COMPARATIVE STUDY OF STRUCTURAL FRAMING SYSTEM: OMRF, IMRF AND SMRF IN REGULAR SHAPE RCC BUILDING

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A thesis submitted to the Department of Civil Engineering in partial fulfillment for the degree of Bachelor of Science in Civil Engineering



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Section: CE0125-Canlaon (24B+24D)
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ABSTRACT

All structural systems are not treated equally when the response to earthquake-induced forces is of concern. Structural configuration, symmetry, mass distribution, and vertical regularity must be considered. The importance of strength, stiffness, and ductility in relation to acceptable response must also be appreciated. While considering the lateral force resisting systems, we came up with many options to have structural systems like Bearing wall systems, Moment Resisting frames, and Lateral Bracing systems, designing the moment resisting concrete frame structures we have the option to use IMRF, OMRF, or SMRF. The basic step in conceptual design is to find the best suitable framing system and then lateral load-resisting mechanism, while designing structures it is often found to be complicated to make decision of Response Modification Factor (R), which is a measure of ductility and over-strength of the structures. It is used to find the base shear, which is distributed on different stories. SMRF and IMRF are emphasized in the research and a detailed computer simulation of the different RCC structures in Zone-II with different R-values i.e., 5 and 8 given in BNBC-2020 are used. In this study, there are a total of 3 models of different frame systems are developed and several comparisons are made among them, such as drift, displacement, sway, column and beam Size comparison, longitudinal reinforcement requirement comparison, column cost analysis, and base shear comparison. Conclusions are drawn from the study after all the comparison analysis it is found that the SMRF frame system is a better and more effective framing system than the other two framing systems such as IMRF and OMRF.

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CHAPTER 1

Introdu-ction

1.1 General

The selection of a particular type of framing system depends on some important parameters, among which the seismic risk of the zone and the budget are important for Bangladesh. Lateral forces acting on any structure are distributed according to the flexural stiffness of the individual elements. The codes of Bangladesh (BNBC) divide the entire country into four seismic zones (II, III, IV, and V) depending on the seismic hazard. OMRF is probably the most widely adopted frame type in low seismic zones. However, as the seismic hazard increases, this becomes insufficient and SMRF or IMRF frames need to be adopted.

1.2 Structural System

In structural engineering, a rigid frame is a load-resisting skeleton constructed mostly of straight or curved members interconnected by rigid connections that resist induced movement at the joints of the members. Its members can carry bending moments, shear, and axial loads. They are of two types: rigid-framed structures and braced-framed structures. Two general assumptions about the behavior of a building frame are that its beams are free to rotate at their joints and that its members are so connected that they form angles. Do not change under load with each other. Moment-resisting frames are rectilinear assemblages of beams and columns, beams rigidly connected in shear, amount of reinforcement, etc. Moment frames have been widely used for earthquake-resistant systems due to their superior deformation and energy dissipation capabilities. A moment frame consists of beams and columns, which are rigidly connected. The elements of a moment frame should resist both gravity and lateral loads. Lateral forces are distributed according to the flexural stiffness of each element.

On the other hand, earthquake-resistant design significantly increases the performance of the structures. The seismic design of structures is based on elastic force; the nonlinear response of a structure is incorporated into the design by using the appropriate response reduction factor (R). The concept of R is to de-amplify the seismic force and incorporate nonlinearity with the help of over strength, redundancy, and ductility. Ductile detailing is done in the structure to increase the ductility and to reduce the amount of damage, compared to a non-ductile detailed structure. A highly ductile designed frame will attract more damage compared to a structure designed for lower ductility, due to large yield excursion (Lu, Hao, & Carydis, 2001). The design seismic forces are reduced drastically by using higher values of R and incorporating

higher ductility. The reduction in seismic forces leads to reduced member cross-section. The capacity of a structure depends on initial stiffness, strength, and ductility. If ductile detailing is required to be done for a building, then only ductility should be increased and the other two parameters to be kept the same for comparatively less damage, above mentioned behavior cannot be achieved using provisions given in the current seismic code. Response reduction factor (R) is defined differently in different countries for different types of structural systems. In BNBC seismic code, the value of R for reinforced concrete structure is specified based on, ordinary moment resisting frame (OMRF), and special moment resisting frame (SMRF), and in the latest proposed draft one additional R-value incorporated for reinforced concrete structure based on Intermediate moment resisting frame (IMRF). Additionally, the rapid urbanization and population growth in Bangladesh have led to the construction of numerous buildings and infrastructures, often without adequate consideration for seismic resilience. This poses a significant challenge in terms of ensuring the safety and structural integrity of these constructions during earthquakes. Given the importance of resilient building design and construction practices, the evaluation and implementation of appropriate seismic-resistant frame systems have become crucial in Bangladesh. Three commonly used frame systems in the country are Special Moment Resisting Frames (SMRF), Intermediate Moment Resisting Frames (IMRF), and Ordinary Moment Resisting Frames (OMRF).

1.3 Earthquake Design Philosophy

The severity of ground shaking during the event of an earthquake can be categorized as minor, moderate, or major. The theoretical aim of the designers is to construct a structure that can resist even major earthquake shaking. However, this major earthquake is very rare and may occur only about once in thousands of years. Thus, it warrants the question- Should we design the buildings as earthquake-proof or Earthquake-resistant? The commonly adopted practice is to make the structures earthquake-resistant. These structures will get damaged during the event of a severe earthquake but will still not collapse. Thus, the safety of the occupants & their commodities is assured and all this is achieved with lesser investment if compared to the investments required for earthquake-proof structures.

1.4 Objectives of the study

The salient objectives of the present study are given below:

- The main aim of the present work is to study the effect of lateral loads on various structural framing systems.

- The comparison of beam and column dimensions, column reinforcement with cost analysis for different structural systems.

1.5 Overview of the Research Program

The research work conducted to achieve the objectives is presented through several chapters of this thesis. There are four more chapters of this thesis excluding the current chapter. Brief discussions of those chapters are stated below.

Chapter 1 (Introduction): This study compares OMRF, IMRF, and SMRF frame systems in terms of seismic performance, material use, and cost. Based on BNBC codes and seismic zones in Bangladesh, it evaluates how different frames handle lateral loads and highlights the need for safer, cost-effective earthquake-resistant designs.

Chapter 2 (Literature Review): This chapter is devoted to the review of past research in Bangladesh and other parts of the world. Details on the various structural framing systems, their types, advantages and disadvantages are discussed here.

Chapter 3 (Methodology): The associated steps related to our thesis work have been discussed in this chapter with the necessary plan, 3-D figure, and properties of materials.

Chapter 4 (Results and Discussion): The main research part of this thesis, describes the computational investigations carried out throughout the study in detail with presentation by various tables and figures after only necessary discussion.

Chapter 5 (Conclusions and Recommendations): The concluding chapter summarizes the whole study. The findings of the research program and related discussions are presented in this chapter. This chapter also includes scopes for future research with specific recommendations.

CHAPTER 2
Literature Review

2.1 General

All structural systems are not treated equally when a response to earthquake-induced forces is of concern. Aspects of structural configuration, symmetry, mass distribution, and vertical regularity must be considered. The importance of strength, stiffness, and ductility in relation to acceptable response must also be appreciated. While considering the lateral force resisting systems, we came up with many options to have structural systems like Bearing wall systems, Moment Resisting frames, and Lateral Bracing systems, designing the moment resisting concrete frame structures we have the option to use IMRF, OMRF, or SMRF. The basic step in conceptual design is to find the best suitable framing system and then lateral load-resisting mechanism, while designing structures in the field most engineers face problems with the decision of Response Modification Factor R which is a measure of ductility and over-strength of the structures. It is used to find the base shear which is distributed on different stories.

2.2 Moment Resisting Frame

Moment-resisting frame is a rectilinear assemblage of beams and columns, with the beams rigidly connected to the columns. Resistance to lateral forces is provided primarily by rigid frame action – that is, by the development of bending moment and shear force in the frame members and joints. By virtue of the rigid beam–column connections, a moment frame cannot displace laterally without bending the beams or columns depending on the geometry of the connection. The bending rigidity and strength of the frame members are therefore the primary source of lateral stiffness and strength for the entire frame. Reinforced concrete is an ideal material for this system by virtue of its naturally monolithic behavior.

2.3 Types of Moment Resisting Frame

When it comes to steel moment frames, there are three types of frames defined in the code - ordinary moment frames (OMF), intermediate moment frames (IMF), and special moment frames (SMF).

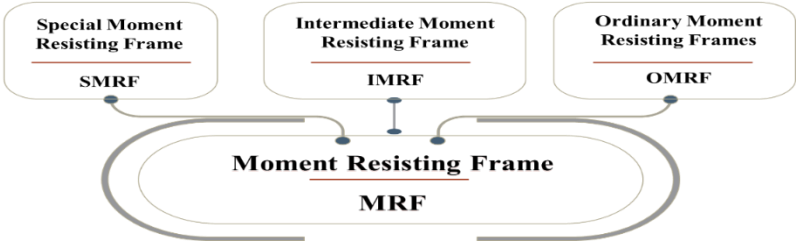


Figure 2-1: Types of Moment Resisting Frame

1. According to an ordinary reinforced concrete moment is permitted to be used in buildings assigned to SDC B
2. Structures assigned to SDC C are permitted to utilize intermediate concrete moment-resisting frames
3. Special reinforced concrete moment frames are required structures assigned to SDC D.

Table 2.1: Minimum Frame Type of Seismic Design Category (SDC)

Seismic Design Category (SDC)	Minimum Frame Type
B	Ordinary
C	Intermediate
D	Special

2.4 Advantages and Disadvantages of Moment Resisting Frame

Advantages of Moment Resisting Frame

- Provides flexibility for architectural design and layout
- Sufficient stiffness to resist wind and earthquake-induced lateral loads in buildings of up to about 25 stories

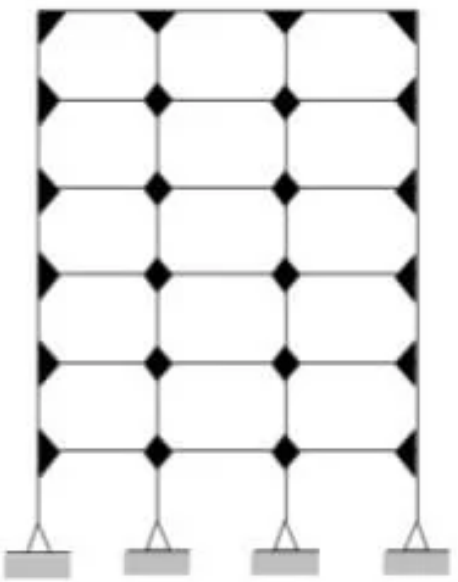


Figure 2-2: Structural framing joint system

Disadvantages of Moment Resisting Frame

- Greater deflection and drift compared to that of braced frames or shear walls.
- localized stress concentrations at rigid joints.
- Requires care in the erection of connections in order to resist lateral loads properly.
- Expensive moment connections
- A highly rigidity in the upper floors, where there is a little deformation more than the lower floors

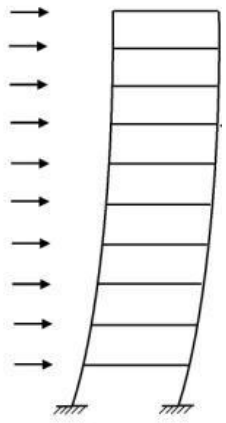


Figure 2-3: Shear mode deformation in rigid frame

2.5 Characteristics of MRF

2.5.1 Drifts in Moment Resisting Frame

In order to prevent story drift under lateral loads, the depths of frame members are frequently governed by stiffness rather than strength. The lateral displacement of one level in relation to the level below is referred to as the story drift. It is a major concern in the serviceability assessment of buildings especially because of the effects of wind. Commonly used drift limitations for wind-related building designs range from 1/400 to 1/500 of the story height. These restrictions are thought to be generally adequate to reduce damage to nonstructural walls and partitions, cladding, and other surfaces. Then inherent flexibility of moment-resisting frames could lead to more drift-induced nonstructural damage than in other systems under seismic loads. It is important to keep in mind that seismic drift, which includes structures' inelastic responses, is normally limited to 1/50 of the story height, which is around ten times bigger than the permitted wind drift. Particularly for frames intended to withstand seismic loads, the strength and ductility of the connections between beams and columns are very important factors to consider.

