ASSESSMENT OF SEISMIC VULNERABILITY INDEX OF RAJUK AREA IN BANGLADESH USING MICROTREMOR MEASUREMENTS

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ABSTRACT

Among empirical methods, a reflexive method increasing in popularity for site response analysis is the Microtremor HVSR (H/V spectral ratio method), also commonly referred to as the Nakamura's method. The aim of this study is achieved by utilizing H/V spectral ratio method for assessment of seismic vulnerability index (K_g) of RAJUK area in and around Dhaka city. Microtremor data has been collected and analyzed in order to determine predominant frequency and amplification factor according to the guideline of SESAME. Finally, seismic vulnerability index (K_g) of site soil using Nakamura's technique has been calculated from predominant frequency and amplification factor parameter. Five Hundred locations in the study area (RAJUK area) have been selected for microtremor observation. The calculated seismic vulnerability index (K_g) for selected 500 sites varies between 0.15 and 124.08. The low K_g values indicates that the areas are very stiff and thick sediment deposit. The high K_g values are scattered in the soft alluvial deposits area. Thus, the higher the K_g values in the area considered as weak zones that may cause very high damage to infrastructure located in those area during an earthquake. Variation in amplification factor, frequencies and seismic vulnerability index in study area have been graphically represented in ArcGIS produced maps to spatially identify the locations with higher vulnerability index.

Keywords: amplification factor, frequency, H/V spectral ratio, Nakamura technique, seismic vulnerability index

1. INTRODUCTION

Bangladesh has not suffered any damaging large earthquakes in recent past; but, in the past few 100 years, several large catastrophic earthquakes have struck this area. So far, all the major recent earthquakes have occurred away from major cities, and have affected relatively sparsely populated areas (Ansary & Raman, 2012). Dhaka city is the most populated city in Bangladesh having population of 19 million. Besides, Bangladesh is located in a region of significant seismic activity, most of the population and policy makers do not perceive seismic risk to be important (Ansary & Rashid, 2016). It is a cause for great concern that it may cause high damage to the infrastructures when the next great earthquake may occur in this region.

In many past and recent earthquakes, it has been observed that the local soil conditions and topographic effects have a great influence in the damage distribution. Severe damage even at large epicentral distances may occur due to the local site effects and double resonance (double resonance is the resonance of body wave frequency with F_0 of soil and then again resonance with the natural frequency of structure) (Shiuly et. al., 2014). Microtremor observations are easy to perform, inexpensive and can be applied to places with low seismicity. The H/V spectral ratio technique of microtremors has gained popularity in the early nineties, after the publication of several papers (Nakamura 1989; Field and Jacob 1993; Lermo and Chavez-Garcia 1994) claiming the ability of this technique to estimate the site response of soft sedimentary deposits satisfactorily.

2. STUDY AREA AND SITE SELECTION

Dhaka is the capital, cultural, political, and financial center of Bangladesh. It is one of the largest and most densely populated cities in South Asia. Microtremor studies have been conducted inside the Dhaka city by several researches, Ansary and Saidur Rahman (2012) and Ministry of Food and Disaster Management (MoFDM) in 2009. In the current study, the location of stations will be considered for the whole Dhaka city and RAJUK (Capital Development Authority) area. The application of microtremor analysis in this study is to determine the seismic vulnerability index (K_g), by using the H/V ratio Method. The primary distribution of the 500 stations is shown in Figure 2.

