Orientation and Location of Shear Walls in RC Buildings to Control Deflection and Drifts

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PROJECT REPORT APPROVAL

The thesis titled "Orientation and Location of Shear Walls in RC Buildings to Control Deflection and Drifts" submitted by M. Fahim Siddique, Ashikur Rahman Simon, Ferdows Kabir Hridoy and Sanjid Ahmed Safat, St. No. 160051007, 160051057, 160051063 and 160051074 has been found as satisfactory and accepted as partial fulfillment of the requirement for the Degree Bachelor of Science in Civil Engineering.

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DECLARATION OF CANDIDATE

We hereby declare that the undergraduate research work reported in this thesis has been performed by us under the supervision of Professor Dr. Tarek Uddin and this work has not been submitted elsewhere for any purpose (except for publication).

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DEDICATION

We dedicate our thesis work to our family. A special feeling of gratitude to our loving parents. We also express our gratitude to our respected supervisor Professor Dr. Md. Tarek Uddin.

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"In the name of Allah, Most Gracious, Most Merciful"

First of all, all the praises to Allah (SWT) who has blessed us with the opportunity to complete this book.

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Finally, we also place on record, our sense of gratitude to one and all, who directly or indirectly, have contributed to this venture.

ABSTRACT

Controlling drift and deflection caused by lateral loads such as wind load and earthquake load is a major concern while constructing high-rise structures. To resist the lateral loads, one of the most feasible and commonly used mechanism are shear wall systems. Shear walls provide high plane stiffness and strength which can be utilized to resist large horizontal loads and support gravity loads simultaneously. While placing the shear walls in a building structure, a major issue is the orientation and location which plays a vital role in seismic performance of such system against lateral loads. If shear walls are not placed properly, they may generate eccentricity in building which is the main cause for torsion. In this study attempt has been carried out find out the proper orientation and location of shear walls in RC building to control drift and deflection by modeling and analyzing of building with different shear wall positions. For this purpose, a 10 storey RC building has been modeled in computer application software ETABS with different locations of shear walls (i.e. shear wall at center, Shear wall at sides & inner wall, Shear wall at periphery, Shear wall at Corners and Shear wall at Center & Edges). The framed structure is subjected to lateral and gravity loading in accordance with BNBC 2017 and the analytical results of each model has been compared with that of the bare frame in terms of storey shear, storey drift, storey displacement, stiffness, torsional irregularity, time period and mode shapes.

Key Words

Shear Wall, Shear Wall Location, Lateral Loads, Drift, Displacement, Time Period, Stiffness, Modal Analysis, ETABS etc.

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Chapter 1

INTRODUCTION

1.1 GENERAL

Bangladesh is such kind of mostly growing populated country in the world. The amount of land isn’t sufficient for the growing population of this country. It’s not possible to increase the usable land for future generation. So high rises buildings are only the solution.

There are some basic elements of high rises RC buildings. They are columns, beams, slabs etc. But these things are not very much suitable for the lateral seismic loads. Bangladesh is situated in a such kind of position where earthquake happens in a regular interval. That’s why shear wall is a much-needed thing we should introduce to the people.

Reinforced concrete (RC) structures frequently have vertical plate-like RC dividers called Shear Walls notwithstanding sections, shafts and segments. Reinforced concrete shear walls speak to a basically productive answer for solidify a structure underlying framework under horizontal burdens. The principle capacity of a shear divider is to expand the unbending nature and strength of the structure for horizontal opposition.

So, what do we mean by shear wall? A shear wall is a vertical structural element that resists lateral forces in the plane of the wall through shear and bending. Shear wall, a rigid vertical diaphragm in building construction capable of moving lateral forces in a direction parallel to their planes from exterior walls, floors, and roofs to the ground base. The reinforced-concrete wall or vertical truss are examples. In addition to the weight of the structure and inhabitants, lateral forces generated by wind, earthquake, and uneven settlement loads produce strong twisting (torsional) forces. These forces can literally break a building apart (shear it). By adding or inserting a solid wall within it, strengthening a frame preserves the form of the frame and prevents movement at the joints.

The shear wall is what prevents structures from blowing over, resisting the lateral forces of wind and seismic activity, while columns and load-bearing walls keep buildings standing up, bringing the structure's compression load down to its base. As a general rule, in high-rise buildings and those homes that need them, the optimal location for shear walls is in the middle of each half of a house. Furthermore, shear walls must be formed along the central axis of the building symmetrically.

In other words, if there is a shear wall on its north side, on its south side it must have an equivalent shear wall. If a shear wall is situated in the southeast corner of a house, then an equivalent shear wall would be positioned in the southwest corner on the opposite side of the central axis.

Types of Shear Walls

- Reinforced Concrete Shear Wall.
- Concrete Block Shear Wall.
- Steel Shear Wall.
- Plywood Shear Wall.
- Mid-Ply Shear Wall.

Reinforced Concrete Shear Wall: A structurally effective approach for stiffening a construction structural framework under lateral loads is reinforced concrete shear walls. For lateral resistance, the main purpose of a shear wall is to increase the rigidity and strength of the construction. As appropriate structural structures, reinforced concrete shear walls have long been recognized, offering both lateral resistance and drift control in RC buildings. These older shear walls, however, were usually intended for combined gravity loads and wind loading behavior.

In day-to-day mid-height building systems, seismic loading and construction have not been considered. In fact, only in the 1970s were seismic provisions introduced; thus, most structures designed and constructed earlier, have design and detailing deficiencies. The defects in these structures of the shear wall make them prone to seismic risk.

Steel Shear Wall: Steel shear walls are an advanced lateral load resistance device capable of bracing a building effectively against both wind and earthquake forces. The structure consists of vertical steel infill plates attached to the surrounding beams and columns, one storey high and one bay wide.

Plywood Shear Wall: The two available types of plywood are Graded and Structural One, but the plywood must have 5 layers for shear wall use. Graded Plywood can be made of any wood species, whereas Structural 1 must be 10 percent stronger, made of denser Southern Pine or Douglas Fir.

Advantages of Shear Wall:

- Provide large strength and stiffness in the direction of orientation.
- Significantly reduces lateral sway.
- Easy construction and implementation.
- Efficient in terms of construction cost and effectiveness in minimizing earthquake damage.
- Thinner walls.
- Light weight.
- Fast construction time.

Disadvantages of shear wall:

- Shear walls are difficult to construct.
- They have a flimsy appearance.
- Also, loud banging sounds associated with buckling of web plates.
- It has low stiffness and energy dissipation capacity.
- Also, requires large moment connections.

From our thesis project, we can say that we took six models. In first model there is no shear wall, in the second one we put shear wall at center, in third one shear wall at sides & inner wall, the fourth one shear wall at periphery, in fifth one shear wall at corners and in last one shear wall at center & edges.

In this study, a 10-storey building with 10 feet height for every storey is chosen. All the models in our study are built in accordance with the BNBC Code 2017. The buildings were modeled using the software ETABS 2016 v16.2.1. Six models were constructed with different locations of shear walls in a building including a no shear wall model. Models were studied in seismic zone II. We've compared parameters such as, lateral displacement, storey drift, torsional irregularity, stiffness for all models.

Total Area of the project is 7 Katha which means 5040 sft. We have calculated FAR & MGC from as per Dhaka Building Construction Rules, 2008. We have found floor area ratio, FAR= 3.75 and maximum ground coverage, MGC= 60%. So, the total usable area will be 3024 sft.

In this study, we have analyzed about the storey shear, drift analysis at X & Y direction, displacement analysis in X & Y direction, stiffness analysis is X & Y direction, torsional irregularity, time period and modal analysis.

Storey Shear: When it comes to lateral load analysis, two very basic and often underestimated methods for the structural engineer are the storey shear and storey drift plots.

The design seismic force is assumed to be applied at each floor level in one method of designing a structure to have seismic resistance. Because of the great width of the frame, the floor slab is known to be very rigid in its own plane. Hence, under seismic forces, all floor slabs are believed to literally travel laterally in their own planes. The seismic design force to be applied at each level of the floor is called floor shear. At - floor stage, it is a fraction of the overall dead load and a part of the live load running.

Storey shear is a kind of graph showing how much lateral load, be it wind or seismic, is acting per storey. The lower we go, the greater the shear becomes. In storey shear, at a given direction, one can imagine the potential governing lateral load on a certain surface. And this will help to explain or examine why wind rules in some directions or vice versa over seismic.

The base shear formula is: $V = 0.2 (W)$ V represents the shear force that will be generated at the base of a building. 0.2 represents earthquake force. W represents the weight of the building. Single storey homes weigh approximately 50 pounds per square foot.

Storey Drift: The lateral displacement of one degree relative to the level above or below is storey drift. Storey drift ratio is the drift of storey divided by the height of the storey.

In terms of total drift (the total lateral displacement at the top of the building), drift has been established and inter-storey drift is defined as the relative lateral displacement between two consecutive building levels. In our study the maximum permissible value of drift is 0.004.

Storey Displacement: Storey displacement is the lateral displacement of the storey relative to the base. The lateral force-resisting system can limit the excessive lateral displacement of the building.

There are some differences between storey drift and displacement. Storey Drift is known as the displacement ratio of two consecutive floors to that floor's height. It's a very important word used in earthquake engineering for research purposes.

Storey Displacement- The total displacement of the storey with respect to the ground is total and the maximum allowable limit for buildings. Our allowable Horizontal Deflection is = H/500 = 2.40 in

Storey Stiffness: The word 'stiffness' in structural engineering refers to the rigidity of a structural element. In general terms, this means the degree to which, under the action of an applied force, the element is able to resist deformation or deflection. Stiffness is calculated in both directions. Higher stiffness means more rigid building.

Torsional Irregularity: Torsional irregularity is the state where the actual storey drift, including unintended torsion, is more than 1.2 times the average of storey drift at the two ends of the structure at one end of the structure transverse to an axis. Torsion is the state of tension in a material that an applied torque has twisted. Whenever a structural feature is subject to a twisting force, it will occur. Torsion produces shear stresses and at right angles equals strain and compression.

Torsional effects can greatly alter the seismic response of buildings, and in many previous earthquakes they have caused serious damage or collapse of structures. The key effect of floor twist is an unequal demand for lateral displacements in the elements of the structure in ductile structures.

The distance (eccentricity) between the centre of stiffness and the centre of mass of the system is the cause of general torsion. This contributes to the torsional action of buildings, which during intense ground movements is one of the most common causes of structural damage and failure.

For the basic static balance of most of the statically defined structures, primary torsion is needed. In the design, this torsional moment must also be taken into account as it is a major component. In order to satisfy the condition of compatibility between members, secondary torsion is required.

