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Earthquake Resistance School Building Using Peninsular Malaysia Bedrock Response Spectrum

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Abstract. Response spectrum is a very useful tool in earthquake engineering for estimating the performance of structures. In this research, attenuation equation will be used to find the response spectrum of bedrock to predict reliable and more accurate ground motions as far 700 km from potential earthquake sources. School building can be made to resist earthquake using the data of this response spectrum. According to historical records, the earthquakes that influenced Peninsular Malaysia are originated from two earthquake faults: the Sumatra subduction zone and Sumatra great fault zone. The worst earthquake ever occurred in Sumatra subduction zone is identified as Mw = 9.11 and Mw = 7.81 for Sumatra fault zone. These data were then used to predict the response spectrum of bedrock in Malaysia using Probabilistic Seismic Hazard Analysis (PSHA). The response spectrum data accumulated is then use to study on the performance of the school building during earthquake. Analysis of building shows that the values of moment for combination load 2 increases about 15.07 percents for column 1 and approximately 4.70 percents for beam 2. Based on the results, the resultant forces of school building during earthquake loadings are larger than without earthquake loading.

Introduction

Despite being located on the stable part of the Eurasian Plate, buildings on the surface of Peninsular Malaysia were occasionally subjected to tremors due to far-field effects from earthquake in Sumatra [1]. For the past few years, several tremors were felt by tall buildings residents in Kuala Lumpur due to large earthquake in Sumatra. The mechanism for such tremors is illustrated in Figure 1.

The seismic waves, generated from an earthquake in Sumatra, travelled long distance before they reach the bedrock of Malaysia. The high frequency earthquake waves were damped out rapidly in the propagation process while the low frequency waves were able to travel long distance as these long period waves are more robust to energy dissipation.

Thus the seismic waves at bedrock of Malaysia Peninsula are rich in long period waves. Additionally, these waves would be significantly amplified due to resonance effects when they propagate upward through the soft soil sites with a period close to the predominant period of the seismic waves. The amplified waves cause resonance in buildings with a natural period close to the period of the site, and the resulting motions of buildings are large enough to be felt by the residence [2].

Malaysia is located in the stable Sunda Shelf with low to moderate seismic activity level, surrounded by Indonesia and the Philippines, which are close to active seismic faults. The fact that Malaysia has not experienced any major earthquake disasters should not be used as an argument to dismiss the need for taking any pro-active steps to look into the earthquake threat. The main objective of this research are as follow;- (1) to identify suitable attenuation equation; (2) to find response spectrum of bedrock, and; (3) to find performance of building with different response spectrum.

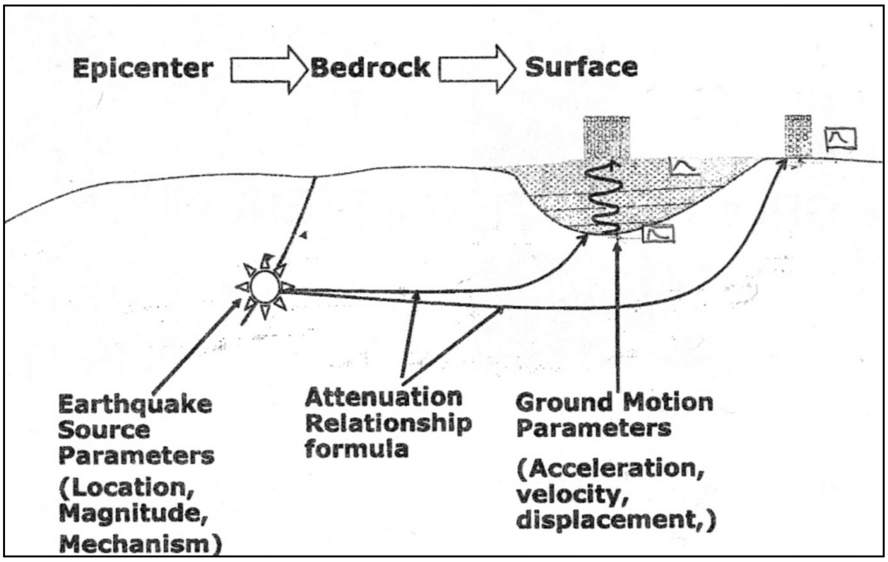

Figure 1 Schematic illustration of wave propagation through engineering bedrock and soil surface [3]

Methodology

This research consisted of four main steps. The first step was collecting data and design specification for reinforced concrete building. This included finding the detailing drawing for standard schools built in Malaysia. The collection of related information on potential seismic risks in the region as well as related research works done by others researchers were emphasized in this stage.

