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Comparative Study of RC Frame Structures for High Seismic, High Wind and Low Seismic, Low Wind Zone

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ABSTRACT
The Bangladesh National Building Code specifies and regulates the general requirements for structural design and design criteria in Bangladesh (BNBC). In the previous two decades, the introduction of new civil engineering techniques, expertise, and materials has resulted in changes to design parameters and methodologies. As a result, BNBC 2017 was written to reflect the change. To further understand the changes in design and analysis, a systematic parametric structural study of RC frame structures was performed, utilizing both codes via FEA for high seismic and high wind zones (Mymensingh) and low seismic and low wind zones (Chapainawabgang). According to the analysis results, the newer code provisions often result in a less economical design with a greater safety margin when compared to the design-based code provisions. The examination of various analysis and design outputs establishes a well-defined comparison between the two seismic zones. The essential distinction between the two seismic zones based on lateral load (wind and earthquake) is provided. In the case of RCC structures, analysis and design are carried out to demonstrate the change in reinforcement required for different column and beam sections, while the building height remains constant. According to BNBC 2017, this comparison study establishes a clear picture of changes in structural details, cost effectiveness, and safety in between the high seismic and low seismic zones by locating two buildings (Mymensingh and Chapainawabganj).

Introduction

Professional engineers in Bangladesh continue to use the Bangladesh National Building Code (BNBC) 1993 in the design of structures. Bangladesh National Building Code 2017 was developed to promote more cost-effective structural design in order to assure higher safety and serviceability. Bangladesh is located in a seismically active zone and is prone to earthquakes. Static analysis has increased in popularity in the country and in many other countries due to its simplicity. This necessitates the use of a well-established and verified construction code in order to assure the safety of the structure and its inhabitants against natural hazards. A total change in wind load and earthquake provisions in the proposed code can be noticed. This research aims to review and compare the current and proposed seismic design provisions dealing with the specification of seismic design forces and wind provisions among the existing and recently proposed BNBC 2017 codes.

Significance

A research is made on comparative analysis of RCC buildings in terms of seismic and wind provisions for existing BNBC 1993 code and proposed BNBC 2017 code. This research is executed by analysis and designing RCC buildings of two 6(six) storied buildings at two different zones in Bangladesh in terms of different seismic and wind categories. Two different cities such as Mymensingh & Chapainawabganj, are selected for high seismic and high wind, low seismic and low wind respectively. After designing RCC buildings, the variation in different parameters and materials including reinforcement, concrete are observed. The material properties (concrete strength f'c) and other Section properties (Beam section, column section) vary from zone to zone with 6(six) stories.

Objectives

The main objective of the research work is to compare the seismic provisions, wind provisions, load combination, base shear, materials requirements, economy of design, safety of design, serviceability of design, and overall costs of the buildings in zone-1 with the same parameters in zone-4. The objectives are as follows:

i. To compare similarities as well as differences between zones 1 and 4.

ii. To compare both seismic and wind load effects on RCC buildings between zone-1 and zone-4

iii. To investigate the effects of changes on RCC buildings in different zones of Bangladesh.

Outline of the Methodology

The analysis and design of buildings of 6 (six) stories is done by ETABS, which is a finite element method based integrated software. A three-dimensional model of the structures was developed using frame and shell elements. The structures are analyzed for different types of loads, such as gravity loads and lateral loads. Gravity loads include dead loads from self-weight, superimposed dead loads, and live loads applied after the construction stage. Lateral loads include both earthquake and wind loads that act on the structures laterally in all directions. Seismic loads vary in different seismic zones in Bangladesh. According to BNBC

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2017, Bangladesh is divided into four different seismic zones. Wind loads also vary with different locations. The research has been done for both low and high seismicity and low and high wind at two cities of different wind and seismic characteristics according to the BNBC 2017 code. Buildings are analyzed and designed for particular load combinations according to code. For the analysis and design of both buildings, some particular superimposed dead and live loads are assumed for the analysis and design. For the same storied building, the beam and column sections change, and the slab thickness, footing size, and floor height are kept unchanged for the same building for the BNBC 2017 code for the convenience of comparing the specific parameters such as base shear, sway, reinforcement, serviceability criteria, etc. for RCC building. Some parameters and assumptions are simplified and generalized for the convenience of comparing the parameters between Zone-1 and Zone-4.

Literature Review

The Bangladesh National Building Code (BNBC-1993) was initially developed in 1993 in response to Ministry of Works orders.The consulting company, Development Design Consultants (DDC), hired Bangladesh University of Engineering and Technology (BUET) to spearhead the development of the country's first building code on behalf of the House Building Research Institute (HBRI). BNBC-1993 (DDC, 1993) provides seismic and wind load design provisions based on information at the time of development. Since then, significant progress has been made in studies across the world, and many building regulations have been updated correspondingly. A substantial quantity of research has also been conducted in Bangladesh. In 2010, HBRI launched an attempt to update the existing building code (BNBC-1993) to reflect improvements in knowledge and experience gained over nearly two decades. HBRI tasked a committee of consultants, primarily comprised of BUET faculty members and some external experts, with preparing the new BNBC 2017.

- F. Atique & Z. Wadudin (2001) published their work titled "Comparison of BNBC-93 with other building codes with respect to Earthquake and Wind analysis." which compared BNBC-93 with other building codes with respect to Earthquake and Wind analysis.
- Research conducted by Md. S. Bari & T. Das (2014) titled "A Comparative Study on Seismic Analysis of Bangladesh National Building Code (BNBC) with Other Building Codes" had been one of the most comprehensive studies where a detailed parametric comparison was put forth based on BNBC-2017, BNBC-1993 and code of India 2005 (NBC-India 2005).
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- The proposed changes to BNBC 1993 was first brought up by the research team of Tahmeed M. Al-Hussaini, Tahsin R. Hossain and M. Nayeem Al-Noman (2012) .They conducted a thorough study based on Peak ground acceleration (PGA) and spectral acceleration. In their paper "Proposed Changes to the Geotechnical Earthquake Engineering Provisions of the Bangladesh National Building Code.
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Methodology

The study aims at BNBC-2017 for designing buildings in different parts of Bangladesh subjected to various intensities of earthquake and wind effects. This requires choosing a typical commercial building plan, framing system, foundation and soil and other material properties.

Preparation

Floor Area

The minimum plot area of a residential building for the RAJUK requirement is 700 sft. Here we used a plot area of 1576 sft and the flat area is 1308 sft.

Stair

One flight of stairs (regular) was considered in the plan of the buildings studied. An equivalent slab (200 mm) is considered for modeling stairs.

Floor System

A 125 mm concrete slab is considered for concrete building modeling. The concrete slab is meshed in the plane of intersection with the visible grid and further meshed manually to a reasonable rectangular shape.

Number of Storey and Floor Heights

In the present study, buildings having 6 (six) stories have been considered. The 3-span by 2-bay floor (overall 15.25 m x 8.34 m plan area) has been used for all the two building heights. The floor-to-floor height has been assumed to be 3.05 m considering the typical plumbing and duct requirements for air conditioning etc. To leave enough space (150mm to 200mm) between the false ceiling and the beam bottom for air-conditioning ducts, and to maintain a clear height of at least 2600mm between the floor and the false ceiling, as well as a floor-to-floor height of 3000mm.

Structural Preparation Foundation

Shallow foundations are commonly used for the construction of non-high-rise buildings in Bangladesh as the soil is mostly alluvial deposits consisting of dense or medium-dense sand, gravel, and stiff clay. Shallow foundations, while less expensive than mat and pile foundations, do not ensure uniform settlement.

Coefficient of Sub Grade Reaction

Shallow foundations are commonly used for the construction of non-high-rise buildings in Bangladesh as the soil is mostly alluvial deposits consisting of dense or medium-dense sand, gravel, and stiff clay. Shallow foundations, while less expensive than mat and pile foundations, do not ensure uniform settlement.

Structural System

The load-bearing subsystem of a building or structure is referred to as a "structural frame." Loads are transferred via the structural system via linked parts or members. According to BNBC 2017, the Chapainawabganj zone requires an Intermediate Moment Resisting Frame (IMRF) system for RCC construction, whereas the Mymensingh zone requires a Special Moment Resisting Frame (SMRF) system. According to BNBC 2017, the Chapainawabganj zone is of low severity, whereas the Mymensingh zone is of high severity, based on seismic design category (SDC), and design requirements are of intermediate special seismic design provisions, taking code stipulated seismic and other loads into account. Table 2 lists the response modification variables that were employed in the design.

