Case Study: Yangon Major City, VS30 Model for Seismic Hazard Assessment

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Abstract

Myanmar is an earthquake-prone country; there is a real need for creditable seismic zoning of the country in order to mitigate its earthquakes. The Sagaing Fault obviously is the main seismic source for this research area. Yangon is only about 30 km away from the seismically still active Sagaing Fault zone that lies to the east. The main seismotectonic structure of the research area is the Sagaing Fault which has caused some moderate to strong earthquakes in the Yangon area. Yangon is the former major capital city in Myanmar. Yangon area is fairly earthquake-prone as Myanmar itself lies in a major earthquake belt of the world. The earthquake hazard map of Yangon area is actually a seismic microzone map. It is noticed that the soil conditions and soil factor are incorporated. This part of fair to good foundation soils lies on a north-south trending anticlinal ridge of Neogene formations. The flanks, covered by the alluvium, are mostly occupied by satellite towns where the period values range from 0.13 to 1.00 seconds. The objective of this research is to estimate VS30 of the seismic motions in Yangon city by utilizing the geological map of Myanmar, transfer function and microtremor H/V ratio methods. Especially for future seismic hazard assessments, transfer function, microtremor observation and SPT of drilling sites are used to develop the site effect condition of Yangon city. This research indicates that the 175 to 360 m/s of the VS30 values are useful parameter for characterization of ground motion. Finally, the VS30 model will relate to the damage area of the Yangon city for the future earthquake.

Key words: Seismic hazard assessment, VS30, Transfer function, HVSR and Yangon major city

Introduction

Myanmar, on the eastern side of this collisional zone, lies east of the boundary between the Indian plate to the west, and the Sunda plate. The deformation and earthquakes in Myanmar and adjacent parts of southeast Asia are driven by the northward movement of the Indian subcontinent as it collides with the Eurasian plate Indian plate moves north-northeast with respect to the Sunda plate at a rate of approximately 45 mm/yr. Most of the differential motion between these two plates in Myanmar is concentrated on the Sagaing Fault, which is a major north-striking, right-lateral fault that has a slip rate of approximately 18 mm/yr based on GPS data. Myanmar can be regarded as one of the highly seismicity countries due to its occurrence of the Alpide Earthquake Belt. Since several hundred years ago, Myanmar has already experienced many destructive major earthquakes with the magnitude > 7.0 (Mw). Yangon, the old capital city (Fig. 1), is one of the cities of Myanmar that low to medium seismicity based on the seismicity and the records of the previous considerably high magnitude earthquakes. The other significant earthquakes are Yangon earthquakes of September 10, 1927 and December 17, 1927. These events also resulted in a certain amount of damage in Yangon. All of these events and their consequences, and the rapid growth of population and various sorts of structures alarm to conduct the seismic hazard analysis for this region and the seismic hazard assessment was therefore performed applying the probabilistic way.

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Indian and Burma Plate (Part of Eurasian Plate), and the Andaman Rift Zone. Moreover, some other faults whose geometry and other parameters are not well-known in and around this region also generated some earthquakes. Small numbers of intermediate and deep focus earthquakes can be seen in this region and those are caused by the subduction zone of Indian-Burma Plates (Mg Thein, 2001).

Regional geology

The Yangon area is underlain by alluvial deposits (Pliestocene to Recent), the non-marine fluvialtile sediments of Irrawady formation (Pliocene), and hard, massive sandstone of Pegu series (early-late Miocene). Alluvial deposits are composed of gravel, clay, silts, sands and laterite which lie upon the eroded surface of the Irrawaddy formation at 3-4.6 m above mean sea level (MSL). The rock type in Yangon is mainly soft rocks, which consist of sandstone, shale, limestones and conglomerate. The main geologic feature of the Yangon area is a low-lying anticlinal ridge that trends from north of Hlawga Lake to Shwe Dagon Pagoda hill for a distance of about 30 km. It is an elongated inlier of the Irrawaddy and Pegu beds surrounded by an alluvial plain. It is made up mainly Irrawaddy beds (Pliocene). Upper Pegu beds (Miocene) occupy only the northwestern part of the ridge. These Neogene rock units are folded into an elongated anticline. The low-lying ridge is flanked by Quaternary valley-filled deposits and alluvium in the west, and by the alluvium in the east (Fig. 3). In this area, the Irrawaddy Formation is subdivided by Wing Naing (1972) into two rock units. The lower unit (Arzarnigon sandrocks) mainly occurs in the northern part, and the upper unit (Danyingon clay) mainly occurs in the southern part. Because of the Monsoon climate, laterites and lateritic soil have been developed locally on these rocks, especially on the latter. The valley-filled deposits of gravels and sands with some clay bands occurs east of the Hlaing River. There is a minor fault trending approximately north-south. A small cross-fault is located north of Mingaladon, with downthrow on the southern side (Mg Thein, 2001).

