بسم الله الرحمن الرحيم

DIFFERENT ORIENTATION OF SHEAR WALL IN A REINFORCED CONCRETE BUILDING TO CONTROL DRIFT AND DEFLECTION

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PROJECT APPROVAL

This is to certify that the dissertation entitled "**Different Orientation of Shear Walls a in Reinforced Concrete Building to Control Drift and Deflection**" submitted by Shahariar Alam, Chowdhury Zubayer Bin Zahid, Azmain Fahik, and Minhaz Imran Khan has been approved as partial fulfillment of the requirement for the Degree Bachelor of Science in Civil Engineering at the Islamic University of Technology (IUT).

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DECLARATION

We declare that the undergraduate research work reported in this thesis has been performed by us under the adept supervision of Professor Dr. Md. Tarek Uddin. Appropriate precautions have been taken to ensure that the work is original. This work has not been plagiarized and submitted elsewhere for any other purpose (except for publication).

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DEDICATION

We dedicate this thesis to our parents, who have sacrificed their valuable time, livelihood, and effort over many years to ensure that we could be who we are today. They have motivated and encouraged us to fulfill our engineering ambitions without ever looking back. We shall be eternally grateful to them.

We would also like to express heartfelt gratitude to our respected supervisor Professor Dr. Md. Tarek Uddin for his continuous support and inspiration, without whom this work would not be possible.

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

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ABSTRACT

In recent times, the construction of high-rise buildings and skyscrapers are becoming the norm in modern cities. However, there is a growing concern about whether the building designs are efficient in developing countries like Bangladesh which lies on the tectonically active Himalayan orogenic belt and is considered one of the high earthquake risk zones. Dhaka has more high-rise buildings than any other cities in Bangladesh, and it is critical to control the lateral loads that cause seismic hazards to the towering structures. Shear wall systems are one of the most feasible and commonly deployed solutions for resisting lateral loads. It can induce eccentricity in a structure, which is the primary source of torsion. This study has attempted to determine the correct orientation and placement of shear walls in a regular G+15 story reinforced concrete building to observe the nature of the structure exposed to the earthquake by adopting Equivalent Static Analysis. The computer application program CSi ETABS 2019 analyzed the drift, displacement, stiffness, story shear, torsional irregularity and compared eight models with different shear wall placements. The analysis featured the seismic zone II and soil type D according to the BNBC 2020 guideline. Results reveal that shear walls placed symmetrically and along the shorter span for the selected structural plan have shown less lateral drift and displacement than structures with other shear wall orientations

Key Words: Shear Wall, Story shear, Drift, Displacement, Stiffness, ETABS.

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1 INTRODUCTION

1.1 General

Earthquake is a global phenomenon that impacts the livelihood of millions of people every year [1]. The increasing number of earthquakes has caused enormous loss of human lives and resources and massive disruption to social organization and infrastructure [2]. An earthquake is the movement or trembling of the earth's tectonic plates caused by a rapid release of energy in the lithosphere, which results in seismic waves. As Bangladesh is located between significant fault lines, the damage due to a major earthquake will be massive [3]–[5]. Dhaka, the capital of Bangladesh, is an earthquake-prone zone and suffering from significant losses due to unplanned development. High population density, unreinforced masonry buildings, adjacent buildings in proximity, unregulated build shape, and other infrastructure inadequacies have made the city vulnerable to imminent earthquakes [6]. As per studies, a magnitude 6.0 earthquake in Dhaka would result in a financial loss of $1,075 million US dollars and the destruction of 78,323 urban structures [7]. Therefore, it is crucial that the buildings in Dhaka city are appropriately designed, maintaining proper codes and specifications.

Bangladesh has been classified as one of the most disaster-prone countries in the world, with 97.7 percent of its total population at risk of numerous hazards, including cyclones [8]. Hence, the wind load and the earthquake load are the prime lateral loads for concern in the case of building structures in Bangladesh. Due to the swift increase in urban population density, the Bangladesh National Building Code (BNBC) 2020 has stressed the stringent seismic design criteria as per ASCE 7-05.

Lateral loads cause sway movement and vibration in structures, rendering them unsuitable for any service. [9]. Story drift and deflection quantify the effects of lateral loads on reinforced concrete structures. The relative difference between the displacement of two consecutive floors is known as story drift. [9]. Story drifts serve as a measure for structural damage and provide a variety of data in case of rigid-body displacement. The total displacement of any story with regard to the ground is known as story deflection. BNBC 2020 and ASCE 7-05 both prescribed a maximum limit for story drift and deflection.

Because of this, the shear wall system has become an essential part of the design to resist in-plane lateral forces, typically wind and seismic loads, by influencing the center of mass and center of rigidity. In recent days, numerous medium to high-rise structures in Bangladesh are being constructed with a shear wall system. Studies have proven that shear wall reduces maximum story drift efficiently and provides better seismic performance for high-rise buildings [10]. The addition of a shear wall makes the building resilient enough to hold the loads coming on the structures [11]. Shear walls are simple to construct since the wall reinforcement detailing is very simple to execute on the job site. Because of its high load capacity, enhanced flexibility, and stiffness, reinforced concrete shear walls are ideal for structures in seismic zones. [12], [13]. It can withstand lateral loads caused by wind, earthquakes, and hydrostatic earth pressure. Shear walls are a typical practice in earthquake-prone regions, and they are also budget-friendly to use in construction. [14].

This study investigates the effect of the shear wall in controlling the lateral loads for different shear wall placements in a regular building plan. The building's stability was assessed using the permissible story drift and deflection limits specified in BNBC 2020 and ASCE 7-05. This research will help future structural designers in Bangladesh and the South Asian area to build more efficient and sustainable earthquake-resistant structures.

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 story 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:

- In the direction of orientation, provide a lot of strength and rigidity.
- Significantly reduces lateral sway.
- Easy construction and implementation.
- Effective in terms of reducing earthquake damage and construction costs.
- Thinner walls.
- Light weight.
- Fast construction time.

Disadvantages of shear wall:

- Flimsy appearance.
- Web plate buckling results in loud banging sounds.
- Low energy dissipation capacity.
- Requires large moment connections
- Can not be constructed on isolated footing

Story Shear: When it comes to lateral load analysis, the story shear and story drift plots are two extremely basic and sometimes overlooked methodologies for the structural engineer. In one technique of constructing a structure for seismic resistance, the design seismic force is assumed to be applied at each floor level. The floor slab is known to be particularly rigid in its own plane due to the large width of the frame. As a result, all floor slabs are thought to move laterally in their respective planes when subjected to seismic energy. Story shear is the seismic design force that must be provided at each level of the floor. It is a fraction of the overall dead load and a part of the live load running at the floor stage.

Story shear is a type of force that depicts the amount of lateral load acting per story, whether caused by wind or seismic activity. The shear grows higher the lower we go. In story shear, one can consider the potential controlling lateral load on a given surface in a particular direction. And this will help to explain or investigate why wind dominates in some regions and seismic in others.

$V = Cs \times W$ is the base shear formula. V represents the shear force created at the base of a building. The number Cs denotes seismic acceleration. The building's weight is denoted by the letter W.

Story Drift: Story Drift is defined as lateral displacement relative to the level below. The story drift ratio is the story drift divided by the story height.

Total drift (the total lateral displacement at the top of the building) has been established, and inter-story drift (the relative lateral displacement between two consecutive levels) has been established. The maximum permissible value of drift in our study is 0.48.

Story Displacement: The lateral displacement of the story relative to the base is known as story displacement. The building's excessive lateral displacement can be limited by the lateral force-resisting system.

The terms "story drift" and "displacement" have some distinctions. The displacement ratio of two consecutive floors to the height of that floor is known as Story Drift. It's a crucial term in earthquake engineering and earthquake research.

Story Displacement- The maximum permitted limit for structures is the overall displacement of the story with respect to the ground. The maximum horizontal deflection we may allow for wind load is = H/500 = 3.60 in.

Story Stiffness: In structural engineering, the term "stiffness" refers to the rigidity of a structural element. In general, this refers to an element's ability to resist deformation or deflection under the influence of an applied force. Both directions are taken into account when calculating stiffness. More stiffness implies a more rigid frame.

Torsional Irregularity: Torsional irregularity is the state where the actual story drift, including accidental torsion, is more than 1.2 times the average of the maximum and minimum displacement at the two corners of the structure. Torsion is the state of stress in a material that an applied torque has twisted. Whenever a structural feature is subject to a twisting force, it will occur. Torsion produces 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 center of stiffness and the center 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.

1.2 Background

By definition shear wall is a rigid vertical diaphragm capable of transferring lateral forces from the exterior structures like walls, floors and roofs to the foundation below ground in a parallel direction to their planes. The proper location and placement of a shear wall is necessary to resist not only the lateral forces but also to improve the safety of the structure. The primary goal of providing shear walls is to reduce the lateral swaying of structures due to factors like wind which can damage to the structure and its components. The orientation of a shear wall is as important as its presence because a defective shear wall can be responsible for destruction of the structure while a properly placed shear wall can protect the structure from lateral loads and sway. Our thesis was focused on finding the proper position and orientation of shear wall for controlling drift & deflections.

1.3 Objective of the Study

The primary objectives of this study are mentioned below:

- To locate the ideal position and orientation of shear wall in order to control deflections and drift from lateral wind and seismic loads in high story buildings.
- To provide adequate strength & stiffness to buildings in order to resist lateral forces.
- To resist sideways sway of the building.
- To minimize damage to structure and its components in calamities like earthquake and cyclones.

1.4 Methodology

A G +15 story regular-shaped building was chosen for the investigation. The structure measured 105 feet by 75 feet in size. Each story had a uniform height of 10 feet. A total of eight models were developed, each with shear walls pointing in different directions. To understand the efficiency of the shear wall, Model 1 had no shear walls. The ETABS software was used for modeling, and the version was ETABS 2019. The soil type was classified as type D in the models as it is mentioned in BNBC 2020 that if we don’t have any soil data, we must use soil type D. The Earthquake zone was seismic zone II under BNBC 2020, with Z = 0.20, because the project was considered in Dhaka. All of the models took into account a variety of characteristics such as lateral displacement, story drift, torsional irregularity, stiffness, and so on. The models were analyzed using the Equivalent Static Analysis.

