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Site Amplification Factors in Koyna Region using Coda Waves

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ABSTRACT
The site amplification factors have been obtained at two sites of Koyna region using the reference site method. The coda waves of 37 local earthquakes have been used for this purpose. The site Warna (WRN) has been taken as reference site on the basis of local geology for the estimation of site amplification factors at Chikali (CKL) and Katwali (KTL). The coda decay curve has been prepared for the three sites in order to validate the spectral ratio method used here. The single back scattering model has been used to obtain the coda decay curve of the region. The coda decay curves have been found to be similar for all source-station pairs in Koyna region except at very low frequencies. The estimated site amplification values show the non-linear variation with frequency at all the sites considered. The amplification factors vary from 1.4 to 3.3 at CKL and 1.6 to 3.1 at KTL. The amplification factors at both the station increase with increase in frequency in the wide range 5 – 13 Hz. The station CKL shows the higher amplification factors as compared to KTL in this frequency range. This reflects the difference in the station site geology as the amplification factors decrease with in increase in geological age. The results presented here are the first order of estimation in this region.

INTRODUCTION

The earthquake ground motions are affected by source, path and site effects characterization. It has now been recognized that the local site effects can cause considerable modification of seismic amplitudes. The effect of sites on earthquake ground motions has been observed during 1989 Loma Prieta earthquake (Singh et al., 1988; Hough et al., 1990). Different site characteristics behave differently for the ground motion, some amplify the motion too much and some do not. In general younger and soft sites amplify the ground motion more when compared to older and compacted sites. Every site has its own natural frequency, which depends upon the thickness of soil cover and geological structures present near the site. The site effect is one of the important information for the Microzonation studies of the regions. The information about local site effects is also necessary for the simulation of realistic strong ground motions at the sites of interest. Therefore, the results of the site response studies are one of the most important inputs for seismic hazard assessment of a region.

It is necessary to remove the effect of source and path from the seismograms to estimate the site amplifications. A number of techniques have been developed to estimate the response of a site. These include empirical as well as theoretical approaches with their own advantages and limitations. The advantage of theoretical approach is that it can give the response corresponding to a large number of possible input ground motions. The limitation is that it requires the detailed knowledge of geotechnical parameters. The empirical techniques can be separated into two categories: reference site and non-reference site techniques. In the reference site method, the spectrum of the site of interest is divided by that of a nearby reference site situated on hard rock. The concept in this technique is that the two sites have similar source and path effects and the reference site has the flat spectrum response. Therefore, the spectral ratio gives the estimate of site characteristics. This concept has been introduced by Borcherdt (1970) and has been widely used in different regions of the world (Jarpe et al., 1988; Margheriti, Wennerberg & Boat Wright 1994). In some studies, this approach has been applied using ambient noise instead of earthquakes (Ohta et al., 1978). In the non-reference site approach, the spectrum of the horizontal component is divided by that of vertical component recorded at the same site. This technique, based on microtremors, has been introduced by Nakamura (1989) and became popular because of its low cost and simple field operations. The numerical experiments demonstrated that the Nakamura (1989) technique predicts only the fundamental resonant frequency (Field & Jacob 1993; Dravinski, Ding & Wen 1996).

The empirical techniques have been developed to estimate the site amplifications using body wave as well as coda waves (Borcherdt, 1970; Tsujiura, 1978; Mayeda, Koyanagi & Aki 1991; Su et al., 1992; Satoh, Kawase & Matsushima 2001). The well established separability of source, path and site effects on coda waves of local seismic events provides the most effective way of estimating the site amplification effect (Su & Aki 1995). The coda waves have been considered to be composed of back scattered S waves by complex heterogeneity of the earth's crust (Aki & Chouet 1975). Therefore, it is expected that coda waves gives stable estimations of site response due to naturally averaging process of scattering. It has been found that spectral ratios between two rock sites obtained from coda waves agree with those estimated from S wave (Tsujiura 1978). A number of studies have been done to estimate site response using coda waves in different regions of the world (Tsujiura 1978; Chin & Aki 1991; Su et al., 1992; Hartzell 1992; Phillips, Kinosita & Fujiwara 1993; Frankel 1994).

A few studies have been done on site amplifications of Indian regions. Nath et al. (2000, 2003) have estimated the site response of sites in Sikkim Himalaya and Delhi region using strong motion and weak motion data respectively. The site amplification functions have been reported for different sectors of Himalaya using the strong motion data of 1986 Dharmsala, 1991 Uttarkashi, and 1999 Chamoli Dharmsala earthquakes (Sriram & Khattri 1997; Sriram, Dinesh Kumar & Khattri 2005; Dinesh Kumar, Sriram & Khattri 2006).

