INTERNATIONAL JOURNAL OF MECHANICS
DOI: 10.46300/9104.2022.16.5 Volume 16, 2022

Site-Specific Ground Response Analysis using the Geotechnical Dataset in Moderate Seismicity Region

Imtiyaz Akbar Najar[1], Raudhah Binti Ahmadi[2]*, Mohd. Azizul Hafiz Jamian[3], Hasmida Binti Hamza[4], Azrin Ahmad[5], Chin Hon Sin[6]
[1,2,4,5]Department of Civil Engineering, Universiti Malaysia Sarawak, Kota Samarahan, Kuching, Sarawak, 94300, Malaysia
[3]Department of Social Sciences and Humanities, Universiti Malaysia Sarawak, Kota Samarahan, Kuching, Sarawak, 94300, Malaysia
[6]Public Works Department of Sarawak, Kuching, Sarawak, 94300, Malaysia

Received: March 26, 2021. Revised: February 7, 2022. Accepted: March 18, 2022.
Published: April 5, 2022.

Abstract— An understanding of the soil response to dynamic waves from the earthquakes is an important aspect of engineering safety measures against tremors. This research presents the equivalent linear site response analysis of the Miri district by using a geotechnical dataset. The main objective of this paper is to study the amplification factor for the district of Miri. Analysis of site response is critical in determining the earthquake risk and harm allocation during earthquakes. The standard penetration test 'N' value (SPT-N) has been used in this study. A specific soil-type relationship has been used between shear wave velocity and SPT-N value to produce profiles of shear wave velocity in each borehole site in the Miri district. For all SPT-N borehole sites, site response parameters were interpolated to produce site response maps and shear wave velocity maps in the geographical information system (GIS) environment. The research showed that the Malaysian national annex to Eurocode 8 (MNA-EC8) site class C, D and E are dominant in the Miri district. Due to the inadequacy of records of input ground motions of low-to-moderate seismicity regions, this research used an earthquake record from other locations well-matched from a target response spectrum with similar characteristics obtained from the Pacific Earthquake Engineering Research Center (PEER) online database (PEER NGA). The equivalent linear method (EQL) using DEEPSOIL is an extensively researched numeric technique that is used for assessment of site response. From the results, it has been found that the amplification ratio varies from 2.1 to 4.79 and it suggests that it is vital to study the site effect in the seismic hazard assessment of the Miri district. The work also emphasizes the relationship between seismic microzonation and site response analysis in order to reduce the adverse effects of earthquakes in Miri city by planning a proper land use.

Keywords—equivalent linear, GIS, site response, target response spectrum.

I. INTRODUCTION

BORNEO is found far from boundaries of major tectonic plates, but there are signs of continuing deformations [1], as appeared by the event of seismic tremors in the area, for the most part on the NW portion [2], [3]. The assessment of the soil reaction to earthquakes is one of the most frequently encountered issues in geotechnical earthquakes. Earthquake is a natural disaster that is unpredictable that creates a huge amount of damage, which affects the communities and their surroundings [4]-[6]. During an earthquake the delicate deposits can cause extensive amplification and boost the span of ground motion, which could thus increase the seriousness of harm and devastation, this occurrence is generally termed as site effect [7]-[10]. Protection against seismic tremor threats can be accomplished by bearing in mind the site security against geotechnical difficulties and structural protection alongside dynamic forces [11]-[13]. Perceptions from earthquakes in the course of recent decades have featured the significance of local site conditions on spread ground movements. It is essential to understand the local site conditions for the estimation of seismic hazard at a site and analysis of conveyed ground motions. Strong motion records from last three decades of various earthquakes 1999 Chi-Chi, 1999 Kocaeli, 1994 Northridge and 1989 Loma Prieta. These occasions shows a significant contrasts between local rock site response and soil sites responses [14]. On 19 September 1985, an earthquake struck the Mexico City with the moment magnitude of Mw 8.0. This earthquake caused the exceptional damage to Mexico city, this is the best example which shows delicate soils can amplify ground movements and result in heavy damage [14], [9]. Hence it is important for the design of earthquake resilient infrastructures and for the seismic risk calculation of an area to take into account the involvement of local site effects [15]. Typically, these site effects are assessed using methods of numerical modelling [16]. Site response analysis is fundamental to expect ground surface motions for calculation of amplification potential and for the development of design response spectra. Shear wave velocity (Vs) is an important parameter for conducting ground response analysis. There are two approaches for site response analysis: (1) equivalent linear via frequency domain analysis and (2) nonlinear method under time-domain analysis [14], [17]-[19]. The equivalent linear method is the most used method to compute the local site effects [20], [21]. According to [9] local site conditions has a necessary character in the propagation of ground motion from the substratum to the surface and also suggests that site effect must be considered in the study of seismic hazard assessment and used the GIS technique in site response analysis to plot the contour maps. Geographical information system provides an ideal environment for an extensive regional assessment of seismic damage [22]. GIS is a PC-based programming intended for catching, putting away, investigating, managing, and showing spatial information speaking to human and natural marvels from this present reality [23].

In present study, geotechnical data (SPT-N values) has been used to conduct site specific ground response analysis.

II. STUDY AREA AND GEOLOGICAL SETTINGS

The study area for this study is Miri district of Sarawak, Malaysia. Miri is a district of Sarawak state and is a coastal city in northeast Sarawak of Malaysia, situated on the island of Borneo, near the border of Brunei. Borneo is an island and is viewed as tectonically dynamic and has experienced major tectonic occasions since Miocene till the current day from both onshore and offshore [24]. Borneo is a fragment of the Sunda plate, and it is caged by the Indo-Australian and Philippine Sea plate [25],[26]. Borneo consists of these states; Kalimantan the state of Indonesia, East Malaysia (Sarawak and Sabah) and Brunei (a separate country between Sarawak and Sabah).

