EFFECT OF STOREY HEIGHT ON SEISMIC PERFORMANCE OF ELEVATED REINFORCED CONCRETE WATER TANK

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ABSTRAK

Kajian ini adalah untuk mengkaji kesan ketinggian tingkat pada kekuatan sisi tangki air konkrit bertetulang disebabkan oleh gempa bumi. Tangki air konkrit bertetulang adalah struktur yang paling penting untuk membekalkan permintaan air kepada pengguna. Oleh itu, struktur ini harus kukuh dan kuat ketika bencana seperti gempa bumi. Ianya juga harus kekal berfungsi selepas bencana gempa bumi berlaku kerana tangki air sangat diperlukan untuk membekalkan air minum dan kerja-kerja memadamkan api. Walaupun begitu, reka bentuk seismik tidak diambil berat oleh jurutera awam di Malaysia bagi hampir semua bangunan. Sejak kebelakangan ini, tanda-tanda gempa bumi mula berlaku di beberapa kawasan dalam Malaysia dan juga negara-negara jiran seperti Indonesia dan Filipina. Gegaran yang berlaku di negara jiran telah meninggalkan kesan kepada struktur konkrit bertetulang di Malaysia di mana struktur yang ada tidak direka bentuk untuk menentang beban seismik. Objektif kajian ini adalah untuk menjadi dan menganalisis kesan ketinggian tingkat kekuatan sisi tangki air konkrit bertetulang yang tinggi dan untuk mengkaji kesan ketinggian tingkat di nisbah tingkat hanyut antara tangki air konkrit bertetulang. Kaedah yang telah digunakan dalam kerja-kerja ini adalah Pushover Analysis (POA) menggunakan perisian SAP 2000. POA adalah salah satu kaedah yang digunakan dalam untuk penialaian prestasi struktur seismik. Projek ini menggunakan dua model asas tangki air konkrit bertetulang yang mempunyai empat dan tujuh tingkat. Dua model ini telah direka bentuk berulang kali dengan ketinggian tingkat yang berbeza. Semua model telah direka bentuk berdasarkan BS8110 untuk mewakili tangki air konkrit bertetulang yang telah sedia ada. Keputusan yang diberi oleh POA menunjukkan keluk kapasiti dalam bentuk tenaga asas ricih berbanding anjakan bahagian tingkat. Daripada keputusan yang diperoleh, kajian ini membuat kesimpulan bahawa model dengan ketinggian tiang pendek cenderung mempunyai daya ricih asas yang lebih tinggi berbanding model dengan ketinggian tiang yang lebih tinggi.

ABSTRACT

This research is to study the effect of storey height on the lateral strength of elevated reinforced concrete (RC) water tank due to earthquake. Elevated RC water tank is the most important structure to supply the water demand for users. Therefore, these structures must survive during disaster like earthquake. It must remain functional even after the earthquakes as water tanks are required to provide water for drinking and firefighting purpose. However, seismic design was not concerned by Civil Engineers in Malaysia almost in all of the building. Recently, few earthquake start occurring in few regions in Malaysia and neighboring country like Indonesia and Philippines. The tremors occur in this neighboring country affect the reinforced concrete structure in Malaysia which the structural in Malaysia are not design to resist seismic loading. The objective of this study is to model and analyses the effect of storey height on the lateral strength of elevated RC water tank and to investigate the effect of storey height on the interstorey drift ratio of elevated RC water tank. Method that been used in this work is the pushover analysis (POA) using SAP 2000 software. POA is the one of the method that been used for seismic performance evaluation of structures. Two basic models of elevated RC water tank which have four and seven storeys has been used for this project. These two models are designed repeatedly with different storey height. All models are designed based on BS8110 to represent the existing elevated RC water tank. The results of the POA give a capacity curve in form of base shear force versus top storey displacement. From the result, this study conclude that model with shorter column height tend to have higher base shear force compared to model with longer column height.

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LIST OF SYMBOLS

kN	kiloNewton
kN/m^2	kiloNewton per square meter
E	Modulus of elasticity
mm	Millimetre
N/mm^2	Newton per square millimetre

LIST OF ABBREVIATIONS

MMD	Malaysian Meteorological Department
RC	Reinforced Concrete
P-M3	Moment-axial load with moment-curvature
M3	Moment-curvature
IDR	Interstorey Drift Ratio

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Earthquake or seismic tremor may cause the building to collapse and the death of thousands of people due to a movement of the surface of earth because of release of internal energy from the core of earth at a sudden. The main cause of quake is the orogenic motion such as mountain building and valley farming, subduction and plate convection followed by geothermal and mechanical disturbances, volcanic activities, and land erosion.

Many earthquakes had happened in the world due to the movement of tectonic plate. Peninsular Malaysia has experienced feeble local earthquakes and been jolted by distant seismic tremors from Sumatera. East Malaysia has recorded moderate scale tremors of magnitudes in the vicinity of 3.6 and 6.5 between year 1984 and 2007 (Sooria and Sawada, 2012). However, in Malaysia, the strongest earthquakes struck Ranau, Sabah, Malaysia on 5 June 2015 at a depth of approximately 10 km. Figure 1.1 presents the location of epicenter which is approximately 15 km north of Ranau and lasting for thirty seconds. The Malaysian Meteorological Department (MMD) reported the earthquake's magnitude to be 6.0 Ritcher scale. The magnitude can be categorized as moderate. Although not as bad as other countries, it still remains a negative impact on the structures. This is because buildings in Malaysia are mostly not built according to seismic design. Murti (2012) stated that earthquake causes shaking of the ground. So a building resting on it will experience motion at its base which later propagates toward the top part of the building.

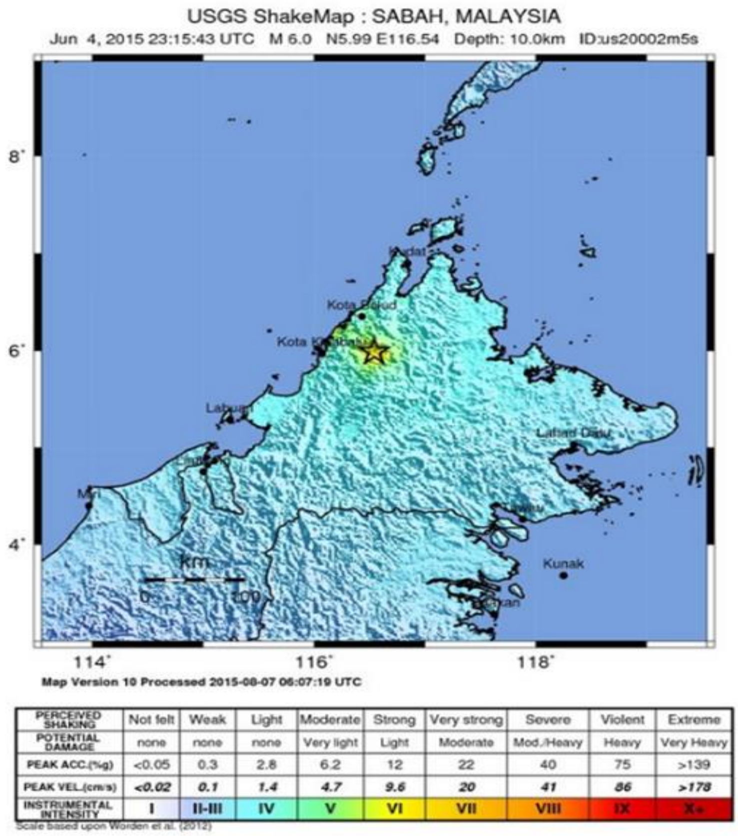


Figure 1.1 Epicentre of the earthquake (USGS, 2016)

The engineers do not attempt to make earthquake proof buildings that will not get damaged even during the rare but strong earthquake. Such buildings will be too robust and also too expensive. Instead, engineering expectation is to make structures as earthquake resistant, which the building resists the impacts of ground shaking, in spite of the fact that it may get damaged severely yet would not collapse during the strong earthquake. Therefore, safety of peoples and contents is assured in earthquake resistant buildings and thereby, a disaster is avoided. This is the main objective of seismic design codes throughout the world. To find out the behavior of structural system, seismic design and assessment of structure can be done. The important parameters such as stiffness, strength and ductility define the behavior of the structures. All those parameters are influenced by the material properties, section properties, member properties and connection properties. In designing the building, the engineers should considering all these parameters to prevent it from failure.

1.2 Problem Statement

Elevated reinforced concrete (RC) water tank is the most important structure to supply the water demand for users. Therefore, these structures must survive during disaster like earthquake. It must remain functional even after the earthquakes as water tanks are required to provide water for drinking and firefighting purpose. If the effects of lateral loading are underestimated, then it could bring failure to the elevated RC water tank. The performance of buildings when subjected to earthquakes depends on its material, section, member, connection, and system properties. Majority of elevated RC water tank in Malaysia had been designed by referring to BS 8110 (1997) without considering seismic load. One of the failure and formation of plastic hinge at the beam-column joint of water tank is shown in Figure 1.2.

The nonlinear static analysis for the lateral load distribution can be carried out with pushover analysis on RC structures to study its vulnerability due to earthquake load. To determine the yield state and ductility of structure, this method is employed. Pushover analysis is mainly based on the assumption that the response of the structure is controlled by the first mode of vibration and mode shape, or by the first few modes of vibration, and that this shape remains constant throughout the elastic and inelastic response of the structure. In pushover analysis, the behavior of the structure is characterized by a capacity curve that represents the relationship between the base shear force and the displacement as illustrated in Figure 1.3.

As mentioned in previous paragraph, the elevated RC water tank in Malaysia had been designed according to BS 8110 (1997) without seismic consideration. Therefore, it is important to evaluate the seismic capacity of existing elevated RC water tank since it is very important in water distribution system. In this study, the seismic capacity of elevated RC water tank had been evaluated by using pushover analysis method.

Figure 1.2 Failure and formation of plastic hinge at the beam-column joint of water tank in the South Andaman Island, India (Rai, 2006)

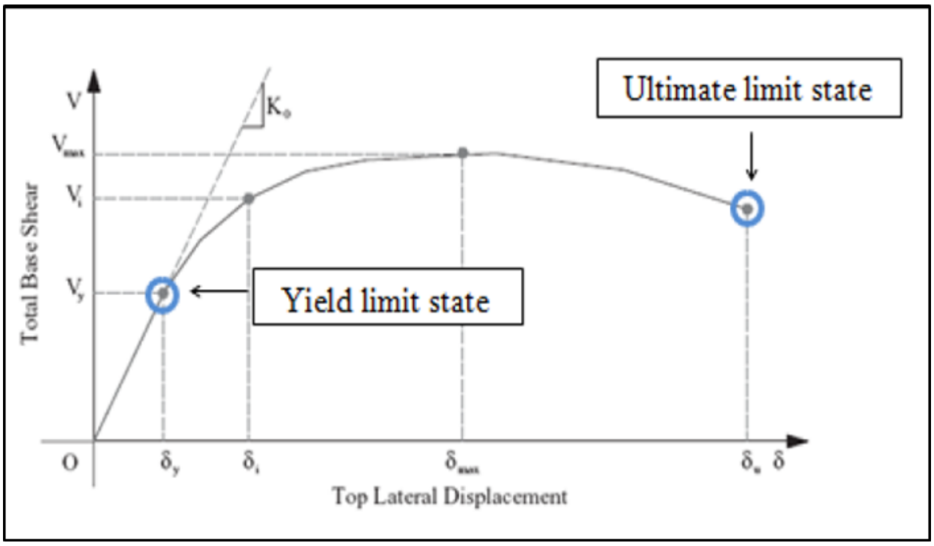


Figure 1.3 Capacity curve, (Elnashai and Sarno, 2008)

1.3 Objective

The main objectives of this research are listed below:

i. To study the effect of storey height on the lateral strength of elevated RC water tank.

ii. To investigate the effect of storey height on the interstorey drift ratio (IDR) of elevated RC water tank.

1.4 Scope of Work

This study covered and focused in the following aspect :

i. Two basic elevated RC water tanks serve as the main model which is four storey and seven storey.

ii. There are five models for each basic elevated RC water tank.

iii. The models been designed based on BS8110 (1997) to represent the existing elevated RC water tank in Malaysia.

iv. Each model had been designed based on different storey height.

v. CUMBIA Program had been used to analyze nonlinear properties of structural members.

vi. Pushover analysis by SAP 2000 been conducted on every model.

vii. The results outcomes are presented in term of capacity curve, lateral displacement at yield, and IDR.

CHAPTER 2

LITERATURE REVIEW

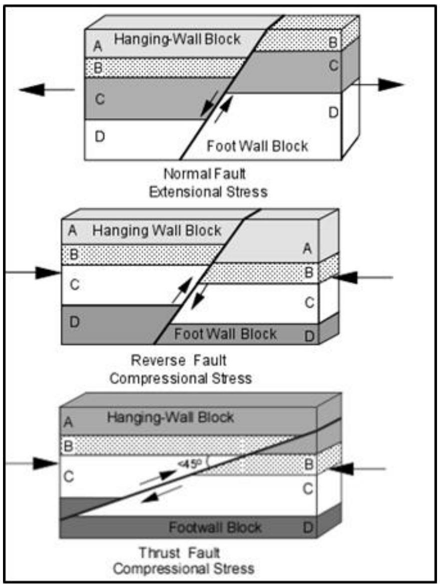
2.1 Introduction

Earthquakes happen when energy stored in elastically strained rocks is suddenly released. This release of energy causes extraordinary ground shaking in the region close to the source of the quake and sends waves of elastic energy, called seismic waves, throughout the Earth. Earthquakes usually occur without warning. Earthquake may cause loss of life and destruction of property. Quakes can last for short or long periods of time and sometimes followed by aftershocks.

Most natural earthquakes are caused by sudden slippage along a fault. Faults happen when brittle rocks fracture and there is displacement of one side of the fracture in respect to the opposite side. There are several types of faults depending on the direction of relative displacement or slip on the fault. However, there are two major classes type of faults which is “dip-slip faults” and “strike-slip faults” as illustrated in Figure 2.1.

Dip-slip faults are faults that have inclined fractures where the blocks have mostly moved vertically. When the block above the fault has moved down, the fault termed as normal faults. Normal faults are faults that effect from horizontal extensional stresses in brittle rocks. While, faults that caused from horizontal compressional stresses in brittle rocks called reverse faults. Reverse faults is where the block upper the fault has moved up. Furthermore, thrust fault is a special case of a reverse fault where the dip of the fault is 45^{o} or less.

