Response spectra for moderate seismic area – application to Miri district of Sarawak, Malaysia

R Ahmadi¹*, I A Najar²*, A F Abdullah³ and T Galin⁴

¹, ² Department of Civil Engineering, Universiti Malaysia Sarawak, 94300, Kota Samarahan, Sarawak, Malaysia
³ Department of Civil and Environmental Engineering, Dhofar University, Salalah, P.O. Box 2509, Sultanate of Oman
⁴ Department of Mineral and Geoscience Malaysia, Kuching, Sarawak, Malaysia
*Corresponding authors: araudhah@unimas.my, imtiyaznajar999@gmail.com

Abstract. The aim of this paper is to estimate the response spectra for moderate seismic area in Sarawak, Malaysia. In the present study, the response spectra for Miri district, in Sarawak, has been obtained by using 1-D equivalent linear site response analysis at 114 borehole locations. All the borehole sites are classified based on average shear wave velocity (Vs30) as per Malaysia National Annex to Eurocode 8 (MNA-EC8) site classifications using the geotechnical relationship. In this study, the input motion was selected from Pacific Earthquake Engineering Research (PEER-NGA) online database compatible with target response spectra of Sarawak at engineering bedrock by considering the seismic hazard map for 2475 years as return period and by following the 475 years return period as shown in (MNA-EC8). From the results of this study, it was found that the maximum response spectral acceleration (response spectra with 5% damping) is 2.25 g, 3.25 g and 1.7 g at the ground surface for MNA-EC8 site classes C, D and E respectively. It was also found that the results are under the provisions of seismic design code of Malaysia. The suggested results in this study can be used as a reference in Malaysia to support the MNA-EC8.

1. Introduction

A response spectrum is a useful tool available to engineers designing earthquake resistant structures. Site response analysis is used to measure ground surface motions, amplification potential and the development of design response spectra. Shear wave velocity (Vs) is an important parameter for conducting ground response analysis [1]. In general, the following three different approaches can be implemented to conduct ground response analyses: (1) use of geotechnical data (i.e. SPT blow counts obtained from bore logs), (2) use of microtremor data (i.e. ambient noise measurement) and (3) use of a geophysical method (spectral analysis of surface wave tests, SASW) [2].

Amirsardari et al. [3] investigated the seismic site response analysis for Australia which has a history of low-to-moderate earthquakes. An equivalent linear program was used to analyze the impacts of the depth of rock/soil to engineering bedrock and the shear wave velocity (Vs30) on the site amplification factors for sand and clay with a plasticity index of 30%. The analysis was completed using the SHAKE2000 program. On the other hand, analysis of the site response was carried out by [4-6] by considering the vertical and horizontal components of ground motions. The analyses were performed using both nonlinear and equivalent linear analyses utilizing the DEEPSOIL program. Furthermore, site
response analysis was carried out by using the software SHAKE and then integrated with probabilistic seismic hazard assessment using MATLAB. Also the matching of response spectrum was carried out using RSPMATCH software [7]. Tsang et al. [8] studied the design spectrum for flexible soil sites in regions of low-to-moderate seismicity. An alternative design model was introduced to consider the soil resonance phenomenon without having the need to conduct computational site response analysis of the subsurface model.

Pappin et al. [9] used the Oasys SIREN program to produce the response spectra by using the one-dimensional site response analysis in the moderate seismicity region of Hong Kong and found that the results obtained were more realistic compared to the SHAKE program. One-dimensional site response analysis was carried using three industry-standard programs, the time domain nonlinear program, DEEPSOIL, and the frequency domain equivalent linear program, SHAKE. Four soil locations, which are deemed suitable for nuclear safety-related building, varying from hard rock to stiff soil were selected. Comparing the forecasts for the various available programs showed that standard programs for locations with stiff soil and low-intensity soil movements are in excellent agreement, however, for analyses involving greater strains and at greater frequencies, there is wide variation [10].

