International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 8, Number 12 (2013) pp. 1459-1477

http://www.ripublication.com/ijaer.htm

Seismic Evaluation of High Rise Structures in Malaysia

**Narayanan Sambu Potty[+], Mohd Redzuan Abdul Hamid
and Muhamad Afiq Rosli**

*Department of Civil Engineering, University Technology PETRONAS,
Bandar Seri Iskandar, 31750, Tronoh, Perak Darul Ridzuan, Malaysia
[+]Corresponding Author Email: narayanan_sambu@petronas.com.my
Telephone: 0060165449842 Fax: 006053656716*

Abstract

Structural design in Malaysia has traditionally not considered earthquake and hurricane loading. The occurrence of several tremors in neighbouring countries has necessitated a relook at the seismic reliability of the existing structures. Major cities like Kuala Lumpur, Penang and Johor may have structures with significant seismic risk. The first step towards mitigation is an effective risk assessment. In this work two methods were used to assess the risk of the buildings namely Rapid Visual Screening and Extended analysis. The former was done by adopting the FEMA-154 procedure, which assigns the basic score depending on the building type, modified based on the number of storeys, the vertical and the plan irregularity, the year of code, Pre or Post benchmark and soil type. 95 structures were evaluated and the final score indicates that three buildings are at risk. The extended analysis started with simple vertical load analysis (the current practice) and then the earthquake and the wind loading were imposed. The integrity of the structures was evaluated in terms of serviceability deflections using UBC 1997, IS 875-3-1987 and IS 1893. Under wind loads, the permissible deflections were exceeded at 40 m/s for 87 m height buildings; at 45m/s for above 70 m height buildings; at 50 m/s for buildings above 59.5 m height. Higher value of ground accelerations (>0.1 g) results in exceedance of the serviceability values of deflections.

KEYWORDS: Risk assessment, Rapid Visual Screening, Extended Analysis, Wind loads, Earthquake, Serviceability

ABBREVIATIONS

IEM	Institution of Engineers Malaysia
SEER	Structural Earthquake Engineering Research
RVS	Rapid Visual Screening
ATC	Applied Technology Council
BS	British Standard
UBC	Uniform Building Code
FEMA	Federal Emergency Management Agency
URM	Unreinforced Masonry
IS	Indian Standard
AASHTO	American Association of State Highway and Transportation Officials

INTRODUCTION

Even though Malaysia is at least 350 km away from significant earthquakes, recent events in Sumatra in 2002 (Mw = 7.4), early 2003 (Mw = 5.8) and Aceh 2004 (Mw = 9.1- 9.3) caused vibrations and panic in several cities in Peninsular Malaysia including Penang and Kuala Lumpur. Cracks were also reported in buildings in Penang due earthquake on 2nd November 2002 [1]. Seismic risk assessments of buildings in Malaysia are thus essential in order to identify deficient buildings and to retrofit them.

LITERATURE REVIEW

During an earthquake buildings vibrate, but not all buildings respond to an earthquake equally. If the frequency of oscillation of the ground is close to the natural frequency of the building, resonance (high amplitude and continued oscillation) may cause severe damage. Small building are more affected by high frequency earthquake waves (short and frequent). Large structures or high rise buildings are more affected by low-frequency, or slow shaking. A skyscraper will sustain greater shaking by long-period earthquake waves than by the shorter waves. The behavior of a building during earthquakes depends critically on its overall shape, size and geometry, in addition to how the earthquake forces are carried to the ground [2]. Hence, at the planning stage, unfavorable features are to be avoided and a good building configuration chosen. Sometimes the shape of the building catches the eye of the visitor, sometimes the structural system appeals, and in other occasions both shape and structural system work together to make the structure a marvel. However, each of these choices of shapes and structure has significant bearing on the performance of the building during strong earthquakes. The wide range of structural damages observed during past earthquakes across the world is very educative in identifying structural configurations that are desirable versus those which must be avoided [3]. Codes of Practice also give recommendations on the EQ resistant features to be adopted in design [4][5][6][7][8].

The earthquake forces developed at different floor levels in a building need to be transferred to the ground by the shortest path; any deviation or discontinuity in this load transfer path results in poor performance of the building [9]. Buildings with vertical setbacks (like the hotel buildings with a few storeys wider than the rest) cause a sudden jump in earthquake forces at the level of discontinuity. Buildings that have fewer columns or walls in a particular storey or with unusually tall storey tend to damage or collapse which is initiated in that storey. Buildings on a sloping ground have unequal height columns along the slope, which causes ill effects like twisting and damage in shorter columns. There are discontinuities in the load transfer path if the building has columns that hang or float on beam at the intermediate storey. Some buildings have reinforced concrete walls to carry the earthquake loads to the foundation. Buildings, in which these walls do not go all the way to the ground but stop at an upper level, are liable to get severely damaged during earthquakes.

In general, buildings with simple geometry in plan have performed well during strong earthquakes [10]. Buildings with re-entrant corners, like those U, V, H and + shaped plans, have sustained significant damage. Many times, the bad effects of these interior corners in the plan of buildings are avoided by making the buildings in two parts. For example, an L-shaped plan can be broken up into two rectangular plan shapes using a separation joint at the junction. Often, the plan is simple, but the columns/walls are not equally distributed in plan. Buildings with such features tend to twist during earthquake shaking [3].

There is a very significant correlation between the number of stories and the severity of building damage. If all buildings conform to modern seismic design codes, then such a distribution would not occur, and a uniform distribution of damage would be expected. However majority of buildings in the earthquake stricken region lack this basic property. Increasing number of stories increase seismic forces linearly whereas the seismic resistances do not increase adequately. Accordingly, damage increases almost linearly with the number of stories. Studies on damage distribution for all 9685 buildings in Düzce after the two earthquakes in 1999 showed that damage grades shift \ linearly with the number of stories [11]. As the number of stories increases, the ratio of undamaged and lightly damaged buildings decreases steadily whereas the ratio of moderately and severely damaged buildings increases in an opposite trend. This is a clear indication that the number of stories is a very significant, perhaps the most dominant, parameter in determining the seismic vulnerability of typical multi-storey concrete buildings in Malaysia.

When the provisions in the code are revised, assessment of structures becomes necessary to verify the safety of the structure under the new provisions. Potty and Nambissan [12] recommended the seismic retrofit measures for Elevated Steel Water Tanks when the seismic zone of the location of the structure changed from Zone 2 to Zone 3 in India. Assessments are also done on fleet of offshore structures to prioritize maintenance by Potty and Mohd Akram [13], Potty and Akram [14], and Potty et al [15]. Seismic evaluation is also undertaken when seismic events cause public concern. Seismic assessment of structures based on questionnaire survey were carried out by Narayanan and Sirajuddin [16] and Potty and Sirajuddin [17] and by non –linear analysis of masonry structures by Potty and Sirajuddin [18] in Kollam, India.

The basic wind speeds (3 second average) specified for different regions in India in IS 875-1987 are 33, 39, 44, 47, 50 and 55 m/s [19]. The design wind speed is calculated using the expression

$$V_z = V_b \times k_1 \times k_2 \times k_3$$

Where k_1 = the risk factor; k_2 = terrain, height and structure size factor and k_3 = topography factor. The values of k_1, k_2 and k_3 are obtained from tables in the code. The design wind pressure is calculated using

$$p_z = 0.6 V_z^{\ 2}$$

MS 1553: 2002 provides 50 – year return period wind speed for zone 1 (33.5 m/s) and zone 2 (35 m/s) [20]. Zone 1 corresponds to narrow belt on the coastal zone and zone 2 constitutes the other regions of Peninsular Malaysia.

Beaufort Scale constitutes a scale from 1 to 12; where the numbers 8 represents Gale (17.2 – 20.7 m/s); number 9 represents Strong Gale (20.8 – 24.4 m/s); number 10 represents Storm (24.5 – 28.4); number 11 represents violent storm (28.5 – 32.6) and number 12 represents Hurricane (> 32.7 m/s). The Saffir – Simpson hurricane scale describes hurricanes as weak (32.7 – 42.6 m/s); moderate (42.7 – 49.5); strong (49.6 – 58.5); very strong (58.6 – 69.4) and Devastating (>69.5 m/s) [21].

