Article ID: 1000-9116(2004)01-0047-07

The coda attenuation of the Yao'an area in Yunnan Province*

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Abstract

An earthquake with M=6.5 happened on January 15, 2000 in Yao′an of Yunnan Province. After the earthquake, a temporary digital network with 6 detectors around the epicenter area was set up. 402 aftershocks were located more precisely. According to coda short recording observed, the coda averaging quality factor has been acquired via Sato′s single scattering model analyses, $Q_c(f)=49f^{0.95}$, f=1.5~20.0 Hz, which has the attenuation characteristics of high structural active region.

Key words: coda Q_c; Sato model; Yao′an of Yunnan
CLC number: P315.5 **Document code**: A

Introduction

The travelling quality factor Q of seismic wave is one of basic physical parameters for measuring the media attenuation (1/Q) in the earth and reflection of inhomogeneity and inelasticity of the media, which is used in studies of focal physics and engineering earthquake. Q is closely related to the regional tectonic activity and seismicity. This feature has been studying as one of factors of earthquake prediction (Chouet, 1979; Jin and Aki, 1986, 1989). In Yunnan region, QIN (1992) and QIN, *et al* (1995) had studied the features of regional variation of coda Q_c and fluctuations before and after great earthquake by analog recordings. It was discovered that the Q_c was higher in near focal area around the epicenter of the main shock before a great earthquake and became 30% smaller afterwards, however, the variation of Q_c was not obvious in far focal area before and after a great earthquake. The study results of Q_c in Yunnan region indicate that the average Q_c is less than 200 in the seismic active region of west Yunnan and Q_c is greater than 200 in the seismic relatively quiescent region of east Yunnan. Namely, the low Q_c background region is located in region with strong tectonic activity and the high Q_c in the relatively quiescent region.

However, it only can be seen the attenuation of so-called major frequency wave shown in the seismogram from the analog recordings, and it is hard to obtain the relationship between the different frequencies and coda attenuation, so the universality of application is restricted.

In 2000, the temporary digital network established around the Yao′an earthquake epicenter had recorded a lot of aftershocks, which provided a chance to study Q_c. The coda Q_c in the crust was measured by Sato′s (1977) single scattering model in the paper.

* **Received date**: 2002-09-02; **revised date**: 2003-04-09; **accepted date**: 2003-06-17.
Foundation item: The Key Science and Technology Project of Yunnan Province during the 10th 5-year Plan (2001NG46).

1 Studied area

The Yao′an seismic area is located in the mid-south part of central platform depression of the central Yunnan Block, Which is situated in the western end of Yangtze quasi-platform, which is surrounded by the first grade faults such as Xiaojiang, Honghe and Anninghe faults and second grade faults, Jianchuan-Lijiang faults, and moves towards SSE as a whole in the late geological time (KAN, *et al*, 1977). The central platform depression in the central Yunnan is the outcome of activation of platform. The neotectonic movement had generated Quaternary quasi molasse formation (WANG, 2001). The crust is divided into 6 layers with total thickness of 53 km (HU, *et al*, 1986).

Around the central platform depression of the central Yunnan, the historical earthquakes occurred frequently in the Mopanshan-Lüzhijiang, Chuxiong-Jianshui, Yongsheng-Binchuan and Jinhe-Chenghai active faults. Many earthquakes with *M*=6 occurred there. But no earthquake with *M*=6 took place within the platform depression in the past. The last earthquake before the Yao′an *M*=6.5 in 2000 is the one with *M*=5.6 on August 4, 1993 near Renhe, which is 7 km south away from Yao′an.

The western part of mobile network is a mountainous area, and the eastern part is Yao′an basin, with sea level above 1800 m. There is no bigger fault within the network. The original fault throughout the seismic area running in the same direction with the seismic fracture of Yao′an earthquake in 2000 is a near vertical dip-slip fault (WANG, 2001). The Yao′an maishock and aftershocks occurred all in near vertical strike-slip fault (WANG, *et al*, 2002; LI, *et al*, 2000b).

