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ESTIMATION OF SITE CHARACTERISTICS IN SAGAING CITY, MYANMAR BY MICROTREMOR SURVEY

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Abstract

Local site effect is one of the most important aspects in the assessment of seismic hazard and many of the destructive earthquakes in the past have shown that local site conditions have major effects on ground shaking. Depending on the local site conditions, the characteristics of seismic waves generated and propagated through different geological formations during the earthquakes can be modified. The microtremor Horizontal-to-Vertical spectral ratios (MHVRs) become an important tool to estimate the fundamental frequencies and amplifications during the ground motion. Many of the former studies have proved that MHVR technique is effective when carried out at the sites with soft deposits by using the long duration ambient seismic noise. However, array measurements of microtremors to obtain phase velocity of Rayleigh wave would be quite effective to invert S-wave velocity structures (e.g., Kawase et al., [1]; Satoh *et al*., [2]) until recently Sanchez-Sesma et al., [3] have proposed a new theory based on the diffuse field concept. Exploration based on the H/V spectral ratio using single-station microtremor records is simple, quick, and inexpensive, and so the MHVR technique with diffuse field theory will be applied to Sagaing City, Myanmar to estimate the site characteristics from the results of single measurement. At the same time the array measurement technique will also be applied to obtain starting velocity model for single station MHVR technique. To achieve this goal, we have conducted over 100 sites of single station and 5 sites of array measurements in and around Sagaing City. Additionally, we selected nearly 25 sites close to the Sagaing Fault including eastern and western sites to investigate the site characteristics across the fault. As a result, lower peak frequency values of (≤1Hz) were observed at western part of Sagaing City. Generally, most of the MHVRs for downtown area of Sagaing City show peaks in the low frequency range of (1Hz-3Hz). MHVRs of eastern and western sites of the Sagaing Fault show systematic difference in peaks in low frequency range. In some places around the Sagaing Fault, MHVRs do not show significant peak amplitude for the lower frequency range. As for the array measurement, we obtained stable Rayleigh wave phase velocity dispersion curve for each array site and the initial S-wave velocity models were created based on the phase velocity and the corresponding wavelength formula. After that, we adjust the theoretical dispersion curves with the observed one and we got good agreement. The results from current research will contribute to seismic microzonation and site amplification information in the Sagaing region. Our final objective of the research is to support in part the implementation of national seismic hazard mitigation program.

Keywords: site effect; MHVRs; Sagaing Fault; array measurement, phase velocity

1. Introduction

The study area, Sagaing City of Myanmar, is located in South East Asia and is an earthquake-prone region because it is located in the Alpide Belt which is one of the major earthquake belts of the world. 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. In addition, the Sagaing Fault, 1,100km long and the most obvious active fault in Myanmar from the past to present [4-5]), is trending from the northernmost part of the Myanmar until the Andaman sea to the south, and it was bisected to many of the major cities of Myanmar along its trend. The target area of this study, Sagaing City, is also included as shown in Fig.1. As a reason, many of the historic earthquakes have been experienced around Sagaing – Innwa area (Innwa is very closed to Sagaing and just only apart by the river) from 1429 to 1956 due to the effect of the Sagaing Fault (Table 1). Recently, several seismic events are occurring at the Sagaing region relating with the Sagaing Fault and expected to cause strong earthquake in near future. Although it is a seismically prone city, a systematic and comprehensive seismic study for Sagaing City have not been established yet and this study expects to fulfil this requirement as a part of seismic hazard estimation through the analysis of microtremors.