1.5 Research Flow Diagram

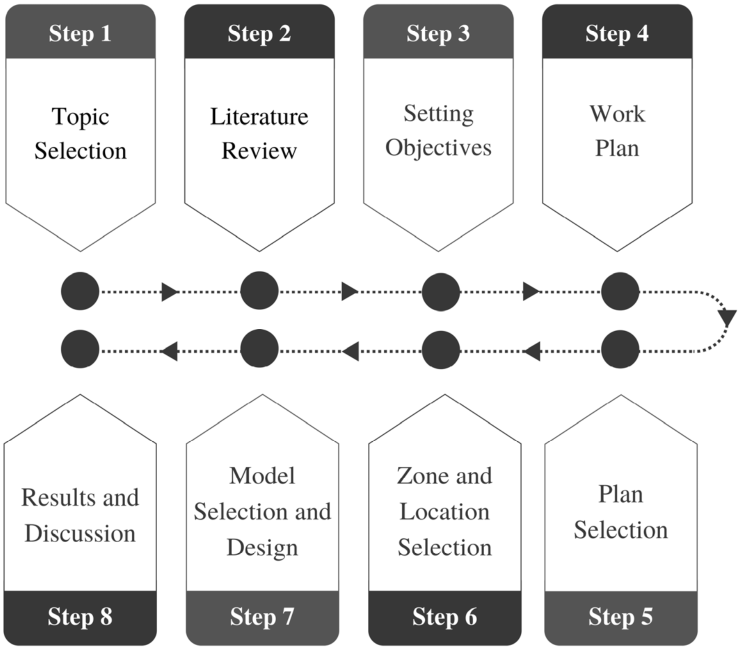

Figure 1: Research Flow Diagram

1.6 Layout of the Thesis

The thesis was organized in the following way.

CHAPTER 1

Introduction - The current chapter, that discusses about the theory, background, objectives, boundaries and work diagram.

CHAPTER 2

Literature Review - The chapter discusses the relevant works in the field by previous authors and comprehensive study of their respective findings.

CHAPTER 3

Methodology - The chapter discusses all the procedures and steps that were followed to conduct the study.

CHAPTER 4

Results and Discussion - Obtained data and their results were included in the chapter. The chapter also includes the findings and mathematical verdicts of the study.

CHAPTER 5

Conclusion and Recommendations - General discussion, limitations, recommendations and future scopes of work was discussed in the chapter.

2 LITERATURE REVIEW

Shahzad Jamil Sardar et al. [15] used ETABS to model a 25-story structure and analyze various characteristics such as story drift, story shear, and displacement by changing the location of the shear wall. The base shear was determined and compared using static and dynamic analysis. When compared to previous models, the model with the shear wall in the center and four shear walls parallel to the X and Y directions demonstrated less displacement and inter-story drift with maximum base shear, as well as higher structure strength and stiffness.

Anuj Chandiwala [16] investigated a ten-story RC structure on medium soil. Shear wall at end of L section, L Shear wall at junction of 2 flange portion, two parallel L shear wall at junction of 2 flange portion, Tube type shear wall at junction of 2 flange portion, two parallel shear wall at end of flange portion were the varied building configurations. The analysis revealed that, as compared to other models, the shear wall at the end of the L section is most suited for base shear since the terminal portion of the flange oscillates more during earthquakes.

Israa H. Nayel et al. [17] have carried out a comparative study on the effect of change in shear wall location on story drift of multistorey building buildings that are subjected to lateral loads. ETABS modeling was carried out on different models based on the finite element method. The main finding was that major displacement is seen in the top story of the buildings with minimum displacement in the lower story. The research also found that buildings with side shear walls resisted the most displacement. The effect on the shear wall on lower story is negligible.

In **Jawid Ahmad Tajzadah et al.** [18] paper the optimum location of the shear wall in an RC building has been studied. It has been found that shear walls positioned at the central core of a building have more resistance to seismic loads because of higher tendency to the attraction of lateral loads. In order to increase the torsional resistance, shear walls should be located far from the building core. Ideally, shear walls should be located in the inner bays of the building. The paper took into account only one seismic zone whereas multiple seismic zones can be included in the study.

Tarun Magendra et. al. [19] concluded that in traditional buildings, shear walls placed in the center or at the corners of the plan form a box representing that the structure is more stable for parameters such as story displacement and story drift, and overturning moments are minimal.

G. GEETHA et al. [20] has performed a study on seismic analysis of multistoried building with shear walls. The study deduced that the structural soundness of a building can be made better using shear walls. The inclusion of shear walls has brought forth increased stiffness to the structure.

Kusuma. S et al. [21] have performed a comparison of response spectrum analysis and time history analysis for a multi-story building using ETABS and discovered that when compared to time history analysis, the response spectrum method gives more accurate results and yields higher base shear values.

Hardik Mandwe et al. [22] have done a seismic analysis of multistory buildings with shear wall using STAAD pro where parameters such as displacement, torsion and deflection were analyzed. It was concluded that the RC framed building with Shear wall has good resistance to earthquake and can sustain the vibrations due to earthquake. It can be observed that the maximum displacement against earthquakes is very less because of shear walls as compared to the bare frames.

M. Jesse Leo et al. [23] analyzed a G + 15 story building by means of Response spectrum and P-Delta effect analysis. It was concluded that the more the number of stories, the more profound was the P-Delta effect. The maximum story displacement and the maximum story drifts of the building acquired by means of P-Delta analysis were more in comparison to the same attained via Response spectrum analysis.

B. Jaswanth et al. [24] analyzed a RC Frames Building for Different Position of Shear Wall by using Etabs. For the analysis of the building for seismic loading with Zone-III is considered with soil III. The analysis of the building is done by using equivalent static method and dynamic method. The analysis of building with Core shear wall and edge shear wall shows that Shear wall at core shows stiffer behavior. When shear walls are provided on edge maximum storey displacement of buildings is increased comparing to when shear walls are provided on center portion.

3 METHODOLOGY

3.1 General

Several critical factors such as story shear, story drift, story stiffness, torsional irregularity, and others were evaluated in the experiment using eight distinct structural models with varying placements of shear walls. Different approaches were used to attain the study's goal, and by adopting these ways, a direct route was established to complete the study's scope. This chapter goes through the experimental methodologies used and the material attributes of the structural models in detail. Furthermore, all of the models in our research adhere to the "Bangladesh National Building Code 2020." The buildings were modeled using the ETABS v 19 program.

3.2 Work Sequence in ETABS

A flow chart depicting the overall work completed using ETABS software is presented in Figure 2.

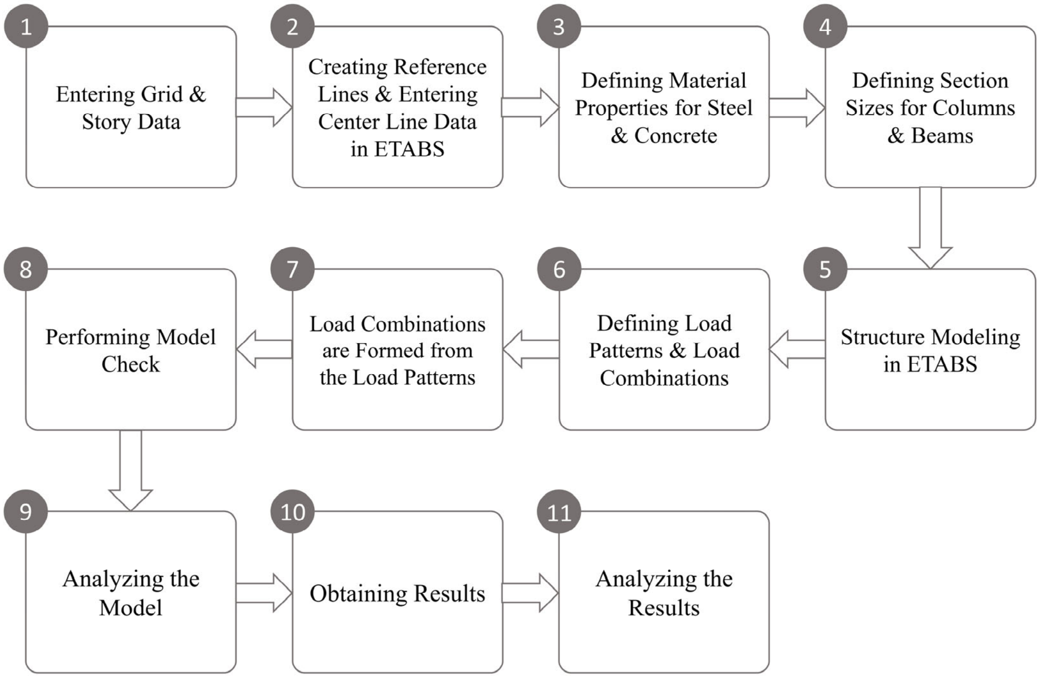

Figure 2: Work Sequence in ETABS

3.3 Structural Plan

The structural plan selected for the study is a regular G +15 story reinforced concrete building. The 2D view and 3D view of the building has been shown in Figure 3 and Figure 4 respectively.

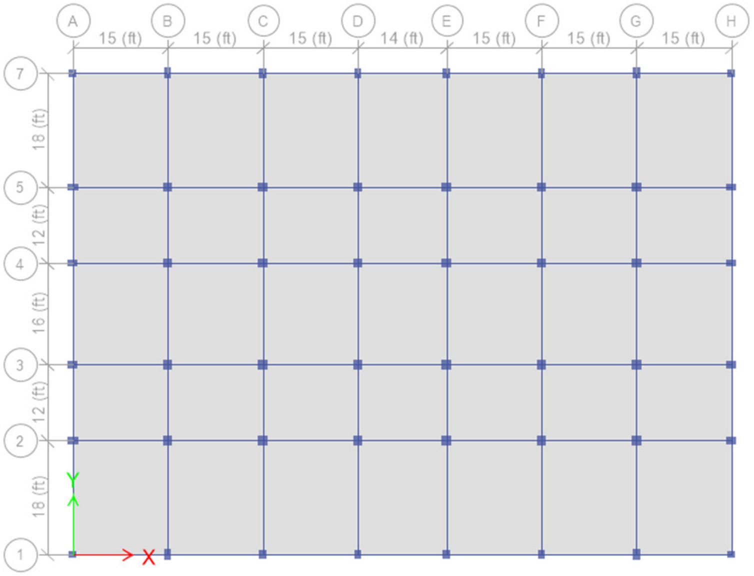

Figure 3: Structural 2D Plan

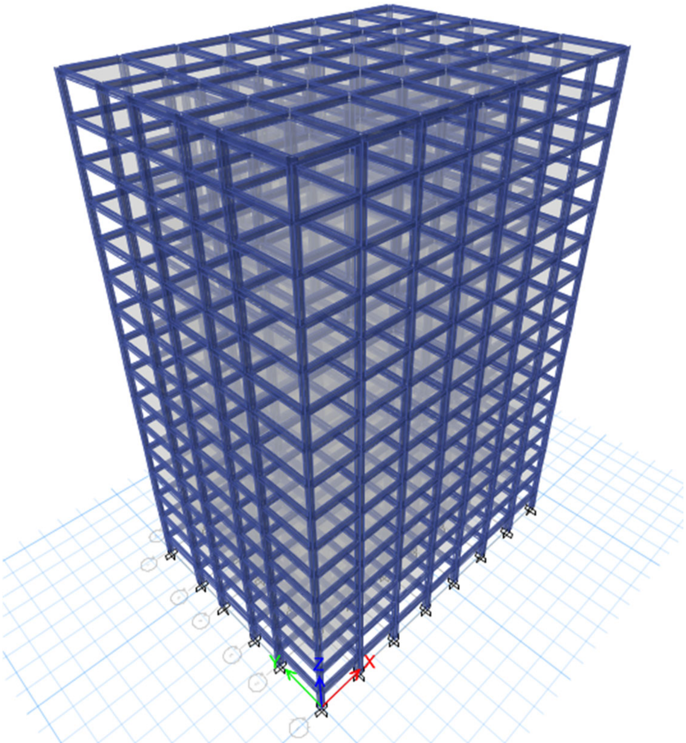

Figure 4: Structural 3D Plan

3.4 Structural Models

For the study, the selected structural models with different shear wall placements are presented below.

