JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

Effect of Shear Wall Arrangements on Building Frames Constructed in High Seismic Zone

This Thesis Submitted to Jimma University Institute of Technology, School of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Civil Engineering (Structural Stream)

By

Kayo Ashebir

November, 2022

Jimma, Ethiopia

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Main Advisor: Dr. Kabtamu Getachew (PhD, Assistant professor)

Co-Advisor: Mr. Ravi Kumar (M.Sc.)

November, 2022

Jimma, Ethiopia

DECLARATION

This Research Thesis entitled “The effect of shear wall arrangement on buildings frames of constructed in High Seismic Zone’ is my original work and has not been presented for a degree in any other university.

Kayo Ashebir ____________ 15/08/2022

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APPROVAL SHEET

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Effect of Shear Wall Arrangements on Building Frames Constructed in High Seismic Zone

Kayo Ashebir

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ABSTRACTS

The use of dual structural system is recently used by structural Engineer to minimize the hazards towards material and life. The effectiveness of dual system on lateral loads is achieved by combining the advantages of frames and shear walls constituents. Shear wall is added to the building frames to increase its stiffness by bracing the frames these venerable to lateral loads. So, the shear wall should be arranged to the building frames at appropriate position of building frames. Even though the shear wall is purposely proposed for the loads comes in longitudinal direction to shear walls, but the effect on shear wall due to the loads is seen in both directions for this kind of lateral loads. The effect of the loads comes to shear wall in transversal and longitudinal directions of each frame and building is studied in the body of this thesis. To address this study, comparative analysis among the arrangement samples of dual system with moment resisting frames is done using ETABS2016 software. The seismic performance of the dual system and frames is evaluated using non-linear static (pushover analysis) by considering as the model is an existed structure and linear dynamic (Response spectrum analysis method) as new building going to constructed in high seismic zone according to euro codes. Three Buildings (G+5, G+10 and G+20) of shear wall at the axis of different distance from center of mass with three cases at each axis are used to examine the effect of different shear walls arrangement on the whole system and their interaction with frames. Storey drift ratio, base shear, storey displacement and storey stiffness are used to determine the best and worst combination of shear wall and frames. The observation of these results shows that the overall seismic resistance capacity is dependent on the shear wall location in single frames and building. For some models the effect of shear wall on the whole building shows better performance, but single frames combined with shear wall of this model shows local failures and finally it brings the arrangements the worst. Therefore, while design and constructing the building with these kind of arrangements caution should have to be taken during designing of this type of dual system in order to avoid premature collapse of shear wall as some arrangement is dangerous and even adverse the advantages of shear wall.

Keywords: Shear wall Arrangements, Lateral load, seismic effect, and dual frame system

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ACRONYMS AND ABBREVIATIONS

ATC	Applied Technology Council
BSE	Basic safety Earthquake
CSM	Capacity Spectrum Method
DE	Design Earthquake
DSM	Displacement Spectrum Method
ETABS	Extended 3D Analysis Building System
ES EN	Ethiopian Standard European Norm
FEMA	Federal Emergency Management Agency
IMRF	Intermediate Moment Resisting Frames
MCE	Maximum Considered Earthquake
ME	Maximum Earthquake
MRF	Moment Resisting Frames
NAHM	National Association of Home Builder
OMRF	Ordinary moment resisting frames
PBD	Performance Based Design
RC	Reinforcement Concrete
SCWB	Strong Column, Weak Beam
SEAOF	Structural Engineers Association of California
SE	Serviceability Earthquake
SMRF	Special Moment Resisting Frames
SPEC X	Spectrum in X-Direction
SPEC Y	Spectrum in Y-Direction

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

High-rise buildings is expected for the shortage of land and as tall building is a symbol of prosperity in many rapidly developing cities and countries are becoming limited to control the increasing number of population. To standardize the life of these uncontrolled populations tall building is among the desired infrastructure desired to construct. However, some part of our world is always distracted by the natural disaster like the earthquake, whirlwind, hurricane, tidal wave, etc. This will induce the structural engineers to design buildings using the building system with good resistance to lateral loads, The extent to which a shear wall contribute to the resistance of overturning moments, storey shear forces and storey torsion depends on its geometric configuration, Shape, height and thickness of shear wall within the building [1]. Shear walls (structural walls) that primarily resist lateral loads due to wind or earthquakes acting on the building, these walls often provide lateral bracing for the rest of the structure [2]. Therefore, the analysis of reinforcing shear wall in consideration shape, location, height and thickness are essential to have built with a good resistance of lateral loads and used to satisfy tall multi-story building required by our country.

Among the bracing methods of frames shear wall is one of excellent ways of providing seismic resistance tall RC buildings. Behavior of structural elements during seismic performance is depends on distribution of weight, stiffness and strength due to its arrangements both in horizontal and vertical planes of buildings. So to reduce seismic effect shear wall is widely used in tall reinforced concrete buildings. Shear wall is very important to ensure lateral stiffness of tall building to resist lateral loads.

Shear wall in high seismic zone needs special detailing. Shear wall buildings are a popular choice in many earthquake prone countries, like Chile, New Zealand and USA. Shear walls are easy to construct and implement on site as reinforcement detailing is straightforward. Shear walls are efficient, both in terms of construction cost and effectiveness in minimizing seismic damage in both for structural elements and non-structural elements.

Most RC building with shear walls also have columns of primarily carry gravity loads which comes from self-weight and building content. Shear walls provide large strength and stiffness to building in the direction of their orientation which significantly reduces lateral sway of the building and thereby reduces damage to structural elements and its contents like walls, Openings of door and window and etc. Shear walls should be provided along preferably both length and width. Door and windows or any openings can be provided in shear walls, but their openings must be small to ensure least interruption to symmetrically locate or the openings also have located symmetrically.

Shear walls are rectangular in cross section, *i.e.*, one dimension of cross section is much larger than other in which it differs from columns. While rectangular cross section is common, L and U shaped are also used. Thin walled hollow reinforced concrete shaft around elevator core of buildings also act as shear wall, and should be taken advantage of to resist earth quake forces.

It is believed that the moment frame pushed over and destroyed the shear wall, leaving the structure defenseless against the lateral force component in the short direction, which caused the building to be declared dangerous to use it [3].

Shear wall provision have to be effective and economical to achieve rigidity. As shear wall is provided to tall building to avoid sudden collapse by forming an efficient lateral force resisting system when shear wall is situated in advantageous position. In seismic zone the criteria in designing RCC structures is control of lateral displacements resulting from lateral force. These criteria made the shear wall for investigate the effective location for lateral displacement and base shear in RCC frames. For this study, three models of buildings according to number of storey with different shear wall arrangements are selected.

The intention of this thesis is therefore; to investigate and evaluate the effect of the arrangement of shear walls in a dual system. The dual system building with the moment frames are designed to resist the lateral forces in longitudinal direction entirely while shear walls are located to center and away from center of frames to out and inner of frames axis of the frames in shorter direction is used for this study. It is going to be done, by carrying out a comprehensive literature survey and analysis of sample buildings.

1.2 statement of the problem

For the rapid worldwide growth of high rise buildings, no probabilistic assessment procedures have been proposed or developed for seismic risk evaluation. This will compel to provide reinforced concrete (RC) buildings often have vertical plate-like RC walls called Shear Walls in addition to slabs, beams, and columns. But random arrangements of shear wall may affect the performance of building frames. So, to address the expected advantage of shear wall and minimize the hazards towards building frames, the position to arrange the shear wall should be investigated with different parameters.

The main aim of this thesis is to study the effect of shear wall arrangements in the frames system where the moment frames are designed to carry lateral forces in longitudinal direction entirely while structural walls are situated centric or eccentric to the frames to resist lateral load that comes in transverse direction of the buildings. This study is carried out by conducting a comprehensive literature survey and by making comparative analysis among the sample buildings with different shear wall arrangement (by placing it at different location). More specifically, this thesis examines whether the centric system have better performance or if shear wall placed somewhere in eccentric to the frame system along Transverse direction of the building is performs better.

1.3 Research Questions

The research questions that this study will go to explains are as follows:

- Which arrangement of shear wall is best or worst depends on it position to frames?
- Can the arrangements of shear wall which offset from center of frames performs better?
- By what parameters the eccentric arrangements of shear wall is better, if any?
- Can the arrangements of shear wall adverse the expected advantage of shear wall due to its positions?

1.4 Objective of the Study

1.4.1 General Objective

The objective of this study is to analyze and evaluate effect shear wall arrangement in building frames constructed in high seismic zone.

1.4.2 Specific Objectives

The specific objective of the study will be:

- To investigate the best and worst combination of shear wall arrangement and its reason
- To deal another options of shear walls arrangements either of centric to buildings frames and the parameters to select one models over the others
- To investigate the model which adverse the advantage of shear walls and never been the options to arrange the shear wall.

1.5 Significance of the Study

This study showed the effect of shear wall due to its arrangements and options of shear wall arrangements to design and construct. Generally the study shows the best and worst combinations of shear walls and the parameters to select from the models. This investigation can help the structural designer's community to choose easily the appropriate shear wall arrangement for good performance. It can contribute significant input for another researcher for further study. Therefore, this research will help any design companies and /or any researchers to have better understand and estimate the behavior of shear walls with different shear wall arrangement within building frames under lateral loads.

1.6 Scope and limitation of the study

This research is limited to symmetric by two bays in Y-Direction and by five bays in X-Direction for all (G+5, G+10 and G+20) multistory RC building which is regular in plan and elevation. The frames are assumed firmly fixed at the bottom and the soil-structure interaction is neglected.

The study covers the investigation of effect of shear wall on building frames due to its positions of arrangement and extended to demonstrate the influence of different arrangements shear wall for frame performance. The study focuses on modeling different shear wall modeling at different position of frame structure by software program of CIS ETABS2016v2.1.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 General

Depends on its Direction loads, on the Buildings is can be categorized into two. These are vertical (dead loads and live loads) and horizontal or lateral loads. Horizontal loads are the hazards towards the building structure which caused due to environmental loads (natural hazards) or man-made loads. Also, they are non-static or dynamic. Typical lateral loads would be a wind load against a facade, an earthquake, the earth pressure against a beach front retaining wall or the earth pressure against a basement wall or induced horizontal force due to the temperature difference (thermal effect) or centrifugal effect. Shear wall are one of the most efficient lateral force resisting elements in building frames of tall buildings. A significant amount of researches work on various structural aspects of shear walls has been done by many investigators and till date the structural walls are among the major focus concern in the area of research. From the survey done in the literature, it can be noted that some of the papers and research work have added a lot of contribution to this work and acted as a strong reference for the adopted methodology and concluding results.

2.2 Lateral Loads

2.2.1 Wind loads

Wind is the term used for air in motion and is usually applied to the natural horizontal motion of the atmosphere. Motion in a vertical or nearly vertical direction is called a current. Movement of air near the surface of the earth is three-dimensional, with horizontal motion much greater than the vertical motion. Vertical air motion is of importance in meteorology but is of less importance near the ground surface. On the other hand, the horizontal motion of air, particularly the gradual retardation of wind speed and the high turbulence that occurs near the ground surface, are of importance in building engineering [5].

The wind load is an external force, the magnitude of which depends upon the height of the building, the velocity of the wind and the amount of surface area that the wind attacks. The determination of wind loads for the design of residential buildings is based on a simplification given by the codes wind provisions (for example ES EN 1995). Therefore, the wind loads are not an exact duplicate. The wind action is represented either by a wind pressure or a wind force and it is assumed to act normal to the surface except where otherwise specified [6].

There is two procedure required to determine design wind loads on a residential building and its components according to ES EN 1995, The first one is a simplified and static analysis procedure which is set by codes including ES EN 1995. It applies to the structures whose structural properties do not make them susceptible to dynamic excitation. This procedure can also be used for the design of mildly dynamic structures whose dynamic coefficient is less than 1.2. The dynamic coefficient takes into account the reduction effects due to the lack of correlation of pressure over the surfaces as well as the magnification effects due to the frequency content of turbulence close to the fundamental frequency of the structure. Its value depends upon the type of the structure (concrete, steel, composite), the height of the structure and its breadth.

The second procedure is a detailed dynamic analysis stiffness evaluation of reinforced concrete shear wall with respect to shape, Height and thickness procedure which is required for the structures that are likely susceptible to dynamic excitation and for the structures whose value of the dynamic coefficient is greater than 1.2 [6]. In such cases, wind tunnel procedure, which is a real-time air pressure testing, is used for determination of wind loads on the building. The wind load determination methods in many codes are considered without taking into account the wind-borne debris protection; however, for regions where hurricanes & tornadoes usually occurred, the building envelope (i.e., windows, doors, sheathing, and especially garage doors) should carefully designed for the required pressures.

2.2.1.1 Wind-Resistant Design Philosophy

Unlike the earthquake, almost all wind hazards (hurricanes, tornados & tropical storms) are relatively predictable. In the case of wind, excitation is an applied pressure or force on the facade of the structure. The loading is dynamic, but the response is nearly static for most structures. Also, deformations are monotonic (unidirectional) except for tornados. Therefore most structures are designed to respond elastically under factored wind loads except for tornadoes which can't be resisted by economically feasible design. As a result, proper bracing should be provided to lessen the damage to the structures that are in near miss from a tornado.

2.2.2 Man-Made/ Blast Effect

In addition to natural hazards man-made or blast is among disaster which have been hindering the communities' development and, in some cases, threatening their existence. This threat is no longer a local problem but has become a global issue, which mandates collaboration between countries to overcome this danger. The attacks can occur anytime and anywhere based on the goals from these attacks. These bombings, typically caused by terrorist attacks, have left substantial losses due to complexity in nature and dynamism goals of these attacks [7]. The blast shock wave from high explosives detonation has a very sharp acting on unprotected people and targeted structures due to high applied pressure. The duration of blast shockwave is very short, typically in order of 10-6 seconds for near-field blast and milliseconds for far- field detonation. The intensity of blast depends on the explosive weight, standoff distance and pressure amplitude of blast wave. Long and short term effects can be noticed on people when exposure directly to the blast. Several studies have investigated and analyzed these effects [8]–[10], but such effects are outside the bounds of the present study. Accordingly, consideration of an appropriate blast-resistant system is required to reduce causalities and losses.

Only federal facilities, military bases, and important governmental buildings had been designed to resist abnormal loadings such as blast due to the high cost, the applicability of protection, and the importance level of the structure. Furthermore, it is not an available option for engineers to strengthen existing residential and commercial buildings to resist large-scale explosions [11], [12]. Therefore, constructing a blast protection wall at an appropriate distance (safe zone) from structures can provide the required level of safety for occupants and property behind/around the blast wall [13], [14]. The blast wall could reflect and/or absorb the blast wave energy by the mass of the system, and energy absorbing mechanism. Fracture or permanent deformation is possible when the applied pressure is higher than the capability of the system to resist the incident/reflected blast wave. In both cases, a blast wall could reduce the blast and protect targeted structures and people.

2.2.3. Earthquake

Among the lateral loads earthquake is the one considered for this thesis as earthquake the major seismic hazard in Ethiopia relative to the other. Severity of ground shaking at a given location during an earthquake can be minor, moderate or strong. Thus relatively, minor shaking occurs frequently; moderate shaking occasionally and strong shaking rarely. For instance, on average annually about 800 earthquakes of magnitude 5.0-5.9 occur in the world while about 18 for magnitude range 7.0-7.9. So we should design and construct a building to resist that rare earthquake shaking that may come only once in 500 years or even once in 2000 years, even though the life of the building may be 50 or 100 years [15].Structural engineering do not attempt to make earthquake proof buildings that will not get damaged even during the rare but strong earthquake since designing such kind of buildings will be too expensive. Instead the engineering intention is to make buildings that resist the effects of ground shaking, although they may get damaged severely but would not collapse during the strong earthquake. These kinds of buildings will assure safety of people and contents, and by this means a disaster is avoided. This is a major objective of seismic design codes throughout the world.

The general philosophy of earthquake resistant building design is that:

A) Under minor but frequent shaking, the structural members of the buildings that carry vertical and horizontal forces should not be damaged; however non-structural buildings parts that do not carry load may sustain repairable damage.

B) Under moderate but occasional shaking, both structural & non-structural members may sustain repairable damage.

C) Under strong but rare shaking, the structural and non-structural members may sustain severe damage, but the building should not collapse.

Earthquake resistant design is therefore concerned about ensuring that the damages in buildings during earthquakes are of acceptable amount, and also that they occur at the right places and in right amounts [16]. Structural members of the building should be ductile enough to avoid collapse.

2.3 Loads Resist Systems

The structural systems mainly used as earthquake (or generally, lateral load) resistant structures are:

- Frame systems
- Wall systems
- Dual systems, i.e. shear walls acting with frames

2.3.1 Frame system

In a recent seismic design of reinforced concrete (RC) building structures, special moment frames are commonly used as seismic resisting systems to withstand earthquake forces by considering a strong column-weak beam (SCWB) concept [17].

In this concept, all moment frame elements (beams, column, and beam-column hinges) should be proportioned and well detailed in order to sufficiently resist flexural, axial, and shearing forces. During strong earthquake ground motion, the building structure sways through multiple displacement cycles due to seismic actions. Given this condition, a reinforced concrete frame should be designed with special proportioning and detailing requirements to resist strong earthquake shaking without its strength reduced.

Rigid frame skeletons generally consist of a rectangular grid of horizontal beams and vertical columns connected together in the same plane by means of rigid joints. Because of its continuity, the rigid frame responds to lateral loads primarily through flexure of the beams and columns. This continuous character of the rigid frame is dependent on the rotational resistance of the member connections not to permit any slippage.

2.3.1.1 Principle of a Strong-Column and Weak-Beam Frame Design

When a building sways during an earthquake, the distribution of damage over height depends on the distribution of lateral drift. If the building has weak columns, drift tends to concentrate in one or a few stories (figure 2.3a), and may exceed the drift capacity of the columns. On the other hand, if columns provide a stiff and strong spine over the building height, drift will be more uniformly distributed (figure 2.3c), and localized damage will be reduced.

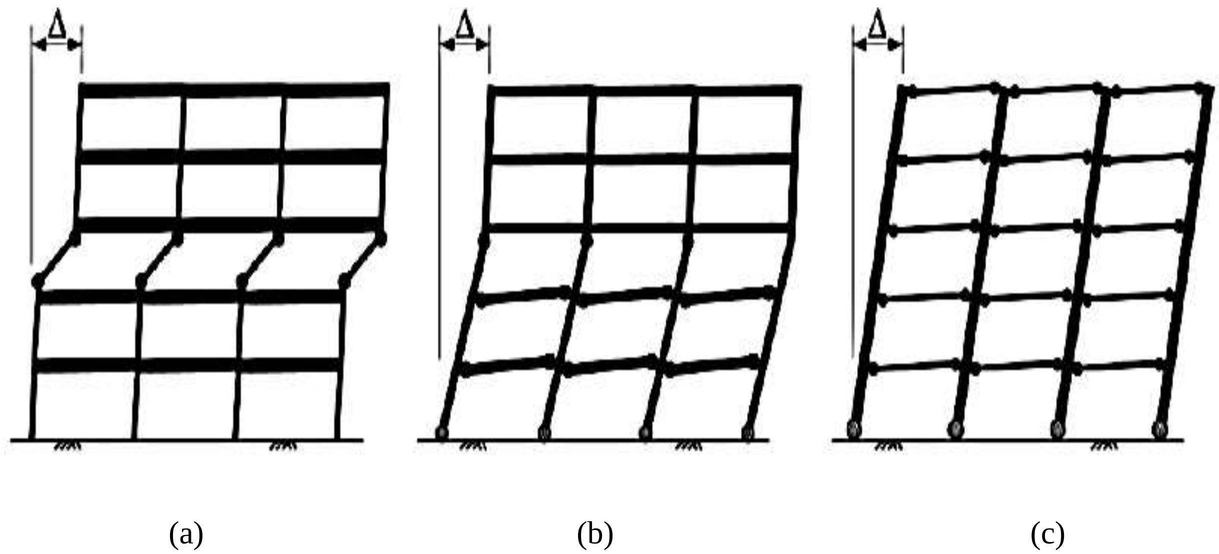


Figure 2. 1 Design of special moment frames aims to avoid the story mechanism (a) and instead achieve either an intermediate mechanism (b) or a beam mechanism (c) [20].

Additionally, it is important to recognize that the columns in a given story support the weight of the entire building above those columns, whereas the beams only support the gravity loads of the floor of which they form a part; therefore, failure of a column is of greater consequence than failure of a beam. Recognizing this behavior, building codes specify that columns be stronger than the beams that frame into them [20]. This strong-column and weak-beam principle is fundamental in achieving safe behavior of frames during strong earthquake ground shaking.

2.3.2 Shear Wall (Wall systems)

The main advantage offered by earthquake resisting reinforced concrete walls is the significant increase in the stiffness of the building, which leads to a reduction of second-order effects and a subsequent increase of safety against collapse, as well as a reduced degree of damage to nonstructural elements, whose cost is often higher than that of the structural elements. Furthermore, the significant reduction of psychological effects on the inhabitants of high rise buildings subjected to earthquake induced displacements should be pointed out.

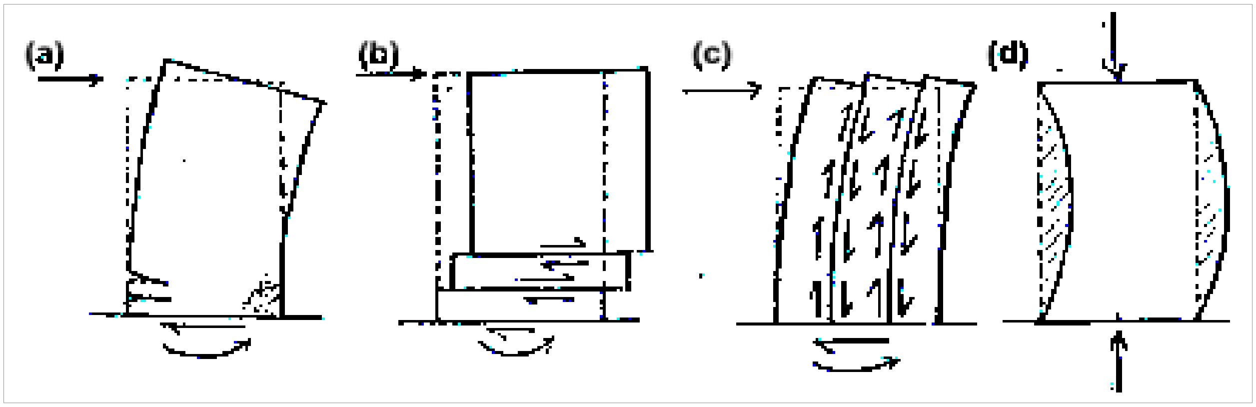


Figure 2. 2 failure mechanism of shear walls (a) flexural failure, horizontal shear, (c) vertical shear, (d) buckling

2.3.3 Dual systems, shear walls acting with frames

Using shear wall alone is not enough to respond to lateral loads for high rise buildings. The lateral rigidity is then greatly improved by using the shear wall system and also the moment resisting frames to resist lateral forces. In dual system the structural behavior of shear walls and frames being clearly different, interaction between them yields a mean deflection pattern and the total deflection of the interacting shear wall and rigid frame systems is obtained by superimposing the individual modes of deformation, i.e. Rigid frame shear mode deformation, and Shear wall bending mode deformation.

The diagram shown below, Fig. 2.3 shows the shear wall-frame interaction and the distribution of total lateral load to the individual shear walls and frames as given by this simple interaction diagram are valid only if one of the following two conditions is satisfied [18].

1. Each shear wall and frame must have constant stiffness properties throughout the height of the building.

2. If stiffness properties vary over the height, the relative stiffness of each wall and frame must remain unchanged throughout the height of the building.

