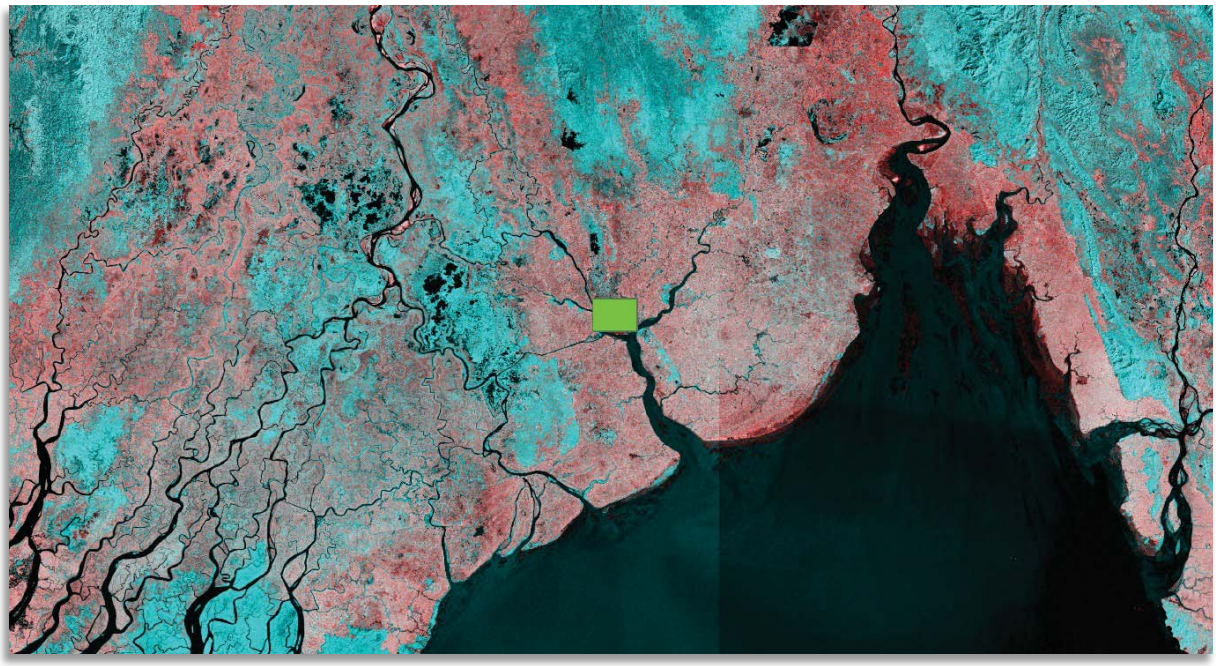
DEVELOPING PROBABILISTIC SEISMIC HAZARD MAPS OF YANGON, YANGON REGION, MYANMAR



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EXECUTIVE SUMMARY

According to the seismicity and the records of the previous considerably high magnitude earthquakes, Yangon Region can be regarded as the low to medium seismicity region. Moreover, tectonically the region is surrounded by the subduction zone between the Indian Plate and Burma Plate to the west and the right lateral Sagaing fault to the east. The most significant earthquake happened around this region is the Bago earthquake of 5th May, 1930 with the magnitude of 7.3. This earthquake caused 500 casualties and great destruction in Bago. However, considerable damage and 50 deaths were recorded in Yangon. It was originated from the Sagaing fault. The seismic hazard analysis is performed for Yangon Region by applying the probabilistic way. In conducting seismic hazard analysis, firstly the most possible seismic sources are identified and the seismic source parameters are then determined for each sources. Based on the seismicity, focal mechanism study of the previous events, and the geological data, the main seismic sources to cause the earthquake potentials for this region are subduction zone of Indian Plate beneath Burma Plate, Sagaing fault, and Kyaukkyan fault.

As the first step, with the aid of the United Nations Human Settlements Programme (UN-HABITAT), Myanmar Geosciences Society (MGS), Myanmar Engineering Society (MES) and Myanmar Earthquake Committee (MEC) conducted the seismic hazard assessment for Yangon City (Yangon Region); and risk assessment for Pyay (Bago Region). This report will represent the results of SHA for one of these three cities, Yangon City, Yangon Region.

The main objective of the present project is to develop the seismic hazard and risk maps of the city. To develop the seismic hazard maps, the methodology of probabilistic seismic hazard assessment (PSHA) is applied and the resulted seismic hazards are presented in terms of peak ground acceleration (PGA), spectral acceleration (SA) and peak

ground velocity (PGV) for 10% and 2% probability of exceedance in 50 years (475 years and 2,475 years recurrence intervals). The resulted seismic hazards are lead to use in the SRA and additionally these hazard maps are very useful for the urban land-use planning and the seismic resistance building construction purposes.

1. INTRODUCTION

Yangon is one of the cities of Myanmar and the former capital (Figure 1), can said that low to medium seismicity based on the seismicity and the records of the previous considerably high magnitude earthquakes. Some of the large earthquakes that caused the considerable damages to some buildings and some casualties in and around Yangon Region can be recognized in the past records, e.g. the magnitude 7.3, earthquake that struck on May 5, 1930 and December 3, 1930 earthquake with the same magnitude (Figure 2). The former earthquake, well-known Bago earthquake, caused 50 deaths and great damages in Yangon while 500 casualties were resulted in Bago. 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.

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). Even though the magnitude cannot definitely be known for those events, all of the events probably areestimated as at least M 6 based on the records of damages (at that time mostly the Pagoda). Within the radius of about 250 km, in the records of the recent and historical earthquakes, the maximum earthquake is Maymyo earthquake and its magnitude is estimated as probable of M > 8.0.

This event was felt in Shan State, Mandalay Region, Ruby Mines, Shwebo, Sagaing, Lower Chindwin Kyaukkse, Myingyan, Meikhtila, Magwe, and Yamethin, and also felt in

Taungoo and Bago cities. The maximum intensity was estimated as Rossi-Forel scale, VII. Several aftershocks happened for three succeeding months and this earthquake was originated from Kyaukkyan strike-slip fault. The damage properties of this earthquake was smaller in amount if compared with the magnitude due to the scarce population and characteristics of houses and dwellings.

As mentioned before, although the magnitude of Maymyo earthquake is very high enough to cause the severe damage and high amount of casualties, the resulted damage properties and number of casualties are very smaller in amount. The high destructive earthquakes happened during 1929 - 1930 in Bago Region, near Taungoo, Bago and Yangon. In 1917, the considerable high magnitude earthquake happened in Bago, however the damage is not so much, just shaking down of the umbrella of Shwemawdaw Pagoda. Moreover, two significant earthquakes also occurred near the vicinity of Yangon in 1927; the first one happened in 10th September and the second one is 17th December. Among them, the second one struck with the intensity of VII, causing the certain amount of damage in Yangon. The major events happened on 8th Aug, 1929 (well-known Swa earthquake), 1930 May 5 (Bago earthquake) and Dec 4, 1930 (Phyu earthquake). Among these events, the most affected earthquake to Bago is the magnitude 7.3 Bago earthquake and this earthquake caused 500 casualties and great damage to properties in Bago and it also resulted many deaths (around 50 persons) and high damage in Yangon. In Bago most portion of the town was considerably ruined and fire, and large ground cracks, exuded sand and water, probably the characteristics of liquefaction also occurred. All of these three events were originated from Sagang right-lateral strike-slip fault.

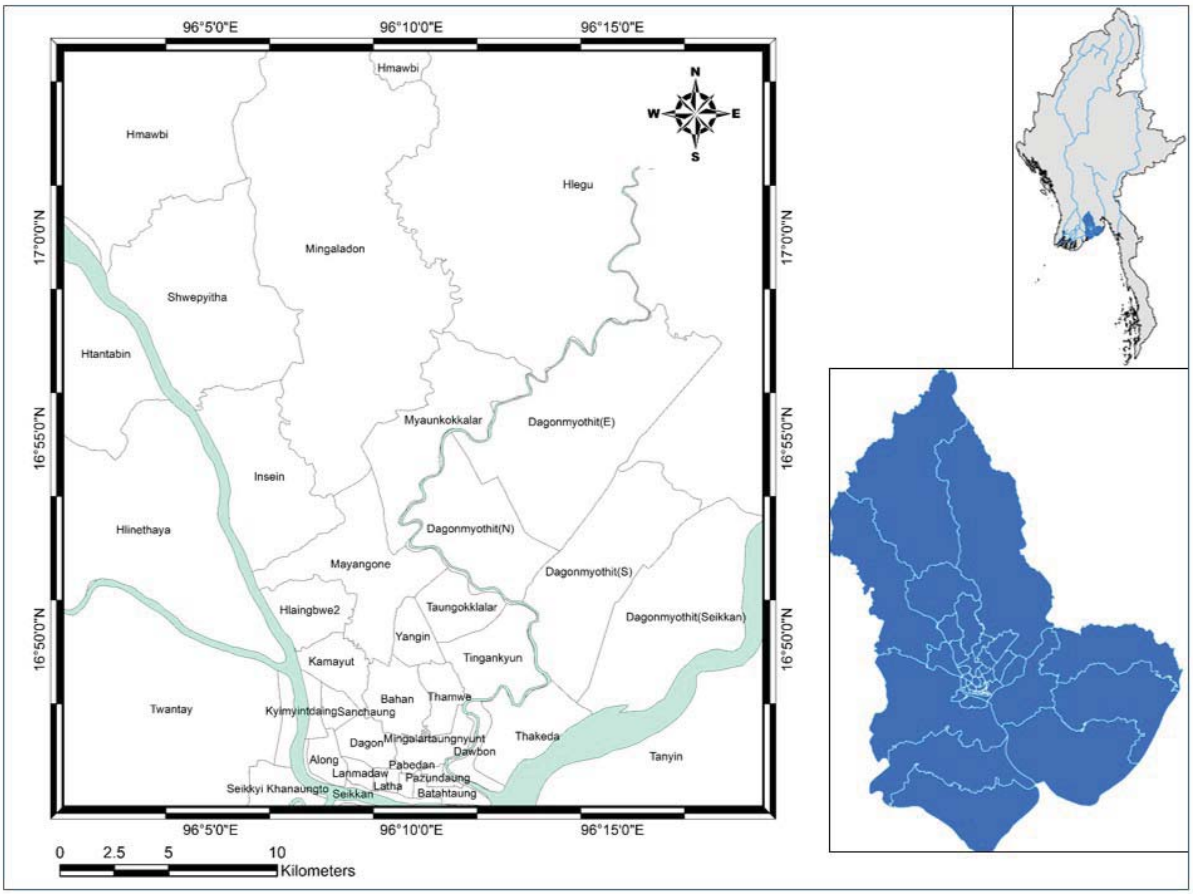


Figure (1) Map of Yangon City

1.1 Purposes of the project

The main purposes of the project are to develop the seismic hazard maps and risk maps for Yangon City, Yangon Region. The followings are the objectives of the project.

1. To develop the probabilistic seismic hazard maps in which the hazard parameters of peak ground acceleration (PGA), spectral acceleration (SA) at the periods of 0.3 s and 1.0 s, and peak ground velocity (PGV) for 10% and 2% probability of exceedance in 50 years (475 years and 2,475 years recurrence interval),
2. To contribute the necessary information that can be used in urban land-use planning by integrating the resulted seismic hazard parameters, and
3. To provide the results for earthquake disaster education and preparedness purposes

The seismic hazard parameters obtained from this project can be used for retrofitting programs for the existing buildings and for seismic resistance designing, etc. It can also be said that the main purpose of the present study is for earthquake effects mitigation.

1.2 Composition of Report

This report is non-technical report and it represents as the general report just to understand the nature of the seismic hazard of Yangon City. Moreover, the report tend to explain how to use these hazard maps for earthquake hazard/risk mitigation purposes to prepare for the earthquake potential that can happen in the future. However, the report also tries to explain the spatial occurrences of the seismic sources in and around the region where the city is located. Especially this report tries to contribute the knowledge related with seismic sources located near the region, such as where the seismic sources are, what kind of seismic sources are present, how large the earthquake potential is and how often these earthquake can happen, etc.

Chapter 1 presents the introduction of the hazard assessment project for Yangon City and others currently conducted by MGS, MES and MEC, together with the purposes of the project. Chapter 2 corresponds to the review of Seismotectonics and geology of the region to understand the nature of the previous earthquakes based on the historical and instrumental records. The methodology of seismic hazard assessment is briefly explained in Chapter 3, together with investigation of site condition. Chapter 4 is continued to explain the results of seismic hazard assessment and finally the Chapter 5 is the recommendation and discussion for the preparedness for earthquake effects mitigation schemes.

2 SEISMOTECTONICS AND GEOLOGY

2.1 Seismotectonics of the region

The major tectonics of Myanmar comprises of the subduction zone of Indian Plate beneath Burma Plate in the west, and the collision zone of Indian Plate with Eurasia Plate in the north. The rate of subduction is 35 – 50 mm/yr and the direction of subduction is NE to NNE. The other major structures present within Myanmar are the major fault systems of well-known Sagaing fault, Kyaukkyan fault, Gwegyo thrust, and West BagoYoma fault. Most of the earthquakes, which occurred in the central region of Myanmar, are related with Sagaing fault, and in the eastern part, the focal depth is not greater than 40 km while the earthquakes in the western portion include from shallow, through intermediate to deep focus earthquakes. The shallow focus earthquakes along the western margin belong to the subduction zone earthquakes and the focal depth of the earthquakes, which are generated from the subduction zone gradually increase to the eastward. In the eastern margin of the Western Ranges or Indoburma Ranges, the shallow focus events indicate their correspondence with the crustal faults.

