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VULNERABILITY OF PUBLIC BUILDINGS SUBJECTED TO EARTHQUAKE BY FINITE ELEMENT MODELLING

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ABSTRACT: Tremors in Peninsular Malaysia and East Malaysia due to Sumatra and Philippine earthquakes have been reported several times. Engineers are concerned of the seismic vulnerability of public buildings due to lack of earthquake consideration in Malaysia's building design procedure. This study addresses the vulnerability of public buildings in Malaysia subjected to earthquakes from Sumatra and Philippines. A case study has been conducted on low rise to medium rise reinforced concrete buildings, which are mostly categorized as moment resisting frames. The buildings are analyzed using Finite Element Modeling (FEM) under different types of analyses including Free Vibration Analysis (FVA), and Time History Analysis (THA) considering low to medium earthquake intensities. The study indicates that more than 50% of the buildings produced dynamic amplification factors of slightly more than one indicating not much of a dynamic response to the buildings. The performances of the structure are shown by the yield point at beam-column connections where the internal forces at beam elements exceed the design capacity of the beams. In the non-linear analysis, the largest damage index is still under the intermediate level where no structural damage is indicated, but some non-structural damage are expected.

Keywords: Building vulnerability, seismic demand, dynamic analysis, non-linear analysis

1. INTRODUCTION

Public building structures in Malaysia include offices, apartment, hospitals, schools have been heavily developed for many states in the country. The performance of the structures against seismic hazard effects human safety, loss of properties and maintenance cost. Despite the fact that Malaysia is free from any major earthquake event, pro-active steps to determine the effect of this disaster to our buildings shouldn't be over looked. Though Malaysia is located in a stable tectonic plate, but being close to Sumatra and Philippines's subduction zones makes us subjected to earthquake risks at any time. The objectives of this research are to determine the structural behavior and vulnerability of our buildings under earthquake, and the maximum intensity load they can resist. These can then be used as a guideline in the future.

Finite element modeling and analysis has been used extensively to solve the complicated structural problems involving non-linear and dynamic problems. IDARC is used as the dynamic non-linear analysis software to analyse the structures. Different intensities of earthquake load are applied to the structures to know the maximum allowable earthquake load intensities for the buildings. The overall vulnerability of the structures can be known from the damage indices.

In order to analyse the seismic performance of the buildings, a single main frame was chosen from each building for the modeling in the finite element analysis. Table 1 shows the list of buildings analysed in this study.

The analyses were carried out using four intensities of seismic load, i.e. 0.05g, 0.10g, 0.15g, and 0.20g. Two types of analysis methods were applied to the model, (i) Free Vibration Analysis (FVA) (ii) Time History Analysis (THA). From the Free Vibration Analysis, the natural period, frequency, angular frequency, and mode shapes were determined. Ground motion data recorded from El-Centro Earthquake in 1940 was used in the Time History Analysis.

Table 1. List of buildings analyzed

No.	Building Name	Story	Height (m)
1	Jabatan Pendaftaran Negara (JPN) Putrajaya	9	43.4
2	Blok 3B, Pangsapuri Parcel 3, Precinct 9, Putrajaya	16	49.0
3	Kompleks Mahkamah Kuala Terengganu	10	36.4
4	Hospital Besar Kota Bharu	5	26.8
5	Mahkamah Syariah Labuan	5	25.2
6	Kuarters Bomba (Kelas F-Type B**)**	4	15.2
7	Kuartrers Kerajaaan Division II & III Kudat	4	14.5

2. FREE VIBRATION ANALYSIS

Free vibration analysis is needed to understand the character of the structures for dynamic impact. The natural periods and mode shapes are the most important factors to determine the dynamic characteristics. Table 2 shows that the dynamic parameter of the public buildings. By identifying those parameters as well as the periods of the earthquakes, the dynamic characteristic can be specified. The factors are calculated by finding the ratio between the periods of earthquakes and the natural periods of the structures. The formulas for damping ratio ξ , frequency ratio β and dynamic amplification factors D (Chopra, 2002) are shown as below:

$$D = \frac{1}{\sqrt{(1-\beta^2)^2 + (2\xi\beta)^2}} \tag{1}$$

Where ξ = C/Cr, (C is structure damping and Cr is critical damping). $\beta = \varpi/\omega$, where ϖ is the frequency of earthquake excitation and ω is the angular frequency of structure.