Strike-slip faults are faults where the displacement on the fault has taken place along a horizontal direction. Strike slip faults can be of two varieties, depending on the displacement. If the block opposite an observer looking across the fault moves to the right, we say that the fault is a right-lateral strike-slip fault. If the block on the other side has moved to the left, the motion is termed left lateral strike-slip fault. An example of a right-lateral strike-slip fault is San Andreas Fault in California. Great San Francisco Earthquake occurs on 18 April 1906 with duration 45 to 60 seconds. The tremor ruptured the San Andreas fault to the north and south of the city. The magnitude reported 7.8 Richter scale. Length of fault ruptures about 300 miles (USGS, 2005).



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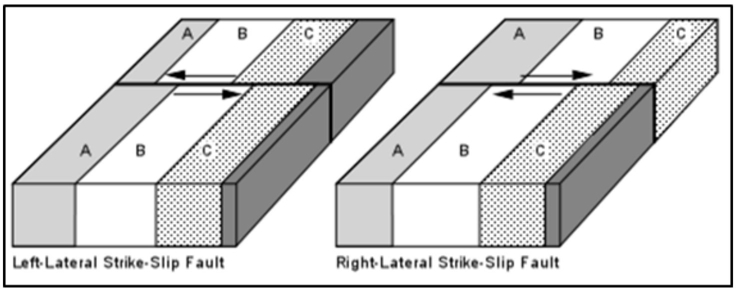


(b)

Figure 2.1 Fault mechanism (a) Dip-slip faults (b) Strike-slip faults (Nelson, 2015)

Malaysia faces low to medium earthquake risks due to fault movements within the country (both onshore and offshore), such as in Sabah, Peninsular Malaysia and Sarawak. Major earthquakes with long period surfaces waves originating from Sumatera, Indonesia, have been felt in Malaysia, particularly along the west coast of Peninsular Malaysia (Adiyanto, 2016). The list of frequency and maximum intensity recorded on each state in Malaysia is described in Table 2.1. Due to the occurrence of earthquakes, the seismic assessment and design of structures is required. Earthquakes are caused by differential movements of the earth's crust (Kramer 1996). In designing the structure, it is important to know the ability of the building when subjected to seismic loading. To estimate strength capacities and deformation demands, non-linear static pushover analysis is a simpler option (Lawson et. al, 1994). It is a tool for seismic performance evaluation of existing and new structure.

Table 2.1 Earthquake Intensity recorded in Malaysia (MMD, 2010)

State	Frequency	Maximum Intensity (Modified Mercalli Scale)
Peninsular Malaysia (1909 - 2010)		
Perlis	3	V
Kedah	18	V
Penang	41	VI
Perak	24	VI
Selangor	52	VI
Negeri Sembilan	14	V
Melaka	19	V
Johor	32	VI
Pahang	35	III
Terengganu	2	IV
Kelantan	3	IV
Kuala Lumpur / Putrajaya	38	VI
Sabah (1897 - 2010)		
Sabah	41	VII
Sarawak (1874 - 2010)		
Sarawak	17	VI

2.2 Nonlinear Static Pushover Analysis

Since inelastic behavior is intended in most structures subjected to infrequent earthquake loading, the use of nonlinear analysis is essential to capture behavior of structures under seismic effects. Due to its simplicity, the structural engineering profession has been using the nonlinear static procedure or pushover analysis (FEMA356, 2000). Pushover analysis is a process where a structure imposed under permanent vertical loads and gradually increasing lateral loads. With the increase in the magnitude of the loading, weak links and failure modes of the structure are found (Habibullah and Pyle, 1998).

Pushover analysis is a method which the building is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is achieved. In pushover analysis, two or three dimensional model must consider nonlinear behavior of structure or elements which is model requires the determination of the nonlinear properties of each component in the structure that are measured by strength and deformation capacities.

Furthermore, pushover analysis can be executed as force-controlled or displacement controlled. Force-controlled should be used when the load such as gravity loading is known. In force-controlled pushover procedure, full load combination is used. In displacement-controlled procedure, the magnitude of applied load is unknown such as seismic loading. The magnitude of load combination is increased or decreased as necessary until the control displacement achieved a specified value. Generally, top displacement at the center of mass of structure is chosen as the control displacement. Chopra (2001) stated that pushover analysis procedure in light of structural dynamic theory, which conceptually and computationally simple maintains current processes with invariant force distribution, but gives high accuracy in estimating seismic demands on structures. Because of that, for seismic performance evaluation of structures by the major rehabilitation guidelines and codes, the pushover analysis method is preferred.

2.3 Outcome from Pushover Analysis

Capacity curve which obtained by pushover analysis represents the relationship between base shear force and top displacement. It explains the behavior of the structure as shown in Figure 2.2. Capacity curve defines how a structure behaves beyond the elastic limit. When lateral load is applied to buildings the damage increase as the load and deformation resistance is lowered. Capacity curve can trace the sequence of yielding and failure on member and structural level.

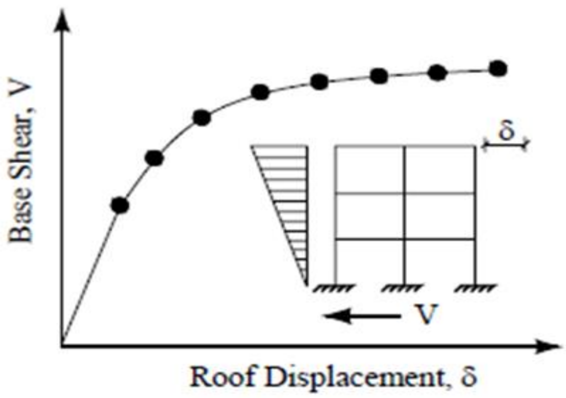


Figure 2.2 Capacity curve of a structure (Oguz, 2005)

Krawinkler and Seneviratna (1998) stated that pushover analysis come out with information on many response characteristics that cannot be obtained from an elastic static or elastic dynamic analysis. There are as following:

- In estimating the interstorey drifts and its distribution along the height
- Determine the force demands on brittle members, such as axial force on columns and moment on beam-column connections
- Identify of location of weak points in the structure
- Significance of strength deterioration of individual members on the behavior of structural system
- Determination of strength discontinuities in plan or elevation that will lead to changes in dynamic characteristics in the inelastic range

- Verification of the completeness and adequacy of load applied

Moreover, pushover analysis also reveals design weaknesses that may remain hidden in an elastic analysis such as story mechanisms, immoderate deformation demands, strength irregularities and overloads on potentially brittle members.

2.4 Moment-Curvature

The section analysis is carried out by tabulating moment and curvature of the member section for increasing levels of concrete strain. Moment-curvature represents the strength and deformation of a building.

Moment-curvature relationships are essential to find out ductility of the structure and the amount of possible redistribution of stresses. Ductility is the deformation capacity of a member or structure after the first yield.

Furthermore, the moment-curvature is commonly used for beam and column members, whereas the moment-axial is used for column member only. Structure is composed of many structural members such as beam and column which is connected to each other in structural system. Thus the nonlinear behavior of a section contributes to the nonlinear behavior of the structure.

The triliniear relation can be illustrated as in Figure 2.3 for light RC section which is under-RC section in the form of typical moment-curvature relationship. This graph represents the strength and deformation information of structural element in flexural. Firstly it will crack, then second stage is to yield of the tension steel, and the third stage is limit of useful strain in concrete (Kwak and Kim, 2002).

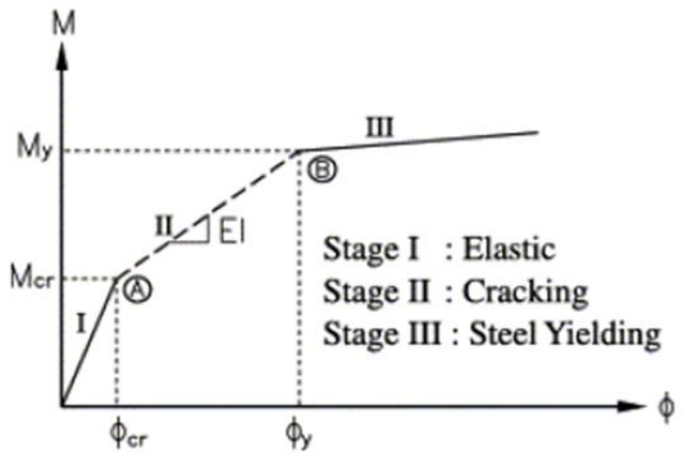


Figure 2.3 Idealized moment-curvature relation (Kwak and Kim, 2002)

2.5 Program Description

In this study, in order to perform monotonic moment-curvature analysis and force displacement response of RC members, CUMBIA program is employed. CUMBIA is a set of Matlab language by Montejo and Kowalsky (2007). The section analyses from CUMBIA program are required as an input to analyze pushover analysis using SAP 2000 software.

Nonlinear static pushover analysis highly offered in the nonlinear version of SAP 2000. Other than that, both two and three dimensional structural models can be performed in pushover analysis. However, in this study, two dimensional model of elevated RC water tank was used. The software of SAP 2000 is the simplest, most helpful, as well as practical solution for the design and structural analysis.

2.6 Summary

Almost all buildings in Malaysia were not designed to resist seismic loading. However, engineers nowadays start to realize about the significance of earthquake hazard in Malaysia. Previous literatures show the methods to evaluate the seismic performance of existing and new structure. The section analysis process comes out the result of moment-curvature and axial-moment interaction. This section analysis is required as input to perform the pushover analysis.

This study presents the comparison of the capacity curve between shorter column height and longer column height of elevated RC water tank using recommended methods which is the pushover analysis by software SAP 2000.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology is an arrangement of technique, guidelines, or thoughts that are vital in a specific technique. Methodology likewise is an arrangement of work or process that we are plan to do from the start of our research until the finish of our research. The methodology must be all around wanted to stay away from any overlapping activities, time conflict in any work, and other unforeseen issues. The best strategy must be considered in deciding the flow of the research so that the objectives and the expecting result can be obtained in the given time.

A methodology flowchart is provided in Figure 3.1. It is set up to simplify the step of work done through this project. The problem statement and scope of study had been determined in the preliminary stage alongside the title of the research. To study the effect of storey height on seismic performance of elevated reinforced concrete (RC) water tank, two basic elevated RC water tanks were selected as the main model which is four and seven storeys. Then, study of literatures review was conducted. All the reviews are from journals, books, and some website. Study the methodology to be utilized as the key part of this research which is modeling and analysis of the structure also had been conducted. Generating the model and run analysis to get the detailing of structural members had done by using ESTEEM software.

Next, CUMBIA program was used to determine the moment-curvature and axial-moment interaction in section analysis for the structural members. It is important to determine the nonlinear properties of every structural member so the nonlinear analysis can be conducted. Then, the outputs from CUMBIA are used as input in SAP 2000. The analysis that carried out in SAP 2000 is pushover analysis. After the results are acquired from the analysis, the conclusions are made together with the recommendation for future work.

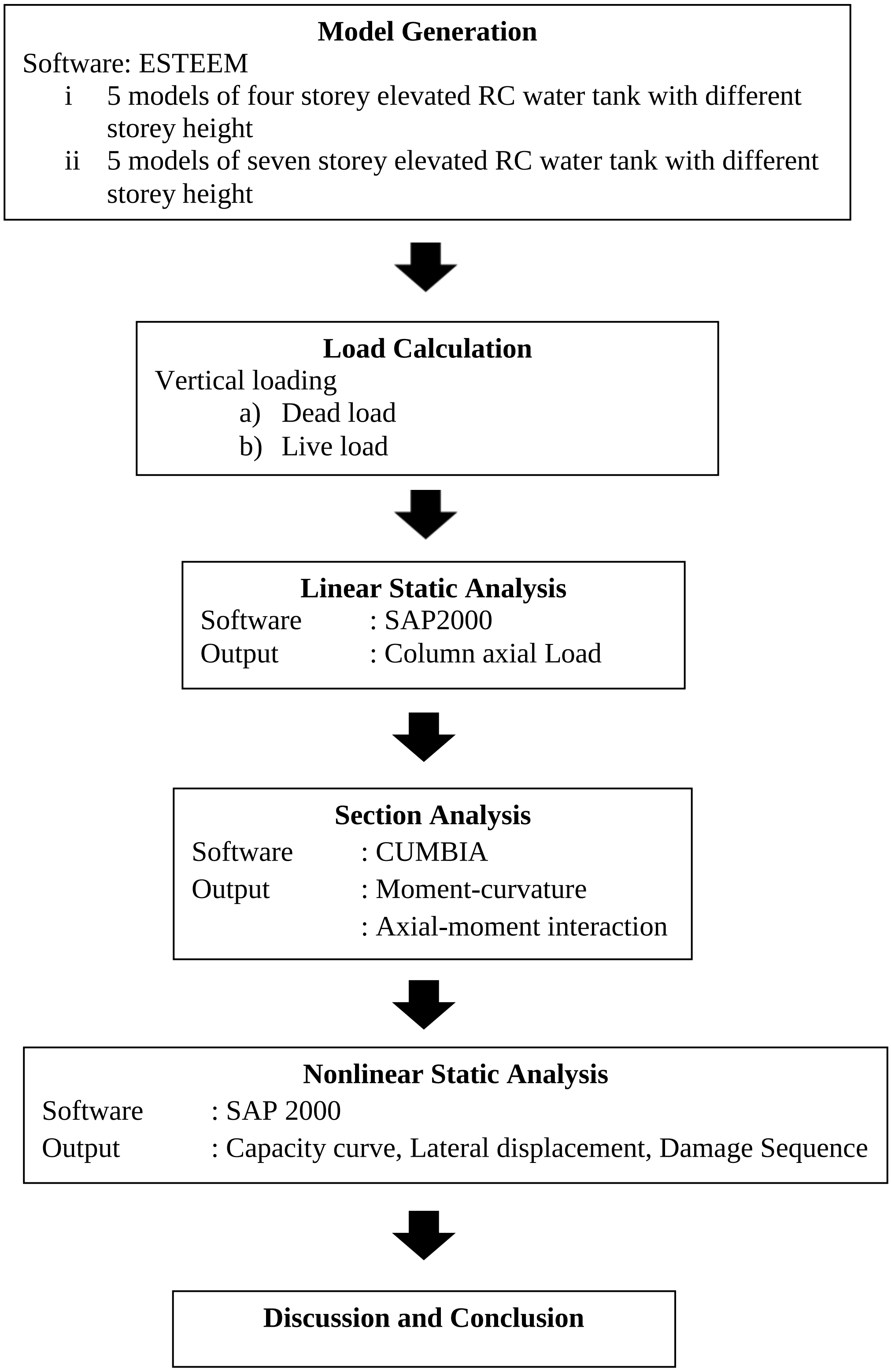


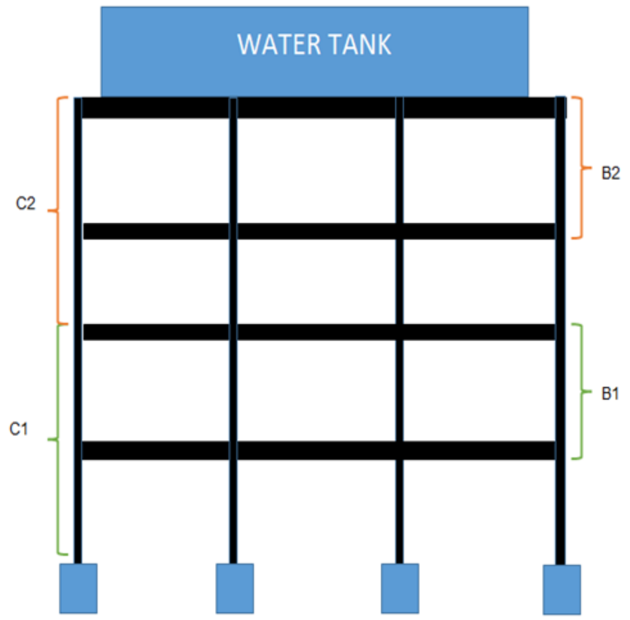
Figure 3.1 Flow chart of research methodology

3.2 Model Generation

Two basic models of elevated RC water tank were selected as the main model which is four and seven storeys. These two models were designed repeatedly with different storey height. There are five models for each basic elevated RC water tank. Each model had been designed according to different storey height. In the end, a total of ten models had been analyzed using the pushover analysis. All models were designed based on BS8110 (1997) to represent the existing elevated RC water tank in Malaysia by using ESTEEM software. The material properties and frame section properties used for the structure in modeling and design are as shown in Table 3.1. Figure 3.2 shows the elevation view of the four and seven storey elevated RC water tank with labeling of beam and column. The detail drawings of these two elevated RC water tank are shown in Appendix A.