There are two causes of lateral drift.

1. Due to cantilever bending of the building (bending deformation), which is approximately 20 percent of the total lateral drift.
2. Due to The bending of beams and columns (shear deformation), approximately 65 percent is due to the bending of the beams, and 15 percent to the columns, totaling approximately 80 percent of the total lateral drift.

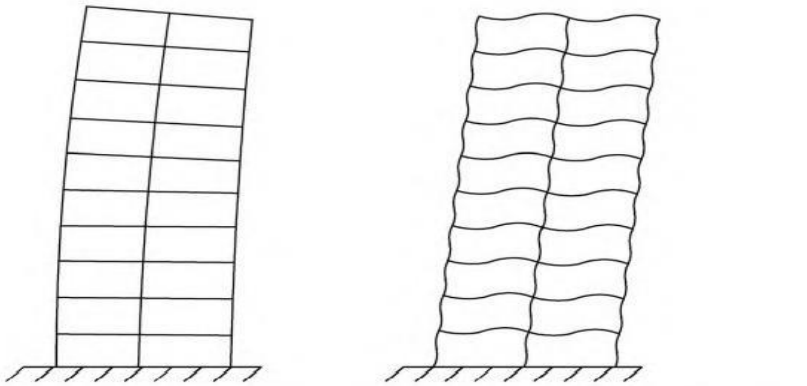


Figure 2-4: Deformation due to Cantilever bending and bending of the column and beams

2.5.2 Definition of Ductility

In earthquake-resistant design, the ability of building materials, systems, or structures to absorb energy by deforming into the inelastic range is a critical aspect. The capacity to absorb energy while undergoing acceptable deformations, without reaching failure, is highly desirable in ensuring the safety and resilience of structures during seismic events. Concrete, being inherently brittle, needs to be reinforced adequately with steel to impart the required ductility for resisting seismic forces effectively. By combining the compressive strength of concrete with the ductility of steel, engineers create reinforced concrete structures that can withstand seismic forces without collapsing. This ductile behavior allows the structure to deform inelastically during an earthquake, absorbing and dissipating the energy generated by seismic waves, thereby reducing the potential for severe damage and protecting lives and property in earthquake-prone regions

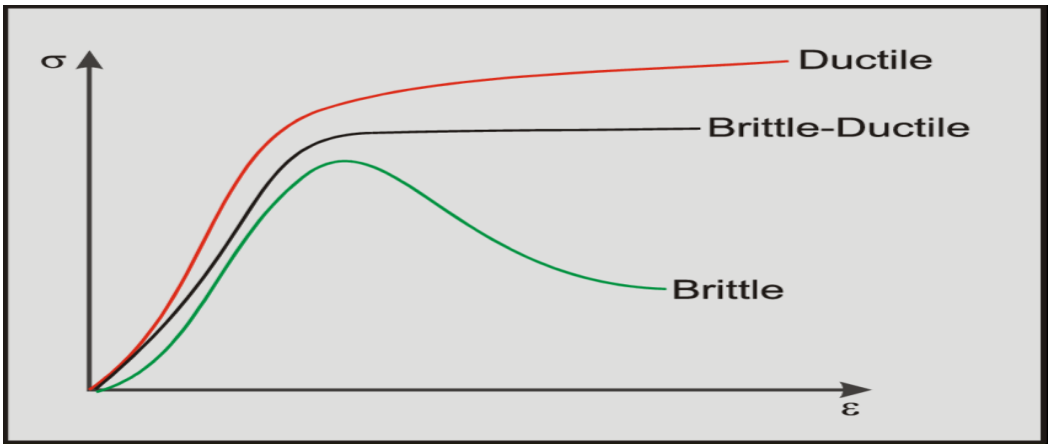


Figure 2-5: Ductile Material Curve

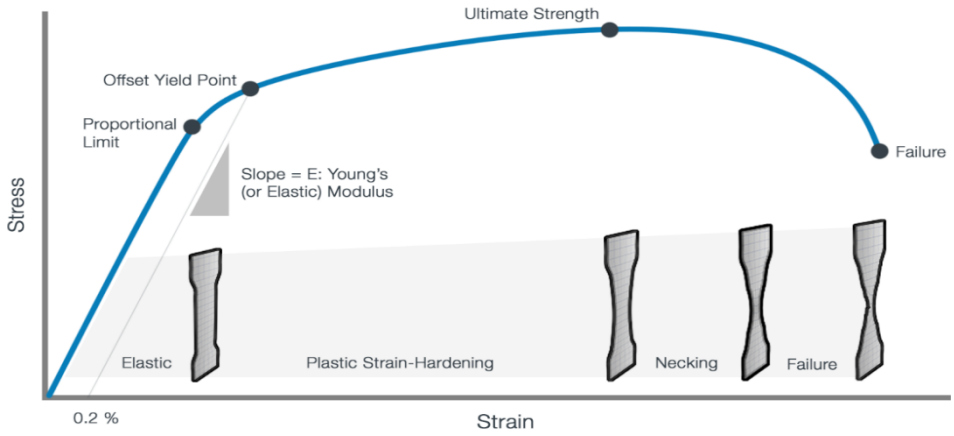


Figure 2-6: Ductile Material Stress-Strain Curve

2.5.3 Strong Column–Weak Beam

The formation of plastic hinges at the beam-column interface can lead to brittle failure due to the significant inelastic strain demands imposed on the connection. However, within the beam span, the formation of plastic hinges can efficiently dissipate substantial amounts of energy without causing failure. To achieve this condition, two approaches can be taken: one involves reducing the section of the beam at the specific location where the plastic hinge is desired, while the other requires reinforcing the beam at the connection to prevent the formation of a hinge in that region. By carefully controlling the formation and location of plastic hinges, engineers can enhance the overall ductility and energy absorption capacity of the structure, mitigating the risk of brittle failure during seismic events or other high-load situations.

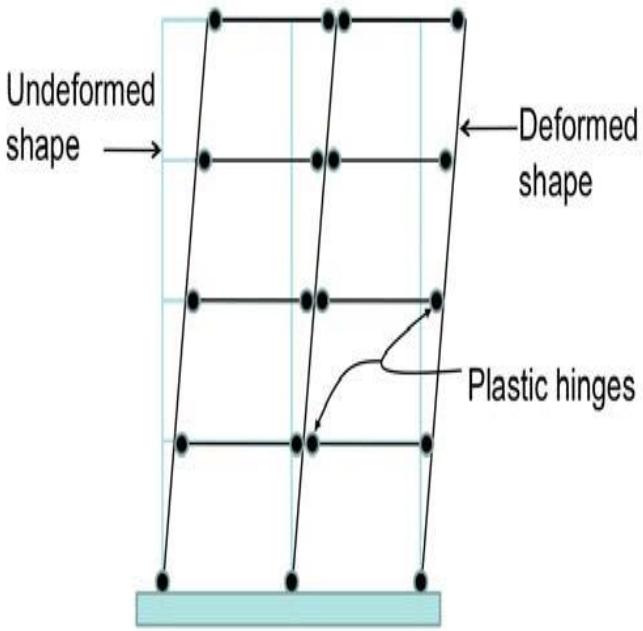


Figure. 2-7: Strong Column–weak Beam

2.5.4 PΔ- Effect

The P-Δ effect, often referred to as the second-order effect or second-order analysis, is a structural engineering concept that considers the additional deformation and bending moments induced in a structure due to the combined action of axial forces (P) and lateral deflections (Δ). In simpler terms, it accounts for the interaction between axial loads and lateral displacements in a structure.

- This additional deflection imposes secondary moments in the column.
- When axial load is imposed on the deflected shape of the frame, additional sway occurs in the frame.

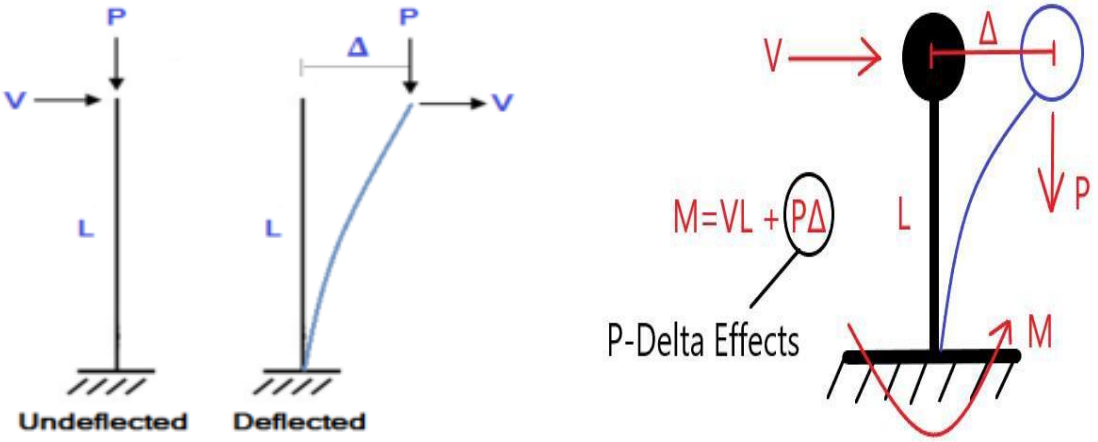


Figure 2.8: PΔ- Effect diagram

$$Stability\ Coefficient, Ø = \frac{Secondary\ Moment}{Primary\ Moment} = \frac{P\Delta}{VLC_d}$$

Table 2-2: Summary of PΔ- Effect

Condition	Observation	Remarks
$Ø < 0.1$	The structure is stable	No P-Delta
$0.1<Ø<Ø_{max}$	The incremental factor shall be determined by rational analysis	P-Delta
$Ø>Ø_{max}$	The structure is potentially unstable and shall be redesigned	P-Delta

2.5.5 Response Reduction Factor (R)

The response reduction factor, denoted by R, is an empirical parameter used in base shear equations in earthquake engineering. It accounts for the ability of a structure to dissipate seismic energy and reduces the design base shear accordingly. A higher value of R implies that the structure is more resilient and can withstand seismic forces more effectively, resulting in a lower design base shear.

For Reinforced Concrete (RC) special moment-resisting frames, R typically has a value of 8, indicating higher resistance to seismic loads. Ordinary moment-resisting frames have a lower R-value of 3, while intermediate frames fall in between with an R-value of 5. The R factor varies based on the structural system's ability to absorb energy through damping and ductility. Damping refers to a structure's capacity to dissipate energy during vibration, while ductility signifies its ability to undergo inelastic deformation without failure. Higher damping and ductility characteristics lead to higher R values and, consequently, lower base shear demands during seismic events.

Table 2-3: Response Reduction Factor, BNBC-2020

Seismic Force-Resisting System	**Response Reduction Factor, *R***	**System Overstrength Factor, Ω_0**	**Deflection Amplification Factor, C_d**	**Seismic Design Category B**	**Seismic Design Category C**	**Seismic Design Category D**
				Height limit (m)		
Special reinforced concrete moment frames	8	3	5.5	NL	NL	NL
Intermediate reinforced concrete moment frames	5	3	4.5	NL	NL	NP
Ordinary reinforced concrete moment frames	3	3	2.5	NL	NP	NP

2.6 Ordinary Concrete Moment Frames SDC-B

2.6.1 General Requirements: Frame Beams

- The flexural reinforcement at both the top and bottom faces of the section must include at least two continuous bars along the span.
- The area of the Continuous bottom bars in the section, shall have an area not less than 25% of the maximum area of bottom bars along the span.
- These bars (flexural RFT.) shall be anchored to develop fy in tension at the face of support.
- These requirements for structures are not expected to be subjected to strong ground motion.

