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Kappa (k) derived from accelerograms recorded in the 2008 Wenchuan mainshock, Sichuan, China

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ABSTRACT

High-frequency spectral decay factor, kappa (k), in the accelerograms of the Wenchuan mainshock was measured using strong motion data from 52 stations within 311 km of the epicenter. The derived k range from 0.0034 s to 0.0468 s. The correlation of k versus fault distance was given, which is $k = 0.01288 + 5.9068 \times 10^{-5} R$ for the N-S component, $k = 0.01881 + 1.4219 \times 10^{-5} R$ for the E-W component, and $k = 0.00855 + 5.6086 \times 10^{-5} R$ for the U-D component. The analysis on the spatial variation of k demonstrates that k relates to source effect and propagation effect besides local site effect. Ground motions for the 52 stations were simulated using derived k and compared to actual recordings in terms of waveforms, amplitude spectra and response spectra. The results show agreement at shorter periods (<1 s), but a slight overestimation at longer periods (1–7 s).

1. Introduction

A general consensus among literatures is that S-wave acceleration spectrum drops off rapidly at frequencies higher than certain threshold (Aki, 1967; Brune, 1970; Hanks, 1982). This spectral decay can be quantified either by a f_{max} operator with the form of $[1 + (f/f_{max})8]^{-1/2}$ (Hanks, 1982) or a kappa operator with the form of $\exp(-\pi fk)$ derived from the slope of the acceleration Fourier spectrum at high frequencies in log-linear space (Anderson and Hough, 1984).

Extensive studies estimate k from earthquake records through regression however the physical origin of k is still unresolved (Atkinson, 1996). While Hanks (1982) attributed it to a propagation path effect related to the competence of the near-surface materials, Papageorgiou and Aki (1983) considered it as a result from source effect related to the size of a minimum cohesive zone. Atkinson (1996) found supports for a site-effect kappa based on data from the Eastern Canada Telemetered Network. Anderson et al. (1996) believe that k_0 (denoted as the intercept of the linear relation of k with distance) is controlled more by propagation effect than local site amplification effect, thus indicating k_0 in southeastern and southwestern Canada could be very different even though the V_{30} (the shear wave velocity averaged over the top 30 m of soil) of the two regions are the same. For the California region, Anderson and Hough (1984) approved an approximate linear dependence of k on epicentral distance. Moreover, they gave a k_0 of 0.04 s for rock sites, 0.065 s for consolidated sediments, and 0.066 s for alluviums. Atkinson and Silva (1997) found a positive correlation between k and magnitude which may relate kappa to the nonlinearity subjected to strong ground motion. Purvance and Anderson (2003) also observed a significant increase of k with magnitude. They considered that the total k value was contributed by both site effect and source effect. Based on 259 three-component records from 22 earthquakes in northern Iran, Motazedian (2006) gave a positive correlation between kappa and epicentral distance for both horizontal and vertical components. He found that k_0 for the vertical component was apparently smaller than that for the horizontal components which is attributed to the less sensitivity of the vertical component to the change of the near-source materials. Parolai et al. (2007), using the records from 523 aftershocks in northwestern Turkey, also found a clear tendency of increasing of kappa with aftershock magnitude, and the slop of the best-fitting line of the increasing is about 0.0071, agreeing with the results obtained by Bindi et al. (2006). Ktenidou et al. (2013) particularly investigated kappa using earthquake data recorded at a vertical array. They found a dependence of vertical-to-horizontal k ratio on site conditions but no correlation of k with magnitude or azimuth.

In this paper, we measured k using strong motion data recorded in the mainshock of the Wenchuan earthquake. We investigated

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Table 1
Geographical location, epicentral distance and site conditions for the 52 selected stations.

