Estimation of Shear Wave Velocity at Mandalay City, Myanmar

Pyi Soe Thein*, Junji Kiyono, Tun Tun Win*****

Abstract

The shear wave velocity of shallow sediments is very important in seismic wave amplification and thus Vs_{30} 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 Vs_{30} were also applied to boreholes with only N-values and corresponding depths of less than 30 m for assessing the Vs_{30} and site class. The shear wave velocity Vs_{30} of the top layer is $Vs_{30} \leq 220$ 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 Vs_{30}, multiple reflection analysis and Sagaing Fault;

Introduction

Mandalay City is the famous cultural center of Myanmar and the population is about one million. There are also greater population, higher urbanization, more industrialization and many infrastructures. Actually, the city is located very closed to the most active dextral Sagaing fault in Myanmar. In the historical record, several earthquakes happened in and around Mandalay, Amarapura, Innwa, Sagaing region from the beginning of the year of 1400. Even a moderately strong earthquake may cause great loss of lives and property damage. This research will solve part of this problem especially for Mandalay City. In this research, the development of a high resolution near-surface Mandalay City Vs_{30} model is presented, including descriptions of the processing steps applied to the SPT dataset, the consideration made for the seismic hazard analysis of the selected spatial interpolation schemes. This Vs_{30} model provides a characterization of the near-surface shear wave velocity of the Mandalay City that has useful connotations for site classification.

Tectonic Setting and Geology

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 (Figure 1). 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, recognized 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

* Lecturer, Dr, Department of Geology, Yadanabon University, Myanmar
** Professor, Graduate School of Global Environmental Studies, Kyoto University, Japan
*** Lecturer, Dr, Department of Geology, University of Mandalay, Myanmar

central part of Myanmar and it includes the major part of the boundary between Sagaing fault in the west (8 km from Mandalay), Shan scarp fault and Kyaukkyan fault in the east, Shweli and Moemeik faults 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; Hla Maung, 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 (Figure 2).

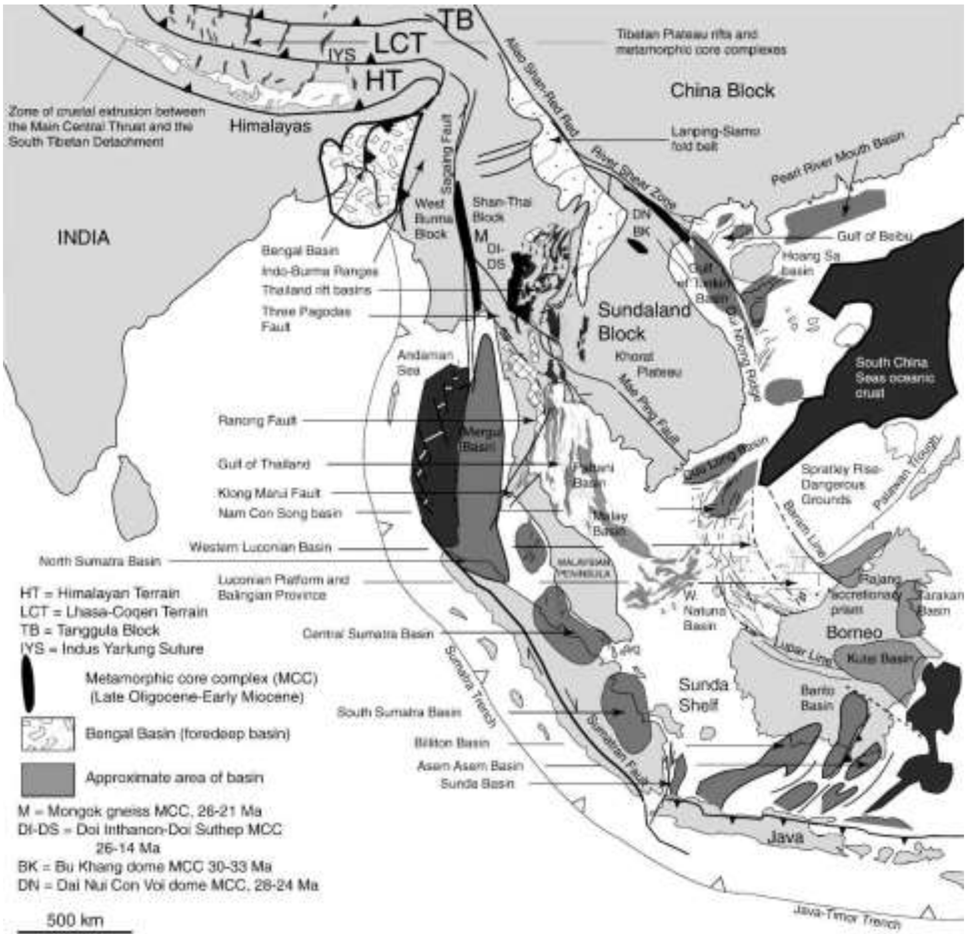


Figure 1 Tertiary tectonic and structural features of Southeast Asia (compiled by Morley, 2002)

