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PREDOMINANT PERIOD AND AMPLIFICATION FACTOR ESTIMATION WITH RESPECT TO GEOMORPHOLOGY - A CASE STUDY OF SYLHET CITY CORPORATION AREA, BANGLADESH

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Abstract

Predominant period and amplification factor of the subsurface soils of Sylhet city corporation area have been estimated using microtremor. Their relation to the geomorphological units of the city has been determined. The estimated predominant periods of alluvial fan, back swamp, flood plain, isolated hills, level hills, piedmont plain, point bar and ridge of the city are 0.60, 0.75, 0.73, 0.23, 0.62, 0.45, 0.73 and 0.66 sec., respectively. With maximum (± 0.88) and minimum (± 0.38) standard deviation amplification factor of alluvial fan, back swamp, flood plain, isolated hills, level hills, piedmont plain, point bar and ridge are 3.1, 4.1, 4.6, 3.75, 2.22, 4.12, 4.18 and 4.42, respectively. According to amplification seismic hazard of different geomorphological units of the city has been ranked from very low to relatively high hazard zone whereas level hill falls under very low, alluvial fan under low, flood plain under relatively high and back swamp, isolated hills, piedmont plain, point bar and ridge falls under moderate hazard zone.

Key words: Predominant period, amplification factor, seismic hazard, geomorphological units, microtremor

Introduction

It is well known that ground surface is always vibrating caused by atmospheric and man-made disturbances with amplitudes of several micrometers and with periods of 0.1 to 10 sec. Such small vibrations are called microtremors (Kanai *et al.* 1954). The use of microtremors turn into one of the most appealing approaches in site effect studies, due to its relatively low economic cost, and the possibility of recordings without strict spatial or time restrictions (Rodriguez and Midorikawa 2002). Although the use of microtremors in site response estimation has long been very controversial in other parts of the world except in Japan. Its use received renewed attention after the Guerreoro-Michigan event of 1985. The ground response information provided by the microtremor was consistent with

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strong motion observations (Kamal and Midorikawa 2006). Many users in developing and moderate seismicity countries are attracted by this low cost convenient technique considering both the increased importance on micro-zoning and site effect after the damage observation in recent earthquakes, such as Mexico 1985, Loma Prieta 1989, Kobe 1995, Taiwan 1999 (Kamal and Midorikawa 2006).

Techniques for analyzing microtremors are generally divided into two main categories: non-reference site (H/V) and reference site (Hs/Hr) techniques (Motamed and Ghalandarzadeh 2004). In practice, adequate reference sites are not always available especially in flat areas. Therefore, methods have been developed that do not need reference sites (Bard 1994). A technique using horizontal to vertical spectral ratios (H/V) of the microtremors, which was first applied by Nogoshi and Igarashi (1970, 1971) and popularized by Nakamura (1989), has been widely used to estimate the site effects. In H/V spectral ratio technique, the ground responses are calculated in terms of predominant period and amplification factor. Some experimental investigations have validated the H/V spectral ratio technique in determining the predominant period of the ground (Lachet and Bard 1995, Lermo and Chavez-Garcia 1993). Predominant period indicates the frequency of the spectrum under which the near-surface soft sediment amplifies the earthquake ground motion, often referred as the site effects. When the predominant period of the sites appears near the period of the structure then the degree of damage caused by earthquake shaking would be larger (Kamal and Midorikawa 2006).

Microtremor has been used to estimate the predominant period and amplification factor for the subsurface geological materials of Dhaka city (Kamal and Midorikawa 2006). Although Sylhet city is located near the seismically active zone, there is no published research on the use of microtremor for predominant period and amplification factor estimation. Therefore, it is necessary to determine the predominant period and amplification factor for seismic design of the structures.

The objective of the present study is to investigate the seismic response of different geomorphological units of Sylhet city corporation area located in the north-eastern part of Bangladesh. The microtremor technique has been employed to quantify the predominant period and amplification factor for the determination of the response of ground motion during an earthquake for each geomorphological unit of the study area.