Borneo is isolated into five zones- zone of east Borneo, Miri zone, Sibu zone, Kuching zone and SW Borneo by Long Aran-Witti-Kinaya fault line, Tinjar fault line, Tatau-Mersing fault line, Lupar fault line, and Adang fault line respectively. Miri zone is a tectonically complex which consists of Palaeocene to Eocene ophiolitic rocks, including basalt, spilite, radiolarian chert and tuff [27].

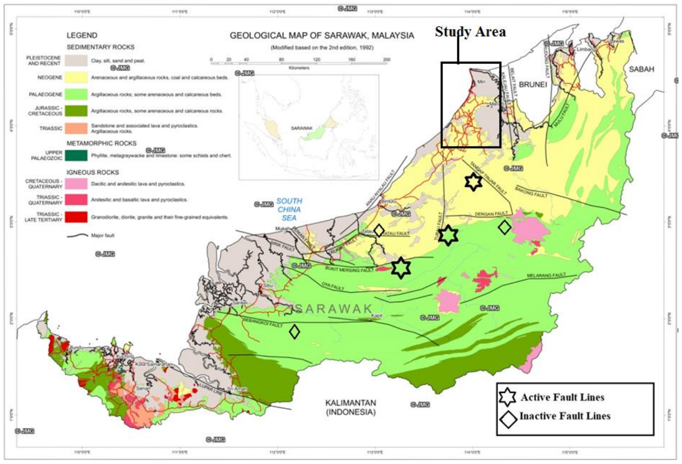

Figure 1. Geology of Borneo, Miri district as study area [28]

The Miri region is dominated by molasses, continental clastics, and post-Eocene carbonates (Figure 1) that have not been strongly deformed by the pre-intensively folded deep-sea Rajang Group [29] shown in Figure 1. The study area is located within longitudes 113° 58′ 46.4″ E to 113°49′ E and latitudes 04° 21′ N to 04° 07′ N shown in Figure 2.

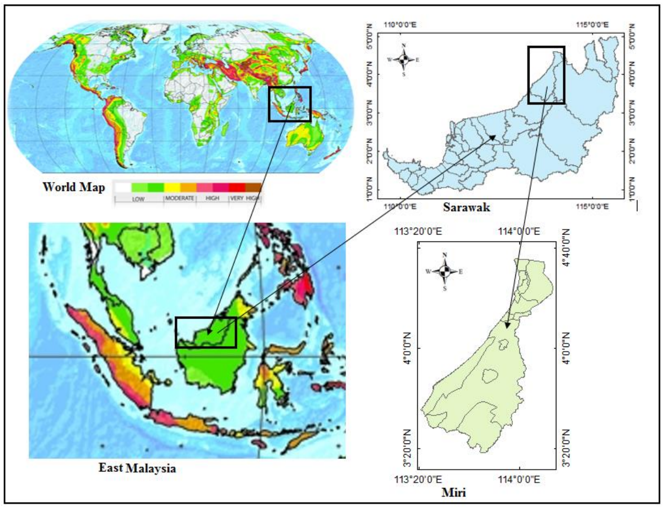

Figure 2. Miri as a study area

III. SEISMICITY OF MIRI DISTRICT

Sarawak and Sabah are the two states of East Malaysia, which are located on the east side of the island of Borneo. East Malaysia has experienced earthquakes of local origin with magnitudes up to 6.0 on the Richter scale. The earthquake happenings in east Malaysia being influenced by shallow crustal earthquakes located in the straits of Makassar, the Sulu Sea and the Celebes Sea from the Philippines and Indonesia. East Malaysia is considered as low-to-moderately active in seismicity. However, east Malaysia is also affected by the large earthquakes distributed over the southern Philippines and the straits of Makassar [30], [31]. There were various seismic tremors in Sarawak between 1874 and 2011, with intensity between 3.0 and 5.3 [32]. Earthquakes ranging from 3.0 to 5.3 have occurred in the Miri district shown in Figure 3.

Sabah another state of east Malaysia is prone to moderate earthquakes. Recently, on 05/June/2015 Ranau Sabah was struck by an earthquake with a moment magnitude of 6.0 on the Richter scale with a depth of 10 Km. Seismic tremors were felt in Miri district. Miri district in Sarawak is about 342.53 Km distant from the Ranau Sabah (USGS). Tremors were also felt in Miri, Lawas and Limbang the divisions of Sarawak, from the Ranau, Sabah earthquakes in 2015. Also a few local seismic inducing faults were discovered in Sarawak like, Belait fault line, West Baram fault line, Tubau fault line, Anyau Nyalau fault line, Kelawit fault line, Bukit Mersing fault line, Lupar fault line, Sebangkoi fault line, Oya fault line, Melarang fault line, Bakong fault line, and Mulu fault line. Therefore, east Malaysia cannot ignore the threat of earthquakes since there is a record of existing earthquakes that affected east Malaysia.

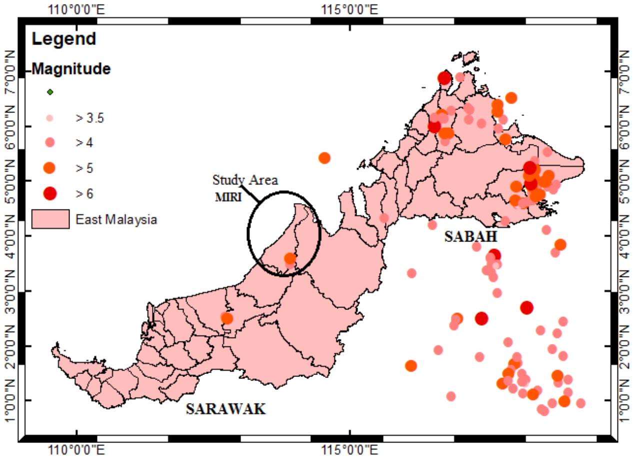

Figure 3. Earthquakes around East Malaysia [33]- [35]

IV. GEOTECHNICAL DATA AND METHODOLOGY

A. Standard Penetration Test Boreholes

SPT-N boreholes were collected from the Malaysian government and private organizations. In order to study the dynamic characteristics of the soil and to assess the conduct of soils with the implementation of seismic load a total of 114 SPT-N boreholes were evaluated, the locations of all boreholes across the Miri district are shown in Figure 4.

