Controlling of Drift and Deflection of RC Buildings in Bangladesh with respect to Aspect Ratio and Breadth to Length Ratio

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Project Report Approval

This is to certify that the thesis entitled **"Controlling of Drift and Deflection of RC Buildings in Bangladesh with respect to Aspect Ratio and Breadth to Length Ratio"**, by Zeba Fariha, M.A. Bashar Bhuiyan, Redwan-Ul-Islam, and Rafszanul Islam has been approved fulfilling the requirements for the Bachelor of Science Degree in Civil & Environmental Engineering.

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Dedication

We dedicate this thesis to our parents, who for many years gave up important time, money, and effort in order for us to be who we are now. We also want to thank Professor Dr. Md. Tarek Uddin, our esteemed supervisor.

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“In the name of Allah, the Most Gracious, the Most Merciful.”

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Abstract

Lateral forces (wind, seismic) generated in RCC building may cause the structure to collapse. Shear wall is one of the effective ways to provide resistance against lateral loads. The present study focuses on drift and defection control of RC symmetrical building by providing core and corner shear walls. Different failure criteria were determined in four seismic zones (Zone-1 to Zone-4) in Bangladesh, based on aspect ratio and proposed breadth to length ratio (B/L ratio). Equivalent Static Analysis in ETABS V.2016 was used to analyze three distinct breadth-to-length ratios – 1, 0.7, and 0.4 for each zone without shear wall and with both core and corner shear walls. Results revealed that corner shear walls acted efficiently compared to core walls to resist lateral loads, drift, and deflection. A descending failure pattern and an incremental tendency of spectral acceleration were observed from lower to higher seismic zones for corresponding breadth to length ratios (B/L).

Keywords: Breadth to length ratio (B/L), Aspect ratio, Equivalent Static Analysis, Core wall, Corner wall, Lateral loads

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1. Introduction

1.1 Background

Bangladesh is situated in Southeast Asia. Southeast Asia is a very high seismic active zone due to tectonic plate movements and active fault lines. So, Bangladesh falls in a vulnerable position for earthquakes. Bangladesh is divided into four seismic zones as per BNBC 2020; Zone-1 to Zone-4 represent lower to higher seismicity in chronological order. Bangladesh is a developing country where lots of Reinforced Cement Concrete multi storied buildings are now constructed. The majority of multi-storey structures in our country are not built following proper seismic code because of lack of awareness of the harm caused by earthquakes, economic considerations, lack of knowledge and so on [1]. Dhaka, the capital of Bangladesh, has a growing tendency of urban population density and is located near the Madhupur Fault, making it more vulnerable to earthquake damage[2]. According to studies, an earthquake with a Richter scale magnitude of 6.0 that strikes Dhaka will cause a total financial loss of $1,075 million and destroy 78,323 urban structures[2]. Earthquake generates lateral force to the structure. Lateral force increases with respect to height of the structure which should be controlled within limit. Drift and Deflection are one of the effects of these lateral forces which may lead to collapse of RCC buildings. So, the use of shear walls is of utmost importance. Without shear walls, the buildings will take a high amount of damage due to earthquake and wind loads and there will be huge deformation and sway of the building which can make it collapse. To counter drift and deflection various methods have been developed like steel bracing, shear wall and so on. Shear walls play effective role to provide resistance against drift and deflection. In terms of structural engineering, a shear wall is a system consisting of Braced Panels (also known as shear panels) that are used to resist and mitigate the impact of lateral loads on structures; vertical elements of the horizontal force resisting system are shear walls. Various kinds of shear wall like core wall, corner shear wall, rectangular etc. can be used to prevent drift and deflection. The effect of lateral stresses on RC structures is measured using storey drift and deflection.

Shear Wall

Shear walls are vertical structural members of a system whose main purpose is to resist wind and seismic loads. Shear walls have been used for decades and researchers are always trying to find a better way to implement or place a shear wall in a building in such a way that it will serve both as a structural member and also as an aesthetic piece. Shear walls are usually used in high-rise buildings to prevent lateral wind and seismic forces. In reinforced concrete framed structures, the effects of wind forces increase in proportion to the height of the structure. How well the shear wall performs depends on its orientation location and the material used in making it [3].

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

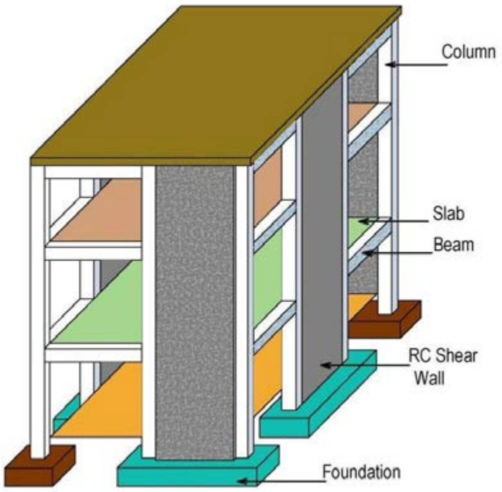

Figure 1: Shear Wall in RC Structure

Story Drift

Story drift is the lateral displacement of a floor relative to the floor below, and the story drift ratio is the story drift divided by the story height [4].

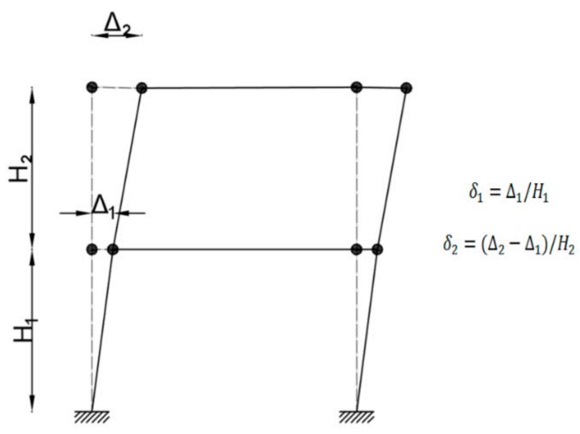

Figure 2: Storey Drift

Story Displacement

Story displacement is the lateral displacement of the story relative to the base. The lateral force-resisting system can limit the excessive lateral displacement of the building. The acceptance lateral displacement limit for wind load case could be taken as H/500 [4].

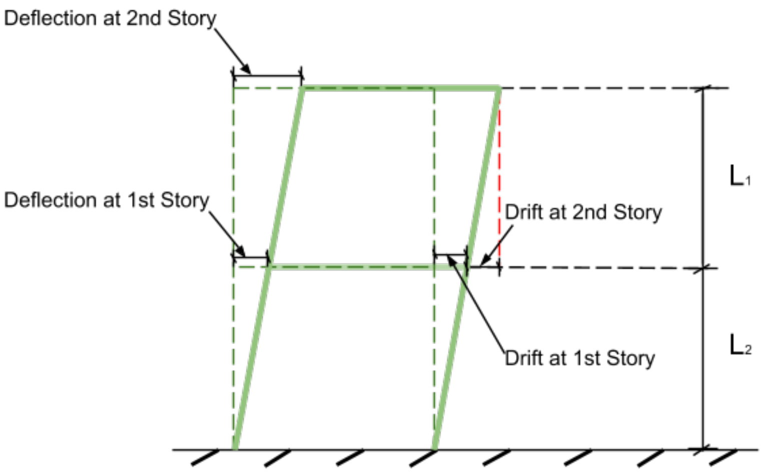

Figure 3: Storey Displacement

Aspect Ratio

The aspect ratio is defined as the height to width ratio of a building. The aspect ratio for a high-rise building should be between 6 and 10, but not less than 4 [5].

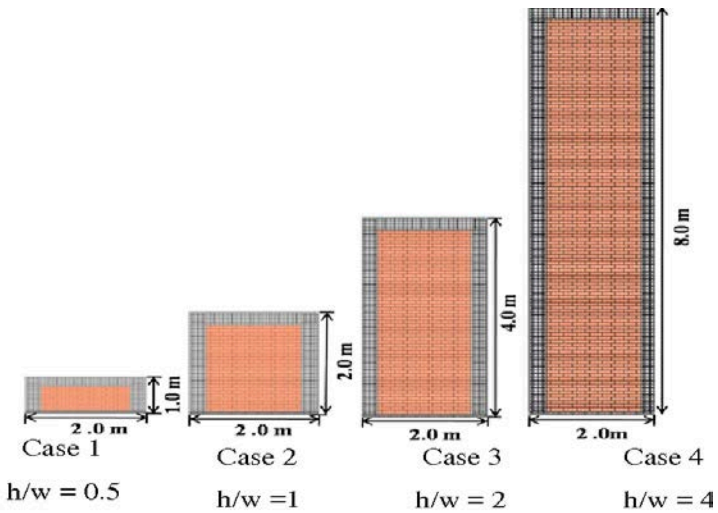

Figure 4: Aspect Ratio (H/B)

Lateral Loads

Lateral loads are horizontal loads that cause shear and sway in a structure. Wind and seismic loads are examples of lateral loads.

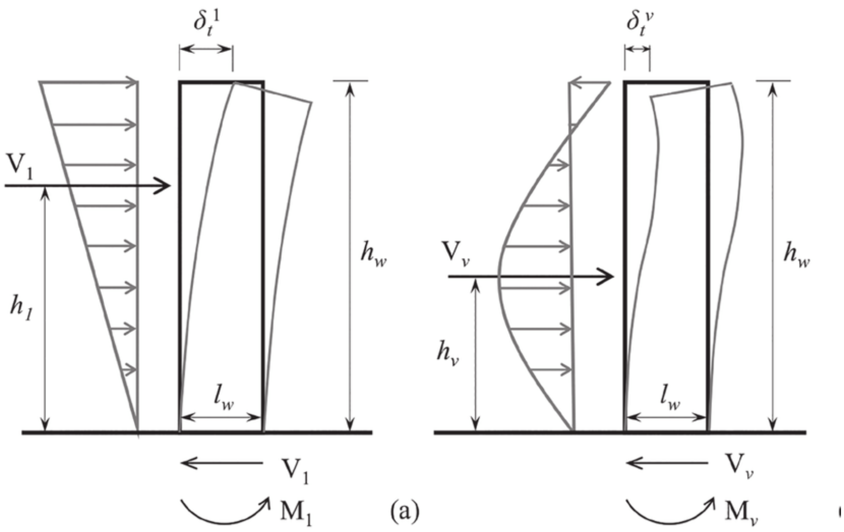

Figure 5: Lateral Loading on Structure

1.2 Primary Research Questions

The primary research questions of this study are as follows-

- What role does shear wall have in aspect ratio?
- When does the aspect ratio of an RC structure fail?
- What is the best zone-by-zone aspect ratio for shear wall construction?
- How do lateral stresses affect a narrow RC structure vs a symmetrical RC structure?

1.3 Key Considerations

By this time, we already know that shear walls resist wind and seismic loads. A building’s aspect ratio (aspect ratio is the ratio height to width of a building) also determines how much resistance it has against shear forces and deformation. Usually when the height of a building increases its resistance to shear and deformation decreases. So, the chance of critical failure increases. And if the building has a set height but has different aspect ratios then the closer the aspect ratio is to 1the better its resistance against shear and deformation. So, it has a lower chance to fail.

Various models were generated using the ETABS software under different aspect ratios and the results were put together in an excel file to further analyze. Additional graphs were also made to understand the results and compare them from one another.

1.4 Research Significance

The study focuses on the relevance of shear walls in RC structures of various forms located in Bangladesh’s various seismic zones, as specified by BNBC 2020. The scientific field isn't completely unexplored. The significance of shear walls has been studied in a number of ways. Because of variable wind speeds and seismic properties, study in this field varies to some degree from place to location. Even though the studies were conducted in specific areas, the findings may be applied to other sites with identical or similar wind and soil characteristics.

A few studies on the relevance of shear walls in resisting lateral loads have been undertaken in Bangladesh. A study on the impacts of shear wall in a flat plate structure based on BNBC 2010 was undertaken in the paper titled ‘Comparative Analysis of a 15 Story Flat Plate Building with and without Shear Wall and Diagonal Bracing Under Wind and Seismic Loads’. The research was carried out using a model developed using the STAAD.Pro program. The research finds that for a structure to operate correctly, it must have lateral resistance. It is vital to acknowledge that lateral forces must be included from the starting and that lateral force-resisting structure must be incorporated in order to complete the basic schematic design appropriately. According to the study, a shear wall should be installed in a flat plate structure [6].