The next stages were collecting and reviewing of appropriate attenuation equation. This formula, also known as ground motion relation, is a simple mathematical model that relates a ground motion parameter (i.e. spectral acceleration, velocity and displacement) to earthquake source parameter (i.e. magnitude, source to site distance, mechanism) and local site condition [4]. It is considered one of the critical factors in seismic hazard analysis. There has been a number of attenuation relations derived in the last two decades since the record of ground motions are becoming more available. In general, they are categorized according to tectonic environment (i.e. subduction zone and shallow crustal earthquakes) and site condition as shown in Table 1.

After finding out the suitable attenuation equation, the probabilistic seismic hazard analysis (PSHA) method was carried out to predict ground motion in Malaysia from Sumatra earthquake sources. The method has allowed uncertainties in the size, location and rate of recurrence of earthquakes and in the variation of ground motion characteristics with earthquake size and location to be explicitly considered in the evaluation of seismic [5]. The results from this method will be the response spectrum of the bedrock in Malaysia.

The Finite Element Modelling (FEM) was used in this research to investigate the seismic performance of building structure. Commercial FEM computer software SAP2000 was used to carry out both static and dynamic linear analysis respectively. The input loading for seismic analysis will be the response spectrum of bedrock with different mechanism's and locations. Table 2 shows the combination loads used in the structural analysis. Combination load 1 only consisted of dead load and live load acting on the superstructure, while combination load 2 would be the same as load 1 but with addition of bedrock response spectrum for dynamic analysis. The results of shear force, axial force and moment were compared to investigate the performance of the building.

Table 1 Table of several worldwide attenuation functions

Model	Calculated	Site Condition	Range	
			R (km)	M_w
Western North America				
Abraham and Silva (1997)	PHA, PVA, S_{ah}, S_{av}	Rock, Deep Soil	0 – 100	4.0 – 8.0
Boore et al. (1997)	PHA, S_{ah}	V_s in upper 30m	0 – 80	5.5 – 7.5
Campbell (1997)	PHA, PVA, PHV, PVV, S_{ah}, S_{av}	Hard Rock, Soft Rock, Soil	0 – 100	4.0 – 9.5
Sadigh et al. (1997)	PHA, S_{ah},	Rock, Deep Soil	0 – 100	4.0 – 8.0
Sadigh and Egan (1998)	PHA, PHV, PHD	Rock, Soil	0 – 100	4.0 – 8.0
Central and Eastern North America				
Atkinson and Boore (1997)	PHA, S_{ah}	Rock	10 – 300	4.0 – 9.5
Toro et al. (1997)	PHA, S_{ah}	Rock	1 – 100	5.0 – 8.0
Campbell (2003)	PHA, S_{ah}	Rock	1 – 1000	5.0 – 8.0
Subduction Zones				
Youngs et al. (1997)	PHA, S_{ah}	Rock, Soil	0 – 100	4.0 – 9.5
Petersen (2004)	PHA	Rock	>200	4.0 – 9.5
Azlan et al. (2005)	PHA	Rock	2 – 1000	5.0 – 8.5
Source : International Seismological Center, Online Bulletin, http://www.isc.ac.uk/Bull, *International Seismology Center, Thatcham, United Kingdom*				

Table 2 Combination loads

Combination Load	Dead Load	Live Load	Response Spectrum
1	√	√	
2	√	√	√

Result And Analysis

The data sources of earthquake for this research were taken from Off the West Coast of Northern Sumatra and Southern Sumatra with magnitude 9.11 for subduction zone and 7.81 for fault zone. The distances between source of subduction zone to Kuala Lumpur and Pulau Pinang are approximately 620km and 550km respectively, while the distance between sources of fault zone to Kuala Lumpur is around 340km and 620km to Pulau Pinang. Response spectrums in these locations were defined by PSHA method with the mentioned distances. Most of the attenuation equations are suitable for distance from source to location below 200 km. hence, the suitable attenuation equation from Campbell (2003) and Peterson (2004) because the closest location from Sumatra to Malaysia is approximately 340km.

