International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 4 Issue 5, July-August 2020 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

# Site Characterization and Seismic Site Response Study for Bagan Area

**Khin Yupar Maung[1], Kyaw Kyaw[2]**

[1,2]Department of Civil Engineering, Yangon Technological University, Yangon, Myanmar

**ABSTRACT**

Bagan, the cultural heritage city of Myanmar located in the Mandalay region, which is very close to the active Sagaing fault. Most of Bagan's cultural heritage monuments have been damaged due to earthquakes. Therefore, seismic response analysis is needed to evaluate site response characteristics for retrofitting and preservation of the historical monuments in Bagan. Site response studies require the characterization of subsurface materials considering local subsurface profiles of the site. The main target of the present study is site characterization and the estimation of seismic site response for the Bagan monument area. For this purpose, a geophysical survey such as microtremors was carried out to determine the variation of soil profile as well as the characteristics of the soil layers within the study site. Shear wave velocities at the study sites were estimated through the inversion of microtremors H/V spectrum. The sites were categorized based on the average shear wave velocity of the overburden soil above the bedrock as Class 'D' (Stiff Soil Profile) and Class 'C' (Very Dense Soil and Soft Rock). Equivalent linear site response analysis of layered soil deposits was carried out using DEEPSOIL software which determines peak ground acceleration (PGA) and response spectrum. The maximum surface PGA was found 0.24g and the maximum acceleration of surface motion is 1.13g at a period of 0.14s.

***KEYWORDS:*** *Bagan, earthquake, site characterization, site response, Peak ground acceleration (PGA), surface motion*

***How to cite this paper:*** Khin Yupar Maung | Kyaw Kyaw "Site Characterization and Seismic Site Response Study for Bagan Area" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-4 | Issue-5, August 2020, pp.1564-1568, URL: www.ijtsrd.com/papers/ijtsrd33190.pdf



## I. INTRODUCTION

Myanmar is earthquake-prone as it lies in one of the two main earthquake belts of the world, the Alpide Belt. There are several faults in Myanmar territory, some of which are active and some are possibly inactive. Among them, Sagaing fault is the most active one and the past earthquakes recorded in Myanmar occurred along this fault. Apart from the right lateral strike-slip Sagaing fault, there were also some strong earthquakes generated along the plate boundary of the Indian and Burma plate with intermediate depth such as the 1975 (Mw=6.9) Bagan earthquake and the significant 2016 ($M_w$=6.8) Chauk earthquake [9]. Both of these 1975 and 2016 earthquakes have destroyed many historical monuments in the Bagan-Nyaung U area with a strong ground shaking effect. In 1975, an earthquake with a magnitude of 6.8 occurred in the subduction zone of the India plate and Burma plate. This earthquake destroyed the land of pagodas in Bagan. The damage to many pagodas and temples was done within seconds. Another serious damage to Bagan occurred in the year of 2016, with a magnitude of 6.8 and also in the subduction zone. The earthquake can be felt in most regions of central Myanmar. Several of the ancient monuments in Bagan had collapsed and the destruction killed at least three people during this earthquake [6].


**Figure 1 Some Damaged Monuments due to 2016 Chauk Earthquake**

Thus, site response analyses are needed to predict ground surface motions for development of design response spectra to evaluate the design and safety of structures. In this study, geophysical measurements were carried out for 52 sites through Old Bagan and Myinkaba region by using a microtremor survey to determine the variation of soil profile as well as the characteristics of the soil layers within the study site. Equivalent linear earthquake site response analysis was carried out by using DEEPSOIL software to determine the response of soil deposit to the motion of the underlying bedrock.

## II. SISMICITY OF CASE STUDY AREA

Bagan, the ancient city of Myanmar, is situated at a Latitude 21°10'18" N and a Longitude 94º51'30" E. The city is situated in the Salin basin and very close to Sagaing fault in NW-SE direction [7]. According to seismic Zones Map of Myanmar, Bagan is located in seismic zone IV (Severe Zone).