Time Period: A building's natural duration is the time taken by it to undergo one full oscillation cycle. It is an intrinsic characteristic of a system governed by its mass m and rigidity k. The natural cycle (with lower stiffness k) is longer than that of light and rigid buildings.

All structures have a natural duration, or resonance, which is the number of seconds it takes for the building to vibrate back and forth naturally. The ground has a particular resonant frequency as well. Hard bedrock has lighter sediments of higher frequencies.

Modal Analysis: Modal analysis is the approach by which the inherent dynamic characteristics of a system are calculated in the form of natural frequencies, damping factors and shapes of modes and used to formulate a mathematical model for its dynamic behavior. Frequency and location physically decompose the dynamics of a structure.

Modal analysis provides us with knowledge about the various modes of vibration, the different shapes that can be taken up during vibration by the structure. This form is called the mode shape in various modes, and all mode shapes have their natural frequency corresponding to it.

1.2 BACKGROUND

Proper location & orientation of shear wall are required to resist the lateral forces as well as to ensure the structural safety. Shear walls provide large strength and stiffness to buildings in the direction of their orientation, which significantly reduces lateral sway of the building and thereby reduces damage to structure and its contents. While properly placed shear wall protects the structure from lateral loads, poorly placed shear wall can be responsible for its destruction. In our research, we focused on finding proper location & orientation of shear wall to control drift & deflections.

1.3 OBJECTIVES OF THE STUDY

The objectives of this study are as follows:

- To find the optimum location & orientation of shear wall to control drift & deflection in high-rise buildings subjected to lateral wind and seismic loads.
- To provide sufficient strength & stiffness to buildings to resist the lateral forces.
- To reduce lateral sway of the building.
- To reduce damage to structure and its contents.

1.4 METHODOLOGY

Methods of Analysis:

- Equivalent Static Analysis
- Response Spectrum Analysis

In this study, a 10-storey building with 10 feet height for every storey is chosen. All the models in our study are built in accordance with the BNBC Code 2017. The buildings were modeled using the software ETABS 2016 v16.2.1. Six models were constructed with different locations of shear walls in a building including a no shear wall model. Models were studied in seismic zone II. We've compared parameters such as, lateral displacement, storey drift, torsional irregularity, stiffness for all models.

1.5 RESEARCH FLOW DIAGRAM

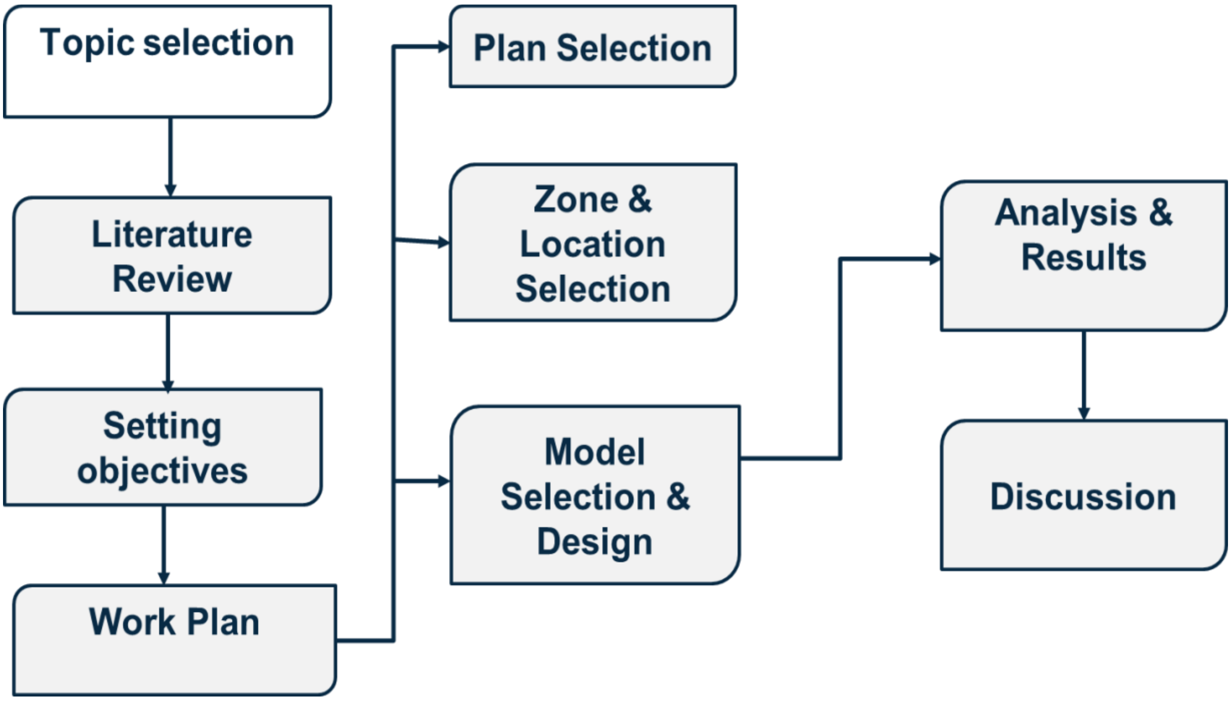


Figure 1-1: Research flow diagram

1.6 LAYOUT OF THE THESIS

The rest of the thesis has been organized as follows:

Chapter 2 **:** Literature Review – this chapter discusses about the past works on similar type of study and will give idea on how the work plan should be done.

Chapter 3 **:** Methodology – in this chapter the procedural steps of the study will be described thoroughly.

Chapter 4 **:** Results and Discussions - analysis of the data collected from the models & obtaining results.

Chapter 5 **:** Conclusions and Recommendations - this chapter will discuss the effectiveness of the study, recommendations & scopes of future studies.

Chapter 2

LITERATURE REVIEW

Belgaonkar et al. (2017) Explained the effectiveness of shear wall orientation in RC framed structures under the action of seismic forces. During the study, several models are analyzed using equivalent static analysis (linear static) and response spectrum analysis (dynamic analysis) method. They showed that the behavior of the shear wall is good when they are provided in Box shape. From their analysis, they also found that model with shear wall at periphery has better resistance to lateral forces as compared to model with core shear wall.

Atmaca et al. (2018) Analyzed and explained the shear wall effect on concrete structures and during the study, several models were studied for parameters like the fundamental period of vibration, lateral displacements, axial and shear forces.

The analysis was performed in two phases, in first Phase the models were analyzed with the symmetrical position of the shear walls and in second Phase, they were analyzed with the unsymmetrical position of shear walls. From the analysis they found that the symmetrical position of shear wall in the structure will be the best for constructions in all the seismic zones.

Halkude et al. (2015) Explained the effect of location of shear walls on seismic performance of buildings. The study was carried out to investigate the behavior of structure by varying percentage length of a shear wall with aspect ratio (L/B) 1 for seismicity. They suggested that shear wall should be provided equally (i.e. 50-50%) in both directions for buildings having square shape in plan configuration. They also observed that, for square type of building having length of shear wall 10 to 20% of plan dimension shows efficient seismic performance.

Ali and Aquil (2014) Studied the strength of RC shear wall at different location of multi-storied residential building subjected to earthquake loading in Hyderabad, India. They found out that shear force was maximum at the ground level for L- shaped shear wall and bending moment was maximum at roof level for periphery shear wall as compared to other locations of shear wall. From the study, it has also been observed that the top deflection is reduced significantly in both X-direction and Y-direction after providing shear walls.

Rao (2018) Aimed to check and compare the seismic response of multi-storied building for different location of shear wall, so that one can choose the best alternative for construction in earthquake-prone area. From the analysis, it is observed that horizontal displacement of a G+14 storied building with shear wall at core+edge faces of the building was lesser when compared to other models. Shear wall at this location had the maximum base shear value, which indicates the maximum lateral force will be resisted.

Tajzadah et al. (2019) Explained the optimum location of shear wall in RC building by modeling and analyzing of a G+9 storied RC building with different shear wall positions modeled in ETABS. The analytical result of each model had been compared with that of bare frame in terms of base shear, top storey displacement, storey drift and time period. After analyzing the models, they suggested to place as much of the shear walls as possible apart from center of mass of the building for the provision of torsional resistance in buildings. From the analytical results they also observed the inner bays of the building to be a feasible location of shear wall.

Ganesh et al. (2016) Explained The Study On The Location Of Shear Wall In A Structure Using ETABS Non-linear. From the analysis, it had been observed that building with shear wall suffers less drift and displacement in both X and Y direction when compared to building without shear wall. They also concluded that L shaped shear wall can be a feasible solution to resist the lateral forces .

Rokanuzzaman et al. (2017) Studied the effect of location of shear wall on performance of building frame subjected to lateral loading. Three different models were studied for critical parameters like displacement and base shear under lateral loading. These buildings were designed in compliance to the Bangladesh National Building Code (BNBC 2006) and for analysis equivalent static analysis method was used. From the study, it was found that shear wall placed at middle of 4 periphery sides of building showed best performance as far as top displacement and base shear were concerned.

Dane and Pendharkar (2019) Explained the effective positioning of shear wall in G+5 storey building on sloping ground. The investigation dealt with the study of a G+5 storey rigid framed concrete structure that rested on an 18.5-degree slope to find out the optimum location of the shear wall. From their analysis, they observed that shear wall provided towards upward slope-side gave minimum storey shear force on each storey but then a huge difference was seen between the storey shear of the first and second storey which can induce the diagonal shear failure on the short-column side. That’s why the second nearest location to upward slope-side was considered as the optimum location of the shear wall.

Chapter 3

METHODOLOGY

3.1 General

In our experiment six different structural models with different positions of shear wall were studied for several important parameters such as storey shear, storey drift, storey stiffness, torsional irregularity etc. To achieve the objective of this study, different methods were adopted and by implementing these methods, a direct approach has been set out to fulfill the scope of the study. This chapter describes the implemented experimental methods and material properties of the structural models thoroughly. In addition, all the models in our study are built in accordance with the BNBC Code 2017. The buildings were modeled using the software ETABS 2016 v16.2.1.

3.2 FAR & MGC Calculation

Total Available Area = 7 Katha = 5040 sft

As per Dhaka Building Construction Rules, 2008,

Floor Area Ratio, FAR = 3.75

Maximum Ground Coverage, MGC = 60%

So, Usable Area = Area*MGC = 3024 sft

3.3 Work Sequence in ETABS

A Flow chart is shown below to overview the total work which is accomplished using ETABS software.