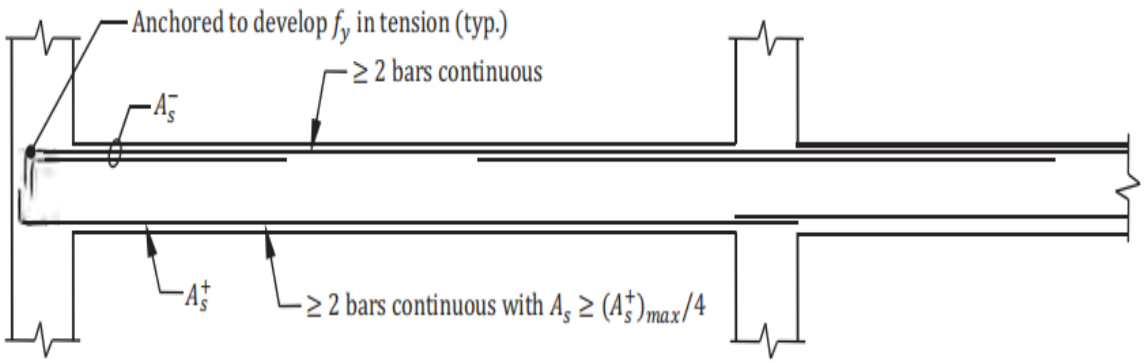


Figure 2-9: General Requirements Frame Beams for OMRF

2.6.2 General Requirements: Frame Columns

- The limits of gross flexural reinforcement ratio $\rho_g \leq 0.08$, $\rho_g \geq 0.01$
- Maximum spacing of ties Shear reinforcement is $s_{max} \leq \begin{pmatrix} 16\ d_b \\ 48\ d_t \\ b \end{pmatrix}$

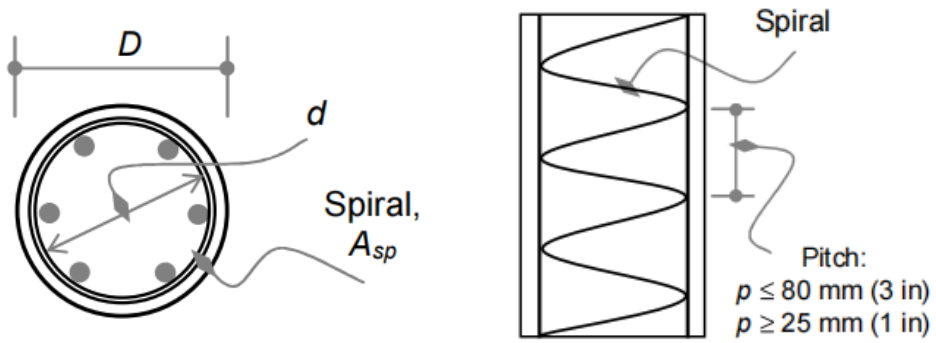


Figure 2-10: General Requirements Frame Columns for OMRF

2.7 Intermediate concrete moment frames (IMRF) SDC-C

2.7.1 Flexural Reinforcement: Frame Beams

- Positive moment strength at joint face ≥ one-third of negative moment strength provided at that face of the joint.
- Neither the negative nor the positive moment strength at any section along the member length shall be less than one-fifth of the maximum moment strength provided at the face of either joint.
- The top reinforcement is usually spliced near mid-span and the bottom reinforcement is spliced near the support.

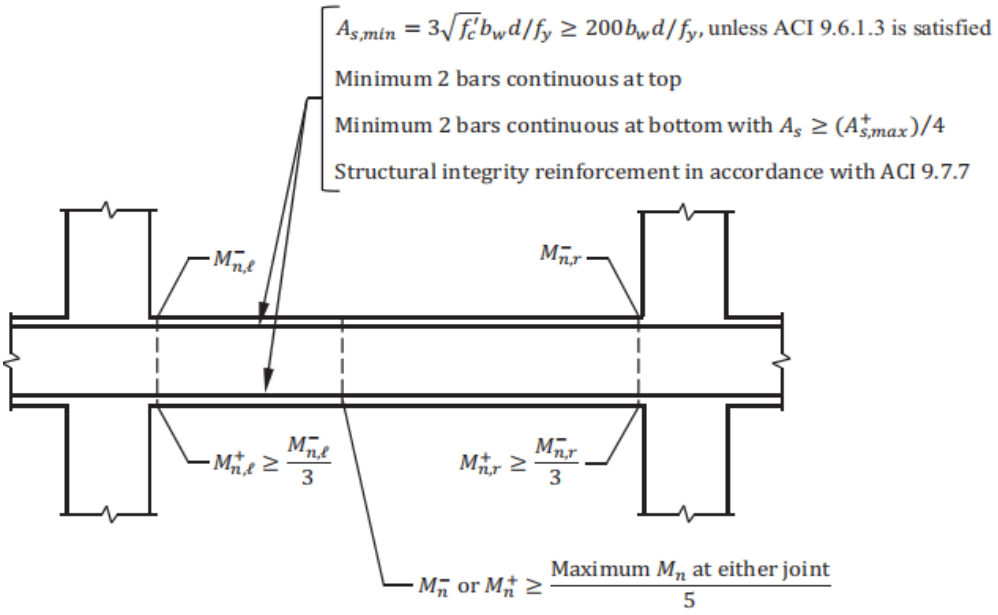


Figure 2-11: Flexural Reinforcement Frame Beams for IMRF

2.7.2 Transverse Reinforcement: Frame Beams

- The potential plastic hinge region is assumed to extend a distance (2h) from the face of the support.
- Stirrups shall be provided at both ends of a member over a length equal to 2h from the face of the supporting member toward mid-span.
- The first stirrup shall be located no more than 2 in or 50mm, from the face of the supporting member.
- Stirrups shall be spaced at no more than d/2 throughout the length of the member.

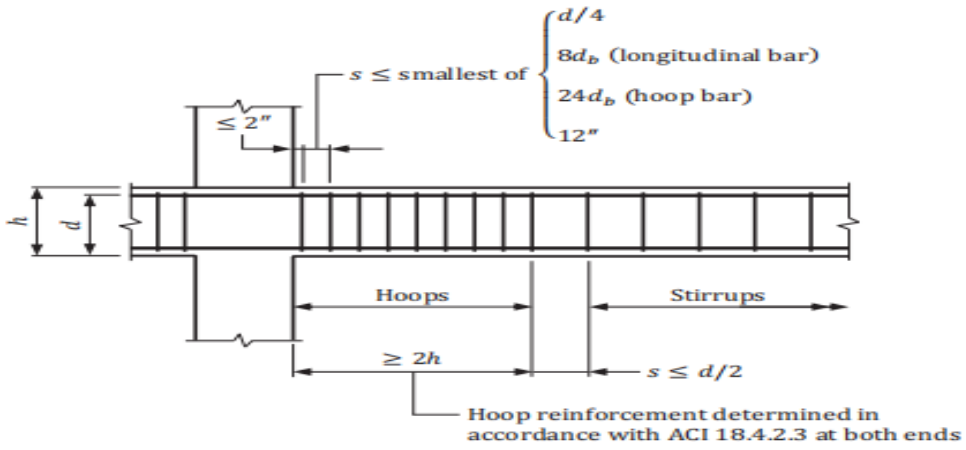


Figure 2-12: Transverse Reinforcement Frame Beams for IMRF

2.7.3 Transverse Reinforcement: Frame columns

- Lo is the assumed length of the anticipated plastic hinge region
- Maximum tie spacing shall not exceed So over a length Lo measured from each joint face.
- The first tie shall be located no farther than So/2 from the joint face.
- Tie spacing outside of the length Lo shall not exceed 2So.

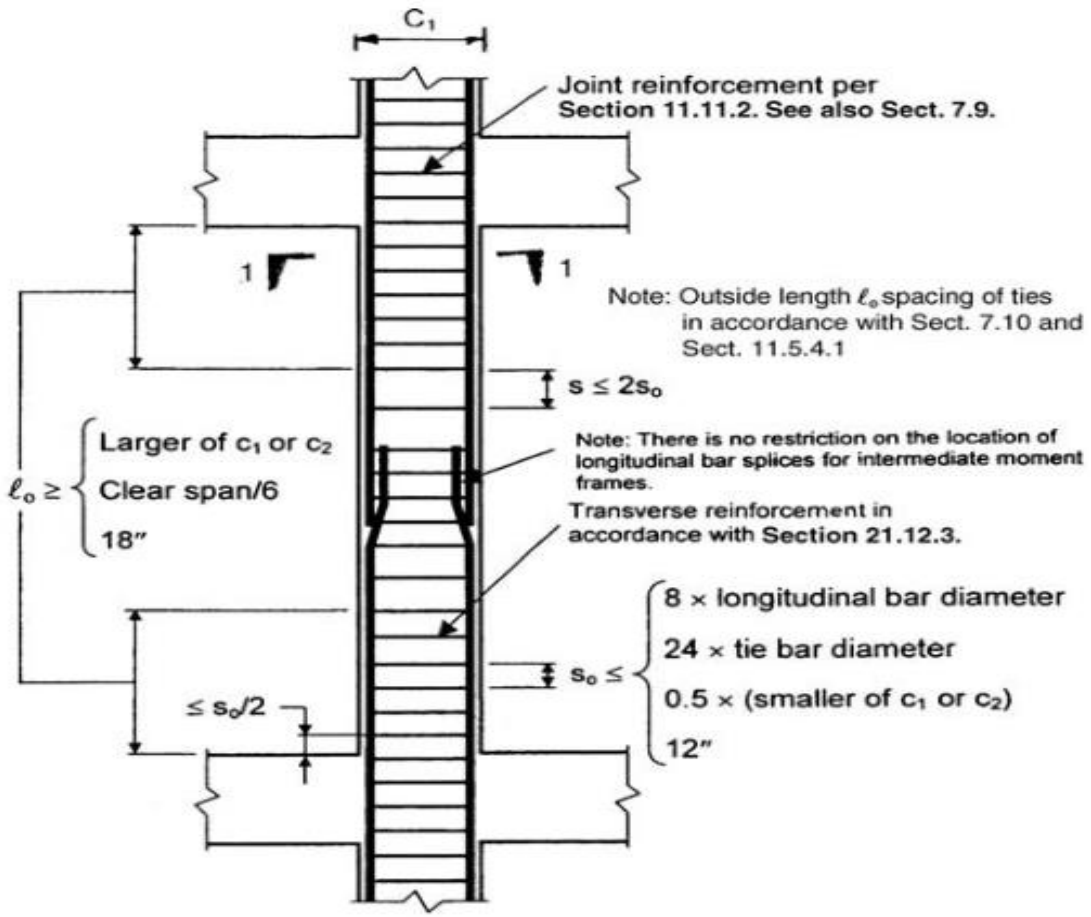


Figure 2-13: Transverse Reinforcement: Frame columns for IMRF

2.8 Special Concrete Moment Frames (SMRF) SDC D

2.8.1 Dimension Limit: Frame Beams

- The web width shall not be less than 0.3 times its height and 250 mm,
- The web width shall be greater than 3C2 andC2+1.5C1
- Projection of the beam width beyond the width of the supporting column on each side shall not exceed the lesser of c2 and 0.75c1.
- The clear span of the beam shall not be less than four times its effective depth.