Material Property

Main construction materials for reinforced concrete structure are concrete. Material properties used for modeling are listed on Table 3 and 4.

Structural Analysis

Loading Analysis

Buildings are analyzed for various loadings, such as gravity loads, wind and seismic loads, whose values differ corresponding to the site location. The loads in ETABS are defined as using static load cases.

Gravity Load Analysis

Structures are analyzed and designed for gravity loads (e.g., dead loads and live loads). Self-weight of building frame and shell elements, floor finish, partition wall, mechanical equipment, and other superimposed loads are examples of dead loads. Live loads include all temporary loads applied after the building's construction. The superimposed dead and live loads that were used for the analysis are as follows:

Live load= 2 KN/m²
Floor Finish= 1 KN/m²
Partition wall= 2.25 KN/m²
Live load due to water tank=15.0 KN/m²

Wind Load Analysis

Wind load analysis is governed by parameters which are as follows-

- Design wind load.
- Basic wind speed.
- Height and exposure coefficient.
- Gust factor.
- Sustained wind pressure.
- External pressure coefficient.
- Exposure condition

Seismic Load Analysis

The design earthquake lateral forces on the primary framing systems of every building or structure shall be calculated based on the provisions set forth in this section. The design seismic forces shall be assumed to act no concurrently in the direction of each principal axis of the building or the structure.

Result and Discussion

The main objective of this thesis is to differentiate between seismic zones 1 and 2. All the comparisons are done with respect to the results found in BNBC 2017. The research scope of this thesis includes concrete buildings of non-high rise, same-story buildings in high seismic, high wind, and low seismic, low wind zones of Bangladesh.

For Concrete Building

Wind (x, y) and earthquake loading analysis data are collected for various story concrete buildings. The comparison between these data sets is presented in graphical format and discussed below.

Conclusion and Recommendation

In order to conduct a comparative study in between zone -1 and zone-4 for differentiate various properties of a regular RCC building based on BNBC 2017. High seismic, high wind & low seismic, low wind zone of Bangladesh (Chapainawabganj & Mymensingh respectively) has been chosen. Two 6(six) storied RCC building with same plan is considered. Finite Element Software ETABS is used to analyze the model. All the parameters to analyze the model are taken according to the instructions of BNBC 2017. Results of base shears for concrete building are presented in charts above.

Based on the findings, following conclusion can be derived for RCC building in high seismic, high wind & low seismic, low wind zone of Bangladesh (Chapainawabganj & Mymensingh respectively).

For RCC building:

I. Finally we get the maximum displacement for wind load is (Zone 1 > Zone 4) in both X & Y direction.

II Also for EQx (Zone 1 > Zone 4) and EQy (Zone 1<Zone 4).

III.Material properties (f’c) also be change, zone one properties is not workable for zone four.

IV. Frame design is economic for zone-1 to zone-4

Recommendations for Further Study

This analysis has been carried considering concrete building having regular geometry. The number of story was limited to 6(six) . In plan, the number of bays and spans were also limited. Considering the limitations, the following recommendations for further study can be made:

a)This study is conducted for high seismic, high wind & low seismic, low wind (Chapainawabganj and Mymensingh) zone of Bangladesh. However the seismic zone coefficient and wind speed varies for different parts of Bangladesh. Similar study can be performed for other parts of Bangladesh especially for high seismic & low wind zone (Sylhet).

b)Only the reinforcement requirement in columns and beams were considered to find the impact on design. This study can be extended on a large scale of analysis including foundations, slabs etc.

c)Comparisons of BNBC 2017 can be made with other codes such as Euro code, Indian code, UBC, Italian code etc.

d)More buildings with different height & plan may be considered to get a more generalized pattern of change between two BNBC codes.

