SEISMIC RETROFITTING OF EXISTING BUILDINGS: X-BRACING & COLUMN JACKETING IMPLEMENTATION FOR DRIFT COMPLIANCE

Submitted by

Aburayhan Md. Jafor Mondol

A Thesis submitted to the Department of Civil Engineering, Daffodil International University in Partial Fulfillment of the Requirements for the Degree of
Bachelor of Science in Civil Engineering

Department of Civil Engineering

Daffodil International University

June 2024

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CERTIFICATION

This is to certify that this thesis entitled **"Seismic Retrofitting of Existing Buildings: X-Bracing & Column Jacketing Implementation for Drift Compliance"** is done by the following student under my direct supervision in partial fulfillment of the requirements for the degree of bachelor of science in civil engineering. The presentation of the work was held on 6th June, 2024.

Signature of the candidates

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The thesis entitled **"Seismic Retrofitting of Existing Buildings: X-Bracing & Column Jacketing Implementation for Drift Compliance"** submitted by Aburayhan Md. Jafor Mondol, ID No: #201-47-359, Session: Fall 2023 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Bachelor of Science in Civil Engineering on 6th June, 2024.

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Dedicated To,

This thesis is dedicated to my beloved family, whose unwavering love, support, and encouragement have been my guiding light throughout this journey.

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I begin by expressing my sincere gratitude to Allah, the source of all knowledge and strength, for granting me the determination and resilience to complete this thesis.

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ABSTRACT

Building safety and structural integrity are put at serious risk by seismic incidents, particularly in areas where earthquakes are common. To reduce possible damage and provide stability in these places, upgrading already-existing structures becomes an essential process. As seismic risk is taken into consider in building regulations and standards, it is becoming more and more important to adapt older structures to meet modern safety requirements. In order to achieve drift compliance in accordance with Bangladesh National Building Code (BNBC) 2020 criteria, this research focuses on the seismic retrofitting of structures built under the Bangladesh National Building Code (BNBC) 2006, with a particular focus on the application of X-bracing and column jacketing as a retrofitting approach. It is essential to assess and upgrade existing structures to bring them into compliance with the enhanced seismic safety criteria as a result of the BNBC 2020 (BNBC, 2020) replacing the BNBC 2006 (BNBC, 2006) in this regard. Retrofitting is a proactive approach to strengthening structures, ensuring their resistance to seismic difficulties, and minimizing possible damage in the event of an earthquake.

CHAPTER-1
INTRODUCTION

1.1 General

Seismic retrofitting of existing buildings is a critical aspect of ensuring structural resilience and safety in regions prone to seismic activity. This thesis delves into the application and effectiveness of various retrofitting techniques, particularly focusing on column jacketing and steel bracing, in enhancing the seismic performance of a six-story residential building located in Gazipur. By investigating these techniques and their impact on structural behavior, this study aims to provide valuable insights into strategies for fortifying existing structures against seismic forces. Through meticulous analysis and modeling using ETABS 2017 (CSI, 2017), this research endeavors to contribute to the ongoing discourse on seismic retrofitting, ultimately promoting safer and more resilient built environments.

The seismic vulnerability of structures is a critical concern, particularly in regions like Bangladesh, which experiences frequent seismic activity due to its geographical location. The BNBC 2006 (BNBC, 2006) provided a framework for construction, but advancements in seismic engineering and understanding of seismic hazards necessitated updates to the code. The BNBC 2020 (BNBC, 2020) incorporates refined criteria, reflecting enhanced insights into earthquake dynamics and the imperative to bolster structural resilience.

Building lateral displacement or movement under seismic pressures is referred to as drift, an essential characteristic in seismic design. Since excessive movement can put a building's structural integrity and functionality at risk, drift control is essential. More controlling drift restrictions are included in BNBC 2020 (BNBC, 2020), which means older structures will need to undergo retrofitting in order to comply with the updated standards.

1.2 Advantages and Disadvantages of Retrofitting Techniques

Understanding the comparative advantages and disadvantages of retrofitting techniques is crucial for informed decision-making in retrofitting projects.

1.2.1 Advantages of X-bracing

- When X-bracing is used, a structure's lateral stiffness increases significantly, which reduces the risk of lateral deformation during earthquakes.

- Considering its adaptability to various building configurations, X-bracing is appropriate for several kinds of structural layouts and designs.
- In comparison to some other retrofitting methods, X-bracing is often considered a cost-effective solution, providing substantial seismic improvements at a reasonable cost.

1.2.2 Disadvantages of X-bracing

- Existing buildings can cause difficulties for the installation of X-bracing, particularly if the retrofitting procedure requires modifying existing areas or conflicts with ongoing activities.
- Although X-bracing is an effective method for increasing lateral stiffness, its ability to withstand vertical loads may not be much increased.
- Retrofitting projects should take into consideration the building's residents' or users' perceptions of the visual impact and potential vibrations during the installation of X-bracing.

1.2.3 Advantages of Column Jacketing

- Column jacketing provides additional strength to existing columns, therefore enhancing a structure's capacity to support vertical loads.
- Structural durability depends on columns' ability to take in and distribute force during seismic incidents, which is improved by the use of jacketing materials.
- Column jacketing offers versatility for retrofitting projects because it can be applied to columns of varying sizes and forms and can be adjusted to fit any kind of structural configuration.

1.2.4 Disadvantages of Column Jacketing

- The addition of materials to column jacketing results in an increase in dead load, which may have an impact on the structure's overall ability to support loads.
- Column jacket installation requires expert labor and intensive details, which might make the retrofitting procedure more difficult.
- Although column jacketing enhances a structure's seismic performance, depending on the specific seismic susceptibility of the building, it fails to provide as much improvement as other types of retrofitting techniques.

1.3 Scope of Study

The focus of this study is on the application of X-bracing and column jacketing as a retrofitting technique. To improve a building's lateral stiffness and resistance to seismic challenges, various retrofitting techniques are followed. This study seeks to evaluate the feasibility and usefulness of this retrofitting technology by analyzing the effectiveness of X-bracing and column jacketing in attaining drift compliance with the BNBC 2020 (BNBC, 2020) regulations in a structure initially built under the BNBC 2006 standards (BNBC, 2006)

1.4 Objective of This Study

The objective of this study is to evaluate the effectiveness of X-bracing and column jacketing for achieving drift compliance with BNBC 2020 (BNBC, 2020) standards in a structure built under BNBC 2006 (BNBC, 2006).

1.5 Outline of Thesis

Chapter-1. The thesis begins with an introduction providing an overview of the research topic.

Chapter-2. This chapter reviews relevant literature to establish the theoretical framework.

Chapter-3. Explores the modeling and analysis of data or concepts, explaining the fundamental methods used.

Chapter-4. Presents the results obtained from the study and initiates a discussion around these findings.

Chapter-5. A summary of the findings is included, as well as recommendations for further study.

CHAPTER-2
LITERATURE REVIEW

2.1 Introduction

Seismic retrofitting of existing buildings is a critical aspect of structural engineering, aimed at enhancing the resilience of structures against seismic hazards. The literature review chapter serves as a foundational component of this thesis, serving as a comprehensive exploration of existing research, scholarly articles, and relevant literature on the topic of seismic retrofitting of existing buildings with a focus on X-bracing and column jacketing techniques. This chapter aims to synthesize and analyze the findings of previous studies to establish a solid theoretical framework and identify gaps in current knowledge. By reviewing key concepts, methodologies, and empirical evidence, this chapter lays the groundwork for the subsequent analysis and discussion, providing essential insights into the effectiveness, challenges, and advancements in seismic retrofitting methodologies.

2.2 Literature Review

Several studies on retrofitting reinforced concrete structures with steel components and RC column jacketing have been done recently, a few of these will be included in the following-

(J. Aguilar, 1989) This study examined 114 structures that underwent retrofitting following the 1985 earthquake in Mexico. It was found that concrete jacketing of columns was the most often utilized retrofit technique in structures under twelve stories.

(M. Rodriguez, 1991) The study on retrofitting RC buildings, more specifically the retrofit of RC columns. They concluded that one of the most effective ways to retrofit RC frames is to use steel bracing after analyzing various retrofitting techniques.

(F. Nateghi-A, 1993) Research on the use of steel braces to reinforce an eight-story residential building. The article covers the steps done to strengthen the building against vertical and lateral stresses, as well as the retrofitting techniques.

(E S Julio, 2003) The effects of steel connections, bonding chemicals, and surface preparation were examined. The study's conclusion was that longitudinal shear strength can be increased by using steel connections, especially in short RC columns. In order to provide appropriate load distribution throughout the jacketing process, temporary shoring is required when reinforcing a loaded part. It is advised to utilize high-performance concrete for increased durability, maintain gaps between slabs for continuity, and space additional reinforcement uniformly.

(Mahmoud R. Maheri, 2003) After performing a pushover analysis on the comparative research to determine the behavior factor of the braced and unbraced moment-resisting frames, they observed that the braced frame has more ductility than the unbraced frame.

(M.A. Youssef, 2006) An experimental investigation on the seismic performance of RC frames modified with concentric steel bracing was carried. Two cyclic loading experiments were performed on a braced RC frame and an RC moment-resistant frame. The study's findings demonstrated that the braced frame had more strength and appropriate ductility than the moment-resisting frame.

(A. P. Lampropoulos, 2011) According to, simulating the interface surface between old and new concrete is necessary to get an accurate prediction of the behavior of the jacketed column under monotonic or cyclic loading. This is because the assumption of a perfect bond between the jacket and the core element leads to an overestimation of the response of the jacketed column.

(A. Ismail, 2013) Using reinforced concrete jacketing, this study used nonlinear statics to assess the behavior of retrofitted reinforced concrete buildings. The analysis's findings demonstrated that the building's overall performance is enhanced in terms of ductility and lateral strength, which are related to the longer sections and the installation of longitudinal reinforcement. However, because of the strengthened structure's higher lateral stiffness, its dynamic characteristics were greatly reduced. This suggests that reinforced concrete jacketing might be a better option when lateral drifts must be kept to a minimum, as this reduces the building's overall damage.

(M. Komathi, 2015) A research group said that after jacketing the columns, the shear strength was significantly enhanced. Additionally, the concrete jacket's shear strength increased in tandem with its compressive strength. Furthermore, even though the jacket's shear strength increased due to its increased reinforcing, this did not change the load at the first shear break. Additionally, shear strength was only slightly enhanced by the presence of axial stress, and both the initial shear fracture load and the final shear crack load increased appropriately with increasing jacket thickness. Conversely, the jacket's shear strength is reduced when the tie spacing increases.

(Mohammed Hyderuddin, 2016) This work discussed the various types of bracing for retrofitting structures. They analyzed the structures after the retrofitting process and found that utilizing x-type bracing reduced drift values by 66.66% when compared to unbraced structures. While other types of bracing provide a minimal amount of axial force, X-type bracing provides the maximum amount.

(Abdul Kalam, 2017) This study examined an earthquake structure must be upgraded as it gives a greater value of deflection. This may be achieved by installing seismic dampers, which minimize drift and displacement by absorbing seismic energy during an earthquake. The study concludes that the unbounded brace, which can provide both the rigidity required to satisfy structural drift limits and a substantial and repeatable energy absorption capability, is a reliable and useful alternative for conventional framing systems in improving the earthquake resistance of both new and existing structures.

(A. Ghobarah, 2020) A research group evaluated the use of eccentric steel bracing in the retrofitting of RC frames. Two eccentric and one concentric steel bracing rehabilitation cases were examined in this study. In comparison to the concentric bracing scenario, eccentric bracing instances showed less deformation and damage when subjected to earthquake ground motions. As long as the building deformation stays below the limits that cause the maximum allowable link deformation angle, the well-designed eccentric bracing rehabilitation is expected to improve the seismic performance of the nonductile building more than the concentric bracing.

(Bharat Diliprao Daspute, 2020) This study discussed the comparative analysis conducted between retrofitting with shear walls and retrofitting with bracing. After analysis, they concluded that both retrofitting methods are advantageous as the shear wall's lateral displacement and drift value are minimal and the bracing system helps to transmit load through axial action.

2.3 Summary

The literature review chapter offers a comprehensive overview of seismic retrofitting techniques, focusing on X-bracing and column jacketing. It synthesizes findings from studies evaluating their effectiveness in enhancing structural strength and ductility. Additionally, investigations on bonding between old and new concrete highlight surface preparation's importance. This chapter identifies key considerations, challenges, and opportunities in seismic retrofitting, informing subsequent analysis and discussion to advance structural engineering knowledge and seismic resilience.

CHAPTER-3
MODELING AND ANALYSIS

3.1 Introduction

For modeling and analysis, which are essential parts of our thesis work on seismic retrofitting, we use ETABS 2017 (CSI, 2017). ETABS is an essential tool to analyze structural behavior and determine the efficiency of proposed retrofitting techniques in achieving drift. Model details are also included in this chapter. There are a few steps that must be taken in order to continue this modeling and analysis. This chapter also includes a description of them.

3.2 Details of Model

This section provides an overview of the details and specifications included in the structural model of a "six-story residential building" located in Gazipur, analyzed using ETABS 2017 (CSI, 2017). In this model, floor to floor height is 10 ft and footing to grade beam height is 17 ft. The dimensions of the balconies are 8ft by 3ft and the dimensions of the stair landings are 8ft-10 inch by 3.5 ft. Here, Fig. 3. 1 represents the plan view and Fig. 3. 2 represent the 3D view of this model.