Design Practice in Malaysia

Design of structures in Malaysia follows British Standard BS 5400 [22], BS 8110 [23], BS 5950 [24]) and other standards. They lack detailed and specific requirements on seismic load. Hence most engineers use AASHTO Specifications [25], Uniform Building Code [26] or EC8:2004 [6] However, the right ground acceleration for Malaysia has to be used. The choice is based on the importance of the structure and severity of failure. The design of Penang Bridge used higher value of ground acceleration compared to design of Bakun Hydroelectric Plant [27]. Prior to 26 December 2004 earthquake, IEM in a position document approved by IEM council had several short and long term recommendations on issues regarding earthquake [28]. Short term initiatives included the need of more seismic monitoring stations in Malaysia, reviewing current Engineering Design and Construction Standards and Practices as well as suggesting the design of high rise buildings to cater for long period vibration. For long term, IEM has suggested the development or adoption of a suitable code of practice for seismic design and also recommended the introduction of earthquake engineering education curriculum in the universities. Sensitive and important structures are also recommended for seismic vulnerability assessment [28]. Seismic zone mapping carried out by SEER recommended for Peninsular Malaysia, the ground acceleration of 0.03g to 0.05g, while in East Malaysia, the level of acceleration recommended increases from Sarawak towards Sabah, due to existence of active fault in Sabah. Maximum ground acceleration for design in Sabah would be 0.15g [29]. Considering the framework to carry lateral loads, the designer usually adopts three systems; moment resisting frames, braced frames, and shear wall. For skyscrapers, the more sophisticated framed tube systems and other complex framing system are adopted. Moment resisting frames are characterized as fixed or semi-rigid wherein the strength and the stiffness of the concrete frame are proportional to the storey height and column spacing. At the same time, slab and walls systems can be designed as moment resisting frames. A steel braced frame contains diagonal x-braces and k-braces to resist lateral loads. For concrete frames, shear wall is usually constructed. Shear wall is characterized as reinforced concrete plane elements having length and thickness.

Majority of the buildings have height between 12m to 99m [30]. The aim of the current work is to assess the seismic vulnerability of buildings using two methods. RVS assesses the building vulnerability based on observation without involving any analysis. This was undertaken in Penang and Ipoh town. The second study involved the detailed analysis of buildings considering earthquake and wind loads. For low rise buildings, the effects of lateral load are considered minimum while for skyscrapers, it is assumed that lateral loads have been considered in design of the structural members and framing systems [31]. An important parameter is the type of framing system, which is kept constant so that the behaviour of structures towards the lateral loads can be fully associated with the height. Different types of framing systems usually carry different level of stiffness and flexibility. Figure 1 shows the height of application (maximum number of storeys) of different framing systems.

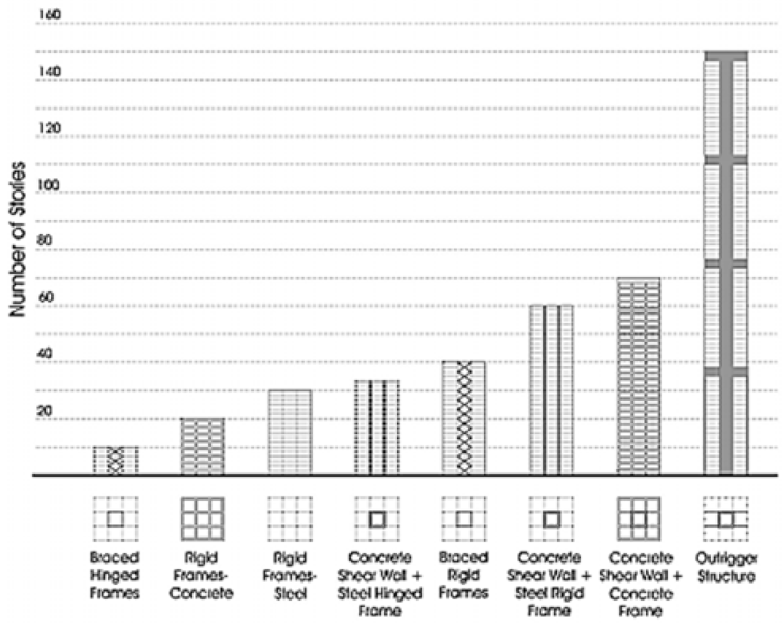


Figure 1 Maximum number of stories Vs Type of framing system [32]

METHODOLOGY

The two components of the work are RVS and Extended Analysis. They are explained below.

RVS is very easy method of assessing the building vulnerability based on observation without involving any analysis [8], [33], [34]. RVS method visually identifies the parameters and ranks buildings that are potentially seismically hazardous. This evaluation using this method takes less than 30 minutes and can be completed from the street view without entering the building. A performance score is calculated for each building based on numerical values on the RVS form for the features of the building [35]. The forms are available for 3 types of seismic regions namely Low, Moderate and High. Each Data Collection Form provides space to record the building identification information, draw a sketch of the building (plan and elevation views), attach a photograph of the building, indicate the occupancy, indicate the soil type, document the existence of falling hazards, develop a Final Structural Score, *S*, for the building from the basic score which depends on the building type (Table 1), indicate if a detailed evaluation is required, and provide additional comments.

Table 1 Building type and Basic Score [8]

BUILDING TYPE		Basic Score
W1	Light wood-frame residential and commercial buildings smaller than or equal to 5, 000 square feet	7.4
W2	Light wood-frame buildings larger than 5, 000 square feet	6.0
S1	Steel moment-resisting frame buildings	4.6
S2	Braced steel frame buildings	4.8
S3	Light metal buildings	4.6
S4	Steel frame buildings with cast-in-place concrete shear walls	4.8
S5	Steel frame buildings with unreinforced masonry infill walls	5.0
C1	Concrete moment-resisting frame buildings	4.4
C2	Concrete shear-wall buildings	4.8
C3	Concrete frame buildings with unreinforced masonry infill walls	4.4
PC1	Tilt-up buildings	4.4
PC2	Precast concrete frame buildings	4.6
RM1	Reinforced masonry buildings with flexible floor and roof diaphragms	4.8
RM2	Reinforced masonry buildings with rigid floor and roof diaphragms	4.6
URM	Unreinforced masonry bearing-wall buildings	4.6