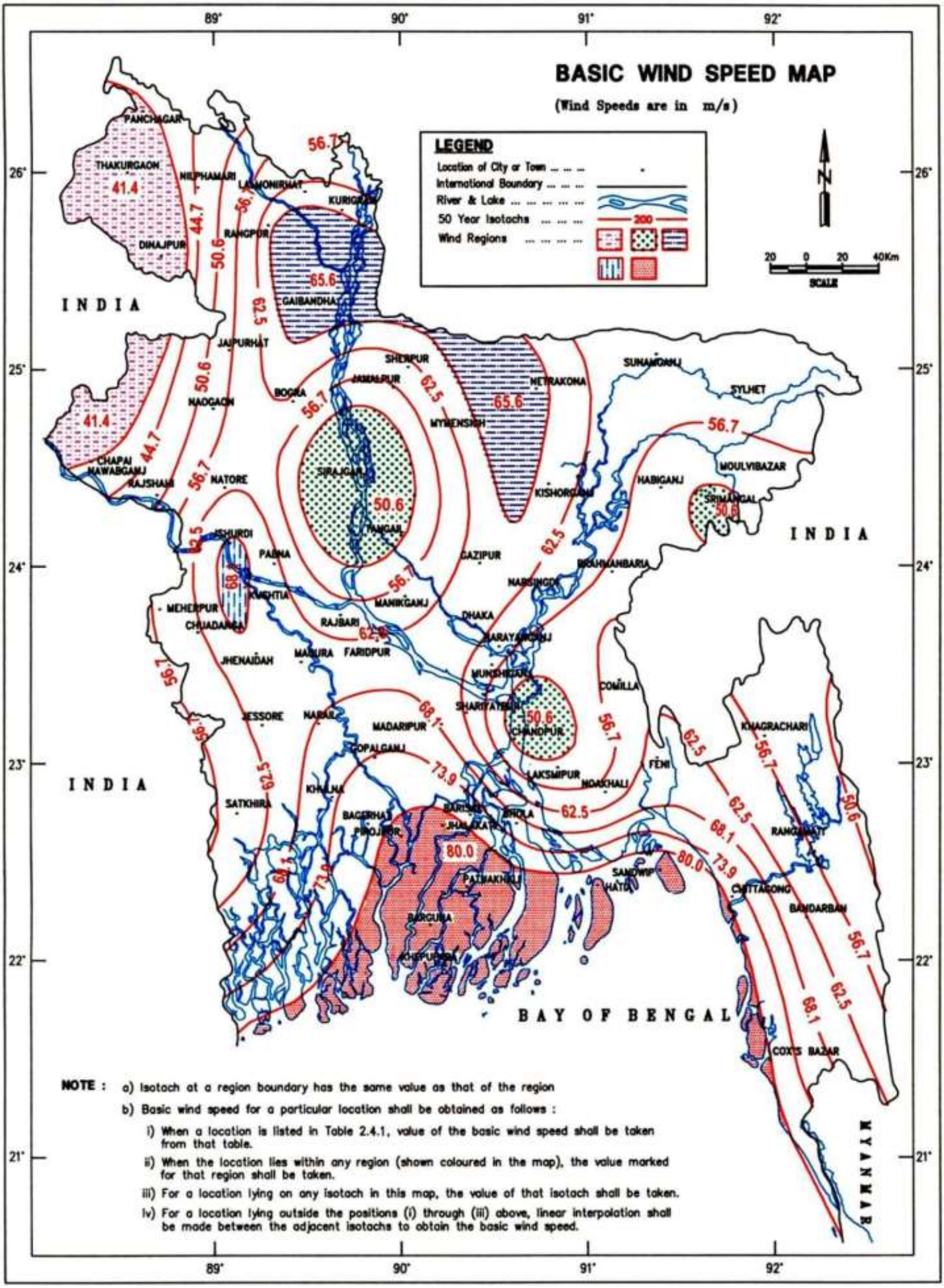


Fig 1. Basic wind speed map

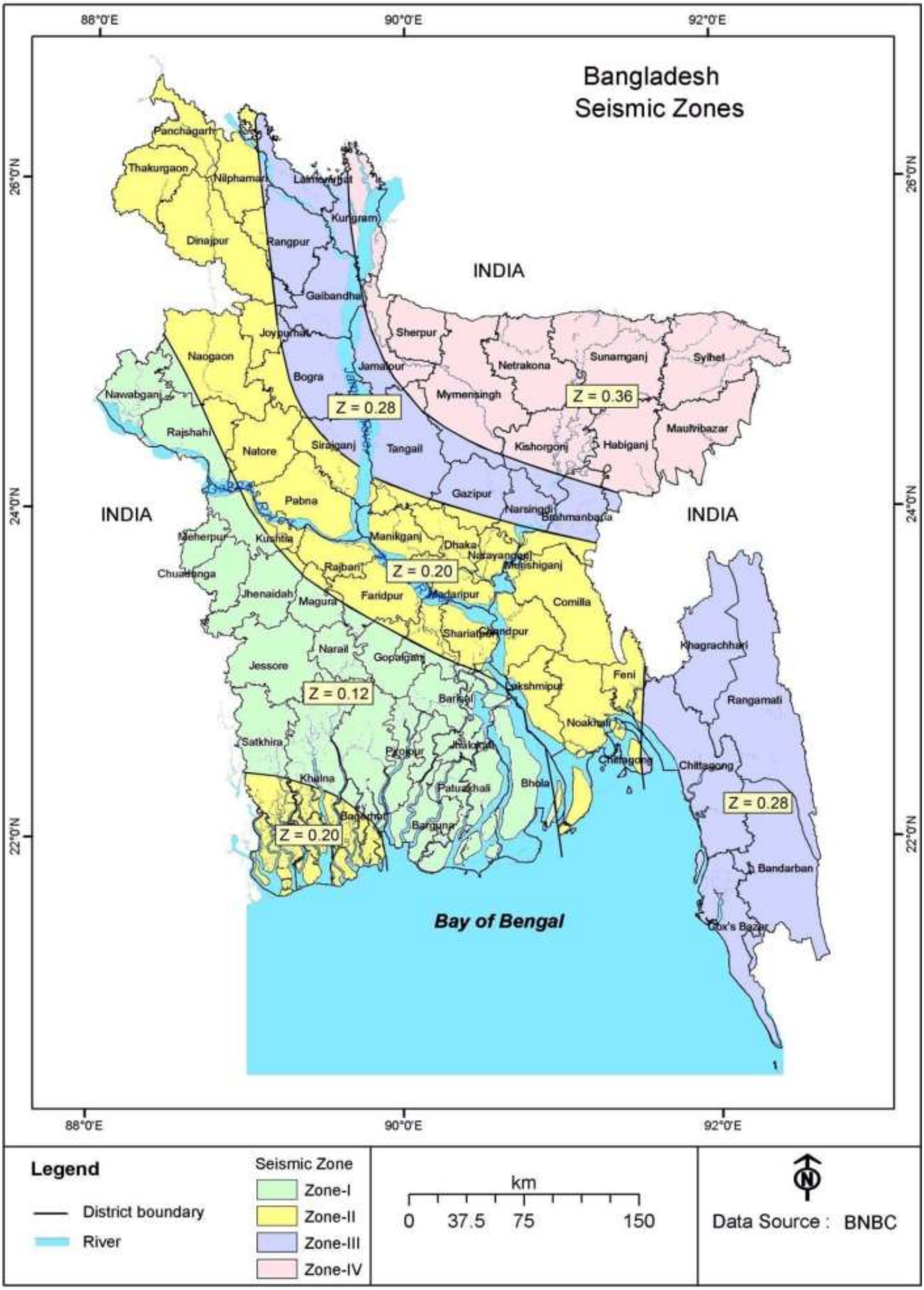


Fig 2. Seismic Zoning Map of Bangladesh

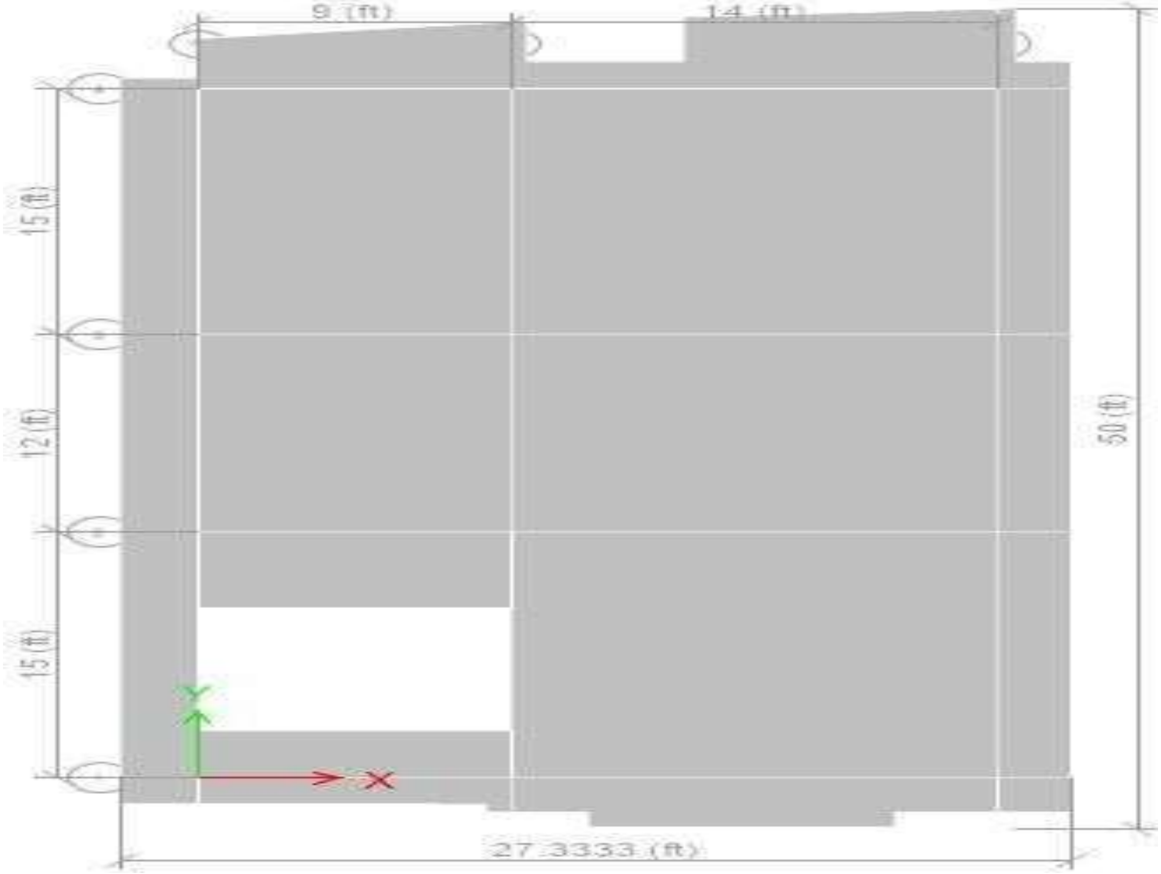


Fig 3. Plan Layout

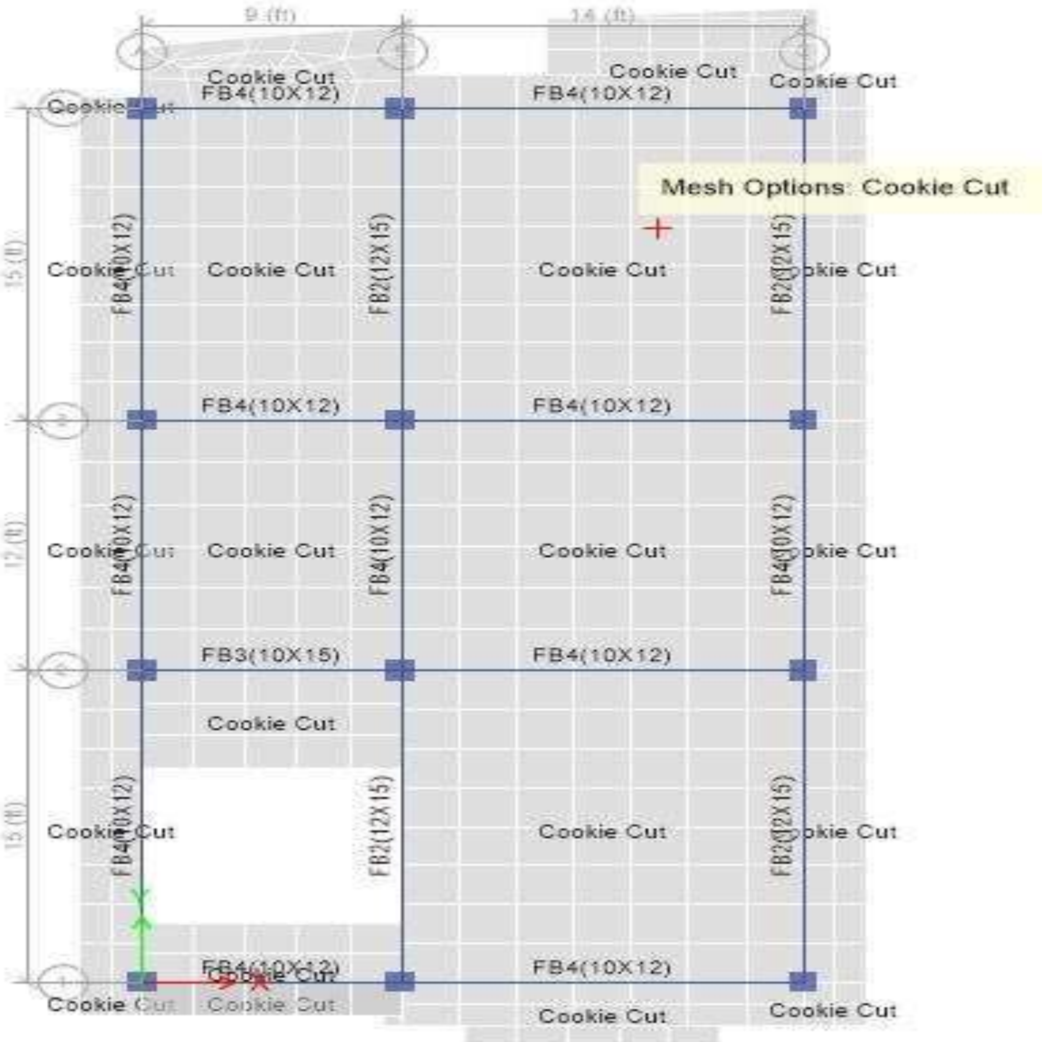


Fig 4. Concrete slab profile and mesh

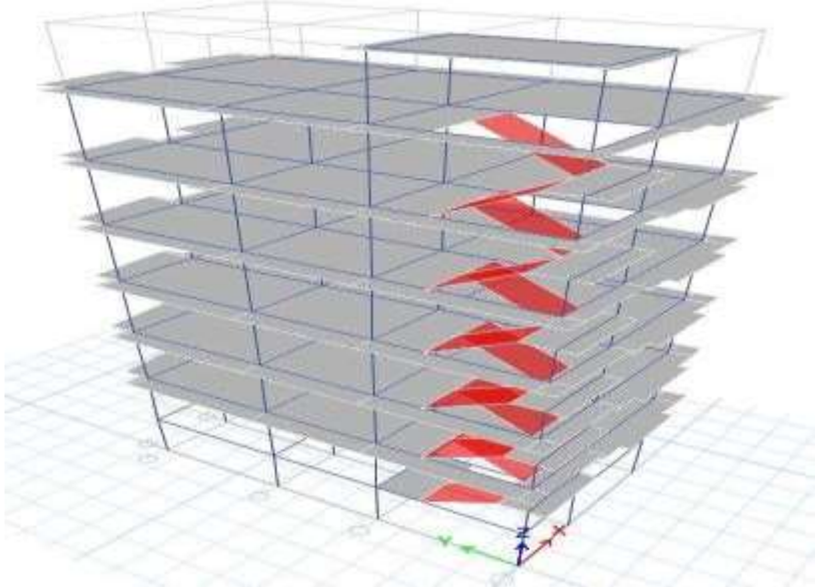