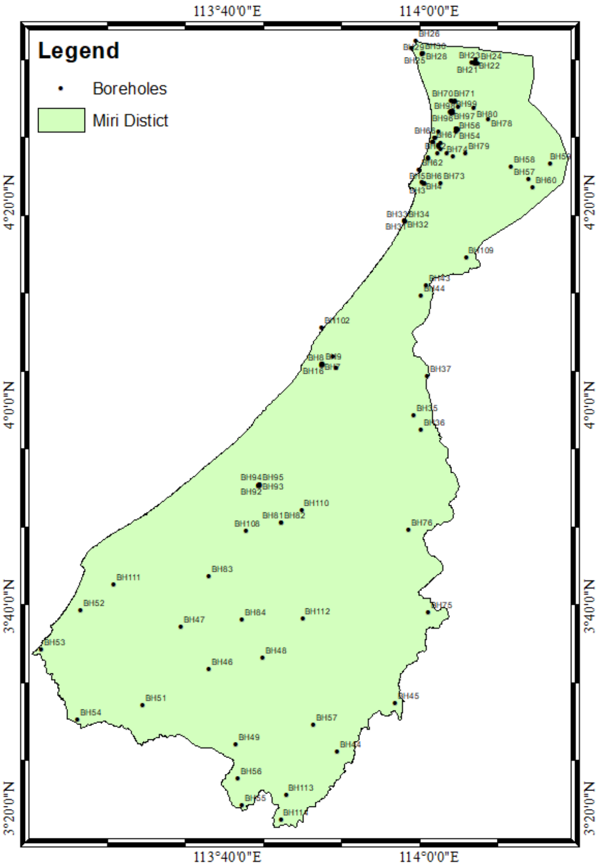

Figure 4. Map showing standard penetration test (SPT-N value) boreholes in Miri district

B. MNA-EC8 Shear Wace Velocity (Vs) Site Classification

According to [36] the acquired SPT-N values give a thought regarding the shear strength of the soil segment and posture of soils under the use of seismic burden. So as to decide the dynamic properties of soil, the achieved SPT-N values are used to assess the shear wave velocity up to a depth of 30 m (Vs30) by utilizing soil type and detailed relationships. According to [9] the parameter Vs30 is used by MNA-EC8 for site classification up to a depth of 30 m to design seismic-resistant infrastructure shown in Table 2.

Table 1. Classification of borehole sites according to MNA-EC8 on the basis of Vs30 up to the depth of 30 m

MNA-EC8 site class	Rock/soil type	Vs30 (m/s)
A	Hard rock	>1500
B	Rock	760-1500
C	Dense soil/soft soil	360-760
D	Stiff soil	180-360
E	Soft soil	<180

This research calculated Vs30 of soil segments utilizing the relationships between SPT-N values and the Vs30. [37] relationship has been used in this research to calculate Vs30. From the previous researches, the relationships among SPT-N values and Vs30 have been studied by many researchers since the 1960s. [37] a relationship for Vs, which depends on N-value [38]. From the obtained results of this study, the SPT-N value versus average shear wave velocity to a depth of 30 m (Vs30) for all soils in Miri adopting [37] relationship and the distribution of Vs30 across the Miri district is shown in Figure 5 and Figure 6 respectively. The Vs30 values obtained show that the site classes C, D, and E of the MNA-EC8 (2015) sites are the dominant classes in the Miri district. Site class D is the predominant one in the Miri district while site classes C and E covers a minor areas of Miri district.

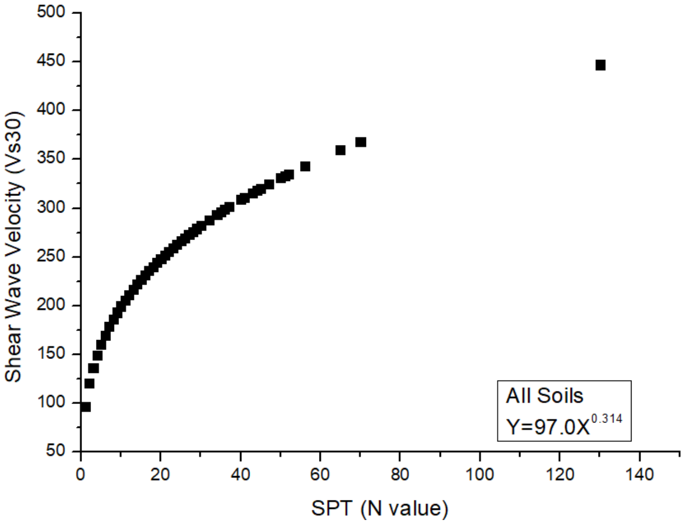

Figure 5. SPT-N value versus average shear wave velocity to a depth of 30 m (Vs30) for all soils in Miri adopting [37] relationship.