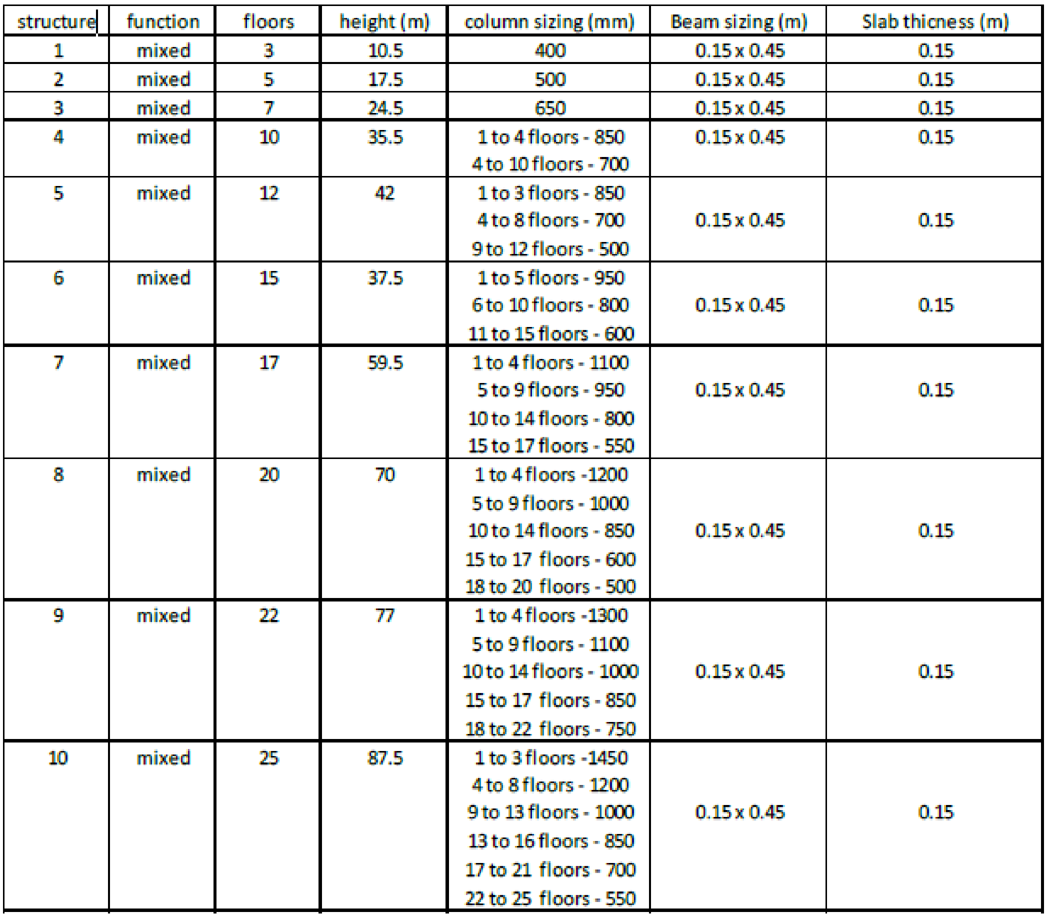
The performance score considers soil condition, earthquake resistance features, as well as the structure. No non-structure interiors are included in evaluation. In low seismicity regions, the Basic Structural Hazard Scores are calculated for buildings built before the initial adoption of seismic codes. For buildings in these regions, the Score Modifier designated as “Pre Code” is not applicable (N/A), and the Score Modifier designated as “Post Benchmark” is applicable for buildings built after the adoption of seismic codes. The score of each building is ranked and advanced analysis is undertaken if the score is less than 2 (Table 2). Though RVS is applicable to all buildings, its principal purpose is to identify (1) older buildings designed and constructed before the adoption of adequate seismic design and detailing requirements, (2) buildings on soft or poor soils, (3) buildings having performance characteristics that adversely affect their seismic response [8]. The final score S typically range from 0- 7, with higher S scores corresponding to better expected seismic performance.

Table 2 Expected Damage Level as a function of RVS score [8]

RVS Score	Damage Potential
S<0.3	High probability of Grade 5 Damage; very high probability of grade 4 damage
0.3<S<0.7	High probability of Grade 4 Damage; very high probability of grade 3 damage
0.7<S<2.0	High probability of Grade 3 Damage; very high probability of grade 2 damage
2.0<S<3.0	High probability of Grade 2 Damage; very high probability of grade 1 damage
S>3.0	Probability of Grade 1 Damage

The extended analysis considers structures up to 40 m height, considering the limit of applicability of framed structures. The floor area of the structures also needs to be assumed. To avoid more complicated parameters and variables, the base areas of the structures are assumed to be square. Three different base areas are assumed (24m x 24m, 30m x 30m, 36m x 36m) to see the relationship between aspect ratio and structural displacement where column-to-column distance is assumed to be 6m. As each span length is same, all beam sizing will be assumed the same (0.15m X 0.45m). Slab thickness is assumed to be 0.15m. Column sizes vary with height (Table 3). All columns are assumed square and sizing are based on column sizing from real structures.

Table 3 Sizing of Members for modeling



structure	function	floors	height (m)	column sizing (mm)	Beam sizing (m)	Slab thicness (m)
1	mixed	3	10.5	400	0.15 x 0.45	0.15
2	mixed	5	17.5	500	0.15 x 0.45	0.15
3	mixed	7	24.5	650	0.15 x 0.45	0.15
4	mixed	10	35.5	1 to 4 floors - 850 4 to 10 floors - 700	0.15 x 0.45	0.15
5	mixed	12	42	1 to 3 floors - 850 4 to 8 floors - 700 9 to 12 floors - 500	0.15 x 0.45	0.15
6	mixed	15	37.5	1 to 5 floors - 950 6 to 10 floors - 800 11 to 15 floors - 600	0.15 x 0.45	0.15
7	mixed	17	59.5	1 to 4 floors - 1100 5 to 9 floors - 950 10 to 14 floors - 800 15 to 17 floors - 550	0.15 x 0.45	0.15
8	mixed	20	70	1 to 4 floors -1200 5 to 9 floors - 1000 10 to 14 floors - 850 15 to 17 floors - 600 18 to 20 floors - 500	0.15 x 0.45	0.15
9	mixed	22	77	1 to 4 floors -1300 5 to 9 floors - 1100 10 to 14 floors - 1000 15 to 17 floors - 850 18 to 22 floors - 750	0.15 x 0.45	0.15
10	mixed	25	87.5	1 to 3 floors -1450 4 to 8 floors - 1200 9 to 13 floors - 1000 13 to 16 floors - 850 17 to 21 floors - 700 22 to 25 floors - 550	0.15 x 0.45	0.15

Two general types of loading are considered namely vertical loads and horizontal loads. This includes the self-weight of the structure, DL and LL. Horizontal load or lateral loads include wind load and earthquake load. DL and LL for slabs are 2 kN/m^2 based on BS 6399 Part 1[36] and Part 2 [37]. Self-weight of structure and loading from brick walls are calculated based on density of concrete and bricks, which are 24 kN/m^3 and 22 kN/m^3 respectively [38]. Static approach of wind load analysis as per UBC 1997 [26] places Kuala Lumpur under Exposure B. Exposure B is terrain with buildings, forest or surface irregularities, covering at least 20 per cent of the ground level area extending 1 mile (1.61 km) or more from the site. Basic wind speed for Kuala Lumpur area is 35.1 m/s, peak 3-second gust at 10m above grade for a 50-year return period [39]; [20]. The modeled frame structure will be imposed to wind speeds from 20 m/s up to 50 m/s (20 m/s, 25 m/s, 30 m/s, 35 m/s, 40 m/s, 45 m/s, 50 m/s). Earthquake loading is also assessed based on UBC 1997 [26]. While wind loading is directly related with the height of the structure, earthquake loading is governed by the total mass of the structure. The total mass of the structure and mass for each floor is evaluated by sizing of structural members. Live load is excluded. Malaysia falls under zone 2A with seismic factor of 0.15 (Table 4). The importance factor is based on the function and occupancy of the structure. Importance factor of 1 is considered (Table 5). R factor is based on framing system. For this analysis, ordinary moment resisting frame system is assumed with R factor of 3.5 (Table 6). The performance of structure toward earthquake loading is also dependent on the type of founding soil. Stronger soil will have lower coefficient with lower amplification of ground acceleration compared to softer soil. The soil is assumed to be type SA where Cv and Ca have values of 0.12 and 0.15 respectively (Table 7). The software used for analysis was STAADPRO [40].

Table 4 Seismic Factor (UBC 1997)

Zone	1	2A	2B	3	4
Z	0.075	0.15	0.20	0.30	0.40

Table 5 Importance Factor I (UBC 1997)

Occupancy Category	Seismic Importance Factor I
Essential Facilities	1.25
2 – Hazardous Facilities	1.25
3 - Special Occupancy Structures	1.00
4 - Standard Occupancy Structures	1.00
5 – Miscellaneous Structures	1.00

Table 6 Importance Factor R (UBC 1997)

Basic Structural system	Description of lateral resisting system	R
Bearing wall	Concrete shear walls	4.5
Building frame	Concrete shear walls	5.5
Moment resisting frame	SMRF IMRF OMRF	8.5 5.5 3.5
Dual	Shear wall SMRF Shear wall IMRF	8.5 6.5
Cantilevered column elements	Cantilevered column elements	2.2

Table 7 Seismic coefficients Cv and Ca for Zone 2A

Soil profile Type	Cv	CA
SA	0.12	0.12
SB	0.15	0.15
SC	0.25	0.18
SD	0.32	0.22
SE	0.50	0.30
SF	See footnote of Code	

RESULTS AND DISCUSSION

The results and discussion are organized into two sections namely (1) RVS and (2) Extended Analysis.