**Figure 2 Seismicity of Bagan (ANSS, USGS, ISC catalogue for the years 1920-2017)**

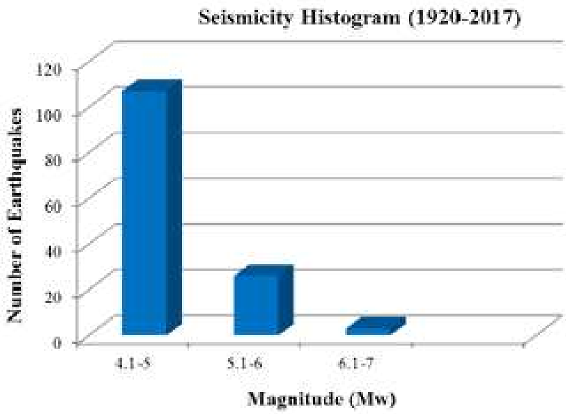


**Figure 3 Histogram showing the cumulative number of earthquakes and magnitudes**

Based on the data from the earthquake catalogue (ANSS, USGS, and ISC), there have been 136 earthquakes around Bagan and Nyaung-U area for the period of 1920 to 2017. The histogram shows the number of earthquakes comparing the magnitudes of 136 earthquakes, and mostly moderate size earthquakes are generating frequently.

## III. SITE CHARACTERIZATION

Site response studies require the characterization of subsurface materials considering local subsurface profiles of the site. Site characterization includes an evaluation of subsurface features, subsurface material types, and subsurface material properties by which it is determined whether the site is safe against earthquake events. Several geophysical methods have been proposed for near-surface characterization. In this study, the shallow geophysical method, microtremor measurement has been used to evaluate shear wave velocity, mass density, thickness of soil layers and average shear wave velocity from the surface to a depth of 30m '$V_{S30}$', which is the most important parameter in the classification of soil.

### A. Microtremor Measurements and Data Analysis

Microtremor analysis focuses on the calculation of the time-depth plot intercept of refracted P-wave and S-wave velocity is an effective parameter for determination of soil stiffness. This study focused on applications and interpretation of single station microtremor survey, with the emphasis on the method proposed by Nakamura (1989) [1].

The single station microtremor observation consisted of twenty minutes of measurement, and horizontal to vertical Fourier amplitude spectral ratio (H/V Nakamura ratio) was computed. The single station method where a three - component (two horizontal and one vertical) record from a single geophone was processed to yield a spectrum of the horizontal-to-vertical particle-motion ratio to provide indications of sediment thickness and shear wave velocity.

The microtremor single satiation measurements had been conducted at 52 sites through Old Bagan and Myinkaba region. The measurement was conducted for twenty minutes at each site at the sampling rate of 200 Hz/s by using the SMAR-6A3P seismometer.

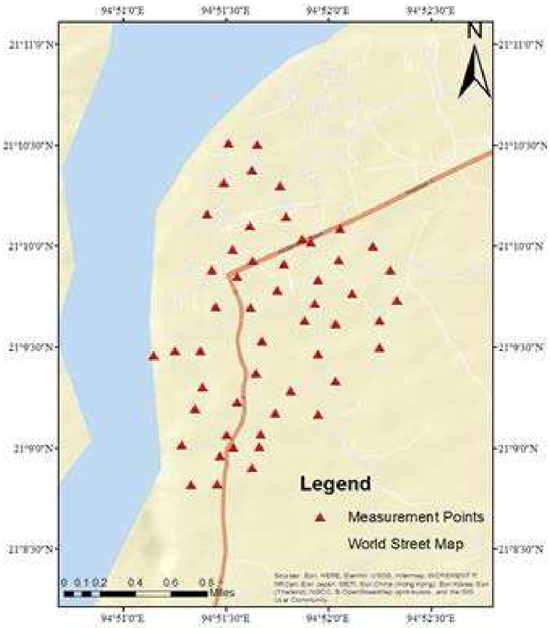


**Figure 4 Location map of study area**

### B. Identification of Shear Wave Velocity (S-Wave) Structure

The shear wave velocity structure was constructed based on the final modified soil model derived from the inversion process each site where microtremor measurement was conducted and identified the S-wave velocity structure of the study area.