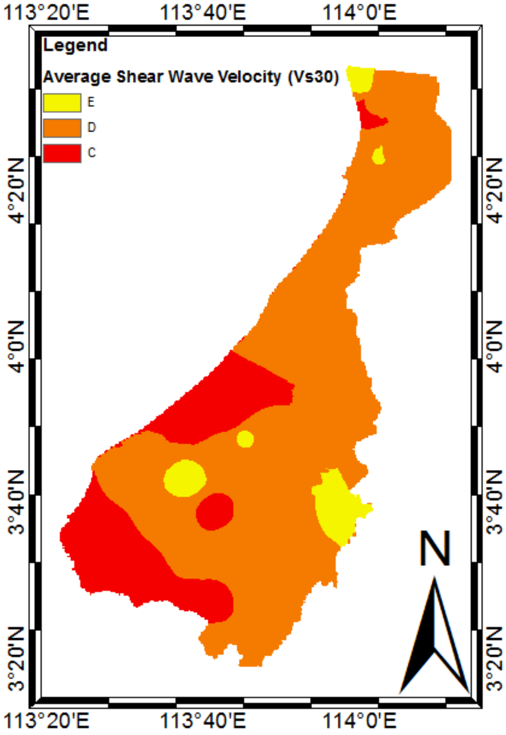

Figure 4. Distribution of Vs30 in Miri district

V. METHODOLOGY

The numerical examination was directed to acquire the site amplification factors of different site profiles. This was accomplished by utilizing a one-dimensional equivalent linear, site-specific response program, DEEPSOIL [39].

A. Equivalent Linear One-Dimensional Ground Response Analysis

The widely used equivalent linear approach is a numerical method used to evaluate the site response analysis and also this method is most extensively used in both engineering and research, for the reason of its flexibility, robustness, and simplicity. 1-D wave propagation analysis is the common method used to evaluate local site effects by performing site response analysis. The main aim of one-dimensional ground response analysis is to examine the vertical transmission of shear waves horizontally through on a level plane layered soil column from the versatile bedrock, which is expected to reach out to a boundless depth. The one-dimensional site response analysis can be carried out by either of two methods; a non-linear method or the equivalent linear method. In the present research, the equivalent linear method was used to calculate the ground response analysis by using a software DEEPSOIL, a one-dimensional site response platform. The equivalent linear methodology introduced by [40] accounts for the non-linearity of the shear-modulus and the damping ratio (%), using an iterative process to obtain modulus values and damping compatible with the actual strains in each layer. By utilizing the small-strain shear modulus reduction $\{{}^{G}/_{Gmax}\}$ and damping ratio (%) versus shear strain curves, each layer is modeled according to soil properties correspondingly, where 'Gmax' is the initial shear modulus and 'G' is the shear modulus. The effective shear strain ratio was considered to be 0.65 during the analysis. The bedrock was considered as rocky with the shear wave velocity as 760 m/sec.

B. Representative Ground Motion Records

Real earthquake records can be utilized as the input motion at the bedrock. Nevertheless, when no real earthquake records are available for the study location, earthquake records from other locations with similar characteristics can be obtained from the Pacific Earthquake Engineering Research Center (PEER) online database (PEER NGA) or any other appropriate earthquake database. Otherwise, synthetic earthquake records generated from seismological source models can also be used [41]. The time histories of bedrock motions are then assigned at the bedrock level to evaluate the free-field ground response spectrum.

For the present research, due to the non-availability of records of input ground motions of low-to-moderate seismicity regions, this research used an earthquake record well-matched from a target response spectrum (shown in Figure 7(b)) with similar characteristics obtained from the Pacific Earthquake Engineering Research Center (PEER) online database (PEER, NGA) by following [42]. There are numerous approaches such as stochastic finite-fault model [43] stochastic point simulation technique [44] and empirical Green's function (EGF) technique [45], [46] existing for the generation of synthetic input motions. Since all these approaches require the complex seismological parameters knowledge, a simple method that generates the artificial ground motion compatible from a target response spectrum. Therefore, this research used an earthquake record well-matched from a target response spectrum with similar characteristics obtained from the Pacific Earthquake Engineering Research Center (PEER) online database (PEER NGA) shown in Table 2, with a moment magnitude of 6.0 by following the approach of [47], [48]. The seismogram of input motion and the compatible target response spectrum used for the analysis is shown Figure 7(a) and Figure 7(b).

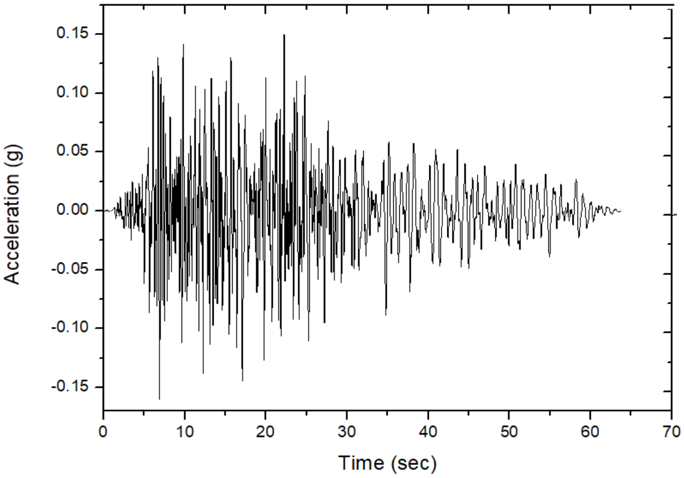

Figure 5. (a) Strong motion for the study area, compatible with target response spectra