The objective of this study is to estimate the site amplification factors in Koyna region. The coda waves recorded by vertical components of 37 local earthquakes have been used for this purpose. The reference site method has been used in the present analysis. The coda decay curve has been prepared for the region using back scattering model. The site amplification factors have been estimated at frequencies of 1.5, 3, 6, 12 and 18 Hz.

GEOLOGY AND SEISMOTECTONICS OF REGION

The Koyna region is a seismically active region of Indian peninsula. The peninsular Indian shield had witnessed the 1967 Koyna, 1993 Killari-Latur and 1997 Jabalpur earthquakes. The Himalayan earthquakes are associated with the collision of Indian plate with the Eurasian plate. The earthquakes of peninsular India are preliminary intraplate activities caused by crustal faults and epirogenic vertical moment of crustal blocks. The region is consists of metasedimentary gneisses, schist and granite of Dhawarian and Cuddapah age (Krishnan 1960).

Seismotectonics and geology of the Koyna region have been studied by many researchers (Rastogi et al., 1992; Rastogi et al., 1997; Rawat 1982). The two lineaments, NW and NE are present in the area. A major lineament is in NW direction coinciding with the Warna River in its southeastern part and which is currently active. A deep NNW trending fault is present in west direction of the Koyna reservoir (Kaila et al., 1981a, b). This fault has probably an eight-meter throw on the western side, which has been observed along the Warna river course for a few meters length in the excavation done for the Warna dam (Rawat 1982). The areas of intersection of NW trend with NE appear to be more seismically active and relocated depths are within 12 km of this region (Rastogi & Talwani 1980). Thirty kilometer long NS seismic zone extending southward from the Koyna Dam has been active all the time from 1967 onwards (Rastogi et al., 1997). Talwani (1997) relocated seismicity between 1963-1995 for Koyna region and concluded that the area lying between Koyna and Warna rivers can be divided into several seismogenic crustal blocks. The fault plane solutions of Koyna earthquakes have been

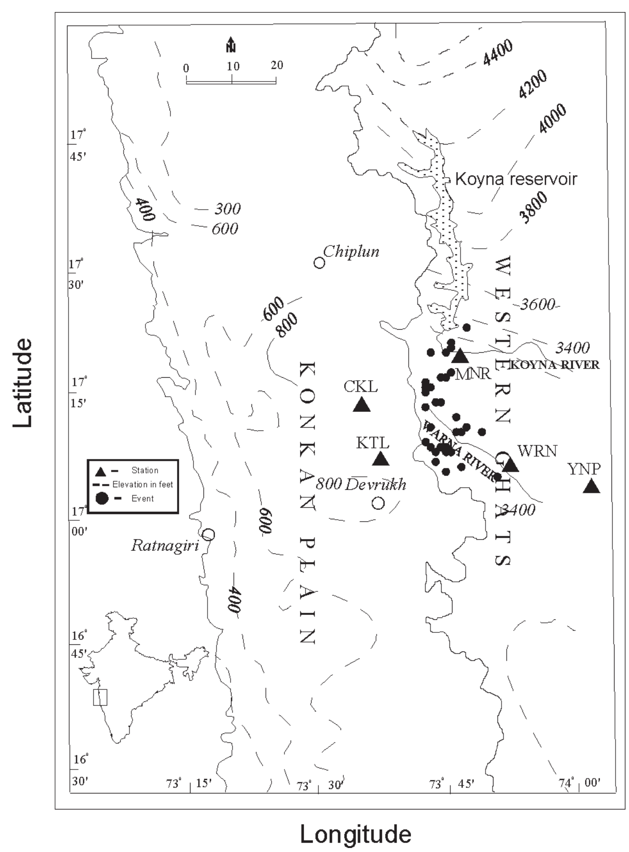

Figure 1. Map showing the Koyna region and seismological network deployed by N.G.R.I., Hyderabad in the Koyna region.

summarized by Chandra(1976). These fault plane solutions indicate a left lateral motion along the northeastern striking plane. The stress pattern of Indian peninsula is affected by continental collision of northward movement of Indian plate (Chandra 1977). The great resistance encountered by the northward drifting plate is also manifested in eastward tilting of many parts of peninsular India cut by transcurrent faults. Figure 1 shows the geological features of Koyna region and seismological network deployed by National Geophysicsl Research Institute (NGRI), Hyderabad in the region alongwith the events used in the present study.