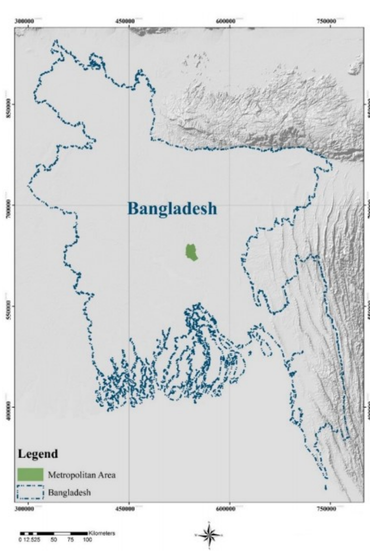

Figure 1: Bangladesh country and metropolitan area within RAJUK area

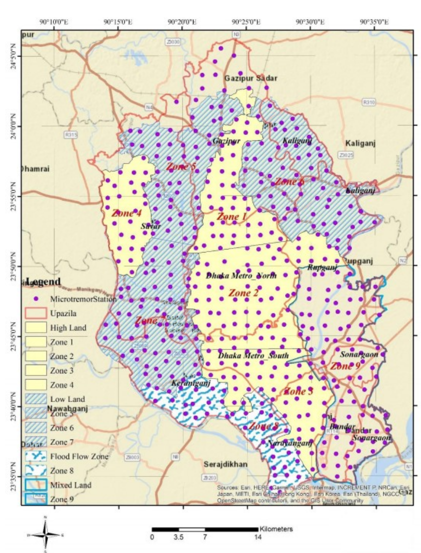

Figure 2: Distribution of the microtremor record stations in RAJUK area

3. DESCRIPTION OF SITE EFFECT

The influence of local geologic and soil conditions on the intensity of ground shaking and earthquake damage has been known for many years. Wood (1908) and Reid (1910) showed that the intensity of ground shaking in the 1906 San Francisco earthquake was related to local soil and geologic conditions. Gutenberg (1927) developed site-dependent amplification factors from recordings of microseisms at sites with different subsurface conditions.

3.1 Effects of local site conditions on ground motion

Local site conditions can profoundly influence all of the important characteristics of strong ground motion including amplitude, frequency content, and duration. The nature of local site effects can be illustrated in several ways: i) simple, theoretical ground response analyses, ii) measurements of actual surface and subsurface motions at the same site, iii) measurements of ground surface motions from sites with different subsurface conditions. Local site effects can be very significant, particularly when long period structures such as bridges and tall buildings are founded on deposits. In general, the effects of topography and basin are the main factors of site effects phenomenon.

3.1.1 Topography effect

The topographic effects caused by simple irregularities can be estimated from exact solutions to idealized problems (Aki, 1988). For a triangular infinite wedge subjected to vertically propagating SH-waves (with particle motion parallel to its axis), apex displacements are amplified by a factor $2\pi\varphi$ where φ is the vertex angle of the wedge (Figure 3 left). This approach can be used to approximate topographic effects for certain cases of ridge-valley terrain (Figure 3 right).

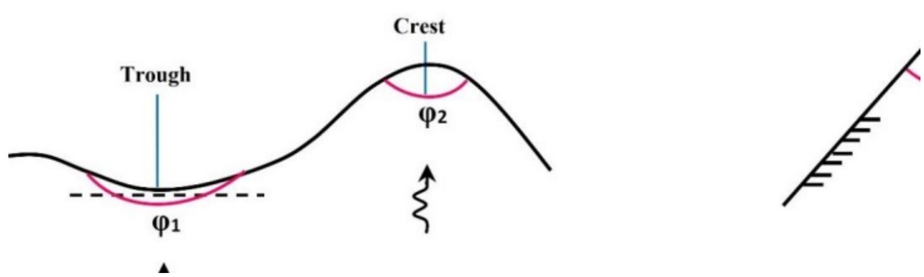

Figure 3: Characterization of simple topographic irregularities: (left) notation for a triangular wedge; (right) approximation of actual ground surface (solid line) at trough and crest by wedges. (After Faccioli, 1991.)

Different geometries and different wave fields have been considered also (e.g., Geli et al., 1988; Sanchez-Sesma, 1990; Faccioli, 1991). A schematic view of topography effect on amplification of horizontal acceleration for a linear elastic slope is presented in Figure 4.

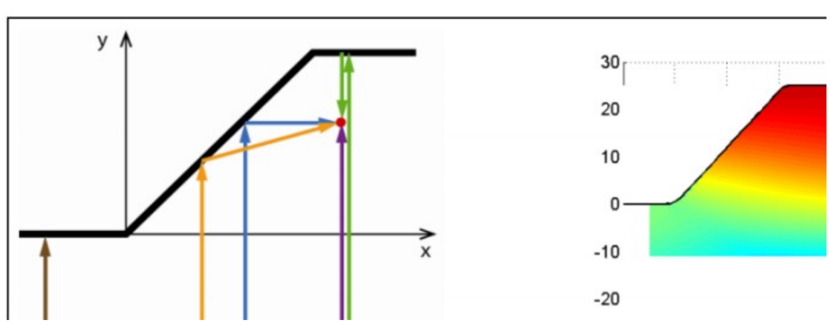

Figure 4: Topography effect on amplification of horizontal acceleration for a linear elastic slope