The plot of dynamic amplification equation is depicted in Figure 2. It shows that the resonance effects occur at beta = 1. If D is equal to 1 the response of structure in dynamic is equivalent to the static response. However if D is less than 1 there is no structural response to the earthquake load. The dynamic characteristic parameters for all buildings are listed in Table 2.

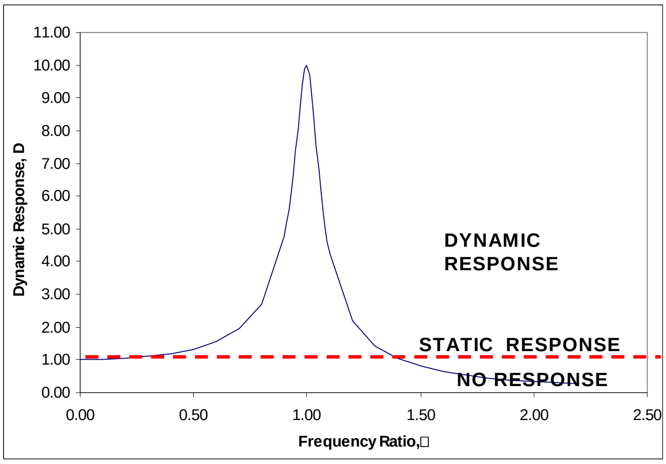


Fig 1. Dynamic amplification for structure (Chopra,2002)

Table 2. Dynamic characteristic parameter for the public buildings in Malaysia

Building Name	**Story**	**Time Period, *T* (sec.)**	**Frequency, *f* (Hz)**	**Angular Frequency, *ω* (rad)**
JPN Putrajaya	9	0.713	1.403	8.808
Block 3B Pangsapuri Putrajaya	16	0.8843	1.130	7.110
Hospital Besar Kota Bharu	5	0.686	1.457	9.156
Mahkamah Persekutuan Kuala Terengganu	10	0.75821	1.3189	8.2869
Mahkamah Syariah Labuan	5	0.525	1.904	11.964
Kuarters Kelas F Miri	4	0.467	2.139	13.442
Kuarters Kerajaaan Div. II & III Kudat	4	0.4170	2.3981	15.0678

Table 3. Dynamic amplification for buildings in Peninsular Malaysia

Site Buildings		**Epicentre**	**Distance (km)**	$\overline{T}$	$\varpi = \frac{2\pi}{\overline{T}}$	ω	$\beta = \frac{\varpi}{\omega}$	$D = \frac{1}{\sqrt{\left(1-\beta^2\right)^2 + \left(2\xi\beta\right)^2}}$
Mahkamah Kuala Terengganu	to	Acheh	825	3.02	2.08	8.29	0.25	1.07
		Nias	750	2.77	2.27	8.29	0.27	1.08
		Semangko	610	1.88	3.34	8.29	0.40	1.19
Blok 3B Kuarters Putrajaya	to	Acheh	625	2.36	2.66	7.11	0.37	1.16
		Nias	500	1.95	3.22	7.11	0.45	1.26
		Semangko	325	1.14	5.50	7.11	0.77	2.45
Jabatan Pendaftaran Negara Putrajaya	to	Acheh	625	2.36	2.66	8.81	0.30	1.10
		Nias	500	1.95	3.22	8.81	0.37	1.15
		Semangko	325	1.14	5.50	8.81	0.62	1.63
Hospital Besar Kota Bharu	to	Acheh	790	2.91	2.16	9.16	0.24	1.06
		Nias	700	2.61	2.41	9.16	0.26	1.07
		Semangko	575	1.79	3.51	9.16	0.38	1.17