DATA

The present analysis is based on thirty-seven local earthquakes recorded during the year 1996 in the Koyna region (Fig.1). All events were recorded digitally on 4 to 7 stations, using short period three component seismometers at the sampling rate of 50 samples/sec, employing Ref-Tek recording instruments. The events recorded on at least five stations have been used for present analysis. The parameters i.e. names, codes and locations of five stations are given in Table 1. The hypocentral parameters, namely origin time, longitude, latitude and focal depth of the events, have been listed in Table 2. All events are of local origin and are recorded in epicentral distance range of 11 to 55 km with shallow focal depths from 0.50 to 8.80 km.

METHODOLOGY

(a) Site amplification factor

The spectral ratio of coda amplitudes have been used to isolate the site response from the coda waves (Mayeda, Koyanagi & Aki 1991, Koyanagi, Mayeda & Aki.1992 and Kato, Aki & Takemuna 1995). The time and frequency dependent amplitude of coda waves can be written as (Aki & Chouet 1975):

$$Aij(f,t) = Si(f)Gj(f)C(f,t) \quad (1)$$

where Aij(f,t) indicates the fourier amplitude of a coda wave for the ith event at the jth station for a lapse time t greater than about twice the S-wave travel time, Si(f) is the source term of the ith event, Gj(f) is the site term of the jth station and C(f,t) is the path term independent of source and station. In order to determine the relative site amplification between two stations j and k(in which k is the reference station), the spectral ratio of Aij(f,t) to Aik(f,t) is taken at the same t from the same event:

$$Aij(f,t)/Aik(f,t) = Si(f)Gj(f)C(f,t)/Si(f)Gk(f)C(f,t) \quad (2)$$

We get the following simple equation:

$$Aij(f,t)/Aik(f,t) = Gj(f)/Gk(f) \quad (3)$$

The assumption in the above equation is that the coda decay curve C(f,t) is same for all source-station pairs. Equation (3) gives the relative site amplification at a station i, with respect to the station k.

(b) Common Coda Decay:

The above method is applicable if there is common coda decay curve. In order to estimate the coda decay curve, the coda-Q has been estimated using back scattering model. The existence of common coda decay has been reported for many regions for t greater than about twice the S-wave travel time(Rautian & Khalturin 1978). It is assumed that the coda waves of local earthquakes are composed of single backscattered body waves. So A(f,t) can be expressed as (Aki and Chouet, 1975):

$$A(f,t) = A_0(f)t^{-1}\exp(-pft/Qc) \quad (4)$$

where $A_0(f)$ is coda source factor that is considered a constant, Qc is the quality factor of the coda waves. Taking natural log of equation (4) we get

$$\ln[A(f,t)t] = C - pft/Qc \; ; \; C = \ln[A_0(f)] \quad (5)$$

The Qc can be estimated from the slope of above equation.

RESULTS AND DISCUSSION

The 37 local events recorded at WRN, CKL and KTL have been used in the present analysis. The nature of rocks below these sites is given in Table 1. We consider the site WRN on the basalt rock as the reference site to estimate the relative site amplifications for the sites CKL and KTL lying on laterite. The vertical components of the seismograms recorded at these sites have been used. According to scattering theory, the coda energy is partitioned equally among three components. The site amplification studies based on vertical components have been done for some regions of the world (Mayeda, Koyanagi & Aki 1991; Su et al., 1992).

First Q_c has been estimated at different stations using equation (5). The seismograms have been band passed using butterworth filter at five different central frequencies i.e. 1.5 (1-2Hz), 3 (2-4 Hz), 6 (4-8Hz), 12 (8-16Hz) and 18 (12-24Hz). Figure 2 shows common coda decay curve for these sites. We note that decay of coda is similar in a wide band except at very low

Table 1. Names, codes, locations and geology of five stations used in the present study.

S.No.	Station Name	Code	Latitude (^{0}N)	Longitude (^{0}E)	Geology in terms of rock
1.	Maneri	MNR	17.34	73.79	Basalt
2.	Chikhali	CKL	17.24	73.59	Laterite
3.	Warna	WRN	17.12	73.88	Basalt
4.	Katwali	KTL	17.12	73.62	Laterite
5.	Yenpe	YNP	17.11	73.04	Basalt

Table 2. Hypocentral parameters of the events considered in the present study.

