EFFECT OF COLUMN SIZE ON THE SEISMIC CAPACITY OF ELEVATED REINFORCED CONCRETE WATER TANK

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for the award of the
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ABSTRACT

One of the major natural calamities is earthquake which have the potential to cause damage to lives and lifeline facilities. Malaysia have experienced many earthquakes from surrounding regions and several local earthquakes. Therefore, it has become a necessary to evaluate the safety of buildings in Malaysia when subjected to seismic action. Elevated reinforced concrete water tanks are one of the most essential structure to major cities and also in rural areas before, during and after a disaster such earthquake. It is important to prevent elevated reinforced concrete water tank from collapse so the water supply can be maintained. One of the methods used to evaluate the seismic capacity of elevated reinforced concrete water tank is the pushover analysis. Pushover analysis is based on the assumption that structure oscillate predominantly in the first mode or in the lower modes of vibration during a seismic event. The objective of this project is to study the effect of column size on the seismic capacity of elevated reinforced concrete water tank. A total number of 10 models of elevated reinforced concrete water tanks consist of 4 storeys and 7 storeys has been used for this project. All models have been designed repeatedly to 5 different size of column, where the beam size is fixed for each model. All models have been designed based on BS8110 to represent the existing elevated reinforced concrete water tanks. Then the pushover analysis has been conducted on all models to study the seismic capacity of elevated reinforced concrete water tank. An adequate information on seismic demands imposed on the structural system and its components by the designed ground motion are provided from the pushover analysis. Based on the pushover analysis conducted in this study, the elevated RC water tank with larger size of column tend to have higher value of force at yield state and ultimate state.

ABSTRAK

Salah satu bencana alam yang utama adalah gempa bumi, di mana ianya mempunyai potensi untuk menyebabkan kerosakan kepada kehidupan dan kemudahan talian hayat. Malaysia telah mengalami banyak gempa bumi daripada kawasan-kawasan sekitarnya dan beberapa kawasan tempatan yang mengalami gempa bumi. Oleh itu, ianya telah menjadi satu kewajipan untuk menilai keselamatan bangunan-bangunan di Malaysia apabila mengalami tindakan seismik. Tangki air konkrit bertetulang tinggi adalah salah satu struktur yang paling penting untuk bandar-bandar utama dan juga di kawasan luar bandar sebelum, semasa dan selepas mengalami bencana gempa bumi. Ianya adalah penting untuk mengelakkan tangki air konkrit bertetulang tinggi daripada runtuh supaya bekalan air dapat dikekalkan. Salah satu kaedah yang digunakan untuk menilai seismik kapasiti tangki air konkrit bertetulang tinggi adalah analisis mahu mengalah. Analisis mahu mengalah adalah berdasarkan kepada andaian bahawa struktur berayun terutamanya dalam mod pertama atau dalam mod getaran yang lebih rendah semasa mengalami tindakan seismik. Objektif projek ini adalah untuk mengkaji kesan saiz tiang pada kapasiti seismik tangki air konkrit bertetulang tinggi. Sebanyak 10 model tangki air konkrit bertetulang tinggi terdiri daripada 4 tingkat dan 7 tingkat telah digunakan untuk projek ini. Semua model telah direka berulang kali untuk 5 saiz tiang yang berbeza, di mana saiz rasuk bagi setiap model adalah tetap. Semua model telah direka berdasarkan BS8110 untuk mewakili tangki air konkrit bertetulang tinggi yang sedia ada. Kemudian analisis mahu mengalah telah dijalankan ke atas semua model untuk mengkaji seismik kapasiti tangki air konkrit bertetulang tinggi. Satu maklumat yang mencukupi mengenai permintaan seismik yang dikenakan ke atas sistem struktur dan komponennya oleh gerakan bumi yang direka akan disediakan dari analisis mahu mengalah. Berdasarkan analisis mahu mengalah yang dijalankan dalam kajian ini, tangki air konkrit bertetulang tinggi dengan saiz tiang yang lebih besar cenderung untuk mempunyai nilai kekuatan tengangan yang lebih tinggi.

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LIST OF SYMBOLS

δu	Ultimate Displacement
δy	Yield Displacement
f_{cu}	Concrete Compressive Strength
f_y	Yield Strength of Steel
f_{yh}	Link Yield Strength
f'_c	Specified Concrete Compressive Strength

LIST OF ABBREVIATIONS

RC	Reinforced Concrete
POA	Pushover Analysis
P	Moment-axial load
M3	Moment-curvature
P-M3	Moment-axial load with moment-curvature
ESRs	Elevated Service Reservoirs
H	Height
B	Width
M_w	Magnitude
E	Modulus of Elasticity
U	Poisson’s Ratio
A	Coefficient of Thermal Expansion
G	Shear Modulus
kN	Kilo newton
LL	Live Load
DL	Dead Load
m	Metre
mm	Millimetre

CHAPTER 1

INTRODUCTION

1.1 Introduction

Earthquake is one of the major natural catastrophe which have the potential to cause damage to lives and lifeline facilities. Futhermore, earthquakes are known as the shaking motion or sudden movement of earth caused by the slippage or rupture of a fault within the earth's crust. As a result the release of elastic energy stored in the earth crust can cause and generate seismic waves. The elastic waves produced radiate outward from the 'source' and vibrate the ground. In an earthquake, seismic vibrations occurs when two sides of a fault suddenly slide past each other, that causes called the initial movement. A fault is a large fracture in rocks, across which the rocks have moved. Furthermore, faults can be microscopic or hundreds-to-thousands of kilometers long and tens of kilometers deep.

When an earthquake occurs, the quantification of earthquake size that is commonly used the most is the magnitude. Magnitude is an instrumental measure of the amplitude of ground shaking. An instrument called a seismograph will be used to measure the magnitude of an earthquake. In addition, the size of an earthquake depends on the area of the fault that ruptured and the distance that the rocks on the two sides of the fault slide past one another.

Small earthquake rupture small sections of large faults or small faults. Fault movement during such events is quick; small quakes last only a fraction of a second and the rocks on either side of the fault don't move very far. Meanwhile, large earthquakes rupture faults that are tens to thousands of kilometers long. Such ruptures can take minutes to complete, so strong shaking near the earthquakes can last several minutes and rocks across the fault can be offset tens of meters during very large earthquakes.

Therefore, this research was carried out using pushover analysis on reinforced concrete water tank due to the importance of water tank before and after an earthquake occurs. This method is mostly employed to determine how a structure will perform when subjected to a given level of earthquake.

Malaysia is one of the safest places in the world where it is are located outside the seismic zone. However, due to the far field effects of Sumatra Andaman and Philippines earthquake, Malaysia are occasionally subjected to tremors. Recently on 5th June 2015, Ranau, Sabah has experienced earthquake with a magnitude of 5.9 which recorded as the strongest tremors to affect Malaysia for the last 45 years. The epicentre of the quake was about 14.1km west-north-west of Ranau and 51.9km east of Kota Kinabalu, Sabah. Figure 1.1 presents the epicentre of the 2015 Ranau earthquake.

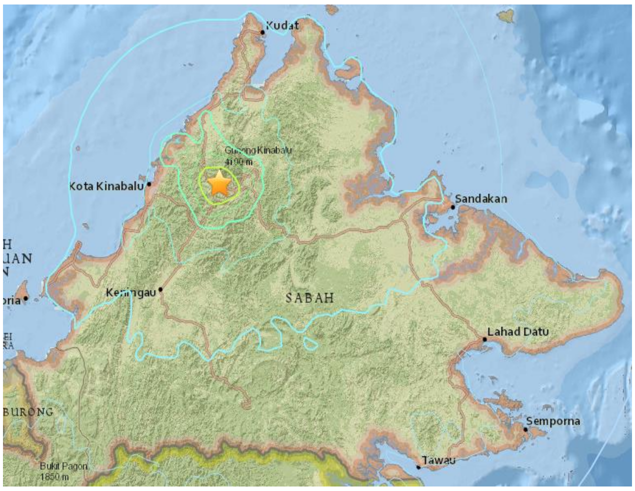


Figure 1.1 Epicentre of 2015 Ranau Earthquake (USGS, 2015)

Pushover analysis has been developed over the past twenty years and has become the preferred analysis procedure for design and seismic performance evaluation purposes as the procedure is relatively simple and considers post-elastic behaviour. However, the procedure involves certain approximations and simplifications that some amount of variation is always expected to exist in seismic demand prediction of pushover analysis.

This well-known method of analysis for design and seismic performance evaluation can be conducted to both regular and irregular frame. In this project, regular frame has been used to all models. Pushover analysis consists of a series of sequential elastic analysis, superimposed to approximate a force-displacement curve of the overall structure. The danger of earthquakes will affect mostly to man-made structures and that will lead to loss of lives. Therefore, the responsibility to build a structure that are able to withstand seismic action should be taken by the structural engineer.

Buildings that are subjected to seismic action (lateral force) tend to deform until it reach the ultimate displacement before its collapse. The behaviour of the structure can be obtained when the seismic design and assessment of structure are completed. The most important parameters that describe the behaviour of the structures are stiffness, strength and ductility. In addition, material properties, section properties, member properties and connection properties affect these parameters. Thus, engineers should be able to design buildings by considering all these parameter to prevent it from failure.

1.2 Problem Statement

Before the disaster of the Sumatra Andaman earthquake in December 2014, the awareness of Malaysian people on earthquake are very little. However, after experiencing several local tremors in Sabah and Peninsular Malaysia and far field tremor from earthquakes occurred in Philippines and Indonesia, the question about ability of buildings in Malaysia to withstand the tremor have been raise. The recent 5.9-magnitude earthquake at Ranau, Sabah on 5th June 2015 had damaged 31 facilities buildings, including one of the Mount Kinabalu’s summit called ‘Donkey’s Ears’, stone resembles a pair of donkey ears fractured, and 18 loss of lives.

In public water distribution system, elevated reinforced concrete (RC) water tank was used widely in the entire world as an important part of lifeline system especially in earthquake prone regions. Due to the most important structure before, during, and after a disaster such as earthquake, it is important to maintain the seismic safety of elevated RC water tanks.

Dhiraj et al. (2015) stated that elevated RC water tanks also called as elevated service reservoirs (ESRs) typically consist of a square/circular shape of container and either concrete or steel supporting tower and a study related to seismic evaluation case study for an existing RC elevated water tank using pushover analysis as per ATC-40 (1996) & FEMA-356 (2000), which provide the target displacement and the yielding mechanism has been conducted.

Elevated RC water tanks are a structure that has a large mass concentrated at the top of slender column which have supporting structure. Hence, these structures are especially vulnerable to horizontal forces due to earthquakes. It is important for elevated RC water tanks to remain functional after the earthquake where water tanks are the most essential as water supply system for providing storage of water, drinking purpose, fire suppression as well as many other applications. Therefore, it is important to investigate the seismic capacity of existing elevated RC water tank in Malaysia to withstand the earthquakes.

1.3 Objectives

The behaviour of an elevated RC water tank has been studied in this research considering the various structural and geometrical parameters using SAP2000 software. The capacity curve, and lateral displacement at yield limit state and ultimate limit state for each water tank models are presented for discussion and conclusion.

The main objectives are as given below:

(a) To investigate the effect of column size on the seismic capacity of elevated RC water tank.

(b) To determine the effect of column size on lateral displacement of elevated RC water tank.

1.4 Scope of Work

In this study, the scope of work for the vertically regular RC frames of elevated water tank is limited to:

(a) A 4 storey and 7 storey regular frame of elevated RC water tank was taken as the model.

(b) 5 sets of 4 storeys and 7 storeys of elevated RC water tanks with different size of column were designed based on BS8110 (1997) using ESTEEM software.

(c) The compressive strength of concrete, f_{cu} was considered as equal to $30N/mm^2$. The yield strength of steel reinforcement, f_y is equal to $460N/mm^2$ and $250N/mm^2$ for flexural and shear reinforcement, respectively.

(d) CUMBIA software by Montejo (2007) were used to analyse the nonlinear properties of structural members.

(e) SAP2000 was used for pushover analysis on all models.

1.5 Summary

This chapter covers the introduction of this project where the formation of earthquake and definition of pushover analysis is explained. The importance of elevated RC water tank in public water distribution system used as the model in this project also briefly discussed. In addition, the objectives and scope of works are also provided and explained.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Since the ancient age until today, there are many earthquake occurred around the world. The recent intensive earthquake had occurred in 2014 in Tarakan, North Kalimantan, Indonesia (M_w 6.1 earthquake), Sandakan, Sabah, Malaysia (M_w 4.1 earthquake) which is also in 2014. The most recent was occurred in 2015 at Ranau, Sabah, Malaysia (M_w 5.9 earthquake) which caused extensive damage to the buildings especially near Mount Kinabalu and leaving many people in need of assistance. This disaster had caused a several types of ground effect such as ground shaking, ground cracking, landslides, and liquefaction.

Figure 2.1 Effect to ground from earthquake at Ranau, Sabah (Sinar Harian, 2015)

Furthermore, Ramli and Adnan (2004) stated that earthquakes are one of nature's greatest disasters in the world. Therefore, the issue on earthquake had become serious around the world. Besides that, several earthquake had occurred in South East Asia especially the country located at boundary of the earth plate. The safety of building in Malaysia subjected to seismic action had become an issue. The discussion has been actively conducted about the necessary of consideration of seismic load on building in Malaysia between the government, local authorities, structural engineer, architect and other related professional. Earthquake happened due to the nature such as movement of tectonic, volcanic activity and meteor impact but earthquakes can also be induced by some human activities like mine blasts and nuclear experimentation.

Earthquake engineering is a sector of civil engineering that deals with the mitigation of earthquake-induced damage on structures and the minimization of loss of life. During the last forty years this sector has advanced considerably due to the rapid developments of computers and programing, the improved experimental facilities, and the development of new methods of seismic design and assessment of structures. This advancement though has not been enough to resist the catastrophic consequences that earthquakes impose. Nevertheless, the characterization of the various performance levels has led to performance-based earthquake engineering; the most recent path of seismic design and assessment.

In addition, an instrument called seismometer can be used to measure the earthquake wave. Richter scale can be used to represent the magnitude (energy that earthquake release) and intensity (depends on the earthquake location) of earthquake. The higher the scale indicates the more harmful is the earthquake. It is impossible to prevent earthquake from occurring, but it is possible to mitigate the effect of seismic hazards (Kramer, 1996). One of the mitigation process is knowing the ability of the structure when subjected to seismic loading.

When structures are subjected to strong earthquake ground motions, they exhibit inelastic behaviour, which cannot be assessed using an elastic analysis. A nonlinear analysis to evaluate the seismic performance of structures considering the post-elastic behaviour is needed, to predict the vulnerability of the structures, and their survivability under severe earthquake ground motions. Various simplified nonlinear analysis methods to estimate the maximum inelastic displacement demand of structures are proposed in literature. The nonlinear static analysis or pushover analysis have been carried out in this study.

The procedures that are recommended for seismic design and assessment purposes are briefly described and their shortcomings are addressed. The theoretical background of the nonlinear static or pushover analysis, is then described together with the various pushover analysis procedures. Finally, a review of the state-of-the-art of research on pushover analysis is presented together with general conclusions on the efficiency of the method derived from the literature.

Buildings are usually designed for seismic resistance using elastic analysis, most of which experiences significant inelastic deformations under large seismic actions. Modern performance based design methods require ways to determine the real behaviour of structures under such conditions. As such, nonlinear analysis can play an important role in the design of new and existing buildings. Nonlinear analysis involves significantly more efforts to perform and should be approached with specific objectives.

In contrast to linear elastic analysis and design methods that are well established, nonlinear inelastic analysis techniques and their application to design are still evolving and may require engineers to develop new skills. Nonlinear analysis requires thinking about inelastic behaviour and limit states that depend on deformations as well as forces.

2.2 Performance-Based Design

Many ways have been discussed on how to minimizing the impact of seismic earthquake to resist the catastrophic consequences that earthquakes impose. However, it has led to some improvement of design and assessment procedures with a shift from traditional force-based procedures to displacement-based procedures, as inelastic displacements have been deemed to be more representative of different structural performance levels. However it is still difficult to physically ‘separate’ these procedures since forces and displacements are strongly related to each other.

Performance based design refers to a methodology in which structural criteria are expressed in terms of achieving a performance objective. This is contrasted to a conventional method in which structural criteria are defined by limits on member forces resulting from a prescribed level of applied shear force. A performance objective specifies the desired seismic performance of the building.

Seismic performance is described by designating the maximum allowable damage state (performance level) for an identified seismic hazard (earthquake ground motion) (The Constructor – Civil Engineering Home). A performance objective may include consideration of damage states for several levels of ground motion and would then be termed a dual or multiple level performance objectives.

