Importance of Shear Wall to Control Deflection and Drift of RC Buildings for Different Earthquake Zones with respect to Aspect Ratio

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A THESIS SUBMITTED FOR THE DEGREE OF BACHELOR OF SCIENCE IN CIVIL ENGINEERING (STRUCTURE)

Department of Civil and Environmental Engineering
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2021

APPROVAL

This is to certify that the dissertation entitled "**Importance of Shear Wall to Control *Deflection & Drift of RC Buildings for Different Earthquake Zones* with respect to Aspect Ratio**", by Muhammad Rafiul Mahdi, Md. Rabib Masnun and Mahedi Hasan Shuvo has been approved fulfilling the requirements for the Bachelor of Science Degree in Civil & Environmental Engineering.

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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. We have taken appropriate precautions to ensure that the work is original. We can corroborate that the work has not been plagiarized. We can also make sure that the work has not been published for any other purpose (except for publication).

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ACKNOWLEDGEMENT

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

All praises belong to the Almighty Allah (SWT) for giving us the strength and courage to successfully complete our Undergraduate Thesis. We would like to extend our special gratitude to our parents for being the constant source of inspiration and support.

We would like to express our heartfelt gratitude and sincere appreciation to our Supervisor **Dr. Mohammad Tarek Uddin, Peng.**, Professor, Department of Civil and Environmental Engineering, Islamic University of Technology, for his gracious guidance, adept advice and continuous encouragement in supervising us. His technical and editorial advice was essential for the completion of this academic research. Without his assistance and guidance, the paper would have never been accomplished.

Furthermore, we would like to extend our gratitude to all the faculty members for their thoughtful recommendations during our study. We are thankful to our friends, juniors, seniors, and batchmates of our departments for their valuable suggestions and cordial assistance.

DEDICATION

We devote this thesis to our parents, who for many years sacrificed their valuable time, livelihood and effort to ensure that we could be who we are today. They motivated and supported us to follow our passion of engineering without ever looking back. Our parents have taught us that perseverance is one of the key traits to achieve success in life. We will forever be indebted to them.

ABSTRACT

Bangladesh is situated in a geographically vulnerable location making it susceptible to major earthquakes and disastrous cyclones in the near future. The situation is exacerbated due to the ever-increasing colossal population density of the country. In this study, the impact of shear wall in controlling lateral loads has been investigated with respect to aspect ratios (Height/Breadth) for different Breadth/Length ratios (0.5, 0.75,1) to realize the effect of narrow and symmetrical buildings. Shear wall is an efficacious alternative for controlling lateral loads of a structure. The building models have been developed in ETABS for four different seismic zones (Z=0.12, 0.2, 0.28, 0.36) to explore the ramifications of earthquakes for each building type. The study concludes that shear wall can reduce story drift and lateral deflection by almost 90 percent irrespective of seismic zones and building shapes. Furthermore, the necessity of shear walls in buildings with a decreasing Breadth/Length ratio and an increasing aspect ratio is relatively higher as they are more vulnerable to lateral loads, which can be visualized from the data obtained from the study. The study also recommends the aspect ratios at which shear walls will be necessary to restrict the deflection and drift within the limit for buildings in different seismic zones mentioned in BNBC 2020.

Keywords: Shear wall, RC building, drift, deflection, BNBC 2020, aspect ratio, seismic zones

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1 INTRODUCTION

Southeast Asia is one of the densely populated areas of the world facing the risk of high seismic activity due to Neo-tectonic depressions and the presence of active geographical fault lines [1]. Furthermore, history dictates that several major earthquakes occurred along the margin of the Indian and Eurasian plate boundaries [2] as a result of subduction tectonics in the northern and north-eastern part of the subcontinent [3]. Bangladesh, one of the major countries of Southeast Asia with a population density of 1103 per sq. km. [4] is more vulnerable to the predicted seismic activity along the region due to rapid and unplanned urbanization [5].

The capital of Bangladesh, Dhaka city has an increasing trend of urban population density and is situated in the vicinity of Madhupur Fault, [6] making it more susceptible to the damages of an earthquake. Studies have forecasted that if in any circumstance an earthquake of Richter scale magnitude of 6.0 originates with the epicentre being Dhaka, will enumerate a total of US $1,075 million financial loss and decimate a staggering 78,323 urban structures [8][6]. And so, the proper consideration of Earthquake Loads during modelling of structures in Bangladesh is of paramount importance [7]. The Bangladesh National Building Code (BNBC) of 1993 did not overly emphasize on the seismic design criteria of a building due to a considerably lower population density then. But as of now, due to the swift increase in urban population density, the latest edition of BNBC 2020 stressed on the stringent seismic design criteria as per ASCE 7-05.

Wind Load is another one of the strong concerns for a lower riparian, deltaic country like Bangladesh. Bangladesh has been ranked as one of the world's most disaster-prone country with 97.7 percent of its total population at risk of numerous hazards including cyclones [9]. The wind speed of the cyclones can go up to 223 km/hr (SIDR,2007) [4] resulting in catastrophic loss of life and devastation of structures. Hence, the wind load and the earthquake load are the prime lateral loads for concern in the case of building structures in Bangladesh.

Lateral loads create sway movement and vibration in structures which makes the structure unsuitable for any kind of service [10]. Effects of lateral loads on RC buildings are measured with the help of story drift and deflection. Story drift is defined as the relative difference between the displacement of two consecutive floors [10]. Story drifts act as the assessment point for structural damages and provide ample information in case of rigid body displacement. Story deflection is defined as the total displacement of any story with respect to ground. Both story drift and deflection have a maximum limit prescribed in BNBC 2020 and ASCE 7-05. Shear wall is one of the most effective vertical structural elements designed to resist in-plane lateral forces, typically wind and seismic loads by influencing the centre of mass and centre of rigidity. Studies have proven that shear wall reduces maximum story drift efficiently and provides better seismic performance [11].

Bangladesh is situated in a geographically vulnerable position and thus prone to severe earthquakes as well as cyclones. Bangladesh, the world's largest river delta is located at the juncture of several active tectonic plate boundaries making it susceptible to large magnitudes of earthquakes.

Lateral loads are live loads that are applied parallel to the ground; that is, they are horizontal forces acting on a structure. They are different to gravity loads for example which are vertical, downward forces. The most common types are: 1. Wind load. 2. Seismic load.

Wind load may not be a significant concern for small, massive, low-level buildings, but it becomes more important with height, the use of lighter materials and the use of shapes that may affect the flow of air, typically roof forms. Significant seismic loads can be imposed on a structure during an earthquake. They are likely to be relatively instantaneous loads compared to wind loads. Buildings in areas of seismic activity need to be carefully designed to ensure they do not fail if an earthquake should occur.

Water pressure tends to exert a lateral load which increases linearly with depth and is proportional to the liquid density. Similarly, earth pressure (such as settlement) can be applied against below-ground structures such as basement walls, retaining walls, and so on. Lateral loads such as wind load, water and earth pressure have the potential to become an uplift force (an upward pressure applied to a structure that has the potential to raise it relative to its surroundings).

Structures should be designed carefully with likely lateral loads in mind. A structural element that is typically used to resist lateral loads is a shear wall. In simple terms, lateral forces could push over parallel structural panels of a building were it not for perpendicular shear walls keeping them upright. In building construction, a rigid vertical diaphragm capable of transferring lateral forces from exterior walls, floors, and roofs to the ground foundation in a direction parallel to their planes. Examples are the reinforced-concrete wall. Lateral forces caused by wind, earthquake, and uneven settlement loads, in addition to the weight of structure and occupants, create powerful twisting (torsional) forces. This leads to the failure of the structures by shear.

Shear walls are especially important in high-rise buildings subject to lateral wind and seismic forces. Generally, shear walls are either plane or flanged in section, while core walls consist of channel sections. They also provide adequate strength and stiffness to control lateral displacements. The shape and plan position of the shear wall influences the behaviour of the structure considerably.

Effect of lateral loads on RC building are measured with the help of storey drift and deflection.

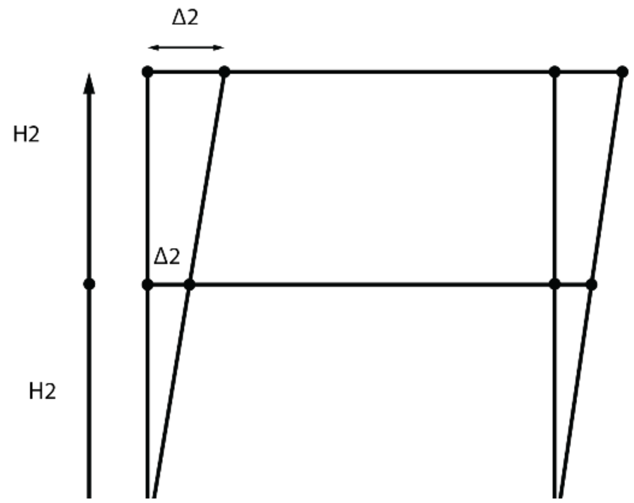

Figure 1 Storey Drift

Storey Drift: It is defined as ratio of displacement of two consecutive floors to height of that floor. It is a significant term used for research purpose in earthquake engineering.

Storey Displacement:

Total displacement of any storey with respect to ground and there is maximum permissible limit prescribed in BNBC Code for buildings. Etabs has been programmed to calculate the storey drift, displacement and shear simultaneously of a structure.

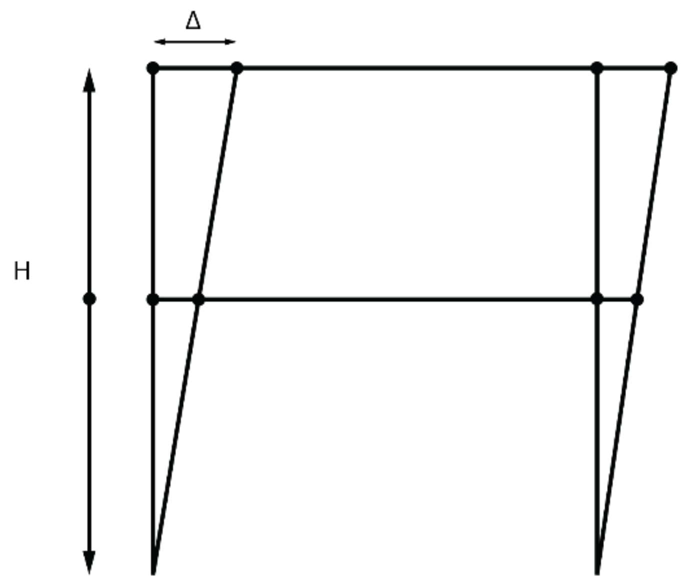

Figure 2 Storey Displacement

Storey Shear:

It is the lateral force acting on a storey due to the forces such as seismic and wind force. It is calculated for each storey, changes from minimum at the top to maximum at the bottom of the building.