Table 3.1 Material properties for design purpose

Material	**Unit**
Unit Weight of concrete	24 kN/m^3
Concrete compressive strength, f_{cu}	30 N/mm^2
Yield strength of steel, f_y	460 N/mm^2
Transverse steel yielding stress, f_{yv}	250 N/mm^2
Concrete cover	30 mm



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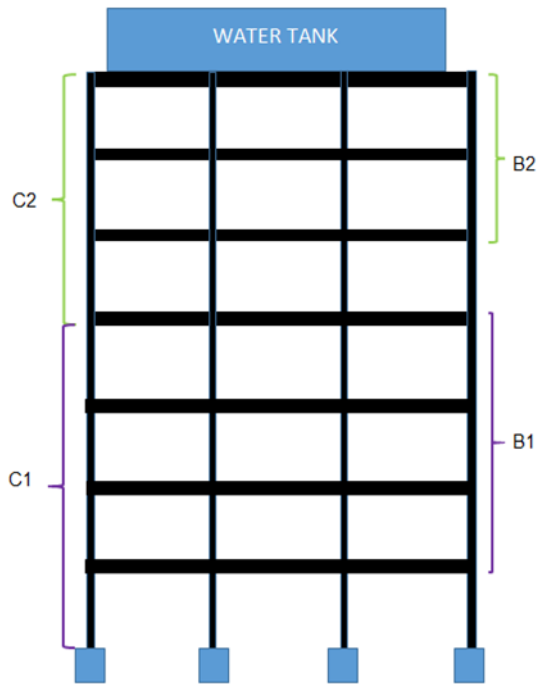


(b)

Figure 3.2 Elevation view for elevated RC water tank models (a) four storey model (b) seven storey model

For the four storey model in Figure 3.2 (a), B1 represents for first and second floor beam which has size 250mm x 450mm. Third and fourth floor beams are represented by B2 that has beam size 200mm x 400mm. C1 represents for columns in first and second floor of the elevated RC water tank. C2 represents as columns in third and fourth floor. The column size of C1 and C2 is 400mm x 400mm and 350mm x 350mm, respectively.

For the seven storey model in Figure 3.2 (b), B1 represents for beams which has size 400mm x 650mm and C1 represents for columns with size 400mm x 400mm in first floor until fourth floor. While, B2 and C2 represent beams and columns, respectively for fifth, six and seven floor. For size of beam B2 and column C2 is 350mm x 650mm and 350mm x 350mm, respectively. Table 3.2 show the storey height of all models used in this research.

Table 3.2 List of storey height (m) for model N4 and N7

Model N4	Model N7	Storey Height (m)
N4A	N7A	3.3
N4B	N7B	3.6
N4C	N7C	3.9
N4D	N7D	4.2
N4E	N7E	4.5

3.3 Loading Calculation

3.3.1 Vertical Loading

Live load and dead load are calculated from the structural plan based on BS8110 (1997). Data required for loading calculation are dimensions of beam, column, concrete grade, slab thickness and size of water tank. Figure 3.3 and Figure 3.4 are the layout for four storey model and seven storey model with frame that had been considered in this project, respectively. The calculation for loading is displayed in Appendix B.

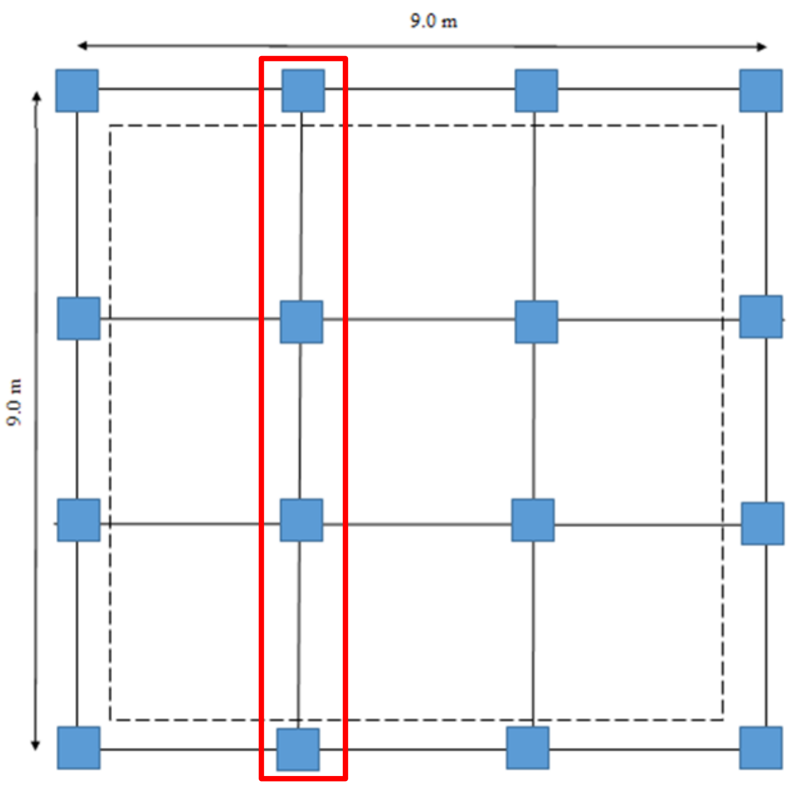


Figure 3.3 Layout for four storey model

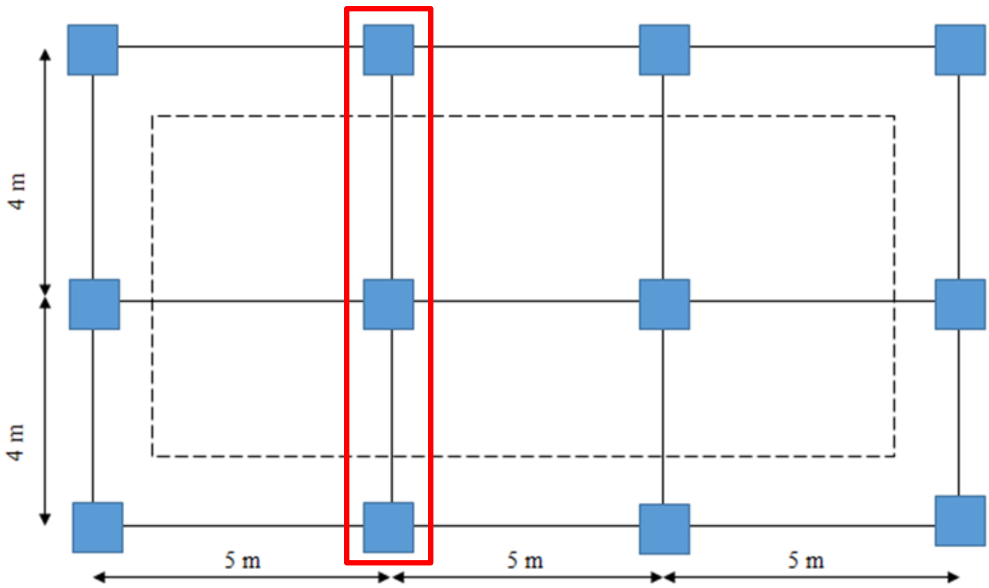


Figure 3.4 Layout for seven storey model

3.4 Linear Static Analysis

To find the axial forces for section analysis, linear static analysis was carried out using SAP 2000. Firstly, the formation of the geometry of structure and member section must be established. By using SAP 2000, started the new model and set the unit kN,m,C. Two-dimensional (2D) frame are selected as shown in Figure 3.5. Then the information of frame which is number of stories, storey height, number of bays and bay width are required in the portal frame dimensions as shown in Figure 3.6. The supports were assigned to be fixed as shown in Figure 3.7.

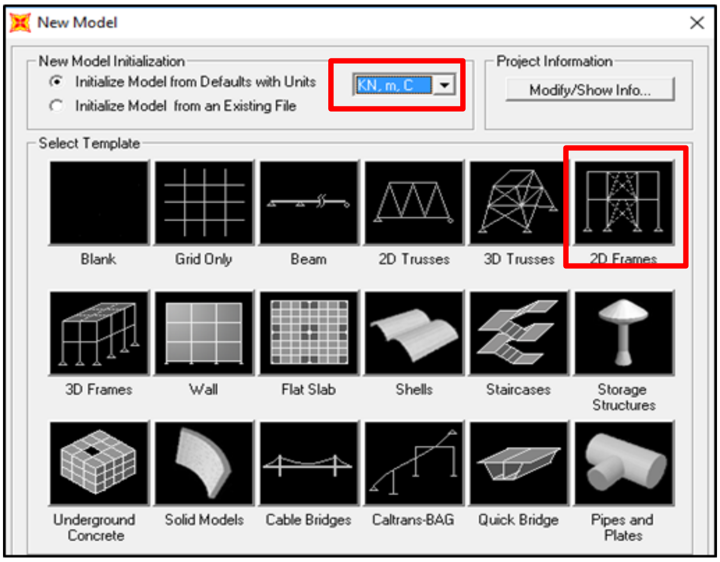


Figure 3.5 Geometry of structure and member section

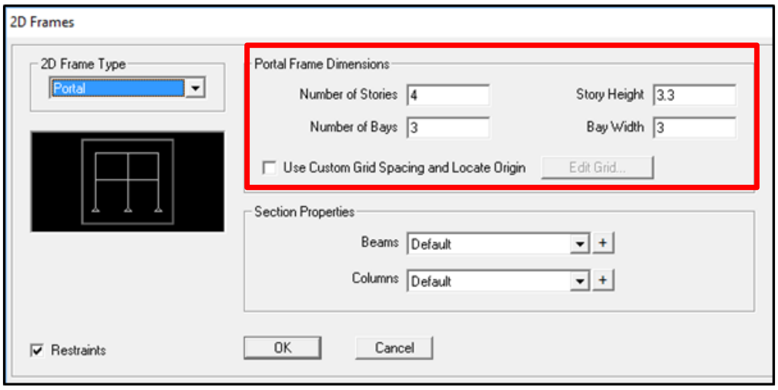


Figure 3.6 Portal frame dimensions

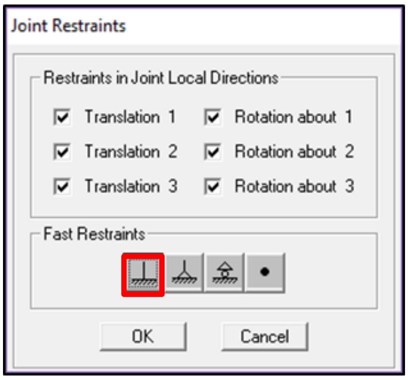


Figure 3.7 Joint restraint for support at base

The material property data as shown in Figure 3.8 is required by adjusting the material name and display code as “CONC” which means material type as concrete. Then, the value of weight per unit volume of concrete and modulus of elasticity, E used as 24 and 30000000 kN/m^2, respectively. The default value is used for other parameters.

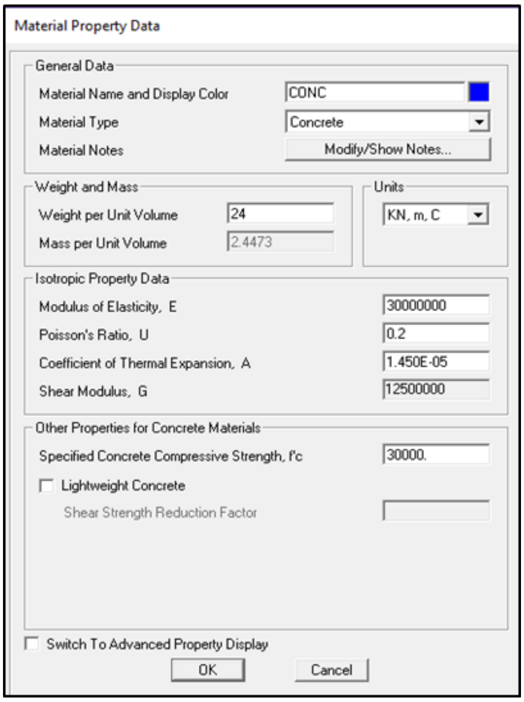


Figure 3.8 Material property data

To define the section properties, select frame property type which is concrete and rectangular as section shape as shown in Figure 3.9. After that, enter the name of the section member and dimensions as shown in Figure 3.10. This step is repeated to add all section members in the frame. Then the loading is specified. Dead load and live load stated in load pattern as shown in Figure 3.11.