Fig 5. 3D view of a 6 (six) storied RCC building in ETABS

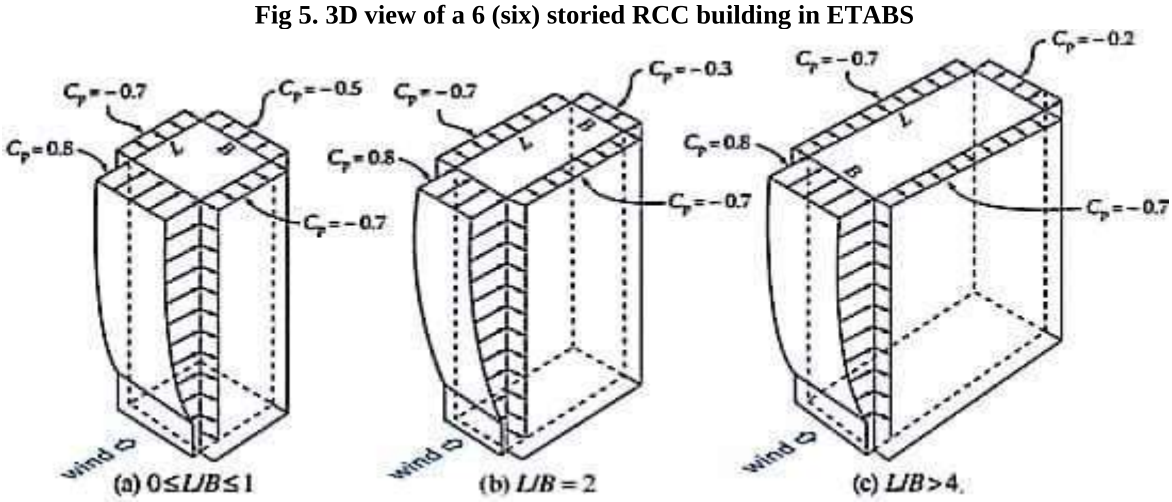


Fig 6.

Comparison for Concrete Strength, F'c (Plan View, Zone-1)

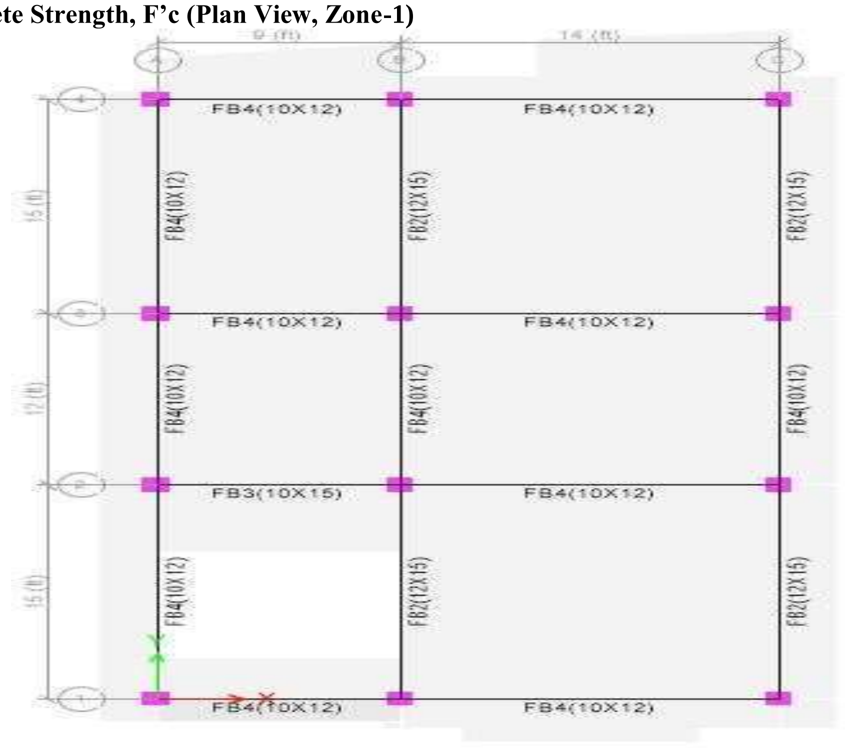


Fig 7. Plan View zone-1,f'c =3000psi All frames are passed

Comparison for Concrete Strength, F'c (Plan View, Zone-4)

