DETERMINATION OF SITE EFFECTS OF SOIL CONDITION ON SPT VALUES FOR GROUND MOTION IN YANGON BUSINESS CITY, MYANMAR

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Abstract

The influence of local geologic and soil conditions on the intensity of ground shaking and earthquake damage has been known for many years. Local site effects play an important role in earthquake resistant design and must be accounted for on case by case basis. The nature and distribution of earthquake damage is strongly influenced by the response of soils conditions. This response is controlled in large part by the mechanical properties of the soil. Yangon, also known as business city, 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. 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 and the magnification factors are 3.2 to 5.0. This research is purposed to determine the predominant periods and amplification factors of Yangon business city by utilizing the geological map of Yangon and transfer function method. Especially for ground motion, transfer function method and SPT of drilling sites are used to develop the site effects condition of Yangon business city.

Keywords: Ground motion, Periods, Magnification factors, Transfer function method and Yangon business city

Introduction

Myanmar is located at the plate boundary between the Indian and Sunda plates. It is one of the most tectonically active regions in Southeast Asia. During the past several hundred years, numerous earthquakes occurred within this region, resulting from the on-going oblique convergence and extrusion processes between the Indian, Eurasian and Sunda plates (Wang, 2013). 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 business largest 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 (Mg Thein, 2001).

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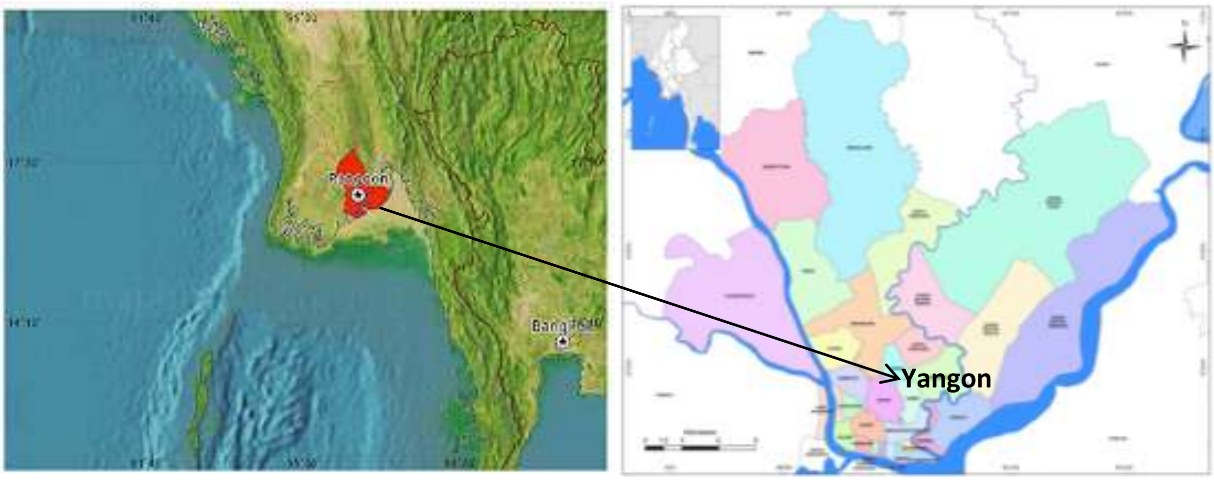

Figure 1 Location maps of the Yangon business region

Tectonic setting

Myanmar spans a very complex and broad tectonic belt that accommodates the northward translation of the Indian Plate past the Sunda Plate (e.g., Socquet *et al*., 2006). This motion is primarily expressed by right-lateral slip on the Sagaing Fault, which bisects Myanmar from south to north (Win Swe, 1970; Curray *et al*., 1979; Le Dain *et al*., 1984), and right-lateral oblique convergence across the northern Sunda megathrust beneath the western coast and adjacent Indo-burman Ranges (Nielsen *et al*., 2004; Socquet *et al*., 2006).