Geomorphology of study area: The investigated area lies between latitude from 24^0 51′ N to $24^0$55′ N and longitude from $91^0$50′ E to $91^0$54′ E having an area of 27.36 sq km in Sylhet division in the north-eastern region of Bangladesh. The city and its adjoining hilly region are extended to the Assam-Meghalaya Hill Range of India. The hills are gently undulated and north of the hills are the great Jainta and Kashi Hills of India. The regional topography of the investigated area is characterized by low rounded hillocks separated by flat to steep valleys. The area is bordered in the north-east by the abrupt scarp of the Shillong Plateau of 4000-6000 feet high and in the east by the Kashi-Jaintia Hill Ranges. The geomorphic units of Sylhet city are delineated during the study of comprehensive disaster management programme (CDMP) in 2009 (Fig. 1). The units are – (A) Denudational landform: (i) Hills, (ii) isolated hills, (iii) level hills, (iv) dissected hills, and (v) Piedmont plain; (B) fluvial landform: (i) Active channel, (ii) seasonal channel, (iii) point bar, (iv) lateral bar, (v) natural levee, (vi) meander scar, (vii) flood plain, (viii) back swamp, (ix) valley fill, (x) depression, (xi) gully fill and (xii) alluvial fan.

The city has no marine influences and the depths of soft sediments vary a lot. Deep incised valleys were filled up with soft sediment. The exact time when this soft sediment started to accumulate has not been fixed as the sediments are not dated. But on the basis

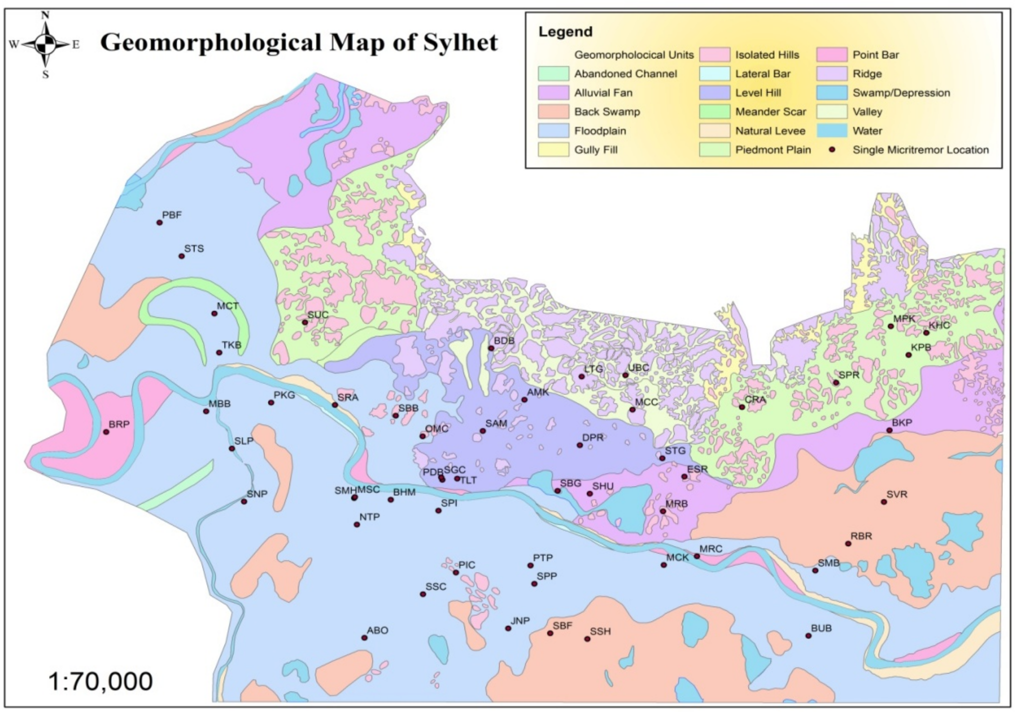

Fig. 1. Geomorphological map of Sylhet city and surrounding area (CDMP 2009).

of degree of compaction or consolidation it has been assumed that the sediments were started to accumulate at the end of the Pleistocene (CDMP 2009). Almost in all places, these unconsolidated sediments are underlain by the Dupi Tila formation of the Plio-Pleistocene age.