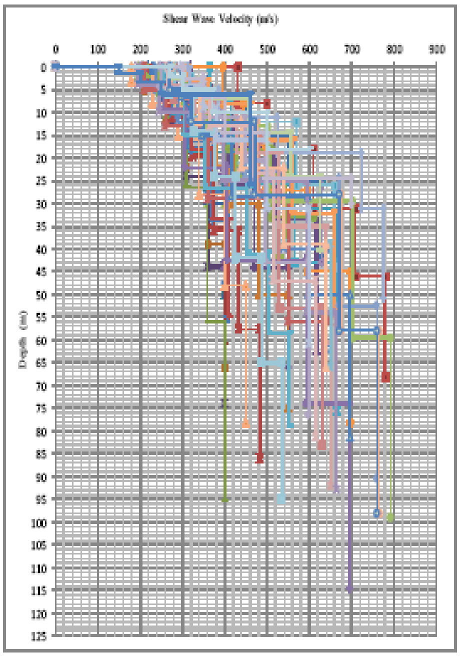

**Figure 5 S- wave velocity profiles**

### C. Determination of Average Shear Wave Velocity '$V_{S30}$' and Seismic Site Categorization

The soil profile is one of the most important factors in earthquake engineering and is closely related to earthquake damage. In earthquake geotechnical practice, the shear wave velocity is often expressed in terms of the average shear wave velocity of the upper 30m ($V_{S30}$)-a widely used parameter to predict the potential amplification of seismic shaking [2]. The average shear wave velocity up to a depth of 30m is shown in Equation 1.

$$V_{s30} = \frac{\sum d_i}{\sum \frac{d_i}{V_{si}}} \qquad (1)$$

where, $d_i$ is the thickness of layer i (feet, m) and $V_{si}$ is the shear wave velocity in layer i (feet/sec, m/sec).

The site class of the Myanmar National Building Code [10] are defined in terms of average shear wave velocity ($V_{S30}$) in Table 1.

**Table 1. Site Classification According to MNBC Code Source [10]**

| Site Class | Soil Profile Name | Average Properties In Top 30 Meter | |
|---|---|---|---|
| | | Soil shear wave velocity, VS, (m/s) | Standard penetration resistance, N |
| A | Hard rock | Vs> 1500 | N/A |
| B | Rock | 760 < Vs ≤ 1500 | N/A |
| C | Very dense soil and soft rock | 360 < Vs ≤ 760 | N > 50 |
| D | Stiff soil | 180 < Vs ≤ 360 | 15 ≤ N ≤ 50 |
| E | Soft clay soil | Vs< 180 | N <50 |

The average shear wave velocity of the top 30m, $V_{S30}$ was calculated by using equation (1) based on estimated S-wave velocity structure of each site.

