A STUDY ON SEISMIC RETROFITTING OF COLUMNS AND BEAMS WITH STEEL JACKETING

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A thesis submitted to the Department of Civil Engineering Sonargaon University (SU) in partial fulfillment for the degree of Bachelor of Science in Civil Engineering

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Sonargaon University
147/I, Green Road, Dhaka-1215, Bangladesh
Section: (26B+27B)
Semester - (Fall-2025)

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DECLARATION

We hereby declare that this thesis is my work and effort and it has not been submitted anywhere for any award. All the contents provided here are based on our labor dedicated to the completion of the experiment of the A Study on Seismic Retrofitting of Columns and Beams with Steel Jacketing. All the sources of information used in this thesis have been acknowledged and the necessary references included for further study.

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To

“MY PARENTS”

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ABSTRACT

Seismic retrofitting is an essential strategy to improve the performance of existing reinforced concrete (RC) buildings against earthquakes. In Bangladesh, where seismic vulnerability has become a growing concern due to increasing urbanization and the country's location in an active seismic zone, strengthening existing structures has high importance. This study focuses on the retrofitting of columns and beams using steel jacketing techniques, with the numerical modeling and analysis carried out in ETABS 17. The objective is to investigate how steel jacketing can improve the load-carrying capacity, stiffness, and ductility of RC members while reducing drift and enhancing resistance against earthquake magnitudes defined in BNBC 2020. Through analytical modeling, both original and retrofitted structures are compared in terms of inter-story drift, base shear, and overall stability during seismic loading. Results demonstrate that steel jacketing significantly increases the lateral strength and reduces seismic drift, thereby providing an effective and economical retrofitting solution in compliance with BNBC 2020 requirements. This research contributes to practical applications in structural engineering, highlighting a feasible method for extending the service life and safety of vulnerable structures in seismic-prone regions.

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LIST OF ABBREVIATIONS

Abbreviations	Definition
BNBC	Bangladesh National Building Code
Z	Seismic Zone
I	Structural Importance
R	Response Factor
T	Time period
V	Base Shear
RC	Reinforced Concrete
EQX	Earthquake in X-direction
EQY	Earthquake in Y-direction
WX	Wind in X-direction
WY	Wind in Y-direction
OMRF	Ordinary Moment Resisting Frames
SMRF	Special Moment Resisting Frames
IMRF	Intermediate Moment Resisting Frames
FRP	Fiber Reinforced Polymer

CHAPTER 1

INTRODUCTION

1.1 Background

Bangladesh lies in a seismically active region where several tectonic plates interact, exposing the country to the risk of moderate to severe earthquakes. With rapid urban growth, many existing reinforced concrete buildings were designed and constructed without full consideration of modern seismic design codes. As a result, these structures often lack sufficient ductility, strength, and lateral stability to withstand strong ground motions. Past earthquakes around the world have repeatedly shown that inadequate structural detailing in columns and beams leads to brittle failure, partial collapse, or even total structural failure. In this context, seismic retrofitting has become a necessary intervention for ensuring the safety of existing buildings and protecting human lives.

Steel jacketing is one of the most widely adopted retrofitting techniques for strengthening RC members. The method involves encasing existing columns and beams with steel plates or angles, which are then welded or bolted and filled with grout or epoxy to ensure composite action. This technique improves confinement, increases axial and flexural strength, enhances ductility, and provides better energy dissipation during seismic events. Compared to other methods like FRP wrapping or concrete jacketing, steel jacketing is cost-effective, provides high strength, and can be implemented with relative ease even in existing buildings without extensive demolition.

The Bangladesh National Building Code (BNBC 2020) provides updated seismic design provisions that must be followed for both new and retrofitted structures. BNBC 2020 specifies seismic zones, design spectra, drift limitations, and performance objectives to ensure life safety and collapse prevention. Many existing buildings, however, were designed according to earlier codes with limited seismic consideration, making them highly vulnerable. Retrofitting such structures with steel jacketing and verifying performance using finite element software such as ETABS 17 ensures that they can meet BNBC 2020 requirements. ETABS provides powerful tools for nonlinear analysis, pushover studies, and performance evaluation, allowing engineers to simulate the effect of retrofitting strategies under realistic earthquake conditions.

This research emphasizes the role of steel jacketing as a practical retrofitting measure to control inter-story drift and improve seismic resilience. By combining ETABS modeling with BNBC 2020 guidelines, the study bridges the gap between theoretical design requirements and practical strengthening techniques. Ultimately, the work highlights how cost-effective retrofitting methods can extend the serviceability of existing RC buildings in Bangladesh, ensuring both structural safety and compliance with modern seismic codes.

1.2 Research Objectives and Overview

The primary objective of this research is to evaluate the effectiveness of steel jacketing as a seismic retrofitting technique for reinforced concrete columns and beams. The study aims to investigate how steel jacketing improves the seismic response of an existing RC building by reducing story drift and displacement while enhancing base shear capacity and overall structural stiffness in accordance with the provisions of BNBC 2020.

To achieve these objectives, a typical multi-storey RC building is selected and modeled using ETABS. Linear dynamic analysis is performed to assess the seismic behavior of the structure under earthquake loading. The building is analyzed in its original condition and then reanalyzed after applying steel jacketing to critical columns and beams. The seismic performance of both models is evaluated and compared using key response parameters such as story drift, story displacement, base shear, and stiffness.

Furthermore, the study considers the influence of different soil site conditions on the seismic response of the structure, as specified in BNBC 2020. A comparative assessment is conducted to examine how soil characteristics affect structural behavior before and after retrofitting. The results are checked against code-specified drift limits to determine the effectiveness and suitability of steel jacketing as a practical retrofitting solution.

The findings of this research are expected to demonstrate that steel jacketing is an effective, feasible, and locally applicable seismic retrofitting technique for existing RC buildings in Bangladesh. The outcomes of the study may provide useful guidance for practicing engineers and researchers in selecting appropriate retrofitting strategies to enhance structural safety and seismic resilience.

1.3 Objectives of the study

This study is guided by the following specific objectives:

1. To model and analyze the seismic performance of a case-study RC building, designed per BNBC 1993/2006, under the seismic load provisions of BNBC 2020 using ETABS 17 software (CSI, 2017; BNBC, 2020).

2. To quantify the seismic deficiencies of the original structure in terms of inter-story drift, story displacement, and base shear demand, and to compare these values against the allowable limits specified in BNBC 2020 (Rahman et al., 2019).

3. To design and implement a steel jacketing retrofitting scheme for critical columns and beams, utilizing Grade 50 steel with a thickness of 8 mm, based on established international practices and local material availability (Xiao & Wu, 2000).

4. To evaluate the performance enhancement achieved through steel jacketing by comparing the retrofitted model's response (drift, displacement, base shear capacity, stiffness) with that of the original model (Pampanin et al., 2005).

5. To assess the compliance of the retrofitted structure with all relevant seismic performance criteria of BNBC 2020, thereby validating steel jacketing as a viable retrofitting strategy for similar vulnerable buildings in Bangladesh (Islam et al., 2021).

1.4 Rationale of the Study

Many reinforced concrete buildings in Bangladesh were designed before BNBC 2020 and therefore lack proper seismic considerations, making them vulnerable during earthquakes. While BNBC 2020 introduces updated seismic provisions, there is limited research on how retrofitting techniques like steel jacketing perform under these requirements. This study is therefore important as it provides practical evidence on the effectiveness of steel jacketing in reducing drift and improving seismic performance. The findings can guide engineers and policymakers in adopting steel jacketing as a reliable retrofit solution for existing vulnerable structures.

This study, therefore, is driven by the urgent need to provide engineers and policymakers in Bangladesh with evidence-based insights into the role of steel jacketing in controlling seismic drift and strengthening RC members.

1.5 Problem Statement

Most existing RC buildings in Bangladesh were not designed with adequate seismic considerations, making them structurally deficient under earthquake loads. In particular, columns and beams often lack proper confinement reinforcement and ductility, which can lead to brittle failure during seismic events. Retrofitting is essential, but engineers face challenges in selecting methods that are both effective and economical.

Steel jacketing has been proven in international studies as a reliable strengthening technique, yet there is limited research in the context of Bangladeshi building stock under BNBC 2020 seismic provisions. Without proper evaluation, engineers may be uncertain about the drift control, strength enhancement, and overall safety improvements achieved through steel jacketing. This knowledge gap necessitates a systematic study using ETABS 17 to compare the seismic performance of original and retrofitted structures according to BNBC 2020 guidelines.

1.6 Research Gap

A comprehensive review of existing study reveals a distinct research gap in the context of Bangladesh. While the effectiveness of steel jacketing for seismic retrofitting of RC members is well-documented globally through extensive experimental and analytical work (e.g., Mander et al. (1988); Xiao & Wu, 2000; Pampanin et al. (2005), its application and performance evaluation specific to Bangladeshi building typologies and code frameworks remain insufficiently explored.

Existing local studies on seismic retrofitting, such as those by Rahman, Alam & Hoque (2019) and Kabir & Hasan (2020), have primarily focused on vulnerability assessment or generic performance evaluation, often relying on simplified models or previous code editions. The introduction of BNBC 2020, with its revised seismic zoning, updated design spectra, and stricter drift control limits (BNBC, 2020), creates a new paradigm for structural assessment. However, there is a notable absence of detailed research that systematically applies these new code provisions to evaluate the performance of steel-jacketed RC frames using sophisticated finite element analysis tools like ETABS.

Therefore, this study aims to address this critical gap by providing a detailed, BNBC 2020-compliant, ETABS-based analytical investigation into the seismic retrofitting of RC buildings using steel jacketing. The findings are intended to offer evidence-based guidance to structural engineers and policymakers in Bangladesh, for whom such code-specific retrofitting studies are currently lacking (Islam et al., 2021).

1.7 Scope of the study

This research is limited to the seismic retrofitting of RC columns and beams using steel jacketing. The analysis is carried out through ETABS 17 software under BNBC 2020 seismic design provisions. Only structural aspects such as drift, base shear, and lateral strength are considered; non-structural elements, cost analysis, and construction methodology are not included in detail. The study focuses on analytical modeling rather than experimental validation, although results are compared with published literature where necessary. The findings are intended for use by structural engineers and policymakers to adopt steel jacketing as an effective retrofit method for vulnerable buildings in seismic-prone areas of Bangladesh.

1.8 Significance of the study

The significance of this study lies in its contribution to ensuring structural safety in Bangladesh’s seismic-prone environment. By systematically evaluating the performance of steel-jacketed RC columns and beams under BNBC 2020 provisions, the research:

1. Provides practical insights into drift reduction and strength enhancement achievable through steel jacketing.
2. Demonstrates the capability of ETABS 17 in modeling and assessing retrofitted structures for compliance with modern seismic codes.
3. Offers engineers and decision-makers a cost-effective and efficient retrofitting solution for existing vulnerable RC buildings.
4. Contributes to disaster risk reduction efforts by enhancing the resilience of Bangladesh’s infrastructure against future earthquakes.

1.9 Organization of the Thesis

This thesis has been organized into several chapters in a systematic manner to present the study clearly and logically.

Chapter 1: Introduction

This chapter discusses the background of seismic vulnerability in Bangladesh, the importance of retrofitting, research objectives, problem statement, research gap, and the overall significance of the study. It also outlines the scope and rationale of adopting steel jacketing for seismic strengthening.

Chapter 2: Literature Review

This chapter presents a comprehensive review of existing studies related to seismic retrofitting of reinforced concrete structures. It highlights previous research on jacketing methods, international and local case studies, and compares steel jacketing with other retrofitting techniques. The role of ETABS in seismic analysis and BNBC 2020 provisions are also discussed.

Chapter 3: Methodology

This chapter explains the methodology followed in the research. It describes the study area, selection of case study building, data collection procedures, materials used, structural modeling, load application according to BNBC 2020, and retrofitting techniques with steel jacketing. Limitations encountered during the modeling are also highlighted.

Chapter 4: Results and Discussion

This chapter presents the analytical results obtained from ETABS 17 for both original and retrofitted structures. Comparisons are made in terms of story drift, displacement, and base shear. The effectiveness of steel jacketing in reducing seismic drift and ensuring compliance with BNBC 2020 is discussed.

Chapter 5: Conclusions and Recommendations

This chapter summarizes the major findings of the study and provides conclusions regarding the role of steel jacketing in seismic retrofitting. It also discusses the limitations of the present research and suggests recommendations for further studies and practical applications in Bangladesh.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A literature review is essential to understand the past research, global practices, and technical advancements related to seismic retrofitting of reinforced concrete (RC) structures. Many developing countries, including Bangladesh, face challenges with existing buildings that were not designed according to modern seismic codes. The review highlights international case studies, the role of steel jacketing in strengthening beams and columns, and comparisons with other retrofitting techniques. Furthermore, it explores the application of advanced analysis tools like ETABS in evaluating the performance of retrofitted structures under seismic loads.

2.2 Seismic Vulnerability of RC Structures

Reinforced concrete structures are widely used due to their durability and cost-effectiveness. However, when designed without seismic considerations, they are highly vulnerable to earthquakes. Deficiencies in such structures include insufficient reinforcement, inadequate confinement, weak beam-column joints, and poor ductility. During earthquakes, these weaknesses often lead to brittle failures, excessive inter-story drift, and eventual collapse. Studies from countries like Turkey, Nepal, and India—regions that share seismic characteristics with Bangladesh—demonstrate that the majority of earthquake-induced collapses occur due to the failure of columns and beams. Therefore, strengthening these structural elements is crucial to improving overall building resilience.

2.3 Prior Research on Seismic Retrofitting

Over the past few decades, researchers have extensively studied the seismic performance of reinforced concrete (RC) structures and the effectiveness of various retrofitting strategies.

Islam, Sarker & Chowdhury (2021) presented a case study on seismic retrofit of RC buildings in Bangladesh using steel jacketing. They demonstrated through analysis and design that retrofitting not only restores but also improves structural resilience against earthquakes compared to the as-built condition.

Kabir & Hasan (2020) evaluated retrofitted RC frames under earthquake loading and confirmed that jacketing substantially reduces inter-story drifts and enhances base shear capacity, aligning with international findings while contextualizing them to Bangladeshi structures.

Rahman, Alam & Hoque (2019) assessed the seismic vulnerability of existing RC buildings in Dhaka and identified widespread deficiencies in seismic detailing. Their findings emphasize the urgent need for systematic retrofitting programs to reduce collapse risks in Bangladesh.

Pampanin, Priestley & Calvi (2005) expanded on retrofit strategies and showed that steel jacketing could successfully restore and even improve the seismic performance of deficient RC buildings. They highlighted cost-effectiveness and constructability as major advantages.

Xiao & Wu (2000) carried out experimental and analytical studies on steel-jacketed RC columns, demonstrating significant improvements in shear strength, ductility, and overall stability under cyclic loading. Their findings confirm that steel jacketing is a reliable and efficient retrofit method for columns in seismic zones.

Mander, Priestley, and Park (1988) developed the theoretical stress–strain model for confined concrete, which became a cornerstone for understanding how confinement (such as steel jacketing) improves ductility and compressive strength of concrete elements. This model directly supports the application of steel jackets in enhancing seismic resistance.

Aboutaha et al. (1996) investigated strengthening of RC beams using steel plates. Their research revealed that externally bonded steel can significantly enhance flexural and shear capacity of beams, indicating that jacketing and plating are viable retrofit options for flexural members.

Mander & Priestley (1993) specifically addressed seismic retrofit of concrete structures, confirming through experiments that confinement by steel jackets restores ductility and enhances seismic capacity of previously deficient members.

2.4 Previous Projects on Retrofitting

Several projects worldwide and in Bangladesh have applied retrofitting techniques to mitigate seismic risk:

Padma Multipurpose Bridge Sub-Structures (Bangladesh, 2016): Although not a building, portions of the foundation piers were retrofitted with steel and concrete jackets to improve confinement and seismic resistance. This demonstrated the effectiveness of jacketing under large axial and lateral loads.

Kamalapur Railway Station (Dhaka, 2012): A structural assessment recommended strengthening of critical RC columns. While FRP wrapping was considered, steel jacketing was chosen in some sections due to cost-effectiveness and availability of materials.

Post-Gorkha Earthquake Projects (Nepal, 2015–2018): Thousands of school and hospital buildings were retrofitted, many with steel jacketing of columns. Shrestha et al. (2018) reported that these retrofitted structures achieved significant reduction in inter-story drift and collapse risk during aftershocks.

Indian School Retrofitting Program (Gujarat, India, 2005–2009): After the 2001 Bhuj earthquake, over 300 RC school buildings were retrofitted. Steel jacketing was one of the main techniques used to improve ductility, since it was faster and cheaper than complete rebuilding.

Japan (1990s–2000s): Numerous office buildings and residential blocks were retrofitted with steel jacketing after the Kobe earthquake (1995). Research showed improved ductility and redistribution of stresses in critical members.