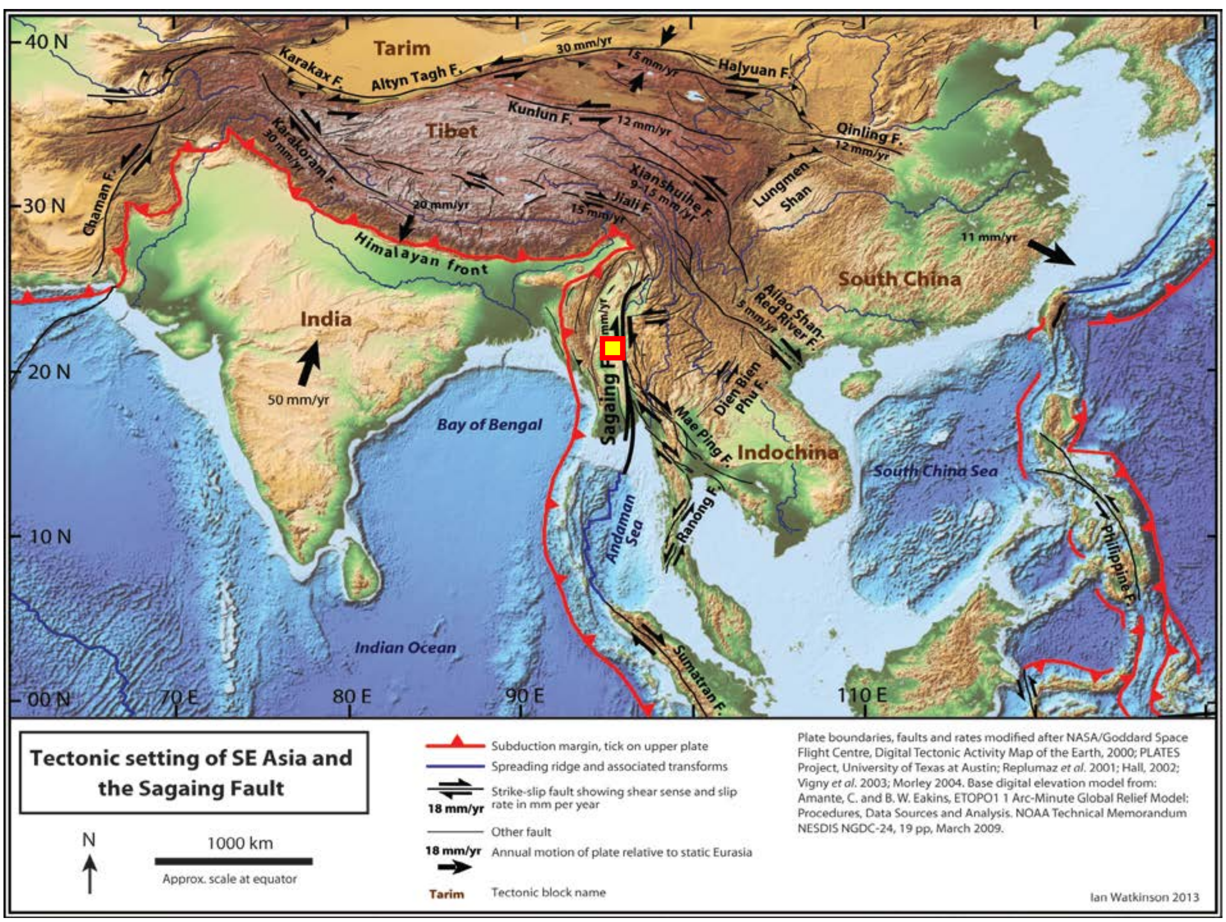


Fig. 1– Tectonic setting of Myanmar and the Sagaing Fault after Ian Watkinson (a red rectangle refers to Sagaing City)

Table 1 – Records of the historical earthquakes in the Sagaing – Innwa area

Date	Location	Magnitude and/or brief description
1429	Innwa	Fire-stopping enclosure walls fell
1467	Innwa	Pagodas, solid and hollow, and brick monasteries destroyed
24 July 1485	Sagaing	3 well known pagodas fell
1501	Innwa	Pagodas, etc. fell
23 June 1620	Innwa	Ground surface broken, river fishes were killed after quake
18 Aug. 1637	Innwa	River water flush
10 Sept. 1646	Innwa	
11 June 1648	Innwa	
1 Sept. 1660	Innwa	
3 April 1690	Innwa	
15 Sept. 1696	Innwa	4 well known pagodas destroyed
8 Aug. 1714	Innwa	Pagodas, etc. fell; the water from the river gushed into the city
15 July 1771	Innwa	
9 June 1776	Innwa	A well-known pagoda fell
26 April 1830	Innwa	
21 March 1839	Innwa	Old palace and many buildings demolished;
23 March 1839	Innwa	Pagodas and city walls fell; ground surface fractured; the river's flow was reversed for sometime; Mingun Pagoda shattered; about 300 to 400 persons were died
16 July 1956	Sagaing	M=7.0 Several pagodas severely damaged (40 to 50 persons killed)

2. Geological Features of Sagaing Region

As a regional geology, the Sagaing area lies between the Shan High-land in the east and central low-land in the west. The low to high-grade pelitic and calcareous metamorphic rocks and sediments of Cenozoic were regarded as Paleozoic age and Miocene-Pliocene age. Sedimentary strata were introduced by the serpentinite of probably Post-Pliocene age in Kyaukta area, northern part of the Sagaing region [6]. Generally, the eastern side of the Sagaing Fault is covered with metamorphic rocks, (locally called **Sagaing Metamorphic**) unit of hornblende amphibolite, marble and gneiss, while the western site of the Sagaing Fault is mainly composed the outcrop of low to medium grade metamorphic rocks from the **Minwun metamorphic**. The main significant feature around the Sagaing area is the Sagaing Fault and other secondary longitudinal faults, but diagonal cross-faults are also observed as the branch faults. The general geological map of the Sagaing area and the Sagaing Fault is shown in Fig.2.