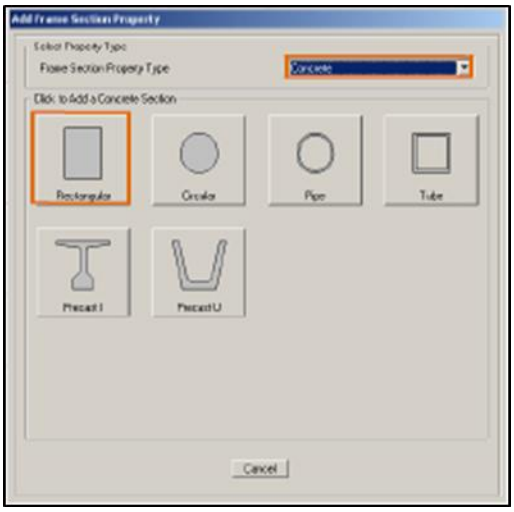


Figure 3.9 Frame section properties

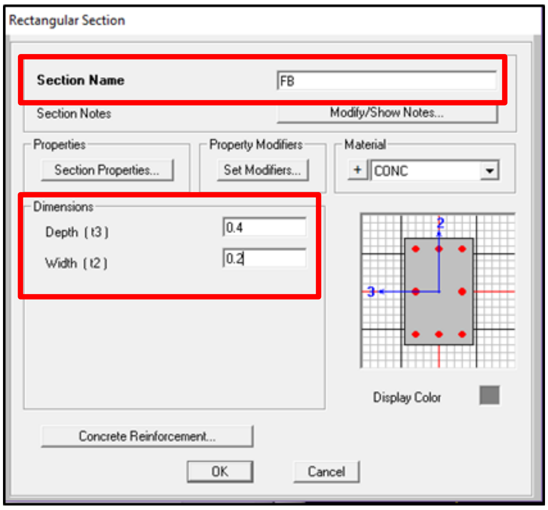
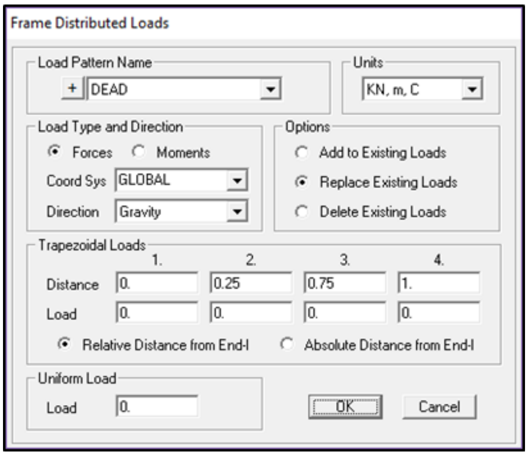
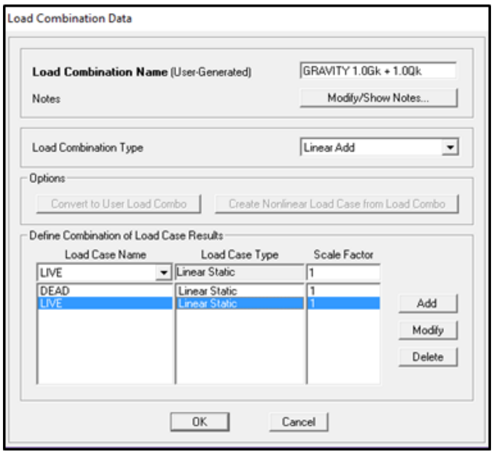


Figure 3.10 Characteristic of rectangular section



(a)



(b)

Figure 3.11 Assigning load process in SAP 2000 (a) Window to assign magnitude of loading (b) Window for load combination

To define the axial force reaction in all columns, elastic static analysis for the gravity load case is run. The values on diagram shown by clicking “display”, “show forces/stresses”, then choose “frame/cables”. Select “gravity” as “case/combo” and choose axial force as component and then the diagram of axial force value will be displayed.

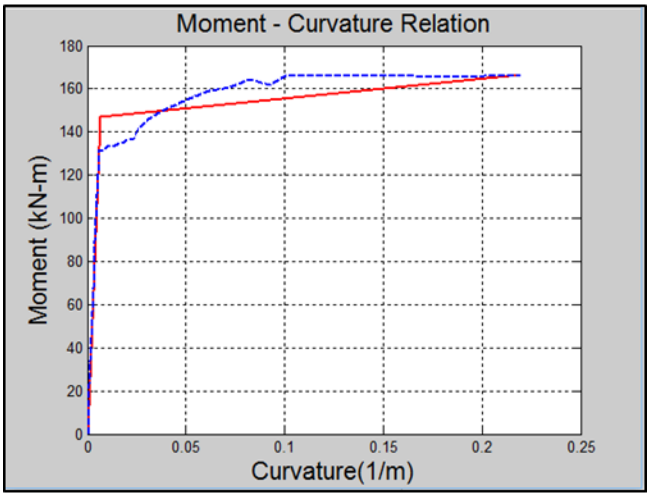
3.5 Section Analysis

In this work, CUMBIA program was used to perform the section analysis for all structural members. The input in CUMBIA program is shown in highlighted box in Figure 3.12. Then, the output in term of moment-curvature relation is shown in Figure 3.13.

```
name = 'N7A FB           '; %identifies actual work, the output file will be name.xls

interaction = 'n';  % if you want to also perform an axial load - moment interaction
                    % analysis type 'y', otherwise type 'n'

% section properties:

H     = 550;                       % section height (mm)- perp to x
B     = 300;                       % section width  (mm)- perp to y
ncx   = 2;                         % # legs transv. steel x_dir (confinement)
ncy   = 2;                         % # legs transv. steel y_dir (shear)
clb   = 40;                        % cover to longitudinal bars (mm)

% member properties

L        = 3650;                   % member clear length (mm)
bending = 'single';                % single or double
ductilitymode = 'uniaxial';         % biaxial or uniaxial

% longitudinal reinforcement details, MLR is a matrix composed by
% [distance from the top to bar center (mm) - # of bars - bar diameter (mm)] each row
% corresponds to a layer of reinforcement:

MLR=[48   3   16
     502  3   16];
```

```
% transverse reinforcement details

Dh      = 10;                      % diameter of transverse reinf. (mm)
s       = 250;                       % spacing of transverse steel (mm)*

% applieed loads:

P      = 0;             % axial load kN (-) tension (+)compression

% material models (input the 'name' of the file with the stress-strain relationship
% to use the default models: Mander model for confined or unconfined  concrete type 'mc' or 'mu'.
% For lightweight confined concrete type 'mclw'
% King model for the steel 'ks', Raynor model for steel 'ra':

confined   = 'mc';
unconfined = 'mu';
rebar      = 'ks';


wi   = [0];                      % vector with clear distances between
                                 % periferical longitudinal bars properly
                                 % restrained or enter zero for automatical
                                 % calculation(used only if the mander model is selected)

% material properties

fpc     = 30;          % concrete compressive strength (MPa)
Ec      = 0;           % concrete modulus of elasticity (MPa) or
                       % input 0 for automatic calculation using
                       % 5000(fpc)^0.5
eco     = 0.002;       % unconfined strain (usually 0.002 for normal weight or 0.004 for lightweight)*
```

Figure 3.12 Detailing of section analysis as the input in CUMBIA program



Bilinear Approximation:							
Curvature	Moment	Displ.	Force			CURVATUI	MOMENT
[1/m]	[kN-m]	[m]	[kN]		YIELD	1	1
0	0	0	0		ULTIMATE	33.48706	1.131359
0.00657	147.23	0.03221	40.34				
0.22001	166.57	0.33392	45.64				

Figure 3.13 Output from CUMBIA Section Analysis

3.6 Nonlinear Static Analysis

In this process, a nonlinear static pushover analysis method is used to capture the behavior of structures under seismic impacts. For nonlinear analysis, pushover analysis curve is obtained. Ductility can be calculated from pushover analysis curve. Furthermore, pushover analysis is a process to evaluate the maximum base shear and top displacement. The outputs from CUMBIA program are required as an input in SAP 2000.

Frame hinge properties as shown in Figure 3.14 is specified in SAP 2000 by clicking “define”, then choose “section properties” and click “hinge properties”. Then, choose deformation control for beam and column. Moment M3 for beam, while Interacting P-M3 for column as shown in Figure 3.15 and Figure 3.16, respectively.

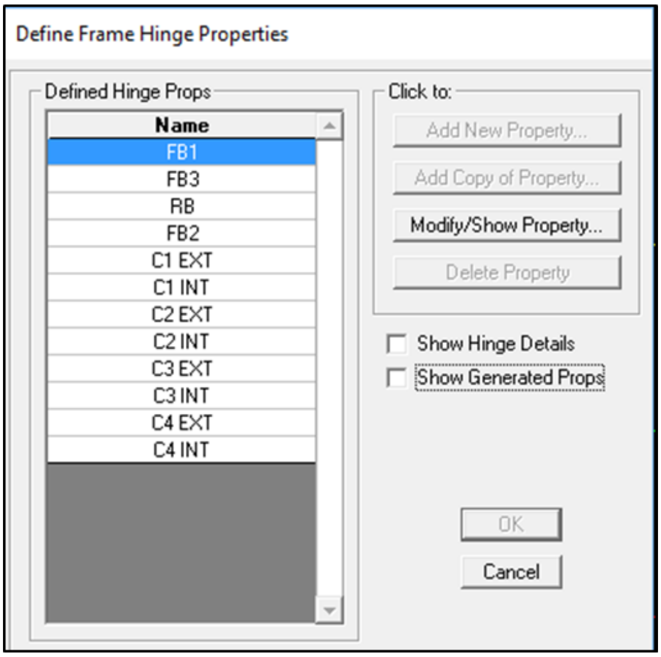


Figure 3.14 Define frame hinge properties

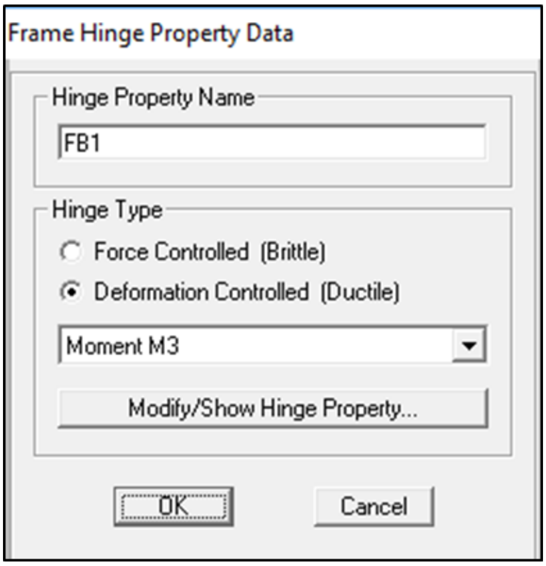


Figure 3.15 Moment M3 chosen for beam

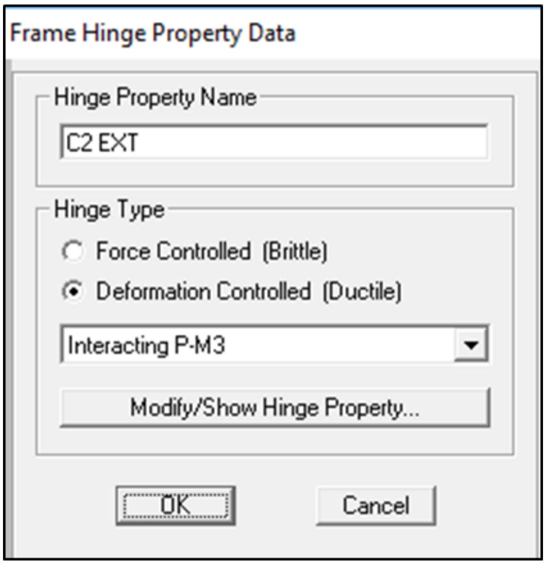


Figure 3.16 Interacting P-M3 chosen for column

Window for frame hinge property data will appear by clicking "modify/show hinge property". After that, choose the type of moment-curvature and specify the hinge-length as 0.1. The output from CUMBIA program which is moment and curvature are inserted into displacement control parameter as shown in Figure 3.17.

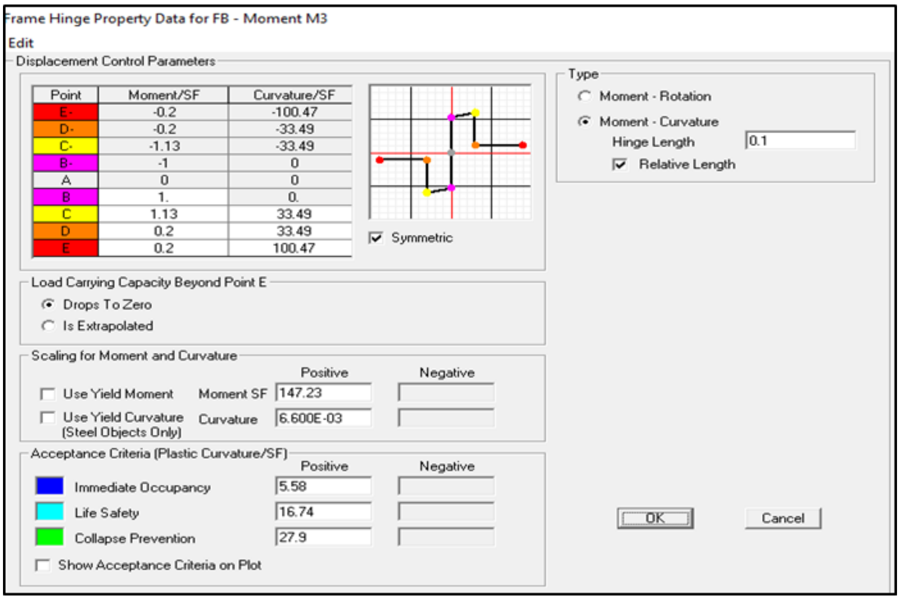


Figure 3.17 Frame hinge property data

In conducting nonlinear static pushover analysis using SAP2000, all gravity loads are nonlinearly analyzed initially in order to reflect the real loading condition. The static analysis case must be set to nonlinear static analysis case before pushover analysis started as shown in Figure 3.18.

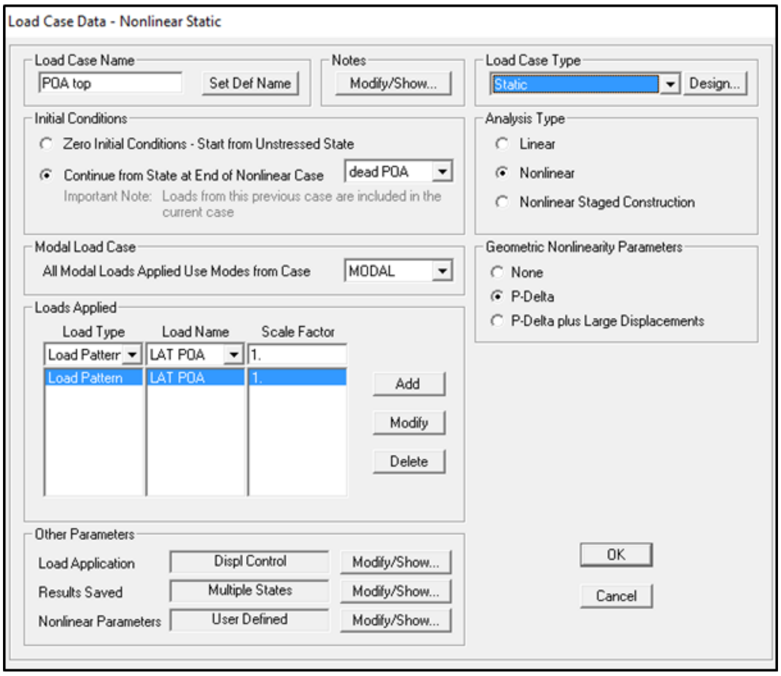


Figure 3.18 Nonlinear static type of load case

3.7 Perform Analysis

Finally the pushover analysis is run in SAP 2000 to obtain the result of capacity curve in the form of base shear against top displacement. After the analysis is complete, the capacity curve can be obtained by selecting “display” and then “show static pushover curve”. Figure 3.19 shows the definition of yield displacement in FEMA P695 (2009). The results is compared and discussed in chapter 4.