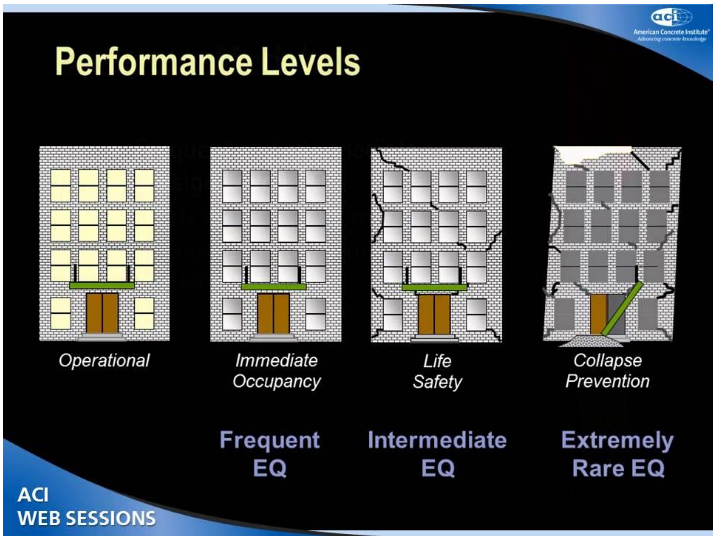


Figure 2.2 Performance levels of a structure

In seismic prone region, the popular method used by engineer and researcher for structural analysis is the performance-based design and assessment. This method is equipped in determining the structures response in the form of drift by nonlinear static analysis and nonlinear time history analysis. Furthermore, to determine the yield state of structure and ductility of structure, nonlinear static analysis is the mostly employed method. Although the weakness of this method cannot reflect any cyclic response of structure having an earthquake motion, but the method is still used extensively in determining the ductility as well (Ade Faisal and Majid, 2010).

2.3 Conceptual Framework

Elnashai and Sarno (2008) stated that focus of conceptual framework is placed on the three response characteristics used as the most important parameters that describe the behaviour of structures and their foundations when subjected to earthquakes. These are stiffness, strength (or capacity) and ductility. Stiffness is stated by Elnashai and Sarno (2008) as the ability of a component or an assembly of components to resist deformations when subjected to actions. It is expressed as the ratio between action and deformation at a given level of either of the two quantities and the corresponding value of the other. Therefore, stiffness is not a constant value.

Meanwhile, for strength, it is defined as the capacity of a component to resist load. It is also not a constant value, as shown in Figure 2.3. Strength (or capacity) is representing both action resistance and the ability to withstand deformation. Finally, for ductility, it is defined as the ability of a component to deform beyond the elastic limit as shown in Figure 2.3. It is shown that the maximum value of a deformation quantity is the yield limit state of a structure. Figure 2.3 shows the displacement ductility, μ which is the ratio of ultimate displacement, δu to the yield displacement, δy.

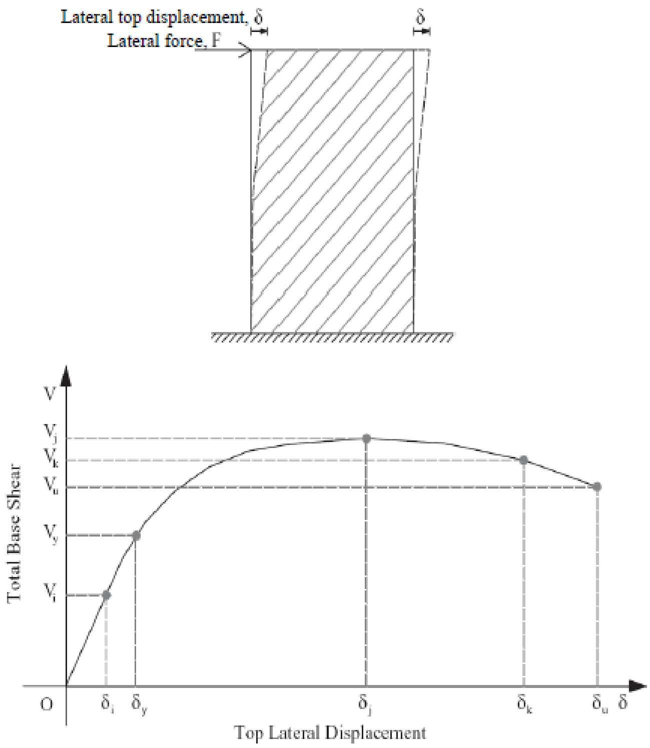


Figure 2.3 Typical capacity curve for structure subjected to horizontal loads (Elnashai and Sarno, 2008)

2.4 Moment-Curvature Curve

Ersoy and Ozebe (1998) stated that the moment-curvature curve represents the strength and deformation of a building as shown in Figure 2.4. According to Alaoui et al. (2007), moment-curvature plots illustrate stiffness, strength, and cross-sectional ductility. The moment-curvature curve is commonly used for beam and column members. Figure 2.4 shows the idealized moment-curvature curve where according to Younggon et al. (1992), at the first stage of yielding, bending and shear cracks occur at the end portions of column. Plastic hinges are formed by bending and shear cracks on column. Other than that, column with rich tie reinforcement are effective for preventing ductile failure. The final stage is reached when splitting bond failure at the middle portions of column.

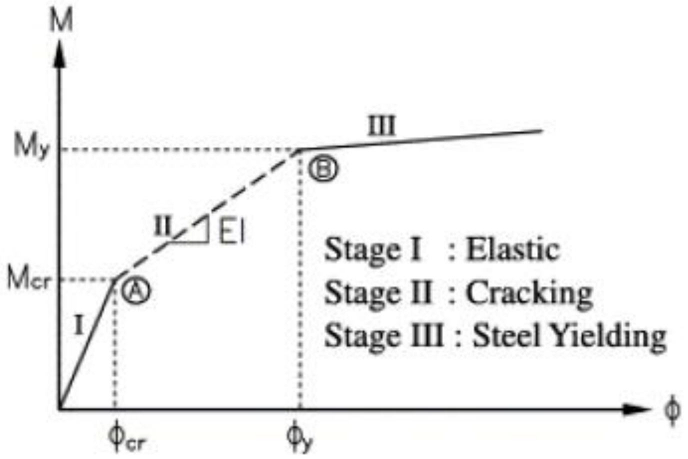


Figure 2.4 Idealized moment-curvature curve of RC section (Kwak and Kim, 2002)

2.5 Moment-Axial Curve

The moment-axial curve is commonly used column members only. Moment-axial curve shows the behaviour of a section under combined axial load and bending moment. It is indicates whether the behaviour is controlled by tension or compression for the reinforcement in concrete. Furthermore, moment-axial curve can only be obtained after the axial load experienced by column are identified.

2.6 Pushover Analysis

According to FEMA NEHRP (2000), nonlinear static or pushover analysis are conducted under the factored gravity load combination and static lateral earthquake forces. Pushover analysis is carried out under permanent vertical loads and gradually increasing lateral loads to calculate the deformation as well as damage pattern of a structure.

Other than that, pushover analysis is a simpler option to estimate strength capacities and deformation demands (Lawson et. al, 1994). A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature weakness. This plot is known as ‘Capacity Curve’.

Pushover analysis can be performed as force-controlled or displacement-controlled. Also, pushover analysis has become the preferred method for seismic performance evaluation of building because it is conceptually and computationally simple. It allows tracing the sequence of yielding of members, plastic hinge formation and failure on member and structural level as well as the progress of overall capacity curve of the structure.

The ultimate deformation capacity of a component depends on the ultimate curvature and plastic hinge length. The used of different criteria for the ultimate curvature and different plastic hinge length will results in different deformation capacities (Inel and Ozmen, 2006).

2.6.1 Concept of Pushover Analysis

The concept of pushover analysis behind the program is still new. The general concept of pushover analysis that is to assess the seismic capacity of reinforced concrete (RC) structures. The application of pushover analysis on the assessment of RC frame by utilizing SAP2000 is used by Ade Faisal and Majid (2010) to analyse the member section.

2.6.2 Advantages of Pushover Analysis

- Allows engineers to understand structure’s nonlinear behavior and progression of damage with increasing ground motion intensity.
- The pushover analysis is expected to provide information on many response characteristics that cannot be obtained from an elastic dynamic or static analysis.
- Does not require selection and scaling of ground motions
- Consequences of the strength deterioration of individual elements on behavior of the structural system.
- Enable to perform with or without nonlinear analysis software.

2.7 Plastic Hinge Properties

The data for plastic hinge properties can be obtained from CUMBIA output. The plastic hinge need to be inserted so that the formation of plastic hinge of the structure can be obtained. Vinay et al. (2012) stated that frame of a structure shown variety failures like beam-column joint failure, flexural failures and shear failures. The prominent failures are joint failures. Basically, hinge properties localized force-displacement relation of a structure element through its elastic and inelastic simulation under seismic loading. There are various types of hinges name. The hinge names are stated as follows:

- Hinges for flexural
- Hinges for shear
- Hinge for axial

Nonlinear behaviour of structural member is the nonlinearity of the material which does not allow only the plastic behaviour of member thus it is necessary to generate the moment-rotation curve which characterizes the yield criteria of nonlinear frame. For each and every degree of freedom define a moment-rotation relation curve that gives the plastic deformation, yield value and the following yield. This is done in terms of an idealized curve with values at five points A-B-C-D-E as shown in Figure 2.5.

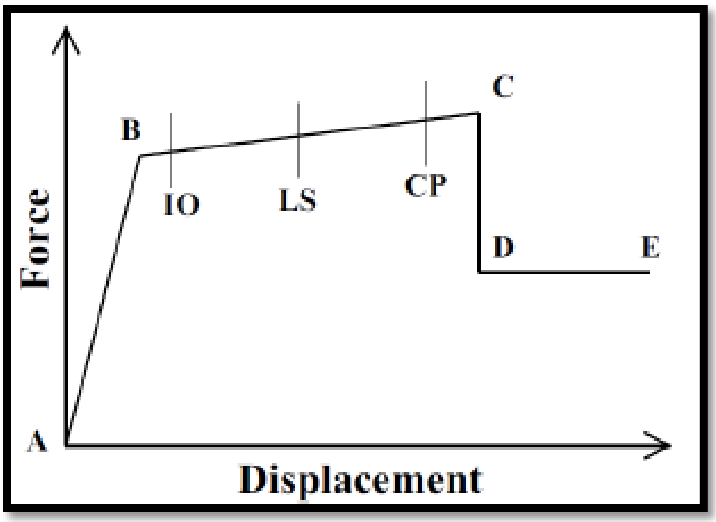


Figure 2.5 Strength and deformation points (FEMA 356, 2000)

The following points are:

- Point A is always will be the origin
- Point B represents start of yielding. Deformation does not occur in the hinge up to point B. Only the plastic deformation beyond point B will be shown by the hinge.
- Point C represents the ultimate capacity of structure by pushover analysis.
- Point D represents a residual strength or after damage of structure.
- Point E shows total failure of structure. Beyond E point the hinge will drop shear down to point F, which is not visible in Figure 2.5, directly below point E on the horizontal axis. If user does not want fail hinge this way, user need to be sure to give a large value for the deformation at point E.

2.8 Capacity Curve

Capacity curve is obtained from the pushover analysis. Zou and Chan (2005) stated that capacity curve represents the structures ability to resists seismic demand. How the structure behaves beyond the elastic limit can be observed from the capacity curve. Other than that, the damage increased as the load and deformation resistance is lowered when applying a lateral load to the buildings.

This will affect changes in stiffness that results from inelastic behaviour of the system due to material nonlinearity. Furthermore, capacity curve also provides information of the identification of the critical regions in which the deformation demands are expected to be high and the strength discontinuities that will lead to the changes in the dynamic characteristic in the inelastic range.

2.9 Summary

According to the most research studies, none of them studied about the comparison of the seismic capacity of elevated RC water tank in Malaysia using pushover analysis. This study will present the comparison of capacity curve, lateral displacement and formation of plastic hinge for 4 storeys and 7 storeys elevated RC water tank. Meanwhile, software SAP2000 is used in this project for pushover analysis.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Nonlinear static analysis, or pushover analysis, could be performed directly by a computer program which can model nonlinear behaviour of lateral load resisting members of a structure. However, the computational scheme and the assumptions involved in modelling nonlinear member behaviour could be different that there may be variations in the pushover results obtained from different software. Therefore, the underlying principles of any software utilized for pushover analysis should be well understood to interpret the results of pushover analysis. The behaviour of structures under seismic actions can be captured using pushover analysis. It is carried out for either default hinge properties or user-defined hinge properties.

In this study, pushover analysis was used to investigate the effect of column size on the seismic capacity of elevated RC water tank by using SAP2000 software. The software is capable to operate nonlinear static and dynamic analysis. Basically, there are six main steps involved in the analysis which include, model generation, section details and loading calculation, linear static analysis, section analysis, pushover analysis, discussion and conclusion as shown in Figure 3.1. BS8110 (1997) was referred to design the elevated RC water tank by using ESTEEM software. Then, CUMBIA software was used for section analysis. The result for section analysis are moment-curvature curve, moment-axial curve, and hinge length. From pushover analysis, capacity curve (base shear force vs top displacement) and lateral displacement is obtained. Structural member failure is observed through deform shape in SAP2000.

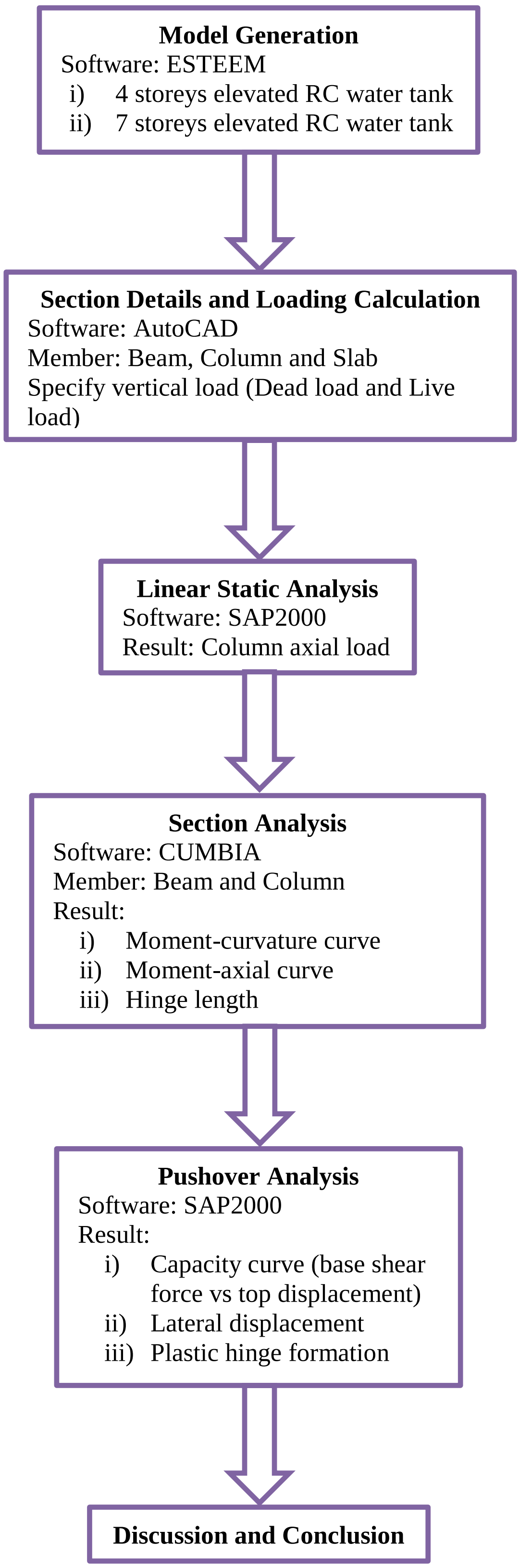


Figure 3.1 Flow chart of research methodology

3.2 Model Generation

In this study, a total number of 10 models of elevated RC water tanks consist of 4 storeys and 7 storeys has been used. All models has been designed repeatedly to 5 different size of column for each storey, where the beam size is fixed for each model. The list of models which has been used in this study is shown in Table 3.1 and Table 3.2 for the 4 storeys and 7 storeys, respectively.

Table 3.1 4 storeys of elevated RC water tank

Models	Column (mm)	Beam (mm)
N4A	300 x 300	200 x 400
N4B	350 x 350	200 x 400
N4C	400 x 400	200 x 400
N4D	450 x 450	200 x 400
N4E	500 x 500	200 x 400

Table 3.2 7 storeys of elevated RC water tank

Models	Column (mm)	Beam (mm)
N7A	400 x 400	250 x 450
N7B	450 x 450	250 x 450
N7C	500 x 500	250 x 450
N7D	550 x 550	250 x 450
N7E	600 x 600	250 x 450

In addition, all models has been designed by using ESTEEM software based on BS8110 (1997) to represent the existing elevated RC water tanks in Malaysia. Details and specification of structural design for 4 storeys and 7 storeys elevated RC water tank model is shown in Table 3.3 and Table 3.4, respectively. Meanwhile, Figure 3.2 and Figure 3.3 show the 4 storeys and 7 storeys elevated RC water tank frame, respectively and the detail drawings of the storey elevated RC water tank from ESTEEM software are shown in Appendix A.