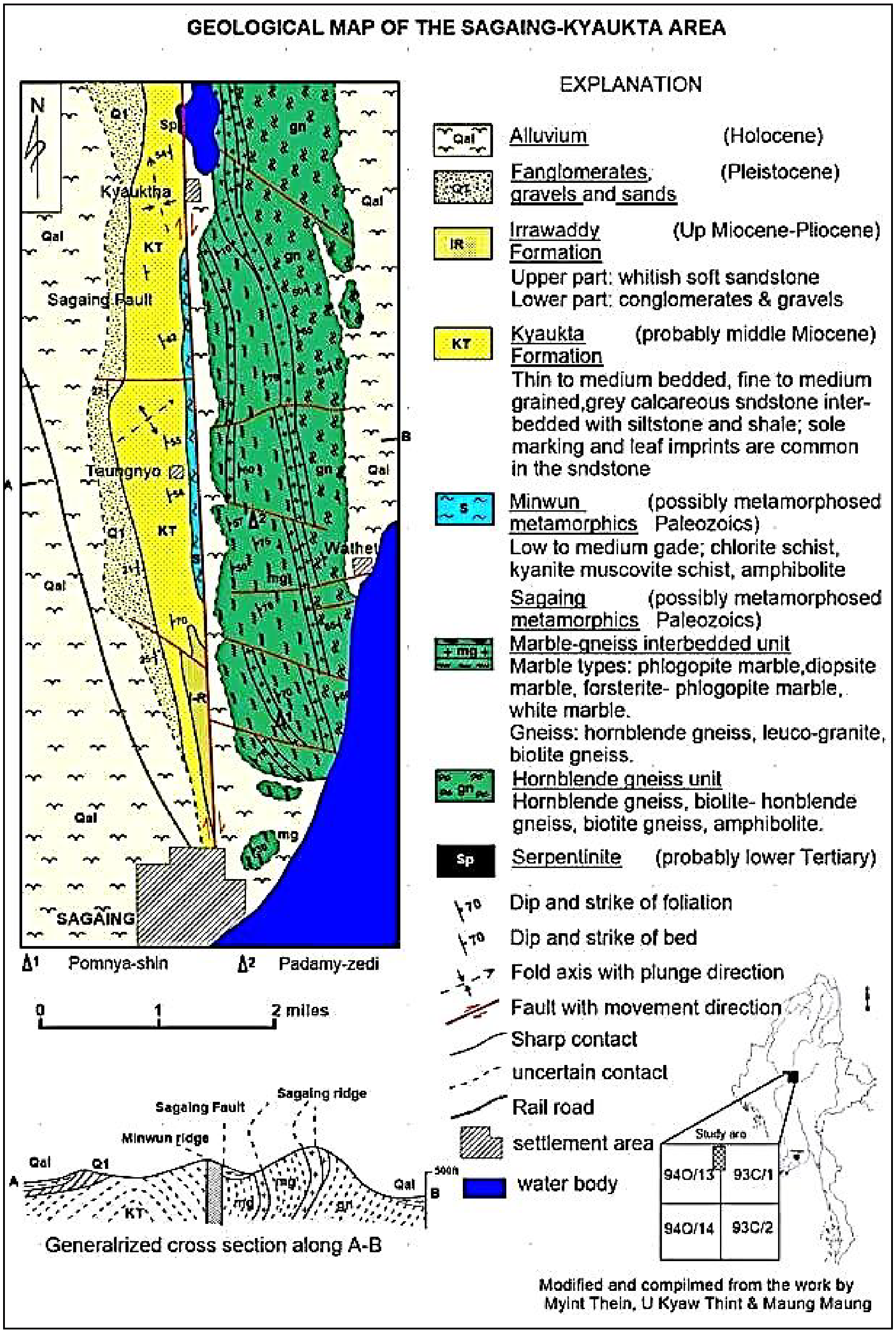


Fig. 2 – Regional geology of Sagaing area [1-2]

3. Microtremor Observations

The two methodologies of microtremor; single-station method and array method were applied to utilize the measured microtremor data at Sagaing City as stated in Fig.3 for microzonation and site responses studies.

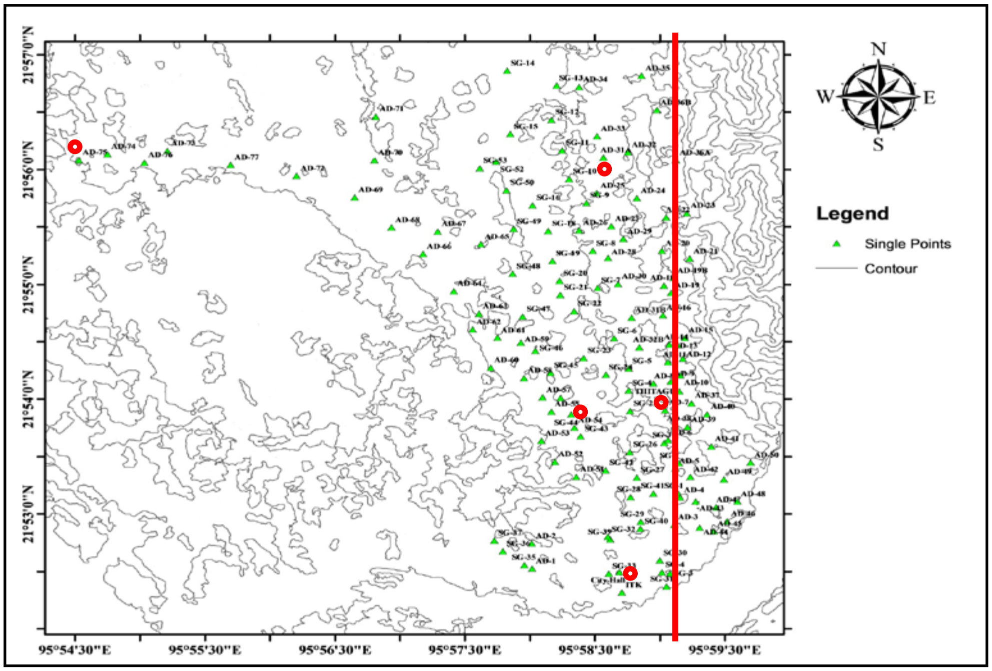


Fig. 3 – Observed microtremor sites at Sagaing City (triangles refer to single sites, circles refer to array sites, and the thick line denotes the Sagaing Fault)

3.1 Single station measurement

The recording and analyzing of ambient noise of microtremor is simple and a few tens of minutes of microtremor data are usually sufficient. The single-station method, where a three-component record from a single seismometer is processed to yield a spectrum of horizontal to vertical spectral ratio and these routine spectral techniques can be easily applied to estimate the dominant frequency of vibration of the sedimentary structure. These frequencies of vibration are closely related to the physical features of the site under study, i.e., layer thicknesses, densities and S-wave velocities. Estimations of these frequencies are useful to constrain the physical properties at a given site. As for the measurement for Sagaing City, over the 100 single station sites, which covered almost the whole area of city including the eastern and western sides of the Sagaing Fault, were measured by using the SMAR-6A3P instrument (Mitsutoyo) with LS8800 data logger (Hakusan Kogyo) as shown in Fig.4 (a). The interval from site to site is approximately 0.5km and the duration of records was 20 minutes for each site.