2.5 Seismic Retrofitting on Global Perspective

Seismic retrofitting refers to upgrading existing structures to improve their performance under earthquake loads. Globally, several methods are practiced, including:

1. Concrete Jacketing – Increasing the size of structural members by adding concrete and reinforcement around them.

Figure 2.1: Concrete Jacketing

Image Source: https://share.google/images/kEmJkHnp7PxD35HqF

2. Fiber Reinforced Polymer (FRP) Wrapping – Using lightweight composite materials to enhance strength and ductility.

Figure 2.2: Fiber Reinforced Polymer (FRP) Wrapping

Image Source: https://share.google/images/yIxrqRURXKQH9587A

3. Base Isolation – Placing isolation devices at the foundation level to reduce seismic energy transfer.

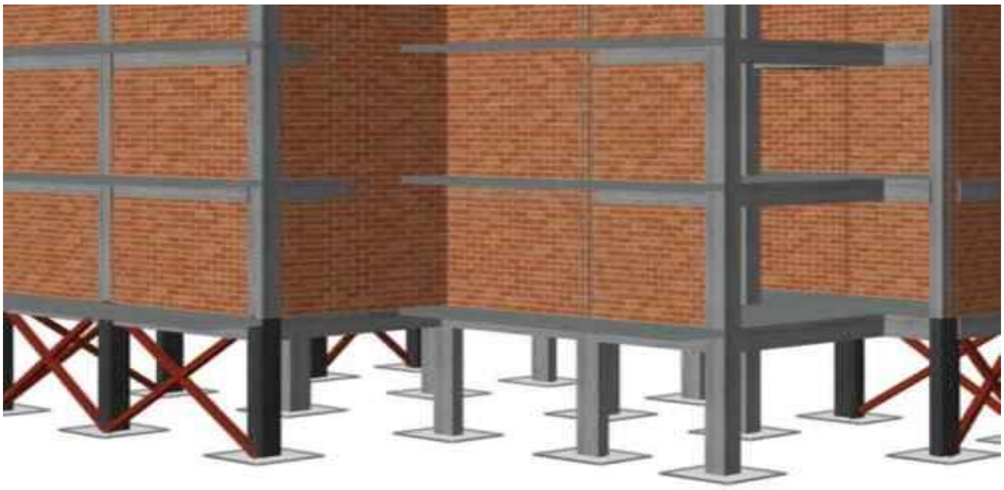


Figure 2.3: Base Isolation

Image Source: https://share.google/images/sOvQP8fHy72pHh6GZ

4. Steel Jacketing – Encasing structural members with steel plates or angles to increase confinement and strength.

Figure 2.4: Steel Jacketing

Image Source: https://share.google/images/gJnsmyt6MVTBwQ98D

Among these, steel jacketing has gained wide acceptance due to its relatively simple application, effectiveness, and adaptability to different structural conditions. Researchers from Japan, Italy, and the United States have shown that steel jacketing significantly improves the lateral load capacity and energy dissipation of RC columns and beams. For example, studies conducted after the Kobe (1995) and Northridge (1994) earthquakes highlighted the effectiveness of steel jacketing in preventing collapse of retrofitted structures.

2.6 Steel Jacketing of Columns and Beams

Steel jacketing involves surrounding the RC member with steel plates or angles, which are fastened by welding or bolting, often with grout or epoxy injection to ensure composite action. Its benefits include:

- Increased axial and flexural strength of columns.
- Improved confinement, leading to enhanced ductility.
- Significant reduction in inter-story drift.
- Prevention of brittle failure in beams and joints.
- Enhanced energy dissipation under cyclic loading.

Numerous experimental and analytical studies have confirmed that steel jacketing delays local buckling, reduces shear deformation, and enhances overall building stability. Compared to other methods, it is more durable than FRP and less invasive than concrete jacketing, which often requires heavy demolition and increases member dimensions excessively.

2.7 Use of Steel Jacketing in Developing Countries

In developing countries, steel jacketing is considered highly practical due to its cost-effectiveness and ease of installation. In India, studies after the Bhuj earthquake (2001) demonstrated that steel-jacketed columns performed significantly better under seismic loads. In Nepal, post-2015 earthquake rehabilitation efforts included retrofitting of school buildings using steel jacketing, which improved both structural safety and public confidence. For Bangladesh, where building density is high and demolition is often impractical, steel jacketing offers an efficient retrofitting approach without significantly altering the usable space of buildings.

2.8 BNBC 2020 and Seismic Retrofitting in Bangladesh

The Bangladesh National Building Code (BNBC) 2020 represents a significant advancement in the country's approach to earthquake-resistant design, aligning more closely with international standards like ASCE 7-05 (BNBC, 2020). It introduces detailed seismic hazard maps, site-specific response spectra, and explicit performance objectives aimed at life safety and collapse prevention. A crucial aspect of BNBC 2020 is its stringent control on inter-story drift, a key parameter linked to both structural and non-structural damage during earthquakes (Hossain & Islam, 2022).

This updated code starkly highlights the vulnerability of the existing building inventory in Bangladesh. A vast number of RC structures, particularly those built before the 1990s or even under earlier BNBC versions, were designed with minimal seismic consideration, lacking proper ductile detailing, confinement, and lateral force-resisting mechanisms (Rahman, Alam & Hoque, 2019). These structures, located in high-risk zones like Dhaka, Chattogram, and Sylhet, are non-compliant with BNBC 2020 and pose a significant risk to life and property.

However, BNBC 2020 primarily provides guidelines for the design of new structures. While it sets the performance benchmark, it offers limited prescriptive guidance on retrofitting methods for existing deficient buildings (BNBC, 2020). This creates a practical challenge for engineers: they must demonstrate compliance with the new code's performance objectives but lack code-endorsed retrofit strategies. Consequently, engineers often resort to adapting international retrofit techniques, such as steel jacketing, without specific validation under Bangladeshi seismic demands and material conditions (Islam et al. (2021). This gap underscores the urgent need for research that evaluates and tailors retrofitting techniques like steel jacketing within the explicit framework of BNBC 2020.

2.9 Role of ETABS in Seismic Analysis

ETABS is one of the most widely used finite element software tools for structural analysis and design. It offers advanced modeling capabilities for both new and retrofitted buildings, including:

- Nonlinear static and dynamic analysis.
- Pushover analysis to assess ductility and capacity.

- Response spectrum and time-history analysis under seismic loads.
- Detailed drift and displacement output for performance-based design.

The software's effectiveness in evaluating retrofitted structures has been validated in numerous international studies. For instance, research following major earthquakes has utilized ETABS to simulate the behavior of jacketed columns and beams, confirming its accuracy in predicting improvements in strength, stiffness, and drift control (Kabir & Hasan, 2020). For the Bangladeshi context, using ETABS 17 ensures that the analysis of the retrofitted case-study building is rigorous, repeatable, and based on globally accepted analytical principles. It allows for a direct comparison of pre- and post-retrofit performance against the quantifiable metrics (e.g., drift ratios) specified in BNBC 2020, thereby providing a reliable digital platform to validate the proposed steel jacketing solution before physical implementation (Islam et al. (2021).

2.10 Comparison with Other Retrofitting Techniques

While other retrofitting techniques are available, steel jacketing offers several advantages:

Concrete Jacketing: Provides strength but increases member size, reducing usable floor area and adding weight.

FRP Wrapping: Lightweight but costly and less durable in humid climates like Bangladesh.

Base Isolation: Highly effective but expensive and not practical for existing buildings without extensive modification.

Steel Jacketing: Cost-effective, durable, easy to implement, and highly effective in improving both strength and ductility.

Given these comparisons, steel jacketing emerges as one of the most suitable retrofitting methods for Bangladesh, balancing technical performance with economic feasibility.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology describes the procedures adopted to evaluate the seismic performance of RC frames before and after retrofitting with steel jacketing. The study uses numerical modeling and analysis in ETABS 17, following BNBC 2020 provisions. This chapter explains the case study building, material properties, modeling assumptions, seismic load definitions, retrofitting procedure, and evaluation criteria.

3.2 Methodology Overview

This research has been conducted through ETABS-17 analysis on a pre-existing building constructed in 2005, located in Gendaria, Dhaka. The analysis is designed to evaluate the structural performance of the building under seismic loading according to BNBC 2020. The primary focus is on story drift check, displacement control, and base shear capacity, and how much steel jacketing retrofitting can enhance the building's resistance against earthquake-induced forces.

3.2.1 Study Area

The selected building has a total height of 75 ft. (22.86 m) with 6 stories, including the stair room roof which is considered as one story. Each floor has a height of 10 ft. (3.05 m), while the foundation extends 8 ft. (2.44 m) below the base level.

The study is based on an existing residential building located at Sutrapur, Gendaria, Dhaka, which lies in Seismic Zone-II according to BNBC 2020, where seismic intensity is categorized as severe. The corresponding zone factor (Z) for this region is 0.20, which has been considered in the ETABS analysis.

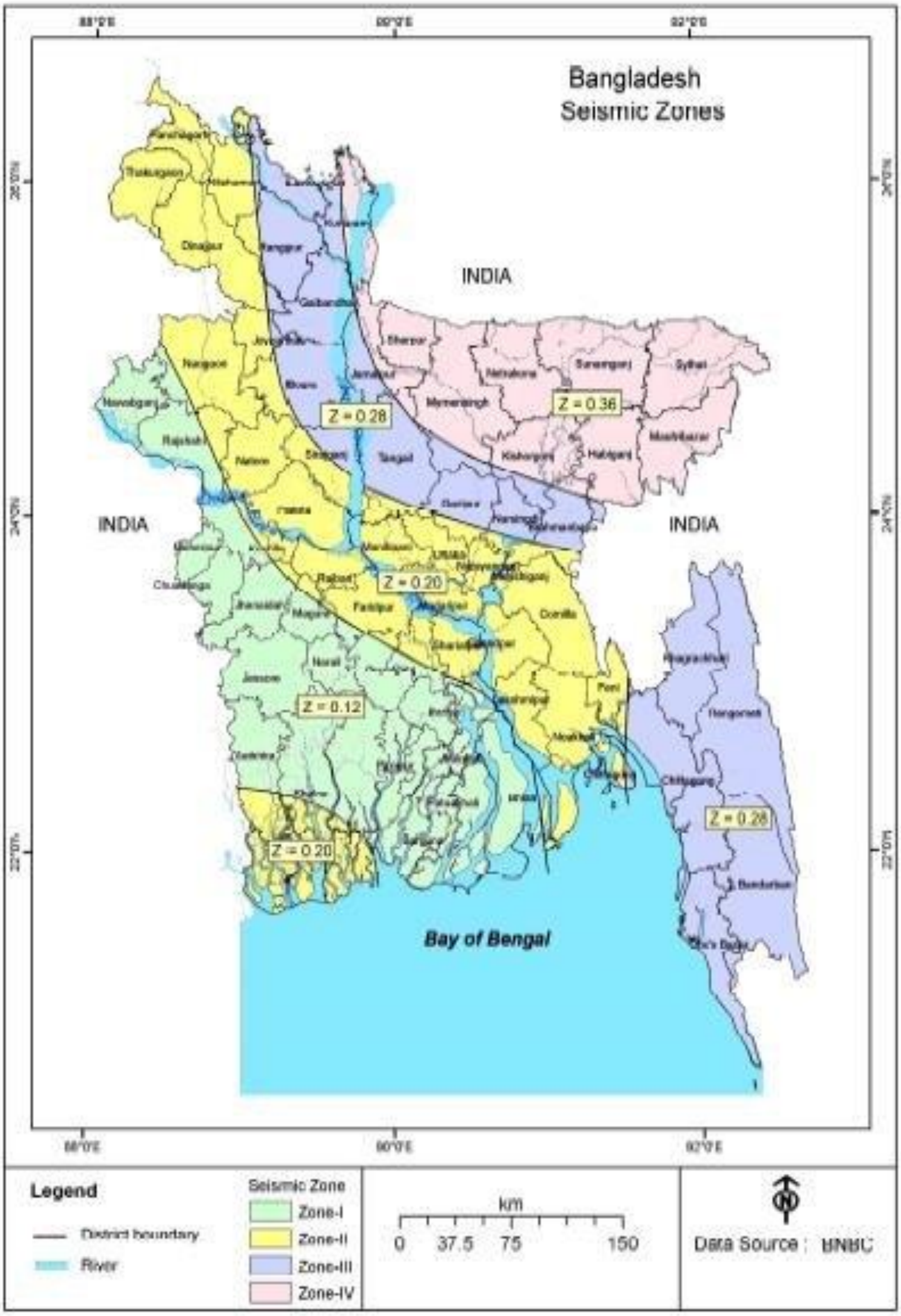


Figure 3.1: Seismic Zone of Bangladesh

Image Source: https://share.google/images/Ji1qKlav2rN6jAbaG

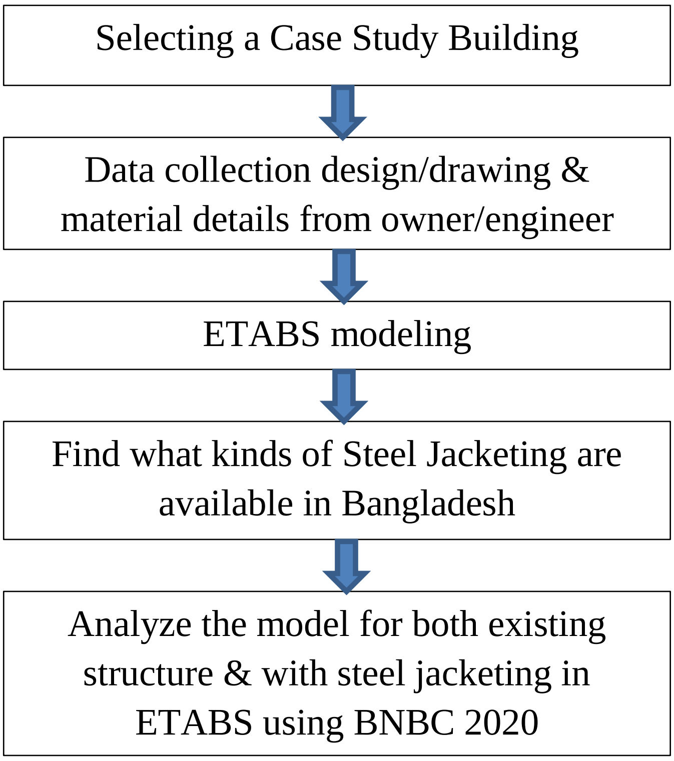
3.3 Research Framework

The research follows a structured framework consisting of the following steps:

1. Selection of a typical multi-story RC building representative of common construction practice in Bangladesh.
2. Modeling of the structure in ETABS 17 with appropriate material properties, dimensions, and reinforcement details.
3. Application of seismic loads, load combinations, and design criteria based on BNBC 2020.
4. Implementation of retrofitting by adding steel jacketing to selected columns and beams.
5. Comparative analysis of original and retrofitted models in terms of inter-story drift, base shear, displacement, and ductility.
6. Evaluation of results against BNBC 2020 performance requirements.

3.4 Data Collection

This data collection method consists of 5 steps work.



3.5 Case Study Building

A representative mid-rise reinforced concrete (RC) moment-resisting frame structure is considered for analysis. The building parameters are as follows:

3.6 Materials Details

The material used in this model was based on BNBC 2006, with some modifications made to enhance the structural strength. This shows that the engineer who designed the building had a clear understanding of seismic loads and took precautionary measures to minimize potential risks. The material properties adopted for this building are as follows:

Table 3.1: Material Properties

Material Properties Name	**Compressive Strength (psi)**
Column	3500
Beam	3500
Slab	2500

- Weight Density of all concrete is 150 lb/ft^3

Table 3.2: Types of Rebar

Type of Rebar	Tensile Strength (ksi)	Modulus of Elasticity (lb/in^2)	Minimum Yield Strength (ksi)	Minimum Tensile Strength (ksi)	Expected Yield Strength (ksi)	Expected Tensile Strength (ksi)
Main Rebar	60	29000000	60.00	90.00	66.00	99.00
Tie Rebar	40	29000000	40.00	60.00	44.00	66.00

- Weight Density of all rebar is 490 lb/ft^3

Table 3.3: Details of Steel Jacketing

Type of Rebar	Tensile Strength (ksi)	Modulus of Elasticity (lb/in^2)	Minimum Yield Strength (ksi)	Minimum Tensile Strength (ksi)	Expected Yield Strength (ksi)	Expected Tensile Strength (ksi)
Steel Plate	50	29000000	50.00	65.00	55.00	71.5