From the above literature review, it is evident that researchers have used several types of data, softwares and methodologies in order to produce the response spectra. In the present study, geotechnical data will be used and evaluated using the 1-D equivalent linear response analysis by utilizing the DEEPSOIL software.

2. Study Area
Miri is a coastal area in northeast of Sarawak, Malaysia. It is situated on the island of Borneo, near the border with Brunei. The study area is located within coordinates longitudes-113° 58′ 46.4″ E to 113°49′ E and latitudes 04° 21′ N to 04° 07′ N. The study area is shown in figure 1.
3. Methodology

The response spectra for various site class profiles for the Miri district were determined with DEEPSOIL software using a 1-D equivalent linear response approach.

3.1 Geotechnical dataset utilized in site response analysis

For this research, standard penetration tests were carried out by various government agencies and geotechnical engineering consultancies of Malaysia, and penetration values (N) were calculated. Data was taken from 114 boreholes, each with a depth not exceeding 30 m. The borehole locations are shown in figure 2.

![Figure 2. Location of boreholes across the Miri district](image)

3.2. MNA-EC8 shear wave velocity (Vs30) site classification

The acquired SPT-N values provide an estimate of the shear strength of the soil segment under consideration. 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 additionally area explicit connections. The parameter Vs is used by the MNA-EC8 [11] for site classification up to a depth of 30 m to design seismic-resistant infrastructure. The recommended site classification according to MNA-EC8 [11] based on average shear wave velocity up to the depth of 30 m is shown in table 1. This research calculated Vs30 of soil segments utilizing the relationships between SPT-N values and the Vs30. Imai and Tonouchi [12] relationship is used to calculate Vs30. This was introduced by Looi et al. [13] by
using it in the Kuching area of Sarawak, Malaysia. The relationships between SPT-N values and Vs30 have been studied by many researchers since the 1960s. Imai and Tonouchi [12] have investigated the largest dataset, including 1654 data pairs from 386 borings at 250 destinations in Japan. It is applicable for all geological ages and all types of soils [13-15]. Imai and Tonouchi [12] created a relationship for Vs, which depends on N-value. The applicable range of N-value is from less than one blow per feet (bpf) to nearly 400 bpf. The relationship used to calculate Vs30 is given in equation 1.

\[ Vs = 97 \times N^{0.314} \]  

(1)

where,  
Vs = shear wave velocity  
N = SPT-N value

Table 1. Classification of borehole sites according to MNA-EC8 [11] on the basis of Vs30 up to a 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       |

The shear wave velocity up to a depth of 30 m (Vs30) was determined for the soil types available in the Miri district based on 114 SPT boreholes data. The obtained Vs30 values showed that the site classes C, D and E of the MNA-EC8 [11] sites are the dominant classes in the Miri district as shown in figure 3. Site class D is the predominant while site classes C and E covers a small area of the Miri district.

Figure 3. Distribution of Vs30 in Miri district
3.3. Input motion
Due to the unavailability of records of input ground motions for low-to-moderate seismicity regions, this research used an earthquake record from other locations well matched from a target response spectrum with similar characteristics. The record was obtained from the Pacific Earthquake Engineering Research Center (PEER) online database (PEER NGA) [16]. The seismogram of the ground motion is shown in figure 4.

![Seismogram of ground motion](image)

**Figure 4.** Input motion for the study area, compatible with target response spectra having moment magnitude 6.0 with PGA 0.15 g

3.4. DEEPSOIL
In the present research, the equivalent linear method was used to calculate the ground response analysis by using DEEPSOIL, a 1-D site response platform. The equivalent linear methodology introduced by Seed and Idriss [17] 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 ($G/G_{max}$), and damping ratio (%) versus shear strain curves, each layer is modeled according to corresponding soil properties. ‘Gmax’ is the initial shear modulus and ‘G’ is the shear modulus. The effective shear strain ratio was taken as 0.65 during the analysis. The bedrock was assumed to be of a rocky nature with a shear wave velocity of 760 m/sec. This equivalent linear method is more suitable for low to moderate levels of earthquakes and is commonly used in engineering.