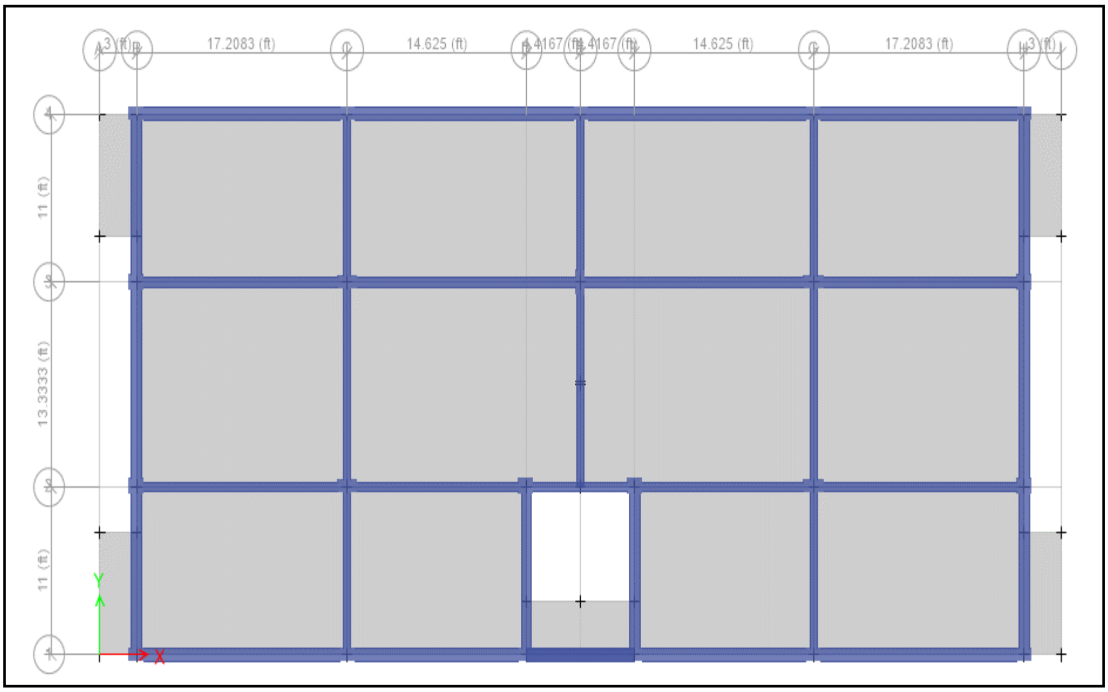


Fig. 3. 1: Typical Plan view

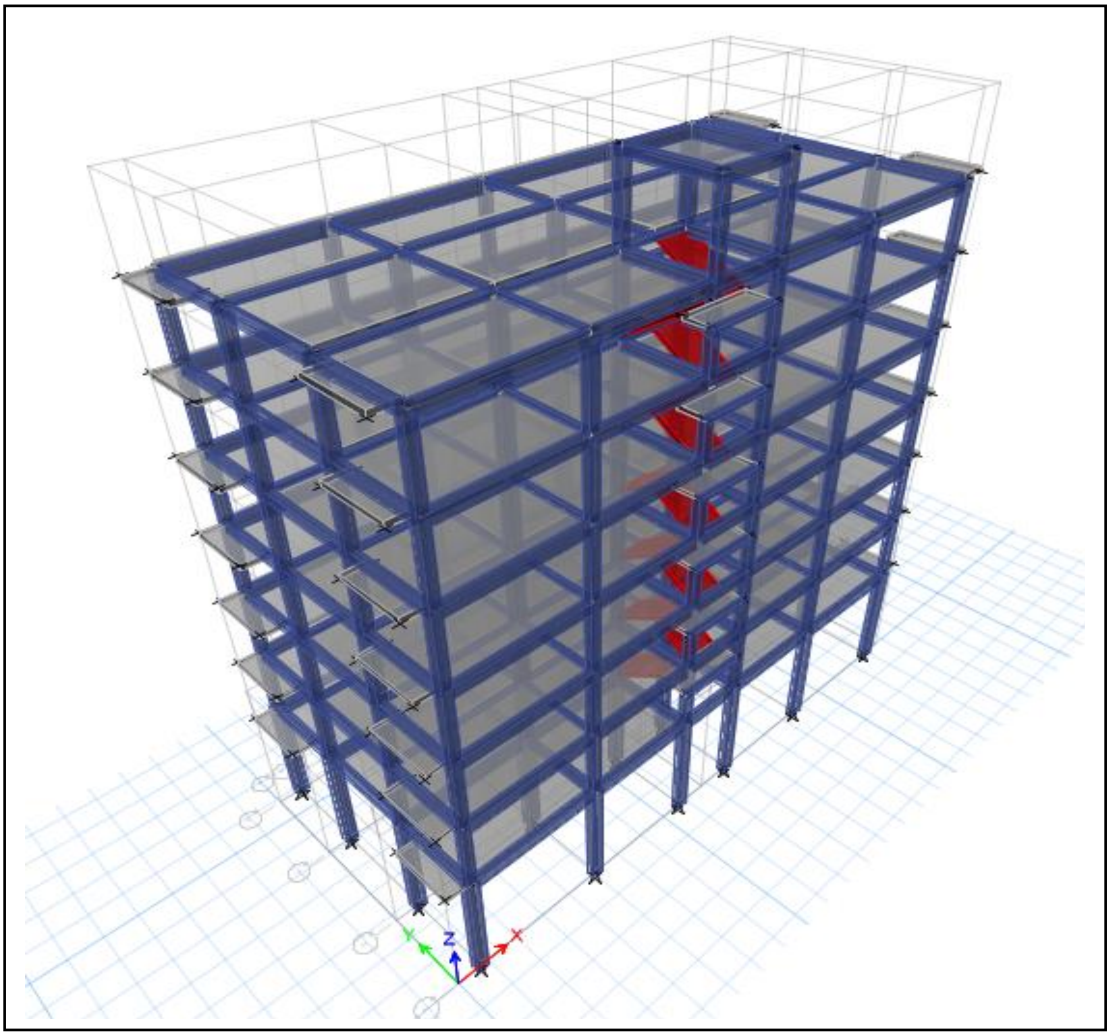


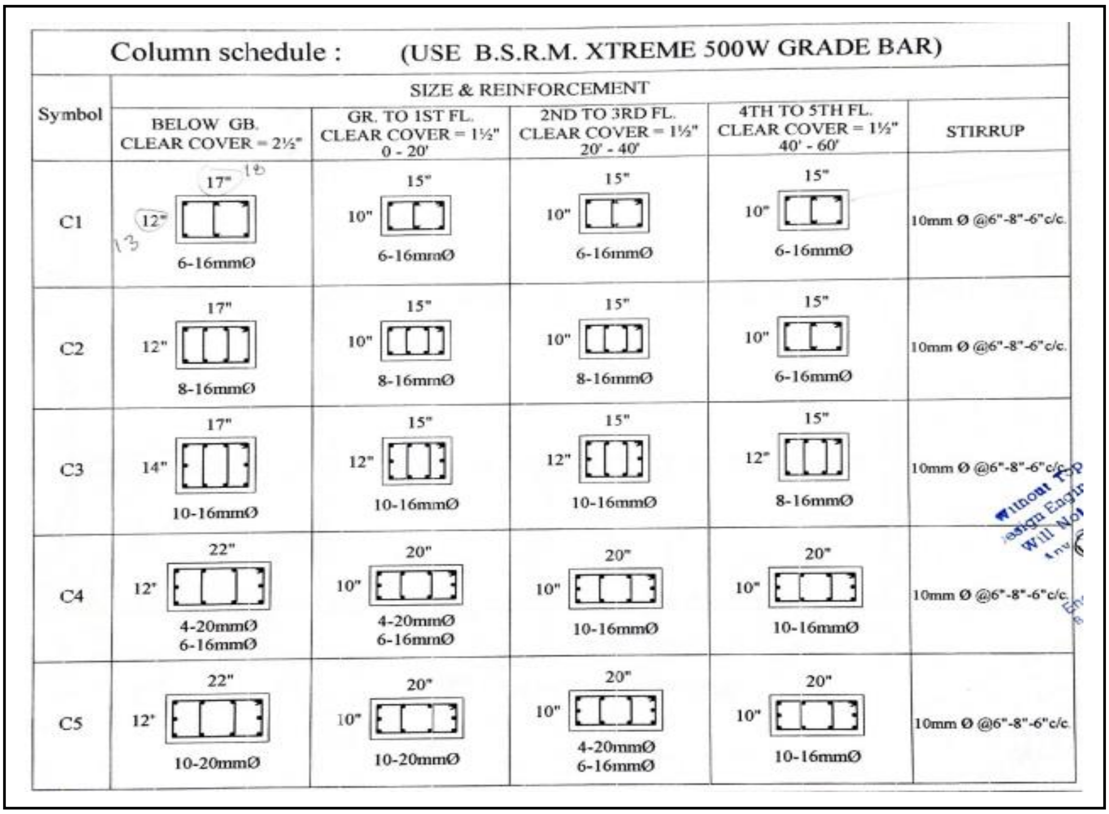
Fig. 3. 2: Typical three-dimensional view

3.2.1 Structural Components

There are several structural components that make up a building structure, and each has a specific purpose and set of criteria. Every element contributes in a unique way to maintaining the structure of the building. The structure is incomplete without them.

3.2.1.1 Column

The six-story residential building's structural framework is made up of reinforced concrete columns. These columns are the major load-bearing components, carrying the structure's whole vertical load. These columns are placed effectively on each floor to provide effective load distribution and structural integrity. In this model, there are five-types of columns and a total of 22 columns are present. Here, Fig. 3. 3 represents their dimensions and detailing and Fig. 3. 4 represents column layout.



Column schedule : (USE B.S.R.M. XTREME 500W GRADE BAR)

Symbol	SIZE & REINFORCEMENT BELOW GB. CLEAR COVER = 2½"	GR. TO 1ST FL. CLEAR COVER = 1½" 0 - 20'	2ND TO 3RD FL. CLEAR COVER = 1½" 20' - 40'	4TH TO 5TH FL. CLEAR COVER = 1½" 40' - 60'	STIRRUP
C1	17" × 12"; 6-16mmØ	15" × 10"; 6-16mmØ	15" × 10"; 6-16mmØ	15" × 10"; 6-16mmØ	10mm Ø @6"-8"-6"c/c.
C2	17" × 12"; 8-16mmØ	15" × 10"; 8-16mmØ	15" × 10"; 8-16mmØ	15" × 10"; 6-16mmØ	10mm Ø @6"-8"-6"c/c.
C3	17" × 14"; 10-16mmØ	15" × 12"; 10-16mmØ	15" × 12"; 10-16mmØ	15" × 12"; 8-16mmØ	10mm Ø @6"-8"-6"c/c.
C4	22" × 12"; 4-20mmØ, 6-16mmØ	20" × 10"; 4-20mmØ, 6-16mmØ	20" × 10"; 10-16mmØ	20" × 10"; 10-16mmØ	10mm Ø @6"-8"-6"c/c.
C5	22" × 12"; 10-20mmØ	20" × 10"; 10-20mmØ	20" × 10"; 4-20mmØ, 6-16mmØ	20" × 10"; 10-16mmØ	10mm Ø @6"-8"-6"c/c.

Fig. 3. 3: Column schedule

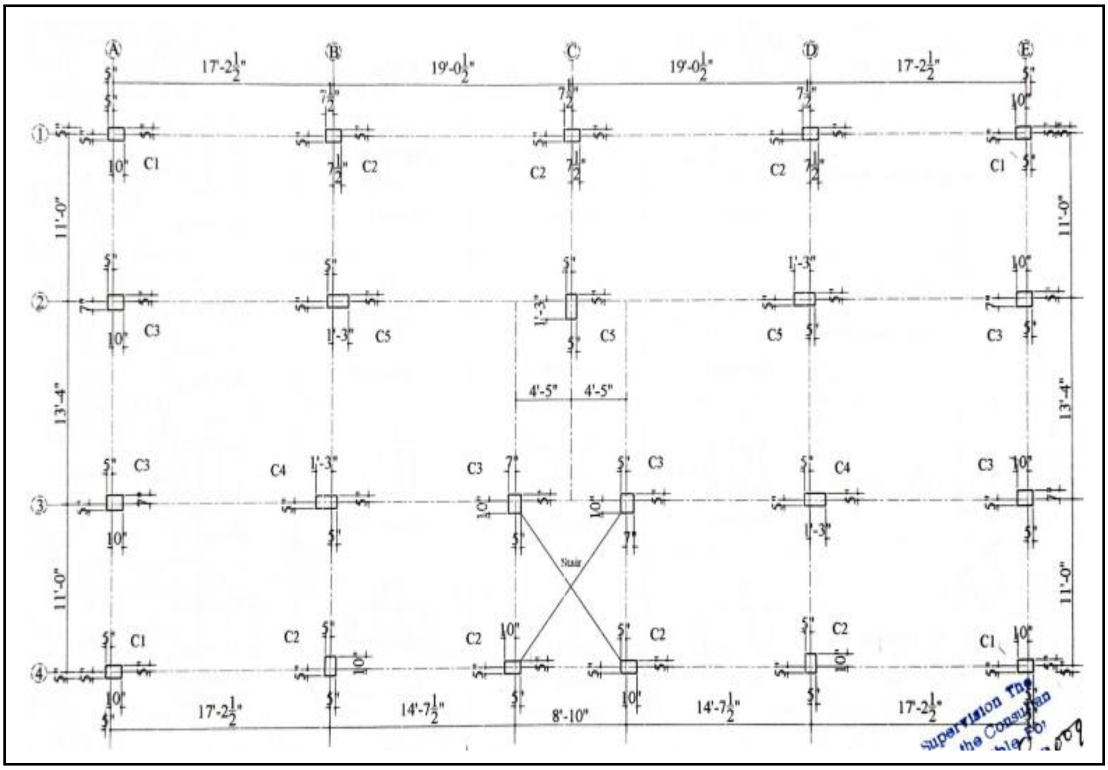


Fig. 3. 4: Column layout

3.2.1.2 Beam

Within the structural framework of the 6-storied residential building, beams are reinforced concrete beams. In this model, there are three-types of grade beam and floor beam and also a stair beam. Clear cover for grade beam is 2.5 inch and floor beam are 1.5 inch. In this Fig. 3. 5, represents dimensions and re-bar details of grade beam. Fig. 3. 6 and Fig. 3. 7 represents dimensions and re-bar details of floor beam and stair beam. Fig. 3. 8 and Fig. 3. 9 represents the layout of grade beam and floor beam.