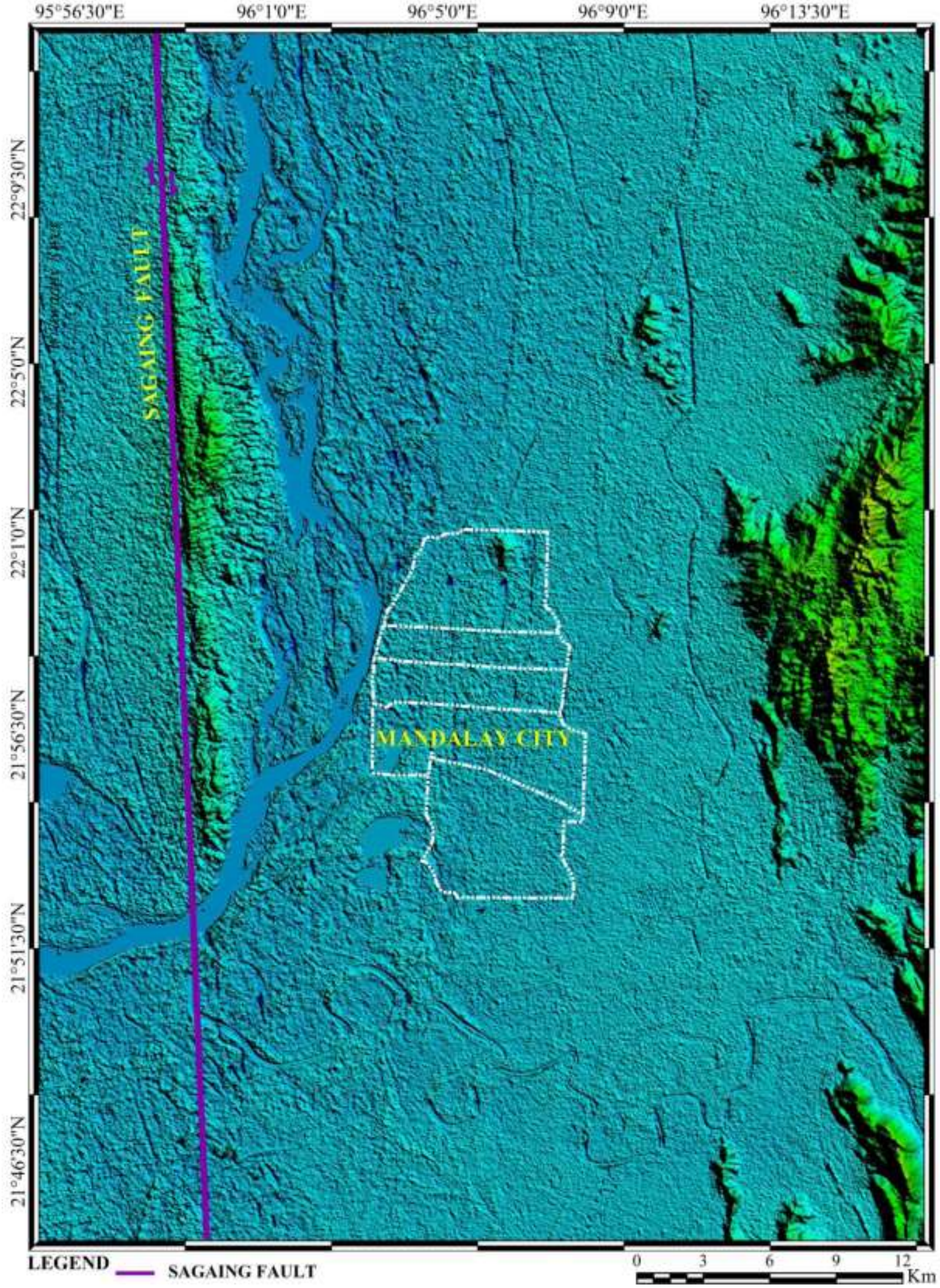


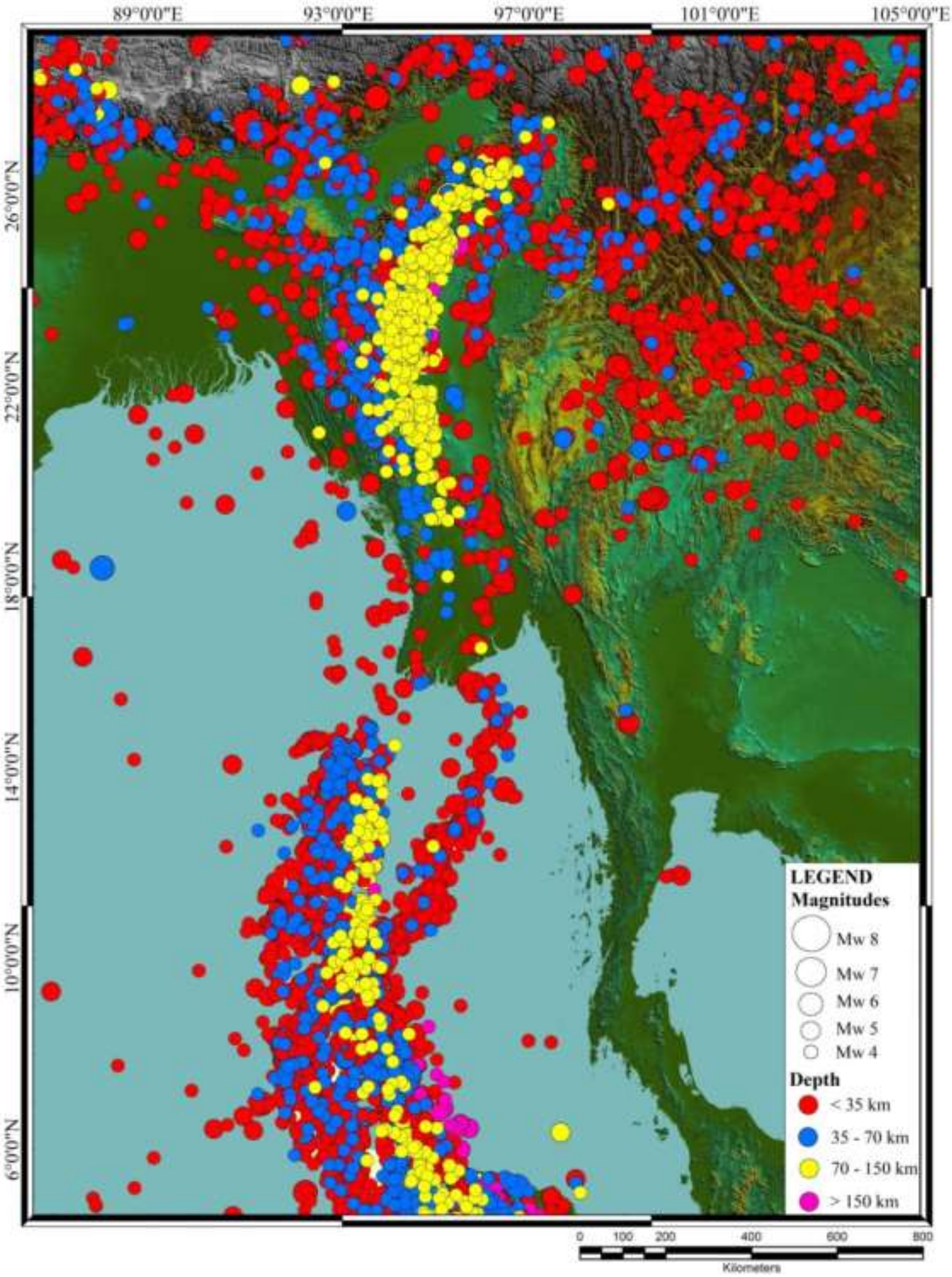
Figure 2 Tectonic features of Sagaing Fault.