Myanmar is currently experiencing strain partitioning between the Indian and Sunda plates. In the west the Indian plate is colliding obliquely with the Burma plate along the northern extension of the Sunda megathrust (Socquet *et. al*., 2006). In the east, relative motion between the Burma and Sunda plates occurs along the 1200 km long Sagaing fault. Farther south, this relative motion rifts the Andaman Sea Basin and bisects Sumatra along the 1900 km long Sumatran fault (Sieh and Natawidjaja, 2000) and West Andaman fault (Berglar *et al*., 2010). Myanmar is located at the very active tectonic area which includes the Burma oblique subduction, the Sagaing strike slip fault system and the southern opening region (Fig. 2). The Burma microplate consists of the Andaman and Nicobar island chains, northern Sumatra, and the Andaman Ocean Basin. Surrounded by the Indian, Sunda, Australian and Eurasian plates, the Burma microplate is in a highly tectonically active region of the world. On the western flank lies the Sunda trench, where the Indian plate is subducting under the overriding Burma microplate. To the east lies the Sunda plate, and to the south lies the Australian plate. Yangon is tectonically bounded by the Indian-Burma plates, subduction in the west, Sagaing fault in the east, West BagoYoma fault in the north, Kyaykkyan fault in the northeast, and the Andaman rift zone in the south.

The earthquakes observed in the Andaman sea region are shallow focus earthquakes that show not only the normal fault mechanisms but also the strike-slip fault mechanisms. In and around Yangon Region, most of the earthquakes happened are shallow focus earthquakes, especially within about 250 km in radius. Most are related with Sagaing Fault, some corresponds to the blind faults located under Yangon Region and subduction zone of 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).

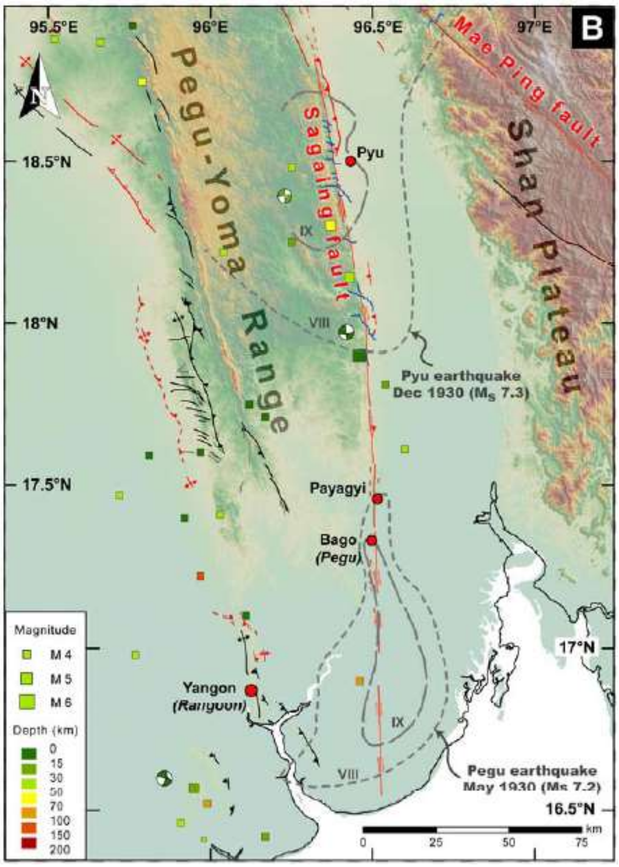

Figure 2 Active tectonic framework and recent earthquake history around Yangon business city (Wang, 2013)

Geology of Study Area

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).