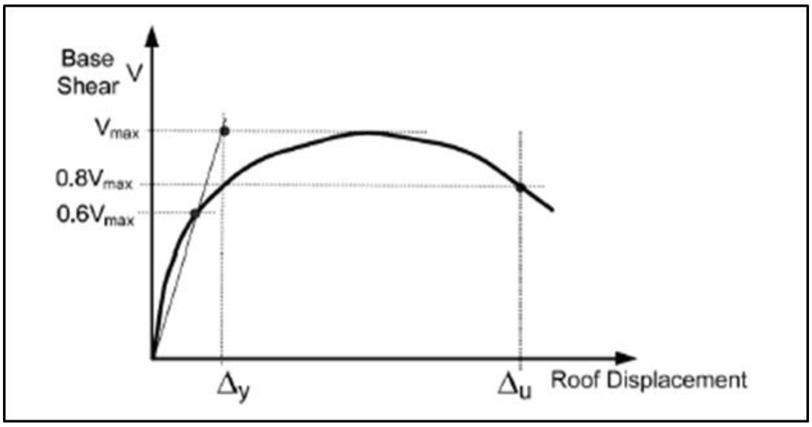


Figure 3.19 Definition of yield displacement (FEMA P695)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the effect of storey height on the lateral strength and interstorey drift ratio (IDR) of elevated reinforced concrete (RC) water tank from the result in section analysis by CUMBIA program and pushover analysis in SAP 2000.

The result of section analysis is discussed using moment-curvature that obtained by CUMBIA program as shown in Appendix C. These outputs are required as an input in SAP 2000 to perform the pushover analysis. A nonlinear static pushover analysis is used to quantify maximum base shear and displacement (FEMA P695, 2009). The pushover analysis contains the application of gravity loads and a representative lateral load pattern.

Moreover, a behavior of elevated RC water tank structure loaded by the gravity load at stress levels in the plastic range can be observed. Several structural members that experience from yielding to total failure can be displayed through damage sequence.

The result outcomes are presented in term of capacity curve, lateral displacement at yield and the IDR. The behavior of elevated RC water tank is discussed based on above criteria.

4.2 Capacity Curve

The capacity curve of the four and seven storey elevated RC water tank are shown in Figure 4.1 and Figure 4.2 in term of base shear force and top displacement, respectively. The trend in the capacity curves of both graph shows exactly same pattern.

Model N4A has the highest yield force compared to others model which is 159.236 kN. Moreover, model N4A is the shortest column height compared to N4B, N4C,N4D, and N4E. Model with highest column height which is N4E has the lowest yield force with only 111.809 kN.

The yield force for model N4B, N4C and N4D is 144.681 kN, 132.473 kN, and 121.466 kN, respectively. This means that, the magnitude of yield force decrease up to 30% as the column height increase.

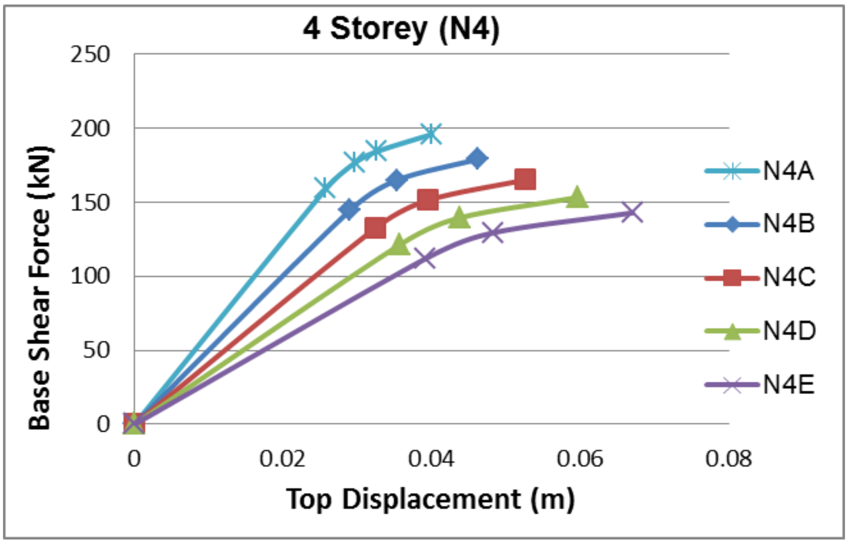


Figure 4.1 Capacity curve for four storey model

For seven storey models, it can be clearly observed that the value of yield force is decreasing as the column height increasing as shown in Figure 4.2. This can be proved with comparison between models with shortest column height and longest column height which is N7A and N7E, respectively. N7A has yield force 176.851 kN, while N7E has yield force 126.094 kN. The magnitude of yield force decreased up to 29% as the column height increase.

While, N7B, N7C and N7D has yield force 160.791 kN, 147.339 kN and 135.913 kN, respectively. In addition, the magnitude of yield force for these three models, N7B, N7C and N7D decreased up to 9%, 17% and 23%, respectively compared to model N7A. As discussed in previous paragraph, model with shorter column height tend to have higher yield force compared to model with longer column height.

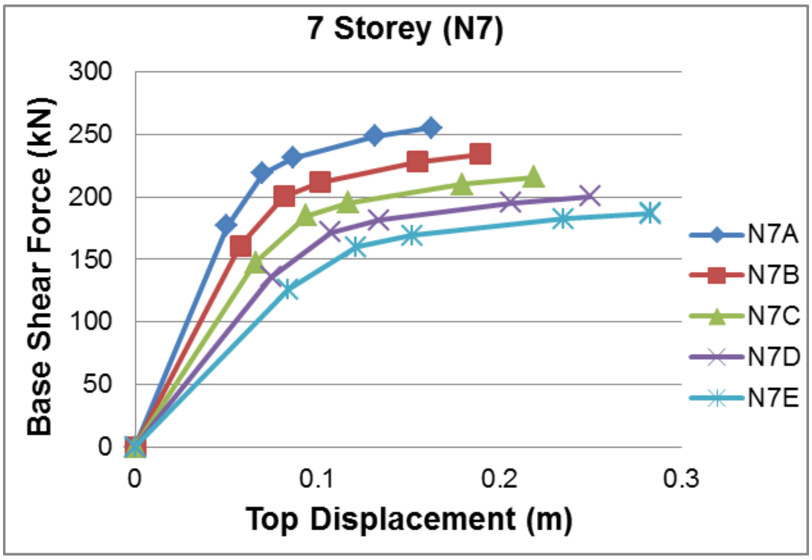


Figure 4.2 Capacity curve for seven storey model

4.3 Lateral Displacement

Lateral displacement at yield were recorded and compared in Figure 4.3 and Figure 4.4 for the four storey and seven storey models, respectively. The graph presents the lateral displacement for every storey. Estimates of yield displacement used for the design of ductile RC structure.

Lateral displacement at yield for top storey model N4A, N4B, N4C, N4D and N4E is 0.026 m, 0.029 m, 0.032 m, 0.036 m and 0.039 m, respectively. It can be clearly observed that, model N4E have highest lateral displacement at yield compared to others model. The different percentage between shorter storey height and longest storey height is about 33.33%. It can be concluded that, the longer the storey height, the higher the lateral displacement at yield.

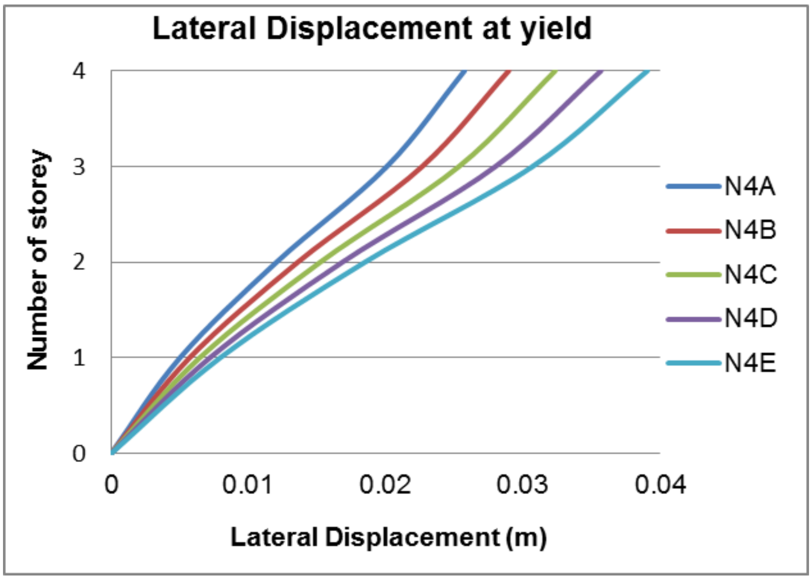


Figure 4.3 Lateral displacement at yield for four storey models

For the seven storey model, lateral displacement at yield for top story model N7A is 0.05017 m shorter than model N7E which is 0.08395 m. Whereas, the lateral displacement at yield for top storey model N7B, N7C and N7D is 0.05784 m, 0.06603 m and 0.07474 m, respectively. It shows that, model with longest storey height has highest lateral displacement as observed for the four storey model. This means that the number of storey did not influencing the pattern of the result.

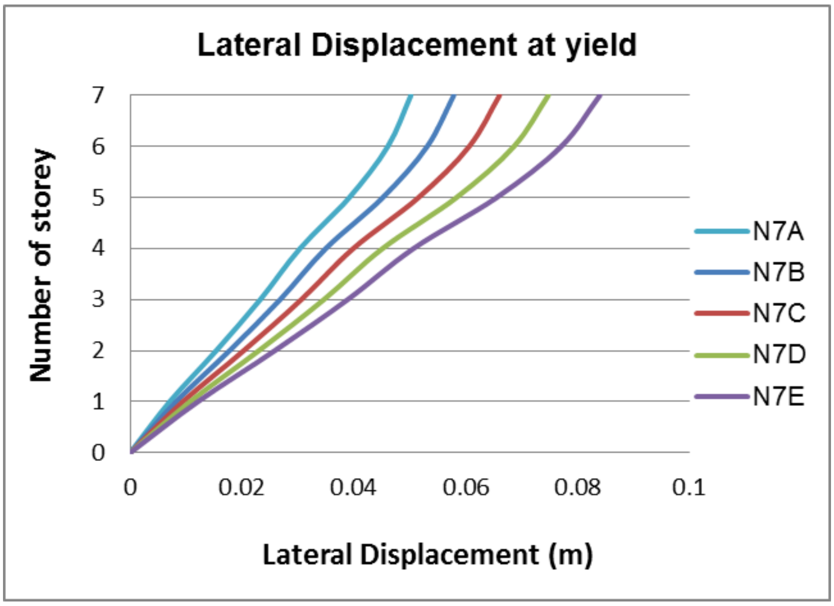


Figure 4.4 Lateral displacement at yield for seven storey models

4.4 Interstorey Drift Ratio

In this study, the performance of all models is evaluated based on the IDR. The IDR can be defined as relative displacement between two adjacent storey, normalized to its storey height. In Figure 4.5 and Figure 4.6, the IDR of both four storey and seven storey models are presented, respectively.

The results from Figure 4.5 shows the value IDR for model N4E is 0.271%, which is highest value compared to others model. Furthermore, model N4E have the longest column storey height. The maximum IDR for model N4A, N4B, N4C and N4D is 0.244%, 0.252%, 0.259% and 0.265%, respectively. The maximum IDR for all models occurred at same storey, which is storey number three.

Figure 4.6 presents the distribution of IDR for all seven storey elevated RC water tank models. It can be clearly observed that the maximum IDR for all seven storey model occurred at same storey, which is storey number five. The IDR of N7E is the highest which is equal to 0.33%. Meanwhile, for model N7A, the IDR is 0.27%. The different percentage for these two models is 18%. However, the IDR for model N7B, N7C and N7D is 0.28%, 0.30% and 0.32%, respectively. In the other word, the model with longest storey height has highest IDR.