Figure (2) shows the seismicity of Myanmar,while Figure (3) illustrates that of Yangon Region.It can be clearly seen that the events happened in the western part of the country are all of the depth range; shallow (0 – 40 km in focal depth), medium (40 – 80 km) and deep (> 80 km) focus earthquakes while the shallow focus earthquakes happened in the central and eastern part. The seismicity of Western Part belongs to the subduction of Indian Plate underneath Burma Platelet (part of Eurasia Plate) and to the south of the region, the Andaman Basin (Spreading Center) is the other main seismogenic source for Yangon Region. The rate subduction of Indian Plate under Burma Plate is estimated as 3.6 cm/yr (Socquet et al., 2006), while the spreading rate of Andaman Basin is about 3.7 cm/yr.

However, in the north of the region the seismic sources that can contribute the major future large earthquakes many thrust faults such as West BgoYoma Thrust, Gwegyo Thrust, and Pyay Thrust, and Kyaukkyan Fault (KK F.), Nampon Fault (NP F.), Papun Wang Chao Fault and Three Pagodas Fault (TP F.) are the main sources from the east. The West Bago Thrust is the east dipping high angle thrust located along the western foothill of West BagoYoma and its trend is generally NNW – SSE. The slip rate of this fault is approximately about 5 mm/yr. Gwegyo Thrust is a west dipping low angle thrust fault running in NNW-SSE direction near Mt. Popa Volcano. The slip rate of this fault is just only about 1 mm/yr. The 2003 Taungdwingyi earthquake is believed to happen from this fault and the fault is therefore significant dextral slip component. Pyay fault is an east dipping low angle thrust fault passing through in the south of Pyay with strike of NNW-SSE direction. The slip rate is estimated as 1 mm/yr. From this fault 1858 Pyay earthquake happened (SoeThuraTun et al., 2011).

The crustal faults in the Eastern Highland, the seismogenic sources for the present area are theKyaukkyan Fault and Nampon Fault. The Kyaykkyan Fault is a right-lateral active strike-slip fault trending generally north- south. The total length of the fault is about 500 km and the slip rate is about 1 mm/yr. Kyaukkyan Fault is terminated in Mogok metamorphic belt in the north and at the Papun Fault in the south.The 1912 Maymyo earthquake is originated from this fault and its magnitude was estimated as > 7.6 (~8.0). Nampon Fault is also the dextral fault, lying in the east of Kyaukkyan Fault in parallel with it. The length is about 85 km and the slip rate is ~ 1 mm/yr (SoeThuraTun et al., 2011). No significant earthquakes happened from this fault.

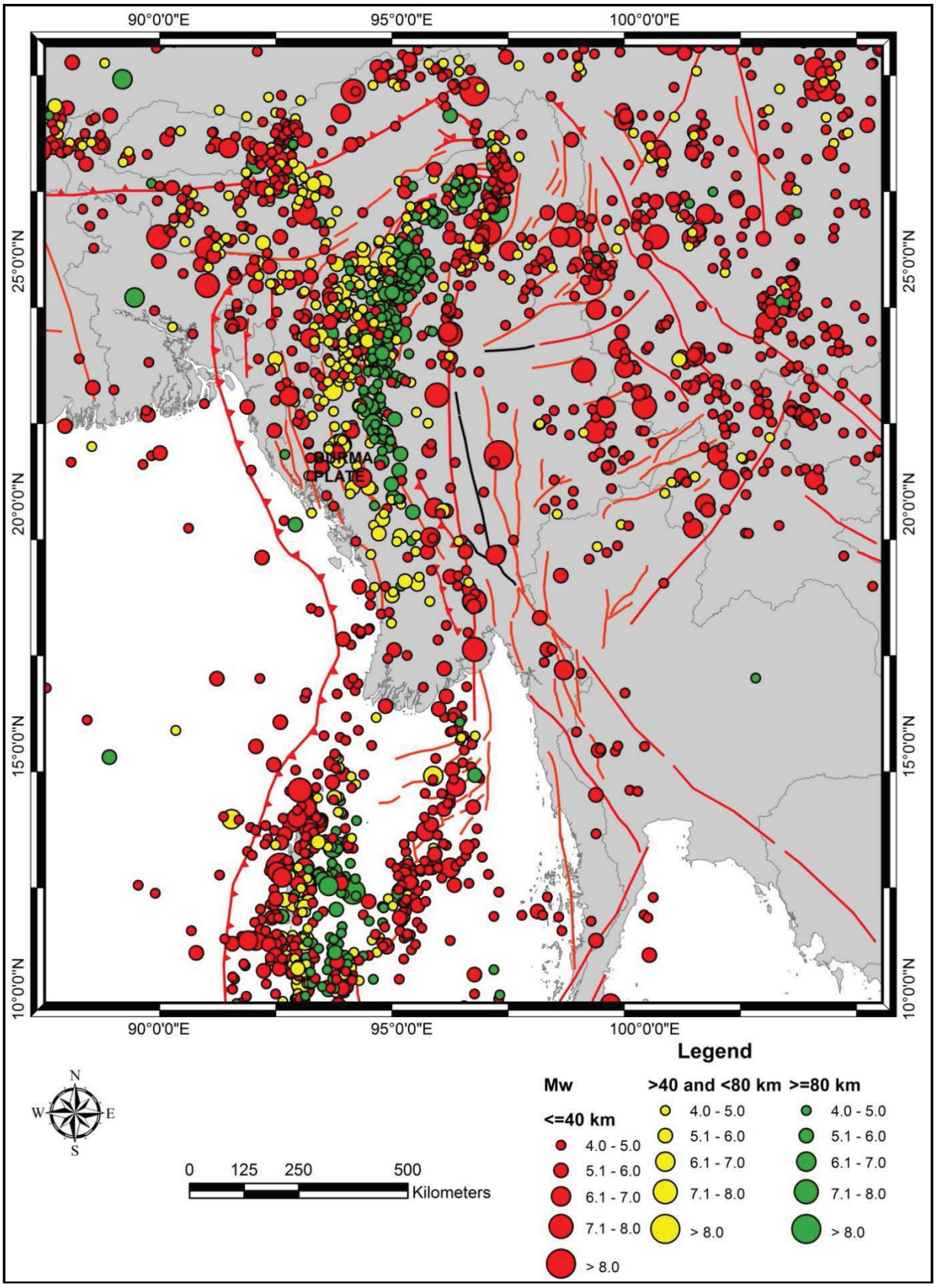


Figure (2) Seismicity map of Myanmar (ISC earthquake catalog, 1906 – 2011)

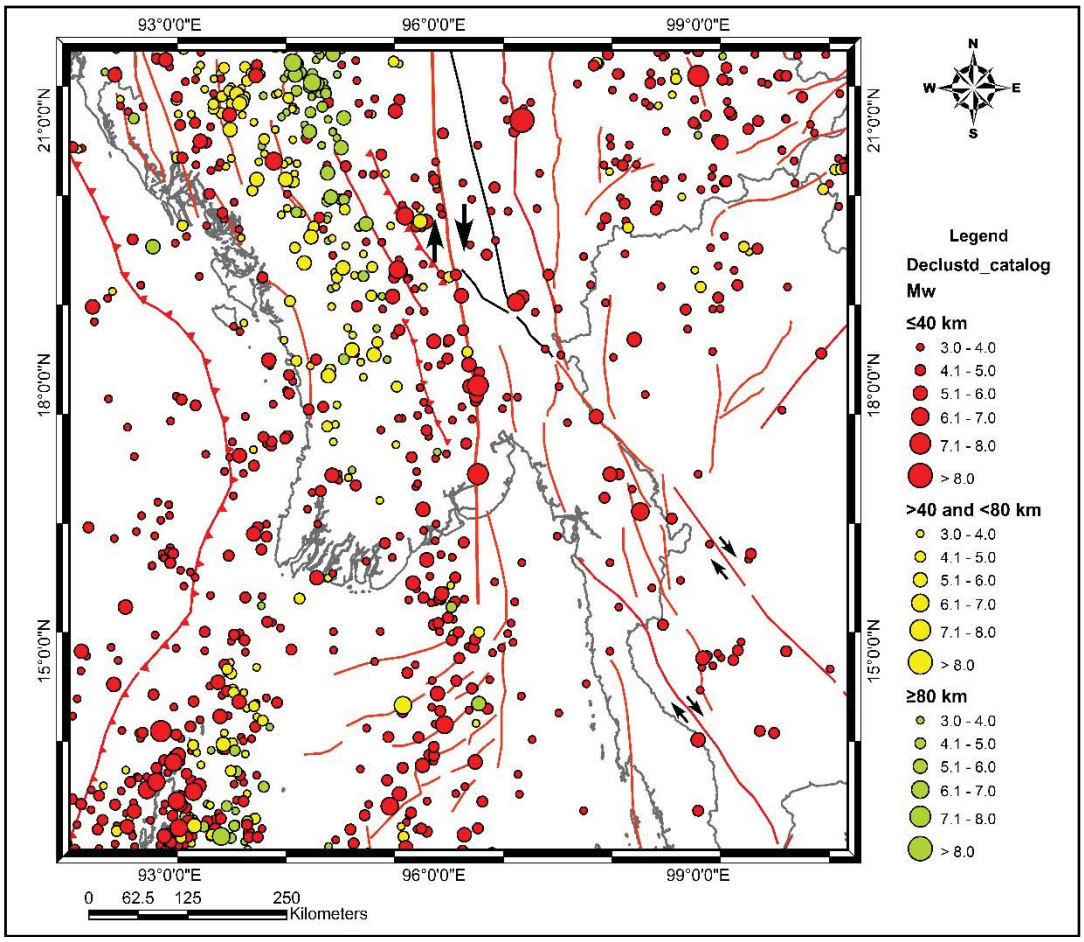


Figure (3) Seismicity map of Yangon area

The right lateral, strike-slip Sagaing fault which caused the 5th July, 1917 event, the magnitude 7.3, May 5, 1930 Bago earthquake and December 3, 1930 (M7.3) earthquake, extends through the central part of the country for a length of more than 1,000 km. It runs from the Gulf of Mataban in the south through Bago, Pyinmana, Yamethin, Tharzi, and Sagaing till Putao in the north. The records of the previous significant earthquakes showed that some destructive earthquakes with the magnitudes ≥ 7 originated from this fault. The focal mechanisms of the previous earthquakes happened along the Sagaing fault represents the strike-slip mechanisms, confirming the compressional force in NE-SW direction and extensional force in NW-SE direction. However, the events that are located in the northernmost part of Sagaing fault, i.e. northern segments, show strike-slip mechanism with the dominant trust mechanism. The slip rate of Sagaing fault is about 20mm/yr. This

character corresponds to the gradual changes or influence of the collision of Eurasia and Burma Plates on the Sagaing fault system. The second-most significant fault system is the Kyakkyan fault that strikes nearly N-S in direction and it extends southward from PyinOoLwin – Naungcho area through Taunggyi – Innle Lake with a length of > 450 km. It is also right lateral strike-slip fault and the slip rate is about 1 mm/yr. The largest earthquake on this fault is the Richter magnitude 8.1 on 23 May, 1912. However, very few (about 5 small events) have been recorded around this fault subsequently.