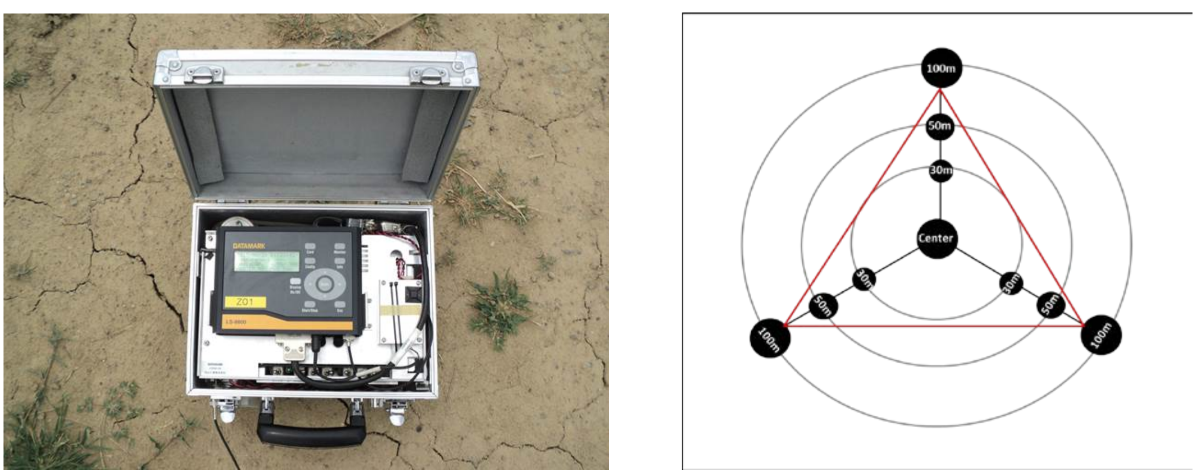


Fig. 4 – (a) Observed microtremor instrument and (b) Shape of the performed array measurement

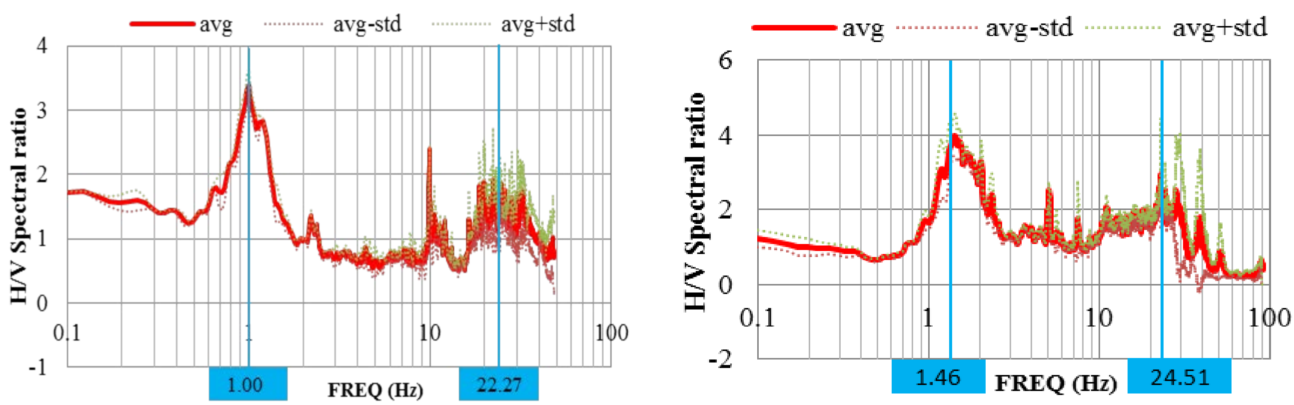
3.1.1 Analyzing parameters for single station measurements

To obtain MHVRs, the waveforms were corrected for baseline and divided to segments of 40.96 seconds with 50 percent overlapping to make it easy to delete unsteady portions. For the edges of these segments, 0.5 seconds cosine tapers were applied and smoothed by Parzen windows of 0.1 Hz. MHVRs were then computed as the average of both horizontal component spectra divided by the vertical spectrum for each window as revealed in Eq. (1). After producing MHVRs, the dominant frequency and maximum amplification were determined.

$$\text{Observed H/V spectral ratio} = \sqrt{\frac{S_x + S_y}{S_z}} \qquad \text{(S = Power spectrum)} \tag{1}$$

3.1.2 Results of single station measurements

The results of microtremor HVRs for a single-station measurement at Sagaing City generally show two prominent peaks, one for deep structure at lower frequency and another one for shallow structure at higher frequency. The smallest fundamental frequencies (≤ 1Hz) were obtained in the western side of Sagaing City as shown in Fig.5 (a). Frequencies in the range of 1 to 3 Hz were observed at most of the sites that are located in the central part of Sagaing City as shown in Fig.5 (b). However, specific frequency could not be identified at some sites due to too wide peaks, two or more peaks in a spectrum, flat spectral ratio, and/or very small amplitude of the peak.



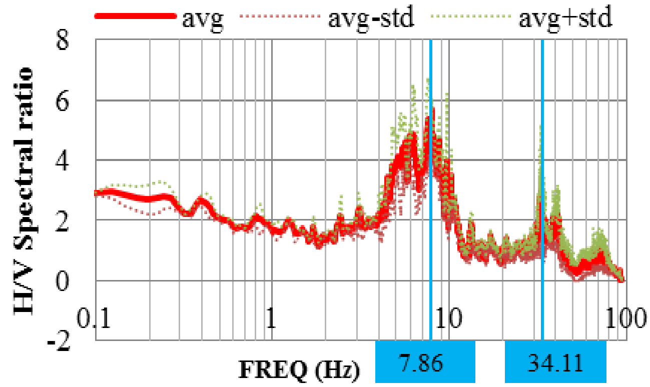
(a) (b)

Fig. 5 – (a) HVRs sites for smallest frequency dominant values of (≤ 1Hz), (b) one of the MHVRs result for central part of Sagaing City