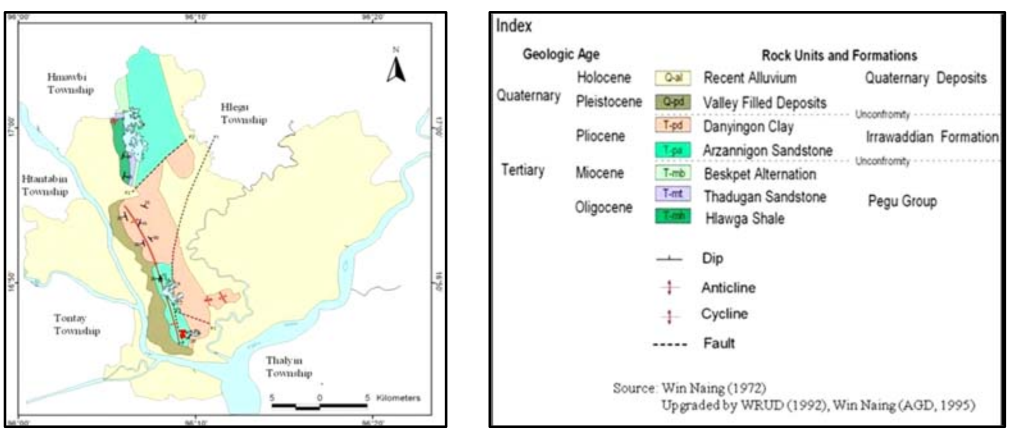

Figure (3). Geological map of around Yangon Region (Win Naing, 1972).

Past Earthquake Events

The Yangon Region is prone to natural disasters, including floods, storms, fires, earthquakes, and disease epidemics. Of all these natural disasters, floods, storms, and earthquakes are the most damaging in the Yangon Region. Among these natural disasters, all but earthquakes are able to receive early warnings for preparedness measures. The country itself is besieged by a series of faults, of which the Sagaing fault is the longest, trending north to south across the central part of the country. Yangon City is about 30 kilometres west of the Sagaing fault. History suggests that earthquakes have had grim consequences on lives, social assets, and physical systems in the region. The Yangon area is fairly earthquake-prone as it lies just outside a major earthquake-hazard zone that lies along the southern segment of the Sagaing Fault. Historical sources recorded that during the 19^{th} Century Yangon, then a mere provincial town, had felt five moderate shocks and five slight shocks which caused little damage to the wooden-fame houses in the town. Since 1900, there have been 14 recorded earthquakes in the Yangon area. These include ten slight shocks, three moderate shocks and only one fairly strong shock. The three moderate shocks with MMI VI-VII intensity, caused some damage, but no deaths. The fairly strong shock of 5^{th} May 1930, however, caused considerable damage and some 50 deaths in the city, this earthquake did not origainate in the Yangon area (Fig. 4). Actually it was merely the shock of the very destructive Bago earthquake of the same date felt at 8:15 p.m. in Yangon. The epicenter lay on the Sagaing Fault about 30 km south of Bago where a very strong shock, it was felt as a fairly strong shock in Yangon even though the city was about 50 km away for the epicenter. The intensity was estimated to range for MMI VII to VIII, depending on the strength of the underlying soils (Mg Thein, 2001).

Figure (4). Historical seismicity of around Yangon Region (Myo Thant *et al*., 2012).

