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Research paper

Investigating Earthquake Resistance School Building in Peninsular Malaysia

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Abstract

The data sources of earthquake from Off the West Coast of Northern Sumatra and Southern Sumatra with magnitude 9.11 for subduction zone and 7.81 for fault zone were investigated. Based on the previous record, 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 purpose of this paper is mainly to identify attenuation equation and response spectrum of bedrock, and to determine performance of building with different response spectrum. Most of the attenuation equations are suitable for distance from source to location below 200 km. The attenuation equations were applied to the data obtained from on the closest location from Sumatra to Malaysia is approximately 340km. Based on the analysis, 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 in Kuala Lumpur with fault zone mechanism, increases about 0.75 percent while shear force for beam 2, it increases by 1.4 percent. The moment reaction increases about 15.07 percents while the moment for increases approximately by 4.70 percent. 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 the ground motion should consider the soils layers and for more accurate analysis, the structure should be analyzed in nonlinear analysis.

Keywords: *Earthquake, seismic waves, attenuation equation, ground motion parameters.*

1. Introduction

Buildings on the surface of Peninsular Malaysia were occasionally be affected by tremors because of far-field effects from earthquake occurred in Sumatra [1]. This is due to its location of the Eurasian Plate, Based on past few years, several tremors were experienced by highrise building residents in Kuala Lumpur area caused by serious earthquake incident in Sumatra. The structure and formation of the tremors is illustrated in Figure 1. On Aug 13, 2017, Minor tremors following the earthquake in Sumatra were felt in several places in Johor Baru. According to a Fire and Rescue Department (JBPM) spokesman, so far, three reports on tremors were received, namely at the Inland Revenue Board (LHDN) building in Jalan Padi Emas 1, Menara Kastam in Jalan Tun Razak and Menara Tabung Haji at Jalan Ayer Molek. However, no injuries or cracks to buildings were reported. Meanwhile, about 400 LHDN staff and the public at the LHDN office were shocked when they were directed out of the building at 11.10am.
Based on analysis, 40 tremors were recorded in Malaysia since the end of 2007. The evidence was that 37 of these seismic incidences occurred along a fault line in Bentong, Pahang. The three others recorded were in Manjung in Perak and Jerantut in Pahang. According to Dr Rosaidi Che Abas, the Meterological Department director indicated that from November 2007 until May last year, Bentong has recorded more than 29 cases of tremors, this phenomenon also called as temblors. The latest tremors were recorded last Oct 8 where there were eight from 4.45am to 12.05pm measuring between 1.1 and 2.8 on the Richter scale. All these tremors were detected at Bukit Tinggi and Janda Baik, along a fault line 15km wide and 70km long. Also, the Meteorological Department detected one strong tremor of 3.5 magnitude on the Richter scale.

Based on analysis, the seismic waves generated from 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.

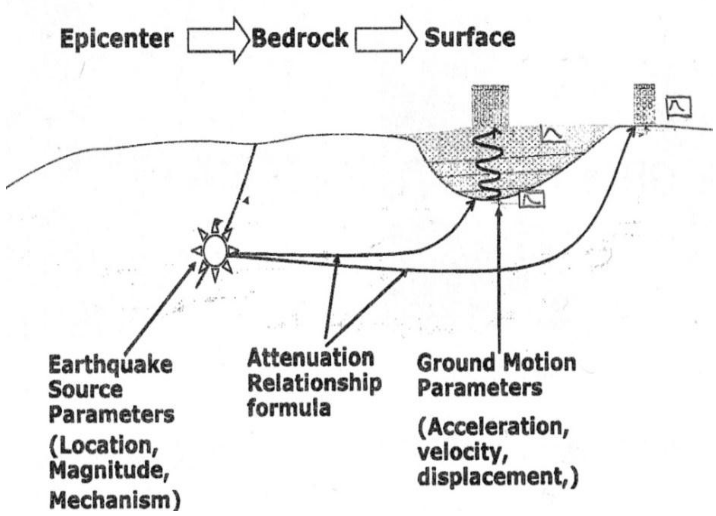

Figure 1: The illustration of wave propagation through soil surface and engineering bedrock [4].