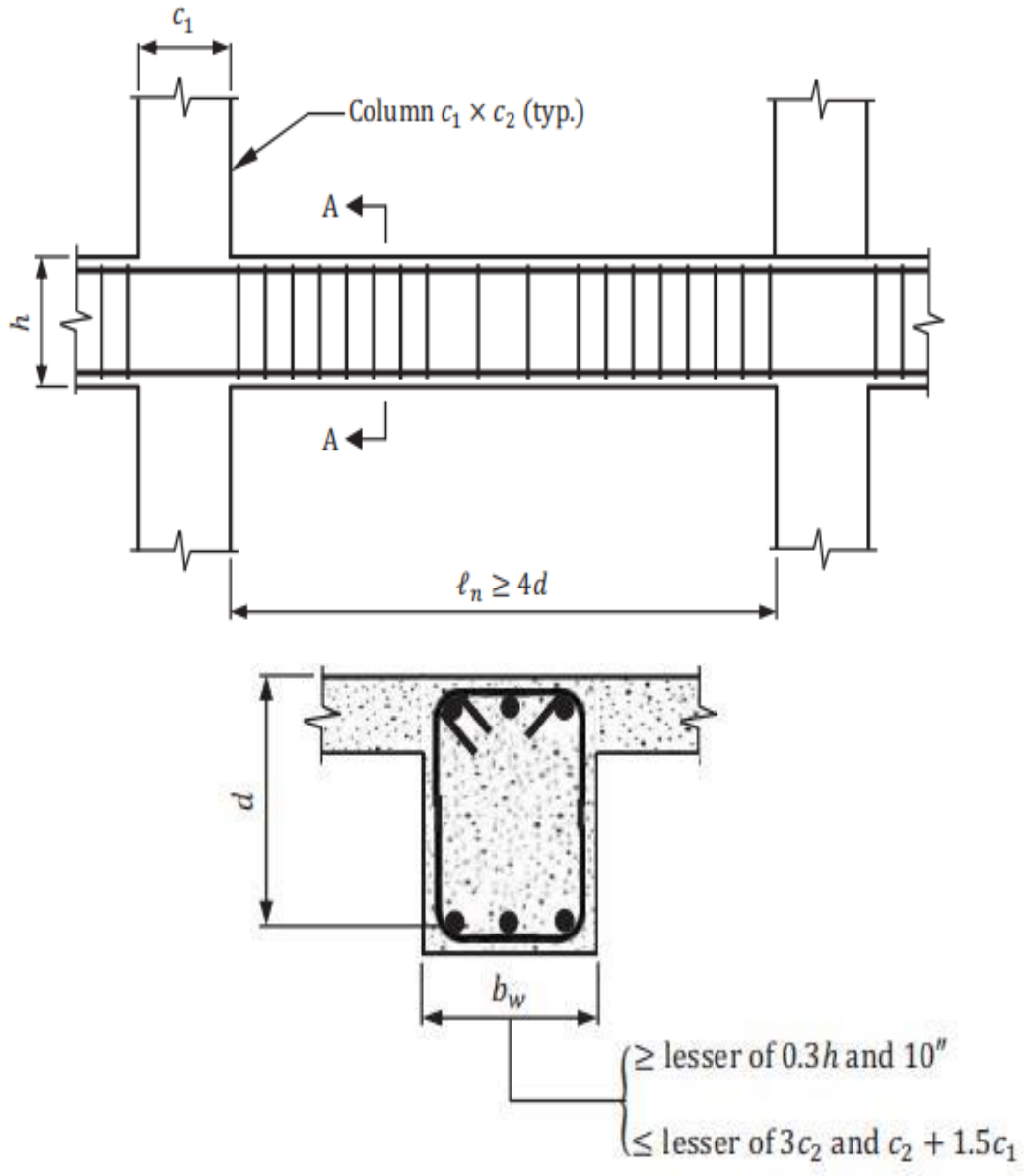


Figure 2-14: Dimension Limit Frame Beams for SMRF

2.8.2 Flexural Reinforcement: Frame Beams

- The positive moment at the face of the column must exceed one-half the negative moment strength provided at the face of the supporting column.
- The minimum positive and negative moments at mid-span must exceed one-fourth the maximum moment strength provided at the face of the supporting column.
- At least two bars at the top and bottom faces of the beam must be continuous.
- The required development length for straight bars are multiples of the hooked bar development lengths in ACI 18.8.5.1:

I. Minimum development length 2.5Ldh for bottom bars

II. Minimum development length 3.25Ldh for top bars

Normalweight concrete	ℓ_{dh} = greater of $\begin{cases} f_y d_b / 65\sqrt{f'_c} \\ 8d_b \\ 6'' \end{cases}$
Lightweight concrete*	ℓ_{dh} = greater of $\begin{cases} f_y d_b / (65 \times 0.75)\sqrt{f'_c} \\ 10d_b \\ 7.5'' \end{cases}$
For epoxy-coated or zinc and epoxy dual-coated bars, multiply ℓ_{dh} by 1.2.	

* Applicable to Grade 60 reinforcement only

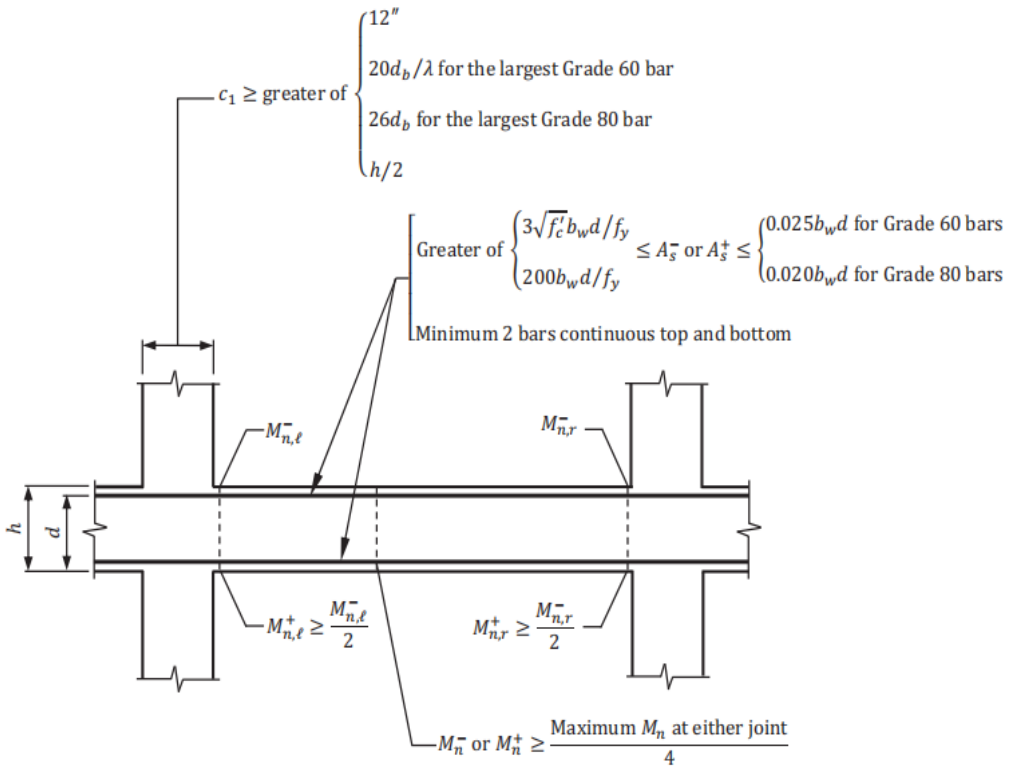


Figure 2-15: Flexural Reinforcement Frame Beams for SMRF

2.8.3 Transversal Reinforcement: Frame Beams

- The calculated hoop spacing, s, within 2h must be less than or equal to the smallest of the following:

$$s \leq \text{smallest of} \begin{cases} d/4 \\ 6 \text{ in.} \\ 6 \times \text{diameter of the smallest longitudinal bar enclosed for Grade 60 bars} \\ 5 \times \text{diameter of the smallest longitudinal bar enclosed for Grade 80 bars} \end{cases}$$

- The center-to-center spacing of the transversely supported longitudinal bars in beams must be less than or equal to 14in

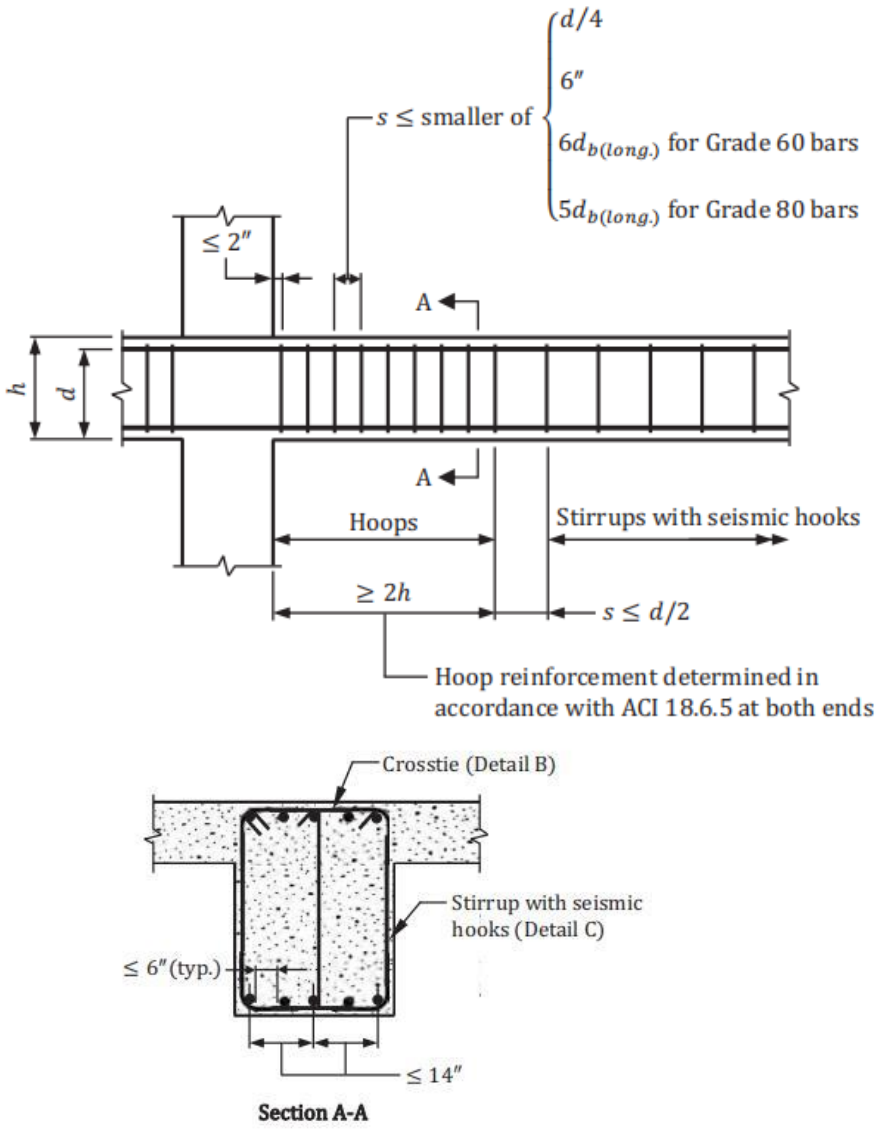


Figure 2-16: Transversal Reinforcement Frame Beams for SMRF

2.8.4 Dimension Limit: Frame Columns

- Shortest cross-sectional dimension measured on a straight line passing through the geometric centroid ≥12 in.
- Ratio of the shortest cross-sectional dimension to the perpendicular dimension ≥0.4.