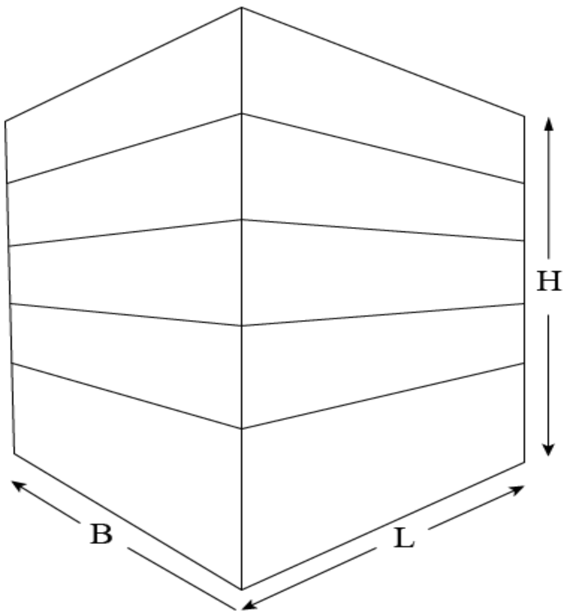

Figure 3 . Aspect Ratio = H/B

Aspect Ratio:

Aspect ratio is defined as the ratio of height to the breadth of building. Preferably for high rise building aspect ratio should be less than 6. If aspect ratio for high rise building is greater than 10, special features to improve wind comfort are included. Aspect ratio for high rise building should be between 6 and 10, but not less than 4.

The study also takes into account the impact of Length/Breadth ratio in context of reinforced concrete structures. As a result, this study, the length of the building has been changed to consider different cases of aspect ratios and the breadth has been kept constant in order to maintain the uniformity. Furthermore, the change of aspect ratio is clearly visible for increasing height or floor of the structure as the breadth of the structure is unchanged or kept constant throughout the study. Therefore, direct correlation among the impact of aspect ratio for changes of shape of the building can be perceived.

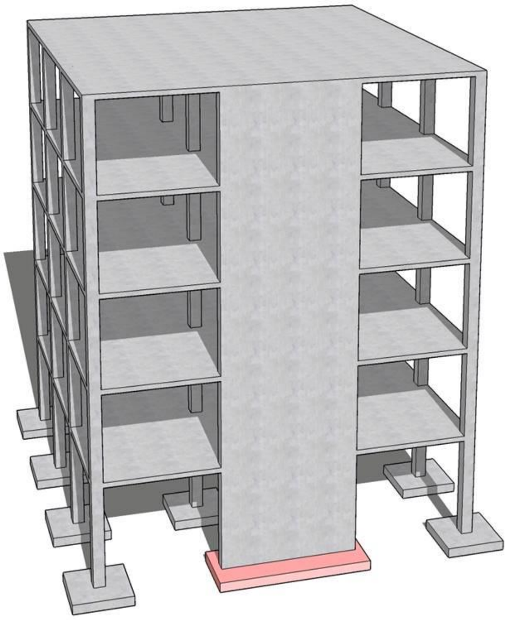

Figure 4 Shear wall

Shear Wall:

Shear wall is a vertical element of a seismic force resisting system that is designed to resist in-plane lateral forces, typically wind and seismic loads. In case of a shear wall, Length ≥ 5 x Thickness. Shear wall also influences Centre of Mass & Centre of Rigidity. Shear Wall controls the drift and deflection by resisting lateral loads. Narrow buildings are more prone to failure in case of lateral loads. Coull and Chowdhury's method describes in detail the importance regarding the importance of implementation of shear wall in order to maintain structural integrity. They also stressed on the fact that shear wall can play a vital role in controlling earthquake loads. It provides large amount of stiffness in direction of orientation and minimizes damages to structural components of the building. Furthermore, it simultaneously reduces construction cost and optimizes the required time. In case of shear wall,

$t/L > 1/15$ then shell thick & $t/L < 1/15$ then shell thin

where t=Thickness of Shear Wall & L= Length of Shear Wall

This study investigates the effect of shear wall in controlling the lateral loads for four different seismic zones and three different Breadth/Length (B/L) ratios with increasing aspect ratio. It also explores the impacts of lateral loads on the structural stability of a narrow building (B/L = 0.5). The stability of the building has been checked with the help of permissible story drift and deflection limit mentioned in BNBC 2020 and ASCE 7-05. This study will aid future structural designers to create efficient and sustainable earthquake-resistant structures in the Southeast Asia region.

1.1 RESEARCH SIGNIFICANCE

The research focuses on the importance of shear wall in reinforced concrete buildings of various shapes, situated at different seismic zones of Bangladesh defined by BNBC 2020. The area of research is not entirely untouched. Various researches have been conducted on the importance of shear walls. The researches on this particular area vary from place to place to some extent because of varying wind speeds and seismic characteristics. Even the researches are done considering some definite locations, the data can be used for other locations of similar or close wind and soil characteristics.

A few researches based in Bangladesh have been conducted on the importance of shear wall in resisting lateral loads. In the research named 'Comparative Analysis of a 15 Story Flat Plate Building with and Without Shear Wall and Diagonal Bracing Under Wind and Seismic Loads', a study on the effects of shear wall in a flat plate building has been conducted based on BNBC 2010. The study has been conducted on a model created on Staad Pro software. The study concludes that the presence of lateral resistance is required for a structure to function properly. To accomplish the initial schematic design correctly, it is critical to recognize that lateral forces must be considered from the beginning and that lateral force-resisting structure must be integrated. Based on the research, it is recommended to install a shear wall in a flat plate construction. [12]

In the research named 'Study of Seismic Performances of RCC Buildings Located in Different Seismic Zones in Bangladesh', a study has been conducted on the base shear, base moment and drifts of the three seismic zones defined in BNBC 1993 and a comparison has been made. The study concludes that base moment and drifts are higher in seismic zone-3 comparing to other zones. It also concludes that shear wall buildings have higher base shear and base moments than buildings without shear walls and shear wall buildings outperform non-shear wall building in higher seismic zones. [13]

In the research named 'A Comparative Study on Seismic Analysis of Bangladesh National Building Code (BNBC) with Other Building Codes', a comparison study on the base shear of a structure among BNBC 1993, BNBC 2010, NBC-India 2005 and ASCE 7 10 has been conducted. The study concludes that among the current codes studied in the paper, BNBC 1993 suggests the least base shear values. While developed countries prefer a more conservative design, BNBC-93's inconsistency may be suicidal. For low-rise buildings across the country, BNBC 2010 base shear values have grown dramatically compared to BNBC 1993. However, for low-story buildings, BNBC 2010 has a lower base shear value than ASCE 7 05. Because the ASCE 7 05 code design parameters are generic, they impose greater base shear values in most cases. Because India is Bangladesh's closest neighbour and shares the same tectonic zone, a comparison to the Indian benchmark will be more meaningful. In comparison to the Indian standard, the design seismic loading specified by BNBC

2010 appears to be adequately justified, given the proposed standard's notional base shears are relatively near to those of NBC-India 2005. As a result, the proposed BNBC 2010 code's increase in the earthquake factor of safety by suggesting greater base shear values is appreciable. [14]

From the above studies, few lackings can be identified. Some of the lackings of the studies are:

1. Concentration on flat plate buildings only.
2. Lack of variation in shapes of the buildings.
3. Lack of variation in the wind and seismic characteristics while analysing the effects of shear walls under lateral load.
4. Drift and lateral deflection determine the lateral stability of a building which lacks in the studies with shear walls.
5. No information has been provided about the optimum shear wall orientation for reinforced concrete buildings.
6. Use of older versions of BNBC (1993 and 2010), which were not adequate in terms of safety and consistency.

This study focuses on the research gaps left on the previously conducted studies on the effects of shear wall in resisting lateral loads like wind load and seismic load. The models in the study have been developed on ETABS and generalized for any kind of reinforced concrete buildings. Three different B/L (Breadth/Length) ratios are considered for varying the shape of the building in the analysis. The models with and without shear walls have been analysed under 4 different conditions of the 4 representative locations (Barisal, Dhaka, Chittagong, Sylhet) of the 4 different seismic zones defined by BNBC 2020. The study focuses on the drift and lateral deflection limits on structures in these 4 locations. An optimum shear wall orientation is also an area of study in this research. The study has been conducted based on the latest building code in Bangladesh named ‘BNBC 2020’ which corresponds to ASCE 7-10. Therefore, as the study covers various uncovered areas of research on shear walls in reinforced concrete buildings, the study is immensely significant and can offer a huge dataset for various study in the future on the relevant topic.

1.2 KEY RESEARCH QUESTIONS

The key research questions of this study are as follows-

- What is the significance of shear wall with respect to aspect ratio?
- When does a RC building fail with respect to aspect ratio?
- What is the zone-wise optimum aspect ratio for the construction of shear wall?
- What is the impact of lateral forces on a narrow RC building compared to a symmetric RC building?

1.3 OBJECTIVES OF THE STUDY

The study will try to achieve the following objectives-

1. To find out the effect of shear wall in controlling the lateral forces of a RC building with respect to aspect ratio.
2. To find out the aspect ratios at which failure of RC building occurs as per BNBC-2020 code.
3. To find out the zone-wise optimum aspect ratio for which shear wall is required to control the drift and deflection of RC buildings for the four seismic zones mentioned in BNBC.
4. To find out the effect of lateral forces on RC buildings with different shapes in respect of aspect ratio.

2 LITERATURE REVIEW

Buildings are vulnerable to lateral loads which include wind load and seismic load. Hosseini and Rao (2018) stated that lateral deflection and drift have three consequences on a structure: they can affect structural parts (like beams and columns), non-structural elements (like windows and cladding), and nearby structures. They also stated that high stresses can be developed as a result of lateral load according to Hosseini & Rao (2018) [10]. They added that sway movement and vibration may also be produced by lateral load. Kamath and Rao (2012) [15] stated that the major factor affecting the design of tall buildings is their sensitivity to lateral load. According to their opinion, the lateral drift at the top is one of the most important criteria for tall buildings. Kamath and Rao (2012) [15] suggested the installing of lateral load resisting structures like shear wall and outrigger to resist the lateral loads and limit the drift and lateral deflection of the buildings. In support of Kamath and Rao (2012) [15], Fintel (1995) [16] has stated that in the past 30 years of the record service history of the tall building containing shear wall element, none has collapsed during strong winds and earthquakes. Therefore, to reduce the effect of lateral load and at the same time, to create safer reinforced concrete buildings, the necessity of shear walls is immense.