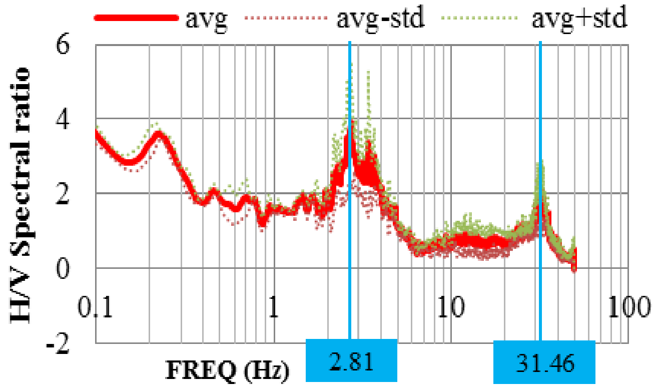
3.1.3 Microtremor observation at Sagaing Fault

Sagaing Fault is currently active as indicated by the seismicity along its trace. It is certainly the biggest single earthquake threat to the people of Myanmar because of its location in well populated central Myanmar. One of the serious earthquake in the Sagaing area due to the Sagaing Fault was 1839 Ava (Innwa) earthquake and 1956 Sagaing earthaquake and these gave a lot to learn for the mitigation of future earthquake disasters.

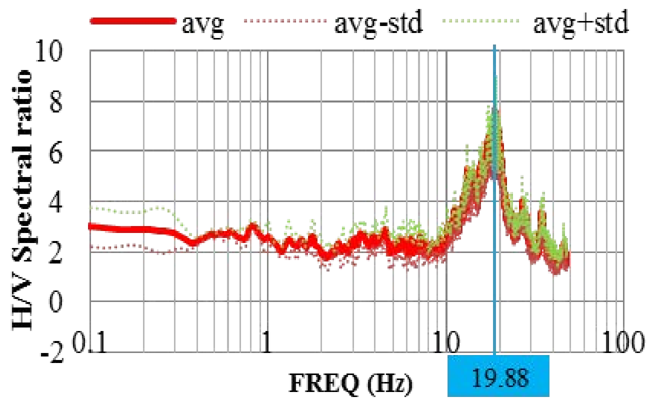
Because of the bad experiences of earthquakes due to the Sagiang Fault, it becomes the best reason to delineate the site charactreistics of the Sagaing Fault with the analysis of microtremor. We have conducted the microtremor measurement along the Sagaing Fault nearly 25 sites including eastern and western sides of the fault. After that, we compared the charactersitcs feature of MHVRs in the eastern and westren sides as shown in Fig.6 (a) and (b). We can see the systematic difference in the lower frequency range for the different sides of the Sagaing Fault. However, in some of the sites around the Sagaing Fault, the MHVR does not shows the dominant frequency in the lower frequency range as shown in Fig.6 (c).



(a)



(b)



(c)

Fig. 6 – (a) HVRs for eastern site of Sagaing City, (b) MHVRs for western site of Sagaing City, and (c) MHVRs site which does not show the dominant frequency for lower peak

3.2 Array measurement

Array observation of microtremors is a potentially useful method for estimating S-wave velocity structures beneath a site where a seismometer array is deployed. The method basically involves extracting surface waves from microtremors in the form of dispersion, and then inverting the dispersion data for one-dimensional S-wave velocity structure. This method is very cheap compared with drilling a deep borehole, despite the fact that it will provide direct data of velocity structures and the validity of the method have been confirmed theoretically and experimentally. In addition, the results of array microtremors method have shown satisfactory agreements with the profiles determined by the other seismic prospecting.

For the Sagaing area, microtremor array measurement was carried out at five sites in Sagaing City. The sites were deployed away from roads with high-traffic, factories, main bus stations, and other man-made temporary noise sources in order to record accurate data. It was conducted with 4 instruments at each array observation site. One of the accelerometer was settled at the center of the circle and another three instruments were arranged to the circumference of the circle, equally separated as shown in Fig.4 (b). The observed duration time was 30 minutes with the sampling frequency of 200 Hz. The sequential observations were conducted three times by changing the array radius with 30m, 50m and 100m respectively at each site. The measurement information of the array sites are described in Table 2.

