Development of Design Response Spectra Based on Various Attenuation Relationships at Specific Location

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Abstract: Peninsular Malaysia is located and lies in a low seismic region. Although Malaysia is not located in the active fault seismic area, it is closed to the Sumatran active seismic zones. Tall building are frequently felt the tremor generated from Sumatran subduction and fault zones especially in the west cost of Peninsular Malaysia such as Johor Bahru, Kuala Lumpur and Penang. Existing design response spectra was developed based on attenuation relationship for each subduction and fault zone. In this study, the design response spectra were developed based on various attenuation relationships for selected location in Kuala Lumpur area, namely, Mutiara Damansara, Bandar Petaling Jaya and Bandar Puteri Puchong. The development of design response spectra based on various attenuation relationships is more reliable in selecting the appropriate attenuation relationship for the study area. Seven attenuations have been chosen and results show that Megawati et al. are the most appropriate attenuation relation for fault zone, where the predicted PGA (peak ground acceleration) is 0.0187 g which is the proposed PGA value for this study area. This study also found that most of soil in the study area can be categorized into S_D (stiff soil) according to site classification in the NEHRP 2000 Provision/UBC 97. Bandar petaling Jaya was found to be highest AF (amplification factor) of 3.74 for stiff soil and Mutiara Damansara with AF of 2.67 for very dense soil or soft rock. The proposed design response spectra for each location were developed based on UBC 1997 (Uniform Building Code 1997). The peak RSA (response spectrum acceleration) of 0.30 g for soil type S_D for Bandar Petaling Jaya is the maximum level of acceleration on the soil surface with a period range of 0.10 to 0.52 seconds. All these values can be used for the seismic safety evaluation of existing structures and as a guideline in designing new structures to resist future earthquake, within the study area.

Key words: Attenuation relationship, PGA (peak ground acceleration), response spectrum acceleration, response spectra, Sumatra subduction zone, Sumatra fault zone.

1. Introduction

The Peninsular Malaysia is located in a low-seismic region where the closest active seismic zones are located approximately 350 km away that generated from the Sumatran seismic zones namely Sumatran subduction and fault zones. Although Peninsular Malaysia lies on seismically stable region but structures in this region frequently felt the earthquake generated from the Sumatran seismic zones as low as magnitudes of 5.0 [1].

According to Megawati et al. [2], it was predicted that an earthquake event at a moment magnitude greater than 7.8 from the Sumatra subduction zone has capability to generate destructive ground motion in Singapore and Kuala Lumpur, even at a distance of 700 km.

Pan [3] stated that even a longer distance may create destructive ground motion, so it seems reasonable to assume that larger and closer earthquake might results in tremendous ground motion to Peninsular Malaysia generally and Kuala Lumpur especially. In addition, Kuala Lumpur was reported as the most frequent earthquake felt area in Malaysia by Malaysian

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Meteorological Services [4].

Kuala Lumpur had rapid development in the past few decades which is also contribute to increasing of the construction of tall building or structures, therefore specific location in Kuala Lumpur area has been chosen as a case study area in order to carry out the earthquake study or seismic hazard analysis which is can be used for future planning especially in safety design of structure.

This study was carried out to achieve three main objectives which are to determine and propose PGA based on various attenuation relationships for study area, to develop spectral acceleration on the specific location in Kuala Lumpur, using NERA program and also to develop design response spectrum using proposed PGA value and according to UBC 1997, for study area.

This research is based on the distant earthquake from Sumatra and limits its scopes of works which are the maximum magnitude value for subduction zone and fault zone are taken from Fadzli [5], three attenuation relationships in determining PGA are Adnan et al. [6], Lam et al. [7], Megawati et al. [2] and Petersen et al. [8], for Sumatra subduction and Campbell [9], Lam et al. [7] and Megawati et al. [10], for Sumatra fault zones, due to availability soil data of Kuala Lumpur, only three locations area will be studied using 28 borelog data, the development of response spectra acceleration based on local site condition, one strong-motion data used in establishing RSA (response spectra acceleration) is El Centro Earthquake, NERA (non-linear Earthquake site Response Analysis) software will be used for performing RSA and design response spectra will be established based on UBC (1997).

2. Theoretical Background

2.1 General Tectonic Setting of Peninsular Malaysia

Malaysia is situated close to two most seismically active plate boundaries namely, the inter-plate boundary between the Indo-Australian Plates and

Eurasian Plates on the west, and the inter-plate boundary between the Eurasian and Philippines Sea on the east.

The India-Australia plate subducted below the Eurasia plate along the arc at a rate of about 67 mm/year and this displacement between the two plates is partly accommodated by sudden movements which can cause earthquakes [11].