Ali and Aquil (2014) [17] have opined about the optimum orientation of shear walls in buildings. According to Ali and Aquil (2014) [17], to reduce unusual behaviors, shear walls have to be symmetrically located. They also stated that shear walls with a variety of cross-sections, ranging from rectangular to more irregular cores such as channel, T, L, barbell shape, box, and so on, can be used. Ali and Aquil (2014) [17] also mentioned that the walls are used to divide and enclose space, whereas cores are used to store and transport utilities such as elevators. Windows in exterior walls, as well as entrances or corridors in inner walls or lift cores, necessitate wall openings. From an architectural and practical standpoint, the size and location of openings may differ. They concluded that a structure with shear wall along the periphery has the most stable shear wall orientation as shear walls located along the exterior perimeter of the building give increased resistance to twisting. Khan and Jamle (2020) [18] argued the orientation of the shear walls differently and stated that as the main goal is to lower the lateral loads operating on it, the usage of the shear wall at corners concentrates the view of structural stability in today's day and its application as a dual system in a multistory structure.

As stated by Ali, J., Bhatti, et al. (2015), [11] shear wall gives better seismic performance and efficient deigning of structure. Maximum storey drift increases by 30.9% before failure and the time period increases 19.6% and 26.4 % reduction in base shear after using shear wall. They also stated that the addition of a shear wall to the structure will reduce the structure's overall weight. As a result, the structure is subjected to minimal base shear stresses, allowing structural elements' cross-sections to be lowered, resulting in total structure economy. According to Barua, S. M. Hasanur Rahman, and S. Das (2013) [7] Bangladesh is located in one of the most active seismic regions of the world, consideration of earthquake loads in structural design has become a significant issue. Ravikumar, C., et al. (2012) [19] stated that the behavior of a building during an earthquake depends on several factors, stiffness, adequate lateral strength and ductility, simple and regular configurations. Sharma (2013) agreed with Ravikumar, C., et al. (2012) [19] and prioritized the significance of lateral stiffness of a building to avoid failure. Kumar and Babu (2016) [20] mentioned that the weakness arises due to discontinuity in mass, stiffness and geometry of structure irregularities are one of the major reasons for failures of structures during earthquakes.

Ahmed, Roy, Das and Hasan (2019) [21] mentioned that Bangladesh's seismic zones have been classified into four categories by the revised BNBC 2017, which are Zone-1, Zone-2, Zone-3, and Zone-4, accordingly. Their seismic zone coefficients are different. They have also stated that for seismic zone-4, base shear and the base moment has increased by 17.90, 37.67 and 60.73% with respect to zone-3, zone-2 and zone-1. Lateral loads are live loads that are applied parallel to the ground and act on a structure as horizontal forces. They're not the same as gravity loads, which are vertical, downward forces. Wind load and seismic loads are the most common types which impacts the structures most.

3 METHODOLOGY

The investigation is going to be carried out by performing equivalent static analysis of buildings in separate regions involving different aspect ratios as well as B/L ratios. Analysis of the building models has been performed in ETABS. The vulnerability of the structure to lateral load will be determined in comparison with the sway limitation and the story drift limitation mentioned in BNBC 2020 [22] and ASCE 7-05. We have considered a three-dimensional RCC frame with dimensions for rectangular shapes only. The structure is considered to be fixed at the base.

Collecting the results of the models of the highest aspect ratio at which the building frames are susceptible to failure, the aspect ratio of the structures is increased with the implementation of shear walls. Shear walls will be oriented along the periphery of the building for higher efficiency. [17]

3.1 EQUIVALENT STATIC ANALYSIS

To evaluate all structures under seismic load, the dynamic nature of the load must be taken into account. In most codes, however, equivalent linear static methods are allowed to be used to analyse normal, low to medium-rise structures. It can be done by calculating the base shear load and its distribution on each storey using the formulas given in the code.

3.2 SAMPLE SELECTION

As per the BNBC 2020 [22], Bangladesh is divided into four earthquake regions which have been duly considered while modeling the buildings. Barisal, Dhaka, Chittagong, and Sylhet have been selected as the representatives of the four earthquake zones. The zone co-efficient and wind speed of the respective locations have been mentioned in Table 1.

Table 1 Wind Speed and Seismic Co-efficient

Location	Basic Wind Speed, V (m/s)	Basic Wind Speed, V (kph)	Seismic zone and Zone coefficient (Z)
Barisal	78.7	283.33	Zone 1: 0.12
Dhaka	65.7	236.53	Zone 2: 0.20
Chittagong	80.0	288.09	Zone 3: 0.28
Sylhet	61.1	219.97	Zone 4: 0.36

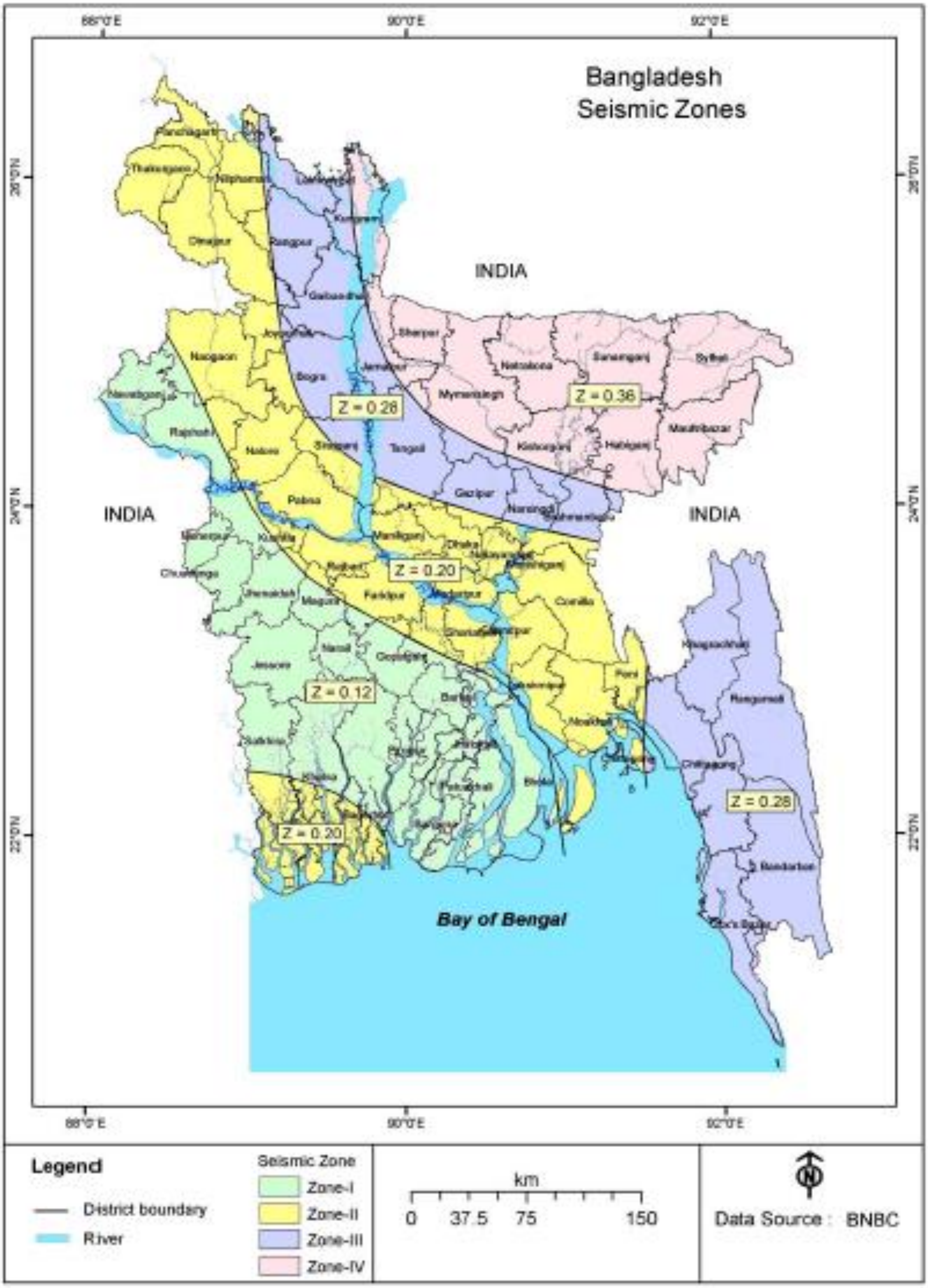

Figure 5 Bangladesh Seismic Zones

Three breadths to length ratios is considered which are 0.5, 0.75, 1 for proper evaluation of the impact of lateral loads on narrow and symmetrical buildings. In this case, the breadth of the building models has been taken as 50 feet and the lengths are considered 100 feet, 66.67 feet, and 50 feet respectively for the aforementioned B/L ratios which are displayed in Figure 6, 7. and 8.