Table 2 – Measurement information of array sites

Sites name	Radius	Date	Position	Start Time	End Time	Latitude	Longitude	Sampling	x-coordinate	y-coordinate
array 1	30m	2015.8.29	center	14:12:00	14:42:00	21.8981	95.97226	200Hz	0	0
			southwest			21.8979	95.9721		-0.01858	-0.02893
			northwest			21.89839	95.972158		-0.01239	0.031154
			northeast			21.898131	95.972575		0.0351	0.003338
	50m	2015.8.29	center	14:54	15:24	21.8981	95.972267	200Hz	0	0
			northwest			21.897672	95.972		-0.02787	-0.04784
			southwest			21.898525	95.971975		-0.02994	0.047843
			northeast			21.898175	95.972797		0.054715	0.008901
	100m	2015.8.29	center	15:35	16:05	21.8981	95.972267	200Hz	0	0
			northwest			21.897411	95.971619		-0.0671	-0.07677
			southwest			21.898953	95.971817		-0.04646	0.094574
			northeast			21.898328	95.973283		0.104268	0.025591
array 2	30m	2015.8.29	center	17:06	17:36	21.932733	95.97245	200Hz	0	0
			southwest			21.932533	95.972231		-0.02271	-0.02225
			northwest			21.932883	95.972183		-0.02787	0.016689
			northeast			21.932844	95.972722		0.027867	0.012239
	50m	2015.8.29	center	17:41	18:11	21.932733	95.97245	200Hz	0	0
			northwest			21.93235	95.972183		-0.02787	-0.04228
			southwest			21.933	95.972017		-0.04438	0.030041
			northeast			21.932889	95.972944		0.050573	0.017802
	100m	2015.8.29	center	18:19	18:49	21.932733	95.97245	200Hz	0	0
			northwest			21.931967	95.971933		-0.05367	-0.08456
			southwest			21.933233	95.971617		-0.08566	0.055632
			northeast			21.933028	95.973361		0.093921	0.033379
array 3	30m	2015.8.30	center	10:44	11:44	21.9398	95.91165	200Hz	0	0
			southwest			21.939589	95.911519		-0.01342	-0.02337
			northwest			21.940033	95.911583		-0.00722	0.025591
			southeast			21.93965	95.91185		0.020641	-0.01669
	50m	2015.8.30	center	11:21	11:50	21.9398	95.91165	200Hz	0	0
			northwest			21.939394	95.911406		-0.02477	-0.04562
			southwest			21.940286	95.911514		-0.01022	0.054519
			northeast			21.939556	95.912094		0.04541	-0.0267
	100m	2015.8.30	center	12:00	12:30	95.91165	21.9398	200Hz	0	0
			northwest			95.911083	21.939033		-0.05883	-0.08567
			southwest			95.91145	21.940667		-0.02064	0.096799
			northeast			95.912467	21.939283		0.084628	-0.05786
array 4	30m	2015.8.30	center	15:52	16:22	21.874183	95.979933	200Hz	0	0
			southeast			21.873953	95.980161		0.023748	-0.02559
			northwest			21.87435	95.979683		-0.02581	0.018915
			northeast			21.874417	95.980133		0.020651	0.026703
	50m	2015.8.30	center	16:29	16:49	21.874183	95.979933	200Hz	0	0
			northwest			21.873767	95.98015		0.022716	-0.04562
			southwest			21.87445	95.979533		-0.0413	0.030041
			northeast			21.874517	95.98025		0.033041	0.03783
	100m	2015.8.30	center	17:01	17:21	21.874183	95.979933	200Hz	0	0
			northwest			21.87345	95.98045		0.053691	-0.08122
			southwest			21.874683	95.97915		-0.08054	0.055632
			northeast			21.874867	95.9806		0.069179	0.076772
array 5	30m	2015.9.3	center	8:42	9:12	21.899167	95.979567	200Hz	0	0
			northwest			21.89935	95.979333		-0.02478	0.020027
			southwest			21.8989	95.979517		-0.00516	-0.03004
			northeast			21.899217	95.97985		0.028906	0.005563
	50m	2015.9.3	center	9:24	9:54	21.899167	95.979567	200Hz	0	0
			northwest			21.89945	95.979233		-0.0351	0.031154
			southwest			21.898733	95.979467		-0.01032	-0.04896
			northeast			21.899267	95.98005		0.049553	0.011126
	100m	2015.9.3	center	10:01	10:31	21.899167	95.979567	200Hz	0	0
			northwest			21.899683	95.9788		-0.07949	0.056744
			southwest			21.898333	95.979267		-0.03097	-0.09346
			northeast			21.8995	95.980517		0.089814	0.040055

3.2.1 Estimation of phase velocities

In order to retrieve the information of Rayleigh wave phase velocity from the array measurement, we used the "BIDO" program of version 2.0 [7]. The Rayleigh wave phase velocity dispersion curves for five array sites in Sagaing City is shown in Fig.7 and these curves were achieved from the vertical components of array measurement by using the method of noise-compensated (nc-CCA) method [8], a revised method of CCA method extended from Spatial Autocorrelation (SPAC) Method.

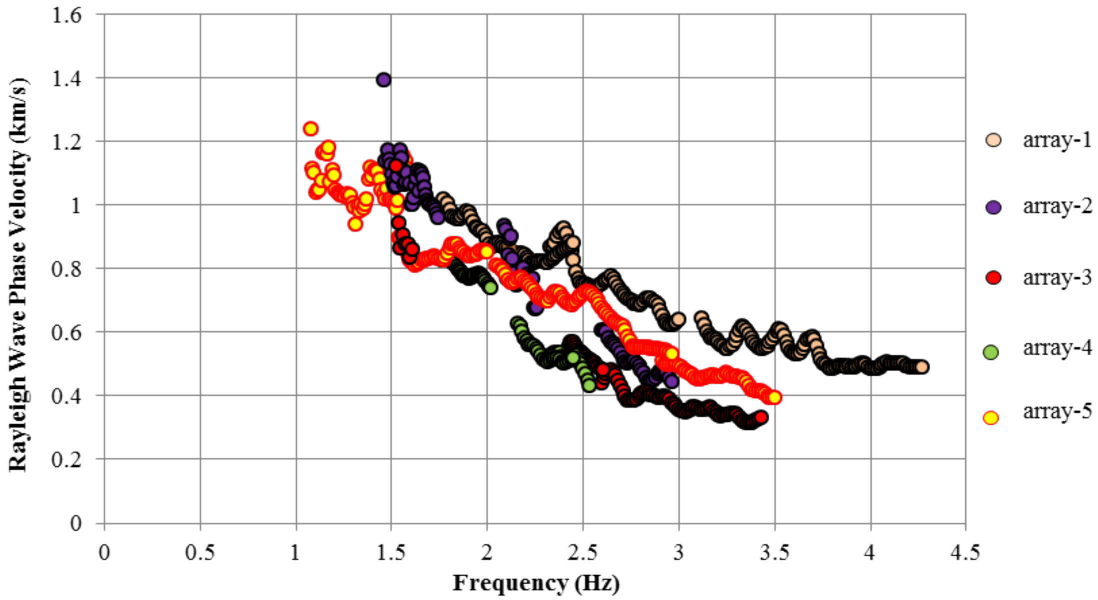


Fig. 7 – Rayleigh wave phase velocity curve for array sites

3.2.2 Inversion from phase velocities to S-wave velocity

S-wave velocity (hereafter Vs) structure is an important parameter in site amplification calculations for earthquake damages scenarios. Estimation of Vs profiles with direct methods, like borehole and drilling, requires geophysical or laboratory testing and imposes significant cost and time constraints. However, there are simple, economical, and rapid indirect methods to evaluate the Vs profiles, like spectral ratios of horizontal-to-vertical components (H/V) and microtremor array data analyses. These microtremor observations have become very popular because they are cost effective and rely on easily collected data for site characterization in terms of microzonation mapping.