Methodology

Spectral ratio between the horizontal and vertical components was first introduced by Nogoshi and Igarashi (1971). To use it as an indicator of the underground structure they showed its relation to the ellipticity curve of Rayleigh wave, and took advantage of the coincidence between the lowest frequency as maximum of this H/V curve with the fundamental resonance frequency. This technique was later revised by Nakamura (1989) who claimed that the spectral ratio is a reliable site transfer function for S-wave which led him to use the name "Quasi-Transfer Spectrum or QTS". Although his semi-qualitative theoretical explanation appeared questionable to many scientists, this technique is very simple and cheap. That's why, it immediately been circulated all over the world, for further checks or even, and indeed often used, for direct applications. To derive his quasi-transfer spectrum (QTS) model, Nakamura (1989) assumed that energy of microtremors comprises both body and the surface waves, and the surface sources generated Rayleigh waves equally affect the horizontal and vertical components of motion (Fig. 2).

On this assumption, he proceeds to estimate the effects of the sources (O_m (f)) as the ratio of the vertical motions registered on the surface (V_s (f)) and at the base layer (V_b (f)):

$$O_m (f) = (V_s (f)) / (V_b (f))$$

However, the transfer function of interest for a site i(G_i (f)) comprises a ratio involving the horizontal motion of microtremor registered at the surface (H_s (f)) and at the base layer (H_b (f)):

$$i(G_i(f))=(H_s(f))/(H_b(f))$$

Then, computing a modified site effects function G_m (f) as the ratio of G_t (f) with respect to O_m (f), we compensate the source effects by the following manner:

$$G_m(f)=G_t(f)/O_m(f)=\frac{Hs(f)/Hb(f)}{Vs(f)/Vb(f)}=\frac{Hs(f)}{Hb(f)}*\frac{Vb(f)}{Vs(f)}=\frac{Hs(f)}{Vs(f)}*\frac{Vb(f)}{Hb(f)}=\frac{Hs(f)/Vs(f)}{Hb(f)/Vb(f)}$$

Now, if the ratio H_b (f)/V_b (F) equals unity within a factor of two over a significant frequency (f) range of interest; an assumption that Nakamura (1989) corroborated at the Kanonomiya and Tabata sites in Japan; we can then estimate the modified site effects function relying only on the surface components:

$$G_m(f)=(H_s(f))/(V_s (f))$$

According to Nakamura (1989), it is effective to identify the fundamental resonant frequency of a sedimentary layer with implied amplification factors that are more realistic than those obtained from sediment to rock site ratios. It has been shown by many researchers (Lermo and Chavez 1993, Field and Jacob 1993, Konno and Ohmachi 1998) that how such H/V ratio of noise can be used to identify the fundamental resonant frequency and amplification factor of sediments.