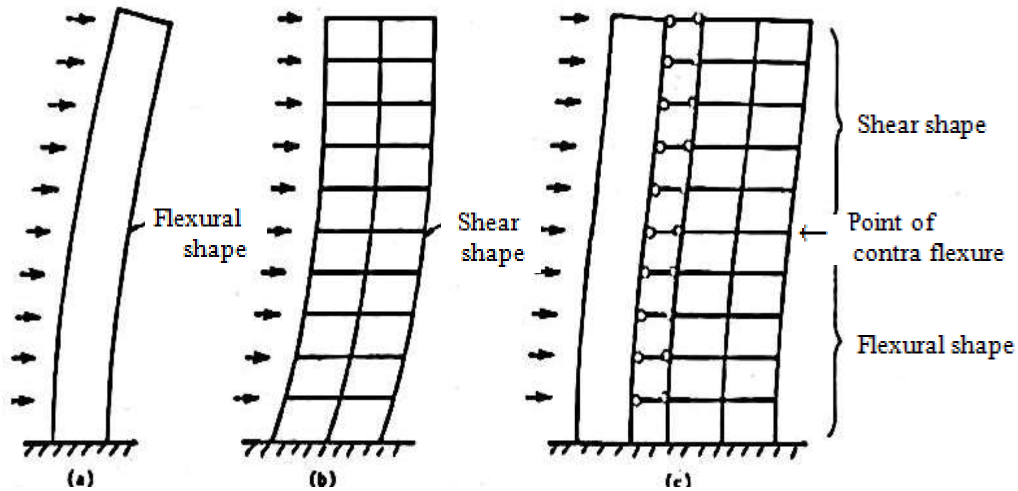


Figure 2. 3 Deformation Patters of Dual system a) shear wall, b) frames, c) dual system [18]

2.4 Non-Linear Analysis of Reinforced Concrete Structures

2.4.1 General

Before the implementation of PBD (Performance based design) in seismic design of structural elements, structural engineers have to perform non-linear analyses of the structures for the designing and maintenance purpose. As a result, non-linear pushover analysis becomes very pretty method since it is easy to use, fairly accurate and suitable in a design office setting usage.

It is performed by subjecting a structure to a monotonically increasing pattern of lateral loads, representing the inertial forces which would be experienced by the structure when subjected to ground shaking.

Non-linear pushover analysis has been the preferred method for seismic performance evaluation of structures by the major rehabilitation guidelines and codes because it is conceptually and computationally simple. Also it allows tracing the sequence of yielding and failure on members and structural levels as well as the progress of overall capacity curve of the structure. In this research, ATC-40, FEMA-273[19] &FEMA-356[20] are used as the reference document for performing the nonlinear push over analysis or nonlinear static procedure.

2.4.2 Definition of Nonlinear pushover analysis

According Federal Emergency Management Agency document 273 [19], Nonlinear Pushover Analysis or Non-Linear Static Procedure is defined as a non-linear static approximation of the response that a structure will undergo when subjected to dynamic earthquake loading. The static approximation consists of applying a vertical distribution of lateral loads to a model which captures the material non-linearity of an existing or previously designed structure and monotonically increasing those loads until the peak response of the structure is obtained on capacity curve (a base shear vs. roof displacement Plot) as shown in figure 2.4. From this plot and other parameters representing the expected or design earthquake, the maximum deformations that the structure is expected to undergo during the design seismic event can be estimated.

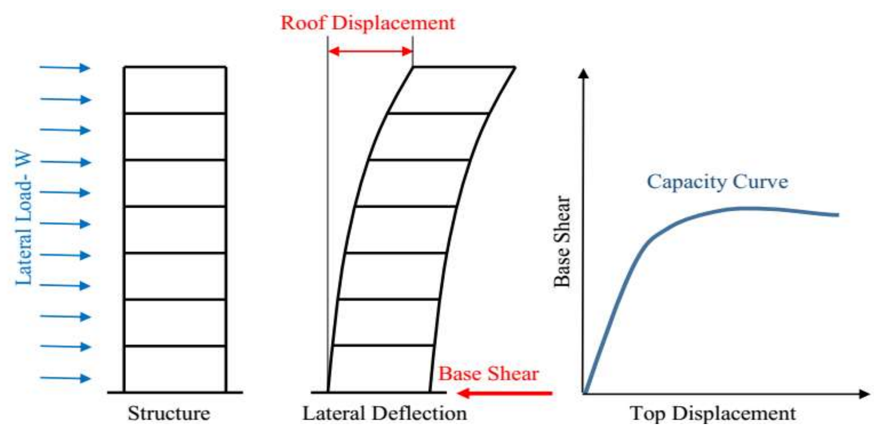


Figure 2. 4 Static approximation used in the pushover analysis [20]

2.4.3 Modeling the sample building for non-linear push over analysis

The other basic part of this research is to model the sample buildings so that push over analysis can be carried out. In ETABS2016, a frame element is modeled as a line element having linearly elastic properties and nonlinear force-displacement characteristics to perform non-linear push over analysis of column-beam frame system. The nonlinear behavior of beams and columns is represented by assigning concentrated plastic hinges at member ends where flexural yielding is assumed to occur. Flexural characteristics of beams and columns, defined by moment-rotation relationships, assigned as moment hinges at the ends of the frames. There are three types of hinge properties in ETABS2016]. They are default hinge properties, user-defined hinge properties and generated hinge properties. Only default hinge properties and user-defined hinge properties can be assigned to frame elements.

When these hinge properties (default and user-defined) are assigned to a frame element, the program automatically creates a new generated hinge property for each and every hinge.

ETABS2016 implements the plastic hinge properties described in FEMA-356[20] or ATC- 40 [24]. As shown in Figure 2.5, five points labeled A, B, C, D, and E define the force– deformation behavior of a plastic hinge. The values assigned to each of these points vary depending on the type of element, material properties, longitudinal and transverse steel content, and the axial load level on the element [24].

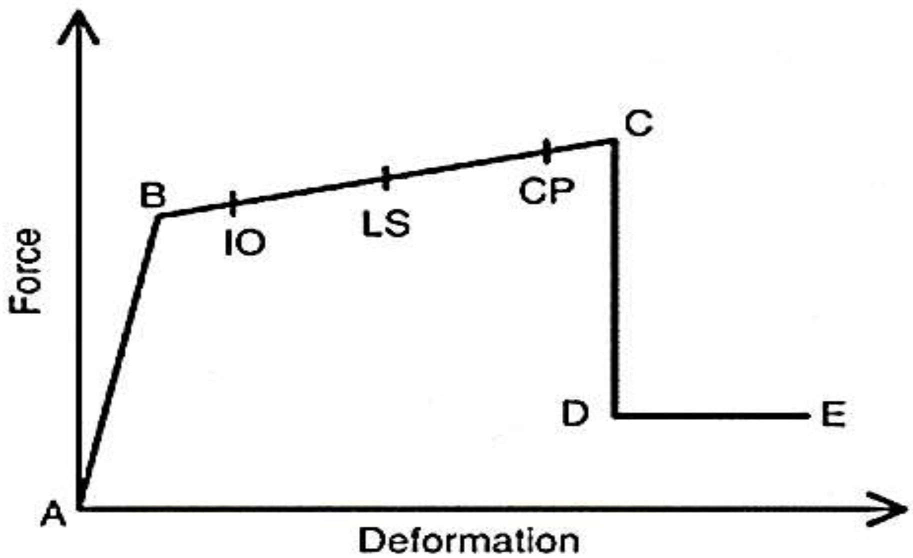


Figure 2. 5 Force-deformation relationship of a typical plastic hinge [24]

The definition of user-defined hinge properties requires moment–curvature analysis of each element. The points B and C on Figure 2.5 are related to yield and ultimate curvatures respectively. Since deformation ductility is not a primary concern, the point B is not the focus, and it is obtained using approximate component initial effective stiffness values according to ATC-40 [24]; 0.5EI and 0.70EI for beams and columns, respectively..

Therefore, moment-curvature relationship has to be converted to moment-rotation relationship for the five points labeled as A, B, C, D and E shown on figure 2.5. Plastic hinge length is used to obtain ultimate rotation values from the ultimate curvatures.

Thus;

$$\theta p = (\Phi u - \Phi y) lp$$

Where:

lp: Plastic hinge length

Φy: Yield curvature

Φu : Ultimate curvature

θp : Plastic rotation

Several plastic hinge lengths have been proposed in different literature but Paulay T. and Priestely M.J.N. [1] proposed that plastic hinge length can be approximated as 0.5h where h is a section depth. Also ATC-40 [24] states that the plastic hinge length, lp = h/2 where h is the section depth in the direction of loading, is an acceptable value that usually gives conservative results. In this study, user-defined plastic hinges, which are obtained from Moment-curvature relation, are assigned to frame elements. Plastic hinge length is taken as half of the section depth of the frame element in the direction of loading.

Following the calculation of the ultimate rotation capacity of an element, acceptance criteria, which are labeled as IO, LS, and CP in figure 2.5, are defined. IO, LS, and CP stand for Immediate Occupancy, Life Safety and Collapse Prevention, respectively. In this study, these three points defined as a point corresponding to 10%, 40%, and 80% use of plastic hinge deformation capacity. Also flexural hinge properties were used and assigned to frames and shear walls because it is intended to evaluate the out-of-plane bending resistance of shear walls in specified type of dual structural system.

2.4.4 Non Linear Pushover Analysis Procedure

Pushover analysis can be performed as either force-controlled or displacement-controlled depending on the physical nature of the load and the behavior expected from the structure. Force-controlled option is useful when the load is known (such as gravity loading) and the structure is expected to be able to support the load. Displacement-controlled procedure should be used when specified drifts are sought (such as in seismic loading), where the magnitude of the applied load is not known in advance, or when the structure can be expected to lose strength or become unstable.

Non-linear version of ETABS2016 can model nonlinear behavior of structures and perform pushover analysis directly to obtain capacity curve for two and/or three dimensional models of the structure. When such programs are not available or the available computer programs could not perform pushover analysis directly, a series of sequential elastic analyses are performed and superimposed to determine a force displacement curve of the overall structure.

There are different simplified non-linear pushover analysis methods to determine the primary elements of a performance-based design procedure, i.e. demand, capacity and performance. The first one is Capacity Spectrum Method (CSM), for which ATC-40[24] is used as a guideline. Capacity spectrum method is a nonlinear static analysis procedure that provides a graphical representation of the expected seismic performance of the existing or retrofitted structure by the intersection of the structure's capacity spectrum with a response spectrum (demand spectrum) representation of the earthquake's displacement demand on the structure. The intersection is the performance point, and the displacement coordinate (dp) of the performance point is the estimated displacement demand on the structure for the specified level of seismic hazard as shown in figure 2.6[15].

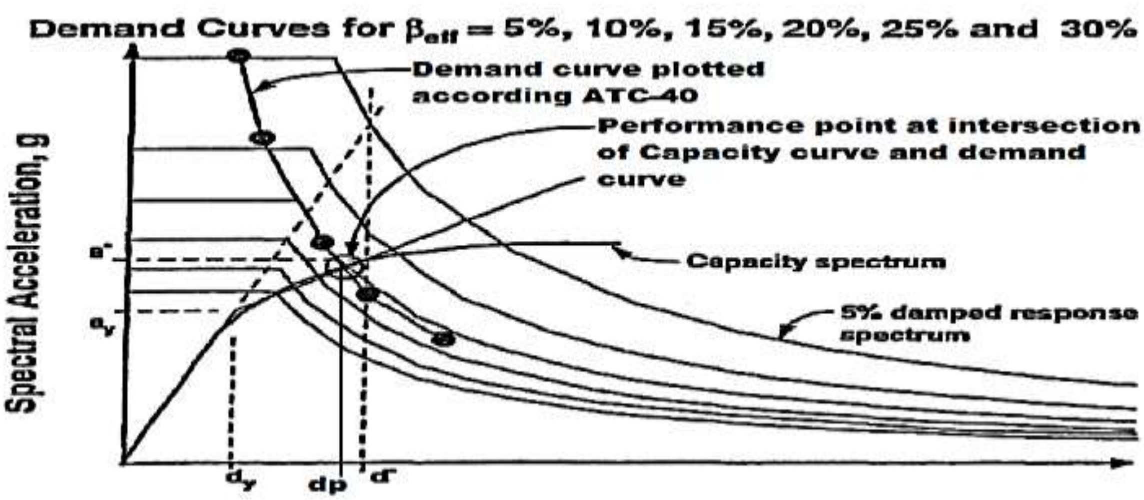
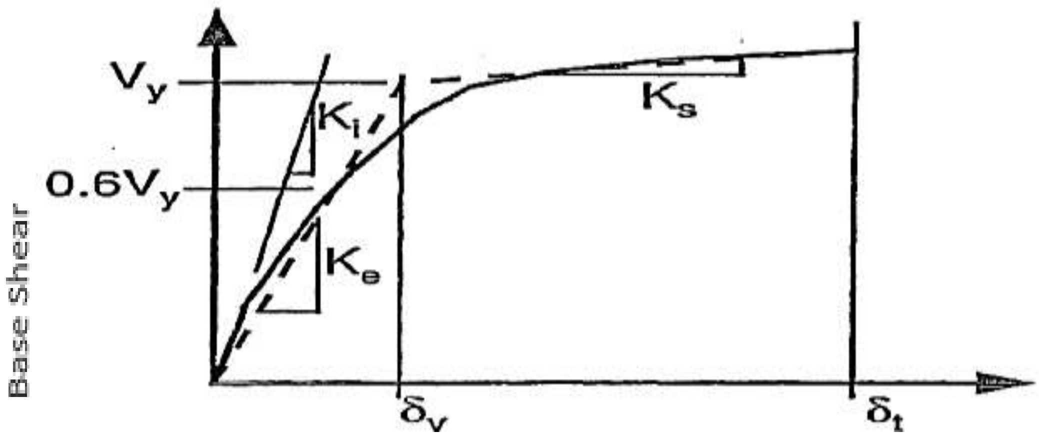


Figure 2. 6 Performance point obtained by capacity spectrum procedure [24]

The other method of non-linear pushover analysis procedure is Displacement Coefficient Method (DCM).FEMA-273 [19] & FEMA-356 [20] is used as guideline for displacement coefficient method.

It is a non-linear static analysis procedure that provides a numerical process for estimating the displacement demand on the structure, by using a bilinear representation of the capacity curve and a series of modification factors, or coefficients, to calculate a target displacement as shown as figure 2.7. The point on the capacity curve at the target displacement in displacement coefficient method is the equivalent of the performance point in the capacity spectrum method [24].



Displacement

Figure 2.7 Bilinear representation of capacity curve for displacement coefficient method

2.5 Description of Building Performance Level

A performance level describes a limiting damage condition which may be considered satisfactory for a given building and a given ground motion. The limiting condition is described by the physical damage within the building, the threat to life safety of the building's occupants created by the damage, and the post-earthquakes serviceability of the building [24]. Hence, building performance can be described qualitatively in terms of the safety afforded to building occupants, during and after the event; the cost and feasibility of restoring the building to pre-earthquake condition; the length of time the building is removed from service to effect repairs; and economic, architectural, or historic impacts on the larger community [19]. The building performance level is a function of the post event conditions of the structural and non-structural components of the structure.

Each building performance level consists of a structural performance level, which defines the permissible damage to structural systems, and a non-structural performance level, which defines the permissible damage to non-structural building components and contents [19].According Federal Emergency Management Agency document 273[19] & 356 [20], the structural performance level is defined as the post – event conditions of the structural building components, which is divided into three levels and two ranges while the non- structural performance level is defined as the post-event conditions of the non-structural components, which is divided into five levels. Consequently, the performance level of building is a combination of the performance level of both structural and non-structural components. Even though there is several performance level of building based on possible combination of structural and non-structural component's performance level, the more common & well established building performance levels are four. These are Operational, Immediate Occupancy, Life Safety and Collapse Prevention level of performances. Some common building performance levels are shown in figure 2.8 and the expected damage on each level is given in table 2.1(taken from table 2.3 of FEMA 273).

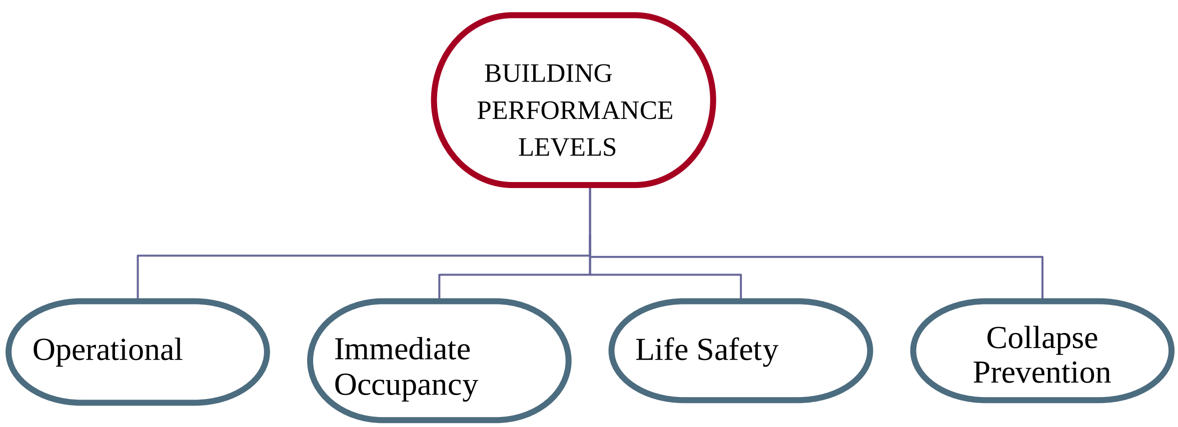


Figure 2. 8 some common building performance levels [19]

Table 2. 1 Damage Control and Building Performance Levels [19]

	Building Performance Levels			
	Collapse Prevention Level	**Life Safety Level**	**Immediate Occupancy Level**	**Operational Level**
Overall Damage	Severe	Moderate	Light	Very Light
General	Little residual stiffness and strength, but loadbearing columns and walls function. Large permanent drifts. Some exits blocked. In fills and un braced parapets failed or at incipient failure. Building is near collapse.	Some residual strength and stiffness left in all stories. Gravity-load-bearing elements function. No out-of-plane failure of walls or tipping of parapets.	No permanent drift. Structure substantially retains original strength and stiffness. Minor cracking of partitions, and as well as structural elements. Elevators can be restarted. Fire protection operable.	No permanent drift; Structure substantially retains original strength and stiffness. Minor as well as structural elements. All systems important to normal operation are functional.
Nonstructural components	Extensive damage.	Falling hazards mitigated but many architectural, mechanical, and electrical systems	Equipment and contents are generally secure, but may not operate due to mechanical failure or lack of utilities.	Negligible damage occurs. Power and other utilities are available, possibly from standby sources.

The owner, architect, and structural engineer can now decide what building performance level they want their building to achieve after a range of ground shakings which are expected to occur at a given design location.

2.6 Seismic Hazard

An important parameter that must be determined for the pushover analysis is the seismic hazard of a given location. The most common earthquake damage to buildings is caused by the ground shaking. The knowledge of seismic hazard or earth quake ground motion is one of the requirements in setting basic safety performance objective. It is combined with a desired performance level to form a performance objective. The earthquake ground motion can be expressed either by specifying a level of shaking associated with a given probability of occurrence (a probabilistic approach), or in terms of the maximum shaking expected from a single event of a specified magnitude on a specified source fault (a deterministic approach). ATC-40 [24] ,FEMA-273[19] & FEMA-356[20] sets three levels of ground shaking for basic safety performance objective with different definition and categorization as shown in table 2.2.

Table 2. 2 Seismic hazard levels defined for basic safety performance objective [24]

Earthquake hard levels accordingATC-40	Description of the seismic hazard level	Earthquake hazard levels according FEMA 273 & FEMA 356	Description of the seismic hazard level
The Serviceability Earthquake (SE):	Ground motion with a 50 % chance of being exceeded in a 50-year period	The Serviceability Earthquake	Earthquake with any defined probability of accidence in 50 years
The Design Earthquake (DE):	Ground motion with a 10 % chance of being exceeded in a 50-year period	Basic Safety Earthquake 1 (BSE-1)	Earthquake ground motion With a 10% probability of accidence in 50 years (10%/ 50 year).
The Maximum Earthquake (ME):	Maximum level of ground motion expected framework due to a specified single event the ground motion with a 5 %chance of being exceeded in 50 year period	Basic Safety Earthquake 2 (BSE2), also termed as Maximum Considered Earthquake (MCE) ground shaking	Earthquake ground motion With a 2% probability of accidence in 50 years (2%/ 50 year).

In addition to ground motion levels described in the table 2.2, performance objectives may be formed considering earthquake ground shaking hazards with any defined probability of exceedance, or based on any deterministic event on a specific fault. For the specific site, ground shaking hazard is determined using a specific study of the faults and seismic source zones that may affect the site, as well as evaluation of the regional and geologic conditions that affect the character of the site ground motion caused by events occurring on these faults and sources.

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Modeling and Analyzing

3.1 General

The research methodology was started with problem identification on dual structural (frames and shear walls together) system arranged in such a way that moment resisting frames resist lateral in longitudinal load while shear walls at each position in both direction take lateral load in transverse direction and setting up the objectives of study. All related literature is reviewed and the background information is collected for this research.

Sample buildings which can represent the building type & structural system mentioned are selected to demonstrate the effect of locating shear wall in different locations. Three types of building structures are established for parametric study. The buildings are assumed to cover the same plan area of 25m*10m meter. But with different storey number and different structural elements' size and appropriate thickness of shear walls as length of building increase. The size of building frames increased realistically as the number of storey is increased. Each building model has ten cases of study based on shear wall arrangement.

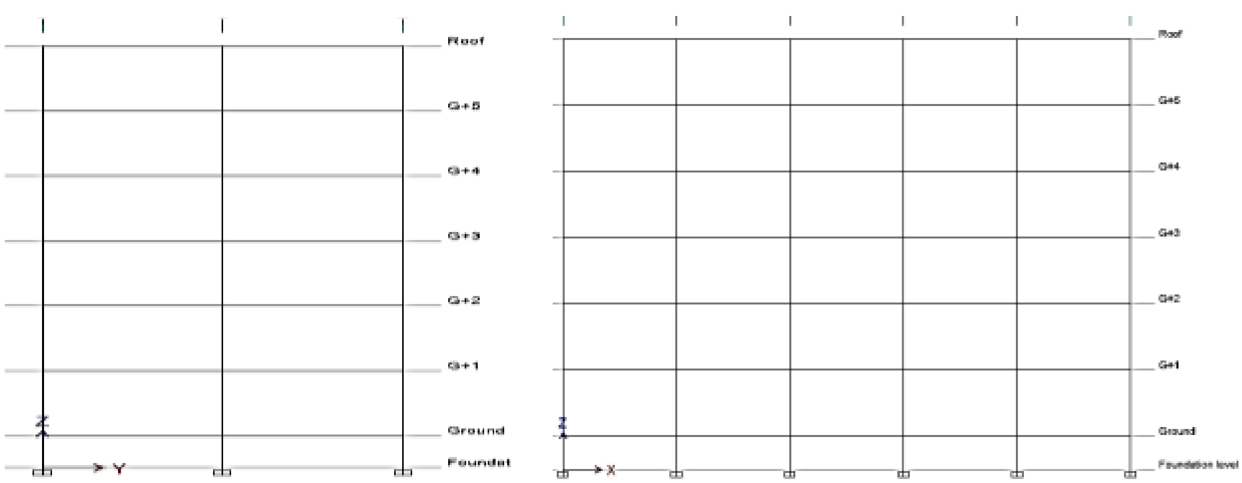
3.2 Description of the Building Structure

Three building structures are considered for this study. The detail of each building model is discussed as follows. Size of all slabs in all floors and all building types are 200mm. The size of shear wall is 200mm for G+5,225mm for G+10 and 250mm for G+20 and height of shear wall is equal to height of building it provided. The frame elements used in all building is shown the table 3.1 shown below.