Table 4. Dynamic amplification for buildings in East Malaysia

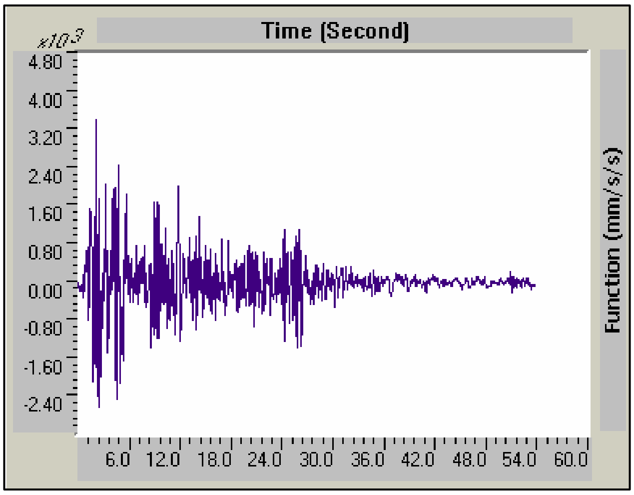
Site Buildings		Epicentre	Distance (km)	$\overline{T}$	$\varpi = \frac{2\pi}{\overline{T}}$	ω	$\beta = \frac{\varpi}{\omega}$	$D = \frac{1}{\sqrt{(1-\beta^2)^2 + (2\xi\beta)^2}}$
Mahkamah Labuan	to	Tawau	275	0.59	10.66	11.96	0.89	4.46
		Bintulu	430	0.81	7.79	11.96	0.65	1.73
Kuarters Kudat	to	Tawau	280	0.60	10.54	15.07	0.70	1.94
		Bintulu	490	0.89	7.06	15.07	0.47	1.28
Kuarters Miri	to	Tawau	475	0.87	7.23	13.44	0.54	1.40
		Bintulu	500	0.90	6.95	13.44	0.52	1.36

To study the impact of earthquake from local faults, several earthquake events originated from the sources had been considered namely; (i) Acheh (ii) Nias (iii) Semangko (iv) Tawau (v) Bintulu earthquakes. Table 3 show the dynamic amplification of the four buildings in Peninsular Malaysia with respect to three types of earthquakes (Acheh, Nias, Semangko) . The results show that the Quarters building in Putrajaya has the largest amplification factors of 2.45 due to Semangko earthquake. Whereas the JPN building in Putrajaya is having a factor of 1.63. Other buildings seem to behave statically under earthquake loads due to the factors of about 1.0. Table 4 listed the results of dynamic amplification factors for three buildings in east Malaysia where the highest value of dynamic factor belongs to Mahkamah building in Labuan with a factor of 4.46. The value suggest that the building suffers an impact of earthquake four times of the static equivalent load. Other buildings experience some amount of dynamic amplification because of the factors more than 1.2.

3. DYNAMIC NON-LINEAR ANALYSIS

3.1 Time History Ground Motion

Only one source of time history ground motion was used in the study. The El-Centro earthquake occurred in May 18, 1940 at Imperial Valley with magnitude 7.1 on the Richter Scale or 0.35g of ground acceleration. The acceleration is simulated to four different intensities, (i) 0.05g, (ii) 0.10g, (iii) 0.15g, and (iv) 0.20g, to match the Malaysian condition. The El-Centro time history data is shown in Figure 4.



Function name: El Centro
Number of points per lane: 8
Number of output time steps: 2688
Time step size: 0.02
Function Units: mm/s/s
Ground Acceleration: 0.35g
Function Scale Factor: 1
Min is –2.631E3 mm/s/s at 2.44sec
Max is 3.417 mm/s/s at 2.12 sec

Fig 4. Time History Record of Imperial Valley Earthquake (May 18,1940 – El Centro)

3.2 Modeling Concept

Figure 5 shows the plan view of the Hospital Besar Kota Bharu building comprises of Figure 6 shows the elevation view of the building. The two bay frames and five floor levels where the dimensions are 2@7.2 m and 6@4.3 m respectively. The size of the beams and columns are 600x600 mm and 300x600 mm respectively for all floor levels. The amount of the reinforcement in the frame element is 20Y32 for columns and 4Y25 at top as well as 3Y25 at bottom for beam element. The materials of the properties are 2500N/mm^2 (Ec), 460N/mm^2 (fy), 27.6 N/mm^2 (fc) and 25 mm for cover (c).The building configurations are shown in Table 5.