1. **Model 1**

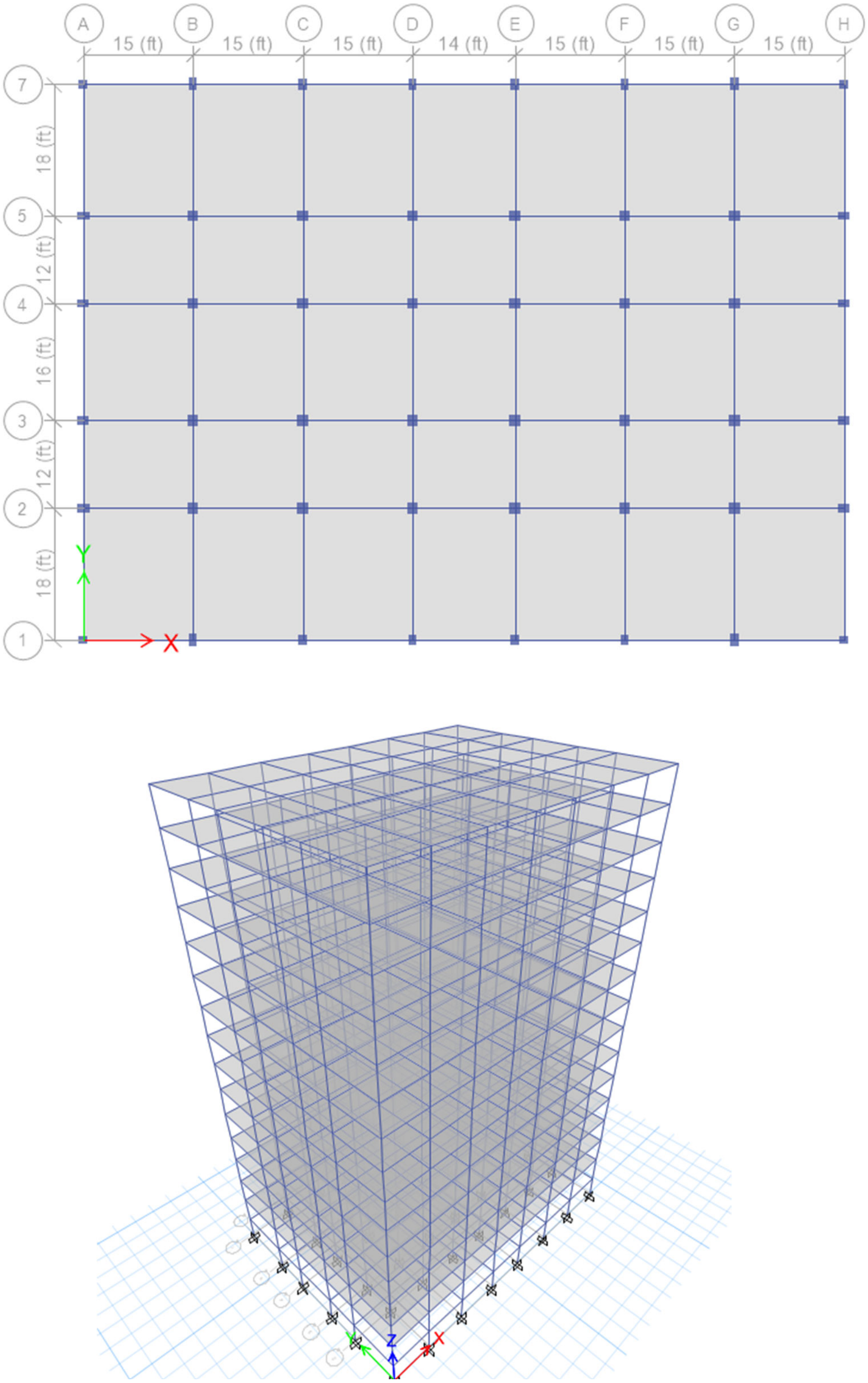

Figure 5: Model 1 Structural Plan

2. Model 2

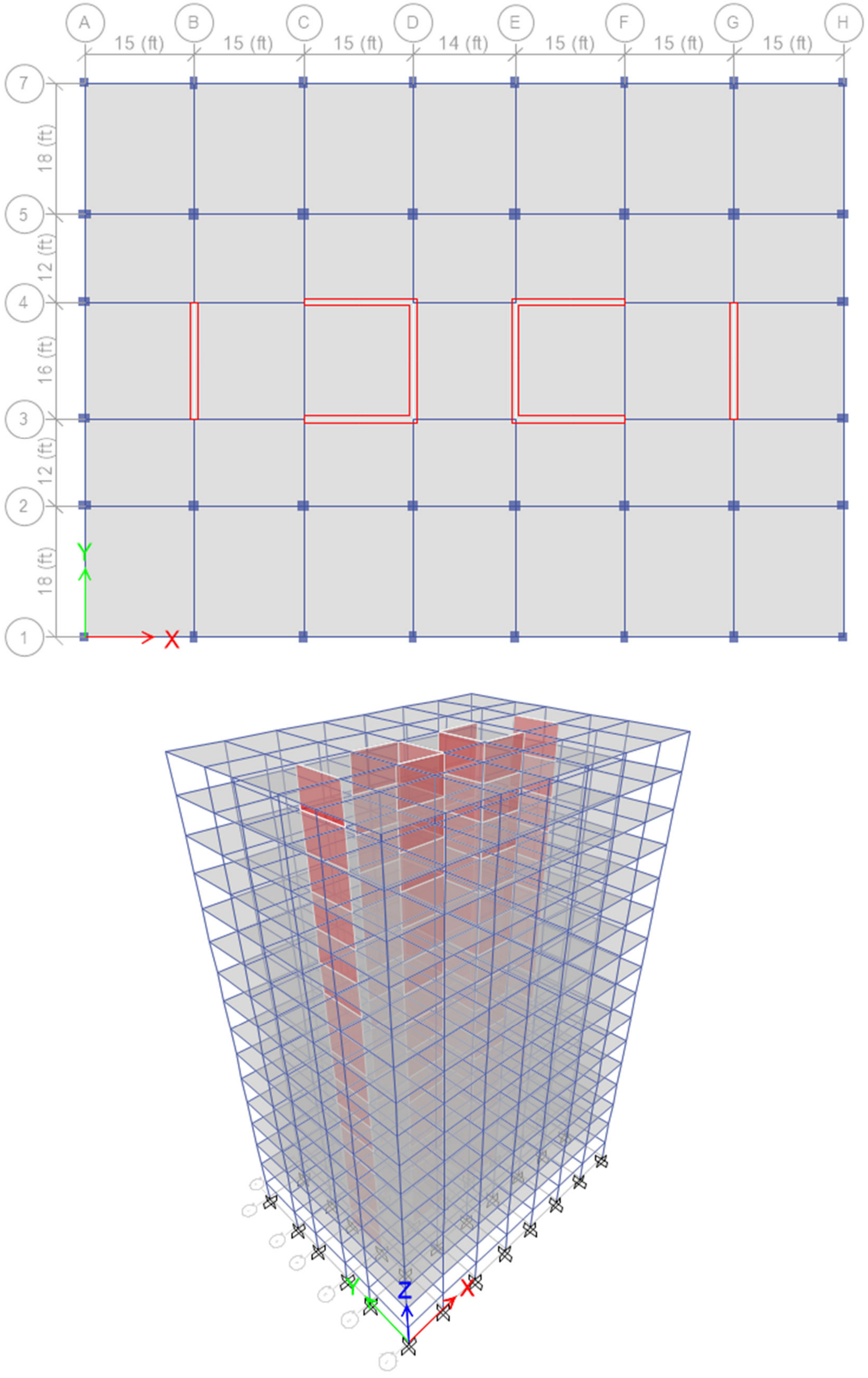

Figure 6: Model 2 Structural Plan

3. Model 3

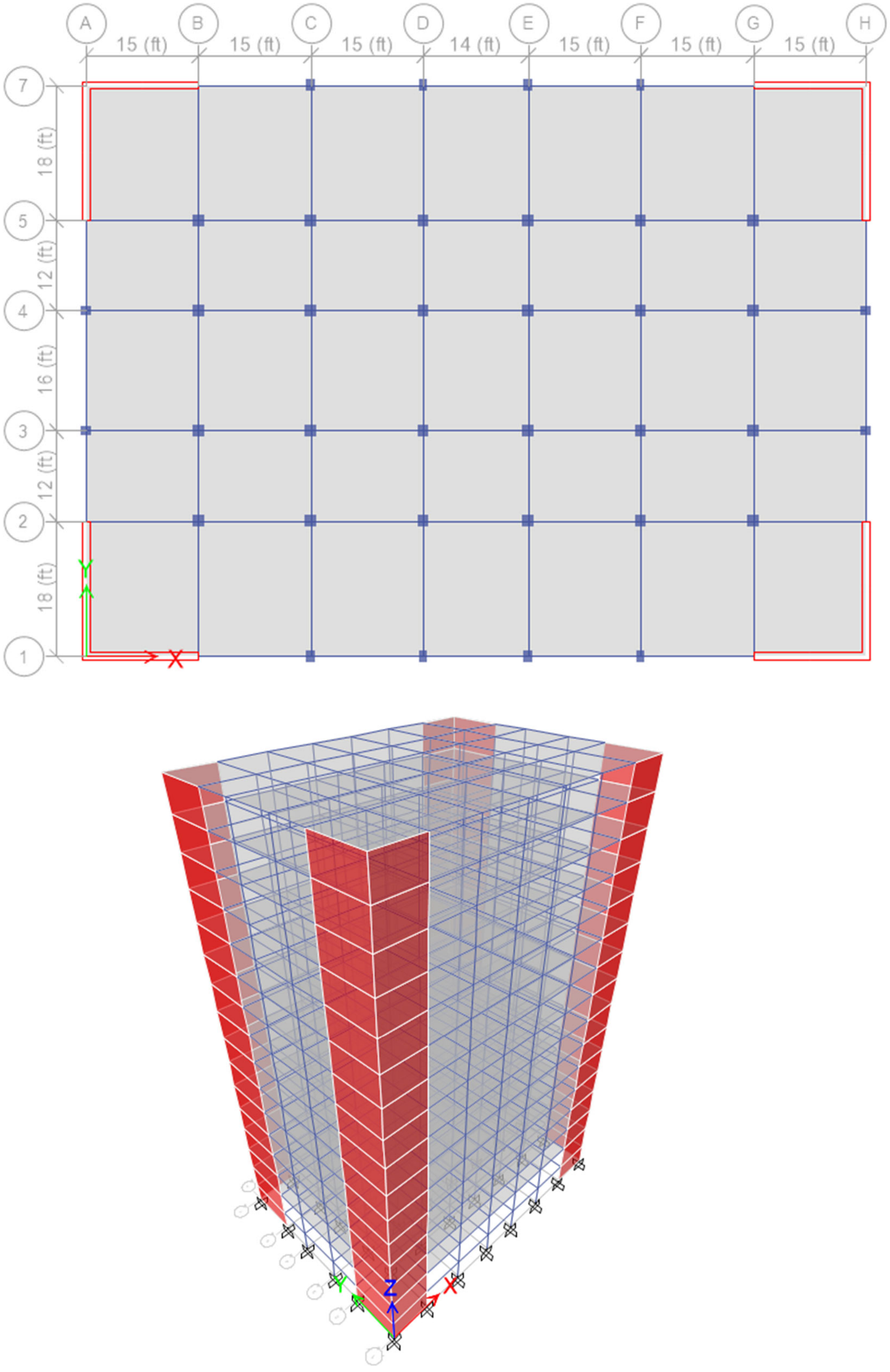

Figure 7: Model 3 Structural Plan