3.7 Structural Modeling

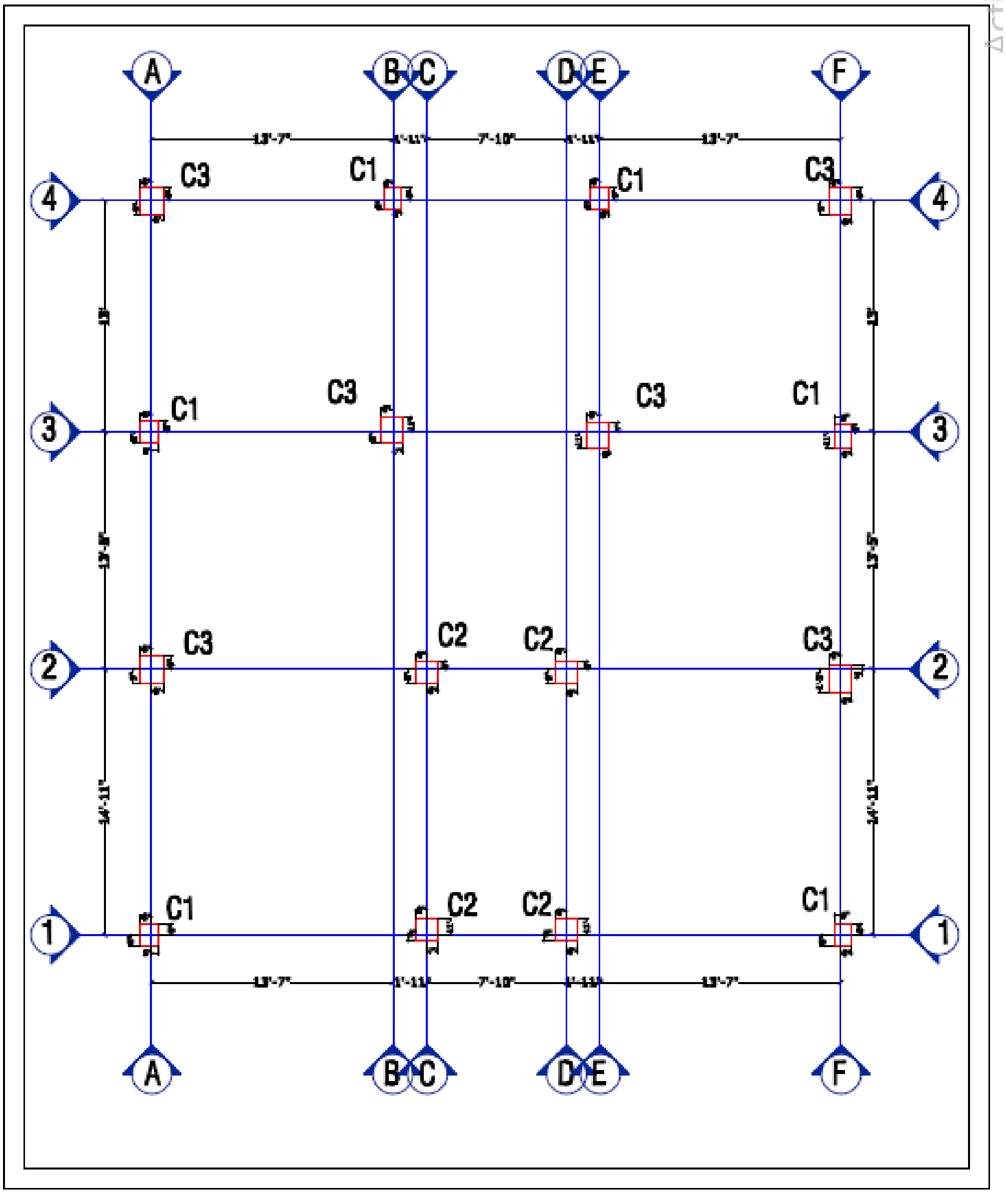


Figure 3.2: Column Layout Plan

3.8 Column, Beam, Slab Dimensions

Name	Dimensions
COLUMN	
C1	12 X 15 in
C2	15 X 15 in
C3	15 X 18 in
BEAM	
FB	10 X 15 in
GB	12 X 15 in
SLAB	
Stair Waist Slab	8 in
All Slab	5 in

3.9 Data Analysis Method

After implementing all the required data into ETABS-17, the building was analyzed according to the load combinations prescribed in BNBC 2020. Since the structure is located in Seismic Zone 2, the analysis method incorporated certain modifications to account for drift behavior. All the load combinations are:

Table 3.4: Load Combinations

(1) 1.4D	(9) 1.2D-1.6Wx+L+0.5Lr	(17) 1.29D + 0.3Ex - Ey + L	25) 0.81D + Ex - 0.3Ey
(2) 1.2D+1.6L+0.5Lr	(10) 1.2D+1.6Wy+L+0.5Lr	(18) 1.29D - 0.3Ex + Ey + L	26) 0.81D - Ex + 0.3Ey
(3) 1.2D+1.6Lr+L	(11) 1.2D-1.6Wy+L+0.5Lr	(19) 1.29D - 0.3Ex - Ey + L	27) 0.81D - Ex - 0.3E
(4) 1.2D+1.6Lr+0.8Wx	(12) 1.29D + Ex + 0.3Ey + L	(20) 0.9D+1.6Wx	28) 0.81D + 0.3Ex + Ey
(5) 1.2D+1.6Lr-0.8Wx	(13) 1.29D + Ex - 0.3Ey + L	(21) 0.9D-1.6Wx	29) 0.81D + 0.3Ex – Ey
(6) 1.2D+1.6Lr+0.8Wy	(14) 1.29D - Ex + 0.3Ey + L	(22) 0.9D+1.6Wy	30) 0.81D - 0.3Ex + Ey

(7) 1.2D+1.6Lr-0.8Wy	(15) 1.29D - Ex - 0.3Ey + L	(23) 0.9D-1.6Wy	31) 0.81D - 0.3Ex - Ey
(8) 1.2D+1.6Wx+L+0.5 Lr	(16) 1.29D + 0.3Ex + Ey + L	24) 0.81D + Ex + 0.3Ey	(32) Envelope

- Note that envelope contains a sum of all the load combinations of the specific seismic zone.

3.10 Application of Loads According to BNBC 2020

The Bangladesh National Building Code (BNBC 2020) provides detailed guidelines for seismic design, closely aligned with international codes such as ASCE 7-05 and ACI 318. Key requirements include:

- Seismic zone: Zone II (Dhaka)
- Soil type: Deposits of loose to medium cohesion less soil (SD)
- Seismic Category: D
- Importance factor (I): 1.0 (for residential buildings).
- Response reduction factor (R): 8.0 (for special reinforced concrete moment).
- Drift Limitations: Maximum story drift ratio = 0.02h (where h = story height).

3.10.1 Seismic Analysis for Different Soil Conditions

In this study, the primary seismic analysis was conducted considering Soil Type SD, as it represents the actual soil condition of the project site according to BNBC 2020. However, to evaluate the influence of soil characteristics on the seismic behavior of the structure, additional analyses were performed using Soil Types SA, SB, SC, and SE.

These additional soil conditions were considered solely for comparative analysis purposes, in order to investigate the variation in seismic response parameters such as base shear, story displacement, and story drift under different site conditions. The comparative evaluation provides a clearer understanding of how changes in soil stiffness and damping characteristics affect the overall seismic performance of the structure. This approach enhances the reliability of the study and allows a broader assessment of structural behavior under varying soil conditions, while maintaining Soil Type SD as the actual design basis of the project.

3.11 Loading and Analysis (BNBC 2020)

Table-3.5: Dead Loads

Loads Name	Concentrated Load
Floor Finish Load on Floor Slab	16.40 psf
Floor Finish Load on Roof Slab	10 psf
Partition Wall Load on Floor Slab	44.70 psf
Partition Wall Load on Beam	0.51 K/ft.

Table-3.6: Live Loads

Loads Name	Concentrated Load
Load on Floor Slab	41.78 psf
Load on Roof Slab	60.58 psf
Stair & Exit Ways	100.27 psf

3.12 Earthquake Magnitude Calculation Process

For earthquake magnitude, moment magnitude (M) method was used. For calculation used formula,

$$\mathrm{M} = \frac{2}{3}\log 10\ \mathrm{M}_0 - 10.7$$

Here,

$\mathrm{M}_0 = \mu \mathrm{AD}$

$\mathrm{M}_0 =$ Earthquake moment in dyne cm

$\mu =$ Modulus of rigidity

$\mathrm{A} =$ Total affected area (seismic zone district area)

$\mathrm{D} =$ Allowable Drift

Modulus of rigidity was found by hooks law,

$\mathrm{E} = 2\mathrm{G}(1 + \nu)$

$\mathrm{G} = 0.5\mathrm{E}/(1 + \nu)$

Here,

$\mathrm{E} =$ Modulus of Elasticity

$\mathrm{G} =$ Modulus of Rogidity

$\nu =$ Poisson′s ratio

3.13 Data Implementation and Limitations

After collecting all the necessary data, including structural dimensions, design details, rebar arrangements, and material properties according to our methodology, the model was implemented in ETABS-17. For all analyses, including steel jacketing retrofitting, we used ASCE 7-05 to define load patterns and load combinations. During the implementation, we faced some limitations.

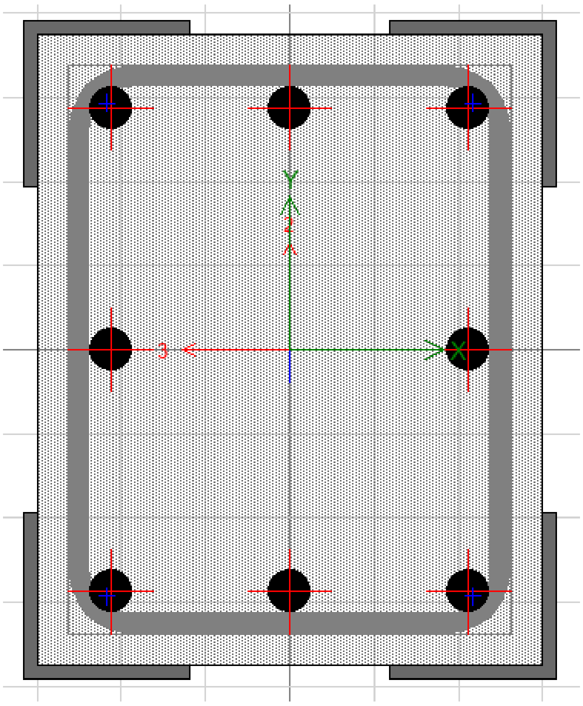
- **Absence of Direct BNBC 2020 Properties in ETABS-17**

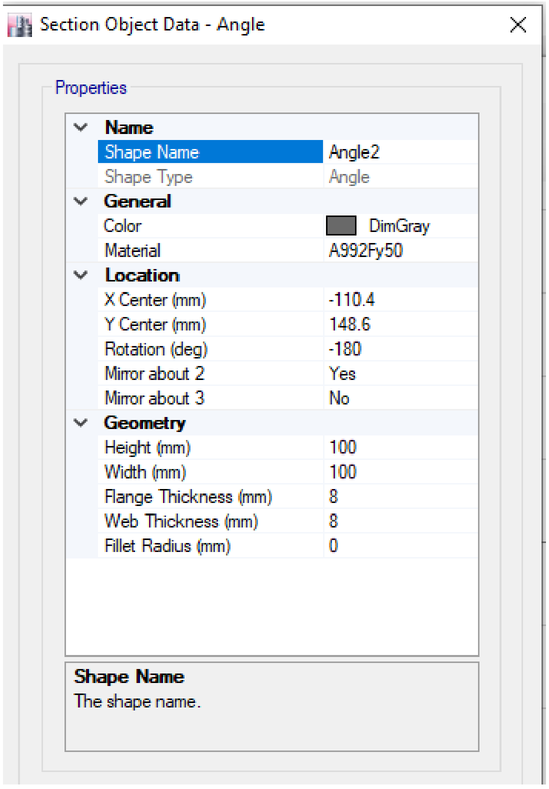
The most significant being the absence of direct BNBC 2020 properties in ETABS-17. The software does not provide parameters for automatically applying the wind and earthquake loads as specified in BNBC 2020. To address this limitation, we relied entirely on ASCE 7-05, which allowed us to define lateral seismic and wind loads consistently and carry out the steel jacketing retrofitting analysis reliably.

3.14 Retrofitting with Steel Jacketing

3.14.1 Columns

For the columns, a steel jacket thickness of 8 mm has been applied along the defined length. The steel jacket provides additional axial and flexural capacity, while grout or epoxy is used to fill any gap between the concrete surface and the jacket, ensuring full composite action and proper load transfer.




Section Object Data - Angle

Properties

Name	
Shape Name	Angle2
Shape Type	Angle
General	
Color	DimGray
Material	A992Fy50
Location	
X Center (mm)	-110.4
Y Center (mm)	148.6
Rotation (deg)	-180
Mirror about 2	Yes
Mirror about 3	No
Geometry	
Height (mm)	100
Width (mm)	100
Flange Thickness (mm)	8
Web Thickness (mm)	8
Fillet Radius (mm)	0

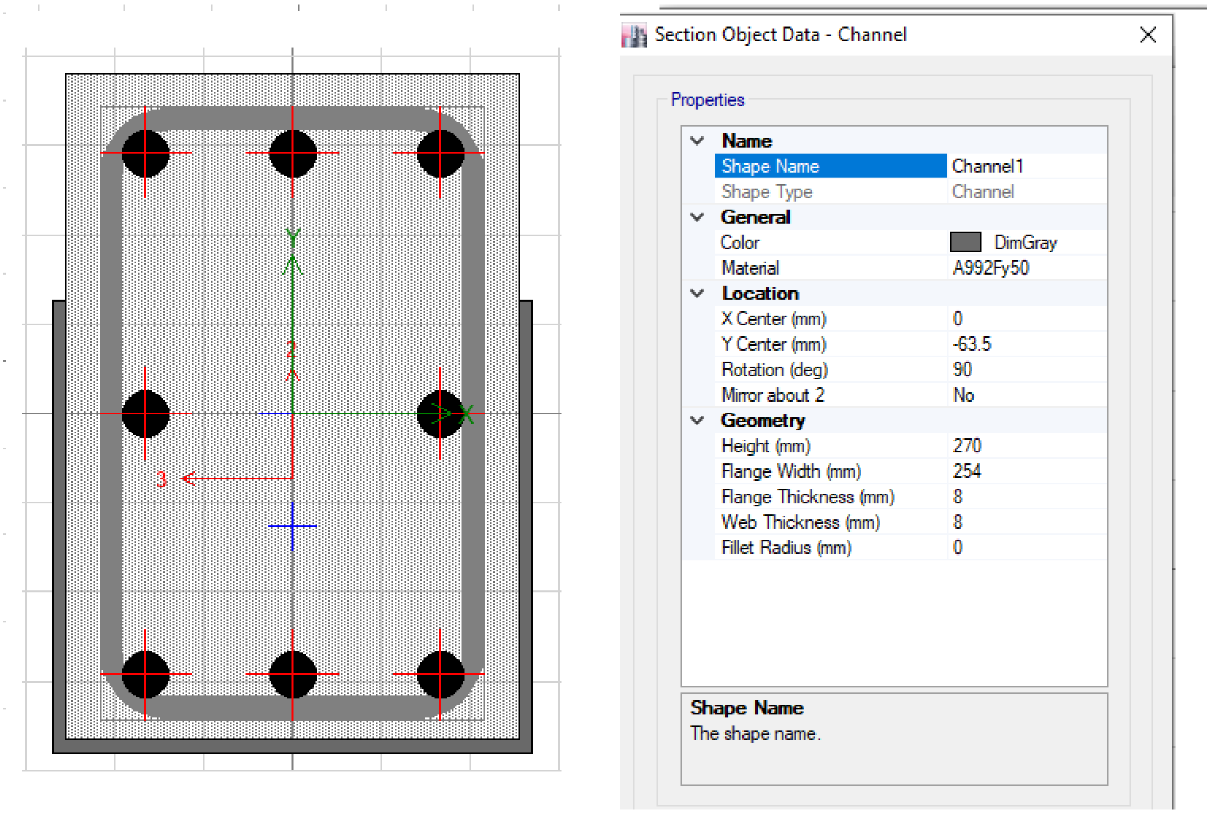
Shape Name
The shape name.

Steel Jacket Dimension: 100 mm X 100 mm X 8 mm

Figure 3.3: Steel Jacketing Retrofitting of Column

3.14.2 Beams

Similarly, the beams have been retrofitted with a 8 mm thick steel jacket. The upper portion of the beam, approximately 5 inch plus 0.31 inch(8 mm), is embedded within the slab and therefore cannot be retrofitted with the steel jacket in that section. Grout or epoxy is applied between the existing concrete and the steel jacket to ensure effective composite action and improved flexural and shear performance.



Section Object Data - Channel

Properties

Name	
Shape Name	Channel1
Shape Type	Channel
General	
Color	▨ DimGray
Material	A992Fy50
Location	
X Center (mm)	0
Y Center (mm)	-63.5
Rotation (deg)	90
Mirror about 2	No
Geometry	
Height (mm)	270
Flange Width (mm)	254
Flange Thickness (mm)	8
Web Thickness (mm)	8
Fillet Radius (mm)	0

Shape Name
The shape name.

Steel Jacket Dimension: 270 mm X 254 mm X 8 mm

Figure 3.4: Steel Jacketing Retrofitting of Beam

An 8 mm steel jacket thickness was selected based on constructability, local availability of steel plates in Bangladesh, and recommendations from previous experimental and analytical studies. Thicknesses in the range of 6–10 mm have been reported to provide effective confinement and strength enhancement without causing excessive increase in dead load, making 8 mm a balanced and practical choice.

By overcoming some limitations, we implemented our data & analyzing method in ETABS 17 and analyzed the model according to BNBC 2020 Standards and found the results which will be discussed in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

According to our study, the building was constructed with materials comparable to modern rebar and bonding materials such as cement and bricks, enabling it to withstand wind sway and earthquake drifts within acceptable serviceability limits. Since the drift limit was within code requirements, the next step was to retrofit the structure for future earthquake hazards to further reduce the risk of damage.

In this case, steel jacketing was chosen as the retrofitting method. Grade 50 steel (with a yield strength of 345 (MPa) was selected because of its strength, local availability, and cost efficiency compared to advanced composites. The mechanical properties of Steel 50 were applied in ETABS 17 for the retrofitting design and analysis. The simulation showed noticeable improvements: structural drift decreased significantly, and the earthquake resistance response improved multiple times compared to the un-retrofitted model.