Rapid Visual Survey

RVS was used to assess 95 buildings in Penang (Georgetown, Gurney, Tanjung Bungah, Tanjung Tokong, Gelugor and Queensbay) and Perak (Ipoh City and Tambun)[41]. These locations consisted of Earthquake Zone II (Low Seismicity). The site survey helped in classification of all buildings into 3 types, C1 (Concrete Moment-Resisting Frame), C2 (Concrete Shear Wall) and C3 (Reinforced Concrete with Unreinforced Masonry Infill), based on their definition in FEMA 154. According to FEMA 154, the lateral-load-resisting system exists only in URM, C2 and C3 types. Thus among the fifteen different types of systems, the buildings in Penang & Perak Cities were found to be of C1, C2, C3 and URM types. The distribution of RVS scores of the 95 buildings surveyed is shown in Table 8. The results show that 40% of buildings had score greater than 4, 47.37% between 3 and 4, 9.47% between 2 and 3, 2.10% between 1 and 2 and only 1.05% under 1. The results show that only 3 building assessed are under seismic risk. Seismically safe buildings have an S value of 2 and above (>2). The rest of the buildings assessed are assessed as safe to earthquake. Because Penang and Perak are far from earthquake epicenter, thus most of buildings are not highly affected by the low intensity seismicity.

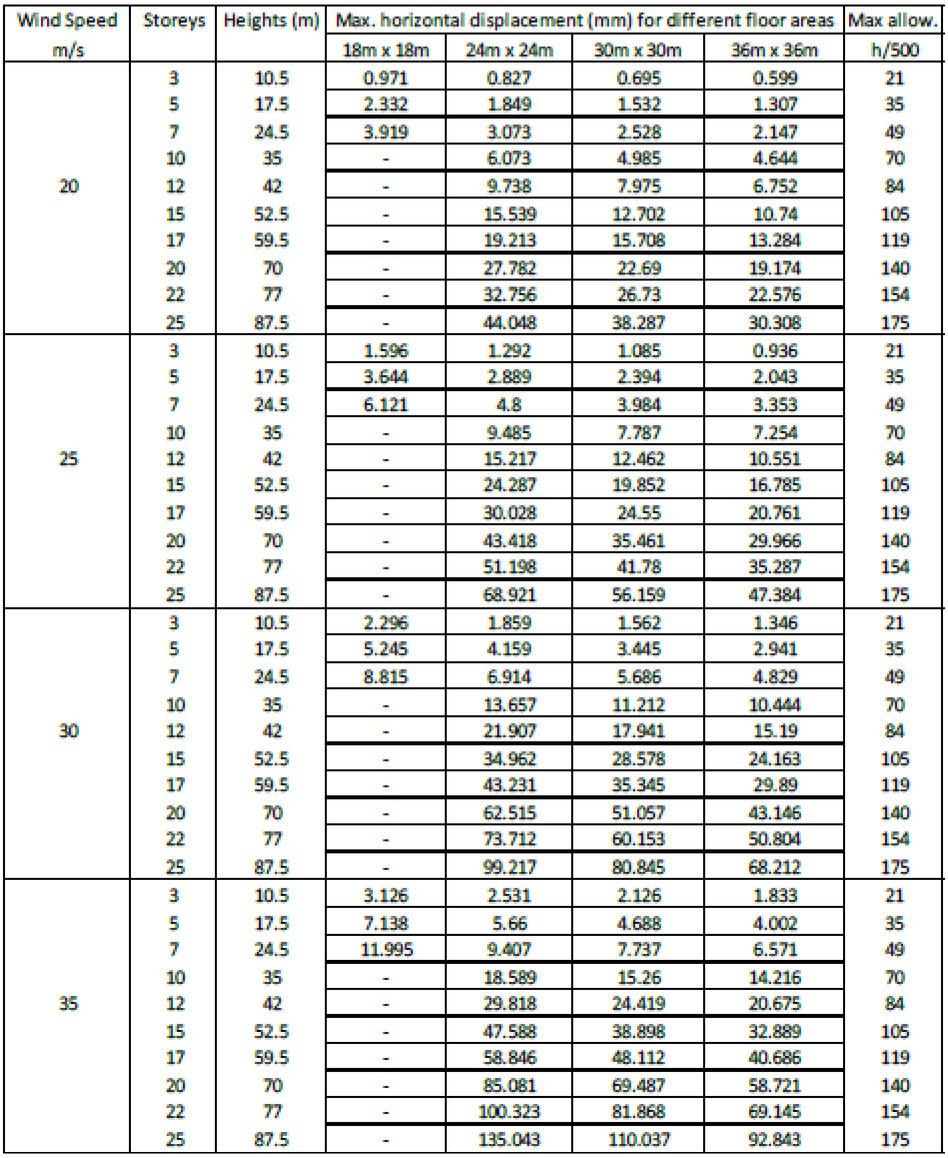
Table 8: Percentage Distribution of Building Score

Score S	Number of Buildings in the score range	%
0-1	1	1.05
1-2	2	2.10
2-3	9	9.47
3-4	45	47.37
>4	38	40.00
Total	95	100

Extended Analysis

For assessing the behaviour of the structure under wind loading, the critical parameter is the maximum displacement of the structure. Serviceability check or deflection index consider H/100 to H/600 for maximum building deflection depending on building type and material used. The value assumed usually is H/400 and H/500 [42][43]. Cooney and King [44] recommends the limit for the sway of columns due to wind as h/500 and less than 4mm per storey. Lateral frame deflections have historically been based on a first order analysis. In this analysis, maximum allowable deflection for a structure is taken as H/500. The structure is assumed to have failed if deflection is more than this value. Apart from that, structural members exceeding maximum stress and deflection are also considered. The maximum displacement of structures of different height, base area and imposed wind loads was evaluated. It is observed that theoretically all buildings studied are safe for wind speed of 20 m/s, 25 m/s, 30 m/s, and 35 m/s even though lateral loads had been excluded in the design (Table 9). This is the reason for the negligible structural damage for buildings in Malaysia where maximum basic wind speed is around 32 m/s to 34 m/s [20]. For each plan size, the practical range of heights for moment resisting frames has been studied. So for plan sizes 18 x 18, 24 x 24, 30 x 30 and 36 x 36, heights of 24.5 m, 87.5 m, 87.5m, and 87.5 m respectively were considered.