Table 3 shows the maximum PGA with different location and mechanism as well as the maximum values for fault zone with 90 gals for Kuala Lumpur and 58.33 gals for Pulau Pinang. In the present study, macrozonation maps for Peninsular Malaysia shows that the peak ground acceleration (PGA) for Kuala Lumpur ranges from 60 gals to 100 gals. Meanwhile, the PGA for Pulau Pinang falls between 40 gals to 60 gals. The results obtained were compared with previous research in figure 4, and it was found that the response spectrums calculated are within the range for 500-year return period events. The figure 2 and figure 3 will be used as input data to analyze four-storey school building by using SAP2000.

Table 3 Maximum value for response spectrum

Type of Mechanism	Location	Response spectrum (gals)
Subduction Zone (Megathrust)	Kuala Lumpur Pulau Pinang	67 57.5
Subduction Zone (Benioff)	Kuala Lumpur Pulau Pinang	60 47.78
Fault Zone	Kuala Lumpur Pulau Pinang	90 58.33

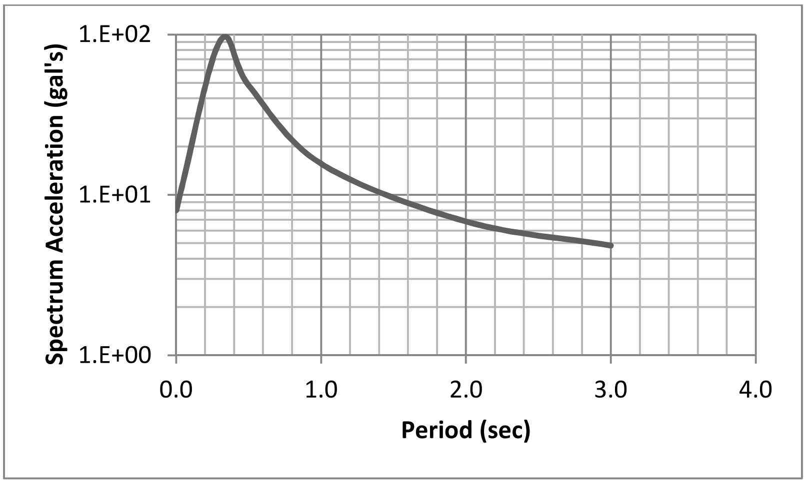

Figure 2: Response Spectrum for fault zone Location in Kuala Lumpur

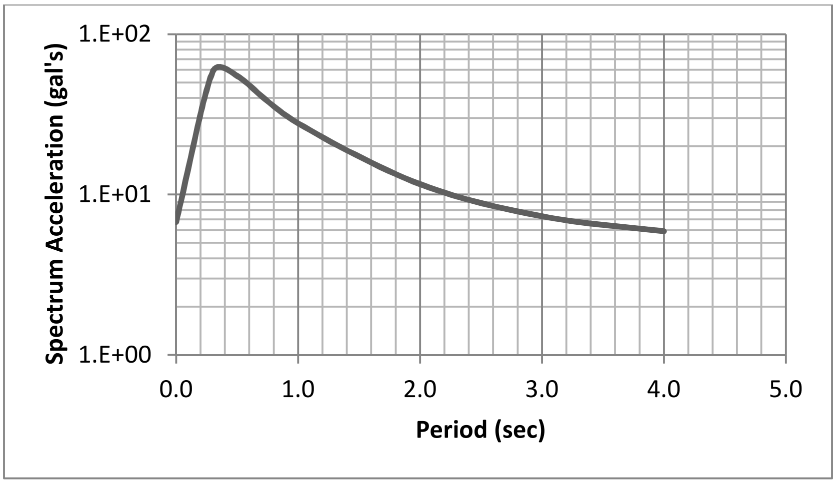

Figure 3: Response Spectrum for fault zone location in Pulau Pinang

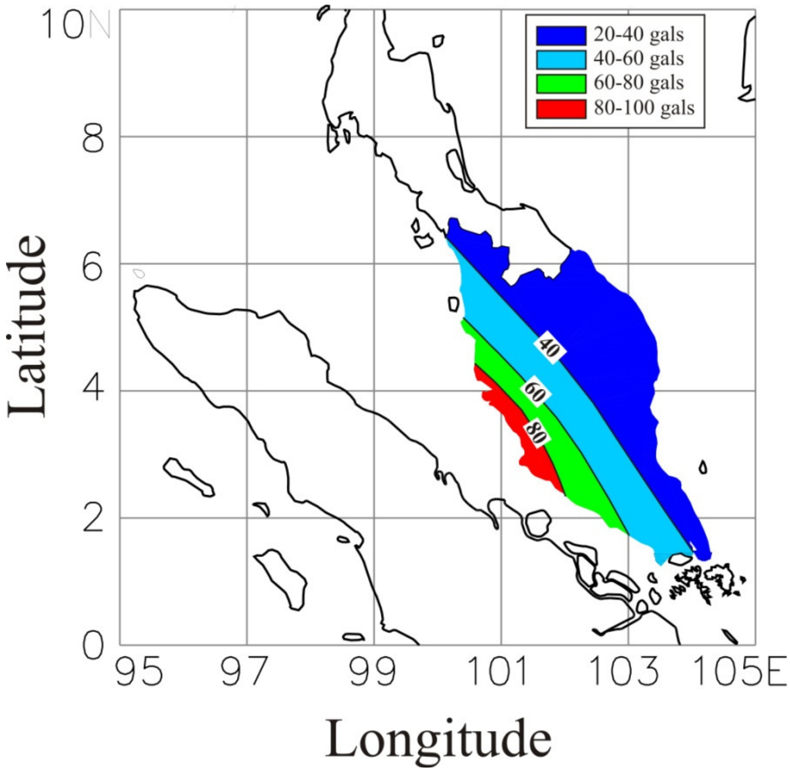

Figure 4: Macrozonation map for the Peninsular Malaysia (T_R=500year).