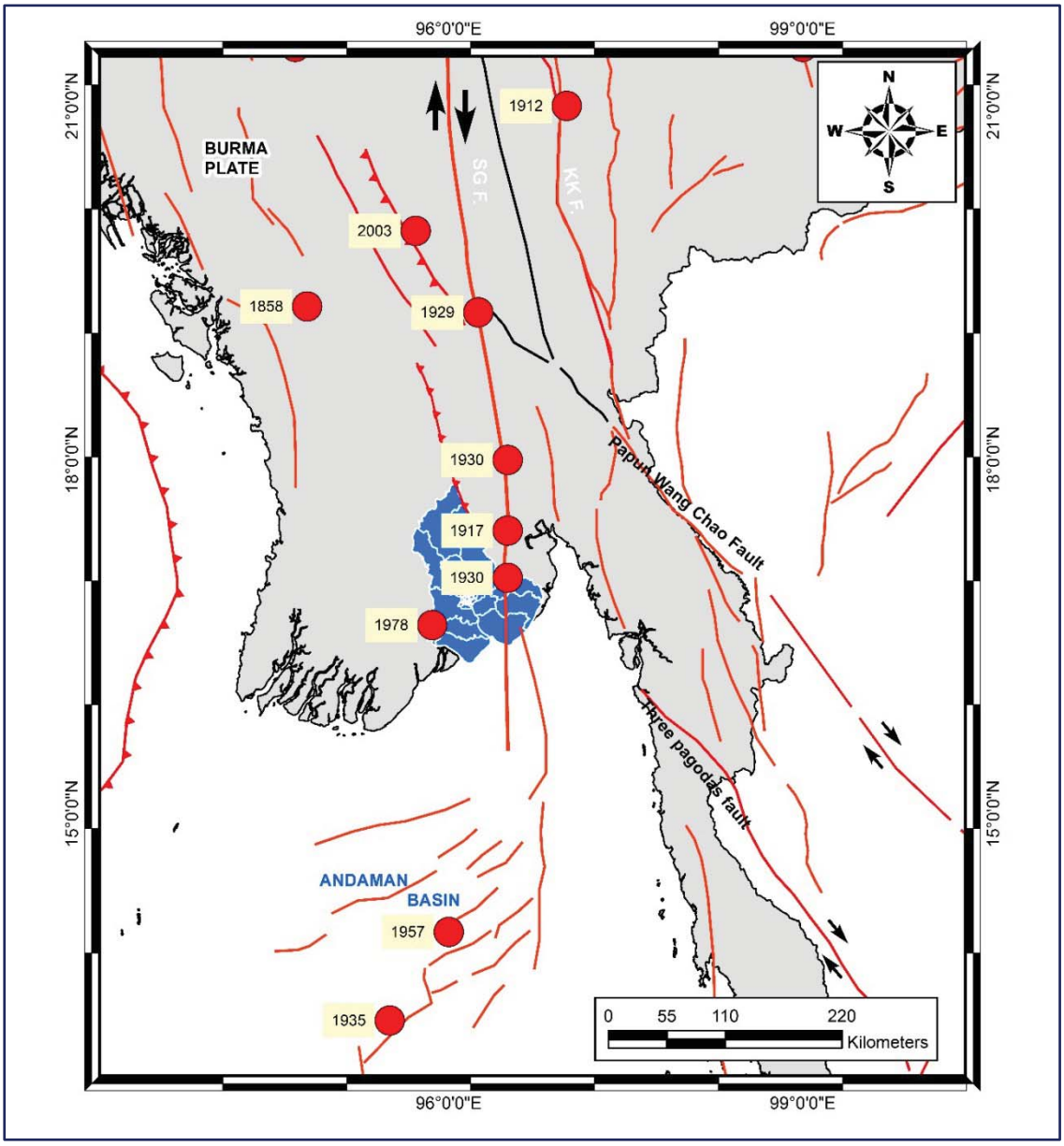


Figure (4) Map of the previous magnitude ≥ 7.0 events happened around Yangon Region

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 north-east, 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 250km 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.

3 METHODOLOGY AND USED DATA

3.1 Methodology for Seismic Hazard Assessment

The classical PSHA developed by Cornell (1968) is utilized and it is the four-steps methodology. The procedure of PSHA (Cornell, 1968, McGuire, 1976, Reiter, 1990 and Kramer, 1996) is mentioned as below.

1. *Identification and characterization of earthquake sources:*Fault specific sources, source areas or zones that can produce the large magnitude earthquake resulting the significant ground motion at the site are firstly defined.
2. *Calculation of the seismic source parameters for each source (fault, zone or area):* A recurrence relationship which specifies the average rate at which an earthquake of some size will be exceeded is used to characterize the seismicity of each source and then the maximum magnitude of the earthquake needed is determined.
3. *Choosing the ground motion prediction equation (GMPE):* By using the predictive equation, producing the ground motion at the site by earthquakes of any possible size at a point in each source is needed to determine to develop. The most suitable ground motion prediction equation is used to choose based on the tectonic environments and fault types, etc.
4. *Integration of variables to estimate the seismic hazard:* By considering the uncertainties of the location, earthquake size, and ground motion parameter prediction and by combining the effects of all the earthquakes with the different magnitude, different distance and diverse occurrence probability on a specific site are integrated in a curve that shows the probability of exceedance of different levels of accelerations for specific periods of time.

Generally three data sets are required to estimate the seismic hazard and they are; 1) Future earthquakes data such as the maximum magnitude, the (temporal and spatial)

occurrences of the earthquakes with certain magnitude, etc., 2) the suitable GMPE, and 3) the site condition.

The existing seismicity data, the active faults data, site geology are collected especially to identify the seismic sources, then seismic source parameters are determined. Secondly the sited investigation is carried out by field methods such as the borehole drilling and geophysical (microtremor) surveying. The various GMPEs are used and the ground motions are calculated and validated based on the resulted PGA, SA and PGV. Then seismic hazards, ground motion parameters [PGA, SA (0.3 s, and 1.0 s) and PGV] are estimated and the probabilistic seismic hazard maps are developed for YangonCity.

3.2 Used Data

3.2.1 Seismic Sources Identification

Myo Thant et al. (2012) developed the seismic hazard maps of Myanmar as the whole country. In that case, they identified the areal seismic sources from those the large earthquake potentials can be expected to happen in the future, especially from each tectonic domains (Subduction zone in the west, collision zone in the north, spreading centre in the south and eastern highland). SoeThuraTun et al. (2011) also developed the active fault sources for this seismic hazard assessment. For current seismic hazard assessment, we identify the fault sources by using the satellite image interpretation and paleoseismic studies. The seismic sources within 250 km radius from Yangon City are chosen as the seismic sources that can contribute the high seismic hazard to the city.

3.2.2 Estimation of seismic source parameters

The estimation of seismic source parameters includes the estimation of the recurrence interval of the earthquake with the certain magnitude, and the maximum magnitude, etc. of the earthquake potentials that can happen in the future from each seismic source. The

estimated magnitude of the earthquake potential from the Andaman Basin is 7.0 Mw and the recurrence interval of magnitude ≥ 6.5 earthquake is 40 years and that of magnitude ≥ 7.0 is 104 years.

The maximum earthquake potentials from the magnitude 8.0 to above 9.0 (~ 9.3) are estimated for the subduction zone tectonic domain (western part of Myanmar) and the recurrence interval for magnitude ≥ 7.0 is estimated as 460 years (above 50 years in some segments) and for magnitude ≥ 8.0 is about 1115 years (275 years in some segments).

From the areal seismic source that comprises the West BagoYoma Thrust and Gwegyo Thrust the maximum magnitude 7.5 earthquake potential can be expected to happen and the recurrence interval is estimated as 380 – 450 years.

With regards to the Sagaing Fault, the magnitude 7.6 event can be expected as maximum earthquake potential and the recurrence interval for the magnitude ≥ 7.0 is determined as 165 years from seismicity and it ranges from 86 to 176 years from geologic parameter of slip rate. The estimated maximum earthquake potential is > 8.0 from Kyaukkyan Fault and the recurrence interval for the magnitude ≥ 7.0 event is also guessed as 2610 years from seismicity and as 2000 – 6000 years from slip rate for different segments of the fault.

3.2.3 Site Investigation

The site condition is one of the important parameters that can strongly influence the seismic hazard for a certain location. In this case, the site investigation is carried out by SPT analysis and borehole drilling, and geophysical survey (microtremor survey and H/V spectral ratio analysis in this project). At Yangon City, microtremor measurement is carried out on 21 July, 2014 to 27 July, 2014. Microtremor measurement was done at eighty sites in Yangon City and the site locations are shown in Figure (5).

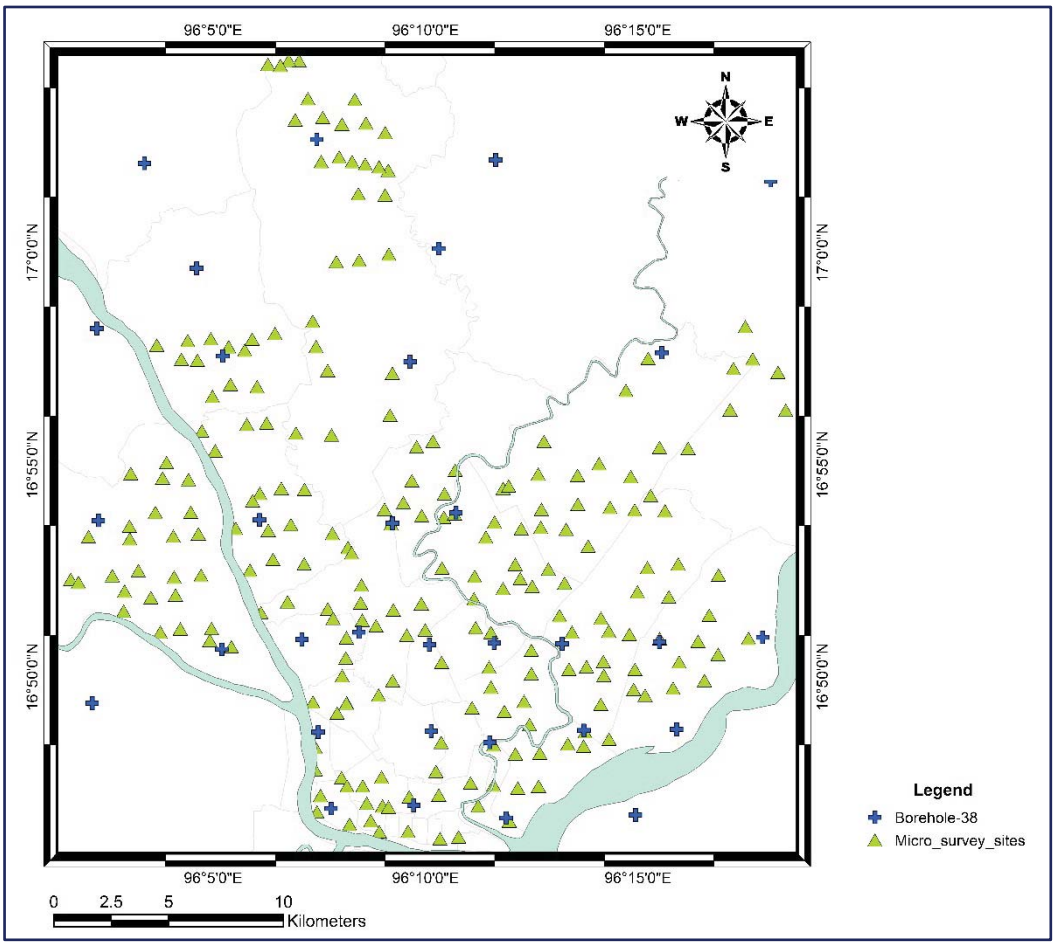


Figure (5) Microtremor measurement points and borehole locations Map of Yangon City

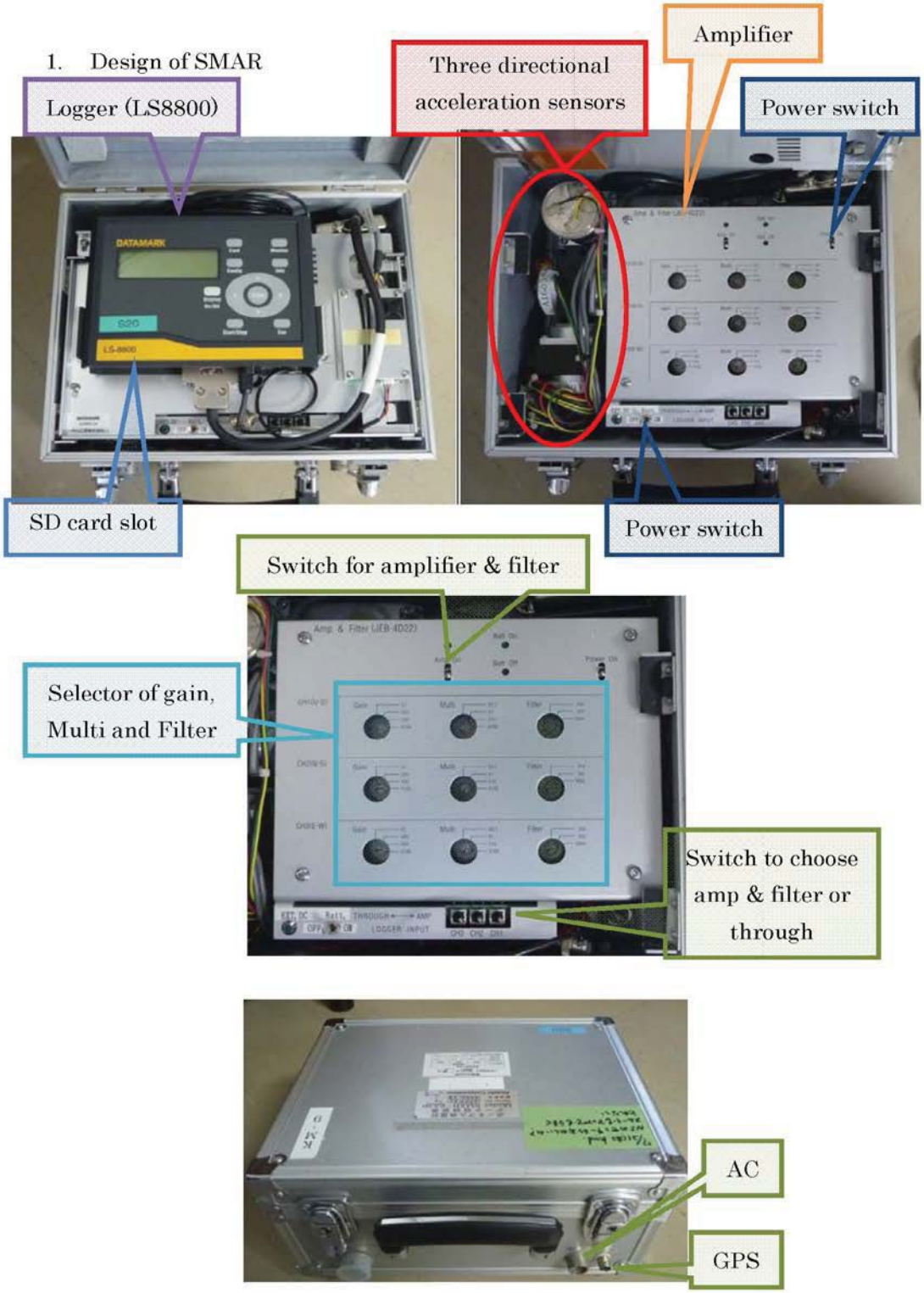


Figure (6) Photo of Microtremor instrument, its parts and the function of each part

In site investigation consists as the field tests, rotary drilling method and standard penetration tests (SPT) are also carried out. During borehole drilling, soil samples at the certain depth are collected and laboratory tests are conducted to delineate the engineering properties of soils. Visual classification is done on all samples during drill hole logging. Bore hole drilling is carried out at 38 sites in Yangon.