3.3 Plastic Hinge

The plastic hinges due to structural local failures normally occur either at beam or column connections for moment resisting frame type of buildings. Figure 7 shows the development of plastic hinge for the building with earthquake intensities vary from 0.05g to 0.02g. At 0.20g, the plastic hinge initially formed on the beam at the first floor and above. It started on beam connection at second floor t = 3.885 sec with 0.10g load intensity, followed other beams at second floor, first floor, and third floor and above until the beam connection at fifth floor at time 7.67 sec. as shown in Figure 7 (d).

The summary of the first development of plastic hings on the local structural element for each building in Malaysia is listed in Table 6. JPN building, Pangsapuri Putrajaya and Mahkamah Labuan developed local failure at beam elements due to the lowest earthquake intensity of (0.05g). It followed by Kuarters Kelas F Miri and Hospital Kota Bharu, with the 0.10g intensity. Mahkamah Kuala Terengganu and Kuarters Kudat are started to have local failure at 0.15g and 0.2g earthquake intensities respectively.

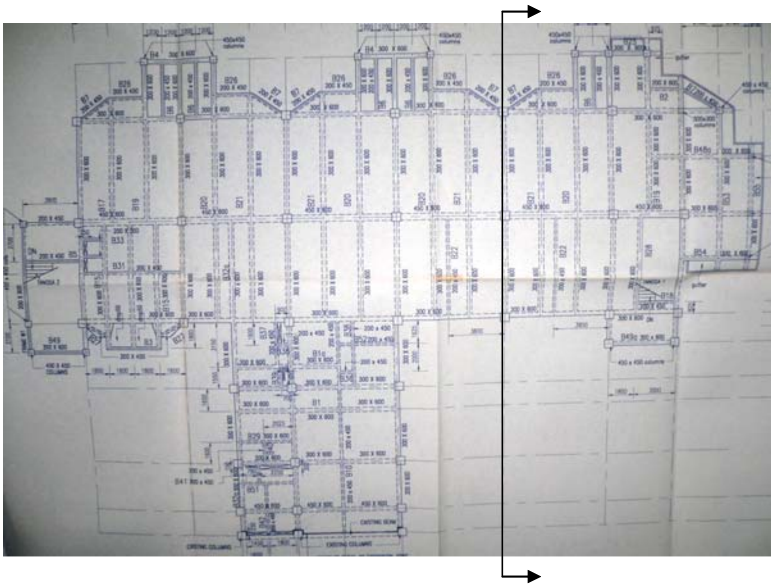


Fig 5. Frame 6/FF-DD of Hospital Kota Bharu building

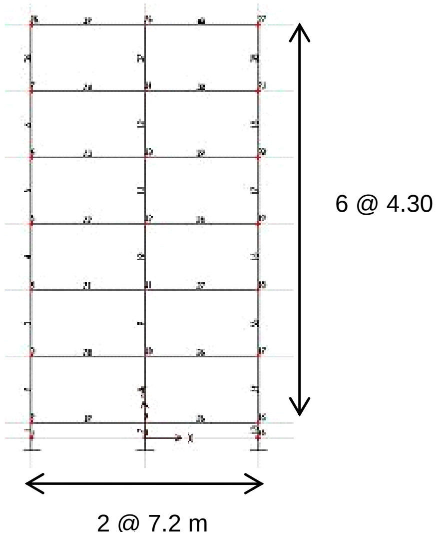
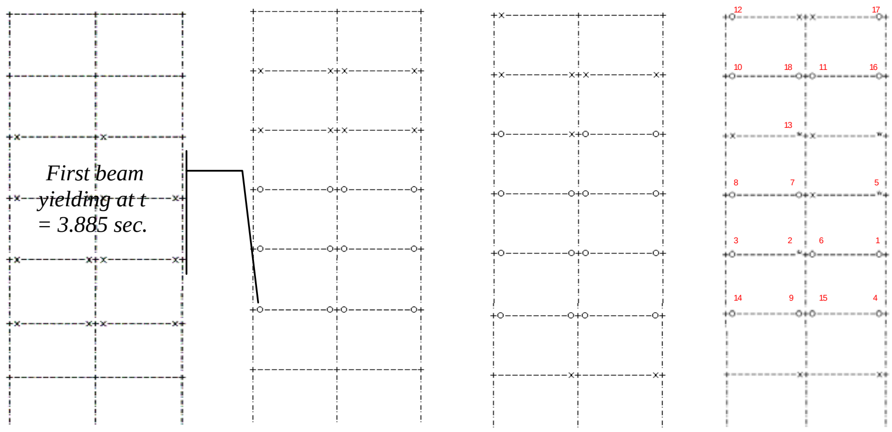


Fig 6. Elevation view of Hospital Besar Kota Bharu

Table 5: Configuration of modeling concept

<table>
<tr><th rowspan="2">Building Name</th><th rowspan="2">Story</th><th colspan="2">Dimension Frame</th><th rowspan="2">Material properties</th><th rowspan="2">Section Element</th></tr>
<tr><th>/ Bay</th><th>/ Floor level</th></tr>
<tr><td>Jabatan Pendaftaran Negara Putrajaya</td><td>9</td><td>8@ 8.4m</td><td>Ground floor: 4.0m
1^{st} – 2^{nd} floor: 5.0m
