. We extract 62.5 second of pre-event data as noise (including the instrument noise and background noise) and the following 125 second of data as seismic signal. The longer the noise we take the more objectively reflecting the level of noise.

We calculate the Fourier amplitudes of the noise and signal, respectively, and are shown in Figure 3.

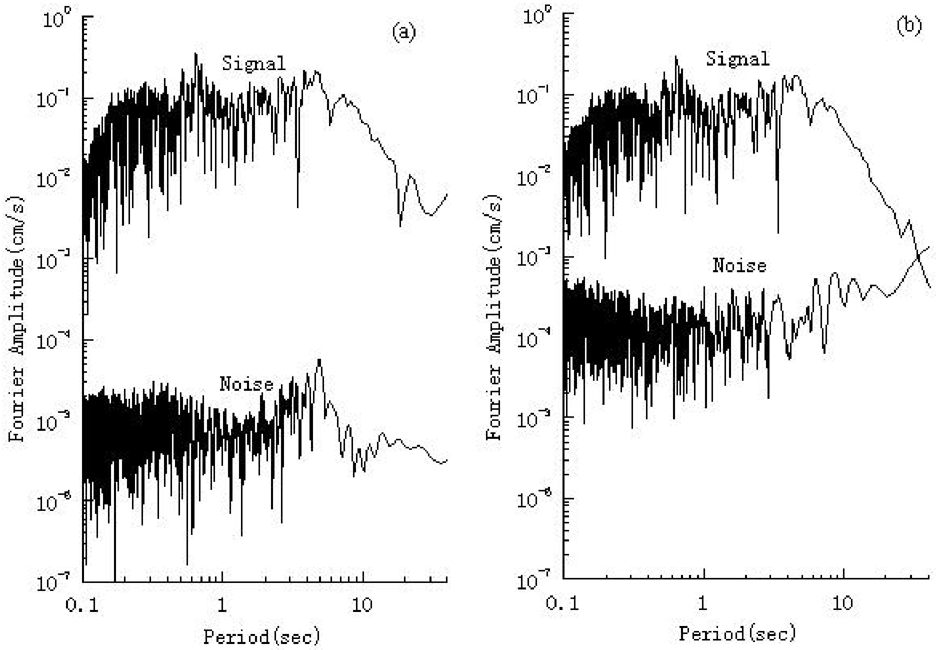

Fig. 3 The comparisons of noise and seismic signals for VBB and LG (a) VBB (b) LG

We can see from Figure 3 that as the VBB record the level of noise is very low and at the period of 20 second the level of seismic signal is about 4 orders higher than the level of noise. So for the study of long-period ground motion the signal-to-noise ratio is satisfactory. The level of noise of LG is about 2 orders higher than that of VBB and at the period of 20 second the levels of noise and signal are at the same level. We must emphasize that the record used here is a weak ground motion which the peak ground acceleration is less than 2 cm/s^2. Considering that the level of noise only reflects the performance of instrument and background noise and is independent of the level of ground motion, when the ground motion is stronger the signal-to-noise ratio is higher. So when the ground motion is strong the LG record can also be used to study the long-period ground motion.

The noise level of traditional digital accelerometer is higher. Figure 4 is quoted from Chiu(1997). This figure shows the comparisons of noise and seismic signals for a typical SMART-2 data. Zhou *et al.*(1997) think that the noise of the period great than 10 second should mainly come from seismograph. If so, these Fourier amplitude analyses will have comparability. That is, the VBB has lowest noise level, then the LG, and the traditional digital accelerometer has the highest noise level and is not suitable for study of long-period ground motion which the period is longer than 10 second.