Historical Seismicity

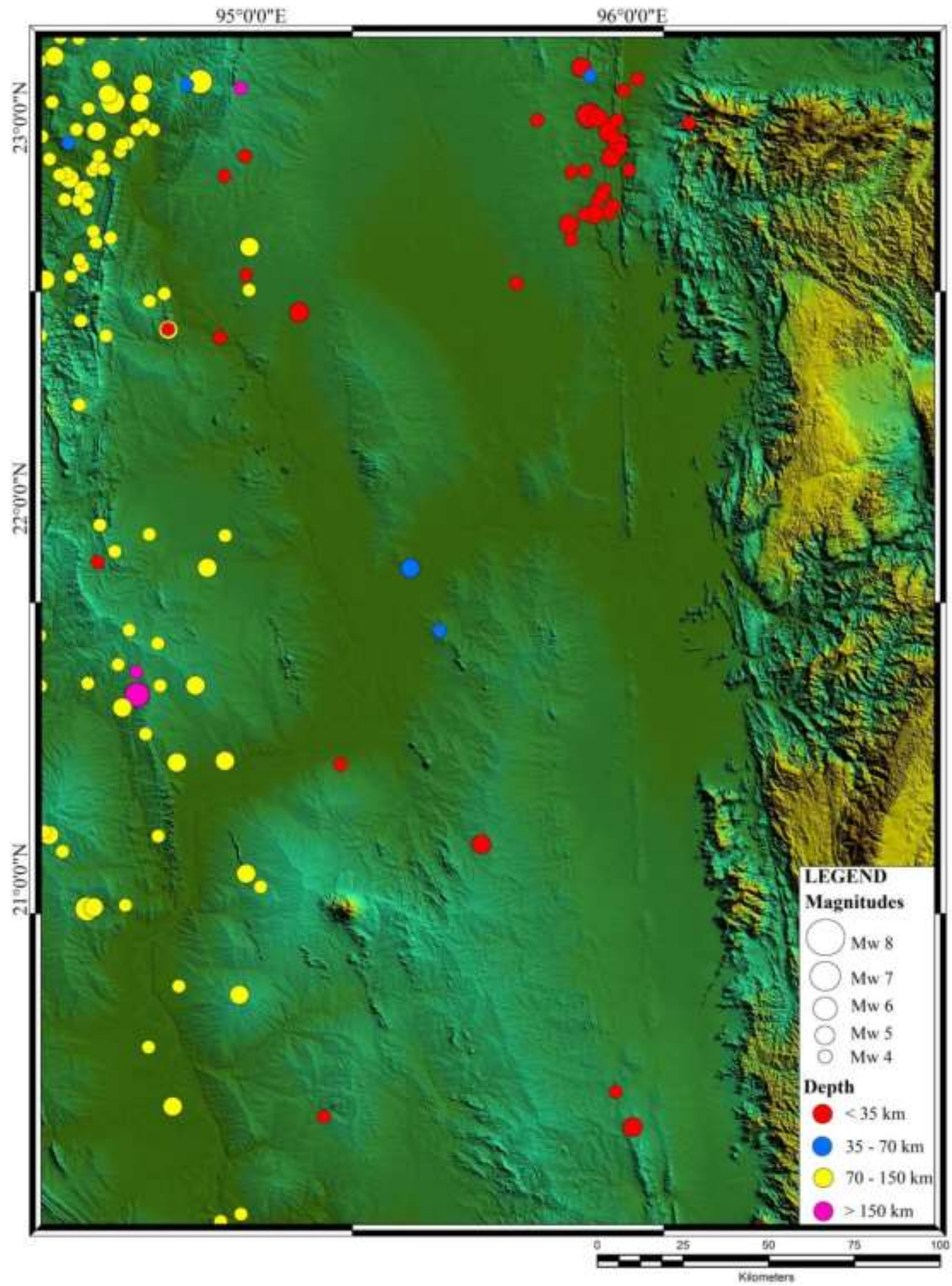
The seismicity of the Myanmar is associated with the activity along the Alpide Seismic Belt, which is one of the most active seismogenic regions in the world. Historical earthquakes events recorded throughout Myanmar exhibit the seismic nature of the country. The Innwa earthquake and the Sagaing earthquake, 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 Sagaing bridge 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 (Figure 3 (a) and (b)). 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.



(a)Myanmar and surrounding area (Source : http:// USGS website)



(b) Near Mandalay Region

Figure 3 Seismicity map showing the distribution of the epicenters of the significant recorded earthquake (Source : http:// USGS website)

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. Fifty boreholes were generally drilled up to 30 m (Figure 4). The SPT dataset is used to develop surfaces describing the distribution of time-averaged shear wave velocity, Vs_{30}, 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 5.

$$Vs_{30} = \frac{\sum d_i}{\sum t_i} = \frac{\sum d_i}{\sum(\frac{d_i}{vs_i})} \qquad (1)$$