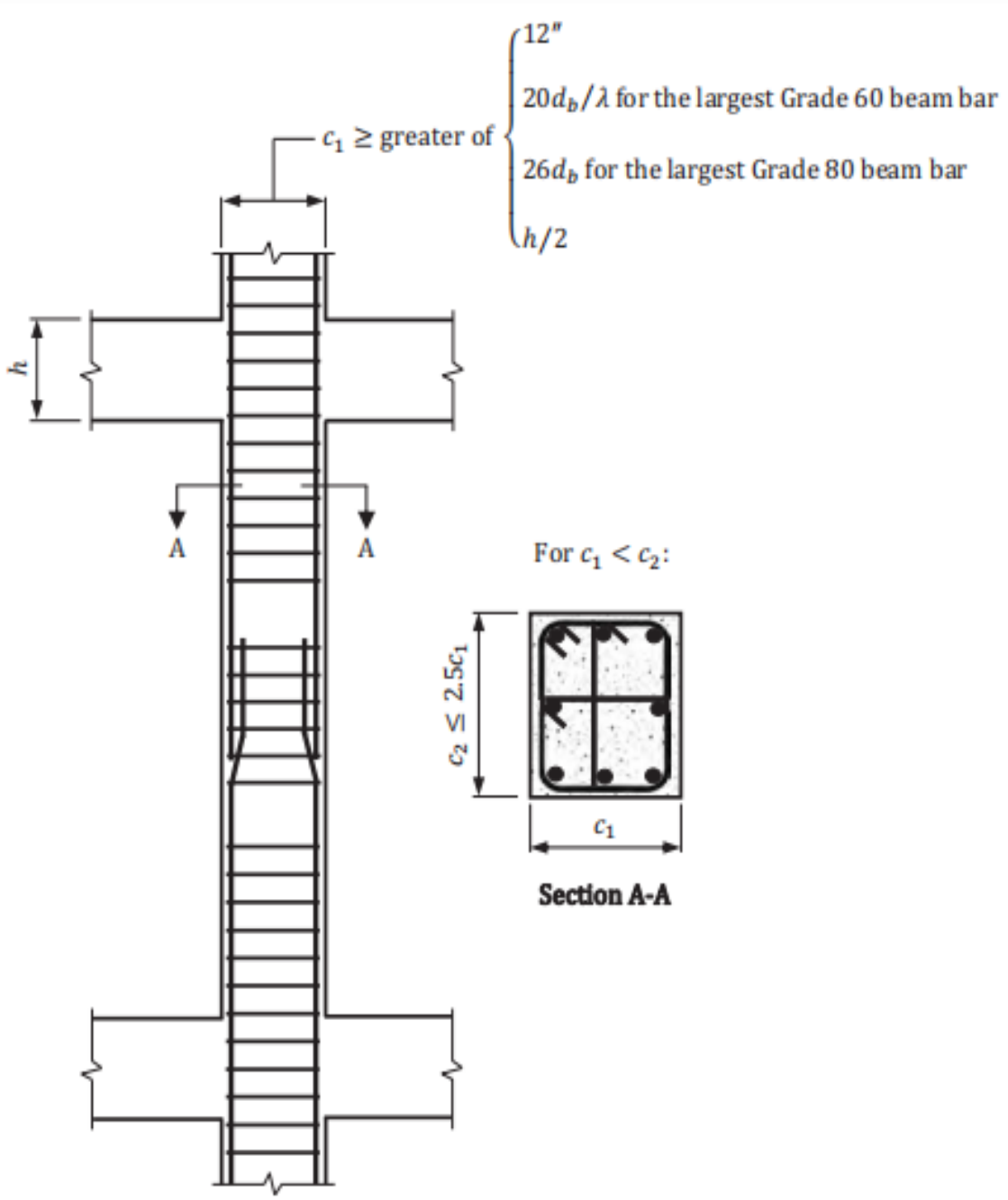


Figure 2-17: Dimension Limit Frame Columns for SMRF

2.8.5 Flexural Reinforcement: Frame Columns

- The splice location shall be limited to the center half of the beam-column to keep the splice outside of the regions of the plastic hinges.
- The clear height of the column is greater than or equal to 2.5 times the tension development length of the bars.
- At least six longitudinal bars are required in columns
- The potential plastic hinge region is assumed to be within a distance (Lo) from the face of the support.
- The minimum length of the plastic hinge region (Lo) is given as a function of the clear span of the column, the dimensions of the section and 500 mm (18 in).

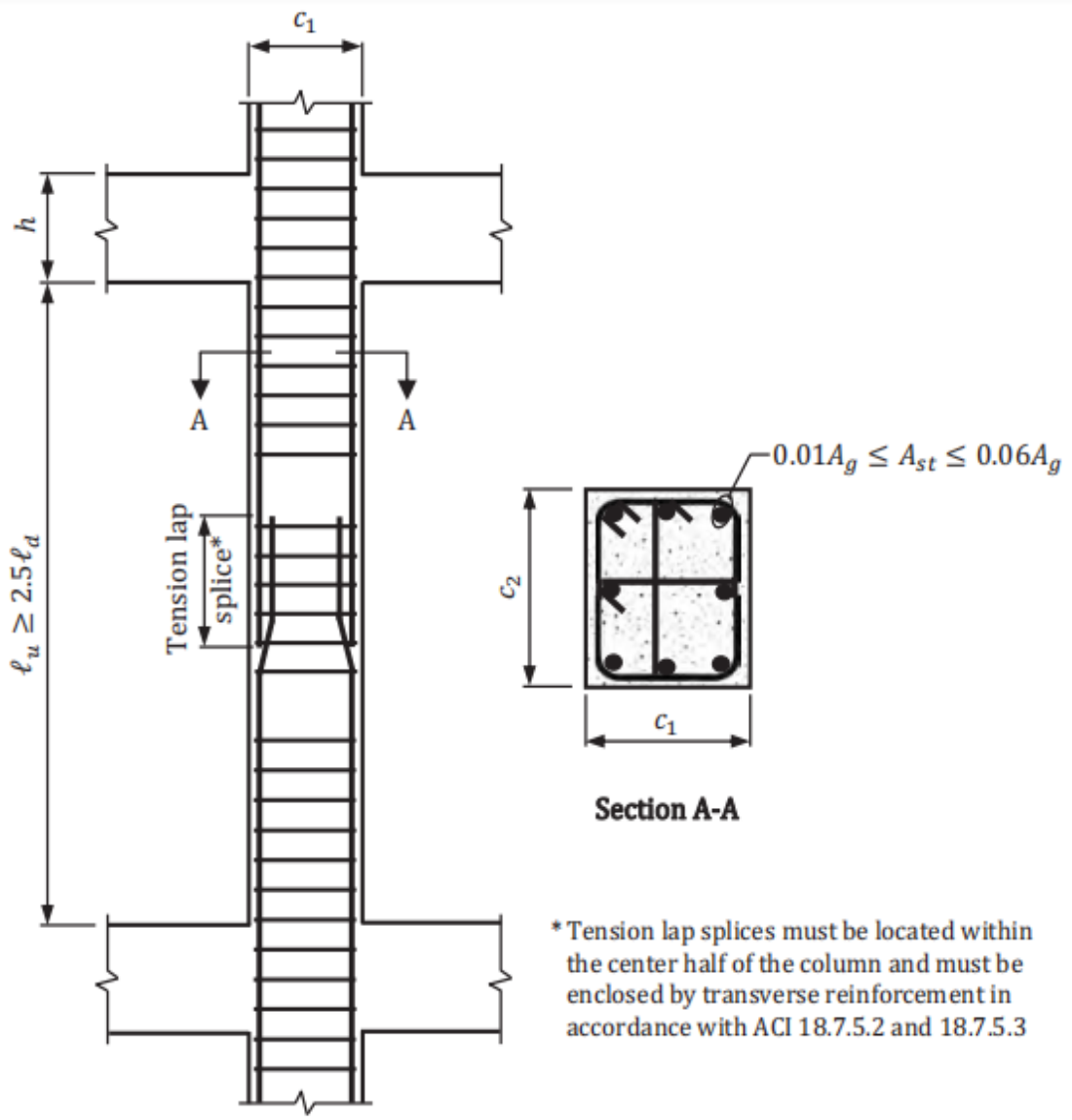


Figure 2-18: Flexural Reinforcement Frame Columns for SMRF

2.8.6 Transversal Reinforcement: Frame Columns

- The amount and spacing of hoops in the plastic hinge region must extend through the joint as shown in the figure.
- The spacing of hoops in the middle of the beam shall neither exceed 6db nor 150 mm (6 in) and 5db.

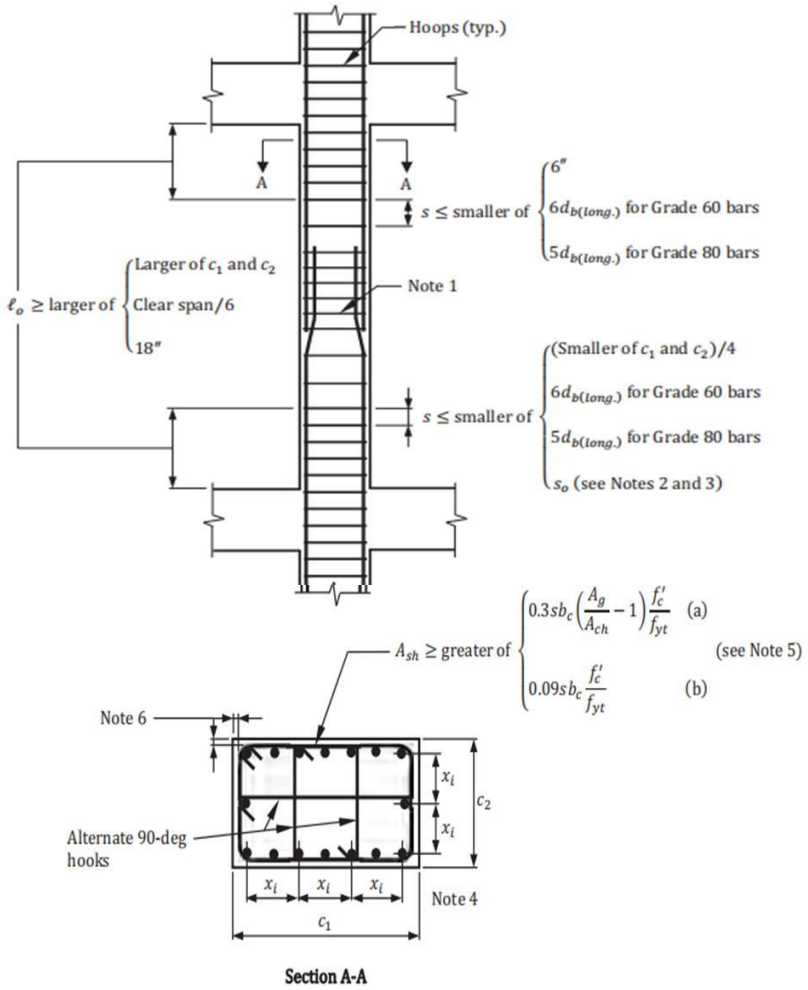


Figure 2.19: Transversal Reinforcement: Frame Columns for SMRF

2.9 Seismic Loads Affect OMRF, IMRF, and SMRF in RCC Buildings

2.9.1 Seismic Effect and Force on Structure

The seismic effect on structure during earthquakes depends critically on its overall shape, size, location of epicenter and geometry, in addition to how the earthquake forces are carried to the ground. It is observed from the past earthquakes that all structural elements do not respond equally. It mainly depends on their location in that structure. When the structures are twisting during earthquake, inertia forces are developed and it flows in different structural member. It is found that due to seismic effect on structure, seismic loads are developed on it. These loads are depended on various factors of structure and surrounding (weight, height, structural system,

soil condition). Effects of inertia forces and calculation of forces in various stories level are given in following section. The Blue Book and the UBC seismic provisions have been recognized throughout the world as leading references for the design of earthquake resistant buildings (Diebold & Moore 2009). [2]

