Development of Seismic Hazard Assessment at Mandalay City, Myanmar

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Abstract

The development of the new seismic hazard map of Mandalay is based on the magnification factor computation using the historical earthquakes data, geology, tectonics, fault activity and seismic sources models in Myanmar. The shear wave velocity of shallow sediments is very important in seismic wave amplification and thus Vs30 is a well-known parameter for site classification. Based on the relationship between Vs and soil indexes, the multiple reflection analysis were evaluated using 50 Standard Penetration Tests (SPT) datasets from the Mandalay City, Myanmar. Regression equations of Vs and the extrapolation of Vs30 were also applied to boreholes with only N-values and corresponding depths of less than30 m for assessing the Vs30 and site class. The shear wave velocity Vs30 of the top layer is Vs30≤ 220 m/s. The highest potential zone of seismic hazard mostly locates the north western marginal part of Mandalay city, in the proximal portion to the dextral Sagaing fault.

Keywords: Standard Penetration Tests (SPT), Shear wave velocity Vs30, multiple reflection analysis and Sagaing Fault

Introduction

The soft sediment deposits overlaid on the hard bedrock are believed to increase seismic amplification and cause increased damage during a large earthquake. This is the so-called site effect, a very important issue in strong ground motion studies. The different characteristics of near-surface layers cause various effects at sites. This so-called Vs30 (the average S-wave velocity of the top 30 m of strata) is recommended as a momentous index for defining the local geological conditions for site classification in recent building codes. In this research, the development of a high resolution near-surface Mandalay City Vs30 model is presented, including descriptions of the processing steps applied to the SPT dataset, the consideration made for the seismic hazard assessment of the selected spatial interpolation schemes.

Tectonic Setting

Tectonically, Myanmar lies in the frontier zone where two major plates namely India Plate which is composed of the Indian continent and Indian Ocean, and Eurasia Plate comprising Europe, part of Asia including Eastern Highlands of Myanmar, and South China Sea, congregate. The Sagaing fault has been suggested as plate boundary, having transform activity, between them and about it the country is divided into two different tectonic terrains viz. Sunda Plate (or Sibumasu Block, by some authors) comprising the Eastern Highlands of Myanmar; and the Burma (Myanmar) Plate (Curray et al., 1979) (West Burma Block, by some authors) which composed of Myanmar west of the Sagaing Fault. The Burma Plate is a sliver platelet bounded by convergence boundary with India Plate in the west, by a transform boundary with Sunda Plate in the east. A spreading center, namely the Andaman Spreading Center divides the Burma Plate from Sumatra Plate, tectonically similar platelet, recognize by some authors as South Burma Plate. As almost all the morphotectonic features in Myanmar follow the tectonic trend that originated by the plate convergence between India and Asia, Neogene or Recent active tectonic activity seems to be subjective to rearrange the physiography as well as geology of the country. Mandalay City covers the central part of Myanmar and it includes the major part of the boundary between Sagaing fault in the west (8

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km from Mandalay), Shan scarp fault and Kyaukkyan fault in the east, Shweli and Moemeikfaults in the north. The Sagaing fault is a major strike-slip right-lateral continental fault that extends over 1200 km and connects to the Andaman spreading center at its southern termination. This fault was noticed early by Noetling (1900), Win Swe (1970 and 1981), Myint Thein et al., 1991, and later confirmed by several authors (Curry *et al*., 1979; Mitchell, 1981; Le Dain et al., 1984; HlaMaung, 1987). Moreover, some active faults also occurred in Myanmar, e.g. Sagaing dextral fault, Kyaukkyan fault, Kyaukme fault, Momeik fault, Shan scarp fault, Kabaw fault, Nama fault and Gwegyo fault, etc. Among them, Sagaing is the most active fault and several high magnitude earthquakes have been originated from this fault.