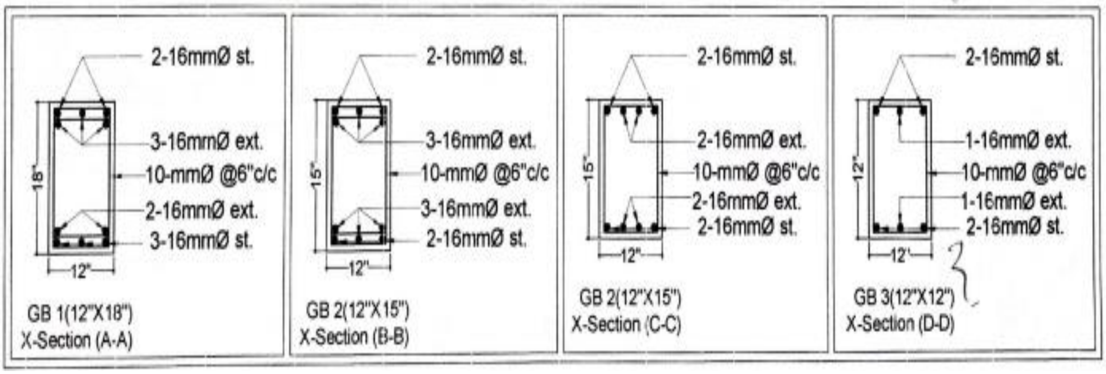


Fig. 3. 5: Section of grade beam

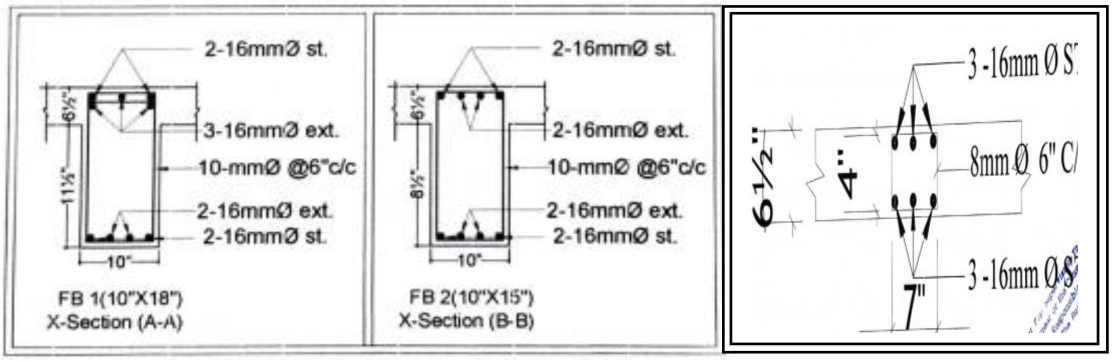


Fig. 3. 6: Section of floor beam

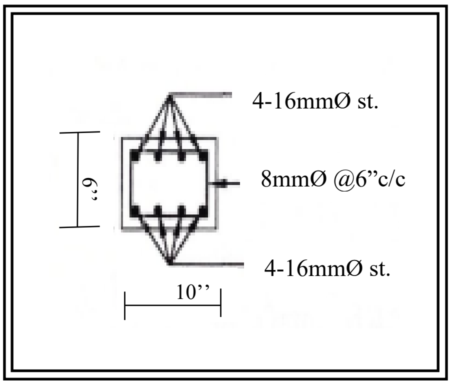


Fig. 3. 7: Section of stair beam

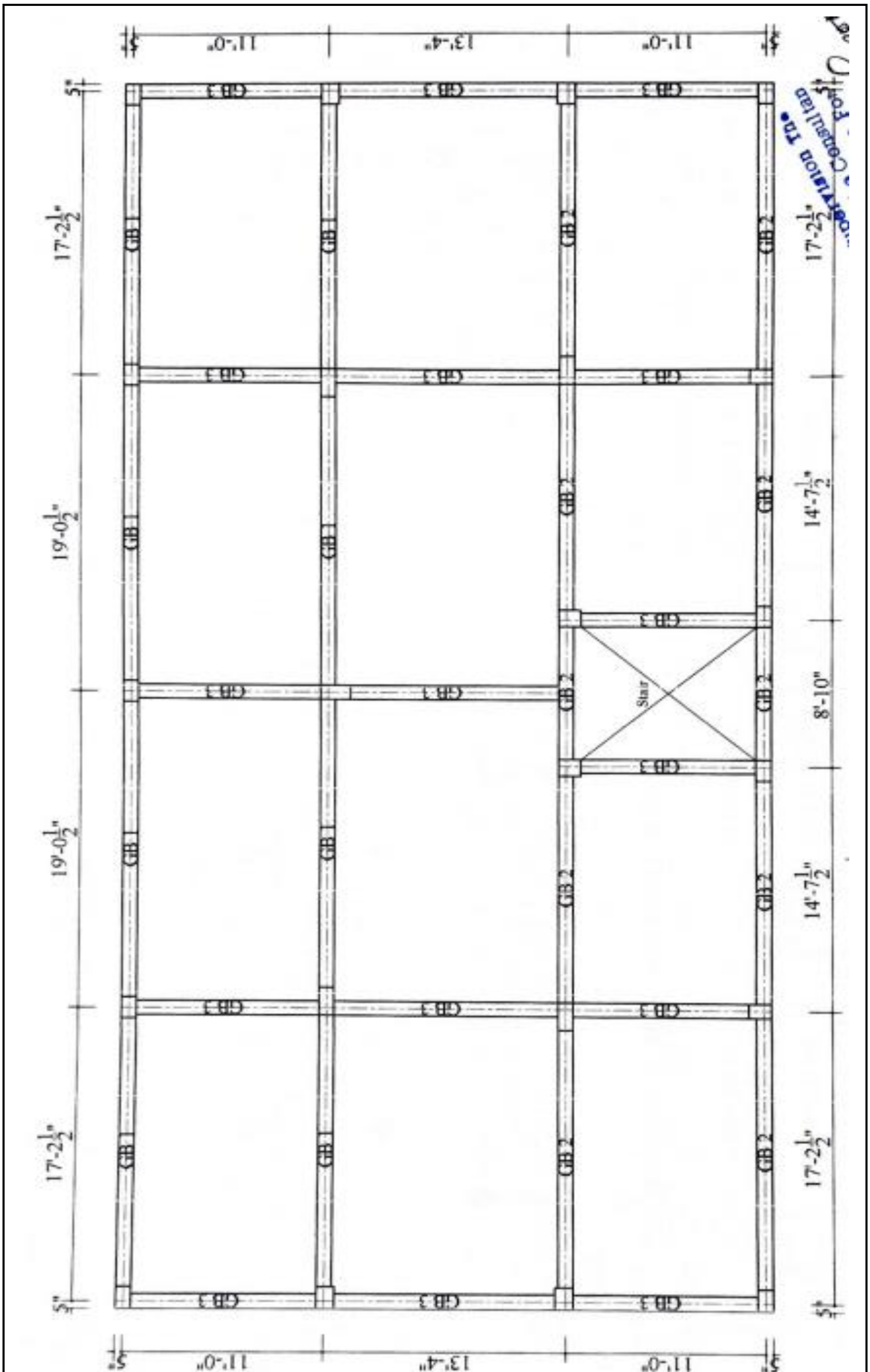


Fig. 3. 8: Grade beam layout

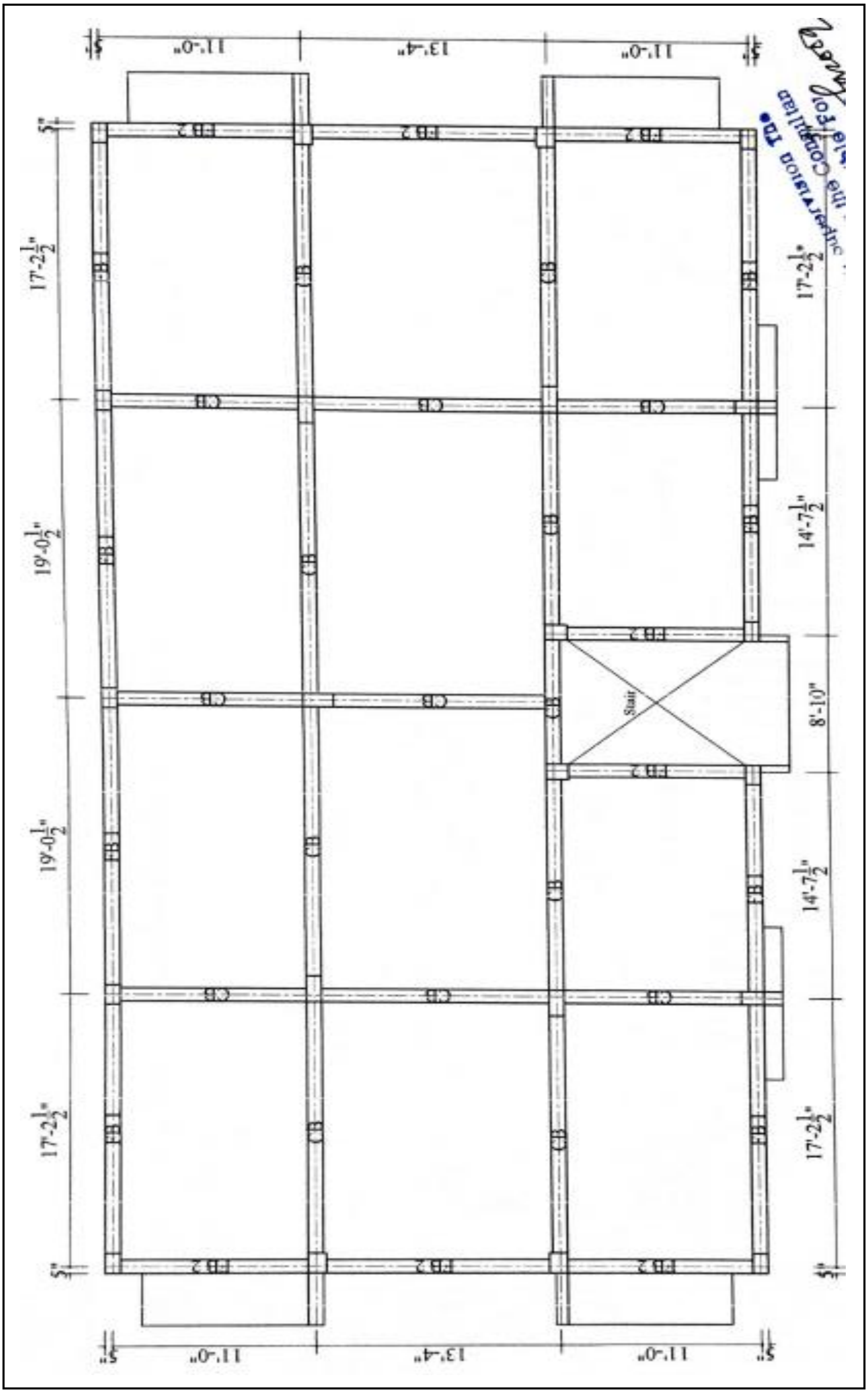


Fig. 3. 9: Floor beam layout

3.2.1.3 Slab

The structural configuration of the six-story residential building includes reinforced concrete slab. In this model, the floor slab thickness is 7 inches and the stair slab thickness is 6 inches.

3.2.2 Material Properties

In this model, the concrete component designed with a concrete compressive strength (f_c') of 4000 psi.

The model uses rebar with a minimum yield stress (F_y) of 60,000 psi and a minimum tensile strength (F_u) of 90,000 psi.

A992F_y50-grade steel has been integrated into the model for bracings, with a minimum yield stress (F_y) of 50,000 psi and a minimum tensile strength (F_u) of 65,000 psi.

3.2.3 Loading Condition

Loading conditions delves into the critical aspects of applied loads according to BNBC 2020 standards (BNBC, 2020). Understanding the magnitude and distribution of loads, including live loads, roof live loads, balcony live loads, floor finish loads, and partition wall loads, is paramount in assessing the structural response to seismic forces. This section elucidates how these loads are determined and applied, providing essential insights into the dynamic behavior of the structure under various loading scenarios.

3.2.3.1 Vertical Load

In this model, the following vertical loads are applied according to BNBC 2020 standards (BNBC, 2020): Live Load (LL) of 42 psf, Roof Live Load of 61 psf, Balcony Live Load of 61 psf, Floor Finish (FF) of 35 psf, and Partition Wall (PW) of 50 psf.

3.2.3.2 Lateral Load

Earthquake Loads are applied according to Bangladesh National Building Code 2020 (BNBC, 2020)

The earthquake load parameters for the structure, ranging from the base to Story 6, include a time period (T) of 0.891 sec and factors such as Response Modification (R) of 4.5, System Overstrength (Ω_o) of 3, Deflection Amplification (C_d) of 4, and Occupancy Importance (I) of 1. Additionally, the seismic coefficients S_s and S_1 are user-defined, with a 0.2 sec spectral acceleration (S_s) of 0.5, 1 sec spectral acceleration (S1) of 0.2, and a long-period transition period of 2 sec. The site class is classified as F, with corresponding site coefficients (F_a) of 1.15 and (F_v) of 1.725.

Wind Loads are applied according to Bangladesh National Building Code 2020 (BNBC, 2020)

For wind load considerations, exposure and pressure coefficients were determined based on the extents of diaphragms. Wind pressure coefficients in the X-direction include windward coefficients (C_{pw}) of 0.8 and leeward coefficients (C_{pl}) of 0.3, while in the Y-direction, windward coefficients (C_{pw}) are 0.8 and leeward coefficients (C_{pl}) are 0.5. Wind exposure parameters were specified with a direction angle of 0 for the X-direction and 90 for the Y-direction, and an e_1 and e_2 ratio of 0.15. Wind coefficients were determined using a wind speed of 147 mph, exposure type C, an importance factor of 1, a topographical factor (K_{zt}) of 0.85, a gust factor of 0.85, and a directionality factor (K_d) of 0.85. The exposure height ranges from the base to Story 6, with a parapet height of 3 ft.

