The Nucleus, **46** (1-2) 2009 : 9-14

The Nucleus
A Quarterly Scientific Journal of Pakistan Atomic Energy Commission
NCLEAM, ISSN 0029-5698

ESTIMATION OF SITE RESPONSE CHARACTERISTICS AT FOUR SITES OF SEISMIC MONITORING NETWORK IN PAKISTAN

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(Received November 17, 2008 and accepted in revised form February 02, 2009)

The widely used approach proposed by Nakamura was adopted for the assessment of site response characteristic parameters namely; resonance frequency and amplification factor that are important for seismic hazard assessment and yield assessment in case of explosions. The technique involves calculation of spectral ratios of the horizontal to vertical components (H/V) of ambient noise recorded at sites of seismic monitoring network. The resonant frequency and amplification factor for four selected sites were estimated. The ambient noise at these sites have ground amplification factor of 1.2 – 3.75 over the frequency range of 1.05 – 4.90 Hz. The normalized spectral ratio reflects the dominant frequency and relative amplification of the selected sites. The amplification factors estimated for Sakesar and Fatehjang sites are higher than Nilore and Nurpur sites. These results are fully supported by the fact that calculated magnitudes of seismic events (local, regional and teleseismic) recorded at Sakesar and Fatehjang show higher values as compared to Nilore and Nurpur sites.

Keywords: Resonant frequency, Amplification factor, Spectral ratio

1. Introduction

Near surface geological and topographical conditions play a major role in the level of ground shaking that causes loss of lives and property during destructive earthquakes. To decrease such losses, it is very important to know the site response characteristic parameters such as resonance frequency and amplification factor. Therefore, mapping of pre-dominant frequency of soil resonance and amplification factor permits identification of zones at risk in seismically prone areas. Damages to property due to destructive earthquakes are larger on unconsolidated deposits than on firm rocks. Since urban areas are developing very fast and their primary locations are river valleys, i.e sites of recent alluvium and glacial deposits, local site amplification becomes major concern for estimating seismic risks. Considerable efforts have been made by various researchers [1-4,7,8,11-17] to develop and apply techniques for the assessment of site response characteristics and other affiliated parameters by analyzing noise and micro tremors. These authors have pointed out the correlation between the H/V peak frequency and the fundamental resonance frequency of the site, and they proposed to use the H/V technique as an indicator of the underground structure features. It was hypothized by Nakamura [12] that the vertical component of ambient noise keeps the characteristics of the source to sediment surface ground and is also influenced by Rayleigh wave and can therefore, be used to remove both these effects from the horizontal components. This technique consists of dividing the spectrum of the horizontal components by that of the vertical component of the ambient noise. The transfer function obtained from the spectral ratio of the ambient noise may or may not be the true transfer function of the input and output of the linear system but is a first step to estimate dynamic soil response and risk mitigation of buildings and lifeline in case of major earthquake.

2. H/V Method

The H/V spectral ratio method also called the 'Nakamura technique' was originally introduced by Nogoshi and Igarashi [15] that was based on the initial studies of Kanai and Tanaka [5] and widespread by Nakamura [12-14]. It consists of estimating the ratio between the Fourier amplitude spectra of the horizontal and the vertical component of ambient noise or micro tremors recorded at the surface. Mathematically, the root mean square (r.m.s) site amplification factor HVSR(f) is represented as

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Table 1

S. No.	Site Name	Latitude	Longitude	Altitude
1	Fatehjang(FAT)	33 36.7911N	72 34.7365E	890m
2	Nilore(NIL)	33 38.9813N	73 15.0968E	588m
3	Sakesar(SAK)	32 32.3886N	71 55.0894E	1400m
4	Nurpur(NPR)	33 45.1237N	73 08.4104E	560m

Table 2

Station	Code	Lithology			Extent	Critical Seismogenic Structures
		Lithology Surface	Extent	Subsurface		
Fatehjang	FAT	Sandstone, dolomite limestone	~350m	Sandstone, shale, limestone, slate	> 5,000m	MBT, Punjab Thrust
Nilore	NIL	Alluvium, Sandstone, shale, argillaceous limestone	~150m	Sandstone, shale, argillaceous limestone	> 5,000m	MBT, Hazara Thrust System
Sakesar	SAK	Massive limestone, anhydrite and salt with shale and sandstone		Shale and sandstone		Salt Range
Nurpur	NPR	Limestone, Sandstone & Shale	~150m	Shale & Sandstone	< 14,000m	MMT, MBT, Punjab Thrust

$$HVSR(f) = \frac{\frac{1}{\sqrt{2}}\sqrt{absH(f)|_{NS}^2 + absH(f)|_{EW}^2}}{absV(f)}$$