A study was done on the base shear, base moment, and drifts of the three seismic zones designated in BNBC 1993 and a comparison was made in the research titled 'Study of Seismic Performances of RCC Buildings Located in Different Seismic Zones in Bangladesh.' According to the findings, seismic zone-3 has a larger base moment and drifts than the other zones. Shear wall buildings have larger base shear and base moments than non-shear wall structures, and shear wall buildings outperform non-shear wall buildings in higher seismic zones, according to the study [7].

A comparative study on the base shear of a building was undertaken between BNBC 1993, BNBC 2010, NBC-India 2005, and ASCE 7-10 in the report titled ‘A Comparative Study on Seismic Analysis of Bangladesh National Building Code (BNBC) with Other Building Codes’. The analysis indicates that BNBC 1993 provides the least base shear values among the current codes analyzed in the publication. While industrialized nations choose a more conservative design, the inconsistency of BNBC-93 might be fatal. BNBC 2010 base shear values for low-rise structures throughout the nation have increased considerably since BNBC 1993. BNBC 2010 has a lower base shear value than ASCE 7-05 for low-story structures. In most circumstances, the ASCE 7-05 code design parameters impose higher base shear values since they are general. A comparison to the Indian standard will be more useful since India is Bangladesh’s nearest neighbor and shares the same tectonic zone. The design seismic loading stated by BNBC 2010 seems to be properly justified in comparison to the Indian standard, considering that the proposed standard's notional base shears are quite close to those of NBC-India 2005. As a consequence, the proposed BNBC 2010 code proposes a significant increase in the earthquake factor of safety by advocating higher base shear values[8].

There are a few gaps in the aforementioned research that may be detected. The studies include a number of flaws, including:

- A focus on flat plate structures solely
- The structures' forms aren't varied enough
- When analyzing the impacts of shear walls under lateral stress, there is a lack of diversity in wind and seismic characteristics
- Drift and lateral deflection define a building's lateral stability, which is lacking in shear wall investigations
- There is no information on the best shear wall orientation for reinforced concrete structures
- The use of earlier BNBC versions (1993 and 2010), which were insufficient in terms of safety and uniformity

This research fills in the gaps left by prior studies on the effects of shear walls in resisting lateral stresses such as seismic and wind loads. The study's models were created using ETABS and adapted to any kind of reinforced concrete structure. In the study, three distinct B/L (Breadth/Length) ratios are evaluated for modifying the design of the structure. The models with and without shear walls were tested in four distinct scenarios at four typical sites (Barisal, Dhaka, Chittagong, and Sylhet) from the four seismic zones established by BNBC 2020. The research focuses on the structure's drift and lateral deflection limitations in these four places. This research is also looking at the best shear wall orientation. The research was based on Bangladesh's most recent building code, known as 'BNBC 2020,' which is equivalent to ASCE 7-10. As a result, since the study covers a variety of hitherto unexplored areas of research on shear walls in reinforced concrete structures, it is very important and may provide a large dataset for future research on the subject.

1.5 Objectives of the Study

The main objectives of this study are to analyze:

1. Influence of wind and seismic loads under different aspects ratios
2. Behavioral change of building within the limitation of drift and deflection under different aspect ratios

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2. Literature Review

Structural behavior during any seismic event depends on several factors; base shear, ductility, stiffness, lateral strength, configurations, and many more [9] [10]. One of the major issues is to investigate the seismic performance of multistoried RCC buildings. Adequate stiffness is necessary in high-rise buildings to increase resistance against the lateral loads brought by wind or seismic events [11]. In addition, RC shear walls are designed for buildings located in seismic areas because of their high strength, stiffness, and ductility. Researchers have studied to control drift and deflection by introducing shear walls to increase structural resistance for these events. Orientation of the shear wall as well as their effective application are some of the key parameters to reduce lateral force effectively.

Dwivedi and Tyagi [12] performed seismic analysis of RCC buildings with and without shear wall and concluded that shear with composite column counter lateral force more effectively. They considered four types of models; RCC, RCC with shear wall, composite column, and composite column with shear wall. The effect of drift and deflection were reduced while using the composite column compared to other models. However, Dwivedi and Tyagi did not include the orientation of shear wall in their study. In our study, we attempt to explore structures with two types of shear wall orientation and analyze overall effect of shear wall on structure.

Dewangan et al. [13] studied the effect of core wall in RC building and found that shear force as well as strength and stiffness increase by using core wall compared to without core wall condition. In our study, we will compare between core and corner shear wall and find out their effectiveness.

Shenbagam and Swathika [14] performed seismic analysis of RC frame structure in ETABS and concluded that applying a shear wall system can merely reduce storey drift and structure displacement owing to lateral stresses.

Karnale and Shinde [15] stated that shear wall in building's core allowed for permitted deflection. But maximum base shear made it more vulnerable to earthquakes whereas the shear wall at the building's corner provided deflection within acceptable limits as well as minimal base shear, making it less resistant to earthquakes.

Dwivedi and Tyagi [16] stated that lateral displacement and drift can be reduced extensively in presence of shear wall. In this case, building with composite column showed minimum displacement. On the contrary, RCC building without shear wall resulted into maximum displacement.

Jaya and Alandkar [17] performed lateral displacement and drift analysis of multistoried building using equivalent static loads. They worked on models of moment resisting frames and shear wall systems. They concluded that models with shear wall system showed comparatively lower lateral displacement and drift than moment resisting frame system.

Bongilwar et al. [11] studied the significance of shear wall in multi-storied structure with seismic analysis. They stated that provision of shear wall increased base shear of RC buildings which proved increment of stiffness.

Patel and Mehta [18] did comparative study on shear wall building and core wall building. Their models showed that core wall was more effective and convenient than shear wall for reducing displacement which aligns with the study of Dewangan et al. [13].

Prakash A N [19] also performed analysis on a multi-storied building with and without shear wall using STAAD Pro. Study showed that there was a considerable reduction of displacement drift in structures with shear wall. He also stated that corner shear wall orientation resulted in least displacement and moment than other orientations which perfectly aligns with our analysis.

Hokmabadi et al. [20] studied on structural inter-storey drifts under earthquake while adopting time-history approach along with equivalent linear method to determine the non-linear cyclic behavior of a 15-storied concrete MRF building using SAP2000 V.14. They focused on performance-based design considering uncertainties during seismic design due to earthquake loads, lateral deflection, inter-storey drifts, effective stiffness and damping properties of structures as well as limitations. Moreover, they compared accuracy of different approaches to analyze. Their study resulted in conclusion that method of predicting the total maximum inter-storey drift considering all time steps should be selected in order to get more accurate result for this performance-based design.

Caterino et al. [21] proposed approximate methods for evaluating storey stiffness and maximum inter-storey drift of RC buildings in seismic areas. One of their objectives was to evaluate the results based on frame types. They analyzed that shear frames performed better and lead to a convergent result than flexural frames. As lateral displacement and storey stiffness are two of the major interrelated parameters for a frame subjected to earthquake events, they suggested to evaluate lateral drifts based on lateral stiffeness of each storey.

Sil and Longmailai [22] attempted to assess a seismically located RC structured based on roof-lateral displacement. They followed both equivalent static force analysis and dynamic analysis for this study. They compared displacement results obtained from SAP2000 with the failure function generated using regression method that included parameters like aspect ratios of column and beam, compressive strength, storey height, seismic weight, etc. Their study resulted in high reliability with negligible error. Their result showed decrement of lateral drift with increment of aspect ratios of beam and column, compressive strength, and total weight of structure.

3. Context of Bangladesh

Bangladesh is at edge of a high risk to any moderate to high level seismic occurrence/earthquake [23]. Buildings without considering seismic parameters are under risk of failure even due to lower level of lateral loading events. There are many researches done in Bangladesh regarding seismic performance evaluation. Researchers mainly focused on effects of lateral loads on RCC buildings by analyzing through various methodologies to ensure effective design, costing, and safety.

Shahrin and Hossain [24] did non-linear inelastic pushover analysis to evaluate seismic performance of residential buildings in Dhaka city. They worked on full infilled, soft ground storey, and irregular structure. The results showed that full infilled structures performed better in terms of stiffness, inter storey drift and lateral displacement, and higher base shear capacity.

Rahman et al. [25] conducted drift analysis due to earthquake load on tall buildings. They analyzed drifts of couple shear wall structure, rigid frame structure, and wall frame structure using C-programming (version C++4.5). However, in case of shear wall structure, drift depends on span and height of structure as well as length and width of column and beam within two walls. Drift increases with increase of structural height as obvious. But drift significantly decreases with increase of span number or building width. Increment of column and beam width helps to enhance lateral support against lateral loads that lessens failure due to drift. In our case, we also attempt to analyze variance of performance depending on structural height, width, and aspect ratio with respect to lateral loading conditions.

Rahman et al.[26] studied on drift analysis due to wind and earthquake loads on tall buildings using C programming language. Their outcome was also similar to pervious study; drift decreased with increased building width, length of shear wall, and cross-section of beam and column.

Haque et al. [27] analyzed seismic performance of RCC building with plan irregularity. Their objective was to run static and dynamic analysis using ETABS and SAP 2000 over different regular and irregular shaped RCC buildings according to Bangladesh National Building Code (BNBC) – 2006. Though their models crossed maximum displacement limit in dynamic analysis, the comparative study showed that significant displacements occurred to buildings with irregular shapes (W-shaped, L-shaped) compared to regular ones (rectangular, square). Difference of displacements within stories increased in higher stories along with plan irregularity. However, their results will be helpful as we plan to analyze regular shaped structures with static analysis method.

Ahmed et al. [28] also studied seismic performance of RCC structures, with and without shear wall, located in different seismic zones in Bangladesh. Their study showed that base shear, base moment, and storey drift increased with higher zone coefficient. Moreover, the results showed shear wall building performs better in higher seismic zones compared to building with no shear wall. They also pointed out that base shear and base moment are higher in case of building with shear wall which results in higher resistance against lateral loads.

Tafheem et al. [29] did a comparative analysis between static (ESF method) and dynamic (RS method) loading condition on a multistoried RC building following BNBC 2006 and analyzed earthquake response as per the methodologies. They focused on variation of storey drift and displacement, base shear, bending moment, and shear force with different storey height. Through analyzing, it showed that maximum sway tended to occur in top storey. However, storey drift showed a decreasing tendency with increased storey height. Equivalent static force method (ESFM) provided more accurate data compared to response spectrum method (RSM) in this particular study. The authors suggested to use RSM as an approximate method considering its restriction to linear elastic analysis.

Another comparative research done by Rahman et al. [30] on seismic performance of RC buildings designed according to Bangladesh (BNBC – 1993), India (IS – 1893), and the United States all have design provisions (ASCE 7-10).Several parameters were considered including zoning system, site classification, vibration period, response reduction factor, importance factor, allowable storey drifts, minimum design lateral force, and design response spectrum. From the then comparative research, it came to light buildings designed with ASCE 7-10 provision showed largest stiffness whereas buildings with BNBC – 1993 provision was more flexible. Overall energy dissipation was consistent for all provision.

4. Methodology

The present study is conducted on drift and defection control of RC symmetrical building by providing core and corner shear walls. Failure criteria were determined in four seismic zones (Zone-1 to Zone-4) in Bangladesh, based on aspect ratio and proposed breadth to length ratio (B/L ratio). Equivalent Static Analysis in ETABS V.2016 was used to analyze three distinct B/L ratios – 1, 0.7, and 0.4 for each zone without shear wall and with both core and corner shear walls.