2 Data

After Yao′an *M*=6.5 earthquake on January 15, 2000, the Seismological Bureau of Yunnan Province had established 6 sets of EDAS-3M digital seismometer with sampling frequency of 100 Hz surrounding the epicentral area. The detector is a JC-V100-3D velocity meter with the natural period of 1 s and band width of 1~80 Hz. The flat range of amplitude-frequency characteristics is in 1~20 Hz with dynamic range of 90 dB. GPS receiver is built in the system with timing precision of 1 μs and positioning precision of 20 m. The network location is shown in Figure 1. The Yao′an station is located in the basin and other 5 stations are all in the west mountainous areas. The station foundations in all 5 stations are soil except red sandstone for the Piela station (YE, 2001).

It is shown in Figure 1 that the seismic stations are established around the epicenters. Most of the earthquakes have wide azimuth distribution observations, which is the necessary precondition for precisely location. The aperture of the network is about 22 km and the epicentral distances are within 25 km, roughly corresponding to 1.7 times of deepest focal depth of 14 km, which provides favorable condition to measure focal depth.

Totally, 3 100 aftershocks had been recorded in the half month from 16h40min of January 15 to February 1. 402 aftershocks were recorded at the same time in above 5 stations. Most of the recordings had clear and sharp P and S phases, S-P of direct wave were within 2~3 s, from which more precise positioning can be obtained.

The focal areas are located near the center of platform depression in central Yunnan, close to the Binchuan-Malong line of Dianshen-82 seismic sounding, just 20 km away (HU, *et al*, 1986).

The velocity model of P wave in the crust around Chuxiong has been used, and velocity of S

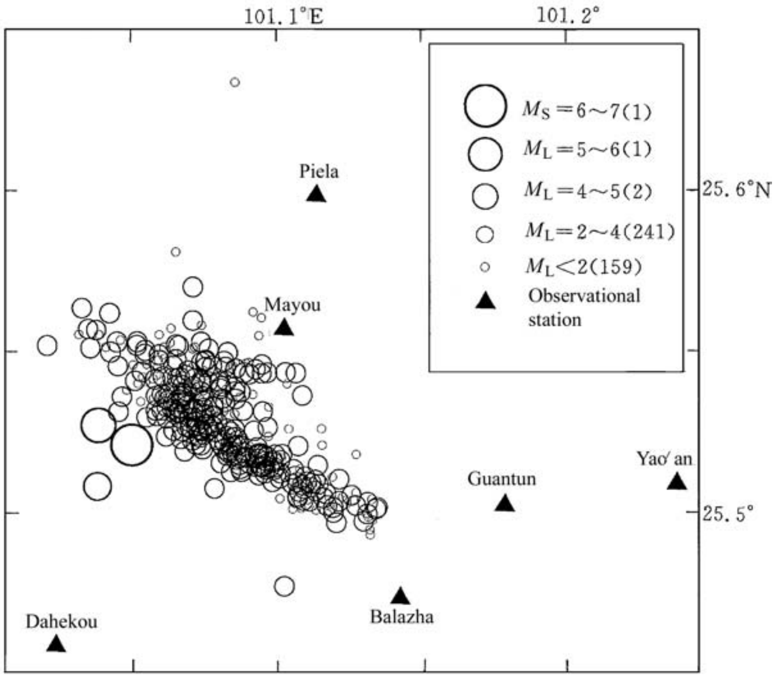

Figure 1 Distribution of epicenters and locations of mobile seismic stations
(M=6.5 mainshock and M=5.9 foreshock are measured by Yunnan Regional Network)

wave is $v_S=v_P/\sqrt{3}$. The positioning results show that the Yao′an earthquake sequence distributes in a fracture belt with length of 17 km, running in NW. The depths of aftershocks are in 2~14 km and P and S waves are both direct ones. Actually, only the parameters in top two layers of the crust model, in which layer 1 is with thickness 1.5 km and v_P=4.30 km/s, layer 2 with 18.5 km and v_P=5.79 km/s, have been used for positioning.