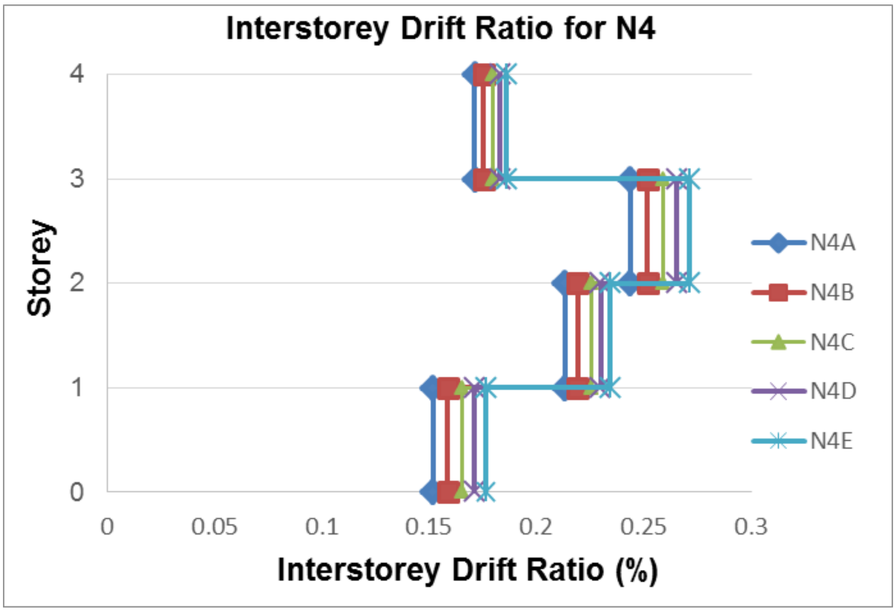


Figure 4.5 Interstorey Drift Ratio for four storey models

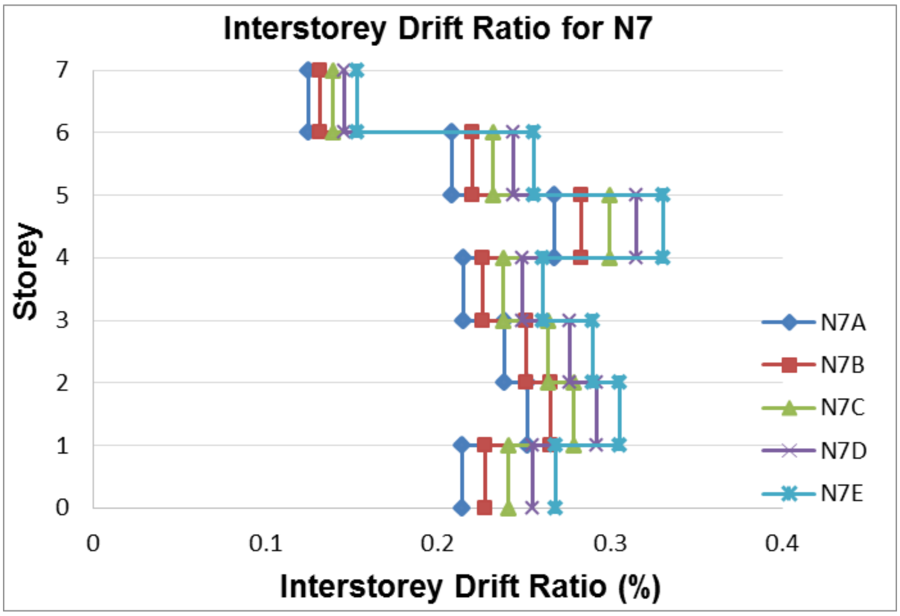


Figure 4.6 Interstorey Drift Ratio for seven storey models

4.5 Damage Sequence

In SAP2000, the behavior of the structure after the yield point is modeled with plastic hinges. This plastic hinges can be defined in an arbitrary number of points along the length of a finite elements of the structure (Rogac, 2010). The formation of a plastic hinge requires a certain length at which the plastification of material will happen.

The symbol notation of plastic hinge according to its strength and deformation points is shown in Figure 4.7. Meanwhile, plastic hinges status is indicated by the color according to Figure 4.8.

Damage sequence of structure can be defined by the formation of plastic hinge which is the critical region of the structure. In this study, the damage sequences for all four storey and seven storey model are shown in Figure 4.9 and Figure 4.10, respectively. The number in brackets indicates the sequence of deformation for column and beam of elevated RC water tank.

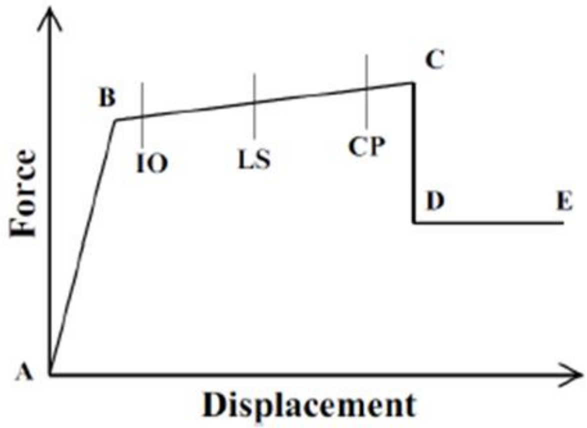


Figure 4.7 Strength and deformation points (FEMA 273, 1997)

Figure 4.8 Color notation at member hinge

Where :

B = Yield point of strength and deformation

IO = Immediate Occupancy

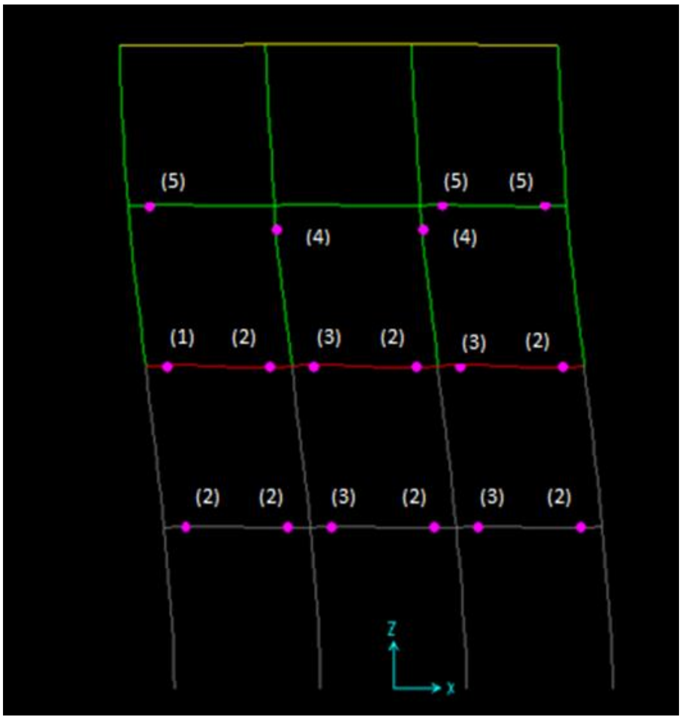
LS = Life Safety

CP = Collapse prevention

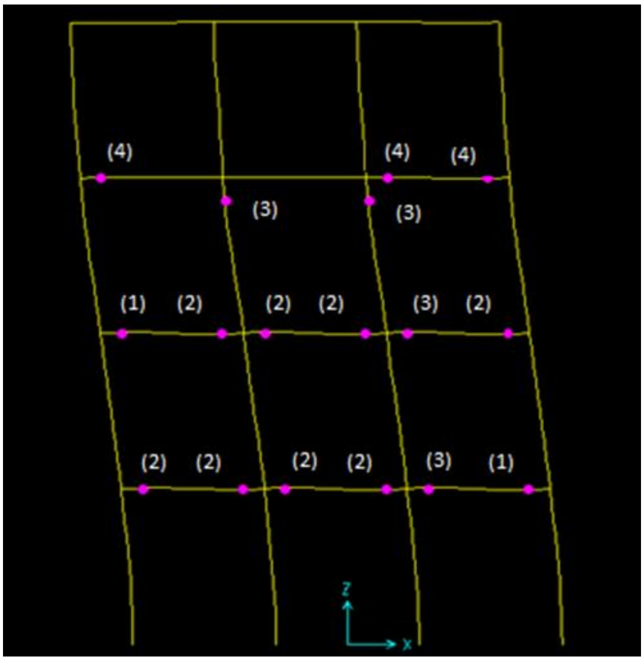
C = Collapse

D= Strength degradation of the member capacity

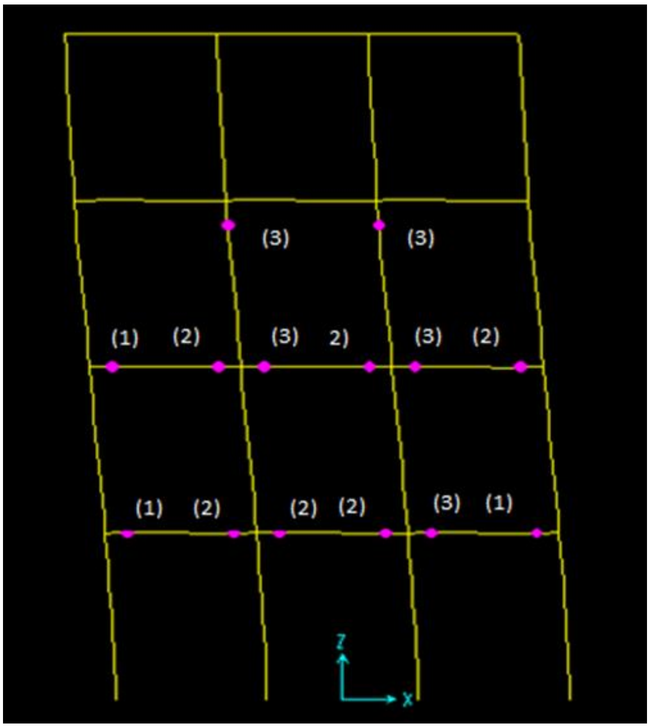
E = Total failure of the member



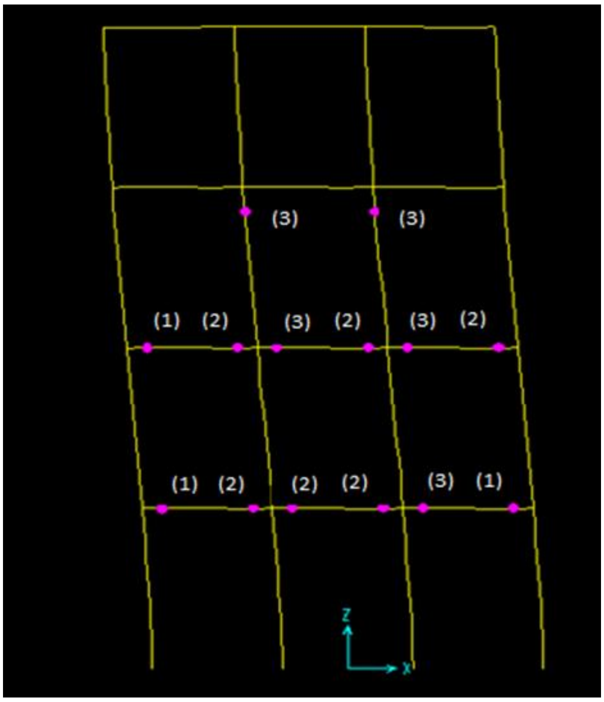
(a)



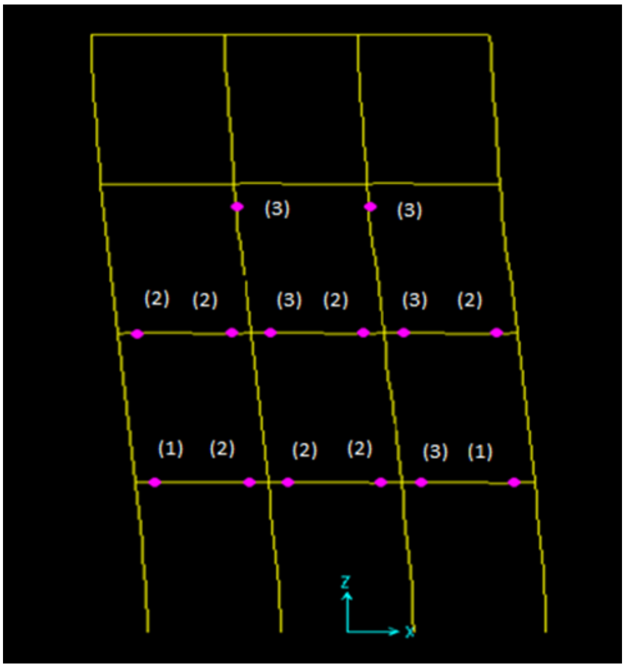
(b)



(c)

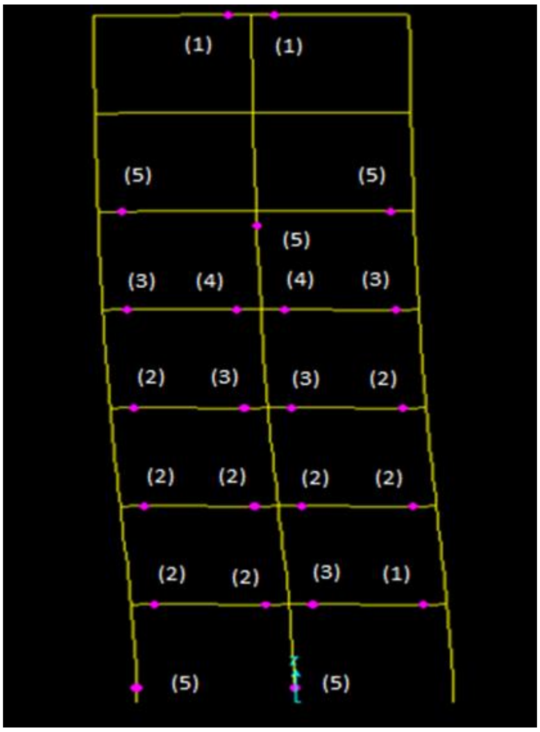


(d)



(e)

Figure 4.9 Sequence of formation plastic hinge for four storey elevated RC water tank models (a) N4A (b) N4B (c) N4C (d) N4D (e) N4E