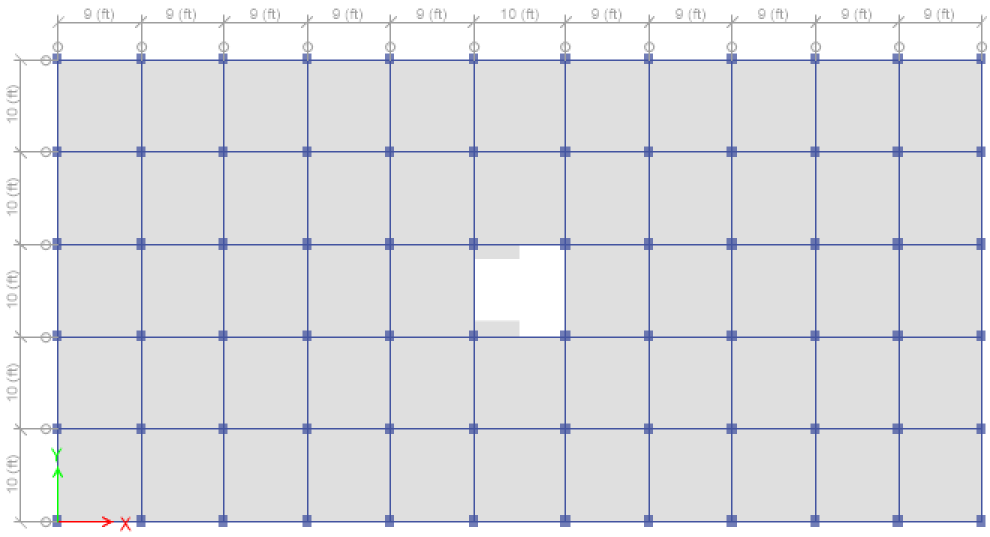

Figure 6 B/L = 0.5

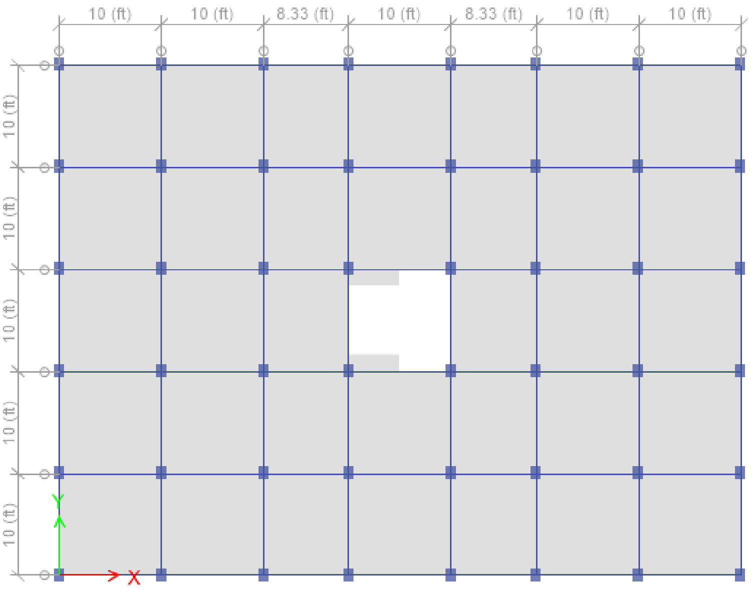

Figure 7 B/L = 0.75

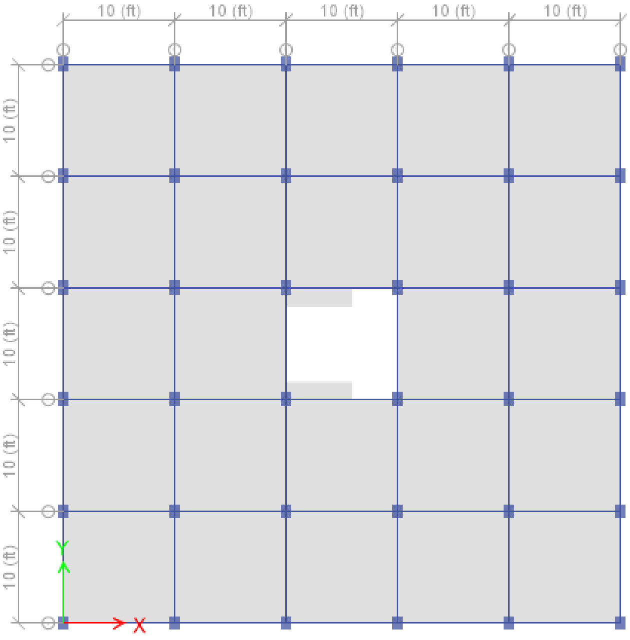

Figure 8 B/L = 1.00

3.3 SAMPLE BASED ON SEISMIC ZONES OF BNBC 2020

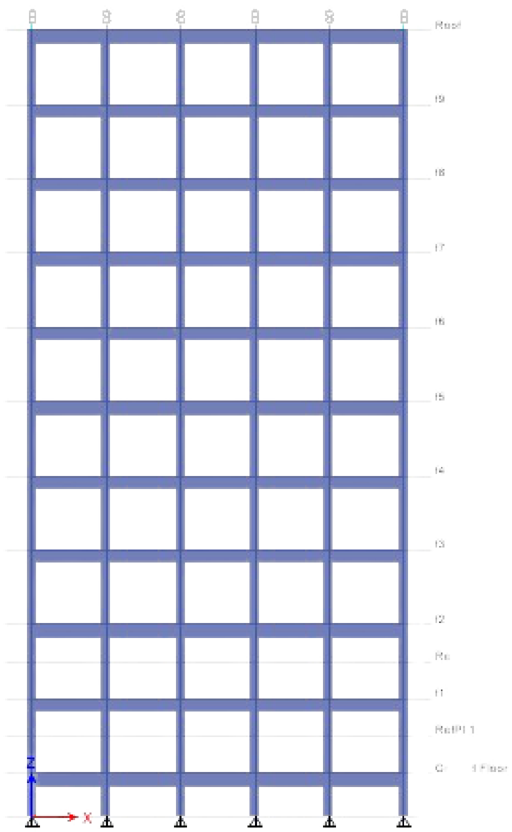

Figure 9 Zone -1 BARISAL (10 Storey)

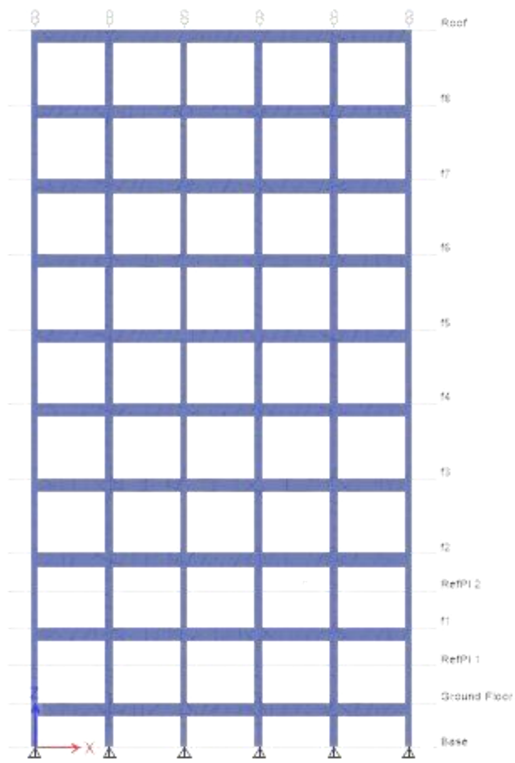

Figure 10 Zone-2 DHAKA (9 Storey)

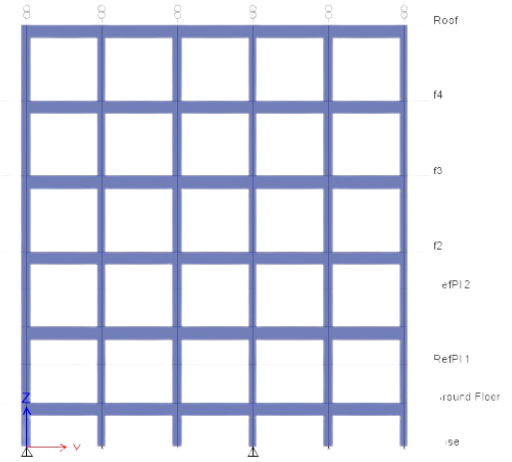

Figure 11 Zone-3 CHITTAGONG (5 Storey)

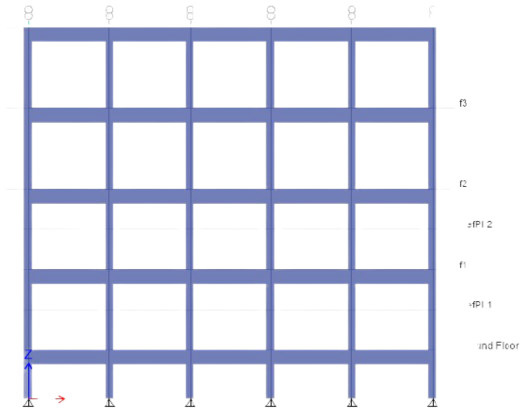

Figure 12 Zone -4 SYLHET (4 Storey)

3.4 STRUCTURAL MODELING

An RCC-framed structure is essentially an interconnected unit of slabs, beams, columns, and foundation. In these systems, the load is transferred from slabs to beams, beams to columns, and finally columns to the base, which then transfers the load to the soil.

A typical residential structure made of reinforced cement concrete (RCC) of 3ksi design strength with a special moment resisting frame (SMRF) is constructed as per ACI 318-14 with Occupancy Category- II. Lateral loads will be considered only in the X and Y direction. The occupancy is considered category II. Serviceability limit state has not been considered for this case. Reinforcement bar has been selected as A615, 60 grade and strength of concrete has been considered 4000 psi. Story height is 10 feet and shear wall thickness has been taken as 10 inches. The earthquake load is calculated using Equation 1 where site class has been considered as SC.

SC - Deep deposits of dense or medium dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres

In order to withstand strong earthquake shaking with severe inelastic activity, special proportioning and detailing requirements are needed. Because of these additional criteria, these moment resisting frames are referred to as Special Moment Frames, which increase the inelastic reaction characteristics of these frames when compared to less stringent detailed Intermediate and Ordinary Moment Frames.