4. Model 4

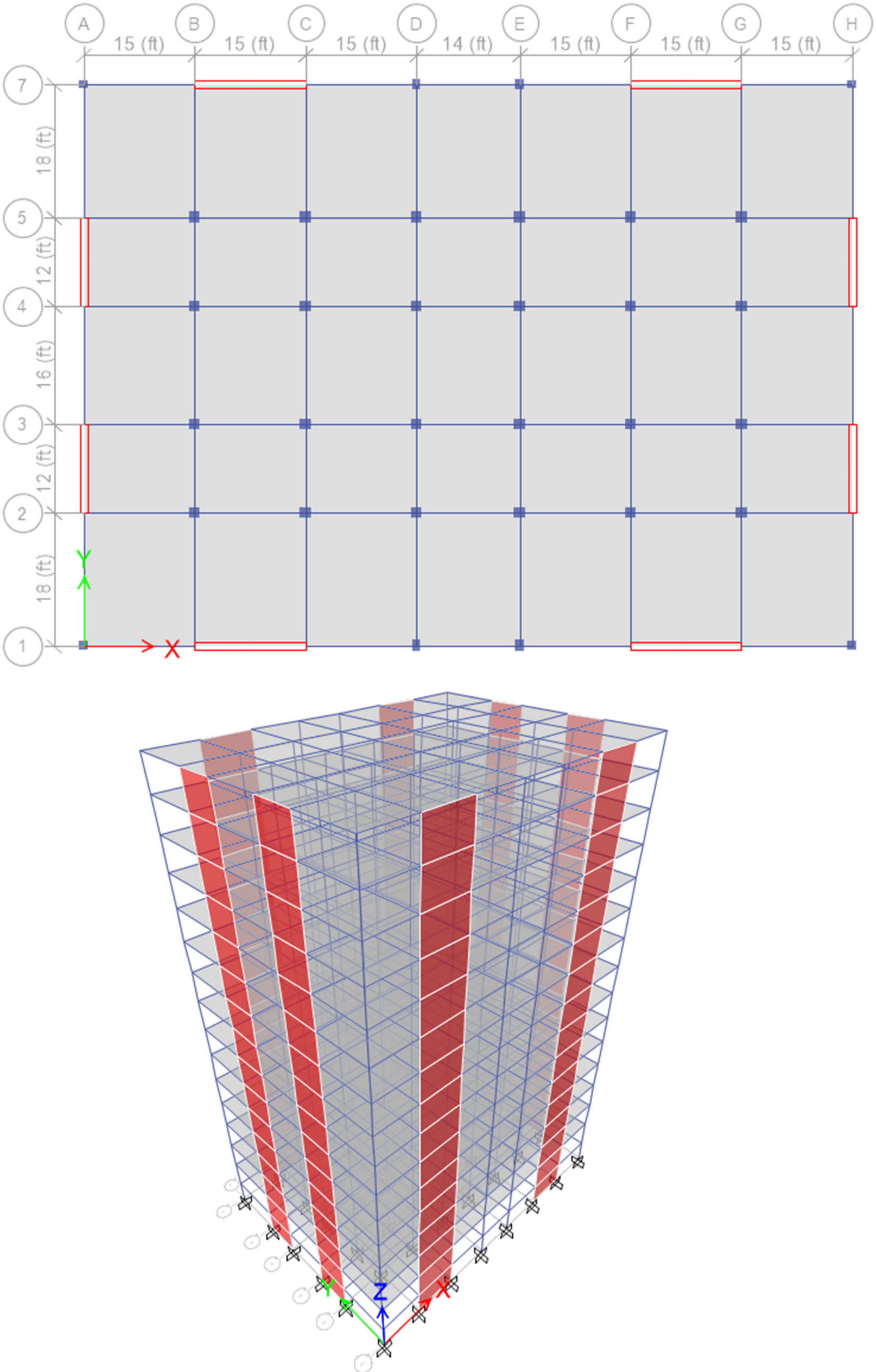

Figure 8: Model 4 Structural Plan

5. Model 5

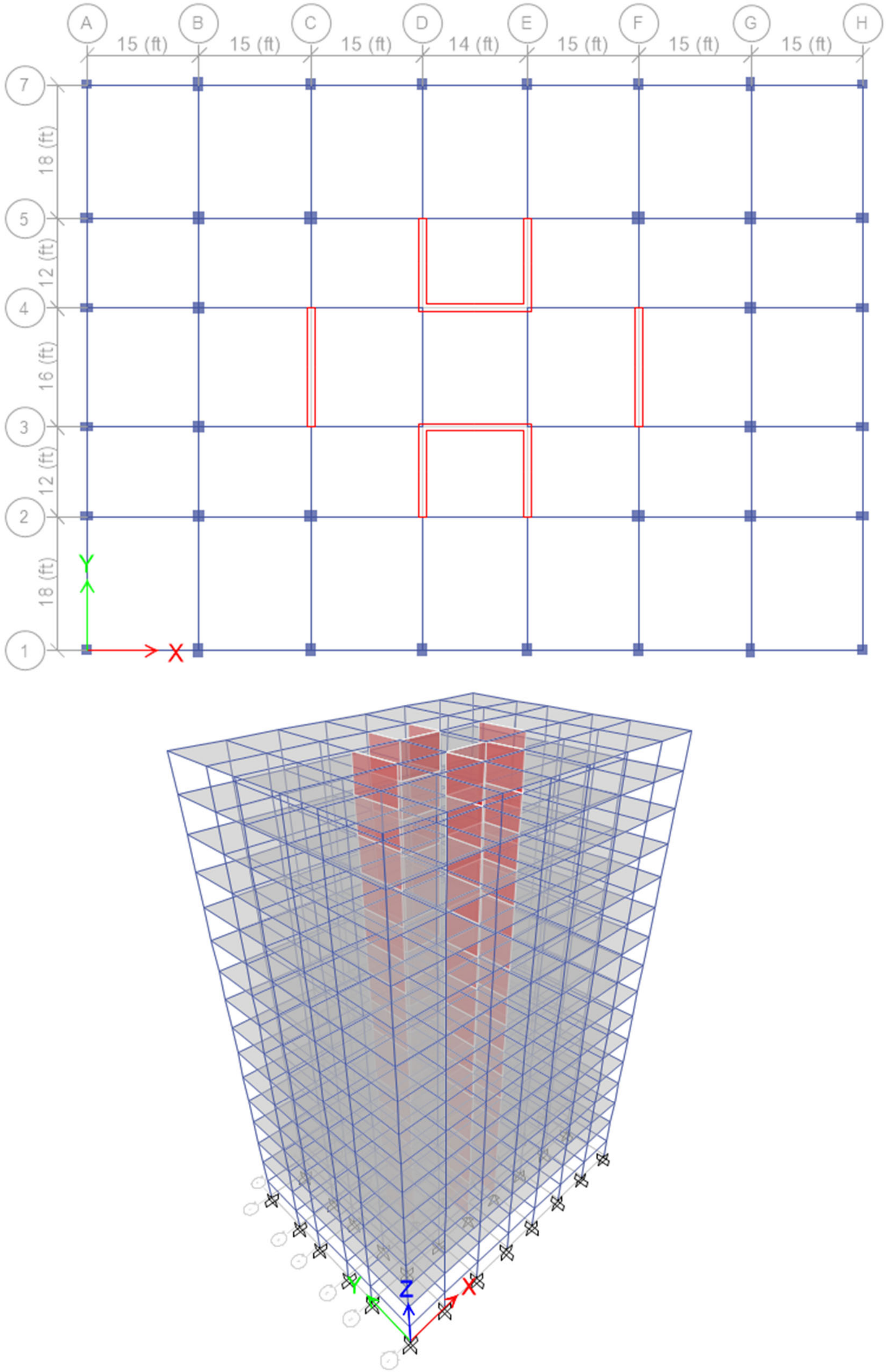

Figure 9: Model 5 Structural Plan

6. Model 6

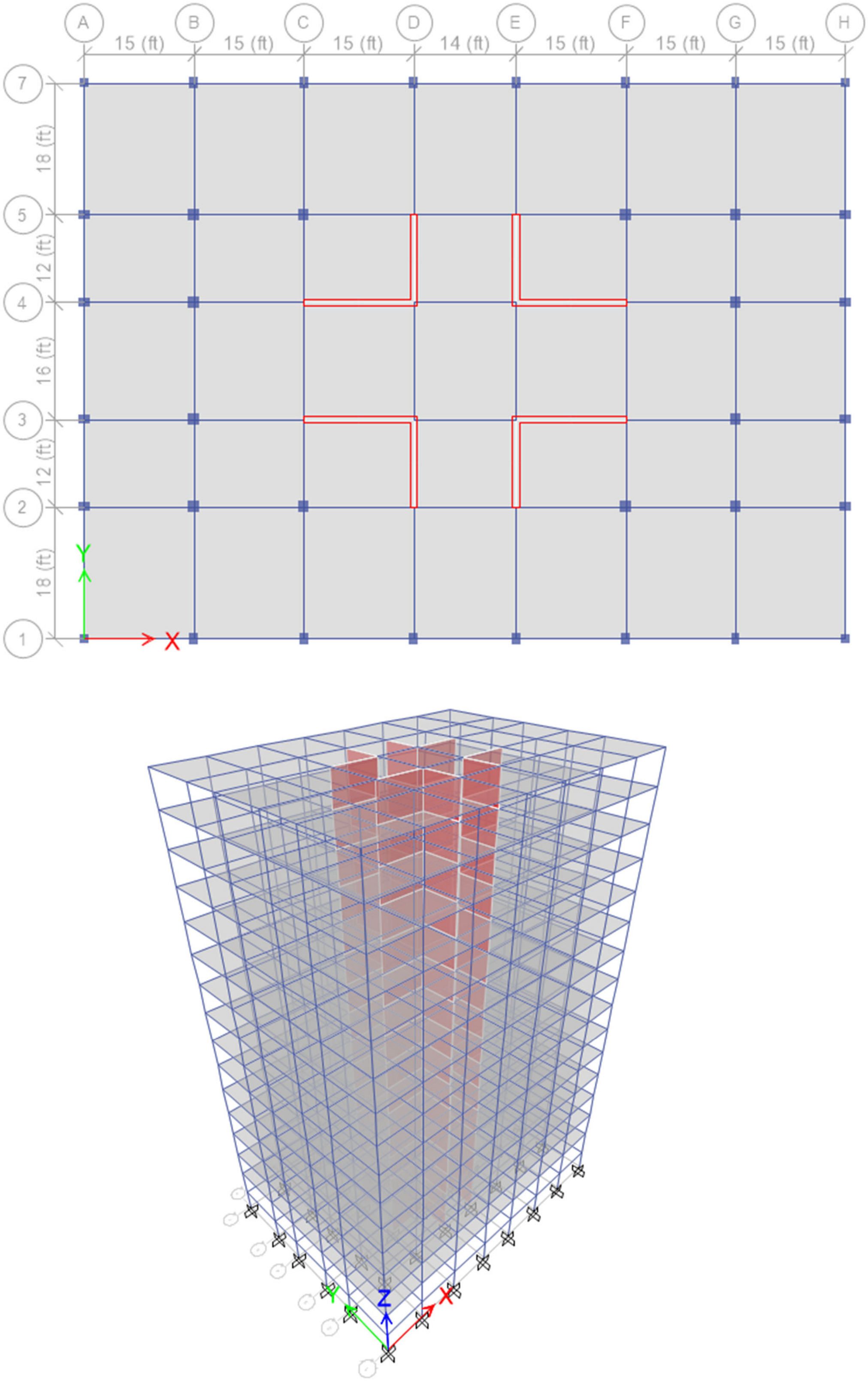

Figure 10: Model 6 Structural Plan