Seismicity

The seismicity of the Myanmar is associated with the activity along the Alpide Seismic Belt, which is one of the most active seismogenic regions in the world. Historical earthquakes events recorded throughout Myanmar exhibit the seismic nature of the country. The Innwa earthquake and the Sagaing earthquake, which occurred in 1839 and 1956 respectively, have been the largest strikes to the Mandalay region. Innwa earthquake affected cities comprise Innwa, Amarapura and Mandalay. The total death tolls are about three to four hundred in Innwa and Mandalay and the earthquake magnitude was also estimated as Mercalli scale IX. In the banks of Ayeyarwady river between Amarapura and Innwa and in Mandalay, several chasms of from five to twenty feet in width were resulted and from which large quantities of water and sand were ejected, representing the liquefaction characteristics. Sagaing earthquake caused 40 to 50 death tolls and several buildings including pagodas were destroyed (Chhibber, 1934). The Sagaingb ridge was displaced for a few feet. The damage properties in Mandalay was as not high as in Sagaing (Myo Thant et al., 2012). Recent earthquakes occurring in central Myanmar with notable magnitudes included, the 1858 Pyay Earthquake (Magnitude?), the 1906 Putao Earthquake (Magnitude 7 on Richter Scale), the 1912 Maymyo Earthquake (Magnitude 8), the 1928 Htawgaw Earthquake (Magnitude ?), the 1930 Bago Earthquake (Magnitude 7), the 1930 Phyu Earthquake (Magnitude 7.6 on Richter Scale), the 1931 Kyaukse Earthquake (Magnitude ?), the 1946 Tagaung Earthquake (Magnitude 7.5), the 1975 Bagan Earthquake (Magnitude 6.5), the 2003 Taungdwingyi Earthquake (Magnitude 6.8), the 2011 Tarlay Earthquake (Magnitude 6.8), the 2016 Kani Earthquake (Magnitude 6.9) and the 2016 Chauk Earthquake (Magnitude 6.8). The most recent 2016 quake has been identified as a deep-thrust event resulting from the east-subducting Indian ocean plate beneath the Burma plate. Many of historical earthquake events had a magnitude of 6 or greater and resulted in severe damages and significant causalities. The evidences of the earthquake that damaged in the past are well demonstrated or observed through the tectonic features such as fault, shear zones, fault scraps, or from historical documented records of eye witness accounts, etc. There are many historical and recent earthquakes that are well-known, not only for its magnitude but also for the casualties it brought forth.

The historical and recent earthquakes data show that Mandalay City is very vulnerable to earthquake disasters. The epicenter distribution of Mandalay City and its vicinity for the years 1968–2017 are compiled from USGS website (Fig. 1). The projections in this figure are based on digital elevation model from SRTM satellite image in 30 meter resolution. The variation in sizes of the circle suggests relative magnitude. Shallow seismicity characterizes along the Sagaing strike-slip fault zone, whereas the India - Eurasia subduction system in the west and Sunda subduction system in the South of Myanmar exhibit high and intermediate-depth seismicity.

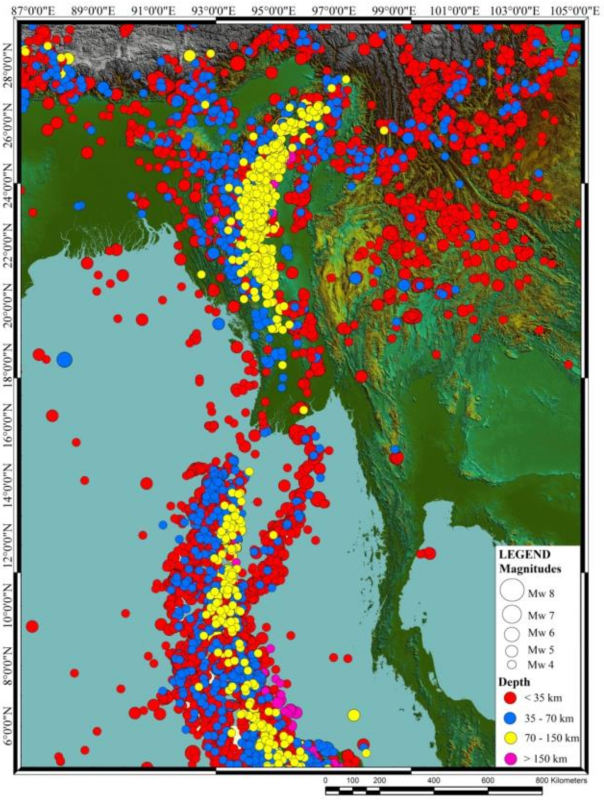


Figure (1). Seismicity map showing the distribution of the epicenters of the significant recorded earthquake in Myanmar and surrounding regions.(Source: http:// USGS website)