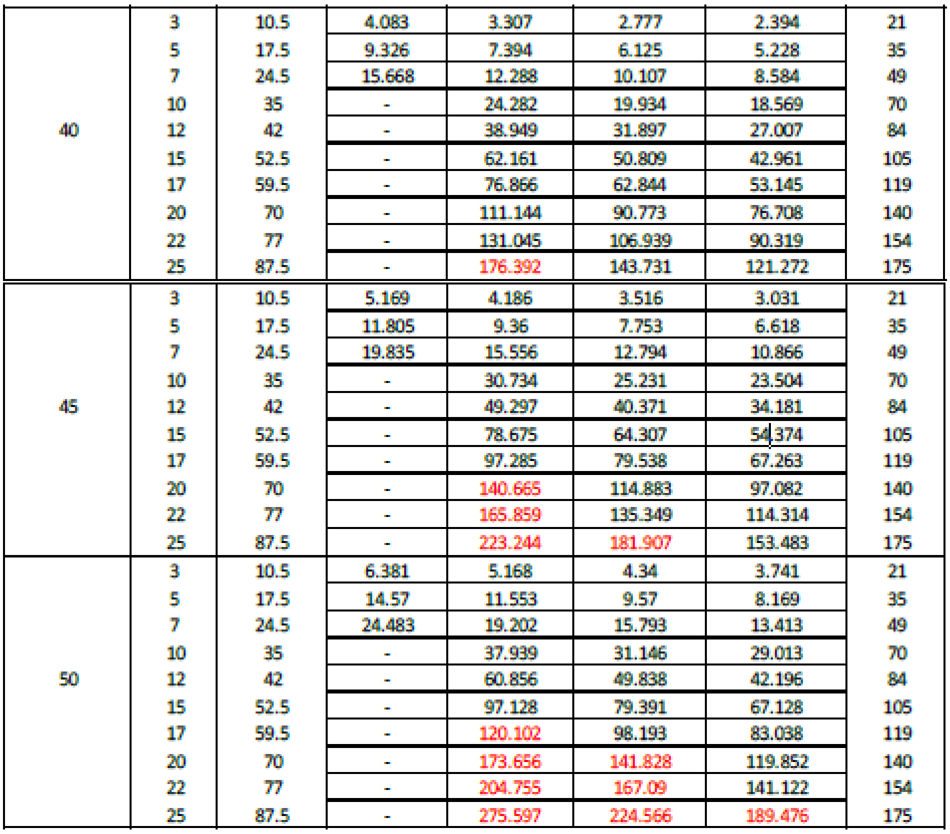
Table 9 Maximum Displacement of Structure at wind speeds up to 35 m/s



Wind Speed m/s	Storeys	Heights (m)	Max. horizontal displacement (mm) for different floor areas				Max allow.
			18m x 18m	24m x 24m	30m x 30m	36m x 36m	h/500
20	3	10.5	0.971	0.827	0.695	0.599	21
	5	17.5	2.332	1.849	1.532	1.307	35
	7	24.5	3.919	3.073	2.528	2.147	49
	10	35	-	6.073	4.985	4.644	70
	12	42	-	9.738	7.975	6.752	84
	15	52.5	-	15.539	12.702	10.74	105
	17	59.5	-	19.213	15.708	13.284	119
	20	70	-	27.782	22.69	19.174	140
	22	77	-	32.756	26.73	22.576	154
	25	87.5	-	44.048	38.287	30.308	175
25	3	10.5	1.596	1.292	1.085	0.936	21
	5	17.5	3.644	2.889	2.394	2.043	35
	7	24.5	6.121	4.8	3.984	3.353	49
	10	35	-	9.485	7.787	7.254	70
	12	42	-	15.217	12.462	10.551	84
	15	52.5	-	24.287	19.852	16.785	105
	17	59.5	-	30.028	24.55	20.761	119
	20	70	-	43.418	35.461	29.966	140
	22	77	-	51.198	41.78	35.287	154
	25	87.5	-	68.921	56.159	47.384	175
30	3	10.5	2.296	1.859	1.562	1.346	21
	5	17.5	5.245	4.159	3.445	2.941	35
	7	24.5	8.815	6.914	5.686	4.829	49
	10	35	-	13.657	11.212	10.444	70
	12	42	-	21.907	17.941	15.19	84
	15	52.5	-	34.962	28.578	24.163	105
	17	59.5	-	43.231	35.345	29.89	119
	20	70	-	62.515	51.057	43.146	140
	22	77	-	73.712	60.153	50.804	154
	25	87.5	-	99.217	80.845	68.212	175
35	3	10.5	3.126	2.531	2.126	1.833	21
	5	17.5	7.138	5.66	4.688	4.002	35
	7	24.5	11.995	9.407	7.737	6.571	49
	10	35	-	18.589	15.26	14.216	70
	12	42	-	29.818	24.419	20.675	84
	15	52.5	-	47.588	38.898	32.889	105
	17	59.5	-	58.846	48.112	40.686	119
	20	70	-	85.081	69.487	58.721	140
	22	77	-	100.323	81.868	69.145	154
	25	87.5	-	135.043	110.037	92.843	175

For 40 m/s wind speed the maximum deflection exceed the permissible values only for 24 x 24 plan size and height of 87.5m (Table 10). For 45 m/s and 50 m/s wind speed, the maximum deflections exceed the permissible values for the cases shown shaded in Table 10. However, based on data taken from Malaysian Meteorological Department, highest maximum wind speed ever recorded was 41.7 m/s, at Kuching, Sarawak on 15 September 1992. This means wind speed beyond 40 m/s was only recorded during the last 20 years in a place located very far away from Kuala Lumpur, where high rise buildings are congested. For wind speed of 45 m/s and 50 m/s, high rise buildings with more than 17 stories, will be severely affected by the lateral loads. Studies also show that low rise and medium rise buildings up to 15 stories performed very well in resisting lateral load without any additional bracing or lateral design. This means that for buildings up to 15 stories / 53m, the loadings are governed by gravity instead of lateral loads. However, for buildings more than 15 stories, the lateral loads gives more effect compared to gravity loads based on the gradient of the displacement curve. On the other hand, the relationship and trends between the base area and the displacement of the buildings are simply interpreted based on the Tables 9 and 10 and Figures 2, 3 and 4.

Table 10 Maximum Displacement of Structure at wind speeds above 35 m/s



40	3	10.5	4.083	3.307	2.777	2.394	21
	5	17.5	9.326	7.394	6.125	5.228	35
	7	24.5	15.668	12.288	10.107	8.584	49
	10	35	-	24.282	19.934	18.569	70
	12	42	-	38.949	31.897	27.007	84
	15	52.5	-	62.161	50.809	42.961	105
	17	59.5	-	76.866	62.844	53.145	119
	20	70	-	111.144	90.773	76.708	140
	22	77	-	131.045	106.939	90.319	154
	25	87.5	-	176.392	143.731	121.272	175
45	3	10.5	5.169	4.186	3.516	3.031	21
	5	17.5	11.805	9.36	7.753	6.618	35
	7	24.5	19.835	15.556	12.794	10.866	49
	10	35	-	30.734	25.231	23.504	70
	12	42	-	49.297	40.371	34.181	84
	15	52.5	-	78.675	64.307	54.374	105
	17	59.5	-	97.285	79.538	67.263	119
	20	70	-	140.665	114.883	97.082	140
	22	77	-	165.859	135.349	114.314	154
	25	87.5	-	223.244	181.907	153.483	175
50	3	10.5	6.381	5.168	4.34	3.741	21
	5	17.5	14.57	11.553	9.57	8.169	35
	7	24.5	24.483	19.202	15.793	13.413	49
	10	35	-	37.939	31.146	29.013	70
	12	42	-	60.856	49.838	42.196	84
	15	52.5	-	97.128	79.391	67.128	105
	17	59.5	-	120.102	98.193	83.038	119
	20	70	-	173.656	141.828	119.852	140
	22	77	-	204.755	167.09	141.122	154
	25	87.5	-	275.597	224.566	189.476	175