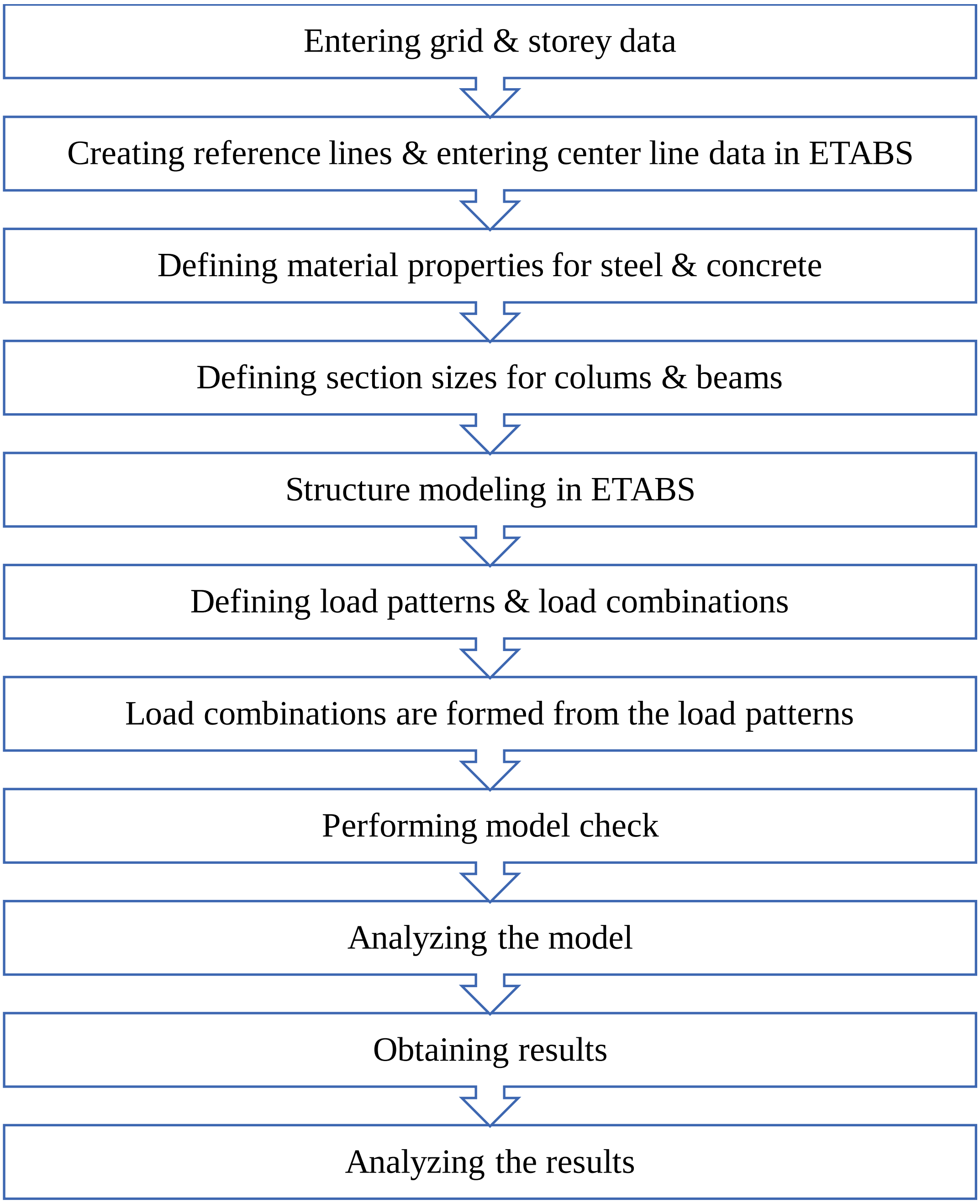


Figure 3-1: Work sequence in ETABS

3.4 Structural Plan

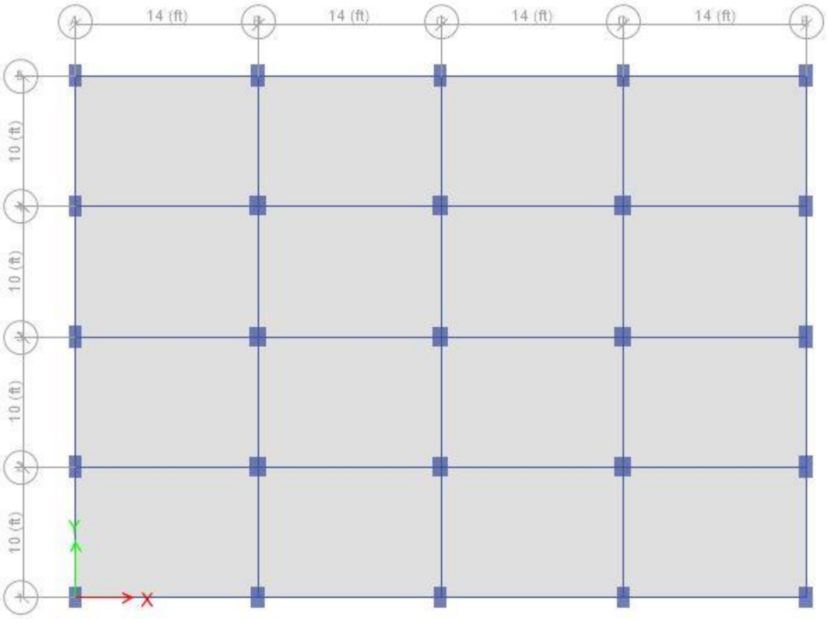


Figure 3-2: Structural plan (40ft x 56ft)

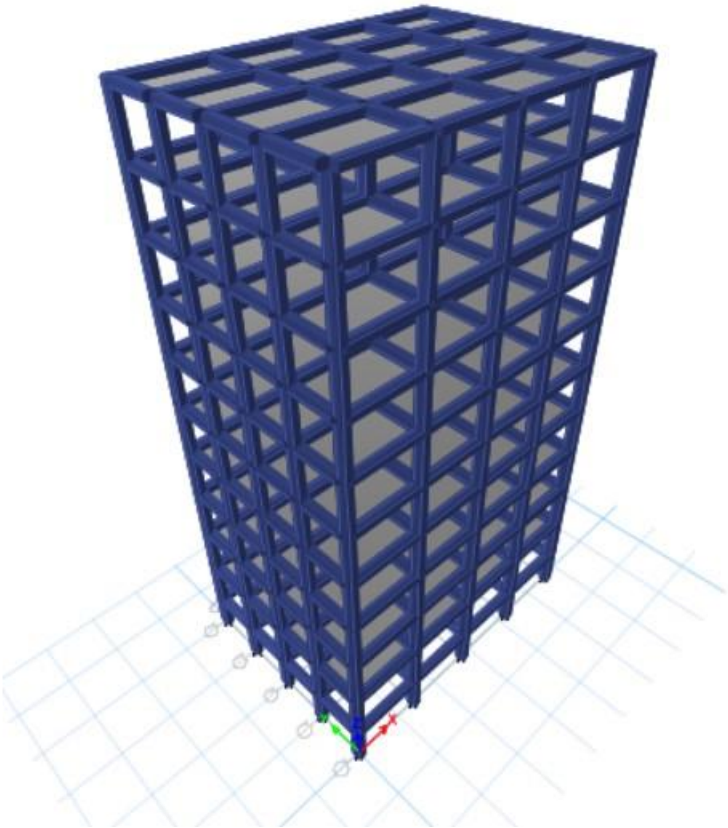


Figure 3-3: (G + 9) Storey Building

3.5 Structural Models

1. Model 1 (No shear wall)

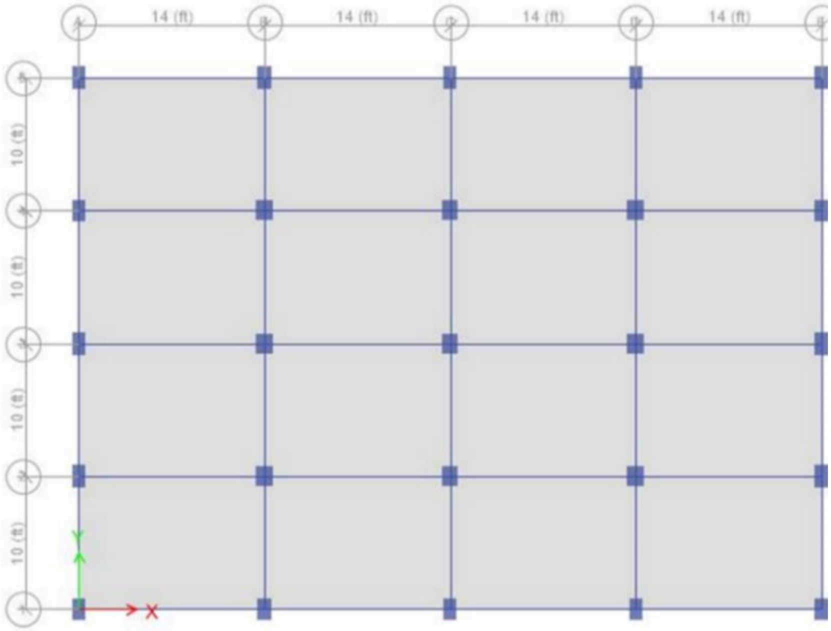


Figure 3-4: Model 1 (No shear wall)

2. Model 2 (Shear wall at Center)

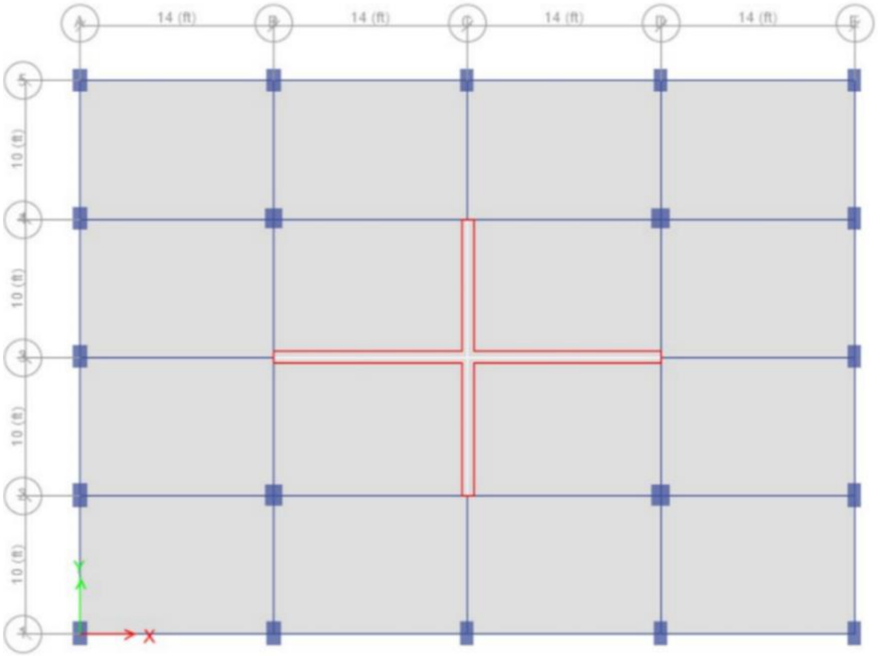


Figure 3-5: Model 2 (Shear wall at center):