The data used in this paper are selected from the 402 aftershocks. An example of recording waveform is shown in Figure 2 (earthquake 2000012537, M_L=2.6).

3 Method

Two sorts of method are used to measure the Q_S of S wave. One, called coda normalization method (Aki, 1980), frequently used by Aki, is using the attenuation property of S wave amplitude with distances. It requires the united usage of many earthquakes distributing in a certain distance range and multi-azimuth for diminishing the direction effects of seismic radiation pattern. Another uses the property of coda amplitude attenuation with time. With the coda recordings of proper length recorded in a single station, the results can be acquired. The one commonly used is the single scattering model of Aki and Chouet (1975) and Sato (1977). The latter sort can be used to measure Q_S. It is because many observation results indicate that the coda is composed of scattering wave of S wave and the coda Q_c is consistent with the Q_S of S wave (Rautian, Khalturin, 1978; Aki, 1980; Herrmann, 1980).

Most of Yao'an aftershocks are small ones of M=2~3, with short recording length. The Sato′s model (1977) incorporates S wave and coda and is favorable to the short recordings (Steck, *et al*, 1989).

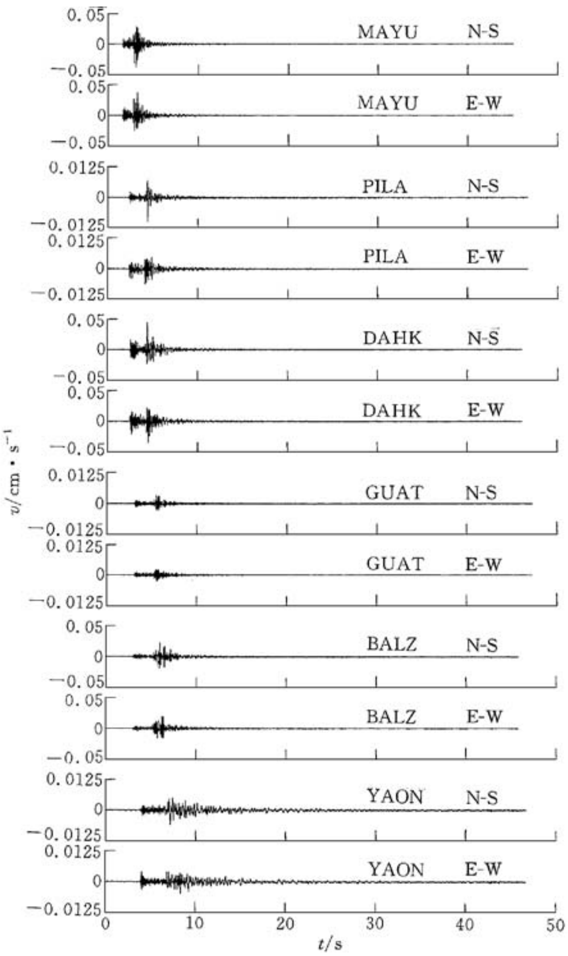

Figure 2 An example of waveform of digital Recordings (horizontal components). Earthquake 2000012517, M_L=2.3. The zero point of time axis corresponds to the moment of earthquake occurrence

According to the variety of Dominguez, *et al* (1997) for Sato′s model the coda amplitude $A_c(t)$ as a function of frequency f and lapse time t can be written as

$$\lg[(A_c(t)/A_S)^2K^{-1}(\alpha)]=C(f)-b(t-t_S) \quad (1)$$

where A_S denotes the largest amplitude of S wave, $A_c(t)$ for the averaging amplitude of coda around the lapse time t and $K(\alpha)$ for the spreading factor depending on the time.

$$K(\alpha)=(1/\alpha)\ln[(\alpha+1)/(\alpha-1)] \quad (2)$$

where $\alpha=t/t_S$, t_S is the lapse time of S wave, $C(f)$ is the source factor of wave of frequency f, can be treated as a constant. $b=\pi f\lg(e)/Q_c$. The least squares method (LSM) is used in equation (1), $Q_c(f)$ can be acquired from b.