3^{rd} – 9^{th} floor: 4.2m</td><td rowspan="7">Ec = 25000 N/mm^2
fy = 460 N/mm^2
fc = 27.6 N/mm^2
fys = 276 N/mm^2
c = 25 mm</td><td>Beam: 600 x 1500 mm
(top:5T25), (btm: 5T25)
Column 1: 800 x 900 mm
(20T25)
Column 2: 600 x 900 mm
(26T25)</td></tr>
<tr><td>Block 3B Pangsapuri Putrajaya</td><td>16</td><td>3.1m, 5.3m, 2.5m</td><td>Ground floor: 4.0m
1^{st} – 16^{th} floor: 3.0m</td><td>Beam 1: 150 x 500 mm
(top: 2T10), (btm:2T10)
Beam 2: 450 x 1125 mm
Column 1: 350 x 600 mm
(16T20)
Column 2: 450 x 600 mm
(16T32)</td></tr>
<tr><td>Hospital Besar Kota Bharu</td><td>5</td><td>2@ 7.2m</td><td>6@ 4.3m</td><td>Beam: 300 x 600 mm
(top: 4Y25), (btm: 3Y25)
Column: 600 x 800 mm
(20Y32)</td></tr>
<tr><td>Mahkamah Persekutuan Kuala Terengganu</td><td>10</td><td>3.5m, 4.0m, 2.5m, 14.0m, 2.5m, 4.0m, 3.5m</td><td>Ground floor: 1.5m
1^{st} floor: 2.6m
2^{nd} – 10^{th} floor: 3.6m</td><td>Beam 1: 300 x 450 mm
(top:5Y25), (btm:3Y25)
Beam 2: 500 x 900 mm
(top:14Y25), (ctr: 3/2Y16) (btm:6Y25)
Column: 1000 x 500 mm</td></tr>
<tr><td>Mahkamah Syariah Labuan</td><td>5</td><td>3m, 2@6m, 9m, 2@6m, 3m</td><td>Ground floor: 3.6m
1^{st} - 2^{nd} floor: 4.8m
3^{rd} – 5^{th} floor: 3.6m</td><td>Beam: 350 x 700 mm
(top:3T20), (btm: 3T20)
Column: 800 x 600 mm</td></tr>
<tr><td>Kuarters Kelas F Miri</td><td>4</td><td>4.8m, 2@4.2m, 4.8m</td><td>Ground floor: 3.15m
1^{st} - 4^{th} floor: 3.0m</td><td>Beam: 200 x 400 mm
(top: 2Y25), (btm: 2Y25)
Column 1: 230 x 400 mm
(6Y25)
Column 2: 230 x 300 mm
(4Y25)</td></tr>
<tr><td>Kuarters Kerajaaan Div. II & III Kudat</td><td>4</td><td>6.1 m</td><td>Ground floor: 2.82m
1^{st} - 3^{rd} floor: 2.9m
4^{th} floor: 2.99m</td><td>Beam: 230 x 460 mm
(top: 2Y20), (btm: 2Y20)
Column: 230 x 300 mm
(4Y25)</td></tr>
</table>