Table 3.3 Details and specification of 4 storey elevated RC water tank models

Model Information	Specification
Number of storey	4
Base	Fixed end support
Width of building	9.0m (3 bays with 3.0m)
Storey Height	3.0m
Beam size	200mm x 400mm
Colum size	Refer Table 3.1
Beam, column, slab cover	30mm
Main bar diameter	16mm to 20mm (Beam) 16mm to 25mm (Column)
Link diameter	6mm to 10mm
Concrete compressive strength, f_{cu}	30 N/mm^2
Yield strength of steel, f_y	460 N/mm^2
Link yield strength, f_{yh}	250 N/mm^2

Table 3.4 Details and specification of 7 storey elevated RC water tank models

Model Information	Specification
Number of storey	7
Base	Fixed end support
Width of building	15.0m (3 bays with 5.0m)
Storey Height	3.5m
Beam size	250mm x 450mm
Colum size	Refer Table 3.2
Beam, column, slab cover	30mm
Main bar diameter	16mm to 20mm (Beam) 16mm to 25mm (Column)
Link diameter	6mm to 10mm
Concrete compressive strength, f_{cu}	30 N/mm^2
Yield strength of steel, f_y	460 N/mm^2
Link yield strength, f_{yh}	250 N/mm^2

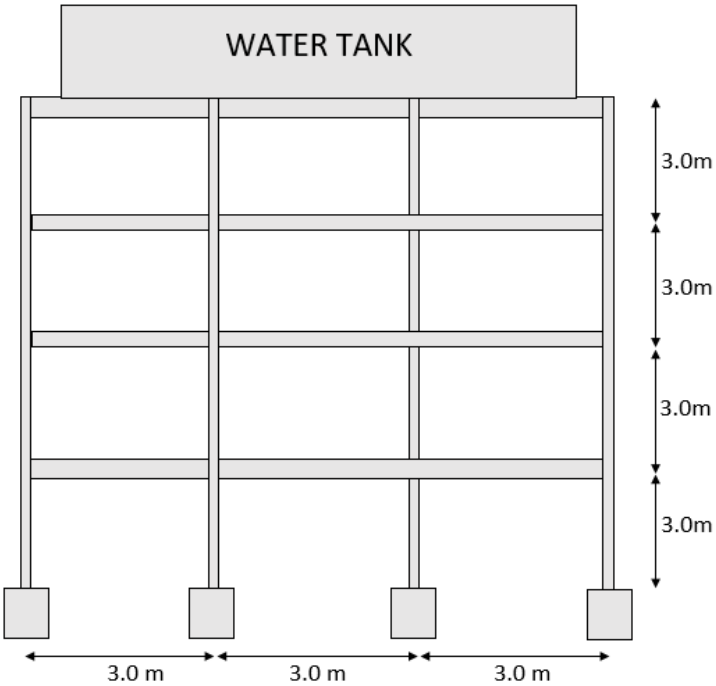


Figure 3.2 4 storeys of elevated RC water tank frame

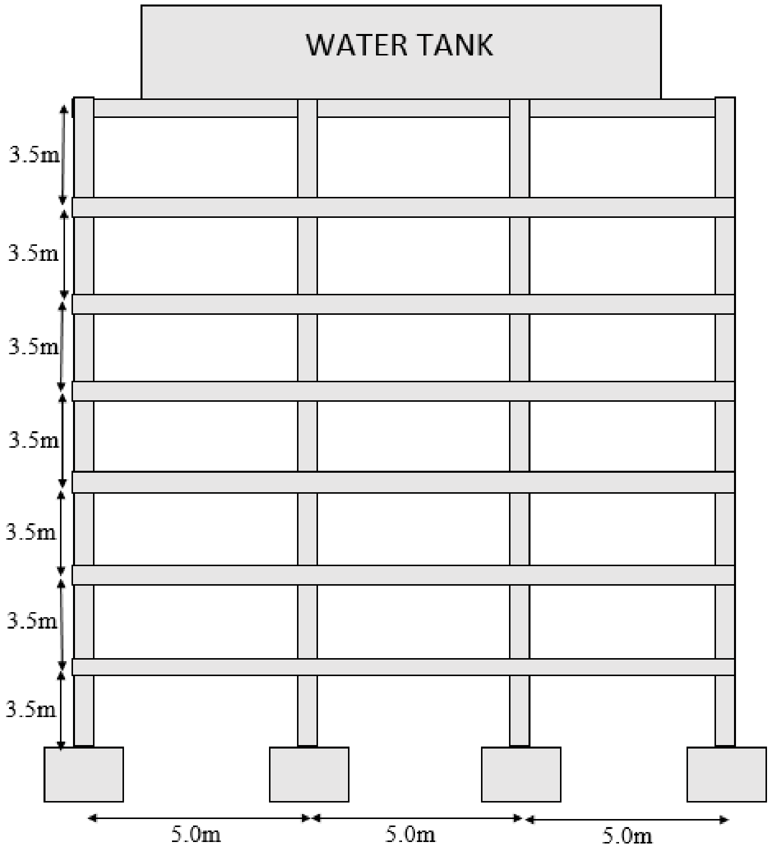
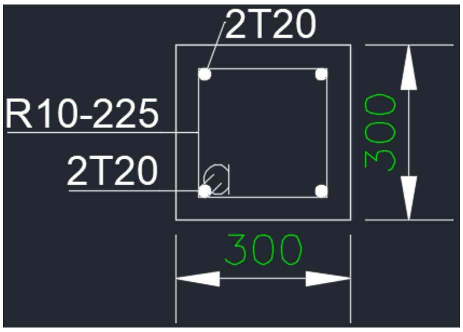


Figure 3.3 7 storeys of elevated RC water tank

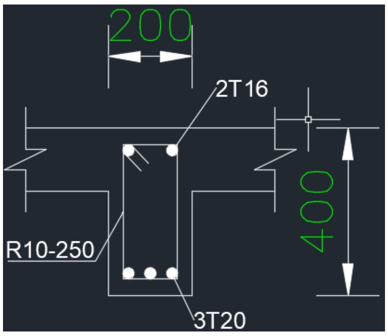
3.3 Section Details and Loading Calculation

3.3.1 Section Details

After designing the models of elevated RC water tank using ESTEEM software, the section details for the structure has been exported into AutoCAD file. In this step, AutoCAD software was used to obtain the section details. The details that had been obtained is size of column and beam, slab thickness, width and length of structure, and reinforcement bar of beam and column. The details that needed for reinforcement bar is diameter main bar, diameter link, and spacing as shown in Figure 3.4.



(a) Column reinforcement bar details



(b) Beam reinforcement bar details

Figure 3.4 Details of reinforcement bar for column and beam

3.3.2 Loading Calculation

The loading that need to be calculated before conducting linear static analysis is the dead load and live load of the structure. The loading calculation for dead load involves the weight of water tank, self-weight of beam, column and slab. Meanwhile, the loading calculation for live load involves the weight of water in the water tank and imposed load on the corridor of the structure. The calculation for the elevated RC water tank loading is shown in Appendix B.

3.4 Linear Static Analysis

Linear static analysis has been conducted using SAP2000 software to determine the axial load for column. The software is started by clicking the File menu, New Model command and New Model button. The form will be displayed as shown in Figure 3.5.

The unit was set as kN-m. Furthermore, the 2D frames was selected as the template. Portal in 2D frame type is chosen and the portal frame dimension is specified.

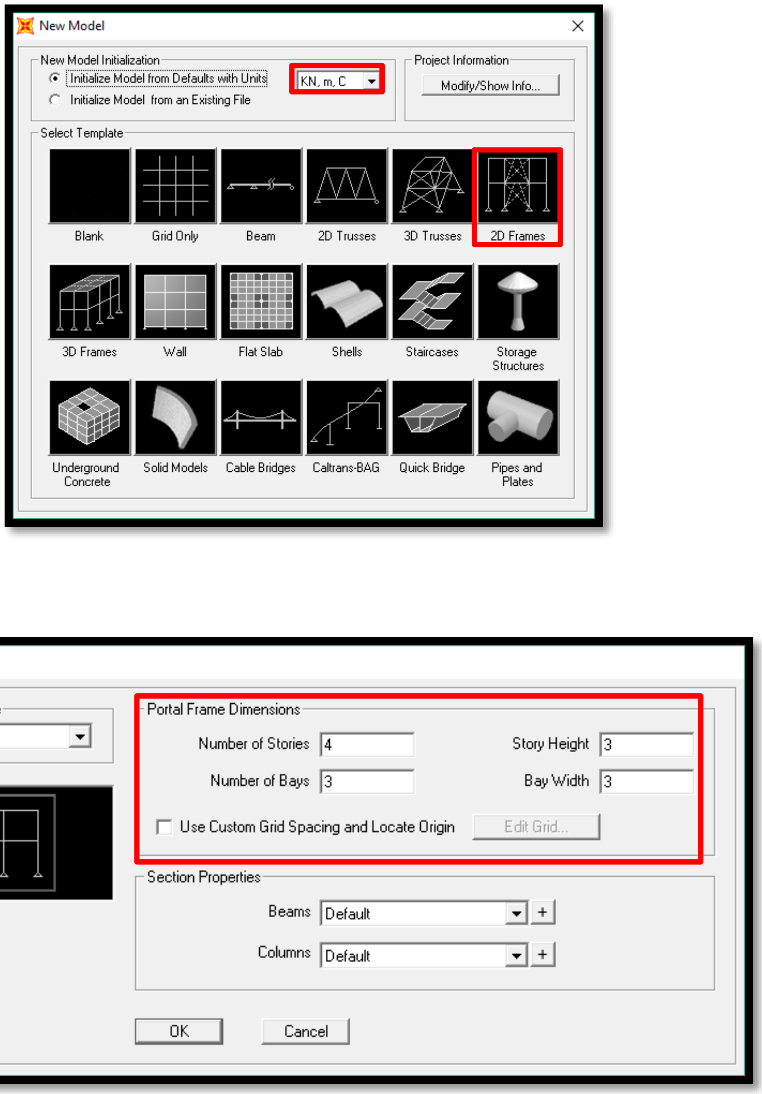
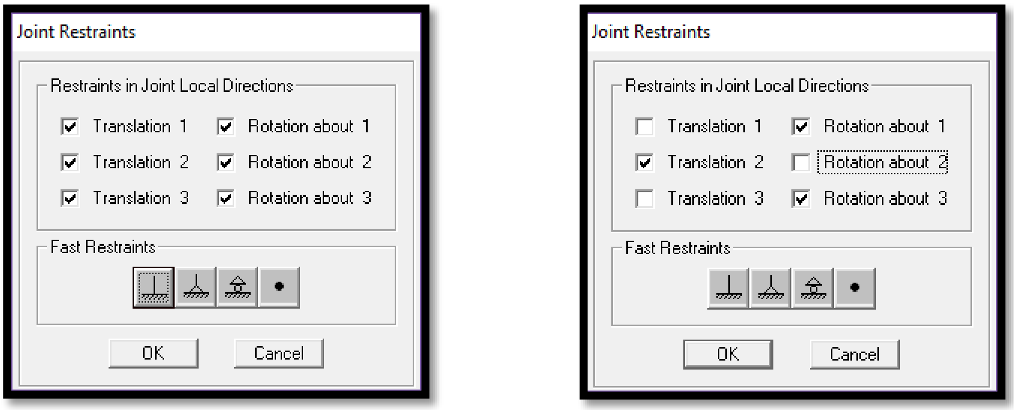


Figure 3.5 New model from SAP2000

After the new model are created in SAP2000, the column supports is assigned to be fixed as shown in Figure 3.6. The function of fixed support is to increase the stiffness and strength of the frame. Figure 3.6 shows the assigning joint for column and foundation. Other than that, all joints in each floor had been assigned with diaphragm constraint.



(a) Joint restraints at foundation (b) Joint restraints at column

Figure 3.6 Assigning joint restraints

Next, the material properties required is defined by adding new materials by clicking the Define menu and Materials button. Since this study focused on elevated RC water tank, the new material that had been added is concrete. The form in Figure 3.7 will be displayed where the value of Weight per Unit Volume of concrete, Modulus of Elasticity (E), Poisson's Ratio (U), Coefficient of Thermal Expansion (A), Shear Modulus (G), and Specified Concrete Compressive Strength (f'c) is shown.

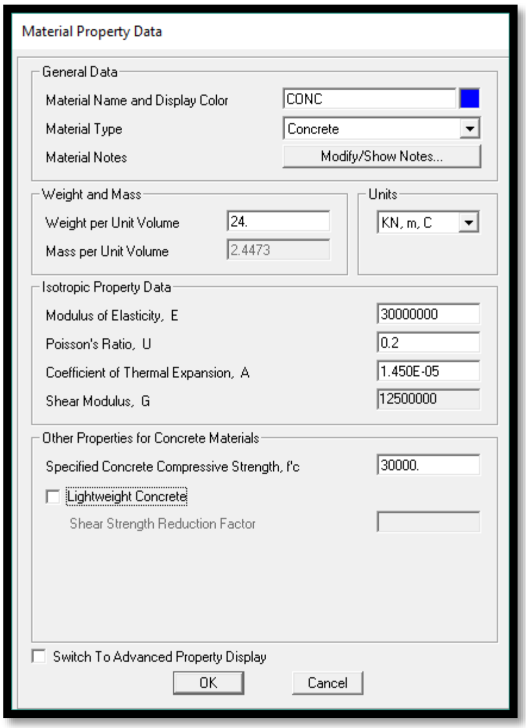


Figure 3.7 Material properties data

The step is continued by defining the frame properties which is the section member of the frame as shown in Figure 3.8. The selected frame property type is concrete and section shape is rectangular. The process is repeated to add all the member section required in the frame.

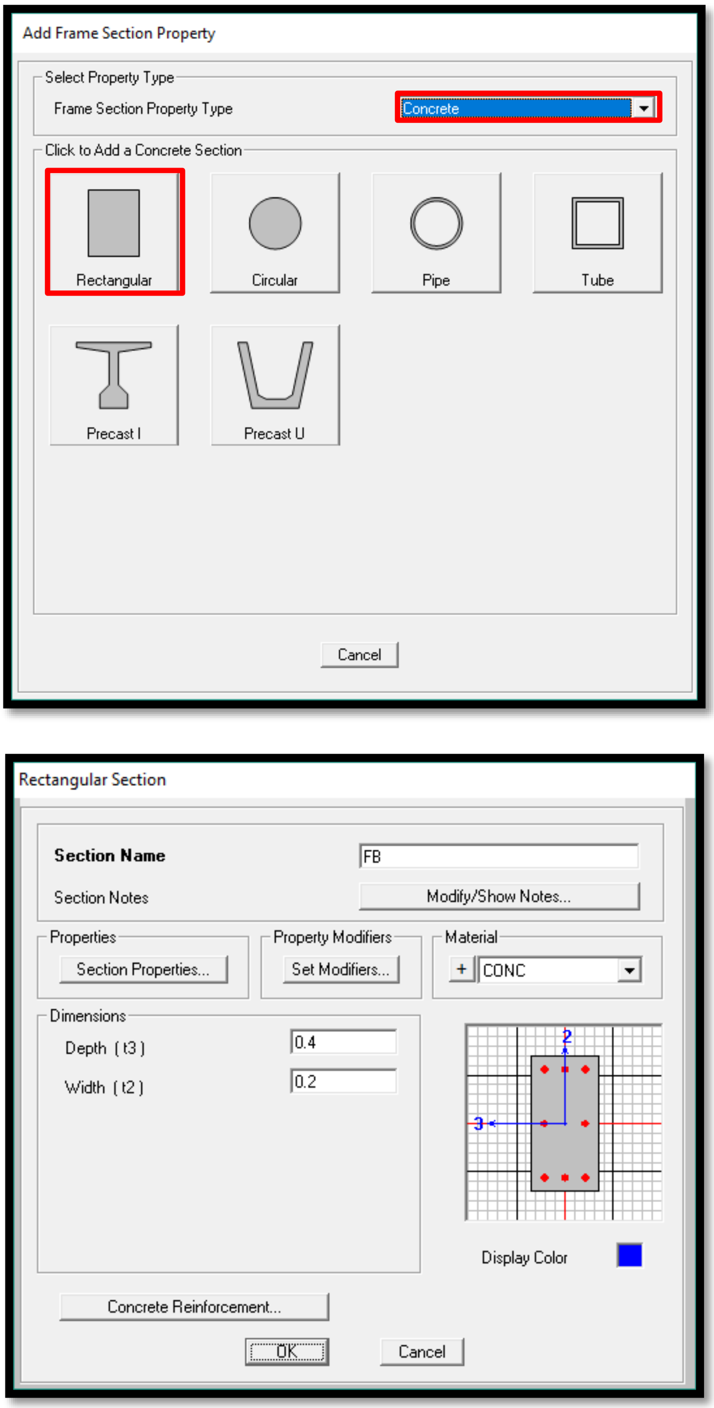
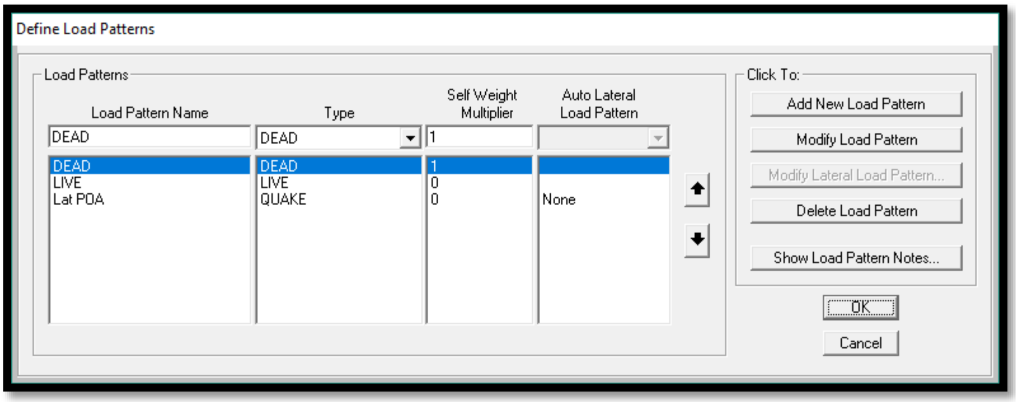