4 Data processing and results

7 central frequencies of 1.5, 3.0, 6.0, 9.0, 12.0, 16.0 and 20.0 Hz are taken to calculate $Q_c(f)$. The 8-pole ellipse band-pass filters with width of $f \pm f/3$ were used to filter the two horizontal components for each earthquake recordings in each station. The figure at the left top in Figure 3 is the recording waveforms of original horizontal component, and the lower one is the filtered waveform of each central frequency. On the filtered seismogram, starting from 1s before the direct S wave arrival, a series of data windows with length of 2 s, repeating 1 s for each window, are taken to calculate the root-mean-square amplitude of coda for each window, which corresponds to the lapse time of the window center. The biggest rms amplitude $A_n(f)$ of 2-second window before the P wave arrival for two horizontal components is taken as the correction value of noisy background, so we have

$$A_c(f,t)=\left(\frac{\sum(A_{EW}(f,t)^2+A_{NS}(f,t)^2-A_n(f)^2)}{m}\right)^{1/2} \quad (3)$$

where m is the sampling number within the window. The curves of $\lg[(A_c(t)/A_S)^2K^{-1}(\alpha)\sim t$ for individual central frequencies are shown on the right side in Figure 3. Examining the figure, cut the part with stable decrease and use the LSM to evaluate its slope b, and then $Q_c(f)$ is obtained.

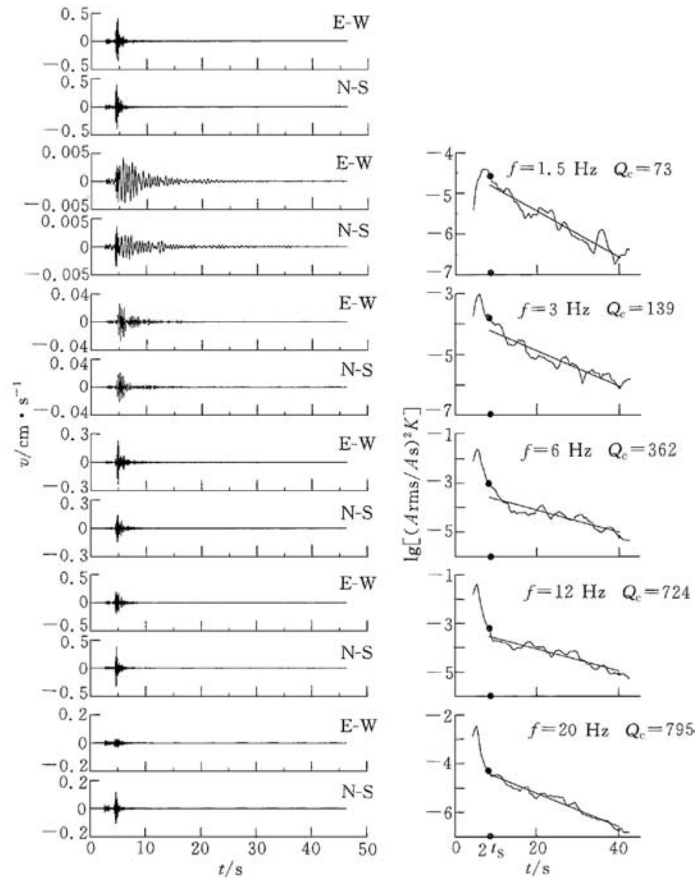

Figure 3 Procedure for getting $Q_c(f)$ from Sato′s model.
Earthquake 200001172336. Station BALZ. The left top two waveforms are the non-filtered ones at horizontal and the lower are the waveforms of each central frequency after filtering. The curve on the right are $[(A_c/A_S)^2/K(\alpha)]\sim t$ corresponding to the left. The direct line is the result by least squares. The data used is the crossing part of the direct line. The zero point on the abscissa corresponds to the occurrence moment of the earthquake