2. Literature Review

Seismic analysis [7] is a subset of structural analysis and is the calculation of the response of a building (or nonbuilding) structure to earthquakes. It is part of the process of structural design, earthquake engineering or structural assessment and retrofit (see structural engineering) in regions where earthquakes are prevalent. A building has the potential to 'wave' back and forth during an earthquake (or even a severe wind storm). This is called the 'fundamental mode', and is the lowest frequency of building response. Most buildings, however, have higher modes of response, which are uniquely activated during earthquakes. The figure just shows the second mode, but there are higher 'shimmy' (abnormal vibration) modes. Nevertheless, the first and second modes tend to cause the most damage in most cases.

The earliest provisions for seismic resistance were the requirement to design for a lateral force equal to a proportion of the building weight (applied at each floor level). This approach was adopted in the appendix of the 1927 Uniform Building Code (UBC), which was used on the west coast of the United States. It later became clear that the dynamic properties of the structure affected the loads generated during an earthquake. In the Los Angeles County Building Code of 1943 a provision to vary the load based on the number of floor levels was adopted (based on research carried out at Caltech in collaboration with Stanford University and the U.S. Coast and Geodetic Survey, which started in 1937). The concept of "response spectra" was developed in the 1930s, but it wasn't until 1952 that a joint committee of the San Francisco Section of the ASCE and the Structural Engineers Association of Northern California (SEAONC) proposed using the building period (the inverse of the frequency) to determine lateral forces.[1]

The University of California, Berkeley was an early base for computer-based seismic analysis of structures, led by Professor Ray Clough(who coined the term finite element[2]). Students included Ed Wilson, who went on to write the program SAP in 1970,[3] an early "finite element analysis" program.

Earthquake engineering has developed a lot since the early days, and some of the more complex designs now use special earthquake protective elements either just in the foundation (base isolation) or distributed throughout the structure. Analyzing these types of structures requires specialized explicit finite element computer code, which divides time into very small slices and models the actual physics, much like common video games often have "physics engines". Very large and complex buildings can be modeled in this way (such as the Osaka International Convention Center).

Equivalent static analysis [12] defines a series of forces acting on a building to represent the effect of earthquake ground motion, typically defined by a seismic design response spectrum. It assumes that the building responds in its fundamental mode. For this to be true, the building must be low-rise and must not twist significantly when the ground moves. The response is read from a design response spectrum, given the natural frequency of the building (either calculated or defined by the building code). The applicability of this method is extended in many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to "yielding" of the structure, many codes apply modification factors that reduce the design forces (e.g. force reduction factors).

Nonlinear dynamic analysis [8-11] utilizes the combination of ground motion records with a detailed structural model, therefore is capable of producing results with relatively low uncertainty. In nonlinear dynamic analyses, the detailed structural model subjected to a ground-motion record produces estimates of component deformations for each degree of freedom in the model and the modal responses are combined using schemes such as the square-root-sum-of-squares [13-20].

In non-linear dynamic analysis, the non-linear properties of the structure are considered as part of a time domain analysis. This approach is the most rigorous, and is required by some building codes for buildings of unusual configuration or of special importance. However, the calculated response can be very sensitive to the characteristics of the individual ground motion used as seismic input; therefore, several analyses are required using different ground motion records to achieve a reliable estimation of the probabilistic distribution of structural response. Since the properties of the seismic response depend on the intensity, or severity, of the seismic shaking, a comprehensive assessment calls for numerous nonlinear dynamic analyses at various levels of intensity to represent different possible earthquake scenarios. This has led to the emergence of methods like the incremental dynamic analysis.[4]

3. Methodology

In this research, various methodologies were conducted to identify the attenuation and response spectrum of bedrock. The performance of building with different response spectrum was investigated. First step, data and design specification were identified for reinforced concrete building. This has included finding the detailed 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[3]:

$$A(M_0, R, f) = E(M_0, f)\, D(R,f)\, P(f)\, I(f) \tag{1}$$

The term $E(M_0, f)$ is the earthquake source spectrum for a specified seismic moment (i.e., Fourier spectrum of the ground acceleration at a distance of 1km), and $D(R, f)$ is a diminution function that models the geometric and anelastic attenuation of the spectrum as a function of hypocentral distance (R) and frequency (f). The term $P(f)$ is a high-cut filter that rapidly reduces amplitudes at high frequencies; it may be based on either the f_{max} model or the kappa model. The $I(f)$ is a filter used to shape the spectrum to correspond to the particular ground-motion measure of interest. For example, for the computation of response I is the response of an oscillator to ground acceleration. For free-field ground-motion parameters, I is simply

$$I(f) = 1/(2\pi f)^P \tag{2}$$

where $P = 0$ for acceleration, 1 for velocity, or 2 for displacement.