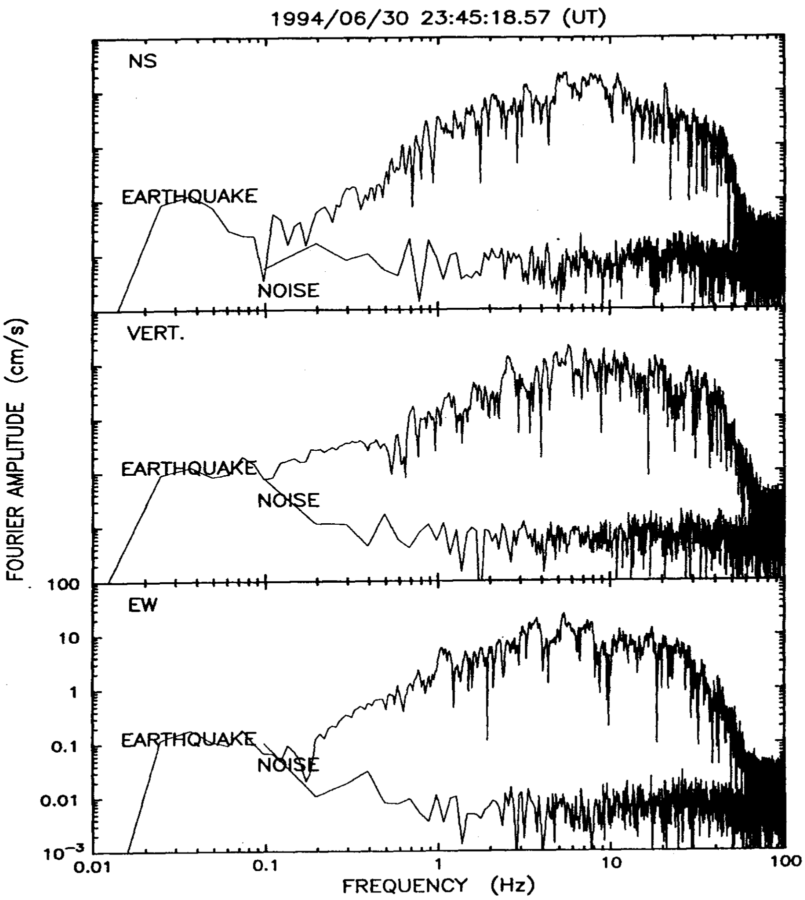

Fig. 4 The comparisons of noise and seismic signals for a typical SMART-2 data(Chiu(1997), Fig. 3)

CALCULATION OF LONG-PERIOD RESPONSE SPECTRUM

We have demonstrated the feasibility and reliability of the digital broad-band record using in study long-period ground motion from the aspects of instrument response, correction procedure and signal-to-noise ratio analysis. To study the characteristics of long-period ground motion, we have collected BB, VBB and LG records of CDSN and VBB records of Wushi seismic station of Geoscope from more than 70 earthquakes occurred after 1986 in China. After recovering ground motion and corrections, we calculated the response spectra of relative displacement, relative velocity and absolute acceleration response spectra for damping ratio of ζ=0, 0.01, 0.02, 0.05 and 0.10. The results of 130 horizontal records of 65 earthquakes refer to (Yu and Wang, 1997; Wang *et al.*, 1998). Here are the parameters of other earthquakes (Table 1).

Table 1 Earthquake catalogue

No.	Date	Time	Location		M_S	Station	Epi. Distance/km	Reference place
	a-mo-d	h:min:s	φ_N/(°)	λ_E/(°)				
1	1996-03-19	23:00:26.0	39.99	76.70	6.9	WUS	251.6	Artux, Xinjiang
2	1997-01-21	09:47:14.3	39.70	76.92	5.8	WUS	256.1	Jiashi, Xinjiang
3	1997-01-21	09:48:21.9	39.65	76.93	6.1	WUS	259.2	Jiashi, Xinjiang
4	1997-03-01	14:04:13.8	39.57	76.95	6.0	WUS	264.0	Jiashi, Xinjiang
5	1997-04-06	07:46:16.3	39.52	77.03	6.4	WUS	263.1	Jiashi, Xinjiang
6	1997-04-06	12:36:32.5	39.55	77.03	6.2	WUS	260.7	Jiashi, Xinjiang
7	1997-04-11	13:34:43.5	39.60	76.97	6.4	WUS	260.5	Jiashi, Xinjiang
8	1997-04-13	05:09:08.7	39.55	77.00	5.5	WUS	262.5	Jiashi, Xinjiang
9	1997-04-16	02:19:09.4	39.69	76.97	6.2	WUS	253.6	Jiashi, Xinjiang
10	1997-05-17	11:58:22.4	39.57	77.00	5.4	WUS	260.9	Jiashi, Xinjiang
11	1998-01-10	11:50:39.0	41.1	114.3	6.2	BJI	197.4	Zhangbei, Hebei