Methodology

Multiple Reflections Analysis for SH-Wave

Transfer Function by (Ohta and Goto, 1976), It is noted that the shear wave velocity structures were calculated by using empirical equations, which mainly contributed on SPT, values for comparative analysis:

$$Vs30 = 62.48N^{0.218}H^{0.228}F \qquad (1)$$

where Vs30=Shear wave velocity (m/s), N=N-value, H=Depth (m), F=Coefficient of soil type, F=1.000 (Clay), F=1.073 (Sand), F=1.199 (Gravel)

N is average number of blows in SPT. Besides, the soil classification is decided by using the results of site investigation of standard penetration testing at twelve bore holes. The average values of N are used for determining the soil classification on each site (Ohta and Goto, 1978). The average values of N until a depth of 30 m at the sites surrounding the studied area vary from 10 to 32. Table 1 displays the relationship of soil types and predominant periods of the ground. Then, the average T_G-values are determined for each layer of evaluated subsurface soil profile by using the following table (Okada, 1971):

Table (1). The relationship of soil types and predominant periods of the ground (Okada, 1971)

Soil types	Periods (s)
I Hard soil	T_G<0.2
II Medium soil	0.2≦T_G<0.6
III soft soil	0.6≦T_G

Microtremor Method

Microtremor is a low amplitude ambient vibration of the ground caused by man-made or atmospheric disturbances. Observation of microtremors can give useful information on dynamic properties of the site such as predominant period and amplitude. Microtremor observations are easy to perform, inexpensive and can be applied to places with low seismicity as well, hence, microtremor measurements can be used conveniently for seismic microzonation. More detailed information on the shear wave velocity profile of the site can be obtained from microtremor array observation. Among various kinds of geological explorations by using microtremor records, the horizontal to vertical spectrum ratio (H/V spectrum) is considered most effective (Nakamura 1989). HVSR (Horizontal-Vertical Spectra Ratio) is consists in estimating the ratio between the Fourier amplitude spectra of the horizontal (H) to vertical (V) components of ambient noise vibrations recorded at one single station. This HVSR method postulates the shape of the Fourier spectrum (Nakamura, 2000). Equation (2) shows the method used to calculate HVSR (Horizontal to Vertical Spectral Ratio) using the observed records:

$$HVSR = \frac{\sqrt{F_{NSi}(\omega)^2 + F_{EWi}(\omega)^2}}{F_{UDi}(\omega)^2} \qquad (2)$$

where $F_{NSi}(\omega)$, $F_{EWi}(\omega)$and $F_{UDi}(\omega)$ denote the Fourier amplitude of the NS, EW and UD components of each interval, respectively, and ω is the frequency. The site effect is given in terms of a transfer function. A hardrock basement is covered by a soft sediment layer of thickness, H and shear wave velocity, Vs. The accuracy of microtremor measurements is qualified using (Dobry, 2000) equation for stations with certain thicknesses and shear-wave velocities;

$$T = 4H/Vs \qquad (3)$$

In the most of early studies, researchers correlated shear wave velocity with Standard Penetration Tests blow counts (Kanai, 1966 and Ohta & Goto, 1976). Site soil conditions are important in determining Seismic Design Category. Hard, competent rock materials efficiently transmit shaking with high-frequency (short-period) energy content but tend to attenuate (filter out) shaking with low-frequency (long-period) energy content. Deep deposits of soft soil transmit high-frequency motion less efficiently but tend to amplify the low-frequency energy content. If the nature and depth of the various soil deposits at a site are known, geotechnical engineers can perform a site response analysis to determine the importance of these effects. The average shear S-wave velocities for all microtremor points are obtained from the shear wave velocity structure at upper 30m depth. The seismic design category classification (IBC, 2009) is shown in Table 2.

Table (2). The International Building Code (IBC, 2009).

Site Class	$\bar{v}_s^{30}$	*SPT* ($\bar{N}$)
E (Soft Soil)	< 600 ft/s (<175 m/s)	< 15
D (Medium Dense or Stiff Soil)	600-1200 ft/s (175-350 m/s)	15-50
C (Dense Soil)	1200-2500 ft/s (>350 m/s)	>50

Research Analysis

The soil classification is decided by using the results of site investigations of standard penetration testing at 22 boreholes in research area as shown in Fig. 5. The average values of *N* are used for determining the soil classification on each site. The average values of N until a depth of 30 m at the sites surrounding Yangon city vary from 10.00 to 86.00. The S-wave velocity structures which give such satisfactory results are at 22 drilling sites. Generally, the predominant periods of the transfer functions are more important and applicable for determination of S-wave velocity because it is more stable and well reflects to sediment depth and S-wave velocity. It was received the realistic shear wave velocities and reliable thickness of soil layers and depths of lose sediment from these 22 drilling sites of S-wave velocity structures.