3.3 Regional Geological Setting

The distinctive lithologic units in the Yangon area are Hlawga Shale, Thadugan Sandstone, Besapet alternations, ArzanigonSandrocks, Danyingon Clays, Valley-filled deposits and recent Alluvium (Figure 7).

HlawgaShales occupied the low land areas in the west of Hlawgalake. Although, the exposures are rare, some outcrops are found along the west bank of Hlawgalake. Shales and laminated clays of this formation are considered to be the core of the Hlawga anticline. Thadugan Sandstone mainly exposes around Thadugan pagoda. This formation consists of bluish grey to brownish grey, fine to medium grained micaceous and argillaceous sandstone with ferrogenous band along the bedding planes.

Besapat Alternations consists of shale and thinly laminated sandstone which expose in the vicinity of Besapetlake. These are characterized by bluish grey to greenish grey, silty shale and yellowish brown, fine to medium-grained, soft micaceous and carbonaceous sandstone with calcareous concretions in places. Arzarnigon sand rocks are the name given to much sandier unit of the Irrawaddy Formation. The type area is at Arzanigon just north of Shwedagon pagoda. These sandrocks are exposed along the Shwedagon ridge and on the east bank of Hlawgalake. This formation is composed of blue and grey clays and sandrocks. These sand rocks may appear clear or contain admixtures of silt, clay and fine gravel.

The Danyingon clays consist mainly of blue clays, yellow clays and siltstones interbedded with sand rocks. The type section can be observed in Danyingon. The clay

bands show current bedding. This formation is mainly exposed in Mingalardon and other exposures can be observed on Pyay road near Mingalandon Airport, Mayangone (8 mile) and Shwegondaing, Insein, Sawbwagyigon, Kyaikkale, Gyogon. Valley-filled deposit occupies the synclinal valley, west of the Yangon ridge. The valley-filled deposits consist of a thick sequence of loose, highly pervious, interbedded sand and fine to very coarse gravels. The valley-filled deposits in the Hlaing-Yangon river valley are the principal aquifers in the area.

Alluvium formation was deposited in recent time which are effected by tidal action. It is estimated to be about 15 m thick with variation according to depositional environments. This formation consists of yellowish grey, bluish grey, brownish grey, silts and clays. It also contains some organic matter such as decomposed wood and traces of sand are found in this deposit. These younger alluvium are mostly exposed along the low lying flat plains.

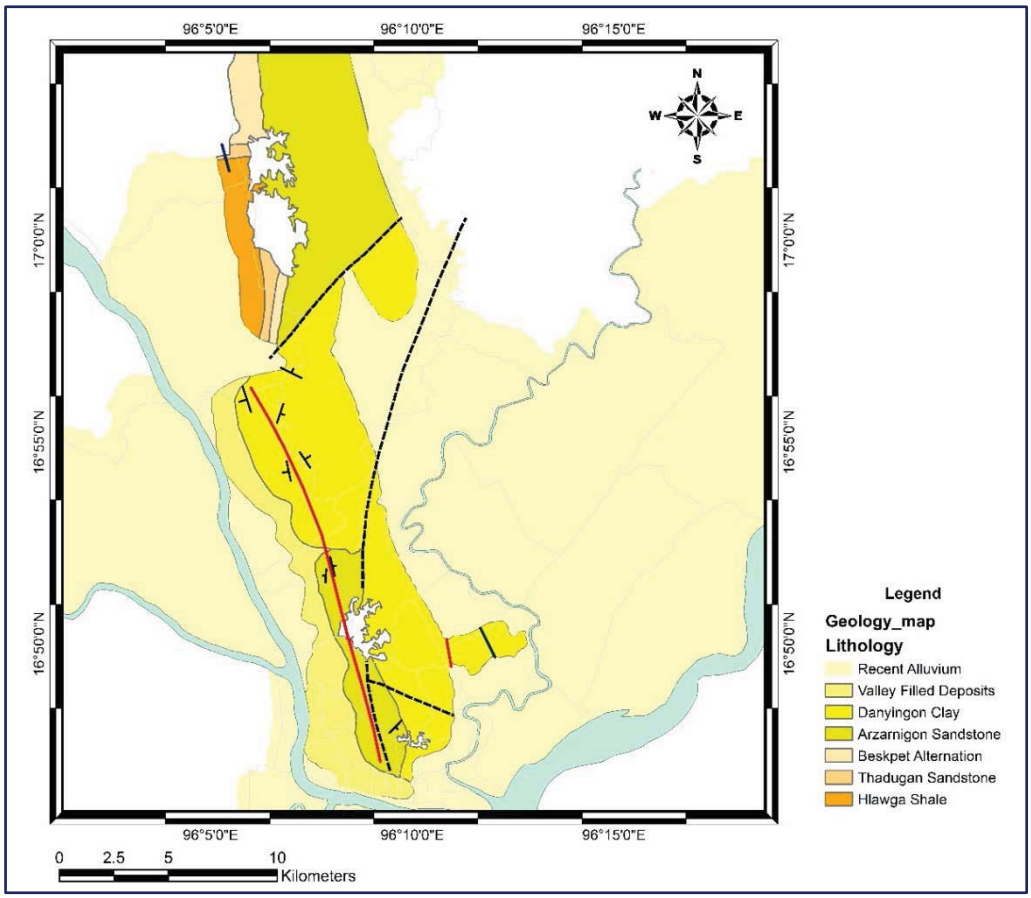


Figure (7) Regional Geological Map of Yangon City (Bender, 1983)

3.3 Ground Motion Prediction Equations (GMPEs)

After correlating the ground motion values as peak ground acceleration (PGA), spectral acceleration (SA) at the periods of 0.2 s, 0.3 s and 1.0 s, and peak ground velocity (PGV), calculated by using the several different ground motion prediction equations (GMPEs), the GMPE of Boore et al. (1997) is used for seismic hazard calculation of PGA and SA, and Boore and Atkinson (2008) NGA is applied for PGV calculation.

4 RESULTS

4.1 Site Condition

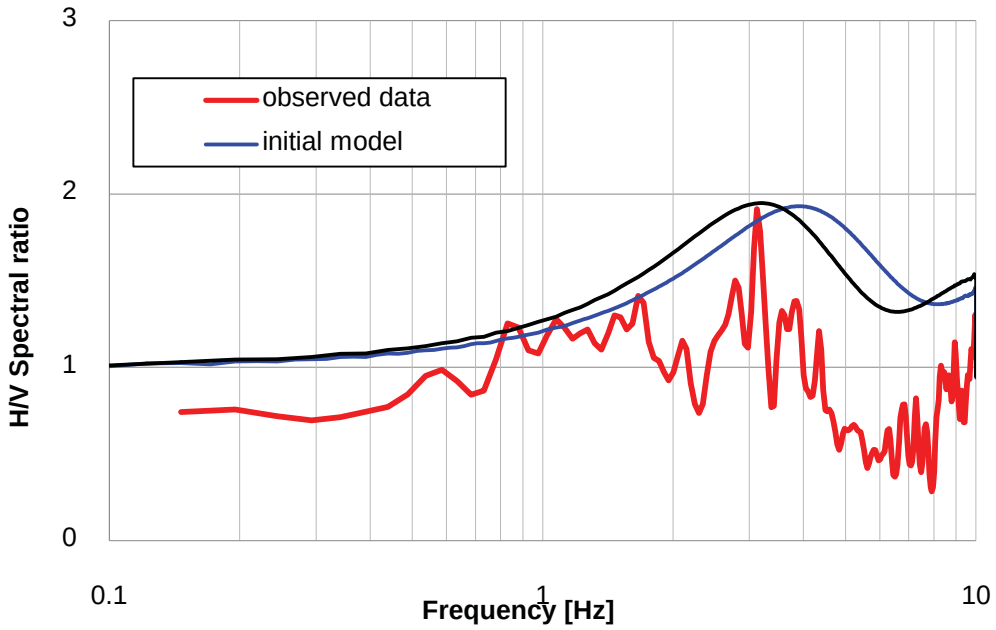
The most important parameter obtained from borehole drilling and SPT analyses are the soil type, density and N-value of each soil layer. By using these obtained parameters and the empirical relationship of N-value and shear wave velocity, the velocity structure model of each location is constructed. The microtremor data analysis is carried out by using this initial model. The final shear wave velocity structures are then developed by H/V spectral ration inversion technique (Figure 8 and 9).

When the seismic hazard assessment, the site parameter used in ground motion prediction equations (GMPEs) is in terms of the average shear wave velocity to the upper 30 m; V_s^{30}. Therefore, V_s^{30} of each microtremor survey locations is determined and then develop the V_s^{30} contour map of Yangon City.

The GMPE used for the estimation of peak ground acceleration (PGA) and spectral acceleration (SA) at the periods of 0.2 s, 0.3 s and 1.0 s is the relationship of Boore et al. (1997). The GMPE for the peak ground velocity (PGV) is the relation of Atkinson Boore and Atkinson (2008) NGA. In all of these GMPEs, V_s^{30} is the applied parameter for site condition.

Moreover, V_s^{30} value can also be sued to classify the soil type. For example, in the soil classification of Uniform Building Code (UBC), Vs30 value less than 180 m/s will represent Soft Soil class (SE), while the V_s^{30} value from 180 to 360 m/s will correspond to Stiff Soil (SD). The site that has V_s^{30} value of 360 – 760 m/s can be classified as very Dense Soil and Soft Rock (SC), and those with 760 – 1500 m/s Vs30 value can be said as Rock (SB). The Hard Rock (SA) will have > 1500 m/s in V_s^{30}. Some detailed soil classification of UBC can be seen in Appendix (E), by comparing with that of Eurocode 8 (EC8).

Based on these description, Figure (10) 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.



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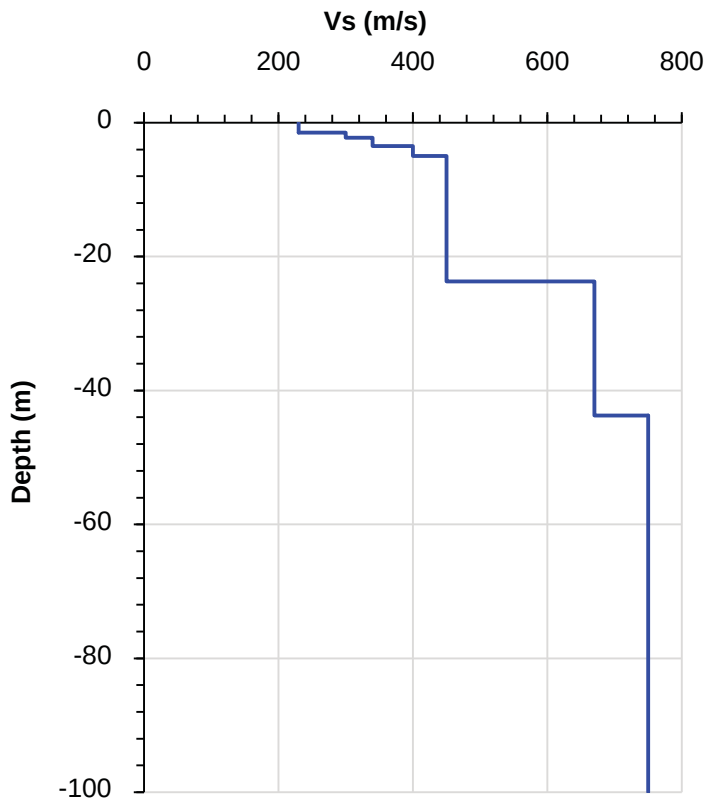
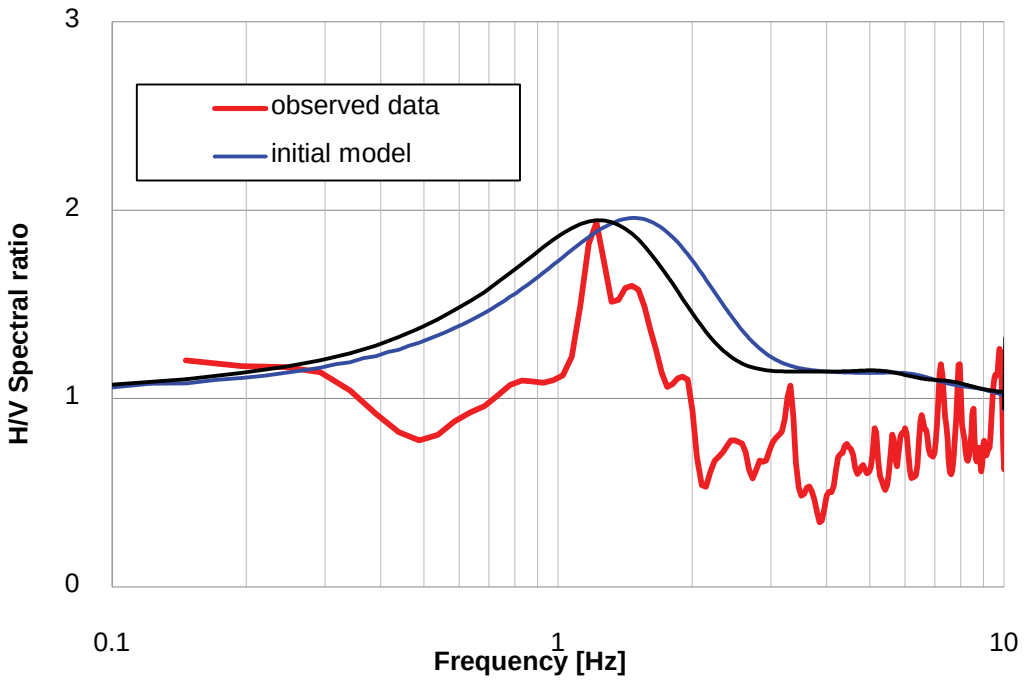