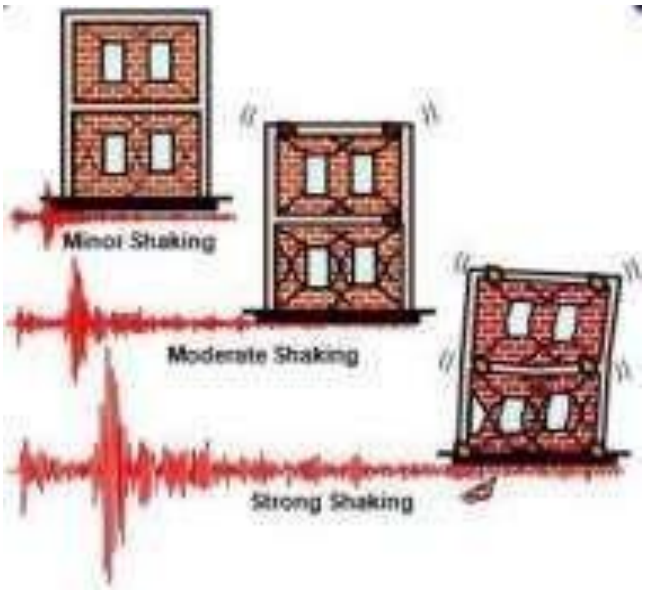


Figure 2-20: Effect on buildings due to ground shaking

2.9.2 How Seismic Loads Affect Frames

Table 2-4: The following table shows how seismic loads affect the frames

Effect	**Description**
Lateral Forces	Ground shaking creates side-to-side motion, causing lateral (horizontal) forces on frames.
Base Shear	Total horizontal force acting at the base of the structure.
Story Drift	Horizontal displacement between floors; excessive drift can damage partitions and infill walls.
Bending Moments	Earthquakes cause bending in columns and beams, especially at joints.
Shear Forces	Lateral loads induce shear stress in beams and columns.
P-Delta Effect	Large displacements can magnify forces and create additional moments.
Torsion	If the mass or stiffness distribution is uneven, the frame can twist during seismic activity.
Resonance	If the structure's natural frequency matches the earthquake frequency, vibration can be amplified.

2.9.3 Comparison Table Summarizing the Key Differences between OMRF, IMRF, and SMRF

Table 2.5: The following table shows the Differences between OMRF, IMRF, and SMRF

Feature	OMRF (Ordinary MRF)	IMRF (Intermediate MRF)	SMRF (Special MRF)
Ductility	Low	Moderate	High
Seismic Resistance	Minimal	Moderate	High
Seismic Detailing Requirements	Minimal (basic)	Moderate	Strict (as per seismic codes)
Design Complexity	Simple	Moderate	Complex
Construction Cost	Low	Moderate	High
Suitable Seismic Zones	Low risk	Moderate risk	High risk
Energy Dissipation Capacity	Low	Moderate	High
Code Reference	Basic structural code	Intermediate detailing (e.g. BNBC, ACI)	Advanced codes (e.g. ACI 318, BNBC-2020)
Use Cases	Low-rise buildings in stable areas	Mid-rise structures in moderate zones	High-rise or critical buildings in seismic zones

CHAPTER 3

Methodology

3.1 General

In this research work, a G+9 story Reinforced Concrete (RCC) building has been designed using ETABS 2017 software. The building has been subjected to both gravitational loads (due to its own weight and the weight of contents) and lateral loads (resulting from seismic forces and wind pressure) as per the guidelines of the Bangladesh National Building Code (BNBC-2020). To assess and compare the structural performance and parameters, three different sets of building models have been created. The variations in these models are achieved by changing their response modification factors. Response modification factors are numerical values used to account for the level of ductility and energy dissipation capacity in a structure under seismic loads. The plan area of all three buildings is kept identical at 40 ft x 48 ft. This means that the footprint or layout of each building is the same. However, the response modification factors are altered to observe their effects on structural behavior and performance. The buildings are designed for seismic zone II, which implies a moderate level of seismic hazard, and the basic wind speed considered is 147 mph. These parameters are crucial in determining the lateral loads acting on the building due to earthquake and wind forces. By conducting a comparative study using different response modification factors, the research aims to understand the influence of these factors on the building's response to seismic and wind loads. The findings of this study will contribute valuable insights to seismic-resistant design practices and aid in optimizing the structural performance and safety of tall buildings in earthquake-prone regions.

3.2 Unit & Codes Used

We using some Units and building codes to complete our Models in ETABs.

- Display Units - U.S Customary
- RCC Design - ACI 318-08
- Seismic Design -User Coefficient
- Wind Loads - ASCE 7-05

RCC Design and Wind Loads design code (ACI 318-08 & ASCE 7-05) is matched with BNBC-2020. The user Coefficient method has been applied as seismic loading for both axes.

3.3 Design Consideration

We have analyzed the G+9th Story building but designed 3 Columns of the 1st floor.

They are the **Corner column, Exterior Column, and Interior Column**.

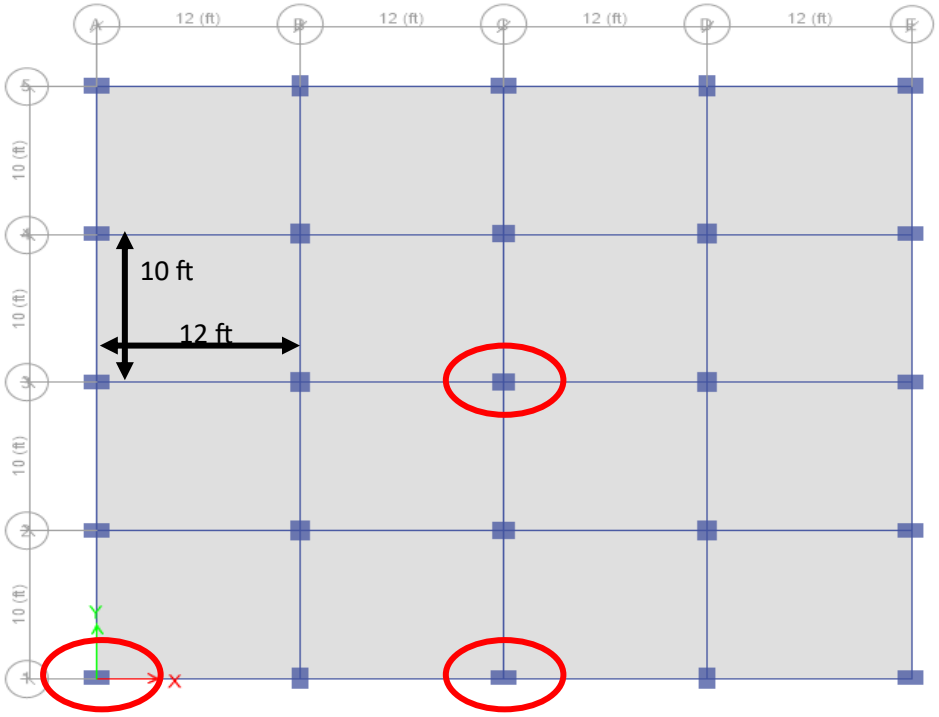


Figure 3-1: Plan view for building model in ETABS

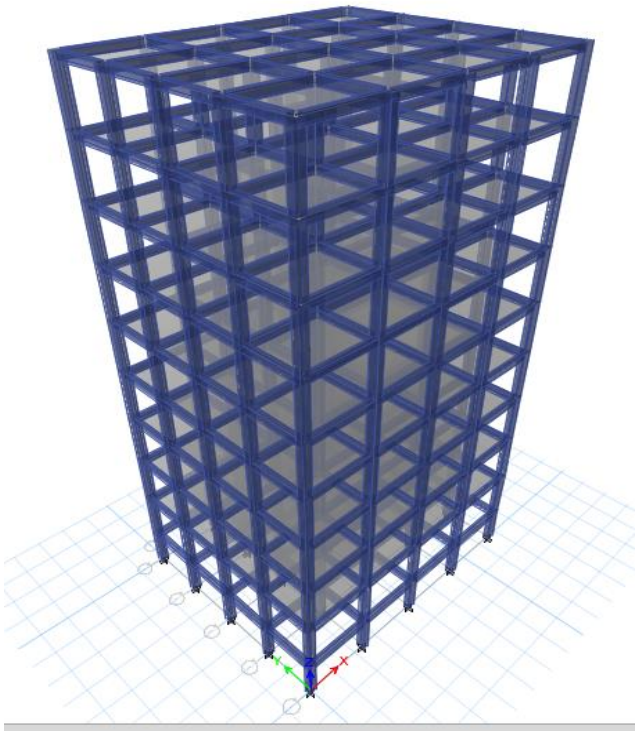


Figure 3-2: 3D Elevations view for building model in ETABS

3.4 Load Combination for 3D Analysis Considered Vertical Seismic Effect

These are added to some load combinations by following BNBC 2020 to consider our building safety. There are 31 load combinations.

1. 1.4D
2. 1.2D+1.6L
3. 1.2D+L
4. 1.2D+0.8WX
5. 1.2D-0.8WX
6. 1.2D+0.8WY
7. 1.2D-0.8WY
8. 1.2D+L+1.6W
9. 1.2D+L-1.6WX
10. 1.2D+L+1.6WY
11. 1.2D+L-1.6WY
12. 0.9D+1.6WX
13. 1.2D+L+EX+0.3EY+ λD
14. 1.2D+L+EX-0.3EY+ λD
15. 1.2D+L-EX-0.3EY+ λD
16. 1.2D+L+EY+0.3EX+ λD
17. 1.2D+L+EY-0.3EX+ λD
18. 1.2D+L-EY+0.3EX+ λD
19. 1.2D+L-EY-0.3EX+ λD
20. 0.9D+1.6WX
21. 0.9D-1.6WX
22. 0.9D+1.6WY
23. 0.9D-1.6WY
24. 0.9D+EX+0.3E- λD
25. 0.9D+EX-0.3E- λD
26. 0.9D-EX+0.3EY- λD
27. 0.9D-EX-0.3EY- λD
28. 0.9D+EY+0.3EX- λD
29. 0.9D+EY-0.3EX- λD
30. 0.9D-EY+0.3EX- λD
31. 0.9D-EY-0.3EX- Λd

3.5 Building Modelling Data

- Building Type - G+9th Story Residential Building
- Building Shapes
  I. X Directional column Length – 12 ft
  II. Y Directional column Length – 10 ft
  III. Floor to floor Height – 10 ft
- Materials
  I. Column Concrete strength- 4000 psi
  II. Beam & Slab Concrete strength- 3500 psi
  III. Rebar grade – 60 grade
- Frame Types
  I. Column – Using Total 5 Groups of Columns in All Models (12x18, 12x20, 12x22, 14x16, 14x22, 14x24)
  II. Beam - Using Total 3 Groups of Beam in All Models (10x15, 12x15, 12x20)
  III. Slab Thickness – 5 inch
- Using Load Pattern
  I. Live Load – 40 psf
  II. Roof Live Load – 100 psf
  III. Floor Finish – 20 psf
  IV. Wall Load on Beam – 70 psf
  V. Partition wall Load – 300 lb/ft
- Seismic Load Pattern
  I. Zone - 2 (0.20)
  II. Soil type - D
  III. Importance Factor (I) - 1.00 (BNBC 2020)
  IV. Response modification coefficient, R
    a. SMRF (R=8)
    b. IMRF (R=5)
    c. 0MRF (R=3)
- Wind Load Pattern
  I. Site Location - Dhaka
  II. Exposure – B (BNBC 2020)
  III. Wind Speed – 147 mph

CHAPTER 4

Analysis of Results and Discussions

4.1 General

In this chapter, the whole thesis data have been shown in terms of tables, bar charts, graphs, and other mediums to make it easy to understand the significance of the result and its effect on the analysis results. This chapter not only shows the data but also the necessary discussion of those data as well as the graphs. It is one of the important chapters of the whole thesis work to understand the effect of the framing system and the behavior of three different moment-resisting frames.