Table 4 Results for Shear Force and Moment with different mechanisms, locations, loadings and capacity.

TYPE	Combination Load 1		Combination Load 2		Capacity	
	Shear Force/Axial Force (kN)	Moment (kNm)	Shear Force (kN)	Moment (kNm)	Shear Force (kN)	Moment (kNm)
Subduction (Megathrust) location in Kuala Lumpur						
Column 1	935.70	33.45	942.52	38.32	1761	129
Column 2	637.89	48.41	641.97	53.55	1761	129
Column 3	339.21	46.69	341.00	50.05	1407	110
Column 4	41.02	30.32	41.43	31.71	1153	61
Beam 1	161.95	178.87	164.68	188.89	324	296
Beam 2	162.81	189.18	165.09	197.77	324	296
Beam 3	162.33	177.28	163.70	182.40	324	296
Beam 4	7.65	14.24	8.05	15.76	156	135.68
Subduction (Megathrust) location in Pulau Pinang						
Column 1	935.70	33.45	941.45	26.83	1761	129
Column 2	637.89	48.41	641.33	52.74	1761	129
Column 3	339.21	46.69	340.73	49.53	1407	110
Column 4	41.02	30.32	41.36	31.50	1153	61
Beam 1	161.95	178.87	164.25	187.32	324	296
Beam 2	162.81	189.18	164.74	196.43	324	296
Beam 3	162.33	177.28	163.49	181.60	324	296
Beam 4	7.65	14.24	7.99	15.52	156	135.68
Subduction (Benioff) location in Kuala Lumpur						
Column 1	935.70	33.45	941.72	37.75	1761	129
Column 2	637.89	48.41	641.50	52.95	1761	129
Column 3	339.21	46.69	340.80	49.66	1407	110
Column 4	41.02	30.32	41.38	31.55	1153	61