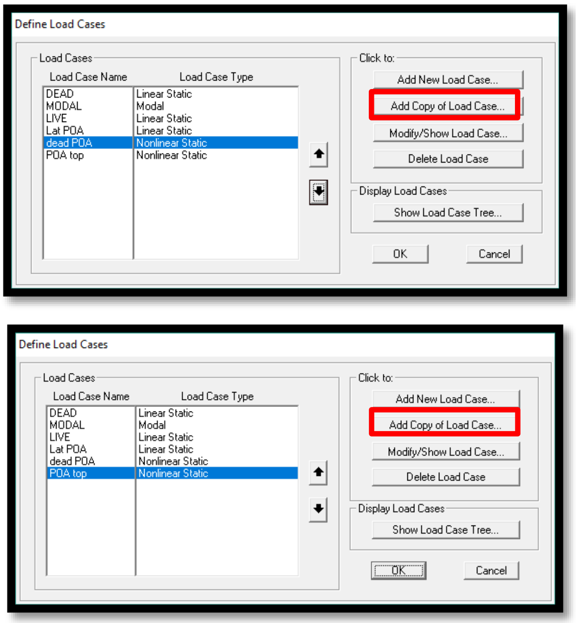
Figure 3.8 Defining frame section properties

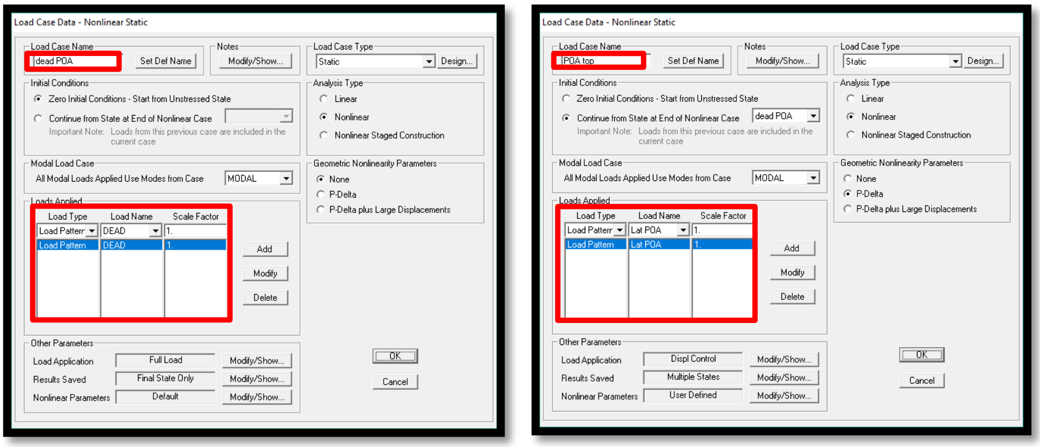
3.4.1 Loading

All load that are calculated in Appendix A which subjected to the RC frame need to be assigned. A new load pattern and load cases can be added in the Define menu and by clicking the Load Pattern button and Load Cases button. A form in Figure 3.9 will be displayed. There are three types of lateral load pattern namely uniform, linear and parabolic pattern. For this study, linear and non-linear load pattern had been used. The dead load, live load and lateral load had been assigned by clicking the Assign menu and joint loads button for dead load, and frame loads button for live load. After assigning all loads to the frame, click the Run menu to run the linear static analysis to obtain the axial load on column.

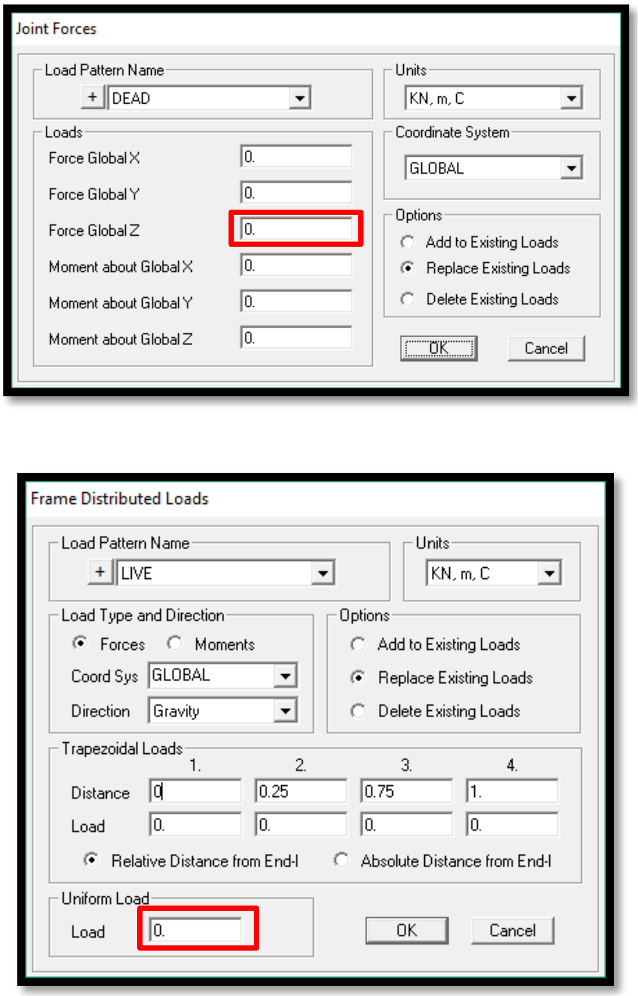


(a) Load pattern





(b) Load cases



(c) Assigning dead load and live load

Figure 3.9 Assigning load window: (a) Adding new load pattern (b) Adding new load cases (c) Assigning dead load and live load to frame structure

3.5 Section Analysis

There are several methods that can be used to perform section analysis of the elevated RC water tank structure. In this study, only plastic hinge method had been used. The outcome for this method is to obtain the moment-curvature curve and moment-axial interaction by using CUMBIA software. CUMBIA software is a set of MATLAB code used to perform monotic moment-curvature analysis of RC members. Both beams and columns having different sizes of reinforcement bars and cross section had been run in this section analysis. The example of sizes of reinforcement bars and cross section of beam and column that need to be obtained has been discussed in previous section.

Firstly, the CUMBIA software is started by opening the MATLAB R2009b software. Then by clicking either beam or column in CUMBIA software for starting the analysis, the form as shown in Figure 3.10 will be displayed. The input as highlighted in text box shows section properties, member properties, longitudinal reinforcement details, transverse reinforcement details and material properties.

After the file is open, the file name is inserted for data input. Then, for beam analysis, 'n' is inserted for interaction and 'y' is inserted for column analysis. For section properties, the section height (H), section width (B), quantity of transverse steel in x-direction (confinement), quantity of transverse steel in y-direction (shear), cover to longitudinal bars (mm) is specified. Next, in member properties, member clear length (mm), bending (single for beam or double for column) and ductility mode as 'uniaxial' for beam and 'biaxial' for column is inserted. Furthermore, the distance of rebar is inserted in MLR which is a matrix composed of [distance from the top to bar centre (mm) of bars – number of bar – bar diameter (mm)]. Each row corresponds to a layer of reinforcement. The example of calculation and detail for MLR is shown in Figure 3.11. Then, for transverse reinforcement details, diameter and spacing of transverse steel is specified. Next, applied load from SAP2000 for column and "0" for beam is inserted. The materials properties is inserted by referring Table 3.3 and Table 3.4.

```
% input data:

name = 'N7CA EXT'; %identifies actual work, the output file will be name.xls

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

% section properties:

H     = 600;                      % section height  (mm)- perp to x
B     = 600;                      % section width   (mm)- perp to y
ncx   = 3;                        % # legs transv. steel x_dir (confinement)
ncy   = 3;                        % # legs transv. steel y_dir (shear)
clb   = 40;                       % cover to longitudinal bars (mm)

% member properties

L        = 3500;                  % member clear length (mm)
bending = 'double';               % single or double
ductilitymode = 'biaxial';        % 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=[52.5   3   25
     300   2   25
     547.5  3   25];

% transverse reinforcement details

Dh       = 10;                    % diameter of transverse reinf. (mm)
s        = 150;                   % spacing of transverse steel (mm)*
```

```
P        = 1188.97;          % 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)*
esm      = 0.12;           % max transv. steel strain (usually ~0.10-0.15)*
espall   = 0.0064;         % max uncon. conc. strain (usually 0.0064)

fy       = 460;            % long steel yielding stress (MPa)
fyh      = 250;            % transverse steel yielding stress (MPa)
Es       = 200000;         % steel modulus of elasticity
fsu      = 600;            % long steel max stress (MPa)*
esh      = 0.008;          % long steel strain for strain hardening (usually 0.008)*
```

Figure 3.10   Section analysis using CUMBIA software

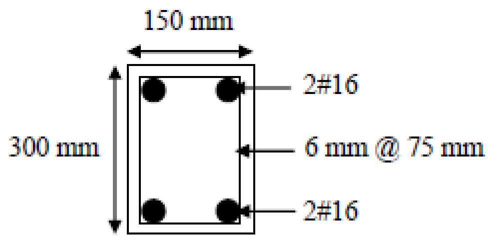
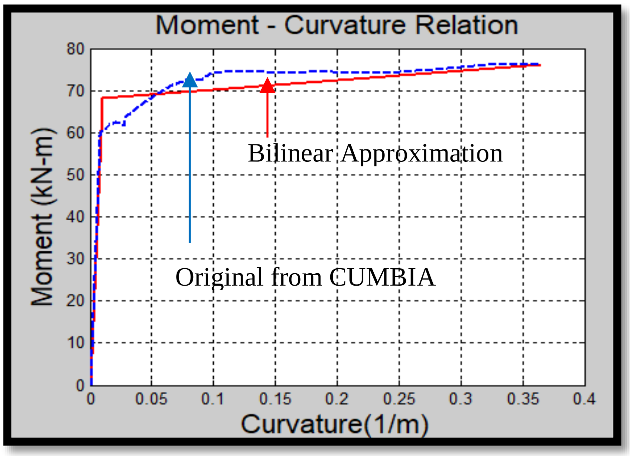


Figure 3.11 Detail of beam

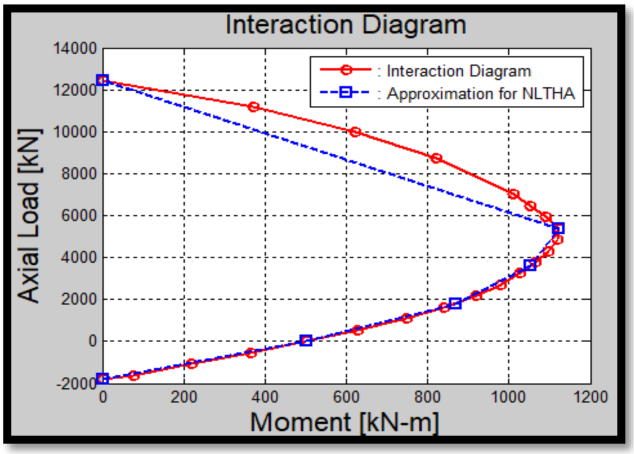
Calculation:

From Top to Center of Top Bar	=	*Cover + Hoops + Radius of bar*
	=	*30 + 6 + 8*
	=	*44 mm*
From Top to Center of Bottom Bar	=	*300 – 44*
	=	*256 mm*

Lastly, ‘debug’ is selected to run the analysis. Several figures will be shown after the process is completed. Figure 3.12 shows the example of moment-curvature curve and moment-axial interaction that need to be obtained. After the analysis have been completed, CUMBIA software will automatically save an output in MS excel file with the name that have been inserted in the data input. User SF, hinge length, ultimate moment, ultimate curvature, yield moment and yield curvature from CUMBIA software are the data specified in SAP2000 for nonlinear analysis. The example of results for bilinear approximation is shown in Table 3.5.



(a) Moment-curvature curve



(b) Moment-axial curve

Figure 3.12 Output from section analysis using CUMBIA software

Table 3.5 Output data from CUMBIA software (Beam)

Curvature (1/m)	**Moment (kN-m)**	**Displacement (m)**	**Force (kN)**
0	0	0	0
0.00968	68.18	0.02642	25.25
0.36501	76.05	0.34356	28.17

From the output data obtained from CUMBIA software, Table 3.6 are determined.

Table 3.6 Data for hinge properties (Beam)

	Curvature (1/m)	Moment (kN-m)
Yield	1	1
Ultimate	37.70764	1.11543

3.6 Pushover Analysis

Pushover analysis is started by continuing the frame model that have been created to conduct the linear static analysis. This is where the output from CUMBIA software are inserted. Firstly, frame hinge properties in SAP2000 is defined by selecting Define menu, choosing 'section properties' and click on 'hinge properties'. Beam and column is defined by choosing deformation controlled. Moment M3 for beam and Interacting P-M3 for column is chosen. Hinge properties for beam and column is inserted by clicking 'modify/show hinge properties' and the form shown in Figure 3.13 will be displayed.

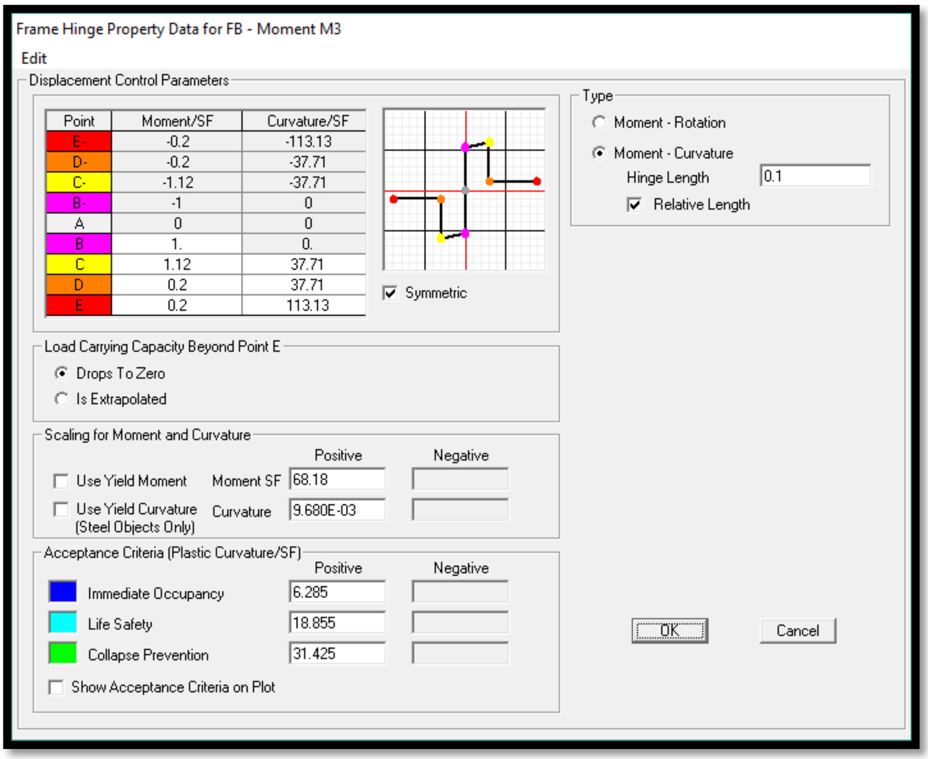


Figure 3.13 Window for hinge properties data of beam

The type of 'moment-curvature' is selected and 'hinge length' is specified. Yield moment, yield curvature, ultimate moment and ultimate curvature from CUMBIA software (Table 3.6) are inserted into displacement control parameter as shown in Figure 3.13. Meanwhile, for column, 'modify/show hinge properties' is selected and a form in Figure 3.14 will be displayed. 'Moment-curvature' is selected and 'hinge length' is specified. The used SF will specified by referring to table exactly like Table 3.5 but for column. Then, the axial force acting on the column is inserted and the yield moment, yield curvature, ultimate moment and ultimate curvature from CUMBIA software exactly as presented in Table 3.6.