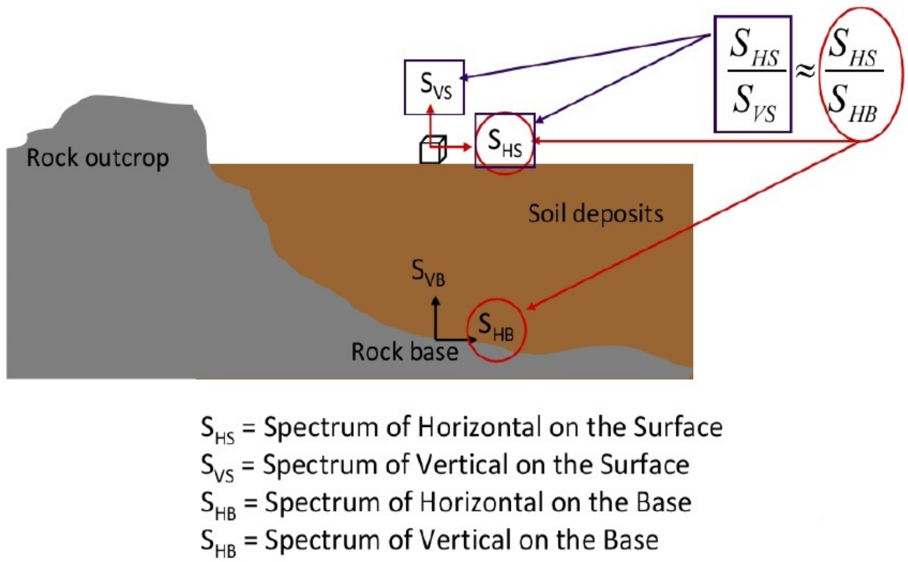

Fig. 2. Single microtremor observation (H/V spectral ratio method by Nakamura 1989)

Microtremor data have been collected using portable equipment, which is equipped with a super-sensitive sensor, a wire comprising a jack in one site and USB port in another site, and a laptop computer is also used. The microtremor equipment has been set on the free surface on the ground without any minor tilting of the equipment. The north-south and east-west directions are properly maintained following the directions arrowed on the body of the equipment. The sampling frequency for all equipments is set at 200 Hz. The low-pass filter of 40 Hz is set in the data acquisition unit. Like the seismometer or accelerometer, the velocity sensor used can measure three components of vibrations: two horizontal and one vertical. The natural period of the sensor is 2 sec and the available frequency response range for the sensor is 0.5 - 10 Hz. A global positioning system (GPS) is used for recording the coordinates of the observation sites. The length of record for each observation was 82 sec. Fifty nine microtremor data have been collected for this research with respect to geomorphic units of Sylhet city corporation area.

Spectral ratio techniques are most often applied methods for estimating effects and these techniques stem from the basic idea that the severity of damages associated to earthquakes depends heavily on the frequency contents of the corresponding ground motions. Moreover, these techniques take into consideration that most of the operations needed to analyze the energy contents of ground motion turn much easier in frequency domain than in time domain. So, in order to determine in which frequency contents of the spectrum the sedimentary packages caused the larger amplifications. We employed the horizontal to vertical spectral ratio technique on microtremors observed at a site with only three-component (NS, EW, UD) sensor. For spectral analysis we took three noise-free portions of 20.48s from each record as the instrumental sampling frequency was 100 Hz. The steps that we followed for estimation of site response from spectral ratio curves are as given below (Kamal and Midorikawa 2006):

(1) Fourier transformation: We have calculated the Fourier spectra of the two horizontal (north-south and east-west) and the vertical (up and down) components. As the Fourier spectra of the two horizontal components looked alike, their horizontally combined spectra were calculated to obtain the maximum Fourier amplitude spectrum as a complex vector in the horizontal plane. Whereas that of the UD component provides the vertical motion spectra.

(2) Smoothing of the spectra: After Fourier transformation, we digitally filtered the combined horizontal and vertical spectra applying a logarithmic window (Konno and Ohmachi 1998, Rodriguez and Midorikawa 2002) with a bandwidth coefficient equal to 15. This filtering technique was applied to reduce the distortion of peak amplitudes.

(3) Calculation of the soil response functions: The smoothened combined horizontal spectrum was divided with the vertical counterpart (H/V) which provided the desired predominant period and corresponding amplification factor of the investigated portions (20.48s) of records.

(4) Normalizing the data set: After calculating three sets of 20.48s H/V ratios for each record, they are normalized by averaging to obtain a relatively non-biased site specific H/V ratio.

Using above mentioned steps 59 microtremor data have been analyzed for different geomorphic units of Sylhet city corporation area. Each geomorphic unit contains one or more than one microtremor data. Finally predominant period and amplification factor have been calculated by averaging (Fig. 3a - h) the best quality data of those geomorphic units and then peak amplitude curve with standard deviation of each geomorphic unit are prepared as shown in Fig. 4.