3. Model 3 (Shear wall at sides & inner wall)

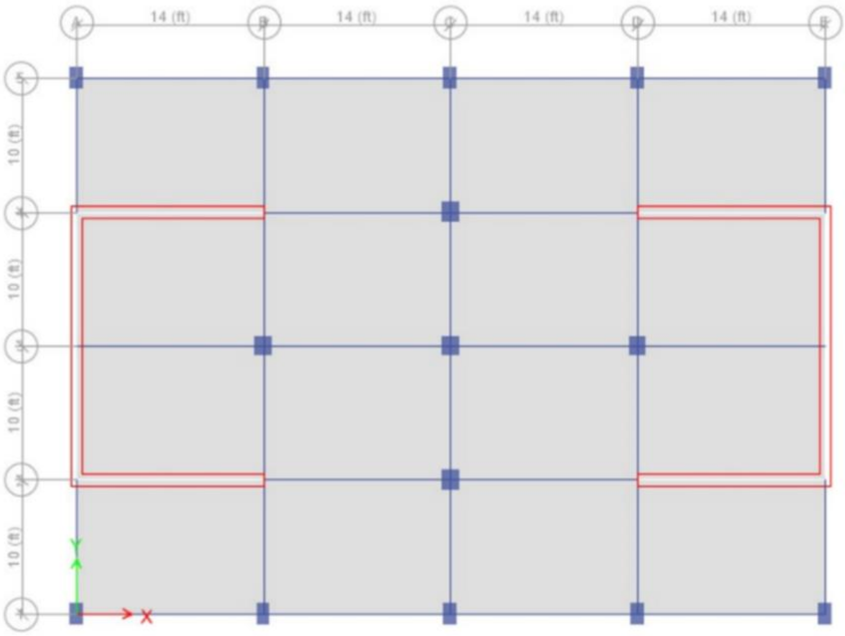


Figure 3-6: Model 3 (Shear wall at sides & inner wall)

4. Model 4 (Shear wall at periphery)

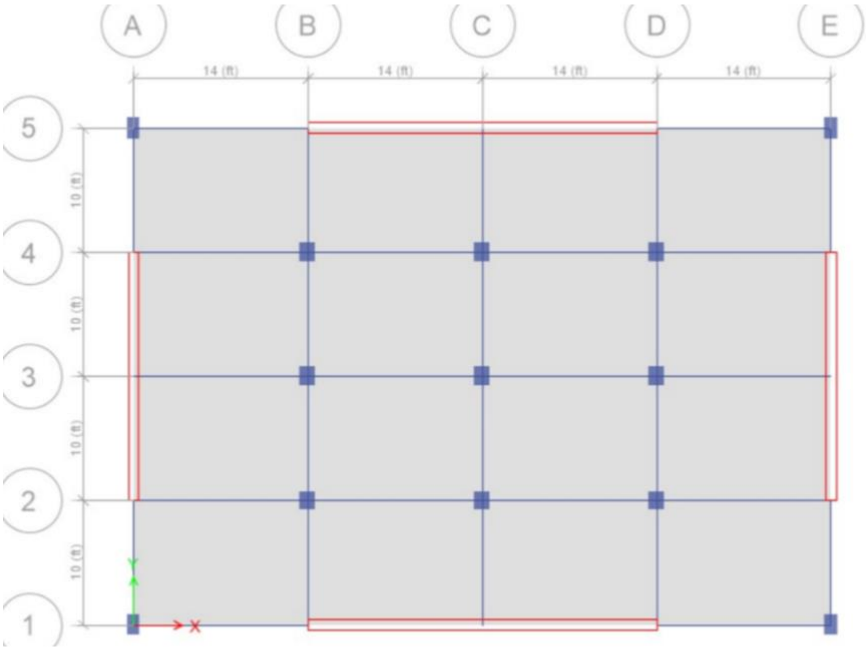


Figure 3-7: Model 4 (Shear wall at periphery)

5. Model 5 (Shear wall at Corners)

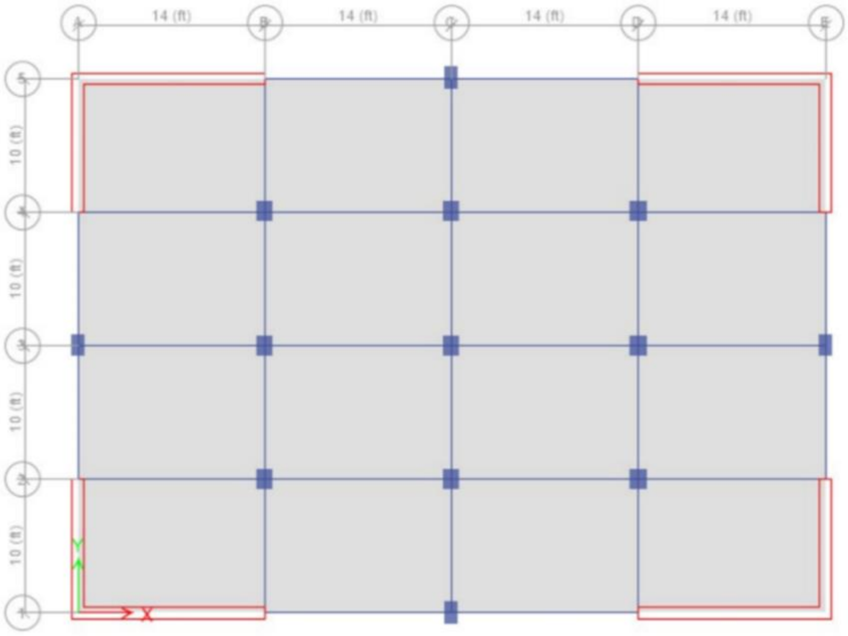


Figure 3-8: Model 5 (Shear wall at corners)

6. Model 6 (Shear wall at Center & Edges)

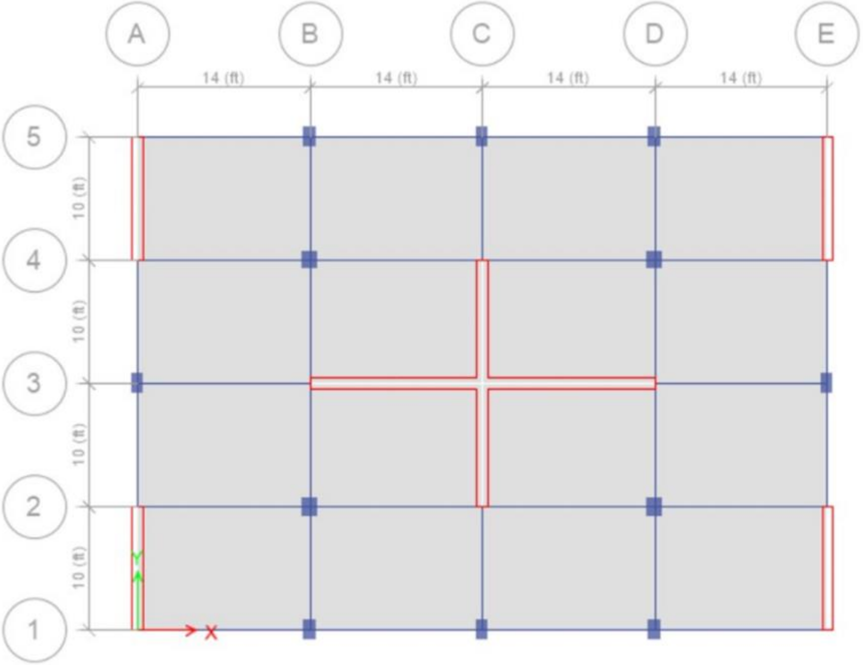
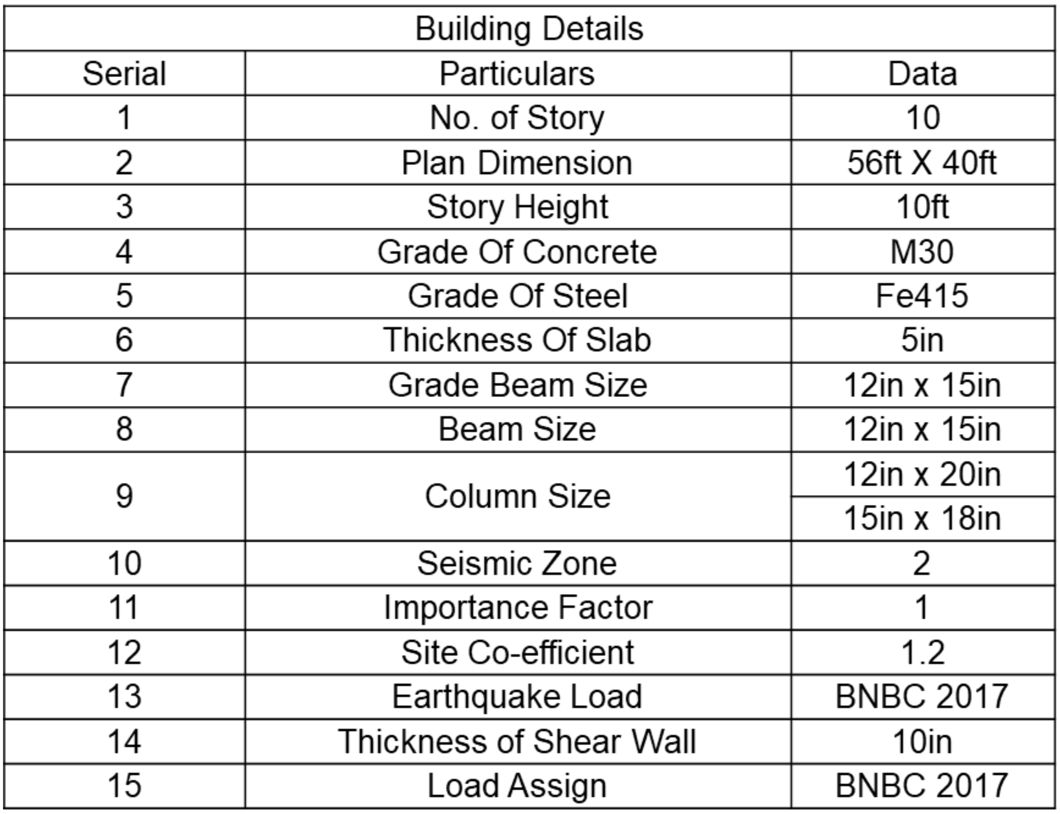