3.2.3.3 Load Pattern

In this model, the following (Table 3. 1) load patterns have been created-

Table 3. 1: Load pattern

Load	Type	Self-weight multiplier
Dead	Dead	1
Live	Live	0
Roof live	Live	0
PW	Super dead	0
FF	Super dead	0
Ex	Seismic	0
Ey	Seismic	0
Wx	Wind	0
Wy	Wind	0
N.B. PW= Partition Wall, FF= Floor Finish, Ex= Earthquake load X direction, Ey= Earthquake load Y direction, Wx=Wind load X direction, Wy= Wind load Y direction		

3.2.3.4 Load Combination

In this model, the following (Table 3. 2) load combination have been created-

Table 3. 2: Load combination

0.9D – 1.6Wx	1.2D – 0.8Wx	1.29D + L + Ex + 0.3Ey
0.9D + 1.6Wx	1.2D + 0.8Wx	1.29D + L + Ey – 0.3Ex
0.9D – 1.6Wy	1.2D – 0.8Wy	1.29D + L + Ey + 0.3Ex
0.9D + 1.6Wy	1.2D + 0.8Wy	1.29D + L – Ex – 0.3 Ey
0.81D + Ex – 0.3Ey	1.2D + 1.6L	1.29D + L – Ex + 0.3 Ey
0.81D + Ex + 0.3Ey	1.2D + L	1.29D + L – Ey – 0.3Ex
0.81D – Ex – 0.3Ey	1.4D	1.29D + L – Ey + 0.3Ex
0.81D – Ex + 0.3Ey	1.2D + L – 1.6Wx	D + 0.5L – 0.7Wx
0.81D + Ey – 0.3Ex	1.2D + L + 1.6Wx	D + 0.5L + 0.7Wx
0.81D + Ey + 0.3Ex	1.2D + L – 1.6Wy	D + 0.5L – 0.7Wy
0.81D – Ey – 0.3Ex	1.2D + L + 1.6Wy	D + 0.5L + 0.7Wx
0.81D – Ey + 0.3Ex	1.29D + L + Ex – 0.3Ey	–
N.B. D= Dead load, L= Live load, Ex= Earthquake load X direction, Ey= Earthquake load Y direction, Wx= Wind load X direction, Wy= Wind load Y direction		

3.2.4 Support Condition

In this model, pin support is applied at the base. This support configuration allows for rotational movement at the base while restraining translational motion, simulating the flexibility of the building's foundation in response to seismic loading. By permitting rotational movement, pin supports help distribute seismic forces and mitigate the effects of ground motion on the structure, enhancing its overall stability and resilience.

3.2.5 Meshing

The "Auto Cookie Cut Object into Structural Elements" option is utilized in the floor meshing process because it easily recognizes structural elements, enhancing the accuracy of the model. A maximum element size of 18 inches was selected within this method, striking a balance between computational efficiency and the need for refined analysis. Fig. 3. 10 presents the plan view of the structure post-meshing. This view offers insights into the discretization of the structure, illustrating how the model has been divided into smaller elements for computational analysis.

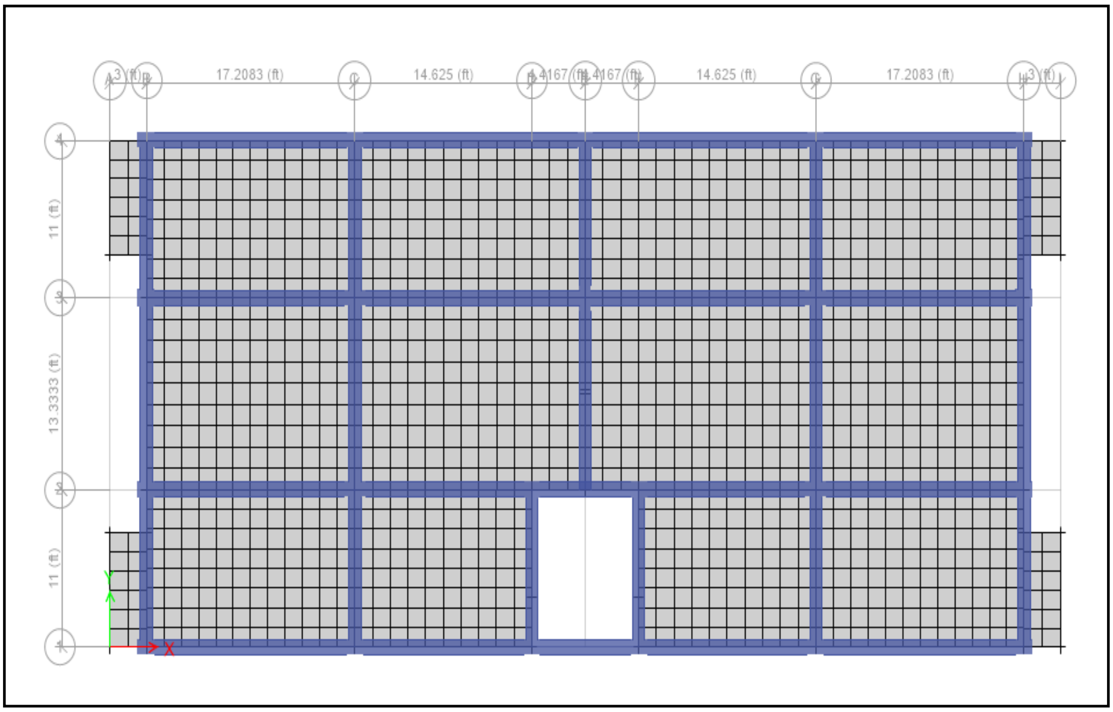


Fig. 3. 10: Plan view after mesh

3.3 Drift Ratio

The drift ratio limit value typically varies depending on the seismic zone, building type, and occupancy classification. According to BNBC 2020 (BNBC, 2020), if Δ_{max} exceeds 1.2 times Δ_{avg}, the irregularity is noted. However, if Δ_{max} surpasses 1.4 times Δ_{avg}, it is classified as extreme torsional irregularity. Fig. 3. 11 represents the limit of irregularity.

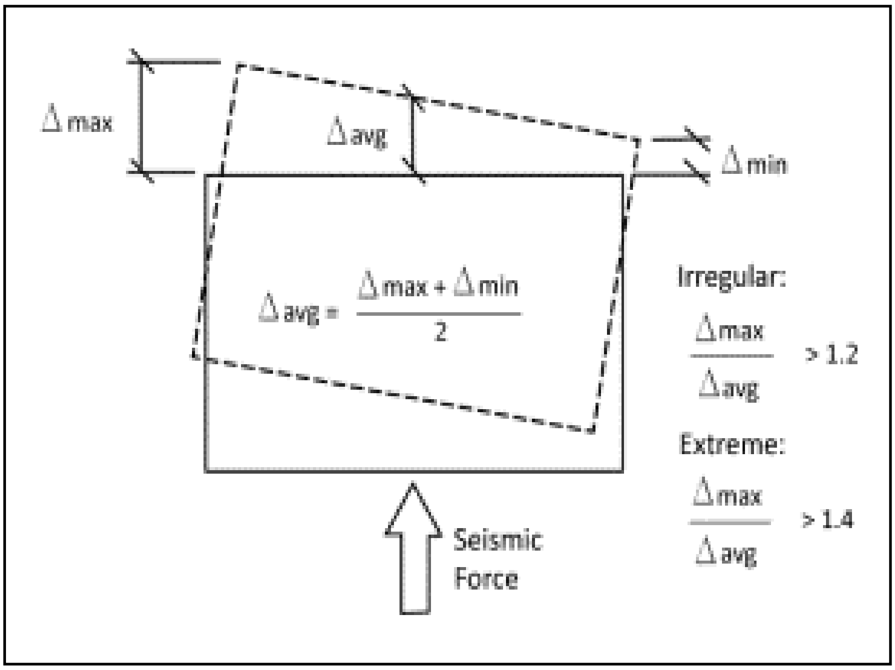


Fig. 3. 11: Torsional irregularity

3.4 Earthquake Requirements Changes: BNBC 2006 to BNBC 2020

The Bangladesh National Building Code (BNBC) 2020 introduces significant updates to earthquake-related requirements compared to BNBC 2006. Seismic zone coefficients have been updated from 0.075, 0.15, and 0.25 in BNBC 2006 (BNBC, 2006) to 0.12, 0.20, and 0.28 in BNBC 2020 (BNBC, 2020) for Zones 1, 2, and 3, respectively. Also, in BNBC 2020 an additional seismic zone, Zone 4, has been introduced with a Z value of 0.36. Occupancy factors are more detailed, maintaining values of 1.0, 1.25, and 1.5 for general, essential, and hazardous facilities, and adding 1.5 for emergency services.

Soil classifications are now detailed from Site Class A to E with specific F_a (0.7 to 1.6) and F_v (0.5 to 2.4) coefficients, unlike the broader categories in BNBC 2006. BNBC 2020 also expands exposure categories to include various ground conditions from hard rock to soft soil.

Seismic load calculations have evolved from the simpler BNBC 2006 formula V=ZIW to more comprehensive methodologies in BNBC 2020, such as the Response Spectrum Method, with the updated formula $V = \frac{ZIW}{R} S_a$. The response modification factor (R) now covers a broader range to reflect different structural systems' performance.

3.5 Retrofitting Techniques

Two primary techniques are applied in the structure of the "six-story residential building's" seismic retrofitting: Column jacketing and X-bracing. For the purpose of strengthening the structure against seismic forces, improving its overall durability, and ensuring that it complies with modern safety standards, these retrofitting techniques are systematically implemented.

3.5.1 X-Bracings

In this model, the following bracings (Table 3. 3) have been selected for the purpose of the trial from the AISC manual (AISC, 2016)-

Table 3. 3: Bracing properties

Section	d (inch)	b_f (inch)	t_f (inch)	t_w (inch)
W36×441	38.9	17.0	2.44	1.36
W36×182	36.3	12.1	1.18	0.725
W27×84	26.7	10.0	0.640	0.460
W21×68	21.1	8.27	0.685	0.430
W16×26	15.7	5.50	0.345	0.250
W14×26	13.9	5.03	0.420	0.255
W12×14	11.9	3.97	0.225	0.200
W10×45	10.1	8.02	0.620	0.350
W10×12	9.87	3.96	0.210	0.190
W8×10	7.89	3.94	0.205	0.170

3.5.2 Column Jacketing

Column jacketing is employed to reinforce specific columns, addressing vulnerabilities and augmenting load-bearing capacity. The retrofitting process involves encasing existing columns with additional materials, typically steel or reinforced concrete, to enhance their structural integrity. The selection of jacketing materials aligns with the properties of the original column materials, ensuring seamless integration.

The primary modification involved increasing the column size by 2.5 inches on each side. The jacketing portion of the columns was executed with meticulous attention to detail, utilizing materials with properties matching those of the main column. This included the incorporation of the same type of material properties and an equivalent number of reinforced steels, ensuring uniformity and consistency in structural performance across the retrofitting elements. Fig. 3. 12 represents the typical RC column jacketing.

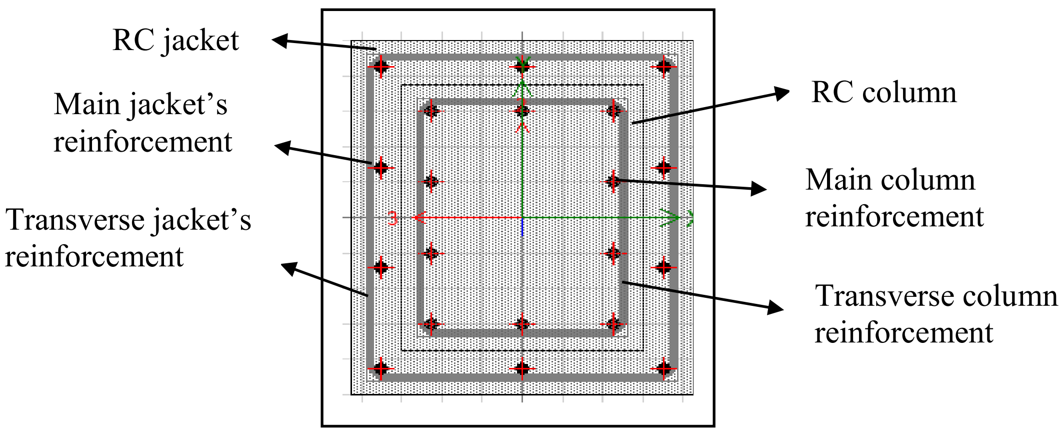


Fig. 3. 12: Typical RC column jacketing

3.6 Summary

The third chapter concentrates on modeling and analysis, which are essential components of our seismic retrofitting thesis work. The chapter begins with an introduction to the use of ETABS 2017 (CSI, 2017) for modeling and analysis purposes. It then delves into the details of the structural model of a six-story residential building in Gazipur, highlighting key specifications such as floor heights, column types, beam details, slab thickness, and material properties. The loading conditions, including vertical and lateral loads, are thoroughly discussed, adhering to BNBC 2020 (BNBC, 2020) standards. Support conditions, meshing techniques, and the computation of drift ratios are also addressed. Additionally, retrofitting techniques, namely X-bracings and column jacketing, are introduced, providing insight into their implementation and properties.

CHAPTER-4
RESULT AND DISCUSSION

4.1 Introduction

The "Results and Discussion" chapter delves into the findings and insights obtained from the seismic retrofitting analysis of the six-storied residential building located in Gazipur, employing X-bracing and column jacketing techniques. This pivotal section provides a detailed examination of the structural performance, retrofitting efficacy, and implications for seismic resilience. By analyzing the results, this chapter offers valuable insights into the effectiveness of the retrofitting strategies and their implications for enhancing structural safety in seismic-prone regions.