(b)

Figure (8)(a) H/V spectral ratio of mictrotremor survey point, YM-309, and (b) Shear wave velocity profile of MSB-04 (Vs30 – 444.818 m/s)



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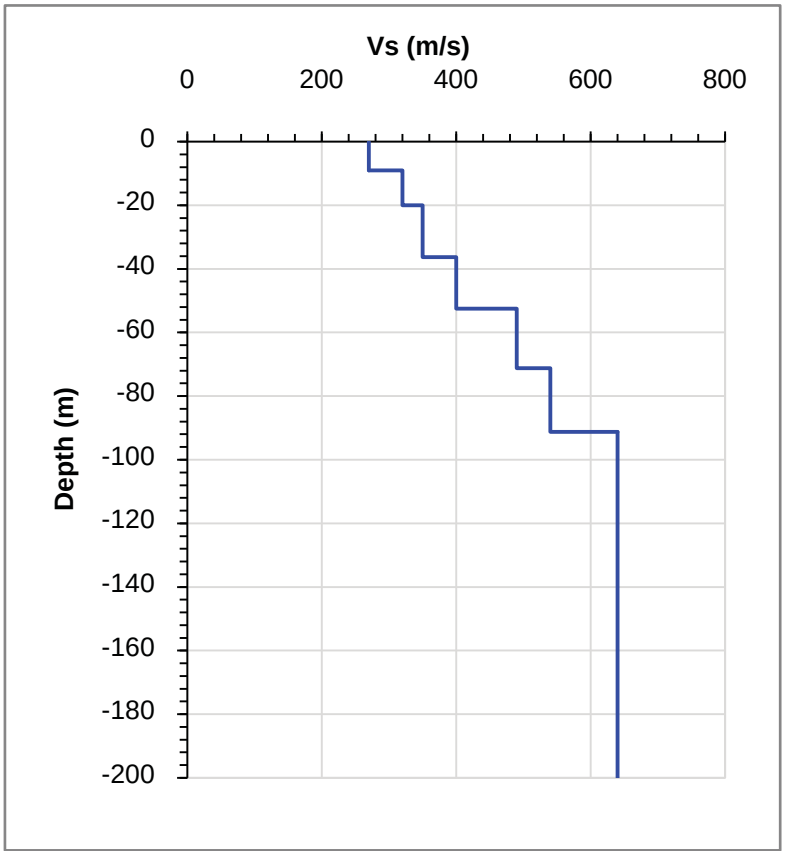

(b)

Figure (9)(a) H/V spectral ratio of mictrotremor survey point, YMMJ-024, and (b) Shear wave velocity profile of MSB-50 (Vs30 – 311.59 m/s)

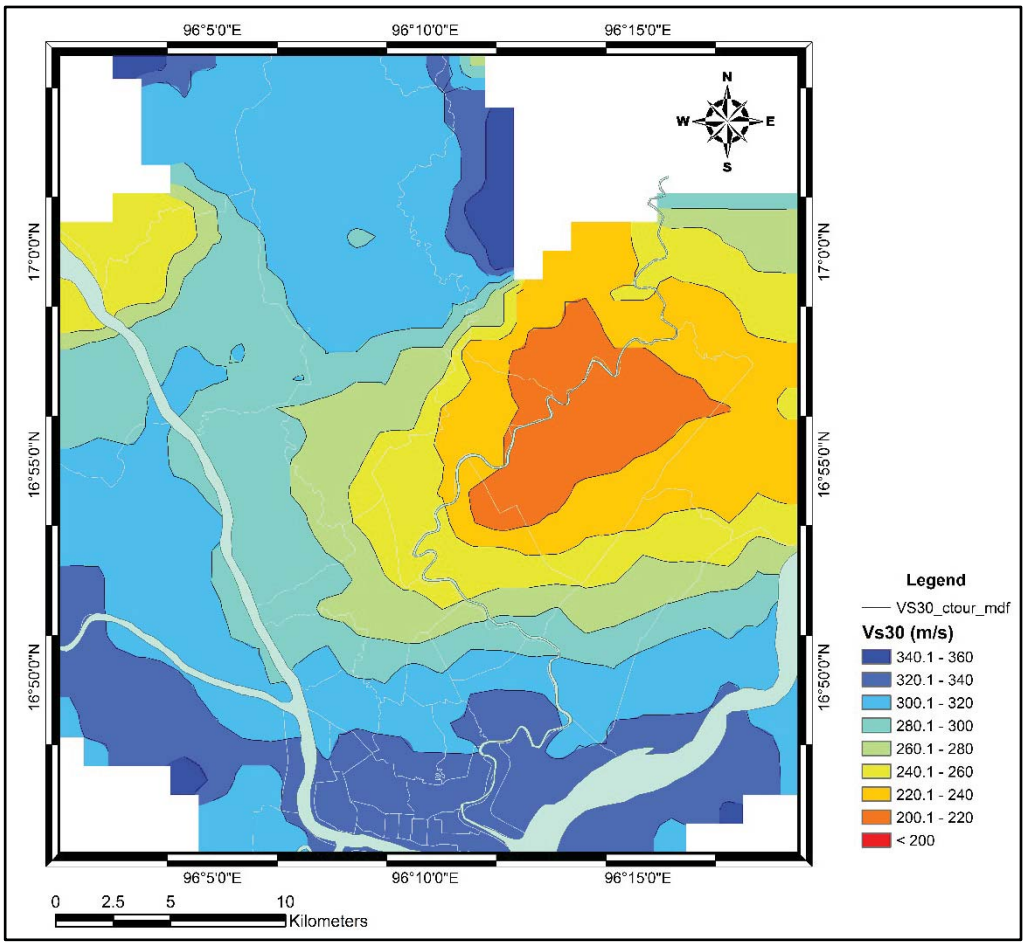

Figure (10) V_s^{30} Contour map of Yangon City, Yangon Region

4.2 Seismic Hazard

4.2.1 Seismic hazards for 475 years recurrence interval

The seismic hazard in term of peak ground acceleration, PGA (in g) for recurrence interval in 475 years (10 % probability of exceedance in 50 years) is shown in Figure (11). The PGA ranged from 0.29 to 0.5 gand the maximum seismic hazard zone comprises the eastern part of Yangon, East Dagon, South Dagon and Dagon MyothitSeikkan (PGA – 0.4 g to 0.5 g). Other wards of Yangon are in the PGA zone of 0.3 g to 0.4 g.

From Figure (12) to (13) depict the seismic hazard maps in terms of spectral acceleration at the periods of 0.2 s (Figure 12) and 1.0 s (Figure 13) for 475 years recurrence interval. These hazard maps can be applied to design the (ordinary) buildings for seismic safety.

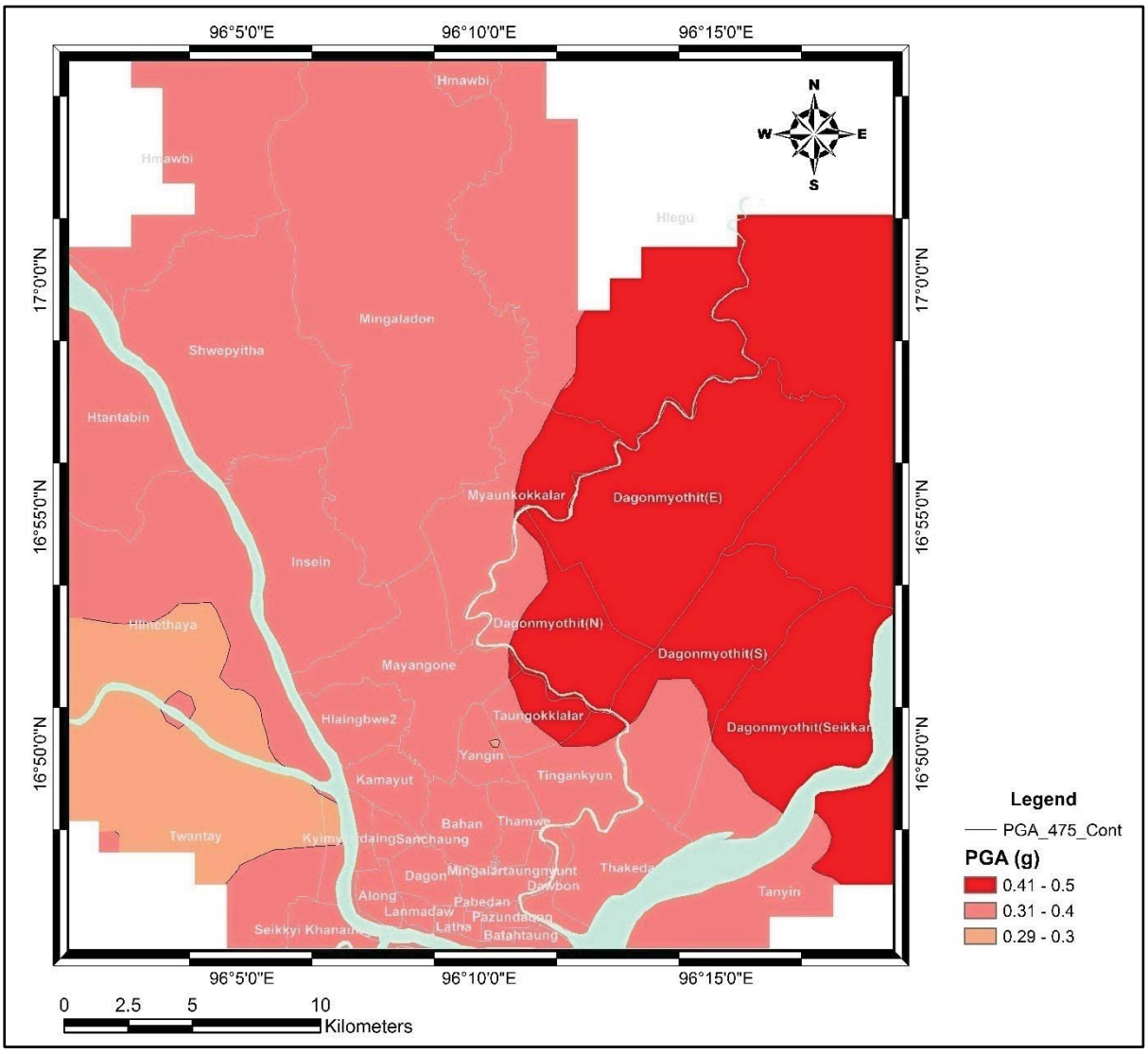

Figure (11)Probabilistic Seismic Hazard Map of Yangon City, Yagon Region, for 10 % probability of exceedance in 50 years, in terms of peak ground acceleration (PGA) in g.