3.5 RESEARCH LAYOUT

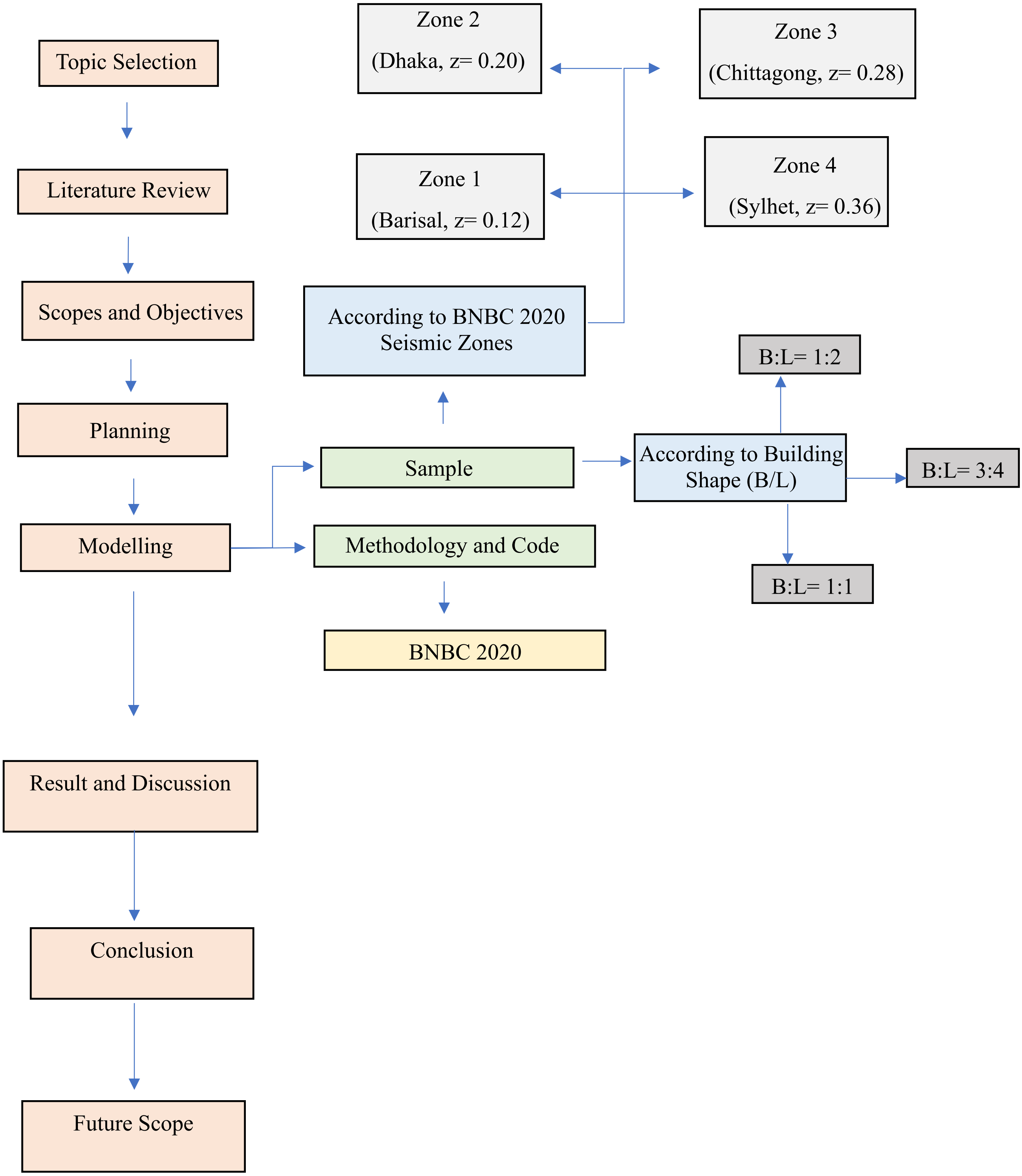

Table 2 Loads

DEAD LOADS	
Dead Load	Calculated by software
SUPER DEAD LOADS	
Floor Finish	16.4 psf [Table 6.2.2] [22]
Floor Finish (Roof)	10 psf
Partition Wall	45 psf [Table 6.2.2] [22]
Partition Wall (Roof)	0 psf
Wall Load	0.51 kip/ft
Wall Load (Roof)	0.15 kip/ft
LIVE LOADS [TABLE 6.2.3] [22]	
Live Load	41.78 psf
Live Load (Roof)	60.58 psf
Stair Load	100 psf

Table 3 Material Properties

Component	Values (unit)
Comprehensive strength of concrete	4000 psi
Modulus of elasticity of concrete	3600 ksi
Shear modulus of concrete	1500 ksi
Unit Weight of concrete	150 pcf
Yield strength of steel	60 ksi

$S_a = (2ZIC_s)/(3R)$ (1)

Where S_a, Z, I, R and C_s represent the design spectral acceleration, seismic zone coefficient, structure importance factor, response reduction factor and normalized acceleration response spectrum respectively. The time period (T) of the building is approximated by using -

$T = C_t\,(h_n)^m$ (2)

Where h_n is the height of the building in meters from the foundation or from the top of the rigid basement.

Table 4 Mass Source

Component	Values (unit)
Dead Load	1
Live Load	0.5
Floor Finish	1
Partition Wall	1
Wall Load	**1**

3.6 Wind Load

The Exposure Category has been considered as A (Category B according to ASCE 7-05) as per 2.4.6.3 of BNBC-2020. [22] The Importance Factor of 1.00 From Table 6.2.9 and topographic factor, Kzt = 1.0 from Sec 2.4.7.2 is taken consecutively

The Wind Directionality Factor, Kd = 0.85 for Buildings (Main Wind Force Resisting System), From Table 6.2.12.

G= 0.925(1+1.7$g_Q \overline{I_z} Q$) / (1+1.7$g_v \overline{I_z}$); where G=Gust Effect Factor (6.2.6)

3.7 Drift and Deflection Limit (BNBC 2020 Art 1.5.6)

Sway (Horizontal Deflection) limitation is 1/500 times of H, where H is the total height of the building. Again, story drift limitation is mentioned in Art 1.5.6.1 of BNBC 2020 which is similar to ASCE 7-05.

$\Delta \leq 0.005h$ for $T < 0.7$ second

$\Delta \leq 0.004h$ for $T \geq 0.7$ second

$\Delta \leq 0.0025h$ for unreinforced masonry structures, where h is the story height.

The response reduction factor (R), System Overstrength Factor (Ω_o), Deflection Amplification Factor (C_d) are considered as mentioned in table 2.

Table 5 Reduction Factor, Overstrength Factor and Amplification Factor

	Without Shear Wall (Special Reinforced Concrete Moment Frames)	**With Shear Wall** (D3 Special Reinforced Concrete Shear Walls)
R	**8**	**7**
Ω_o	**3**	**2.5**
C_d	**5.5**	**5.5**

The load combinations considered for modelling in ETABS are listed in table.

Table 6 Load Combinations [Sec 2.7.3.1] BNBC-2020 [22]

No.	BNBC 2.7.3.1	LOAD COMBINATIONS USED
1	1.4(D + F)	$1.4D$
2	$1.2(D + F + T) + 1.6(L + H) + 0.5(Lr\ or\ R)$	$1.2D + 1.6L$
3	$1.2(D + F + T) + 1.6(L + H) + 0.5(Lr\ or\ R)$	$1.2D$ + L + $0.8W$
4	$1.2D + 1.6W + L + 0.5(Lr$ or $R)$	$1.2D + 1.6W + L$
5	$1.2D + 1.0E + 1.0L$	$1.2D + 1.0E + 1.0L$
6	$0.9D + 1.6W + 1.6H$	$0.9D + 1.6W$
7	$0.9D + 1.0E + 1.6H$	$0.9D + 1.0E$

where D= Dead load; L= Live load

F= Loads due to weight and pressures of fluids with well-defined densities and controllable maximum heights or related internal moments and forces

T= Self-straining forces and cumulative effect of temperature, creep, shrinkage, differential settlement, and shrinkage-compensating concrete, or combinations thereof, or related internal moments and forces.

H=Loads due to weight and pressure of soil, water in soil, or other materials, or related internal moments and forces

Lr= Roof Live Loads

R= Rain Load

E= Earthquake Load

W=Wind Load

Base shear is calculated and matched with the V/W value from the ETABS to check the model. V/W is calculated by using the following equations

$S_a = 2(ZIC_s) / 3R = 0.0672$

Where Z= 0.28; I=1; $C_s = 2.88$

$S_a(min) = 0.67\beta ZIS = 0.032$

Here $S_a > S_a(min)$

We know,

$V = S_a W$

So, $V/W = S_a$

Therefore, V/W = 6.7%

From Etabs, V/W = (325.7319/4855.6309) x 100 % = 6.7%

Direction	Period Used (sec)	C_s	W (kip)	V (kip)
X	0.599	0.067083	4855.6309	325.7319
Y	0.599	0.067083	4855.6309	325.7319
X + Ecc. Y	0.599	0.067083	4855.6309	325.7319
Y + Ecc. X	0.599	0.067083	4855.6309	325.7319
X - Ecc. Y	0.599	0.067083	4855.6309	325.7319
Y - Ecc. X	0.599	0.067083	4855.6309	325.7319

Figure 13 Calculated Base Shear from Etabs

Therefore, it can be observed that the base shear from hand calculation and program calculated matches perfectly.

4 RESULTS & DISCUSSIONS

4.1 SHEAR WALL ORIENTATION

Shear walls have been provided along the periphery of the building models as the reduction of deflection and drift is maximum in this type of orientation. This result resembles other researches as this type of orientation reduces the deflection up to 33.31% and 32.03% compared to L type and cross-type shear wall orientations. [17]

Shear Wall can be arranged in different types of orientations. Each orientation has its own perks but if the focus is on maintaining the structural integrity of the structure, then placing shear walls along the periphery have proved to be more effective. The other types of orientation that can be maintained are as follows-

1. Along the lift core
2. Along the shorter side
3. L Shaped along the corners of the building
4. At the center of gravity of the building

The main purpose of shear wall is to increase the structural integrity of a building with respect to lateral loads by increasing its stiffness along the direction of orientation. It is also one of the easiest ways and optimized ways to tackle the lateral loads.

Therefore, it is important to consider the effective orientation of shear wall along the periphery to make the structure more durable against lateral forces.