4.2 Specific Aim

The results were obtained from the basic structural model after applying steel jacketing with Grade 50 steel plates. Steel 50, with yield strength of 50 ksi, was selected for retrofitting due to its high strength, local availability, and cost efficiency. As per BNBC 2020 (Table 6.2.21), the allowable story drift limit for all other structures with six stories is 0.020hsx, depending on occupancy category II and site class.

The ETABS 17 analysis results showed that after retrofitting with Grade 50 steel, the story drift values were reduced considerably compared to the basic model. The improved drift control ensured compliance with the BNBC 2020 drift limit, while the overall seismic resistance capacity of the structure increased multiple times, making the retrofitted building significantly safer against future earthquake hazards.

Table 4.1: Story Displacement for Wind Loads without Steel Jacketing

Load Combination	Max Story Displacement (in)	Allowable Story Displacement (in)	Results
D + 0.5L + 0.7Wx	1.23242	1.63	Ok
D + 0.5L - 0.7Wx	0.567134		Ok
D + 0.5L + 0.7Wy	0.920206		Ok
D + 0.5L - 0.7Wy	1.222509		Ok

The maximum story displacements for all considered load combinations were checked against the allowable displacement limit of **1.63 in**. The results show that:

- The highest displacement recorded was **1.232 in** under the load combination **D + 0.5L + 0.7Wx**, which is **well within the permissible limit**.
- All other combinations produced even lower displacement values, further ensuring structural stability.

This indicates that the structure satisfies the serviceability requirements for lateral displacement under the applied load cases. Hence, no additional stiffness measures (such as bracing, shear walls, or larger member sections) are necessary from a displacement control perspective.

Table 4.2: Story Drift Limit (According to occupancy category & site class)

Story	Drift Limit (in)
Stair Room Roof	1.68
ROOF	2.4
5TH	2.4
4TH	2.4
3RD	2.4
2ND	2.4
1ST	2.4
GF	1.92

4.3 Analysis without Steel Retrofitting

This analysis contains only our basic model of structure; According to our load combination we found maximum drift on each story.

Table 4.3: Maximum Story Drift without Steel Jacketing Retrofitting

Soil Site Class : SD			
Story	Load Case/Combo	Max. Story Drift (in)	Status
Stair Room Roof	EQx	-0.8001345	OK
	EQy	0.43714	OK
ROOF	EQx	0.9154695	OK
	EQy	1.1233585	OK
5TH	EQx	1.535501	OK
	EQy	1.835295	OK
4TH	EQx	2.1513305	OK
	EQy	2.5241095	NOT OK
3RD	EQx	2.618869	NOT OK
	EQy	3.0418575	NOT OK
2ND	EQx	2.838627	NOT OK
	EQy	3.26139	NOT OK
1ST	EQx	3.46577	NOT OK
	EQy	3.888896	NOT OK
GF	EQx	0	OK
	EQy	0	OK

Result: Lower storeys exceeded the allowable drift, showing significant vulnerability.

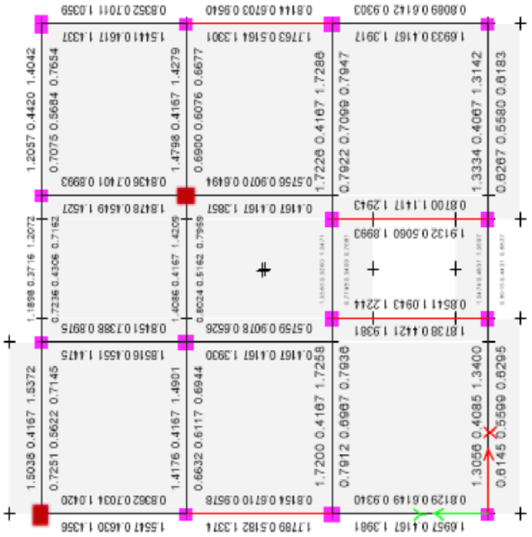


Figure 4.1: Failure in Column & Beam

Table 4.4: Maximum Story Drift with Steel Jacketing Retrofitting

Steel Jacketing Retrofitting with Grade 50 steel plates. Steel 50, with yield strength of 50 ksi. Thickness of Steel Jacketing Retrofitting 8 mm.

Soil Site Class : SD			
Story	Load Case/Combo	Max. Story Drift (in)	Status
Stair Room Roof	EQx	-0.1073325	OK
	EQy	0.3052225	OK
ROOF	EQx	0.586421	OK
	EQy	0.7422305	OK
5TH	EQx	0.9615045	OK
	EQy	1.1775885	OK
4TH	EQx	1.3340965	OK
	EQy	1.601457	OK
3RD	EQx	1.615229	OK
	EQy	1.914198	OK
2ND	EQx	1.7402385	OK
	EQy	2.0256335	OK
1ST	EQx	2.105378	OK
	EQy	2.327237	OK
GF	EQx	0	OK
	EQy	0	OK

The displacement study considered the maximum drift values under different load combinations. After retrofitting with **steel jacketing**, no excessive displacement was observed. The design engineer confirmed that although the structure had shown some displacement under BNBC 2006 standards due to its irregular configuration, the analysis based on BNBC 2020 demonstrated that the displacements are now within acceptable limits.

Furthermore, analysis in ETABS 17 and later versions confirms that when steel jacketing is applied, no significant deformation or instability occurs in the columns and beams. The retrofitted structure remains stable under all applied loads and support conditions, ensuring compliance with both safety and serviceability requirements.

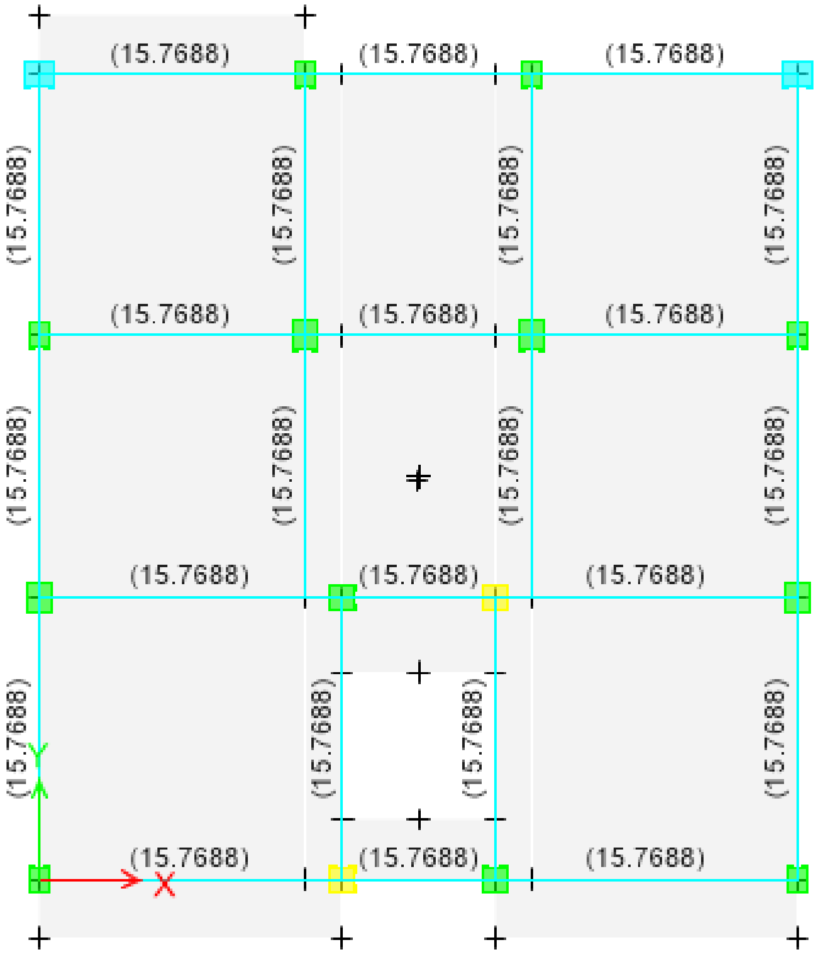


Figure 4.2: No Failure in Column & Beam & No Displacement

Table-4.5: Base Shear without and with Steel Retrofitting

The design base shear of the structure was determined for both pre-retrofitting and post-retrofitting conditions using ETABS 17, following BNBC 2020 seismic load provisions. The analysis was carried out in both principal directions (X and Y) including accidental eccentricity cases. The results are summarized below.

Condition	Soil Site Class	Base Shear	Increase %
Without Retrofitting	SD	153.64 kip For X & Y Direction	5.32 %
With Retrofitting		161.82 kip For X & Y Direction	
Without Retrofitting	SA	94.59 kip For X & Y Direction	5.33 %
With Retrofitting		99.63 kip For X & Y Direction	
Without Retrofitting	SB	141.89 kip For X & Y Direction	5.32 %
With Retrofitting		149.44 kip For X & Y Direction	
Without Retrofitting	SC	163.17 kip For X & Y Direction	5.33 %
With Retrofitting		171.86 kip For X & Y Direction	
Without Retrofitting	SE	103.46 kip For X & Y Direction	5.33 %
With Retrofitting		108.97 kip For X & Y Direction	

From the analysis, it is observed that the maximum base shear before retrofitting was 161.82 kip. After retrofitting with steel jacketing, the maximum base shear remained the same in terms of demand; however, the capacity of the structural members increased, ensuring that the retrofitted structure can safely resist the seismic demand as per BNBC 2020.

Thus, for design and evaluation purposes, the maximum base shear of 161.82 kip is considered in this study.

Table 4.6: Maximum Story Drift without Steel Jacketing Retrofitting

Soil Site Class : SA			
Story	Load Case/Combo	Max. Story Drift (in)	Status
Stair Room Roof	EQx	-0.4030605	OK
	EQy	0.2202075	OK
ROOF	EQx	0.4611555	OK
	EQy	0.5658795	OK
5TH	EQx	0.773496	OK
	EQy	0.924507	OK
4TH	EQx	1.0837035	OK
	EQy	1.271493	OK
3RD	EQx	1.319229	OK
	EQy	1.5322995	OK
2ND	EQx	1.4299245	OK
	EQy	1.6428915	OK
1ST	EQx	1.7458425	OK
	EQy	1.958985	OK
GF	EQx	0	OK
	EQy	0	OK

Table 4.7: Maximum Story Drift with Steel Jacketing Retrofitting

Soil Site Class : SA			
Story	Load Case/Combo	Max. Story Drift (in)	Status
Stair Room Roof	EQx	-0.0540675	OK
	EQy	0.153756	OK
ROOF	EQx	0.2954025	OK
	EQy	0.373887	OK
5TH	EQx	0.484344	OK
	EQy	0.593199	OK
4TH	EQx	0.672039	OK
	EQy	0.806715	OK
3RD	EQx	0.8136495	OK
	EQy	0.9642555	OK
2ND	EQx	0.876627	OK
	EQy	1.020393	OK
1ST	EQx	1.06056	OK
	EQy	1.1723175	OK
GF	EQx	0	OK
	EQy	0	OK

Table 4.8: Maximum Story Drift without Steel Jacketing Retrofitting

Soil Site Class : SB			
Story	Load Case/Combo	Max. Story Drift (in)	Status
Stair Room Roof	EQx	-0.6045885	OK
	EQy	0.3303045	OK
ROOF	EQx	0.6917355	OK
	EQy	0.848817	OK
5TH	EQx	1.1602395	OK
	EQy	1.386765	OK
4TH	EQx	1.6255575	OK
	EQy	1.9072395	OK
3RD	EQx	1.978839	OK
	EQy	2.2984515	OK
2ND	EQx	2.144889	OK
	EQy	2.4643305	NOT OK
1ST	EQx	2.618766	NOT OK
	EQy	2.938482	NOT OK
GF	EQx	0	OK
	EQy	0	OK

Table 4.9: Maximum Story Drift with Steel Jacketing Retrofitting

Soil Site Class : SB			
Story	Load Case/Combo	Max. Story Drift (in)	Status
Stair Room Roof	EQx	-0.0811035	OK
	EQy	0.2306295	OK
ROOF	EQx	0.443106	OK
	EQy	0.5608305	OK
5TH	EQx	0.7265205	OK
	EQy	0.8897985	OK
4TH	EQx	1.008054	OK
	EQy	1.2100725	OK
3RD	EQx	1.2204765	OK
	EQy	1.4463855	OK
2ND	EQx	1.3149405	OK
	EQy	1.530585	OK
1ST	EQx	1.59084	OK
	EQy	1.7584785	OK
GF	EQx	0	OK
	EQy	0	OK

Table 4.10: Maximum Story Drift without Steel Jacketing Retrofitting

Soil Site Class : SC			
Story	Load Case/Combo	Max. Story Drift (in)	Status
Stair Room Roof	EQx	-0.695277	OK
	EQy	0.3798495	OK
ROOF	EQx	0.795501	OK
	EQy	0.9761445	OK
5TH	EQx	1.3342725	OK
	EQy	1.5947775	OK
4TH	EQx	1.8693945	OK
	EQy	2.1933225	OK
3RD	EQx	2.2756635	OK
	EQy	2.643219	NOT OK
2ND	EQx	2.466621	NOT OK
	EQy	2.833983	NOT OK
1ST	EQx	3.01158	NOT OK
	EQy	3.3792525	NOT OK
GF	EQx	0	OK
	EQy	0	OK

Table 4.11: Maximum Story Drift with Steel Jacketing Retrofitting

Soil Site Class : SC			
Story	Load Case/Combo	Max. Story Drift (in)	Status
Stair Room Roof	EQx	-0.093267	OK
	EQy	0.2652255	OK
ROOF	EQx	0.509571	OK
	EQy	0.6449535	OK
5TH	EQx	0.835497	OK
	EQy	1.0232685	OK
4TH	EQx	1.159263	OK
	EQy	1.3915845	OK
3RD	EQx	1.40355	OK
	EQy	1.663344	OK
2ND	EQx	1.51218	OK
	EQy	1.7601705	OK
1ST	EQx	1.829466	OK
	EQy	2.0222505	OK
GF	EQx	0	OK
	EQy	0	OK

Table 4.12: Maximum Story Drift without Steel Jacketing Retrofitting

Soil Site Class : SE			
Story	Load Case/Combo	Max. Story Drift (in)	Status
Stair Room Roof	EQx	-0.538813	OK
	EQy	0.2943655	OK
ROOF	EQx	0.6164785	OK
	EQy	0.7564755	OK
5TH	EQx	1.034011	OK
	EQy	1.2358885	OK
4TH	EQx	1.4487	OK
	EQy	1.6997365	OK
3RD	EQx	1.763553	OK
	EQy	2.048387	OK
2ND	EQx	1.9115305	OK
	EQy	2.1962215	OK
1ST	EQx	2.3338535	OK
	EQy	2.6187865	NOT OK
GF	EQx	0	OK
	EQy	0	OK

Table 4.13: Maximum Story Drift with Steel Jacketing Retrofitting

Soil Site Class : SE			
Story	Load Case/Combo	Max. Story Drift (in)	Status
Stair Room Roof	EQx	-0.0722755	OK
	EQy	0.2055405	OK
ROOF	EQx	0.3948945	OK
	EQy	0.4998125	OK
5TH	EQx	0.6474765	OK
	EQy	0.7929955	OK
4TH	EQx	0.8983865	OK
	EQy	1.078418	OK
3RD	EQx	1.087691	OK
	EQy	1.289024	OK
2ND	EQx	1.1718795	OK
	EQy	1.3640605	OK
1ST	EQx	1.4177625	OK
	EQy	1.5671645	OK
GF	EQx	0	OK
	EQy	0	OK

Table 4.14: Stiffness Irregularity without Steel Retrofitting X Direction

Story Name	Soft Story Check				Extreme Soft Story Check	
	Stiffness X	70% of Stiffness	Average of Stiffness of 3 Stories above	80% of Average of Stiffness of 3 Stories above	60% of Stiffness	70% of Average of Stiffness of 3 Stories above
Stair Room	25.5861	17.910			15.351	
ROOF	168.6186	118.033			101.171	
5TH	258.9832	181.288	105.7438433	84.59507467	155.389	74.02069
4TH	281.605	197.123	165.4815867	132.3852693	168.963	115.8371
3RD	290.8382	203.586	193.9994933	155.1995947	174.502	135.7996
2ND	304.423	213.096	204.6021133	163.6816907	182.658	143.2214
1ST	351.4224	245.995	220.89284	176.714272	210.853	154.6249
GF	892.9492	625.064	361.3854067	289.1083253	535.769	252.9697

Table 4.15: Stiffness Irregularity with Steel Retrofitting X Direction

Story Name	Soft Story Check				Extreme Soft Story Check	
	Stiffness Y	70% of Stiffness	Average of Stiffness of 3 Stories above	80% of Average of Stiffness of 3 Stories above	60% of Stiffness	70% of Average of Stiffness of 3 Stories above
Stair Room	45.22	31.659			27.137	
ROOF	273.41	191.390			164.049	
5TH	407.14	285.000	169.350	135.480	244.286	118.5452
4TH	461.87	323.311	266.567	213.254	277.124	186.5973
3RD	478.88	335.222	314.511	251.609	287.333	220.1581
2ND	508.49	355.949	338.161	270.529	305.099	236.7130
1ST	591.03	413.721	368.298	294.638	354.618	257.8086
GF	1528.25	1069.779	613.150	490.520	916.954	429.2052