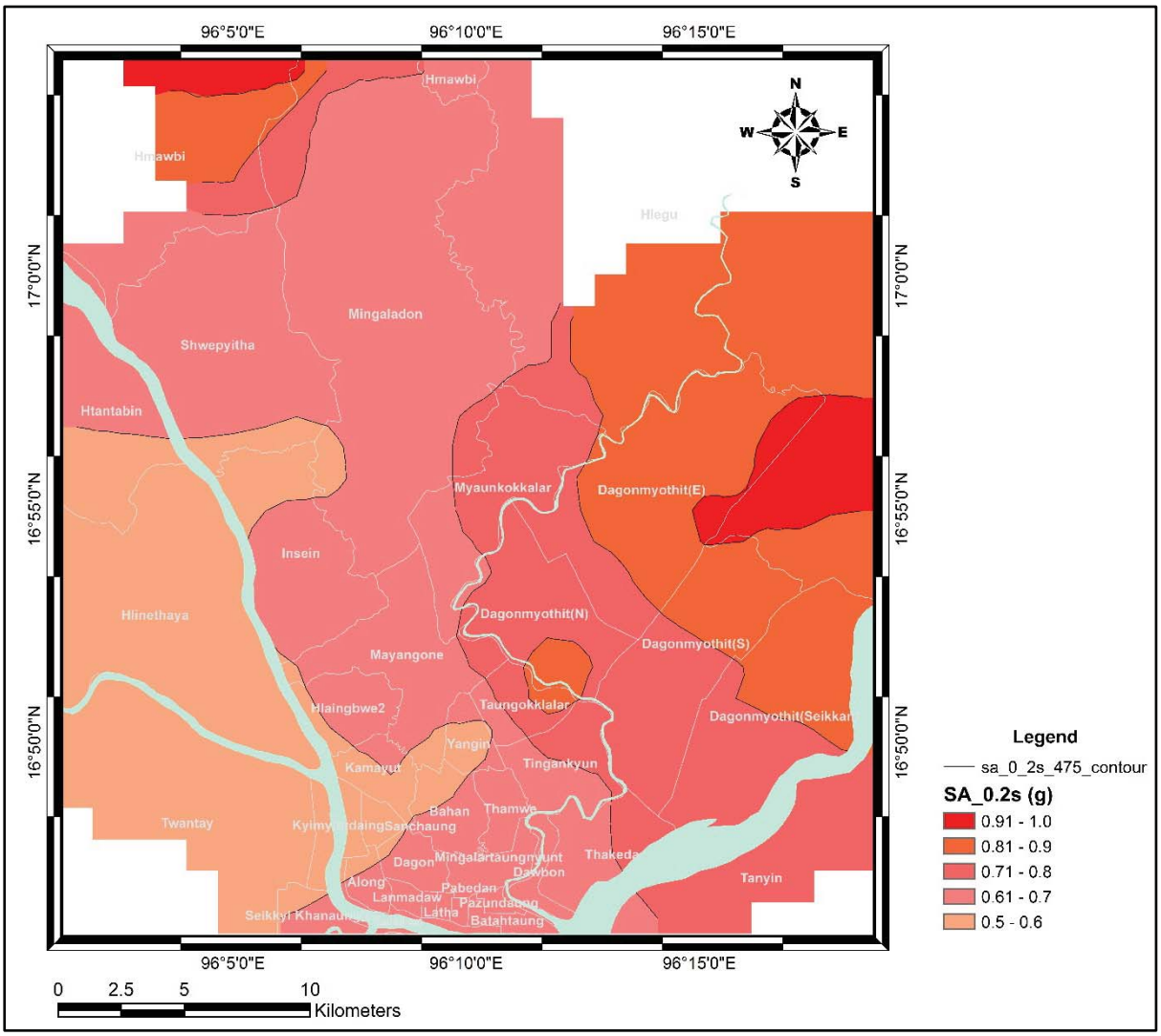

Figure (12)Probabilistic Seismic Hazard Map of Yangon City, Yangon Region, for 10 % probability of exceedance in 50 years, in terms of spectral acceleration (SA) in g at the period of 0.2 s.

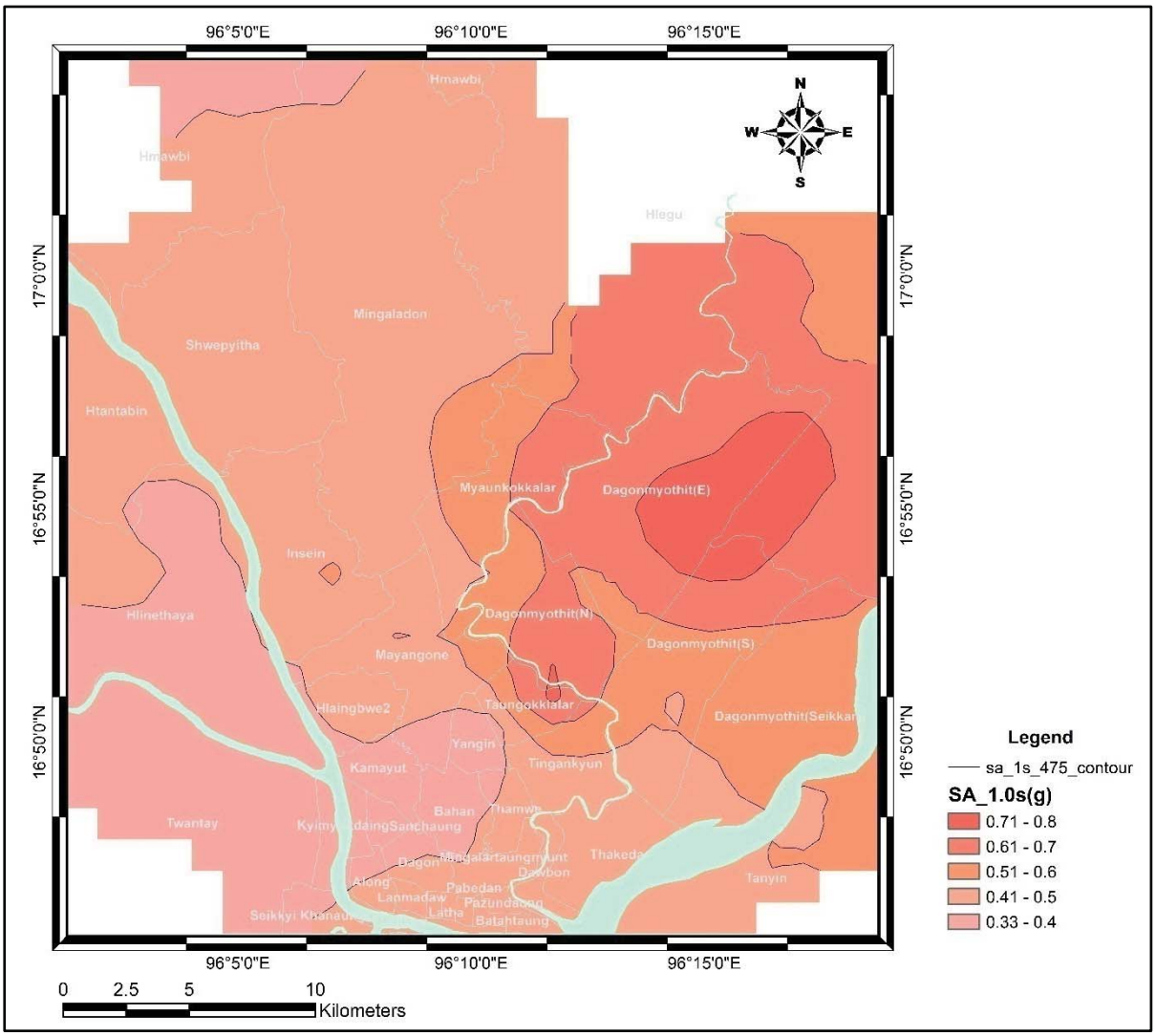

Figure (13)Probabilistic Seismic Hazard Map of Yangon City, Yangon Region, for 10 % probability of exceedance in 50 years, in terms of spectral acceleration (SA) in g at the period of 1.0 s.

4.2.2 Seismic hazards for 2475 years recurrence interval

The seismic hazard maps for 2475 years recurrence interval (2 % probability of exceedance in 50 years) can be seen in Figure (14) to (56). Figure (14) illustrates the peak ground acceleration (PGA) map of Yangon City and the PGA value ranges from 0.475 to 0.8 g.

The spectral acceleration maps for 2475 years recurrence interval at the period of 0.2 s is shown in Figure (15), and at the period of 1.0 s in Figure (16).

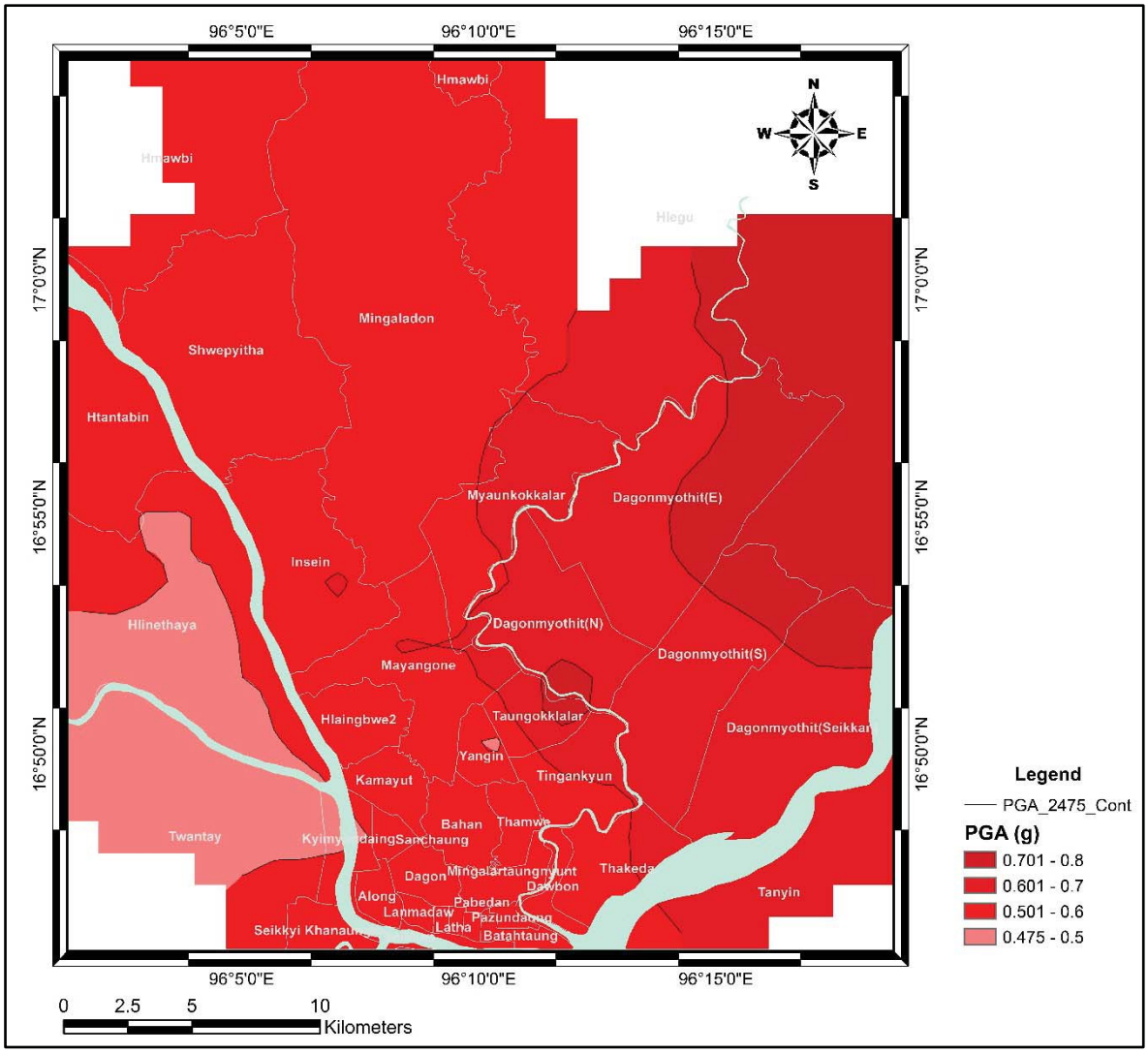

Figure (14)Probabilistic Seismic Hazard Map of Yangon City, Yangon Region, for 2 % probability of exceedance in 50 years, in terms of peak ground acceleration (PGA) in g.