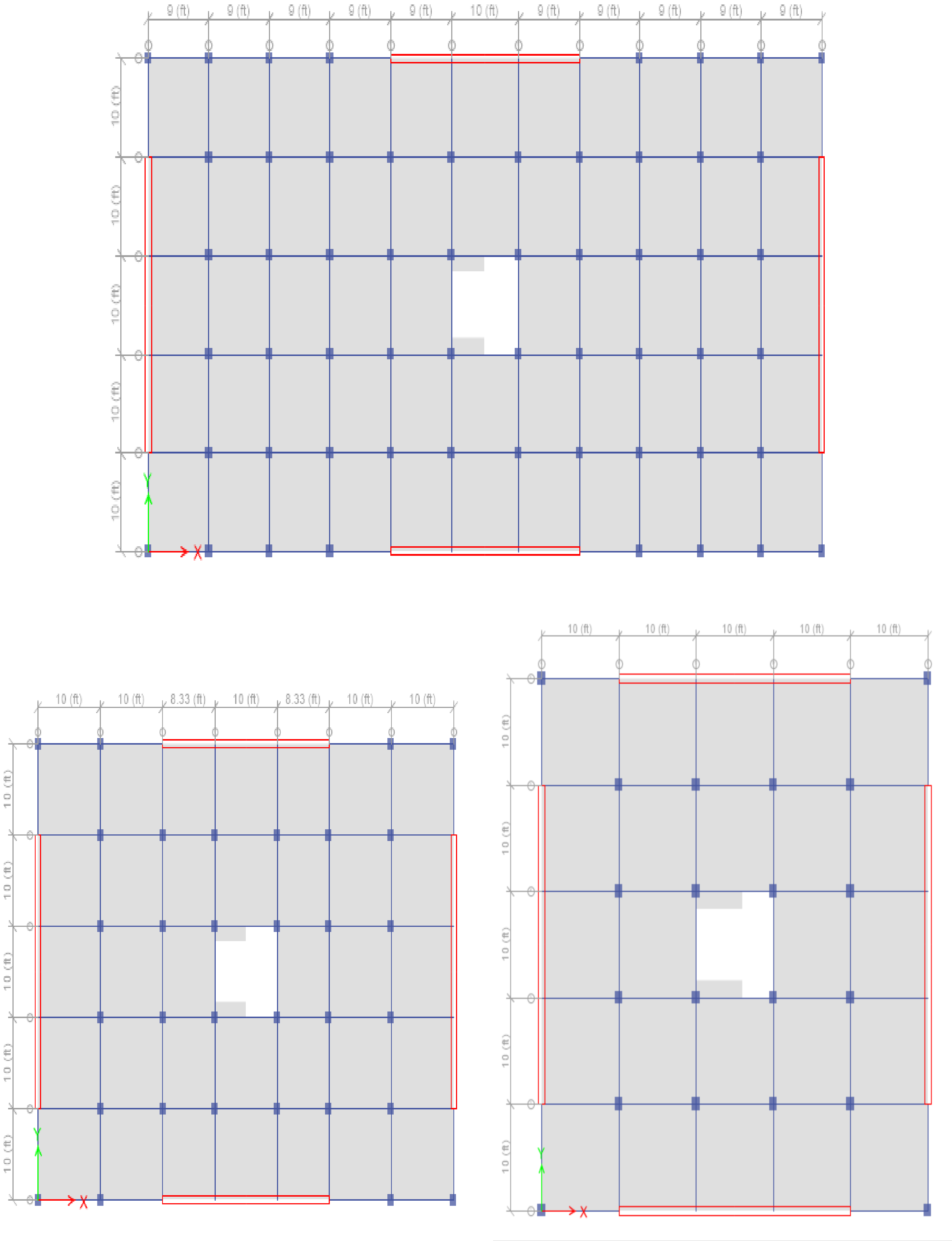

Figure 14 Shear Wall Orientation

4.2 CONTROL OF DEFLECTION AND DRIFT FOR DIFFERENT SEISMIC ZONES AND B/L RATIOS

As per BNBC 2020, comparisons have been made for four seismic zones taking Barisal, Dhaka, Chittagong and Sylhet as the representatives of zone-1 (z= 0.12), zone-2 (z= 0.20), zone-3 (z= 0.28) and zone-4 (z= 0.36) respectively.

The models with B/L ratio 0.5 for zone-1, zone-2, zone-3 and zone-4 exceed either the deflection limit or the drift limit as per BNBC 2020 at aspect ratios 1.32, 1.52, 0.92 and 0.72 respectively. For zone-1, at an aspect ratio 1.32, the deflection and drift values are 1.83 inches and 0.0149m respectively whereas the maximum allowable deflection and drift limits are 1.58 inches and 0.0153m respectively. Providing shear wall at the periphery of the model controls both the deflection and drift as the values go down to 0.16 inches and 0.00072 m respectively, which is within the maximum allowable deflection and drift limits. For zone-2, at an aspect ratio 1.52, the deflection and drift values are 1.85 inches and 0.0119m respectively whereas the maximum allowable deflection and drift limits are 1.82 inches and 0.0122m respectively. Providing shear wall at the periphery of the model controls both the deflection and drift as the values go down to 0.30 inches and 0.00123 m respectively, which is within the maximum allowable deflection and drift limits. For zone-3, at an aspect ratio 0.92, the deflection and drift values are 1.35 inches and 0.0147m respectively whereas the maximum allowable deflection and drift limits are 1.10 inches and 0.0153m respectively. Providing shear wall at the periphery of the model controls both the deflection and drift as the values go down to 0.20 inches and 0.00059 m respectively, which is within the maximum allowable deflection and drift limits. For zone-4, at an aspect ratio 0.72, the deflection and drift values are 1.09 inches and 0.0146m respectively whereas the maximum allowable deflection and drift limits are 0.86 inches and 0.0153m respectively. Providing shear wall at the periphery of the model controls both the deflection and drift as the values go down to 0.06 inches and 0.00065 m respectively, which is within the maximum allowable deflection and drift limits.

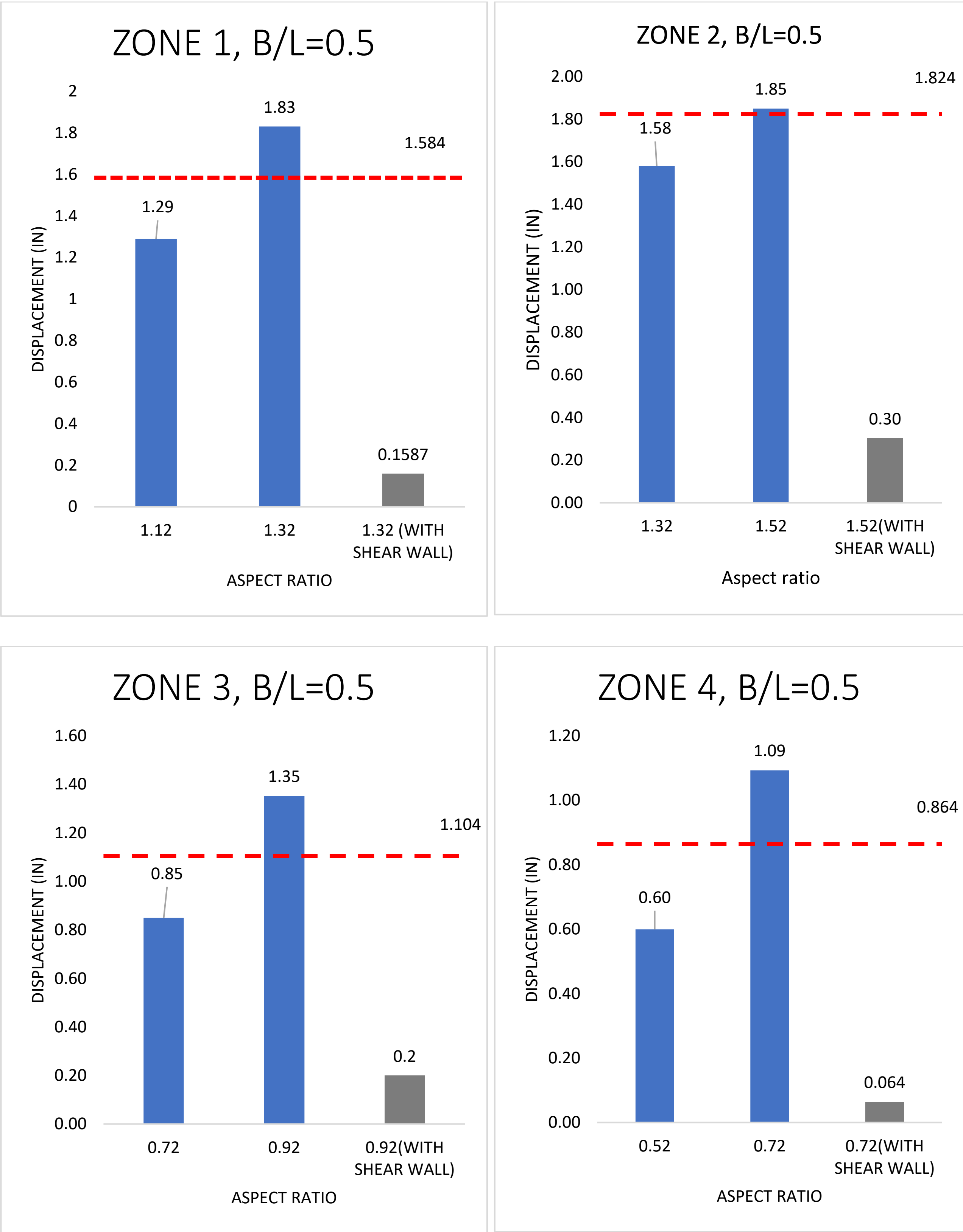

Figure 15 Analysis Results of Building Models of B/L Ratio 0.5 in Graph Plot

Table 7 Analysis Results of Building Models of B/L Ratio 0.5

B/L ratio	Seismic Zone	Unsafe Aspect Ratio	Deflection			Story Drift		
			Limit (in.)	No Shear Wall (in.)	With Shear Wall (in.)	Limit (m.)	No Shear Wall (m.)	With Shear Wall (m.)
0.50	1	1.32	1.58	1.83	0.16	0.0153	0.0149	0.00072
	2	1.52	1.82	1.85	0.30	0.0122	0.0119	0.00123
	3	0.92	1.10	1.35	0.20	0.0153	0.0147	0.00059
	4	0.72	0.86	1.09	0.06	0.0153	0.0146	0.00065

The models with B/L ratio 0.75 for zone-1, zone-2, zone-3 and zone-4 exceed either the deflection limit or the drift limit as per BNBC 2017 at aspect ratios 1.92, 1.72, 0.92 and 0.92 respectively. For zone-1, at an aspect ratio 1.92, the deflection and drift values are 2.43 inches and 0.0141m respectively whereas the maximum allowable deflection and drift limits are 2.30 inches and 0.0122m respectively. Providing shear wall at the periphery of the model controls both the deflection and drift as the values go down to 0.37 inches and 0.00117 m respectively, which is within the maximum allowable deflection and drift limits. For zone-2, at an aspect ratio 1.72, the deflection and drift values are 2.07 inches and 0.0122m respectively whereas the maximum allowable deflection and drift limits are 2.06 inches and 0.0122m respectively. Providing shear wall at the periphery of the model controls both the deflection and drift as the values go down to 0.31 inches and 0.00110 m respectively, which is within the maximum allowable deflection and drift limits. For zone-3, at an aspect ratio 0.92, the deflection and drift values are 1.11 inches and 0.0131m respectively whereas the maximum allowable deflection and drift limits are 1.10 inches and 0.0153m respectively. Providing shear wall at the periphery of the model controls both the deflection and drift as the values go down to 0.11 inches and 0.00069 m respectively, which is within the maximum allowable deflection and drift limits. For zone-4, at an aspect ratio 0.92, the deflection and drift values are 1.25 inches and 0.0146m respectively whereas the maximum allowable deflection and drift limits are 0.86 inches and 0.0153m respectively. Providing shear wall at the periphery of the model controls both the deflection and drift as the values go down to 0.07 inches and 0.00046 m respectively, which is within the maximum allowable deflection and drift limits.