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

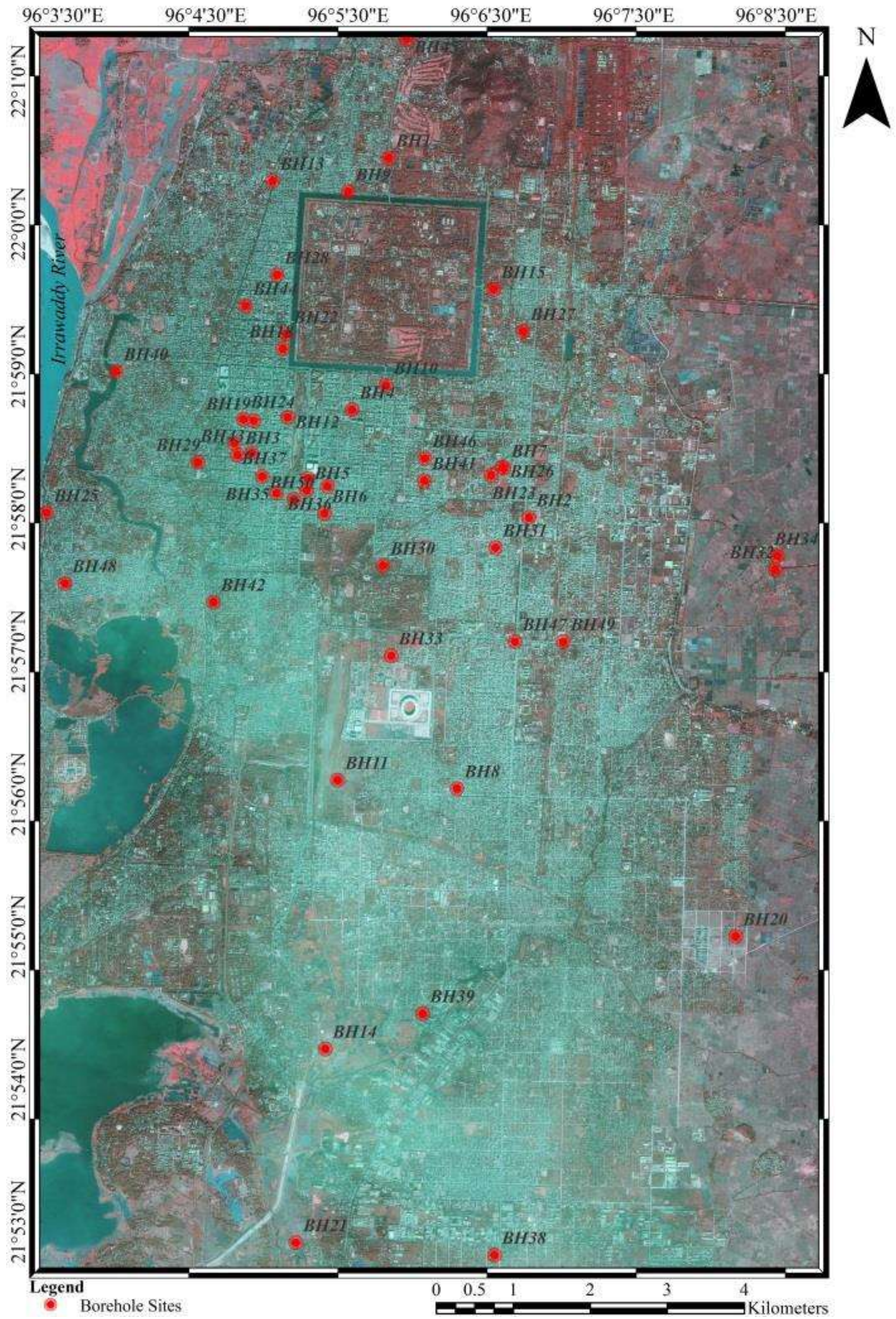


Figure 4 Satellite image of Mandalay City with 50 borehole sites.