Where $H(f)_{NS}$, $H(f)_{EW}$ and V(f) represent Fourier spectra of the NS, EW and vertical components of ambient noise respectively. The average spectral ratio of N different samples is estimated as

$$HVSR(f)_{av} = \frac{\sum_{i=1}^{N} HVSR(f)}{N}$$

To apply Nakamura's [12] technique, four sites were randomly selected within seismic monitoring network, operated by Pakistan Atomic Energy Commission, for the assessment of dynamic soil response.

2.1. Sites characteristics

Ambient noise analysis was carried out at four sites mentioned in Table 1 and shown in Figure 1. Three of the sites are situated in the suburbs of Islamabad while the fourth one is situated at about 150 km south of Islamabad, the capital of Pakistan. A very brief description of the geology of the selected sites is given below in Table 2.

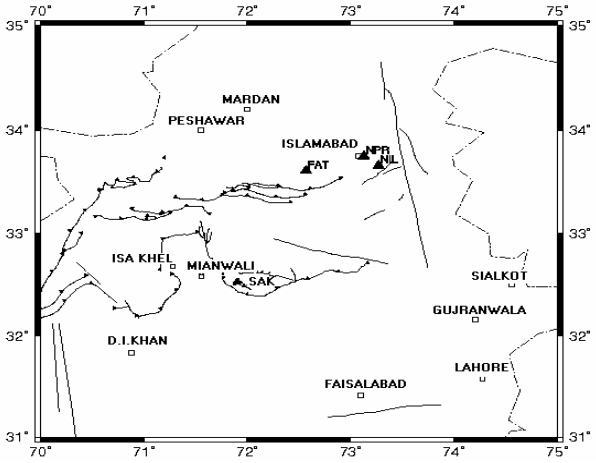

Figure 1. Map showing location of selected sites.

2.2 Data sets and methodology adopted

The seismometers installed at the four selected sites are Guralp's 3CMG_ESP velocity transducers having 1 Hz as their natural frequency and their smooth response (bandwidth) is from 60 seconds to 50 Hz. These sensors are installed in proper vaults, so that cultural noises can be minimized. The sampling rate was fixed at 50 samples per

second (sps) and data was recorded on personal computer (PC) with the help of Scream software [19] in continuous mode.

Two days data was selected randomly for spectral ratio analysis. Initially, the data was manually scanned and all those samples which were carrying abnormal cultural or environmental noise were dropped. The selected data was then divided into 60 seconds time windows and spectrum of each segment was calculated using Seismic Analysis Code (SAC) [18]. A Sample data set of the ambient noise for the four selected sites is presented in Fig. 2. Spectral ratios for each site were calculated by dividing horizontal components (east west and north south) to the vertical component at each frequency interval and averaging them.

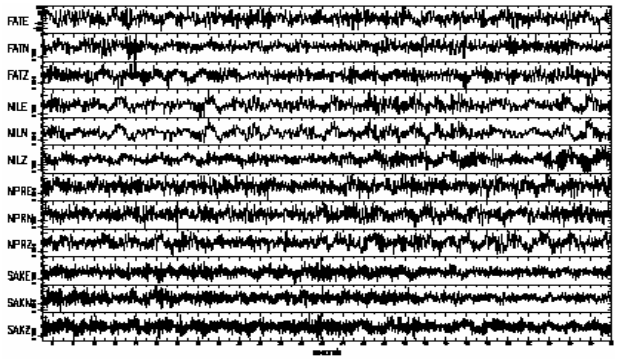

Figure 2: Sample ambient noise segment.

3. Results and Discussions

3.1. Sakesar site

A comparison of average spectra for three components (two horizontal and one vertical) and average H/V spectral ratios from ambient vibration recorded at Sakesar site are presented in Figure 3a and 3b respectively. An increase in the spectral levels of the horizontal components is clear within frequency band of .4 to 5 Hz. while the average H/V spectral ratios curve show amplification factor as 3.25 at the fundamental frequency of 3.5 Hz.