There are various active approaches to determine the response of a single degree of freedom (SDOF). The Duhamel integral solutions, the frequency-domain solution and the Newmark β method can all be used to analyse the response spectra. For the present study, the frequency domain solution approach has been used to estimate the response of SDOF systems and to solve the dynamic equilibrium equation defined in [18-19] by using the DEEPSOIL software, as shown in equation 2.

$$m\ddot{u} + c\dot{u} + ku = -m\ddot{g}$$

where
- $m$ = mass
- $c$ = viscous damping
- $k$ = system stiffness of SDOF system
- $\ddot{u}$ = nodal accelerations
- $\dot{u}$ = relative velocities
- $u$ = relative displacements
- $\ddot{g}$ = the exciting acceleration at the base of SDOF.
In the frequency-domain solution, the Fourier Amplitude Spectra (FAS) input motion is modified by a transfer function as defined in equation 3:

\[
H(f) = \frac{-f_n^2}{(f_n^2 - f^2 - 2i\xi f_n)}
\]

where

\[
f_n = \text{natural frequency of the oscillator which is calculated as in equation 4:}
\]

\[
f_n = \frac{1}{2\pi} \sqrt{\frac{k}{m}}
\]

\[
\xi = \text{damping ratio which is calculated as in equation 5:}
\]

\[
\xi = \frac{c}{2\sqrt{km}}.
\]

The-frequency-domain-solution-requires the use of FFTs (Fast Fourier Transforms)-to-move between the frequency-domain, where the oscillator transfer function is applied, and the time-domain, where the peak-oscillator-response is-estimated. Over-the-frequency-range-of the-ground-motion, the frequency-domain solution is exact.

4. Results and Discussion

The-PGA-of soil is not enough to describe the ground-motion since the-frequency parameter of the motion is not taken into account. The response of the building-depends on the frequency-content and it is standard practice to describe ground-motion in terms of response-spectra [20]. Response spectra provide the peak structural responses in the linear range, which can be utilized for acquiring lateral forces created in structures in response seismic activity. This knowledge is essential in designing earthquake-resistant structures. Engineers and designers need a response spectrum of accelerations in order to design a seismic resistant building structure. Ground response analysis has been carried out for 114 boreholes across the Miri district. From the results of this study, it was found that the maximum response spectral acceleration (response spectra with 5% damping) is 2.25 g, 3.25 g and 1.7 g at the ground surface for MNA-EC8 site classes C, D and E respectively. The spectral accelerations (response-spectra-with 5% damping) at the ground surface are shown in figure 5, figure 6 and figure 7 respectively. They were compared to the response spectra at surface according to MNA-EC8. It was found that the computed surface acceleration obtained from site-specific ground response analysis corresponding to response spectrum of published MNA-EC8 [11] are in close agreement with the target (surface measurements) for Sarawak, Malaysia.

![Figure 5. Response spectra for 5% damping at the ground surface of the Miri district for site class C as per MNA-EC8](image_url)
5. Conclusions
In this study, response spectra of Miri district have been developed by using a 1-D-equivalent-linear-response-analysis under frequency-domain-approach using DEEPSOIL software corresponding to 2475 years of return period. For the study, the input-motion was selected by considering the seismic hazard map for 2475 years as return period by following the Malaysia National Annex to Eurocode 8 (MNA-EC8). In this study, the ground response spectra have been evaluated for all locations and for all the soil types of Miri district and these results were compared with MNA-EC8 and showed that results of spectral acceleration of this study are in close agreement with the design response spectra provided by MNA-EC8.
Acknowledgments
Authors wishing to acknowledge the financial support from Cross Disciplinary Research Grant, F02/CDRG/1817/2019. Acknowledgement is also given to the Department of Mineral and Geoscience, Sarawak Branch for this research collaboration and financial support.

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