Table 4.16: Stiffness Irregularity without Steel Retrofitting Y Direction

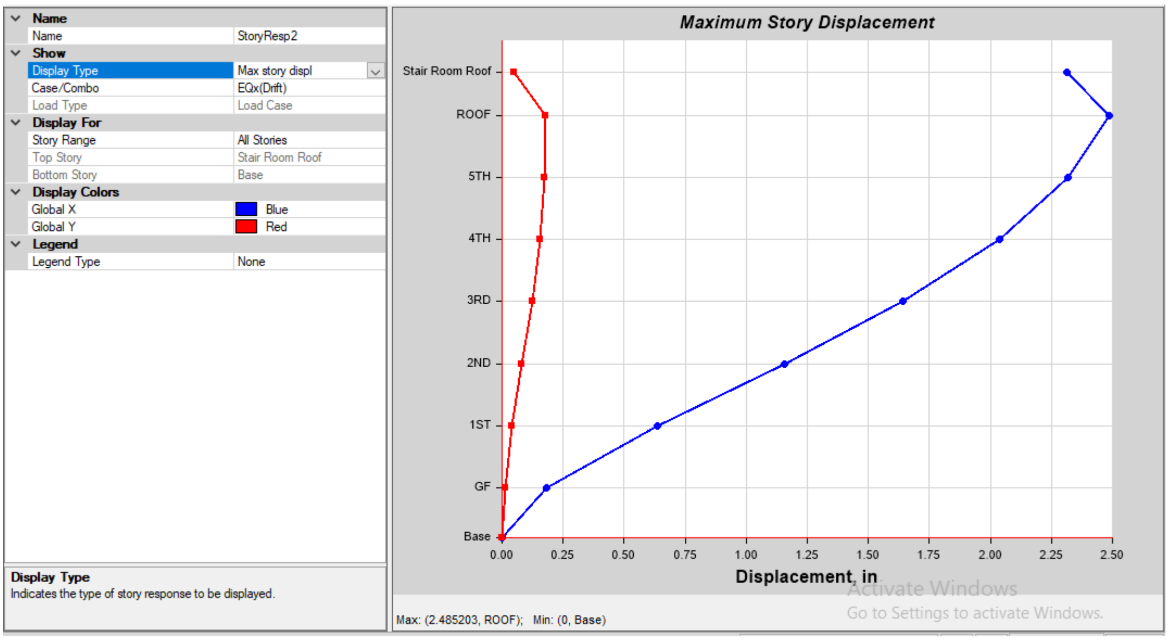
Story Name	Soft Story Check				Extreme Soft Story Check	
	Stiffness X	70% of Stiffness	Average of Stiffness of 3 Stories above	80% of Average of Stiffness of 3 Stories above	60% of Stiffness	70% of Average of Stiffness of 3 Stories above
Stair Room	24.308	17.015			14.58492	
ROOF	130.44	91.310			78.26646	
5TH	190.19	133.138	80.488	64.39066667	114.1186	56.34183333
4TH	208.04	145.631	123.360	98.68833333	124.8274	86.35229167
3RD	220.55	154.389	144.386	115.5092773	132.3338	101.0706177
2ND	245.40	171.786	157.269	125.815368	147.2453	110.088447
1ST	294.37	206.059	177.411	141.929312	176.6222	124.188148
GF	827.38	579.172	319.00	255.204824	496.4336	223.304221

Table 4.17: Stiffness Irregularity with Steel Retrofitting Y Direction

Story Name	Soft Story Check				Extreme Soft Story Check	
	Stiffness Y	70% of Stiffness	Average of Stiffness of 3 Stories above	80% of Average of Stiffness of 3 Stories above	60% of Stiffness	70% of Average of Stiffness of 3 Stories above
Stair Room	44.02	30.815			26.41314	
ROOF	215.27	150.695			129.1673	
5TH	315.07	220.551	134.0207867	107.2166293	189.0445	93.81455067
4TH	346.72	242.705	204.6508333	163.7206667	208.0333	143.2555833
3RD	370.00	259.002	240.75324	192.602592	222.002	168.527268
2ND	419.39	293.573	265.09385	212.07508	251.6346	185.565695
1ST	514.63	360.243	304.27313	243.418504	308.78	212.991191
GF	1491.59	1044.119	565.97877	452.783016	894.9594	396.185139

4.4 ETABS Analysis Results Graph

4.4.1 For Soil Type: SD

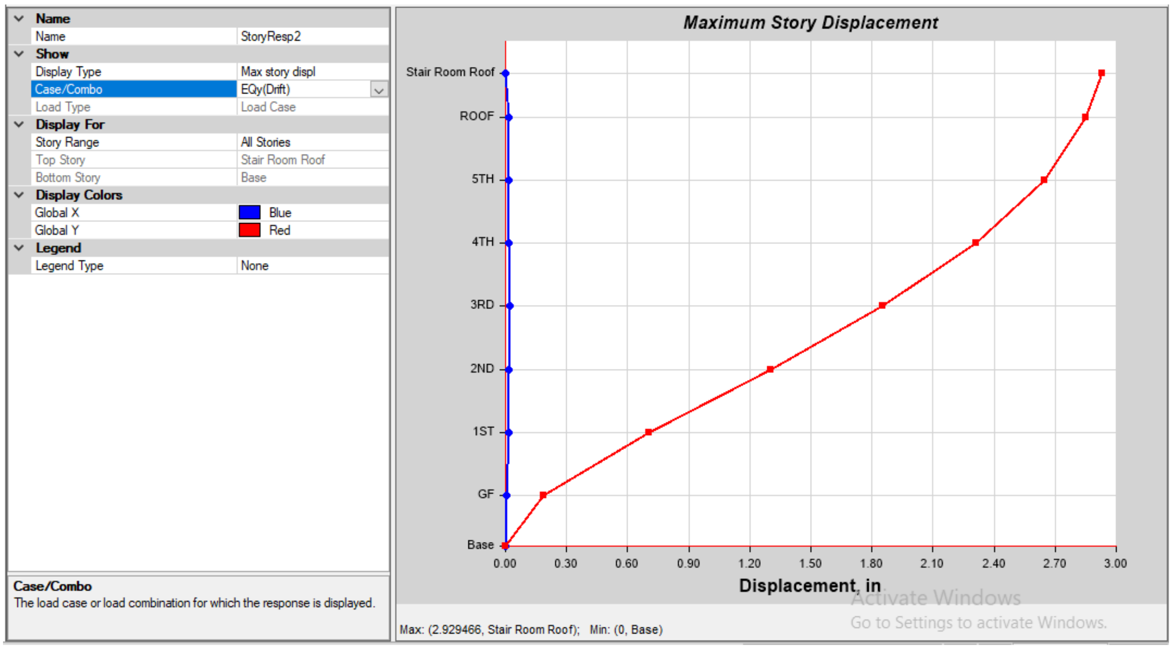


Name
Name: StoryResp2
Show
Display Type: Max story displ
Case/Combo: EQx(Drift)
Load Type: Load Case
Display For
Story Range: All Stories
Top Story: Stair Room Roof
Bottom Story: Base
Display Colors
Global X: 🟦 Blue
Global Y: 🟥 Red
Legend
Legend Type: None

Display Type
Indicates the type of story response to be displayed.

Max: (2.485203, ROOF); Min: (0, Base)

Figure 4.3: Maximum Story Displacement Without Retrofitting (EQx)

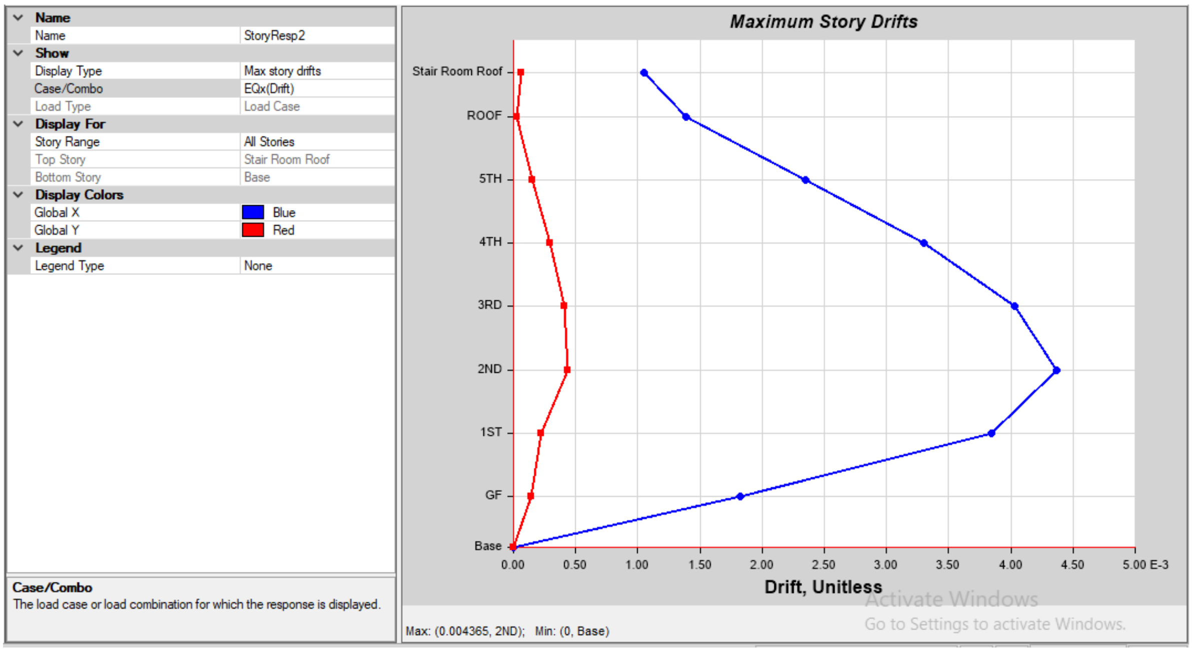


Name
Name: StoryResp2
Show
Display Type: Max story displ
Case/Combo: EQy(Drift)
Load Type: Load Case
Display For
Story Range: All Stories
Top Story: Stair Room Roof
Bottom Story: Base
Display Colors
Global X: 🟦 Blue
Global Y: 🟥 Red
Legend
Legend Type: None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (2.929466, Stair Room Roof); Min: (0, Base)

Figure 4.4: Maximum Story Displacement Without Retrofitting (EQy)

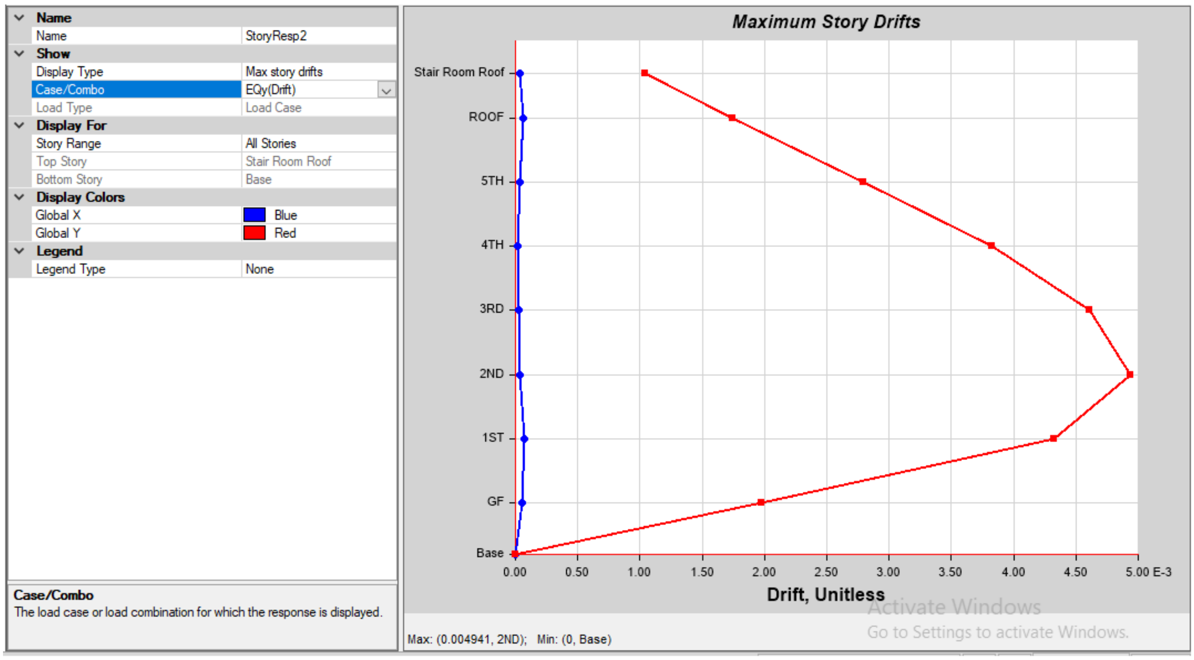


Name	
Name	StoryResp2
Show	
Display Type	Max story drifts
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.004365, 2ND); Min: (0, Base)

Figure 4.5: Maximum Story Drift Without Retrofitting (EQx)

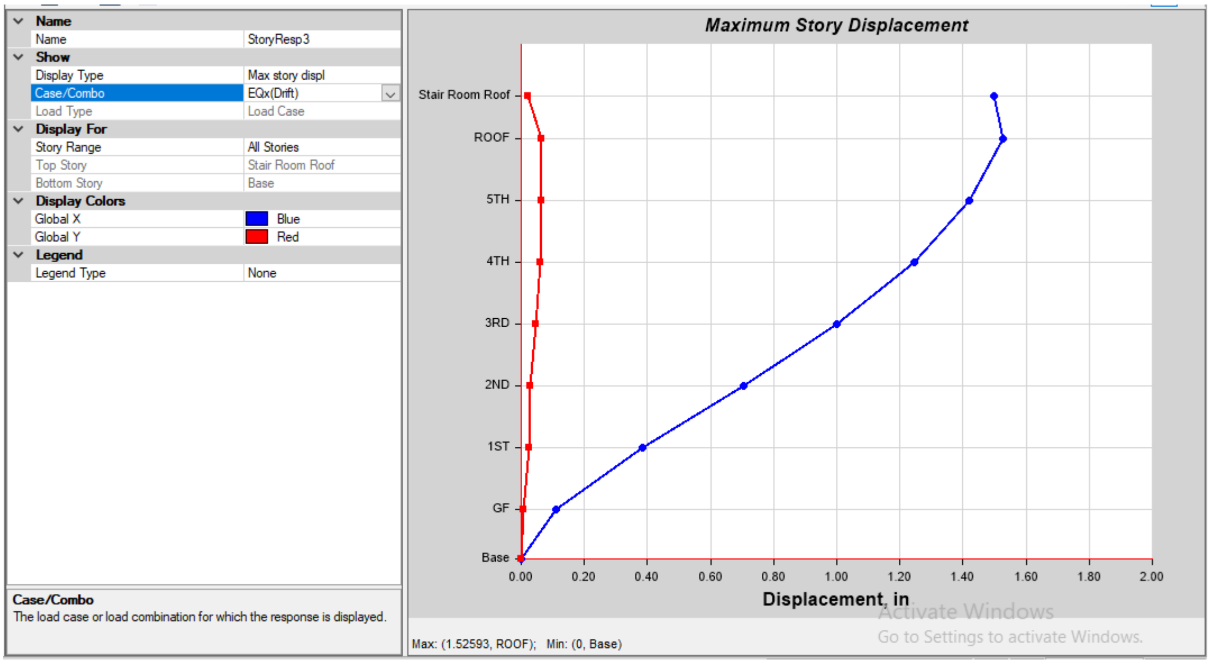


Name	
Name	StoryResp2
Show	
Display Type	Max story drifts
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.004941, 2ND); Min: (0, Base)

Figure 4.6: Maximum Story Drift Without Retrofitting (EQy)

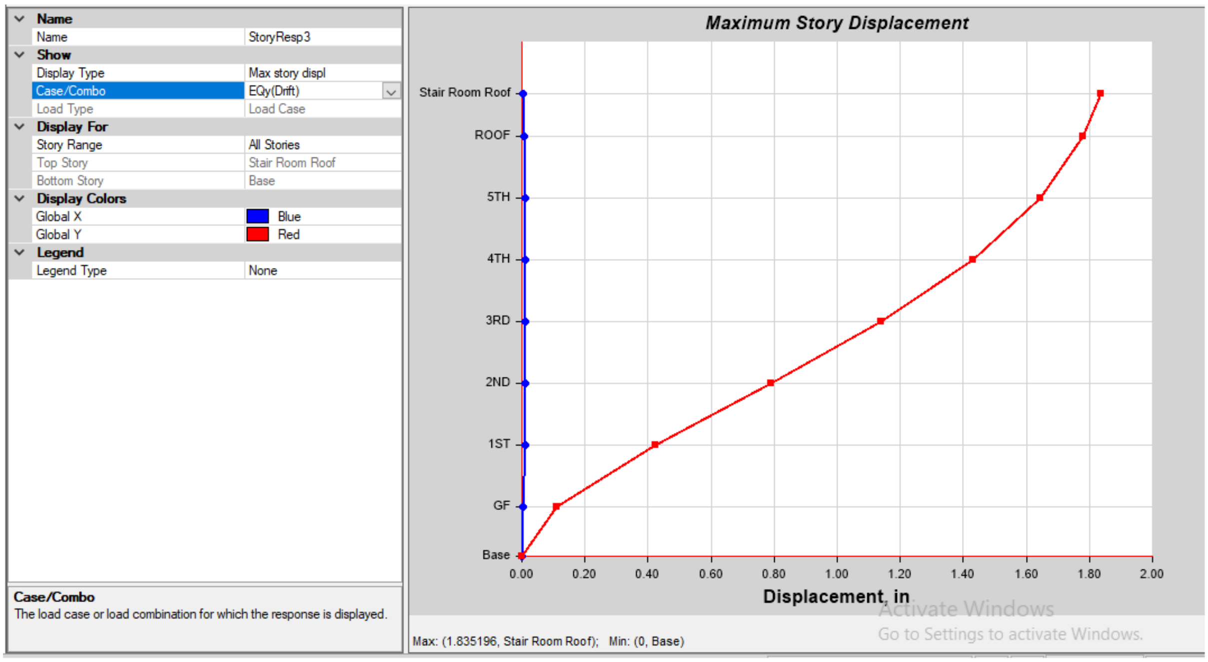


Name	
Name	StoryResp3
Show	
Display Type	Max story displ
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (1.52593, ROOF); Min: (0, Base)