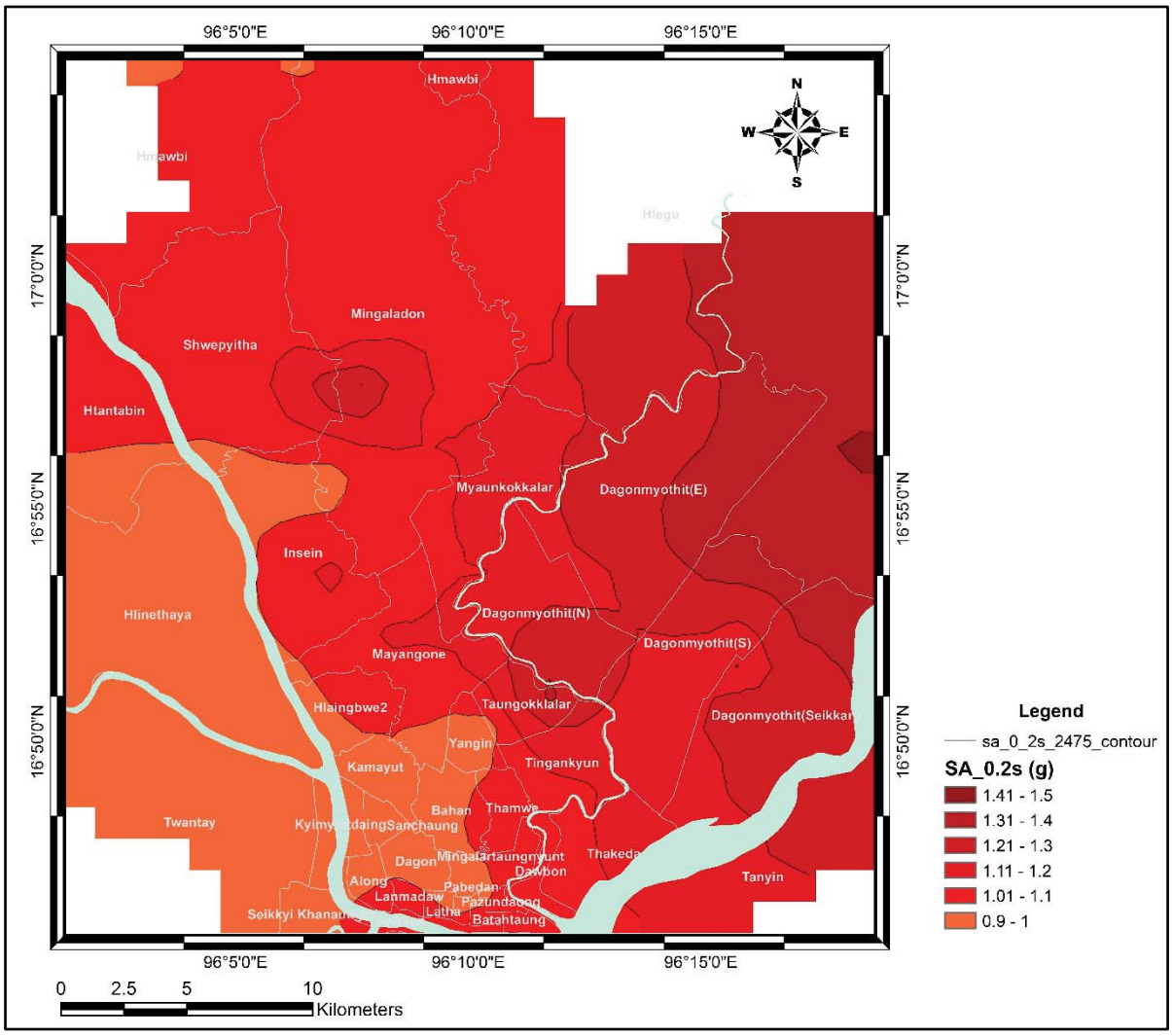

Figure (15)Probabilistic Seismic Hazard Map Yangon, Yangon Region, for 2 % probability of exceedance in 50 years, in terms of spectral acceleration (SA) in g at the period of 0.2 s.

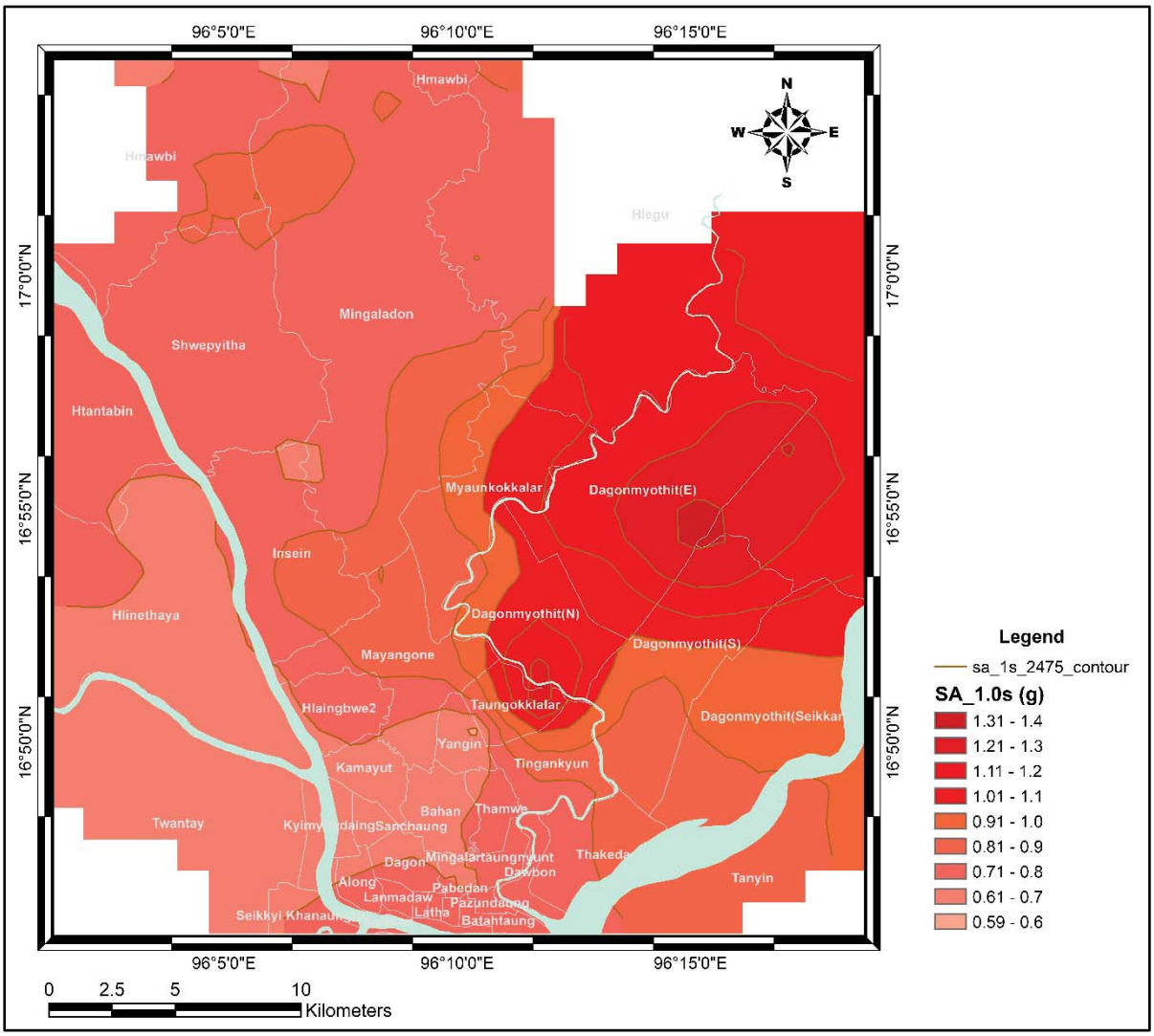

Figure (16)Probabilistic Seismic Hazard Map of Yangon City, Yangon Region, for 2 % probability of exceedance in 50 years, in terms of spectral acceleration (SA) in g at the period of 1.0 s.

5 DISCUSSION AND RECOMMENDATION

Seismic hazard assessment is carried out for Yangon (Yangon Region) and seismic risk assessment for Pyay (Bago Region) in 2014. The report is prepared for the seismic hazard assessment of Yangon City, Yangon Region. We develop ten seismic hazard maps for 475 years (10 % probability of exceedance in 50 years) and 2,475 years recurrence interval (2 % probability of exceedance in 50 years). Therefore, the seismic hazard maps will currently be 3 for each recurrence interval. Among the seismic hazard maps for each recurrence interval, there will be one PGA map, and two SA (at the periods of 0.2 s, and 1.0 s) maps.

Regards to PGA for 475 years recurrence interval, the wards of the city, lied in the seismic hazard zone with PGA range from 0.29 – 0.5 g, are in very strong to severe zone of perceived shaking, moderate to heavy in potential damage, and VII and VIII in instrumental intensity. The wards with PGA range of 0.4 – 0.5 g, asDagonmyothit (E), Dagonmyothit (N), Dagonmyothit (S) and Dagonmyothit (Seikkan) are in severe zone of perceived shaking, Moderate to heavy in potential damage, and VIII in instrumental intensity.

The eastern part of Yangon city that includes Myaukokkalar, Dagonmyothit (E), Dagonmyothit (N), Dagonmyothit (S), Taungokkalar, eastern part of Thingankyun, Dagonmyothit (Seikkan) and Tanyin is in the highest seismic hazard zone of PGA range > 0.6 – 0.8 g, lying in the violentzone of perceived shaking, heavy in potential damage and IX in the intensity scale, for 2,475 years recurrence interval. The PGA 0.5 g – 0.6 g zone comprises the NS running central parts of the city such as the downtown areas, Mingaladon, Shwepyitha, Insein, Mayangone, Hlaingbwe-2, Kamayut, Yangin, Bahan, Sanchuang, Tarmwe, Dagon, Alon, Mingalartaungnyunt, Dawbon, Thaketa, Lanmadaw, Pazundaung, Latha, and Botahtaung are in the zone of the severe of perceived shaking, moderate/heavy in potential damage, and VII in instrumental intensity.

The above mentioned maps can be used in land-use planning, the purposes of earthquake disaster management, etc. The spectral acceleration maps are for seismic resistant designing for the buildings/infrastructures for certain projects. Depends on the types of project, it may need to conduct the site specific detailed seismic hazard assessment rather than these maps.

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APPENDICES

Appendix A

The maximum magnitude of earthquake potential expected to happen by fault specific sources can be determined by using the following relationships of earthquake magnitude and fault length.

Inoue et al., AIJ (1993); $0.5M = Log\ L + 1.9$ (A-1)

Ambraseys's equation (1988); $M_{sc} = 1.43\ logL + 4.63$ (A-2)

in which M_{sc} is the expected surface wave magnitude and L is the fault length.

Mohammadioun&Serva (2001); $M_s = 2\ log\ L + 1.33\ log\ \Delta\sigma + 1.66$ (A-3)

where, M_s is the surface wave magnitude, L is the fault rupture length (km) and $\Delta\boldsymbol{\sigma}$ is the stress drop released by the earthquake (in bars) that depends on the width of the faults and type (kinematics) of the faults. Stress drop parameters for each fault are calculated by applying the following relationships (Mohammadioun and Serva, 2001);

$\Delta\sigma N = 10.6 \times W^{0.5}$ (A-4)

$\Delta\sigma SS = 8.9 \times W^{0.8}$ (A-5)

$\Delta\sigma R = 4.8 \times W^{1.6}$ (A-6)

in which $\Delta\sigma N, \Delta\sigma SS$ and $\Delta\sigma R$ are stress drop (in bars) for normal, strike-slip and reverse faults and W is the fault width (km) which is also determined by utilizing the relation of fault length and fault width; $L = 2W$ (Bormann and Baumbach, 2000).

$M = (LogL+6.4)/1.13$ (Ambraseys and Zatopek, 1968) (A-7)

$M = 2.0\ logL_{max} + 3.6$ (Otsuka, 1964) (A-8)

$M = 2.0\ logL_{max} + 3.5$ (Iida, 1965) (A-9)

$M = 2.0\ logL_{max} + 3.7$ (Yonekura, 1972) (A-10)

in which L_{max} is the maximum earthquake fault length,

$M = 1.7\ LogL + 4.8$ (Matsuda, 1977) (A-11)

and, $0.5\ M = Log\ L + 1.86$ for oblique faults (A-12)

$0.59\ M = Log\ L + 2.3$ for Strike slip faults (A-13)

(Papazachos et al., 2004)

Appendix B

The maximum magnitude of the earthquake potentials which can be originated from all areal seismic sources are determined by using the relationship of Kijko (2004);

$$m_{\max} = m_{\max}^{obs} + [\{E_1(n_1) - E_2(n_2)\}/\{\beta \exp(-n_2)\}] + m_{\min} \exp(-n) \quad \text{(B-1)}$$

where, $E_1(z) = \{(z^2 + a_1 z + a_2)/ [z (z^2 + b_1 z + b_2)]\} \exp(-z)$ (B-2)

$n_1 = n / \{1 - \exp [-\beta(m_{\max} - m_{\min})]\}$ (B-3)

$n_2 = n_1 \exp [-\beta(m_{\max} - m_{\min})]$ (B-4)

in which n is the number of earthquakes greater than or equal m_{min}, $a_1 = 2.334733$, $a_2 = 0.250621$, $b_1 = 3.330657$, and $b_2 = 1.681534$.

It must be noted that Equation 2.23 does not constitute a direct estimator for m_{max} since expressions $n_1$and n_2, which appear on the right-hand side of the equation, also contain m_{max}. Generally the assessment of m_{max} is obtained by the iterative solution of Equation (B-1).

However, when $m_{max} - m_{min} \leq 2$, and $n \geq 100$, the parameter m_{max} in n_1 and n_2 can be replaced by $m_{max}(obs)$, providing m_{max} estimator which can be obtained without iterations (Kijko, 2004).

Appendix (C)

The mathematical expression of the probability of the ground motion parameter *Z* will exceed a specified value *z*, during a specified time period *T* at a given site is as follow:

$$P(Z > z) = 1 - e^{-v(z)\cdot t} \qquad \text{(C.1)}$$

where *v*(*z*) is the mean annual rate of events from which the ground motion parameter *Z* will exceed *z* at a certain site resulting from the earthquakes from all seismic sources in a region. It can be calculated by applying the following equation:

$$v(z) = \sum_{n=1}^{N} \lambda(m_i) \int\int f_M(m)\, f_R(r) \cdot P(Z > z / m, r)\, dr dm \qquad \text{(C.2)}$$

where $\lambda(m_i)$ = the frequency of earthquakes on seismic source *n*above a minimum magnitude of engineering significance, m_i ;

$f_M(m)$ = the probability density function of event size on source *n*between m^0 and maximum earthquake size for the source, m^u;

$f_R(r)$ = the probability density function for distance to earthquake rupture on source *n*, which may be conditional on the earthquake size; and

P(Z>z|m,r)= the probability that, at a given a magnitude *m*earthquake and at a distance *r*from the site, the ground motion exceeds value *z*.