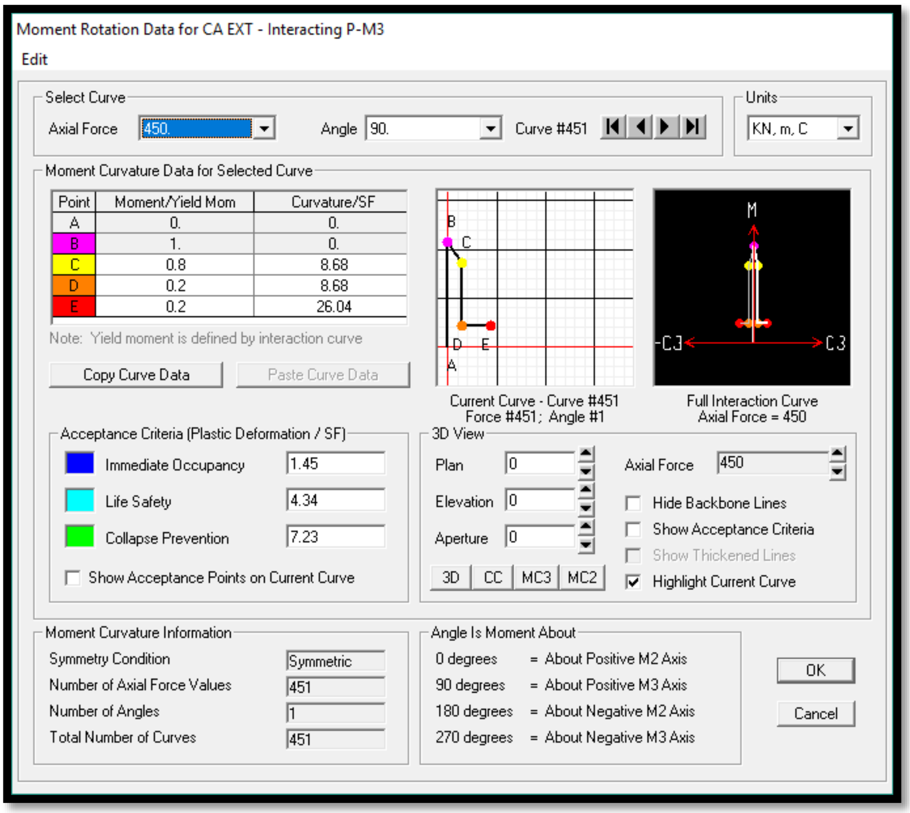


Figure 3.14 Window for hinge properties data of column

The plastic hinge that are defined earlier is used to assign the location of plastic hinge to the frames member. The plastic hinge is assigned at each member of the structure which couples with 0 and 1 of Relative Distance mean the near and the far ends position as shown in Figure 3.15.

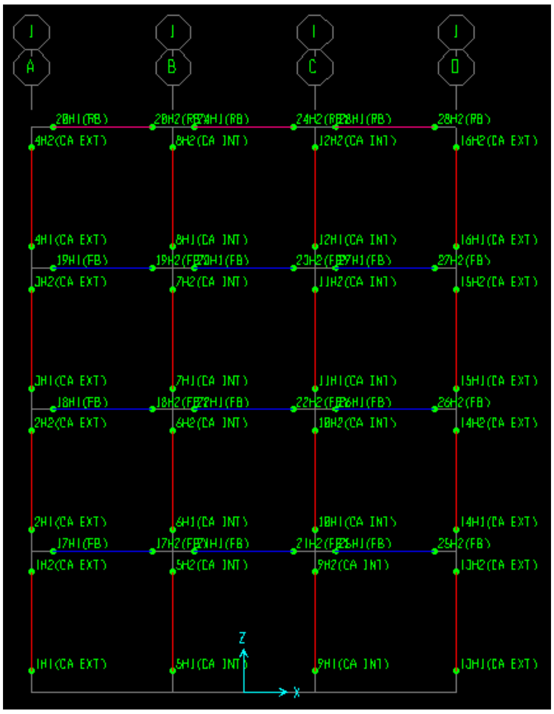


Figure 3.15 Plastic hinges on frame structure.

Finally, by using SAP2000 the analysis is run by selecting the Run menu to run the pushover analysis. Capacity curve will be obtained after the process are completed. In general, the curve is reflecting the linear and plastic conditions of structural response. Example of capacity curve are shown in Figure 3.16.

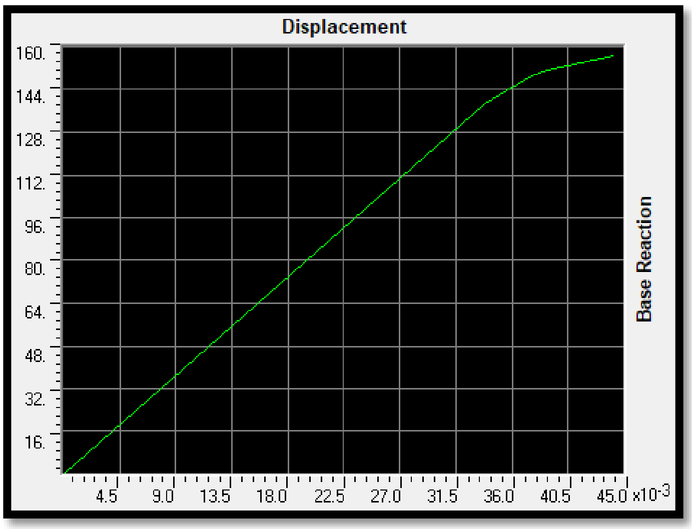


Figure 3.16 Capacity curve from SAP2000

3.7 Output of Pushover Analysis

The result of capacity curve for base shear force against top displacement is obtained by selecting ‘display’ and then ‘show static pushover curve’. The value for the ultimate displacement and yield displacement can be obtained from table where ductility is defined as the ratio between ultimate displacement and yield displacement. Several structural members that experience from yielding to total failure can be displayed through the formation of plastic hinge. Other than that, the lateral displacement at yield and ultimate also can be obtained after the analysis is done. The ultimate displacement and yield displacement for 5 sets of model for 4 storeys and 7 storeys elevated RC water tank are compared in Chapter 4. The lateral displacement at yield and ultimate for all models of 4 storeys and 7 storeys elevated RC water tank are also being compared for discussion.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the effect of column size on the seismic capacity of 4 storeys and 7 storeys elevated RC water tank by pushover analysis in SAP2000. The results are obtained by determine the yield and ultimate limit state, and lateral displacement at yield and ultimate of the elevated RC water tank structure. The result give a capacity curve in the form of base shear force against top diplacement.

Five capacity curves for 4 storeys frame with different plastic hinge definition are used and the result is compared. Other than that, another five capacity curve for 7 storeys frame are also being compared. Each of the capacity curve of yield point defines the ductility and strength of the model. Meanwhile, lateral displacement for each elevated RC water tank frame model define the stiffness of the structure. Finally, the plastic hinge formation is to detect the position of critical region of structure and defines the damage sequence for member collpase.

4.2 Result of Capacity Curve

The single output of capacity curve from pushover analysis on each models is shown in Appendix C. Meanwhile, Figure 4.1 and Figure 4.2 shows the capacity curve of five sets of model with different size of column for 4 storeys and 7 storeys of elevated RC water tank, respectively.

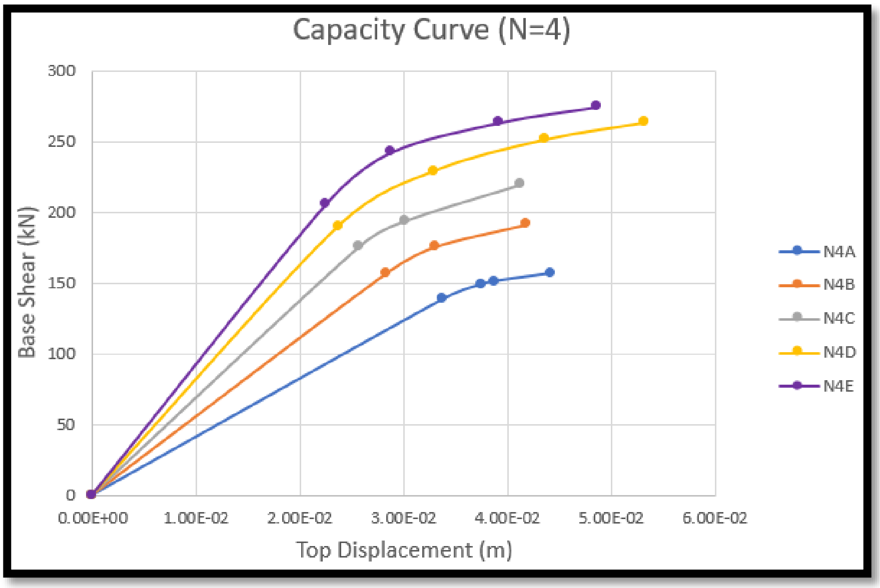


Figure 4.1 Capacity curve for 4 storey elevated RC water tank

The strength for all five models in Figure 4.1 are increased from smaller to larger size of column. First, there could be strength degradation associated with low fatigue damage of various components in the lateral force resisting system. Consequently, strength is lost due to component damage as deformations increase monotonically. From the capacity curve in Figure 4.1, the yield and ultimate forces for each of the elevated RC water tank is shown in Table 4.1.

Table 4.1 Yield and ultimate force for 4 storeys elevated RC water tank

Models	Yield (kN)	Ultimate (kN)
N4A	138.97	157.01
N4B	157.36	191.85
N4C	176.11	220.12
N4D	190.51	263.78
N4E	205.70	274.93

Table 4.1 shows that the larger size of column used in the elevated RC water tank, the longer the structure takes to yield and reach its ultimate state. Model N4E with 500mm x 500mm size of column has the highest yield and ultimate forces with value of 205.70kN and 274.93kN, respectively where it is indicate that model N4E structure is stronger compared to other models.

The value of yield force for model N4E is 48%, 30%, 16.8%, and 8% higher than model N4A, N4B, N4C, and N4D, respectively. Other than that, the ultimate force that can be resisted by model N4E is higher than the other models where the value of ultimate force for model N4E is increased 75%, 43%, 25%, and 4.2% than model N4A, N4B, N4C, and N4D, respectively.

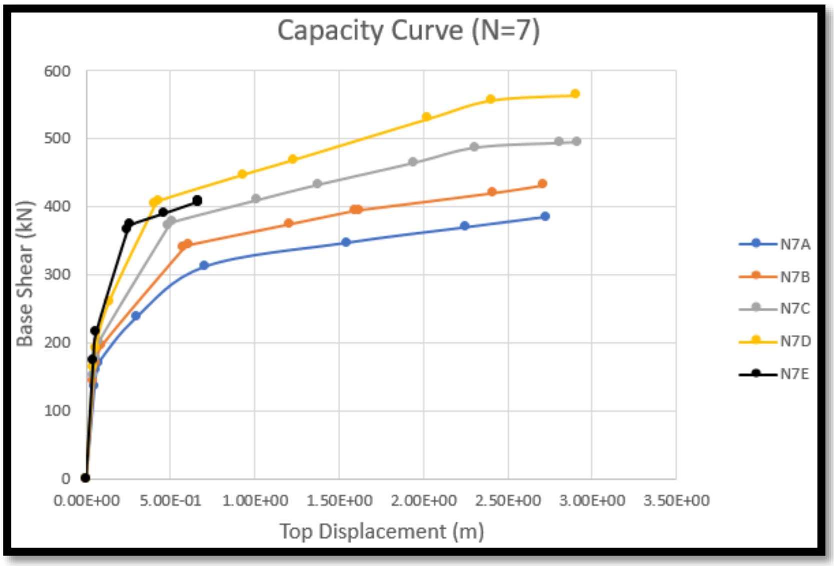


Figure 4.2 Capacity curve for 7 storey elevated RC water tank

The pattern of strength for all five model in Figure 4.2 are almost similar. From the capacity curve in Figure 4.2, the yield and ultimate forces for each of the elevated RC water tank is shown in Table 4.2.

Table 4.2 Yield and ultimate force for 7 storeys elevated RC water tank

Models	Yield (kN)	Ultimate (kN)
N7A	236.92	384.58
N7B	339.15	431.44
N7C	372.46	495.43
N7D	403.75	593.69
N7E	336.40	405.62

Table 4.2 shows that model N7D with 550mm x 550mm size of column has the highest yield and ultimate forces with value of 403.75kN and 593.69kN respectively where it is indicate that model N7D structure tend to cracking and collapse longer compare to other models. The value of yield force for model N7D is increased 70%, 20%, 19%, and 8.4% than model N7A, N7E, N7B, and N7C, respectively. Other than that, the ultimate force that can be resisted by model N7D is higher than the other models where the value of ultimate force for model N7D is 54.4%, 46.4%, 35.7%, and 19.8% higher than model N7A, N7E, N7B, and N7C, respectively.

4.3 Lateral Displacement

According to Elnashai and Sarno (2008), there are different types of method to determine the yield displacement and ultimate displacement. Yield displacement can be determined based on first yield point, equivalent elastic-plastic yield, equivalent elastic-plastic energy absorption or reduced stiffness equivalent elastic-plastic yield. For ultimate displacement, it can be determined based on a limiting compressive strain, peak load, and significant load capacity after peak load or fracture and buckling.

In this study, yield displacement are determined based on the first yield point as shown in Figure 4.3 and ultimate displacement are determined based on the significant load capacity after peak load or fracture and buckling as shown in Figure 4.4.

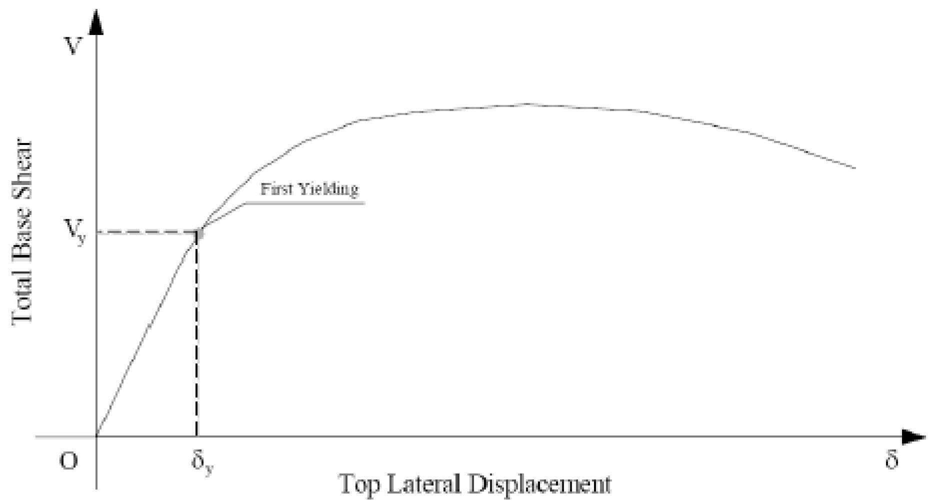


Figure 4.3 Yield displacement based on first yield, Elnashai and Sarno (2008)

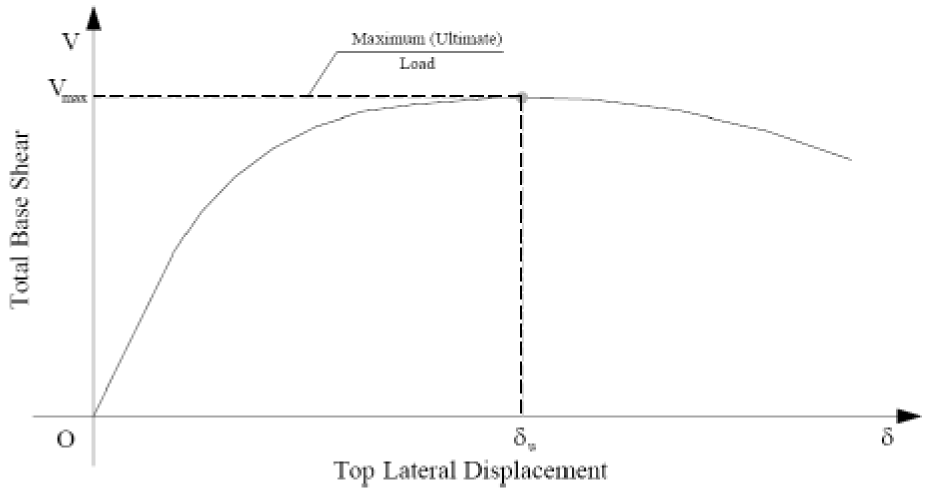


Figure 4.4 Ultimate displacement based on peak force, Elnashai and Sarno (2008)

4.3.1 Lateral Displacement at Yield State

The result of lateral displacement at yield for 4 storeys and 7 storeys elevated RC water tank is shown in Figure 4.5 and Figure 4.6, respectively. Lateral displacement at yield for 4 storeys and 7 storeys models are analysed to investigate the stiffness of the structure with different size of column. It is understood that the lower stiffness in the frame increases the flexibility of column to undergo inelastic deformation. Therefore, elevated RC water tank with smaller column size tends to have higher lateral displacement due to lower stiffness.