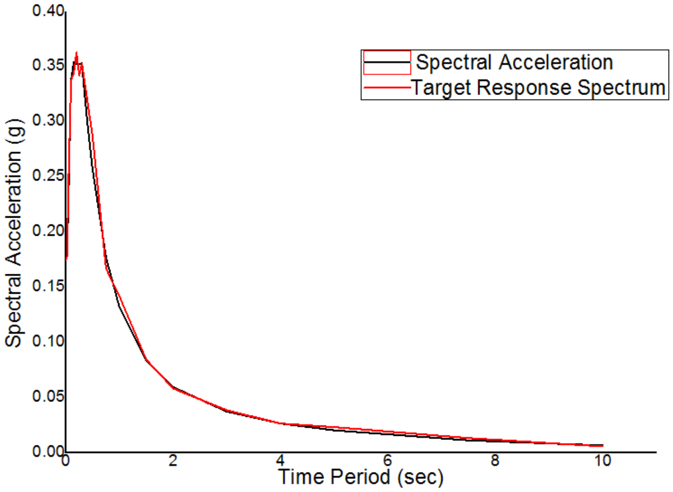

Figure 6. (b) Compatibility between observed and target response

Table 2. Details of the earthquake from PEER, which was used during the site response analysis

Parameter	Value
Name	Parkfield-02-CA
Magnitude	6.0
PGA	0.15 g
Station	Shandon-1-storey-high school building
Year	2004
Spectral ordinate	SRSS
Scale factor	1.761
D5-75	5.8 (sec)
D5-95	16.2 (sec)
Arias intensity	0.1 (m/s)
Mechanism	Strike-slip
Rjb (km)	14.19
Rrup (km)	14.46
Lowest useable frequency	0.1625 (Hz)

VI. RESULTS AND DISCUSSIONS

In the GIS environment, the obtained site response parameters have been interpolated to produce the site response contours for the entire Miri district. The peak ground acceleration (PGA), site amplification ratio and predominant frequency at the ground surface level of Miri district corresponding to an earthquake with a magnitude of 6.0.

A. Peak Ground Acceleration (PGA)

The PGA on the surface ranges from 0.03 g to 0.56 g and cannot be spread uniformly throughout the Miri district owing to differences in the land profile. Evidently, the closeness to the epicenter determines the PGA of the engineering bedrock while the soil profile is significant on the ground level. In the northern portion of the Miri district, PGA is significantly greater. The site impact is illustrated by the unevenness of the PGA distribution in the central portion of the Miri district with comparatively dense deposits of soft sediment. In terms of seismic hazard, PGA movements of ≥ 0.3 g are much damaging for engineering structures. However, raised PGA, with very higher frequencies and a brief period, is less damaging for engineering structures [9]. In the present research, the central and northern parts of the Miri district is having the high values of PGA. The result of the PGA contour is shown in Figure 9.

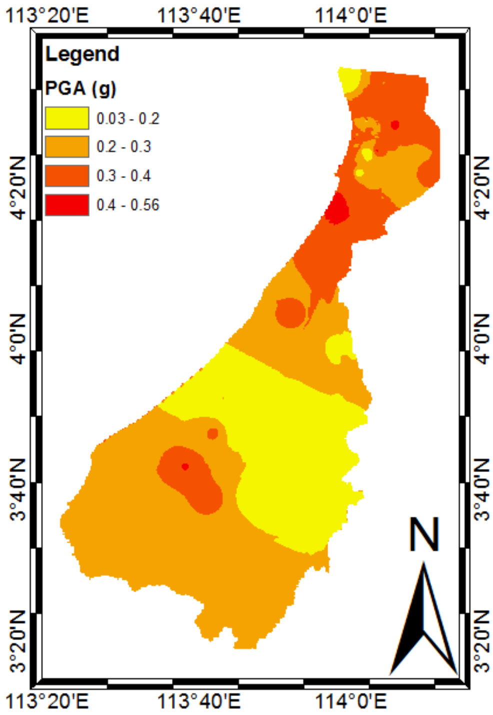

Figure 7. Peak ground acceleration (PGA) map of an earthquake (Mw 6.0) at the surface level in the Miri district

B. *Amplification Ratio*

The amplification ratio has been described as the factor that raises the PGA from the bedrock to the ground. The nature of the subsurface can affect the seismic response of buildings by amplifying the soil, in order to modify the seismic excitation in the basement when transmitted through the soils. This can lead to amplification effects. Soft sites are more likely to amplify low-frequency (long-term) rock motions than the locations having stiff soils, and high frequency (short-term) movements are more likely to be contrary. The findings of the amplification ratio evaluation indicate that in the Miri district, this ratio varies from 2.1 to 4.79 with the south-west portion of the Miri district is greater shown in Figure 10. The predominant frequency and the amplification are both significantly affecting the harm caused by an earthquake to structures [15].

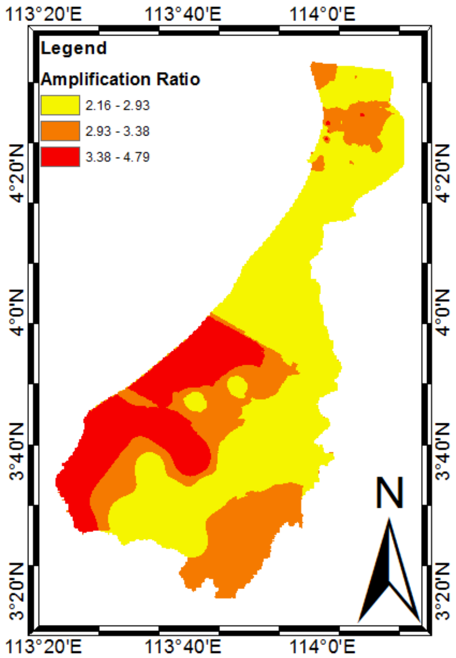

Figure 8. Amplification ratio map of the Miri district

C. *Predominant Frequency*

The predominant frequency of the Fourier spectrum varies from 0.22 to 1.56 Hz shown in Figure 11. The predominant frequency and the amplification are both significantly affecting the harm caused by an earthquake to structures. Low-rise structures are more susceptible to powerful, high-frequency soil movements that are closest to the epicenter, and dissipate with growing distances, for high-rise buildings, solid and low-frequency ground movements are more damaging.