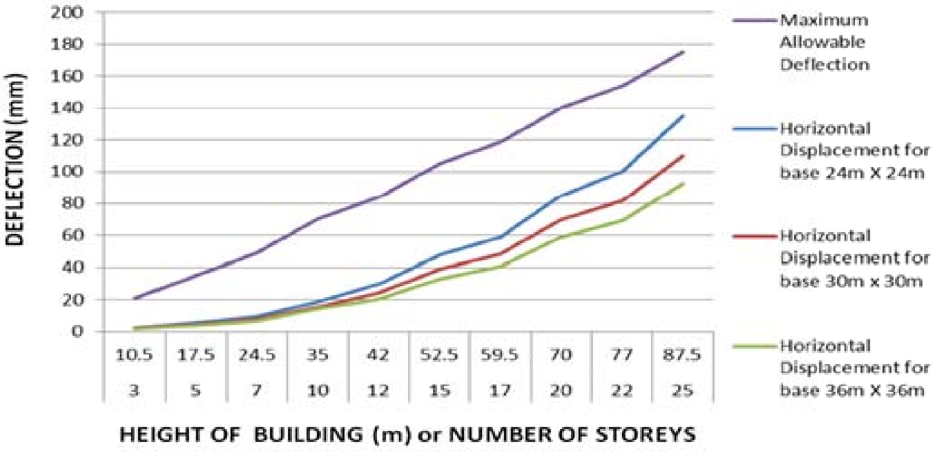


Figure 2 Deflection Vs. height of buildings for wind speed of 35 m/s

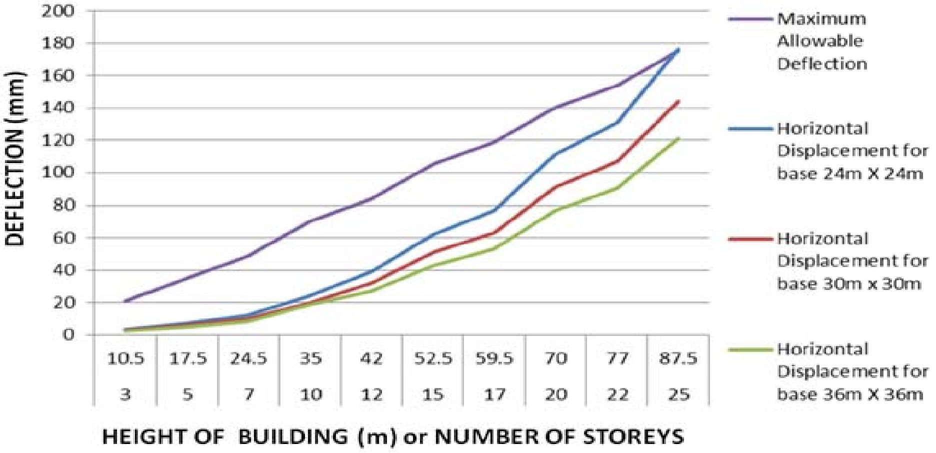


Figure 3 Deflection Vs. height of buildings for wind speed of 40 m/s

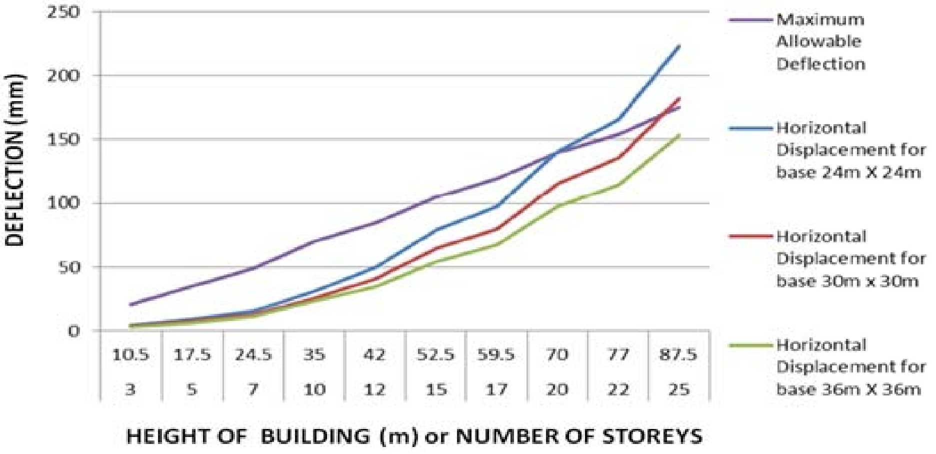


Figure 4 Deflection Vs. height of buildings for wind speed of 45 m/s

Figure 5 shows the plot of vulnerability of structure vs. height of building. The resistance of structure contributed by the column is represented with the number of column given in a structure. The ratio between exposed surface area (to wind) and number of columns represent the resistance of structure towards lateral loadings. Higher ratio characterizes lower vulnerability of structure towards wind loads and vice versa. The difference of resistance given for different base area also increases with height. This answers the higher differences in deflections for high rise structure compared to medium and low rise structure with respect to different base areas.

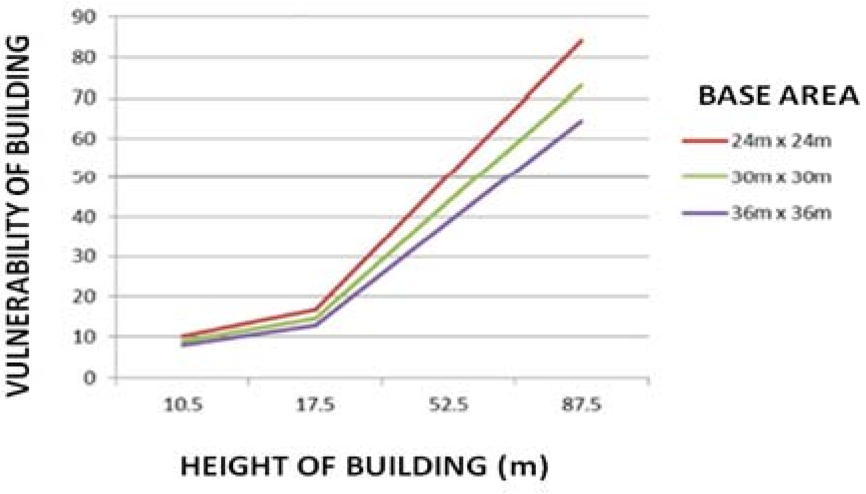
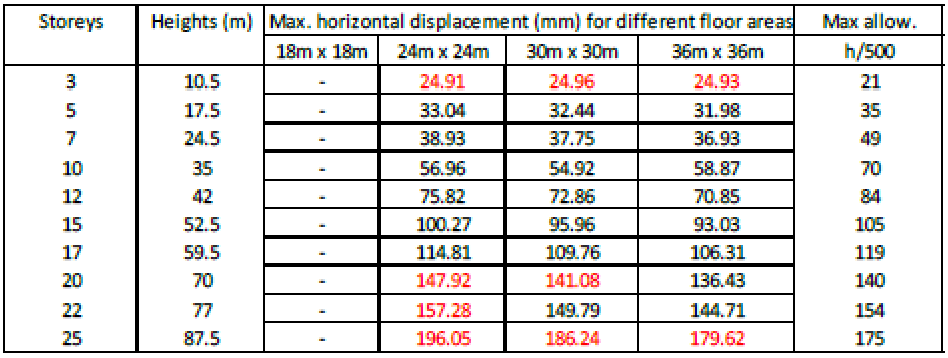


Figure 5 Relationship between height and resistance given by the column

For assessing the behaviour of the structure under earthquake loading, the equivalent lateral load imposed due to seismic action is based on UBC 1997 for zone 2A with ground acceleration of 0.15g. The horizontal displacement of each analyzed building is tabulated in Table 11. However, the data presented in Table 11 is based on zoning categories in UBC 1997, in which Malaysia falls in Zone 2A. All coefficients and constants are pre-determined by zoning. Alternately, IS 1893 has simpler and direct method for determining the equivalent lateral loads. As most of the constants and coefficients in IS 1893 [7] is not determined by zoning criteria, the ground acceleration appropriate for Malaysia can be chosen. The study is done using ground acceleration of 0.1g, 0.15g and 0.2g. Using this code, Buildings with 3, 5, 15, and 25 storeys are analyzed, representing low, medium and high rise buildings. The tabulated data is presented in Table 12. Table 11 is plotted as Figure 6 to observe the trends of the deflections with respect to the height of the structures. Based on Figure 6 and Table 11, it is observed that very low rise and high rise structures tend to have more effect toward seismic loading compared to medium rise structure, having deflection more than permissible values. However, UBC 1997[26] has seismic zoning location which is pre-determined in the code.