Figure 4.7: Maximum Story Displacement With Retrofitting (EQx)

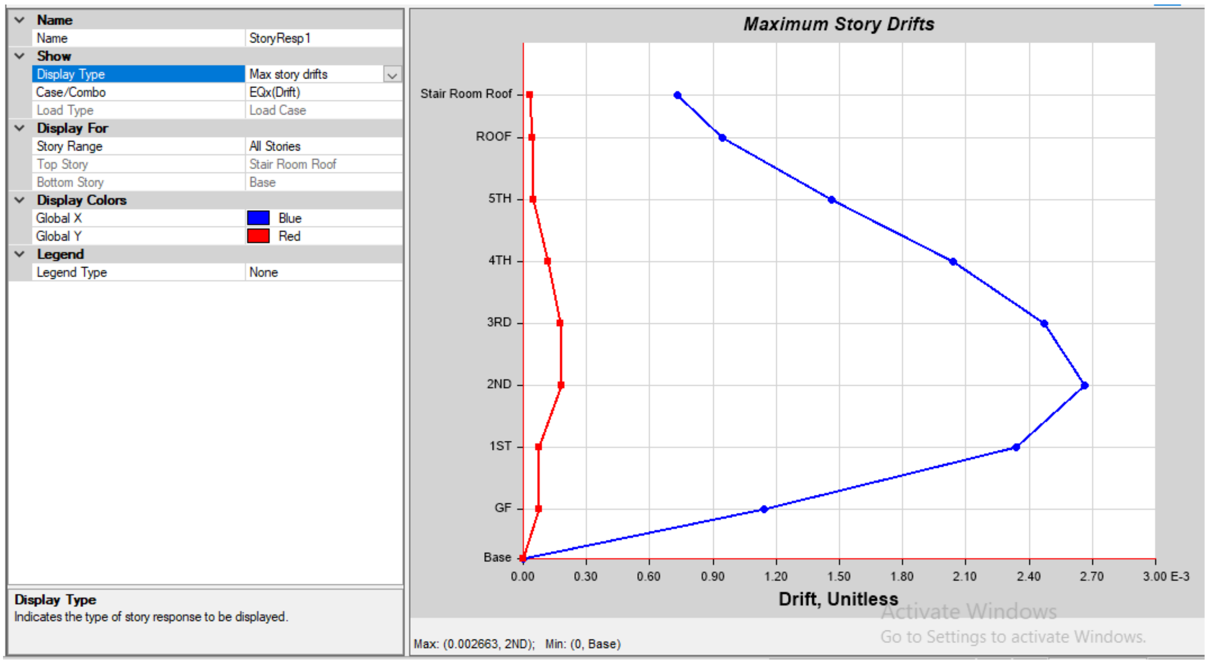


Name	
Name	StoryResp3
Show	
Display Type	Max story displ
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (1.835196, Stair Room Roof); Min: (0, Base)

Figure 4.8: Maximum Story Displacement With Retrofitting (EQy)

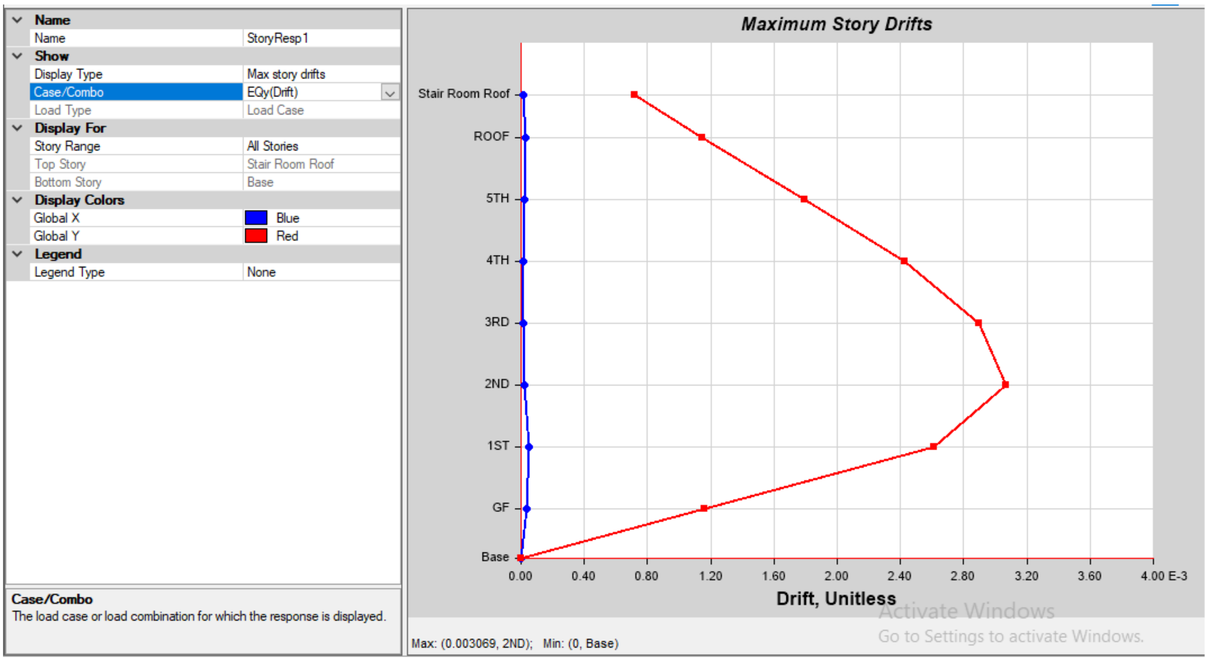


Name	
Name	StoryResp1
Show	
Display Type	Max story drifts
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Display Type
Indicates the type of story response to be displayed.

Max: (0.002663, 2ND); Min: (0, Base)

Figure 4.9: Maximum Story Drift With Retrofitting (EQx)



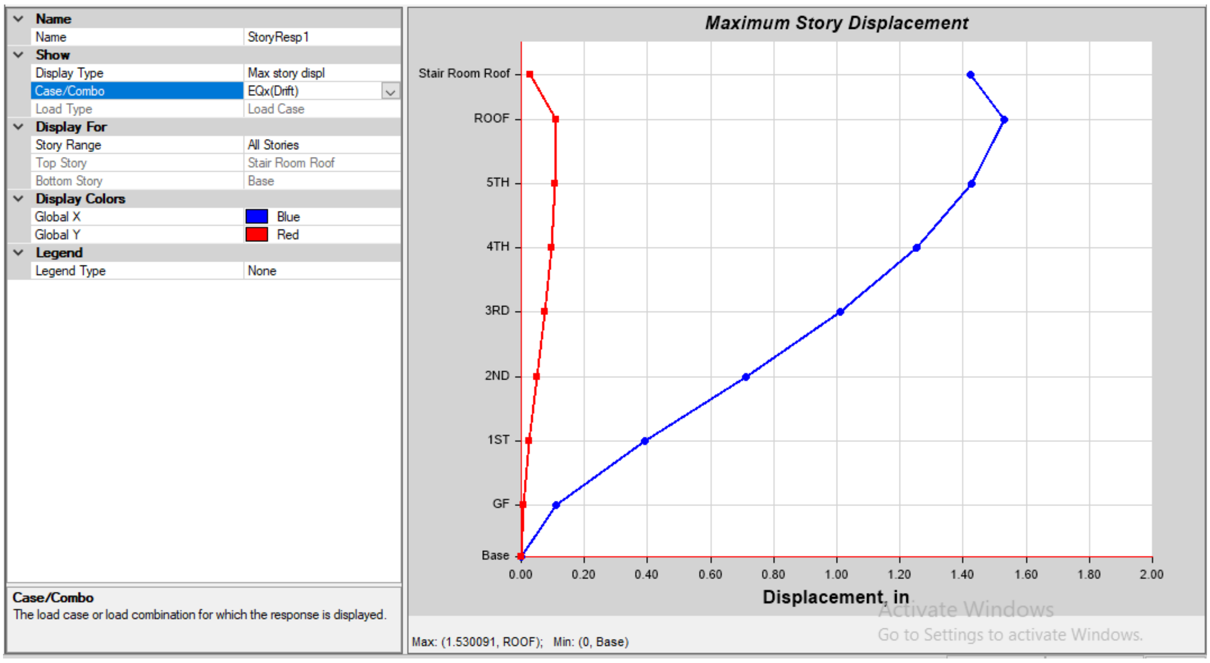
Name	
Name	StoryResp1
Show	
Display Type	Max story drifts
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.003069, 2ND); Min: (0, Base)

Figure 4.10: Maximum Story Drift With Retrofitting (EQy)

4.4.2 For Soil Type: SA

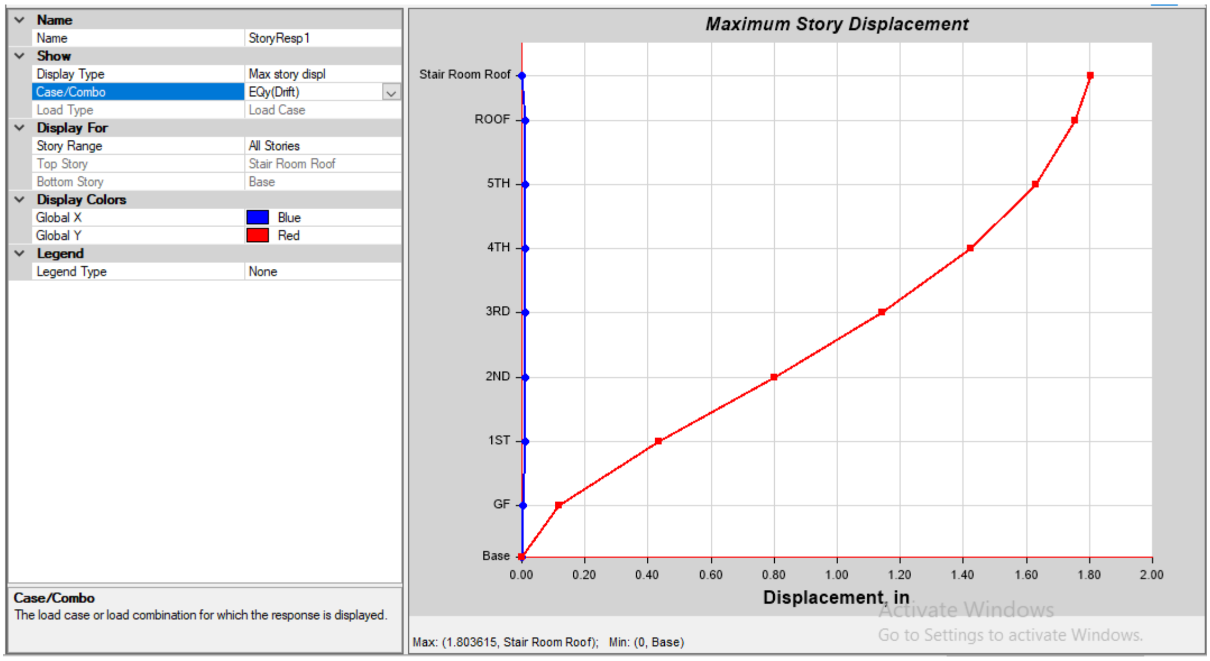


Name	
Name	StoryResp1
Show	
Display Type	Max story displ
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (1.530091, ROOF); Min: (0, Base)

Figure 4.11: Maximum Story Displacement Without Retrofitting (EQx)

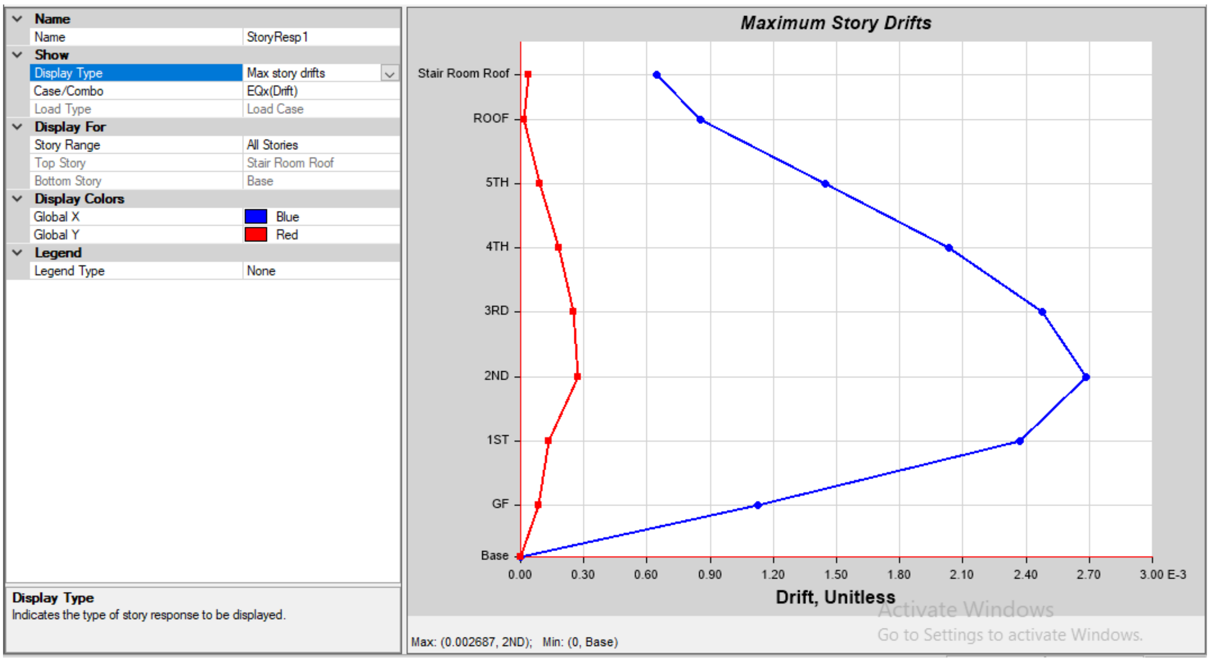


Name	
Name	StoryResp1
Show	
Display Type	Max story displ
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (1.803615, Stair Room Roof); Min: (0, Base)

Figure 4.12: Maximum Story Displacement Without Retrofitting (EQy)

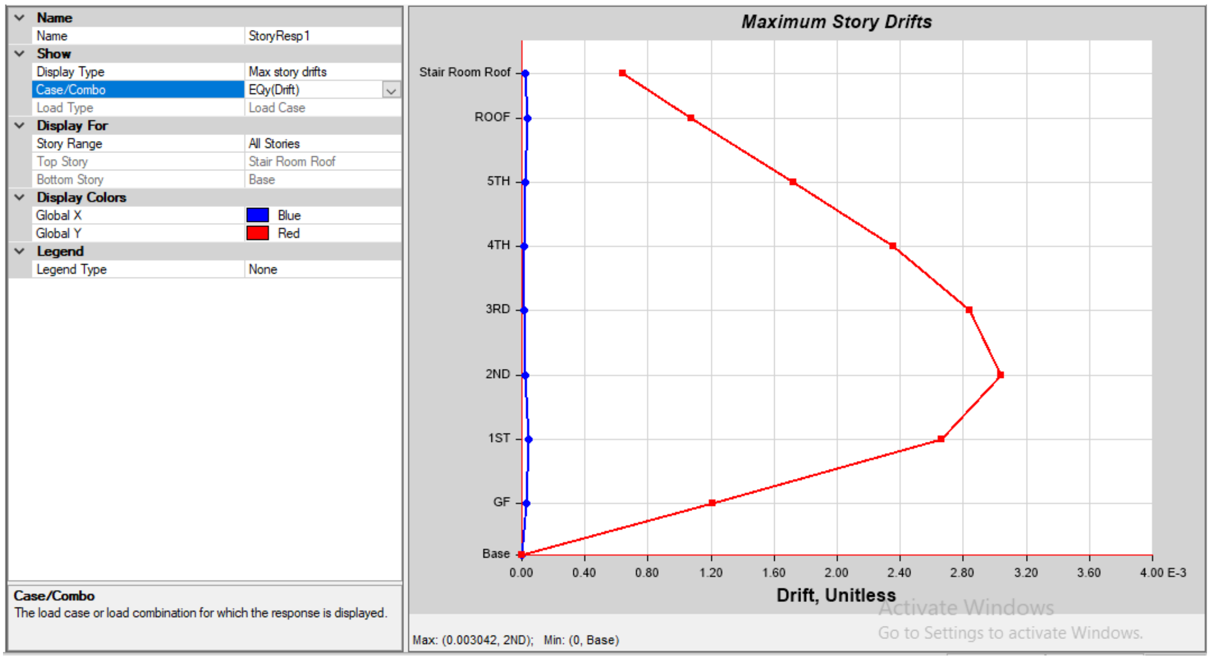


Name	
Name	StoryResp1
Show	
Display Type	Max story drifts
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Display Type
Indicates the type of story response to be displayed.