Beam 1	161.95	178.87	164.36	187.72	324	296
Beam 2	162.81	189.18	164.83	196.77	324	296
Beam 3	162.33	177.28	163.54	181.80	324	296
Beam 4	7.65	14.24	8.00	15.58	156	135.68
Subduction (Benioff) location in Pulau Pinang						
Column 1	935.70	33.45	940.60	36.95	1761	129
Column 2	637.89	48.41	640.82	52.10	1761	129
Column 3	339.21	46.69	340.50	52.63	1407	110
Column 4	41.02	30.32	41.31	31.32	1153	61
Beam 1	161.95	178.87	163.91	186.06	324	296
Beam 2	162.81	189.18	164.45	195.35	324	296
Beam 3	162.33	177.28	163.31	180.96	324	296
Beam 4	7.65	14.24	7.94	15.33	156	135.68
Fault Zone location in Kuala Lumpur						
Column 1	935.70	33.45	942.75	38.49	1761	129
Column 2	637.89	48.41	642.11	53.72	1761	129
Column 3	339.21	46.69	341.07	53.81	1407	110
Column 4	41.02	30.32	41.44	31.77	1153	61
Beam 1	161.95	178.87	164.77	189.22	324	296
Beam 2	162.81	189.18	165.17	198.06	324	296
Beam 3	162.33	177.28	163.75	182.59	324	296
Beam 4	7.65	14.24	8.07	15.82	156	135.68
Fault Zone location in Pulau Pinang						
Column 1	935.70	33.45	941.82	37.82	1761	129
Column 2	637.89	48.41	641.55	53.02	1761	129
Column 3	339.21	46.69	340.82	53.30	1407	110
Column 4	41.02	30.32	41.38	31.56	1153	61
Beam 1	161.95	178.87	164.40	187.86	324	296
Beam 2	162.81	189.18	164.86	196.88	324	296
Beam 3	162.33	177.28	163.56	181.87	324	296
Beam 4	7.65	14.24	8.01	15.59	156	135.68

The school building was modeled as plan two-dimensional structure. The base support and connection between beam and column were modeled as rigid. The main materials of the structures were concrete and steel bar reinforcement. The loading for the structure will be calculated referring to BS8110 bases on materials, dimension of the structures and type of usage of the structures.

Six different seismic loading in different locations and mechanisms has been imposed on the structure to analyze the behavior of the structure. The analysis has been done to:

(i) Find the shear force, axial load and moment of the beams and columns for each floor.

(ii) Compare the shear force, axial load, moment with the capacity of the building.

Table 4 shows the results for axial load, shear force and moment with different mechanisms, locations, loadings and capacity of the school building with each floor. The maximum values for the axial load and shear force of the structures shows that the column 1 and beam 2 are higher values for all mechanism's and locations. Kuala Lumpur with fault zone shows that the column 1 for combination load 1 is 935.70kN, and combination load 2 is 942.75kN and capacity is 1761kN. The values beam 2 for combination load 1 is 162.81kN, combination load 2 is 165.17kN and capacity is 324kN. These values show that the structural responses for both combination 1 and combination 2 are within the capacity level (figure 5) of the corresponding structural elements.