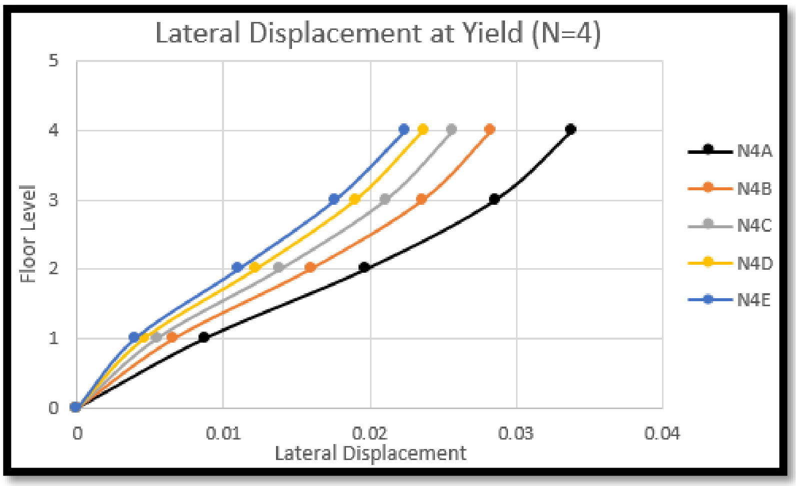


Figure 4.5 Lateral displacement at yield for 4 storeys elevated RC water tank

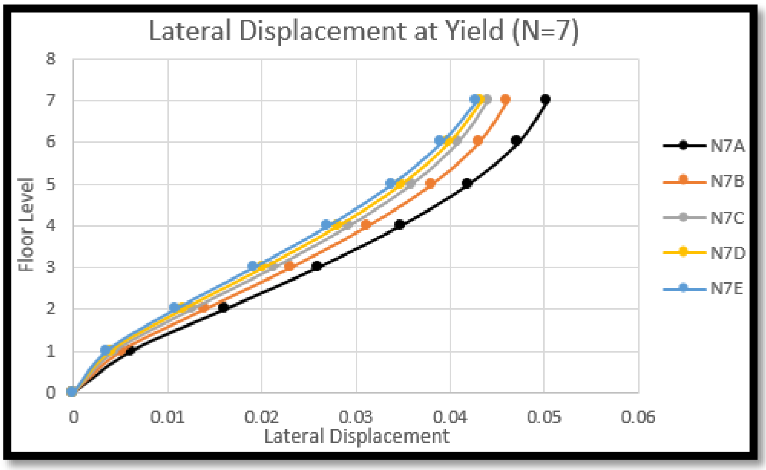


Figure 4.6 Lateral displacement at yield for 7 storeys elevated RC water tank

Figure 4.5 and Figure 4.6 shows that the lateral displacement at yield for both type of models displayed that the larger size of column used, the smaller the lateral displacement occurred to the structure. Furthermore, Figure 4.5 shows that model N4E has the lowest value of lateral displacement which is decreased around 35%, 21%, 15% and 8.3% from model N4A, N4B, N4C and N4D, respectively. Meanwhile, Figure 4.6 shows that model N7E has the lowest value of lateral displacement which is decreased around 16%, 8.7%, 4.5% and 2.3% from model N7A, N7B, N7C and N7D, respectively.

4.3.2 Lateral Displacement at Ultimate State

The result of lateral displacement at ultimate for 4 storeys and 7 storeys elevated RC water tank is shown in Figure 4.7 and Figure 4.8, respectively. Lateral displacement at yield for 4 storeys and 7 storeys models are analysed to investigate the stiffness of the structure with different size of column. It is understood that the lower stiffness in the frame increases the flexibility of column to undergo inelastic deformation. Therefore, elevated RC water tank with smaller column size tend to have higher lateral displacement due to lower stiffness.

Figure 4.7 and Figure 4.8 shows that the lateral displacement at ultimate for both type of models displayed that there is no typical pattern occurred to the structure. Furthermore, Figure 4.7 shows that model N4C has the lowest value of lateral displacement which is decreased around 2.4%, 6.8%, 16.3% and 22.6% from model N4B, N4A, N4E and N4D, respectively. Meanwhile, Figure 4.8 shows that model N7E has the lowest value of lateral displacement which is decreased around 76%, and 77% from model N7A and N7B, N7C and N7D, respectively.

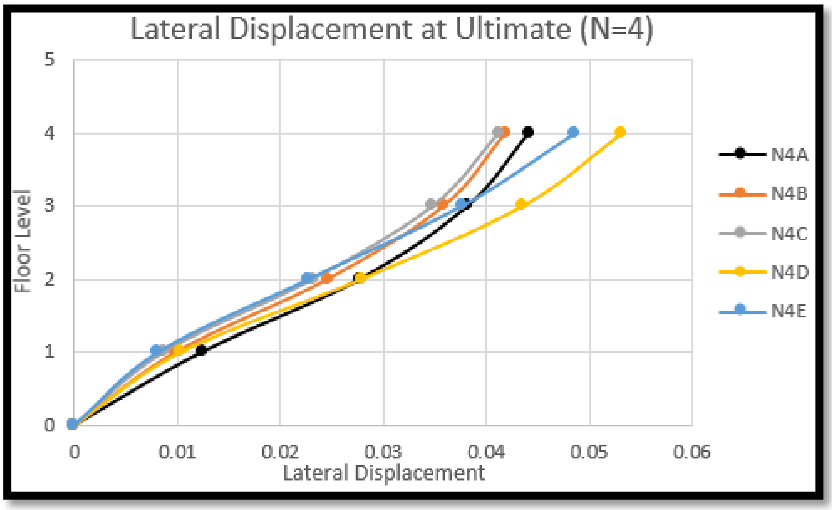


Figure 4.7 Lateral displacement at ultimate for 4 storeys elevated RC water tank

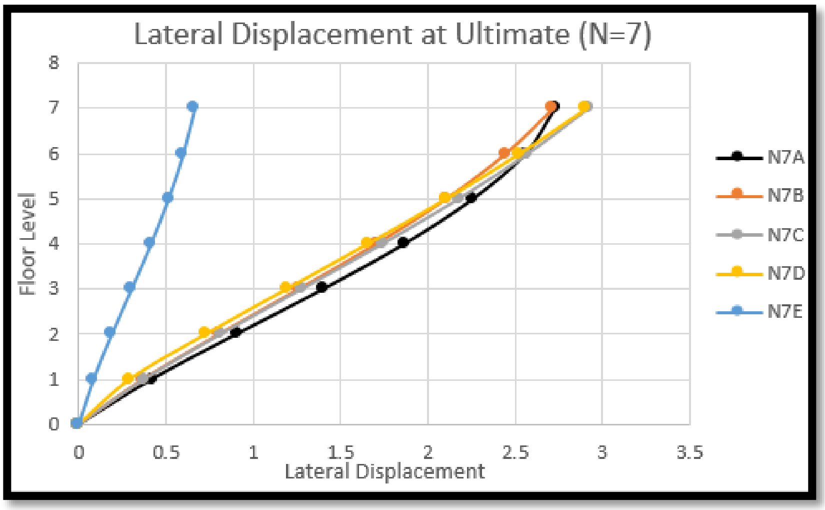
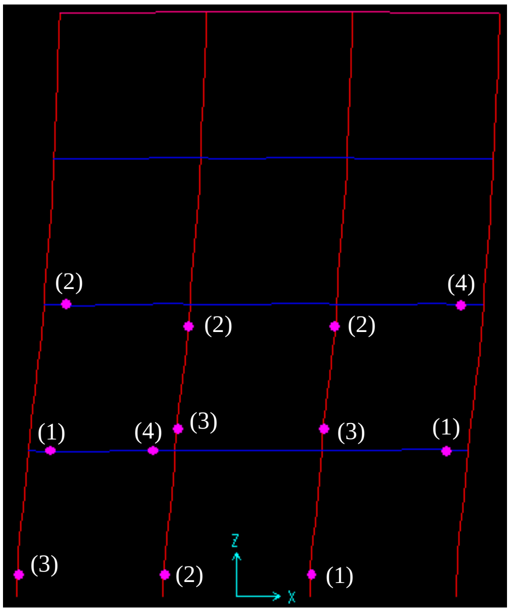


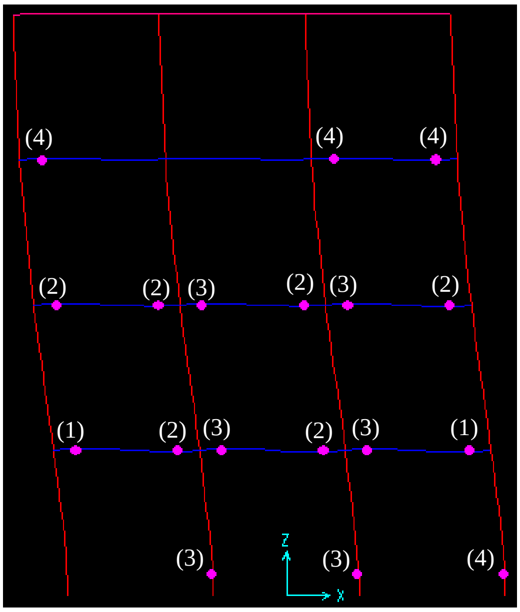
Figure 4.8 Lateral displacement at ultimate for 7 storeys elevated RC water tank

4.4 Damage Sequence

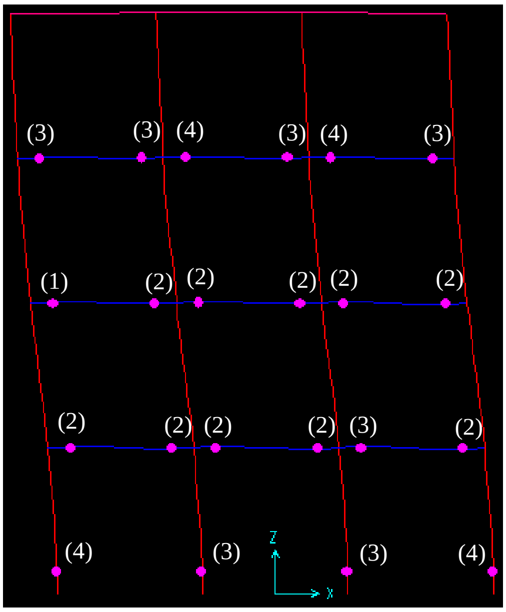
Damage sequence of a structure can be determined based on the formation of plastic hinge pattern where it is to detect the position of critical region of a structure. Figure 4.9 and Figure 4.10 show the sequence of damage for each of the model for 4 storeys and 7 storeys elevated RC water tank, respectively. The number in the brackets indicate the sequence of deformation for column and beam. According to FEMA 356 (2000), collapse prevention performance level is met when the post-earthquake damage state is on the verge of collapse. This limit state is assumed to occur at a lateral story drift ratio of approximately 5%. FEMA 356 (2000) states that at collapse prevention level, extensive cracking and hinge formation in ductile elements limited cracking or splice failure in some non-ductile columns, severe damage in short columns and major flexural and shear cracks at concrete walls will be found.



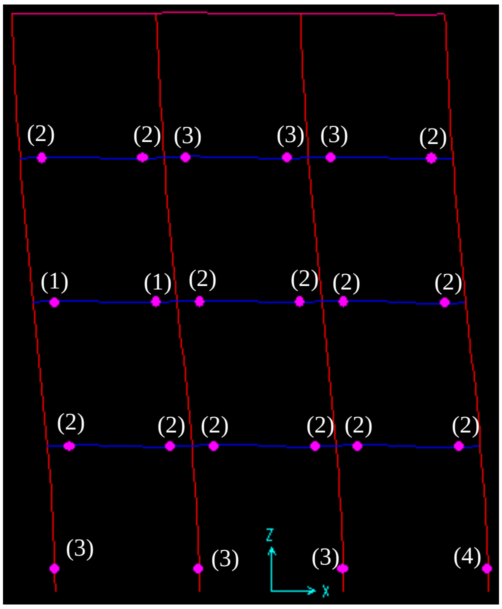
(a) N4A



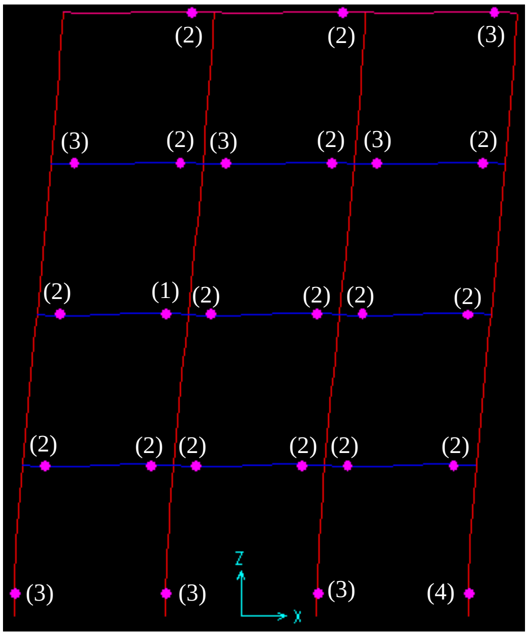
(b) N4B



(c) N4C

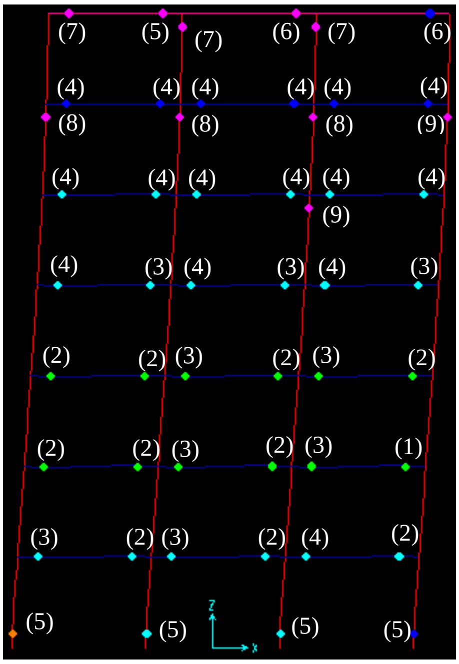


(d) N4D

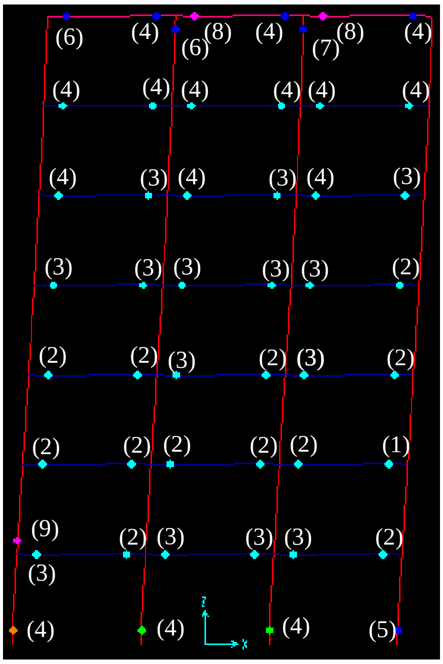


(e) N4E

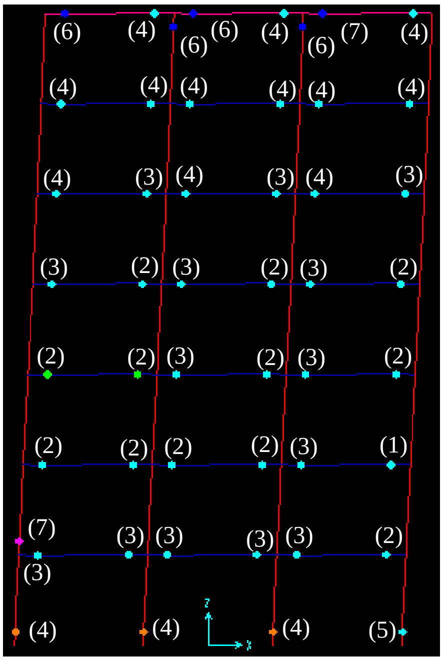
Figure 4.9 Sequence of formation of plastic hinges for 4 storeys elevated RC water tank models



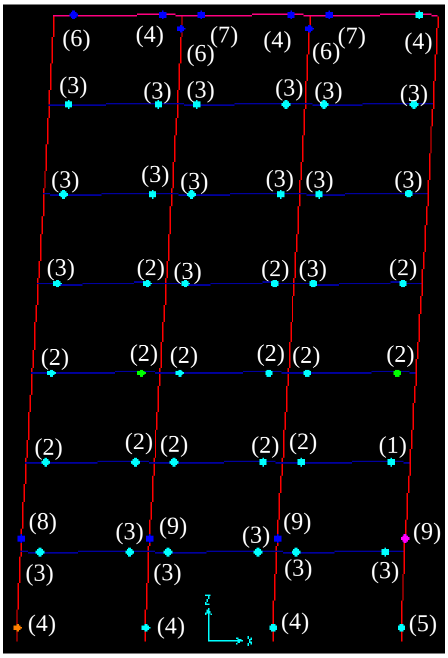
(a) N7A



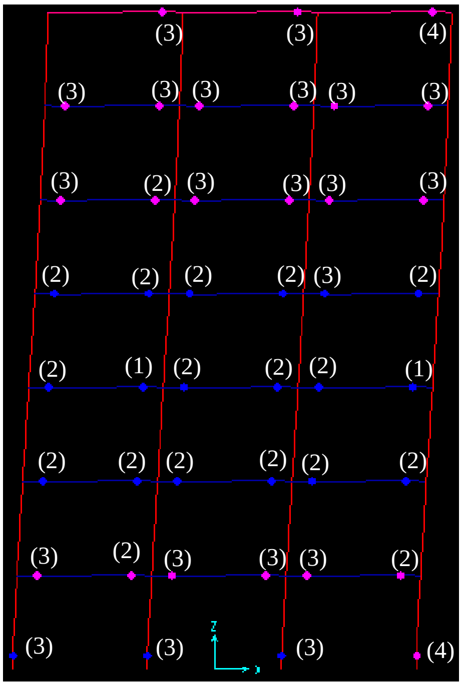
(b) N7B



(c) N7C



(d) N7D



(e) N7E

Figure 9.10 Sequence of formation of plastic hinges for 7 storeys elevated RC water tank models

Colour 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

CHAPTER 5

CONCLUSION

5.1 Conclusion

This study has presented the effect of column size on the seismic capacity of 4 storeys and 7 storeys elevated RC water tank. The typical elevated RC water tank is designed based on BS8110 (1997) to represent the existing elevated RC water tanks in Malaysia. A total number of 10 models of elevated RC water tanks consist of 4 storeys and 7 storeys has been used for the pushover analysis by using SAP2000 to obtain the capacity curve, and lateral displacement at yield state and ultimate state for each water tank models. There are few conclusions that can be drawn from this study as follows:

- Elevated RC water tank with larger size of column also tend to have higher value of force at yield state and ultimate state, where model N4E for 4 storeys and model N7D for 7 storeys elevated RC water tank has the value of yield and ultimate force of 205.70kN and 274.93kN, 403.75kN and 593.69kN, respectively which is higher compare to the other models.