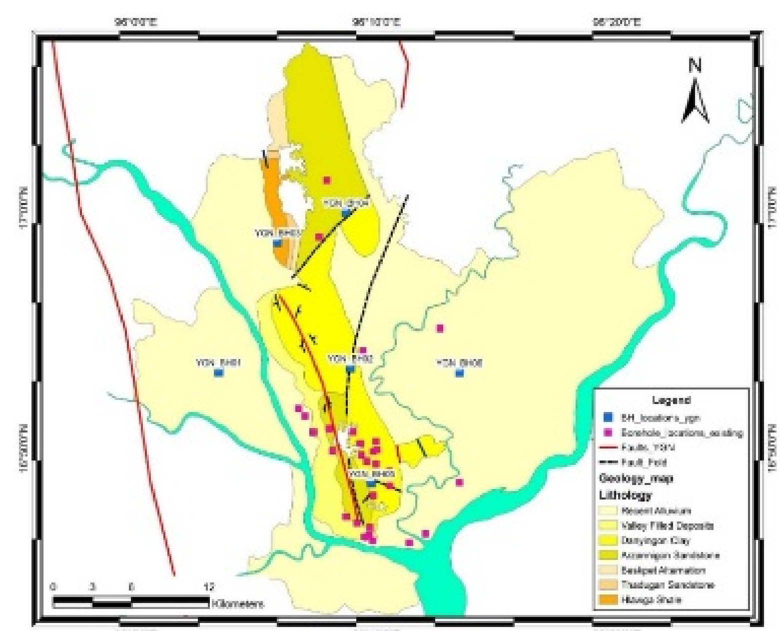

Figure (5). Location map of the borehole sites in Yangon city

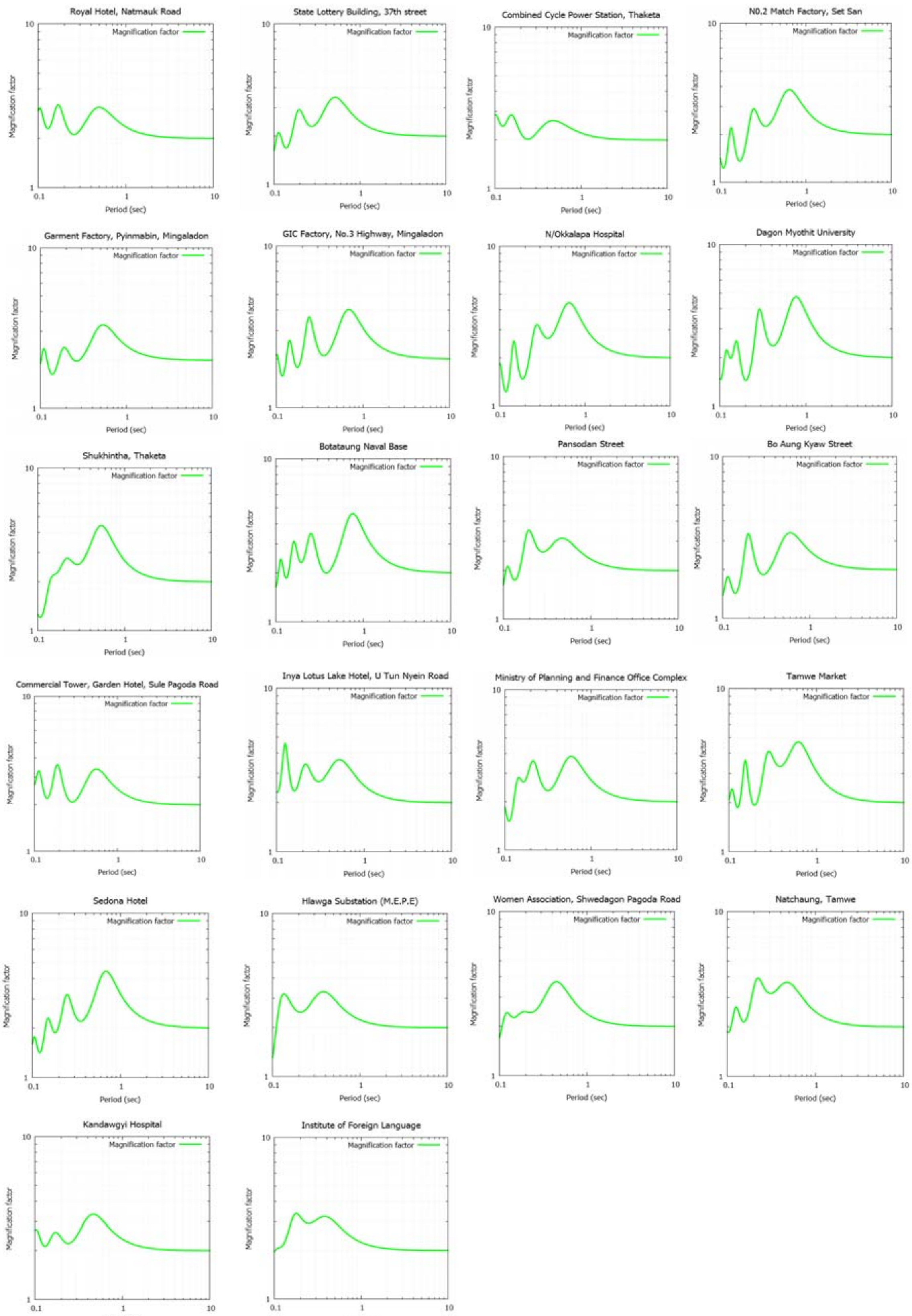

Figure (6). The magnification factors and period (sec) by using the transfer functions in Yangon City.

Table (3). The theoretical calculation of predominant periods of the transfer function.

No.	Name	Depth (m)	Long	Lat	Freq (Hz)	Period (Sec)	MAX (MF)
1	Royal Hotel, Natmauk Road	30	96.1275	16.8008	5.90	**0.17**	3.210
2	Yangon Commercial Tower, Sule Pagoda Road	30	96.1586	16.7725	5.30	**0.19**	3.618
3	Inya Lotus Lake Hotel, U Tun Nyein Road	30	96.1503	16.8453	8.00	**0.13**	4.575
4	Institute of Foreign Langauge (I.F.L)	30	96.1414	16.8253	5.60	**0.18**	3.388
5	Pansodan Street	30	96.1622	16.7789	5.10	**0.20**	3.518
1	Garment Factory, Pyinmabin, Mingaladon	30	96.1322	17.0192	1.90	**0.53**	3.299
2	Thaketa Shukhintha	30	96.2006	16.7747	1.90	**0.53**	4.412
3	State Lottery Building, 37th Street	30	96.1617	16.7736	2.00	**0.50**	3.496
4	Bo Aung Kyaw Street, Zabyu Aung Construction Site	30	96.1642	16.7697	1.70	**0.59**	3.384
5	Ministry of Planning and Finance Office (Yankin)	30	96.16	16.8247	1.70	**0.59**	3.846