In this study, the observed phase velocities were used for an estimation of S-wave velocity structure profiles with the Ballard's method [9] to reference in constructing the initial model, which is a useful method even for an area of having poor data of geology .Its equation is described in Eq. (2).

$$Z = \tfrac{1}{3}\lambda,\ Vsz = 1.1\, C_{\lambda} \tag{2}$$

where, Z refers to the depth (m), Vsz means S-wave velocity at the depth Z (m/sec) and C_{λ} means phase velocity (m/sec) at λ, the wavelength.

For the theoretical dispersion curve, it was calculated by using the program based on the reflection/transmission (R/T) matrix method to obtain the dispersion curves steadily [10]. Firstly, we construct the initial model as described in Table 3 and then try to get the good agreement between the observed phase velocities and calculated one though forward modeling. The layer model is characterized by four parameters: thickness (h), density (ρ), P-wave velocity (Vp) and S-wave velocity (Vs) for each layer and the main significant parameters for modification of the model are thickness and S-wave velocity to achieve the final model as designated in Table 4. Actually, P-wave velocity (Vp) and density (ρ) are not inverted but derived from S-wave velocity by using the empirical relation by Ludwig et al., [11] as revealed in Eq. (3) and (4). We tried to attempt trial and error to obtain the good fits between the observed and calculated velocities for all sites and finally it was rewarding as seen in Fig.8. The comparison with the agreement of Vs and Vp profiles for the final models including their deviation (plus or minus) of each array site are described in Fig.9.

$$Vp\ (km/sec) = 0.9409 + 2.0947\ Vs - 0.8206\ Vs^2 + 0.2683\ Vs^3 - 0.0251\ Vs^4 \quad (3)$$

$$\rho\ (g/cm^3) = 1.6612Vp - 0.4721Vp^2 + 0.0671\ Vp^3 - 0.0043\ Vp^4 + 0.0000106\ Vp^5 \quad (4)$$

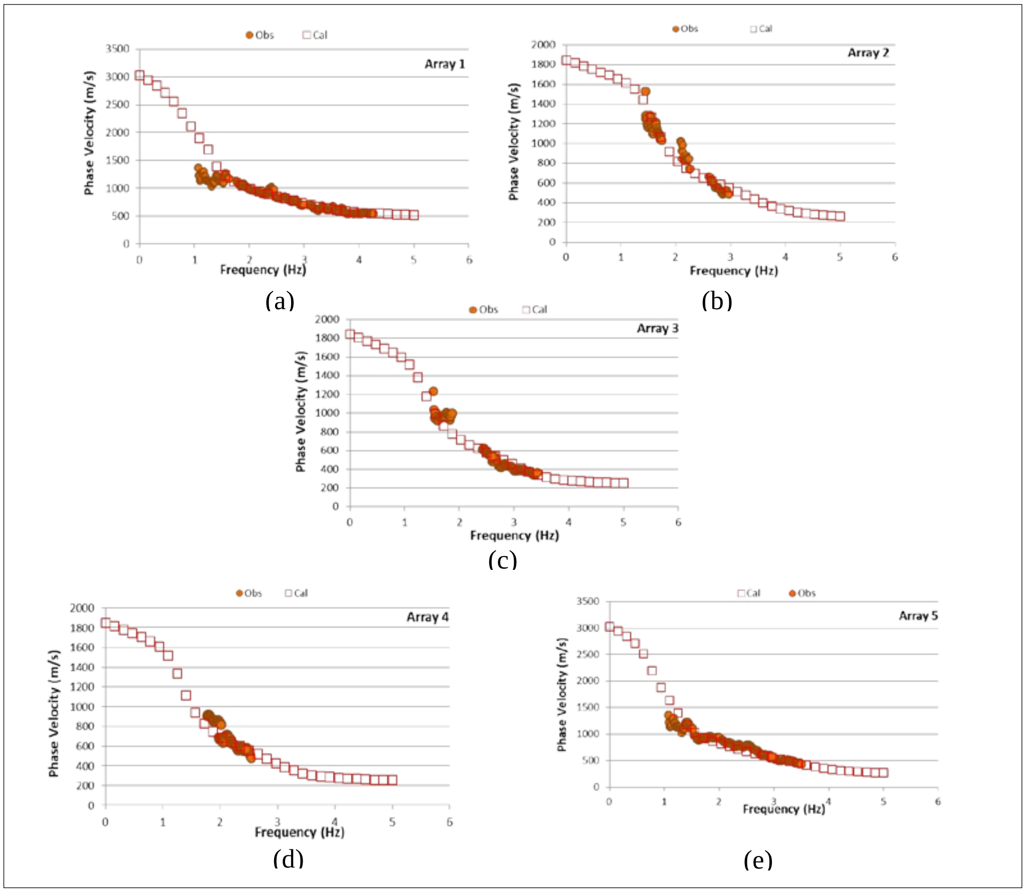


Fig. 8 – Comparison between the observed (filled circle) and calculated (open rectangle) phase velocities for each array sites

Table 3 – Initial model for Array 1

Array 1	Thickness (m)	Density (g/cm^2)	Vp (m/s)	Vs (m/s)
1	35	1.73	1664.01	400
2	50	1.82	1815.07	500
3	95	1.97	2155.58	750
4	165	2.04	2340.57	900
5	250	2.08	2458.2	1000

