Estimation of the subsurface sedimentary structure of Amarapura township (Mandalay Region) based on microtremor survey

P S Thein¹, K M O Kyaw², J Kiyono³, S Pramumijoyo⁴, T T Nu⁵, K H Khaing⁶, W M Than⁷, T T Win⁸ and M Thant⁹

¹Department of Geology, University of Magway, Myanmar
²Department of Geology, University of Mandalay, Myanmar
³Graduate School of Global Environmental Studies, Kyoto University, Japan
⁴Geological Engineering Department, Gadjah Mada University, Indonesia
⁵Department of Geology, University of Mandalay, Myanmar
⁶Department of Geology, Defence Services Academy, Myanmar
⁷Department of Geology, Sittwe University, Myanmar
⁸Department of Geology, Kyaukse University, Myanmar
⁹Department of Geology, University of Yangon, Myanmar

*E-mail: pyisoethein@yahoo.com

Abstract. In this study, we investigated the underground structure for Amarapura township, Mandalay region. One of the major structures in Myanmar is the Sagaing Fault system. Several powerful earthquakes have struck along the Sagaing Fault during recent years, one of the largest of which was an M 7.0 event that occurred on July 16, 1956 and caused several casualties. Following the event, we conducted a microtremor survey to estimate the shaking intensity distribution during the earthquake. Seven boreholes were drilled throughout the basin, especially in Amarapura township to evaluate the geotechnical properties of subsurface soil layers. The H/V analysis of the noise measurements reveals frequency peak values ranging from 0.5 to 3 Hz on the Amarapura township. The shear wave velocity becomes less than 190 m/s in some areas, which causes severe damage for buildings in high probability. The sediment thickness values range from less than 50 m to greater than 320 m on Amarapura township, Mandalay region. In this way, the accomplished work has contributed to the characterization of the underground structure and the identification of sites prone to amplify soil shaking during a possible strong earthquake.

1. Introduction
Mandalay is the second largest capital city in Myanmar and the population is 1.727 million. This city is located very close to the most active Sagaing fault in Myanmar [1],[2]. Mandalay region, where a destructive earthquake is expected in the near future, is considered to be a target area. The geometry of the underground structure and plate tectonic movement are at the origin of ground vibration during destructive earthquakes [3]. We carried out geophysical and geotechnical survey in Amarapura township, Mandalay region. Based on the survey data, we calculated the distribution of the sediment thickness and Vs30 of Holocene deposits.
2. Seismic Sources of Myanmar

Tectonically, Myanmar lies in the frontier zone which consists of two major plates, the India Plate and the Eurasia Plate. Numerous historic earthquake events recorded throughout Myanmar exhibit the seismic nature of the country. Since the 18th century, at least 15 major earthquakes including events in 1762 (north Rakhine Coast) and 1839 (Innwa Ancient Capital) occurred in Myanmar territory. Recent earthquakes occurring in Central Myanmar with notable magnitudes include the 1975 Bagan Earthquake (Magnitude 6.5), the 2003 Taungdwingyi Earthquake (Magnitude 6.7) and the 2011 Tarlay Earthquake (Magnitude 6.8).

2.1. Historical Seismicity around Mandalay Region

2.1.1. Innwa Earthquake (1839)

The Innwa earthquake occurred at about 4 am on 23 March 1839. Its epicenter was estimated at 22° North and 96° East with the maximum intensity of XI (Modified Mercalli Intensity Scale). The shock was accompanied by a tremendous roar and lasted about 20 seconds. While the damage was experienced in neighboring areas such as Amarapura, Innwa sustained extensive destruction. It is estimated that about 300 to 400 people were killed in the event [4].

2.1.2. Maymyo Earthquake (1912)

A disastrous intraplate earthquake occurred in 1912 at 97°E and 21°N with a moment magnitude of 8.0. The damage was severe in Maymyo (Pyin Oo Lwin). Railway lines were bent where they crossed the fault and massive landslides occurred. Aftershocks occurred for six months following the event.

2.1.3. Kyaukse Earthquake (1931)

Occurring on 19 August 1931, the Kyaukse earthquake was strong enough to cause minor cracking to buildings in Mandalay and to knock light articles over in Kalaw.

2.1.4. Sagaing Earthquake (1956)

The epicenter of the Sagaing earthquake was at 24.6°N and 99°E near Sagaing in central Myanmar with the depth between 8 and 10 km. It occurred at 15:07 hours GMT on 16 July 1956 and had a magnitude of 7.0 on the Richter scale. The earthquake was destructive in Upper Myanmar causing property damage at Mandalay and damaging 80% of the houses in Sagaing (22 km from Mandalay) as well as causing up to 50 casualties and 50 injuries [4].