Table 3. 1 Size of structural elements used in buildings while Modeling ETABS2016

BLDG type	Column	Location	Beam	Location
G+5	500mm*500mm	0-1.50m up to 3+00	400mm*400mm	All beam in this building.
	400mm*400mm	0+3.00m up to 0+21.00m		
G+10	600mm*600mm	0-2.00m up to 0+9.00m	500mm*600mm	for ground,G+1 and G+2 floor beams
	500mm*600mm	0+9.00m up to 0+18.00m	500mm*500mm	For G+3,G+4 and G+5 floor beams
	500mm*500mm	0+18.00m up to 0+24.00m	400mm*400mm	For G+6 up to roof beams
	400mm*500mm	0+24.00m up to 0+33.00m		
G+20	600mm*600mm	0-2.5.00m up to 0+0.15.00m	500mm*600mm	For Ground up to G+9 floor beams
	500mm*600mm	0+15.00m up to 0+30.00m	500mm*500mm	For G+10 up to G+14 floor beams
	500mm*500mm	0.30.00m up to 0+45.00m	400mm*400mm	for G+15 Up to G+20 floor beams
	400mm*500mm	0+45.00m up to 0+63.00m		

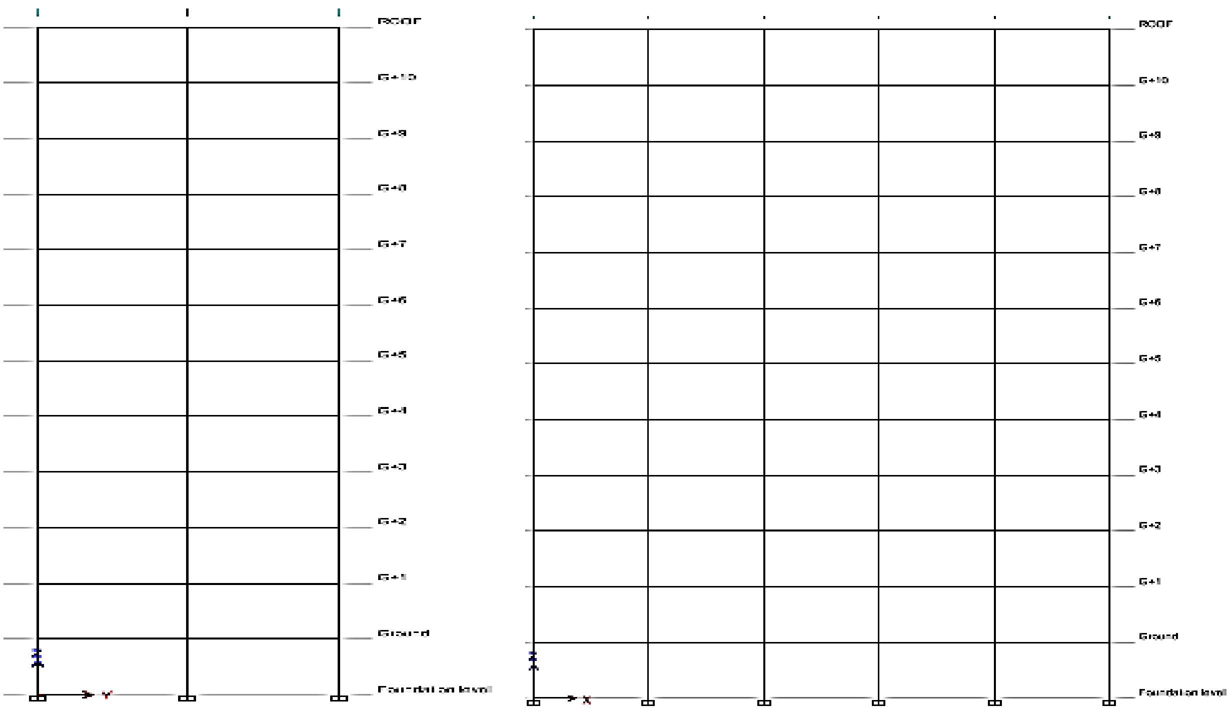
Building A: The typical floor height is taken as 3.0 meters throughout the building and 2.0 meters for footing column. This is G+5 building with 25m*10m width. The foundation is assumed to be structurally rigid.



(a) (b)

Figure 3. 1 Building A, Transverse (a) and (b) Longitudinal Directions of Buildings

Building B: The typical floor height is taken as 3.0m throughout the building and 2.5m for footing column. This building type is G+10 building with equal size with building A and size of structural elements in table 3.1. The foundation is assumed to be structurally rigid.



(a) **(b)**

Figure 3. 2 Building B, Transverse (a) and (b) Longitudinal Directions of Buildings

Building C: The typical floor height is taken as 3.0m throughout the building and 3.0m for footing column. The building is a G+20 with equal size with building A and building B having structural elements of size in table 3.1. The foundation is assumed to be structurally rigid.

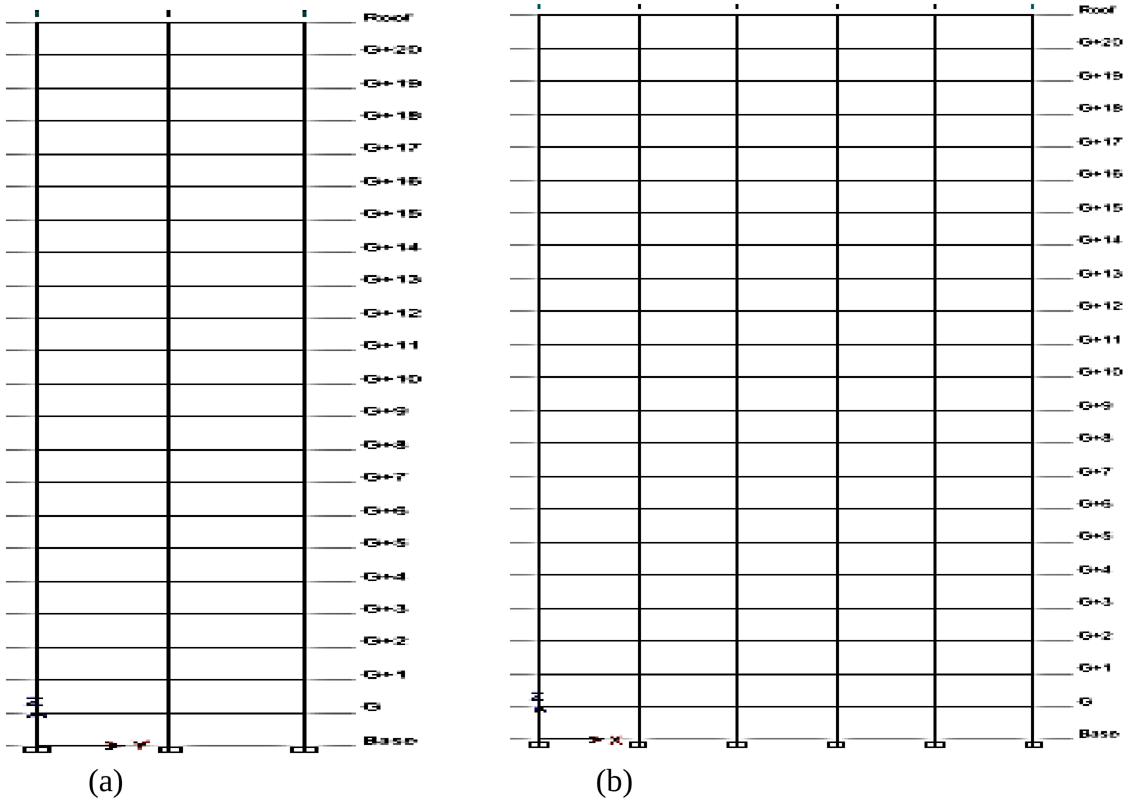


Figure 3. 3 Building C, Transverse (a) and (b) Longitudinal Directions of Buildings

3.2.1 Description of case study

Based on the shear wall arrangements, there are nine cases of study for each sample building model. In all cases, shear walls are arranged symmetrically, so that torsional effects are not introduced in the sample buildings. The effect of shear wall arrangement in all cases is compared with load resisting frames without shear wall and finally to each other. There are three Models for this study and all with three cases of shear wall arrangements and a case with no shear wall. Model-1 is when shear wall is at end of the building which is 12.5m from center of mass; Model-2 is shear wall at second axis of building from corner which 7.5m from center of mass and Model-3 is when shear wall is at the axis next to center of mass of the building. The cases for Model-1 are described below and for Model-2 and Model-3 its similar arrangements of shear wall to frames but shifting the shear wall to the indicated axis.

Case 1 frame system without shear wall, but with the same structural elements.

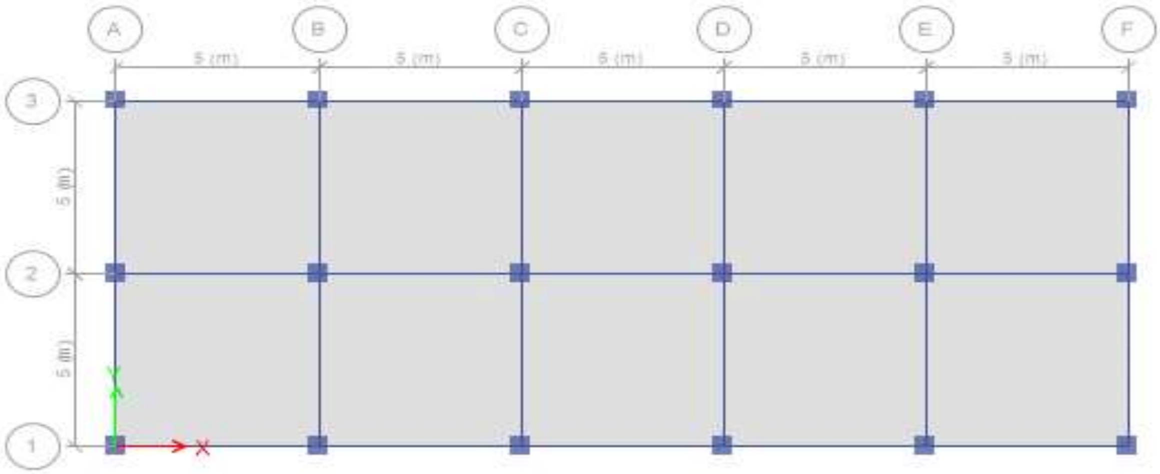


Figure 3. 4 Model-1Building frames without shear wall

Case 2: Dual structural system with shear wall placed at the end of the building in the short direction as shown in figure 3.5. This arrangement is when all shear walls, beams and columns in same axis are casted with their each centroid at one grid line.

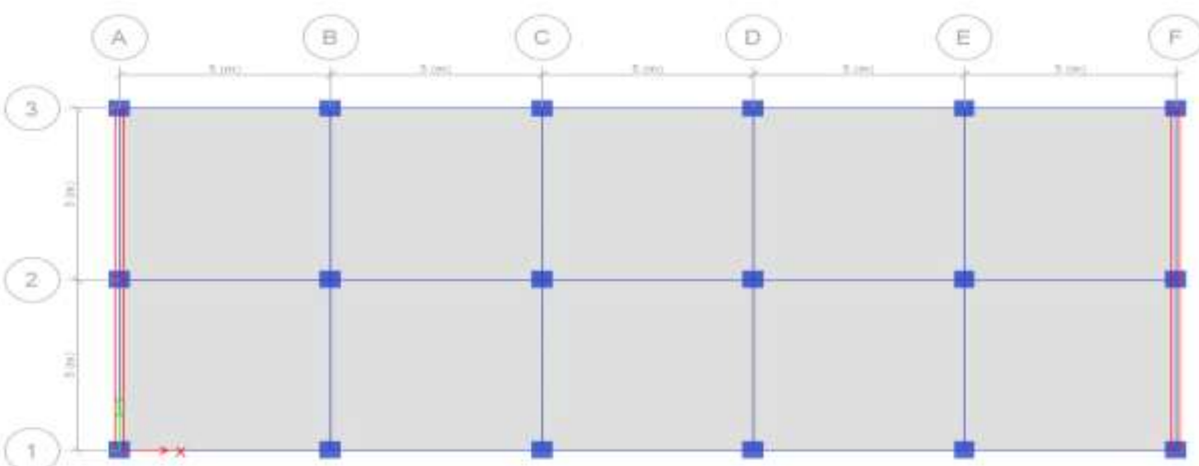


Figure 3. 5 Shear walls are placed at 12.5m from CM at center line of building frames

Case 3: Dual structural system with shear wall placed at the end of the building in the short direction as shown in figure 3-6. This arrangement is when shear walls at the same axis with frame is casted by offset from center line of that frames to edge of columns at inner phase of the frames in the direction to CM of building, but all beams and columns casted to each other with their centroid at one grid lines.

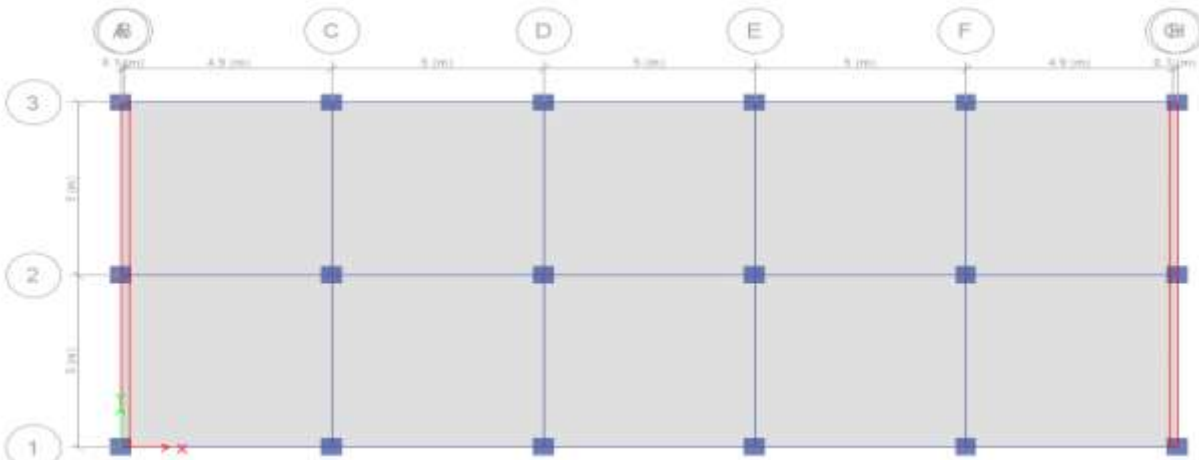


Figure 3. 6 Shear walls are placed at 12.5m from CM which offset to inner of frames

Case 4: Dual structural system with shear wall placed at the end of the building in the short direction as shown in figure 3.7. This arrangement is when shear walls at the same axis with frame is casted by offset from center line of that frames to edge of columns at outer phase in opposite direction to CM of the building, but all beams and columns casted to each other with their centroid at one grid lines.

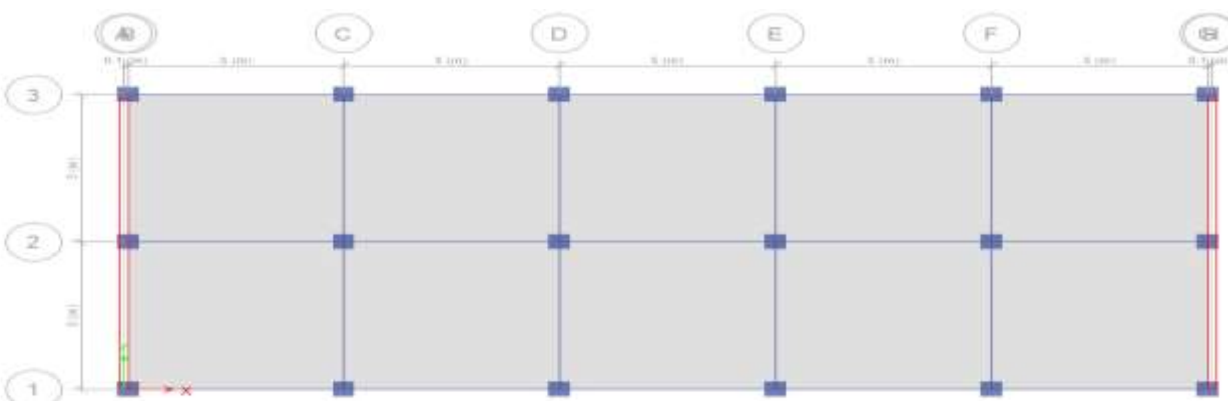


Figure 3. 7 Shear walls are placed at 12.5m from CM which offset to out of the building frames

3.2.2 Designing of Sample Building Models

Each sample buildings are designed according to the ES EN-2 (Eurocodes-2) [22] and EN ES-8 (Eurocodes-8) [23] seismic design requirements. They are assumed as commercial buildings located in high seismic zone, which is zone 5 according to Eurocode-8[23]. A subsoil class C is also adopted to obtain the site coefficient S. Equivalent static method is used for obtaining lateral loads. Additional Eccentricities in order to cover uncertainties in the location of masses, which may induce accidental torsional effect, are considered in designing the sample building models as specified by Eurocode-8[23]. Since the plan areas of the building model floors are the same, all floors will have the same center of mass at the geometric center. The point at which lateral load is applied in order to account for accidental torsional effect of each floor is shown table 3.2.Seismic loads are computed based on equivalent static procedure and the distribution of the lateral force over the height of the building is calculated.

Table 3. 2 Additional Eccentricities to account for accidental torsional effect of each floor

Floor level	Centre of mass(X)	Centre of mass(Y)	Accidental Eccentricities in long direction in m (±0.05Li)	Accidental Eccentricities in short direction in m (±0.05Li)
Roof Level	0	0	±0.5	±1.25
Other Floor	0	0	±0.5	±1.25

3.2.3 Modeling in ETABSv16.2.1

The following assumptions were made before the start of the modeling procedure so as to maintain similar conditions for all models:

- Only the main block of the building is considered. The staircases are not considered in the design procedure.
- The building is to be used for commercial, though no walls are installed as the study focuses only on the response of Frame configuration.
- On the ground floor, slabs are not installed and the plinth is resting 1.5m, 2m and 3m for G+5, G+10 and G+20 respectively above ground.
- The beams are resting centrally on the columns so as to avoid the conditions of eccentricity. This is achieved automatically in ETABS.
- The footings are not designed. Supports are assigned in the form of fixed supports.

3.2.4 Analytical Techniques of Evaluating the Shear Wall Arrangement

Research, the effects of shear wall arrangement in the dual system building shown in pervious section is evaluated by comparing the overall seismic performance of the building for each case of sample models. Seismic performance of those sample buildings can be evaluated by carrying out non-linear push over analysis, which could be used to determine the lateral load resisting capacity of structure and the maximum level of damage in the structure at the ultimate load. Therefore the performance based parameters used to evaluate the shear wall arrangements are lateral load resisting capacity curve and plastic hinge mechanism.

In non-linear 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 of the roof. This is a very convenient representation in practice, and can be visualized easily by the engineer. Using the roof displacement for the capacity curve is a widely accepted practice all over the world. Furthermore, performance point or target displacement is one of non-linear pushover analysis parameters which may use for performance evaluation purpose. The other parameter in pushover analysis, which is used for performance evaluation, is plastic hinge mechanism. The hinging patterns provide information about local and global failure mechanisms in the structure. Also it shows the extent of damage that the structure has suffered in relative to established performance level.

3.3 Modeling approach

Modeling rules presented in chapter nine of ATC-40[24] is used as a guide for modeling the structure considered for this study. ETABS is utilized to run non-linear push over analysis. It is one of the powerful computer programs which have a capability to perform non-linear push over analysis as either force-controlled or displacement-controlled. The other advantage of using ETABS is that it considers the effect of geometric nonlinearity of the structure (i.e. P-Δ effect) simultaneously with non-linear pushover analysis.

3.4 Study Variables

3.4.1 Dependent Variables

The dependent variables, which are to be observed and measured to determine the effect of the independent variables, are listed below.

- Storey drift
- Base shear
- Storey Displacement
- Storey stiffness

3.4.2 Independent Variables

The independent variables, which are to be measured and manipulated to determine its relationship to observed phenomena, are selected and listed below:

- Shear wall arrangement (shear wall centric to the frames and as shear wall eccentric to outer of the building and eccentric to inner of the building.

3.5 Population and Sampling Method

For this study there was thirty (30) number of shear wall arrangement these selected as a sample with different independent variable. For the entire assembly the lateral load is applied to models for analysis. These shear walls are centric or eccentric (both to outer face and inner face of the building frames) in the shorter direction of the three building samples. For the entire sample, the load applied on the shear wall and frames are both lateral loads and self-weight of the structural elements**.**

3.6 Data Quality Assurance

In order to assure data quality the following measures are taken:

- The structural modeling, the loading and the different connections of the frame system and the lateral load resisting system are double checked to remove errors.
- In case of any unreliable (illogical) results due to some unobserved errors, the structure is re-modeled and reanalyzed.
- A due attention and care is taken when extracting results from ETABS and plotting them in Excel.

3.7 Data Collection Process

Since this research is mainly about the effect of shear walls on building frames, The effect of shear wall on building frames is considering G+5, G+10 and G+20 commercial from medium to high raise RC buildings of lateral loads resisting systems, aiming to compare the change after shear wall provided to buildings' frames with a building without shear wall. The position of shear model for this study is as follow:

1) Shear wall at center of frames for axis 12.5m apart from center of mass (Case-2)
2) Shear wall at inner edge of frames for 12.5m apart from center of mass (Case-3)
3) Shear wall at outer edge of frames for 12.5m apart from center of mass (Case-4)
4) Shear wall at center of frames for axis 7.5m apart from center of mass (Case-2)
5) Shear wall at inner edge of frames for 7.5m apart from center of mass (Case-3)
6) Shear wall at outer edge of frames for 7.5m apart from center of mass (Case-4)
7) Shear wall at center of frames for axis 2.5m apart from center of mass (Case-2)
8) Shear wall at inner edge of frames for 2.5m apart from center of mass (Case-3)
9) Shear wall at outer edge of frames for 2.5m apart from center of mass (Case-4)
10) Building frames without shear wall for all building type (Case-1)

The analysis is done by a linear and dynamic analysis. Then, four critical parameters that can help to show effect of shear wall arrangements and used to compare the lateral load resisting systems. Data of models are extracted from ETABS (i.e. storey Drift ratio, Base Shear, storey displacement and storey Stiffness for linear analysis and capacity curve for dynamic analysis). Finally, tabulating and graphing the ETABS results in Excel for further study.

3.7.1 Considered Loadings

The major loadings considered are:

A) Vertical Loadings (Gravity Loads):

- ✦ Dead Load (DL):- Self Weight, Wall Load, and Finishing Load, Roof Load, partition load
- ✦ Live Load (LL):- Expected service loads from a live load on the respective purpose of the structure Specified in ES EN1; 5KN/m2 the detail DL and LL calculation is presented in Appendix A.

B) Lateral Loadings:

Calculation of earthquake load and wind load as per ES EN-1 and ES EN-8

- Wind Load (WL)and
- Dynamic and Static Seismic Load (Earth Quake load)

The loadings make up for the following thirty seven load combinations as shown in table 3.3

Table 3. 3 Load combination used for modeling according eurocode

No	Load Combination name	Vertical and Lateral Loading	EQ Eccentricity
1	Comb 1	1.35DL+1.5LL	
2	Comb2	DL+LL	
3-6	Comb3-Comb6	DL+0.6LL±EQXL±0.3EQYL	5%
7-10	Comb7-Comb10	DL+0.6LL±EQXL±0.3EQYR	5%
11-14	Comb11-Comb14	DL+0.6LL±EQXR±0.3EQYL	5%
15-18	Comb15-Comb18	DL+0.6LL±EQXR±0.3EQYR	5%
19-23	Comb19-Comb23	DL+0.6LL±EQYL±0.3EQXL	5%
24-27	Comb24-Comb27	DL+0.6LL±EQYL±0.3EQXR	5%
28-31	Comb28-Comb31	DL+0.6LL±EQYR±0.3EQXL	5%
32-34	Comb32-Comb34	DL+0.6LL±EQYR±0.3EQXR	5%
35	Envelope1	Max of Com1 up to Comb 18	
36	Envelope2	Max of Comb1,Comb2 and Comb19-Comb34	
37	Envelope3	Max of all Comb1-Comb34	

3.8 Study Design

A study design frame is the process that guides researchers on how to collect, analyze and interpret observations. Therefore, the objective of the research would be achieved by the procedure outlined below. This research is theoretical research; there is no need of laboratory test throughout the work, but, the ETABS 2016 used throughout the process completing this research paper.