- Elevated RC water tank with smaller size of column tend to have higher value of lateral displacement, where model N4A for 4 storeys and model N7A for 7 storeys has lateral displacement equal to 35% and 16%, respectively higher than the other models.

5.2 Future Recommendations

Believing that the effect of lateral forces (earthquake load) is very important in designing the elevated RC water tank, for future enhancement and improvement of this study, the following areas of investigation are recommended:

i) This study has examined the effect of column size in the seismic capacity. The effect of beam size on elevated RC water tank can be investigated since there are mostly beam member that are affected in this study.

ii) Further investigate the effect of different building material under pushover analysis for example steel material.

iii) Using different software (RAUAMOKO, and TEMPEST) for non-linear analysis and (RESPONSE2000, USC_RC, and XTRACT) for section analysis.

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APPENDIX A

OUTPUT DRAWING FROM ESTEEM SOFTWARE

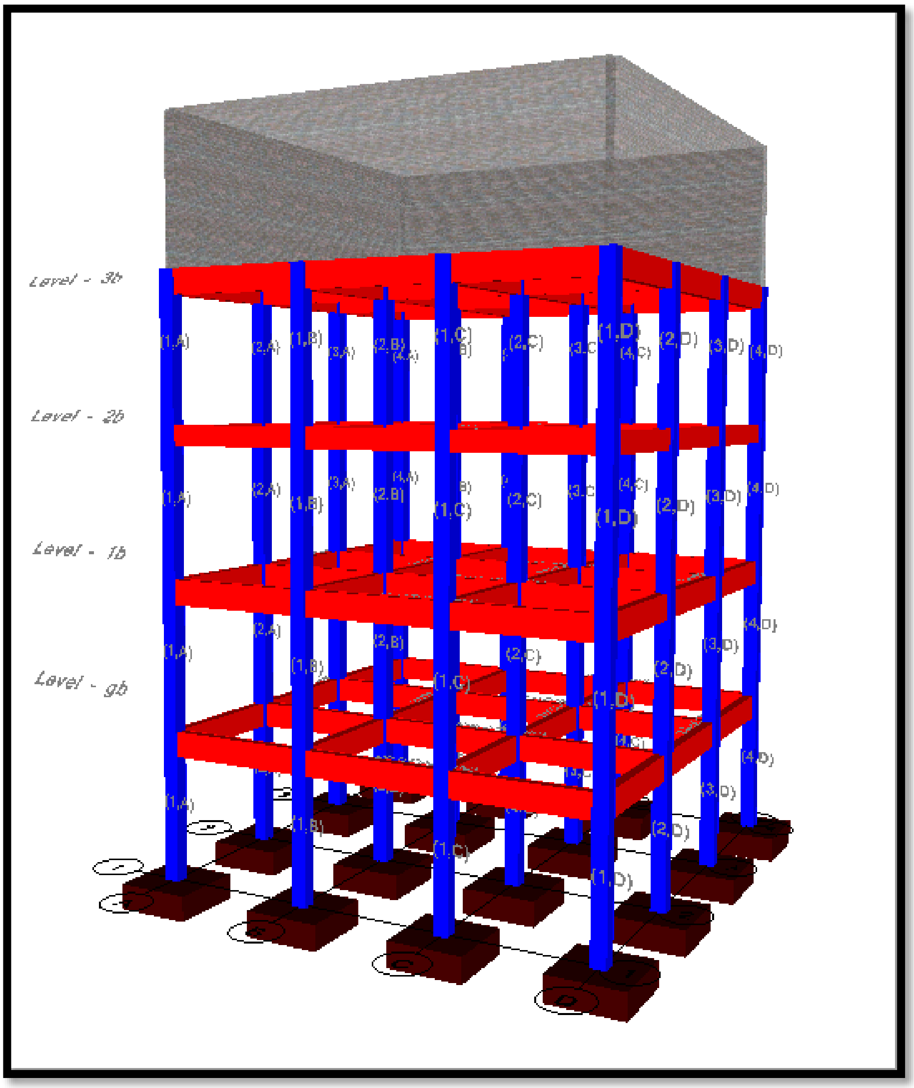

Figure A.1. Three dimensional drawing of 4 storeys elevated RC water tank model

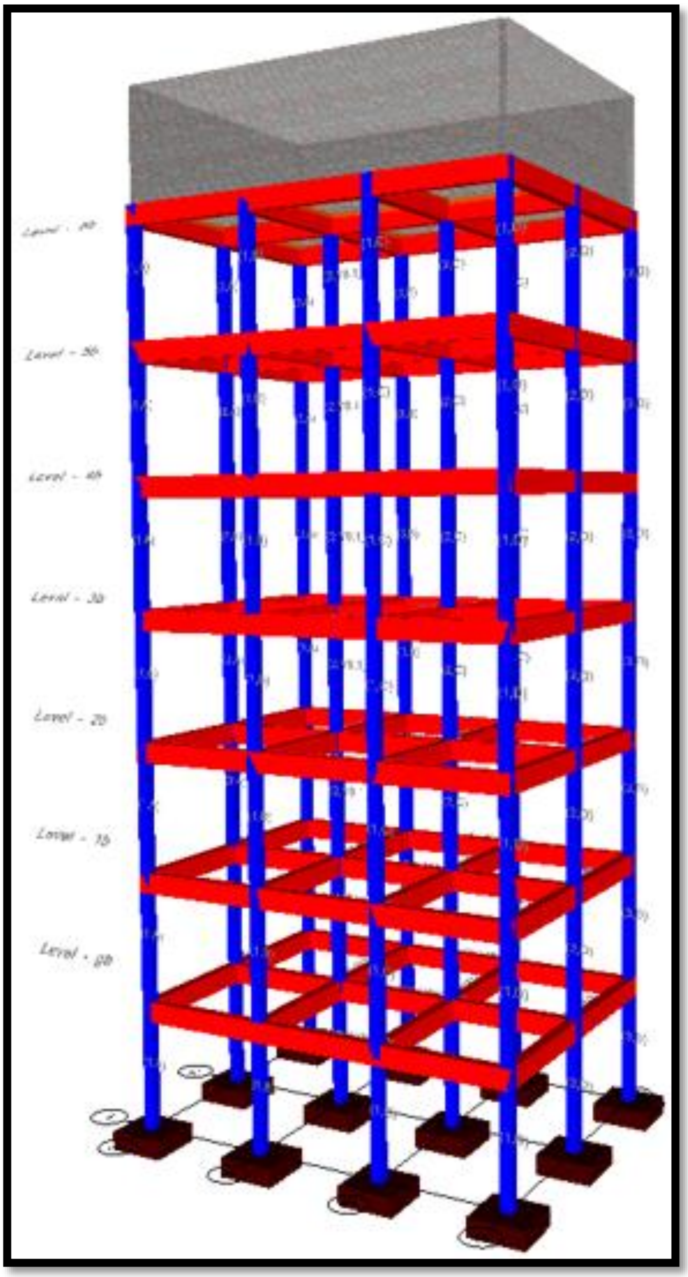

Figure A.2. Three dimensional drawing of 7 storeys elevated RC water tank model

APPENDIX B

CALCULATION OF LOADING

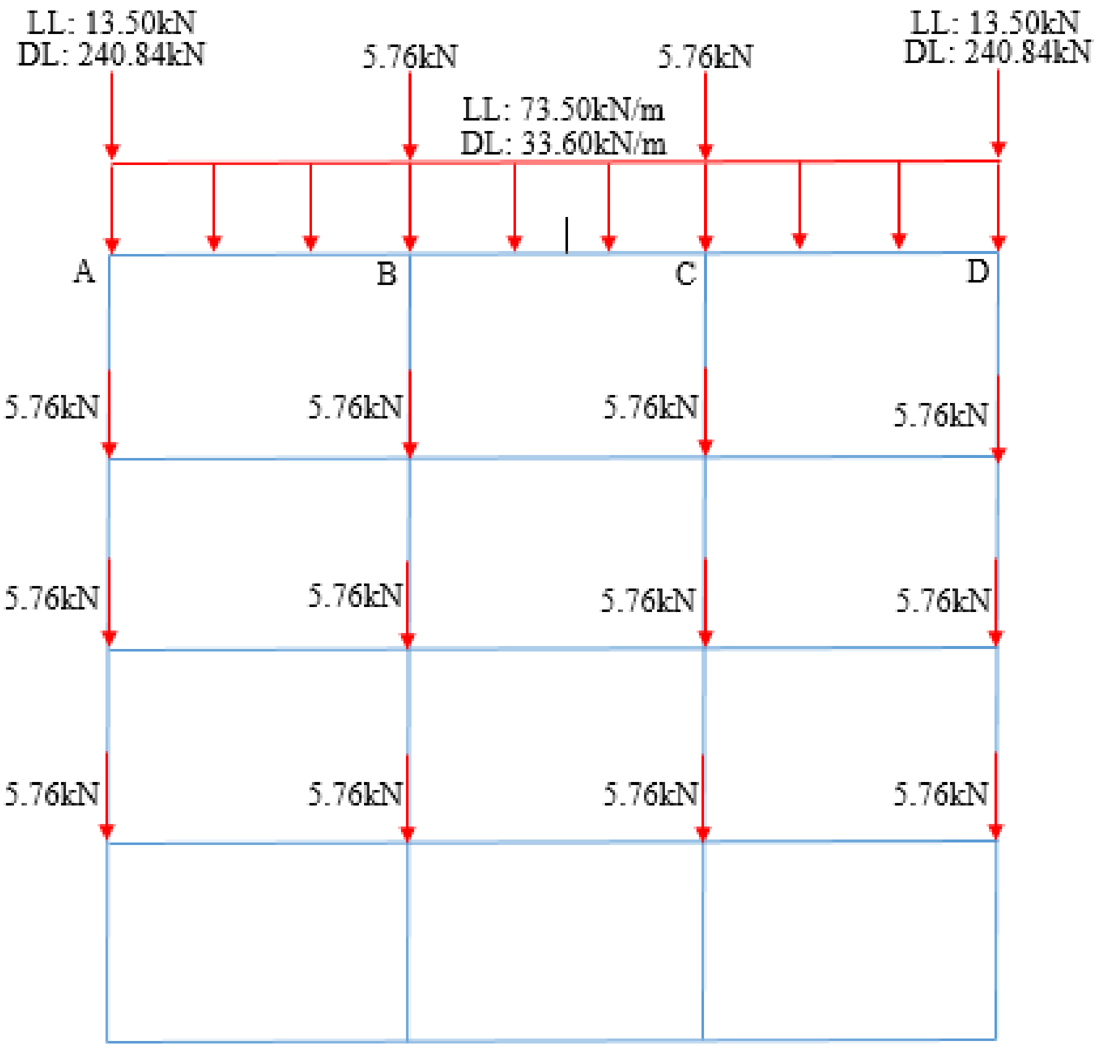

Figure B.1. Loading for 4 storeys elevated RC water tank model

Dead Load:

- UDL = slab thickness x length x width x unit weight of concrete + 1.2

  = (0.15 x 3 x 3 x 24) + 1.2

  = 33.60 kN/m

- Point Load:
  - Self-weight of beam (on corridor) = B x H x unit weight of concrete x length

    = 0.2 x 0.4 x 24 x 1.5

    = 2.88 kN
  - Self-weight of slab (outside frame) = thickness x unit weight of concrete x length x width

    = 0.15 x 24 x 1.5 x 3

    = 16.20 kN
  - Self-weight of beam (outside frame) = B x H x unit weight of concrete x length

    = 0.2 x 0.4 x 24 x 3

    = 5.76 kN
  - Weight of water tank = unit weight of concrete x length x height

    = 24 x 3 x 3

    = 216 kN

- At point A and D = Self-weight of beam (on corridor) + Self-weight of slab + Self-weight of beam (outside frame) + weight of water tank

  = 2.88 + 16.20 + 5.76 + 216

  = 240.84 kN

- At point B, C and other floor = Self-weight of beam (outside frame)

  = 5.76 kN

Live Load:

- UDL = 24.5 x length

  = 24.5 x 3

  = 73.50 kN/m

- Point Load = imposed load on corridor

  = unit weight of corridor x length x width

  = 3 x 1.5 x 3

  = 13.50 kN

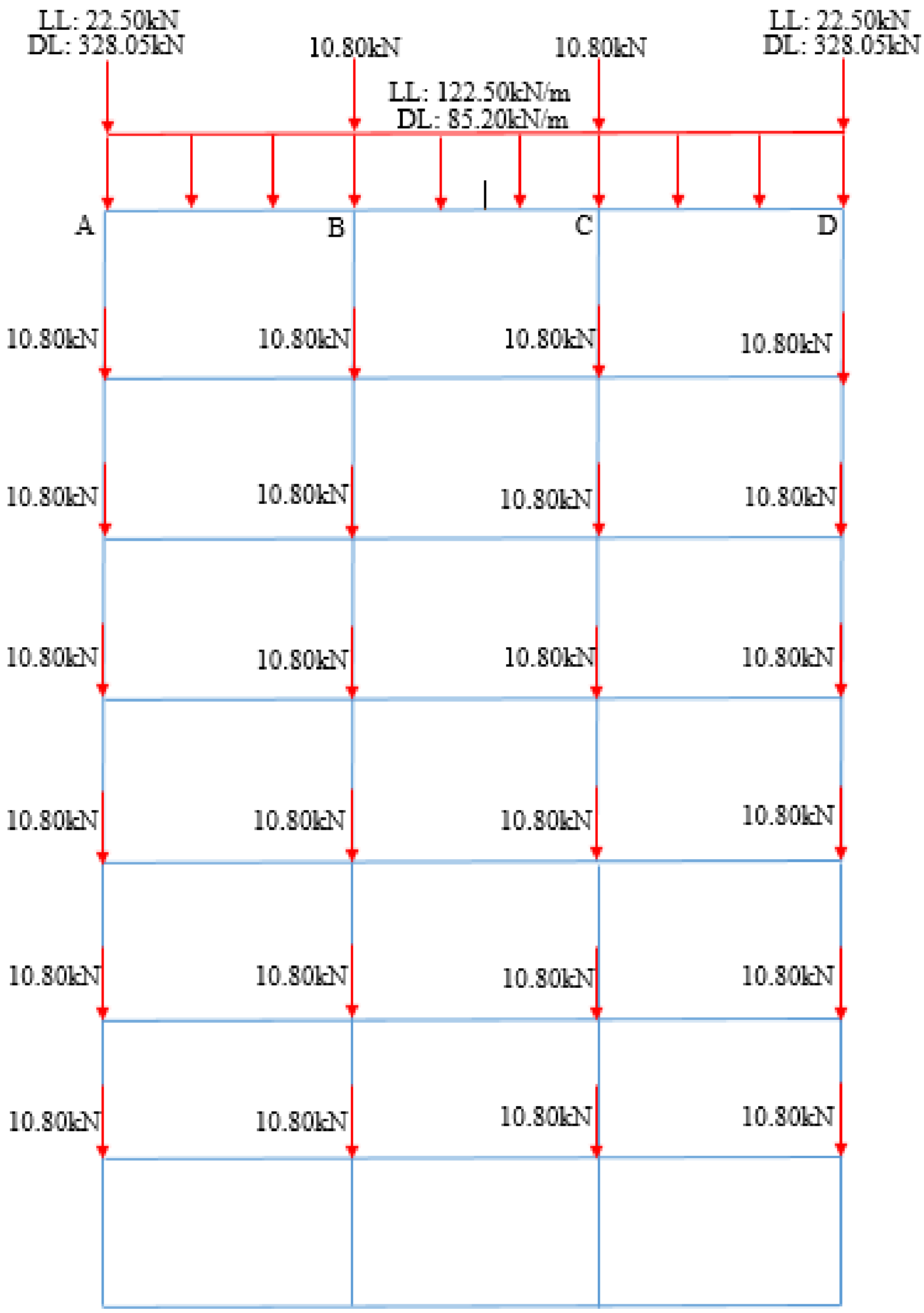

Figure B.2. Loading for 7 storeys elevated RC water tank model

Dead Load:

- UDL = slab thickness x length x width x unit weight of concrete + 1.2

  = (0.175 x 4 x 5 x 24) + 1.2

  = <u>85.20 kN/m</u>

- Point Load:

  - Self-weight of beam (on corridor) = B x H x unit weight of concrete x length

    = 0.25 x 0.45 x 24 x 1.5

    = 4.05 kN

  - Self-weight of slab (outside frame) = thickness x unit weight of concrete x length x width

    = 0.175 x 24 x 1.5 x 4

    = 25.20 kN

  - Self-weight of beam (outside frame) = B x H x unit weight of concrete x length

    = 0.25 x 0.45 x 24 x 4

    = 10.80 kN

  - Weight of water tank = unit weight of concrete x length x height

    = 24 x 3 x 4

    = 288 kN

- At point A and D = Self-weight of beam (on corridor) + Self-weight of slab + Self-weight of beam (outside frame) + weight of water tank

  = 4.05 + 25.20 + 10.80 + 288

  = <u>328.05 kN</u>

- At point B, C and other floor = Self-weight of beam (outside frame)