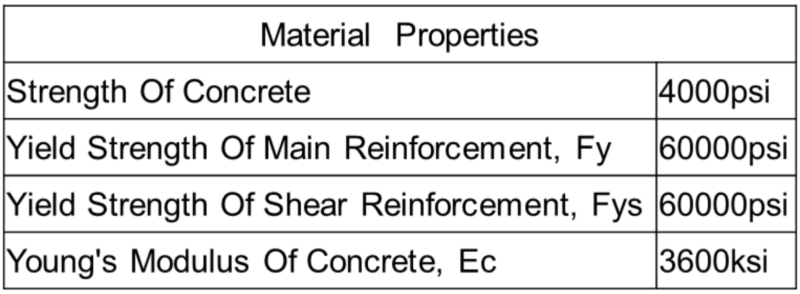
Figure 3-9: Model 6 (Shear wall at center & edges)

3.6 Building Details and Material Properties



Building Details		
Serial	Particulars	Data
1	No. of Story	10
2	Plan Dimension	56ft X 40ft
3	Story Height	10ft
4	Grade Of Concrete	M30
5	Grade Of Steel	Fe415
6	Thickness Of Slab	5in
7	Grade Beam Size	12in x 15in
8	Beam Size	12in x 15in
9	Column Size	12in x 20in
		15in x 18in
10	Seismic Zone	2
11	Importance Factor	1
12	Site Co-efficient	1.2
13	Earthquake Load	BNBC 2017
14	Thickness of Shear Wall	10in
15	Load Assign	BNBC 2017

Table 3-1: Building details



Material Properties	
Strength Of Concrete	4000psi
Yield Strength Of Main Reinforcement, Fy	60000psi
Yield Strength Of Shear Reinforcement, Fys	60000psi
Young's Modulus Of Concrete, Ec	3600ksi

Table 3-2: Material Properties

3.7 Methods of Analysis

Equivalent Static Analysis

The equivalent static analysis is a simplified technique that substitutes the dynamic loading effect of an expected earthquake by a static force distributed laterally on the building structure. In this technique it is considered that the building responds in its own fundamental mode when the vibrations due to earthquakes are generated. In order for this to be valid, the building must be low rise and must be sufficiently symmetrical to prevent torsional motion under ground motion.

This method of analysis can be applicable to the buildings whose seismic response in each direction is not significantly influenced by contributions from modes higher than the fundamental mode.

According to BNBC 2017, this requirement can be satisfied by fulfilling the following two conditions:

1. The building period in the two horizontal directions needs to be smaller than both $4T_C$ (T_C is the upper limit of the period of the constant spectral acceleration branch given as a function of site class) and 2 seconds.
2. The building should not possess any irregularity in elevation as defined in BNBC.

Response Spectrum Analysis (Dynamic Analysis)

The response spectrum analysis shows the structure's dynamic behavior under peak ground acceleration and is useful for assessing the structure's behavior under dynamic excitation. It is also known as modal analysis because it takes into account multiple types of structure vibration and integrates the effects of different modes. In ETABS, response spectrum analysis is performed using mode superposition, and either eigenvector or Ritz vectors can be used. Ritz vectors are usually recommended because, for the same number of modes, they provide more detailed and accurate results

Chapter 4

RESULTS AND DISCUSSIONS

4.1 General

As per the objectives of the experimental methods stated above a number of models have been prepared. Thus, the data obtained from the models have been analyzed so that some conclusions can be drawn. Moreover, this chapter contains detailed analysis & discussion of all the parameters to obtain required results.

4.2 Storey Shear

Storey	**Storey Shear, kip**					
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
ROOF	59.901	64.182	67.143	64.143	64.078	63.568
Storey9	127.404	132.7	135.002	129.217	129.11	130.702
Storey8	188.019	194.225	195.936	187.65	187.506	190.986
Storey7	241.746	248.76	249.947	239.444	239.267	244.419
Storey6	288.585	296.302	297.032	284.597	284.391	291.002
Storey5	328.536	336.853	337.194	323.109	322.88	330.734
Storey4	361.599	370.413	370.431	354.982	354.733	363.616
Storey3	387.774	396.981	396.743	380.215	379.949	389.648
Storey2	407.06	416.557	416.132	398.807	398.53	408.829
Storey1	419.459	429.142	428.596	410.759	410.475	421.159
GF	422.714	432.417	431.756	413.672	413.384	424.312

Table 4-1: Storey shear:

In storey shear table, we can see that shear is gradually decreasing as we go all the way up to the top storey. As seismic activity happens, it directly affects the ground floor first because it is nearer to the soil. The effect of earthquake thus gradually goes on decreasing to the top stories. In our analysis, Model -1 (no shear wall case) got storey shear of 422.714 kip. We got highest storey shear in Model-2 (shear wall at center) ground floor. The second highest one is Model-3(Shear wall at sides and inner wall). The values are 432.417 kip & 431.756 kip respectively. On the contrary, Model-4 (Shear wall at periphery) & Model-5 (Shear wall at corner) has relatively low shear values in ground floor. The last one is Model-6 (Shear wall at center & edges) has a medium value of 424.312 kip.

So, we can come to a conclusion that by moving the shear wall location away from center to periphery storey shear force has reduced to some extent. If we see model 2 ,3 & 6 shear wall implementation has rather increased the storey shear compared to the original case M1 which has no shear wall. So, we can sum up that **Model 4 & 5** are the best one considering storey shear.

4.3 Storey Drift

4.3.1 Storey Drift in X Direction

Storey	Direction	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Maximum Limit
ROOF	X	0.002909	0.001249	0.001143	0.000673	0.001148	0.001211	0.004
Storey9	X	0.004884	0.001269	0.001155	0.000681	0.001158	0.001227	0.004
Storey8	X	0.006969	0.001275	0.001155	0.000681	0.001156	0.00123	0.004
Storey7	X	0.008896	0.001264	0.001139	0.000671	0.001137	0.001216	0.004
Storey6	X	0.01059	0.001228	0.001101	0.000648	0.001097	0.001179	0.004
Storey5	X	0.012022	0.001161	0.001036	0.000609	0.00103	0.001113	0.004
Storey4	X	0.013156	0.001058	0.000938	0.000552	0.00093	0.001012	0.004
Storey3	X	0.01387	0.000915	0.000804	0.000474	0.000795	0.000871	0.004
Storey2	X	0.013722	0.000725	0.000628	0.000373	0.00062	0.000688	0.004
Storey1	X	0.011098	0.000501	0.000425	0.000258	0.000417	0.000491	0.004
GF	X	0.004781	0.000303	0.000202	0.000159	0.000195	0.000279	0.004

Table 4-2: Storey Drift in X Direction

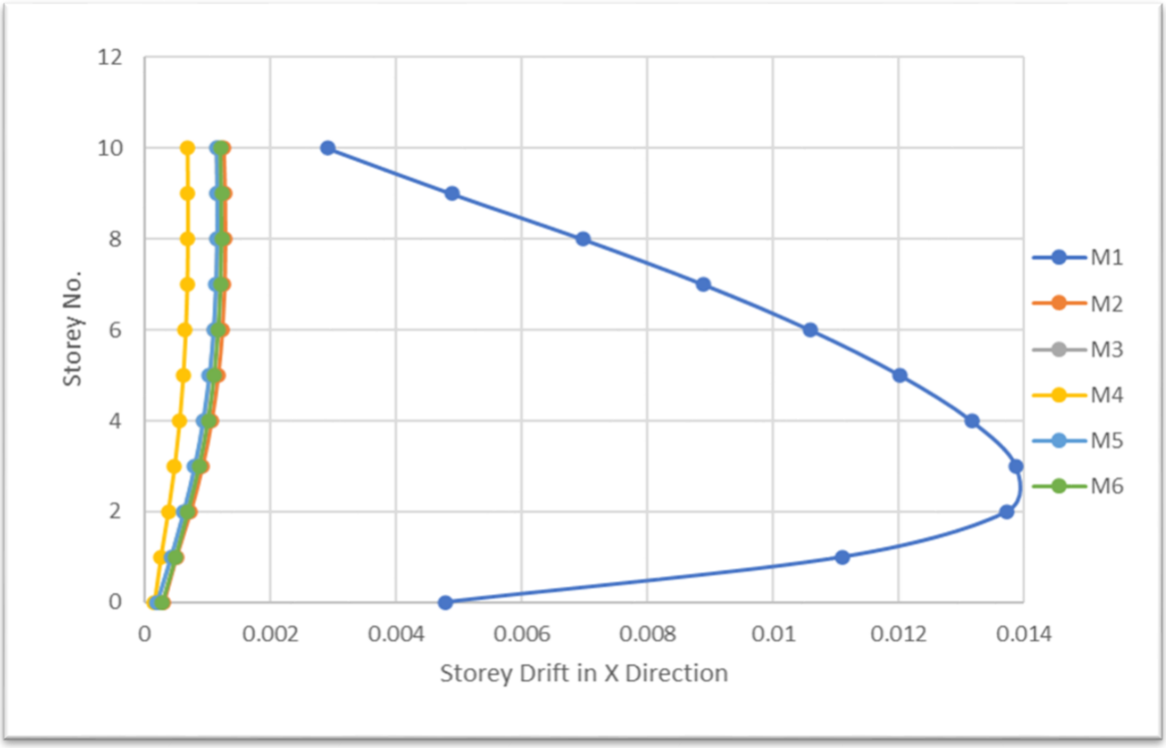


Figure 4-1: Storey Drift in X Direction

It has been seen our analysis that by implementing shear wall we can greatly reduce drift in our building. While analyzing X Direction, in model 1, some values of drift are greater than the permissible value of 0.004 according to BNBC-2017. Model-4 has the lowest drift value among all other models and values are also within the permissible limit. It has shear wall along periphery which helped it to have less drift less value against seismic activity Compared to other models. Model -3 has the next lowest value in the table. It can be seen that, Model-2 has the highest value of drift because it has shear wall placed at the center. As shear wall distance from center, we can see low drift in Model 4. Except no shear wall case all the values in our model meets the permissible value requirement.