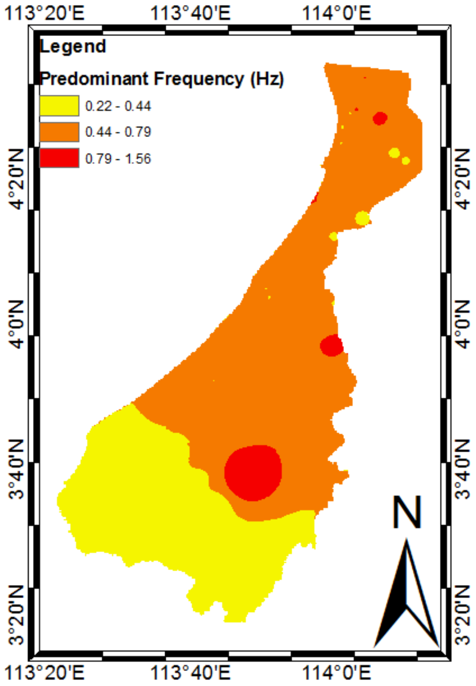

Figure 9. Predominant frequency (Hz) map of the Miri district

Small-frequency earth movements disappear much less than high-frequency earth movements and this could result in harm from the epicenter at large distances. The maps of spectral acceleration at 0.5, 1.0, 2.0, 5.0 and 10.0 Hz are shown in Figure 12. At these frequencies, spectral accelerations have been assessed as the natural frequencies of single-story buildings through to high-rise structures fall under this range [9].

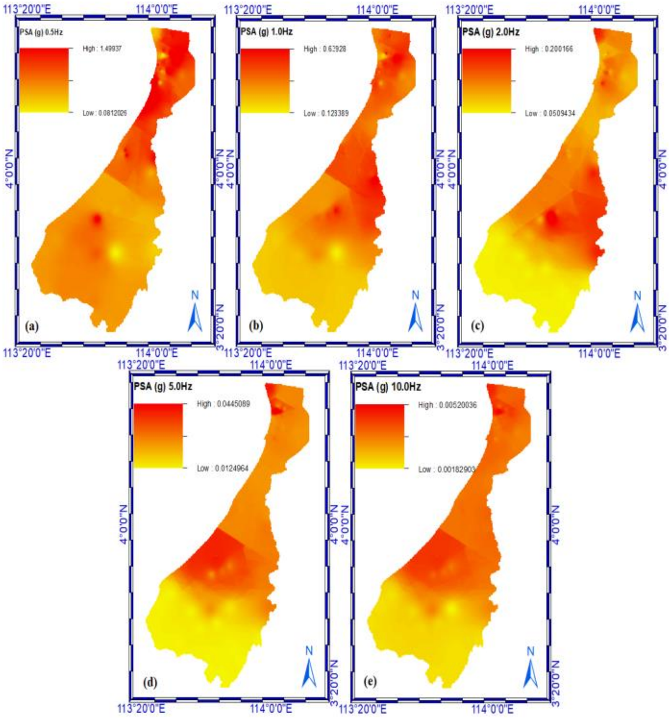

Figure 10. Pseudo-spectral acceleration (PSA) (g) distribution with 5% damping at frequencies of 0.5, 1.0, 2.0, 5.0 and 1.0 Hz

VII. CONCLUSION

The ground response analysis of the Miri district using an equivalent linear method by using DEEPSOIL is presented in this paper. In order to investigate the soil's dynamic characteristics and assess the soil's compatibility with seismic load, 114 SPT-N borehole drills were evaluated. In all borehole places, SPT-N values were used to assess the Vs30. C, D, and E are predominant site classes in the Miri district within the MNA-EC8 site classification scheme and site class D is the dominant one. The PGA on the surface ranges from 0.029 g to 0.48 g. In the northern portion of the Miri district, PGA is significantly greater. This improper allocation in the PGA is also an example of a lack of uniformity in the lithological characteristics of the alluvium in the Miri district. The value of PGA rises at the surface and shows a substantial increase with a reduction in depth up to the surface, thus explaining the site effect. In the Miri district, the amplification ratio is between 2.1 and 4.5 with higher values in the southern part. The range of predominant frequency varies from 0.22 to 1.5 Hz.

ACKNOWLEDGMENT

The authors wish to acknowledge the financial support provided by Universiti Malaysia Sarawak (UNIMAS) under the Cross-disciplinary Grant, F02/CDRG/1817/2019.

REFERENCES

[1] F. Sapin, M. Pubellier, A. Lahfid, D. Janots, C. Aubourg, J.C. Ringen-bach, “Onshore Record of the Subduction of a Crustal Salient: Example of the NW Borneo Wedge,” Terra Nova, vol. 23, no. 4, pp. 232-240, Apr. 2011.

[2] Y. Wang, S. Wei, X. Wang, E. O. Lindsey, F. Tongkul, P. Tapponnier, K. Bradley, C.-H. Chan, E. M. Hill, K. Sieh, “The 2015 Mw 6.0 Mt. Kinabalu Earthquake: an Infrequent Fault Rupture within the Crocker Fault System of East Malaysia,” Geosci. Lett. Vol. 4 no. 6, pp. 6-18, Jun. 2017.

[3] R. Hall, H. T. Breitfeld, “Nature and Demise of the Proto-South China Sea, Bull,” Geol. Soc. Malaysia, vol. 63, no.63, p. 6187, 2017.

[4] K. Kahandawa, N. Domingo, K. S. Park, S. Uma, “Earthquake Damage Estimation Systems: Literature Review,” Procedia Eng. Vol. 212, pp. 622-628, 2018.