3.1.2 Basin effect

Since many large cities are located on or near alluvial valleys, the effects of basin geometry on ground motion is of great interest in geotechnical earthquake engineering. The curvature of a basin in which softer alluvial soils have been deposited can trap body waves and cause some incident body waves to propagate through the alluvium as surface waves (Vidale and Helmberger, 1988). These waves can produce stronger shaking and longer durations than would be predicted by one dimensional analysis that consider only vertically propagating S-waves.

3.2 Methodology to evaluate site effect

The most preferred methodology in estimating PGA on bedrock is to use attenuation relations. Though, all the building structures are not situated on the bedrock, they are mostly located on soil surface. Consequently, applying attenuation relations will be accompanied by high uncertainties, while local site effect needs to be assessed. The common approaches for evaluation of local site effects are categorized as follows:

- Level 1: evaluating the local site effects using existing information that is readily available from published reports and other sources.
- Level 2: methods require additional investigations including geotechnical investigations, geophysical testing and soil sampling from boreholes for laboratory tests.
- Level 3: methods of zonation require the conducting of ground response analyses (including the one-dimensional equivalent-linear and nonlinear analyses, and 2D and 3D analyses).

3.2.1 Microtremor survey method

The surface of the earth is always in motion at seismic frequencies, even without earthquakes. These constant vibrations of the earth's surface are called microseisms or microtremors. The amplitude of these microtremors is, with some extreme exceptions, generally very small. Although they are very weak, they represent a source of noise to researchers of earthquake seismology; if amplifier gain is increased to record earthquake signals from a distance source, the amplitude of microtremors proportionally increases, and the desired earthquake signal is buried in the "noise" of microtremors. Elimination of this background noise is technically extremely difficult or impossible to achieve.

3.2.2 H/V determination based on Nakamura technique

The method use for data analysis is the Horizontal to Vertical Spectral Ratio (HVSR) approach developed by Nakamura (1989). The HVSR approach is applied to ambient noise and generates a Fourier spectral ratio of amplitude versus frequency. The HVSR method divides the horizontal component of noise to the vertical component to remove source effects as shown in Figure 5. The spectral ratio is calculated by taking the Fourier transform (Welch, 1967) of the ambient noise recordings.

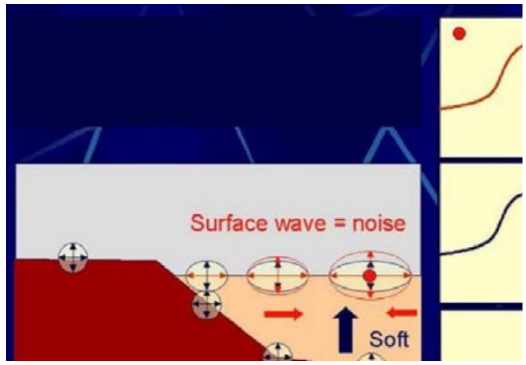

Figure 5: Schematic of H/V method (Nakamura, 2008)

H/V technique has been frequently adopted in seismic microzonation investigation due to its low-cost both for the survey and analysis. The method is especially recommended in areas of low and moderate seismicity, due to the lack of significant earthquake recordings, as compared to high seismicity areas. This technique consists in estimating the ratio between the Fourier amplitude spectra of the horizontal (H) to vertical (V) components of the ambient noise vibrations recorded at one single station. There have been some criteria given by SESAME European research project (2004), in order to obtain a reliable H/V curve and clear H/V peak, which are not mentioned here.

4. MICROTREMOR DATA COLLECTION AND ANALYSIS

The microtremor survey has been carried out in 500 locations in RAJUK area. At first, a regular square network with approximately 1.7 kilometers sides was considered which; one station was implemented in each square. The regularity of the stations then was disoriented based on the nearest sensitive center inside the square (i.e. health facilities, police stations, fire stations and, educational centers) and accessibility through the roads. Then, the stations were omitted from military area and flood plains. A few coordinates of the planned stations are presented in Table 1.