3.8.1 Study Procedure

The general flow of work in this research;

Step1:-Analysis of different arrangement of RC shear wall configuration for different number of stories and compare the output result storey drift ratio, base shear, storey displacement and storey stiffness from ETABS.

Step2:-Analysis all possible arrangement of shear wall shape configuration in shorter direction and determine which have minimum storey drift ratio and storey displacement and maximum Stiffness after providing shear wall.

3.8.2 The Major Limitation Made In This Study Design

- Each shear wall shown in the plan is 10m wide span width. A thickness of the shear wall is uniform in a plan, and the boundary elements are not considered.
- All of the models in this study are symmetric along X & Y axis of plan. As a result, a center of mass and a center of rigidity in all of the models will be at the center of the plan, and therefore, the only torsional forces that will be applied to these structures is the torsion caused by accidental eccentricity.
- Analyze all of the models, and the preliminary design was performed to verify that failure does not occur in any of the elements under pre described loads. Therefore, all of the models described in this chapter are stable and do not fail under different load combinations described in table 3.3.
- Slabs are assumed to act as rigid diaphragms. Both slabs and shear walls are created using shell elements in ETABS. Stiffness Evaluation of Reinforced Concrete Shear Wall and Buildings frames are with Respect to shear wall arrangement and number of stories.
- Shear walls and columns are modeled as are fixed at the base.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 General

Distribution of walls in a building plan can have a very important role in determining Lateral stiffness and other related factors. Most of the time, structural engineers may not have many options to choose from because of limitations caused by architectural engineers due to use of a building or other utilities. For instance, large windows or openings, shear wall shape are some of the main reasons that prevent engineers from placing shear walls at a certain location. A common practice among engineers is to minimize the distance from a center of mass to the center of rigidity which is provided by shear walls and frames. The reason is that lateral loads are applied to the center of mass and if there is a substantial distance between where the load is applied and where a center of rigidity is, significant torsional moments will be generated. But assuming there are several positions that shear walls can be placed and in all of the possibilities, the distance between center of mass to center of rigidity is minimized and in the same point, then which factors should be considered in choosing the shear wall arrangement in a plan. To answer several questions of effect of shear wall on building major types of buildings are considered in this chapter are, G+5, G+10 and G+20 with different shear wall arrangement of building. The influence of shear wall Arrangement with all possible cases and analysis results based on ETABS2016 are compared in parameters such as base shear, lateral stiffness, lateral displacements, and storey drifts ratio.

4.2 Results of Models with different Parameters (RSA)

4.2.1 Storey Drift Ratio

Table 4. 1 Storey Drift Ratio for all Buildings by RSA methods of Analysis in both Directions

		Case-1		Case-2		Case-3		Case-4	
		Ave-X	Ave-Y	Ave-X	Ave-Y	Ave-X	Ave-Y	Ave-X	Ave-Y
G+5	Model-1	0.0013	0.0015	0.0013	0.0002	0.0013	0.0002	0.0015	0.0018
	%			-0.66%	-87.64%	-1.06%	-87.59%	15%	14%
	Model-2	0.0013	0.0015	0.0012	0.0002	0.0012	0.0002	0.0012	0.0002
	%			-2.97%	-85.27%	-2.67%	-84.67%	-3%	-84.92%
	Model-3	0.0013	0.0015	0.0013	0.0004	0.0013	0.0004	0.0012	0.0004
	%			-3.80%	-72%	-3.80%	-71%	-6.92%	-73%
G+10	Model-1	0.001	0.0013	0.0012	0.0006	0.0013	0.0006	0.0013	0.0017
	%			13.21%	-51.81%	31.48%	-52.14%	28.50%	26%
	Model-2	0.001	0.0013	0.0011	0.0007	0.0011	0.0007	0.0011	0.0007
	%			12.41%	-46.46%	11.47%	-46.07%	12.47%	-46%
	Model-3	0.001	0.0013	0.0012	0.001	0.0012	0.001	0.0011	0.001
	%			14.66%	-24.61%	13.46%	-27.50%	12.39%	-25%
G+20	Model-1	0.0023	0.0034	0.0024	0.0007	0.0023	0.0007	0.0023	0.0034
	%			3.90%	-79.15%	-2.14%	-79.14%	-0.60%	-2%
	Model-2	0.0023	0.0034	0.0022	0.008	0.0018	0.0008	0.0022	0.0008
	%			-3.80%	-76.72%	-23.82%	-76.80%	-6.83%	-78%
	Model-3	0.0023	0.0034	0.0011	0.001	0.0022	0.001	0.0021	0.001
	%			-54.82%	-71.63%	-4.73%	-71.44%	-11.53%	-72%

From the analysis shown in the above table, the worst and best combination of the dual system is seen according to storey drift ratio. Depends on shear wall in the frames, the result is varied in all building types modeled for this study.

For G+5, model-1, case-3, at inner edge of frames performs better in both directions. This is because of the shear wall supports the building frames at the back of building frames while seismic loads. But the case-2 of model-1 performs better for loads in Y-direction because of it braces the buildings frames greater because of it fits the center of frames with its center line. But this model is lesser performance in X-direction because of the shear wall bends outs of the plane. Model-1, case-4 shows worst combination as the arrangement is at out of frames and similarly out of the building. So because of their different deformation pattern and as the frames and shear wall is not attached to each other, this type of arrangement affect the building's frames negatively. This arrangement of shear wall even increases the storey drift ratio which is non-expected.

For G+10, case case-3 of model-1 shows better performance in y-direction, but not in x-direction which is opposite to G+5 of the same case and model as shown in table 4.1. This model negatively affect the amount of storey drift ratio in X-direction by 13.21%, but this model is still better than other models and the cases for this building. Similar to model-1, case-4 of G+5, and this kind of arrangement adverse the advantage of shear wall added to buildings.

For G+20, model-3, case-2, the shear wall at center of frames shows amazing improvement of storey drift ratio both in X-Direction (54.82%) and Y-Direction (71.63%). For the arrangements of shear wall these adverse the advantage against to storey drift ratio is seen smaller relative to other arrangements for this building type.

For G+5 and G+10 the shear wall arrangements at the end of the building shows better performance for storey drift ratio. But for G+20 the shear wall arrangement closer to center of mass shows better performance for the storey drift ratio. For most models, as the shear wall arrangement close to the center of mass of the building, the amount of storey drift ratio decreased due to shear wall is decreased in Y-direction and increased in X-direction. But the advantage of shear wall along Y-direction or transverse to the building is needed rather than the lateral loads come to in longitudinal direction to the building.

4.2.2 Base Shear

One of the factors that base shear depends on is building's weight. For all cases (case-2, case-3 and case-4) the same structural elements (RC Shear wall) is added to buildings with different arrangements. It shows that position of structure also change the result of base shear. When shear wall is arranged at outer edge of frames for model-1, it increases the buildings' contact area that decreases the magnitude of base shear in all building types of this study. If it were performing well against storey drift ratio, it will select. The next smallest base shear in both directions is case-2 which is also good arrangement depends on storey drift ratio reducing. But for G+20, case-2 of model-3 shows better for both storey drift ratio and base shear values. Why some shear wall arrangements changes the value of base shear is due to is structural configuration.

Table 4. 2 Base Shear for all Buildings by RSA methods of Analysis in both Directions

		Case-1		Case-2		Case-3		Case-4	
		Spec-X	Spec-Y	Spec-X	Spec-Y	Spec-X	Spec-Y	Spec-X	Spec-Y
G+5	Model-1	893.27	878.89	1011.09	2114.04	1014.21	2118.22	1014.89	987.122
	%			13.19%	140.54%	13.54%	141.01%	13.63%	12.31%
	Model-2	893.27	878.89	1039.5	2400.49	1047.55	2407.33	2418.57	2418.57
	%			16.37%	140.60%	17.27%	141.29%	17.05%	142.40%
	Model-3	893.27	878.89	1046.46	2399.94	1053.79	2403.84	1089.76	2407.01
	%			17.15%	173.07%	17.97%	173.51%	22%	173.90%
G+10	Model-1	1059.11	953.37	1376.37	3137.8	1525.76	3051.43	1376.12	1186.34
	%			30%	229%	44%	220%	30%	24%
	Model-2	1059.11	953.37	1354.73	3130.07	1352.16	3134.45	1278.02	3066.61
	%			28%	228%	28%	229%	21%	222%
	Model-3	1059.11	953.37	1375.83	3058.33	1083.79	2403.84	1111.78	2407.01
	%			30%	221%	2%	152%	5%	152%
G+20	Model-1	1898.93	1862.98	2200.99	2180.34	2211.48	2197.08	2015.29	2019.44
	%			16%	17%	16%	18%	6%	8%
	Model-2	1898.93	1862.98	2129.79	2129.18	1707.86	2507.93	2129.86	2174.51
	%			12%	18%	-10%	35%	12%	17%
	Model-3	1898.93	1862.98	2137.11	2176.2	2198.6	2183.65	2222	2244.31
	%			13%	17%	16%	17%	17%	20%

4.2.3 Storey Displacement

Table 4. 3 Storey Displacements by RSA methods of Analysis in both Directions

		Case-1		Case-2		Case-3		Case-4	
		X	Y	X	Y	X	Y	X	Y
G+5	Model-1	14	14.67	14.39	1.76	14.31	1.77	16.27	17.05
	%			2.70%	-88%	2.20%	-87.96%	16.20%	16.20%
	Model-2	14	14.67	13.86	1.98	13.82	1.99	13.89	2
	%			-1%	-86.50%	-1.30%	-86.43%	-0.80%	-86.40%
	Model-3	14	14.67	13.85	1.76	13.79	1.78	13.77	1.8
	%			-1%	-87.97%	-1%	-87.90%	-2%	-87.76%
G+10	Model-1	17	19.17	20.17	9.24	23.25	8.17	22.33	25.16
	%			19%	-52%	37%	-55%	31%	31%
	Model-2	17	19.17	19.96	9.04	19.78	9.06	19.9	9.04
	%			17%	-53%	16%	-53%	17%	-53%
	Model-3	17	19.17	20.12	9.15	19.89	9.13	19.73	9.16
	%			18%	-52%	17%	-52%	16%	-52%
G+20	Model-1	72.83	94.27	79.25	16.88	75.8	16.96	72.82	94.26
	%			9%	-82%	4%	-82%	0%	0%
	Model-2	72.83	94.27	72.61	16.35	57.45	18.7	69.99	16.09
	%			-0.30%	-83%	-21%	-80%	-4%	-83%
	Model-3	72.83	94.27	70.66	16.9	71.57	16.97	68.13	17.4
	%			-3%	-82%	-2%	-82%	-6%	-82%

Case-4 of model-3 shows better performance due to its arrangements that gives high structural configuration. Storey displacement depends on stiffness if structural elements. The case which is best for storey displacement reduction may not best for storey drift ratio. For this case the base shear is increased by 22% and 173% in x and y direction respectively. .

4.2.4 Storey Stiffness

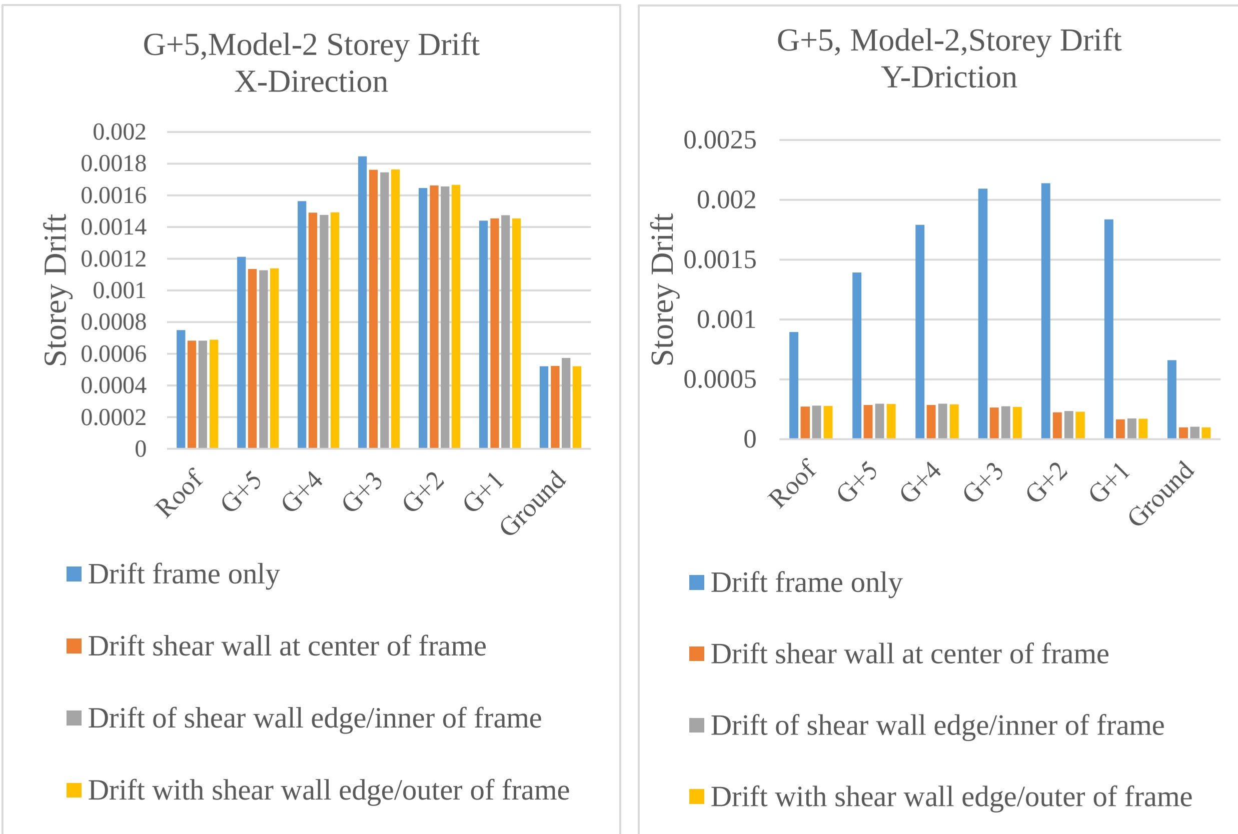
Table 4. 4 Storey Stiffness for all Buildings by RSA methods of Analysis in both Directions

		Case-1		Case-2		Case-3		Case-4	
		Ave-X	Ave-Y	Ave-X	Ave-Y	Ave-X	Ave-Y	Ave-X	Ave-Y
G+5	Model-1	287463	244668	321437	4704635	326470	4678808	51529	459276
	%			12%	1823%	14%	1812%	-82%	88%
	Model-2	287463	244668	340425	4323310	303487	3881621	342638	4280879
	%			18%	1667%	6%	1486%	19%	1650%
	Model-3	287463	244668	340862	2744020	346325	2672312	358908	2826283
	%			19%	1022%	20%	992%	25%	1055%
G+10	Model-1	258058	193872	286838	1712649	275229	1676483	2641	3662298
	%			11.15%	783.39%	6.65%	764.74%	-99%	89%
	Model-2	258058	193872	285605	1601384	287487	1592378	273905	1584431
	%			10.67%	726.00%	11.40%	721.35%	6%	717%
	Model-3	258058	193872	285988	1164707	287884	1149595	287744	1180090
	%			10.82%	500.76%	11.56%	492.97%	12%	509%
G+20	Model-1	207085	151363	229960	1128648	239662	1129894	6002	274668
	%			11.05%	645.66%	15.73%	646.48%	-97%	81%
	Model-2	207085	151363	235495	1050048	238306	1055824	242516	1067086
	%			13.72%	593.73%	15.08%	597.55%	17%	605%
	Model-3	207085	151363	240394	801890	243655	794397	255333	823321
	%			16.08%	429.78%	17.66%	424.83%	23%	444%

The storey stiffness in X direction after shear wall is increase and decrease in Y direction as the arrangement is close to center of mass. But the advantage of shear wall in Y direction is more desired than in X direction if it affects the property of building frames in X direction. So, while decide the position of shear wall, the designer have to balance the advantage and disadvantage of position of shear wall.

Generally for RSA analysis the result of each model is the same manner and enough to conclude the best and worst combinations of shear wall and frames for all building type.

From each model's result the effect of shear wall in X- direction due to the lateral loads in both direction less than that Y-direction. The figure below indicates the effect of shear walls in X and Y- direction.



(a) (b)

Figure 4. 1 Model-2 Storey Drift Due to Earth quake in (a), X-Direction and (b), in Y-Direction

4.5 Non-linear Analysis

4.5.1 Pushover Analysis

4.5.1.1 Results of Models with Pushover analysis (G+5)

Table 4. 5 Data for Static pushover analysis for G+5, due to Push-Y

Step	Case-1 Displ (mm)	Case-1 Base Force (kN)	Case-2 Displ (mm)	Case-2 Base Force (kN)	Case-3 Displ (mm)	Case-3 Base Force (kN)	Case-4 Displ (mm)	Case-4 Base Force (kN)
0	-2.41E-12	0	5.29E-12	0	-1.10E-12	0	0	0
1	-30	1095.724	-30	1457.432	-30	1672.133	-22.585	2302.779
2	-42.202	2544.771	-60	2914.865	-60	3344.266	-103.715	4357.719
3	-73.126	3662.688	-64.25	4121.333	-63.56	4842.714	-109.687	4921.918
4	-104.75	4459.628	-96.382	5381.324	-95.615	5914.347	-109.978	4932.152
5	-126.963	4608.269	-126.966	6118.289	-126.191	6739.427		
6	-127.213	4621.423	-127.445	6136.79	-158.104	7423.988		
7			-127.682	6145.585	-168.437	7605.061		
8			-128.486	6175.239	-168.437	7605.063		
9			-129.092	6183.148	-169.001	7612.448		
10			-143.74	6194.558	-169.004	7671.059		
11			-158.761	6198.086	-183.326	7720.224		
12			-158.761	6218.375	-184.449	7726.275		
13			-160.599	6223.833	-185.853	7739.406		
14			-160.6	6253.784	-188.661	7758.764		
15					-189.091	7763.545		

After sequential yield analysis the intensity of lateral loads is seen in the above table. The intensity slowly increased and failure of various structural components is recorded. Because of the iterative analysis process continues until the design satisfies pre-defined performance criteria of the worst and best combination of shear wall and frames is identified.

Case-3 shows better performance for future earth quakes or lateral loads up to about 189mm top roof displacement by 7763.5 kN applied lateral loads. Outer arrangement of shear wall to frames seen as strong but brittle and building without shear wall is weak and ductile as seen by figure 4.46 below.

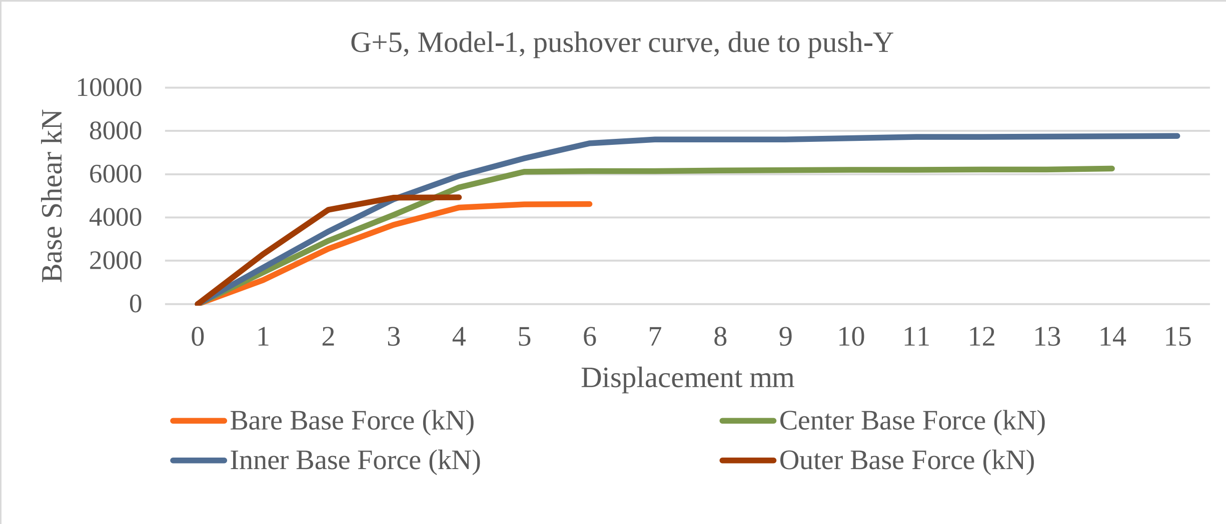


Figure 4. 2 Monitored displacement Vs. Base shear capacity curve

4.5.1.2 Results of Models with Pushover Analysis (G+10)

Table 4. 6 Data for Static pushover analysis for G+10

Step	Case-1 Displ (mm)	Case-1 Base Force (kN)	Case-2 Displ (mm)	Case-2 Base Force (kN)	Case-3 Displ (mm)	Case-3 Base Force (kN)	Case-4 Displ (mm)	Case-4 Base Force (kN)
0	0	0	5.10E-11	0	0.009	0	-1.28E-08	0
1	-30	1276.74	-30	1429.849	-29.991	1428.213	-30	1808.93
2	-44.879	2309.952	-60	2859.698	-59.991	2856.426	-60	3387.86
3	-78.015	3510.957	-90	4289.547	-89.991	4284.639	-90	4896.79
4	-109.775	4341.986	-97.064	5611.912	-97.562	5630.518	-102.132	5089.436
5	-139.948	4615.967	-127.348	6627.061	-128.291	6672.417	-102.371	5217.342
6	-163.192	4790.626	-159.075	7545.251	-158.675	7453.922		
7			-190.101	8461.076	-177.495	8076.902		
8			-190.105	8461.271	-177.498	8076.932		
9			-190.108	8460.854	-180.313	8190.145		
10			-190.277	8467.263	-180.316	8189.92		
11			-190.28	8467.256	-180.573	8199.832		
12			-206.853	8535.982				

Similar G+5, but case-2 arrangements of shear wall to frames perform better the case-3 for G-5. The case for the building without shear wall and shear wall at outer or case-4 is the same.