[5] R. B. Ahmadi, I. A. Najar, N. M. Sa’don, H. Hamza, & N. A. Najar, “Computational Investigation of Soil Liquefaction Susceptibility Based on Standard Penetration Test Value of Miri District of Sarawak Malaysia,” Int. J. Adv. Sci. Tech., vol. 29, no. 7 pp. 2735-2748, May. 2020.

[6] I. A. Najar, R. B. Ahmadi, H. Hamza, N. M. Sa'don, A. Ahmad, “First Order Seismic Microzonation of Miri District of Sarawak Malaysia using AHP-GIS Platform,” Test Eng. and Manage, vol. 83, no. 2 pp. 13918-13928. Apr. 2020.

[7] N. Laouami, A. Slimani, “Earthquake Induced Site Effect in the Algiers Boumerdes Region: Relation between Spectral Ratios Higher Peaks and Observed Damage during the May 21st Mw 6.8 Boumerdes Earthquake (Algeria),” Pure Appl. Geophys, vol. 170, no. 11 pp. 1785-1801, Nov. 2013.

[8] H. Sana, “Seismic Microzonation of Srinagar City, Jammu and Kashmir,” Soil Dyn. Earthquake Eng., vol. 115, pp. 578-588, 2018.

[9] H. Sana, S. K. Nath, & K. S. Gujral, “Site Response Analysis of the Kashmir Valley during the 8 October 2005 Kashmir Earthquake (Mw 7.6) using a Geotechnical Dataset. Bull. Eng. Geol. Environ., vol. 78, no. 4 pp. 2551–2563, Apr. 2019.

[10] R. B. Ahmadi, M. H. M. A. Suhaili, I. A. Najar, M. A. Ladi, N. A. Bakie, & A. F. Abdullahi, “Evaluation on the Soil Flexibility of the Largest HEP Dam Area in East Malaysia using 1-D Equivalent Linear Analysis,” Int. J. Adv. Sci. Eng. Tech., vol. 11, no. 4, pp. 1535-1542, Aug. 2021.

[11] N. D. Satyam, I. Towhata, “Site-Specific Ground Response Analysis and Liquefaction Assessment of Vijayawada city (India),” Nat. Hazard, vol. 81, pp. 705-

724, 2016.

[12] K. Afshari, &, J. P. Stewart, “Insights from California Vertical Arrays on the Effectiveness of Ground Response Analysis with Alternative Damping Models,” Bull. Seism. Soc. of America, vol. 109, no. 4, pp. 1250–1264, 2019.

[13] R. B. Ahmadi, I. A. Najar, A. F. Abdullahi & T. Gallin, “Response spectra for moderate seismic area – application to Miri district of Sarawak, Malaysia,” in proc. 14th EnCon, IOP Conf. Series: Mat. Sci. and Eng. Kuching, Sarawak, Malaysia, pp. 1-9, 2021.

[14] D. Groholski, “Seismic Site Response Analysis and Extraction of Dynamic Soil Behaviour and Pore Pressure Response from Downhole Array Measurements,” Ph.D. thesis, Dept. Civ. Eng., Univ. of Illinois at Urbana-Champaign, 2012.

[15] D. Bindi, S. Parolai, F. Cara, G. Di Giulio, G. Ferretti, L. Luzi, G. Monachesi, F. Pacor, A. Rovelli, “Site Amplifications Observed in the Gubbio Basin, Central Italy: Hints for Lateral Propagation Effects,” Bull. Seismo. Soc. Am., vol. 99, pp. 741-760, 2009.

[16] G. Zalachoris, E. M. Rathje, “Evaluation of One-Dimensional Site Response Techniques Using Borehole Arrays,” J. Geotech. Geoenviron. Eng., vol. 141, 01-15, 2015.

[17] C. C. Tsai, C.-W. Chen, “Comparison Study of One-Dimensional Site Response Analysis Methods,” Eq. Spec., vol. 32, pp. 1075-1095, 2016.

[18] B. Ahmad, I. A. Najar, “Comparative Seismic Analysis of El Centro And Japan Earthquakes Using Response Spectra Method,” Int. J. Curr. Eng. Tech., vol. 6 no. 5, pp. 1859-1865, Oct. 2016.

[19] C. C. Tsai, & H. W. Liu, “Site Response Analysis of Vertical Ground Motion in Consideration of Soil Non-linearity,” Soil. Dyn. Eq. Eng., vol. 102, no. 2, pp. 124–136, 2017.

[20] C. Bolisetti, A. S, Whittaker, H. B. Mason, I. Almufti, & M. Willford, “Equivalent Linear and Nonlinear Site Response Analysis for Design and Risk Assessment of Safety-Related Nuclear Structures,” Nuc. Eng. Desg., vol. 275, pp. 107–121, 2014.

[21] B. Setiawan, “Site Specific Ground Response Analysis for Quantifying Site Amplification at a Regolith Site,” Indonesian J. Geosci., vol. 4 no. 3, pp. 159-167, Aug. 2017.

[22] J. N. Kumar, P. Anbazhagan, T. Sitharam, “GIS Integration for Microzonation Hazard Mapping-A Case Study of Bangalore City,” India, 2009.

[23] P. Tarolli, M. Cavalli, G.-H. Protection, “Geographic Information Systems (GIS) and Natural Hazards,” J. Geol. Soc. India., vol. 72 pp. 299-311, Jan. 2013.

[24] N. A. Siddiqui, A. H. A. Rahman, C. W. Sum, M. J. Mathew, M. Hassaan, D. Menier, “Generic Hierarchy of Sandstone Facies Quality and Static Connectivity: An Example from the Middle-Late Miocene Miri Formation, Sarawak Basin, Borneo,” Arab. J. of Geosci. Vol. 10, p. 237, 2017.