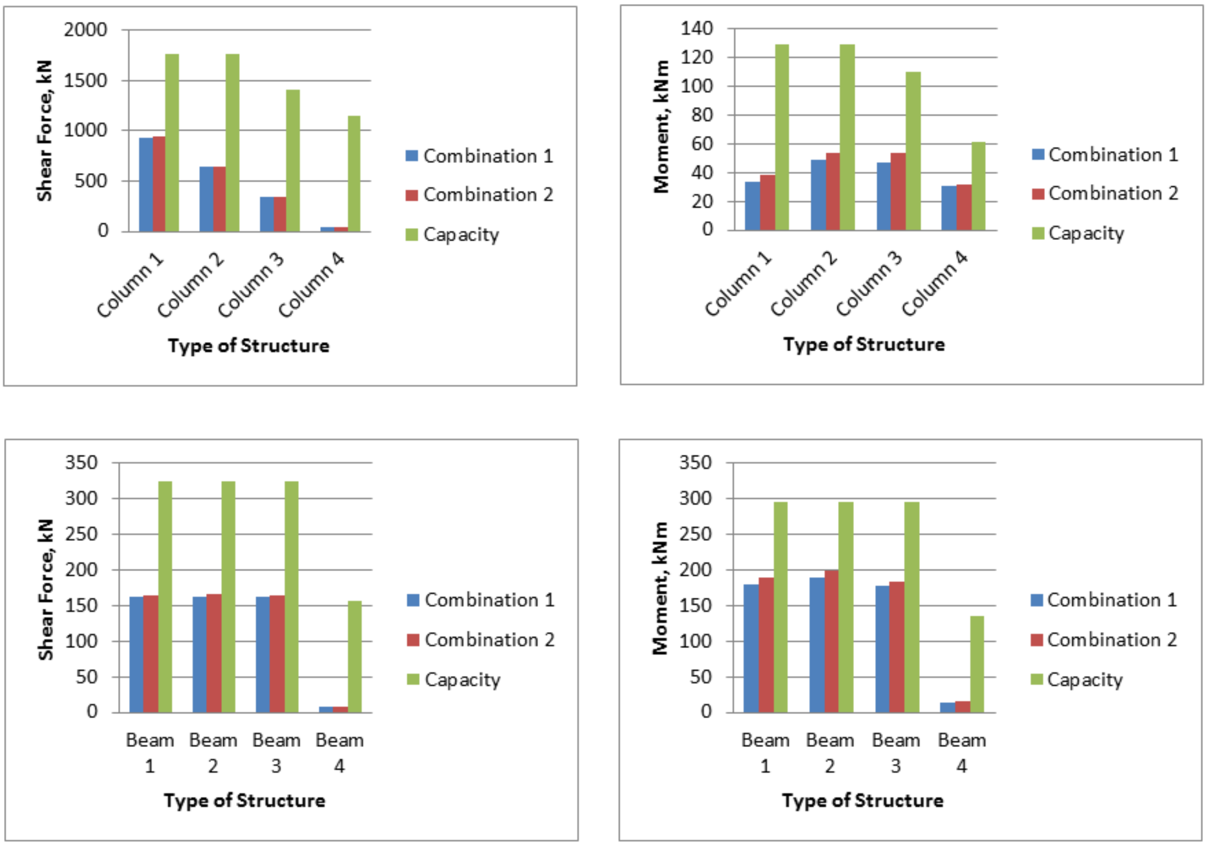

Figure 5: Shear Force and Moment at columns and beams for fault zone in Kuala Lumpur

Conclusion

From the research, the suitable attenuation for distance more than 200km from sources Sumatra Subduction zone and Sumatra Fault zone to location Kuala Lumpur and Pulau Pinang are Campbell (2003) and Petersen (2004). The result of PGA on bedrock for each mechanisms and site locations are acceptable if compare with the previous researcher. The maximum value is 90 gals for mechanism fault zone and the site location Kuala Lumpur while Pulau Pinang 58.33 gals. The source location is Bengkulu, Southern Sumatra to Malaysia are very close compare to others mechanism.

The performance of building with different combination loads and response spectrum on bedrock would affect the shear force, axial force and moment values of the structural elements. The axial force of structure for column 1 in Kuala Lumpur with fault zone mechanism, increases about 0.75 percents while shear force for beam 2, it increases by 1.4 percents. The moment reaction of column 1 increases about 15.07 percents while the moment for beam 2 increases approximately by 4.70 percents. However, the results for both combination loads are still within the capacity level of the structure.

The possible factors that affect the result for this research are (1) the ground motion should consider the soils layers and (2) for more accurate analysis, the structure should be analyzed in nonlinear analysis.

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