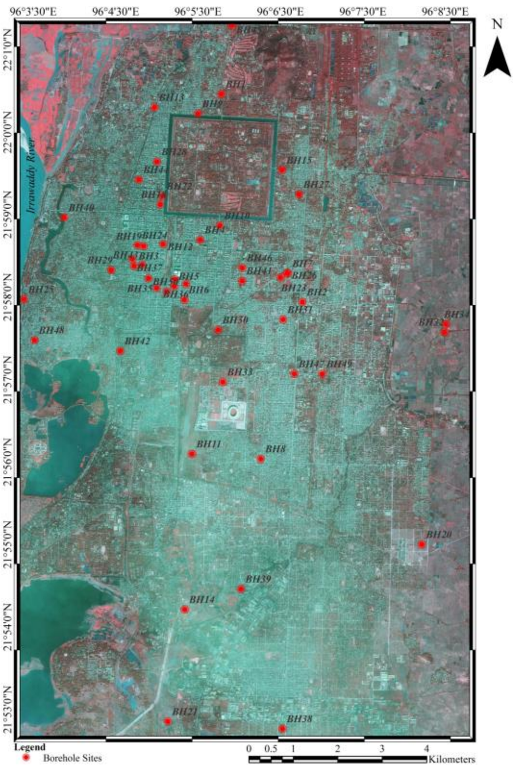


Figure (2). Satellite image of Mandalay City with the available borehole data are also indicated.

SPT Data sets and Vs30 model

The subsurface profiles and related geotechnical parameters have been evaluated in fifty borehole sites for seismic hazard analyses. The detailed drilling program had been carried out for subsurface investigation in Mandalay City (Fig. 2). Fifty boreholes were generally drilled up to 30 m. The SPT dataset is used to develop surfaces describing the distribution of time-averaged shear wave velocity, Vs30, across the greater Mandalay urban area. Target profile depths of 5, 10, 20, 30 m were considered to allow for an assessment of the distributions of soil stiffness with depth across the region. Vs30 values are computed for each target depth, as equation 1 (Bernard et al., 2012). The evaluated subsurface profiles for each area in Mandalay City are shown in the following figure (3).

$$Vs30=\frac{\sum d_i}{\sum t_i} = \frac{\sum d_i}{\sum(\frac{d_i}{vs_i})} \qquad (1)$$

where in which v_{si} is shear wave velocity, d_i thickness of i layer and t_i one way traveltime in ith layer

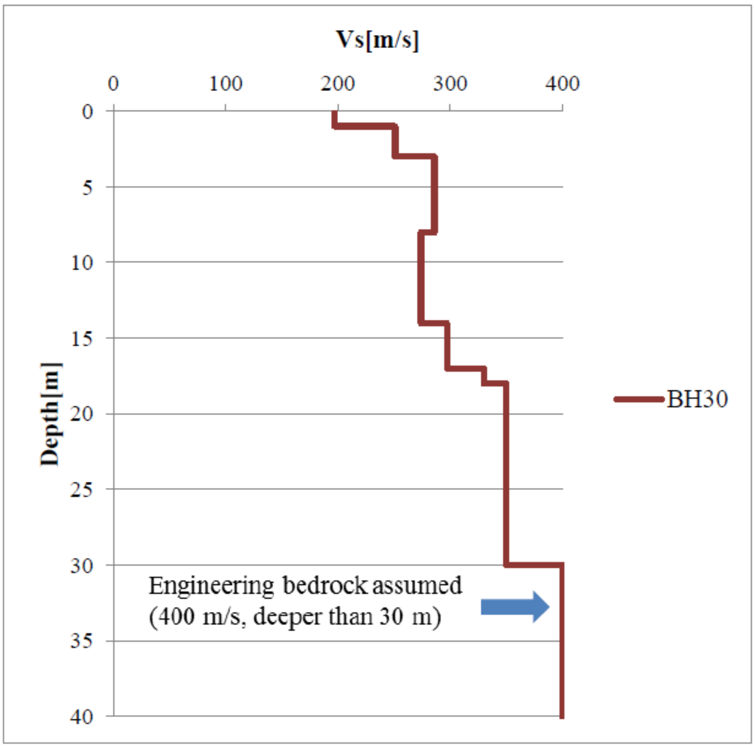


Figure (3). Example of Vs profile at Mahaaungmye Township, Mandalay City.