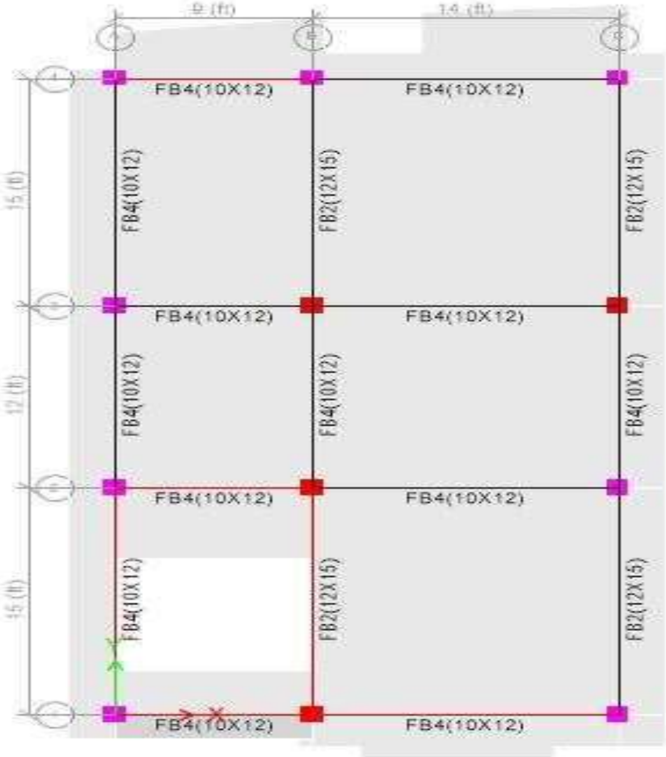


Fig 8. Plan View zone-4 *ZONE-4* f'c =3000psi and Same frame section of zone-1 Some frames are failed

Comparison For Concrete Strength, F'c (Elevation View, Zone-1)

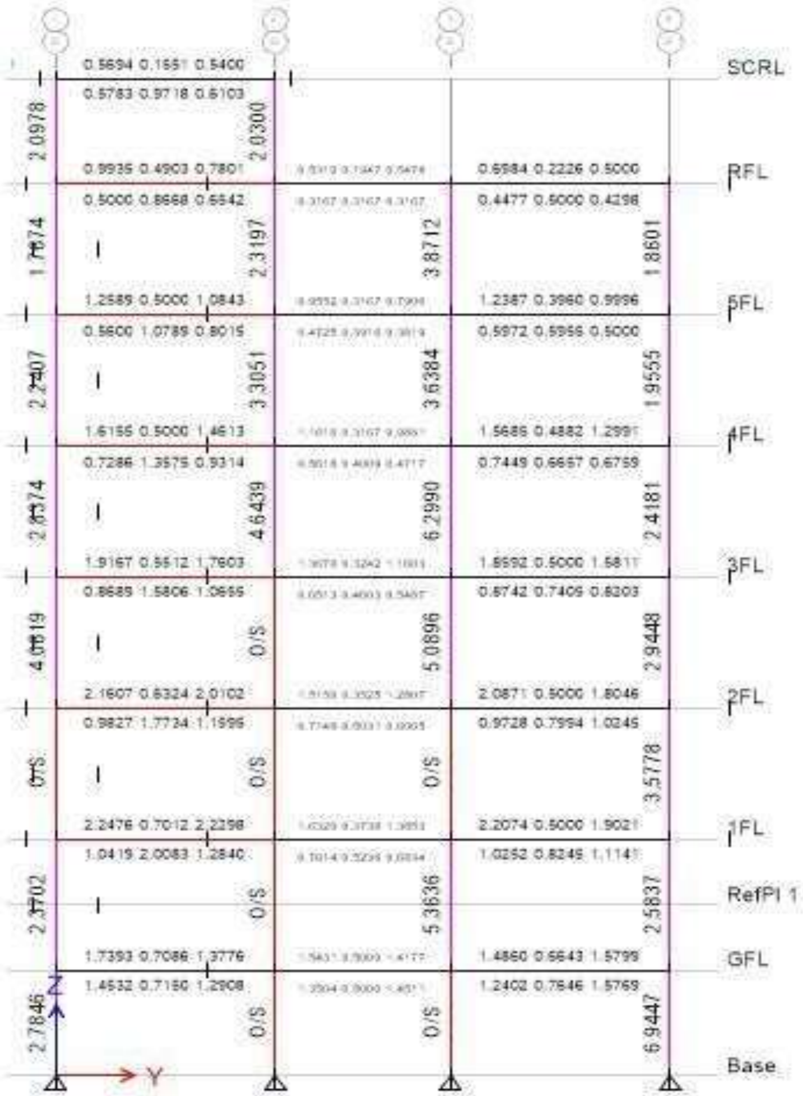


Fig 9. Elevation View zone-4 *ZONE-4* f'c =3000psi and same frame section of zone-1 some frames are failed

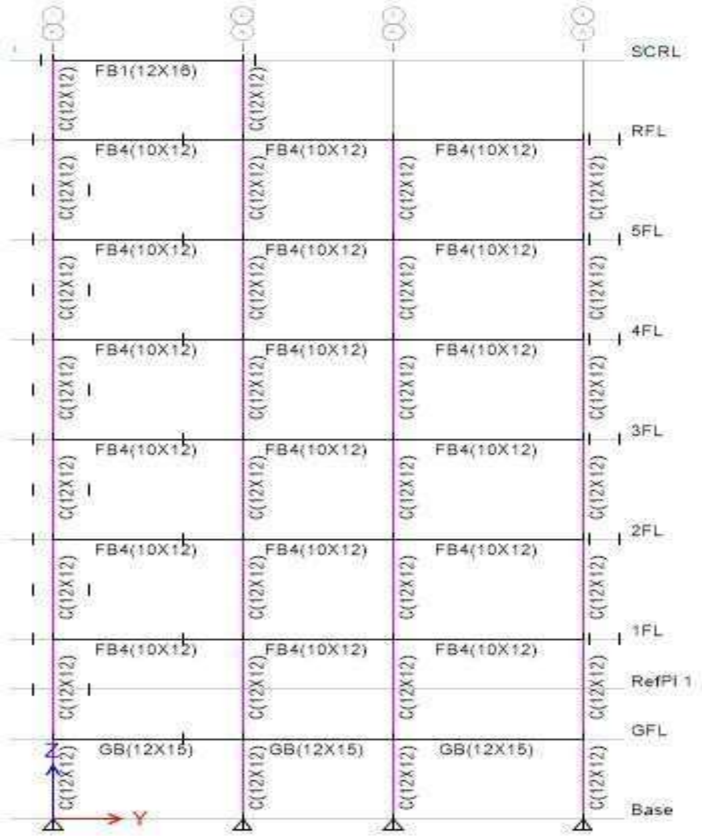


Fig 10. Elevation View zone-4 *ZONE-4* f'c = 4000 psi and increase frame section ALL frames are passed

Note: in this case the structure is failled due to concrete strength (f'c), for that's reason avoid this graphical structure.

Comparison For Wind Effect (Combination For Wind: D+0.5l+0.7w)

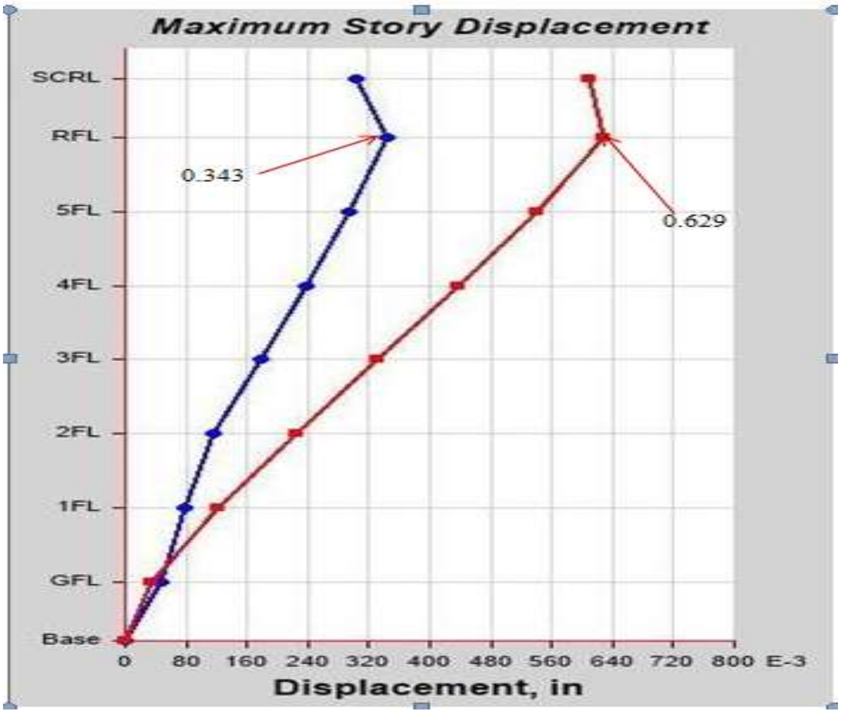


Fig 11. Story displacement for wind, zone-1

Remarks

Max allowable Deflection Limit = $\frac{h}{500} = \frac{720}{500}$

= 1.44 in

X- Axis

Y- axis

For 70% wind effect

So, Our Building is safe

Zone-1 (Chapai Nawabganj)

