The Coda Site Amplification Factors at Frequencies 1.5, 3.0, 6.0 and 12.0 Hz for Central California

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Method

Since the pioneering work of Aki (1969), the fundamental separability of source, site and path effects in the coda wave power spectrum has been confirmed by many researchers (Aki and Chouet, 1975; Phillips and Aki, 1986, Su et al., 1990; Mayeda et al., 1991). We use the same formula to isolate the site effect by considering the coda power spectrum $p(\omega/t) = Source(\omega)* Site(\omega)* path(\omega/t)$, here ω is the circular frequency and t is the lapse time measured from the origin time of an event. Under the assumption that the coda energy is the sum of back-scattered wave energy from heterogeneities in all directions we derived a matrix form from above expression:

$$\mathbf{Gv} + \mathbf{n} = \mathbf{d}$$

where **d** is the data vector which can be obtained from the observed coda power spectrum and **v** is the model vector which contains the relative site amplification factors to be determined and **n** is a noise vector. **G** is a real matrix. In practice, this matrix could be huge and very sparse. By applying the recursive stochastic inversion method (Zeng et al., 1991) we are able to solve our problem efficiently.

Data

A total of 185 earthquakes located in the central California area recorded by 134 short-period seismic stations of USGS at Menlo Park from 1984 to 1990 were collected for this study. The magnitude of these earthquakes ranged from 1.8 to 3.5 and their depths ranged from 0 to 20 km. These 134 seismic stations are located on a wide variety of geologic settings ranging from alluvium to Mesozoic rocks. All the seismograms used were recorded by USGS standard vertical instruments with the natural frequency of 1 Hz. All seismograms were corrected for instrument response by the use of the calibration information provided by Eaton (1980). Since instrument gain settings changed frequently over the time period spanning our collected events, special care was taken to ensure the proper gain corrections by using station history files. Since the calibration curve is non-linear above 16 Hz, our octave bands are limited to center frequencies from 1.5 to 12 Hz.

Results

(1) The coda site amplification in central California.

The final inversion results of relative site amplification factors are listed in Table 1. The typical standard errors, in natural log, are about 0.065, 0.056, 0.051 and 0.050 for frequencies 1.5, 3.0, 6.0 and 12.0 Hz separately.

In general, from Table 1, we found that the site amplification factor of a station is mainly controlled by its underlying surface geology. The site amplification is high for young, Quaternary sediments and decreased with increasing geologic age at all frequencies between 1.5 and 12.0 Hz. The rate of decrease varies with frequency. Site amplification factors decrease faster at low frequencies than that at higher frequencies.

(2) The relation of coda site amplification factors with surface geology.

To quantify the relation between site amplification factor and site geology condition, the surface geology of station sites was classified into five groups: (a) Quaternary sediment, (b) Tertiary Pliocene sediments, (c) Tertiary Miocene through Cretaceous sediments, (d) Franciscan formation and Mesozoic granitic rocks, (e) pre-Cretaceous metamorphic rocks. The station site amplification factors in each group were logarithmically averaged and the mean value was assigned to the median geologic age of that group. Figure 1 shows the mean values versus their median geologic age. The standard error as well as standard error of the mean are also shown. A smooth power law relation is observed between mean site amplification and the median geologic age. This relation provides a simple way to estimate site effect at a specific site with known surficial geology.

(3) The correlation between coda site amplification factors and earthquake ground motion.

A remarkable linear correlation was found between logarithmic amplification factor and the magnitude site residual for the USGS seismic network at Menlo Park determined by Eaton (1991), as shown in Fig. 2, where XMGK is amplitude magnitude residual and FMGK is duration magnitude residual. This results suggests that our method provides an effective means of weak motion site amplification estimation.

Comparison of our site amplification factors with strong motion results obtained from the Loma Prieta earthquake (Shakal et al., 1989; Chin and Aki, 1991) suggest that weak and strong motion site amplification correlate well in the region outside the epicentral source region beyond epicentral distance of about 50 km. Within this region, however, the weak motion amplification factor estimated from coda wave do not agree with observed site effect on strong ground motion suggesting a non-linear site effect within epicentral source region at sediment sites for strong motion.