4.3.2 Storey Drift in Y Direction

Storey	Direction	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Maximum Limit
ROOF	Y	0.002387	0.002328	0.000397	0.0014	0.001867	0.001766	0.004
Storey9	Y	0.003628	0.002387	0.000409	0.001421	0.0019	0.001789	0.004
Storey8	Y	0.004991	0.002423	0.000415	0.001429	0.001919	0.0018	0.004
Storey7	Y	0.006272	0.002433	0.000415	0.001419	0.001914	0.00179	0.004
Storey6	Y	0.007402	0.002395	0.000406	0.001381	0.001873	0.001745	0.004
Storey5	Y	0.008343	0.002294	0.000388	0.001308	0.001782	0.001655	0.004
Storey4	Y	0.009051	0.002115	0.000358	0.001192	0.001633	0.00151	0.004
Storey3	Y	0.00941	0.001843	0.000316	0.001027	0.001414	0.001301	0.004
Storey2	Y	0.00909	0.001466	0.00026	0.000807	0.001117	0.00102	0.004
Storey1	Y	0.007117	0.000987	0.000202	0.000533	0.000746	0.00068	0.004
GF	Y	0.002938	0.000484	0.000134	0.000264	0.000314	0.000321	0.004

Table 4-3: Storey Drift in Y Direction

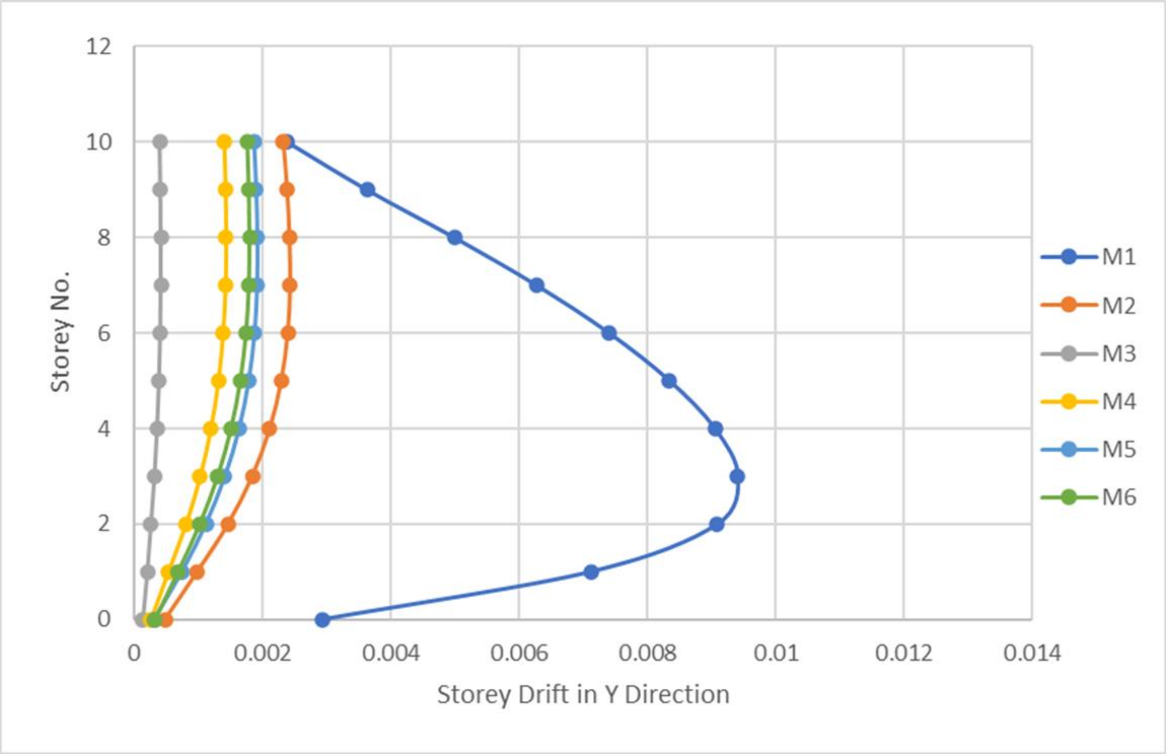


Figure 4-2: Storey Drift in Y Direction

In Y direction, Model -1 which is no shear wall case doesn't meet the permissible value. All other models in the table except Model-1 meets the permissible value. Model-3 performs best in Y direction as it has shear wall at sides an inner wall.

Here in graph, M1 has a large value of drift but all other models have relatively less value. Values of drift in Y direction are more distinguishable than X direction. We can clearly see that M-3 case is the best as it has lowest value here.

In both X and Y direction we can finally conclude that incorporating shear wall has reduced the drift value. Among all the models, Model-4 performs best in X direction as it has shear wall support in X direction and Model-3 performs best in Y direction also.

4.4 Storey Displacement

4.4.1 Storey Displacement in X Direction

Storey	Direction	Displacement (in)					
		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
ROOF	X	12.2247	1.2967	1.1569	0.6835	1.1521	1.2433
Storey9	X	11.8756	1.1469	1.0197	0.6027	1.0143	1.0980
Storey8	X	11.2896	0.9946	0.8812	0.5210	0.8754	0.9508
Storey7	X	10.4532	0.8416	0.7426	0.4393	0.7367	0.8033
Storey6	X	9.3857	0.6899	0.6059	0.3587	0.6003	0.6573
Storey5	X	8.1149	0.5425	0.4738	0.2809	0.4686	0.5158
Storey4	X	6.6722	0.4032	0.3495	0.2078	0.3451	0.3822
Storey3	X	5.0935	0.2761	0.2369	0.1416	0.2334	0.2608
Storey2	X	3.4291	0.1664	0.1405	0.0848	0.1380	0.1563
Storey1	X	1.7825	0.0794	0.0651	0.0401	0.0636	0.0737

Table 4-4: Storey Displacement in X direction

Storey Displacement or sway is usually found in a structure when it is subjected to wind or seismic load. In X direction, Model 1 has the greatest displacement value as expected because it has no shear wall.

According to BNBC -2017 the permissible limit of storey displacement is (h/500) which is in our case 2.4 inch for the topmost floor. The highest value of displacement in Model-1 is 12.2247 inch which is greater than permissible limit. All other models meet the criteria.

In Model- 4 we have the lowest displacement value and the second best one is Model-5.

Model-2 which has shear wall at center has relatively larger value than these two models.

If we compare model 3 &4 with Model 2 then it is clearly visible than as we go further away from center, displacement value decreases in X direction.

4.4.2 Storey Displacement in Y Direction

Storey	Direction	Displacement (in)					
		Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
ROOF	Y	8.4041	2.5168	0.4359	1.4490	1.9645	1.8273
Storey9	Y	8.1176	2.2374	0.3883	1.2811	1.7405	1.6153
Storey8	Y	7.6823	1.9510	0.3392	1.1105	1.5125	1.4006
Storey7	Y	7.0834	1.6602	0.2895	0.9391	1.2822	1.1846
Storey6	Y	6.3307	1.3683	0.2397	0.7688	1.0525	0.9698
Storey5	Y	5.4425	1.0810	0.1910	0.6031	0.8278	0.7604
Storey4	Y	4.4413	0.8057	0.1445	0.4461	0.6139	0.5617
Storey3	Y	3.3552	0.5519	0.1015	0.3031	0.4180	0.3805
Storey2	Y	2.2260	0.3307	0.0637	0.1799	0.2483	0.2243
Storey1	Y	1.1352	0.1547	0.0325	0.0831	0.1143	0.1019

Table 4-5: Storey Displacement in Y direction

In Y direction, Model-1 didn't meet the permissible limit. Here, Model-3 has the lowest displacement value. As shear walls are located at sides & inner wall, it has great advantage against seismic activity. Model -4 has the next lowest value. Both models have shear wall support at Y direction which helped in reducing the displacement value.

Model-2 has displacement value of 2.5168 inch & Model- 6 has a displacement value of 1.8273 inch. By seeing their model, it can be concluded that if we have to place shear wall at both short & long direction to see better results. Also, Displacement in Y direction decreases as we go further away from C.G.

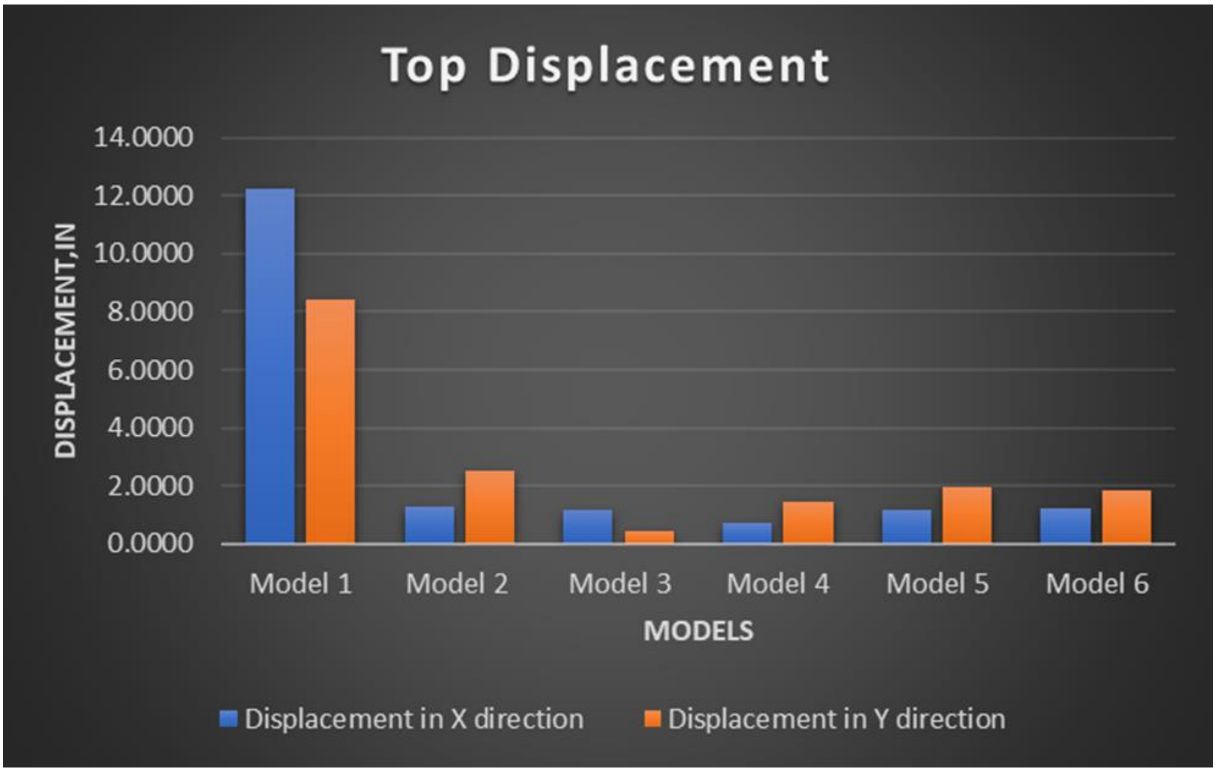


Figure 4-3: Top displacement

4.5 Storey Stiffness

4.5.1 Storey Stiffness in X Direction

Storey	**Direction**	**Stiffness (kip/in)**					
		Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
ROOF	X	171.5762	428.3949	489.3482	793.7056	464.9803	437.5657
Storey9		217.4004	871.4406	974.3542	1581.093	929.3949	887.9225
Storey8		224.8159	1269.285	1413.998	2296.543	1352.256	1294.267
Storey7		226.4525	1639.943	1828.61	2973.014	1753.045	1674.521
Storey6		227.089	2010.501	2247.827	3658.689	2160.158	2056.249
Storey5		227.7239	2416.938	2712.895	4419.265	2613.412	2476.549
Storey4		229.048	2916.219	3290.92	5361.016	3178.035	2994.931
Storey3		232.9831	3617.415	4114.064	6690.624	3983.001	3726.608
Storey2		247.2041	4787.555	5517.964	8919.651	5353.38	4954.59
Storey1		316.0141	7550.292	8961.552	14190.61	8692.83	7711.704
GF		928.7843	19166.16	25043.4	36486.52	25231.81	22188.32