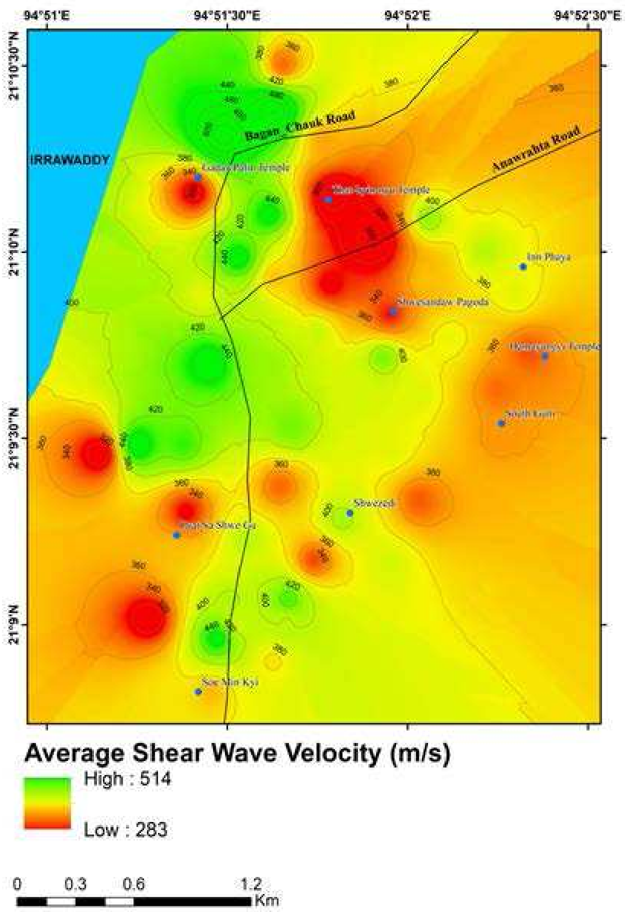


**Figure 6 Average Shear Wave Velocity ($V_{S30}$) Map of Bagan Area**

According to the result, the values of shear wave velocity at 30m depth ($V_{S30}$) for the study area are ranging from 283m/s to 514 m/s. Most of the soil classes of the sites are SC (very dense soil and soft rock) and SD (stiff soil profile) according to MNBC (2016).

## IV. 1D SITE RESPONSE ANALYSIS USING EQUIVALENT LINER APPROACH

Ground response analysis is employed to evaluate ground surface motions and design response spectra, and to carry out the evaluation of dynamic stresses and strains for liquefaction hazards. Different methods of ground response analysis have been developed including one dimensional, two dimensional and three-dimensional analyses. One-dimensional (1D) analysis is assumed that the soil profile extends to infinity in all horizontal direction and the response of a soil deposit is caused by horizontal shear waves propagating vertically from the underlying bedrock. Theoretical modelling of 1D ground response can generally be accomplished using equivalent-linear (EL) or nonlinear (NL) analysis. In this study, an equivalent linear method of ground response analysis was carried out by using DEEPSOIL Version 7.0 [8].

Equivalent linear ground response modelling is widely used in practice to simulate the true nonlinear behaviour of soil. Since the soil behaviour is nonlinearity, the linear approach must be modified to provide reasonable estimates of ground response for practical problems of interest. The actual nonlinear hysteretic stress-strain behaviour of cyclically loaded soils can be approximated by equivalent linear soil properties. The effective shear strain is generally regarded as 65% of the peak strain [3]. Input data necessary for the analysis are seismic input motion, dynamic soil properties, and soil profiles of the site.

### A. Seismic input motion

The study area, Bagan, was severely devastated by big earthquakes such as the 1975 Bagan Earthquake and 2016 Chauk Earthquake with the same magnitude of 6.8 (Mw= 6.8). The analysis in this study considered the ground motion record of the 2016 Chauk earthquake from Nyaung–U Seismic Station.

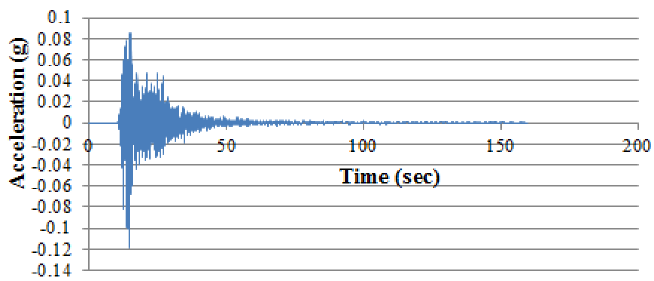


**Figure 7 Acceleration- time histories due to 2016 Chauk earthquake (PGA-0.12g)**

### B. Dynamic Soil Properties and Soil Profiles

The parameters used for the analysis are dynamic soil properties and soil profiles of the sites. The subsurface soil profiles used in the analysis are soil density, thickness of soil layers, and shear wave velocity. The single station microtremor observation was processed to produce a spectrum of the horizontal to vertical particle motion ratio to provide sediment thickness and shear wave velocity. The depth of layers of soil can be carried out and beyond this depth, the hypothetical bedrock is considered.