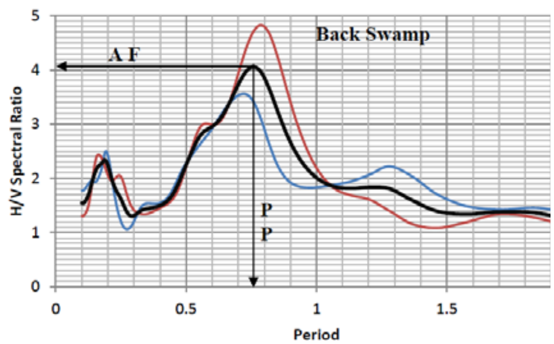

Fig. 3a. Averaging H/V spectral ratio of back swamp.

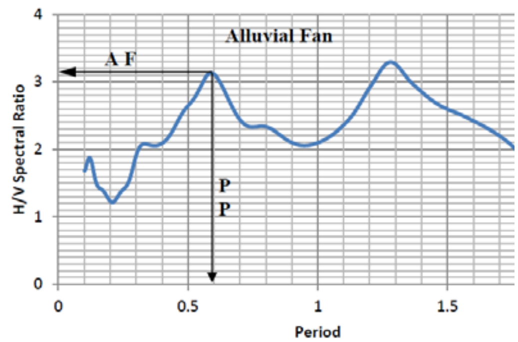

Fig. 3b. Averaging H/V spectral ratio Alluvial fan.

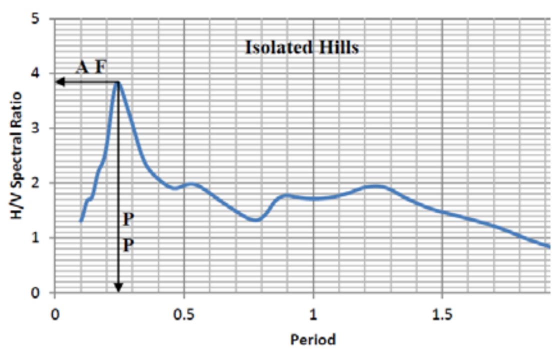

Fig. 3c. Averaging H/V spectral ratio of isolated hills.

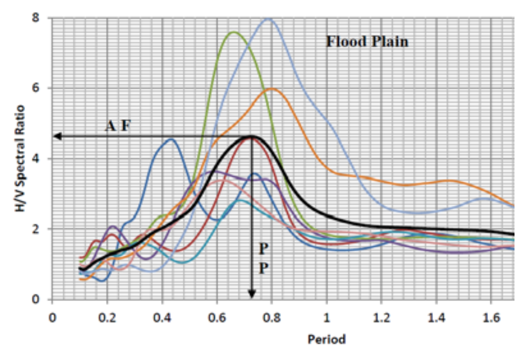

Fig. 3d. Averaging H/V spectral ratio of flood plain.

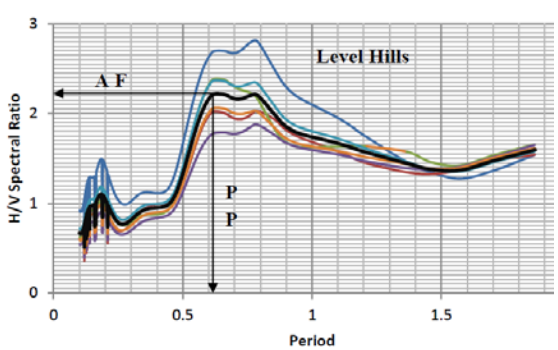

Fig. 3e. Averaging H/V spectral ratio of level hills.

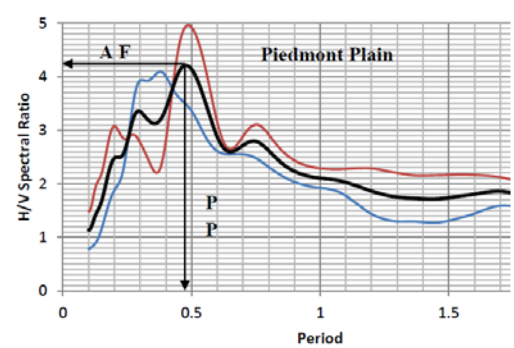

Fig. 3f. Averaging H/V spectral ratio of piedmont plain.