Name	Latitude	Longitude	Epicentral distance	Site types
AXT	31.54	104.30	102.0337	SOIL
BXD	30.37	102.82	87.98911	SOIL
BXZ	30.49	102.88	73.30815	ROCK
CDZ	30.55	104.09	80.30125	ROCK
CXQ	31.74	105.93	249.837	SOIL
DXY	30.59	103.52	45.49186	SOIL
DYB	31.29	104.46	109.8652	SOIL
GYS	32.15	105.84	263.5703	SOIL
GYZ	32.62	106.10	311.0613	SOIL
HSD	32.07	102.98	128.0526	SOIL
HSL	32.06	103.26	122.6808	SOIL
HYT	29.91	103.37	122.3145	SOIL
JYC	31.90	104.99	181.7992	SOIL
JYD	31.78	104.74	152.1071	SOIL
JYH	31.78	104.63	144.5151	SOIL
JZB	33.33	104.11	264.1024	SOIL
JZG	33.12	104.32	248.438	SOIL
JZW	33.03	104.21	234.8366	ALLUVIUM
JZY	33.24	104.25	258.9022	SOIL
JZZ	33.3	103.8	258.5059	SOIL
LDD	29.6	102.2	193.6663	SOIL
LDJ	29.7	102.2	184.8099	SOIL
LDL	29.8	102.2	176.2104	SOIL
LDS	29.91	102.24	167.907	SOIL
LSF	30.07	102.92	110.9394	SOIL
LSH	30.08	102.91	110.9394	SOIL
LSJ	30.16	102.93	101.0112	SOIL
LXM	31.57	103.34	67.39011	SOIL
LXS	31.53	102.91	73.14553	SOIL
LXT	31.56	103.45	67.39011	SOIL
MED	31.90	102.22	151.5681	SOIL
MEZ	31.87	102.29	144.5791	SOIL
MXD	32.04	103.68	114.7749	SOIL
MXN	31.58	103.73	72.55054	SOIL
MXT	31.68	103.85	91.17525	ROCK
MZQ	31.52	104.09	86.71246	SOIL
PJD	30.25	103.41	77.83654	SOIL
PJW	30.29	103.63	80.15332	SOIL
PWM	32.62	104.52	206.0559	SOIL
PXZ	30.91	103.76	39.73285	ROCK
QLY	30.42	103.26	67.3986	SOIL
SFB	31.28	103.99	66.12778	SOIL
SPA	32.51	103.64	167.861	SOIL
SPC	32.78	103.62	201.0393	SOIL
SPT	32.64	103.60	178.9129	ROCK
WCW	31.04	103.18	19.06297	ALLUVIUM
XJB	30.99	102.37	76.25042	SOIL
XJD	30.97	102.64	95.31267	SOIL
XJL	30.38	103.8	76.90131	ROCK
YAD	29.99	102.98	117.6138	SOIL
YAL	29.9	102.9	131.3698	SOIL
YAS	29.9	103	128.1836	SOIL

the dependence of k versus distance and the relation of k to source effect, propagation effect and local site effect. We then simulate ground motions at 52 stations using stochastic finite-fault modeling approach to test the effect of using derived k. We did not use data from aftershocks because our aim and scope in this exercise is to reveal the kappa behavior in the great Wenchuan mainshock, rather than to provide regional attenuation parameter.

2. Data

A total of 420 three-component acceleration records were collected by China Strong Motion Net Center (CSMNC) after the Wenchuan mainshock. More than 50 stations along the Longmenshan mountain fault zone recorded peak acceleration over 100 gals (Yu et al., 2009). We used 152 accelerograms, including horizontal and vertical components, recorded at 52 stations within 311 km of the epicenter (Table 1 and Fig. 1). Before k measurement, each accelerogram is tapered using a 5% cosine taper on the end of the time series and zero-padded to the next greatest power of 2. The accelerogram is then truncated from the S-wave arrive time picked by visual inspection to the time where 80% of the energy (integral of squared acceleration) is accumulated. After truncation the accelerogram is filtered by a Butterworth low-cut filter with corner frequency of 0.02 Hz to remove noises (Purvance and Anderson, 2003). Using FFT technique the Fourier spectrum of the filtered accelerogram is obtained, from which the frequency range of the amplitude decay is assessed from visual inspection. The frequencies where the amplitude decay begins and ends are denoted as f_e and f_x respectively. A robust straight-line fit with minimum absolute deviation (Press et al., 1992) is applied to the spectral amplitude over the frequency range ($f_e \sim f_x$), and the k value is then measured by dividing the slope of the best-fitting line by π.