References

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Table 1

Station	Location	Site Amplification Ln(A/A) 1.5 Hz	3 Hz	6 Hz	12 Hz	Geologic Symbol
JPRV	37 47.70 122 28.43	-0.05	0.18	0.44	0.50	Qs
PPTV	36 6.50 120 43.27	0.52	0.98	1.01	0.55	Qal,Pml
BHRV	36 43.67 121 15.83	1.18	0.57	0.46	0.65	Qf
CDUV	38 1.78 122 0.05	1.95	2.04	1.77	1.51	Q
PSAV	36 1.52 120 53.30	1.75	1.36	0.97	1.31	Qt,Pml
HCOV	36 53.31 121 42.34	1.32	1.07	0.76	0.70	Qc
JPLV	36 58.62 121 49.93	1.59	1.35	1.04	0.83	Qc
HPHV	36 51.38 121 24.37	1.98	1.78	1.56	1.37	Qp
JLTV	37 21.22 122 12.25	0.45	0.91	1.15	0.80	Qp
MYLV	37 23.02 120 25.16	0.17	0.31	0.62	0.50	Qp,Pmlc
BEHV	36 39.88 121 10.45	0.82	0.55	0.47	0.34	Qp
HFHV	36 53.29 121 28.13	1.70	0.95	0.76	0.71	Qp
JSGV	37 16.96 122 3.00	0.45	0.24	0.28	0.18	Qp
JSJV	37 20.03 122 5.48	0.65	0.60	0.57	0.73	Qp
NHMV	38 9.28 121 48.02	1.01	0.68	0.11	0.32	Qpc
HKRV	36 54.10 121 25.56	1.77	1.02	1.11	0.94	Qp
BSLV	36 46.53 121 20.96	1.69	1.24	0.99	0.87	Pc
HORV	36 55.03 121 30.46	1.64	0.89	0.53	0.66	pc
NOLV	38 2.50 122 47.64	0.65	0.79	0.80	0.71	P
NCFV	38 19.28 122 47.73	0.05	0.26	0.69	0.96	P
CMCV	37 46.88 122 10.55	0.10	-0.37	0.00	0.51	Pvr
CDOV	37 43.80 121 50.12	0.77	0.76	0.44	0.38	Pmlc
CRAV	37 46.03 121 56.25	0.64	0.35	-0.03	-0.33	Pmlc
BBNV	36 30.60 121 4.53	0.34	0.21	0.14	-0.08	Pmlc
JTGV	37 1.71 121 52.58	0.91	0.75	0.58	0.95	Pml
JBZV	37 1.07 121 49.15	0.99	0.98	1.45	1.25	Pml
JPSV	37 11.94 122 20.90	0.45	0.40	0.19	-0.13	Pml
JRGV	37 2.22 121 57.87	0.57	1.03	0.94	1.04	Pml
HPRV	36 57.19 121 41.70	1.00	0.53	0.49	0.41	Pml
PBWV	36 18.90 120 55.75	0.41	0.25	0.38	0.80	Pml
PLOV	36 14.79 121 2.55	0.56	1.22	1.01	0.85	Pml
JBGV	37 20.52 122 20.34	0.94	0.63	0.53	0.41	Pml
CBRV	37 48.97 122 3.72	-0.09	-0.66	-0.78	-0.80	Mu
CBWV	37 55.45 122 6.40	0.35	-0.15	-0.36	-0.13	Mu
CMJV	37 31.25 121 52.23	-0.54	-0.56	-0.28	-0.75	Mu
CACV	37 58.57 121 45.62	0.94	0.43	0.10	0.90	Mu
HQRV	36 50.02 121 12.76	-0.45	-0.38	-0.52	-0.90	Mv
HSFV	36 48.72 121 29.97	0.78	0.70	0.32	0.03	Mv
JSMV	37 12.74 122 10.06	0.47	0.26	0.42	-0.02	Mvb
BPIV	36 29.40 121 10.11	-0.79	-0.60	-0.44	-0.47	Mvr
BRVV	36 25.49 121 1.10	0.32	0.23	0.03	0.42	Mmc
HCBV	36 55.88 121 39.63	0.42	0.42	0.35	-0.18	Mm,Pml
CSPV	37 57.45 122 18.65	0.09	-0.07	-0.04	-0.44	Mm,Pml,Qal