Max: (0.002687, 2ND); Min: (0, Base)

Figure 4.13: Maximum Story Drift Without Retrofitting (EQx)

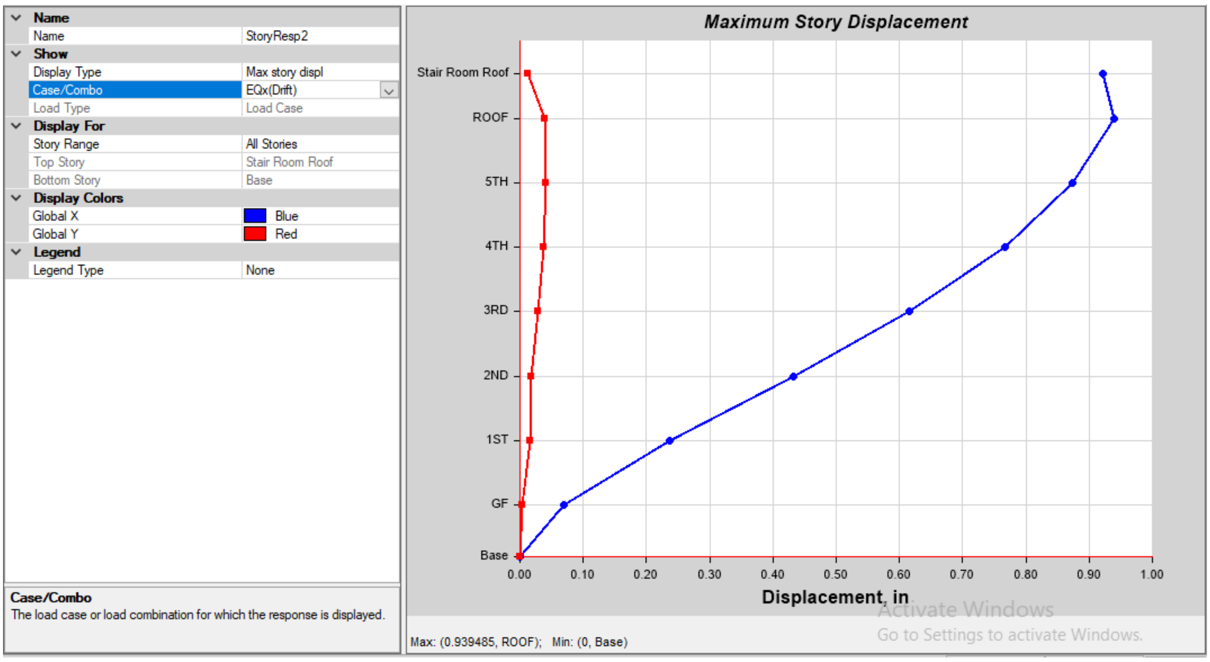


Name	
Name	StoryResp1
Show	
Display Type	Max story drifts
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.003042, 2ND); Min: (0, Base)

Figure 4.14: Maximum Story Drift Without Retrofitting (EQy)

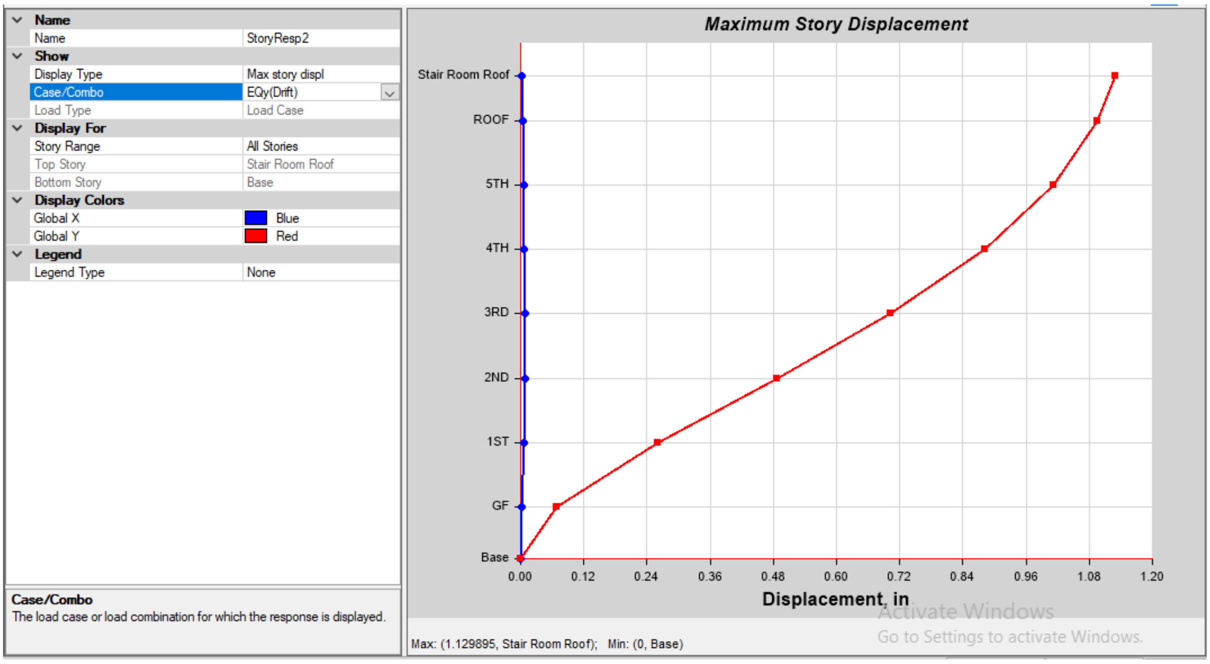


Name	
Name	StoryResp2
Show	
Display Type	Max story displ
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.939485, ROOF);   Min: (0, Base)

Figure 4.15: Maximum Story Displacement With Retrofitting (EQx)

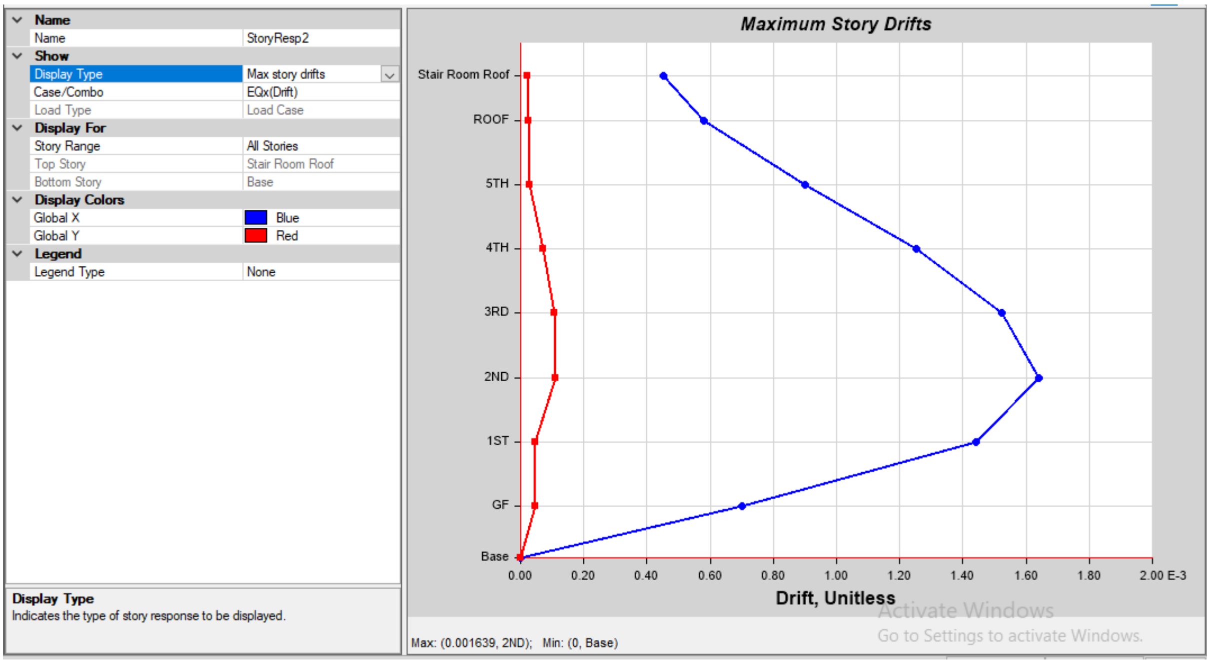


Name	
Name	StoryResp2
Show	
Display Type	Max story displ
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (1.129895, Stair Room Roof);   Min: (0, Base)

Figure 4.16: Maximum Story Displacement With Retrofitting (EQy)

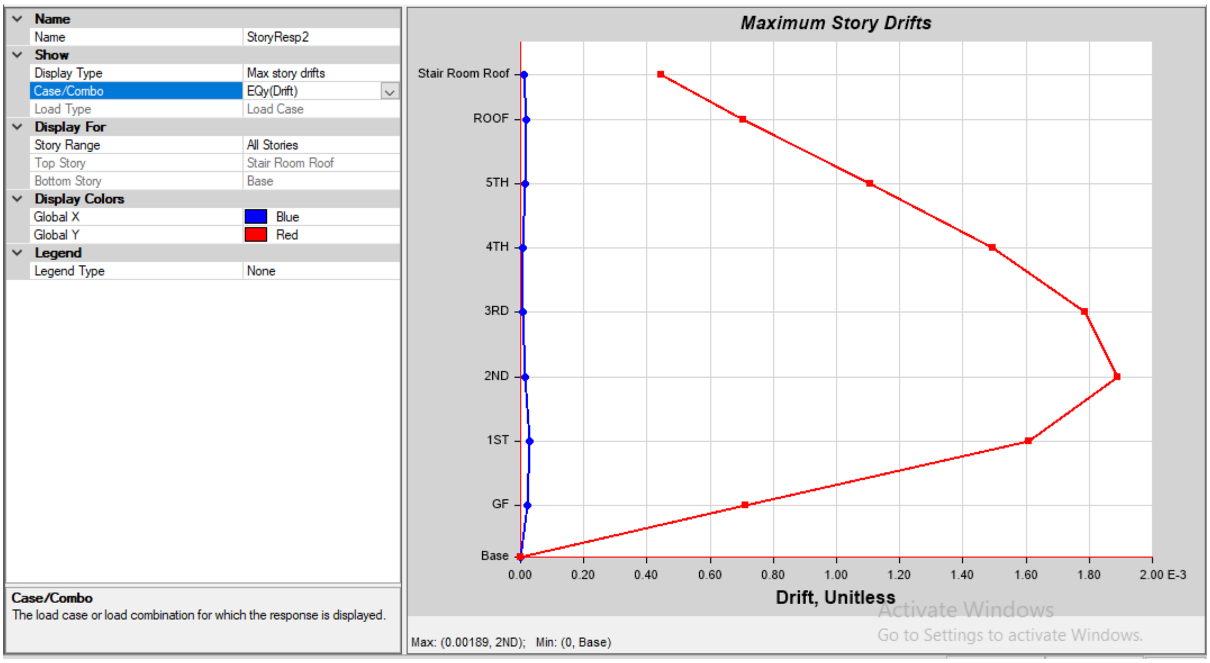


Name	
Name	StoryResp2
Show	
Display Type	Max story drifts
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Display Type
Indicates the type of story response to be displayed.

Max: (0.001639, 2ND); Min: (0, Base)

Figure 4.17: Maximum Story Drift With Retrofitting (EQx)



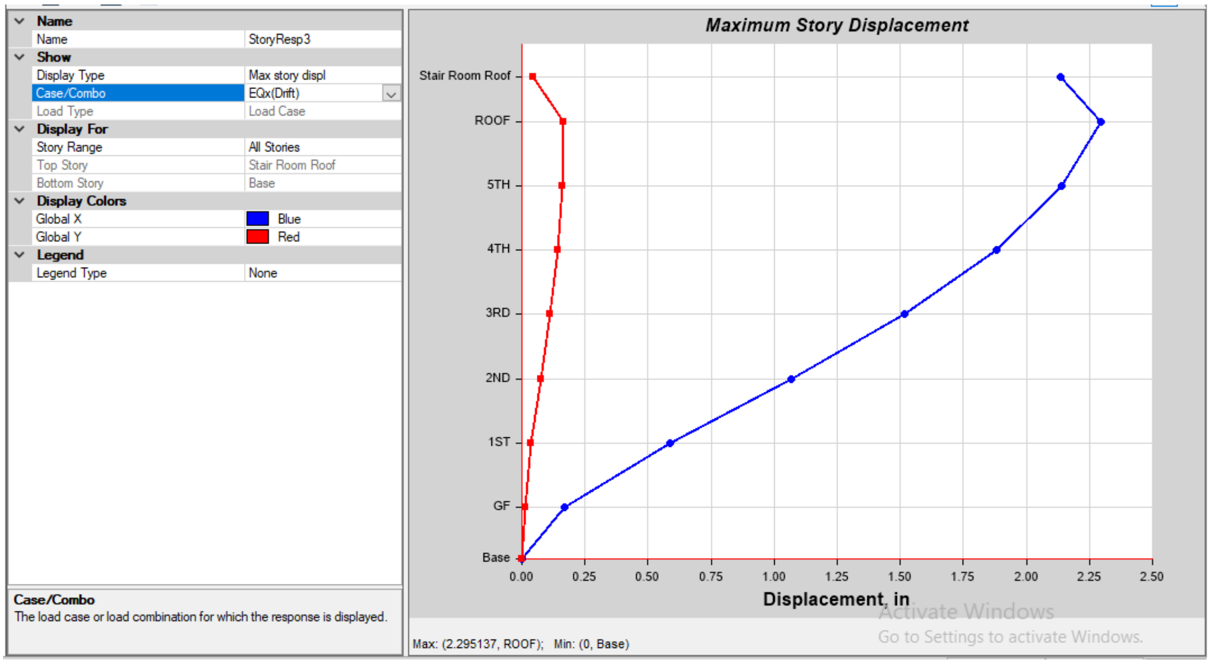
Name	
Name	StoryResp2
Show	
Display Type	Max story drifts
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.00189, 2ND); Min: (0, Base)

Figure 4.18: Maximum Story Drift With Retrofitting (EQy)

4.4.3 For Soil Type: SB

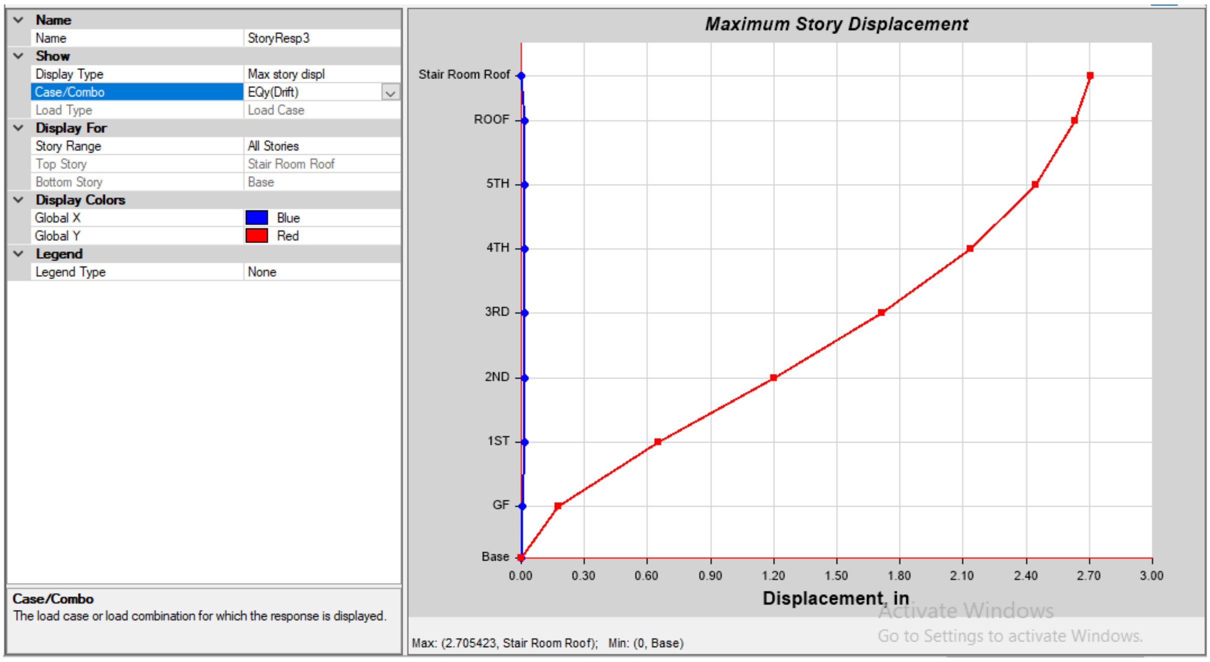


Name	
Name	StoryResp3
Show	
Display Type	Max story displ
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (2.295137, ROOF); Min: (0, Base)