COMPARISON FOR WIND EFFECT (Combination for Wind: D+0.5L+0.7W)

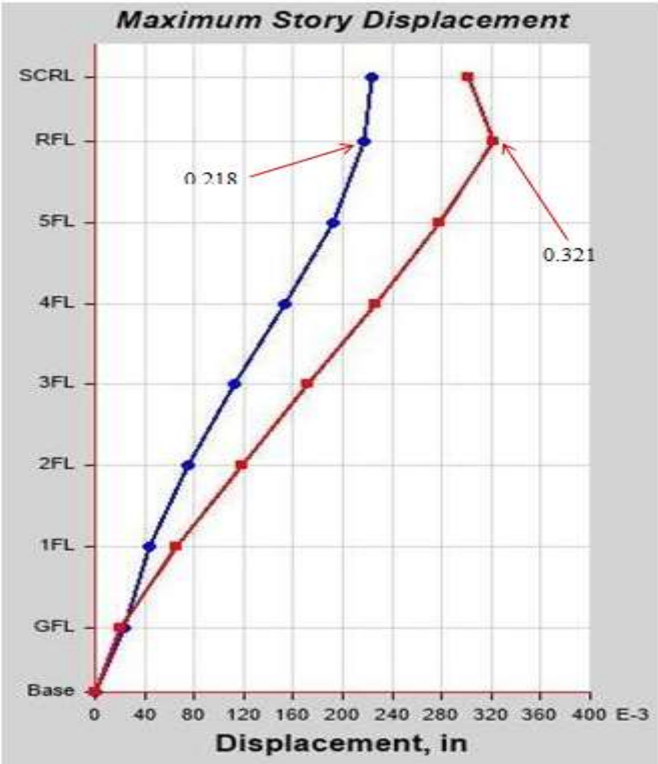


Fig 12. Story displacement for wind, zone-4

Remarks

Max allowable Deflection Limit = $\frac{h}{500} = \frac{720}{500}$

= 1.44 in

X- Axis

Y- axis

For 70% wind effect

So, Our Building is safe

Zone-4 (Mymensingh)

Comparison for Earthquake, Eqx

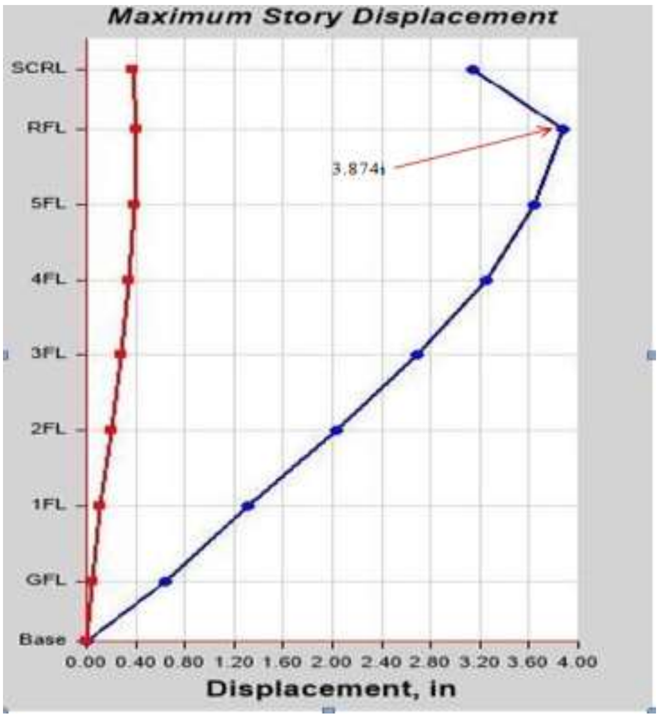
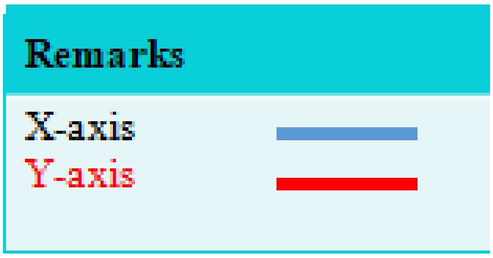
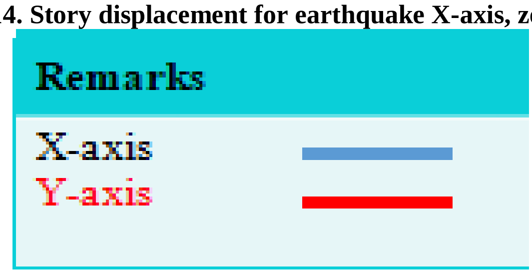


Fig 13. Story displacement for earthquake X-axis, zone-1



Zone-1 (Chapai Nawabganj)

Fig 14. Story displacement for earthquake X-axis, zone-4



Zone-4 (Mymensingh)

Comparison for Earthquake, Eqy

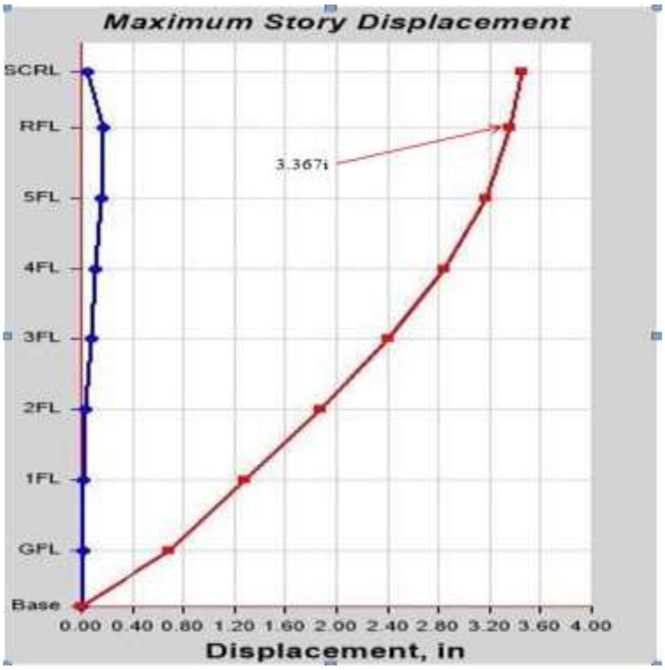
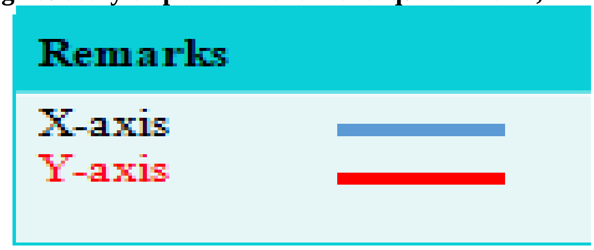


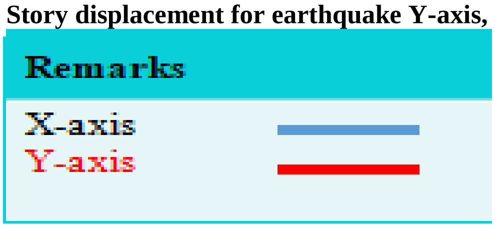
Fig 15. Story displacement for earthquake Y-axis, zone-1



Zone-1 (Chapai Nawabganj)

Comparison for Earthquake, Eqy

Fig 16. Story displacement for earthquake Y-axis, zone-4



Zone-4 (Mymensingh)

Comparison for Drift Check Floor to Floor, Eqx

ZONE-1 (CHAPAI NAWABGANJ)			
FLOOR	**S_2**	**S_1**	**$S_X=S_2-S_1$**
GF			**0.646**
1ST FLOOR	1.305	0.646	0.659
2ND FLOOR	2.026	1.305	0.721
3RD FLOOR	2.693	2.026	0.667
4TH FLOOR	3.244	2.693	0.551
5TH FLOOR	3.643	3.244	0.399
RF	3.874	3.643	0.231

ZONE-4 (MYMENSINGH)			
FLOOR	**S_2**	**S_1**	**$S_X=S_2-S_1$**
GF			0.672
1ST FLOOR	1.348	0.672	0.676
2ND FLOOR	1.988	1.348	0.64
3RD FLOOR	2.556	1.988	0.568
4TH FLOOR	3.024	2.556	0.468
5TH FLOOR	3.363	3.024	0.339
RF	3.564	3.363	0.201

Remarks

Δ = Story drift, Floor to floor max allowable drift limit as follows-
1. $\Delta \leq 0.005h$ for $T < 0.7$ second
2. $\Delta \leq 0.004h$ for $T \geq 0.7$ second
3. $\Delta \leq 0.0025h$ for unreinforced masonry structures

$\Delta \leq 0.004 \times 60 \times 12 = 2.88$ in drift (Here, T=0.742)

So our building is safe.