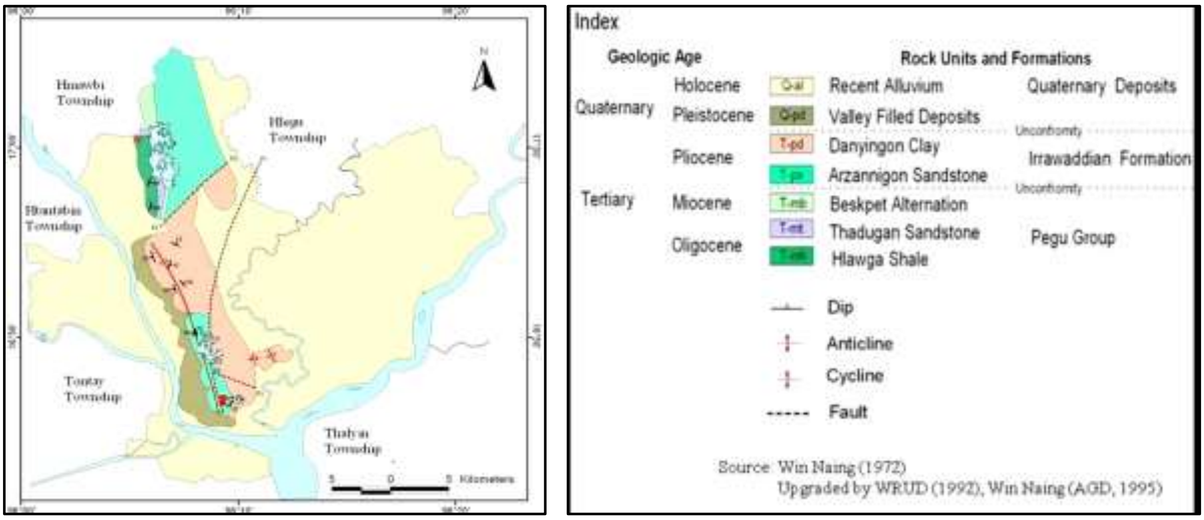

Figure 3 Geological map of around Yangon Region (Win Naing, 1972)

Historical Earthquakes

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.

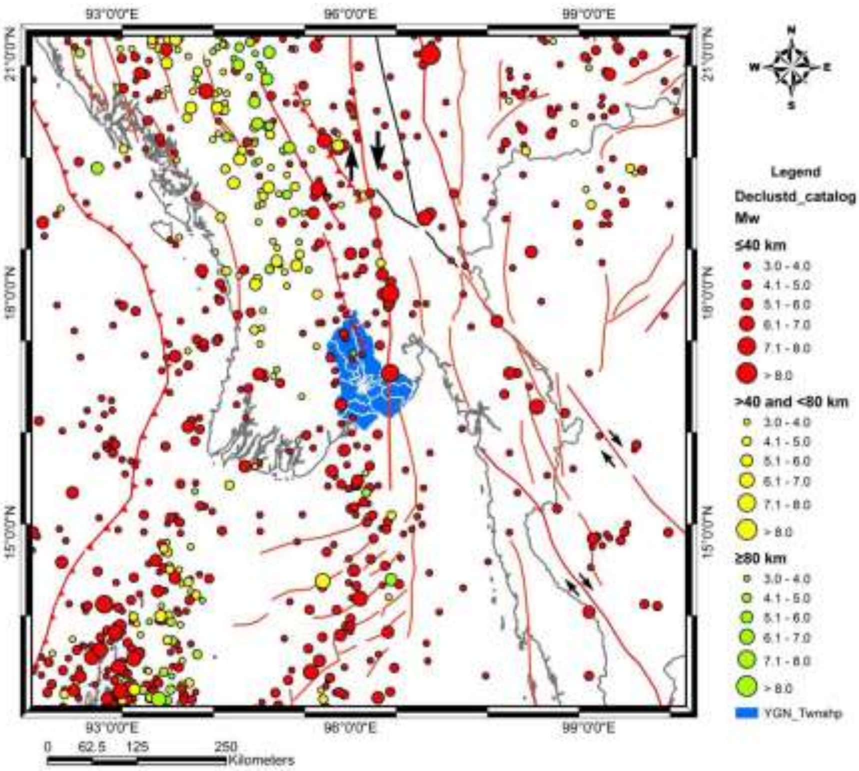

Figure 4 The seismicity of Yangon region (Data Source – ANSS earthquake catalog, 1963 – 2012) (Myo Thant, *et. al*., 2012)

Yangon City is about 30 kilometers 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 19th 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 5th May 1930, however, caused considerable damage and some 50 deaths in the city, this earthquake did not originate in the Yangon region (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).

Research Methodology

Local site conditions can profoundly influence all of the important characteristics; amplitude, frequency content, and duration of strong ground motion. The extent of their influence depends on the geometry and material properties of the subsurface materials, on site topography, and on the characteristics of the input motion. The nature of local site effects can be illustrated in several ways: by simple, theoretical ground response analyses, by measurements of actual surface and subsurface motions at the same site, and by measurements of ground surface motions from sites with different surface conditions (Kramer, 1996).