4.1 Structural Model Selection and Description

Following the latest Bangladesh National Building Code (BNBC 2020) [30], four earthquake zones of Bangladesh were selected as primary site location. Jessore, Dhaka, Gazipur, and Mymensingh districts were selected as representatives of zone-1, zone-2, zone-3, and zone-4 respectively. This study is repeated for models with three breadth-to-length ratios (B/L ratio) – 1, 0.7, and 0.4 **(Figure 6)** for each zone for three cases - without shear wall, with core wall, and corner shear wall. The breadth was fixed as 60 feet while the length varied according to B/L ratios. The lengths are 60 ft, 85.71 ft, and 150 ft for B/L ratios of 1, 0.7, and 0.4 accordingly. Storey height is taken as 10 ft. Similar cross-sections of beam, column, and slab are considered for all the models. Here, a key consideration is to fixate building breadth for all models to observe how the buildings behave in terms of drift and deflection if the length is increased while the breadth remains constant. Table **(Table 9)** for seismic zone-coefficient and wind speed of the respective selected locations are attached at the appendix section. Structural model descriptions and material properties are given in the **Table 1** below.

Table 1: Model and Material Properties

Model Description		**Material Properties**	
Provided B/L Ratios	B/L = 1; B/L = 0.7; B/L = 0.4	Material Type	Concrete
Breadth of Model	60’	Comprehensive Strength of Concrete	4000 psi
Column Size	17” X 17"	Weight per Unit Volume	150 pcf
Ground Column	19" X 19"	Mass per Unit Volume	4.662 lb-s^2 / ft^4
Floor Beam	14" X 20"	Modulus of Elasticity (E)	3605 ksi
Grade Beam	16" X 22"	Shear Modulus of Concrete (G)	1502 psi
Slab Thickness	5 "	Yield Strength of Steel	60 ksi
Shear Wall Thickness	8 "		
Interior Wall	5 "		
Exterior Wall	10 "		

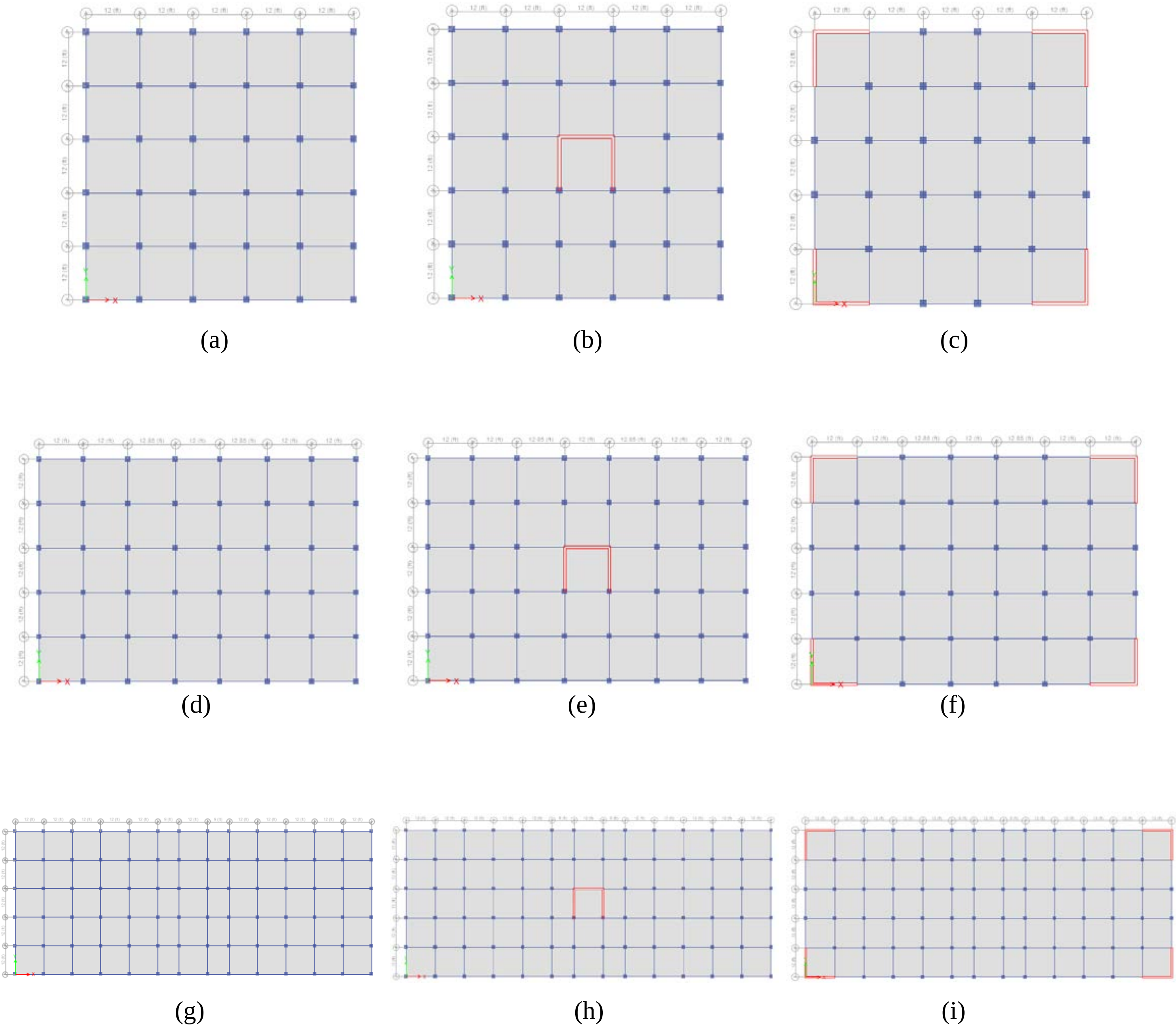


Figure 6: Models configurations using ETABS; (a) B/L = 1 without shear wall, (b) B/L = 1 with core wall, (c) B/L = 1 with corner shear wall, (d) B/L = 0.7 without shear wall, (e) B/L = 0.7 with core wall, (f) B/L = 0.7 with corner shear wall, (g) B/L = 0.4 without shear wall, (h) B/L = 0.4 with core wall, (i) B/L = 0.4 with corner shear wall

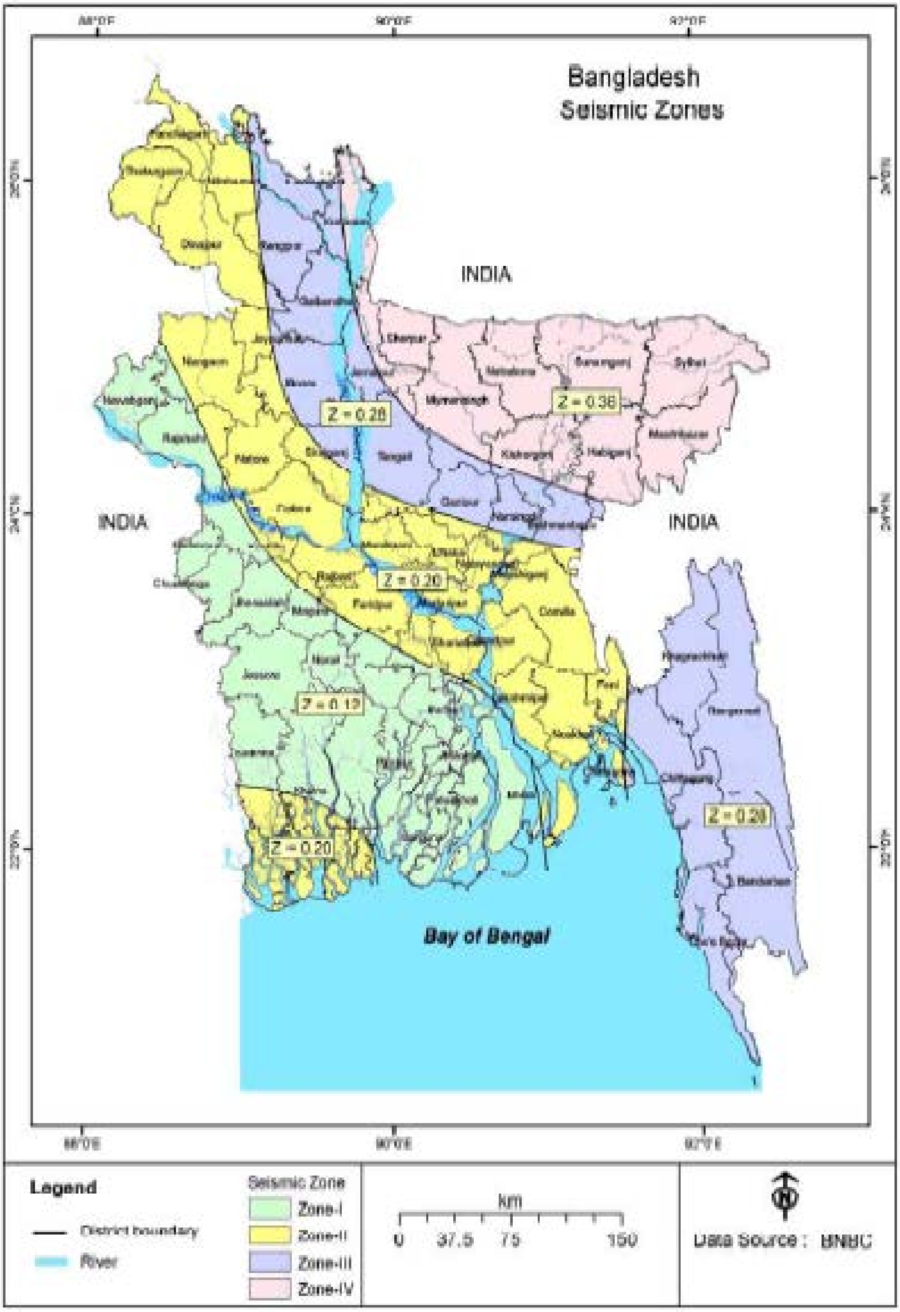


Figure 7: Seismic Zoning Map of Bangladesh (BNBC 2020)

4.2 Structural Modelling

We have considered special moment resisting frame (SMRF) for our study. There are interconnected units of structural components; load is transferred from slabs to beams, beams to columns, and columns to base or foundation.

We considered the structure as a residential one with occupancy category – II where site class has been selected as SC (Deep deposits of dense or medium dense sand, gravel or stiff clay with thickness from several tens to many hundreds of meter; SPT 15-50). A615, 60 grade reinforcement bars have been selected for this purpose with concrete strength of 4 ksi. Lateral loads including wind load and earthquake load can be imposed on the structure. Overall structural and location conditions align with exposure category A with reference to BNBC 2020 (Exposure category B according to ASCE 7-05). The basic wind speed (V) is used in the determination of design wind loads on buildings and other structures.

Compared to ordinary moment resisting frame (OMRF) and intermediate moment resisting frame (IMRF), special moment resisting frame (SMRF) provides higher elastic characteristics in case of drift or displacement due to lateral loading. As we opt for developing a seismic-force resisting system, SMRF can be the best solution against strong earthquake with severe inelastic activity. This system can help to keep critical failure parameters within limit and provide structural rigidity.

4.3 Equivalent Static Analysis

Equivalent Static Method is used for analyzing drift and deflection using ETABS V.2016 for this purpose. For simple regular or symmetrical structures, analysis by equivalent linear static method is often sufficient; this is permitted in most of the codes of practice for regular and low to medium-rise buildings and ensures resistance against torsional movement [31] which is based on the fundamental natural period of vibration of the structure. ESM analysis can be depended on modes [32]. It is a simplified technique to distribute dynamic loading of an earthquake into static form. The structure must be able to resist effects caused by seismic forces in either direction, but not in both directions simultaneously.

4.3.1 Spectral Acceleration

SA (spectral acceleration) is approximately what is experienced by a building, as modeled by a particle on a massless vertical rod having the same natural period of vibration as the building. It is a unit measured in g (the acceleration due to Earth's gravity, equivalent to g-force) that describes the maximum acceleration in an earthquake on an object – specifically a damped, harmonic oscillator moving in one physical dimension [33].

Sa = 2ZICs/3R

Here,

S_a = Design spectral acceleration that is not less than 0.67ZIS (in units of g).
β = Coefficient used to calculate lower bound for S_a. Recommended value for β is 0.11
Z = Seismic zone coefficient
C_s = A function of building period and soil type (site class); normalized acceleration response spectrum
R = Response reduction factor
I = Structure importance factor

4.3.2 Base Shear

The seismic design base shear force in a given direction will be calculated from the following relationship: $V = S_aW$ [33]

Here,

S_a = Lateral seismic force coefficient; design spectral acceleration (units of g) corresponding to the construction time T

W = Total seismic weight of the building

To check the accuracy of the model, V/W value of the model is compared to the calculated value using equation $S_a = 2ZIC_s/3R$.