(1)
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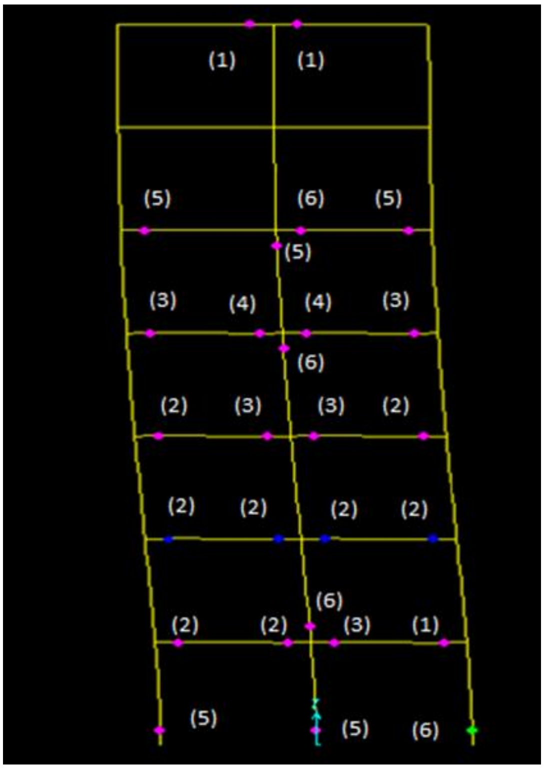
(a)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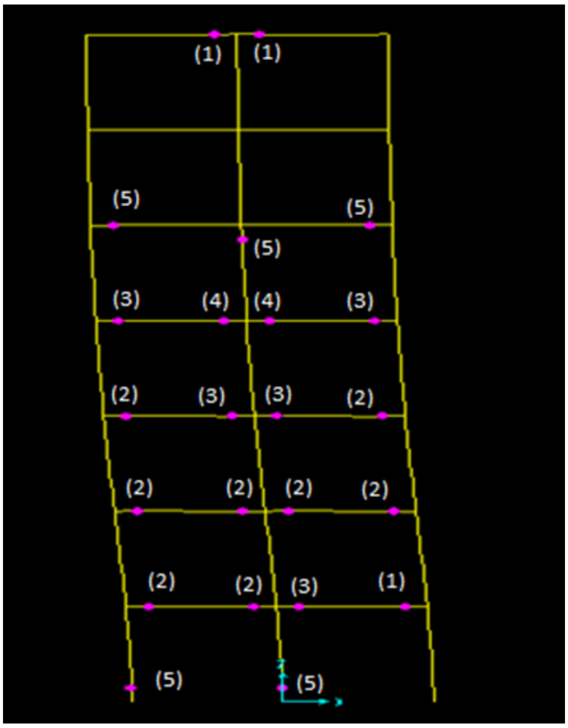
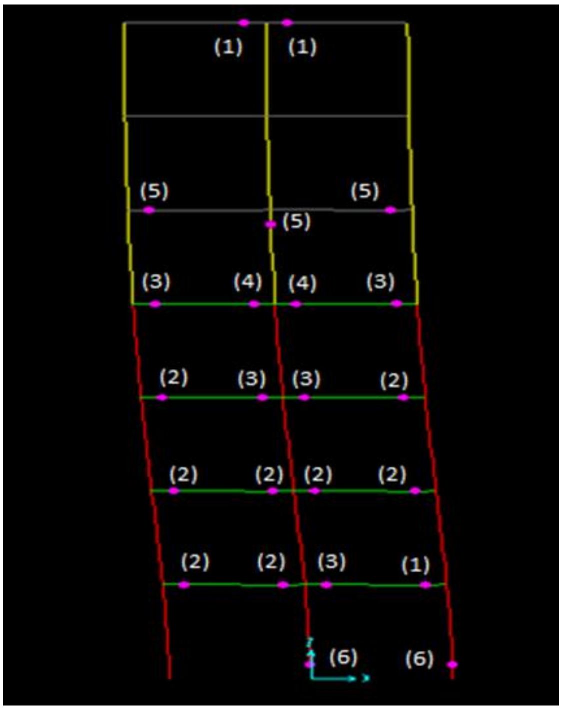
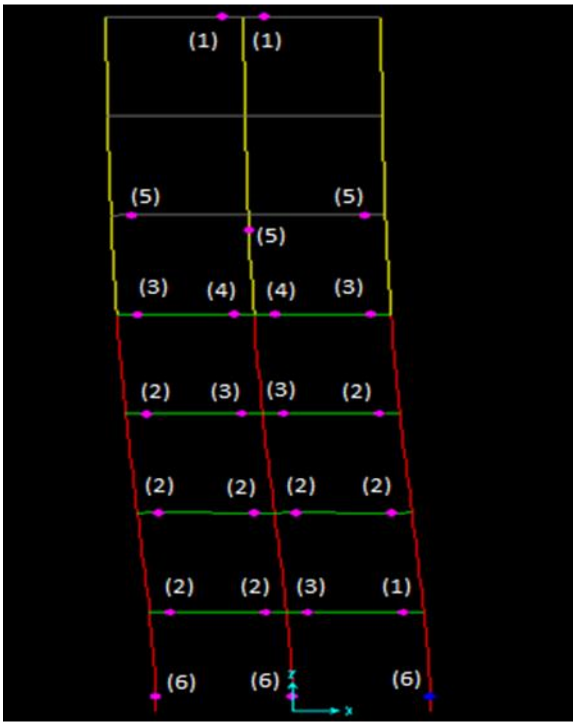
(b)



(c)



(d)



(e)

Figure 4.10 Sequence of formation plastic hinge for seven storey elevated RC water tank models (a) N7A (b) N7B (c) N7C (d) N7D (e) N7E

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The objectives of this study are to investigate the effect of storey height on the lateral strength of elevated reinforced concrete (RC) water tank. In addition, the effect of storey height on the interstorey drift ratio (IDR) of elevated RC water tank was also studied. To achieve these objectives, two basic models having number of storey equal to four and seven were used. Each model analyzed repeatedly with different height storey. The pushover analysis has been conducted on elevated RC water tank models. The conclusions reached from this project are as follows:

- Model with shorter column height tends to have higher base shear force compared to model with longer column height. This mean that's model with shorter storey height are stronger to resist earthquake load. The base shear force varies in range of 9% to 29%.

- Model with longer column height contributes higher value of IDR compared to the model with shorter column height. The greater the IDR, the greater the likelihood of damage during earthquake. In the other word, model with shorter column height is stronger than the model with longer column height.

5.2 Future Recommendation

The impact of lateral forces is essential in designing the building; this study can be additionally enhanced with different aspects. Some of the recommended studies for the future are as follow:

- Using pushover analysis, study the effect of other structural form when subjected to lateral load.
- High rise building gives more significant effect of earthquake. Therefore, similar study can be conducted all high rise buildings.
- The utilization of earthquake data for Malaysia is suggested in order to make this project more practical to Malaysia's condition.

REFERENCES

Adiyanto. M.I. (2016). Influence of behaviour factor on seismic design and performance of reinforced concrete moment resisting frame in Malaysia, PhD Thesis, Universiti Sains Malaysia.

Applied Technology Council,ATC (2009). Quantification of Building Seismic Performance Factors (FEMA P695). Chap 6. pp.6-8

BS8110 (1997). structural use of concrete- part 1: Code of practice for design and construction

BSSC (1997). NEHRP Guidelines for the Seismic Rehabilitation of Buildings (FEMA273). Building Seismic Safety Council (BSSC), Washington D.C. U.S.A.

Chopra A.K. and Goel R.K. (2001). A Modal Pushover Analysis Procedure to Estimating Seismic Demands for Buildings: Theory and Preliminary Evaluation, PERR Report 2001/03, Pacific Earthquake Engineering Research Center, University of California, Berkeley.

Murti C.V.R. (2012). Department of Civil Engineering Indian Institute of Technology Kanpur, Learning Earthquake Design and Construction, pp.9

Rai D. (2006). Lifeline Systems in the Andaman and Nicobar Islands (India) after the December 2004 Great Sumatra Earthquake and Indian Ocean Tsunami. Earthquake Spectra.

Elnashai, A.S. and Sarno, L.D. (2008). Fundamental of Earthquake Engineering, John Wiley & Sons, Ltd, USA and Italy, pp. 47-115.

ESTEEM, General Manual for the application of the ESTEEM tool, Project co-funded by the European Commission within the Sixth Framework programme (Contract n°518351 - 2002/2006).

Federal Emergency Management Agency, (2000). FEMA356. Prestandard and commentary for seismic rehabilitation of buildings. Washington (DC)

Habibullah, A. and Pyle, S. (1998). Practical three dimensional nonlinear static pushover analysis. Structure Magazine.

Kramer, L.S. (1996). Geotechnical Earthquake Engineering, Prentice-Hall International Series in Civil Engineering and Engineering Mechanics, United State, pp. 1-17.

Krawinkler H. and Seneviratna G.D.P.K. (1998). Pros and Cons of a Pushover Analysis of Seismic Performance Evaluation, Engineering Structures, Vol.20, 452-464.

Kwak, H.G. and Kim, S.P. (2002). Nonlinear analysis of RC beams based on moment-curvature relation. Computers & Structures, 80, 615-628.

Lawson, R.S., Vance, V. and Krawinkler, H. (1994). Nonlinear static push-over analysis – why, when and how?. National Conference on Earthquake Engineering 1994, Volume 1, 283-292.

Malaysian Meteorological Department. (2016) Senarai Gempa Bumi. [Online], [Accessed 25 Nov 2016]. Available from World Wide Web: http://www.met.gov.my/web/metmalaysia/listofrecentearthquake/earthquaketsunami/2015/06

MMD and ASM, (2009). "Seismic and Tsunami Hazards and Risks Study in Malaysia", Final Report, 1-200

Montejo, L.A., and Kowalsky, M.J. (2007). CUMBIA – a set of codes for the analysis of reinforced concrete members, Report No. IS-07-01, North Carolina State University, USA.

Nelson S.A, (2015) *Earthquakes and the Earth's Interior*, Physical Geology, Tulane University

Oguz S, (2005). evaluation of pushover analysis procedures for frame structures. Middle East Technical University

Rogac M. (2010), "Plastic Analysis of Steel Frame Structure-Calculation of Ultimate Gravitational Load", Seminar paper of the course Theory of Plasticity, Civil Engineering Faculty in Podgorica, Podgorica, pp 60.

SAP2000 (2002) Analysis reference manual. Computers and Structures, Inc., Berkeley.

Sooria S.Z. and Sawada S, (2012), Department of Urban Management, Kyoto University, Japan, Proposal for Seismic Resistant Design in Malaysia: Assessment of Possible Ground, pp.2

U.S Geological Survey: Last Earthquake in Malaysia, *ShakeMap M 6.0 - 14km WNW of Ranau, Malaysia* [Online], [Accessed 15 Oct 2017]. Available from World Wide Web: https://earthquake.usgs.gov/earthquakes/eventpage/us20002m5s#shakemap

APPENDIX A

DRAWING OF FOUR STOREY ELEVATED REINFORCED CONCRETE WATER TANK GENERATED BY ESTEEM SOFTWARE

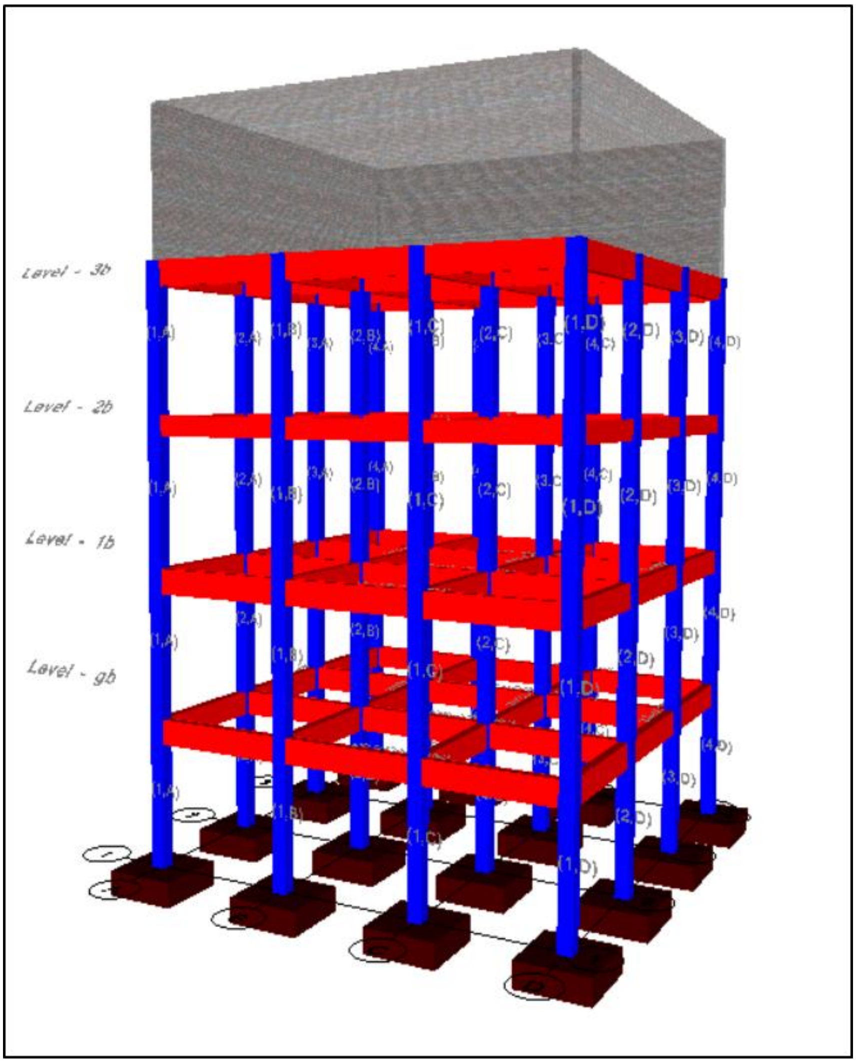


Figure A.1 Four storey elevated RC water tank

DRAWING OF SEVEN STOREY ELEVATED REINFORCED CONCRETE WATER TANK GENERATED BY ESTEEM SOFTWARE

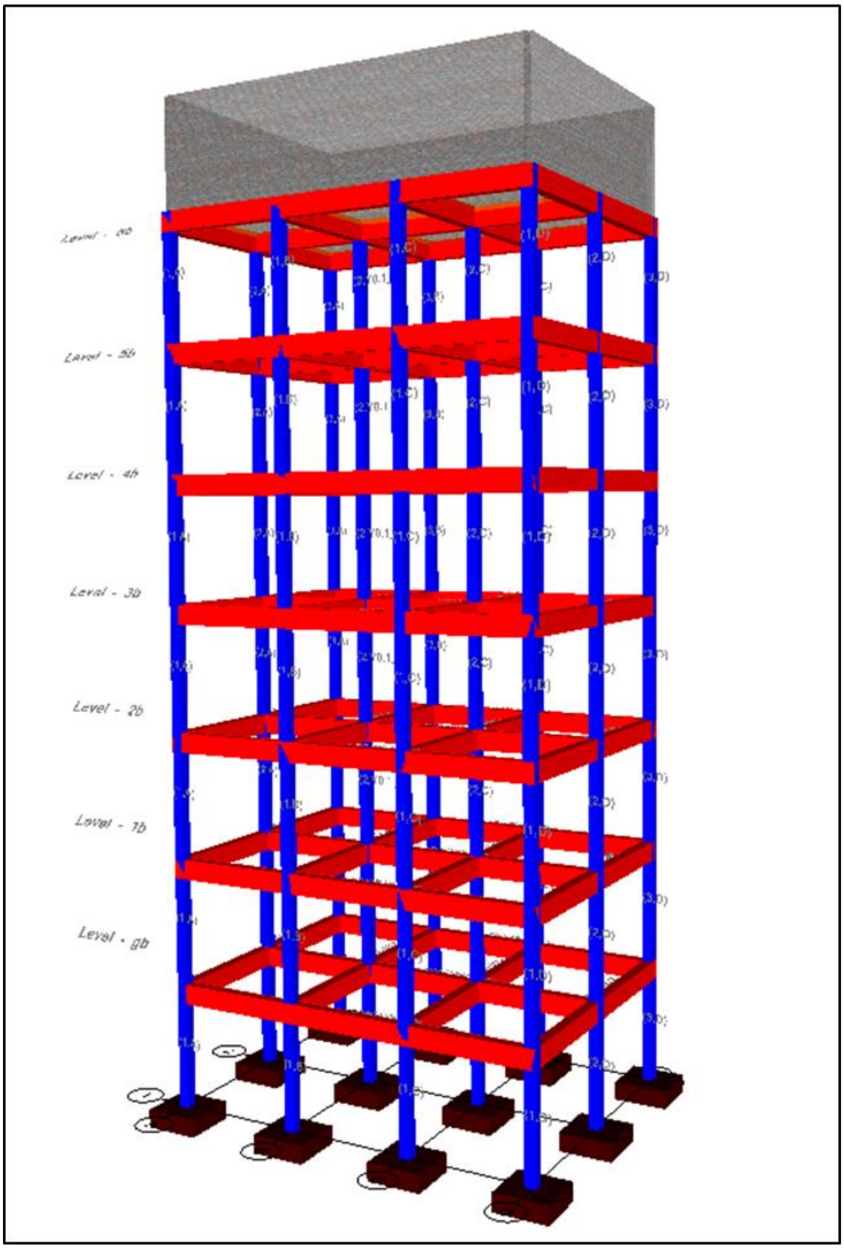


Figure A.2 Seven storey elevated RC water tank

APPENDIX B
LOADING CALCULATION

For four storey elevated RC water tank

Dead Load = Area of Beam x Density of concrete

<u>Dead load (UDL),</u>

Slab	= 0.15 m x 24 kN/m^3 x 3 m x 3 = 32.4 kN/m
Finished	= 1.2 kN/m
Total	= 33.6 kN/m