Table 1: Coordinate of a few microtremor stations

No.	Station No.	Longitude	Latitude	No.	Station No.	Longitude	Latitude
1	P307	90.350592	23.854833	4	P373	90.433492	23.89947
2	P308	90.361233	23.857776	5	P390	90.368273	23.916326
3	P309	90.3823	23.854792	6	P391	90.385777	23.914658

4.1 Data Acquisition

Microtremor data were collected on a three component Sensors of GS11D Geospace Technology with an internal 12V rechargeable lead battery with the capability of 5 hours continues recording. More over the data logger having the characteristics are- A/D converter: 24-bit monolithic sigma- delta converter, 1 per channel, Sensitivity: 78 v/m/s (±10%) Natural Frequency: 4.5 Hz (±15%) etc. Data were acquired using Seismowin Software. Surveys were made at 100 samples per second.

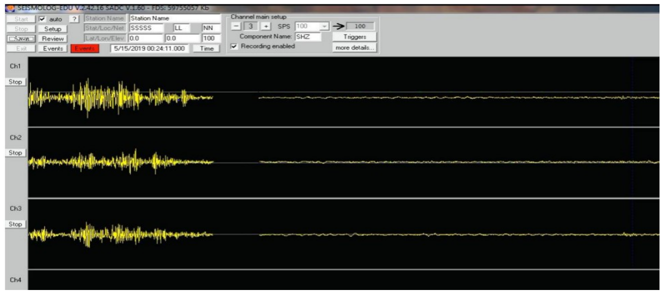

Figure 6: Illustration of a Seismowin Software during data acquisition in the field

4.2 Data Analysis and Obtaining the H/V curve

All 500 recorded data were analyzed by expert seismologists. The H/V method is applied to obtain the natural frequency and amplification factor in the stations. The obtained graph from all the record and after noise removal are shown in Figure 7 and Figure 8. The assessed parameters including natural frequency, amplification factor and natural period in station 5 are presented in Table 2.

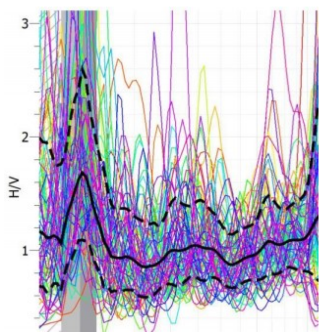

Figure 7: The H/V graph for all length of the record in station 5

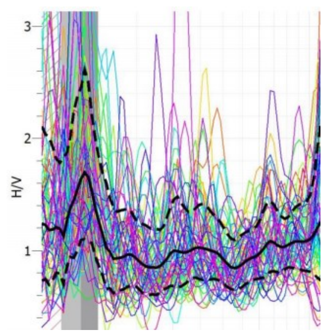

Figure 8: The H/V graph of the station 5 after noise removal

Table 2: The obtained results of H/V graph for station 23

Station No.	**Longitude**	**Latitude**	**Natural Frequency f_0 (Hz)**	**Amplification Factor(A_0)**	**Natural Period (s)**	**Vulnerability Index ($K=A_0^2/f_0$)**	**Remarks**
5	90.4372	23.6236	0.9606	1.6401	1.041	2.8003	low

5. RESULTS

Seismic vulnerability index (Kg) is an index indicating the level of vulnerability of a layer of soil to deform. Therefore, this seismic vulnerability index is helpful for locating of areas that are weak zone (unconsolidated sediment) during occurrence of earthquakes. Some studies like Nakamura (2000) showed a good correlation between seismic vulnerability index (Kg) and the distribution of earthquake disaster damage. This index is obtained from the peak value of HVSR squared, divided by the value of the predominant frequency. The seismic vulnerability index has been classified into four major types. These are Low (0–5), Moderate (6–10), High (11–20), and Very High (>20). The highest Kg value has been obtained at station P326 (90.346478, 23.8654). It may be concluded that this location is relatively weaker than other locations. Most of the zones having higher Vulnerability Index (Kg) are situated in reclaimed areas. In the following Figure 9 and Figure 10 the zonation maps of the natural frequency and amplification factor are presented.