PANV	35 46.78 120 54.44	0.99	0.65	0.40	0.69	Mm
BVLV	36 34.51 121 11.34	0.23	0.15	-0.20	-0.35	Mm
PJLV	36 5.39 121 9.33	0.10	0.17	0.09	0.07	Mm
CMHV	37 21.57 121 45.38	-0.28	-0.26	-0.38	-0.35	Mm,Mu
JECV	37 3.04 121 48.56	-0.11	0.11	-0.04	-0.46	Mm,Pml
JSFV	37 24.31 122 10.55	0.65	0.37	0.02	0.11	Mm
JSCV	37 17.07 122 7.42	-0.53	-0.21	-0.06	-0.21	Ml,Kjf
JPPV	37 15.81 122 12.78	0.29	0.34	-0.01	0.15	Ml,E
HBTV	36 51.01 121 33.04	-0.05	-0.22	-0.58	-0.32	ol,gr,Qt
JBCV	37 9.62 122 1.57	0.40	0.44	0.38	0.07	E
JHPV	37 26.65 122 18.09	0.25	0.43	0.12	0.08	E
NGVV	38 16.84 122 12.89	-0.09	-0.14	-0.15	-0.26	Tv
NTYV	38 23.37 122 39.70	0.86	0.15	-0.09	-0.35	Tv
NSPV	38 10.96 122 27.20	-0.02	-0.10	-0.05	-0.26	Tv
CPLV	37 38.25 121 57.64	-0.44	-0.63	-0.55	-0.40	K
HCAV	37 1.52 121 29.02	-0.07	-0.34	-0.48	-0.42	K
HSPV	37 6.91 121 30.94	-0.10	0.08	-0.20	-0.46	K
CMOV	37 48.68 121 48.15	0.33	0.15	0.08	-0.22	K
BMSV	36 39.78 120 47.51	-0.26	0.29	0.15	-0.36	Ku
NAPV	38 26.34 122 14.99	0.75	-0.16	-0.52	-0.50	Ku,Tv,Um
BBGV	36 34.70 121 2.31	0.88	0.82	0.59	0.19	Ku
CMPV	37 21.46 121 18.51	-0.69	-0.61	-0.74	-0.75	Ku
HCPV	37 11.67 121 11.08	-0.47	0.27	0.50	-0.09	Ku
NLHV	38 7.19 122 8.87	0.21	0.46	0.39	-0.13	Ku
HSLV	37 1.16 121 5.13	-0.08	0.49	0.39	0.09	Ku
HFEV	36 59.00 121 24.09	-0.02	-0.25	-0.33	-0.42	Ku
CLCV	37 44.28 122 3.83	0.25	0.47	0.36	0.30	Ku
HJSV	36 48.99 121 17.92	0.07	-0.32	-0.50	-0.45	Ku
CBSV	37 49.06 121 38.43	0.44	0.87	0.77	0.59	Ku
HLTV	36 53.07 121 18.49	-0.34	-0.62	-0.71	-1.02	Ku
JHLV	37 6.54 121 49.99	-0.87	-0.82	-0.40	0.05	Ku
BRMV	36 50.70 120 49.40	0.01	0.56	0.72	0.25	Ku
JALV	37 9.50 121 50.82	-0.83	-0.53	-0.05	-0.05	Kjf (Franciscan)
CMRV	37 35.68 121 38.22	-0.60	-0.73	-0.79	-0.81	Kjf
HGSV	37 5.75 121 26.83	-0.78	-0.78	-0.79	-0.85	Kjf
JSSV	37 10.17 121 55.84	-0.64	-0.41	-0.61	-0.47	Kjf
JBMV	37 19.09 122 9.16	-0.52	-0.52	-0.51	-0.47	Kjf
HGWV	37 1.02 121 39.20	-0.76	-0.78	-0.82	-0.91	Kjf
COSV	37 30.51 121 22.44	-0.87	-0.69	-0.66	-0.55	Kjf
CAOV	37 20.96 121 31.96	-0.74	-0.63	-0.76	-0.96	Kjf
ADWV	38 26.35 120 50.89	-0.69	-0.38	-0.14	-0.69	Kjf
CSCV	37 17.11 121 46.35	0.34	0.18	-0.02	-0.14	Kjf
JLXV	37 12.11 121 59.17	-0.63	-0.39	-0.15	-0.02	Kjf
NLNV	38 9.15 122 42.75	-0.48	-0.20	0.05	0.39	Kjf
BPFV	36 13.82 121 46.32	-0.51	-0.20	-0.12	0.04	Kjf