3.2. Fatehjang site

A comparison of average horizontal (NS and EW) and vertical components spectra from ambient vibration recorded at site Fatehjang and average H/V spectral ratios are shown in Figure 4a and 4b. The general character of these spectra is that the spectral levels for vertical components follows the levels for the horizontal components except within the frequency range 0.4 to 2 Hz. where the vertical component show a prominent drop in its level relative to horizontal components. Spectral ratios show a prominent peak at about 1.07 Hz with amplification up to 3.75 for this site.

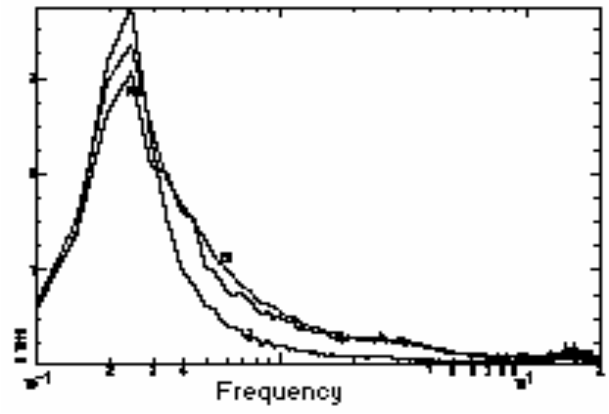

Figure 3a. Average Fourier spectra of three components for the Sakesar site.

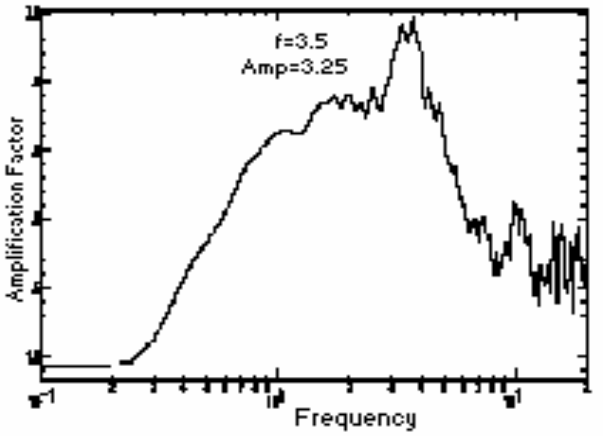

Figure 3b. Average spectral ratio obtained for the Sakesar site.

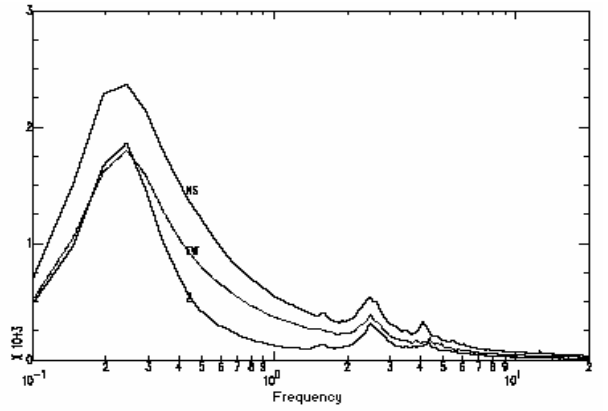

Figure 4a. Average Fourier spectra of three components for the Fatehjang site.

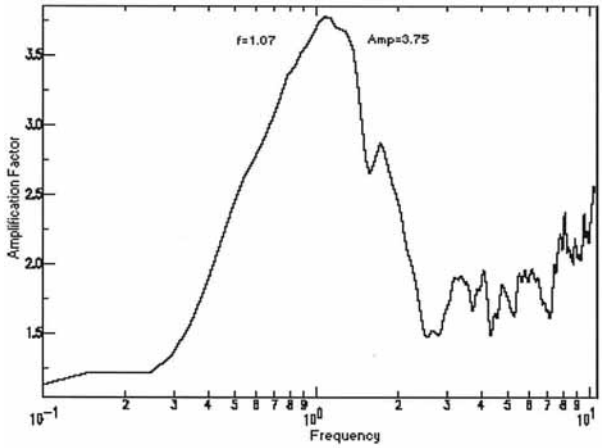

Figure 4b. Average spectral ratio obtained for the Fatehjang site.