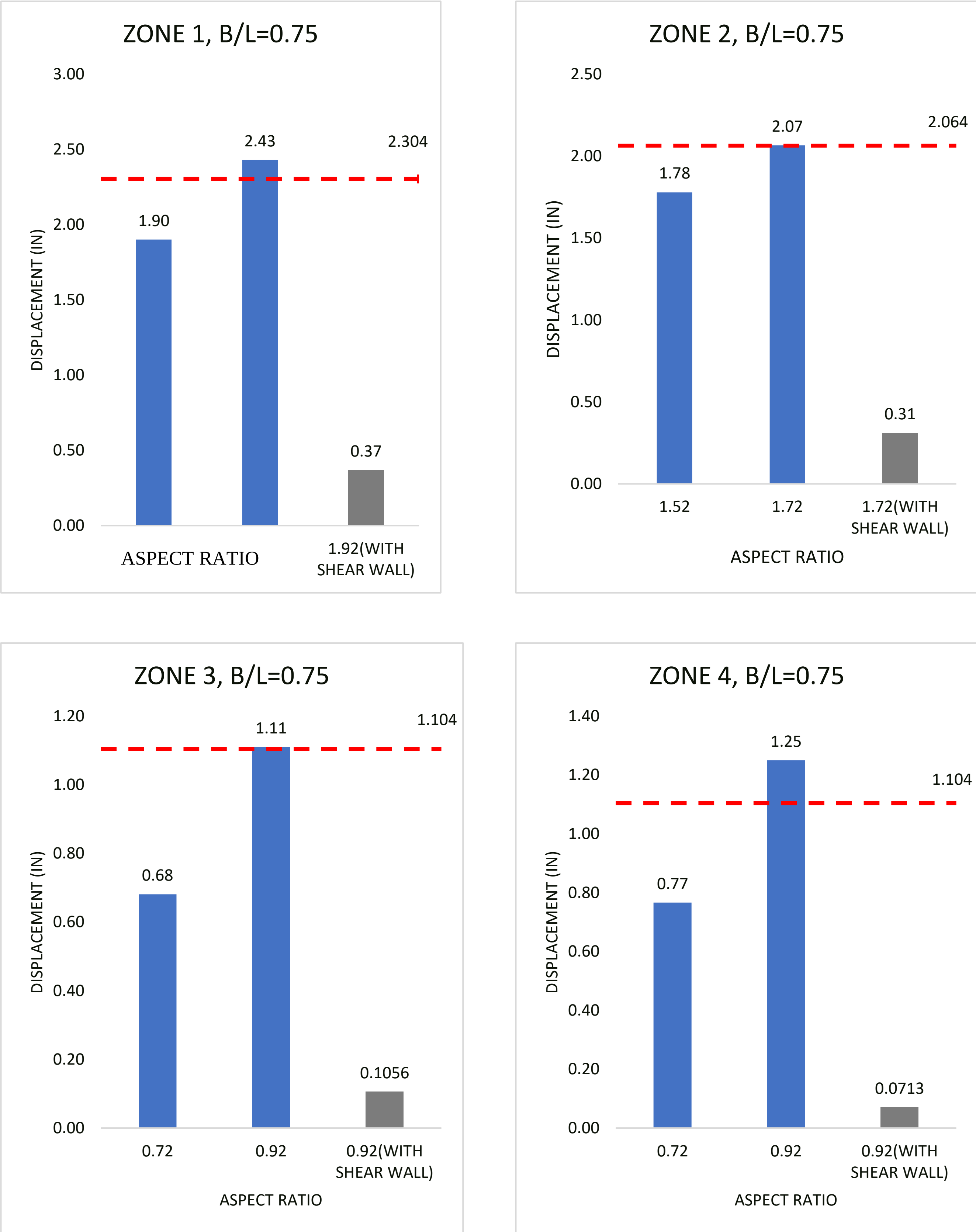

Figure 16 Analysis Results of Building Models of B/L Ratio 0.75 in Graph Plot

Table 8 Analysis Results of Building Models of B/L Ratio 0.75

B/L ratio	Seismic Zone	Unsafe Aspect Ratio	Deflection			Story Drift		
			Limit (in.)	No Shear Wall (in.)	With Shear Wall (in.)	Limit (m.)	No Shear Wall (m.)	With Shear Wall (m.)
0.75	1	1.92	2.30	2.43	0.37	0.0122	0.0141	0.00117
	2	1.72	2.06	2.07	0.31	0.0122	0.0122	0.00110
	3	0.92	1.10	1.11	0.11	0.0153	0.0131	0.00069
	4	0.92	0.86	1.25	0.07	0.0153	0.0146	0.00046

The models with B/L ratio 1.00 for zone-1, zone-2, zone-3 and zone-4 exceed either the deflection limit or the drift limit as per BNBC 2017 at aspect ratios 2.12, 1.92, 1.12 and 0.92 respectively. For zone-1, at an aspect ratio 2.12, the deflection and drift values are 2.38 inches and 0.0127m respectively whereas the maximum allowable deflection and drift limits are 2.54 inches and 0.0122m respectively. Providing shear wall at the periphery of the model controls both the deflection and drift as the values go down to 0.40 inches and 0.00115 m respectively, which is within the maximum allowable deflection and drift limits. For zone-2, at an aspect ratio 1.92, the deflection and drift values are 2.35 inches and 0.0126m respectively whereas the maximum allowable deflection and drift limits are 2.30 inches and 0.0122m respectively. Providing shear wall at the periphery of the model controls both the deflection and drift as the values go down to 0.26 inches and 0.00084 m respectively, which is within the maximum allowable deflection and drift limits. For zone-3, at an aspect ratio 1.12, the deflection and drift values are 1.40 inches and 0.0128m respectively whereas the maximum allowable deflection and drift limits are 1.34 inches and 0.0153m respectively. Providing shear wall at the periphery of the model controls both the deflection and drift as the values go down to 0.09 inches and 0.00047 m respectively, which is within the maximum allowable deflection and drift limits. For zone-4, at an aspect ratio 0.92, the deflection and drift values are 1.20 inches and 0.0132m respectively whereas the maximum allowable deflection and drift limits are 1.10 inches and 0.0153m respectively. Providing shear wall at the periphery of the model controls both the deflection and drift as the values go down to 0.06 inches and 0.00037 m respectively, which is within the maximum allowable deflection and drift limits.

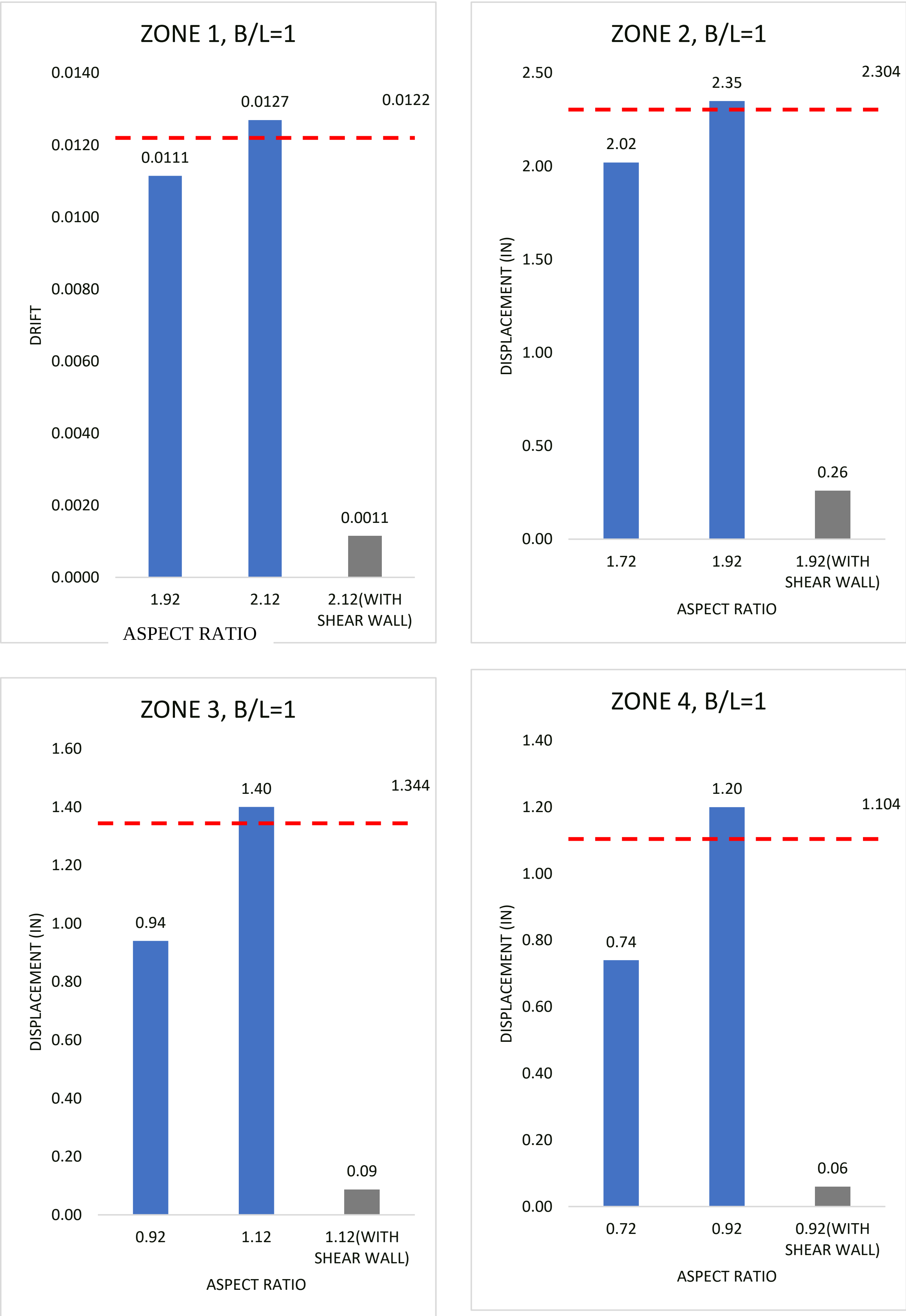

Figure 17 Analysis Results of Building Models of B/L Ratio 1 in Graph Plot

Table 9 Analysis Results of Building Models of B/L Ratio 1

B/L ratio	Seismic Zone	Unsafe Aspect Ratio	Deflection			Story Drift		
			Limit (in.)	No Shear Wall (in.)	With Shear Wall (in.)	Limit (m.)	No Shear Wall (m.)	With Shear Wall (m.)
1.00	1	2.12	2.54	2.38	0.40	0.0122	0.0127	0.00115
	2	1.92	2.30	2.35	0.26	0.0122	0.0126	0.00084
	3	1.12	1.34	1.40	0.09	0.0153	0.0128	0.00047
	4	0.92	1.10	1.20	0.06	0.0153	0.0132	0.00037

4.3 FAILURE PATTERN WITH RESPECT TO ASPECT RATIO AND DIFFERENT SEISMIC ZONES

For B/L ratio 0.5, the aspect ratios at which the maximum deflection or drift limits are exceeded are 1.32, 1.52, 0.92 and 0.72 for zone-1, zone-2, zone-3 and zone-4 respectively. For B/L ratio 0.75, the aspect ratios at which the maximum deflection or drift limits are exceeded are 1.92, 1.72, 0.92 and 0.92 for zone-1, zone-2, zone-3 and zone-4 respectively. Similarly for B/L ratio 1.00, the aspect ratios are 2.12, 1.92, 1.12 and 0.92 respectively.