Comparison For Drift Check Floor To Floor, Eqy

ZONE-1 (CHAPAINAWABGANJ)			
FLOOR	S_2	S_1	$S_X=S_2-S_1$
GF			**0.687**
1ST FLOOR	1.278	0.687	0.591
2ND FLOOR	1.871	1.278	0.593
3RD FLOOR	2.407	1.871	0.536
4TH FLOOR	2.849	2.407	0.442
5TH FLOOR	3.173	2.849	0.324
RF	3.367	3.173	0.194

ZONE-4 (MYMENSINGH)			
FLOOR	S_2	S_1	$S_X=S_2-S_1$
GF			**0.862**
1ST FLOOR	1.628	0.862	0.766
2ND FLOOR	2.278	1.628	0.65
3RD FLOOR	2.846	2.278	0.568
4TH FLOOR	3.309	2.846	0.463
5TH FLOOR	3.646	3.309	0.337
RF	3.846	3.646	0.2

Remarks

Δ = Story drift, Floor to floor max allowable drift limit as follows-
1. $\Delta \leq 0.005h$ for $T < 0.7$ second
2. $\Delta \leq 0.004h$ for $T \geq 0.7$ second
3. $\Delta \leq 0.0025h$ for unreinforced masonry structures

$\Delta \leq 0.004 \times 60 \times 12 = 2.88$ in drift (Here, T=0.742)

So our building is safe.

Comparison for Reinforcement

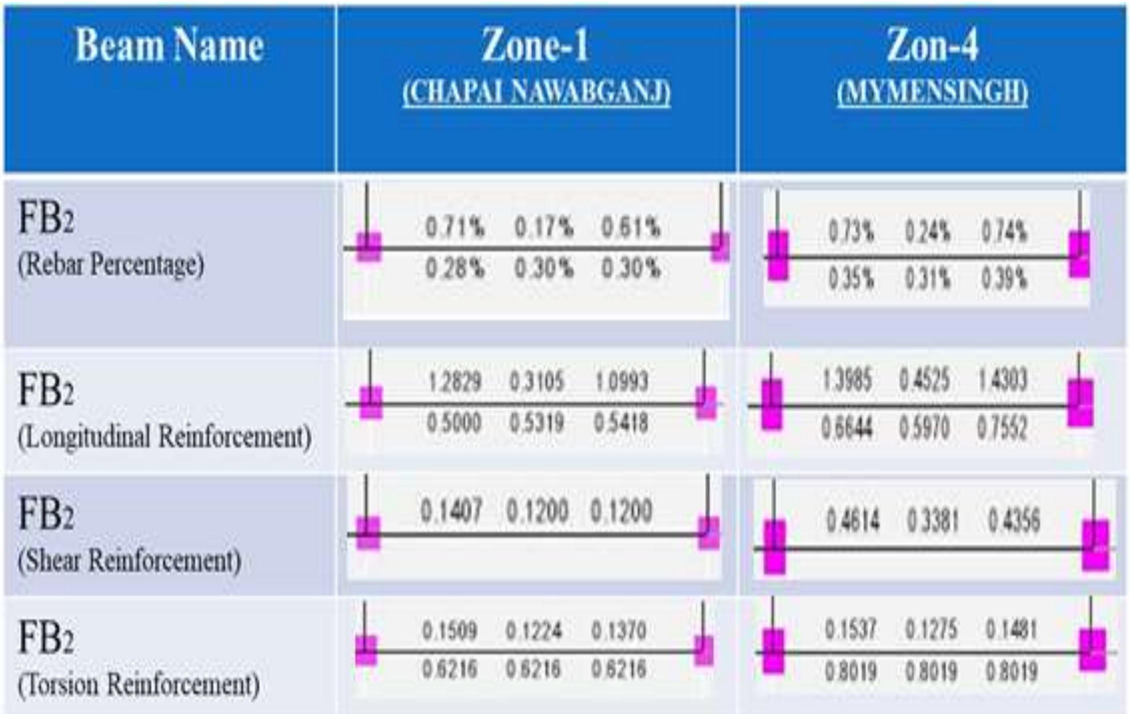


Fig 17. Beam reinforcement, zone-1 & zone-4

Remarks

Our selected beam FB2

Here we have compare rebar percentage, longitudinal reinforcement, shear reinforcement & torsional reinforcement are zone-1 < zone-4

Comparison for Restraint Reaction, Eq_x

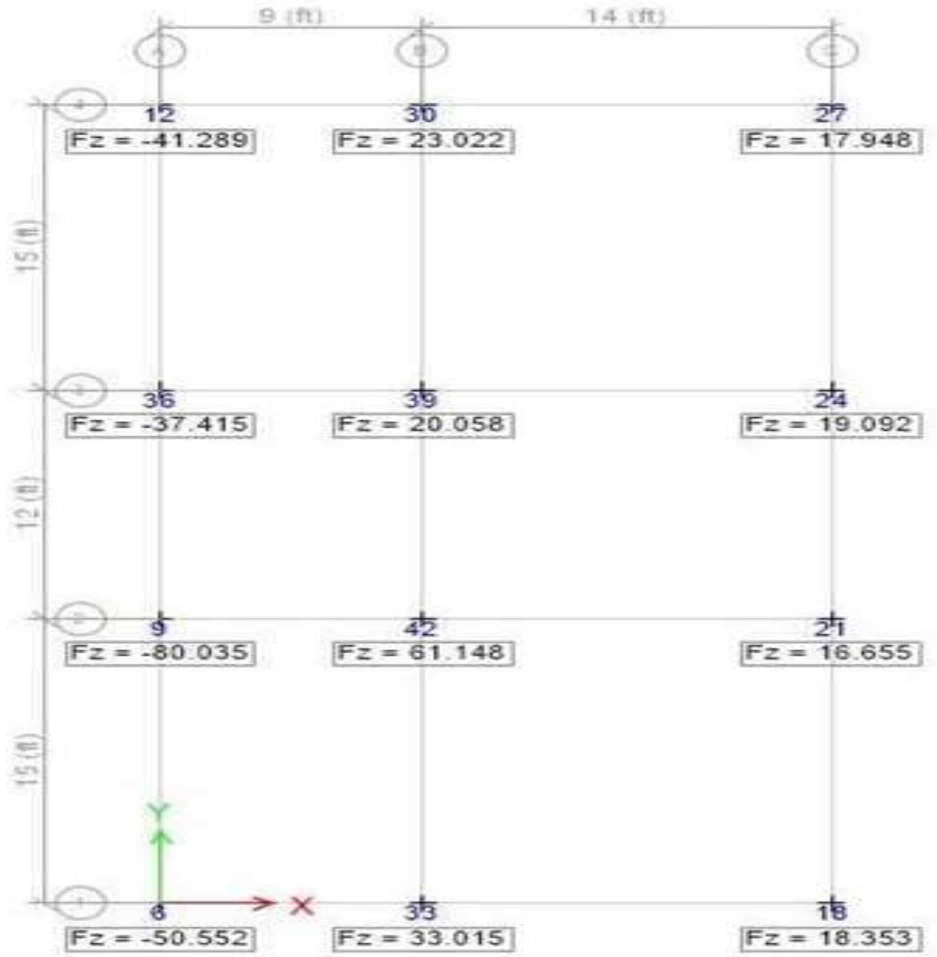


Fig 18. Restraint reaction (Base) X-axis zone-1 ZONE-1 (CHAPAINAWABGANJ)