7. Model 7

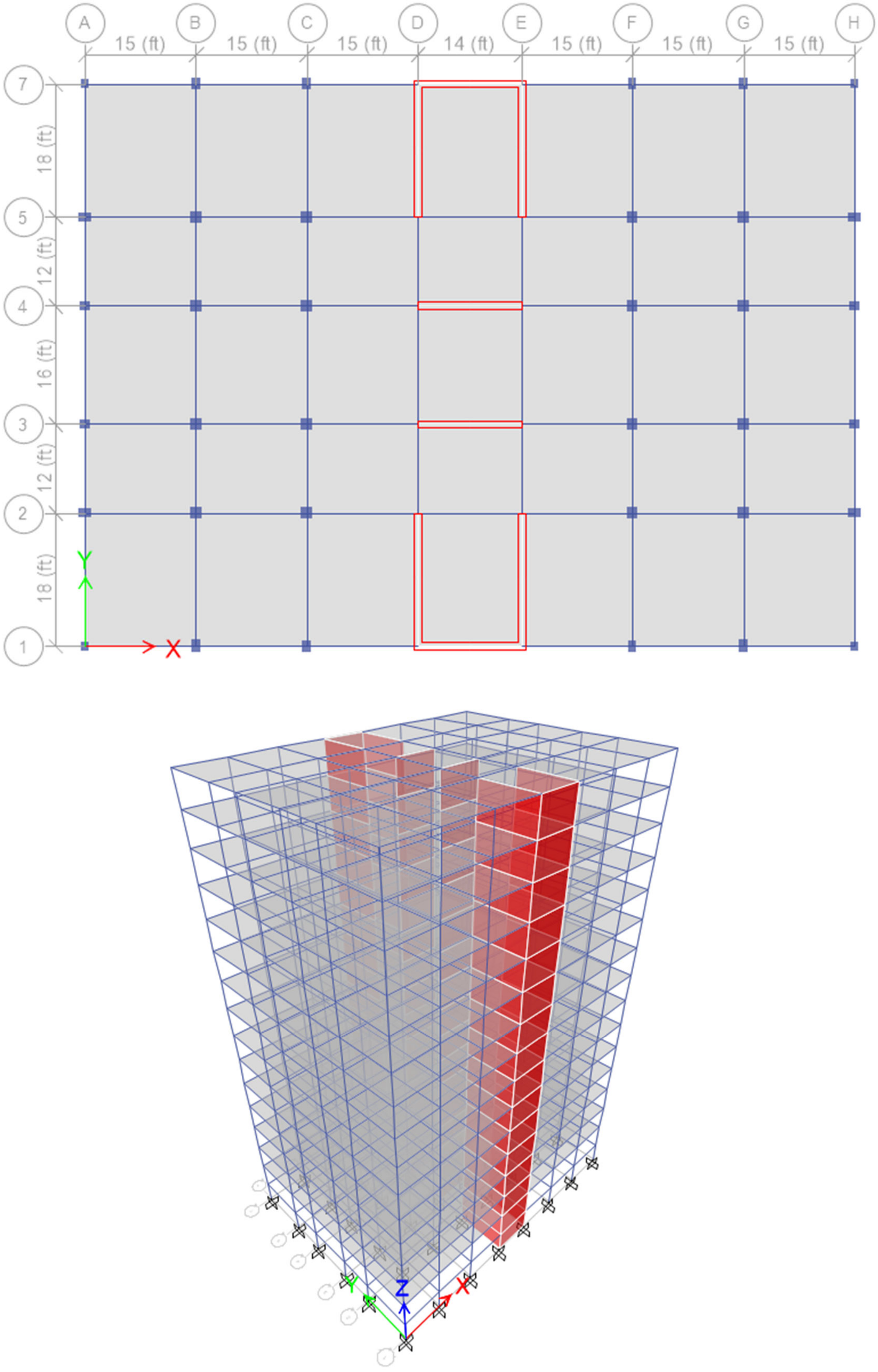

Figure 11: Model 7 Structural Plan

8. Model 8

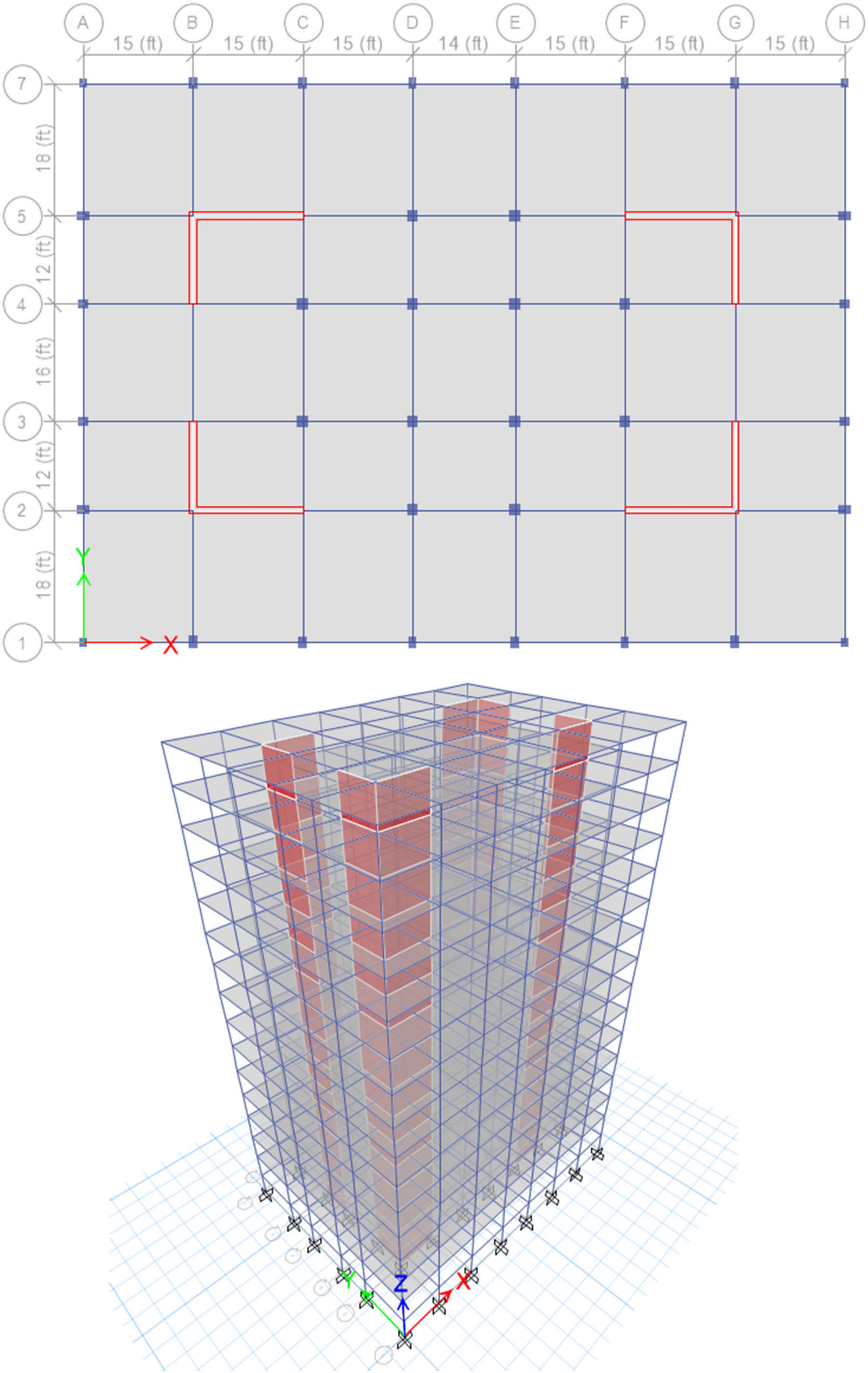

Figure 12: Model 8 Structural Plan

3.5 Column Layout

The column layout for the selected structural plan is showed in Figure 13.