The earthquake source spectrum $E(M_0, f)$ for the horizontal component of ground motion is given by a functional from that represents the addition of two Brune spectra:

$$E(M_0, f) = C(2\pi f)^2 M_0\{(1-\epsilon)/[1+(f/f_A)^2] + -\epsilon/[1+(f/f_B)^2]\} \tag{3}$$

where $C = R_p FV/(4\pi\rho\beta^3 R)$, with R = 1km, R_p= average radiation pattern (= 0.55), F = free-surface amplification (=2.0), V = partition onto two horizontal components (= 0.71), ρ = crustal density (=2.8 gm/cm^3), β = shear-wave velocity (= 3.8km/sec). The values for the crustal constants are based on the seismic reflection/refraction data for the average focal depth of events in the region (10km).

This formula, also known as ground motion relation, is a 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 [3]. 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 hazards [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.

4. Performance Analysis and Results

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 [3] and [5] 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 1: The attenuation functions and site condition

Model	Calculated	Site Condition	Range	
			R (km)	Mw
Western North America				
Abraham and Silva (1997)	PHA, PVA, Sah, Sav	Rock, Deep Soil	0 – 100	4.0 – 8.0
Boore et al. (1997)	PHA, Sah	Vs in upper 30m	0 – 80	5.5 – 7.5
Campbell (1997)	PHA, PVA, PHV, PVV, Sah, Sav	Hard Rock, Soft Rock, Soil	0 – 100	4.0 – 9.5
Sadigh et al. (1997)	PHA, Sah,	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, Sah	Rock	10 – 300	4.0 – 9.5
Toro et al. (1997)	PHA, Sah	Rock	1 – 100	5.0 – 8.0
Campbell (2003)	PHA, Sah	Rock	1 – 1000	5.0 – 8.0
Subduction Zones				
Youngs et al. (1997)	PHA, Sah	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 : InternationalSeismologycal Center, Online Bulliten, http://www.isc.ac.uk/Bull, International Seismology Center. Thatcham, United Kingdom				

Table 2: The Combination and update of loads

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

Table 3: Analysis on types of mechanism over 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