Figure 5 is the absolute acceleration response spectrum calculated from E-W component of VBB of BJI station for Zhangbei earthquake. Considering that the sampling rate of VBB is 20sps, when calculating the response spectrum, the short-period end is set to 0.1 second and the long-period end is 20 second.

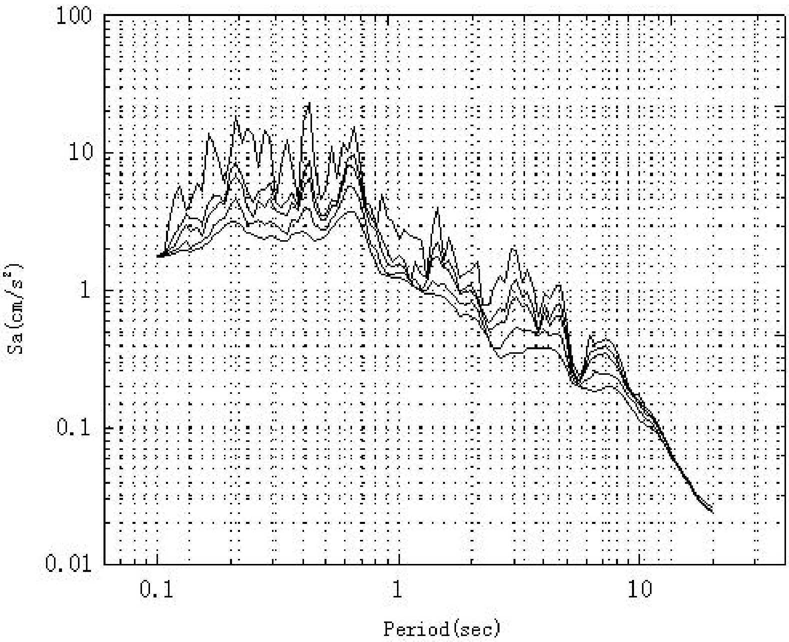

Figure 5 The absolute acceleration response spectra from E-W component of VBB of BJI for Zhangbei earthquake. From top to bottom ζ=0, 0.01, 0.02, 0.05, 0.10

By accumulating the observation data and assisted with appropriate physical model, we can derive the long-period attenuation law and serve the seismic design of some important large-scale structures.

DISCUSSION AND CONCLUSION

Discussion

When the record of digital seismometer is integrated to displacement, the long-period noise will cause large baseline error. So a series of correction procedures are applied, among which the high-pass filtering is important. Because of the instrument noise the cut-off frequency of the high-pass filter usually set to 0.1Hz and thus causes the long-period signal which the period is longer than 10 second to be filtered. Relatively, when integrated from acceleration to velocity, the baseline drift is not severe. Likewise, when integrated from velocity to displacement, the baseline drift is also not severe. The response amplitudes of BB and VBB are flat relative to velocity, so the records of them are somewhat like velocity records. Therefor the long-period error will be relatively small and the corresponding cut-off frequency of high-pass filter can be set lower to 0.025Hz in this paper. Considering that differentiating from velocity to acceleration only bring high-frequency error, and the records we used have high signal-to-noise ratio in long-period range, the records are favorable to be used to study the characteristics of long-period ground motion. So when studying long-period ground motion, the velocity record has more advantage over acceleration record. The VBB and LG system of Global Seismographic Network(GSN) and TERRAscope of US are similar to the VBB and LG system of CDSN, so the records of them can also be used to study long-period ground motion. A disadvantage is that these seismographs are used to record weak ground motion, so their sensitivity is usually high. Although their dynamic range is high, when recording great or close earthquake, the record sometimes is clipped. In this situation, the LG record can be used because of low-gain. Because the operating environment of LG is better than the accelerometer, when the ground motion is strong, the LG has a high signal-to-noise ratio.