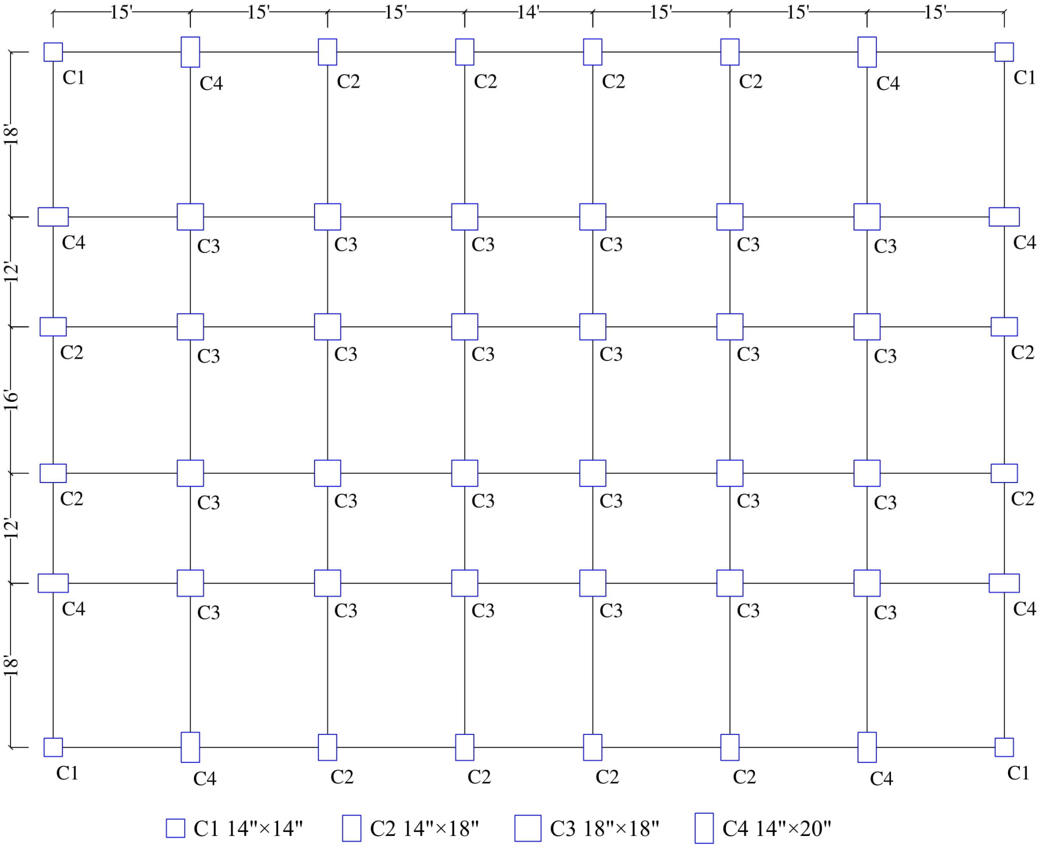

Figure 13: Column Layout

The column sizes were finalized after several trials to keep the reinforcement ratio within 1% - 4% for all practical purposes. This would not affect on the overall result of drift and deflection, but it was done to keep the reinforcement ratio within a proper range.

3.6 Building Details and Material Properties

The building and material details considered for the building are mentioned in **Table 1**.

Table 1: Building Details and Materials

BUILDING DETAILS	
No. of Story	15
Plan Dimension	104 ft × 76 ft
Story Height	10 ft
Thickness of Slab	5"
Grade Beam Size	14" × 18"
Beam Size	12" × 16"
Column Size	14" × 14"
	14" × 18"
	18" × 18"
	14" × 20"
Column Size Below Ground	16" × 16"
	16" × 20"
	20" × 20"
	16" × 22"
Thickness of Shear Wall	12"
Seismic Zone	II
Load Assign	BNBC 2020

MATERIALS	
Beam (Concrete)	4000 psi
Slab (Concrete)	4000 psi
Column (Concrete)	6000 psi
Grade of Steel	60000 psi

Dead load and Live load considered for the analysis is mentioned in **Table 2**.

Table 2: Dead Loads and Live Loads

DEAD LOADS	
Floor Finish	25.00 psf
Partition wall (Exterior)	1.00 K/ft
Partition wall (Interior)	0.50 K/ft
Railing (Roof)	0.15 K/ft

LIVE LOADS	
Typical Floors	50.00 psf
Roof	20.00 psf

The wind input parameters considered for the analysis are mentioned in **Table 3**.

Table 3: Wind Input Parameters

WIND INPUT PARAMETERS	
Wind Velocity	147.00 mph
Exposure	A (B in ETABS)
e_1	0.15
e_2	0.15
Importance Factor	1
Topographical Factor	1
Gust Factor	0.85
Directionality Factor	0.85

The seismic input parameters considered for the analysis are mentioned in **Table 4**.

Table 4: Seismic Input Parameters

SEISMIC INPUT PARAMETERS	
Time Period, T	1.52 sec
Response Reduction Factor, R	8
System Overstrength Factor, Ω	3
Deflection Amplification Factor, C_d	5.5
0.2 sec spectral acceleration, S_S	0.5
1 sec spectral acceleration, S_1	0.2
Site factor, F_a	1.35
Site Factor, F_v	2.7
Damping Ratio	5%

3.7 Structural Analysis According to BNBC 2020

3.7.1 Story Shear Calculation

Story shear comes from mainly the base shear. The base shear is distributed along the height of the structure according to the weight in each story. The story shear in a particular story in the cumulative of all forces above that story. According to BNBC 2020, the total base shear can be calculated using following equations (1) and (2),

$$S_a = \frac{2}{3} \times \frac{ZI}{R} \times C_s \tag{1}$$

$$V = S_a \times W \tag{2}$$

The distribution of forces can be done by the following equation (3),

$$F_x = V \times \frac{W_x\, {h_x}^k}{\sum W_i\, {h_i}^k} \tag{3}$$

3.7.2 Story Drift Calculation

According to BNBC 2020, the allowable story drift can be calculated using the equations (4) and (5),

$$\Delta \leq 0.005\text{h for T} < 0.7\text{s} \tag{4}$$

$$\Delta \leq 0.004\text{h for T} > 0.7\text{s} \tag{5}$$

Where, Z = zone co-efficient, I = importance factor, R = response modification factor,

Cs = Normalized acceleration response spectrum, W = seismic weight

According to Table 6.2.21 of BNBC 2020, Allowable story drift for earthquake (6),

$$0.02h_{sx}$$

According to BNBC 2020, the allowable story drift for our structure is 0.48 which (6)

indicates that all of our models are withing the allowable limit.

3.7.3 Story Displacement Calculation

According to BNBC 2020, the allowable story deflection for wind load is,

$$h/500 \tag{7}$$

The allowable displacement for our structure is 3.6 inch as per BNBC 2020. So, all of our models are withing the allowable limit.

3.8 Method 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 applicable, the building must be low rise and must be free from irregularity.

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.

4 RESULTS AND DISCUSSIONS

4.1 General

As mentioned earlier, to attain the objective of this research, total eight models have been created. After analyzing the results obtained from these models, some judgements can be made. This chapter includes all the details related to obtain the essential outcome.

4.2 Story Shear

The story shear for the building models which are obtained from ETABS are shown in **Table 5**.

Table 5: Story Shear (kip)

Story	Story Shear (kip)							
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Roof	74.29	78.25	77.30	76.27	77.61	77.61	78.16	77.61
14th	194.75	203.08	198.80	196.55	201.59	201.59	202.47	201.59
13th	303.11	315.38	308.10	304.75	313.13	313.13	314.29	313.13
12th	399.83	415.61	405.66	401.33	412.68	412.68	414.10	412.68
11th	485.35	504.24	491.92	486.72	500.71	500.71	502.35	500.71
10th	560.16	581.76	567.37	561.41	577.70	577.70	579.55	577.70
9th	624.75	648.69	632.52	625.90	644.18	644.18	646.19	644.18
8th	679.63	705.57	687.88	680.71	700.67	700.67	702.83	700.67
7th	725.37	752.96	734.01	726.37	747.74	747.74	750.03	747.74
6th	762.53	791.48	771.50	763.48	786.00	786.00	788.38	786.00
5th	791.76	821.76	800.97	792.66	816.07	816.07	818.54	816.07
4th	813.71	844.51	823.11	814.58	838.67	838.67	841.19	838.67
3rd	829.12	860.48	838.66	829.97	854.54	854.54	857.10	854.54
2nd	838.84	870.55	848.46	839.67	864.54	864.54	867.12	864.54
1st	843.82	875.72	853.49	844.65	869.66	869.66	872.26	869.66
GF	844.15	876.12	853.90	845.04	870.06	870.06	872.68	870.06

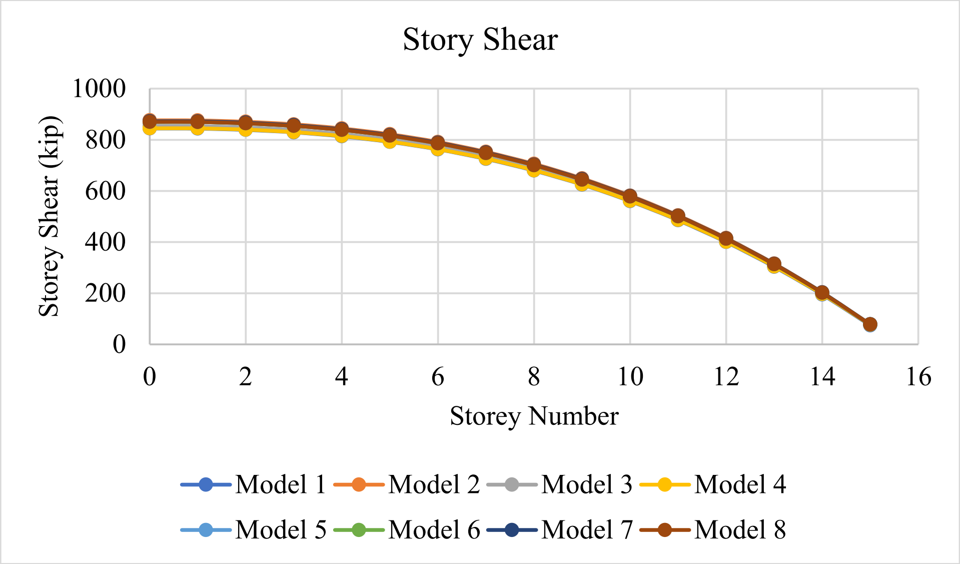

Figure 14 Story Shear for Different Models

From the table above, it is quite visible that the story shear increases as it goes down from top. Once a structure is hit by and earthquake, the ground moves back and forth beneath the structure which forces the structure to respond as well. A tremendous quantity of base shear is created in the bottom of the structure and this the force is distributed evenly across the height of the structure in a highly complicated way. The base shear is distributed along the height of the structure as story forces which results in story shear. According to the data above, the Model 4 has the lowest story shear, and the Model 2 has the largest shear when compared to the other models that have shear wall. This is because the entire length of the shear wall in Model 4 is the shortest, resulting in a lesser weight of the structure and, consequently, a lower inertia force from which story shears are generated.