Predominant Periods

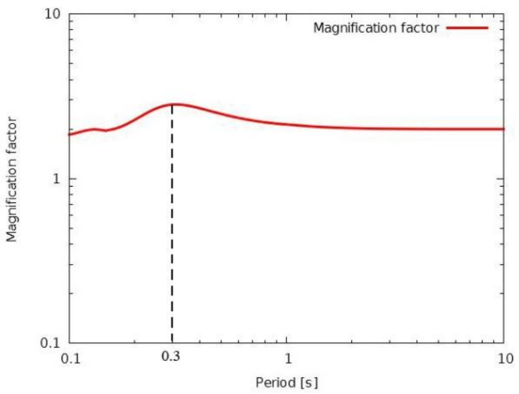
The Multiple Reflection Analysis was used to calculate the transfer function, which express the relation between the period and the corresponding magnification factor. Calculation of predominant period by using boring data and the ground model profile is done according to the Multiple Reflection Analysis (MRA).The governing equation is

$$\rho \frac{\delta^2\mu}{\delta t^2} = G\frac{\delta^2\mu}{\delta Z^2} + \eta\frac{\delta^3\mu}{\delta Z^2\delta t} \qquad (2)$$

in which μ is the displacement of horizontal S-wave (SH), Z the direction of wave propagation (up-down), t the time, ρ the density, G the shear modulus and η the coefficient of visco-elasticity. The soil damping is considered by giving the complex value to the shear modulus and solve the equation 2. The damping constant is 5% of critical damping for each layer.

The H/V spectral ratio of microtremor observation is frequently used for estimating predominant period of the surface ground. We here estimate the predominant period by calculating transfer function of model ground based on the SPT data. The multiple reflection analysis is the linear analysis, however, above H/V ratio results also obtained as linear vibration phenomena. Therefore we adopted this method for the determination of ground motion parameter. Figure (4) shows examples of transfer functions.

Distinct peaks express the characteristics of the layers for which the shear wave velocity is quite different. The shorter and longer periods are corresponding to a shallow and a deep soil layer or hard and soft soil. Figure (5) reflects an effect of different soil characteristics, respectively. Although the predominant period does not always indicate the characteristics of an individual layer because typically the actual shaking mode of the ground is complex, it was assumed that the long and short periods reflected information from each layer. Although there are 50 observation points, the points are not adequate to cover all the target area. If each value of the predominant period obtained is considered to be a realization of a stochastic random field. Space interpolation is conducted by ordinary kriging technique (Kiyono et al., 1996), (Noguchi et al., 2009) and (Thein et al, 2015).



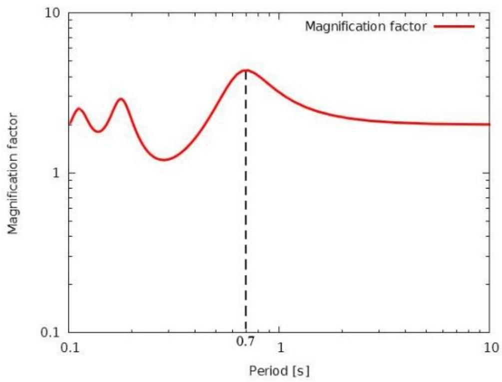


Figure (4). Example of the predominant periods, (a) Predominant period appears in a shorter period, (b) Predominant period appears in a longer period

Peak Ground Acceleration

The PGA map in the city of Mandalay was estimated by performing seismic response analyses at all sites of SPT measurements. In the seismic hazard assessment, the input motions were selected based on the Probabilistic PGA (Peak Ground Acceleration) (g) Map of Myanmar for 10% probability of exceedance in 50 years, for engineering bedrock condition (Myo Thant et al., 2012). The ground response analyses were conducted by using the assumption of vertical propagation of shear waves from the engineering bedrock to the ground surface. The peak horizontal ground acceleration of these seismic events ranged from 0.35 g to 0.65 g with corresponding of magnification ranging from 2.2 to 3.8. The estimated PGA results are illustrated in Figure 6. The highest seismic hazard zones mostly constitute the north western marginal part of Mandalay city, located in the proximal portion to the

Sagaing fault. In both cases, the highest seismic zone comprises the western part of Aungmyethazan, Chanayethazan and Mahaaungmye township, and the second-most highest zone consists of Amarapura, Chanayethazan, Mahaaungmye, Chanmyathazi and Pyigyidagun townships and the eastern-most part of Patheingyi township.