2.1.5. Bagan Earthquake (1975)

The Bagan earthquake on 8 July 1975 was the most memorable in recent Myanmar history. It had a magnitude of 6.8, but its destruction horrified the people of Myanmar. The epicenter lies at latitude 21.48° N and longitude 94.70°E which is located in the northern part of Tankgyi Taung. Tremors of three aftershocks with moderate intensity were felt in Bagan and its surrounding area.

3. The GIS-Based Model proposed for Strong Ground Motion Analysis

The GIS based model involves three types of objectives. These are interpretation of vector, tabular and raster database. The imageries such as aerial photographs and satellite images were used for the generation of stereo-pairs in order to generate geomorphological map of Mandalay region. The necessary analysis was carried out for the generation of GIS layer models and lithological cross section. The strategy for earthquake risk assessment is shown in figure 1.
Figure 1. Data workflow diagram of earthquake risk assessment.

4. Regional Geology
Mandalay region is tectonically bounded by the Shan Plateau in the east, in which several lateral strike-slip faults are included such as Moemeik fault, Shweli fault, and Namma fault etc., and the subduction zone of Indian plate beneath Burma plate in the west and these tectonic environs are the main seismic sources of causes rather than Sagaing fault [5]. The Holocene sediments were deposited on Mandalay City. Geological map of Mandalay region is shown in figure 2 [6].
Figure 2. Geological map of Mandalay region [6].
5. Microtremor Survey

Microtremor instrument developed by Akashi Corporation, Model SMAR 6A3P was used in our site investigation. Microtremor measurements were taken in the Amarapura township in March 2020. In this research, 21 microtremor measurements were performed that sampled every district of Amarapura Township (figure 3).

![Figure 3. Location map of the boreholes and microtremor measurements [7].](image-url)
6. Evaluation of Subsurface Soil Profile from Borehole data

Geotechnical site investigation is carried out to determine the subsurface soil structure and rocks. This investigation consisted of seven bore holes which were drilled up to 30m depth (Figure 3). In Mandalay region, bore hole drilling is carried out on 27 November 2020 to 9 January 2021. The subsurface soil profile of bore hole site no.1 is shown in figure 4. Shear wave velocity is an important parameter for estimation of the soil dynamic properties in the shallow subsurface. $V_{S30}$ values are computed for each target depth as equation 1 [8]

$$V_{S30} = \frac{\sum d_i}{\sum t_i} = \frac{\sum d_i}{\sum \frac{d_i}{v_{si}}}$$

where, $v_{si}$ = shear wave velocity, $d_i$ = thickness of i layer and $t_i$ = one-way travel time in i-th layer.

According to subsurface investigation, seven standard penetration test (SPT) had been carried and the correlation result of $V_s$ profile and depth is shown in figure 5. These soil profiles and properties are fundamental input parameters for ground response analyses.

![Figure 4. Subsurface soil profile at BH site no. 1.](image-url)
7. Modelling of Sedimentary Layered Media

The multiple reflection analysis was used to calculate the transfer function, which expresses the relation between the period and the corresponding magnification factor. Calculation of predominant period by using borehole data and the ground model profile is done according to the multiple reflection analysis. The governing equation is

\[ \rho \frac{\delta^2 \mu}{\delta t^2} = G \frac{\delta^2 \mu}{\delta Z^2} + \eta \frac{\delta^3 \mu}{\delta Z^2 \delta t} \]

Where, \( \mu \) is the displacement of horizontal S-wave (SH), \( Z \) the direction of wave propagation (up-down), \( t \) the time, \( \rho \) the density, \( G \) the shear modulus and \( \eta \) the coefficient of visco-elasticity. The soil damping is considered by giving the complex value to the shear modulus and solving equation 2. The damping constant is 5% of critical damping for each layer [9]. The H/V spectral ratio of microtremor observation is frequently used for estimating the predominant period of the surface ground [10]. We estimate here the predominant period by calculating the transfer function of model ground based on the borehole 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 the ground motion parameter. Figure 6 shows examples of transfer functions.