4.2 Code & Software Consideration

Guidelines and considerations were followed from BNBC 2020 for structural analysis and design. Other necessary codes, standards, and specifications like ACI 318-08, and ASCE 7-10, have been utilized as required in structural design and detailing. In this whole research work, the assistance of ETABS software is mentionable. It is one of the most used 3-D structural software for structural engineers. For analyzing and comparing the number of storey displacements, inter-storey drift, and base shear we made 3 models of different frame systems. The same uniform dead loads, live loads, seismic and wind loads have been applied. Then we compared them by means of bar charts and graphs. In this thesis work the dimension of the beam, column, and slab section kept the same.

4.3 Maximum Story Displacement

Maximum Story Displacement: Story displacement means the displacement that occurred at each story level. In multi-storied buildings maximum story, displacement will be observed at the top stories. As the height increases the story displacement will have maximum value.

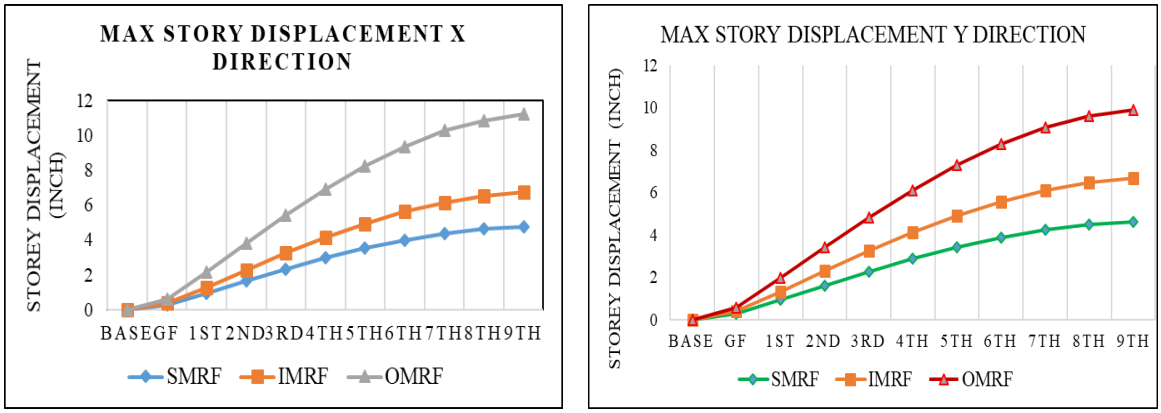


Figure 4-1: Max Story Displacement X Direction & Y Direction

- From the above figure it can be said that the OMRF building has shown maximum story displacement in X & Y directions however SMRF possesses minimum displacement.
- About 115% and 45%, displacement decreases for X and 136% and 42% for Y direction for SMRF compared to OMRF and IMRF respectively.

4.4 Maximum Story Drift Ratio

Max story drift measures the relative horizontal movement between adjacent floors in a building during seismic or lateral loading events. It is defined as the ratio of displacement of two consecutive floors to the height of that floor. It is a very important term used for research purposes in earthquake engineering.

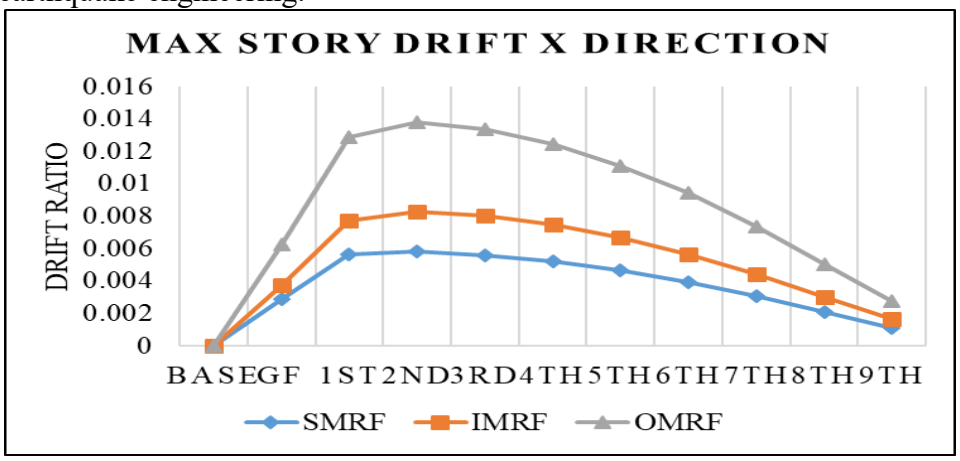


Figure 4-2: Max Story Drift X Direction

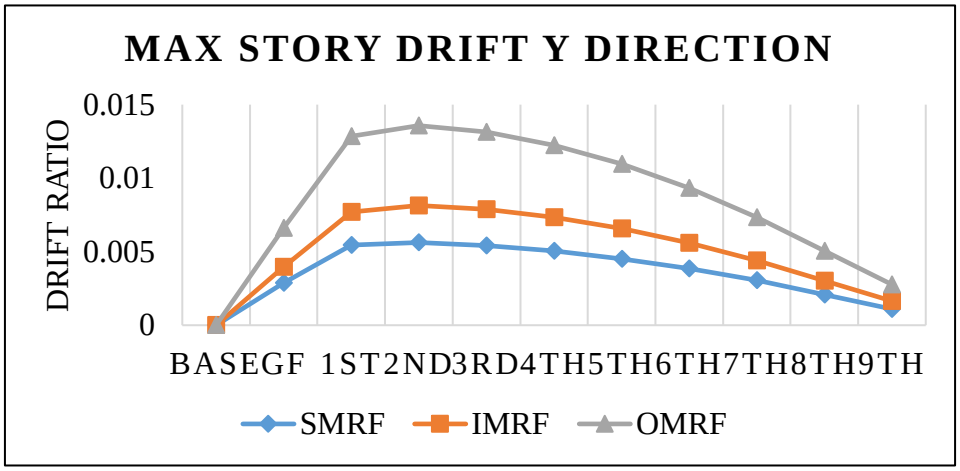


Figure 4-3: Max Story Drift Y Direction

- From the above figure it can be said that the OMRF building has shown maximum story Drift in the X Direction & Y direction however SMRF possesses minimum Drift.
- About 120% & 86%, drift decreases for X direction and 137% & 41% for Y direction for SMRF compared to OMRF and IMRF respectively.

4.5 Wind Serviceability (Sway) Check

Sway Check Due to Wind Forces According to BNBC 2020

Using Load Combination in ETABS 2017

D+0.5L+0.7Wx

D+0.5L+0.7Wy

Allowable sway Calculation

$$\Delta \leq \boldsymbol{H/500}$$

$$\Delta \leq 1080/500$$

$$= 2.16 \text{ inch}$$

Table 4-1: Sway Check Calculation X and Y direction

System	Direction	Sway (inch)	Allowable Sway (inch)	COMMENT
OMRF	X Direction	1.88	2.16	NOT OK
	Y Direction	2.21		
IMRF	X Direction	1.62	2.16	OK
	Y Direction	1.96		
SMRF	X Direction	1.62	2.16	OK
	Y Direction	1.96		

There is an allowable sway of 2.16 inches, but the OMRF frame system has crossed the

4.6 Column & Beam Size Comparison

Using a Total 5 Groups of Columns and 3 Groups of Beams in All Models.

Table 4-2: Beam size comparison

Systems	Beam Size
SMRF	10X15
IMRF	12X20
OMRF	12X20

Table 4-3: Column size comparison

Column Size Comparison			
Framing Systems	Corner Column Size	Exterior Column Size	Interior Column Size
SMRF	12x18	12x18	14x16
IMRF	12x20	12x20	12x22
OMRF	14x22	14x22	14x24

- ✓ From the above bar chart it is seen that column and beam dimensions of the SMRF system are less than OMRF and IMRF systems.
- ✓ It means the architectural view of SMRF systems will be more lucrative than the others.

4.7 Longitudinal Reinforcement Requirement Comparison in Column

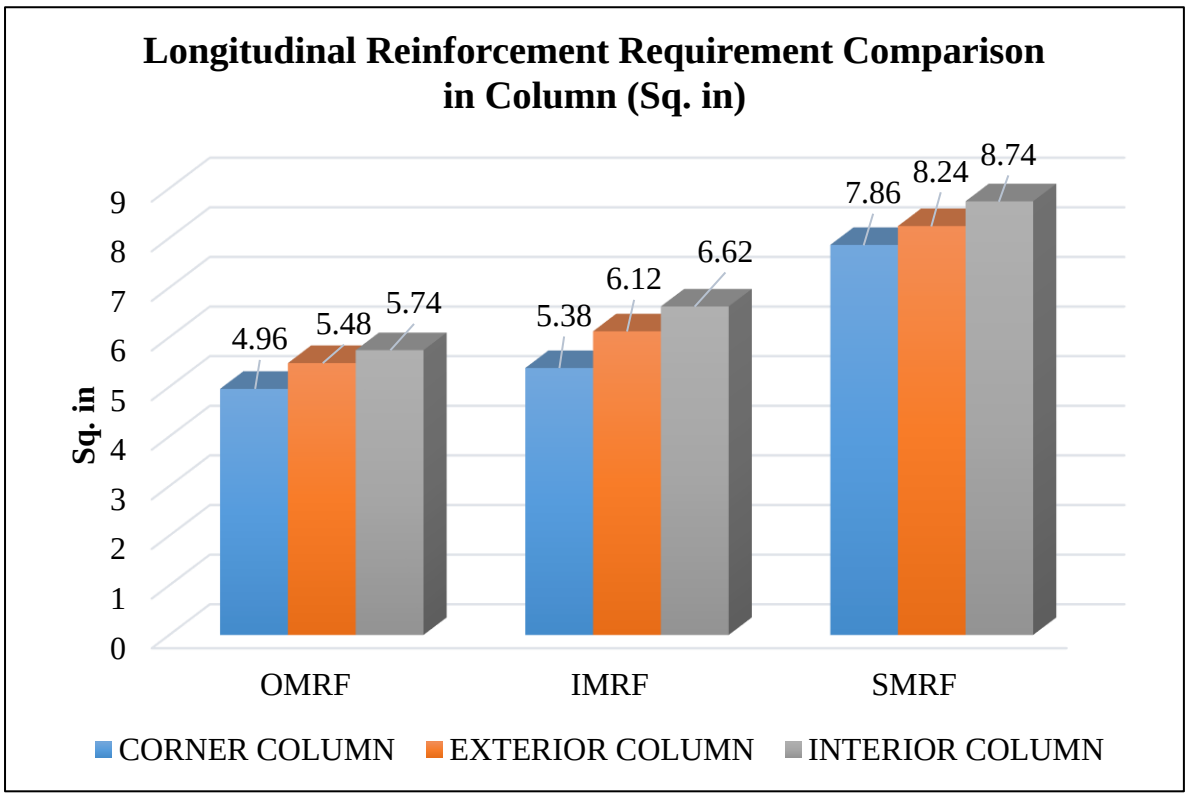


Figure 4-4: Longitudinal Reinforcement Requirement Comparison in corner Column (Sq. in)

- From the above bar chart about 59% & 9% more longitudinal reinforcement is required for the corner column for using SMRF compared to OMRF and IMRF respectively.
- About 51% & 12% more longitudinal reinforcement is required for exterior columns for using SMRF compared to OMRF and IMRF respectively.
- About 53% & 16% more longitudinal reinforcement is required for the interior column for using SMRF compared to OMRF and IMRF respectively.

4.8 Longitudinal Reinforcement Cost of Columns

There is Longitudinal Reinforcement cost in Column. As per the Current market rate.