[25] R. Hall, “Reconstructing Cenozoic SE-Asia,” Geol. Soci, London, Special Publications, vol. 106 pp. 153-184, 1996.

[26] C. S. Hutchison, “Geological Evolution of South-East Asia,” Clarendon Press Oxford, 1989, vol. 13, pp. 101-109.

[27] M. Madon, “Geological Setting of Sarawak, the Petroleum Geology and Resources of Malaysia,” vol. 1, pp. 273-290, 1999.

[28] Department of Minerals and Geosciences Malaysia (Jmg). Ministry of Land, Water and Natural Resources. [online] Availabe at: https://www.jmg.gov.my/add_on/mt/swk/ tiles/ [Accessed on 15 September 2018].

[29] P. Wang, S. Li, L. Guo, S. Jiang, I. Somerville, S. Zhao, B. Zhu, J. Chen, L. Dai, Y. Suo, “Mesozoic and Cenozoic Accretionary Orogenic Processes in Borneo and their Mechanisms,” Geol. J., vol. 51, pp. 464-489, 2016.

[30] A. Adnan, A. Marto, M. Irsyam, “Seismic Hazard Assessment for Peninsular Malaysia Using Gumbel Distribution Method,” J. Tek, vol. 42, pp. 57-73, 2005.

[31] I. A. Najar, R. B. Ahmadi, N. A. Najar, S. Akbar, N. S. Binti, “Review of Impact of 2004 Great Sumatra-Andaman Mega Thrust Earthquake and Tsunami on Affected Countries using ECLAC DaLA Framework,” J. Environ. Eng. Stud., vol. 5, no. 1, pp. 36-45, 2020.

[32] A. Y. S. Wah, “Geological Assessments of the Earthquake Sources and Hazard in Malaysia,” in proc. Sem. Teknikalgempabumi, Malaysia, 2011.

[33] Hendriyawan, “Seismic Macrozonation of Peninsular Malaysia and Microzonation of Kuala Lumpur City Center and Putrajaya,” Ph.D. thesis, Dept. Civil. Eng., Uni. Tekn. Malaysia, 2007.

[34] United States Geological Survey (USGS), Earthquake Catalog Record. Available at: https://earthquake.usgs.gov/earthquakes/search/. [Accessed on 12 October 2018].

[35] Malaysian Meteorological Department (MMD), Collection of Earthquake Data. Available at:

[36] F. Castelli, A. Cavallaro, S. Grasso, V. Lentini, “Seismic Microzoning from Synthetic Ground Motion Earthquake Scenarios Parameters: the Case Study of the City of Catania (Italy),” Soil Dyn. Earthquake Eng., vol. 88, pp. 307-327, 2016.

[37] T. Imai, & Tonouchi, “Correlation of N Value with S-Wave Velocity and Shear Modulus,” 1982.

[38] B. R. Wair, J. T. DeJong, T. Shantz, “Guidelines for Estimation of Shear Wave Velocity Profiles,” Available through: Uni. of California, Berkeley, (2012). [Accessed on 10 August 2018].

[39] Y. M. Hashash, “Nonlinear and Equivalent Linear Seismic Site Response of One-Dimensional Soil Columns,” User Manual v. 7. 0, Deepsoil Software, 2016.

[40] H. B. Seed, I. M. Idriss, “Influence of Soil Conditions on Ground Motions during Earthquakes,” J. Soil Mech.

Found. Div., vol. 95 pp. 99-138, 1969.

[41] I. Hajirasouliha, P. Asadi, K. Pilakoutas, "An Efficient Performance-Based Seismic Design Method for Reinforced Concrete Frames," Earthquake Eng. Struct. Dyn., vol. 41 pp. 663-679, 2012.

[42] Y. Bozorgnia, N. A. Abrahamson, L. A. Atik, T. D. Ancheta, G. M. Atkinson, J. W. Baker, A. Baltay, D. M. Boore, K. W. Campbell, B. S. J. Chiou, "NGA-West2 Research Project," Earthquake Spec., vol. 30, pp. 973-987, Jun. 2014.

[43] I. A. Beresnev, G. M. Atkinson, "Stochastic Finite-Fault Modeling of Ground Motions from the 1994 Northridge, California, Earthquake. I. Validation on Rock Sites," Bull. Seismol. Soc. Am., vol. 88, pp. 1392-1401, Jun. 1998.

[44] D. M. Boore, "Simulation of Ground Motion Using the Stochastic Method," Pure Appl. Geophys., vol. 160, pp. 635-676, Sep. 2003.

[45] S. H. Hartzell, "Earthquake Aftershocks as Green's Functions," Geophys. Res. Lett., vol. 5, pp. 1-4, 1978.

[46] K. Irikura, "Semi-Empirical Estimation of Strong Ground Motions during Large Earthquakes," Bull. Disaster Prev. Res. Inst., vol. 33, pp. 63–104, Jun. 1983.

[47] N. James, T. Sitharam, G. Padmanabhan, C. Pillai, "Seismic Microzonation of a Nuclear Power Plant Site with Detailed Geotechnical Geophysical and Site Effect Studies," Nat. Hazard., vol. 71, no. 1, pp. 419-462, Nov. 2013.

[48] R. Sarkar, S. Bhattacharya, & B. K. Maheshwari, "Seismic Requalification of Pile Foundations in Liquefiable Soils," Indian Geotech. J., vol. 44, no. 2, pp. 183–195, Mar. 2014.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

The authors wish to acknowledge the financial support provided by Universiti Malaysia Sarawak (UNIMAS) under the Cross-disciplinary Grant, F02/CDRG/1817/2019.

Creative Commons Attribution License 4.0 (Attribution 4.0 International, CC BY 4.0)