6	Hlawga Substation (M.E.P.E)	30	96.1269	16.9803	2.60	**0.38**	3.309
7	Women Association, Dagon	30	96.1531	16.7819	2.20	**0.45**	3.723
8	Tamwe Natchaung	30	96.1756	16.8183	4.50	**0.22**	3.941
9	Kandawgyi Hospital	30	96.1644	16.8011	2.20	**0.45**	3.337
10	Tamwe Market	30	96.1759	16.8077	1.60	**0.63**	4.706
1	N0.2 Match Factory, Set San	30	96.1561	16.8467	1.00	**1.00**	3.833
2	GIC Factory, No.3 Highway, Mingaladon	30	96.16	16.778	1.50	**0.67**	4.043
3	N. Okkalapa Hospital	30	96.1573	16.901	1.50	**0.67**	4.434
4	Dagon Myothit University	30	96.2109	16.9169	1.30	**0.77**	4.766
5	Botataung Naval Base	30	96.1894	16.7683	1.30	**0.77**	4.637
6	Sedona Hotel, Kabaaye Pagoda Road	30	96.1561	16.829	1.50	**0.67**	4.428

The values of S-wave velocity from the 22 drilling sites were generally calculated between 170 and 360 m/s. Therefore, it is clearly found that it was utilized to take the S-wave velocity from the 22 drilling sites to calculate the predominant periods. Fig. 6 is shown as the magnification factors and period (sec) by using the transfer functions in Yangon City.