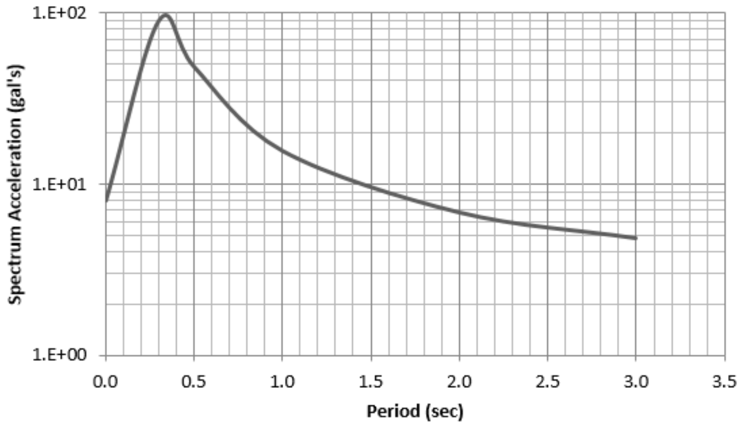

Figure 2: The spectrum acceleration analysis for Kuala Lumpur based fault zone

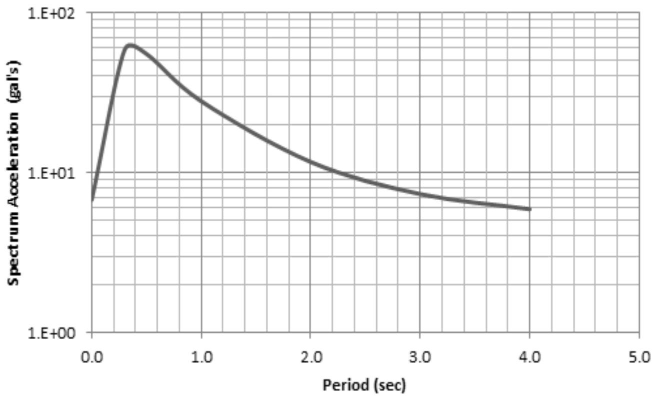

Figure 3: The spectrum acceleration analysis for fault zone in Pulau Pinang

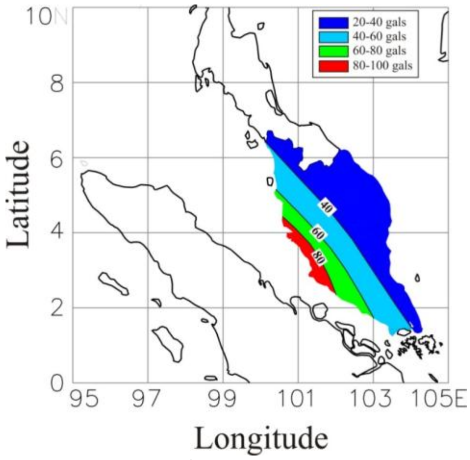

Figure 4: Macrozonation map for the Peninsular Malaysia (TR=500year).

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 loadings in different locations and mechanisms have been imposed on the structure to analyse the behavior of the structure. The analysis was designed to:

(i) Identity 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 3 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.

Table 4: Analyses on Shear Force and Moment with different mechanisms, locations, loadings and capacity.

Subduction (Megathrust) location in Kuala Lumpur						
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)
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

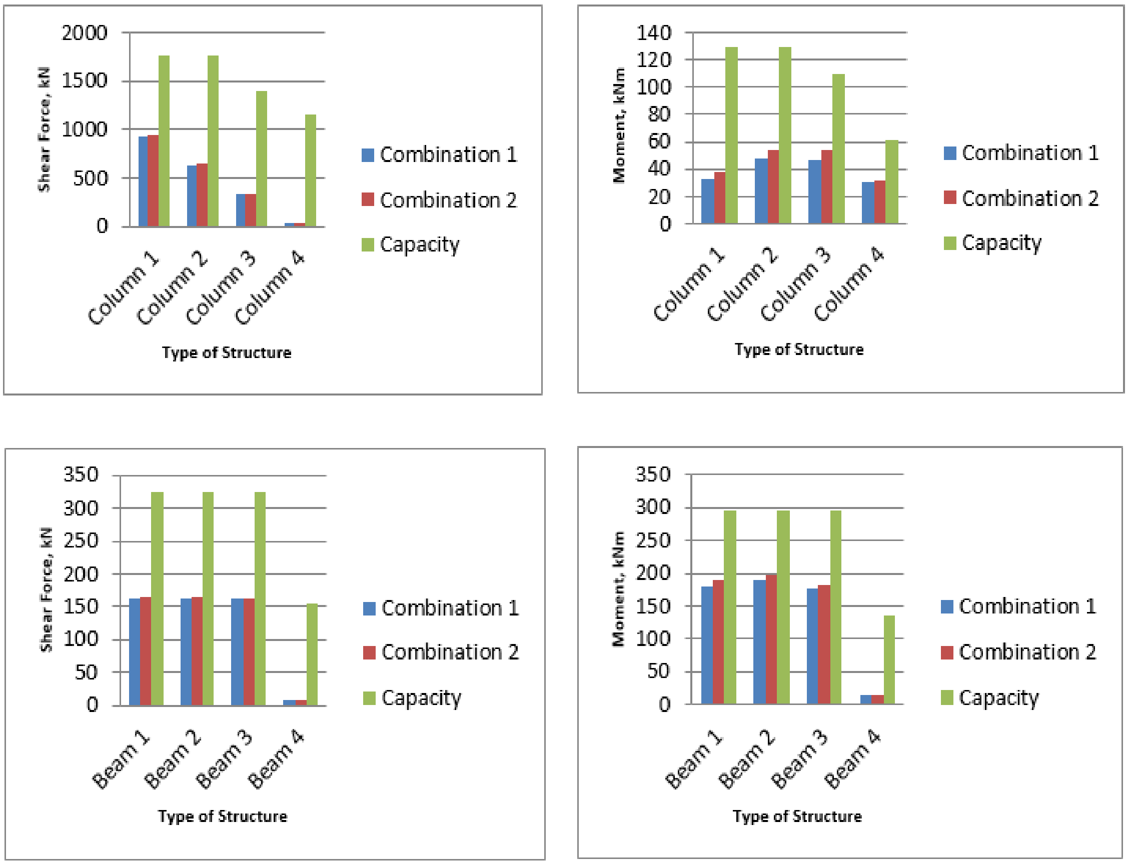

Figure 5: Analysis on Shear Force and Moment at columns and beams for Kuala Lumpur based fault zone.

5. Conclusion

Based on the research findings, 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 invesitigated. 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 non linear analysis.

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