$S_a = 2(ZIC_s) / 3R = 2.48\%$, where Z = 0.2, I = 1, $C_s = 1.49$, R = 8

$Sa_{min} = 0.67\beta ZIS = 0.0169$

Here $Sa > Sa_{min}$

$V = S_aW$

So, $V/W = S_a$

From ETABS, V/W = (457.7263/18627.4711) x 100 % = 2.48%

Direction	Period Used (sec)	C_s	W (kip)	V (kip)
X	1.17	0.024573	18627.4711	457.7263
Y	1.17	0.024573	18627.4711	457.7263
X + Ecc. Y	1.17	0.024573	18627.4711	457.7263
Y + Ecc. X	1.17	0.024573	18627.4711	457.7263
X - Ecc. Y	1.17	0.024573	18627.4711	457.7263
Y - Ecc. X	1.17	0.024573	18627.4711	457.7263

Figure 8: Base Shear Calculation from ETABS

4.3.3 Building Period

The building period T (in sec) may be calculated by the following relationship [33]:

$T = C_t (h_n)^m$

Here,

h_n = Building height in meter measured from the foundation or the top of the rigid basement. This does not include the basement levels, which are linked to the ground floor deck or installed between the building columns. It does, however, include the basement levels when they are not as well connected.

4.4 Loading Criteria

Applied loads on structures included dead load, live load, wind load, and seismic load according to BNBC 2020 [33].

4.4.1 Load Combinations

Load combinations are selected based on effective parameters according to research purpose.

Where,

D denotes Dead Load
L denotes Live Load
W denotes Wind Load
E denotes Earthquake Load
R denotes Rain Load
Lr denotes Roof Live Load
F denotes weight loads and pressures of fluids with well-defined densities with regulated maximum heights or corresponding internal moments and forces
T denotes self-staining forces as well as the cumulative impact of temperature, creep, differential settlement, shrinkage, and shrinkage compensating concrete.
H denotes Soil pressure and weight loads, existing water in soil loads, or associated internal forces and moments
Load considerations, and combinations are briefly presented in Table 2 and Table 3 respectively.

Table 2: Load Considerations for the Models According to BNBC 2020 [33]

Load Considerations		
Load Pattern	**Definition**	**Value**
Dead Load	Self-weight/other dead loads	Auto calculated by software
Super Dead Load (Shell) [Ref Table 6.2.2]	Partition Wall	25 psf
	Partition Wall (Roof)	0 psf
	Floor Finish	25 psf
	Floor Finish (Roof)	25 psf
Super Dead Load (Frame) [Ref Table 6.2.2]	Exterior Walls	1 kip/ft
	Interior Walls	0.5 kip/ft
	Parapet	0.15 kip/ft
Live Load [Ref Table 6.2.3]	Floor Live Loads (LL)	41.77 psf
	Roof Live Load (Lr)	60.57 psf

Table 3: Load Combinations According to BNBC 2020 [33]

Load Combinations [Ref Sec 2.7.1.3 BNBC 2020]			
Case	Basic Load Combinations [Sec 2.7.3.1]	Used combinations	Considered Zones
1	1.4 (D+F)	1.4D	All
2	1.2(D+F+T) + 1.6(L+H) + 0.5(Lr or R)	1.2D + 1.6L + 0.5Lr	All
3	1.2D + 1.6(Lr or R) + (L or 0.8W)	1.2D + 1.6Lr + L	All
		1.2D + 1.6Lr ± 0.8W	All
4	1.2D + 1.6W + L + 0.5(Lr or R)	1.2D ± 1.6W + L + 0.5Lr	All
5	1.2D + 1.0E + 1.0 L	1.246D ± 1.0E + 1.0 L	Zone 1
		1.2767D ± 1.0E + 1.0 L	Zone 2
		1.3073D ± 1.0E + 1.0 L	Zone 3
		1.338D ± 1.0E + 1.0 L	Zone 4
6	0.9D + 1.6W + 1.6H	0.9D ± 1.6W	All
7	0.9D + 1.0E + 1.6H	0.854D ± 1.0 E	Zone 1
		0.8233D ± 1.0 E	Zone 2
		0.7927D ± 1.0 E	Zone 3
		0.762D ± 1.0 E	Zone 4

4.4.2 Wind Load

In our study, overall structural and location conditions align with exposure category A with reference to BNBC 2020 (Exposure category B according to ASCE 7-05). The basic wind speed (V) is used in the determination of design wind loads on buildings and other structures. Tornadoes were not taken into account while creating the fundamental wind-speed distributions.

In our case, we considered rigid structures with Main Wind Force Resisting System; the gust-effect factor is taken as 0.85, the wind directionality factor as 0.85 (K_d), and the building importance factor as 1(I). Reference table **(Table 11)** for gust factor is attached in the appendix.

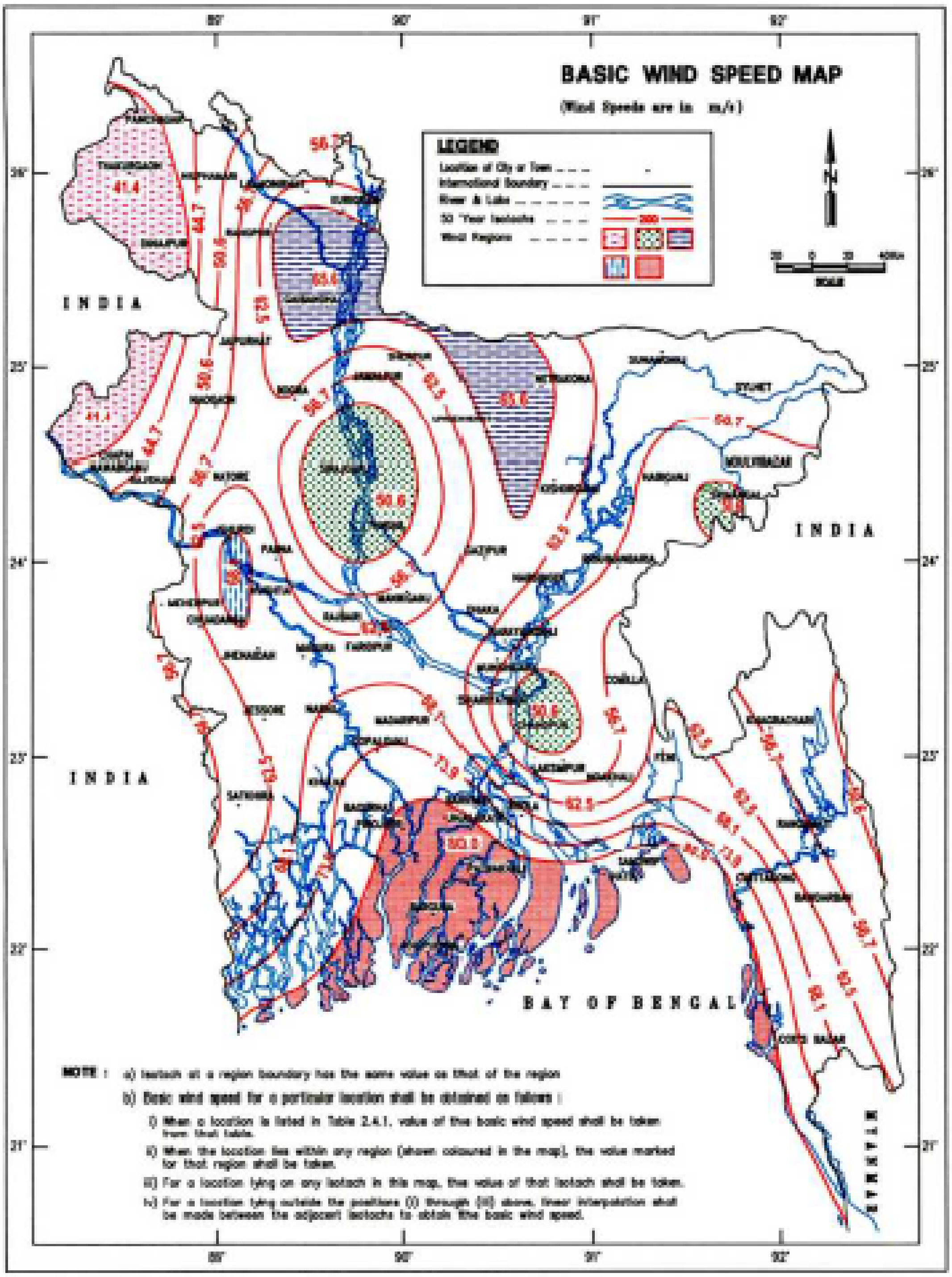


Figure 9: Basic Wind Speed Map (BNBC - 2020)

4.5 Drift and Deflection Limitation

According to BNBC 2020 act, there are limitations for particular structural drift and deflection depending on structure height (H), time period (T), deflection amplification factor (Cd), response reduction factor (R), and system overstrength factor (Ωo).

Sway (Horizontal Deflection): Sway limitation is H/500, where H is the building height.

The deflections (δ_x) of level x at the center of the mass shall be determined in accordance with the following equation:

$$\delta_x = C_d \, \delta_{xe} / I$$

Where,
C_d = Deflection amplification factor
δ_{xe} = Deflection determined by an elastic analysis
I = Importance factor

Drift: As per BNBC 2020 [33], drift limitation ranges within

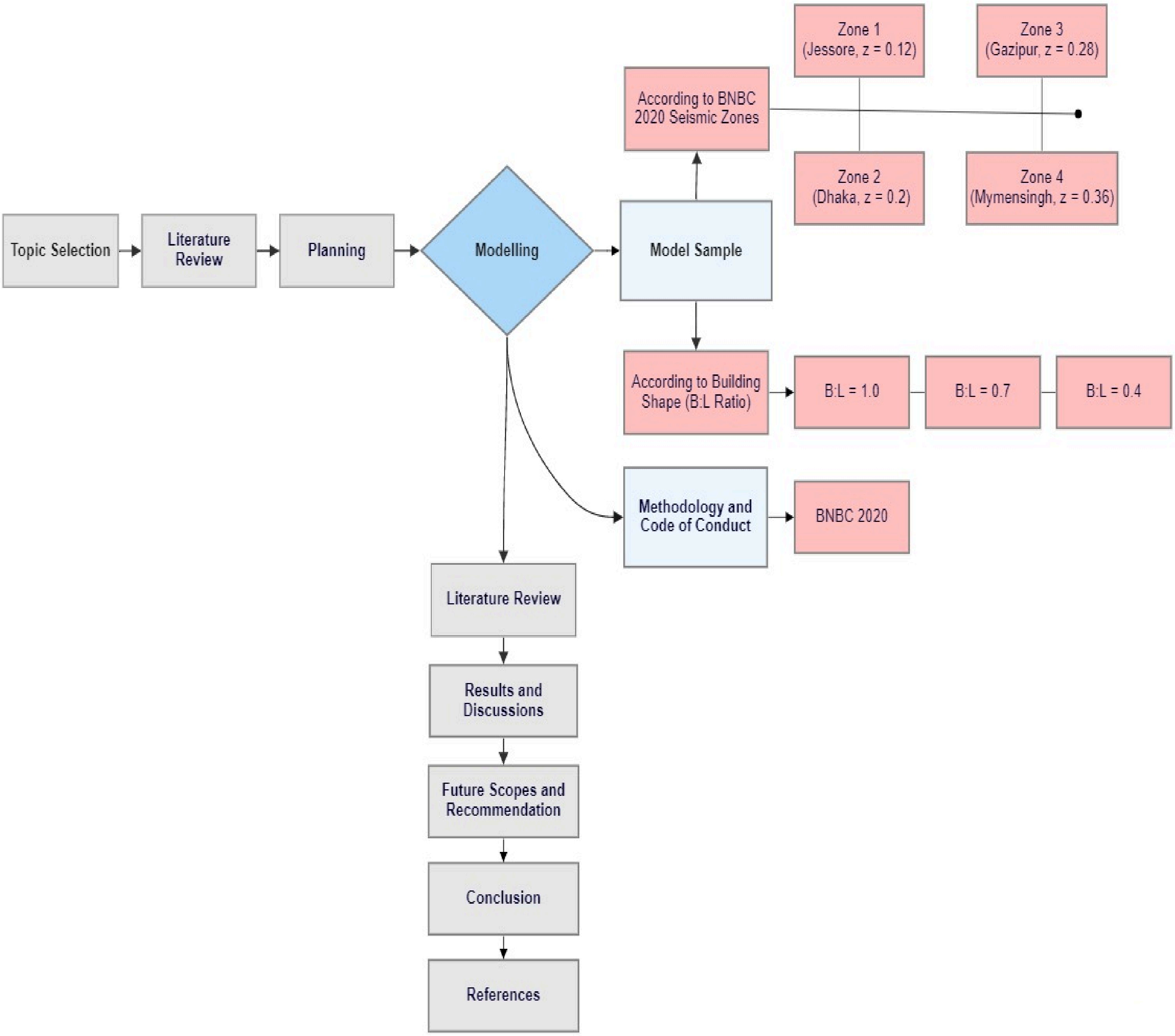
$\Delta \leq 0.005h$ when $T < 0.7$ second
$\Delta \leq 0.004h$ when $T \geq 0.7$ second
$\Delta \leq 0.0025h$ in the favor of unreinforced masonry structures, as h is the story height of the structure height

We considered structures with special moment resisting frames (SMRF) for developing a seismic-force resisting system. The considered response reduction factor (R), system overstrength Factor (Ωo), and deflection amplification factor (Cd) based on our system are mentioned in Table.