NTAV	37 55.43 122 35.70	-0.63	-0.70	-0.61	0.10	Kjf
HPLV	37 3.13 121 17.40	-0.60	-0.46	-0.32	-0.59	Kjf
BEMV	36 39.68 121 5.76	-0.56	0.31	-0.13	-0.27	Kjf
PAPV	35 54.77 121 21.70	-1.05	-0.55	-0.41	-0.53	Kjf
CMLV	37 28.64 121 39.09	-0.90	-0.90	-0.81	-0.26	Kjf
PHRV	36 22.38 120 49.10	-0.05	-0.29	-0.51	-0.54	Kjf
CMMV	37 27.34 121 29.62	-0.75	-0.87	-1.07	-0.92	Kjf
JRRV	37 3.27 121 43.61	-0.97	-0.86	-0.17	0.03	Kjf
BAVV	36 38.75 121 1.79	-0.67	-0.86	-0.88	-1.19	Kjf
CALV	37 27.07 121 47.95	-0.71	-0.65	-0.61	-0.77	Kjf
CAIV	37 51.68 122 25.77	-0.67	-0.52	0.17	0.12	Kjfv
JMGV	37 38.22 122 28.43	-0.46	-0.42	-0.28	0.44	Kjfv
CCYV	37 33.10 122 5.45	-0.98	-1.04	-0.76	-0.27	Kjfv
HCRV	36 57.46 121 35.01	-0.65	-0.92	-0.70	-0.22	Kjfv
JSAV	37 34.95 122 25.03	-0.30	-0.23	-0.06	0.26	Kjfv
JEGV	37 30.84 122 27.74	-0.52	-0.21	0.10	0.37	gr
MHDV	37 7.36 119 53.60	-0.20	0.06	0.42	0.29	gr
BPCV	36 34.32 121 37.56	0.30	0.16	0.16	0.19	gr
BVYV	36 44.96 121 24.80	-0.66	-0.80	-0.73	-0.44	gr
HMOV	36 36.03 121 55.06	-0.86	-0.89	-0.62	-0.07	gr
HAZV	36 53.08 121 35.45	-0.26	-0.71	-1.05	-0.87	gr
BAPV	36 10.55 121 38.56	-0.79	-0.08	0.36	0.12	gr,m
BJCV	36 32.82 121 23.53	-1.56	-1.43	-1.15	-0.69	gr
BPPV	36 10.12 121 22.68	-1.22	-0.61	-0.49	-0.76	gr
BPRV	36 24.42 121 43.77	-0.72	-0.38	-0.44	-0.25	gr,m
BJOV	36 36.65 121 18.81	-0.96	-0.73	0.44	0.62	gr
HDLV	36 50.12 121 38.64	-0.68	-0.55	-0.24	-0.20	gr
BSCV	36 38.50 121 15.59	-0.11	-0.35	-0.63	-0.60	gr
BSGV	36 24.83 121 15.22	-1.05	-0.80	-0.18	0.63	gr
JBLV	37 7.69 122 10.08	-0.88	-0.89	-0.72	-0.36	gr
BCGV	36 42.55 121 20.60	0.07	-0.06	0.13	0.07	gr
HJGV	36 47.88 121 34.43	-0.52	-0.74	-0.66	-0.42	gr
BSRV	36 39.99 121 31.12	-0.92	-0.58	0.20	0.63	gr
CRPV	37 54.75 121 54.33	0.20	0.79	0.41	0.07	ub,ku,gr
CADV	37 9.83 121 37.55	-0.21	-0.79	-0.35	0.03	ub
JCBV	37 6.71 121 41.33	-0.49	0.17	0.05	-0.28	ub
JSTV	37 12.41 121 47.84	-0.26	-0.40	-0.38	-0.13	ub,Kjf
CSHV	37 38.88 122 2.57	-0.54	-0.54	-0.44	0.30	ub,Jk
CCOV	37 15.46 121 40.35	-0.08	-0.25	-0.58	-0.72	Jk
BHSV	36 21.35 121 32.41	-0.68	0.28	0.66	0.58	m,Mm,gr
BCWV	36 18.40 121 33.96	-1.01	-0.66	-0.11	-0.31	m
BSMV	36 23.03 121 25.63	-0.68	-0.24	-0.06	-0.31	m
JUCV	37 0.07 122 2.91	-0.43	-0.53	-0.32	-0.05	ms
HFPV	36 45.22 121 29.43	-1.14	-1.22	-1.24	-1.14	lS