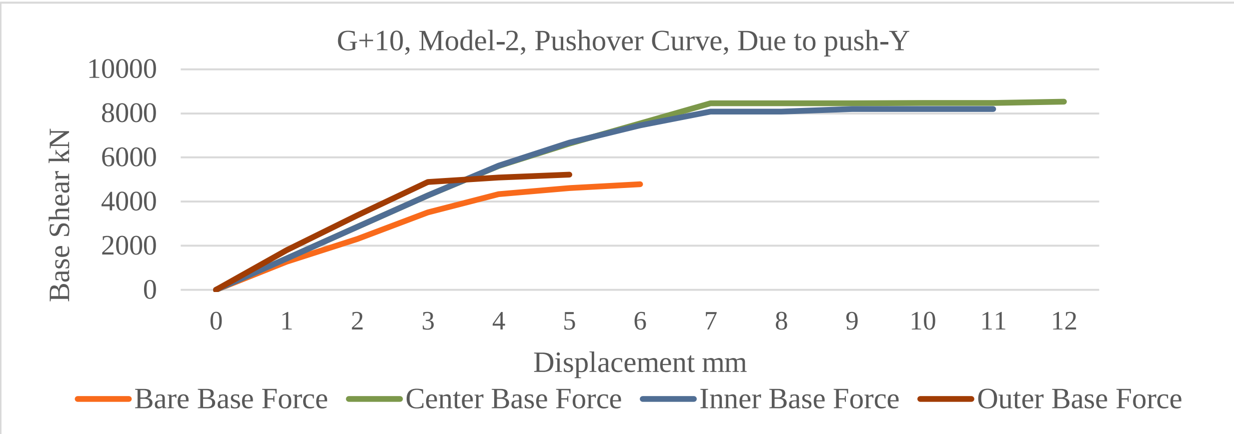


Figure 4. 3 Monitored displacement Vs. Base shear capacity curve

4.5.1.3 G+20 Model-2 compare

Table 4. 7 Data for Static pushover analysis for Building-B

Step	Case-1 Displ (mm)	Case-1 Base Force (kN)	Case-2 Displ (mm)	Center-2 Base Force (kN)	Case-3 Displ (mm)	Case-3 Base Force (kN)	Case-4 Displ (mm)	Case-4 Base Force (kN)
0	-5.37E-11	0	9.05E-10	0	-8.10E-10	0	1.02E-10	0
1	-30	1008.069	-30	1634.015	-30	1634.281	-30	2048.086
2	-60	1816.137	-60	3218.029	-60	3168.562	-60	4296.172
3	-90	2724.206	-90	4592.044	-90	4202.843	-90	4944.258
4	-120	3232.274	-120	5497.059	-120	4837.124	-120	5092.344
5	-150	3610.343	-150	6170.073	-150	5471.405	-150	5107.859
6	-180	3644.345	-180	6704.088	-180	5805.685	-180	5188.516
7	-210	3654.545	-201.71	6912.652	-200.67	6042.809	-195.3	5211.134
8	-235.745	3857.667	-236.5	7319.832	-240.59	6201.338	-229.53	5213.681
9	-276.672	3866.324	-267.18	7434.838	-272.51	6318.202		
10			-299.46	7481.165	-290.089	6409.271		
11			-300.482	7478.812	-303.728	6501.657		
12			-411.871	7478.112	-401.859	6510.39		
13			-412.267	7492.232	-402.297	6523.52		
15			-415.349	7493.839	-407.491	6543.32		
16			-415.341	7493.942	-411.948	6567.26		

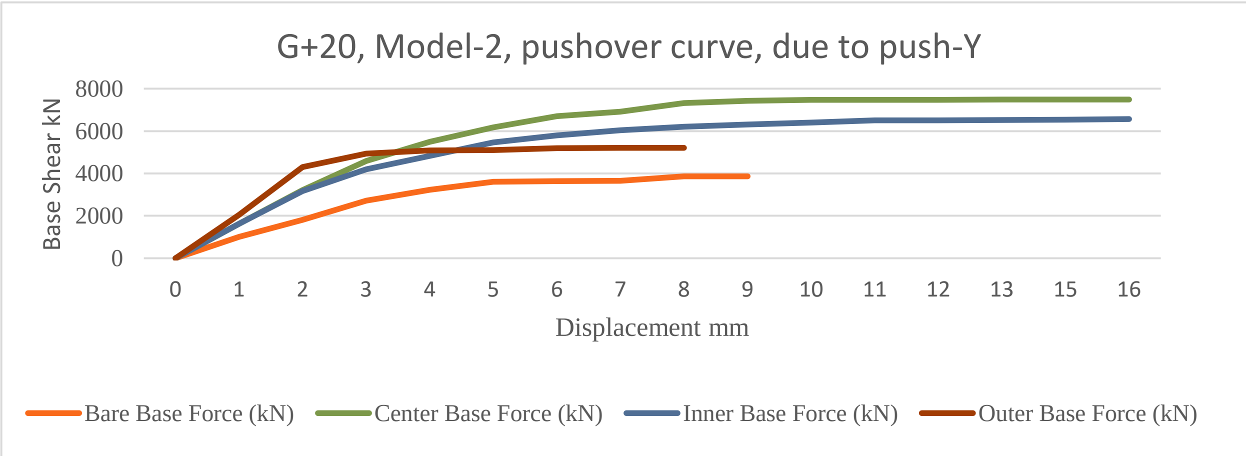


Figure 4. 4 Monitored displacement Vs. Base shear capacity curve

From the above data the outer arrangement is seen worst than the other. Even it may seems improve the property of the building, but it make the buildings frames more brittle and result in sudden fuilure. Similar of RSA analysis case-2 and case-3 can used interchangebly by little compensation according to the interest of architecturalal and client.

4.6.1. Storey Response of G+5

4.6.1.1. Storey Drift Due to Push-Y for G+5, Model-1

Table 4. 8 Storey Drift Data of Building one due to push-Y

Storey	Case-1	Case-2	Case-3	Case-4
Roof	6.908698	3.568077	2.434985	5.999234
G+5	7.310694	4.719877	2.522179	6.325721
G+4	7.830481	4.968447	2.52255	6.435779
G+3	7.296871	5.173149	2.395142	6.229294
G+2	7.037757	5.781819	2.105547	5.622455
G+1	6.493328	5.334547	1.62384	4.592462
G	2.483644	2.04042	1.09252	3.169098
Base	0	0	0	0

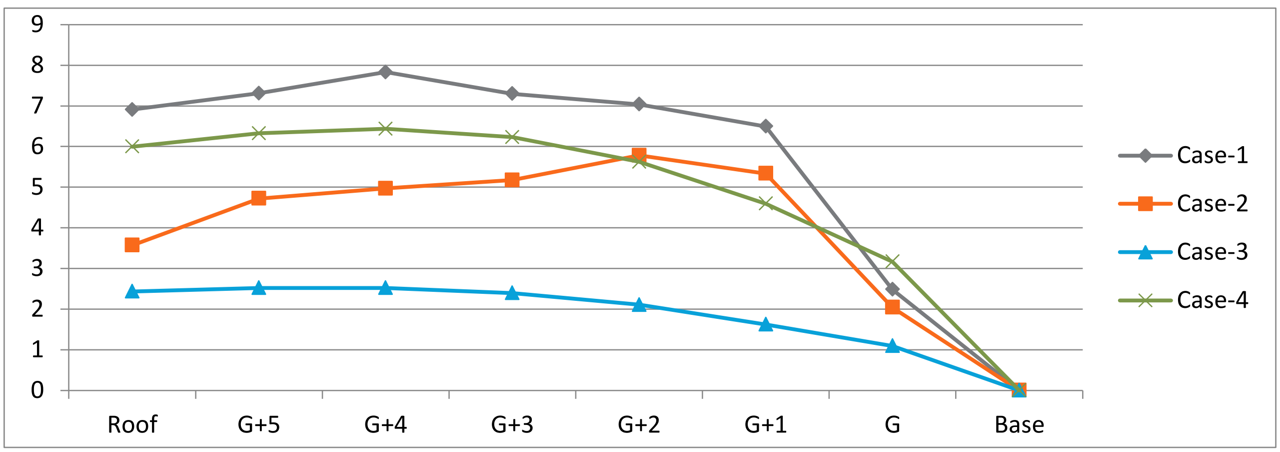


Figure 4. 5 Storey Drift of Building A (G+5) Due to Push-Y

4.6.1.2 Model-1, G+5, Plastic hinge formation

By providing plastic hinge for both columns and beams for models the best and worst arrangements of frames and shear wall is seen as figure 4.6 below. From figure below case-2 or shear wall at center of frames shows better performance. This is similar for all building types of this study as shown on the figure 4.8 and 4.10 of plastic hinge formation.

4.6.1.2 G+5, Model-1, Plastic hinge formation

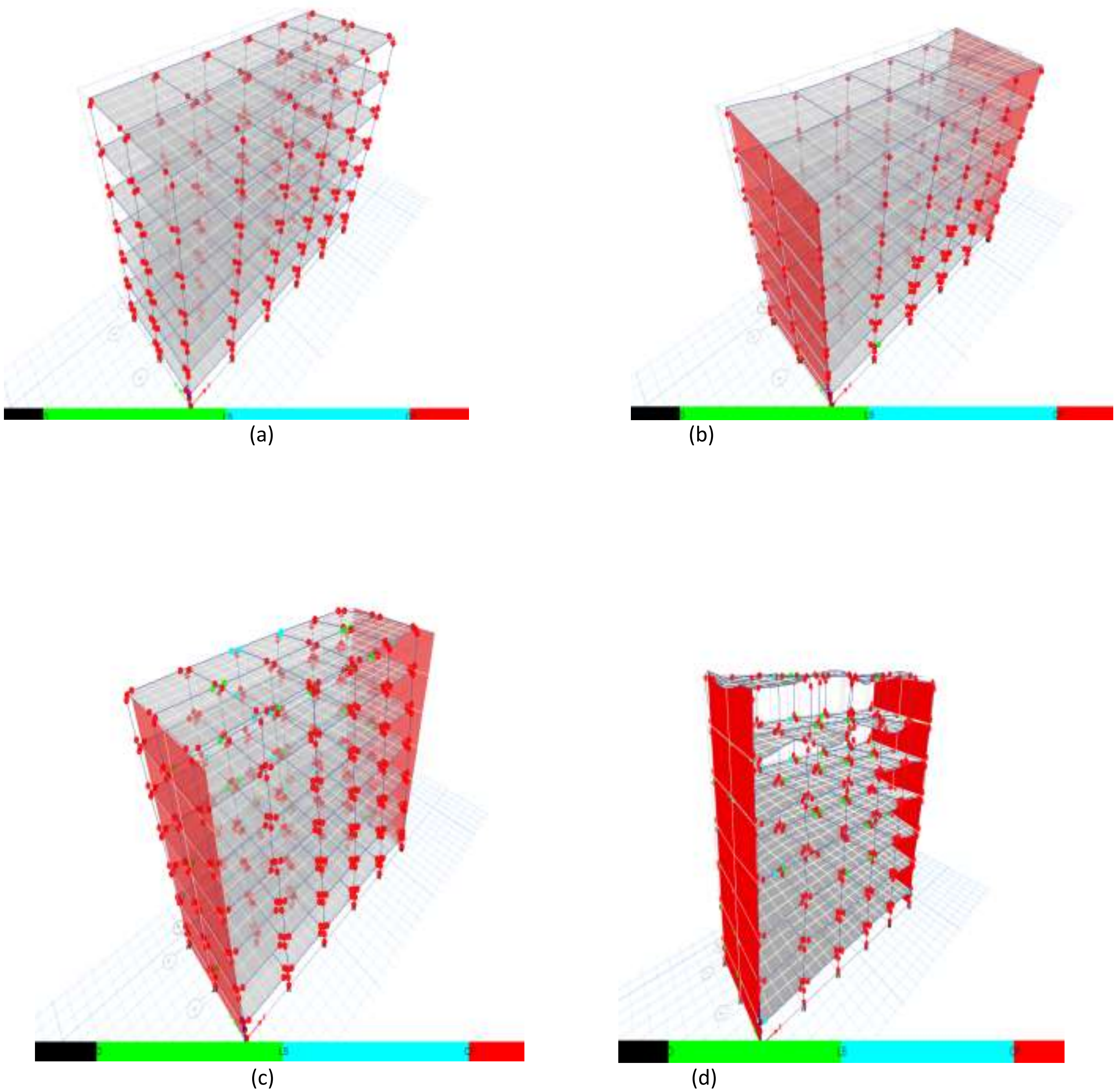


Figure 4. 6 plastic hinge formation of G+5,cases of a) Case-1, b) Case-2, ,c) Case-3 and d) Case-4

4.6.2 G+10 Storey Response

4.6.2.1 Storey Drift

Table 4. 9 Storey Drift Data Of Building-B

Storey	Case-1	Case-2	Case-3	Case-4
ROOF	0.413519	0.329992	0.001105	2.602309
G+10	0.640858	0.335312	0.001122	2.644376
G+9	0.885036	0.338712	0.001134	2.670028
G+8	0.970726	0.338455	0.001133	2.671537
G+7	1.109142	0.3353	0.001123	2.637543
G+6	1.070414	0.325333	0.001089	2.552015
G+5	1.083615	0.308967	0.001034	2.413765
G+4	1.184335	0.283725	0.00095	2.21623
G+3	1.244797	0.248461	0.000833	1.92342
G+2	0.977082	0.205527	0.00069	1.591125
G+1	0.961948	0.16119	0.000541	1.246043
Ground	0.599447	0.098307	0.00033	0.75812
Basement	0	0	0	0

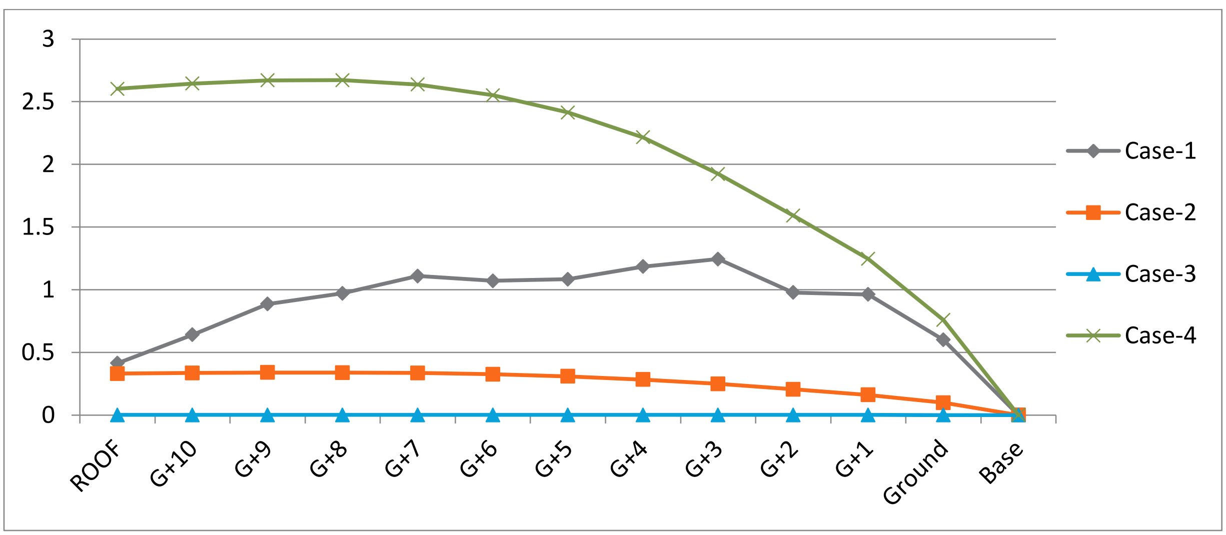


Figure 4. 7 Storey Drift for G+10, Model-2 Due to Push-Y

4.6.2.2 G+10, Model-2, Plastic hinge formation

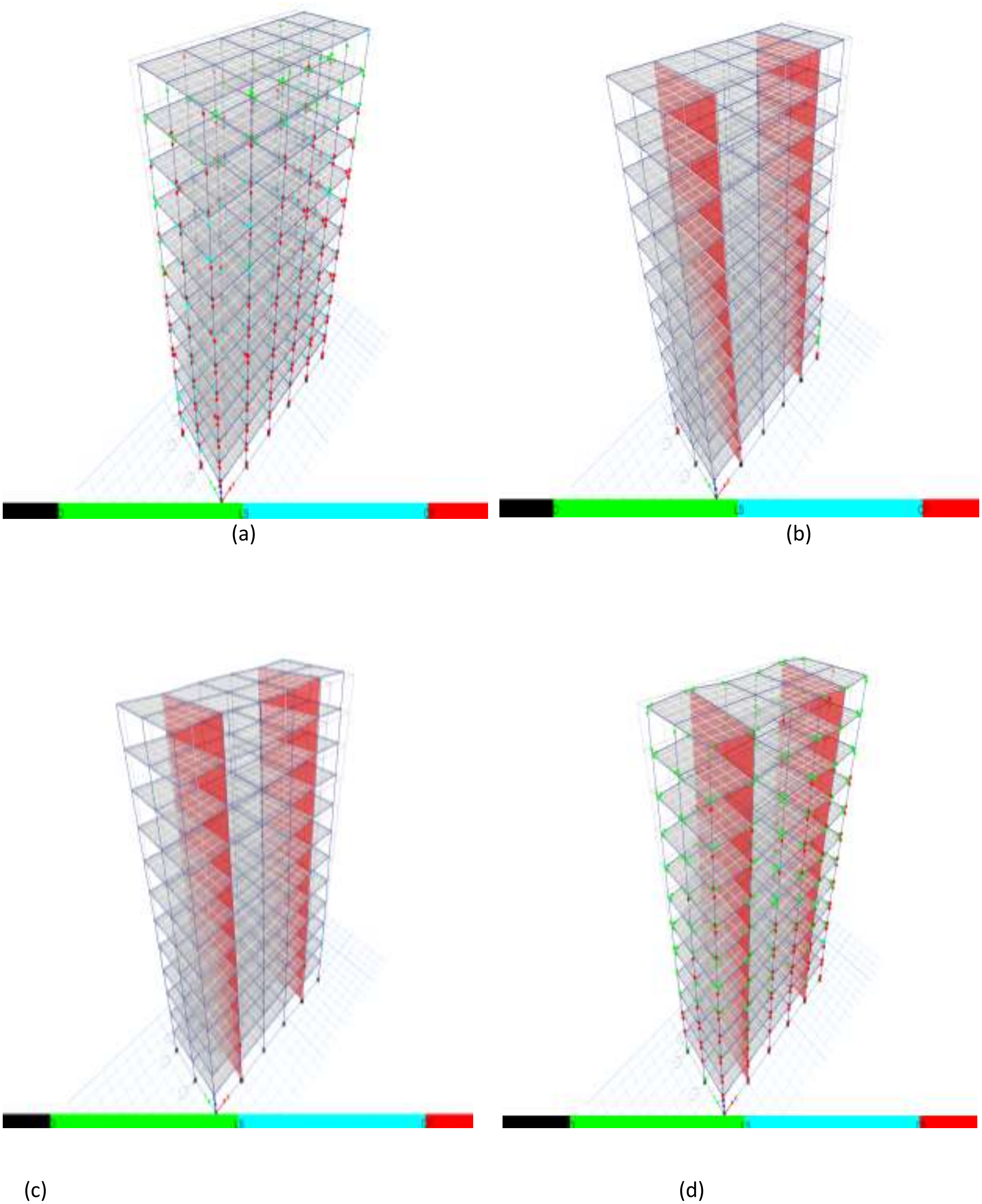


Figure 4. 8 plastic hinge formations a) Case-1, b) Case-2, c) Case-3 and d) Case-4

4.6.3 Storey Response of G+20

4.6.3.1 Storey Drift

Table 4. 10 Storey Drift Data for Building-C

Storey	Case-1	Case-2	Case-3	Case-4
Roof	1.286127	0.467848	0.057405	0.081107
G+20	1.292511	0.470072	0.057678	0.092944
G+19	1.297658	0.471852	0.057896	0.105631
G+18	1.301845	0.473282	0.058072	0.118331
G+17	1.303774	0.473903	0.058148	0.130877
G+16	1.302355	0.473331	0.058078	0.143223
G+15	1.296676	0.471244	0.057821	0.15534
G+14	1.285574	0.46724	0.05733	0.161168
G+13	1.269563	0.461491	0.056625	0.171881
G+12	1.24628	0.453167	0.055603	0.181865
G+11	1.21512	0.442046	0.054237	0.187914
G+10	1.172796	0.426999	0.052394	0.175349
G+9	1.121362	0.407735	0.050031	0.156257
G+8	1.062187	0.385017	0.04724	0.15836
G+7	0.991777	0.357924	0.043915	0.161945
G+6	0.908976	0.326116	0.040011	0.164441
G+5	0.812762	0.289214	0.035473	0.161266
G+4	0.70665	0.250229	0.030691	0.136557
G+3	0.599148	0.211987	0.026009	0.137809
G+2	0.475373	0.16815	0.020622	0.138071
G+1	0.335542	0.118638	0.014538	0.130169
G	0.170154	0.060118	0.007364	0.08019
Base	0	0	0	0

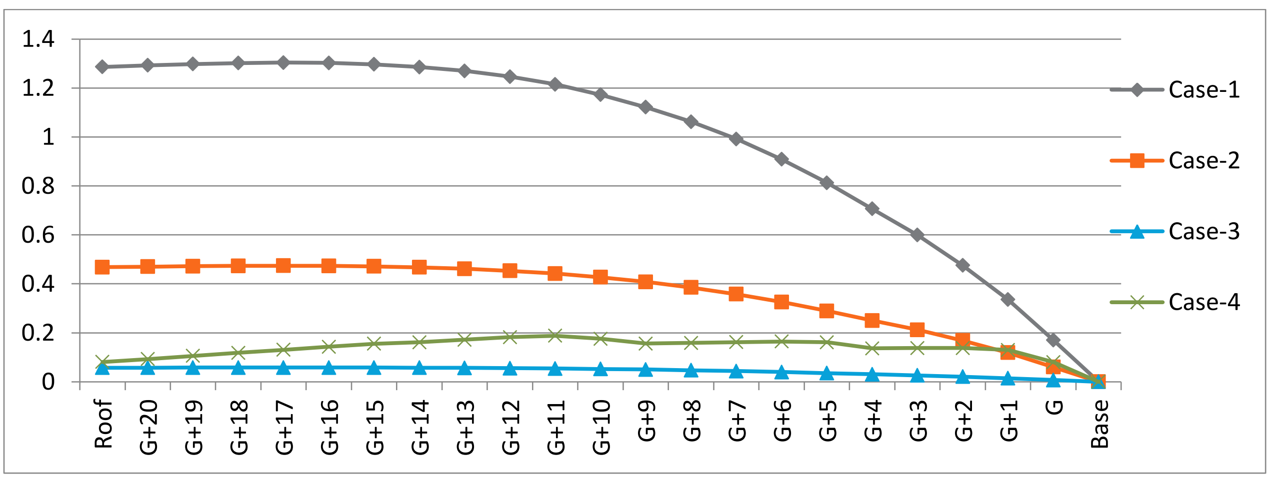


Figure 4. 9 Storey Drift of Building-C, Model-2 Due to Push-Y

4.6.3.2 G+20, Model-2 plastic hinge formation

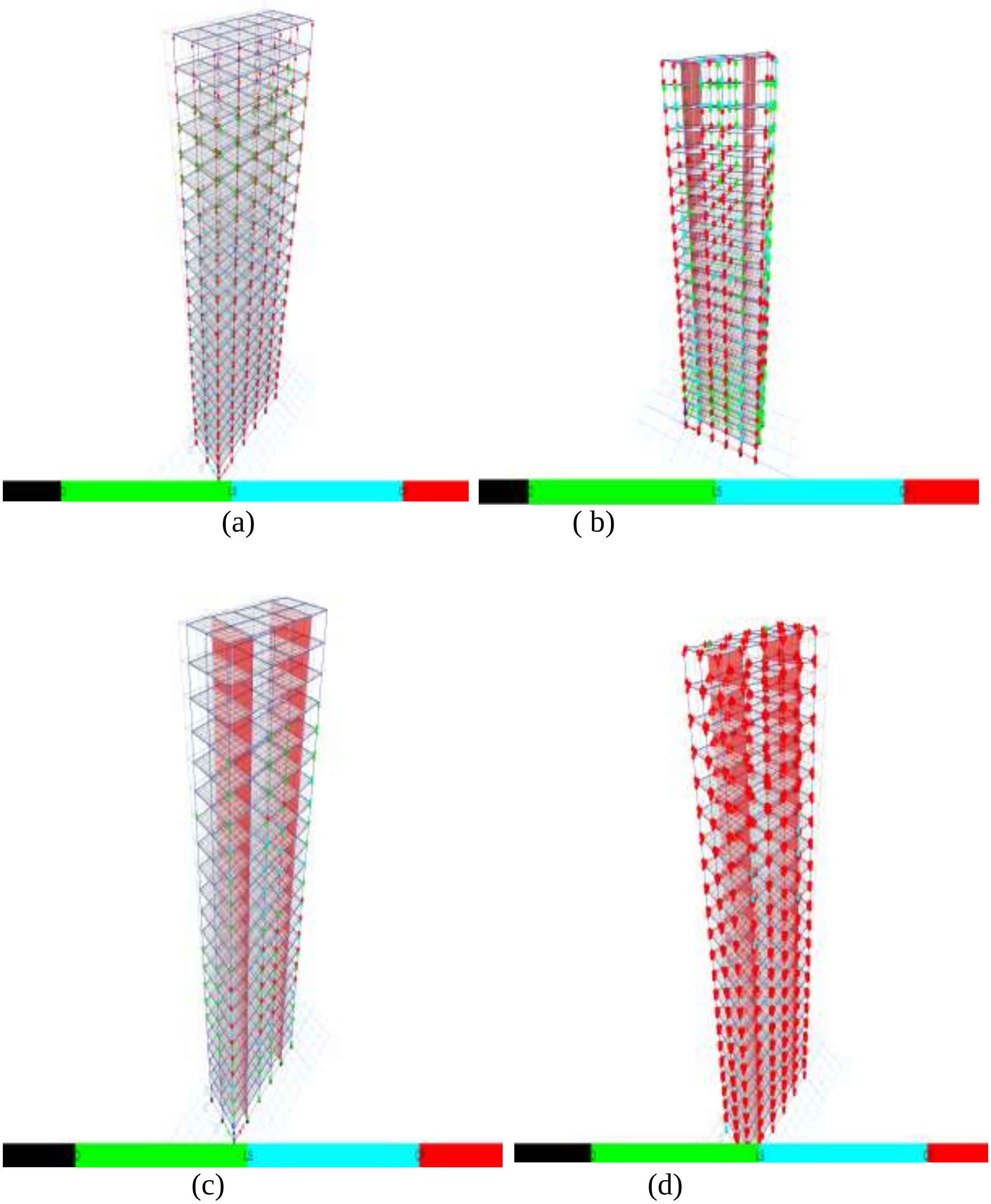


Figure 4. 10 plastic hinges a) Case-1, b) Case-2 c) Case-3 and d) Case-4

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The act of reinforced concrete dual structural system quantified in this study is investigated using the linear dynamic (RSA) and non-linear static (pushover analysis). The effect of placing or arranging shear walls in different positions along shorter direction or transversal direction of building is evaluated in terms of the whole building performance. After careful going-over and comparison of the output of RSA for linear dynamic and non-linear pushover analysis for different arrangement of shear walls, the following conclusions are drawn:

For Building A;

If model-1, case-3, which is best to reduce the storey drift ratio of building, is selected;

- ✦ It increases the storey displacement in X-direction but model-3; case-4 reduces the storey displacement well.
- ✦ Good against base shear but not as model-1, case-2
- ✦ Best for storey stiffness in x-direction and good for y-direction but not as model-1, case-2 which stiffer against loads in Y-direction.