Comparison For Restraint Reaction, Eq_x

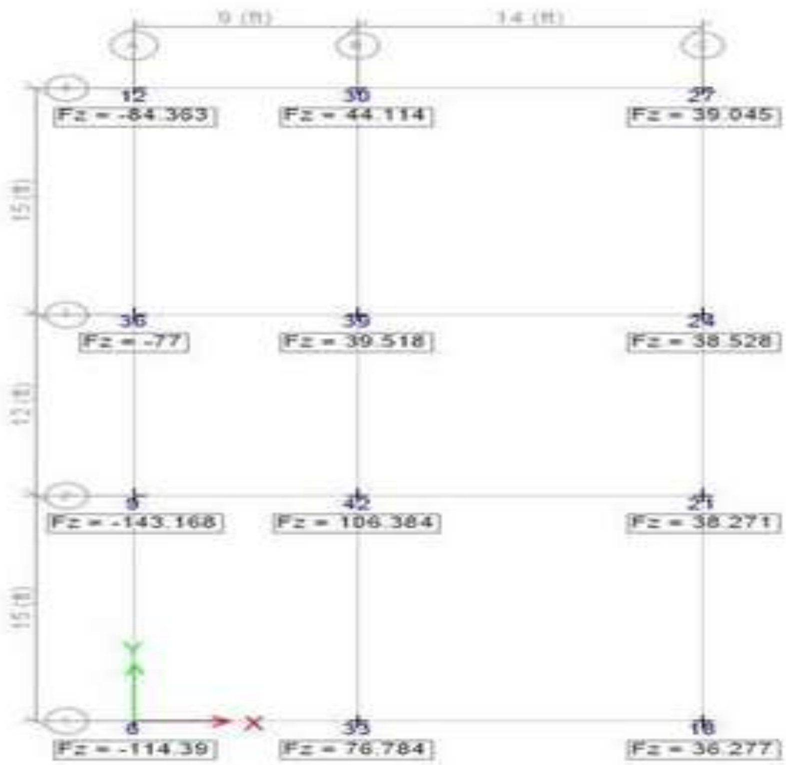


Fig 19. Restraint reaction (Base) X-axis zone-4 ZONE-4 (MYMENSINGH)

Comparison For Restraint Reaction, Eqy

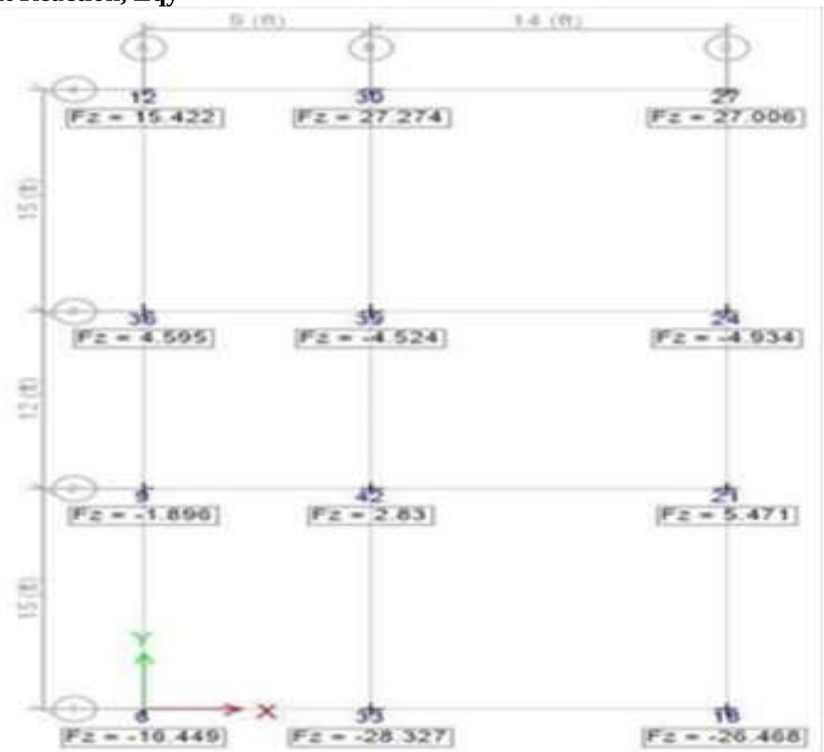


Fig 20. Restraint reaction (base) y-axis zone-1 zone-1 (chapainawabganj)

Comparison For Restraint Reaction,Eqy

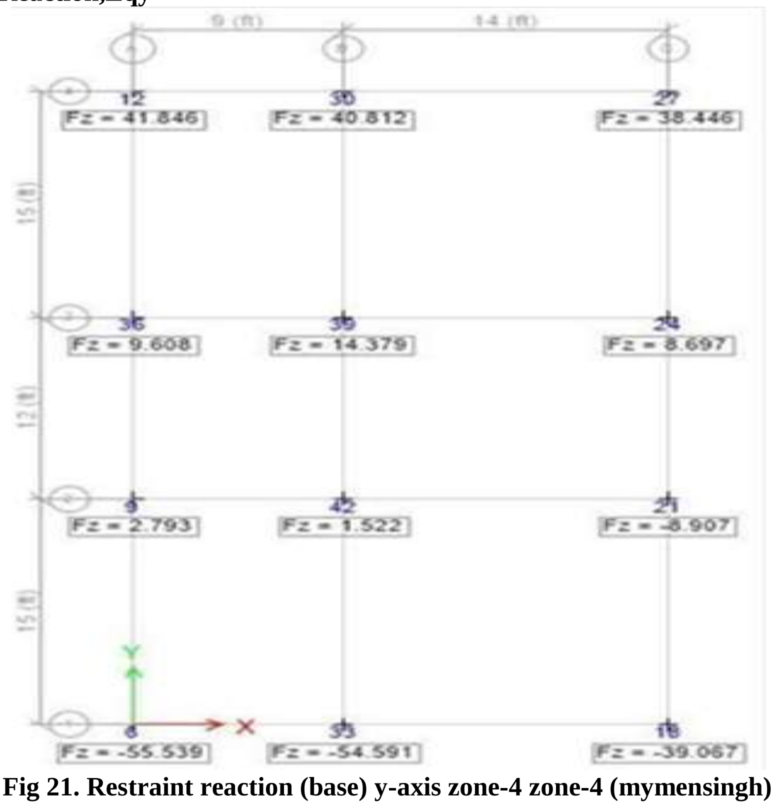


Fig 21. Restraint reaction (base) y-axis zone-4 zone-4 (mymensingh)

Table 1. Ks values for foundation on sand and clayey soil

Soil Characteristics	**K_s – KN/m^3**
Loose sand	4800-16000
Medium dense sand	9600- 80000
Dense sand	64000-128000
Clayey medium dense sand	32000-80000
Silty medium dense sand	24000-48000
Clayey soil	
$q_a \leq 200$ kPa	12000-24000
$200 < q_a \leq 800$ kPa	24000-48000
$q_a > 800$ kPa	>48000

Table 2. Response Modification Factors and Lateral load resisting systems

Structural System	**Description of Lateral Force Resisting System**	**Response Modification Factor, R BNBC 2017**
Concrete	Specialconcretemoment resisting frame	8
	Intermediate concrete moment resisting frame	5

Table 3. Material strength and property for RCC Buildings

RCC Building			
Properties	Number of story	Zone	Compressive
Concrete	6	1	3000
	6	4	4000

Table 4. Wind load in different story level

Wind load for X direction (KN)	**Wind load for Y direction (KN)**	
ROOF-1	ROOF-1	
38.97		50.95
ROOF	ROOF	
95.29		138.64
7F	7F	
111.55		173.43
6F	6F	
108.45		168.96
5F	5F	
104.96		163.92
4F	4F	
100.92		158.10
3F	3F	
96.08		151.12
2F	2F	
89.91		142.21
1F	1F	
83.79		133.39
GF	GF	
41.89		66.69

Table 5. Earthquake load parameter

Earthquake load parameter for BNBC 2017
Typical Eccentricity = 5% Eccentricity Overrides: No C = 0.0441 K=1.12

Table 6. Earthquake load in different story level

Earthquake load for BNBC 1993 (KN)		**Earthquake load for BNBC 2017 (KN)**
ROOF-top		ROOF-top
	355.45	191.08
ROOF		ROOF
	350.26	338.86
7F		7F
	318.67	296.31
6F		6F
	278.83	247.89
5F		5F
	239.00	201.75
4F		4F
	199.17	158.14
3F		3F
	159.33	117.37
2F		2F
	119.50	79.92
1F		1F
	79.67	46.49
GF		GF
	48.44	22.38

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