(a) 0.05g *(b) 0.10g* *(c) 0.15g* *(d) 0.20g*

Fig 7. Damage state of frame under varies intensities for Hospital Kota Bharu

Table 6: Summerisation of first yielding point for all buildings

Building Name	Story	Plastic hinge location	Floor level	Intensities (g)	Time , sec. (First yield)
Jabatan Pendaftaran Negara Putrajaya	9	Beam	1	0.05	6.41
Block 3B Pangsapuri Putrajaya	16	Beam	10	0.05	3.24
Hospital Besar Kota Bharu	5	Beam	2	0.10	3.885
Mahkamah Persekutuan Kuala Terengganu	10	Column	4	0.15	4.205
Mahkamah Syariah Labuan	5	Beam	2	0.05	3.15
Kuarters Kelas F Miri	4	Beam	2	0.10	3.865
Kuarters Kerajaaan Div. II & III Kudat	4	Beam	1	0.20	4.39

3.4 Performance Level of the Structure

The performance level is a qualitative statement of damage. For it to be quantitatively defined, the performance level must be converted to the limiting values in the structural response parameter, which reflect the expected damage state. The ATC-13 damage level (Surya, 1992) in (Nur Asmawisham, 2002) was adopted in defining of the damage state level by referring to Table 8.

Table 7 shows the story level damage index under varies earthquake intensities for building of Hospital Kota Bharu. For intensity of 0.05g most damage occurs at the beam-slab region and the damage index is 0.03. This value indicates that the structure is at the moderate damage criteria where there is light damage to the structure includes no structural damage but possibilities for some non-structural damage.

At 0.01g the damage index has increased to 0.019, which is only a slight increase in values and structural damage at the moderate level. When intensities are increased to 0.15g and 0.2g the index values are 0.023 and 0.069 respectively. These values show that the damage levels for all the intensities are still at the moderate level where no structural damage will occur. However the building is expected to experience some non-structural element damage.

Table 9 shows the overall damage index for four buildings in Peninsular Malaysia and three buildings in East Malaysia. The largest damage index value is 0.107, which belongs to the Pangsapuri Block 3B precinct 9 Putrajaya for the intensities 0.20g. This index that the building is at moderate earthquake level where there is no structural damage, but some non-structural damage are expected as referred in Table 8.

Table7: Story level damage index under variety earthquake intensity

Time History Analysis (El-Centro)-0.05g Earthquake Intensity			
Story	Beam-Slab damage	Col-Wall Damage	Weighting Factor
7	0.000	0.000	0.000
6	0.000	0.000	0.000
5	0.011	0.000	0.087
4	0.013	0.000	0.276
3	0.014	0.000	0.301
2	0.014	0.000	0.334
1	0.000	0.000	0.002
Overall Structural Damage: 0.013			
Time History Analysis (El-Centro)-0.10g Earthquake Intensity			
Story	Beam-Slab damage	Col-Wall Damage	Weighting Factor
7	0.000	0.000	0.000
6	0.012	0.000	0.060
5	0.014	0.000	0.054
4	0.015	0.000	0.082
3	0.021	0.000	0.418
2	0.021	0.000	0.385
1	0.000	0.000	0.000
Overall Structural Damage: 0.019			
Time History Analysis (El-Centro)-0.15g Earthquake Intensity			
Story	Beam-Slab damage	Col-Wall Damage	Weighting Factor
7	0.011	0.000	0.007
6	0.014	0.000	0.042
5	0.018	0.000	0.077
4	0.020	0.000	0.164
3	0.025	0.000	0.387
2	0.025	0.000	0.320
1	0.008	0.000	0.003
Overall Structural Damage: 0.023			
Time History Analysis (El-Centro)-0.20g Earthquake Intensity			
Story	Beam-Slab damage	Col-Wall Damage	Weighting Factor
7	0.019	0.000	0.072
6	0.027	0.000	0.114
5	0.045	0.000	0.083
4	0.068	0.000	0.269
3	0.122	0.000	0.275
2	0.057	0.000	0.168
1	0.006	0.000	0.019
Overall Structural Damage: 0.069			