The characteristics of seismic waves during earthquakes were mainly influenced by the local site conditions. The unconsolidated soil deposits tend to amplify certain frequencies of ground motion and extend the duration of the shaking which may cause further earthquake damage. According to the geological site conditions, the expected variation in the ground motion makes it necessary to perform a more detailed seismic hazard assessment as the research area. The nature and distribution of earthquake damage is strongly affected by the response of soils which is controlled in layers part by the mechanical properties of soil. Table (3) is displayed as the theoretical calculation of predominant periods of the transfer function.

Based on the fundamental periods of the ground for each observation site, the hard soil has seen in Royal Hotel, Yangon Commercial Tower, Inya Lotus Lake Hotel, Institute of Foreign Language and Pansodan Street sites of Yangon city because the smaller than 0.2 sec of the fundamental periods of the ground fine by the theoretical calculation. The recent alluvial and valley filled deposits sediments of the research area, the fundamental period identified from the S-wave velocity are mostly in the range of 0.22 - 0.63 sec, therefore these fundamental period obtained may indicate the presence of generally medium sediments in the alluvial and valley filled deposits sediment of study areas. The N0.2 Match Factory, GIC Factory, N. Okkalapa Hospital, Dagon Myothit University, Botataung Naval Base and Sedona Hotel sites are situated on the soft soils (0.6 sec≤ T_G) because these location sites are less than 0.6 sec in the study area. Moreover, the magnification factors of Yangon city are between 3.00 and 5.00 (Fig. 7).

The results may confirm the suitability of using the S-wave velocity of transfer functions as a geophysical exploration tool in those structures with significant impedance contrast between sedimentary layers and the assume bedrock. Thus the ground motion amplification due to medium soils, common in urban of Yangon city, is a major contributor to increasing damage and number of casualties.

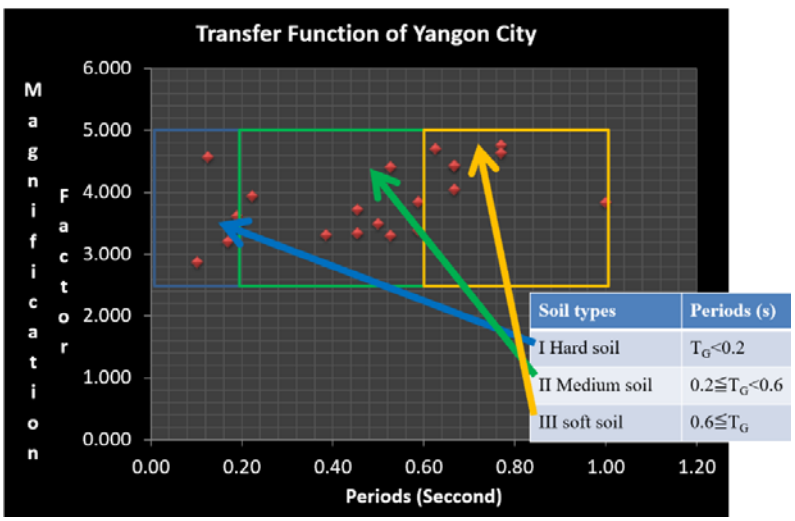

Figure (7). The relationship of the transfer function and magnification factor.

Microtremor Survey Sites

Microtremor is a low amplitude ambient vibration of the ground caused by man-made or atmospheric disturbances. Observation of microtremors can give useful information on dynamic properties of the site such as predominant period and amplitude. Microtremor measurement is an efficient alternative method, which will be used for detecting both stratigraphy in terms of the stiffness and resonant frequency. Both results (stratigraphy-stiffness and resonant frequency) will be compared with results from seismic prospecting and transfer functions from earthquakes as well as from more conventional geotechnical data (borehole lodging, in-situ and laboratory tests). Moreover, the single microtremors observations of 119 sites in Yangon City as shown in the Fig. 9-a. The measurements were carried out during the daytime using a microtremor instrument which is model of Mitutoyo-GPL-6A3P and serial No. 0418707 as shown in Fig. 8. A single seismic station was used for the microtremor measurements. It was composed of a short-period, three-component seismometer with natural period of one second, a 24-bit A/D converter with GPS time, sampling each channel at 100, and a laptop computer to control the system and store the data. At each sites microtremors were recorded with a sampling rate of 100 Hz for 30 minutes. During the measurements particular attention was given to keep the recordings free from very local noise sources, like e.g. passing pedestrians, vehicles or operating machineries. Meteorological disturbances, e.g. rainfall or gusty wind, did not occur during the observation period. The site's topography and local peculiarities were also considered, e.g. artificial soil replenishments, floor coverings, paved or tarmac roads, and neighboring elevated structures. The microtremor data analysis is carried out by using this initial model.