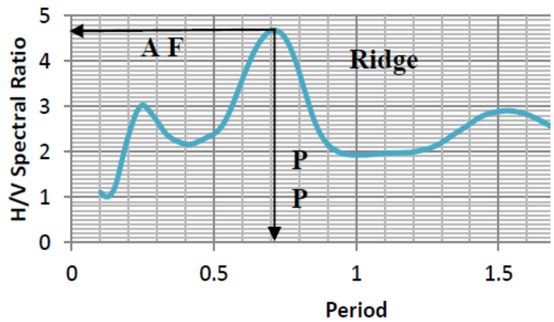

Fig. 3g. Averaging H/V spectral ratio of ridge.

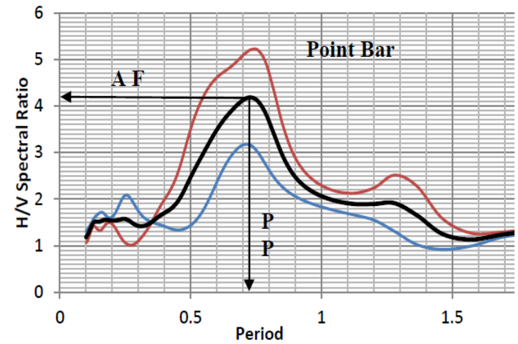

Fig. 3h. Averaging H/V spectral ratio of point bar.

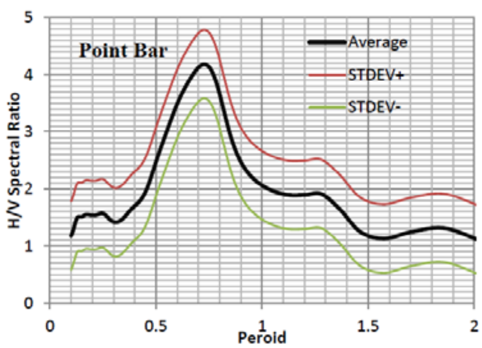

Fig. 4. Average H/V spectral ration with STDEV.

AF= Amplification factor

PP= Predominant period

STDEV= Standard deviation

Results and Discussions

The soil response of each geomorphic unit is measured in terms of predominant period and amplification factor shown in Table 1. In the table, amplification factor varies from 2.22 to 4.6 with maximum standard deviation value ± 0.88 and minimum standard deviation ± 0.38. Predominant period varies from 0.23 to 0.75 sec.

Table 1. Soil response of each geomorphic unit in terms of predominant period and amplification factor with STDEV.

Geomorphic unit	Predominant period (Sec)	Amplification factor with SD
Alluvial fan	0.60	3.1 ± 0.46
Back swamp	0.75	4.1 ± 0.53
Flood plain	0.73	4.6 ± 0.86
Isolated hills	0.23	3.75 ± 0.72
Level hills	0.62	2.22 ± 0.38
Piedmont plain	0.45	4.12 ± 0.84
Point bar	0.73	4.18 ± 0.61
Ridge	0.66	4.42 ± 0.88

With reference to the amplifications and seismic hazard ranks (Table 2), the seismic hazard rank of different geomorphic units based on their amplification have been categorized. Among them Level Hill falls under Very Low Hazard zone, Alluvial Fan under Low Hazard zone, Flood Plain under Relatively High Hazard zone and Back Swamp, Isolated Hills, Piedmont Plain, Point Bar and Ridge falls under Moderate Hazard Zone.

Table 2. Table shows the amplifications and seismic hazard ranks (Kamal and Midorikawa 2006).