Table 8: ATC-13 Damage levels (Surya, 1992)

SEAOC Earthquake Level	SEAOC Damage	ATC-13 Damage Factors (State)
Minor	Without any damage	D.F.* = 0 (None) D.F. < 0.01 (Slight)
Moderate	No structural damage, some non-structural damage	0.01 < D.F.<= 0.10 (light) 0.10 < D.F.<= 0.30 (Moderate)
Major	No collapse, some structural damage, non-structural damage considerable	0.30 < D.F.<= (Heavy) 0.60 < D.F.<= (Major)
Collapse	Collapse	D.F. = 1.0 (Destroyed)

D.F* = damage Factor

Table 9: Overall damage Index of each buildings

Building Name	Overall Structural Damage Index			
	0.05g	0.10g	0.15g	0.20g
Peninsular Malaysia:				
Jabatan Pendaftaran Negara, Putrajaya	0.012	0.019	0.033	0.054
Pangsapuri (Precinct 9), Putrajaya	0.019	0.039	0.066	0.107
Hospital Besar Kota Bharu	0.013	0.019	0.023	0.069
Mahkamah Kuala Terengganu	0.000	0.010	0.015	0.035
Sabah:				
Mahkamah Labuan	0.017	0.027	0.048	0.056
Perumahan Kastam Kudat	0.011	0.020	0.028	0.035
Sarawak:				
Kuarters Bomba (Kelas F-Type B), Miri	0.000	0.022	0.025	0.038

4. CONCLUSION

From the FVA on seven public buildings in Malaysia, most buildings have dynamic amplification factor between 1.0 and 2.0. These values show that the buildings are subjected to static response more than the dynamic response. There are only two buildings that have dynamic amplification factor more then 2.0 which means the buildings tend to have more dynamic response and therefore they should be analyzed using dynamic analysis method. These buildings are subjected to high dynamic amplification factor due to their structure height and location where both buildings are high rise and located close to the earthquake epicenter.

Most buildings that have been analyzed subjected to the El-Centro earthquake ground motion, have a damage indexes in the range of 0.0 to 0.1. This low index shows that the buildings have only light or moderate damage level. Local failures are mostly developed at beam connections followed by column connections. In general, there are no significant damage occurred to the structure. However some non-structural elements of the building are expected to experience minor damages. From the overall analyses, it can be concluded that the high rise buildings in this study are affected by earthquake load more than the low rise buildings.

5. ACKNOWLEDGEMENT

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6. REFERENCES

Chopra, Anil K.(2000). Dynamic of Structure: Theory and Application to Earthquake Engineering. 2nd ed. Upper Saddle River, N.J.: Prentice-Hall.

Mohd Nur Asmawisham (2002). Performance of Low and Medium –Rise Steel Frames Under Low Intensities Earthquake, Masters Thesis, University of Technology Malaysia.

Park,Y.J., Ang,A.H-S., and Wen,Y.K. (1985). Damage Limiting Asesimic Design of Buildings, Urbana, Illionois : Earthquake Spectra.

Surya Kumar V.Gunturi (1992). Building Specific Earthquake Damage Estimation, Doctor of Philosophy Dissertation, Stanford University, San Francisco.