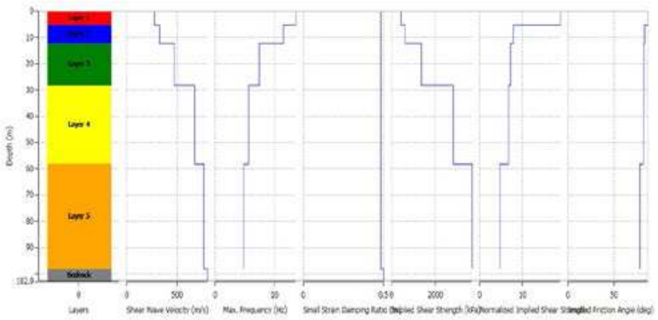

**Figure 8 Soil Profile Plot in DEEPSOIL**

In the equivalent linear one-dimensional analysis, dynamic soil properties are defined by the damping ratio and shear modulus degradation curves. In the absence of site-specific modulus reduction and damping ratio curves, standard curves proposed by Seed and Idriss [4] and Vucetic and Dobry [5] have been used for clays and sands respectively. These are included in DEEPSOIL database.

### C. Generation of Peak Ground Acceleration (PGA)

The variations of PGA at different depths for the study area are shown in Figure 9. The surface PGA is found to vary 0.14g to 0.24g. The values of PGA at the surface of the soil deposits are greater than the PGA at the other depths. At higher acceleration level, the lower stiffness of the soil deposit (represented by its shear wave velocity, $V_S$).

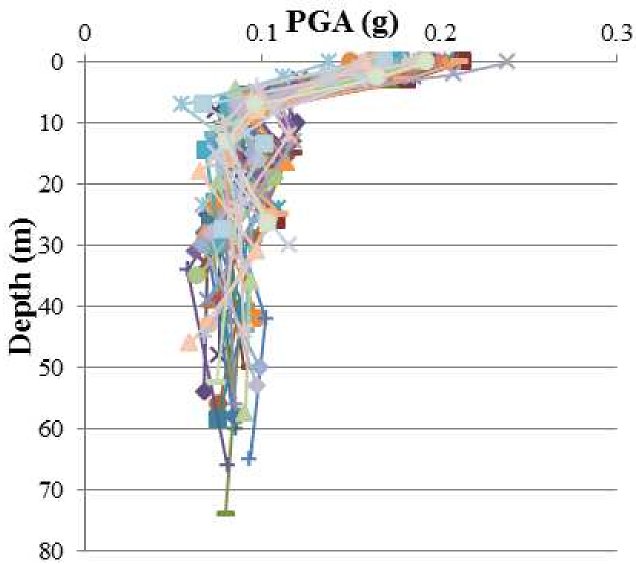


**Figure 9 Variation of PGA with depth**

The PGA map of Bagan area was prepared based on the peak value of acceleration time histories as shown in Figure 10.