Therefore the calculation of the seismic hazards will be included the following steps;

1) Calculating the frequency of the occurrence of the event of magnitude *m* on source *n*,

2) Computing the probability density function of event size on source *n*

between m^0 and m^u,

3) Computing the probability distribution for the distance from the site to source *n* where the event with the magnitude *m* will occur, and

4) Calculating, at each distance, the probability that an event with magnitude *m* will exceed the specified ground motion level *z*, i.e. calculating the ground motion amplitude parameters for a certain recurrence interval.

The seismic hazard values can be obtained for individual source (zones) and then combined to express the aggregate hazard. The probability of exceeding a particular value *Z*, of a ground motion parameter, *z*, is calculated for one possible earthquake at one possible source location and then multiplied by the probability that the particular magnitude earthquake would occur at that particular location. The process is then repeated for all possible magnitudes and locations, and then summed all of the probabilites on these variables (Kramer, 1996).

Calculation of the Event Rate

The first step is the computation of the rate of occurrence of events of magnitude ***m***. The annual rate of exceedance for a particular magnitude can also be determined by using Gutenberg-Richter recurrence law.

$$Log\ N_c(m) = a - bm \qquad \text{(C.3)}$$

where $N_c(m)$ is the yearly occurrence rate of earthquakes with magnitude ≥ *m* in a particular source zone, *a* and *b* are constants specific to the seismic source zone, and these can be estimated by a least square analysis of the data base of the past seismicity from each seismic source. These values may vary in space and time. While the ***a***-value generally characterizes the level of seismicity in a given area i.e. the higher the ***a***-value, the higher the seismicity, the ***b***-value describes the relative likelihood of large and small earthquakes, i.e. the ***b***-value increases, the number of larger magnitude earthquakes decreases compared to smaller.

Probability of the Event Magnitude

The second step of the seismic hazard analysis is the calculation of the probability that the magnitude will be within an interval of the lower bound magnitude m^l and the upper bound magnitude m^u. It can be calculated by the following relation:

$$f_M(m) = P(m/m^l < m < m^u) = \frac{\beta \exp[-\beta(m - m^0)]}{1 - \exp[-\beta(m_{\max} - m^0)]}(m^u - m^l) \qquad \text{(C.4)}$$

where, β = 2.303b, m_{max} is the maximum magnitude of the earthquake potential for a specific seismic source (Kramer, 1996).

Probability of the Source-to-site Distance

The probability for the source-to-site distance can be computed as the same in the second step and can be expressed by the following equation:

$$f_R(r) = P(r/r^l < r < r^u) = \frac{\beta \exp[-\beta(r - r^0)]}{1 - \exp[-\beta(r_{\max} - r^0)]} \cdot (r^u - r^l) \qquad \text{(C.5)}$$

in which r_{max} is the longest source-to-site distance, r^0 is the shortest distance, r^l is the lower bound source-to-site distance, andr^u is the upper bound distance.

Probability of Ground Motion Parameter

The probability for a certain ground motion parameter, Z that will exceed z from the specified magnitude, m and at the specific location (source) with the distance r, can be calculated by utilizing the following relation:

$$P(Z > z/m, r) = 1 - F\left(\frac{\ln(z) - \ln(PHA)}{\sigma_{\ln y}}\right) \qquad \text{(C.6)}$$

where ***PHA*** is the peak horizontal acceleration and σ_{lny} is the standard deviation of that attenuation relation.By multiplying these probabilities from each sources and repeated again for all possible seismic sources together with the above mentioned steps, the Probabilistic PGA map can be developed for a certain area of interest or region.

Probability of Exceedance

The assumption called no memory (*Poisson Model*) is used the occurrence of certain magnitude earthquake in any particular year, the return period (*T*) of an event exceeding a particular ground motion level is represented by the mathematical expression as:

$$T = 1/v = - \Delta t / \ln (1 - P(Z>z)) \qquad (C.7)$$

In this equation, P(Z>z) is the desired probability of exceedance during the time T.

Appendix (D)

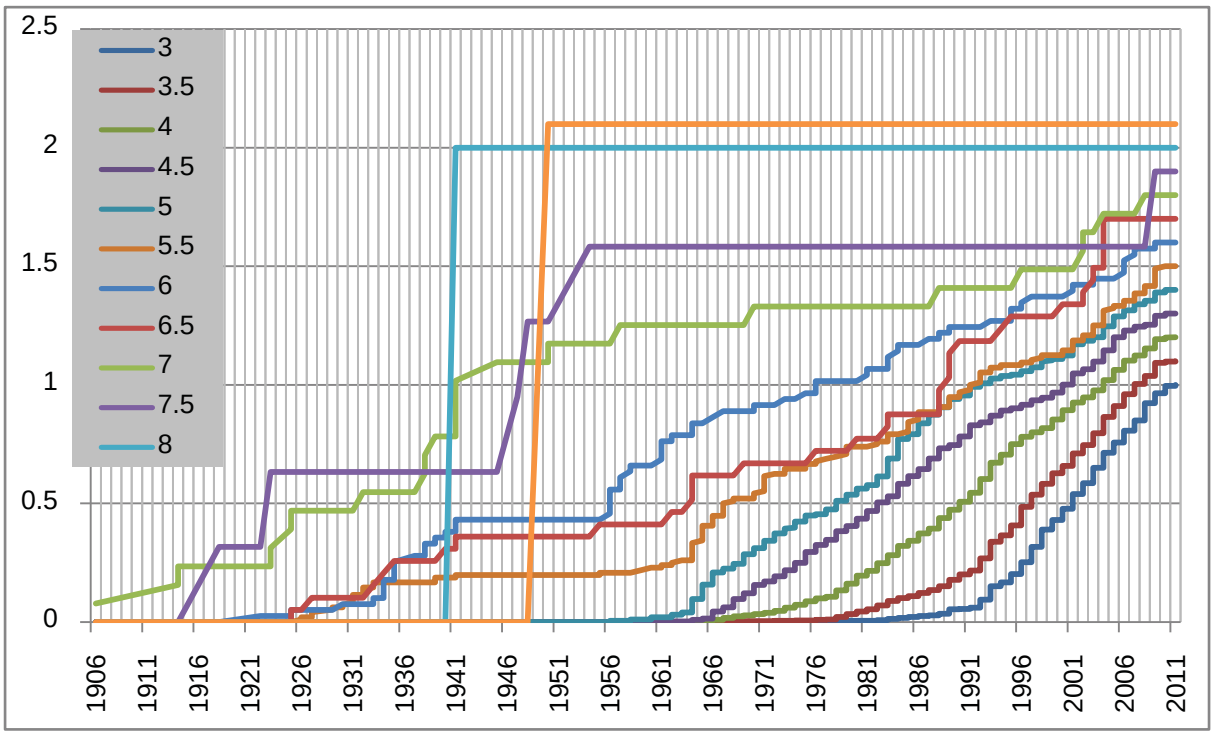

Figure (D-1). Diagram representing the relationship of normalized frequency of events of certain magnitude with respect to time (year) for Myanmar region (in which magnitude roundness is 0.25).

Table (D-1). Time of completeness for the events with certain magnitude for Myanmar region.

Magnitude	Incremental Frequency	Time of Completeness
3.0	791	1992
3.5	876	1992
4	1055	1978
4.5	541	1966
5	266	1964
5.5	89	1964
6	60	1933
6.5	33	1925
7	23	1925
7.5	6	1918
8	1	1906
8.5	1	1906

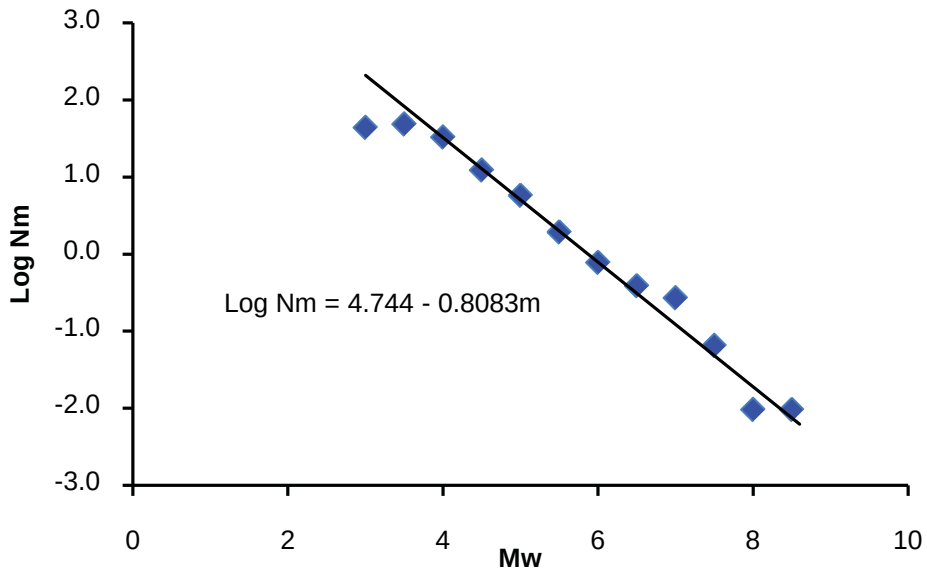

Figure (D-2). The Gutenberg-Richter relation for Myanmar region.

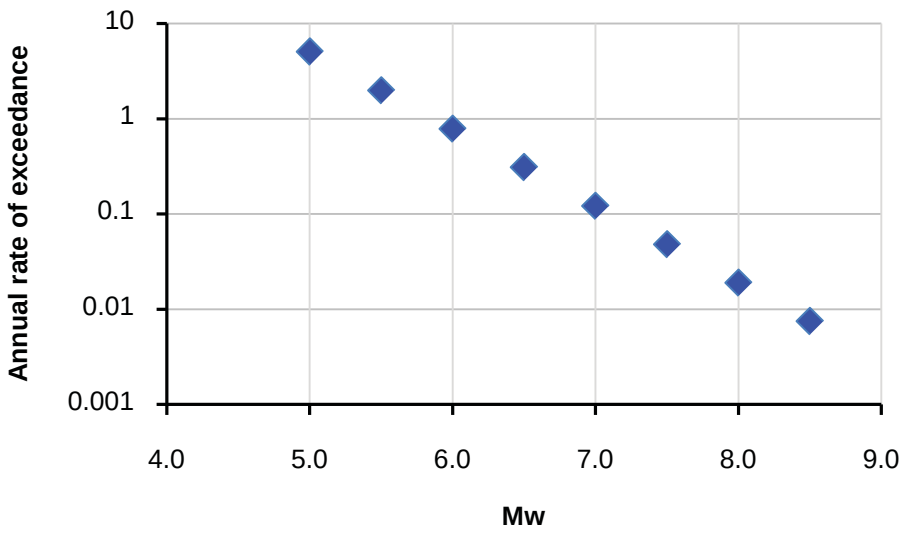

Figure (D-3). The diagram illustrating the annual rate of exceedance of certain magnitude earthquake for Myanmar region.

Appendix (E)

Table (E-1) Ground profile (soil) types or classification of subsoil classes according to UBC (Uniform Building Code) and EC8 (Eurocode 8) standards based onthe V_s^{30} values (modified from Sˆeco e Pinto 2002; Dobry*et al.* 2000; Sabetta & Bommer 2002). (Source-Kanl1 et al., 2006).

Ground profile (Soil) type (UBC) or Subsoil Class (EC8)	Ground description (UBC)	Description of stratigraphic profile (EC8)	Shear wave velocity V_{s30} (m s^{-1})
*S*A(UBC)	Hard rock	—	>1500 (UBC)
*S*B(UBC) or A (EC8)	Rock	Rock or other rock-like geological formation, including at most 5m of weaker material at the surface	760–1500 (UBC) or >800 (EC8)
*S*C(UBC) or B (EC8)	Very dense soil and soft rock	Deposits of very dense sand, gravel or very stiff clay, at least several tens of m in thickness, characterized by a gradual increase of mechanical properties with depth	360–760 (UBC) or 360–800 (EC8)
*S*D(UBC) or C (EC8)	Stiff soil	Deep deposits of dense or medium-denses and, gravel or stiff clay with thickness from several tens to many hundreds of m.	180–360 (UBC and EC8)
*S*E(UBC) or D (EC8)	Soft soil	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil	<180 (UBC and EC8)
*S*F(UBC) or E (EC8)	Special soils	A soil profile consisting of a surface —alluvium layer with *V*30s values of class C or D and thickness varying between about 5 m and 20 m, underlain by stiffer	—

		material with V_{s30} >800 m s^{-1}	
*S*1 (EC8)	—	Deposits consisting—or containing a layer at least 10 m thick—of soft clays/silts with high plasticity index (*PI* >40) and high water content	<100 (EC8)
*S*2 (EC8)	—	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in classes A–E or *S*1	— (EC8)