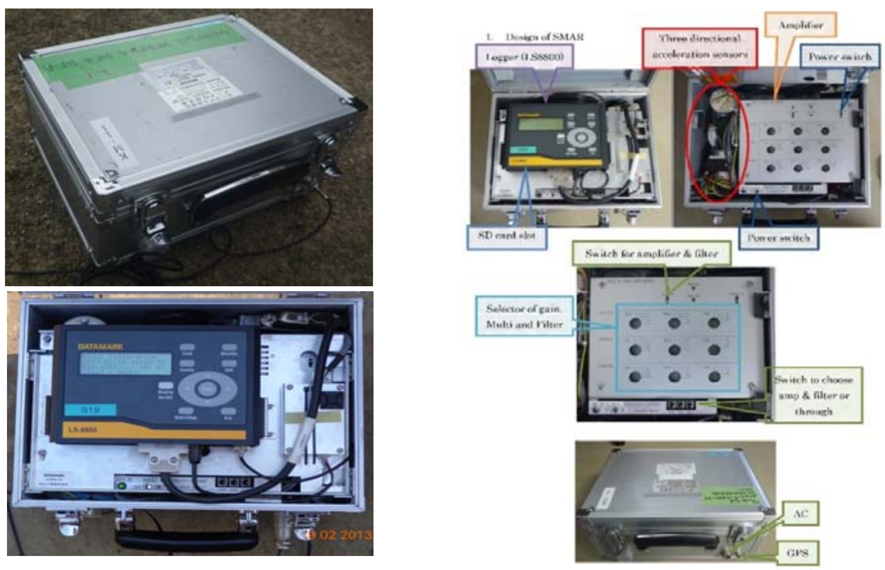

Figure (8). The microtremor devices (model of Mitutoyo GPL 6A3P and serial No. 0418707)

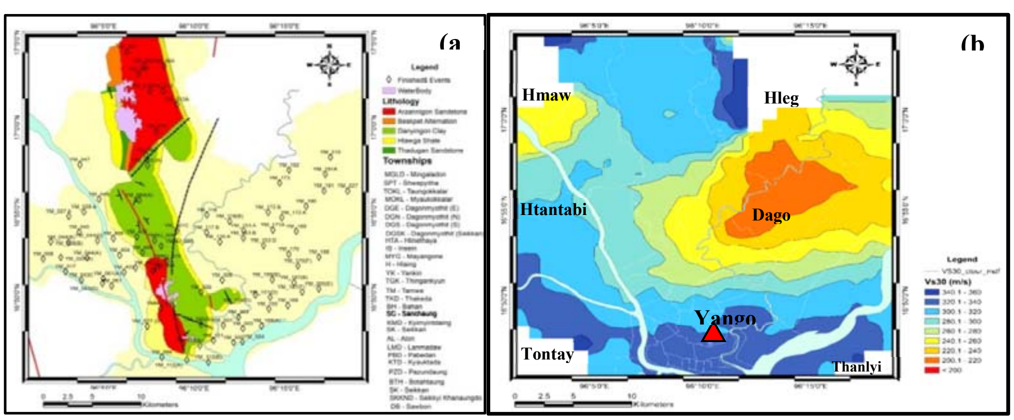

Figure (9). (a) Microtremor measurement points in Yangon City and (b) the Vs 30 Contour map of Yangon City, Yangon Region.

The final shear wave velocity structures are then developed by H/V spectral ration inversion technique (Figs. 10-a&b). The site parameter is used in terms of the average shear wave velocity to the upper 30 m; Vs30. Therefore, Vs30 of each microtremor survey locations is determined and then develop the Vs30 contour map of Yangon City. For Yangon city, it is showed that the typical average shear wave velocity approximately is 200 to 350 m/s for the sediment layer from the surface to the bedrock according to the microtremor results.