Table 4: Response Reduction Factor (R), System Overstrength Factor (Ωo), and Deflection Amplification Factor (Cd)

Factors [Ref BNBC 2020: Table 6.2.19]	**Special Reinforced Concrete Moment Frames**	**Special Reinforced Concrete Shear Walls**
	Without Shear Wall	**With Shear Wall**
R	8	7
Ωo	3	2.5
Cd	5.5	5.5

4.6 Research Layout



5. Data Analysis and Discussion on Results

5.1 Shear Wall Orientation

In most of the cases, it is found that the behavior of the shear wall is good when they are provided in Box shape structure. But from various analysis, model with shear wall at periphery shows higher resistance for lateral forces as compared to model with core shear wall. Again, corner shear wall provides better service than core wall in order to increase structural resistance.

In our study. we considered two orientation of shear wall for each model –

1. Core Shear Wall
2. Corner Shear Wall

No model showed failure pattern due to exceeding drift limit. Application of core wall and corner shear wall significantly improved resistant patterns; deflection and drift values were under the maximum allowable limits. But corner shear walls proved to be more effective in terms of controlling drift and deflection of a RC structure rather than core wall.

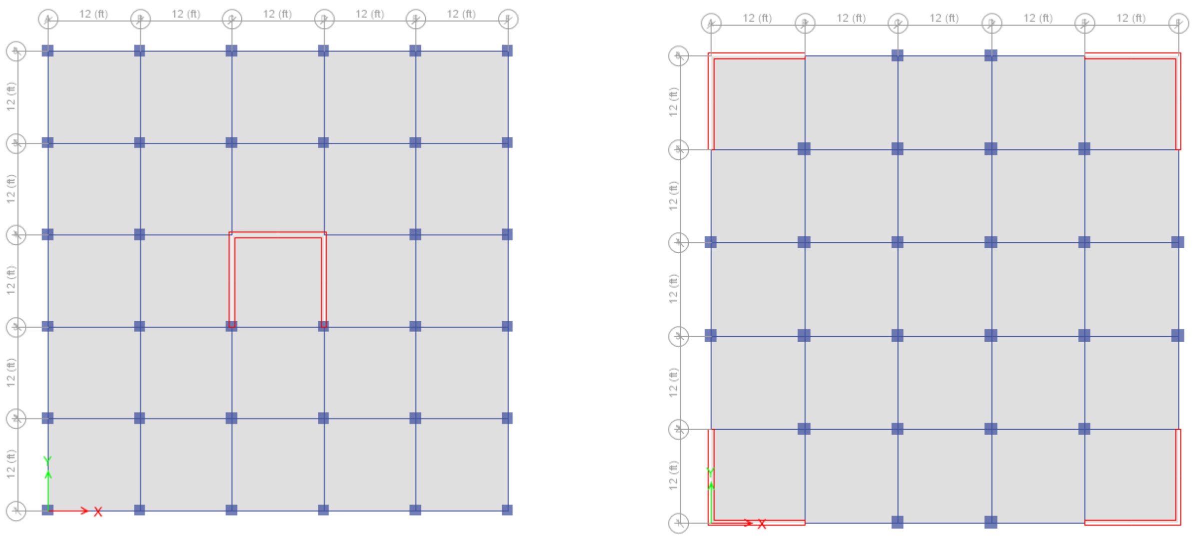


Figure 10: Shear Wall Orientations

5.2 Deflection and Drift Analysis for Various Seismic Zones and B/L Ratios

Drift and deflection analysis of RC buildings with respect to aspect ratio were done in four consecutive seismic zones. For overall comparison and analysis (according to BNBC 2020), four models were selected with B/L ratio of 1, 0.7, and 0.4. Jessore, Dhaka, Gazipur, and Mymensingh; these areas were selected as the testing locations of zone-1, zone-2, zone-3, and zone-4 accordingly. The structural models were analyzed for both core wall and corner shear wall.

Following graphs are drawn by using the obtained results from ETABS analysis. These graphs represent displacement and drift limitations of four seismic zones with respect to B/L ratio. Each of these models considered without shear wall, with core wall, and corner shear wall conditions and the results were compared accordingly.

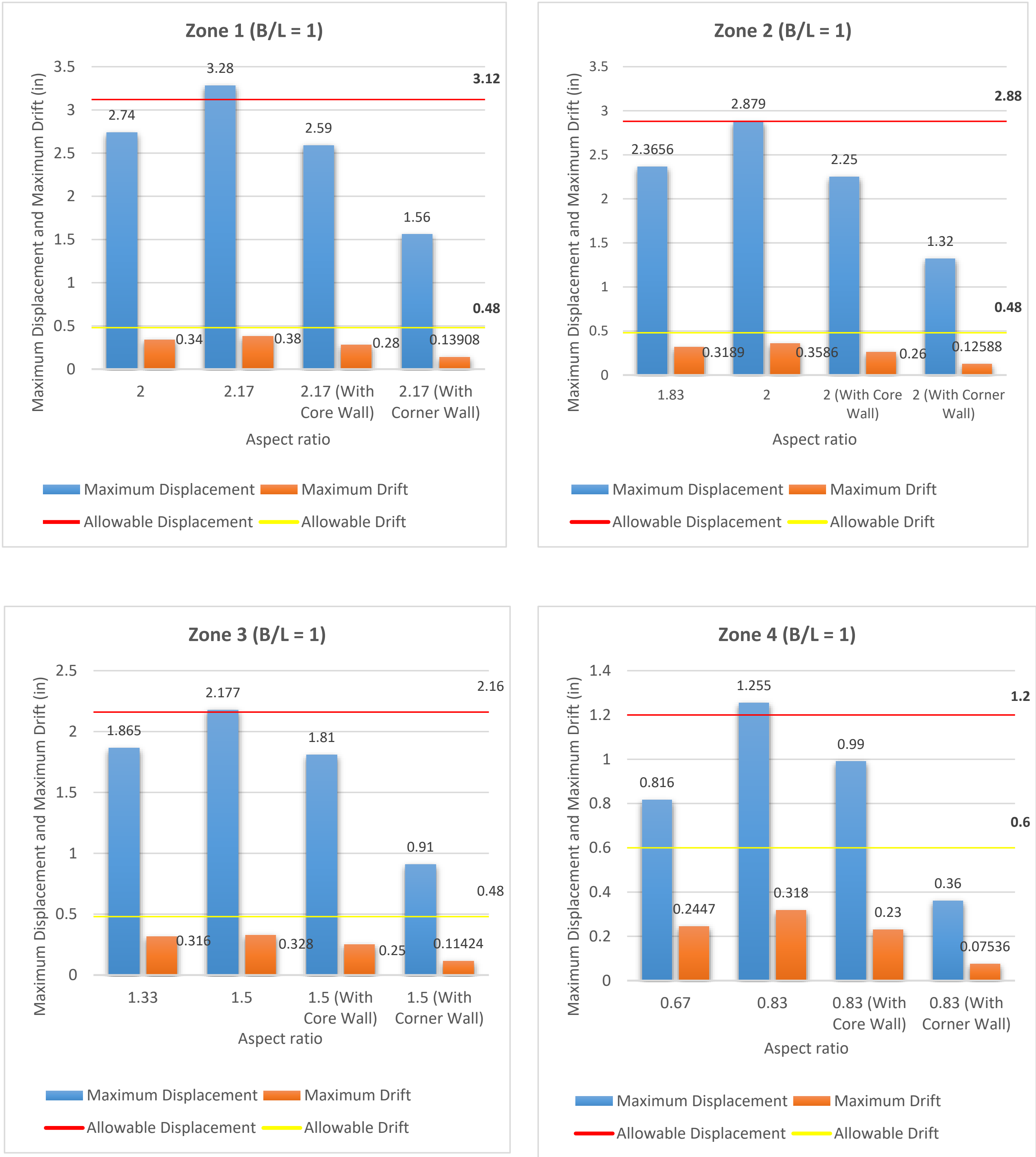


Figure 11: Analysis Results for B/L Ratio 1

Table 5: Analysis Result for B/L = 1

Zone	Unsafe Aspect Ratio (H/B)	Time period (T)	Allowable Displacement	Allowable Drift	Without Shear Wall		Shear Wall (Core)		Shear Wall (Corner)	
					Maximum Displacement	Maximum Drift	Maximum Displacement	Maximum Drift	Maximum Displacement	Maximum Drift
		(s)	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)
1	2.17	1.34	3.12	0.48	3.28	0.38	2.59	0.28	1.56	0.15
2	2	1.26	2.88	0.48	2.88	0.36	2.25	0.26	1.32	0.13
3	1.5	0.99	2.16	0.48	2.17	0.33	1.81	0.25	0.91	0.11
4	0.83	0.62	1.2	0.6	1.25	0.32	0.99	0.23	0.36	0.08

At aspect ratios of 2.17, 2, 1.5, and 0.83, the highest displacement was seen in both the model without and with shear wall (core wall and corner wall).

For Zone-1, the deflection value is 3.28 inches, while the drift value is 0.38 inches., at an aspect ratio of 2.17. The highest permissible limits are 3.12 inches for deflection and 0.48 inches for drift. The addition of a core wall to the model's perimeter reduces both deflection and drift to 2.59 inches and 0.28 inches. Deflection and drift are reduced to 1.56 inches and 0.139 inches, correspondingly, by adding a corner wall to the model's perimeter. In addition, there is less deflection and drift from the viewpoint of the core wall.

For Zone-2, the deflection value is 2.879 inches while the drift value is 0.3586 inches, at an aspect ratio of 2. The highest permitted limits are 2.88 inches for deflection and 0.48 inches for drift. The addition of a core wall to the model's perimeter reduces both deflection and drift to 2.25 inches and 0.26 inches, correspondingly. Deflection and drift are reduced to 1.32 inches and 0.12588 inches, respectively, by adding a corner wall to the model's perimeter. Furthermore, there is less deflection and drift from the core wall's perspective, and it is more effective.

For Zone-3, the deflection value is 2.177 inches while the drift value is 0.328 inches, at an aspect ratio of 1.5. The highest permitted limits are 2.16 inches for deflection and 0.48 inches for drift. The addition of a core wall to the model's perimeter reduces both deflection and drift to 1.81 inches and 0.25 inches, correspondingly. Deflection and drift are reduced to 0.91 inches and 0.11424 inches, respectively, by adding a corner wall to the model's perimeter. Furthermore, there is less deflection and drift from the standpoint of the core wall, making it more effective.