S No.	Date	Origin time hr	min	sec	Latitude (^{0}N)	Longitude (^{0}E)	Focal depth (km)
1.	2/12/96	8	52	15.56	17.29	73.75	7.73
2.	2/12/96	23	55	43.27	17.27	73.72	8.71
3.	3/12/96	07	48	54.12	17.39	73.78	0.50
4.	5/12/96	12	23	49.61	17.18	73.77	7.35
5.	5/12/96	21	07	34.63	17.19	73.71	3.21
6.	6/12/96	08	30	23.40	17.14	73.75	0.86
7.	18/12/96	00	59	35.34	17.26	73.70	0.68
8.	19/12/96	00	58	19.64	17.15	73.71	4.27
9.	19/12/96	21	37	47.31	17.18	73.76	5.44
10.	28/11/96	09	05	46.33	17.11	73.77	4.84
11.	28/11/96	16	20	19.98	17.24	73.72	1.41
12.	25/10/96	04	03	39.60	17.14	73.72	4.97
13.	28/10/96	09	58	23.26	17.10	73.74	4.20
14.	3/12/96	14	50	01.60	17.29	73.74	6.20
15.	9/10/96	20	48	38.29	17.23	73.70	7.26
16.	24/11/96	00	59	46.75	17.12	73.72	4.65
17.	14/11/96	05	39	00.18	17.24	73.73	4.97
18.	18/12/96	02	06	10.47	17.27	73.70	3.71
19.	18/12/96	02	30	24.72	17.27	73.70	3.77
20.	18/12/96	06	59	00.71	17.09	73.84	0.69
21.	7/12/96	10	46	28.03	17.15	73.74	4.97
22.	7/12/96	14	14	10.19	17.16	73.71	6.32
23.	9/12/96	13	34	59.58	17.34	73.74	6.91
24.	13/12/96	00	09	54.21	17.11	73.77	5.00
25.	16/12/96	13	40	34.01	17.21	73.76	7.92
26.	19/10/96	14	30	58.12	17.14	73.75	5.01
27.	21/10/96	19	45	29.40	17.14	73.72	5.37
28.	20/10/96	14	56	16.39	17.29	73.73	3.01
29.	20/10/96	16	29	27.26	17.35	73.75	5.72
30.	20/10/96	11	52	30.32	17.16	73.70	6.19
31.	20/10/96	13	41	37.89	17.19	73.77	8.80
32.	20/10/96	16	56	02.61	17.36	73.75	5.18
33.	17/11/96	04	14	30.72	17.15	73.74	4.90
34.	17/11/96	05	51	58.64	17.15	73.73	4.73
35.	25/11/96	02	17	59.04	17.29	73.74	7.40
36.	26/11/96	04	30	45.32	17.18	73.81	2.08
37.	26/11/96	19	08	10.84	17.14	73.74	4.81

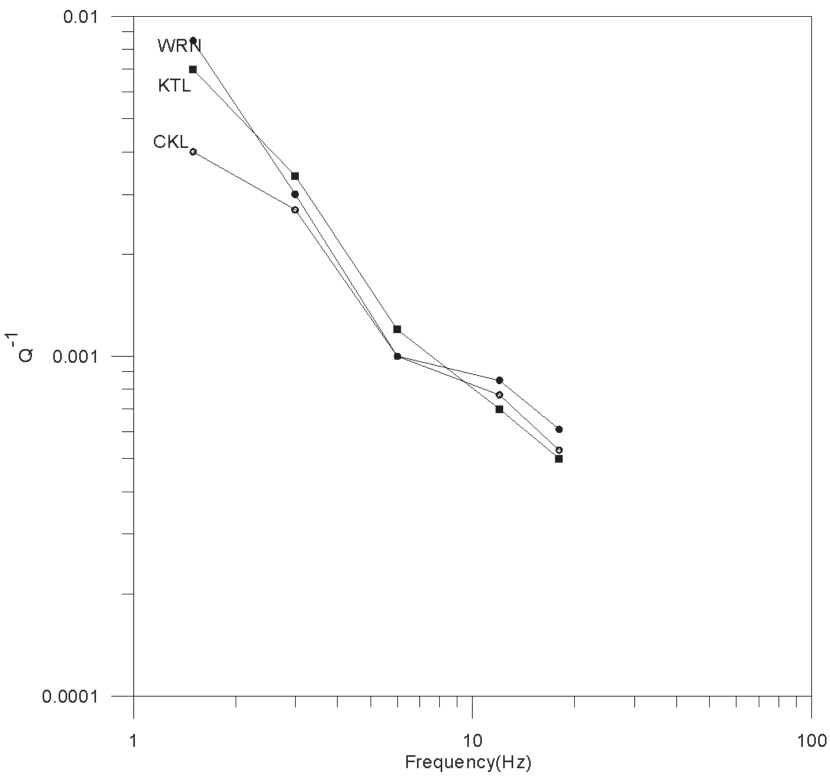

Figure 2. Common coda decay curve at WRN, KTL and CKL.