From the analysis, a descending pattern can be observed among the aspect ratios from zone-1 to zone-4 models, at which the maximum allowable deflection and drift limits are exceeded for a particular B/L ratio. An exception can be obtained for the models with B/L ratio 0.5 among zone-1 and zone-2 as the aspect ratio at which the maximum deflection or drift limits are exceeded in the

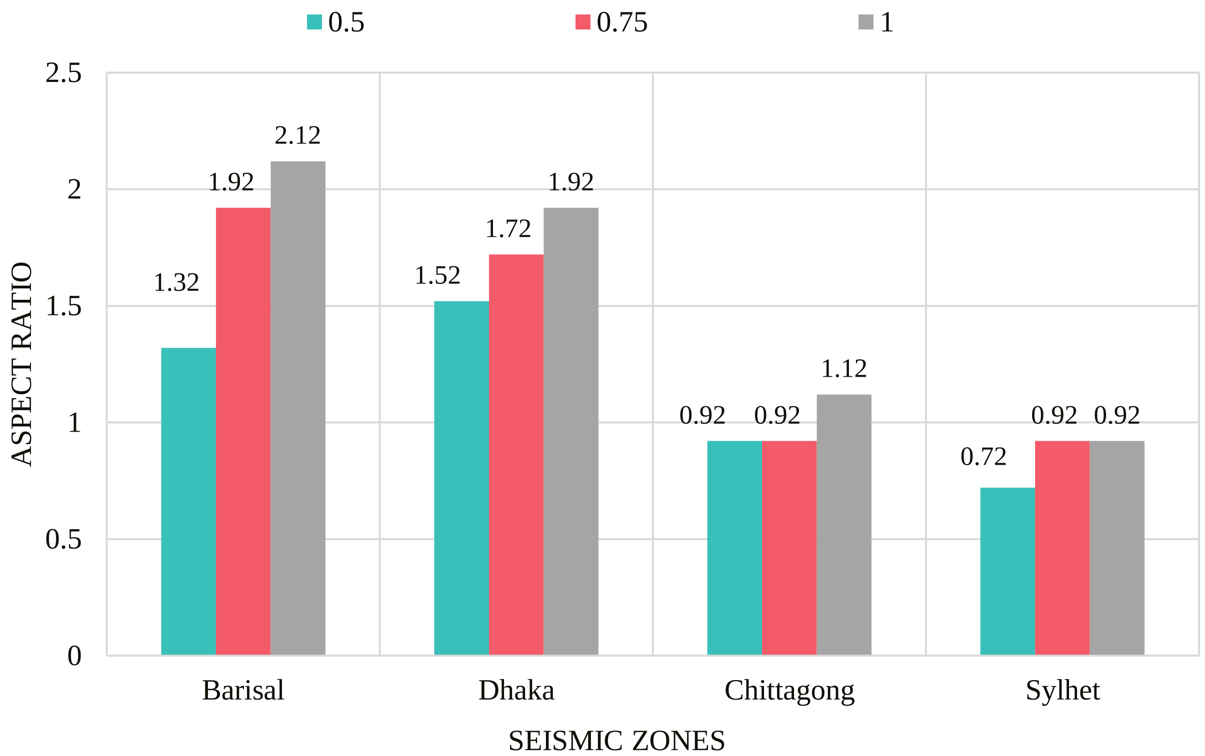

Figure 18 Unsafe Aspect Ratio for Different Seismic Zones

zone-1 model is less than that of the zone-2 model. The reason for the exception is the difference in wind speed between zone-1 (176.05 mph) and zone-2 (146.97 mph) which affects only the models with B/L ratio 0.5 as the building models are slender.

4.4 FAILURE PATTERN WITH RESPECT TO ASPECT RATIO AND DIFFERENT B/L RATIOS

For zone-1, aspect ratios at which the maximum deflection or drift limits are exceeded are 1.32, 1.92, 2.12 for B/L ratios 0.5, 0.75 and 1.00 respectively. For zone-2, aspect ratios at which the maximum deflection or drift limits are exceeded are 1.52, 1.72, 1.92 for B/L ratios 0.5, 0.75 and 1.00 respectively. Similarly for zone-3 and 4, aspect ratios at which the maximum deflection or drift limits are exceeded are 0.92, 0.92, 1.12 and 0.72, 0.92, 0.92 for B/L ratios 0.5, 0.75 and 1.00 respectively.

From the analysis, an ascending pattern can be observed among the aspect ratios from models with B/L ratio 0.5 to 1.00, at which the maximum allowable deflection and drift limits are exceeded for a particular B/L ratio.

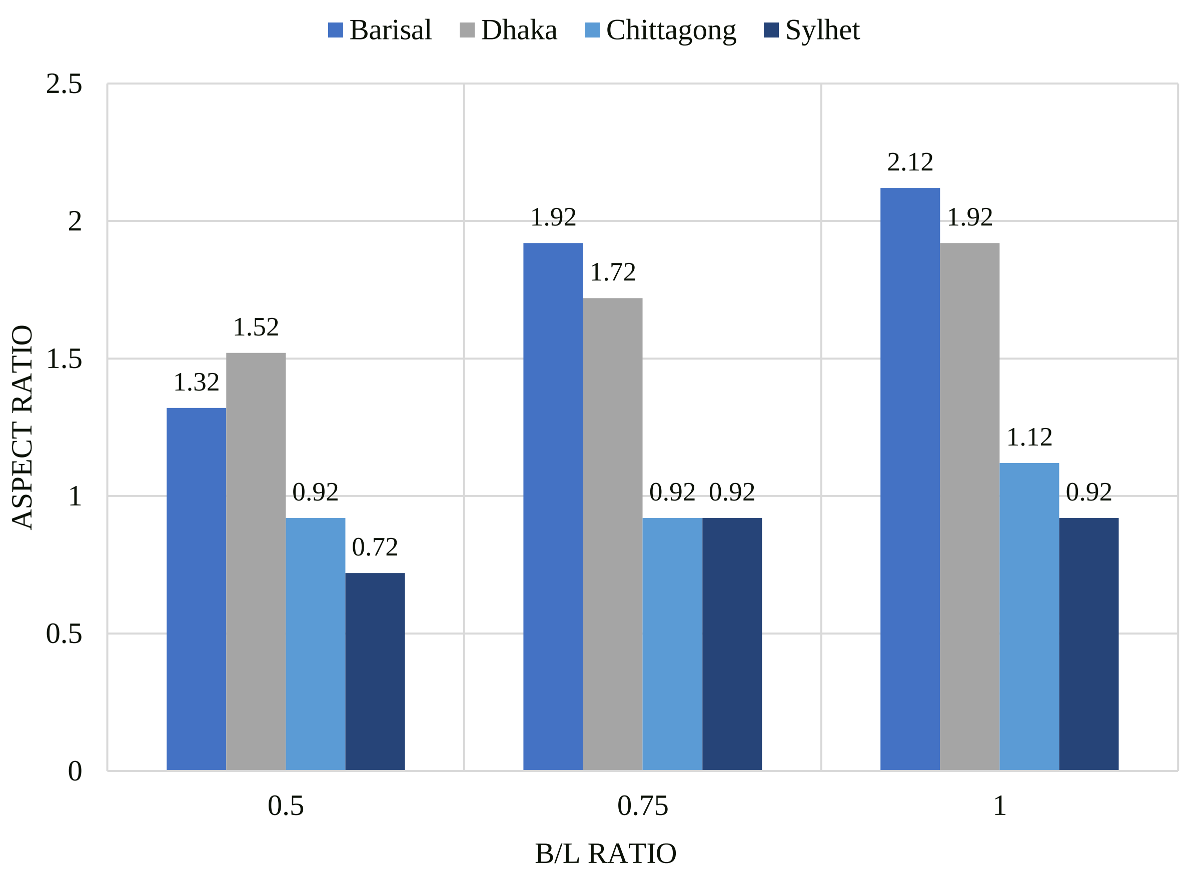

Figure 19 Unsafe Aspect Ratio for Different B/L Ratios

5 FUTURE SCOPES

The study has been conducted based on 4 representative locations of the 4 seismic zones defined in BNBC 2020 which can be expanded and turned into a database for all the districts of Bangladesh. This database will include data of more than 60 districts and will serve as a guideline for engineers in local RC building projects to find out the optimum aspect ratios at which shear walls will be necessary. The database will not only provide guidance to the local engineers but will also help structural engineers of different international projects with almost similar soil, seismic and wind characteristics to develop an understanding of the necessity of shear wall with respect to aspect ratio. Using the same methodology, the optimum aspect ratios at which shear walls will be necessary for RC buildings can be obtained for any place around the globe if the soil, seismic and wind data are provided.

6 CONCLUSIONS

i) As the value of the seismic zone coefficient (z) increases, the buildings become more vulnerable towards lateral deflection and story drift. To counter the lateral deflection and story drift, buildings in higher seismic zones need shear walls at a lower aspect ratio.

ii) As the B/L ratio decreases, that is the buildings become narrower, it is more vulnerable towards lateral deflection and story drift. As a result, buildings in lower B/L ratios need shear walls at a lower aspect ratio.

iii) Shear walls are provided to add stiffness to the structures which decreases the lateral deflection and story drift. From the obtained data, providing shear walls in an RC building can reduce the lateral deflection and story drift by up to 90%.

iv) The buildings located on seismic zone-1, zone-2, zone-3, and zone-4 (as per BNBC-2020) need a shear wall if the aspect ratios of the buildings exceed 1.32, 1.52, 0.92, and 0.72 respectively, irrespective of their B/L ratios (considering the B/L ratio does not go below 0.5).

v) In terms of building floors, the buildings located on seismic zone-1, zone-2, zone-3, and zone-4 (as per BNBC-2020) need a shear wall if the aspect ratios of the buildings exceed 6 storeys, 7 storeys, 4 storeys, and 3 storeys respectively, irrespective of their B/L ratios (considering the B/L ratio does not go below 0.5).

vi) The buildings with B/L ratios 1.00, 0.75, and 0.50 need a shear wall if the aspect ratio of the buildings exceeds 0.92, 0.92, and 0.72 respectively, without considering the seismic zones they are located on. Therefore, as the B/L ratio of a building moves closer to 1, the building becomes more resistant towards lateral loads like wind load and earthquake load.

Here, four representative locations have been considered for the aforementioned four seismic zones, namely-

Zone 1 – Barisal

Zone 2 – Dhaka

Zone 3 – Chittagong

Zone 4 – Sylhet

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