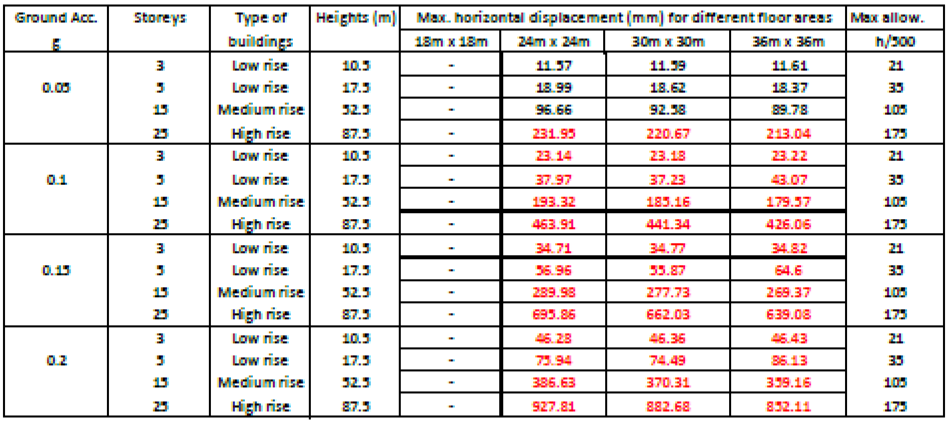
To study the horizontal displacements of buildings due to different magnitude ground accelerations, IS 1893 [7] is used. Based on table 12, low rise and medium rise buildings seem to be able to survive in ground acceleration of 0.05g. SEER mapping shows that Peninsular Malaysia so far only experience ground acceleration between 0.03g to 0.05g. Kuala Lumpur and Penang have not experienced 0.05g ground acceleration and no structural damage is reported due to earthquake so far. However, the study suggests that structural improvement for existing high rise with more than 77 meter height is required when ground acceleration is considered. Ground acceleration beyond 0.1g will cause severe damages to all moment resisting frame structure regardless their height. Having examined both UBC 1997 [26] and IS 1893 [7], it is seen that the behaviour of structures toward seismic load is independent of their base areas. Unlike wind loading where lateral load is represented by imposed area, seismic load is characterized by the weight of the whole structure. Lighter structures with lower base shear usually survive seismic load. As number of column usually proportionate to the weight of the building, proportional resistance also given by the column to resist seismic load. That explains the differences of deflection with respect to base areas are much lower compared to wind loading.

Table 11 Horizontal displacement based on UBC 1997 for Zone 2A



Storeys	Heights (m)	Max. horizontal displacement (mm) for different floor areas				Max allow.
		18m x 18m	24m x 24m	30m x 30m	36m x 36m	h/500
3	10.5	-	24.91	24.96	24.93	21
5	17.5	-	33.04	32.44	31.98	35
7	24.5	-	38.93	37.75	36.93	49
10	35	-	56.96	54.92	58.87	70
12	42	-	75.82	72.86	70.85	84
15	52.5	-	100.27	95.96	93.03	105
17	59.5	-	114.81	109.76	106.31	119
20	70	-	147.92	141.08	136.43	140
22	77	-	157.28	149.79	144.71	154
25	87.5	-	196.05	186.24	179.62	175

Table 12 Horizontal displacement for different ground accelerations based on IS 1893



Ground Acc. g	Storeys	Type of buildings	Heights (m)	Max. horizontal displacement (mm) for different floor areas				Max allow.
				18m x 18m	24m x 24m	30m x 30m	36m x 36m	h/500
0.05	3	Low rise	10.5	-	11.57	11.59	11.61	21
	5	Low rise	17.5	-	18.99	18.62	18.37	35
	15	Medium rise	52.5	-	96.66	92.58	89.78	105
	25	High rise	87.5	-	231.95	220.67	213.04	175
0.1	3	Low rise	10.5	-	23.14	23.18	23.22	21
	5	Low rise	17.5	-	37.97	37.23	43.07	35
	15	Medium rise	52.5	-	193.32	185.16	179.57	105
	25	High rise	87.5	-	463.91	441.34	426.06	175
0.15	3	Low rise	10.5	-	34.71	34.77	34.82	21
	5	Low rise	17.5	-	56.96	55.87	64.6	35
	15	Medium rise	52.5	-	289.98	277.73	269.37	105
	25	High rise	87.5	-	695.86	662.03	639.08	175
0.2	3	Low rise	10.5	-	46.28	46.36	46.43	21
	5	Low rise	17.5	-	75.94	74.49	86.13	35
	15	Medium rise	52.5	-	386.63	370.31	359.16	105
	25	High rise	87.5	-	927.81	882.68	852.11	175

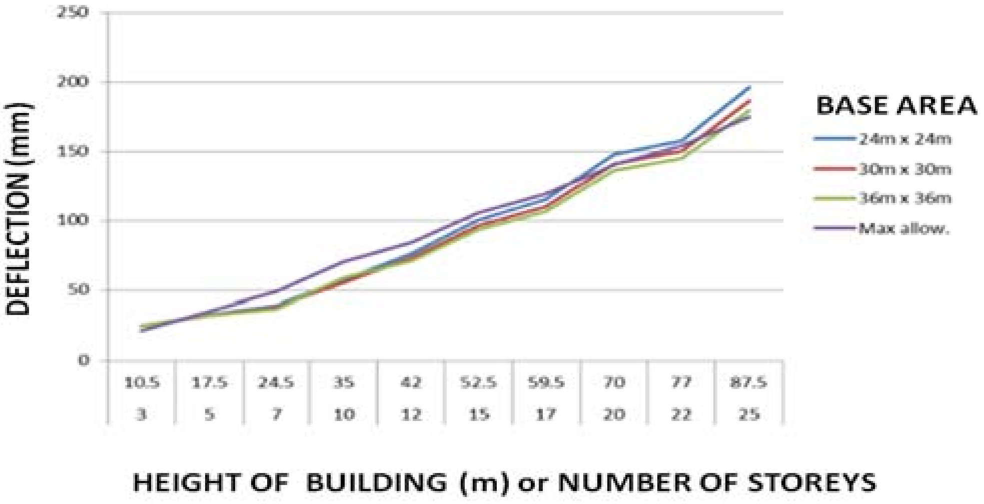


Figure 6 Maximum deflections vs. height of the structures due to EQ (UBC 1997)

CONCLUSIONS

The results of the study are presented in two sections.

The RVS study shows that most buildings in Penang & Perak are seismically safe (S>=2 low to moderate risk). The earthquake force on a building is a function of mass. Thus, seismic safety demands that the buildings be as light as possible, consistent with structural safety and functional requirements. Cantilever or projected parts should be avoided as far as possible. In order to minimize “torsion and stress concentration”, a building should have a simple rectangular plan, and should be symmetrical, both with respect to the mass and the rigidity of the structure [45]. For buildings with a basement, the ties should be placed at the level of the basement floor and should be designed to carry the load of the panel walls. These should also be designed to “tension” and “compression” loads, in addition to the axial load of not less than the earthquake force acting on the heaviest column connected [46]. Basement walls provide a “thrust area” which reduces the lateral force on the foundations. Raft foundations located on the well-compacted soil give added advantage. Existing building should be maintained properly to ensure the materials are well preserved and avoiding any cracks in concrete or corrosion of steel. If the final score, S, for the buildings is below 2; the surveyed buildings are hazardous and require detailed seismic evaluation (FEMA 154). From classification of the database result, most of high rise building in Penang and Perak are safe. This is because of most of the building use C1 (reinforced concrete moment resisting frame). For future high-rise project, improved design incorporating damper or base isolation system can be adopted. The structures can be analyzed using Response Spectrum Method or Dynamic Analysis.

The extended analysis gives the following conclusions:

1. The practical height of moment resisting frame without lateral loads design is

restricted at 25 storey (87.5m). Moment resisting frames are not recommended for structures beyond this height.