4.2 Existing Building Evaluation

Finally, after finishing every procedure reached the analysis stage. Following the analysis, find out drift ratio tables from ETABS 2017 (CSI, 2017). According to BNBC 2020 (BNBC, 2020) the allowable drift ratio is less than 1.2. And the following load combinations are being used to check the drift ratio-

- Ex
- Ey
- D+0.5L+0.7Wx
- D+0.5L-0.7Wx
- D+0.5L+0.7Wy
- D+0.5L-0.7Wy

4.2.1 Drift Ratio Without Applying Retrofitting Techniques

Table 4. 1, represents the maximum and average drift ratios for different load cases and directions in a six-storied residential building without applying any kind of retrofitting techniques. The drift ratios are calculated based on the application of various loads, including seismic loads, and are compared against the allowable drift ratio specified by BNBC 2020 (BNBC, 2020). Values exceeding the allowable drift ratio stipulated by BNBC 2020, highlighted in red. (BNBC, 2020)

Table 4. 1: Story Max/Avg Drifts (No bracings and column jacketing)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.089	Story4	D+0.5L+0.7Wx	1.112
Stair Roof	Ey	1.006	Story4	D+0.5L+0.7Wx	2.687
Stair Roof	D+0.5L-0.7Wx	1.138	Story4	D+0.5L+0.7Wy	1.004
Stair Roof	D+0.5L-0.7Wx	1.104	Story3	Ex	1.139
Stair Roof	D+0.5L-0.7Wy	1.029	Story3	Ey	1.006
Stair Roof	D+0.5L+0.7Wx	1.035	Story3	D+0.5L-0.7Wx	1.141
Stair Roof	D+0.5L+0.7Wx	1.022	Story3	D+0.5L-0.7Wx	3.819
Stair Roof	D+0.5L+0.7Wy	1.005	Story3	D+0.5L-0.7Wy	1
Story6	Ex	1.037	Story3	D+0.5L+0.7Wx	1.134
Story6	Ey	1.003	Story3	D+0.5L+0.7Wx	3.86
Story6	D+0.5L-0.7Wx	1.047	Story3	D+0.5L+0.7Wy	1.003
Story6	D+0.5L-0.7Wx	1.326	Story2	Ex	1.162
Story6	D+0.5L-0.7Wy	1.002	Story2	Ey	1.006
Story6	D+0.5L+0.7Wx	1.038	Story2	D+0.5L-0.7Wx	1.169
Story6	D+0.5L+0.7Wx	1.265	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L+0.7Wy	1.004	Story2	D+0.5L+0.7Wx	1.161
Story5	Ex	1.09	Story2	D+0.5L+0.7Wy	1.003
Story5	Ey	1.006	Story1	Ex	1.141
Story5	D+0.5L-0.7Wx	1.089	Story1	Ey	1.012
Story5	D+0.5L-0.7Wx	1.896	Story1	D+0.5L-0.7Wx	1.146
Story5	D+0.5L-0.7Wy	1.002	Story1	D+0.5L-0.7Wy	1.008
Story5	D+0.5L+0.7Wx	1.082	Story1	D+0.5L+0.7Wx	1.14
Story5	D+0.5L+0.7Wx	1.869	Story1	D+0.5L+0.7Wy	1.01
Story5	D+0.5L+0.7Wy	1.006	GF	Ex	1.035
Story4	Ex	1.119	GF	Ey	1.005
Story4	Ey	1.008	GF	D+0.5L-0.7Wx	1.037
Story4	D+0.5L-0.7Wx	1.119	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wx	2.684	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L-0.7Wy	1.001	GF	D+0.5L+0.7Wy	1.002

4.2 Existing Building Retrofit with X-Bracings

a) I choose the W36×441 bracing for this trial. Table 4. 2, represents the maximum and average drift ratios for different load cases and directions in a six-storied residential building applying W36×441 bracings. I applied this bracing in between stories 2, 3, 4 and 5 at elevation 4 at positions between 4B, 4C and 4G, 4H. After applying this bracing, we observe that the drift ratio in this trial exceeds the drift ratio observed before without applying any retrofitting technique.

Table 4. 2: Story Max/Avg Drifts (Applying W36×441 bracing)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.095	Story4	D+0.5L+0.7Wx	3.184
Stair Roof	Ey	1.006	Story4	D+0.5L+0.7Wy	1.006
Stair Roof	D+0.5L-0.7Wx	1.153	Story3	Ex	1.454
Stair Roof	D+0.5L-0.7Wx	1.09	Story3	Ey	1.005
Stair Roof	D+0.5L-0.7Wy	1.029	Story3	D+0.5L-0.7Wx	1.463
Stair Roof	D+0.5L+0.7Wx	1.027	Story3	D+0.5L-0.7Wx	4.103
Stair Roof	D+0.5L+0.7Wx	1.013	Story3	D+0.5L-0.7Wy	1
Stair Roof	D+0.5L+0.7Wy	1.005	Story3	D+0.5L+0.7Wx	1.47
Story6	Ex	1.012	Story3	D+0.5L+0.7Wx	4.397
Story6	Ey	1.004	Story3	D+0.5L+0.7Wy	1.005
Story6	D+0.5L-0.7Wx	1.003	Story2	Ex	1.144
Story6	D+0.5L-0.7Wx	1.014	Story2	Ey	1.005
Story6	D+0.5L-0.7Wy	1.001	Story2	D+0.5L-0.7Wx	1.134
Story6	D+0.5L+0.7Wx	1.007	Story2	D+0.5L-0.7Wx	3.467
Story6	D+0.5L+0.7Wx	1.033	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L+0.7Wy	1.004	Story2	D+0.5L+0.7Wx	1.126
Story5	Ex	1.262	Story2	D+0.5L+0.7Wx	3.507
Story5	Ey	1.009	Story2	D+0.5L+0.7Wy	1.003
Story5	D+0.5L-0.7Wx	1.272	Story1	Ex	1.162
Story5	D+0.5L-0.7Wx	2.301	Story1	Ey	1.012
Story5	D+0.5L-0.7Wy	1.005	Story1	D+0.5L-0.7Wx	1.148
Story5	D+0.5L+0.7Wx	1.277	Story1	D+0.5L-0.7Wy	1.008
Story5	D+0.5L+0.7Wx	2.373	Story1	D+0.5L+0.7Wx	1.142
Story5	D+0.5L+0.7Wy	1.008	Story1	D+0.5L+0.7Wy	1.009
Story4	Ex	1.36	GF	Ex	1.053
Story4	Ey	1.008	GF	Ey	1.005
Story4	D+0.5L-0.7Wx	1.365	GF	D+0.5L-0.7Wx	1.037
Story4	D+0.5L-0.7Wx	3.061	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wy	1.003	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L+0.7Wx	1.37	GF	D+0.5L+0.7Wy	1.002

b) In this trial, I choose the W36×182 bracing. Table 4. 3, represents the maximum and average drift ratios for different load cases and directions in a six-storied residential building applying W36×182 bracings in different location. I applied this bracing in between stories 3, 4 and 5 at elevations B and H, at positions between 3B, 4B and 3H, 4H. Also at elevation 4, I applied it at positions between 4B, 4C and 4G, 4H. From the positions described above where the W36×182 bracing was applied, we observe that, at two positions on story 6 where no bracing was applied, according to BNBC 2020 (BNBC, 2020)the drift ratio exceeded 1.2. However, the drift ratio at those two positions has decreased to less than 1.2. compared to before, and the drift ratio at other positions has decreased significantly as well. Values exceeding the allowable drift ratio stipulated by BNBC 2020, highlighted in red. We need a bracing system such that upon application, all drift ratios for the targeted load combinations are less than 1.2. Additionally, for this purpose, bracing of different sizes will be applied to other positions to conduct further trials.

Table 4. 3: Story Max/Avg Drifts (Applying W36×182 bracings)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.091	Story4	D+0.5L+0.7Wy	1.005
Stair Roof	Ey	1.007	Story3	Ex	1.126
Stair Roof	D+0.5L-0.7Wx	1.149	Story3	Ey	1.008
Stair Roof	D+0.5L-0.7Wx	1.097	Story3	D+0.5L-0.7Wx	1.119
Stair Roof	D+0.5L-0.7Wy	1.039	Story3	D+0.5L-0.7Wx	3.038
Stair Roof	D+0.5L+0.7Wx	1.022	Story3	D+0.5L-0.7Wy	1.002
Stair Roof	D+0.5L+0.7Wx	1.012	Story3	D+0.5L+0.7Wx	1.112
Stair Roof	D+0.5L+0.7Wy	1.007	Story3	D+0.5L+0.7Wx	3.137
Story6	Ex	1.018	Story3	D+0.5L+0.7Wy	1.005
Story6	Ey	1.001	Story2	Ex	1.175
Story6	D+0.5L-0.7Wx	1.001	Story2	Ey	1.006
Story6	D+0.5L-0.7Wx	1.005	Story2	D+0.5L-0.7Wx	1.173
Story6	D+0.5L-0.7Wy	1.003	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L+0.7Wx	1.009	Story2	D+0.5L+0.7Wx	1.165
Story6	D+0.5L+0.7Wx	1.055	Story2	D+0.5L+0.7Wy	1.003
Story6	D+0.5L+0.7Wy	1.002	Story1	Ex	1.152
Story5	Ex	1.265	Story1	Ey	1.012
Story5	Ey	1.007	Story1	D+0.5L-0.7Wx	1.148
Story5	D+0.5L-0.7Wx	1.266	Story1	D+0.5L-0.7Wy	1.008
Story5	D+0.5L-0.7Wy	1.005	Story1	D+0.5L+0.7Wx	1.143
Story5	D+0.5L+0.7Wx	1.262	Story1	D+0.5L+0.7Wy	1.01
Story5	D+0.5L+0.7Wy	1.004	GF	Ex	1.044
Story4	Ex	1.26	GF	Ey	1.005
Story4	Ey	1.008	GF	D+0.5L-0.7Wx	1.037
Story4	D+0.5L-0.7Wx	1.261	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wy	1.006	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L+0.7Wx	1.257	GF	D+0.5L+0.7Wy	1.002

c) I choose the W21×68 bracing for another trial. Table 4. 4, represents the maximum and average drift ratios for different load cases in a six-storied residential building applying W21×68 bracings. I applied this bracing in between stories 3, 4 and 5 at elevations B and H, at positions between 2B, 3B and 2H, 3H. Values exceeding the allowable drift ratio stipulated by BNBC 2020 (BNBC, 2020), highlighted in red. Upon applying the W21×68 bracing at the positions described above, we observe that for only one load combinations of stories 6, the drift ratio exceeds 1.2 (BNBC, 2020). Further trials are necessary to reduce the drift ratio.

Table 4. 4: Story Max/Avg Drifts (Applying W21×68 bracings)

Story	Load Case/Combo	Ratio	Story	Load Case/Combo	Ratio
Stair Roof	Ex	1.09	Story4	D+0.5L+0.7Wx	1.016
Stair Roof	Ey	1.007	Story4	D+0.5L+0.7Wy	1.006
Stair Roof	D+0.5L-0.7Wx	1.138	Story3	Ex	1.125
Stair Roof	D+0.5L-0.7Wx	1.112	Story3	Ey	1.008
Stair Roof	D+0.5L-0.7Wy	1.046	Story3	D+0.5L-0.7Wx	1.128
Stair Roof	D+0.5L+0.7Wx	1.035	Story3	D+0.5L-0.7Wy	1.001
Stair Roof	D+0.5L+0.7Wx	1.024	Story3	D+0.5L+0.7Wx	1.121
Stair Roof	D+0.5L+0.7Wy	1.009	Story3	D+0.5L+0.7Wy	1.005
Story6	Ex	1.016	Story2	Ex	1.16
Story6	Ey	1	Story2	Ey	1.006
Story6	D+0.5L-0.7Wx	1.029	Story2	D+0.5L-0.7Wx	1.167
Story6	D+0.5L-0.7Wx	1.24	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L-0.7Wy	1.006	Story2	D+0.5L+0.7Wx	1.159
Story6	D+0.5L+0.7Wx	1.02	Story2	D+0.5L+0.7Wy	1.004
Story6	D+0.5L+0.7Wx	1.169	Story1	Ex	1.14
Story6	D+0.5L+0.7Wy	1.002	Story1	Ey	1.012
Story5	Ex	1.022	Story1	D+0.5L-0.7Wx	1.145
Story5	Ey	1.003	Story1	D+0.5L-0.7Wy	1.008
Story5	D+0.5L-0.7Wx	1.024	Story1	D+0.5L+0.7Wx	1.139
Story5	D+0.5L-0.7Wy	1.004	Story1	D+0.5L+0.7Wy	1.01
Story5	D+0.5L+0.7Wx	1.017	GF	Ex	1.035
Story5	D+0.5L+0.7Wy	1.006	GF	Ey	1.005
Story4	Ex	1.02	GF	D+0.5L-0.7Wx	1.037
Story4	Ey	1.004	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wx	1.021	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L-0.7Wy	1.003	GF	D+0.5L+0.7Wy	1.002

d) I choose the W16×26 bracing for this trial. Table 4. 5, represents the maximum and average drift ratios for different load cases in a six-storied residential building applying W16×26 bracings. I applied this bracing at the same positions as the previous trials. From this table we observe that we observe that for only one load combinations of stories 6, the drift ratio exceeds 1.2 (BNBC, 2020). We need more trials.

Table 4. 5: Story Max/Avg Drifts (Applying W16×26 bracings)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.09	Story4	D+0.5L+0.7Wx	1.023
Stair Roof	Ey	1.007	Story4	D+0.5L+0.7Wy	1.006
Stair Roof	D+0.5L-0.7Wx	1.138	Story3	Ex	1.126
Stair Roof	D+0.5L-0.7Wx	1.111	Story3	Ey	1.008
Stair Roof	D+0.5L-0.7Wy	1.043	Story3	D+0.5L-0.7Wx	1.129
Stair Roof	D+0.5L+0.7Wx	1.035	Story3	D+0.5L-0.7Wy	1.001
Stair Roof	D+0.5L+0.7Wx	1.024	Story3	D+0.5L+0.7Wx	1.122
Stair Roof	D+0.5L+0.7Wy	1.008	Story3	D+0.5L+0.7Wy	1.004
Story6	Ex	1.017	Story2	Ex	1.16
Story6	Ey	1	Story2	Ey	1.006
Story6	D+0.5L-0.7Wx	1.03	Story2	D+0.5L-0.7Wx	1.167
Story6	D+0.5L-0.7Wx	1.242	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L-0.7Wy	1.005	Story2	D+0.5L+0.7Wx	1.159
Story6	D+0.5L+0.7Wx	1.021	Story2	D+0.5L+0.7Wy	1.004
Story6	D+0.5L+0.7Wx	1.173	Story1	Ex	1.14
Story6	D+0.5L+0.7Wy	1.002	Story1	Ey	1.012
Story5	Ex	1.025	Story1	D+0.5L-0.7Wx	1.145
Story5	Ey	1.003	Story1	D+0.5L-0.7Wy	1.008
Story5	D+0.5L-0.7Wx	1.027	Story1	D+0.5L+0.7Wx	1.139
Story5	D+0.5L-0.7Wy	1.004	Story1	D+0.5L+0.7Wy	1.01
Story5	D+0.5L+0.7Wx	1.02	GF	Ex	1.035
Story5	D+0.5L+0.7Wy	1.006	GF	Ey	1.005
Story4	Ex	1.027	GF	D+0.5L-0.7Wx	1.037
Story4	Ey	1.005	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wx	1.028	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L-0.7Wy	1.002	GF	D+0.5L+0.7Wy	1.002

e) I choose the W12×14 bracing for this trial. Table 4. 6, represents the maximum and average drift ratios for different load cases in a six-storied residential building after applying W12×14 bracing. Again, I applied this bracing at the same positions as the previous trials. From this table we observe that according to BNBC 2020 (BNBC, 2020)for only two load combinations of stories 5 and 6, the drift ratio exceeds 1.2 (BNBC, 2020). Further trials are necessary to reduce the drift ratio values below 1.2 (BNBC, 2020) for all cases.