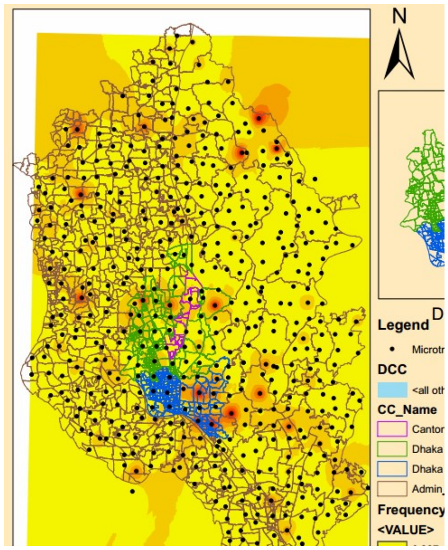

Figure 9: Natural frequency variation in RAJUK area

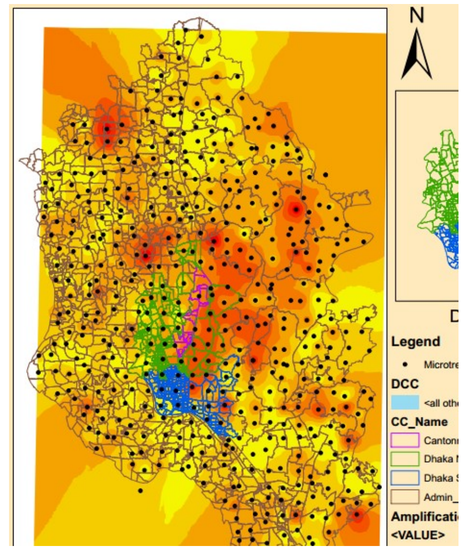

Figure 10: Amplification factor variation in RAJUK area

Figure 11 shows the vulnerable area in GIS map of 500 locations using Nakamura's Vulnerability Index (Kg). The number of low vulnerability type locations, which is 381, is the most common among 500 locations. The second most predominant number of vulnerability type is moderate type, which varies between 6 and 10. The number of very high type vulnerable site is seven.

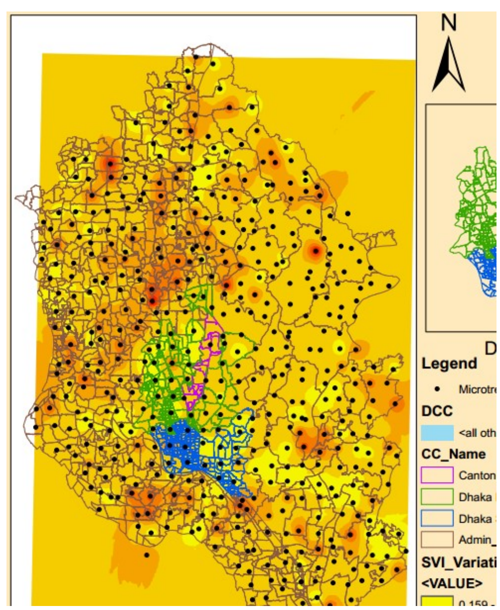

Figure 11: Seismic vulnerability index variation in RAJUK area

6. CONCLUSIONS

The microtremor investigation has been conducted within the RAJUK area. A network of 500 stations has been designed, considering the sensitive centers, roads, restricted areas, and flood plains. The outputs of the study have been presented in the form of natural frequency, amplification factor and seismic vulnerability index distribution. The predominant frequencies of the study area are relatively uniform, ranging from 0.2 to 8.0 Hz. The low frequencies are obtained to soft soil sites in maximum measurements and the high frequencies are obtained to stiff soil sites in a few measurements. The amplification factor (A_0) or peak of H/V spectral ratio is in investigation sites ranging from 0.8 to 6.6. Low values are measured for stiff soil sites and high values for soft soil sites. The seismic Vulnerability Index (Kg) varies between 0.2 and 124. The low seismic vulnerability index indicates that the areas are very stiff as well as thick sediment deposit. Seismic vulnerability index (Kg) in the study area has been found that the high values are scattered in the soft alluvial deposits area having a high seismic vulnerability indication. The results of microtremor investigation can be used as the input of many other studies, such as the site selection of geotechnical boreholes.

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