**Figure 5.** The evaluated Vs profiles and depth at Amarapura Township.

\[
\begin{align*}
0 & \quad 50 \quad 100 \quad 150 \quad 200 \quad 250 \quad 300 \quad 350 \quad 400 \\
\text{Vs [m/s]} & \\
\text{Depth [m]} & \\
\text{BH 1} & \quad \text{BH 2} & \quad \text{BH 3} & \quad \text{BH 4} & \quad \text{BH 5} & \quad \text{BH 6} & \quad \text{BH 7} \\
0 & \quad 5 & \quad 10 & \quad 15 & \quad 20 & \quad 25 & \quad 30 & \quad 35 & \quad 40
\end{align*}
\]
Figure 6. Example of the predominant periods. (a) Predominant period appears in a shorter period (b) predominant period appears in a longer period.

We could obtain Vs structures at microtremor survey. We proposed three-layer model with inversion methods in Amarapura township by using the microtremor sites (Figure 7). Periods parameters are computed for each target depth as equation 3 [11].

$$T = \frac{4H}{Vs}$$  

where, $H$ is a thickness of a layer, $Vs$ shear wave velocity and $T$ predominant period. The distribution of sediment thickness map is shown in figure 8.

Figure 7. (a) The evaluated Vs profile from inversion of microtremor site no. 3, and (b) H/V Spectral ratio at microtremor site no.3.
8. Conclusions
This research mainly focuses on the results of seismic microzonation based on 7 boreholes and 21 microtremor data, which covered almost the whole township area of Amarapura. Shear wave velocity ($V_s^{30}$), frequency distribution and sediment thickness are produced as the main results for seismic microzonation in Amarapura township. The kriging interpolation method was used for subsurface information such as predominant periods, frequency, shear wave velocity and sediment thickness with the GIS software [12]. The frequency distribution events ranged from less than 0.5 Hz to greater than 3 Hz and the $V_s^{30}$ of the top layer is $V_s \leq 190$ m/s. The sediment thickness values ranged from less...
than 50 m to greater than 320 m. The deepest layer of sediment belongs to the Eastern parts of the Irrawaddy River and the thickness value is 110 – 320 m. This portion includes the Southern part of Shan gale gyun, the western parts of Amarapura and the ancient Amarapura palace. The outputs of this research would be very applicable for the seismic risk assessments, urban land use planning, retrofitting the various sorts of building after assessing the vulnerability, in designing the future construction of the various sorts of structures and earthquake preparedness, thereby reducing earthquake risk in Amarapura.

Acknowledgments
This research project is supported by Department of Higher Education, Upper Myanmar, Ministry of Education. We would also like to thank to all researchers who provided advice regarding the writing of this research paper.

References
[1] Swei W 1970 Rift-features at the Sagaing-Tagaung Ridge Abstract, Burma Research Congr Rangoon 101.
[2] Thein M, Tint K and Aung A K 1991 On the lateral displacement of the Sagaing fault, Georeports 1 pp 23–34
[3] Kramer S L 1996 Geotechnical Earthquake Engineering Prentice-Hall International Series in Civil Engineering and Engineering Mechanics p 653
[4] Chibber H L 1934 The Geology of Burma Macmilland Com. and Limited, London p 538.
[5] Maung H 1987 Transcurrent movements in the Burma-Andaman Sea region Geology 15 pp 911–912
[6] Myanmar Geoscience Society 2014 Geological map of Burma Partly based on Geological Map of the Socialist Republic of the Union of Burma (1977 (Scale 1:1,000,000))
[7] http://www.esri.com/metadata/esriprof80.dtd
[8] Bernard R W, Jason T D and Thomas S 2012 Guidelines for Estimation of Shear Wave Velocity Profiles Pacific earthquake engineering research center, PEER Report 2012/08
[9] Thein P S, Kiyono J, Win T T, Nu T T and Aung D W 2018 Seismic microzonation of Mandalay City, Myanmar, Journal of Geological Resources and Engineering 6, pp 1–13
[10] Nakamura Y 2000 Clear identification of fundamental idea of Nakamura’s technique and its application World Conference of Earthquake Engineering
[11] Thein P S, Pramunjiyo S, Brotopuspito K S, Wilopo W, Kiyono J and Setianto A 2013 Investigation of subsurface soil structure by microtremor observation at Palu, Indonesia the 6th ASEAN Civil Engineering Conference (ACEC) & ASEAN Environmental Engineering Conference (AEEC), Civil and Environmental Engineering for ASEAN Community, Bangkok, Thailand p C–6
[12] Kiyono J and Suzuki M 1996 Conditional Simulation of Stochastic Waves by Using Kalman Filter and Kriging Techniques Proc. of the 11th World Conference on Earthquake Engineering Acapulco Mexico 1620