Generally tectonic features affected Peninsular Malaysia can be divided by two different classifications, which is subduction and fault zone. The nearest distance of earthquake epicentre from Malaysia is approximately 350 km [6]. Numerous earthquakes ranging from magnitude 6.5 to 9 have occurred in both the Sumatran fault system and the subduction interfaces as reported by Sieh and Natawidjaja [12] (Fig. 1).

2.2 Sumatran Subduction and Fault Zone

The Sumatra subduction zone is defined as one of the most active plate in the world tectonic margins accommodating about 49 to 60 mm/year [10] and has been the focus of several and large earthquake [8]. The latest earthquake disaster occurred on the 26 December 2004 that is great Sumatra-Andaman earthquake and

Fig. 1 Active tectonics and seismologic summary of the Sumatra plate boundary [13].

was the largest seismic event ever recorded with magnitude of 9.3 that generating tsunami.

Strike slip faults is caused by relative horizontal displacement of the two sides of faults taking place along an essentially vertical fault plane, as occurred at Sumatra great fault zone. The Sumatran fault's ranking as one of the great strike-slip fault on earth, it is high in level seismicity and it is major role in active tectonic and seismic hazard of Southeast Asia [12]. Several large earthquakes have occurred in this zone as mentioned by Adnan et al. [6] with magnitude between 6.7 and 7.5.

In this study, the earthquakes sources data from each Sumatran subduction and fault zone were first selected where earthquake event with magnitude less than 5 will be neglected, as suggested by Petersen et. al. [8] and maximum magnitude values for subduction and fault zone was taken from study done by Fadzli [5] where the maximum magnitude for subduction and fault zones are 9.24 and 7.7, respectively.

2.3 PGA (Peak Ground Acceleration)

PGA is a measure of earthquake intensity. According to Sokolov [14], the PGA is strictly depending on earthquake magnitude, distance and local geological condition. The high peak acceleration gives more destructive effect than lower peak acceleration, with percentage of structure damages depending on the period of PGA. According to Fadzli [5], the attenuation relations relate the peak ground acceleration is important parameters in seismic hazard analysis.

In order to study the effect of earthquake to building in Malaysia, the first step is to establish the PGA where the derivations of PGA are based on attenuation relationship. Adnan et al. [6] stated that the appropriate attenuation function is the basic fundamental to perform seismic hazard analysis. Numbers of previous researcher are developing the response spectral attenuation relationships for Peninsular Malaysia, therefore this study was conducted in order to make

suggestion on the best attenuation relationship that suitable to use in order to develop the design response spectra for specific location in Kuala Lumpur.

Due to lack of attenuation relations developed for the distant earthquakes for Peninsular Malaysia, far distant attenuation functions were chosen in prediction of PGA value in this study (at study area). According to Adnan et al. [6], Peninsular Malaysia is affected seismically by far field earthquake events from Sumatra fault or Sumatra subduction, therefore the selection of the attenuation relationship should consider the effects of far field earthquakes from Sumatra.

In this study four selected attenuation relations were used for Sumatran subduction zone namely Megawati et al. [2], Lam et al. [7], Adnan et al. [6] and Petersen et al. [8], while Megawati et al. [10], Lam et al. [7] and Campbell [9] were applied in Sumatran fault zone.

As suggested by Fahmy [1], comparison between prediction values of PGA and the measured peak ground acceleration values recorded by seismology stations in Malaysia were carried out in this study. This is because to select the most suitable attenuation model to be used for the development of the RSA on the soil surface at the study area. The measured PGA data from seismometers were collected from Malaysia Meteorological Service [15]. The comparisons were done by looking to the percentage different DP% between both values using Eq. (1) [1].

$$DP\% = \left(\frac{\text{Predicted PGA} - \text{Measured PGA}}{\text{Measured PGA}} \right) \times 100 \quad (1)$$

Where DP% is percentage of different and measured, PGA is the peak ground acceleration recorded by the seismometers in positive value.

The attenuation relations for each subduction and fault zone that produced the lowest percentage of DP% with positive values were then chosen as the appropriate or suitable attenuation relationship used for the study area.

2.4 Design Response Spectra

The design response spectra is typically the starting point of most codified seismic design and assessment procedures and is predominantly used to prescribe the applied inertia forces induced by earthquake ground motions [16]. Design response spectra representing the response spectrum of acceleration, in which the RSA is used as an input [5]. In this study, NERA program was used to develop RSA (response spectra of acceleration) for the specific location in study area where the results from soil data analysis are used as an input parameter in generated the RSA before the design response spectra based on available code can be developed. Besides that, the determination of AF (amplification factor) and site classification also involved in development of design response spectra in study area. In this study, the results from soil data analysis such as value of unit weight was taken from Coduto [17] and shear wave velocity was determine based on empirical equations from Ohta and Goto [18], as shown in Eq. (2).

$$V_S = 85.3 N^{0.341} \quad (2)$$

where, V_S is shear wave velocity and N is value of soil penetration.