4.3 Story Drift

4.3.1 Story Drift in X Direction

Story drift in X direction is found to be as mentioned in **Table 6** and represented in **Figure 15**.

Table 6: Story Drift in X Direction

Model	Maximum Drift Ratio X Direction	Drift (in)
1	0.006537	0.7844
2	0.001965	0.2358
3	0.001828	0.21936
4	0.002614	0.31368
5	0.002093	0.25116
6	0.001989	0.23868
7	0.001517	0.18204
8	0.001820	0.2184

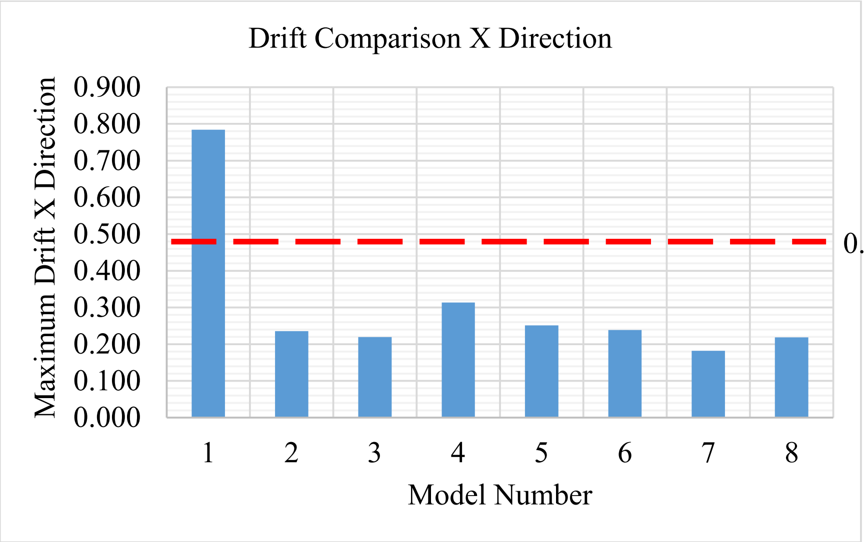

Figure 15 Drift Comparison X Direction

From the experiment it is quite evident that shear walls play an important role in controlling drift. The table and graph above clearly show that Model 1 has no shear wall, and the graph shows that it has a significant amount of drift when compared to the other models that have shear walls in various locations. After constructing a total of 8 models, the Model 7 gives us the lowest drift value in X direction. Plan of the model is given in the earlier chapter.

4.3.2 Story Drift in Y Direction

Story drift in Y direction is found to be as mentioned in **Table 7** and represented in **Figure 16**.

Table 7: Story Drift in Y Direction

Model	Maximum Drift Ratio Y Direction	Drift
1	0.007192	0.86304
2	0.001628	0.19536
3	0.001426	0.17112
4	0.003499	0.41988
5	0.002541	0.30492
6	0.003066	0.36792
7	0.001665	0.1998
8	0.002487	0.29844

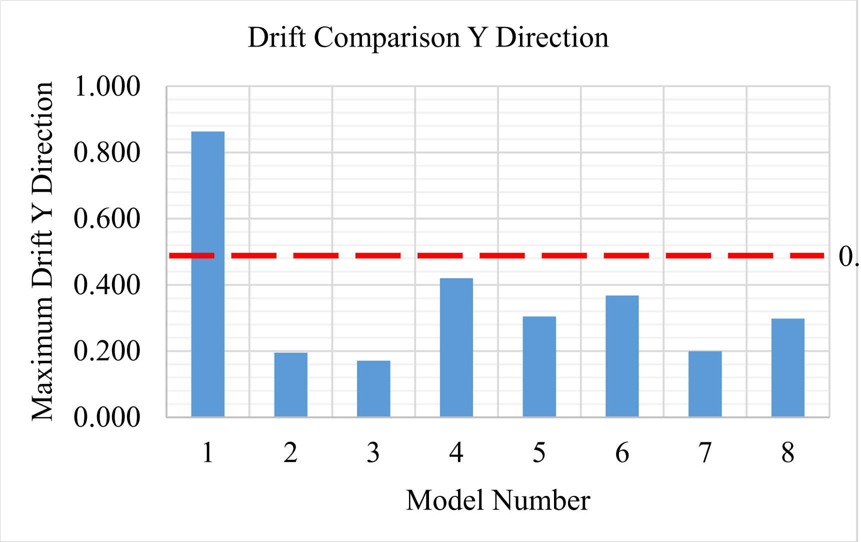

Figure 16 Drift Comparison Y Direction

Like the X direction drift, the drift in Y direction has some similar result. In X direction drift, the model 7 gave the lowest value. The result can be drawn in the Y direction drift as well. The Model 3 gave the lowest value for Y direction drift and the model 7 shows value very close to model 3. So, the drift limitation is 0.004*120 = 0.48 in. According to table 6.2.21, allowable storey drift for earthquake is 2.4 in. Which indicates that all of our models are withing the allowable limit. So, a conclusion can be made here that if shear wall orientation is provided as given in model 7, it will provide the lower drift in both X and Y direction.

4.4 Story Displacement

4.4.1 Story Displacement in X Direction

Story displacement in X direction is found to be as mentioned in **Table 8** and represented in **Figure 17**.

Table 8: Story Displacement in X Direction

Model	Maximum Deflection X Direction
1	8.631
2	3.002
3	2.766
4	3.967
5	3.231
6	3.057
7	2.314
8	2.778

Figure 17: Deflection Comparison X Direction

Story displacement is a result of lateral force mostly wind and earthquake load. In the X direction, the model 1 shows the highest story displacement as expected as it has no shear wall in it. Similar to story drift, the deflection value in the X direction is also the smallest in the model 7. The model 3 and model 8 shows relatively similar value.

According to BNBC 2020, the allowable story deflection is h/500 or in our case it is 150*12/500 = 3.6 inch. It seems that our model 1 and model 4 has exceeded the allowable deflection. The model 1 was expected to fail as there is no shear wall in it. But the model 4 even after having good amount of shear wall, it has exceeded the allowable deflection limit a little bit. And all other models are within the allowable limit.

4.4.2 Story Displacement in Y Direction

Story displacement in Y direction is found to be as mentioned in **Table 9** and represented in **Figure 18**.

Table 9: Story Displacement in Y Direction

Model	Maximum Deflection Y Direction
1	9.556
2	2.501
3	2.136
4	5.208
5	3.864
6	4.685
7	2.522
8	3.803

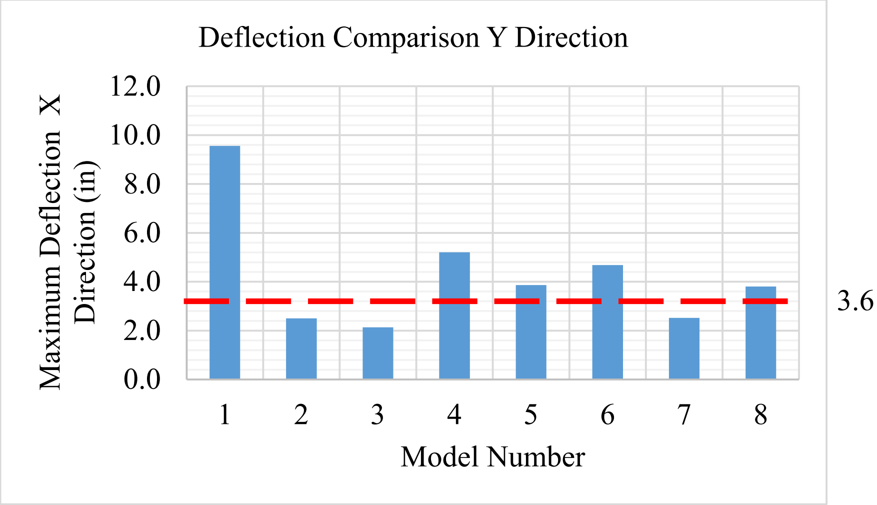

Figure 18: Deflection Comparison Y Direction

Similar to X direction, the deflection in Y direction also exceeds allowable limit for Model 1 as expected. But this time the difference in Model 4, 5, 6 and 8 also exceeds allowable limit by a significant amount. But the Model 3 shows the best result in this case and similar to story drift, model 7 shows value close to model 3. So, it can be concluded that Model 7 keeps performs better as it has great strength in both X and Y direction.

4.5 Story Stiffness

4.5.1 Story Stiffness in X Direction

Story stiffness in X direction is found to be as mentioned in **Table 10** and represented in **Figure 19**.