Table 4. 6: Story Max/Avg Drifts (Applying W12×14 bracings)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.09	Story4	D+0.5L+0.7Wx	1.031
Stair Roof	Ey	1.007	Story4	D+0.5L+0.7Wy	1.005
Stair Roof	D+0.5L-0.7Wx	1.138	Story3	Ex	1.128
Stair Roof	D+0.5L-0.7Wx	1.11	Story3	Ey	1.008
Stair Roof	D+0.5L-0.7Wy	1.041	Story3	D+0.5L-0.7Wx	1.13
Stair Roof	D+0.5L+0.7Wx	1.035	Story3	D+0.5L-0.7Wy	1.001
Stair Roof	D+0.5L+0.7Wx	1.023	Story3	D+0.5L+0.7Wx	1.123
Stair Roof	D+0.5L+0.7Wy	1.008	Story3	D+0.5L+0.7Wy	1.004
Story6	Ex	1.019	Story2	Ex	1.16
Story6	Ey	1.001	Story2	Ey	1.006
Story6	D+0.5L-0.7Wx	1.031	Story2	D+0.5L-0.7Wx	1.167
Story6	D+0.5L-0.7Wx	1.246	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L-0.7Wy	1.005	Story2	D+0.5L+0.7Wx	1.159
Story6	D+0.5L+0.7Wx	1.022	Story2	D+0.5L+0.7Wy	1.004
Story6	D+0.5L+0.7Wx	1.178	Story1	Ex	1.14
Story6	D+0.5L+0.7Wy	1.002	Story1	Ey	1.012
Story5	Ex	1.029	Story1	D+0.5L-0.7Wx	1.145
Story5	Ey	1.003	Story1	D+0.5L-0.7Wy	1.008
Story5	D+0.5L-0.7Wx	1.03	Story1	D+0.5L+0.7Wx	1.139
Story5	D+0.5L-0.7Wx	1.674	Story1	D+0.5L+0.7Wy	1.01
Story5	D+0.5L-0.7Wy	1.003	GF	Ex	1.035
Story5	D+0.5L+0.7Wx	1.024	GF	Ey	1.005
Story5	D+0.5L+0.7Wy	1.005	GF	D+0.5L-0.7Wx	1.037
Story4	Ex	1.035	GF	D+0.5L-0.7Wy	1.001
Story4	Ey	1.006	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L-0.7Wx	1.036	GF	D+0.5L+0.7Wy	1.002
Story4	D+0.5L-0.7Wy	1.001			

f) Again, I choose the W12×14 bracing for another trial. Table 4. 7, represents the maximum and average drift ratios for different load cases in a six-storied residential building after applying W12×14 bracings. But this time I applied the bracing in different positions. I applied this bracing in between stories 3, 4 and 5 at elevations B and H, at positions between 2B, 3B and 2H, 3H. And between stories 5, 6 at positions between 1B, 2B and 3B, 4B and at elevation H, in corresponding positions to those of elevation B. Also, I applied this bracing in between stories 6 and stair roof at elevations F, at positions between 1F and 2F. Upon applying the W12×14 bracing at the positions described above, we observe that there are no highlighted areas in this table. From this, we can infer that the drift ratio is less than 1.2 (BNBC, 2020) for all load combinations.

Table 4. 7: Story Max/Avg Drifts (Applying W12×14 bracings)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.038	Story4	D+0.5L+0.7Wx	1.031
Stair Roof	Ex	1.158	Story4	D+0.5L+0.7Wy	1.005
Stair Roof	Ey	1.027	Story3	Ex	1.128
Stair Roof	D+0.5L-0.7Wx	1.101	Story3	Ey	1.008
Stair Roof	D+0.5L-0.7Wx	1.1	Story3	D+0.5L-0.7Wx	1.13
Stair Roof	D+0.5L-0.7Wy	1.004	Story3	D+0.5L-0.7Wy	1.001
Stair Roof	D+0.5L-0.7Wy	1.001	Story3	D+0.5L+0.7Wx	1.123
Stair Roof	D+0.5L+0.7Wx	1.034	Story3	D+0.5L+0.7Wy	1.004
Stair Roof	D+0.5L+0.7Wx	1.022	Story2	Ex	1.16
Stair Roof	D+0.5L+0.7Wy	1.035	Story2	Ey	1.006
Story6	Ex	1.004	Story2	D+0.5L-0.7Wx	1.167
Story6	Ey	1.001	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L-0.7Wx	1.01	Story2	D+0.5L+0.7Wx	1.159
Story6	D+0.5L-0.7Wy	1.007	Story2	D+0.5L+0.7Wy	1.003
Story6	D+0.5L+0.7Wx	1.004	Story1	Ex	1.14
Story6	D+0.5L+0.7Wy	1.005	Story1	Ey	1.012
Story5	Ex	1.028	Story1	D+0.5L-0.7Wx	1.145
Story5	Ey	1.003	Story1	D+0.5L-0.7Wy	1.008
Story5	D+0.5L-0.7Wx	1.029	Story1	D+0.5L+0.7Wx	1.139
Story5	D+0.5L-0.7Wy	1.003	Story1	D+0.5L+0.7Wy	1.01
Story5	D+0.5L+0.7Wx	1.023	GF	Ex	1.035
Story5	D+0.5L+0.7Wy	1.006	GF	Ey	1.005
Story4	Ex	1.035	GF	D+0.5L-0.7Wx	1.037
Story4	Ey	1.006	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wx	1.036	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L-0.7Wy	1.001	GF	D+0.5L+0.7Wy	1.002

g) In this trial, I choose the W10×12 bracing. Table 4. 8, represents the maximum and average drift ratios for different load cases in a six-storied residential building after applying W10×12 bracings. I applied this bracing at the same positions as the fifth trial. Despite this bracing being smaller in size than the previous bracing, we can observe that there are no highlighted areas in this table as well.

Table 4. 8: Story Max/Avg Drifts (Applying W10×12 bracing)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.039	Story4	D+0.5L+0.7Wy	1.005
Stair Roof	Ex	1.165	Story3	Ex	1.128
Stair Roof	Ey	1.025	Story3	Ey	1.007
Stair Roof	D+0.5L-0.7Wx	1.102	Story3	D+0.5L-0.7Wx	1.13
Stair Roof	D+0.5L-0.7Wx	1.1	Story3	D+0.5L-0.7Wy	1.001
Stair Roof	D+0.5L-0.7Wy	1.002	Story3	D+0.5L+0.7Wx	1.124
Stair Roof	D+0.5L+0.7Wx	1.033	Story3	D+0.5L+0.7Wy	1.004
Stair Roof	D+0.5L+0.7Wx	1.021	Story2	Ex	1.16
Stair Roof	D+0.5L+0.7Wy	1.033	Story2	Ey	1.006
Story6	Ex	1.005	Story2	D+0.5L-0.7Wx	1.167
Story6	Ey	1.001	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L-0.7Wx	1.011	Story2	D+0.5L+0.7Wx	1.159
Story6	D+0.5L-0.7Wy	1.006	Story2	D+0.5L+0.7Wy	1.003
Story6	D+0.5L+0.7Wx	1.005	Story1	Ex	1.14
Story6	D+0.5L+0.7Wy	1.005	Story1	Ey	1.012
Story5	Ex	1.03	Story1	D+0.5L-0.7Wx	1.145
Story5	Ey	1.003	Story1	D+0.5L-0.7Wy	1.008
Story5	D+0.5L-0.7Wx	1.031	Story1	D+0.5L+0.7Wx	1.14
Story5	D+0.5L-0.7Wy	1.003	Story1	D+0.5L+0.7Wy	1.01
Story5	D+0.5L+0.7Wx	1.024	GF	Ex	1.035
Story5	D+0.5L+0.7Wy	1.006	GF	Ey	1.005
Story4	Ex	1.038	GF	D+0.5L-0.7Wx	1.037
Story4	Ey	1.006	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wx	1.039	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L-0.7Wy	1.001	GF	D+0.5L+0.7Wy	1.002
Story4	D+0.5L+0.7Wx	1.034			

4.3 Existing Building Retrofit with Column Jacketing

a) Table 4. 9, represents the maximum and average drift ratios for different load cases in a six-storied residential building after applying column jacketing. Values exceeding the allowable drift ratio stipulated by BNBC 2020 (BNBC, 2020), highlighted in red. For this trial, I applied column jacketing from top to bottom on the C3 columns at elevations B and H. As a result, we observe that for two specific load combinations in story 3, where no retrofitting technique was applied, the drift ratio, which initially exceeded 1.2 (BNBC, 2020), has decreased to less than 1.2. Further trials are necessary to reduce the drift ratio values below 1.2 (BNBC, 2020) for all cases.

Table 4. 9: Story Max/Avg Drifts (Applying column jacketing on C3 column, Ele-B, H)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.092	Story4	D+0.5L-0.7Wy	1.009
Stair Roof	Ey	1.006	Story4	D+0.5L+0.7Wx	1.077
Stair Roof	D+0.5L-0.7Wx	1.142	Story4	D+0.5L+0.7Wx	2.358
Stair Roof	D+0.5L-0.7Wx	1.107	Story4	D+0.5L+0.7Wy	1.01
Stair Roof	D+0.5L-0.7Wy	1.037	Story3	Ex	1.095
Stair Roof	D+0.5L+0.7Wx	1.033	Story3	Ey	1.013
Stair Roof	D+0.5L+0.7Wx	1.02	Story3	D+0.5L-0.7Wx	1.096
Stair Roof	D+0.5L+0.7Wy	1.008	Story3	D+0.5L-0.7Wy	1.009
Story6	Ex	1.036	Story3	D+0.5L+0.7Wx	1.093
Story6	Ey	1.011	Story3	D+0.5L+0.7Wy	1.01
Story6	D+0.5L-0.7Wx	1.038	Story2	Ex	1.11
Story6	D+0.5L-0.7Wx	1.334	Story2	Ey	1.014
Story6	D+0.5L-0.7Wy	1.009	Story2	D+0.5L-0.7Wx	1.115
Story6	D+0.5L+0.7Wx	1.036	Story2	D+0.5L-0.7Wy	1.01
Story6	D+0.5L+0.7Wx	1.32	Story2	D+0.5L+0.7Wx	1.111
Story6	D+0.5L+0.7Wy	1.009	Story2	D+0.5L+0.7Wy	1.012
Story5	Ex	1.061	Story1	Ex	1.091
Story5	Ey	1.012	Story1	Ey	1.016
Story5	D+0.5L-0.7Wx	1.061	Story1	D+0.5L-0.7Wx	1.094
Story5	D+0.5L-0.7Wx	1.713	Story1	D+0.5L-0.7Wy	1.013
Story5	D+0.5L-0.7Wy	1.01	Story1	D+0.5L+0.7Wx	1.091
Story5	D+0.5L+0.7Wx	1.058	Story1	D+0.5L+0.7Wy	1.014
Story5	D+0.5L+0.7Wx	1.715	GF	Ex	1.03
Story5	D+0.5L+0.7Wy	1.011	GF	Ey	1.006
Story4	Ex	1.08	GF	D+0.5L-0.7Wx	1.031
Story4	Ey	1.013	GF	D+0.5L-0.7Wy	1.003
Story4	D+0.5L-0.7Wx	1.08	GF	D+0.5L+0.7Wx	1.03
Story4	D+0.5L-0.7Wx	2.312	GF	D+0.5L+0.7Wy	1.003

b) Table 4. 10, represents the maximum and average drift ratios for different load cases in a six-storied residential building after applying column jacketing. Values exceeding the allowable drift ratio stipulated by BNBC 2020 (BNBC, 2020), highlighted in red. In this trial, I applied column jacketing from top to bottom on the C1 and C3 columns at elevations B and H. Also, I applied column jacketing from top to bottom on the C2 columns at elevations 1 and 4, at positions 1C, 1G and 4C, 4G. As a result, we observe that the drift ratios marked in red have decreased compared to before. We need to take more trial with applying column jacketing to other positions.

Table 4. 10: Story Max/Avg Drifts (Applying column. jacketing on C1, C2, C3 column, Ele-B, H, 1 and 4)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.116	Story4	D+0.5L-0.7Wy	1.008
Stair Roof	Ey	1.006	Story4	D+0.5L+0.7Wx	1.073
Stair Roof	D+0.5L-0.7Wx	1.173	Story4	D+0.5L+0.7Wx	2.2
Stair Roof	D+0.5L-0.7Wx	1.102	Story4	D+0.5L+0.7Wy	1.012
Stair Roof	D+0.5L-0.7Wy	1.04	Story3	Ex	1.092
Stair Roof	D+0.5L+0.7Wx	1.048	Story3	Ey	1.013
Stair Roof	D+0.5L+0.7Wx	1.023	Story3	D+0.5L-0.7Wx	1.096
Stair Roof	D+0.5L+0.7Wy	1.008	Story3	D+0.5L-0.7Wy	1.008
Story6	Ex	1.04	Story3	D+0.5L+0.7Wx	1.088
Story6	Ey	1.011	Story3	D+0.5L+0.7Wy	1.012
Story6	D+0.5L-0.7Wx	1.047	Story2	Ex	1.105
Story6	D+0.5L-0.7Wx	1.379	Story2	Ey	1.013
Story6	D+0.5L-0.7Wy	1.005	Story2	D+0.5L-0.7Wx	1.112
Story6	D+0.5L+0.7Wx	1.033	Story2	D+0.5L-0.7Wy	1.009
Story6	D+0.5L+0.7Wx	1.272	Story2	D+0.5L+0.7Wx	1.104
Story6	D+0.5L+0.7Wy	1.013	Story2	D+0.5L+0.7Wy	1.013
Story5	Ex	1.061	Story1	Ex	1.08
Story5	Ey	1.012	Story1	Ey	1.015
Story5	D+0.5L-0.7Wx	1.064	Story1	D+0.5L-0.7Wx	1.083
Story5	D+0.5L-0.7Wx	1.699	Story1	D+0.5L-0.7Wy	1.011
Story5	D+0.5L-0.7Wy	1.008	Story1	D+0.5L+0.7Wx	1.078
Story5	D+0.5L+0.7Wx	1.054	Story1	D+0.5L+0.7Wy	1.013
Story5	D+0.5L+0.7Wx	1.619	GF	Ex	1.026
Story5	D+0.5L+0.7Wy	1.013	GF	Ey	1.006
Story4	Ex	1.079	GF	D+0.5L-0.7Wx	1.027
Story4	Ey	1.013	GF	D+0.5L-0.7Wy	1.003
Story4	D+0.5L-0.7Wx	1.081	GF	D+0.5L+0.7Wx	1.026
Story4	D+0.5L-0.7Wx	2.254	GF	D+0.5L+0.7Wy	1.003

c) Table 4. 11, represents the maximum and average drift ratios for different load cases in a six-storied residential building after applying column jacketing. For this trial, I applied column jacketing from top to bottom on the C3 columns at elevations B and H. Also, I applied column jacketing from top to bottom on the C2 columns at elevation 4, at positions 4C and 4G. Upon applying the column jacketing at the positions described above, we observe that there are no highlighted areas in this table. From this, we can infer that the drift ratio is less than 1.2 (BNBC, 2020) for all load combinations.