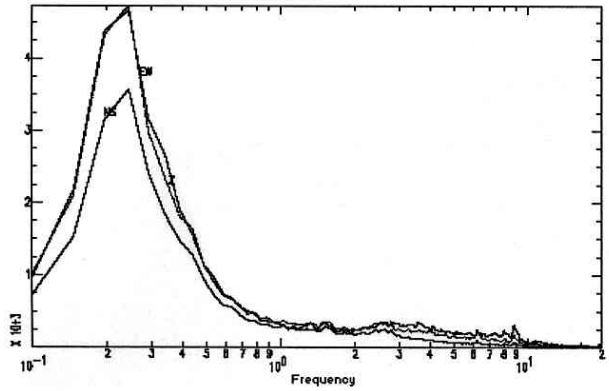

Figure 5a. Average Fourier spectra of three components for the Nilore site.

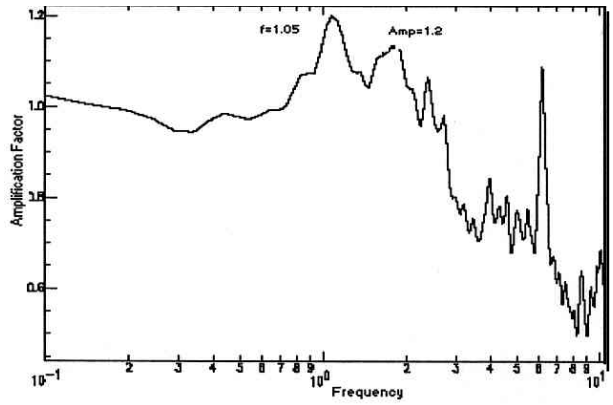

Figure 5b. Average spectral ratio obtained for the Nilore site

3.3. Nilore site

Figure 5a and 5b represent the average spectra of the three components of the recorded ambient noise at Nilore site alongwith average spectral ratios between two horizontal and one vertical component respectively. It can be clearly seen that the level of vertical component exceeds the level of horizontal components except for a very narrow frequency band between 0.8 to 1.1 Hz. The average spectral ratio graph shows a peak around frequency at 1.05 Hz. and the calculated amplification factor comes out to be 1.2.

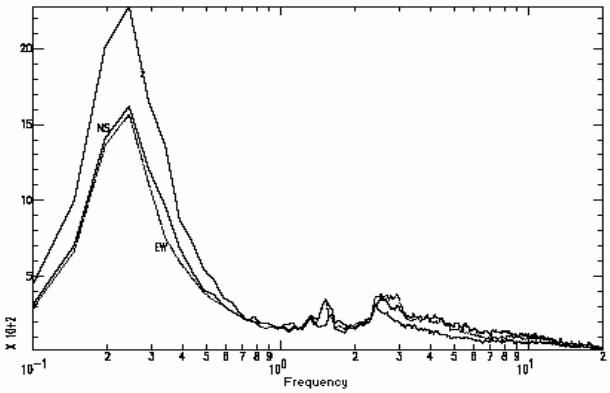

Figure 6a. Average Fourier spectra of three components for the Nurpur site.

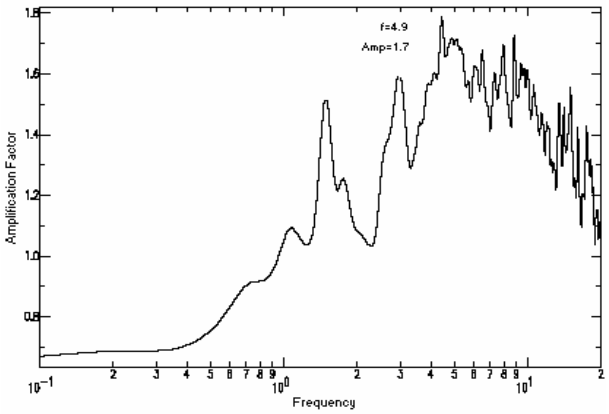

Figure 6b. Average spectral ratio, obtained for the Nurpur site.