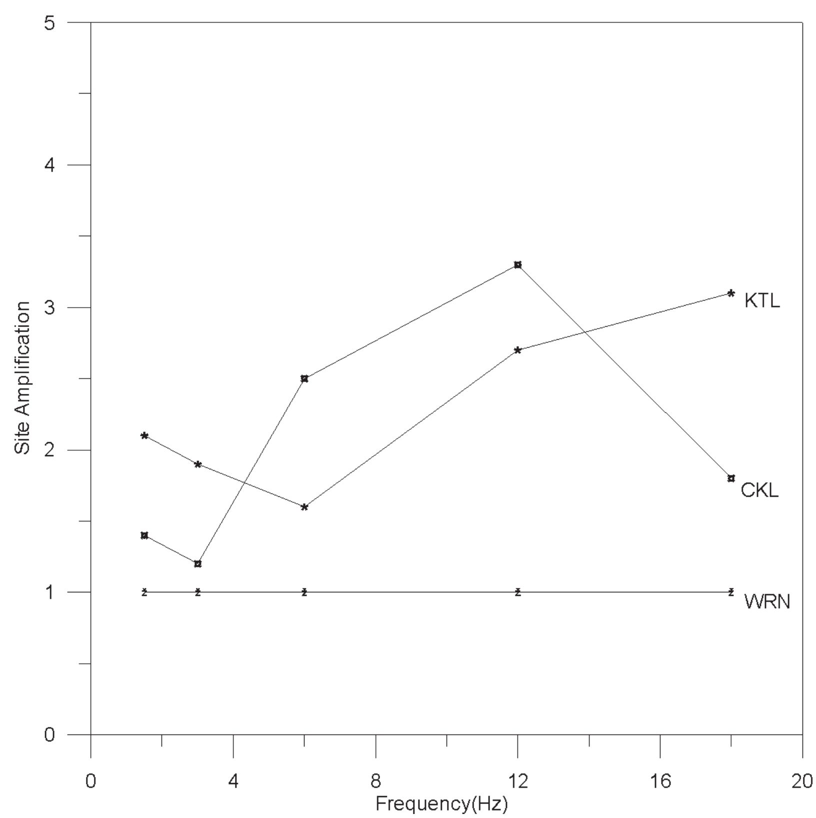

Figure 3. Site Amplification factor at KTL and CHK with reference to WRN.

Table 3. Average and relative Site amplification factor at CKL and KTL with reference to WRN.

Frequency (Hz)	Site amplification factor (CKL)	Site amplification factor (KTL)
1.5	1.4	2.1
3	1.2	1.9
6	2.5	1.6
12	3.3	2.7
18	1.8	3.1

frequencies. The relative site amplification factors are determined by taking spectral ratio of coda amplitudes for each lapse time window recorded at two stations for the same event. At each station spectral ratios are logarithmically averaged for central frequencies of 1.5, 3, 6, 12 and 18 Hz. The average site amplification factors estimated for CKL and KTL at different frequencies are given in Table 3. We note that the amplification is 1.4 at 1.5 Hz and 3.3 at 12 Hz for the station CKL. On the other hand it is 2.1 and 2.7 for the station KTL at the same frequencies. Figure 3 shows the variation of site amplification factors with frequency. The site amplification is non- linear function of frequency at these two sites. We note that for the frequency band 5 – 13 Hz the coda site amplification factors are increasing with increase in frequency at both the sites. However, the amplification factors at KTL are less than those of at CKL in the same frequency band (Figure 3). This reflects the difference in the subsurface geology at these two station sites. It has been found that the site amplification factors decrease with increase in geological age of the rocks (Su and Aki, 1995). The results obtained in this study are useful for the prediction of earthquake strong ground motion in the region.

CONCLUSIONS

The importance of local site amplifications on earthquake ground motions has been well recognized now. The relative site amplification factors have been estimated at two sites CKL and KTL in the Koyna region. The amplification factors have been obtained using coda waves at five central frequencies of 1.5, 3, 6, 12, and 18 Hz. The amplification factors are found to be non-linear function of the frequency in the region. The amplification factors vary from 1.4 to 3.3 at CKL and 1.6 to 3.1 at KTL. The amplification factors at both the station increase with increase in frequency in the wide range 5 – 13 Hz. The station CKL shows the higher amplification factors as compare to KTL in this frequency range. This reflects the difference in the station site geology as the amplification factors decrease with in increase in geological age. The results presented here are the first order of estimation in this region. They are useful for the prediction of earthquake ground motion in the region. The site amplification factors may also be obtained using body waves for the detail analysis.

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