Multiple Reflections Analysis for SH-Wave

There are important theoretical reasons why ground surface motions should be influenced by local site conditions. At most sites the density and S-wave velocity of materials near the surface are smaller than at greater depths. The characteristics of local soil deposits can also influence the extent to which ground motion amplification will occur when the specific impedance is constant (Kramer, 1996). 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). Table 1 displays the relationship of soil types and predominant periods of the ground and Table 2 shows the international building code (IBC, 2009). 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	$0.2\leqq T_G<0.6$
III soft soil	$0.6\leqq T_G$

Table 2 The International Building Code (IBC, 2009)

Site Class	$\overline{v}_s^{30}$	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.

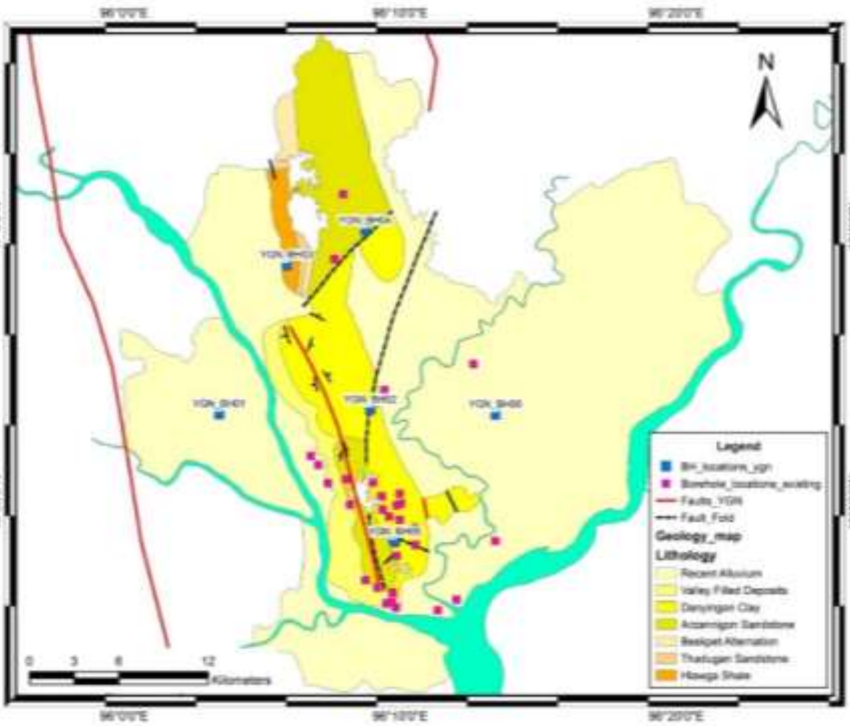

Figure 5 Location map of the borehole sites in Yangon business city

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. 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 example of the magnification factors and period (sec) by using the transfer functions method in Yangon City.

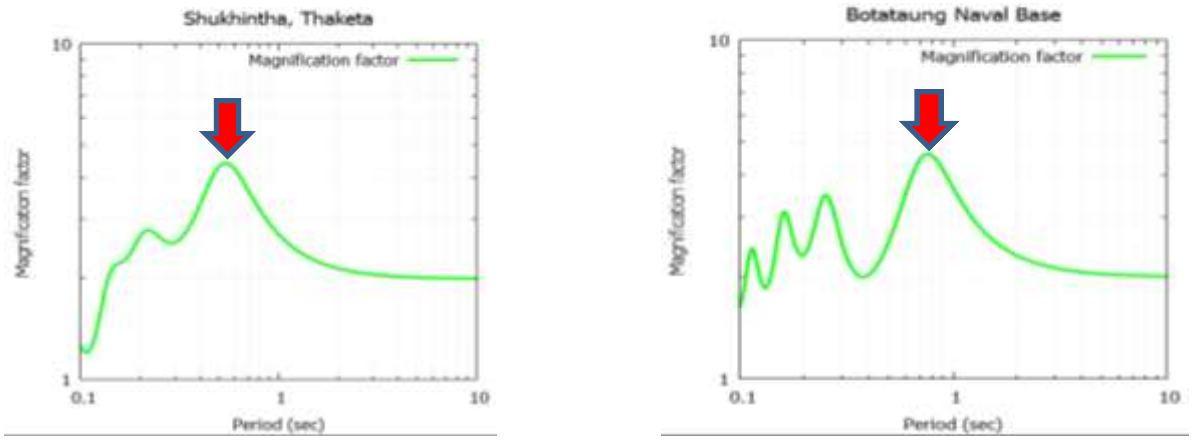

Figure 6 Example of the magnification factors and period (sec) by using the transfer functions method in Yangon business city