In order to determine the site classification (based on NEHRP 2000 Provision/UBC 97 site classification) and amplification factor in study area, Eqs. (3) and (4) as follows are used, respectively:

$$v_s = \frac{\sum_{i=1}^n d_i}{\sum_{i=1}^n \frac{d_i}{v_{si}}} \quad (3)$$

$$\sum_{i=1}^n d_i \text{ is equal to } 30 \text{ m}$$

where, v_{si} is the shear wave velocity in m/s and d_i is the thickness of any layer between 0 to 30 m from surface.

$$\text{Amplification factor} = \frac{PSA}{PGA} \quad (4)$$

where, PSA is peak surface acceleration and PGA is peak ground of acceleration of the bedrock.

Uniform Building Codes 1997 or known as (UBC 97) are used in this study in order to determine the response spectra in study area.

3. Results

Results obtained throughout this research are presented into two phases accordingly which are Phase 1: PGA (peak ground acceleration) and Phase 2: Design response spectra

3.1 Phase 1: PGA

According to Table 1, it can be seen that the PGA values for subduction zone ranged from 0.0172 g to 0.0695 g while for fault zone ranged from 0.0187 g to 0.0314 g. Petersen et al. [8] (for subduction zone) and Megawati et al. [10] (for fault zone) attenuation relationships were taken as the most appropriate attenuation model for this study based on the capability of the equations to predict the PGA values which were closest to the measured PGA recorded by Malaysian Meteorological Service. Therefore, PGA values of 0.0172 g and 0.0187 g were selected for subduction and fault zone respectively in this study. The maximum value of PGA (0.0187 g) is taken as proposed PGA value that will be used for further analysis in phase 2 of this study.

3.2 Phase 2: Design Response Spectra

Results obtained in this phase are summarized in table form as follows:

It is found that most of study locations soil classified into S_D (Table 2). By referring to Table 3, Bandar petaling Jaya was found to be in critical condition with maximum AF 3.74 for stiff soil and Mutiara Damansara with AF of 2.67 for S_D . The peak RSA (response spectrum acceleration) of 0.30 g (S_D) for

Table 1 Summary of PGA values for subduction and fault zone based on various attenuation relationship.

Zone	Attenuation	PGA (g)
Subduction	Megawati et al. [2]	0.0695
	Lam et al. [7]	0.0564
	Adnan et al. [6]	0.0259
	Petersen et al. [8]	0.0172
Fault	Megawati et al. [10]	0.0187
	Lam et al. [7]	0.0558
	Campbell [9]	0.0314

Table 2 Summary of data site classification for study location.

Locations	Borelog	Site classification				
		S_A	S_B	S_C	S_D	S_E
Bandar Puteri Puchong	10	-	-	-	10	-
Mutiara Damansara	10	-	-	1	9	-
Bandar Petaling Jaya	8	-	-	1	7	-

Table 3 Summary of AF results.

Locations	AF	
	S_C	S_D
Bandar Puteri Puchong	-	2.67
Mutiara Damansara	2.67	3.74
Bandar Petaling Jaya	2.14	3.74

Table 4 Summary of proposed design response spectra for each site.

Locations	S_C		S_D	
	Peak of RSA (g)	Period range (s)	Peak of RSA (g)	Period range (s)
Bandar Puteri Puchong	-	-	0.18	0.09-0.47
Mutiara Damansara	0.25	0.07-0.35	0.23	0.12-0.59
Bandar Petaling Jaya	0.23	0.08-0.38	0.30	0.10-0.52

Bandar Petaling Jaya has been found as the highest value of *RSA* with period range of 0.10 s to 0.52 s and peak *RSA* of 0.25 g (S_C) at period range 0.07 to 0.35 seconds for Mutiara Damansara (Table 4). The long period range about 0.47 s with peak *RSA* 0.23 g (S_D) show by Mutiara Damansara.

4. Conclusions

Based on the development of design response spectra based on various attenuation relationships at specific location in this study, it can be concluded S_D has a long range of period at peak spectral acceleration compared to S_C , where out of three locations, Mutiara Damansara has a longer periods at 0.12 s to 0.59 s for peak spectral acceleration of 0.32 g which is classified as stiff soil. All these values are important in analyze the structural design of building that has a period of vibration at this range of period which is particularly for building at all three locations in this study namely, Bandar Puteri Puchong, Mutiara Damansara and

Bandar Petaling Jaya.

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