If model-3, case-4 which is best by reducing story displacement in both direction and storey drift ratio in X-direction is selected,

- ✦ It increases the base shear in both directions which is worse than others and less stiff.

If model-1, case-2 which is best in storey stiffness and base shear is selected,

- ✦ It increases the storey displacement in X-direction but it’s good in y-direction storey displacement.

After careful observation, when shear wall arrangement of model-1, case-2 is selected which is best for story stiffness and base shear and good for Storey drift and storey displacement in Y-direction, it only affect (increased) the storey displacement in X-direction. However, case-3 of model-1 can selected if it desired by architectural or interest of the owner by compensating its weakness as optional and case-4 of this building is the worst and never be a choice.

Building B;

For this kind of building similar to building-A case-2 of model-1 is best one respect to other cases of each models. For this building type the optional arrangement of shear wall is case-3 of model-2 if desired and case-4 of all models is the worst arrangement and it is out of choice.

For Building C;

For each parameters of study four options to choose with different limitations. If model-3, case-2 which is best for storey drift reducing is selected;

- Its good in reducing base shear of buildings, but not as model-1, case-3
- Good in reducing storey displacement but not as model-2, case-2
- Poor in reducing storey stiffness, while model-1, case-2 is best in storey displacement reducing

If model-1, case-3 which is best in reducing the base shear of the building is selected;

- Poor in storey drift ratio reduction
- Poor storey displacement
- Poor in story stiffness

If model-2, case -3 which is best for storey displacement reducing is selected;

- Good for storey drift ratio, but not as model-3, case-2
- Good for base shear reducing, but not as model-1, case-3
- Medium for story stiffness increasing, but not as model-1.case-2

If model-1, case-2 which is best for rising storey stiffness

- Good for storey displacement reduction, but not as model-2, case-3
- Good for base shear reduction, but not as model-1, case-3
- Best for storey drift ratio reduction in y-direction, but not good for storey drift ratio in x-direction

After all case-2 of model-1 shows performance by considering all parameters together which followed by case-3 of model-2 as optional similar to building-A.

5.2 RECOMMENDATIONS

A positioning of shear walls in many cases might not be a choice for structural engineers, and it can be dictated by architectural plans. Therefore, architectural have conceptual understanding and select from different options that are available, and engineers must take the most advantage and based on priorities and conditions choose the best layout which satisfies the requirements properly while optimizing the design. It is important to minimize the position between the center of mass and center of rigidity by using a proper layout to reduce torsion.

For these entire models, the shear wall arrangements at out of frames in opposite direction of center of mass for model-1 are not prefer. Even the building is seen affected due the arrangement of shear wall than the building without shear wall. But if the architectural designer is interested for both the shear wall arrangement at center of frames and at the edge of frames in the direction center mass can be used interchangeably by treating each deficiency by structural engineers.

In this paper the alternative arrangement of shear wall of the building such as one side at center of frame and the other sides at both edge is for both sides of lateral loads is not considered. The left is for further researcher or will be deep to detail for next study.

The building plan and vertical storey arrangement is regular. The only non-linearity considered for this study is material non-linearity. The next researcher may use storey height different from one another and irregular building plan.

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Appendix-A: Articles, graphs and tables referred in the paper from ES-EN 1998-1:2013

A 1 Method of analysis

There are four methods that can be used to analyze the response of a structure subjected to an Earthquake. The choice of the method depends on the structure and on the objectives of the analysis.

1) Linear-elastic analysis
   a) Lateral force method of analysis (Static)
   b) Modal response spectrum analysis (Dynamic)
2) Non-linear analysis
   c) Non-linear static (pushover) analysis
   d) Non-linear time history (dynamic) analysis

For non-base-isolated buildings, linear methods of analysis may always be used.

A.2 Ground types, Seismic zones and Importance classes

Ground types A, B, C, D, and E described by the stratigraphic profiles and parameters given in Table 3.1 of EBCS EN 1998 may be used to account for the influence of local ground conditions on the seismic action.

According to Ethiopian building code EBCS EN 1998-1, 2014 the seismic hazard map is divided into 5 zones, where the ratio of the design bedrock acceleration to the acceleration of gravity g =αo for the respective zone is described in table below.

Table A. 1: Bedrock Acceleration Ratio αo

Zone	5	4	3	2	1	0
αo =ag/g	0.2	0.15	0.1	0.07	0.04	0

Source: Table A1 of EBCS EN 1998-1, 2014

Buildings are classified in 4 importance classes, depending on the consequences of collapse for human life, on their importance for public safety and civil protection in the immediate post-earthquake period, and on the social and economic consequences of collapse.

Table A. 2: Importance class of bilding

Importance class	Buildings
I	Buildings of minor importance for public safety, e.g. agricultural buildings ,etc.
II	Ordinary buildings, not belonging in the other categories.
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc.
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.

The value of γI for importance class II shall be, by definition, equal to 1.0. The recommended values of γI for importance classes I, III and IV are equal to 0.8, 1.2 and 1.4, respectively.

Table A. 3: Values of the parameters describing the recommended Type 1 elastic response Spectra

Ground type	S	TB(s)	TC(s)	TD(s)
A	1	0.5	0.25	1.2
B	1.35	0.5	0.25	1.2
C	1.5	0.1	0.25	1.2
D	1.8	0.1	0.3	1.2
E	1.6	0.5	0.25	1.2

Structural types

a) Frame system

Structural system in which both the vertical and lateral loads are mainly resisted by spatial frames whose shear resistance at the building base exceeds 65% of the total shear resistance of the whole structural system

b) Dual system

Structural system in which support for the vertical loads is mainly provided by a spatial frame and resistance to lateral loads is contributed to in part by the frame system and in part by structural walls coupled or uncoupled.

Frame-equivalent dual system,

Dual system in which the shear resistance of the frame system at the building base is greater than 50% of the total shears resistance of the whole structural system.

Wall-equivalent dual system,

Dual system in which the shear resistance of the walls at the building base is higher than 50% of the total seismic resistance of the whole structural system.

c) Ductile wall system (coupled or uncoupled)

d) System of large lightly reinforced walls

e) Inverted pendulum system

f) Torsionally flexible system

Behaviour factors

To avoid explicit inelastic structural analysis in design, the capacity of the structure to dissipate energy, through mainly ductile behaviour of its elements and/or other mechanisms, is taken into account by performing an elastic analysis based on a response spectrum reduced with respect to the elastic one, henceforth called a ‘‘design spectrum". This reduction is accomplished by introducing the behaviour factor q.

The behaviour factor q is an approximation of the ratio of the seismic forces that the structure would experience if its response was completely elastic with 5% viscous damping, to the seismic forces that may be used in the design, with a conventional elastic analysis model, still ensuring a satisfactory response of the structure.

The upper limit value of the behaviour factor q, to account for energy dissipation capacity, shall be derived for each design direction as follows:

$q= qokw\geq 1.5$

Where qo is the basic value of the behaviour factor, dependent on the type of the structural system and on its regularity in elevation Kw is the factor reflecting the prevailing failure mode in structural systems with walls

For buildings that are regular in elevation the basic values of qo for the various structural types are given in the following table. For buildings which are not regular in elevation, the value of qo should be reduced by 20%.

Table A. 4: Basic value of the behaviour factor, qo, for systems regular in elevation

STRUCTURAL TYPE	DCM	DCH
Frame system, dual system, coupled wall system	$3.0\alpha u/\alpha 1$	$4.5\alpha u/\alpha 1$
Uncoupled wall system	3	$4.0\alpha u/\alpha 1$
Torsional flexible system	2	3
Inverted pendulum system	1	2

The maximum value of $\alpha u/\alpha 1$ that may be used in the design is equal to 1.5, even when the analysis based on pushover analysis results in higher values. When the multiplication factor $\alpha u/\alpha 1$ has not been evaluated through an explicit calculation, for buildings which are regular in plan the following approximate values of $\alpha u/\alpha 1$ may be used.

a) Frames or frame-equivalent dual systems.

- One-storey buildings: $\alpha u/\alpha 1=1.1$;
- Multistorey, one-bay frames: $\alpha u/\alpha 1=1.2$;
- Multistorey, multi-bay frames or frame-equivalent dual structures: $\alpha u/\alpha 1=1.3$.

b) - Wall- or wall-equivalent dual systems.

- Wall systems with only two uncoupled walls per horizontal direction: $\alpha u/\alpha l =1.0$;
- Other uncoupled wall systems: $\alpha u/\alpha 1=1.1$;
- Wall-equivalent dual, or coupled wall systems: $\alpha u/\alpha 1=1.2$.

The factor kW reflecting the prevailing failure mode in structural systems with walls shall be taken as follows:

$K_W = 1$, for frames and frames equivalent system or

$= (1+ \alpha_0)/3 \leq 1$, But not less than 0.5, for wall-equivalent torsionally flexible system

Where αo is the prevailing aspect ratio of the walls of the structural system. 79

$\alpha o= \Sigma\ hwi/ \Sigma lwi$

Where: hwi is the height of wall i; And lwi is the length of the section of wall i.

Appendix B: Result from ETABS2016V2.1

Table B. 1: Model-1 Storey Drift Ratio due to earth quake in X-Direction

G+5,Model-1, Storey Drift Ratio X- Direction				
Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.000743	0.000726	0.000735	0.000833
G+5	0.00122	0.001194	0.001195	0.001409
G+4	0.001587	0.001569	0.001564	0.001833
G+3	0.001865	0.001841	0.001833	0.002152
G+2	0.001696	0.001718	0.001711	0.001965
G+1	0.001481	0.001486	0.00147	0.00171
Ground	0.000536	0.000534	0.000523	0.000615
Average	0.001304	0.001295429	0.001290143	0.001502429
%		-0.66%	-1.06%	15%

Table B. 2: Model-1 Storey Drift Ratio Due to Earth quake in Y-Direction

G+5,Model-1, Storey Drift Ratio Y- Direction				
Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.000895	0.00024	0.00024	0.000999
G+5	0.001391	0.000252	0.000252	0.001583
G+4	0.001791	0.00025	0.000251	0.00204
G+3	0.002093	0.000231	0.000232	0.002379
G+2	0.002139	0.000195	0.000196	0.002439
G+1	0.001836	8.40E-05	8.50E-05	0.002089
Ground	0.00066	8.40E-05	8.50E-05	0.000747
Average	0.001543571	0.000190857	0.000191571	0.001753714
		-87.64%	-87.59%	14%

Table B. 3: Model-2 Storey Drift Ratio Due to Earth quake in X-Direction

Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.000749	0.000683	0.000683	0.000688
G+5	0.001212	0.001135	0.001127	0.001139
G+4	0.001563	0.00149	0.001477	0.001493
G+3	0.001845	0.00176	0.001744	0.001762
G+2	0.001646	0.001663	0.001656	0.001666
G+1	0.00144	0.001454	0.001475	0.001453
Ground	0.00052	0.000523	0.000573	0.000521
Average	0.001282143	0.001244	0.001247857	0.001246
%		-2.97%	-2.67%	-3%

Table B. 4: Model-2 Storey Drift Ratio Due to Earthquake in Y-Direction

Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.000895	0.000272	0.000281	0.000278
G+5	0.001391	0.000286	0.000296	0.000293
G+4	0.001791	0.000285	0.000295	0.000291
G+3	0.002093	0.000264	0.000274	0.00027
G+2	0.002139	0.000223	0.000233	0.000229
G+1	0.001836	0.000165	0.000174	0.000169
Ground	0.00066	9.70E-05	0.000103	9.90E-05
Average	0.001543571	0.000227429	0.000236571	0.000232714
%		-85.27%	-84.67%	-84.92%

Table B. 5: Model-3 Storey Drift Ratio Due to Earth quake in X-Direction

G+5,Model-3, Storey Drift Ratio-X Direction				
Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.00074	0.00069	0.00069	0.00064
G+5	0.00122	0.00114	0.00114	0.00102
G+4	0.00159	0.0015	0.0015	0.00136
G+3	0.00187	0.00177	0.00177	0.00162
G+2	0.0017	0.00168	0.00168	0.00176
G+1	0.00148	0.00147	0.00146	0.00154
Ground	0.00054	0.00053	0.00052	0.00055
Average	0.0013	0.00125	0.00125	0.00121
Improvement due to SW		-3.80%	-3.80%	-6.92%

Table B. 6: Model-3 Storey Drift Ratio Due to Earth quake in Y-Direction

G+5,Model-3, Storey Drift Ratio Y- Direction				
Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.0009	0.00047	0.00048	0.00045
G+5	0.00139	0.00052	0.00053	0.0005
G+4	0.00179	0.00053	0.00055	0.00051
G+3	0.00209	0.00051	0.00053	0.0005
G+2	0.00214	0.00045	0.00047	0.00044
G+1	0.00184	0.00035	0.00036	0.00034
Ground	0.00066	0.00017	0.00018	0.00017
Average	0.00154	0.00043	0.00044	0.00042
Improvement due to SW		72.30%	71.30%	73.10%

Table B. 7: Model-1, Base Reaction Due to Earth quake in Y-Direction

Load Case/Combo	Case-1 Fy(kN)	Case-2 Fy(kN)	Case-3 Fy(kN)	Case-4 Fy(kN)
EY 1	-891.6051	-2405.5995	-2408.8678	-987.961
EY 2	-891.6051	-2405.5995	-2408.8678	-987.961
SPEC Y Max	893.2693	2114.0352	2118.2238	987.1228
%		136.66%	137.13%	10.51%

Table B. 8: Model-1, Base Reaction Due Earth quake in X-Direction

Load Case/Combo	Case-1 Fx(kN)	Case-2 Fx(kN)	Case-3 Fx(kN)	Case-4 Fx(kN)
EX 1	-891.6051	-1001.3412	-1006.0252	-1018.8282
EX 2	-891.6051	-1001.3412	-1006.0252	-1018.8282
SPEC X Max	893.2693	1173.5756	1014.2108	1014.9988
%		13.19%	13.54%	13.63%

Table B. 9: Model-2, Base Reaction Due to Earth quake in X-Direction

Load Case/Combo	Case-1 Fx(kN)	Case-2 Fx(kN)	Case-3 Fx(kN)	Case-4 Fx(kN)
EX 1	-891.6051	-1037.2504	-1043.7187	-1042.8804
EX 2	-891.6051	-1037.2504	-1043.7187	-1042.8804
SPEC X Max	893.2693	1039.5019	1047.552	1045.5764
%		16.37%	17.27%	17.05%

Table B. 10: Model-2, Base Reaction, Due Earth quake in Y-Direction

Load Case/Combo	Case-1 Fy(kN)	Case-2 Fy(kN)	Case-3 Fy(kN)	Case-4 Fy(kN)
EY 1	-864.5924	-2405.5995	-2408.8678	-2424.0716
EY 2	-864.5924	-2405.5995	-2408.8678	-2424.0716
SPEC Y Max	997.6985	2400.4912	2407.3293	2418.5674
%		140.60%	141.29%	142.41%

Table B. 11: Model-3, Base Reaction, Due Earth quake in X-Direction

Load Case/Combo	Case-1 Fx(kN)	Case-2 Fx(kN)	Case-3 Fx(kN)	Case-4 Fx(kN)
EX 1	-891.6051	-1042.0387	-1048.8165	-1090.9248
EX 2	-891.6051	-1042.0387	-1048.8165	-1090.9248
SPEC X Max	893.2693	1046.4613	1053.7941	1089.764
%		17.15%	17.97%	22.00%

Table B. 12: Model-3, Base Reaction, Due Earth quake in Y-Direction

Load Case/Combo	Case-1 Fy(kN)	Case-2 Fy(kN)	Case-3 Fy(kN)	Case-4 Fy(kN)
EY 1	-864.5924	-2405.5995	-2408.8678	-2449.0598
EY 2	-864.5924	-2405.5995	-2408.8678	-2449.0598
SPEC Y Max	878.8877	2399.9406	2403.8383	2407.0095
%		173.07%	173.51%	173.87%

Table B. 13: Model-1, Storey Displacement Due to lateral loads in X-Direction.

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	24.527	25.086	25.019	28.516
G+5	22.74	23.296	23.199	26.441
G+4	19.607	20.146	20.038	22.795
G+3	15.287	15.752	15.65	17.775
G+2	9.987	10.373	10.291	11.602
G+1	5.084	5.251	5.189	5.888
Ground	0.779	0.8	0.784	0.897
Average	14.00157143	14.38628571	14.31	16.27342857
%		2.7%	2.2%	16.2%

Table B. 14: Model-1, Storey Displacement Due to lateral loads in Y-Direction.

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	25.446	3.665	3.671	29.585
G+5	23.508	3.016	3.022	27.334
G+4	20.356	2.335	2.341	23.667
G+3	16.092	1.658	1.664	18.711
G+2	10.919	1.033	1.037	12.691
G+1	5.511	0.504	0.507	6.388
Ground	0.84	0.114	0.115	0.968
Average	14.66742857	1.760714286	1.765285714	17.04914286
%		-88.00%	-87.96%	16.2%

Table B. 15: Model-2, Storey Displacement Due to lateral loads in X-Direction.

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	24.527	24.086	24.048	24.152
G+5	22.74	22.386	22.336	22.437
G+4	19.607	19.381	19.329	19.419
G+3	15.287	15.207	15.159	15.234
G+2	9.987	10.073	10.032	10.088
G+1	5.084	5.127	5.092	5.128
Ground	0.779	0.781	0.77	0.778
Average	14.00157143	13.863	13.82371429	13.89085714
%		-1.0%	-1.3%	-0.8%

Table B. 16: Model-2, Storey Displacement Due to lateral loads in Y-Direction.

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	25.446	4.113	4.131	4.156
G+5	23.508	3.388	3.405	3.423
G+4	20.356	2.626	2.64	2.654
G+3	16.092	1.868	1.879	1.888
G+2	10.919	1.165	1.173	1.178
G+1	5.511	0.57	0.574	0.576
Ground	0.84	0.13	0.131	0.131
Average	14.66742857	1.98	1.990428571	2.000857143
%		-86.50%	-86.43%	-86.4%

Table B. 17: Model-3, Storey Displacement Due to lateral loads in X-Direction.

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	24.527	24.01	23.94	23.419
G+5	22.74	22.346	22.268	21.818
G+4	19.607	19.369	19.295	19.085
G+3	15.287	15.211	15.148	15.277
G+2	9.987	10.083	10.035	10.588
G+1	5.084	5.135	5.098	5.389
Ground	0.779	0.782	0.771	0.815
Average	14.00157143	13.848	13.79357143	13.77014286
%		-1%	-1%	-2%

Table B. 18: Model-3, Storey Displacement Due to lateral loads in Y-Direction,.