Table 3 The theoretical calculation of frequency, predominant periods and magnification factors of the transfer functions method

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
6	Garment Factory, Pyinmabin, Mingaladon	30	96.1322	17.0192	1.90	0.53	3.299
7	Thaketa Shukhintha	30	96.2006	16.7747	1.90	0.53	4.412
8	State Lottery Building, 37th Street	30	96.1617	16.7736	2.00	0.50	3.496
9	Bo Aung Kyaw Street, Zabyu Aung Construction Site	30	96.1642	16.7697	1.70	0.59	3.384
10	Ministry of Planning and Finance Office (Yankin)	30	96.16	16.8247	1.70	0.59	3.846
11	Hlawga Substation (M.E.P.E)	30	96.1269	16.9803	2.60	0.38	3.309
12	Women Association, Dagon	30	96.1531	16.7819	2.20	0.45	3.723
13	Tamwe Natchaung	30	96.1756	16.8183	4.50	0.22	3.941
14	Kandawgyi Hospital	30	96.1644	16.8011	2.20	0.45	3.337
15	Tamwe Market	30	96.1759	16.8077	1.60	0.63	4.706
16	N0.2 Match Factory, Set San	30	96.1561	16.8467	1.00	1.00	3.833
17	GIC Factory, No.3 Highway, Mingaladon	30	96.16	16.778	1.50	0.67	4.043
18	N. Okkalapa Hospital	30	96.1573	16.901	1.50	0.67	4.434
19	Dagon Myothit University	30	96.2109	16.9169	1.30	0.77	4.766
20	Botataung Naval Base	30	96.1894	16.7683	1.30	0.77	4.637
21	Sedona Hotel, Kabaaye Pagoda Road	30	96.1561	16.829	1.50	0.67	4.428

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 the frequency, predominant periods and magnification factors of the transfer functions method.

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 business 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 periods 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 (Fig. 7). Moreover, the magnification factors of Yangon city are between 3.00 and 5.00 (Fig. 8). The map of predominant periods and the map of magnification factors are very reliable for the site effects of ground motion in this research area.

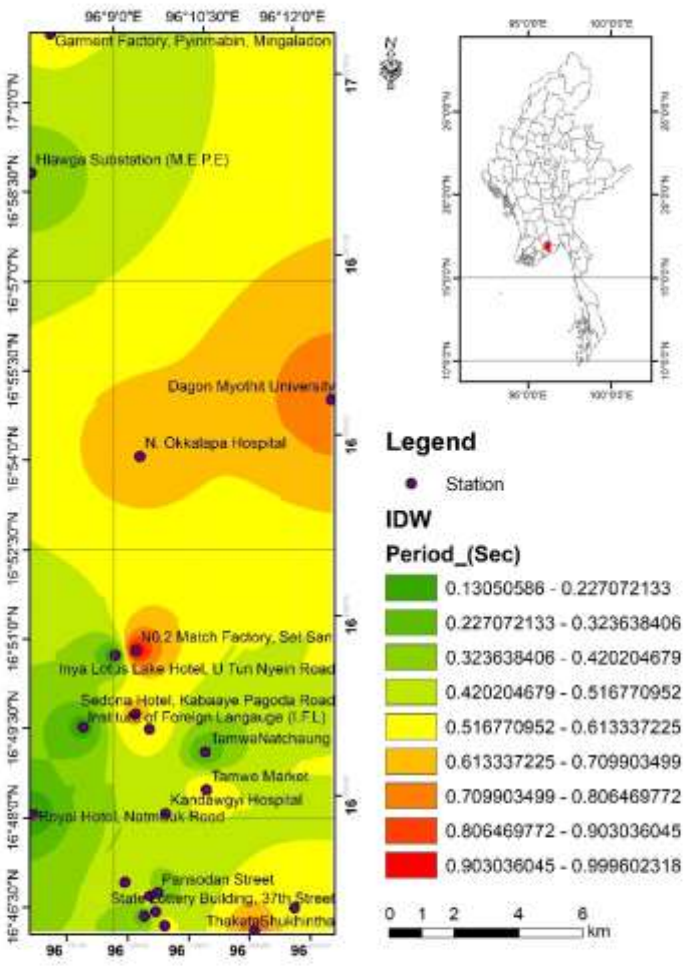

Figure 7 The predominant periods map of the research area

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.