For Zone-4, the deflection value is 1.255 inches while the drift value is 0.318 inches, at an aspect ratio of 0.67. The highest permitted limits are 1.2 inches for deflection and 0.6 inches for drift. The addition of a core wall to the model's perimeter reduces both deflection and drift to 0.99 inches and 0.23 inches, correspondingly. Deflection and drift are reduced to 0.36 inches and 0.07536 inches, respectively, by adding a corner wall to the model's perimeter. So, there is less deflection and drift from the standpoint of the core wall, making it more effective.

The inclusion of the core wall and the corner wall has resulted in a considerable change. A shear wall has a considerable impact on this structure.

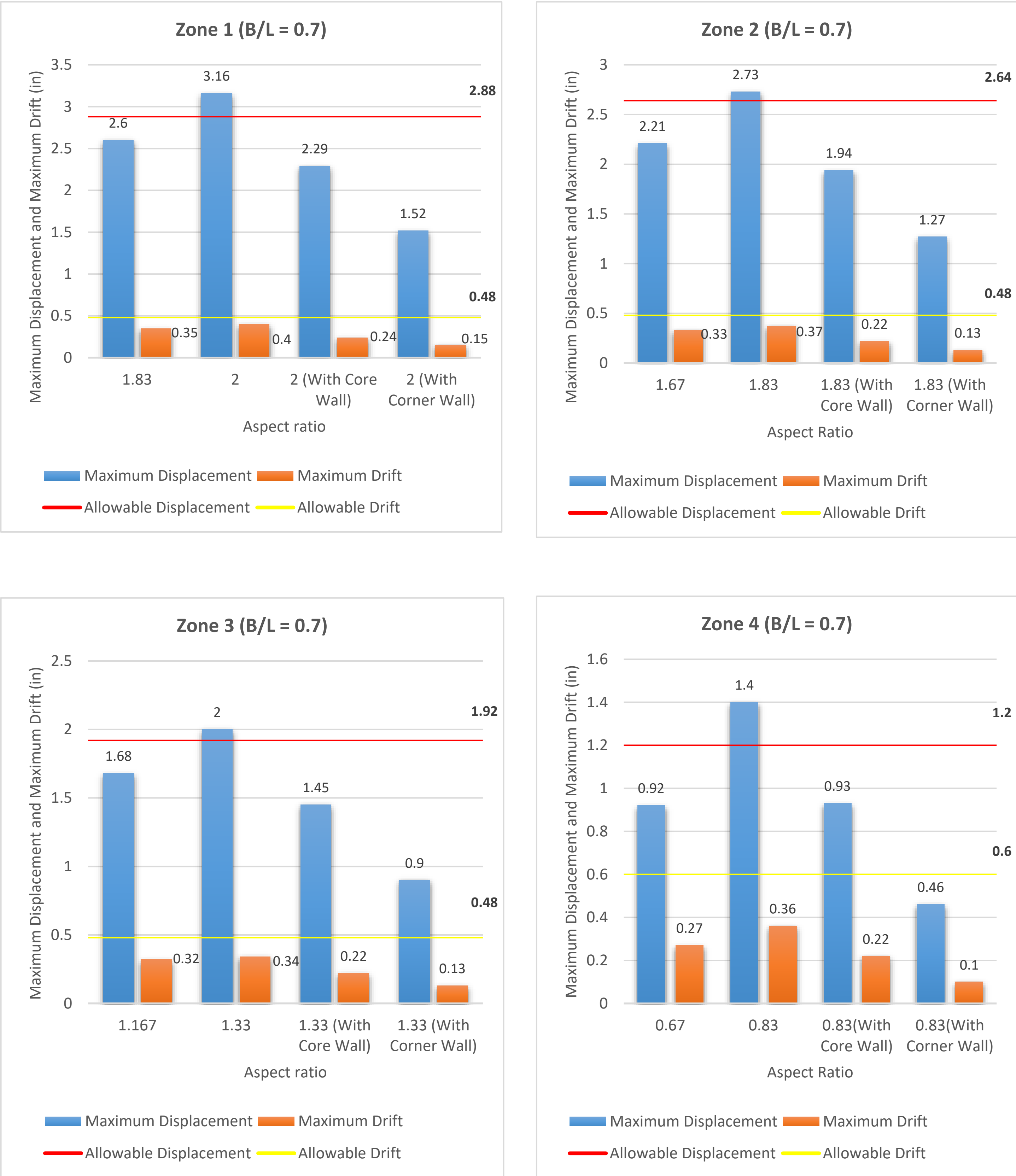


Figure 12: Analysis Results for B/L Ratio 0.7

Table 6: Analysis Result for B/L = 0.7

Zone	Unsafe Aspect Ratio (H/B)	Time period (T)	Allowable Displacement	Allowable Drift	Without Shear Wall		Shear Wall (Core)		Shear Wall (Corner)	
					Maximum Displacement	Maximum Drift	Maximum Displacement	Maximum Drift	Maximum Displacement	Maximum Drift
		(s)	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)
1	2	1.26	2.88	0.48	3.16	0.40	2.29	0.24	1.52	0.15
2	1.83	1.17	2.64	0.48	2.73	0.37	1.94	0.22	1.27	0.13
3	1.33	0.9	1.92	0.48	2.00	0.34	1.45	0.22	0.90	0.13
4	0.83	0.62	1.2	0.6	1.40	0.36	0.93	0.22	0.46	0.10

At aspect ratios of 2, 1.83, 1.33, and 0.83, the highest displacement was seen in both the model without and with shear wall (core wall and corner wall).

For Zone-1, the deflection value is 3.16 inches while the drift value is 0.4 inches, at an aspect ratio of 2. The highest permissible limits are 2.88 inches for deflection and 0.48 inches for drift. The addition of a core wall to the model's perimeter reduces both deflection and drift to 2.29 inches and 0.24 inches, correspondingly. Deflection and drift are reduced to 1.52 inches and 0.15 inches, respectively, by adding a corner wall to the model's perimeter. In addition, there is less deflection and drift from the viewpoint of the core wall.

For Zone-2, the deflection value is 2.73 inches while the drift value is 0.37 inches, at an aspect ratio of 1.83. The highest permitted limits are 2.64 inches for deflection and 0.48 inches for drift. The addition of a core wall to the model's perimeter reduces both deflection and drift to 1.94 inches and 0.22 inches, correspondingly. Deflection and drift are reduced to 1.27 inches and 0.13 inches, correspondingly, by adding a corner wall to the model's perimeter. Furthermore, there is less deflection and drift from the core wall's perspective, and it is more effective.

For Zone-3, the deflection value is 2 inches while the drift value is 0.34 inches, at an aspect ratio of 1.33. The highest permitted limits are 1.92 inches for deflection and 0.48 inches for drift. The addition of a core wall to the model's perimeter reduces both deflection and drift to 1.45 inches and 0.22 inches, correspondingly. Deflection and drift are reduced to 0.9 inches and 0.13 inches, correspondingly, by adding a corner wall to the model's perimeter.

Furthermore, there is less deflection and drift from the standpoint of the core wall, making it more effective.

For Zone-4, the deflection value is 1.4 inches while the drift value is 0.36 inches, at an aspect ratio of 0.83. The highest permitted limits are 1.2 inches for deflection and 0.6 inches for drift. The addition of a core wall to the model's perimeter reduces both deflection and drift to 0.93 inches and 0.22 inches, correspondingly. Deflection and drift are reduced to 0.46 inches and 0.1 inches, correspondingly, by adding a corner wall to the model's perimeter. So, there is less deflection and drift from the standpoint of the core wall, making it more effective.

A considerable change has occurred as a result of the addition of the core wall and the corner wall. This structure is significantly influenced by a shear wall.

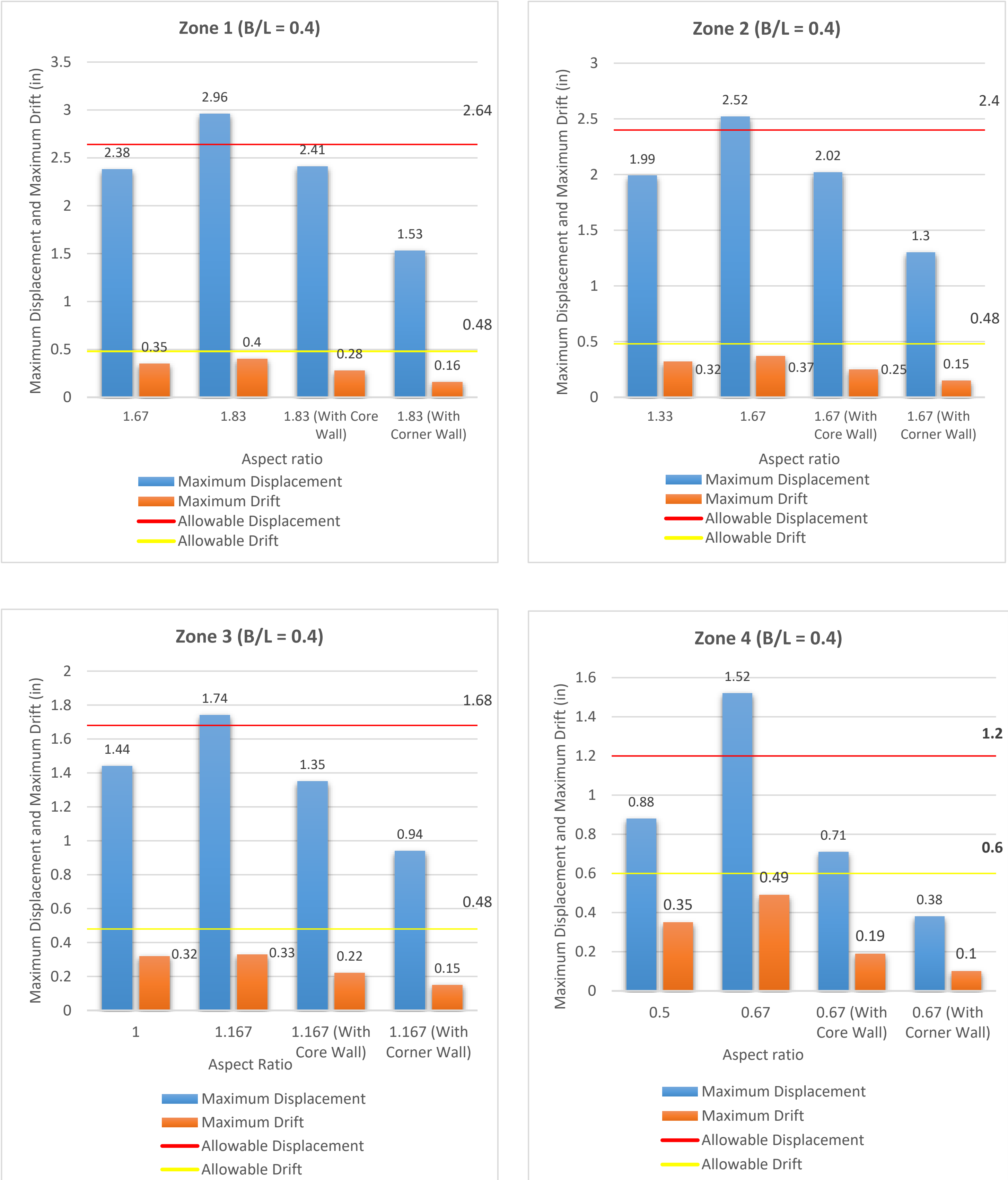


Figure 13: Analysis Results for B/L Ratio 0.4

Table 7: Analysis Result for B/L = 0.4

Zone	Unsafe Aspect Ratio (H/B)	Time period (T)	Allowable Displacement	Allowable Drift	Without Shear Wall		Shear Wall (Core)		Shear Wall (Corner)	
					Maximum Displacement	Maximum Drift	Maximum Displacement	Maximum Drift	Maximum Displacement	Maximum Drift
		(s)	(in)	(in)	(in)	(in)	(in)	(in)	(in)	(in)
1	1.83	1.17	2.64	0.48	2.96	0.40	2.41	0.28	1.53	0.16
2	1.67	1.08	2.4	0.48	2.52	0.37	2.02	0.25	1.30	0.15
3	1.167	0.81	1.68	0.48	1.74	0.33	1.35	0.22	0.94	0.15
4	0.67	0.52	1.2	0.6	1.52	0.49	0.71	0.19	0.38	0.10

At aspect ratios of 1.83, 1.67, 1.167, and 0.67, the highest displacement was seen in both the model without and with shear wall (core wall and corner wall).