2. For new structures, it is recommended to consider seismic loadings for the design of low rise shop-house or bungalows as they are theoretically more vulnerable to seismic forces compared to medium rise structures
3. As current condition in Malaysia, study shows that all structures are safe for 35 m/s wind load and medium rise structures are safe for ground acceleration of 0.05g. These explain the zero documented structural failure so far due to these loads in Malaysia.
4. However, all structures theoretically will fail if the magnitude of wind loadings and ground accelerations are slightly increased beyond typical condition on Malaysia. So, most of old structures without enhancement could possibly fail if geological conditions in Malaysia get worse than the historical events.
5. Analysis using static method is considered as very conventional and conservative. Dynamic analysis method can be used as it includes the damping of the structures as well as the time factor of the loadings being imposed. It is always good to have comparison between the results of both static and dynamic analysis to see which one is more critical.

ACKNOWLEDGEMENTS

This paper was prepared as partial fulfillment of two undergraduate projects[30][41], and supported by the Universiti Teknologi PETRONAS, under the URIF PROJECT titled “Seismic vulnerability Assessment, Analysis and Retrofit of Special Structures”.

REFERENCES

[1] Adnan, A., Hendriyawan and Masyhur Irsyam, 2002, The Effect Of The Latest Sumatra Earthquake To Malaysian Peninsula, Journal Of Civil Engineering, 15, 2.

[2] Lagorio, H. J., 1990, Earthquakes: An Architect’s Guide to Non-Structural Seismic Hazard, John Wiley & Sons, Inc., USA.

[3] Murty, 2005, Learning Earthquake Design and Construction, IIT Kanpur – BMPTC Earthquake Tips. March.

[4] EC 2 Eurocode 2: Design of concrete structures: Part 1-1: General rules and rules for buildings

[5] EC 3 Eurocode 1993-1-1:2005: Design of Steel Structures. Part 1-1. General Rules for and rules for buildings.

[6] EC 8 Eurocode 1998-1:2004 Design of Structures for Earthquake Resistance – Part 1: General Rules, Seismic Actions and Rules for Buildings.

[7] IS 1893 Criteria for EQ Resistant Design of Structures Part 1 General Provisions

[8] FEMA 154, 2002, Rapid Visual Screening of Buildings for Potential Seismic Hazards: A handbook, March 2002

[9] Murty, 2013, Learning Earthquake Design and Construction, Classroom material, published by Resonance Coaching Centre. With permission.

[10] Arnold, C., and Reitherman, R., 1982, Building Configuration and Seismic Design, John Wiley, USA.

[11] Sucuoglu H. and Yılmaz, T., 2001, Düzce, Turkey: A city hit by two major earthquakes in 1999 within three months, Seismological Research Letters, 72(6), 679-689.

[12] Potty, N.S and Nambissan S., 2008, Seismic Retrofit Of Elevated Steel Water Tanks, International Conference on Construction and Building Technology ICCBT 2008, 16-20 June, Kuala Lumpur, Malaysia.

[13] Potty N.S. and Mohd Akram M.K.B., 2009, Structural Integrity Management For Fixed Offshore Platforms in Malaysia, World Academy of Science, Engineering and Technology, 58, pp. 1079 - 1087.

[14] Potty N.S. and Akram M.K.M., 2011, Development of a Risk Based Underwater Inspection (RBUI) Methodology for Malaysia Fixed Offshore Structure, 2011 National Postgraduate Conference – Energy and Sustainability: Exploring the Innovative Minds, NPC 2011, art. 6136363.

[15] Potty, N.S, Ahmad Fawaz, Nur Ilyani Hasimy, N.J. Cossa and Akram MKM, 2013, Strength Assessment of Fixed Offshore Platforms for life extension, IJAER.

[16] Narayanan, S.P. and M. Sirajudin, 2011, " Assessment of Building for Seismic Resistance", Malaysian Journal of Civil Engineering, 23, 1, 86-104 (Malaysian Journal of Civil Engineering (MJCE) is indexed by MyAIS and Malaysian Citation Index)

[17] Potty N.S. and Sirajuddin, M, 2011b, Seismic Risk Assessment Of Buildings In Kollam India, Bitech2011 International Building And Infrastructure Technology Conference 2011, June 7-8. ISBN 978-967-394-029-5.

[18] Potty N.S. and M.Sirajjudin, 2011a, Non Linear Seismic Analysis of Masonry Structures, Journal of Design and Built environment, University Malaya, 9, 1-16, December.

[19] IS 875(3) 1987 – COP for Design loads for buildings and structures: Wind Loads. Indian Standard.

[20] MS 1553:2002, Malaysian Standard, COP on Wind Loading for Building Structure.

[21] Bhandari N.M., Prem Krishna, Krishen Kumar, Abhay Gupta, An explanatory HB on proposed IS 875 (3): Wind Loads on Buildings and Structures, IITK – GSDMA Project on Building Code.

[22] BS 5400 - 2: 1978 British Standard. Steel, concrete and composite bridges

[23] BS 8110-1:1997 British Standard Structural use of concrete

[24] BS 5950 - 1- Structural use of steelwork in building

[25] AASHTO. 2007. LRFD Bridge Design Specifications, 4th Ed., American Association of State Highway and Transportation Officials, Washington, DC.

[26] UBC 1997, Uniform Building Code.

[27] Koong, N. K., & Won, K. W., 2005, Earthquake Hazard and Basic Concepts of Seismic Resistant Design of Structures. Master Builders.

[28] IEM, 2005, Position Paper on Issues Related to Earthquake. Petaling Jaya: The Institution of Engineers, Malaysia.

[29] Ngu, K., 2005, Earthquake Hazard and Basic Concept of Seismic Resistant Design of Structure. Master Builders 4th quarter, pp. 90-95.

[30] Hamid, M.R.A, 2012, Analysis of Existing High-Rise Reinforced Concrete Structures in Malaysia Subjected to Earthquake and Wind Loadings, UG Thesis, Department of Civil Engineering, UTP, September.

[31] Wikipedia, 2012, October 17, Skyscraper Design and Construction. Retrieved November 8, 2012, from Wikipedia : http://en.wikipedia.org/wiki/Skyscraper_design_and_construction.

[32] Ali, M. M., & Moon, K. S., 2007, Structural Development in Tall Buildings: Current Trends and Future Prospects. Architectural Science review, 205-223.

[33] FEMA 155, 2002, Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation, March 2002

[34] Jain S. K., Mitra, K. Praseeda K. I., 2004, A Proposed Rapid Visual Screening Procedure for Seismic Evaluation of Buildings in India, January, 2004.

[35] ATC-21, (2004). Rapid visual screening of buildings for potential seismic hazards: A handbook, Applied Technology Council, Second Edition, CA, USA.

[36] BS 6399: 1: 1997 British Standards. Loads for buildings: COP for dead and imposed loads

[37] BS 6399: 2: 1997 British Standards. Wind loads for buildings

[38] BS 648: 1964 British Standard. Schedule of weights of building materials

[39] Shafii, F. and Othman, M. Z., 2004, Country Report: Wind Loading for Structural Design in Malaysia. APEC-WW-21st Century Centre of Excellence Programme. Kanagawa: Universiti Teknologi Malaysia.

[40] Bentley System, Inc., 2012, Top Reasons To Buy STAADPro.

[41] Rosli, M. A, 2012, Seismic rating on High-Rise Building in Penang and Perak, UG Thesis, Department of Civil Engineering, UTP, May.

[42] Griffis, L., 2003, Serviceability Limit States under Wind Load. Engineering Journal/American Institute of Steel Construction.

[43] ASCE, 1988, Wind Drift Design of Steel-Framed Buildings: State-of-the-Art Report, " Journal of Structural Engineering, Volume 114, No. 9, September.

[44] R.C. Cooney and A.C King, 1988, The Branz Report: Serviceability Criteria for Buildings, Building Research Association of New Zealand.

[45] Sharfuddin, M. 2000. Earthquake hazard analysis for Bangladesh. M.Sc. Engg. Thesis, BUET.

[46] Ansary, M.A., 2001, Earthquake damage scenario for Sylhet, Bangladesh. 7th US National Conference on Earthquake Engineering.