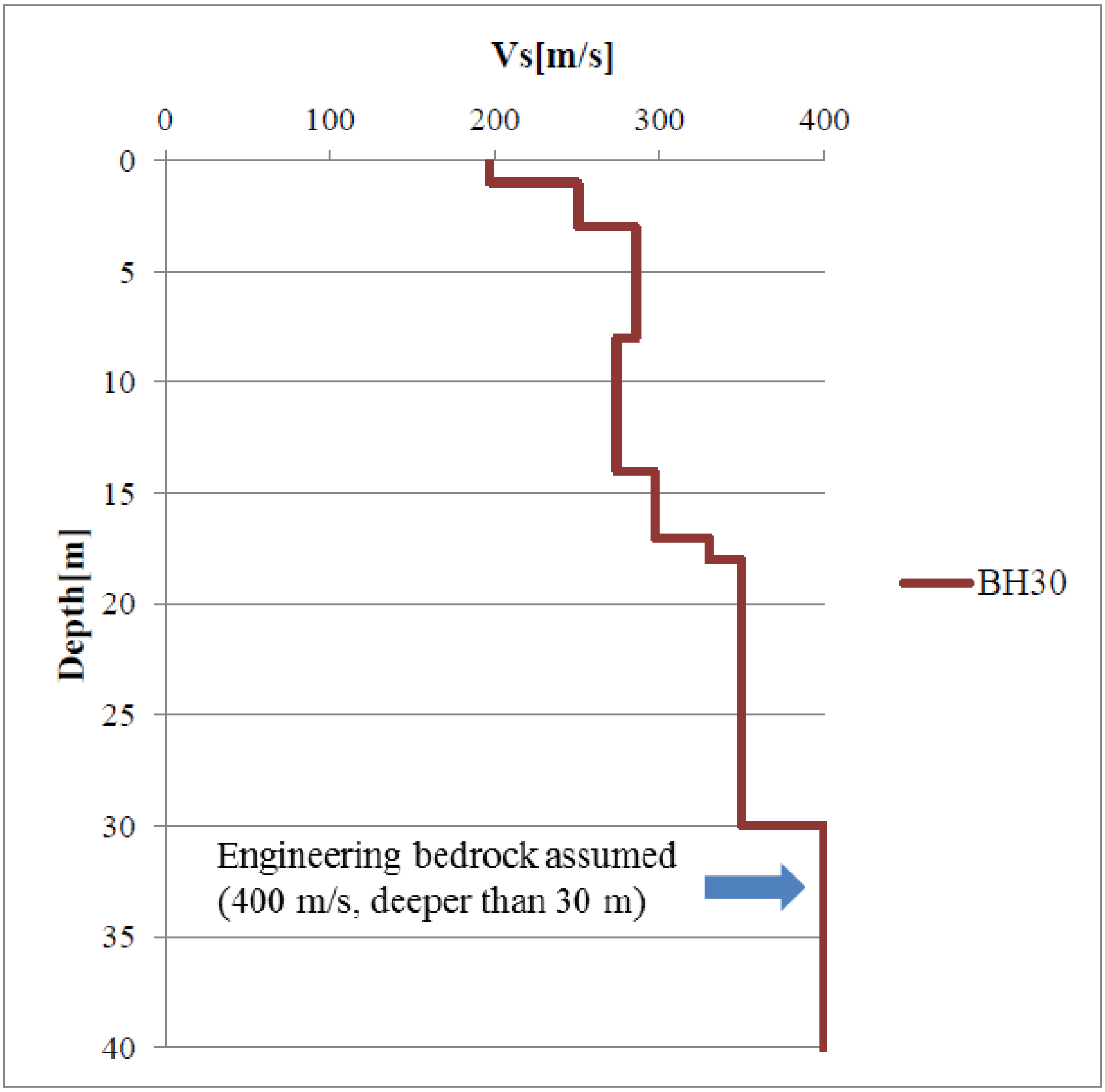


Figure 5 Example of Vs profile at Mahaaungmye Township, Mandalay City.

Predominant Periods

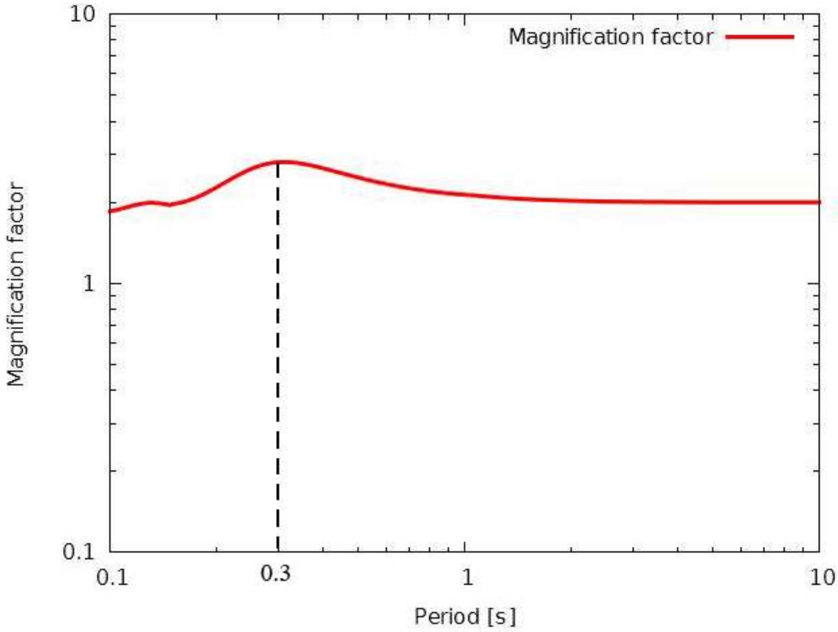
The Multiple Reflection Analysis was used to calculate the transfer function, which express the relation between the period and the corresponding magnification factor. Calculation of predominant period by using boring data and the ground model profile is done according to the Multiple Reflection Analysis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