<u>Dead load (Point load at A and B),</u>

Selfweight of beam	= 0.2 x 0.4 x 24 x 1.5 = 2.88 kN
Selfweight of slab	= 0.15 x 24 x 1.5 x 3 = 16.2 kN
Selfweight of beam	= 0.2 x 0.4 x 24 x 3 = 5.76 kN
Selfweight of tank	= 3 x 3 x 24 = 216 kN
Total	= 240.84 kN

<u>Dead load (Point load at C and D),</u>

Selfweight of beam (storey above)	= 0.2 x 0.4 x 24 x 3 = 5.76 kN
Selfweight of beam (storey below)	= 0.25 x 0.45 x 24 x 3 = 8.10 kN

Live load = s/w x Lx x Ly

<u>Live Load (UDL),</u>

Water = *pgh* =1000 x 9.81 x 2.5 = 24.5(3m) = 73.5 kN/m

<u>Live Load (Point load),</u>

Corridor = 3 x 1.5 x 3 = 13.5 kN

For seven storey elevated RC water tank

Dead Load = Area of Beam x Density of concrete

<u>Dead load (UDL),</u>

Slab	= 0.2 m x 24 kN/m^3 x 5 m x 4 = 96 kN/m
Finished	= 1.2 kN/m
Total	= 97.2 kN/m

<u>Dead load (Point load at A and B),</u>

Selfweight of beam	= 0.35 x 0.6 x 24 x 1.5 = 7.56 kN
Selfweight of slab	= 0.2 x 24 x 1.5 x 5 = 36 kN
Selfweight of beam	= 0.35 x 0.6 x 24 x 4 = 20.16 kN
Selfweight of tank	= 4 x 5 x 24 = 480 kN
Total	= 543.72 kN

<u>Dead load (Point load at C and D),</u>

Selfweight of beam (storey above)	= 0.35 x 0.6 x 24 x 4 = 20.16 kN
Selfweight of beam (storey below)	= 0.4 x 0.65 x 24 x 4 = 24.96 kN

Live load = s/w x Lx x Ly

<u>Live Load (UDL),</u>

Water = *pgh* =1000 x 9.81 x 2.5 = 24.5(5m) = 122.5 kN/m

<u>Live Load (Point load),</u>

Corridor = 3 x 1.5 x 5 = 22.5 kN

APPENDIX C
OUTPUT DATA FROM CUMBIA

SAMPLE OF N4A

Column Floor 1 (External)

Rectangular Section

Normal weight concrete
Width: 400.0 mm Height: 400.0 mm
cover to longitudinal bars: 40.0 mm

Dist.Top (mm)	# Long Bars	Diameter (mm)
48	3	16
195	2	16
352	3	16

diameter of transverse steel: 10.0 mm
spacing of transverse steel: 175.0 mm
legs transv. steel x_dir (confinement): 3.0
legs transv. steel y_dir (shear): 3.0
axial load: 480.30 kN
concrete compressive strength: 30.00 MPa
long steel yielding stress: 460.00 MPa
long steel max. stress: 600.00 MPa
transverse steel yielding stress: 250.00 MPa
Member Length: 3300.0 mm
Double Bending
Biaxial Bending
Longitudinal Steel Ratio: 0.010
Average Transverse Steel Ratio: 0.004
Axial Load Ratio: 0.100

Moment [kN-m]	Curvature [1/m]	Force [kN]
0	0	0
31.26	0.00048	18.95
55.09	0.00106	33.39
69.24	0.00183	41.97
83.8	0.00268	50.79
96.75	0.00361	58.64
108.94	0.00459	66.03
120.99	0.00559	73.33
132.13	0.00662	80.08
145.02	0.0076	87.89
155.97	0.00862	94.53
167.37	0.00959	101.44
174.06	0.01076	105.49
177.22	0.01206	107.41
180.36	0.01339	109.31
183.03	0.01471	110.93
186.25	0.01743	112.88
193.3	0.0199	117.15
197.05	0.02726	119.42
199.39	0.03469	120.84
201.45	0.04191	122.09
202.07	0.04924	122.46
202.68	0.05609	122.83
202.64	0.06248	122.81
200.02	0.07141	121.22
193.85	0.07575	117.48
189.28	0.08153	114.72
187.88	0.08845	113.87
187.4	0.09597	113.58
187.04	0.11246	113.36
187.31	0.12813	113.52
186.6	0.14264	113.09
186.01	0.15514	112.73
185.01	0.17045	112.13
185.06	0.18401	112.16
183.12	0.19214	110.98
182.66	0.20582	110.7
181.91	0.21972	110.25

Bilinear Approximation:							
Curvature	Moment	Displ.	Force			CURVATURE	MOMENT
[1/m]	[kN-m]	[m]	[kN]		YIELD	1	1
0	0	0	0		ULTIMATE	18.38661088	0.900233
0.01195	202.07	0.02621	122.46				
0.21972	181.91	0.24853	110.25				

E: 27386127875.26 Pa
G: 11776034986.36 Pa
A: 0.1600 m2
I: 0.000617 m4
Bi-Factor: -0.006
Hinge Length: 0.324 m
Tension Yield: 739907.90 N
Compression Yield: 5711446.96 N
Moment Yield: 202065.46 N-m

Interaction Surface
Concrete limit strain: 0.0040
Steel limit strain: 0.0150

NLTHA Approximation:	
PT: -739.9 kN	
PC: 5350.8 kN	
PB: 2160.0 kN	MB: 310.5 kN-m
(1/3)PB: 720.0 kN	(1/3)MB: 230.0 kN-m
(2/3)PB: 1440.0 kN	(2/3)MB: 286.5 kN-m

Moment (kN-m)	Axial Load (kN)
0	-739.91
21.59	-665.92
59.1	-443.94
98.47	-221.97
134.6	0
170.63	240
202.13	480
229.95	720
254.67	960
272.7	1200
286.54	1440
296.67	1680
305.08	1920
310.53	2160
306.85	2400
298.57	2640
287.31	2880
275.01	3120
230.69	3745.59
175.53	4280.67
105.85	4815.76
0	5350.84

Beam N4A (Floor Beam 1)

Rectangular Section			
normalweight concrete			
Width: 250.0 mm Height: 450.0 mm			
cover to longitudinal bars: 36.0 mm			
Dist.Top	# Long	Diameter	
[mm]	Bars	[mm]	
44	2	16	
406	2	16	

Bilinear Approximation:							
Curvature	Moment	Displ.	Force			CURVATURE	MOMENT
[1/m]	[kN-m]	[m]	[kN]		YIELD	1	1
0	0	0	0		ULTIMATE	39.302843	1.113115
0.00809	79.3	0.0209	30.5				
0.31796	88.27	0.28544	33.95				

SAMPLE OF N7A

Column Floor 1 (External)

Rectangular Section

Normal weight concrete
Width: 400.0 mm Height: 400.0 mm
cover to longitudinal bars: 40.0 mm

Dist.Top (mm)	# Long Bars	Diameter (mm)
48	3	16
195	2	16
352	3	16

Diameter of transverse steel: 10.0 mm
spacing of transverse steel: 175.0 mm
legs transv. steel x_dir (confinement): 3.0
legs transv. steel y_dir (shear): 3.0
axial load: 1244.07 kN
concrete compressive strength: 30.00 MPa
long steel yielding stress: 460.00 MPa
long steel max. stress: 600.00 MPa
transverse steel yielding stress: 250.00 MPa
Member Length: 3300.0 mm
Double Bending
Biaxial Bending
Longitudinal Steel Ratio: 0.010
Average Transverse Steel Ratio: 0.004
Axial Load Ratio: 0.259

Moment [kN-m]	Curvature [1/m]	Force [kN]
0	0	0
8.81	0.00015	5.34
39.83	0.00064	24.14
69.26	0.00113	41.97
97.01	0.00163	58.79
118.78	0.00218	71.99
136.18	0.00279	82.53
150.7	0.00345	91.33
163.22	0.00415	98.92
175.16	0.00486	106.16
185.3	0.00561	112.3
195.62	0.00636	118.56
204.66	0.00712	124.04
212.85	0.00791	129
221.19	0.00867	134.05
237.36	0.01018	143.85
251.24	0.01168	152.27
265.92	0.01588	161.16
271.58	0.02021	164.59
275.51	0.02436	166.98
275.75	0.0279	167.12
272.9	0.0312	165.39
268.74	0.03402	162.87
253.12	0.03873	153.4
236.83	0.04288	143.53
228.71	0.04773	138.61
225.72	0.05283	136.8
223.02	0.05761	135.16
215.88	0.06734	130.83

Bilinear Approximation:								
Curvature	Moment	Displ.	Force			CURVATURE	MOMENT	
[1/m]	[kN-m]	[m]	[kN]		YIELD	1	1	
0	0	0	0		ULTIMATE	4.966076696	0.782883	
0.01356	275.75	0.02935	167.12					
0.06734	215.88	0.08425	130.83					

for non-linear THA:			
E: 27386127875.26 Pa			
G: 11776034986.36 Pa			
A: 0.1600 m2			
I: 0.000743 m4			
Bi-Factor: -0.055			
Hinge Length: 0.324 m			
Tension Yield: 739907.90 N			
Compression Yield: 5711446.96 N			
Moment Yield: 275747.92 N-m			

Interaction Surface		
Concrete limit strain: 0.0040		
Steel limit strain: 0.0150		
Moment	Axial Load	
[kN-m]	[kN]	
0	-739.91	
21.59	-665.92	
59.1	-443.94	
98.47	-221.97	
134.6	0	
170.63	240	
202.13	480	
229.95	720	
254.67	960	
272.7	1200	
286.54	1440	
296.67	1680	
305.08	1920	
310.53	2160	
306.85	2400	
298.57	2640	
287.31	2880	
275.01	3120	
230.69	3745.59	
175.53	4280.67	
105.85	4815.76	
0	5350.84	

NLTHA Approximation:				
PT: -739.9 kN				
PC: 5350.8 kN				
PB: 2160.0 kN		MB: 310.5 kN-m		
(1/3)PB: 720.0 kN		(1/3)MB: 230.0 kN-m		
(2/3)PB: 1440.0 kN		(2/3)MB: 286.5 kN-m		

Beam N7A (Floor Beam 1)

Rectangular Section			
normalweight concrete			
Width: 350.0 mm Height: 600.0 mm			
cover to longitudinal bars: 40.0 mm			
Dist.Top	# Long	Diameter	
[mm]	Bars	[mm]	
48	3	16	
552	3	16	

Bilinear Approximation:									
Curvature	Moment	Displ.	Force			CURVATURE	MOMENT		
[1/m]	[kN-m]	[m]	[kN]		YIELD	1	1		
0	0	0	0		ULTIMATE	37.24703892	1.109654		
0.00591	163.24	0.02771	45.34						
0.22013	181.14	0.32427	50.32						

APPENDIX D
OUTPUT DATA FROM SAP 2000

4 Storey Elevated RC Water Tank

Table D.1 Pushover Curve - POA top for N4A

Step	Displacement (m)	Base Force (kN)
0	8.836E-18	0
1	0.025738	159.236
2	0.029566	176.429
3	0.032483	184.243
4	0.039982	196.09
5	-0.038295	-193.436

Table D.2 Pushover Curve - POA top for N4B

Step	Displacement (m)	Base Force (kN)
0	8.721E-18	0
1	0.028972	144.681
2	0.035302	165.071
3	0.046093	179.174
4	-0.065816	-194.81

Table D.3 Pushover Curve - POA top for N4C

Step	Displacement (m)	Base Force (kN)
0	9.395E-18	0
1	0.032352	132.473
2	0.039463	151.416
3	0.052623	165.363
4	-0.049698	-162.509

Table D.4 Pushover Curve - POA top for N4D

Step	Displacement (m)	Base Force (kN)
0	1.258E-17	0
1	0.035692	121.466
2	0.043683	139.515
3	0.059581	153.391
4	-0.055648	-150.359

Table D.5 Pushover Curve - POA top for N4E

Step	Displacement (m)	Base Force (kN)
0	1.441E-17	0
1	0.039073	111.809
2	0.048164	129.389
3	0.066984	142.981
4	-0.06324	-140.577

7 Storey Elevated RC Water Tank

Table D.6 Pushover Curve - POA top for N7A

Step	Displacement (m)	Base Force (kN)
0	2.201E-16	0
1	0.050166	176.851
2	0.070138	218.71
3	0.08674	231.111
4	0.13156	248.436
5	0.162688	255.357
6	-0.139375	-251.326

Table D.7 Pushover Curve - POA top for N7B

Step	Displacement (m)	Base Force (kN)
0	2.469E-16	0
1	0.057839	160.791
2	0.081692	200.268
3	0.101212	211.565
4	0.154808	227.705
5	0.189576	233.895
6	-0.281024	-241.918

Table D.8 Pushover Curve - POA top for N7C

Step	Displacement (m)	Base Force (kN)
0	2.673E-16	0
1	0.066029	147.339
2	0.094112	184.67
3	0.116783	195.046
4	0.179894	210.158
5	0.218986	215.722
6	-0.204003	-214.421

Table D.9 Pushover Curve - POA top for N7D

Step	Displacement (m)	Base Force (kN)
0	2.885E-16	0
1	0.074735	135.913
2	0.107409	171.321
3	0.134185	181.167
4	0.206566	195.184
5	0.249944	200.207
6	-0.256096	-200.681

Table D.10 Pushover Curve - POA top for N7E

Step	Displacement (m)	Base Force (kN)
0	3.289E-16	0
1	0.083955	126.094
2	0.12155	159.726
3	0.15218	168.935
4	0.235377	182.147
5	0.283305	186.726
6	0.283353	186.016
7	-0.292274	-187.209