Rebar price- 1 lakh tk/ton

Concrete price (RMC)-320 tk/cft

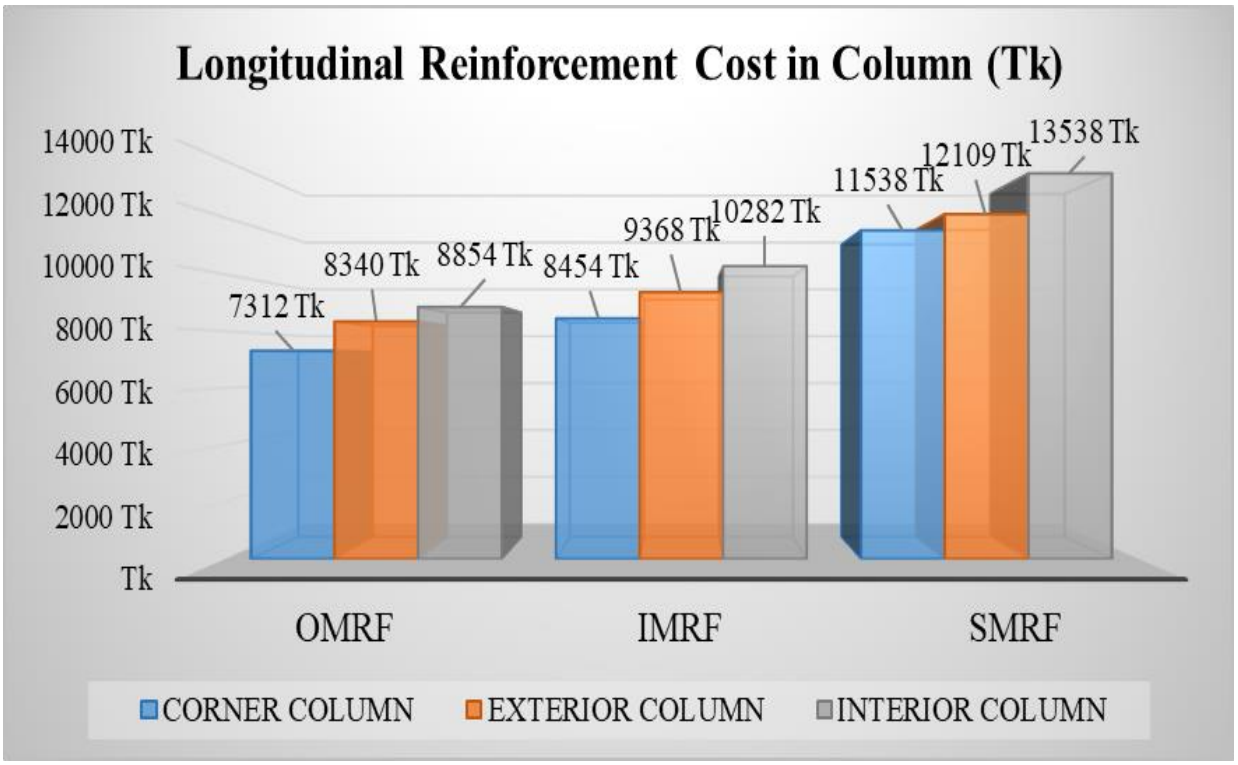


Figure 4-5: Longitudinal Reinforcement Cost in Column (Tk)

From the above bar chart about 53% & 34% more tk are required for the corner Column, about 44% & 29% more tk are required for the exterior column and 52% & 30% more tk are required for the interior column by using SMRF comparing to OMRF & IMRF respectively.

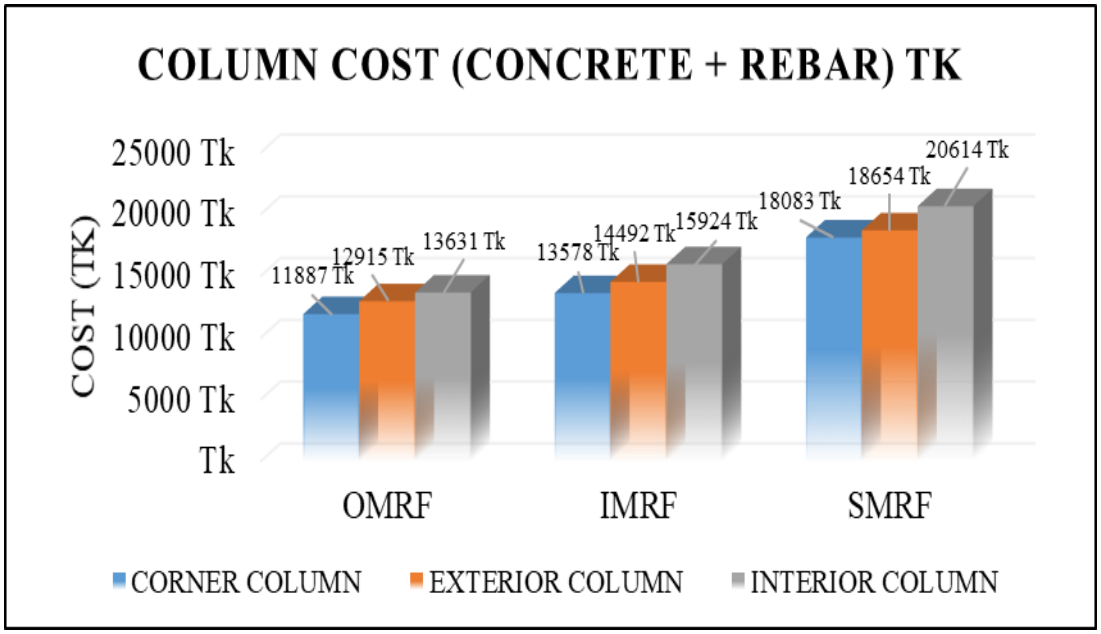


Figure 4-6: Column Cost (Concrete + Rebar) Tk

From the above bar chart about 53% & 34% more tk are required for the corner Column, about 44% & 29% more tk are required for the exterior column and 52% & 30% more tk are required for the interior column by using SMRF comparing to OMRF & IMRF respectively.

4.9 Concrete Requirement Comparison of a RCC Beam

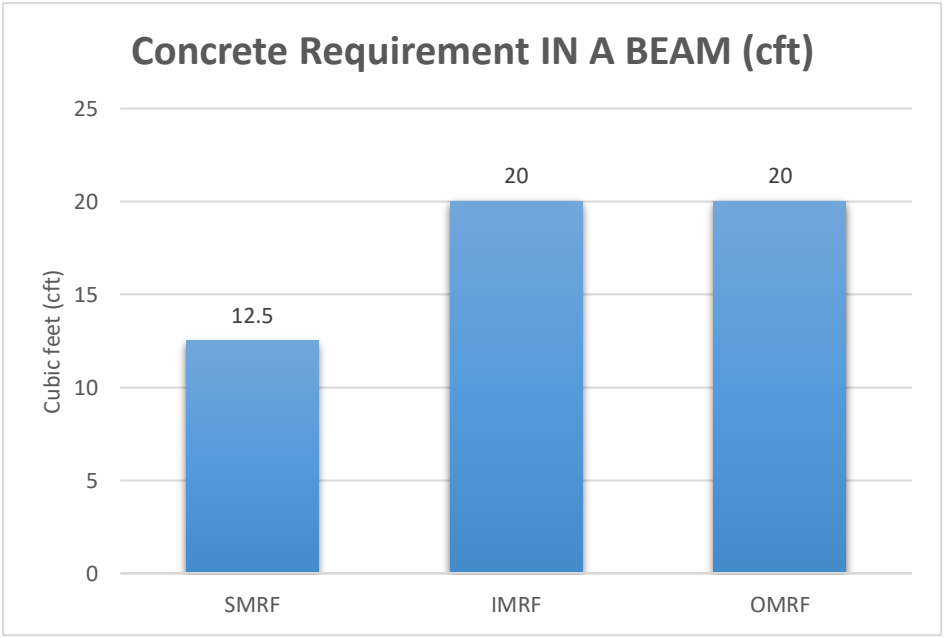


Figure 4-7: Concrete Requirement IN A BEAM (cft)

From the above bar chart, it is seen that 60% less concrete is required for a single beam of model for the SMRF system. Since the beam dimension of the SMRF system is less than OMRF and IMRF systems.

4.10 Base Shear Comparison

Base shear is an estimate of the maximum expected lateral force on the base of the structure due to seismic activity.

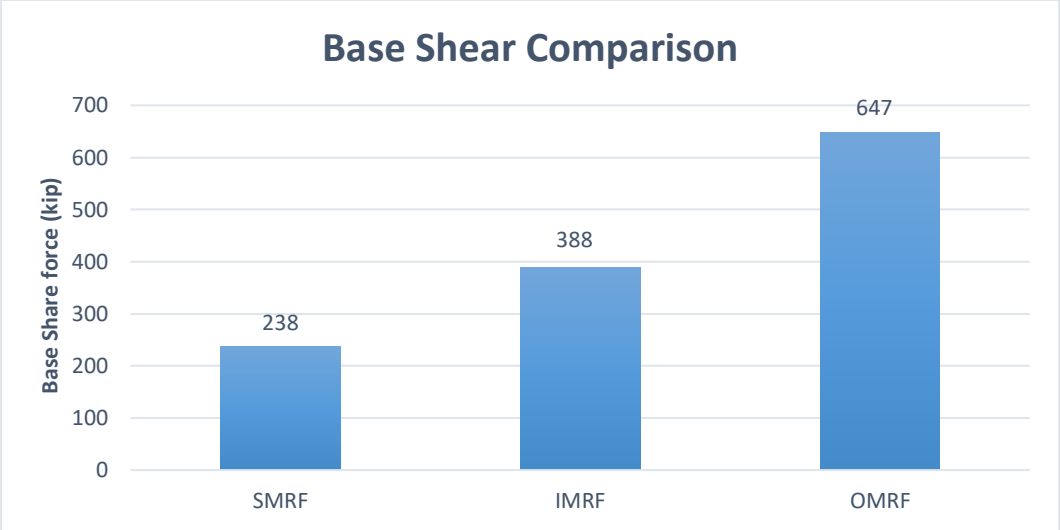


Figure 4-8: Base Shear Comparison

From the above bar chart, it can be seen that about 29% & 64% base shear can be reduced by using the SMRF system compared to IMRF and OMRF.

CHAPTER 5

Conclusions and Recommendations

5.1 General

The study compares three structural systems for earthquake design: Special Moment-Resisting Frame (SMRF), Ordinary Moment-Resisting Frame (OMRF), and Intermediate Moment-Resisting Frame (IMRF). It concludes that SMRF is more efficient in earthquake resistance than the other two systems in a specific seismic zone. SMRF exhibits lower design base shear, average displacement, and story drift compared to OMRF and IMRF.

5.2 Conclusions from the present study

- ✓ In terms of base shear, SMRF shows reductions of 64% and 29% when compared to OMRF and IMRF, respectively. The displacements in SMRF are significantly lower as well with reductions of 115% and 45% in the X direction and 136% and 42% in the Y direction, as compared to OMRF and IMRF.
- ✓ SMRF provides better structural detailing and is safer under seismic loads, leading to an extended structural lifespan due to its improved lateral load resistance. However, the SMRF system requires higher reinforcement compared to the other two systems, which may affect construction costs.
- ✓ The study highlights that OMRF exhibits the maximum displacement and drift, making it less desirable in areas prone to high seismic activity. On the other hand, SMRF structures, despite having smaller dimensions than OMRF and IMRF structures, demonstrate better resilience against lateral forces.
- ✓ In conclusion, the research establishes that the SMRF structural system outperforms OMRF and IMRF systems in terms of earthquake resistance for the specified seismic zone.

5.3 Future Scopes and Recommendations

- Other seismic zones & high-rise buildings could be introduced.
- Other types of building such as steel buildings and composite structures could be introduced.

5.4 Limitation

Only three columns (corner, exterior and interior) & only one zone on the all floor are designed. This does not represent the behavior of the full structural system.

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