  = <u>10.80 kN</u>

Live Load:

- UDL = 24.5 x length

  = 24.5 x 5

  = <u>122.50 kN/m</u>

- Point Load = imposed load on corridor

  = unit weight of corridor x length x width

  = 3 x 1.5 x 5

  = <u>22.50 kN</u>

APPENDIX C

CAPACITY CURVE (SAP2000)

1) 4 storeys Elevated RC Water Tank Models

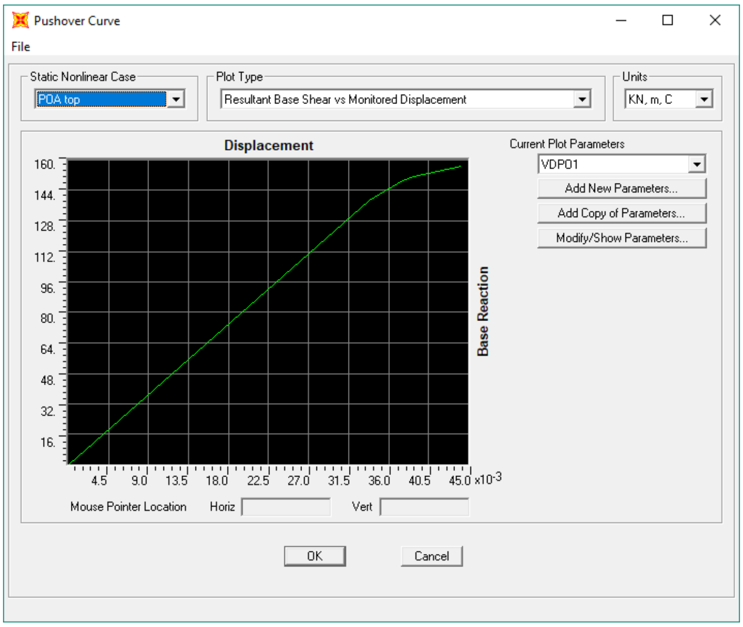

Figure C.1. Capacity curve for model N4A

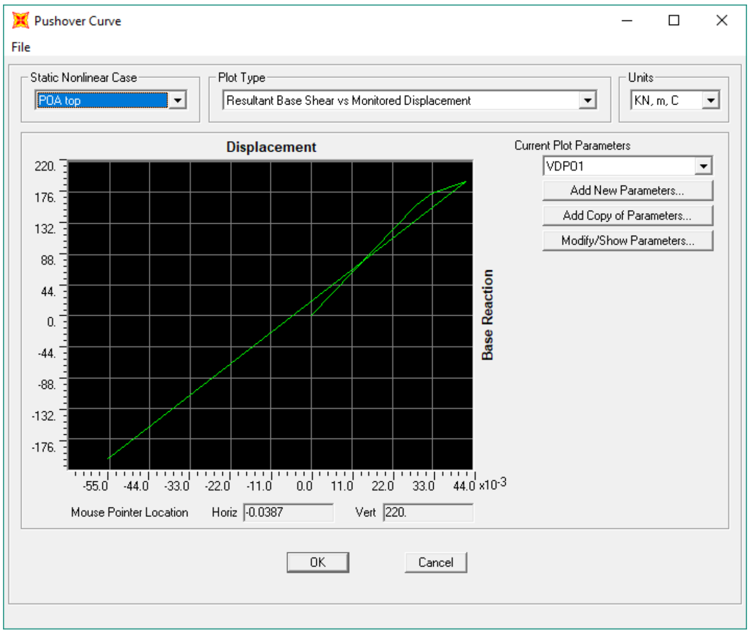

Figure C.2. Capacity curve for model N4B

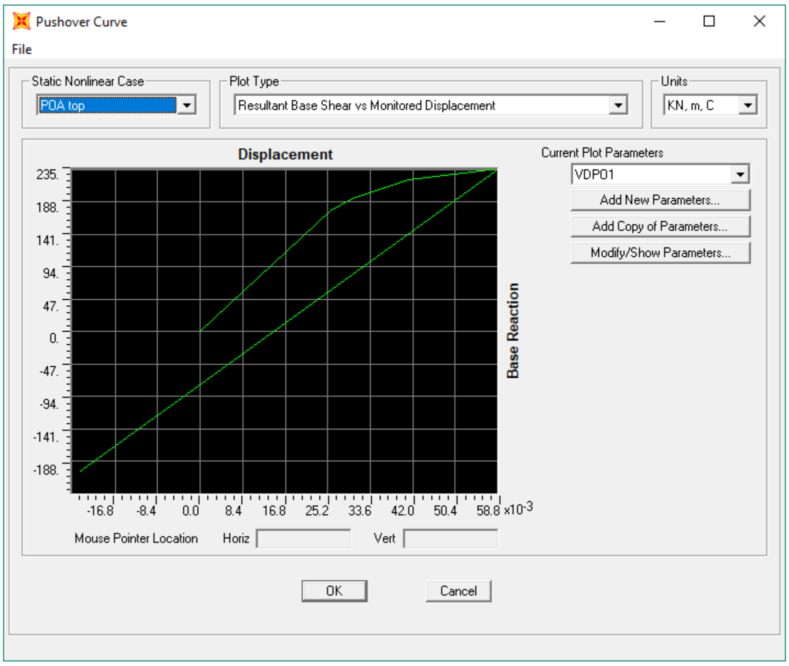

Figure C.3. Capacity curve for model N4C

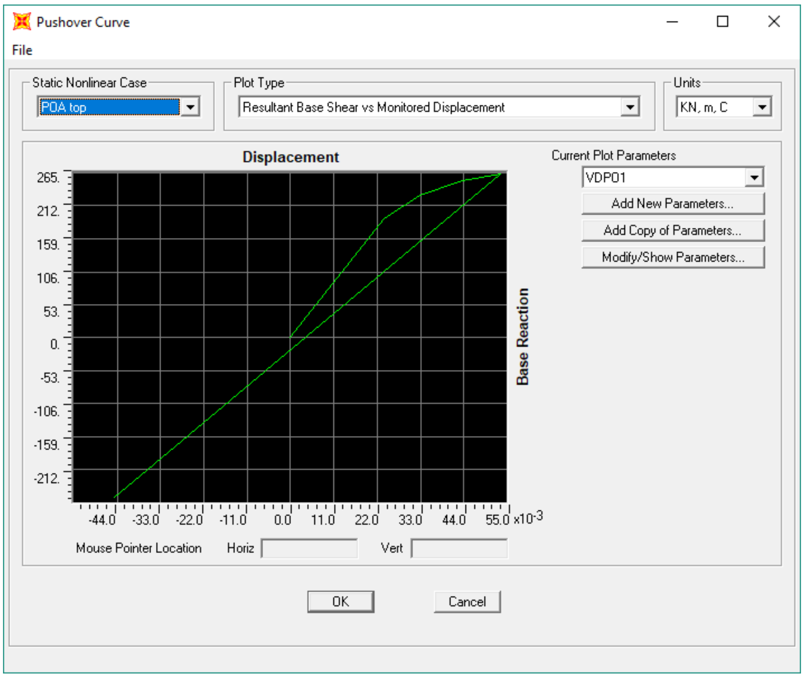

Figure C.4. Capacity curve for model N4D

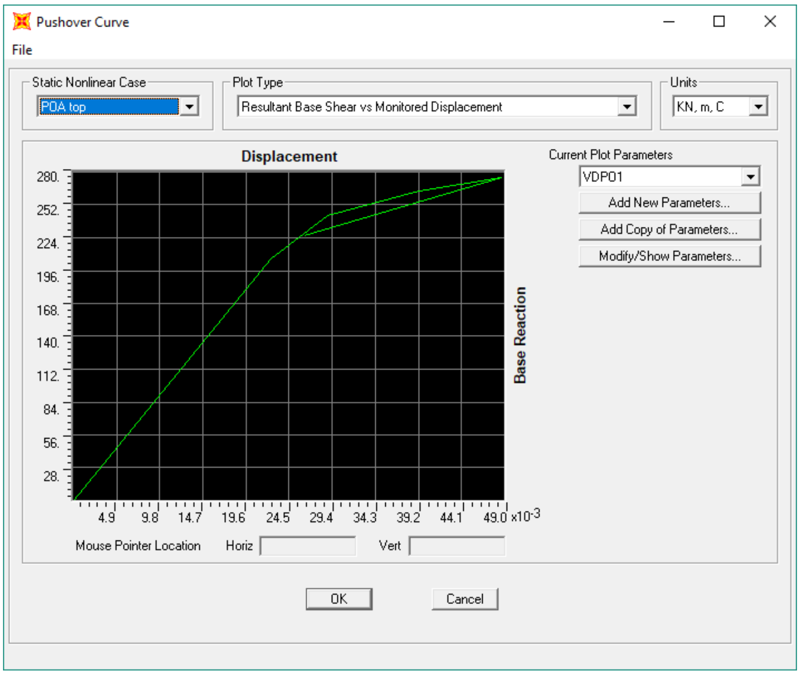

Figure C.5. Capacity curve for model N4E

2) 7 storeys Elevated RC Water Tank Models

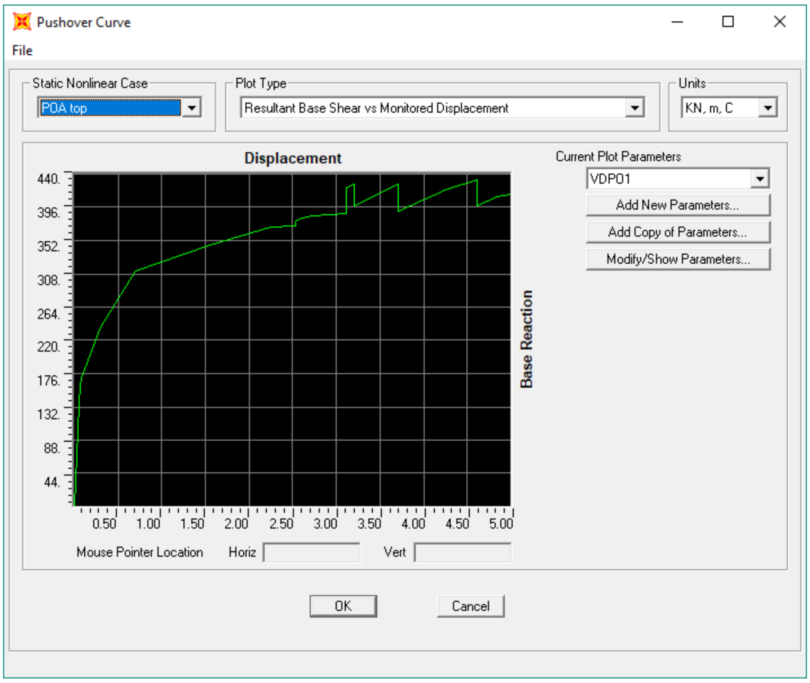

Figure C.6. Capacity curve for model N7A

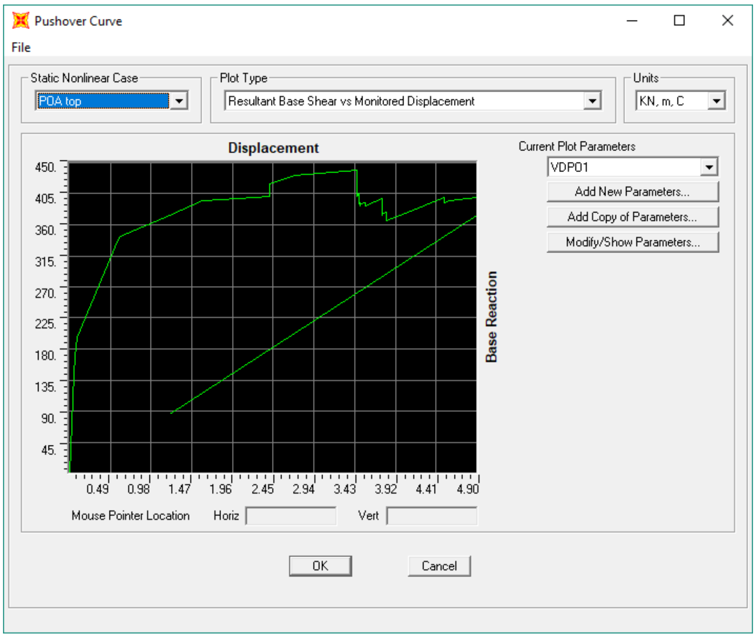

Figure C.7. Capacity curve for model N7B

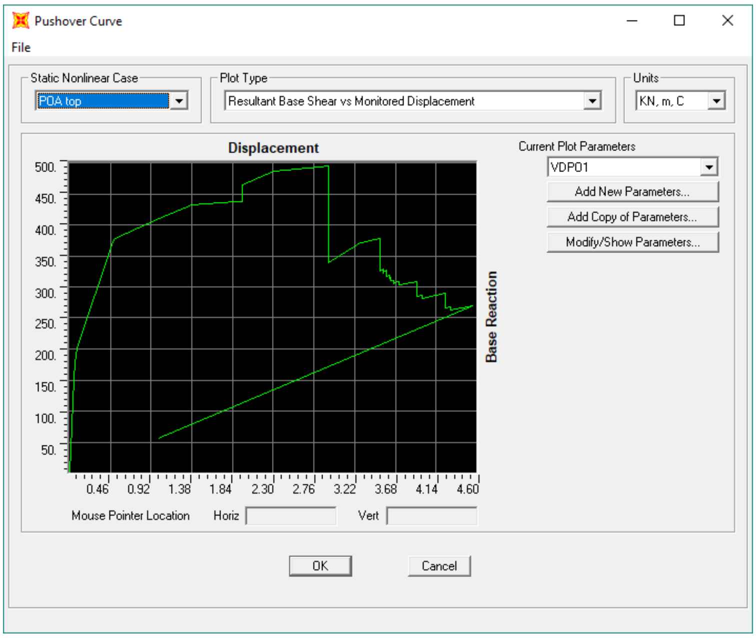

Figure C.8. Capacity curve for model N7C

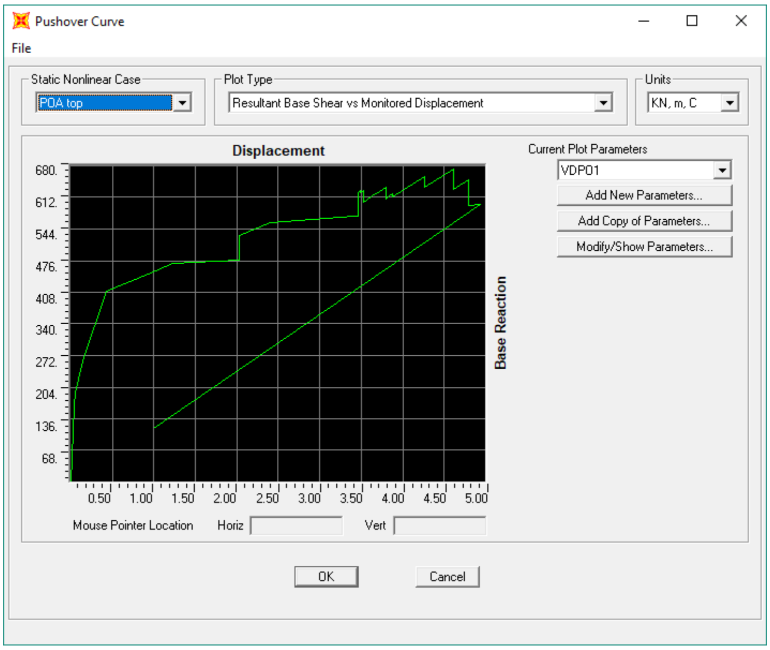

Figure C.9. Capacity curve for model N7D

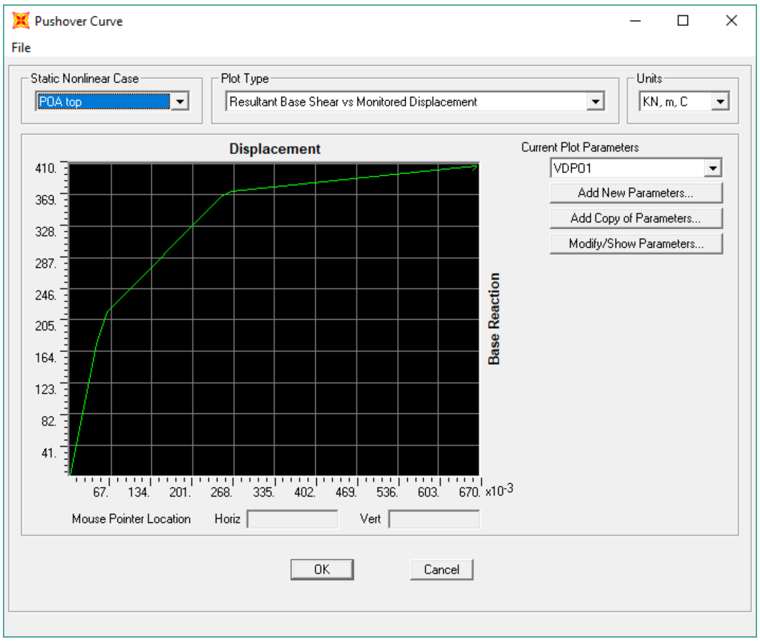

Figure C.10. Capacity curve for model N7E