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	25.446	3.673	3.694	3.714
G+5	23.508	3.022	3.0400	3.067
G+4	20.356	2.339	2.354	2.384
G+3	16.092	1.662	1.672	1.702
G+2	10.919	1.034	1.041	1.064
G+1	5.511	0.505	0.508	0.519
Ground	0.84	0.114	0.116	0.118
Average	14.66742857	1.764142857	1.775	1.795428571
%		-87.97%	-87.90%	-87.76%

Table B. 19: Model-1, Storey Stiffness Due lateral Loads in X-Direction

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	123949.563	136681.322	135780.405	4329.037
G+5	128107.977	144497.654	144923.146	7948.671
G+4	126632.722	142301.696	143137.494	10828.33
G+3	127047.788	143356.342	144439.878	14427.694
G+2	158974.858	174947.193	176200.665	21471.576
G+1	199681.606	222267.697	225206.92	38971.472
Ground	1147845.563	1286006.423	1315599.317	262729.134
Average	287462.8681	321436.9039	326469.6893	51529.41629
%		11.82%	13.57%	-82%

Table B. 20: Model-1, Storey Stiffness Due lateral Loads in Y-Direction

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	106626.77	854655.703	855310.171	193439.914
G+5	115751.857	1511543.093	1511270.553	219566.83
G+4	115516.744	2044459.671	2043138.683	219392.999
G+3	116663.68	2626250.794	2622104.526	221225.845
G+2	129922.072	3468328.234	3457811.684	248007.279
G+1	166232.375	5018742.275	5000760.338	316368.11
Ground	961963.994	17408461.8	17261259.62	1796931.88
Average	244668.2131	4704634.509	4678807.94	459276.1224
%		1822.86%	1812.31%	45927512%

Table B. 21: Model-2, Storey Displacement Due lateral Loads in X-Direction

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	123949.563	147045.045	147688.678	147060.098
G+5	128107.977	155464.688	156880.22	155852.477
G+4	126632.722	154169.606	155692.531	154626.262
G+3	127047.788	154811.436	156227.954	155291.263
G+2	158974.858	186608.552	187391.617	187072.165
G+1	199681.606	233988.908	231218.988	235138.429
Ground	1147845.563	1350888.202	1089311.975	1363427.536
Average	287462.8681	340425.2053	303487.4233	342638.3186
%		18.42%	5.57%	19%

Table B. 22: Model-2, Storey Displacement Due lateral Loads in Y-Direction

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	106626.77	793056.546	771401.908	788369.402
G+5	115751.857	1400010.408	1363303.326	1390568.944
G+4	115516.744	1890251.107	1840369.579	1876514.561
G+3	116663.68	2422778.079	2353578.235	2403843.656
G+2	129922.072	3191006.209	3083974.757	3164292.548
G+1	166232.375	4598523.836	4403174.609	4559199.066
Ground	961963.994	15967541.01	13355545.72	15783363.96
Average	244668.2131	4323309.599	3881621.162	4280878.877
%		1667.01%	1486.48%	1650%

Table B. 23: Model-3, Storey Displacement Due lateral Loads in X-Direction

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	123949.563	148448.796	149073.082	163925.487
G+5	128107.977	156409.276	157899.636	181523.842
G+4	126632.722	154890.244	156539.494	181049.768
G+3	127047.788	155379.824	157078.932	181949.038
G+2	158974.858	186982.192	188696.203	190462.998
G+1	199681.606	234101.809	237077.593	237515.01
Ground	1147845.563	1349820.432	1377907.933	1375932.42
Average	287462.8681	340861.7961	346324.6961	358908.3661
%		18.58%	20.48%	24.85%

Table B. 24: Model-3, Storey Displacement Due lateral Loads in Y-Direction

Storey	Case-2 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	106626.77	536562.294	529303.713	562263.761
G+5	115751.857	910001.793	893341.865	960048.281
G+4	115516.744	1197092.656	1170746.746	1261951.231
G+3	116663.68	1491537.136	1452689.169	1565757.255
G+2	129922.072	1919919.457	1861489.319	1983425.454
G+1	166232.375	2671023.931	2584209.572	2762583.029
Ground	961963.994	10482004.48	10214407.01	10687950.47
Average	244668.2131	2744020.25	2672312.485	2826282.783
%		1021.53%	992.22%	1055.15%

Table B. 25: Model-1, Storey Drift Due lateral Loads in X-Direction

G+10,Model-1, Storey Drift-X Direction				
Storey	Case-1	Case-2	Case-3	Case
Roof	0.0006	0.00064	0.00073	0.00071
G+10	0.00095	0.00103	0.00117	0.00118
G+9	0.00122	0.00135	0.00152	0.00157
G+8	0.00132	0.0015	0.00176	0.00172
G+7	0.00139	0.00158	0.00187	0.00181
G+6	0.00121	0.00135	0.00166	0.00156
G+5	0.001	0.00108	0.00131	0.00129
G+4	0.00105	0.00114	0.00137	0.00136
G+3	0.00108	0.00123	0.00141	0.0014
G+2	0.00091	0.00111	0.00122	0.00118
G+1	0.00089	0.00108	0.0012	0.00115
Ground	0.00056	0.00067	0.00077	0.00071
Average	0.00101	0.00115	0.00133	0.0013
%		13.21%	31.48%	28.50%

Table B. 26: Model-1, Storey Drift Due lateral Loads in Y-Direction

G+10,Model-1, Storey Drift Ratio-Y Direction				
Storey	Casee-1	Case-2	Case-3	Case-4
Roof	0.00089	0.00082	0.00082	0.00104
G+10	0.00136	0.00083	0.00083	0.00166
G+9	0.00169	0.00084	0.00084	0.00214
G+8	0.00164	0.00083	0.00083	0.00211
G+7	0.0017	0.0008	0.0008	0.00217
G+6	0.0015	0.00076	0.00076	0.0019
G+5	0.00139	0.00071	0.0007	0.00175
G+4	0.00143	0.00063	0.00062	0.00182
G+3	0.00145	0.00053	0.00052	0.00186
G+2	0.0011	0.00042	0.00041	0.00141
G+1	0.00105	0.00031	0.0003	0.00133
Ground	0.00064	0.00017	0.00017	0.00079
Average	0.00132	0.00064	0.00063	0.00166
%		-51.81%	-52.14%	26%

Table B. 27: Model-2, Storey Drift Ratio Due lateral Loads in X-Direction

G+10,Model-2, Storey Drift-X Direction				
Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.000598	0.000645	0.000644	0.000628
G+10	0.000947	0.001019	0.001011	0.000981
G+9	0.001215	0.001313	0.001302	0.001252
G+8	0.00132	0.001449	0.001438	0.001427
G+7	0.001391	0.001534	0.00152	0.001513
G+6	0.001212	0.001363	0.001351	0.001378
G+5	0.001004	0.001157	0.001147	0.001323
G+4	0.001049	0.001204	0.001193	0.001466
G+3	0.001075	0.001231	0.00122	0.001158
G+2	0.000907	0.001067	0.001058	0.00099
G+1	0.00089	0.001043	0.001033	0.00097
Ground	0.000559	0.000652	0.000646	0.000609
Average	0.00101	0.00114	0.00113	0.00114
%		12.41%	11.47%	12.56%

Table B. 28: Model-2, Storey Drift Ratio Due lateral Loads in Y-Direction

G+10,Model-2, Storey Drift-Y Direction				
Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.00089	0.0009	0.000905	0.000906
G+10	0.00136	0.000918	0.000924	0.000923
G+9	0.00169	0.000924	0.00093	0.000929
G+8	0.00164	0.000914	0.000921	0.000921
G+7	0.0017	0.000893	0.000899	0.000895
G+6	0.0015	0.000849	0.000855	0.000849
G+5	0.00139	0.000786	0.000791	0.000782
G+4	0.00143	0.0007	0.000705	0.000699
G+3	0.00145	0.000592	0.000597	0.000585
G+2	0.0011	0.000468	0.000473	0.000463
G+1	0.00105	0.000347	0.000351	0.000342
Ground	0.00064	0.000192	0.000194	0.000188
Average	0.00132	0.00071	0.00071	0.00071
%		-46.46%	-46.07%	-46%

Table B. 29: Model-3, Storey Drift Due lateral Loads in X-Direction

G+10,Model-3, Storey Drift-X Direction				
Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.000598	0.000645	0.000641	0.000636
G+10	0.000947	0.001027	0.001016	0.001007
G+9	0.001215	0.001327	0.001313	0.001301
G+8	0.00132	0.001468	0.001453	0.00144
G+7	0.001391	0.001559	0.001542	0.001527
G+6	0.001212	0.001391	0.001376	0.001362
G+5	0.001004	0.001187	0.001175	0.001164
G+4	0.001049	0.001238	0.001224	0.001214
G+3	0.001075	0.001267	0.001253	0.001242
G+2	0.000907	0.001098	0.001087	0.001075
G+1	0.00089	0.001073	0.001061	0.00105
Ground	0.000559	0.000671	0.000664	0.000657
Average	0.00101	0.00116	0.00115	0.00114
%		14.66%	13.46%	12.39%

Table B. 30: Model-3, Storey Drift Due lateral Loads in Y-Direction

G+10,Model-3, Storey Drift Ratio Y-Direction				
Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.000894	0.001165	0.00111	0.00116
G+10	0.001361	0.00123	0.001177	0.00122
G+9	0.001688	0.001268	0.001217	0.001256
G+8	0.001642	0.001264	0.001214	0.001251
G+7	0.001703	0.001258	0.00121	0.001243
G+6	0.001502	0.001192	0.001146	0.001178
G+5	0.001387	0.001108	0.001064	0.001095
G+4	0.001433	0.001013	0.000976	0.001
G+3	0.001446	0.000885	0.000856	0.000872
G+2	0.0011	0.000697	0.000676	0.000687
G+1	0.001054	0.000552	0.000537	0.000542
Ground	0.000635	0.000314	0.000305	0.000308
Average	0.00132	0.001	0.00096	0.00098
%		-24.61%	-27.50%	-25%

Table B. 31: Model-1,Base shear after shear wall of Earth quake in X-Direction

Load Case/Combo	Case-1 Fx(kN)	Case-2 Fx(kN)	Case-3 Fx(kN)	Case-4 Fx(kN)
EX 1	-1092.9231	-1375.3741	-1320.4717	-1375.3301
EX 2	-1092.9231	-1375.3741	-1320.4717	-1375.3301
SPEC X Max	1059.1109	1376.3733	1525.7563	1376.1201
%		30%	44%	30%

Table B. 32: Model-1, Base shear after shear wall of Earth quake in Y-Direction

Load Case/Combo	Case-1 Fy(kN)	Case-2 Fy(kN)	Case-3 Fy(kN)	Case-4 Fy(kN)
EY 1	-965.0044	-3111.3936	-3045.28	-1214.3577
EY 2	-965.0044	-3111.3936	-3045.28	-1214.3577
SPEC Y Max	953.369	3137.7999	3051.427	1186.3428
%		229%	220%	24%

Table B. 33: Model-2 Base shear after shear wall of Earth quake in X-Direction

Load Case/Combo	Case-1 Fx(kN)	Case-2 Fx(kN)	Case-3 Fx(kN)	Case-4 Fx(kN)
EX 1	-1092.9231	-1349.0831	-1355.6314	-1281.5057
EX 2	-1092.9231	-1349.0831	-1355.6314	-1281.5057
SPEC X Max	1059.1109	1354.7275	1352.1636	1278.022
%		28%	28%	21%

Table B. 34: Model-2 Base shear after shear wall of Earth quake in Y-Direction

Load Case/Combo	W/shear wall Fy(kN)	Shear wall at center Fy(kN)	Shear wall at edge/inner Fy(kN)	Shear wall at edge/outer Fy(kN)
EY 1	-965.0044	-3123.0552	-3126.4611	-3055.1014
EY 2	-965.0044	-3123.0552	-3126.4611	-3055.1014
SPEC Y Max	953.369	3130.0704	3134.4467	3066.6136
%		228%	229%	222%

Table B. 35: Model-3 Base shear after shear wall of Earth quake in X-Direction

Load Case/Combo	Base Reaction W/O shear wall FX(kN)	Shear wall at center FX(kN)	Shear wall at edge/inner FX(kN)	Shear wall at edge/out FX(kN)
EX 1	-1092.9231	-1357.6765	-1048.8165	-1090.9248
EX 2	-1092.9231	-1357.6765	-1048.8165	-1090.9248
SPEC X Max	1059.1109	1375.8326	1083.7941	1111.7781
%		30%	2%	5%

Table B. 36: Model-3 Base shear after shear wall of Earth quake in Y-Direction

Load Case/Combo	W/shear wall Fy(kN)	Shear wall at center Fy(kN)	Shear wall at edge/inner Fy(kN)	Shear wall at edge/outer Fy(kN)
EY 1	-965.0044	-3057.9899	-2408.8678	-2449.0598
EY 2	-965.0044	-3057.9899	-2408.8678	-2449.0598
SPEC Y Max	953.369	3058.3338	2403.8383	2407.0095
%		221%	152%	152%

Table B. 37: Model-1, Storey Displacement Due to lateral loads in Y-Direction.

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	30.96	36.196	41.806	40.709
G+10	29.674	34.811	40.241	39.039
G+9	27.608	32.49	37.654	36.32
G+8	24.862	29.326	34.144	32.686
G+7	21.767	25.697	29.924	28.609
G+6	18.416	21.774	25.302	24.218
G+5	15.408	18.344	21.08	20.269
G+4	12.758	15.396	17.521	16.767
G+3	9.868	12.141	13.628	12.92
G+2	6.827	8.537	9.515	8.868
G+1	4.211	5.256	5.89	5.423
Ground	1.627	2.017	2.313	2.078
Average	16.99883333	20.16541667	23.2515	22.3255
%		18.63%	36.78%	31.34%

Table B. 38: Model-1, Storey Displacement Due to lateral loads in Y-Direction.

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	35.822	20.53	20.358	47.095
G+10	34.044	18.325	18.159	44.787
G+9	31.367	16.088	15.926	41.261
G+8	27.944	13.844	13.687	36.728
G+7	24.491	11.629	11.475	32.183
G+6	20.822	9.471	9.329	27.38
G+5	17.495	7.421	7.298	23.012
G+4	14.235	5.526	5.434	18.697
G+3	10.735	3.839	3.776	14.02
G+2	7.113	2.415	2.379	9.18
G+1	4.317	1.289	1.275	5.507
Ground	1.623	0.458	0.463	2.048
Average	19.16733333	9.23625	9.129916667	25.15816667
%		-51.81%	-52.37%	31.26%

Table B. 39: Model-2, Storey Displacement Due to lateral loads in X -Direction.

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	30.96	35.862	35.558	35.704
G+10	29.674	34.435	34.133	34.348
G+9	27.608	32.147	31.861	32.204
G+8	24.862	29.096	28.833	29.367
G+7	21.767	25.61	25.372	25.989
G+6	18.416	21.811	21.608	22.261
G+5	15.408	18.331	18.161	18.719
G+4	12.758	15.196	15.054	15.096
G+3	9.868	11.791	11.682	10.987
G+2	6.827	8.211	8.136	7.636
G+1	4.211	5.057	5.007	4.712
Ground	1.627	1.948	1.929	1.82
Average	16.99883333	19.95791667	19.77783333	19.90358333
%		17.41%	16.35%	17.09%

Table B. 40: Model-2, Storey Displacement Due to lateral loads in Y-Direction.

Storey	Case-1 (mm)	Case-2 (mm)	Case-4 (mm)	Case-4 (mm)
Roof	35.822	20.037	20.06	20.11
G+10	34.044	17.902	17.924	17.954
G+9	31.367	15.732	15.753	15.763
G+8	27.944	13.551	13.57	13.561
G+7	24.491	11.393	11.411	11.381
G+6	20.822	9.287	9.303	9.262
G+5	17.495	7.284	7.298	7.251
G+4	14.235	5.428	5.441	5.397
G+3	10.735	3.774	3.785	3.742
G+2	7.113	2.378	2.386	2.356
G+1	4.317	1.272	1.277	1.258
Ground	1.623	0.453	0.455	0.447
Average	19.16733333	9.040916667	9.05525	9.040166667
%		-52.83%	-52.76%	-52.84%

Table B. 41: Model-3, Storey Displacement Due to lateral loads in X-Direction.

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	30.96	35.937	35.535	35.254
G+10	29.674	34.577	34.182	33.909
G+9	27.608	32.342	31.969	31.712
G+8	24.862	29.326	28.986	28.75
G+7	21.767	25.858	25.553	25.343
G+6	18.416	22.058	21.8	21.62
G+5	15.408	18.563	18.347	18.198
G+4	12.758	15.403	15.222	15.096
G+3	9.868	11.959	11.82	11.719
G+2	6.827	8.332	8.237	8.162
G+1	4.211	5.133	5.072	5.025
Ground	1.627	1.978	1.955	1.937
Average	16.9988	20.1222	19.8898	19.7271
%		18.37%	17.01%	16.05%

Table B. 42: Model-3, Storey Displacement Due to lateral loads in Y-Direction.

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	35.822	20.357	19.376	20.369
G+10	34.044	18.169	17.295	18.181
G+9	31.367	15.948	15.182	15.96
G+8	27.944	13.72	13.063	13.732
G+7	24.491	11.52	10.97	11.532
G+6	20.822	9.378	8.932	9.388
G+5	17.495	7.342	6.995	7.354
G+4	14.235	5.46	5.204	5.472
G+3	10.735	3.788	3.612	3.799
G+2	7.113	2.379	2.27	2.387
G+1	4.317	1.268	1.209	1.273
Ground	1.623	0.449	0.428	0.451
Average	19.16733333	9.148166667	8.711333333	9.158166667
%		-52.27%	-54.55%	-52.22%

Table B. 43: Model-1, Storey Stiffness Due to lateral loads in X-Direction.

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	127090.817	143320.582	142267.498	294.679
G+10	139799.132	158953.617	159154.754	568.347
G+9	140021.08	158620.983	158772.13	777.833
G+8	148358.82	166749.788	158662.291	928.337
G+7	154641.645	174823.183	163808.773	1046.255
G+6	189906.107	220316.292	197650.03	1171.043
G+5	248872.664	298469.91	270267.689	1371.485
G+4	261484.768	311111.007	283294.002	1698.082
G+3	279117.538	316178.017	301470.945	2216.033
G+2	360102.363	382191.172	379407.214	3123.822
G+1	394766.017	416623.016	416495.857	5012.639
Ground	652537.254	694700.436	671494.113	13481.975
Average	258058.1838	286838.1669	275228.7747	2640.8775
%		11.15%	6.65%	-99%

Table B. 44: Model-1, Storey Stiffness Due to lateral loads in Y-Direction.

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	85008.196	233501.679	230920.423	144412.541
G+10	94362.874	433204.704	428404.648	173416.474
G+9	95271.763	584015.283	576706.139	180340.257
G+8	111281.728	712268.401	699660.281	211991.399
G+7	117828.009	832381.753	818775.929	222981.983
G+6	143562.426	968620.651	954467.63	270563.187
G+5	169134.097	1158419.401	1144401.291	320012.847
G+4	179480.428	1423367.193	1402984.536	341769.882
G+3	194291.766	1821038.475	1793048.291	371622.806
G+2	278485.165	2449455.047	2418149.682	532823.21
G+1	314347.617	3471795.555	3444860.274	597045.472
Ground	543411.143	6463722.756	6205420.27	1028596.231
Average	193872.101	1712649.242	1676483.283	366298.0241
%		783.39%	764.74%	89%

Table B. 45: Model-2, Storey Stiffness Due to lateral loads in X-Direction.

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	127090.817	143059.508	143195.275	143130.907
G+10	139799.132	162277.758	163179.862	163453.048
G+9	140021.08	163467.07	164499.985	164766.346
G+8	148358.82	171631.697	172574.442	164963.441
G+7	154641.645	178521.947	179731.619	169736.7
G+6	189906.107	215565.222	216982.349	199526.607
G+5	248872.664	275191.687	276787.009	225929.74
G+4	261484.768	289155.59	291269.581	220039.434
G+3	279117.538	308510.916	310813.477	303093.077
G+2	360102.363	387598.977	389978.082	389020.922
G+1	394766.017	425390.671	428756.451	429503.116
Ground	652537.254	706890.945	712077.892	713701.81
Average	258058.1838	285605.1657	287487.1687	273905.429
%		10.67%	11.40%	6%

Table B. 46: Model-2, Storey Stiffness Due to lateral loads in Y-Direction.

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	85008.196	222293.145	221630.827	220346.873
G+10	94362.874	413407.216	412036.366	408765.983
G+9	95271.763	557524.285	555524.228	550261.317
G+8	111281.728	680040.069	677322.826	667707.264
G+7	117828.009	795629.882	792194.522	781326.194
G+6	143562.426	925897.866	921965.552	910469.985
G+5	169134.097	1100299.555	1095873.064	1087337.022
G+4	179480.428	1342693.235	1336977.516	1312324.975
G+3	194291.766	1705497.619	1696767.013	1681484.365
G+2	278485.165	2287723.941	2273645.827	2259638.872
G+1	314347.617	3224148.5	3202776.071	3197023.469
Ground	543411.143	5961455.479	5921820.997	5936486.738
Average	193872.101	1601384.233	1592377.901	1584431.088
%		726.00%	721.35%	717%

Table B. 47: Model-3, Storey Stiffness Due to lateral loads in X-Direction.

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-3 (kN/m)
Roof	127090.817	146797.701	147055.863	146781.65
G+10	139799.132	164928.559	165994.765	165729.695
G+9	140021.08	165633.591	166798.838	166527.32
G+8	148358.82	173675.587	174724.168	174456.746
G+7	154641.645	180337.306	181635.339	181416.608
G+6	189906.107	217162.765	218651.049	218550.098
G+5	248872.664	275942.214	277574.04	277297.704
G+4	261484.768	289000.889	291124.639	290639.378
G+3	279117.538	307527.036	309828.376	309494.107
G+2	360102.363	385772.125	388078.85	388272.563
G+1	394766.017	422884.44	426076.302	426290.379
Ground	652537.254	702189.286	707070.829	707473.989
Average	258058.1838	285987.6249	287884.4215	287744.1864
%		10.82%	11.56%	12%

Table B. 48: Model-3, Storey Stiffness Due to lateral loads in Y-Direction.

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	85008.196	180765.92	180579.248	181722.148
G+10	94362.874	329027.836	327765.872	331533.711
G+9	95271.763	436077.81	433418.758	440083.644
G+8	111281.728	527434.772	523558.361	532455.585
G+7	117828.009	606765.861	601448.303	613108.094
G+6	143562.426	708388.593	702532.041	715454.522
G+5	169134.097	840521.036	833808.817	849185.603
G+4	179480.428	1007318.893	997609.076	1019395.832
G+3	194291.766	1250901.181	1235231.165	1268092.292
G+2	278485.165	1690354.284	1667155.392	1712582.848
G+1	314347.617	2274714.751	2236724.135	2310168.17
Ground	543411.143	4124215.735	4055306.551	4187296.283
Average	193872.101	1164707.223	1149594.81	1180089.894
%		500.76%	492.97%	509%

Table B. 49: Model-1, Storey Drift Due to lateral loads in X-Direction.

G+20,Model-1, Storey Drift-X Direction				
Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.000982	0.000805	0.00065	0.000966
G+20	0.001467	0.001258	0.001023	0.001454
G+19	0.001893	0.001687	0.001659	0.001883
G+18	0.002245	0.002056	0.002072	0.002232
G+17	0.002555	0.002388	0.002397	0.002539
G+16	0.002843	0.002701	0.002691	0.002828
G+15	0.003108	0.002996	0.002935	0.003092
G+14	0.002869	0.003266	0.002822	0.002851
G+13	0.003038	0.003507	0.002993	0.00302
G+12	0.003184	0.003708	0.003145	0.003167
G+11	0.003217	0.003787	0.003177	0.0032
G+10	0.002771	0.003321	0.002779	0.002755
G+9	0.002503	0.002522	0.002525	0.002488
G+8	0.002518	0.002529	0.002547	0.002504
G+7	0.002574	0.002608	0.00262	0.002561
G+6	0.00261	0.002665	0.002671	0.002596
G+5	0.002528	0.002569	0.002567	0.002512
G+4	0.001815	0.001939	0.001946	0.001803
G+3	0.001822	0.00194	0.001949	0.001811
G+2	0.001821	0.001945	0.00195	0.001812
G+1	0.001716	0.001829	0.001824	0.001705
G	0.001047	0.001093	0.001089	0.001038
Average	0.002323909	0.0024145	0.002274136	0.002309864
%		3.90%	-2.14%	-0.60%

Table B. 50: Model-2, Storey Drift Ratio Due to lateral loads in X-Direction.

Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.000982	0.000982	0.000782	0.000962
G+20	0.001467	0.001382	0.001097	0.001356
G+19	0.001893	0.001757	0.001393	0.001725
G+18	0.002245	0.002075	0.001644	0.002039
G+17	0.002555	0.002354	0.001865	0.002314
G+16	0.002843	0.002611	0.002066	0.002565
G+15	0.003108	0.002838	0.002246	0.002789
G+14	0.002869	0.002763	0.00219	0.002715
G+13	0.003038	0.002921	0.002315	0.002868
G+12	0.003184	0.003054	0.002418	0.002994
G+11	0.003217	0.003082	0.002438	0.003015
G+10	0.002771	0.002704	0.002141	0.002638

G+9	0.002503	0.002442	0.001936	0.002268
G+8	0.002518	0.002445	0.001935	0.002262
G+7	0.002574	0.002485	0.001966	0.002299
G+6	0.00261	0.002506	0.001981	0.002319
G+5	0.002528	0.002415	0.001909	0.002243
G+4	0.001815	0.001872	0.001483	0.001851
G+3	0.001822	0.001869	0.001482	0.001848
G+2	0.001821	0.001856	0.00147	0.001833
G+1	0.001716	0.001731	0.001369	0.001706
G	0.001047	0.001037	0.000821	0.001023
Average	0.002323909	0.0022355	0.001770318	0.002165091
%		-3.80%	-23.82%	-6.83%

Table B. 51: Model-2, Storey Drift Ratio Due to lateral loads in Y-Direction.