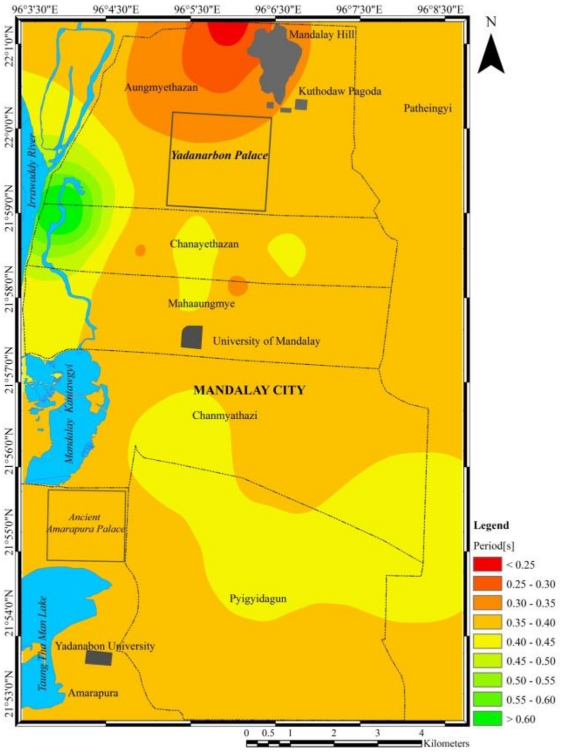


Figure (5). Predominant periods in Mandalay City

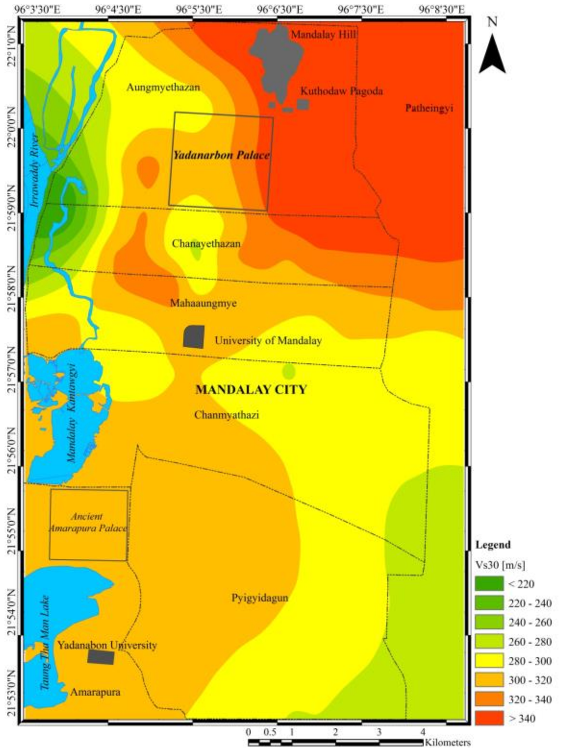


Figure (6). Spatial variation of Vs30 in the Mandalay City

Conclusions

This research mainly focuses on the results of seismic microzonation based on collected fifty SPT data, which covered almost the whole city area. The purpose of this research was to calculate the shear wave velocity of the top 30 m Vs30of the soil profile. In general, it is recommended that engineers consider all available data including site geology, available measured profiles, and site-specific geotechnical data. Shear wave velocity Vs30, predominant periods and estimated PGA maps are produced as the main results for seismic microzonation in Mandalay City. The kriging method can be used for the interpolation of subsurface information such as predominant period, shear wave velocity and PGA with the QGIS software. By combining the 2012, PSHA model Myanmar and the results of site magnification parameters, we proposed the distribution of the estimated peak ground acceleration of the urban Mandalay City, Myanmar. The PGA, average shearwave velocity Vs30 and predominant period maps are the basic needs for engineering purposes for every seismically active area or region. From this research, seismic microzonationwas carried out by means of PGA at Mandalay City. Because of gradual growth of the population and the high-rise building, seismic microzonation analysis in absolutely needed to perform. These results are enormously required for Mandalay region for engineering purposes. The outputs of this research would be very applicable for both engineering purpose and to identify and mitigate the seismic risk for Mandalay City, Myanmar.

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