Table 4. 11: Story Max/Avg Drifts (Applying column. jacketing on C2, C3 column, Ele-B, H and 4)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.089	Story4	D+0.5L+0.7Wy	1.004
Stair Roof	Ey	1.006	Story3	Ex	1.084
Stair Roof	D+0.5L-0.7Wx	1.142	Story3	Ey	1.006
Stair Roof	D+0.5L-0.7Wx	1.12	Story3	D+0.5L-0.7Wx	1.085
Stair Roof	D+0.5L-0.7Wy	1.033	Story3	D+0.5L-0.7Wy	1
Stair Roof	D+0.5L+0.7Wx	1.027	Story3	D+0.5L+0.7Wx	1.08
Stair Roof	D+0.5L+0.7Wx	1.019	Story3	D+0.5L+0.7Wy	1.003
Stair Roof	D+0.5L+0.7Wy	1.008	Story2	Ex	1.104
Story6	Ex	1.009	Story2	Ey	1.006
Story6	Ey	1.003	Story2	D+0.5L-0.7Wx	1.109
Story6	D+0.5L-0.7Wx	1.012	Story2	D+0.5L-0.7Wy	1.001
Story6	D+0.5L-0.7Wy	1.001	Story2	D+0.5L+0.7Wx	1.103
Story6	D+0.5L+0.7Wx	1.005	Story2	D+0.5L+0.7Wy	1.004
Story6	D+0.5L+0.7Wy	1.004	Story1	Ex	1.085
Story5	Ex	1.043	Story1	Ey	1.009
Story5	Ey	1.005	Story1	D+0.5L-0.7Wx	1.086
Story5	D+0.5L-0.7Wx	1.041	Story1	D+0.5L-0.7Wy	1.005
Story5	D+0.5L-0.7Wy	1.002	Story1	D+0.5L+0.7Wx	1.082
Story5	D+0.5L+0.7Wx	1.036	Story1	D+0.5L+0.7Wy	1.007
Story5	D+0.5L+0.7Wy	1.005	GF	Ex	1.006
Story4	Ex	1.067	GF	Ey	1.004
Story4	Ey	1.007	GF	D+0.5L-0.7Wx	1.004
Story4	D+0.5L-0.7Wx	1.065	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wy	1.001	GF	D+0.5L+0.7Wx	1.003
Story4	D+0.5L+0.7Wx	1.06	GF	D+0.5L+0.7Wy	1.002

4.4 Summary

This chapter includes a full description of all of the gathered results from the analysis performed in the study, as well as a detailed explanation of any prevalent pattern in the data collected. The chapter is divided into many sections, each of which presents a concise summary of a particular study outcome. Tables have been formed in sets based on the information obtained from ETABS analysis.

CHAPTER-5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The retrofitting of existing buildings to enhance seismic resilience is a critical endeavor, particularly in regions prone to seismic activity. In this study, two distinct retrofitting techniques were evaluated: X-Bracing and Column Jacketing. Each technique was applied in separate trials, with drift ratios measured across various load combinations to assess effectiveness. The analysis performed using ETABS 2017 software.

Notable findings obtained from this analysis are as follows:

- **i.** According to BNBC 2020, for few load combinations in stories 3, 4, 5, and 6 of the existing building, the drift ratio exceeds 1.2.

- **ii.** Based on the presented results of the tables in chapter-4, it's evident that the retrofitting techniques have effectiveness in reducing the drift ratios of the building.

- **iii.** In the case of larger-sized bracing, it is observed that in few load combination, the drift ratio is higher.

- **iv.** This study conducted several trials by applying bracings of different sizes at various positions to retrofit the structure by using X-bracing. Among these trials, the W10×12 bracing seems to be the most effective, as it consistently keeps the drift ratios below the allowable limit of 1.2 for all load combinations.

- **v.** In the case of column jacketing, increasing the size of Column 2 and Column 3 by 2.5 inches on each side and providing reinforcement in the jacketed portion similar to the previous column resulted in the most favorable outcome.

In conclusion, the findings underscore the effectiveness of both X-Bracing and Column Jacketing as viable retrofitting strategies for reducing drift ratios in existing buildings. By implementing robust retrofitting strategies such as X-Bracing and Column Jacketing, engineers and policymakers can bolster the structural integrity of buildings and enhance overall community resilience to seismic hazards.

5.2 Future Recommendation

While this thesis focuses on the application of X-bracing and column jacketing, future research could explore the use of-

i. Investigate the effectiveness of Fiber Reinforced Polymer (FRP) wrapping as an independent retrofitting technique for existing buildings, focusing on its ability to enhance structural integrity and resilience.

ii. Assess the feasibility of implementing base isolation systems as a seismic retrofitting strategy to mitigate the impact of seismic forces on existing buildings, considering factors such as cost-effectiveness and practicality.

iii. Conduct research on damping devices such as tuned mass dampers to determine their applicability and effectiveness in retrofitting existing buildings for improved seismic performance and vibration control.

iv. Explore the potential benefits of incorporating external post-tensioning systems into existing buildings to augment lateral stiffness and enhance overall structural stability, particularly in high seismic risk areas.

v. Evaluate the feasibility and advantages of integrating shear walls or concrete infills as retrofitting measures to bolster lateral stability and mitigate the effects of seismic forces on existing buildings, considering both technical and economic factors.

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APPENDIX

The trials conducted for this thesis are illustrated in the following tables-

Table A. 1: Story Max/Avg Drifts (Applying W27×84 bracing at elev. B, H)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.089	Story4	D+0.5L+0.7Wx	1.015
Stair Roof	Ey	1.007	Story4	D+0.5L+0.7Wy	1.006
Stair Roof	D+0.5L-0.7Wx	1.138	Story3	Ex	1.125
Stair Roof	D+0.5L-0.7Wx	1.112	Story3	Ey	1.008
Stair Roof	D+0.5L-0.7Wy	1.046	Story3	D+0.5L-0.7Wx	1.128
Stair Roof	D+0.5L+0.7Wx	1.035	Story3	D+0.5L-0.7Wy	1.001
Stair Roof	D+0.5L+0.7Wx	1.024	Story3	D+0.5L+0.7Wx	1.121
Stair Roof	D+0.5L+0.7Wy	1.009	Story3	D+0.5L+0.7Wy	1.005
Story6	Ex	1.016	Story2	Ex	1.16
Story6	Ey	1	Story2	Ey	1.006
Story6	D+0.5L-0.7Wx	1.029	Story2	D+0.5L-0.7Wx	1.167
Story6	D+0.5L-0.7Wx	1.239	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L-0.7Wy	1.006	Story2	D+0.5L+0.7Wx	1.159
Story6	D+0.5L+0.7Wx	1.02	Story2	D+0.5L+0.7Wy	1.004
Story6	D+0.5L+0.7Wx	1.168	Story1	Ex	1.14
Story6	D+0.5L+0.7Wy	1.002	Story1	Ey	1.012
Story5	Ex	1.022	Story1	D+0.5L-0.7Wx	1.145
Story5	Ey	1.003	Story1	D+0.5L-0.7Wy	1.008
Story5	D+0.5L-0.7Wx	1.023	Story1	D+0.5L+0.7Wx	1.139
Story5	D+0.5L-0.7Wy	1.004	Story1	D+0.5L+0.7Wy	1.01
Story5	D+0.5L+0.7Wx	1.017	GF	Ex	1.035
Story5	D+0.5L+0.7Wy	1.006	GF	Ey	1.005
Story4	Ex	1.019	GF	D+0.5L-0.7Wx	1.037
Story4	Ey	1.004	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wx	1.02	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L-0.7Wy	1.003	GF	D+0.5L+0.7Wy	1.002

Table A. 2: Story Max/Avg Drifts (Applying W14×26 bracing at elev. B, H)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.09	Story4	D+0.5L+0.7Wx	1.023
Stair Roof	Ey	1.007	Story4	D+0.5L+0.7Wy	1.006
Stair Roof	D+0.5L-0.7Wx	1.138	Story3	Ex	1.126
Stair Roof	D+0.5L-0.7Wx	1.111	Story3	Ey	1.008
Stair Roof	D+0.5L-0.7Wy	1.043	Story3	D+0.5L-0.7Wx	1.129
Stair Roof	D+0.5L+0.7Wx	1.035	Story3	D+0.5L-0.7Wy	1.001
Stair Roof	D+0.5L+0.7Wx	1.024	Story3	D+0.5L+0.7Wx	1.122
Stair Roof	D+0.5L+0.7Wy	1.008	Story3	D+0.5L+0.7Wy	1.004
Story6	Ex	1.017	Story2	Ex	1.16
Story6	Ey	1	Story2	Ey	1.006
Story6	D+0.5L-0.7Wx	1.03	Story2	D+0.5L-0.7Wx	1.167
Story6	D+0.5L-0.7Wx	1.242	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L-0.7Wy	1.005	Story2	D+0.5L+0.7Wx	1.159
Story6	D+0.5L+0.7Wx	1.021	Story2	D+0.5L+0.7Wy	1.004
Story6	D+0.5L+0.7Wx	1.173	Story1	Ex	1.14
Story6	D+0.5L+0.7Wy	1.002	Story1	Ey	1.012
Story5	Ex	1.025	Story1	D+0.5L-0.7Wx	1.145
Story5	Ey	1.003	Story1	D+0.5L-0.7Wy	1.008
Story5	D+0.5L-0.7Wx	1.027	Story1	D+0.5L+0.7Wx	1.139
Story5	D+0.5L-0.7Wy	1.004	Story1	D+0.5L+0.7Wy	1.01
Story5	D+0.5L+0.7Wx	1.02	GF	Ex	1.035
Story5	D+0.5L+0.7Wy	1.006	GF	Ey	1.005
Story4	Ex	1.027	GF	D+0.5L-0.7Wx	1.037
Story4	Ey	1.005	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wx	1.028	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L-0.7Wy	1.002	GF	D+0.5L+0.7Wy	1.002

Table A. 3: Story Max/Avg Drifts (Applying W10×12 at elev. B, H)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.089	Story4	D+0.5L+0.7Wy	1.005
Stair Roof	Ey	1.002	Story3	Ex	1.128
Stair Roof	D+0.5L-0.7Wx	1.139	Story3	Ey	1.007
Stair Roof	D+0.5L-0.7Wx	1.12	Story3	D+0.5L-0.7Wx	1.13
Stair Roof	D+0.5L-0.7Wy	1.559	Story3	D+0.5L-0.7Wy	1.001
Stair Roof	D+0.5L-0.7Wy	1.052	Story3	D+0.5L+0.7Wx	1.124
Stair Roof	D+0.5L+0.7Wx	1.033	Story3	D+0.5L+0.7Wy	1.004
Stair Roof	D+0.5L+0.7Wx	1.023	Story2	Ex	1.16
Stair Roof	D+0.5L+0.7Wy	1.014	Story2	Ey	1.006
Story6	Ex	1.005	Story2	D+0.5L-0.7Wx	1.167
Story6	Ey	1.001	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L-0.7Wx	1.011	Story2	D+0.5L+0.7Wx	1.159
Story6	D+0.5L-0.7Wy	1.006	Story2	D+0.5L+0.7Wy	1.003
Story6	D+0.5L+0.7Wx	1.005	Story1	Ex	1.14
Story6	D+0.5L+0.7Wy	1.005	Story1	Ey	1.012
Story5	Ex	1.03	Story1	D+0.5L-0.7Wx	1.145
Story5	Ey	1.003	Story1	D+0.5L-0.7Wy	1.008
Story5	D+0.5L-0.7Wx	1.031	Story1	D+0.5L+0.7Wx	1.14
Story5	D+0.5L-0.7Wy	1.003	Story1	D+0.5L+0.7Wy	1.01
Story5	D+0.5L+0.7Wx	1.024	GF	Ex	1.035
Story5	D+0.5L+0.7Wy	1.006	GF	Ey	1.005
Story4	Ex	1.038	GF	D+0.5L-0.7Wx	1.037
Story4	Ey	1.006	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wx	1.039	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L-0.7Wy	1.001	GF	D+0.5L+0.7Wy	1.002
Story4	D+0.5L+0.7Wx	1.034			

Table A. 4: Story Max/Avg Drifts (Applying W16×26 bracing at elev. B, H and F)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.035	Story4	D+0.5L+0.7Wx	1.023
Stair Roof	Ex	1.14	Story4	D+0.5L+0.7Wy	1.006
Stair Roof	Ey	1.033	Story3	Ex	1.126
Stair Roof	D+0.5L-0.7Wx	1.1	Story3	Ey	1.008
Stair Roof	D+0.5L-0.7Wx	1.101	Story3	D+0.5L-0.7Wx	1.129
Stair Roof	D+0.5L-0.7Wy	1.07	Story3	D+0.5L-0.7Wy	1.001
Stair Roof	D+0.5L-0.7Wy	1.007	Story3	D+0.5L+0.7Wx	1.122
Stair Roof	D+0.5L+0.7Wx	1.038	Story3	D+0.5L+0.7Wy	1.004
Stair Roof	D+0.5L+0.7Wx	1.024	Story2	Ex	1.16
Stair Roof	D+0.5L+0.7Wy	1.039	Story2	Ey	1.006
Story6	Ex	1.002	Story2	D+0.5L-0.7Wx	1.167
Story6	Ey	1.001	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L-0.7Wx	1.007	Story2	D+0.5L+0.7Wx	1.159
Story6	D+0.5L-0.7Wy	1.008	Story2	D+0.5L+0.7Wy	1.004
Story6	D+0.5L+0.7Wx	1.002	Story1	Ex	1.14
Story6	D+0.5L+0.7Wy	1.007	Story1	Ey	1.012
Story5	Ex	1.024	Story1	D+0.5L-0.7Wx	1.145
Story5	Ey	1.003	Story1	D+0.5L-0.7Wy	1.008
Story5	D+0.5L-0.7Wx	1.026	Story1	D+0.5L+0.7Wx	1.139
Story5	D+0.5L-0.7Wy	1.004	Story1	D+0.5L+0.7Wy	1.01
Story5	D+0.5L+0.7Wx	1.019	GF	Ex	1.035
Story5	D+0.5L+0.7Wy	1.007	GF	Ey	1.005
Story4	Ex	1.027	GF	D+0.5L-0.7Wx	1.037
Story4	Ey	1.005	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wx	1.028	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L-0.7Wy	1.002	GF	D+0.5L+0.7Wy	1.002