G+20,Model-2, Storey Drift Ratio Y-Direction				
Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.002087	0.001072	0.001205	0.001022
G+20	0.002584	0.00108	0.001215	0.00103
G+19	0.003059	0.001084	0.00122	0.001035
G+18	0.003472	0.001085	0.00122	0.001035
G+17	0.003835	0.00108	0.001214	0.00103
G+16	0.004162	0.001069	0.001202	0.001019
G+15	0.004454	0.001053	0.001184	0.001003
G+14	0.004541	0.001031	0.001159	0.000982
G+13	0.004743	0.001005	0.001131	0.000957
G+12	0.004893	0.000974	0.001096	0.000926
G+11	0.004881	0.000938	0.001055	0.000891
G+10	0.004267	0.000895	0.001006	0.000849
G+9	0.003581	0.000844	0.00095	0.000802
G+8	0.003507	0.00079	0.000889	0.000753
G+7	0.003486	0.00073	0.000821	0.000698
G+6	0.003435	0.000662	0.000745	0.000637
G+5	0.003243	0.000586	0.00066	0.000568
G+4	0.002668	0.000506	0.00057	0.000493
G+3	0.00261	0.00043	0.000484	0.000418
G+2	0.002535	0.000342	0.000385	0.000332
G+1	0.002304	0.000242	0.000273	0.000235
G	0.001333	0.000123	0.000141	0.000121
Average	0.00344	0.000800955	0.000801136	0.000765273
%		-76.72%	-76.80%	-78%

Table B. 52: Model-3, Storey Drift Ratio Due to lateral loads in X-Direction.

G+20,Model-3, Storey Drift Ratio X-Direction				
Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.000982	0.000865	0.000881	0.000871
G+20	0.001467	0.00014	0.001295	0.001277
G+19	0.001893	0.001277	0.001673	0.001648
G+18	0.002245	0.001651	0.001994	0.00196
G+17	0.002555	0.001968	0.002275	0.002227
G+16	0.002843	0.002246	0.002534	0.00243
G+15	0.003108	0.002504	0.00277	0.002389
G+14	0.002869	0.002737	0.002722	0.002061
G+13	0.003038	0.002684	0.002889	0.002171
G+12	0.003184	0.002848	0.003027	0.002293
G+11	0.003217	0.002986	0.003059	0.002386
G+10	0.002771	0.003022	0.002689	0.002356
G+9	0.002503	0.002654	0.002433	0.002425
G+8	0.002518	0.002398	0.002442	0.00248
G+7	0.002574	0.00241	0.002491	0.002533
G+6	0.00261	0.002459	0.002522	0.002562
G+5	0.002528	0.00249	0.002442	0.002483
G+4	0.001815	0.002411	0.001909	0.001939
G+3	0.001822	0.00188	0.001913	0.00194
G+2	0.001821	0.001882	0.001903	0.001926
G+1	0.001716	0.001872	0.001775	0.001795
G	0.001047	0.00175	0.001068	0.001078
Average	0.002323909	0.00105	0.002213909	0.002055909
%		-54.82%	-4.73%	-11.53%

Table B. 53: Model-1, Storey Drift Ratio Due to lateral loads in Y-Direction.

G+20,Model-3, Storey Drift Ratio Y-Direction				
Storey	Case-1	Case-2	Case-3	Case-4
Roof	0.002087	0.001187	0.001185	0.001194
G+20	0.002584	0.001221	0.001222	0.001225
G+19	0.003059	0.001242	0.001245	0.001243
G+18	0.003472	0.001257	0.001261	0.001254
G+17	0.003835	0.001264	0.001269	0.001255
G+16	0.004162	0.001262	0.001268	0.001247
G+15	0.004454	0.001254	0.001261	0.001219
G+14	0.004541	0.001232	0.001239	0.001175
G+13	0.004743	0.001211	0.001219	0.001152
G+12	0.004893	0.001182	0.00119	0.001125
G+11	0.004881	0.001148	0.001156	0.001095

G+10	0.004267	0.00109	0.001097	0.001061
G+9	0.003581	0.001026	0.001031	0.001022
G+8	0.003507	0.000977	0.000982	0.000979
G+7	0.003486	0.000921	0.000928	0.000927
G+6	0.003435	0.000857	0.000866	0.000865
G+5	0.003243	0.00078	0.00079	0.000789
G+4	0.002668	0.000676	0.000685	0.000685
G+3	0.00261	0.000597	0.000607	0.000605
G+2	0.002535	0.000498	0.000508	0.000503
G+1	0.002304	0.000379	0.000389	0.000382
G	0.001333	0.000207	0.000213	0.000209
Average	0.00344	0.000975818	0.000982318	0.000964136
%		-71.63%	-71.44%	-72%

Table B. 54: Model-1,After shear wall for Earth quake X-Direction

Load Case/Combo	Case-1 Fx(kN)	Case-2 Fx(kN)	Case-3 Fx(kN)	Case-4 Fx(kN)
EX 1	-1859.9327	-2170.0411	-2202.1343	-2182.3374
EX 2	-1859.9327	-2170.0411	-2202.1343	-2182.3374
SPEC X Max	1898.9325	2200.985	2211.4842	2015.2851
%		16%	16%	6%

Table B. 55: Model-1,After shear wall for Earth quake Y-Direction

Load Case/Combo	Case-1 Fy(kN)	Case-2 Fy(kN)	Case-3 Fy(kN)	Case-4 Fy(kN)
EY 1	-1859.9327	-2170.0411	-2202.1343	-2182.3374
EY 2	-1859.9327	-2170.0411	-2202.1343	-2182.3374
SPEC Y Max	1862.981	2180.3443	2197.0761	2019.4402
%		17%	18%	8%

Table B. 56: Model-2,After shear wall for Earth quake X-Direction

Load Case/Combo	Case-1 Fx(kN)	Case-2 Fx(kN)	Case-3 Fx(kN)	Case-4 t Fx(kN)
EX 1	-1859.9327	-2183.4523	-2186.6532	-2179.2883
EX 2	-1859.9327	-2183.4523	-2186.6532	-2179.2883
SPEC X Max	1898.9325	2129.7883	1707.8621	2129.862
%		12%	-10%	12%

Table B. 57: Model-2,After shear wall for Earth quake Y-Direction

Load Case/Combo	Case-1 Fy(kN)	Case-2 Fy(kN)	Case-3 Fy(kN)	Case-4 Fy(kN)
EY 1	-1859.9327	-2183.4523	-2186.6532	-2179.2883
EY 2	-1859.9327	-2183.4523	-2186.6532	-2179.2883
SPEC Y Max	1862.981	2191.1771	2507.9292	2174.5079
%		18%	35%	17%

Table B. 58: Model-3,After shear wall for Earth quake X-Direction

Load Case/Combo	Case-1 Fx(kN)	Case-2 Fx(kN)	Case-3 Fx(kN)	Case-4 Fx(kN)
EX 1	-1859.9327	-2182.3374	-2186.6532	-2230.0663
EX 2	-1859.9327	-2182.3374	-2186.6532	-2230.0663
SPEC X Max	1898.9325	2137.1111	2198.5988	2221.998
%		13%	16%	17%

Table B. 59: Model-3,After shear wall for Earth quake Y-Direction

Load Case/Combo	Case-1 Fy(kN)	Case-2 Fy(kN)	Case-3 Fy(kN)	Case-4 Fy(kN)
EY 1	-1859.9327	-2182.3374	-2186.6532	-2230.0663
EY 2	-1859.9327	-2182.3374	-2186.6532	-2230.0663
SPEC Y Max	1862.981	2176.1964	2183.6541	2244.307
%		17%	17%	20%

Table B. 60: Model-1, Storey Displacement Due to Earth Quake in X-Direction

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	139.207	148.394	140.099	139.207
G+20	136.781	146.535	138.556	136.781
G+19	133.269	143.611	136.116	133.268
G+18	128.67	139.53	132.076	128.669
G+17	123.054	134.338	126.839	123.054
G+16	116.488	128.092	120.569	116.488
G+15	109.034	120.851	113.349	109.033
G+14	100.762	112.683	105.332	100.762
G+13	93.04	103.66	97.527	93.04
G+12	84.789	93.865	89.167	84.788
G+11	76.081	83.422	80.313	76.079
G+10	67.243	72.697	71.323	67.241
G+9	59.603	63.269	63.433	59.602

G+8	52.629	56.062	56.21	52.627
G+7	45.571	48.789	48.883	45.568
G+6	38.325	41.252	41.309	38.322
G+5	30.942	33.511	33.548	30.941
G+4	23.746	26.003	26.043	23.744
G+3	18.552	20.295	20.312	18.545
G+2	13.303	14.542	14.53	13.286
G+1	8.029	8.742	8.716	8.005
G	3.046	3.273	3.259	3.03
Average	72.82563636	79.24618182	75.79586364	72.82181818
%		8.82%	4.08%	0%

Table B. 61: Model-1, Storey Displacement Due to Earth Quake in Y-Direction

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	189.591	40.177	40.212	189.591
G+20	184.218	37.676	37.74	184.218
G+19	177.809	35.171	35.255	177.809
G+18	170.338	32.671	32.77	170.338
G+17	161.871	30.182	30.296	161.871
G+16	152.486	27.714	27.841	152.485
G+15	142.262	25.277	25.414	142.261
G+14	131.28	22.881	23.027	131.28
G+13	119.992	20.538	20.69	119.992
G+12	108.168	18.257	18.411	108.167
G+11	95.944	16.051	16.2	95.942
G+10	83.728	13.931	14.068	83.727
G+9	72.998	11.909	12.033	72.998
G+8	63.944	10.003	10.106	63.943
G+7	55.067	8.215	8.3	55.065
G+6	46.247	6.561	6.629	46.244
G+5	37.558	5.059	5.112	37.557
G+4	29.342	3.728	3.767	29.341
G+3	22.515	2.577	2.603	22.51
G+2	15.82	1.601	1.618	15.805
G+1	9.313	0.827	0.836	9.29
G	3.407	0.281	0.284	3.391
Average	94.26809091	16.87668182	16.96418182	94.26477273
%		-82.10%	-82.00%	0%

Table B. 62: Model-2, Storey Displacement Due to Earth Quake in X-Direction

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	139.207	137.212	108.568	132.676
G+20	136.781	134.714	106.581	130.241
G+19	133.269	131.289	103.865	126.892
G+18	128.67	126.886	100.38	122.581
G+17	123.054	121.559	96.166	117.36
G+16	116.488	115.367	91.268	111.287
G+15	109.034	108.366	85.734	104.423
G+14	100.762	100.641	79.628	96.846
G+13	93.04	93.034	73.602	89.383
G+12	84.789	84.92	67.176	81.426
G+11	76.081	76.372	60.414	73.056
G+10	67.243	67.702	53.563	64.585
G+9	59.603	60.078	47.532	57.154
G+8	52.629	53.143	42.041	50.726
G+7	45.571	46.16	36.518	44.271
G+6	38.325	39.023	30.877	37.674
G+5	30.942	31.786	25.158	30.979
G+4	23.746	24.764	19.609	24.459
G+3	18.552	19.284	15.269	19.04
G+2	13.303	13.768	10.897	13.586
G+1	8.029	8.257	6.532	8.142
G	3.046	3.096	2.452	3.056
Average	72.82563636	72.61004545	57.44681818	69.99286364
%		-0.30%	-21.12%	-4%

Table B. 63: Model-2, Storey Displacement Due to Earth Quake in Y-Direction

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	189.591	38.723	44.269	37.967
G+20	184.218	36.335	41.541	35.637
G+19	177.809	33.944	38.808	33.301
G+18	170.338	31.555	36.077	30.968
G+17	161.871	29.176	33.358	28.644
G+16	152.486	26.815	30.659	26.337
G+15	142.262	24.482	27.992	24.058
G+14	131.28	22.187	25.369	21.816
G+13	119.992	19.94	22.8	19.621
G+12	108.168	17.748	20.294	17.481
G+11	95.944	15.622	17.864	15.406

G+10	83.728	13.573	15.522	13.406
G+9	72.998	11.614	13.283	11.495
G+8	63.944	9.761	11.164	9.684
G+7	55.067	8.023	9.178	7.98
G+6	46.247	6.414	7.339	6.396
G+5	37.558	4.952	5.667	4.949
G+4	29.342	3.655	4.183	3.655
G+3	22.515	2.53	2.897	2.53
G+2	15.82	1.576	1.805	1.575
G+1	9.313	0.817	0.936	0.816
G	3.407	0.279	0.32	0.279
Average	94.26809091	16.35095455	18.69659091	16.09095455
%		-82.65%	-80.17%	-83%

Table B. 64: Model-3, Storey Displacement Due to Earth Quake in X-Direction

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	139.207	131.737	133.385	124.393
G+20	136.781	129.652	131.26	122.269
G+19	133.269	126.618	128.186	119.211
G+18	128.67	122.618	124.137	115.199
G+17	123.054	117.703	119.166	110.291
G+16	116.488	111.929	113.328	104.567
G+15	109.034	105.35	106.679	98.191
G+14	100.762	98.033	99.285	91.821
G+13	93.04	90.773	91.932	86.238
G+12	84.789	82.994	84.052	80.299
G+11	76.081	74.771	75.73	73.977
G+10	67.243	66.406	67.275	67.358
G+9	59.603	59.046	59.827	60.794
G+8	52.629	52.349	53.041	53.995
G+7	45.571	45.576	46.186	47.002
G+6	38.325	38.621	39.149	39.817
G+5	30.942	31.533	31.981	32.502
G+4	23.746	24.622	24.988	25.366
G+3	18.552	19.203	19.491	19.764
G+2	13.303	13.732	13.933	14.116
G+1	8.029	8.248	8.365	8.469
G	3.046	3.097	3.145	3.182
Average	72.82563636	70.66413636	71.56913636	68.12822727
%		-2.97%	-1.73%	-6%

Table B. 65: Model-3, Storey Displacement Due to Earth Quake in Y-Direction

Storey	Case-1 (mm)	Case-2 (mm)	Case-3 (mm)	Case-4 (mm)
Roof	189.591	40.127	40.285	41.231
G+20	184.218	37.643	37.791	38.681
G+19	177.809	35.154	35.293	36.127
G+18	170.338	32.669	32.8	33.577
G+17	161.871	30.196	30.317	31.039
G+16	152.486	27.743	27.855	28.524
G+15	142.262	25.32	25.424	26.041
G+14	131.28	22.938	23.033	23.603
G+13	119.992	20.606	20.693	21.222
G+12	108.168	18.333	18.411	18.899
G+11	95.944	16.129	16.2	16.645
G+10	83.728	14.005	14.068	14.47
G+9	72.998	11.975	12.03	12.387
G+8	63.944	10.055	10.104	10.408
G+7	55.067	8.256	8.297	8.551
G+6	46.247	6.593	6.627	6.831
G+5	37.558	5.082	5.109	5.268
G+4	29.342	3.744	3.765	3.881
G+3	22.515	2.587	2.601	2.682
G+2	15.82	1.606	1.616	1.666
G+1	9.313	0.829	0.835	0.86
G	3.407	0.282	0.283	0.292
Average	94.26809091	16.90327273	16.97440909	17.40386364
%		-82.07%	-81.99%	-81.54%

Table B. 66: Model-1, Storey Stiffness Due to Earth Quake in X-Direction

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	80201.645	104053.929	123004.101	556.819
G+20	98572.704	126483.498	160084.165	1058.78
G+19	103344.642	129573.134	135926.83	1434.562
G+18	105418.687	130362.878	132334.684	1723.8
G+17	106971.148	130927.919	132198.172	1979.087
G+16	108468.703	131671.441	132886.796	2220.165
G+15	109995.806	132439.383	135294.381	2440.796
G+14	130161.573	133098.377	154082.419	2646.257
G+13	132631.121	133729.882	157089.28	2843.294
G+12	135113.017	134930.61	159791.608	3033.267
G+11	141547.188	139694.797	167572.426	3220.126
G+10	172648.257	167319.949	201512.396	3418.478
G+9	201163.557	231882.639	233641.611	3668.334
G+8	209785.154	242497.991	242771.801	3964.376
G+7	213930.348	245056.98	245727.657	4317.965
G+6	218381.766	248180.197	249204.618	4755.518
G+5	232105.036	264903.492	266687.842	5341.783
G+4	333448.139	361107.161	361827.649	6241.192
G+3	342999.309	371677.428	371783.214	7698.831
G+2	353697.894	380988.125	381886.868	10361.607
G+1	385098.132	414793.145	417643.998	16184.24
G	640179.941	703744.895	709605.647	42942.639
Average	207084.7167	229959.9023	239661.7347	6002.359818
%		11.05%	15.73%	-97%

Table B. 67: Model-1, Storey Stiffness Due to Earth Quake in Y-Direction

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	38445.893	107779.387	106509.815	51664.37
G+20	56930.751	200457.641	211158.904	82459.741
G+19	65333.506	264785.417	275362.975	98029.133
G+18	70178.127	306863.16	316595.18	107103.607
G+17	73795.19	332637.424	341656.89	114585.92
G+16	76999.779	347355.201	355966.127	122051.405
G+15	79903.745	355916.422	364232.511	129252.422
G+14	85485.058	363232.746	371195.747	140467.671
G+13	88216.307	374301.077	381290.92	147884.555
G+12	91130.816	394115.659	400110.999	155902.93
G+11	96520.175	427059.657	431876.89	167882.347
G+10	115750.686	477307.675	481095.057	201799.59

G+9	145187.403	555086.111	557575.375	252193.482
G+8	155684.698	658805.239	660637.924	274902.837
G+7	163510.527	792816.745	793799.356	293817.041
G+6	172113.996	964152.191	964247.183	314279.935
G+5	188067.683	1188748.454	1187371.854	347227.311
G+4	235204.961	1487811.682	1484645.755	434735.381
G+3	248196.251	1873010.282	1868640.639	467784.951
G+2	263461.32	2481015.035	2473392.739	506944.078
G+1	297456.555	3637949.613	3622806.425	584064.832
G	522408.348	7239040.703	7207495.236	1047669.76
Average	151362.808	1128647.615	1129893.841	274668.3318
%		645.66%	646.48%	81%

Table B. 68: Model-2, Storey Stiffness Due to Earth Quake in X-Direction

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	80201.645	83907.491	84673.257	86332.808
G+20	98572.704	113331.863	114720.557	116152.327
G+19	103344.642	122143.152	123751.448	124951.046
G+18	105418.687	126199.738	127845.856	128944.206
G+17	106971.148	129006.712	130651.861	131716.253
G+16	108468.703	131548.347	133245.93	134287.778
G+15	109995.806	134395.475	136105.957	137076.18
G+14	130161.573	151064.239	152684.396	153932.166
G+13	132631.121	154432.291	156061.134	157276.097
G+12	135113.017	157785.212	159596.482	160830.522
G+11	141547.188	165540.832	167624.309	169008.394
G+10	172648.257	198552.186	200848.662	203139.978
G+9	201163.557	231610.318	234040.124	248883.294
G+8	209785.154	242573.035	245455.367	261332.809
G+7	213930.348	248524.461	251603.417	267658.815
G+6	218381.766	254974.575	258304.416	274513.113
G+5	232105.036	272361.945	275882.411	292172.337
G+4	333448.139	361765.986	365793.15	364821.31
G+3	342999.309	373158.028	377044.077	376435.192
G+2	353697.894	386360.514	390811.496	390399.17
G+1	385098.132	423959.694	429746.671	429472.387
G	640179.941	717697.754	726240.594	726020.527
Average	207084.7167	235495.1749	238305.9805	242516.214
%		13.72%	15.08%	17%

Table B. 69: Model-2, Storey Stiffness Due to Earth Quake in Y-Direction

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	38445.893	103307.49	104289.42	107310.5
G+20	56930.751	192269.77	194097.53	199708.86
G+19	65333.506	254239.16	256671.92	264067.06
G+18	70178.127	295091.79	297924.65	306543.25
G+17	73795.19	320484.42	323560.16	333070.34
G+16	76999.779	335421.07	338629.88	348918.1
G+15	79903.745	344324.77	347589.22	358743.79
G+14	85485.058	351784.18	355082.19	367324.89
G+13	88216.307	361767.66	365140.24	378710.49
G+12	91130.816	379673.66	383176.11	398348.41
G+11	96520.175	409493.26	413230.83	430269.91
G+10	115750.69	455560.52	459768.72	478953.15
G+9	145187.4	526956.15	531891.06	551996.28
G+8	155684.7	622854.73	628646.26	647685.27
G+7	163510.53	746502.98	753426.47	769942.84
G+6	172114	904315.45	912629.12	924676.08
G+5	188067.68	1110875.3	1120494.5	1124565.9
G+4	235204.96	1386273.6	1397886.3	1396291.2
G+3	248196.25	1738058.6	1753036.6	1751899.1
G+2	263461.32	2291646.5	2309933.6	2311973.2
G+1	297456.56	3338713.3	3360961.6	3370448.3
G	522408.35	6631450.7	6620060.7	6654446.5
Average	151362.81	1050048.4	1055824	1067086.1
%		593.73%	597.55%	605%

Table B. 70: Model-3, Storey Stiffness Due to Earth Quake in X-Direction

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	80201.645	95733.949	96824.47	95685.317
G+20	98572.704	123226.293	125177.455	124195.756
G+19	103344.642	130673.685	132824.824	131919.136
G+18	105418.687	133855.668	136048.388	135243.995
G+17	106971.148	136019.022	138209.791	137872.576
G+16	108468.703	138010.245	140237.487	142483.451
G+15	109995.806	140222.418	142434.124	160686.42
G+14	130161.573	156639.043	158764.467	206002.053
G+13	132631.121	159609.66	161711.946	213882.079
G+12	135113.017	162683.646	164950.742	218709.311
G+11	141547.188	170296.501	172858.37	224633.86

G+10	172648.257	204173.225	207017.151	240998.735
G+9	201163.557	238162.117	241182.684	246649.78
G+8	209785.154	248502.684	251997.357	252341.744
G+7	213930.348	253559.837	257229.111	256799.623
G+6	218381.766	259026.155	262904.956	262321.136
G+5	232105.036	275414.542	279449.636	278623.933
G+4	333448.139	364003.22	368529.437	367558.847
G+3	342999.309	374379.344	378584.422	378117.798
G+2	353697.894	386616.848	391257.217	390927.963
G+1	385098.132	423171.079	429039.429	428767.245
G	640179.941	714678.664	723168.729	722914.429
Average	207084.7167	240393.5384	243654.6451	255333.4176
%		16.08%	17.66%	23%

Table B. 71: Model-3, Storey Stiffness Due to Earth Quake in Y-Direction

Storey	Case-1 (kN/m)	Case-2 (kN/m)	Case-3 (kN/m)	Case-4 (kN/m)
Roof	38445.893	94523.537	94884.206	96078.431
G+20	56930.751	173905.12	174356.7	177548.46
G+19	65333.506	227760.31	228149.43	233567.85
G+18	70178.127	261679.83	261958.05	269787.02
G+17	73795.19	281845.79	281995.26	292373.85
G+16	76999.779	292896.29	292916.47	305752.45
G+15	79903.745	298248.62	298118.25	315491.56
G+14	85485.058	303426.06	303189.76	325567.57
G+13	88216.307	309891.98	309507.94	333838.53
G+12	91130.816	323491.31	322937.68	349678.15
G+11	96520.175	346876.15	346169.92	376008.81
G+10	115750.69	387400.33	386888.03	415891.85
G+9	145187.4	449929.11	449638.81	473437.44
G+8	155684.7	526410.06	525703.09	548369.62
G+7	163510.53	622275.63	620802.05	642310.51
G+6	172114	741234.19	738497.46	759900.21
G+5	188067.68	893544.82	888597.24	911498.33
G+4	235204.96	1114266	1107436.8	1131278.7
G+3	248196.25	1358084	1347500.3	1377882.7
G+2	263461.32	1730629.5	1711294.8	1756538.6
G+1	297456.56	2393572.3	2355423	2433658.4
G	522408.35	4509693.9	4430771.4	4586602.7
Average	151362.81	801890.22	794397.12	823320.99
%		429.78%	424.83%	444%