Examining visually the figures of expression (1) is an important step. The look-like normal and stable attenuation wave viewed on seismogram or its filtered waveform could have strong fluctuation in the figure of (1). It indicates that there is disturbance overlapping on it, the recording is not suitable for use. In addition, as an editing controlling criteria, $Q_c(f)$ with standard deviation greater than 15% will be removed from the calculating results.

Though taking the S wave amplitudes of equation (1) may start from the largest for Sato′s model (Steck, *et al*, 1989), in most of our recordings, there is a steep descent for a short time from the largest and then change into gentle and steadily decay from about 2 t_S (t_S is the travel time of S wave), as shown in the right of Figure 3. A few recording can form a direct line from the largest amplitude of S wave continuing to coda.

The $Q_c(f)$ values obtained from 168 recordings of 59 earthquakes are listed in Table 1. $Q_c(f)=49f^{0.95}$ is obtained by fitting $Q_c(f)=Q_0f^h$.

Table 1 Averaging coda $Q_c(f)$ in Yao′an seismic area (Sato′s model)

Frequency/Hz	Q_c	Standard deviation	Sample number
1.5	67	2	137
3.0	108	1	141
6.0	228	9	141
9.0	368	7	140
12.0	468	12	138
16.0	689	11	136
20.0	804	10	136

5 Discussion and conclusions

Using Sato′s (1977) single scattering model to study the coda attenuation of geothermal area in Cerro Prieto of Baja California, Mexico, Dominguez, *et al* (1997) could not obtain Q_c for frequencies less than 6 Hz. It was considered that Q_c with low frequencies could not be obtained by Sato′s model. Wong (2001) had gotten the same conclusion with Dominguez, *et al* (1997) when using the same model and method to study the coda attenuation in Tres Virgenes volcano in Baja California, Mexico.

According to our experiences, the problem of above two examples is possibly less effective due to the filter for low frequencies, instead of Sato′s model (1977) itself. The filters used for above two examples are all 8-pole Butterworth filters. We have once used the 8-pole, even higher Butterworth filter to the digital recordings of Yao′an earthquake. Certainly, the effective filtering results of less than 6 Hz could not be obtained. Later on, 8-pole ellipse filters were used to the same recording, and then good outputs had been acquired. Certainly, the low frequency filtering output could not be gotten from some recordings in our processed data. The reason is probably that the too small earthquakes cannot induce low frequency waves strong enough. Therefore, we believe that the Sato′s model (1977) is suitable to analyze coda attenuation of less than 6 Hz.

Most of the codas used in this paper are within 30 seconds of lapse time. With velocity of 3.3 km/s to calculate, the S wave travelling distance is 100 km and the depth reaches about 50 km. The thickness of crust in Yao'an is 53 km (HU, 1986), therefore, what the Q_c reflects is an averaging attenuation property for the whole crust.

LI, *et al* (2000a) had used the Aki and Chouet′s (1975) single scattering model to study the coda attenuation of Wuding aftershocks occurred in 1995. The results are $Q_c(f)=59f^{0.95}$ for Tianxin station and $Q_c(f)=52f^{0.90}$ for Yunlong station. They are very close to $Q_c(f)=49f^{0.95}$ for Yao'an area in this paper. They belong to the coda property in the active tectonic areas with characteristics of low Q_0 and high h. Actually, both of Wuding and Yao'an are located in the central Yunnan Block, having similar seismicity, inhomogeneous media and scattering. So, reflecting consistent $Q_c(f)$ is the reasonable results. This is also that the central platform depression in central Yunnan is the inevitable results of activation of Yangzi quasi platform.

Acknowledgements The author would like to thank to the reviewers for their suggestion .

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