Table A. 5: Story Max/Avg Drifts (Applying W10×45 bracing at elev. B, H and F)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.033	Story4	D+0.5L+0.7Wx	1.018
Stair Roof	Ex	1.129	Story4	D+0.5L+0.7Wy	1.007
Stair Roof	Ey	1.036	Story3	Ex	1.126
Stair Roof	D+0.5L-0.7Wx	1.098	Story3	Ey	1.008
Stair Roof	D+0.5L-0.7Wx	1.1	Story3	D+0.5L-0.7Wx	1.128
Stair Roof	D+0.5L-0.7Wy	1.111	Story3	D+0.5L-0.7Wy	1.001
Stair Roof	D+0.5L-0.7Wy	1.012	Story3	D+0.5L+0.7Wx	1.121
Stair Roof	D+0.5L+0.7Wx	1.039	Story3	D+0.5L+0.7Wy	1.005
Stair Roof	D+0.5L+0.7Wx	1.025	Story2	Ex	1.16
Stair Roof	D+0.5L+0.7Wy	1.041	Story2	Ey	1.006
Story6	Ex	1	Story2	D+0.5L-0.7Wx	1.167
Story6	Ey	1.001	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L-0.7Wx	1.006	Story2	D+0.5L+0.7Wx	1.159
Story6	D+0.5L-0.7Wy	1.01	Story2	D+0.5L+0.7Wy	1.004
Story6	D+0.5L+0.7Wx	1	Story1	Ex	1.14
Story6	D+0.5L+0.7Wy	1.008	Story1	Ey	1.012
Story5	Ex	1.022	Story1	D+0.5L-0.7Wx	1.145
Story5	Ey	1.003	Story1	D+0.5L-0.7Wy	1.008
Story5	D+0.5L-0.7Wx	1.024	Story1	D+0.5L+0.7Wx	1.139
Story5	D+0.5L-0.7Wy	1.004	Story1	D+0.5L+0.7Wy	1.01
Story5	D+0.5L+0.7Wx	1.017	GF	Ex	1.035
Story5	D+0.5L+0.7Wy	1.007	GF	Ey	1.005
Story4	Ex	1.022	GF	D+0.5L-0.7Wx	1.037
Story4	Ey	1.005	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wx	1.023	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L-0.7Wy	1.003	GF	D+0.5L+0.7Wy	1.002

Table A. 6: Story Max/Avg Drifts (Applying W8×10 bracing at elev. B, H and F)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.04	Story4	D+0.5L+0.7Wx	1.038
Stair Roof	Ex	1.176	Story4	D+0.5L+0.7Wy	1.005
Stair Roof	Ey	1.023	Story3	Ex	1.128
Stair Roof	D+0.5L-0.7Wx	1.102	Story3	Ey	1.007
Stair Roof	D+0.5L-0.7Wx	1.099	Story3	D+0.5L-0.7Wx	1.131
Stair Roof	D+0.5L-0.7Wy	1.004	Story3	D+0.5L-0.7Wy	1.001
Stair Roof	D+0.5L+0.7Wx	1.031	Story3	D+0.5L+0.7Wx	1.124
Stair Roof	D+0.5L+0.7Wx	1.02	Story3	D+0.5L+0.7Wy	1.004
Stair Roof	D+0.5L+0.7Wy	1.031	Story2	Ex	1.16
Story6	Ex	1.006	Story2	Ey	1.006
Story6	Ey	1.001	Story2	D+0.5L-0.7Wx	1.167
Story6	D+0.5L-0.7Wx	1.012	Story2	D+0.5L-0.7Wy	1
Story6	D+0.5L-0.7Wx	1.259	Story2	D+0.5L+0.7Wx	1.159
Story6	D+0.5L-0.7Wy	1.006	Story2	D+0.5L+0.7Wy	1.003
Story6	D+0.5L+0.7Wx	1.006	Story1	Ex	1.14
Story6	D+0.5L+0.7Wx	1.135	Story1	Ey	1.012
Story6	D+0.5L+0.7Wy	1.005	Story1	D+0.5L-0.7Wx	1.145
Story5	Ex	1.032	Story1	D+0.5L-0.7Wy	1.008
Story5	Ey	1.003	Story1	D+0.5L+0.7Wx	1.14
Story5	D+0.5L-0.7Wx	1.033	Story1	D+0.5L+0.7Wy	1.01
Story5	D+0.5L-0.7Wy	1.002	GF	Ex	1.035
Story5	D+0.5L+0.7Wx	1.026	GF	Ey	1.005
Story5	D+0.5L+0.7Wy	1.006	GF	D+0.5L-0.7Wx	1.037
Story4	Ex	1.042	GF	D+0.5L-0.7Wy	1.001
Story4	Ey	1.006	GF	D+0.5L+0.7Wx	1.036
Story4	D+0.5L-0.7Wx	1.043	GF	D+0.5L+0.7Wy	1.002
Story4	D+0.5L-0.7Wy	1.001			

Table A. 7: Story Max/Avg Drifts (Applying column jacketing on C1 and C3 column at elev. B, H and #9 bar use as main rein. in jack.)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.093	Story4	D+0.5L-0.7Wy	1
Stair Roof	Ey	1.006	Story4	D+0.5L+0.7Wx	1.068
Stair Roof	D+0.5L-0.7Wx	1.143	Story4	D+0.5L+0.7Wx	2.296
Stair Roof	D+0.5L-0.7Wx	1.111	Story4	D+0.5L+0.7Wy	1.003
Stair Roof	D+0.5L-0.7Wy	1.04	Story3	Ex	1.085
Stair Roof	D+0.5L+0.7Wx	1.034	Story3	Ey	1.005
Stair Roof	D+0.5L+0.7Wx	1.021	Story3	D+0.5L-0.7Wx	1.088
Stair Roof	D+0.5L+0.7Wy	1.009	Story3	D+0.5L-0.7Wy	1
Story6	Ex	1.038	Story3	D+0.5L+0.7Wx	1.084
Story6	Ey	1.003	Story3	D+0.5L+0.7Wy	1.003
Story6	D+0.5L-0.7Wx	1.04	Story2	Ex	1.098
Story6	D+0.5L-0.7Wx	1.4	Story2	Ey	1.006
Story6	D+0.5L-0.7Wy	1.001	Story2	D+0.5L-0.7Wx	1.102
Story6	D+0.5L+0.7Wx	1.035	Story2	D+0.5L-0.7Wy	1.001
Story6	D+0.5L+0.7Wx	1.35	Story2	D+0.5L+0.7Wx	1.098
Story6	D+0.5L+0.7Wy	1.004	Story2	D+0.5L+0.7Wy	1.003
Story5	Ex	1.055	Story1	Ex	1.08
Story5	Ey	1.004	Story1	Ey	1.007
Story5	D+0.5L-0.7Wx	1.056	Story1	D+0.5L-0.7Wx	1.082
Story5	D+0.5L-0.7Wx	1.73	Story1	D+0.5L-0.7Wy	1.003
Story5	D+0.5L-0.7Wy	1	Story1	D+0.5L+0.7Wx	1.079
Story5	D+0.5L+0.7Wx	1.051	Story1	D+0.5L+0.7Wy	1.004
Story5	D+0.5L+0.7Wx	1.692	GF	Ex	1.028
Story5	D+0.5L+0.7Wy	1.004	GF	Ey	1.004
Story4	Ex	1.071	GF	D+0.5L-0.7Wx	1.029
Story4	Ey	1.006	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wx	1.072	GF	D+0.5L+0.7Wx	1.028
Story4	D+0.5L-0.7Wx	2.309	GF	D+0.5L+0.7Wy	1.002

Table A. 8: Story Max/Avg Drifts (Applying column jacketing on C3 column at elev. B, H and #9 bar use as main rein. in jack.)

Story	Load Cas	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.09	Story4	D+0.5L-0.7Wy	1
Stair Roof	Ey	1.006	Story4	D+0.5L+0.7Wx	1.089
Stair Roof	D+0.5L-0.7Wx	1.139	Story4	D+0.5L+0.7Wx	2.508
Stair Roof	D+0.5L-0.7Wx	1.107	Story4	D+0.5L+0.7Wy	1.004
Stair Roof	D+0.5L-0.7Wy	1.033	Story3	Ex	1.112
Stair Roof	D+0.5L+0.7Wx	1.034	Story3	Ey	1.006
Stair Roof	D+0.5L+0.7Wx	1.022	Story3	D+0.5L-0.7Wx	1.114
Stair Roof	D+0.5L+0.7Wy	1.007	Story3	D+0.5L-0.7Wy	1
Story6	Ex	1.037	Story3	D+0.5L+0.7Wx	1.108
Story6	Ey	1.003	Story3	D+0.5L+0.7Wy	1.003
Story6	D+0.5L-0.7Wx	1.043	Story2	Ex	1.13
Story6	D+0.5L-0.7Wx	1.356	Story2	Ey	1.006
Story6	D+0.5L-0.7Wy	1.002	Story2	D+0.5L-0.7Wx	1.136
Story6	D+0.5L+0.7Wx	1.035	Story2	D+0.5L-0.7Wy	1.001
Story6	D+0.5L+0.7Wx	1.288	Story2	D+0.5L+0.7Wx	1.129
Story6	D+0.5L+0.7Wy	1.004	Story2	D+0.5L+0.7Wy	1.004
Story5	Ex	1.071	Story1	Ex	1.111
Story5	Ey	1.005	Story1	Ey	1.009
Story5	D+0.5L-0.7Wx	1.072	Story1	D+0.5L-0.7Wx	1.114
Story5	D+0.5L-0.7Wx	1.827	Story1	D+0.5L-0.7Wy	1.005
Story5	D+0.5L-0.7Wy	1	Story1	D+0.5L+0.7Wx	1.11
Story5	D+0.5L+0.7Wx	1.065	Story1	D+0.5L+0.7Wy	1.007
Story5	D+0.5L+0.7Wx	1.773	GF	Ex	1.032
Story5	D+0.5L+0.7Wy	1.006	GF	Ey	1.004
Story4	Ex	1.095	GF	D+0.5L-0.7Wx	1.033
Story4	Ey	1.007	GF	D+0.5L-0.7Wy	1.001
Story4	D+0.5L-0.7Wx	1.095	GF	D+0.5L+0.7Wx	1.032
Story4	D+0.5L-0.7Wx	2.534	GF	D+0.5L+0.7Wy	1.002

Table A. 9: Story Max/Avg Drifts (Applying column jacketing on C1, C2 and C3 column at elev. B, H, 1, 4 and #9 bar use as main rein. in jack.)

Story	Load Case	Ratio	Story	Load Case	Ratio
Stair Roof	Ex	1.056	Story4	D+0.5L+0.7Wx	1.077
Stair Roof	Ey	1.005	Story4	D+0.5L+0.7Wx	1.726
Stair Roof	D+0.5L-0.7Wx	1.125	Story4	D+0.5L+0.7Wy	1.004
Stair Roof	D+0.5L-0.7Wx	1.049	Story3	Ex	1.094
Stair Roof	D+0.5L-0.7Wy	1.791	Story3	Ey	1.006
Stair Roof	D+0.5L-0.7Wy	1.074	Story3	D+0.5L-0.7Wx	1.101
Stair Roof	D+0.5L+0.7Wx	1.037	Story3	D+0.5L-0.7Wx	2.311
Stair Roof	D+0.5L+0.7Wx	1.012	Story3	D+0.5L-0.7Wy	1.001
Stair Roof	D+0.5L+0.7Wy	1.01	Story3	D+0.5L+0.7Wx	1.092
Story6	Ex	1.043	Story3	D+0.5L+0.7Wx	2.312
Story6	Ey	1.004	Story3	D+0.5L+0.7Wy	1.005
Story6	D+0.5L-0.7Wx	1.045	Story2	Ex	1.105
Story6	D+0.5L-0.7Wx	1.21	Story2	Ey	1.009
Story6	D+0.5L-0.7Wy	1.002	Story2	D+0.5L-0.7Wx	1.114
Story6	D+0.5L+0.7Wx	1.044	Story2	D+0.5L-0.7Wx	3.487
Story6	D+0.5L+0.7Wx	1.201	Story2	D+0.5L-0.7Wy	1.004
Story6	D+0.5L+0.7Wy	1.002	Story2	D+0.5L+0.7Wx	1.103
Story5	Ex	1.063	Story2	D+0.5L+0.7Wy	1.009
Story5	Ey	1.005	Story1	Ex	1.079
Story5	D+0.5L-0.7Wx	1.066	Story1	Ey	1.014
Story5	D+0.5L-0.7Wx	1.41	Story1	D+0.5L-0.7Wx	1.085
Story5	D+0.5L-0.7Wy	1.001	Story1	D+0.5L-0.7Wy	1.01
Story5	D+0.5L+0.7Wx	1.06	Story1	D+0.5L+0.7Wx	1.077
Story5	D+0.5L+0.7Wx	1.389	Story1	D+0.5L+0.7Wy	1.014
Story5	D+0.5L+0.7Wy	1.004	GF	Ex	1.033
Story4	Ex	1.08	GF	Ey	1.006
Story4	Ey	1.006	GF	D+0.5L-0.7Wx	1.036
Story4	D+0.5L-0.7Wx	1.085	GF	D+0.5L-0.7Wy	1.003
Story4	D+0.5L-0.7Wx	1.751	GF	D+0.5L+0.7Wx	1.034
Story4	D+0.5L-0.7Wy	1	GF	D+0.5L+0.7Wy	1.004