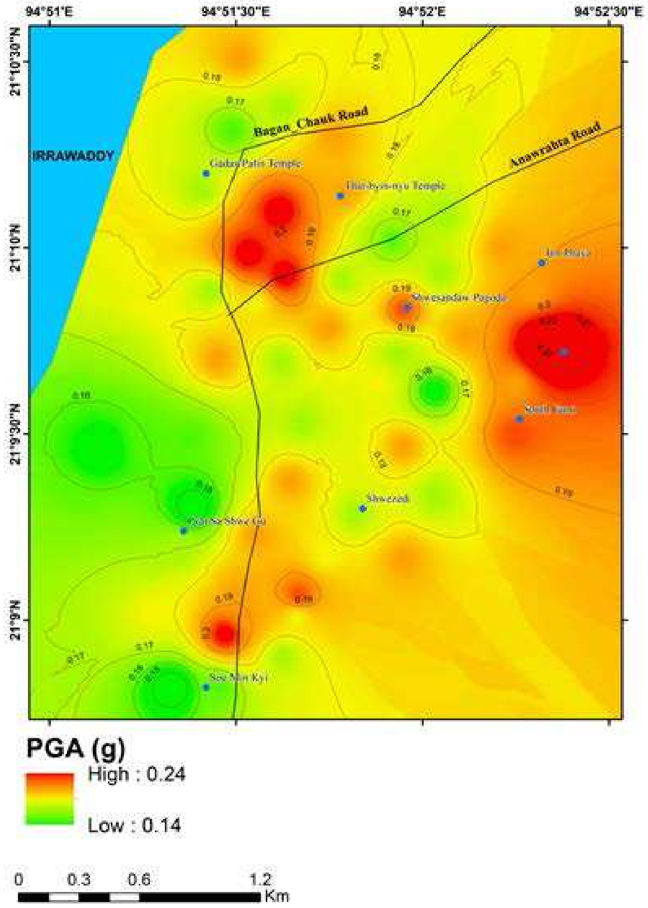


**Figure 10 Peak Ground Acceleration (PGA) Map of Bagan Area**

According to this map, the red colour zones represent higher acceleration zones while green colour zone are lower acceleration zones. Ground motion with high peak acceleration is usually more destructive than motions with lower peak acceleration. So, the monuments in red colour are expected to be suffered stronger shaking and likely to be severe damage during earthquakes.

### D. Spectral Acceleration

The earthquake amplitudes are represented usually by the peak ground acceleration. However, in the structural design of the building codes, the most widely used parameter is spectral acceleration and corresponding period. Peak spectral acceleration (PSA) and period corresponding to PSA of each site for the study area have been computed.

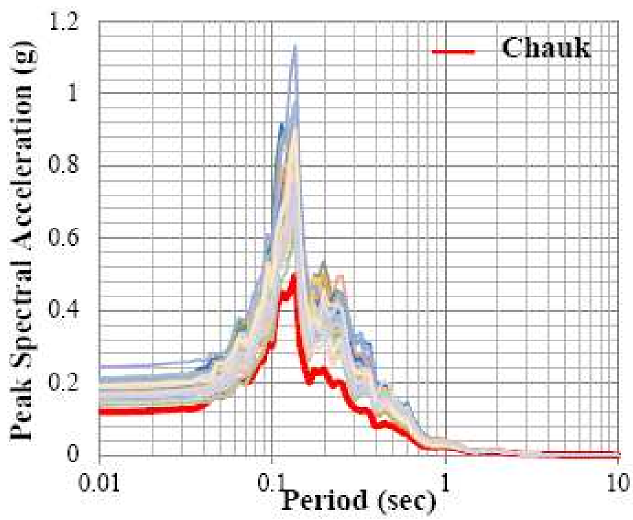


**Figure 10 Response Spectra for study area and Chauk earthquake**

The maximum surface spectral acceleration is found to be 1.13g at 0.14s. From this result, it was found that stiff soils generally tend to have a higher spectral acceleration at shorter periods.