Table 4 – Final model for Array 1

Array 1	Thickness (m)	Density (g/cm^2)	Vp (m/s)	Vs (m/s)
1	15	1.58	1417.38	250
2	60	1.85	1887.1	550
3	80	2.04	2340.57	900
4	105	2.12	2572.5	1100
5	250	2.21	2959.89	1450
6	9999	2.63	5582.31	3300

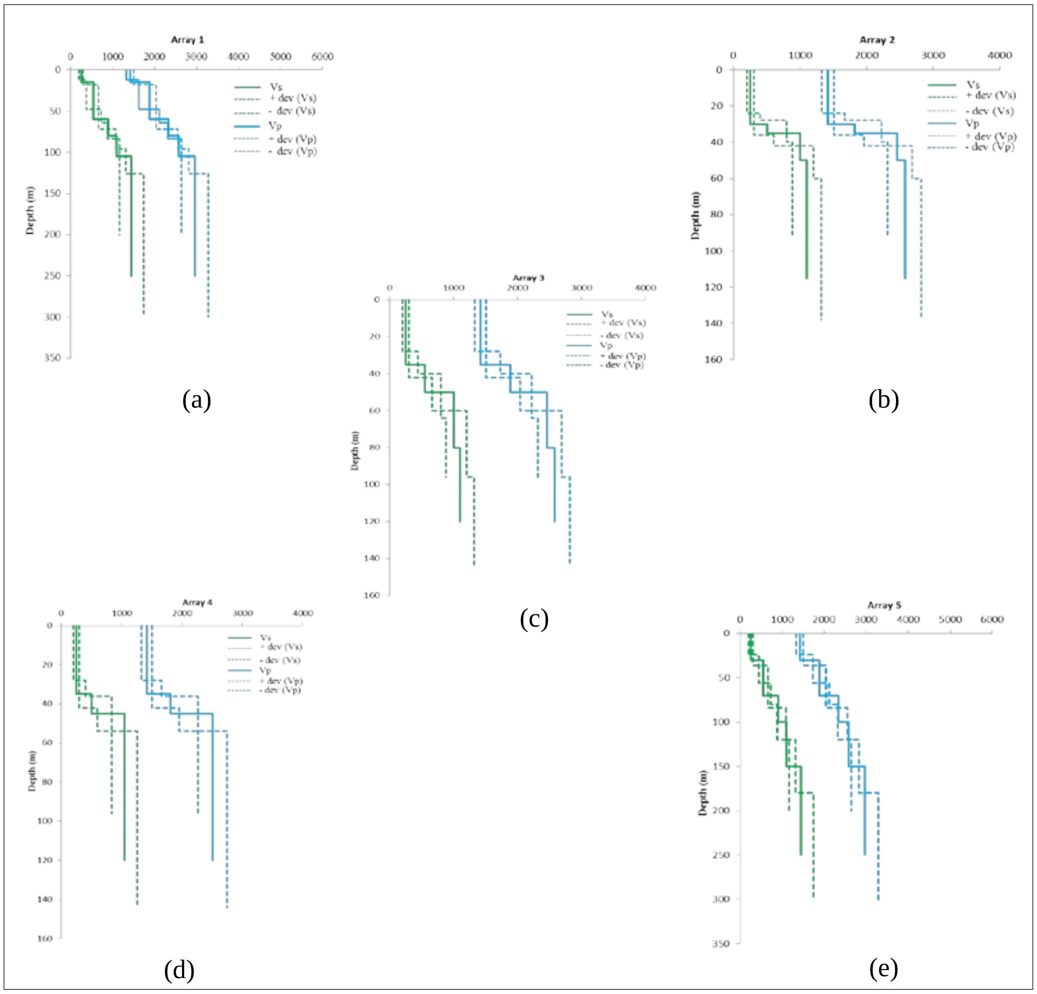


Fig. 9 – Comparison between Vs and Vp structures for the final models of each array

4. Conclusion and Discussion

We have conducted single-station and array microtremor measurements in order to estimate the S-wave velocity profile for Sagaing City, Myanmar. Totally, over 100 sites for single station and five sites for array were performed at Sagaing area.

As an agreement for the single station measurement, the smallest value of dominant frequency (≤1 Hz) at the western site of Sagaing City shows correlation with the alluvium formation of Holocene sediments. Peaks at higher frequencies around the Sagaing Fault have the linking with metamorphic rocks of Paleozoic age. Our measurement could agree with the findings in that there are transient zones between different geological site conditions. (Alluvium and Paleozoic rocks).

From the analysis of array measurement, we obtained stable phase velocities for each array sites. From this information, we could create initial models and finally we could establish the final models by undertaking over and over to describe the S-wave velocity profile of the area.

These microtremor surveys have been conducted in Sagaing City expected to support the national seismic hazard analysis of Myanmar. Current results will contribute to valuable preliminary microzonation and site response information.

As for the future task, we will use the velocity inversion technique for MHVR proposed by Sanchez-Sesma [3] together with the velocity profiles at five array sites as initial models and underground subsurface soil profiles for the whole area of Sagaing City will be constructed through the results that we obtained now. After that, the site amplification characteristics along the Sagaing Fault will be analyzed.

5. Acknowledgements

Firstly, we would like to express our gratefulness to authorized persons from Sagaing Co-operative University for their assistances during the field trip in Sagaing City. Special thanks are due to Prof. Dr. Thura Oo, Rector of Sagaing University, for his continuous supports and arrangement during the field study. We also would like to say our thanks to Disaster Prevention Research Institute, Kyoto University, for supporting the microtremor instruments during the study at Sagaing City. Finally, we would like to express our thanks to students from Yangon University for their participating throughout the field trip.

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