For Zone-1, the deflection value is 2.96 inches while the drift value is 0.4 inches, at an aspect ratio of 1.83. The highest permissible limits are 2.64 inches for deflection and 0.48 inches for drift. The addition of a core wall to the model's perimeter reduces both deflection and drift to 2.41 inches and 0.28 inches, correspondingly. Deflection and drift are reduced to 1.53 inches and 0.16 inches, correspondingly, by adding a corner wall to the model's perimeter. In addition, there is less deflection and drift from the viewpoint of the core wall.

For Zone-2, the deflection value is 2.52 inches while the drift value is 0.37 inches, at an aspect ratio of 1.67. The highest permitted limits are 2.4 inches for deflection and 0.48 inches for drift. The addition of a core wall to the model's perimeter reduces both deflection and drift to 2.02 inches and 0.25 inches, correspondingly. Deflection and drift are reduced to 1.3 inches and 0.15 inches, correspondingly, by adding a corner wall to the model's perimeter. Furthermore, there is less deflection and drift from the core wall's perspective, and it is more effective.

For Zone-3, the deflection value is 1.74 inches while the drift value is 0.33 inches, at an aspect ratio of 1.167. The highest permitted limits are 1.68 inches for deflection and 0.48 inches for drift. The addition of a core wall to the model's perimeter reduces both deflection and drift to 1.35 inches and 0.22 inches, correspondingly. Deflection and drift are reduced to 0.94 inches and 0.15 inches, correspondingly, by adding a corner wall to the model's perimeter. Furthermore, there is less deflection and drift from the standpoint of the core wall, making it more effective.

For Zone-4, the deflection value is 1.52 inches while the drift value is 0.48 inches, at an aspect ratio of 0.67. The highest permitted limits are 1.2 inches for deflection and 0.6 inches for drift. The addition of a core wall to the model's perimeter reduces both deflection and drift to 0.42 inches and 0.13 inches, correspondingly. Deflection and drift are reduced to 0.38 inches and 0.1 inches, correspondingly, by adding a corner wall to the model's perimeter. So, there is less deflection and drift from the standpoint of the core wall, making it more effective.

The addition of the core wall and the corner wall has resulted in a significant modification. A shear wall has a significant influence on this construction.

No model showed failure pattern due to exceeding drift limit. Application of core wall and corner shear wall significantly improved resistant patterns; deflection and drift values were under the maximum allowable limits. But corner shear walls proved to be more effective in terms of controlling drift and deflection of a RC structure rather than core wall.

5.2 Limitation Analysis for various Seismic Zones with Aspect Ratio

For zone-1, the limitation exceeded for aspect ratio of 2.17 for B/L ratio 1. The limitations for zone-2 are surpassed at an aspect ratio of 2. Similarly. For B/L ratio 1, maximum displacement or drift limitations were exceeded for zone-3 at an aspect ratio of 1.5 and zone-4 at an aspect ratio of 0.83. For B/L ratios of 0.7, the maximum deflection and drift limitations are exceeded for aspect ratios of 2, 1.83, 1.33, and 0.83 for zone-1,2,3, and 4. Aspect ratios for B/L ratio 0.4 are 1.83, 1.67, 1.167, and 0.67 correspondingly.

Figure 14 shows a descending failure pattern from zone-1 to zone-4 models, where the maximum permissible limits for each B/L ratio are exceeded. Buildings located in greater seismic zones require shear walls at smaller aspect ratio. According to this, buildings in Zone 4 are the most vulnerable ones as these have higher deflection and drift and fails at a lesser aspect ratio.

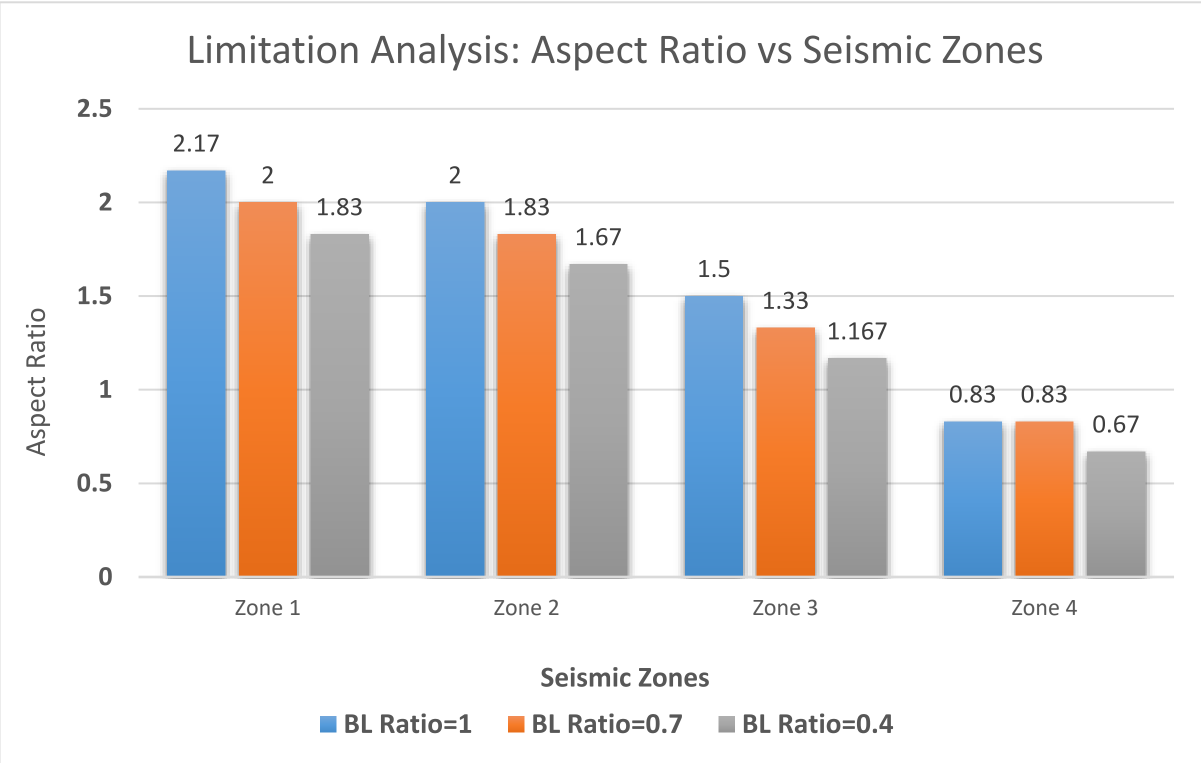


Figure 14: Limiting Aspect Ratio for Different Seismic Zones

5.3 Limitation Analysis for various B/L Ratios with Aspect Ratio

At aspect ratios of 2.17, 2, and 1.83, respectively, the extreme displacement or drift constraints are surpassed for B/L ratios of 1, 0.4, and 0.7. For B/L ratios of 1, 0.7, and 0.4, the maximum deflection or drift limitations are surpassed at aspect ratios of 2, 1.83, and 1.67, respectively that took place in zone 2. Similarly, for B/L ratios of 1, 0.7, and 0.4, the maximum deflection or drift limitations are surpassed at aspect ratios of 1.5, 1.33, and 1.167 for zone 3. For B/L ratios of 1, 0.7, and 0.4 the maximum deflection or drift limitations are surpassed at aspect ratios of 0.83, 0.83, and 0.67, respectively that happened in zone 4.

The study demonstrates an escalating trend in aspect ratios from 0.4 to 1.00, when the highest allowed deflection and drift limits for each B/L ratio are exceeded. From the figure 15, it is clear that the zone 4 is the most critical zone.

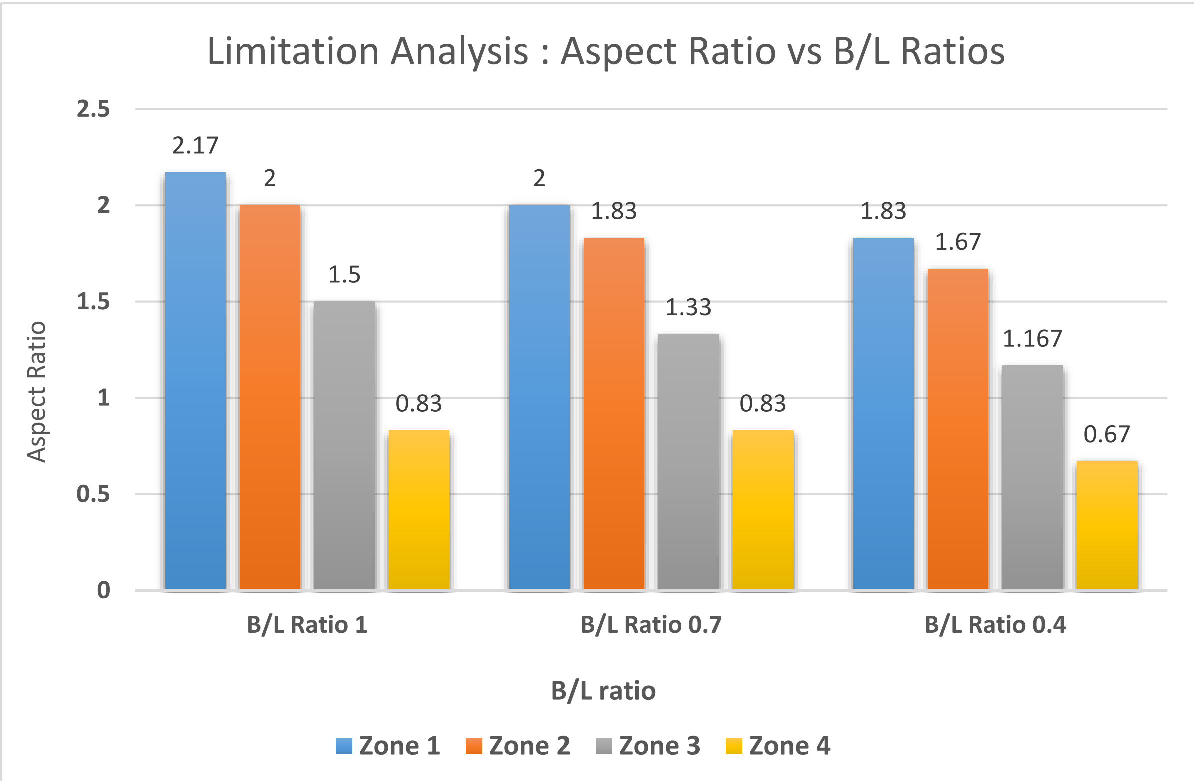
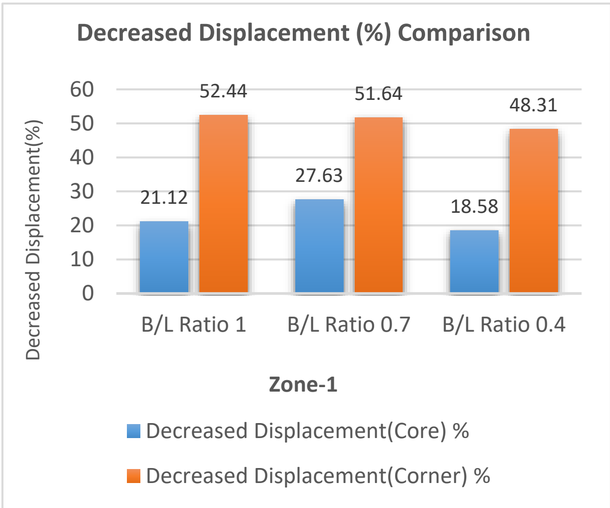