Amplification	Rank
1.0 - 2.5	Very low hazard
2.5 - 3.5	Low hazard
3.5 - 4.5	Moderate hazard
4.5 - 7.0	Relatively high hazard

There is a relation between S-wave velocity and amplification factor, such as, generally low S-wave velocity gives high amplification factor and high S-wave velocity gives low amplification factor. Microtremor method is good for determining predominant period and amplification factor. Sometimes microtremor gives slightly higher value in terms of amplification factor. The possible reason for this deviation may be due to noise or acquisition errors (Hossain *et al.* 2013). For seismic hazard assessment long term record of microtremor is necessary in order to properly differentiate the portion of signal and noise of the microtremor data in the waveform.

Conclusion

Amplification factor and predominant period are essential for seismic hazard assessment. Based on amplification factor back swamp, isolated hills, piedmont plain, point bar and ridge falls under moderate hazard zone where amplification value varies from 3.5 to 4.5. level hills fall under very low hazard zone where value varies from 1 to 2.5. alluvial fan and flood plain falls under low hazard zone and relatively high hazard zone where amplification value varies from 2.5 to 3.5 and 4.5 to 7, respectively. The Predominant periods of different geomorphic units of the city range from 0.23 to 0.75 sec. If the predominant period is known at the site of construction, engineer can design the structure in such that the natural period of the structure does not coincide with the predominant period.

References

Bard, P. Y. 1994. Effect of surface geology on ground motion: Recent results and remaining issues. 10th European Conference on Earthquake Engineering. pp. 305-323.

Comprehensive Disaster Management Programme (CDMP). 2009. Engineering geological map for seismic hazard and vulnerability assessment of Dhaka, Chittagong and Sylhet city corporation area of Bangladesh.

Field, E.H. and K. H. Jacob. 1993. The theoretical response of sedimentary layers to ambient seismic noise. *Geophy. Res. Let*. **20**: 2925-2928.

Hossain, M.S., B.M.R Hossain., A.K.M.F Kabir., A.S.M Woobaidullah., A.S.M.M Kamal and C. Quamruzzaman. 2013. Correlation of geophysical and geotechnical investigations for seismic hazard assessment in Dhaka city, Bangladesh. *Global J. Bio-sci. and Biotech.* **2**(2): 139-144.

Kamal, A.S.M.M. and S. Midorikawa. 2006. Geomorphological approach for seismic microzoning within Dhaka city area, Bangladesh. *International Association for Engineering Geology and the Environment* **457:** 1-2.

Kanai, K., T. Tanaka. and K. Osada. 1954. Measurements of microtremors. *Bulletin of Earthquake Research Institute, Tokyo University* **32**: 199-210.

Kanai, K. and T. Tanaka.1961. On microtremors, VIII, *Bull. Earthq. Res. Inst*. **39**: 97-114.

Konno, K. and T. Ohmachi. 1998. Ground-motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremor. *Bulletin of the Seismological Society of America* **88**(1): 228-241.

Lachet, C. and P.Y. Bard. 1995. Theoretical investigation of the Nakamura's technique. Proceedings of the 3rd international conference on recent advances in geotechnical earthquake engineering and soil dynamics **2**: 617-675.

Lermo, J. and F.J. Chavez-Garcia. 1993. Site effect evaluation using spectral ratios with only one station. *Bulletin of the Seismological Society of America* **83**: 1574-1594.

Motamed, R. and A. Ghalandarzadeh. 2004. Seismic microzonation of urmia city by means of microtremor measurements. 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada **1052**: 1-2.

Nakamura, Y. 1989. A method for dynamic characteristics of sub-surface using microtremors on the ground surface. Quick Report of Railway Technical Research Institute **30**(1): 25.

Nogoshi, M. and T. Igarashi. 1970. On the propagation of characteristics of microtremors. *J. Seism. Soc. Japan* **23**: 264-280.

Nogoshi, M. and T. Igarashi. 1971. On the Amplitude characteristics of microtremors. *J. Seism Soc. Japan* **24**: 24-40.

Rodriguez, V. H. S. and S. Midorikawa. 2002. Applicability of H/V spectral ratio of microtremors in assessing site effects on seismic motion. *Earthquake Engineering and Structural Dynamics* **31**: 261-279.

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