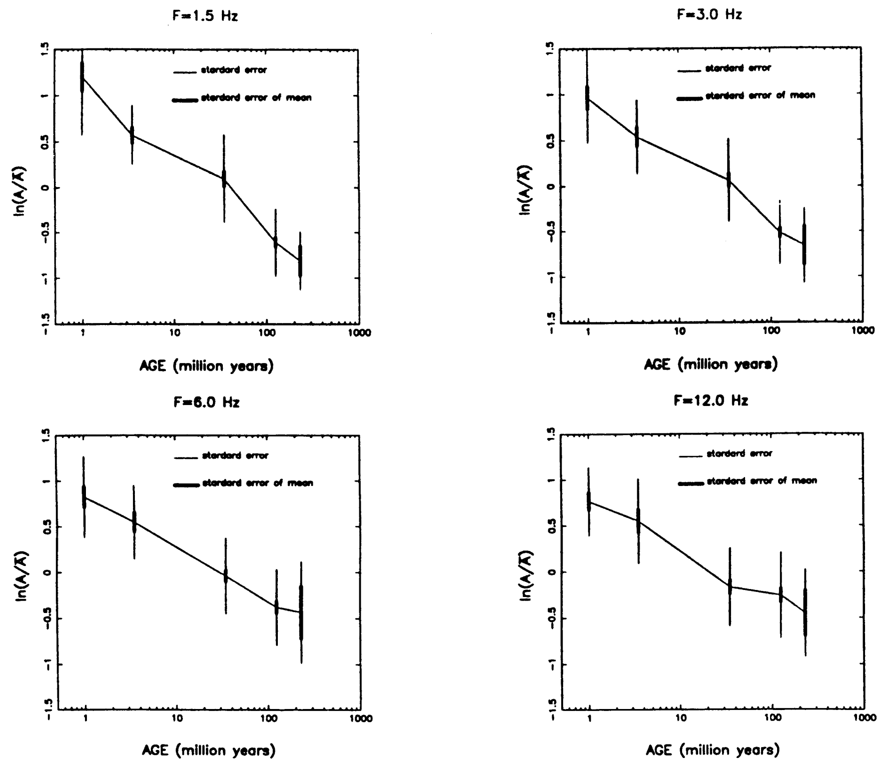

Figure 1