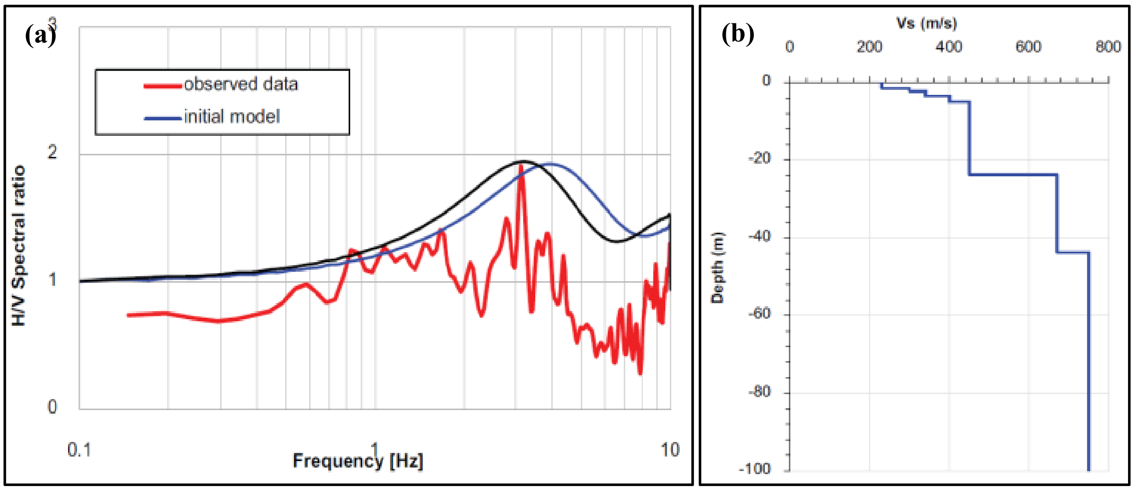

Figure (10). (a) The H/V spectral ratio of mictrotremor survey point and (b) the shear wave velocity profile of MSB-04 (Vs30 – 444.818 m/s).

Site Class is determined based on the average properties of the soil within 100 feet (30 meters) of the ground surface. Geotechnical engineers use a variety of parameters to characterize the engineering properties of these soils, including general soil classifications as to the type of soil, (e.g. hard rock, soft clay), the number of blows (*N*) needed to drive a standard penetration tool 1 foot into the soil using a standard hammer, the velocity (V_s) at which shear waves travel through the material as measured by on-site sonic and other tests, and the shear resistance of the soil (S_u) as measured using standard laboratory test procedures.

Based on these description, Fig. 9-b depicting the Vs30 contour show the site condition of Yangon City and then can present the respective soil class of each portion of the city. In Fig. 9, the medium soil condition governed to the research area ($175 \leq \overline{V}s < 350$). The hard soil investigated the small region in the research area which are north and southwest of the studied area are (≥350 m/s). That is why, it is verified that the research area is influenced the medium soil condition according to the calculation of the Vs 30 from the distribution of the single microtremor observations. When the sites are located over the same structure, it can be assume that the S-wave velocity is approximately constant from site to site. Inversely, if it can be assume that in a certain region the surface layers have approximately a constant thickness, the dominant frequency at each point would be then related to an S-wave velocity and a map of surface velocities could be obtained. Therefore the almost of the research area is also found the medium soil in the studied area.

Conclusions

Yangon, the old capital city, is one of the cities of Myanmar that low to medium seismicity based on the seismicity and the records of the previous considerably high magnitude earthquakes. The main geologic feature of the Yangon area is a low-lying anticlinal ridge that trends from north of Hlawga Lake to Shwe Dagon Pagoda hill for a distance of about 30 km. Among various kinds of geological explorations by using microtremor records, the horizontal to vertical spectrum ratio (H/V spectrum) is considered most effective. For Yangon city, it is showed that the typical average shear wave velocity approximately is 175 to 360 m/s for the sediment layer from the surface to the bedrock according to the microtremor results. It is verified that the research area is influenced the medium soil condition according to the calculation of the Vs 30 from the distribution of the single microtremor observations. According to the Vs30 map, the shear wave velocity of the around of Yangon city is also found the medium soil class. Thus the ground motion amplification due to medium soils (0.22 - 0.63 sec), common in urban of Yangon city, is a major contributor to increasing damage and number of casualties.

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