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

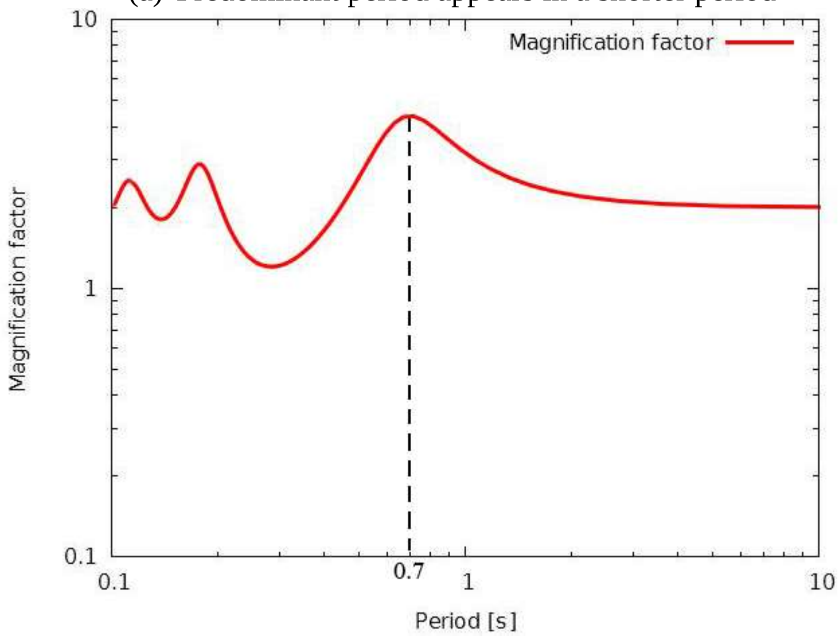
in which μ is the displacement of horizontal S-wave (SH), Z the direction of wave propagation (up-down), t the time, ρ the density, G the shear modulus and η the coefficient of visco-elasticity. The soil damping is considered by giving the complex value to the shear modulus and solve the equation 2. 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 6 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 6 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).



(a) Predominant period appears in a shorter period



(b) Predominant period appears in a longer period

Figure 6 Example of the predominant periods

Vs_{30}

The weighted average value of shear wave velocity, Vs, in the upper 30 m of ground is denoted as Vs_{30} and is being used extensively worldwide to characterize a site in terms of the expected characteristics of earthquake shaking, despite the criticism expressed by several investigators. Based on the existing borehole data and the shear wave velocity data, the Vs_{30} map is developed for this city. The spatial variation of Vs_{30} in the urban area of Mandalay is shown in the Figure 7. Uniform Building Code and Eurocode 8 utilize the Vs_{30} to characterize soil categories (A, B, C, D and E) according to the following limit values :A: Vs_{30} > 800 m/s, B: 360 m/s < Vs_{30}< 800 m/s, C:180 m/s <Vs_{30} < 360 m/s, D:180 m/s > Vs_{30}, E:soil profile consisting of a surface alluvium layer with Vs values of type C or D and thickness varying between 5m and 20m, underlain by stiffer material with Vs >800 m/s. The results indicate that almost the entire part of the formations underlying the urban area are classified in category C with only a small portion in the western area of the city close to the Irrawaddy river section falling in category D. With regards to the site class, nearly all of the sites comprise the C class with the Vs_{30} range of 220 – 340 m/s, therefore stiff soil. The lateral changes of the soil properties, in terms of Vs_{30} values are in East-West direction. The minimum Vs_{30} range, 220 – 320 m/s, constitutes in the western part of the city, comprising Aungmyethazan, Chanayethazan, Mahaaungmye, Chanmyathazi, Pyigyidagun and Amarapura townships. The maximum Vs_{30} values can be observed in the northeastern part of the city, with the range of 320 – 340 m/s in Patheingyi township.