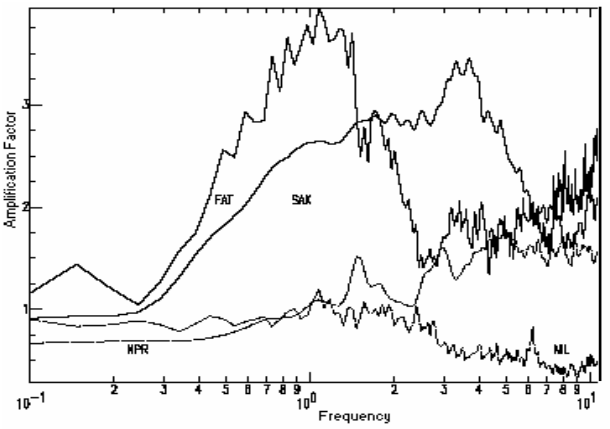

Figure 7. Comparison of spectral ratios estimated at the four selected sites (FAT, SAK, NIL, NPR) of seismic monitoring network in Pakistan.

Table 3

S. No.	Station	Resonance Frequency	Amplification Factor
1	Sakesar(SAK)	3.50 Hz.	3.25
2	Fatehjang(FAT)	1.07 Hz.	3.75
3	Nilore(NIL)	1.05 Hz.	1.20
4	Nurpur(NPR)	4.90 Hz.	1.70

Table 4

S. No	Date	Time	Location	Calculated Magnitude			
		Hr : Min		SAK	FAT	NIL	NPR
1	12/08/2007	13 : 28	Mansehra	5.0	4.8	4.3	4.4
2	19/10/2007	07 : 19	Baluchistan	5.0	5.4	5.2	5.2
3	12/12/2007	07 : 16	Mansehra	4.7	4.6	4.2	4.5
4	08/05/2008	03 : 37	Hindu Kush	5.2	5.3	5.1	4.9
5	11/07/2008	02 : 03	Hindu Kush	5.9	6.0	5.6	5.5
6	13/07/2008	08 : 50	Hindu Kush	5.5	5.7	5.3	5.4
7	05/09/2008	04 : 57	Hindu Kush	6.3	6.5	6.0	6.0
8	06/09/2008	05 : 47	Hindu Kush	6.6	6.6	6.4	6.5
9	10/09/2008	11 : 00	Iran	6.3	6.3	6.2	5.8
10	24/09/2008	17 : 59	Hindu Kush	5.8	5.6	5.4	5.5
11	07/10/2008	02 : 53	Hindu Kush	5.2	5,2	5.1	4.9
12	26/10/2008	01 : 28	Hindu Kush	6.0	6.1	5.9	5.9
13	16/11/2008	17 : 02	Indonesia	6.7	6.6	6.5	6.5
14	09/12/2008	22 : 52	Baluchistan	6.3	6.2	6.1	6.0
15	03/01/2009	19 : 43	Papua New Guinea	6.7	6.8		
16	03/01/2009	22 : 33	Papua New Guinea	6.9	7.1	6.8	6.8
17	20/01/2009	09 : 26	Afghanistan	5.4	5.4	5.1	5.2

3.4. Nurpur site

Average spectra of the ambient noise of the three components recorded at Nurpur is shown in Figure 6a, while average spectral ratio in Figure 6b. The site resonance frequency is about 4.9 Hz. and the associated amplification factor comes out to be 1.7.

Relative spectral ratio and amplification factor for the four selected sites of seismic monitoring network in Pakistan is presented in Fig. 7. Table 3 represents the estimated amplification factor and resonance frequency of each selected site.

4. Conclusions

The estimated amplification factor and their resonant frequencies for the selected sites using average spectral ratios method lie between 1.2–3.75 and 1.05–4.90 Hz. respectively. The amplification factors estimated for Sakesar and Fatehjang sites are higher than Nilore and Nurpur sites as indicated in Table 3. These results are fully supported by the fact that calculated magnitudes of seismic events (local, regional and teleseismic) recorded at Sakesar and Fatehjang show higher values as compared to Nilore and Nurpur sites as shown in Table 4. This method has proven to be useful to estimate the fundamental period of soil deposits but alone is not sufficient to characterize the complexity of the site effects. However, the analysis of data should be carried out with caution. The H/V technique is an initial step, inspite of its limitations and robustness, but is an important step to estimate site characteristics for microzonation studies of interested area.

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