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.

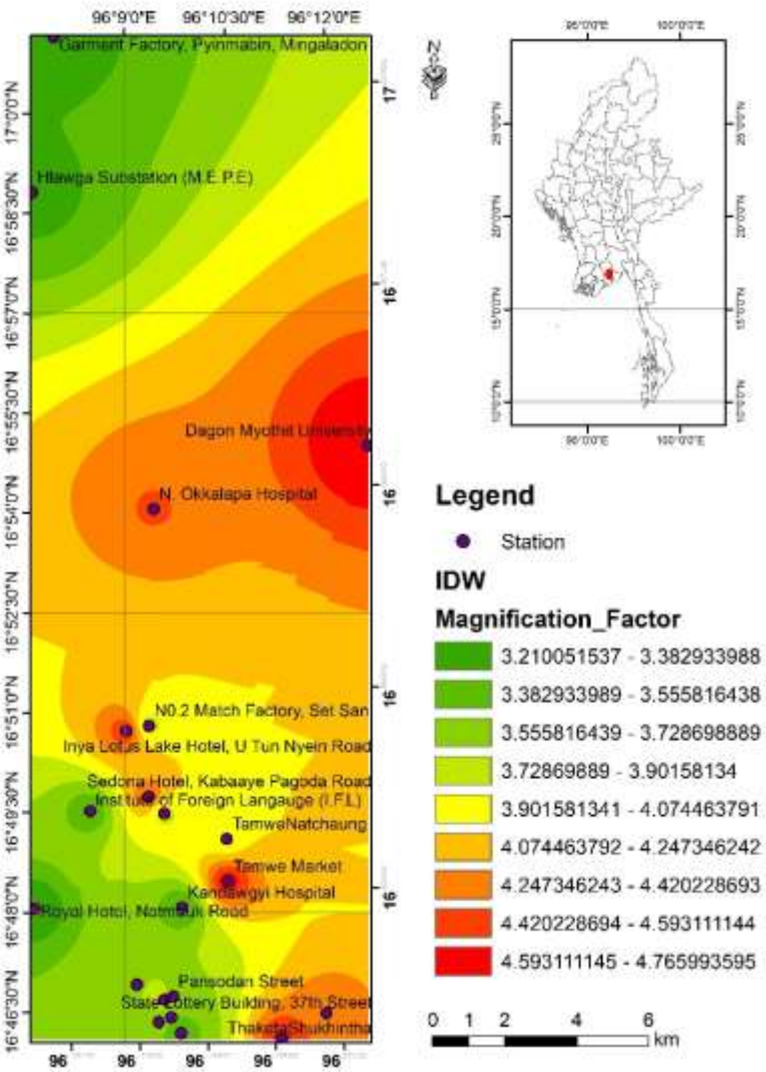

Figure 8 The magnification factors map of the research area

Based on this description, the Vs30 contour show the site condition of Yangon business city and then can present the respective soil class of each portion of the city. The medium soil condition governed to the research area (175≤$\bar{V}$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 Vs30 from the distribution of the 22 bore-hole sites. When the sites are located over the same structure, it can be assumed that the S-wave velocity is approximately constant from site to site. Inversely, if it can be assumed 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 business city, known as largest city, is one of the cities of Myanmar that low to medium seismic region 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. For Yangon business city, it is verified that the research area is influenced the medium soil condition (170 m/s to 360 m/s) according to the calculation of the Vs30 from the distribution of the SPT values. Moreover, the magnification factors of Yangon city are between 3.00 and 5.00. The map of predominant periods and the map of magnification factors are very reliable for the site effects of ground motion in the research area. Thus, the ground motion amplification due to medium soils (0.22 - 0.63 sec), common in business Yangon city, is a major contributor to increasing damage and number of casualties in the future.

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