There is also a disadvantage to use the accelerometer to record long-period ground motion. Generally the accelerometer operates by triggering. When the ground motion acceleration is less than a threshold the accelerometer will stop recording, so the recording of the accelerometer is usually not long. However, the long-period acceleration may be very small, but its displacement may be large and the duration is long (see Figure 2). If the record of accelerometer is used, it may only have several vibration periods, thus it may underestimate the strength of long-period ground motion. The VBB or BB record is continuously recorded and the duration is long. When studying the long-period ground motion, it may be more appropriate to define duration of the record by displacement than by acceleration.

Conclusion

In this paper we demonstrated the feasibility and reliability of the digital broad-band record using in study long-period (10 to 20 second) ground motion from the aspects of instrument response, correction procedure and signal-to-noise ratio analysis. The result shows that it is practical to use digital broad-band record to calculate long-period response spectrum and the result is dependable. It is more advantageous to use velocity record than acceleration record to study long-period ground motion.

REFERENCES

Chiu H. C., 1997. Stable baseline correction of digital strong-motion data. *Bull. Seism. Soc. Am.*, **87**(4): 932~944.

Lai D., Liu X., Yang Y., *et al*., 1994. Station system of the new CDSN. *Seismological and Geomagnetic Observation and Research*, **15**(6):56~62.(in Chinese)

Li H., 1992. Determination of the ground displacement using FFT and modern control engineering. *Acta Geophysica Sinica*, **35**(1):37~43.(in Chinese)

Lu H., 1995. *Demarcation of Response Spectrum and its Long-period Extrapolation*. Master theis of Institute of Geophysics, China Seismological Bureau. 43~46(in Chinese)

Trifunac M. D., 1993. Long period Fourier amplitude spectra of strong motion acceleration. *Soil Dynam. Earthq. Engng*., **12**(6): 363~382.

Trifunac M. D., 1995. Pseudo relative velocity spectra of earthquake ground motion at long period. *Soil Dynam. Earthq. Engng*., **14**(6): 331~346.

Wang S., Yu Y. and Lu H., 1998. Study of characteristics of long-period ground motion response spectra by using broad-band records of the Chinese Digital Seismograph Network. *Acta Seismologica Sinica*, **11**(5):557~564).

Wu Z., Chen Y. and Mu Q., 1994. *Outline of Nuclear Explosion Seismology*. Beijing:Seismological Press, 95~98.(in Chinese)

Xie L., Zhou Y., Hu C. *et al*., Characteristics of response spectra of long-period earthquake ground motion. *Earthquake Engineering and Engineering Vibration*, **10**(1): 1~20.(in Chinese)

Yu Y. and Wang S., 1997. The long-period ground motion response spectra of southern Yellow Sea earthquake, November 9, 1996. *Earthquake*, **17**(4): 363~370.

Zhou G., Lai D. and Yao L., 1995. The China Digital Seismograph Network and its second-phase technical upgrade. In:Chen Y. T.(ed), *Observation Techniques of Geosciences and Space Sciences*. Beijing:Seismological Press, 68~73.(in Chinese).

Zhou Y., Zhang W. and Yu H., 1997. Analysis of long-period error for accelerograms recorded by digital seismographs. *Earthquake Engineering and Engineering Vibration*, **17**(2):1~9.(in Chinese)