Table 4-6: Storey Stiffness in X direction

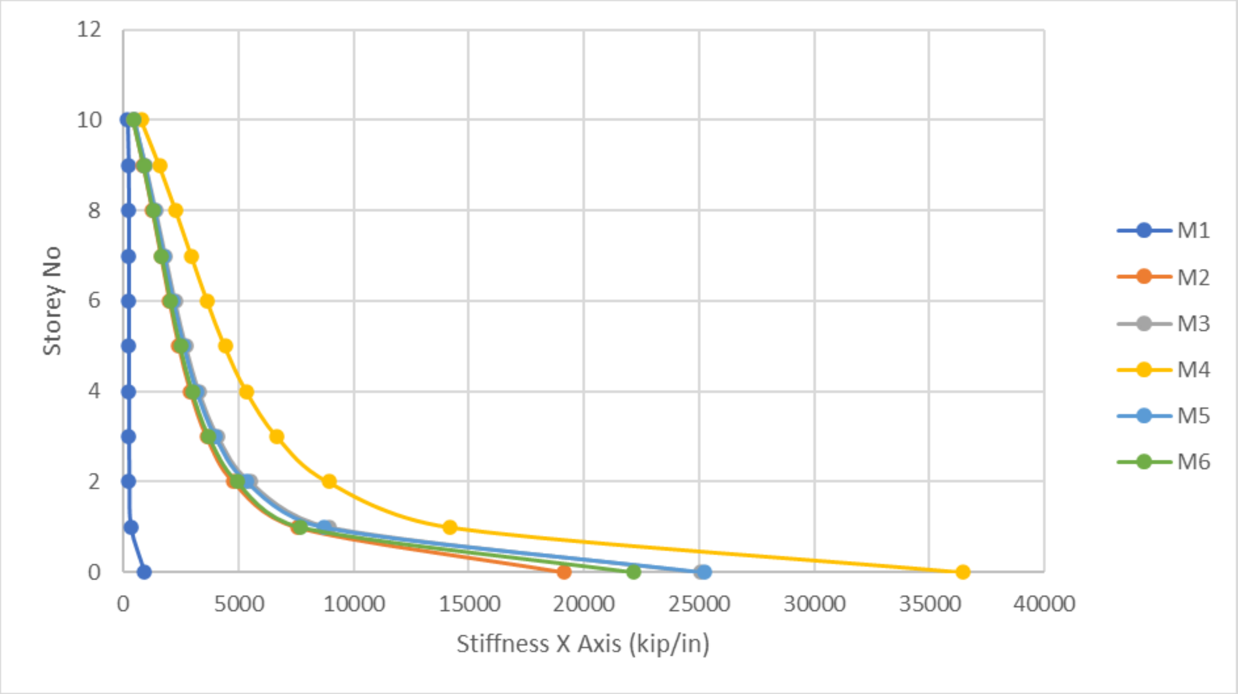


Figure 4-4: Storey Stiffness in X direction

From the above table it is seen that, Model-4 (Shear wall at periphery) has the highest value of stiffness which is 36486.52 Kip/in in ground floor. So, we can consider this model as best one in X direction. Model -1 (No shear wall) has the lowest value of stiffness which not desirable at all. Model-2 ,3& 6 has greater value of stiffness than Model-1. There is inverse relationship between stiffness and displacement. Model with shear wall at periphery has the lowest amount of drift in X direction. So, stiffness is maximum in this model in X direction. Comparing with other models at X- direction we can conclude that placing shear wall close to C.G. reduces the value of stiffness which is seen in Model-2 (Shear wall placed at center). On the other hand, stiffness Increases as we place shear wall away from C.G symmetrically at periphery which is seen in Shear wall at periphery case.

4.5.2 Storey Stiffness in Y Direction

Storey	**Direction**	**Stiffness (kip/in)**					
		Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
ROOF	Y	209.1224	229.7208	1410.241	381.904	286.0793	299.89
Storey9		292.6602	463.2626	2753.626	757.7103	566.169	608.7353
Storey8		313.9588	667.9845	3937.8	1094.444	814.2487	883.9728
Storey7		321.1803	852.1998	5024.639	1406.412	1041.548	1137.898
Storey6		324.8939	1031.055	6095.939	1717.256	1265.614	1389.527
Storey5		328.1392	1223.683	7248.549	2058.676	1509.762	1665.012
Storey4		332.9386	1459.574	8624.021	2481.619	1810.663	2006.235
Storey3		343.4071	1794.641	10472.62	3085.473	2239.108	2495.24
Storey2		373.1773	2367.193	13352.57	4120.41	2973.191	3340.798
Storey1		491.4322	3742.887	18795.8	6606.948	4751.628	5411.459
GF		1500.736	10793.72	44531.46	19526.5	14815.36	17598.36

Table 4-7: Storey Stiffness in Y direction

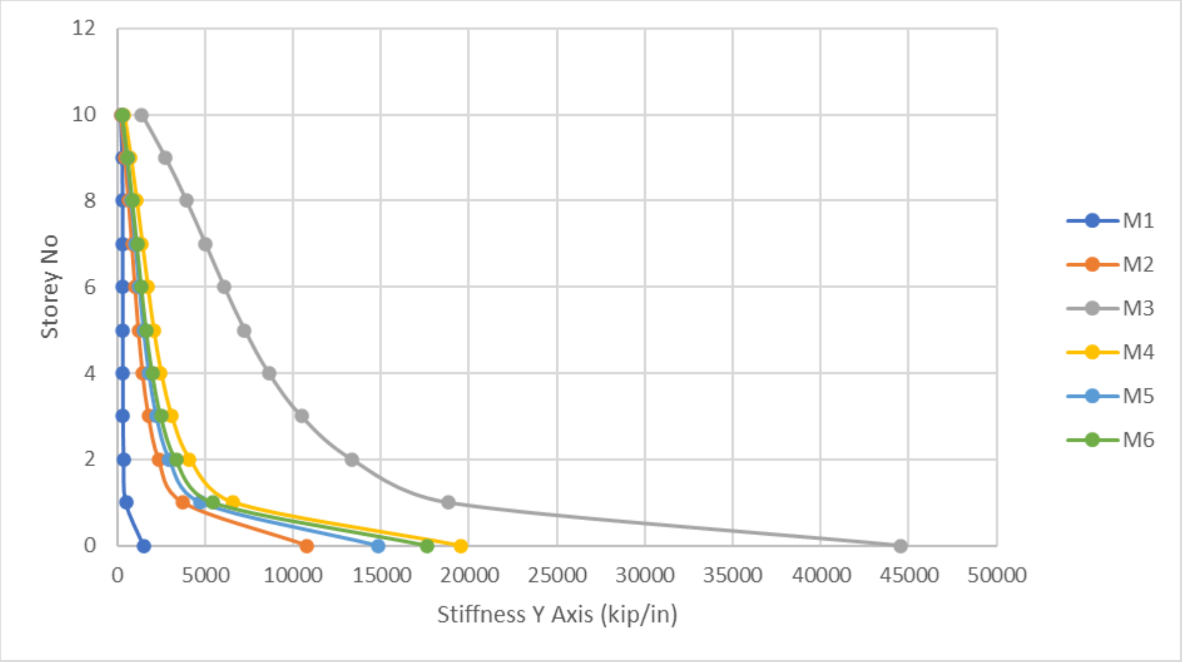


Figure 4-5: Storey Stiffness in Y direction

In Y direction, Model -3 (shear wall at sides & inner wall) has the greatest value of stiffness which is 44531.46 kip/in at Ground floor. As it has a low value of top displacement in Y direction (0.4359 in) it resulted in high stiffness value. Next, no shear wall model has the lowest value of stiffness of 1500.736 kip/in. Comparing Model-3 with other models it can be observed that providing shear wall in Both X and Y direction increases stiffness significantly. Next, Model-4 has the second highest value of stiffness which has a value of 19526.5 kip/in in ground floor. Both Model 3 and 4 has shear wall at Both direction which helped them to have a high stiffness value than others. Moreover, shear wall location is further away from C.G which also contributed in this matter.

In conclusion, Model-4 (shear wall at periphery) performs well in X direction & model-3 (shear wall at sides & inner wall) performs well in Y direction

4.6 Torsional Irregularity

9th Floor								
Model No	**Direction**	**Δ1**	**Δ2**	**Δmax**	**Δavg**	**Δmax/Δavg**	**Allowable Limit**	**Comment**
1	X	8.467457	8.467457	8.467457	8.467457	1	1.2	OK
	Y	5.787965	5.787965	5.787965	5.787965	1		OK
2	X	0.817754	0.817754	0.817754	0.817754	1		OK
	Y	1.595323	1.595323	1.595323	1.595323	1		OK
3	X	0.727076	0.727076	0.727076	0.727076	1		OK
	Y	0.276844	0.276844	0.276844	0.276844	1		OK
4	X	0.429738	0.429738	0.429738	0.429738	1		OK
	Y	0.913412	0.913412	0.913412	0.913412	1		OK
5	X	0.723228	0.723228	0.723228	0.723228	1		OK
	Y	1.241029	1.241029	1.241029	1.241029	1		OK
6	X	0.782897	0.782897	0.782897	0.782897	1		OK
	Y	1.151756	1.151756	1.151756	1.151756	1		OK

Table 4-8: Torsional Irregularity

According to BNBC torsional irregularity exists when ratio of maximum storey drift to the average of storey drifts in any direction is more than 1.2. If the values are more than 1 then we have to take measures to reduce torsional force. In above table we can see that, all of our ratio in both X and Y direction is 1 as our building is symmetrical and rectangular. So, we can conclude saying that all the values are within permissible limit & our models won’t have any torsional irregularity in any direction.