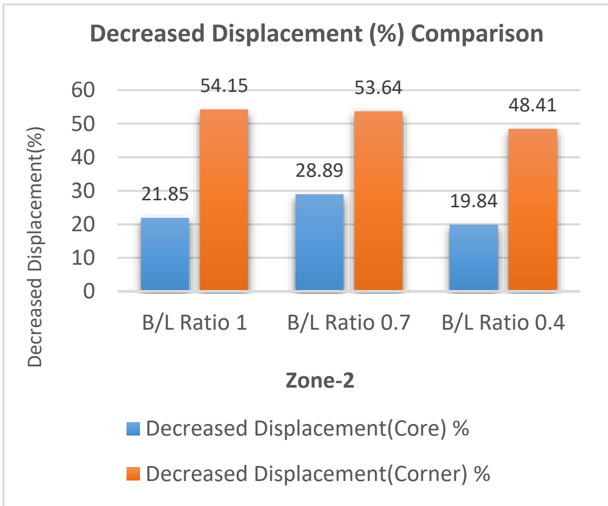
Figure 15: Limiting Aspect Ratio for Different B/L Ratios

5.4 Displacement Reduction Based on Shear Wall Orientation

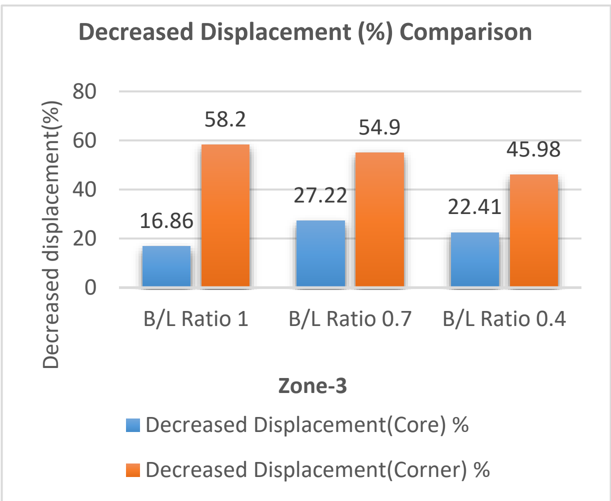
Including of shear wall significantly reduced the model's displacement. However, the percent reduction of displacement varies with shear wall orientation. From Figure 16, it is observed that the percentage of deflection in buildings with corner shear wall decreases more than double that of with core walls in maximum cases. As the zone with high seismicity and risks, buildings of zone-4 face greater seismic loads and fail with high deflection at a lower aspect ratio for any range of B/L ratio. This problem can be effectively handled if these are provided with adequate shear walls, specifically corner oriented shear walls. The models of zone-4 resulted in a larger proportion of reduced displacement than the other three zones that verifies greater stiffness of structure.



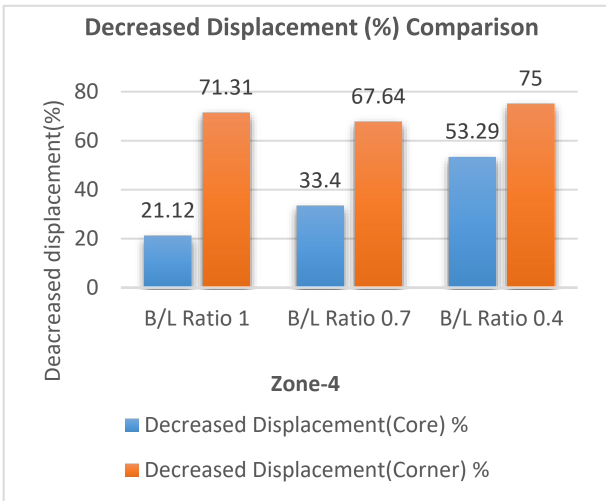
(a)



(b)



(c)

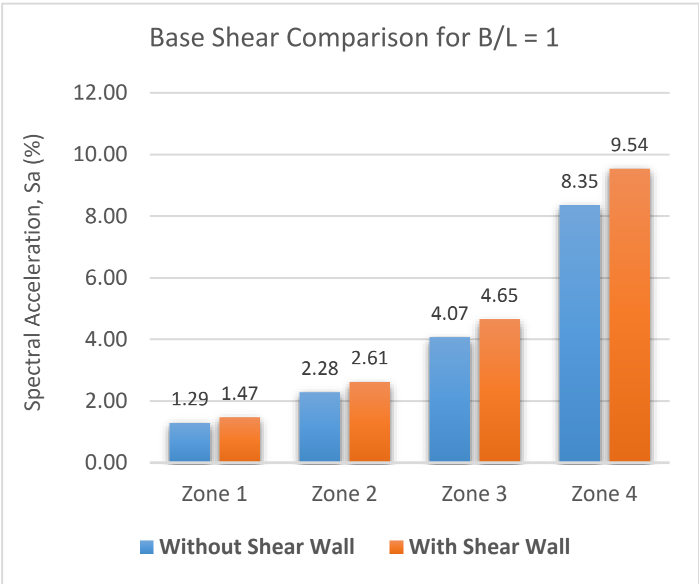


(d)

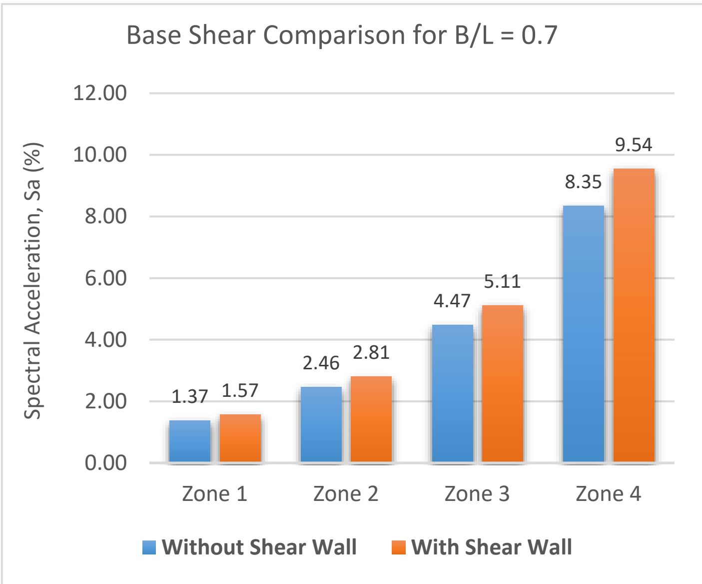
Figure 16: Displacement Decrement (%) Based on Shear Wall Orientation for (a) Zone-1, (b) Zone-2, (c) Zone-3, (d) Zone-4

5.5 Base Shear Evaluation

Figure 17 represent base shear comparison for structures deprived of shear wall and with shear wall for models with B/L ratio of 1, 0.7, and 0.4 respectively. From the analytical result, a number of observations can be noted. In comparison to models without a shear wall, base shear rises in models with a shear wall. This aligns with the studies conducted by Bongliwar et al. [34] and Singh and Kumar [35] . Moreover, acceleration values increase with increasing seismic zone-coefficient values; incremental tendency of spectral acceleration was observed from lower (zone-1) to higher (zone-4) seismic zones for each B/L ratio [36].



(a)



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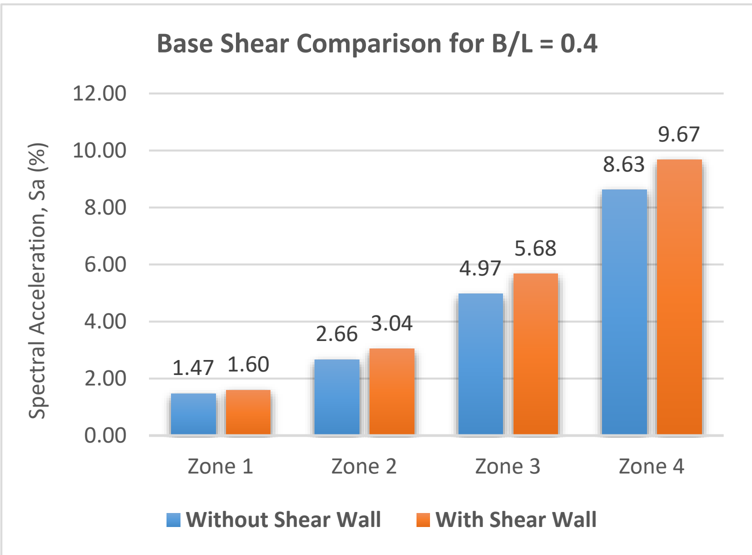

(c)

Figure 17: Base shear evaluation for (a) B/L =1, (b) B/L=0.7, (c) B/L=0.4

6. Limitations, Implementations, and Future Scopes

One of the major limitations is that this analysis was limited for low-rise buildings only. We approached with ESM that is suitable for low-rise structures rather than high-rise ones. We analyzed models for four selected areas of the four seismic zones which obviously did not cover the whole picture of seismic conditions. However, this analysis will help to form a guideline to find out the optimum aspect ratio to provide shear wall based on zonal characteristics. Proper implementation will ensure effective design, costing, and safety. Up to now, this study represents results based on structural models of four representative zonal areas following the Bangladesh National Building Code (BNBC-2020). However, number of locations can be extended for data collection. This would help to sort out construction patterns based on seismic conditions, soil types, exposure condition, wind speed, and other characteristics. Moreover, dynamic analysis can be introduced to work with high-rise buildings along with pushover analysis [24]; data from Equivalent Static Method, both limitations and implementation patterns can be effective to analyze and apply on high-rise RC structure.

7. Conclusion

The following observations were found based on the analytical study-

1. Drift and deflection of high-rise structure should be considered in areas with higher seismic zone coefficient due to notable magnitude.
2. It is perceived that the inclusion of shear walls increases seismic load resistance and performance.
3. Buildings with shear walls perform better in larger seismic zones than buildings without shear walls because shear walls enhance overall structural stiffness and strength.
4. When compared to core walls, corner shear walls are more capable in countering lateral loads, drift, and deflection.
5. The percentage of deflection in buildings with corner shear wall decreases more than double that of with core walls.
6. In comparison to models without shear walls, the analytical result reveals that base shear rises in models with shear walls. Moreover, an incremental tendency of spectral acceleration is observed from zone-1 to 4 for each B/L ratio. This result verifies increased stiffness and resistance provided by shear wall against lateral seismic loads.
7. For comparable B/L ratios where the maximum permitted deflection and drift restrictions were exceeded, a declining failure shape can be seen among the aspect ratios. Buildings in greater seismic zones are found to require shear walls with a lesser aspect ratio.
8. The resulted aspect ratios show a declining failure pattern for models with B/L ratios of 1, 0.7, and 0.4, respectively. It is observed that structures become slender with decreased B/L ratio which results in lower stiffness and resistance against lateral loads. As a result, structures fail at lower aspect ratios.
9. However, buildings with lower aspect ratio (low-rise buildings) do not show significant change in structural behavior under seismic loads even after providing shear walls.
10. Among three parameters (width, length, height), width of building was considered constant while other parameters were changed according to conditions. This was done for simpler variable assigning and analysis.

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9. Appendix

[Reference: Bangladesh National Building Code – BNBC 2020] [30]

Table 8: Mass Multipliers for Load Patterns

Mass Multipliers	
Load Patterns	**Multipliers**
Dead Load	1
Partition Wall	1
Floor Finish	1
Live Load	0.25
Roof Live Load	0.25
Earthquake Load	1
Wind Load	1

Table 9: Seismic Co - efficient and Wind Speed

Seismic Co - efficient and Wind Speed				
Location	**Seismic Zones**	**Zone Co- efficient (z) [Table 6.2.14]**	**Basic Wind Speed (V) [Table 6.2.8]**	
			m/s unit	**mph unit**
Jessore	Zone 1	0.12	64.1	143.39
Dhaka	Zone 2	0.2	65.7	146.97
Gazipur	Zone 3	0.28	66.5	148.76
Mymensingh	Zone 4	0.36	67.4	150.77

Table 10: Site Dependent Factors

Site Factors Depending on Seismic Zones					
Zone (z)	**SS**	**S1**	**Fa**	**Fv**	**Gust factor**
1 (0.12)	0.3	0.12	1.15	1.725	0.85
2 (0.2)	0.5	0.2	1.15	1.725	0.85
3 (0.28)	0.7	0.28	1.15	1.725	0.85
4 (0.36)	0.9	0.36	1.15	1.725	0.85