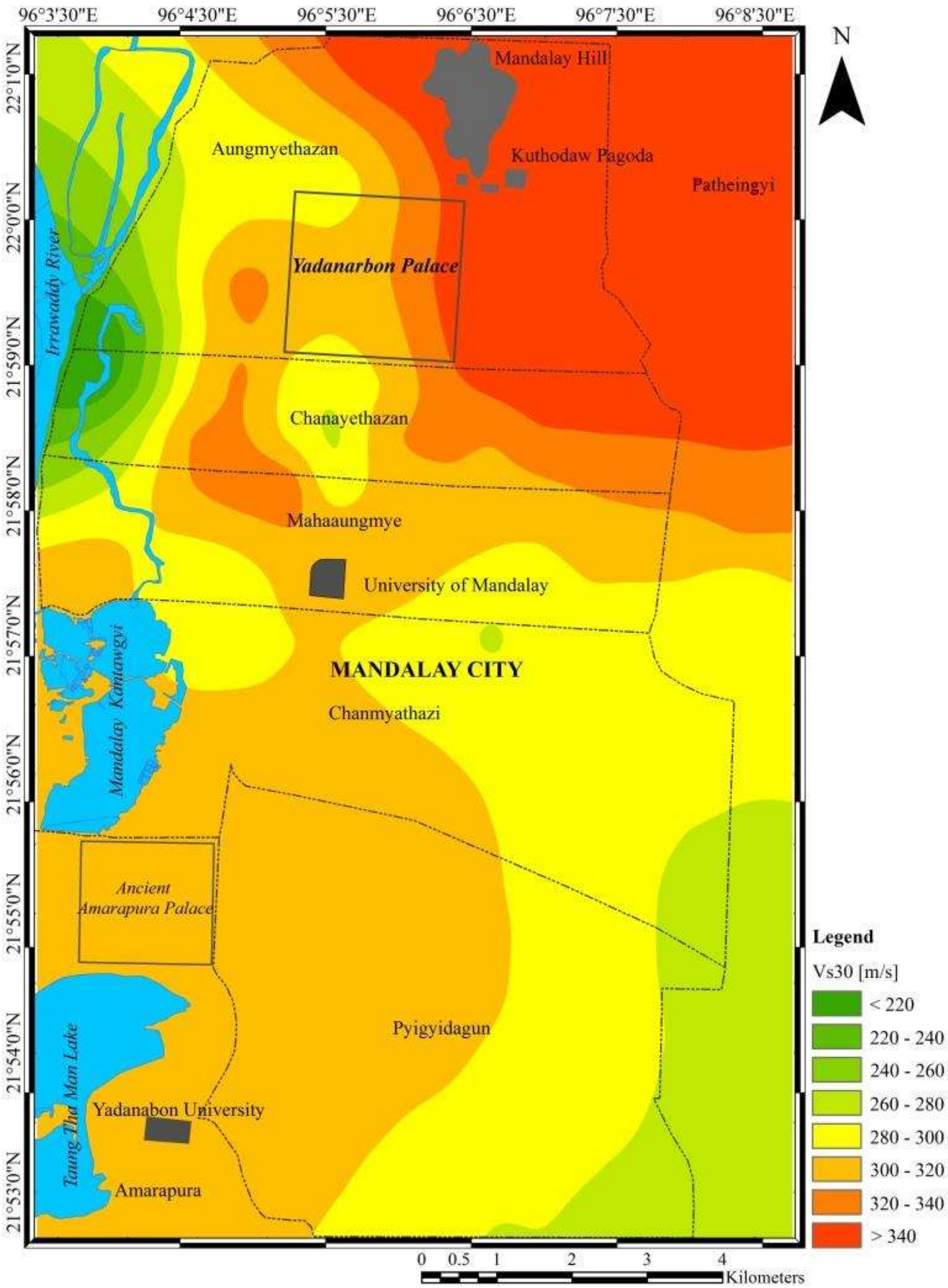


Figure 7 Spatial variation of Vs30 in the Mandalay City

Conclusions

This research mainly focuses on the results of 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 of the soil profile Vs_{30}. 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 Vs_{30}, predominant periods and site classification are produced as the main results for seismic hazard analysis in Mandalay City. The kriging method can be used for the interpolation of subsurface information such as the predominant period and shear wave velocity and with the QGIS software. 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.

Suggestions

The seismic ground motion GPS network should be established in Mandalay City, so that actual parameters of the earthquakes can be used for input motion in future seismic microzonation analysis. The future large array microtremors and geoelectric survey should conduct among the previous borehole sites in order to investigate thoroughly the whole City area. That kind of survey is in need to prepare adequate and satisfactory input data for future seismic hazard analysis in Mandalay City, Myanmar.

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