4.7 Time period

Model	**Time Period**
M1	3.75
M2	2.813
M3	1.011
M4	1.137
M5	1.328
M6	1.488

Table 4-9: Time period

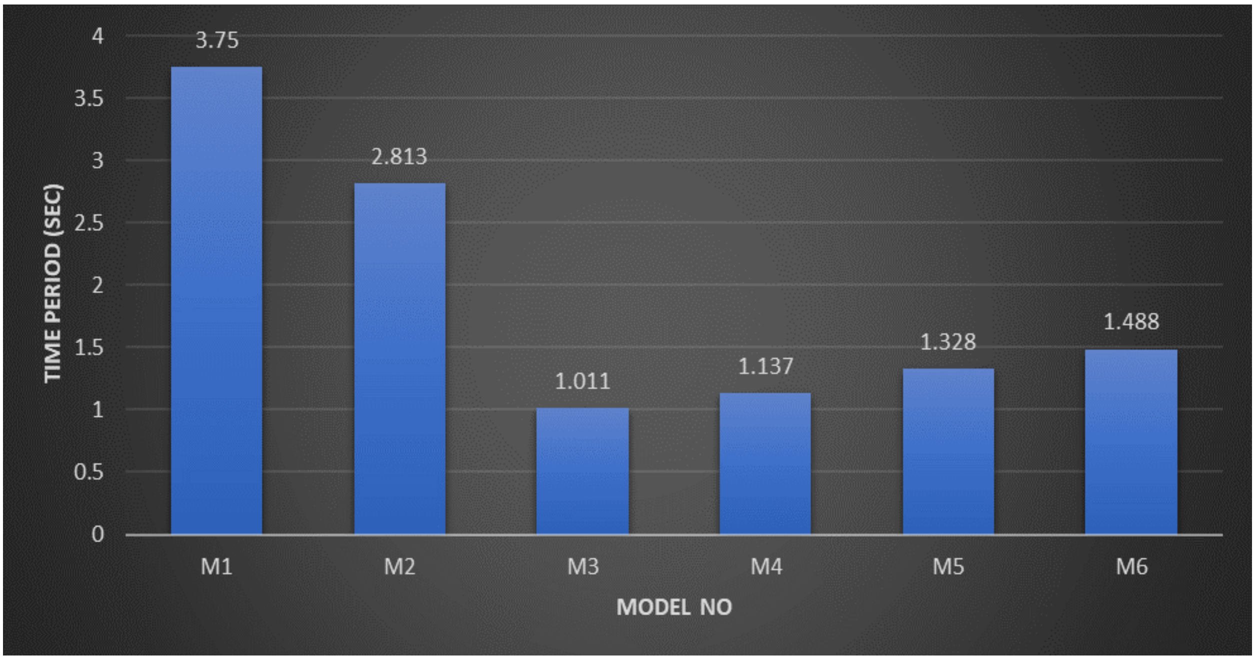


Figure 4-6: Time period comparison

From above statistics we can see that no shear wall case has the highest value of time period, about 2 times more comparing to other models in our study.

As, T= $\frac{2\pi}{p}$ where, T= time period in seconds and

p = Frequency in rad/sec.

As frequency decreases, time period increases and vice versa. If shear wall is located in the direction of seismic force then a greater value of time period is observed.

In above stats, Model-2 (shear wall at center) and Model-6 (shear wall at center & edges) has a time period value of 2.813 sec and 1.488 sec respectively. It's because in Model-2 (shear wall at center model) shear wall is located only in center compared to Model-6 (shear wall at center & edges) which has also shear wall support at edges. For this reason, Model-2 has greater value of time period.

Model-3 (shear wall at sides & inner wall) has the smallest value of time period among others which is 1.011 sec. Model -4 (Shear wall at periphery) has the second smallest value of time period in our analysis which is 1.137 sec. If we compare Model 3 & 4 with Model-2 (shear wall at center) it is seen that if shear walls are placed far away from the C.G then a lesser value of time period is obtained which is more desirable. Also, shear wall at sides and inner wall model has 3.7 times less time period than no shear wall case.

As placing shear walls in both directions away from C.G. gives lesser time period, we can finally conclude that Model-3 & 4 are the best desirable models among others against seismic activity.

4.7 Modal Analysis

Model	**1st Mode Shape**	**2nd Mode Shape**	**3rd Mode Shape**	**Comment**
M1	Translation(X)	Translation(Y)	Torsion(Z)	OK
M2	Torsion(Z)	Translation(Y)	Translation(X)	Not Desirable
M3	Translation(X)	Translation(Y)	Torsion(Z)	OK
M4	Translation(Y)	Translation(X)	Torsion(Z)	OK
M5	Translation(Y)	Translation(X)	Torsion(Z)	OK
M6	Torsion(Z)	Translation(Y)	Translation(X)	Not Desirable

Table 4-10: Modal analysis

In Modal analysis, first three mode of vibration are mainly considered. Translation is acceptable in first two modes and Torsion in the third mode.

From above table we see that Model 1,3,4 & 5 has met our requirements and thus shows no governing torsion. As torsion causes failure of structure it is not acceptable at all. On the other hand, Model-2 (shear wall at center) shows Torsion governing at its first mode of vibration which is not acceptable. Model-6 (Shear wall at center & edges) also exhibits same kind of behavior.

So, in Modal analysis, it can be concluded that only no shear wall model, Shear wall at sides & inner wall model, Shear wall at periphery model & shear wall at corners model are desirable.

Judging all the criteria which are Storey shear, Storey drift, Storey Displacement, Storey Stiffness, Torsional Irregularity Check, Time Period Analysis & Modal Analysis we can come to a conclusion that Shear wall at sides & inner wall and shear wall at periphery performs best which are Model 3 & 4 respectively.

Both model 3 & 4 perform well in our selected criterions. But Model-4 (shear wall at periphery) is the most desirable because it incorporates less storey shear at ground floor than Model-3 (Shear wall at sides & inner wall). By adopting model 4's shear wall orientation and location we can reduce the effects of seismic activities on RC building greatly to some extent.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 General

The main objective of this study was to find the optimum location and orientation of shear wall to resist the lateral forces. This chapter describes the summary of the research findings based on the results and discussions in chapter 4. Moreover, recommendation and future works related to this investigation are also mentioned in this chapter.

5.2 Conclusions

Based on the experimental result of this study, the following conclusions are drawn:

- It has been observed that the utilization of shear wall can contribute in decreasing lateral displacements, storey drift and increasing stiffness of structure.
- By comparing shear wall at center model and shear wall at center & edges model, we can conclude that shear wall should be placed in both short and long direction.
- Shear wall at periphery model undergoes less drift and displacement in X direction. On the contrary, shear wall at sides & inner wall model undergoes less drift and displacement in Y direction.
- Lateral displacement of no shear wall model is more than permissible limit prescribed in the code (h/500). Other than that, displacement in each direction is within the limit for other models except for shear wall at center model.
- With increasing length of shear wall, the stiffness of the structure also increases. In this study, Shear wall at periphery (X direction), shear wall at sides & inner wall (Y direction) model shows maximum storey stiffness.

- No torsional irregularity was found in any case because of symmetrical building shape
- Shear wall at periphery and shear wall at sides & inner wall model shows relatively low natural time period among all.
- From modal analysis it has been found that torsion is governing the first mode of vibration in shear wall at center and shear wall at center & edges which are not desirable.
- Assessing all the parameters Shear wall at periphery model is found relatively better.

5.3 Recommendations

From this study, this is evident that shear walls work better when they are placed in both directions compared to the cases where shear walls are placed in only one direction. Again, among all the cases it is seen that shear walls provide maximum resistance to lateral forces when they are placed along the periphery. So, for a symmetrical or nearly symmetrical high-rise building it would be very effective to provide shear walls along the periphery in both directions.

5.4 Future Scopes

- This study was performed for a 10 storey building in seismic zone II of Bangladesh. Further study can be carried out for higher storey buildings in other seismic zones of Bangladesh.
- All the important parameters like storey shear, storey drift and displacement, stiffness, torsional irregularity etc. are considered in this study. However, some other parameters such as soft storey effect can be introduced for further analysis.
- This whole study is performed for a symmetrical structure. If the structure is unsymmetrical, the optimum location and orientation of the shear walls may vary. There have been very few works on unsymmetrical structures and so there is a huge scope of further study and analysis of optimum location of shear wall in unsymmetrical structures.

REFERENCES

Belgaonkar, S., Amarnath, A., Bevinakatti, S., Pise, N., & Auti, K. (2017). Effectiveness of Shear wall Orientation in RC Framed Structures under the action of Seismic Forces. International Journal Of Emerging Technology And Advanced Engineering(ISSN 2250-2459, Volume 7, Issue 3, March 2017).

Atmaca, N., Sangola, S., & Atmaca, A. (2018). The Shear Wall Effect On Concrete Structures. In 3rd International Energy & Engineering Congress Proceedings Book. Gaziantep University, Turkey.

Halkude, S., Konapure, C., & Birajdar, S. (2015). Effect of Location of Shear Walls on Seismic Performance of Buildings. International Journal Of Current Engineering And Technology, Vol.5, April 2015.

Ali, S., & Aquil, M. (2014). Study of Strength of RC Shear Wall at Different Location on Multi-Storied Residential Building. Int. Journal Of Engineering Research And Applications, ISSN : 2248-9622,, Vol. 4(Issue 9(Version 5), pp.134-141, September 2014)

Rao, M. (2018). Optimum location of a shear wall in a R.C building. International Journal Of Scientific & Engineering Research, Volume 9, Issue 7, July-2018, ISSN 2229-5518.

Tajzadah, J., Desai, A., & Agrawal, V. (2019). Optimum Location of Shear Wall in RC Building. 2019 JETIR April 2019, Volume 6, Issue 4.

Ganesh, C., Jagan, S., & Muthukannan, M. (2016). International Journal of Advances In Mechanical And Civil Engineering, (ISSN: 2394-2827 Special Issue, Sep.-2016).

Rokanuzzaman, M., Khanam, F., Das, A., & Chowdhury, S. (2017). Effective Location Of Shear Wall On Performance Of Building Frame Subjected To Lateral Loading. International Journal Of Advances In Mechanical And Civil Engineering, ISSN: 2394-2827 Volume-4, Issue-6, Dec.-2017.

Dane, A., & Pendharkar, U. (2019). Effective Positioning of Shear Wall in G+5 Storey Building on Sloping Ground. International Journal Of Engineering And Advanced Technology (IJEAT), ISSN: 2249 – 8958, Volume-9 Issue-2, December, 2019.

Prasad, V., Sujatha, M., & Supriya, M. (2014). Optimum Location of a Shear Wall in High Rise U-Shape Building. International Journal Of Engineering Research & Technology (IJERT), Vol. 3(Issue 8, August - 2014).

Mishra, S., Rai, R., & Mishra, N. (2018). Effective location of Shear Wall, its significance and displacement analysis. International Research Journal Of Engineering And Technology (IRJET), Volume: 05(Issue: 03).

Sreeram, K., Singh, R., & Kumar, S. (2017). Effective Location Of Shear Walls And Bracings For Multistoried Building. International Research Journal of Engineering And Technology (IRJET), Volume: 04(Issue: 01).