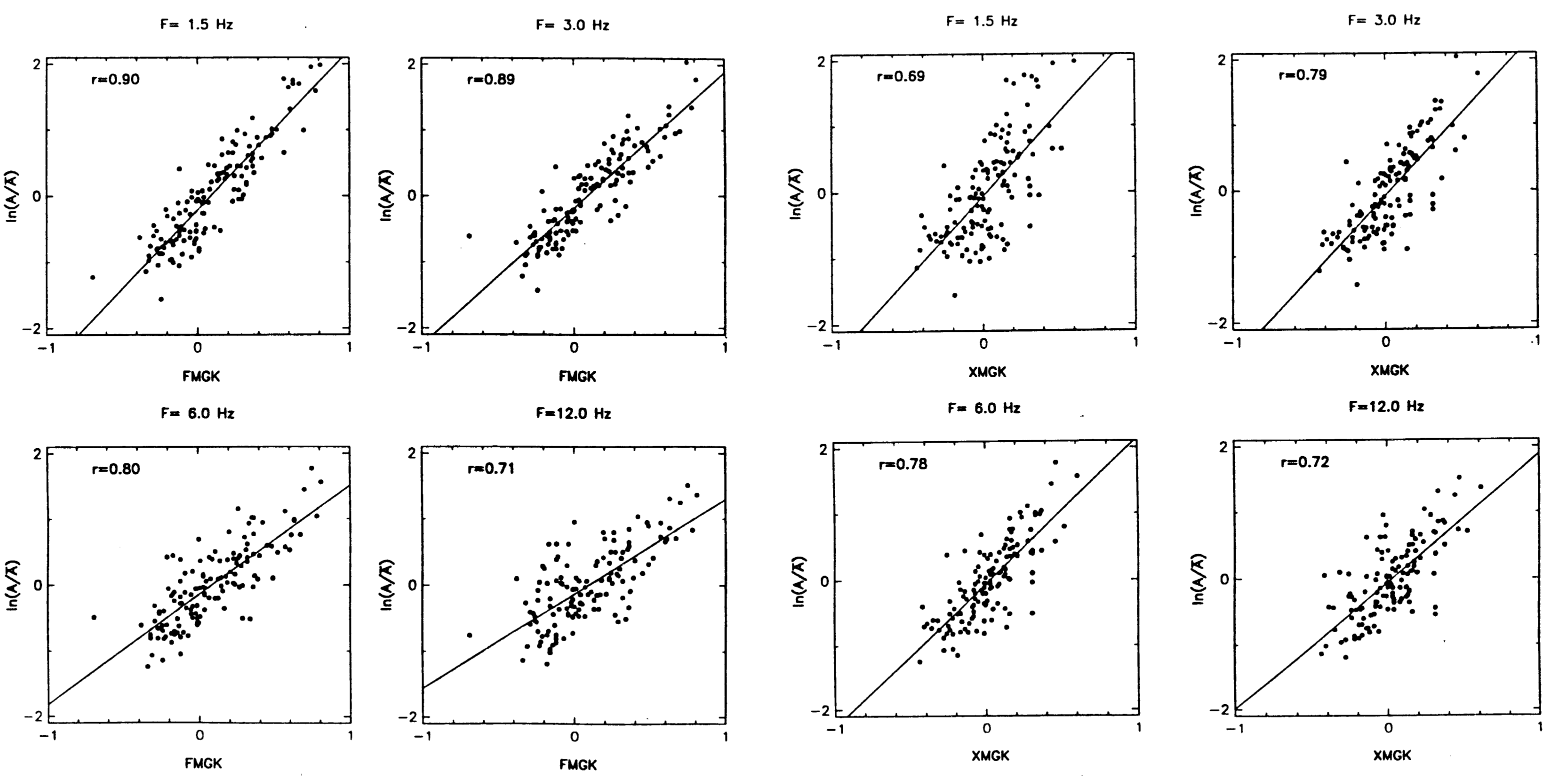

Figure 2