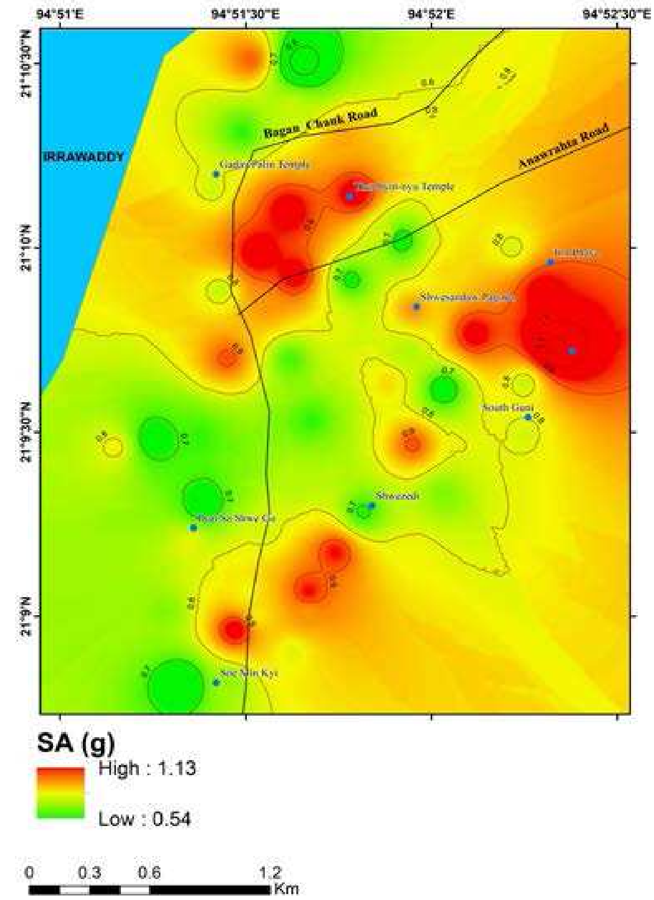


**Figure 11 Spectral Acceleration Map of Bagan area with 5% damping**

Figures 11 shows the spectral acceleration (SA) maps at short period of the study area with 5% damping. The spectral acceleration (SA) values are varied from 0.54g to 1.13g. The higher spectral acceleration occurs in the red colour zone and it can generally be regarded that the monument buildings in the area which have high spectral acceleration are more dangerous for the events of earthquake.

## V. CONCLUSION

The seismic refraction method (microtremor measurements) was applied in the study area to characterize the subsurface structure. The $V_{S30}$ values for different sites in the study area are ranging from 283m/s to 514 m/s. Most of the soil classes of the sites are $S_C$ (very dense soil and soft rock) and $S_D$ (stiff soil profile) according to MNBC (2016).

A one-dimensional site response analysis has been carried out at the study area using acceleration time histories of Chauk earthquake (2016) as an input motion. The maximum peak ground acceleration values of the surface are observed to be 0.14g to 0.24g. From the acceleration spectrum responses, the spectral acceleration (SA) values are varied from 0.54g to 1.13g and the maximum acceleration occurs at a short period of 0.14s. And then, the response of surface spectral acceleration is more than the response of Chauk. The surface acceleration value obtained from the analysis is much higher than the acceleration of input motion that shows the ability of local soil to amplify the input ground motion acceleration. It has been seen that soil deposits of the Bagan area tend to increase the amplification of ground motions. The surface of the soil is vulnerable to the Mw-6.8 Chauk earthquake. The response spectra and surface acceleration time histories developed for this study area can be used for the dynamic analyses of repairing and retrofitting of historical monuments in Bagan.

## REFERENCES

[1] Nakamura, Y. 1989. "A Method for Dynamic Characteristics Estimation of Surface Using Microtremor on the Ground Surface", Quaterly Report of Railway Technical Research Institute 30 no.1 (March): 25-33.

[2] Holzer, T. L., Padovani, A. C., Bennett, M. J., T. E., Noce, T. E., and Tinsely, J. C. 2005. "Mapping VS30 site classes, Earthquake Spectra" Earthquake Engineering Research Institute 21 (May): 353-370.

[3] Kramer, S. L. (2005). Geotechnical Earthquake Engineering, Prentice Hall, USA.

[4] Seed, H. B. and Idriss, I. M. (1970). "Soil Moduli and Damping Factors for Dynamic Response Analysis." Report No. EERC 70-10, University of California, Berkeley, December.

[5] Vucetic, M. and Dobry, R. (1991). "Effect of Soil Plasticity on Cyclic Response", Journal of the Geotechnical Engineering, ASCE, Vol 117, No.1, pp89-107.

[6] Saw Htwe Zaw, Teraphan Ornthammarath & Nakhorn Poovarodom (2017). Seismic reconnaissance and observed damage after the Mw 6.8, 24 August Chauk (central Myanmar) earthquake, Journal of Earthquake Engineering, DOI: 10.1080/ 13632469.2017.1323050

[7] Hla Hla Aung, Myanmar Earthquakes History ,3rd Edition, August, 2017.

[8] Hashash, Y. M. A., Musgrove, M. I., Harmon, J. A., Ilhan, O., Groholski, D. R., Phillips, C. A., and Park, D. (2017) "DEEPSOIL 7.0, User Manual".

[9] Report On Seismic Hazard And Vulnerability Assessment For Bagan/ Nyaung U Area 2019, August. bagan

[10] MNBC 2016: Myanmar National Building Code (2016).