Table 10: Story Stiffness in X Direction

Story	Story Stiffness X direction (kip/in)							
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
Roof	682.66	431.09	385.75	321.38	410.54	440.88	501.38	424.71
14th	1022.44	1089.11	972.93	799.48	1030.50	1115.97	1267.10	1076.39
13th	1084.50	1644.99	1481.98	1189.01	1559.13	1689.61	1925.31	1632.28
12th	1102.54	2107.41	1920.79	1498.06	2004.65	2171.49	2490.12	2101.55
11th	1110.63	2497.25	2305.56	1745.38	2387.55	2582.16	2984.77	2503.61
10th	1115.57	2836.51	2653.48	1950.22	2727.15	2943.39	3432.12	2859.04
9th	1119.19	3148.00	2983.26	2130.97	3043.60	3277.90	3855.90	3189.59
8th	1122.17	3455.24	3315.55	2305.07	3357.82	3609.54	4281.41	3518.23
7th	1124.88	3784.85	3675.15	2490.76	3693.77	3965.66	4738.38	3871.60
6th	1127.63	4171.26	4095.67	2710.39	4082.49	4382.01	5266.16	4284.73
5th	1131.03	4666.51	4629.12	2996.86	4570.22	4912.74	5924.35	4810.93
4th	1137.05	5362.61	5368.05	3408.14	5236.21	5653.25	6816.71	5544.39
3rd	1153.48	6452.11	6506.07	4066.74	6238.44	6801.61	8155.60	6681.35
2nd	1214.52	8436.44	8544.04	5299.25	7948.17	8866.06	10480.41	8728.60
1st	1520.29	13246.12	13420.17	8355.83	11417.79	13818.13	15787.54	13640.39
GF	5020.87	42008.42	42373.80	28784.48	33965.86	43289.70	48550.38	42776.16

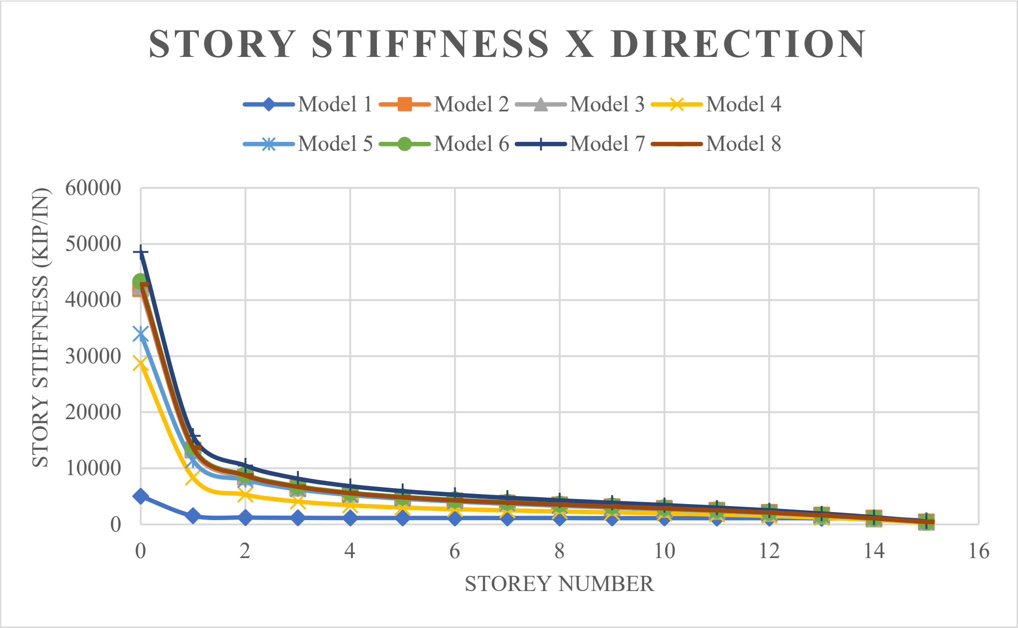

Figure 19: Story Stiffness X Direction

Stiffness in the force required for a unit deformation to take place. In case of building, story stiffness is the force required to cause a unit story displacement. From the table and graph above, it is quite visible that, the Model 7 provides the best result among all other models. Whereas the Model 1 shows the lowest value among all, and the value is way below than other models which is completely expected as it does not have any shear wall.

4.5.2 Story Stiffness in Y Direction

Story stiffness in Y direction is found to be as mentioned in **Table 11** and represented in **Figure 20**.

Table 11: Story Stiffness in Y Direction

Story	**Story Stiffness Y direction (kip/in)**							
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
Roof	607.66	600.44	503.14	294.44	391.08	314.78	475.91	344.05
14th	948.53	1521.59	1273.26	717.37	989.70	793.09	1210.03	864.19
13th	1023.45	2314.59	1947.79	1037.83	1491.88	1193.39	1847.00	1295.23
12th	1048.73	2995.85	2537.67	1270.50	1906.59	1523.05	2395.87	1646.22
11th	1061.16	3592.92	3063.09	1440.23	2252.96	1798.10	2876.63	1935.60
10th	1069.01	4133.15	3545.61	1569.27	2551.73	2035.12	3310.77	2182.25
9th	1074.81	4645.19	4009.15	1675.92	2824.07	2250.93	3721.94	2404.81
8th	1079.57	5159.76	4480.81	1775.20	3091.53	2462.46	4136.26	2621.70
7th	1083.87	5713.12	4994.04	1881.00	3378.20	2688.49	4585.23	2852.90
6th	1088.15	6353.47	5595.04	2008.97	3715.00	2952.89	5111.68	3123.46
5th	1093.15	7154.03	6356.10	2181.21	4148.60	3291.33	5782.16	3470.47
4th	1101.07	8242.53	7406.38	2436.21	4761.79	3766.30	6715.74	3958.59
3rd	1120.09	9879.89	9015.24	2855.41	5729.37	4507.83	8162.27	4722.38
2nd	1184.88	12727.34	11874.81	3657.38	7512.10	5852.19	10770.96	6109.27
1st	1494.34	19058.74	18599.98	5695.74	11946.41	9146.25	16945.75	9511.25
GF	4962.06	59270.63	56861.57	19873.85	38590.06	29623.09	53775.38	30467.27

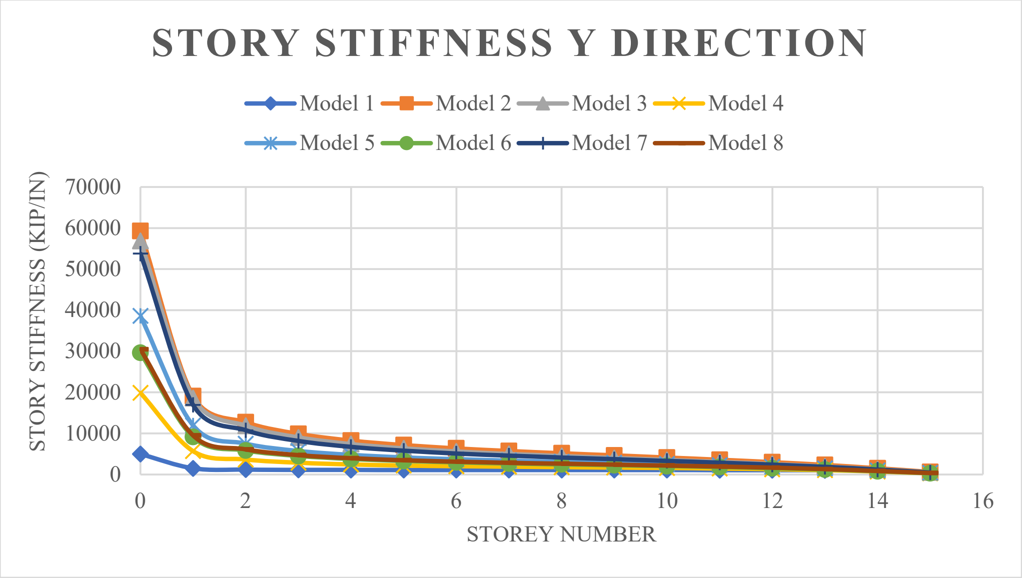

Figure 20: Story Stiffness Y Direction

In Y direction, the results are quite interesting. The Model 2 shows the highest story stiffness and Model 3 shows the second highest and then the Model 7. And as earlier, the Model 1 shows significantly lower stiffness. But if compared both X and Y, the Model 7 can be recommended for all practical purpose.

4.6 Torsional Irregularity

Torsional Irregularity of the building is shown in **Table 12**.

Table 12 Torsional Irregularity

15th Floor								
Model No.	**Direction**	**Δ1**	**Δ2**	**Δmax**	**Δavg.**	**Δmax/ Δavg**	**Allowable limit**	**Comment**
1	X	7.91	7.91	7.91	7.91	1	1.2	OK
	Y	8.21	8.21	8.21	8.21	1	1.2	OK
2	X	2.62	2.62	2.62	2.62	1	1.2	OK
	Y	1.78	1.78	1.78	1.78	1	1.2	OK
3	X	2.7	2.7	2.7	2.7	1	1.2	OK
	Y	2	2	2	2	1	1.2	OK
4	X	3.73	3.73	3.73	3.73	1	1.2	OK
	Y	4.77	4.77	4.77	4.77	1	1.2	OK
5	X	2.71	2.71	2.71	2.71	1	1.2	OK
	Y	2.89	2.89	2.89	2.89	1	1.2	OK
6	X	2.5	2.5	2.5	2.5	1	1.2	OK
	Y	3.64	3.64	3.64	3.64	1	1.2	OK
7	X	2.14	2.14	2.14	2.14	1	1.2	OK
	Y	2.2	2.2	2.2	2.2	1	1.2	OK
8	X	2.56	2.56	2.56	2.56	1	1.2	OK
	Y	3.41	3.41	3.41	3.41	1	1.2	OK

According to BNBC 2020, the allowable ratio of maximum deflection to average deflection is 1.2. All the structural plans and shear wall orientation are symmetrical, and all the models have zero eccentricity between center of mass and center of rigidity. That is the reason why all values found out to be 1. Therefore, there is no torsional irregularity available in the structure.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 General

The primary objective of this study was to determine the best placement and orientation for a shear wall to withstand lateral loads. 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

The following conclusions are drawn from this study's experimental results:

- It has been observed that the utilization of shear wall can contribute in decreasing lateral displacements, story drift and increasing stiffness of structure.
- By comparing shear wall position among all the models, we can conclude that shear wall should be placed in both short and long 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, providing more length of the wall in the shorter direction of the building shows maximum story stiffness.
- No torsional irregularity was found in any case because of symmetrical building shape.
- Assessing all the parameters, shear wall placed in Model 7 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, shear walls provide the best lateral resistance in all of the scenarios when they are set like Model 7 for a symmetrical or nearly symmetrical high-rise structure.

5.4 Future Scopes

- This study was performed for a G +15 story regular shaped building in seismic zone II of Bangladesh. Further study can be carried out for higher story buildings in other seismic zones of Bangladesh.
- Thickness of the shear wall was considered 12 inch in this study. Different variation of shear wall thickness can be introduced to see the comparisons with similar models.
- Different site classes could be considered for future research, as site class D was in this study.
- All the important parameters like story shear, story drift and displacement, stiffness, torsional irregularity are considered in this study. However, some other parameters such as soft story effect, P-delta 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.

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