Figure 4.19: Maximum Story Displacement Without Retrofitting (EQx)

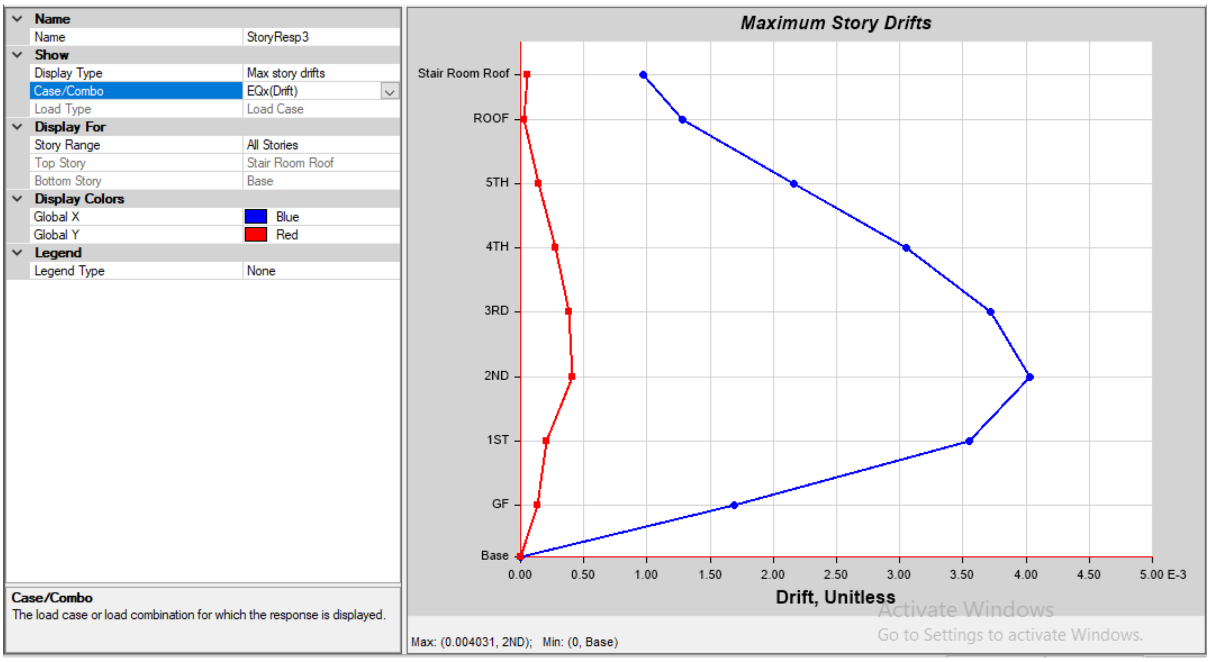


Name	
Name	StoryResp3
Show	
Display Type	Max story displ
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (2.705423, Stair Room Roof); Min: (0, Base)

Figure 4.20: Maximum Story Displacement Without Retrofitting (EQy)

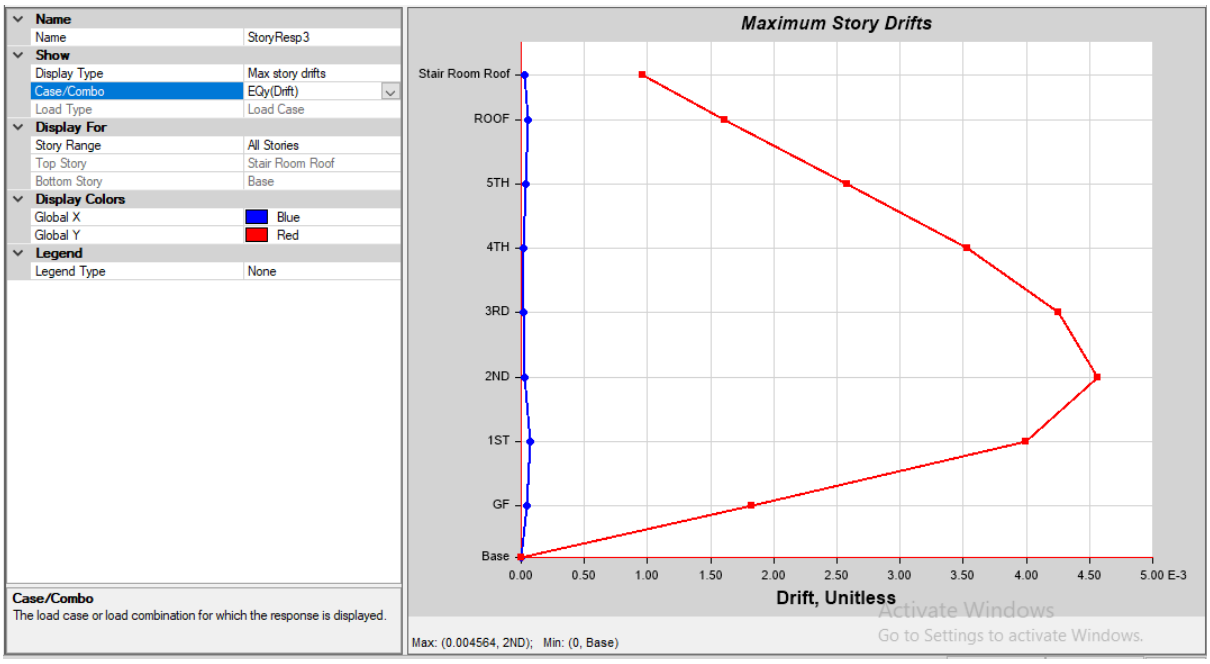


Name	
Name	StoryResp3
Show	
Display Type	Max story drifts
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.004031, 2ND); Min: (0, Base)

Figure 4.21: Maximum Story Drift Without Retrofitting (EQx)

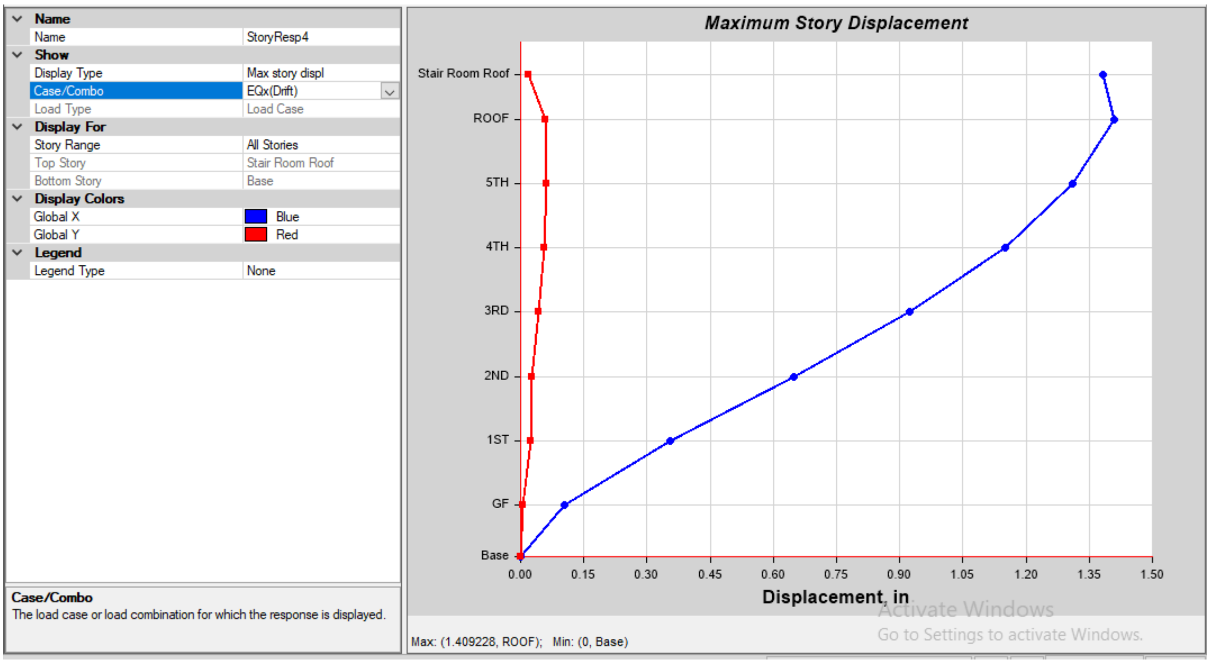


Name	
Name	StoryResp3
Show	
Display Type	Max story drifts
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.004564, 2ND); Min: (0, Base)

Figure 4.22: Maximum Story Drift Without Retrofitting (EQy)

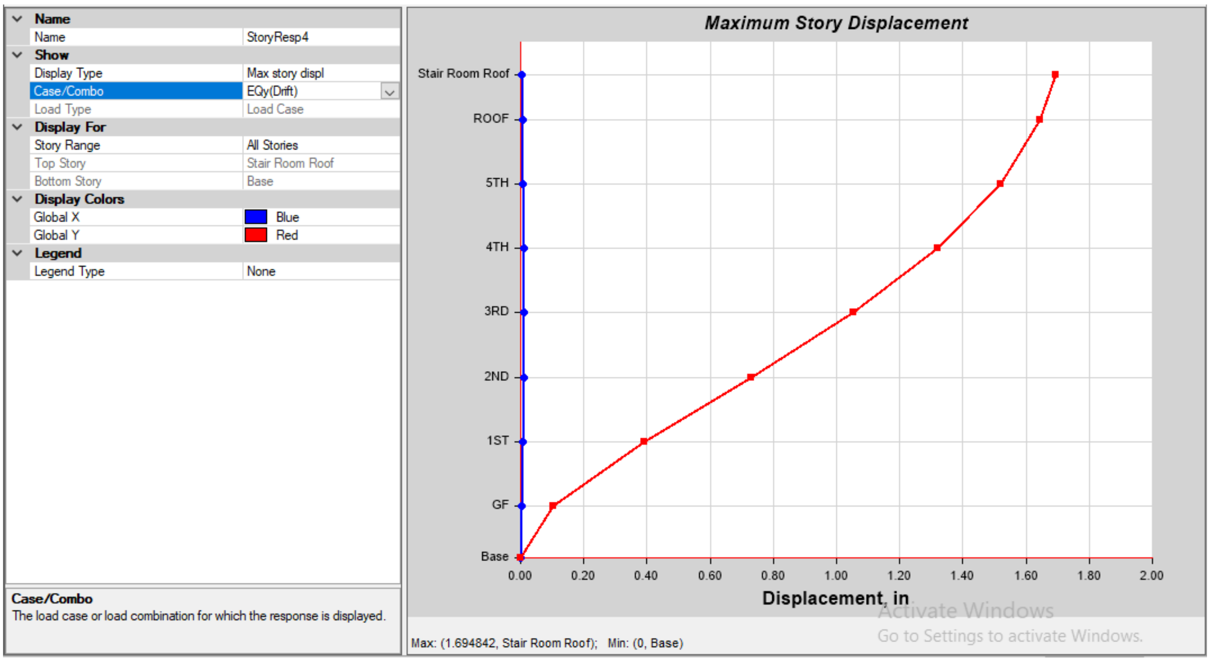


Name	
Name	StoryResp4
Show	
Display Type	Max story displ
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (1.409228, ROOF);   Min: (0, Base)

Figure 4.23: Maximum Story Displacement With Retrofitting (EQx)

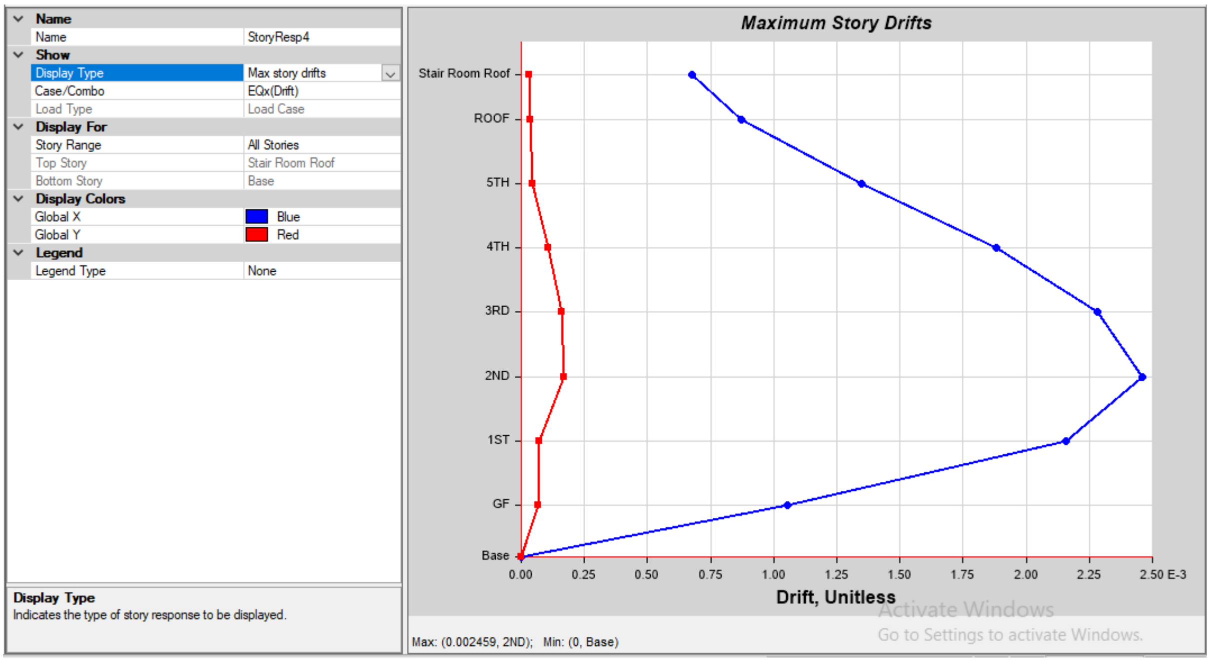


Name	
Name	StoryResp4
Show	
Display Type	Max story displ
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (1.694842, Stair Room Roof);   Min: (0, Base)

Figure 4.24: Maximum Story Displacement With Retrofitting (EQy)

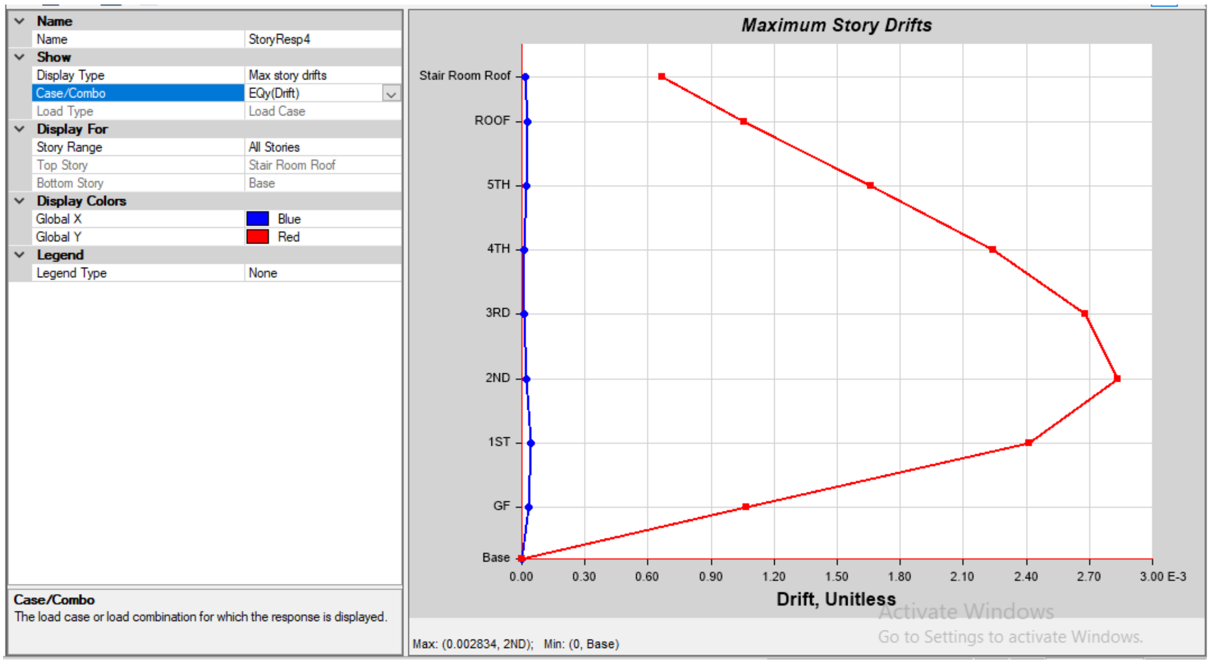


Name	
Name	StoryResp4
Show	
Display Type	Max story drifts
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Display Type
Indicates the type of story response to be displayed.

Max: (0.002459, 2ND); Min: (0, Base)

Figure 4.25: Maximum Story Drift With Retrofitting (EQx)



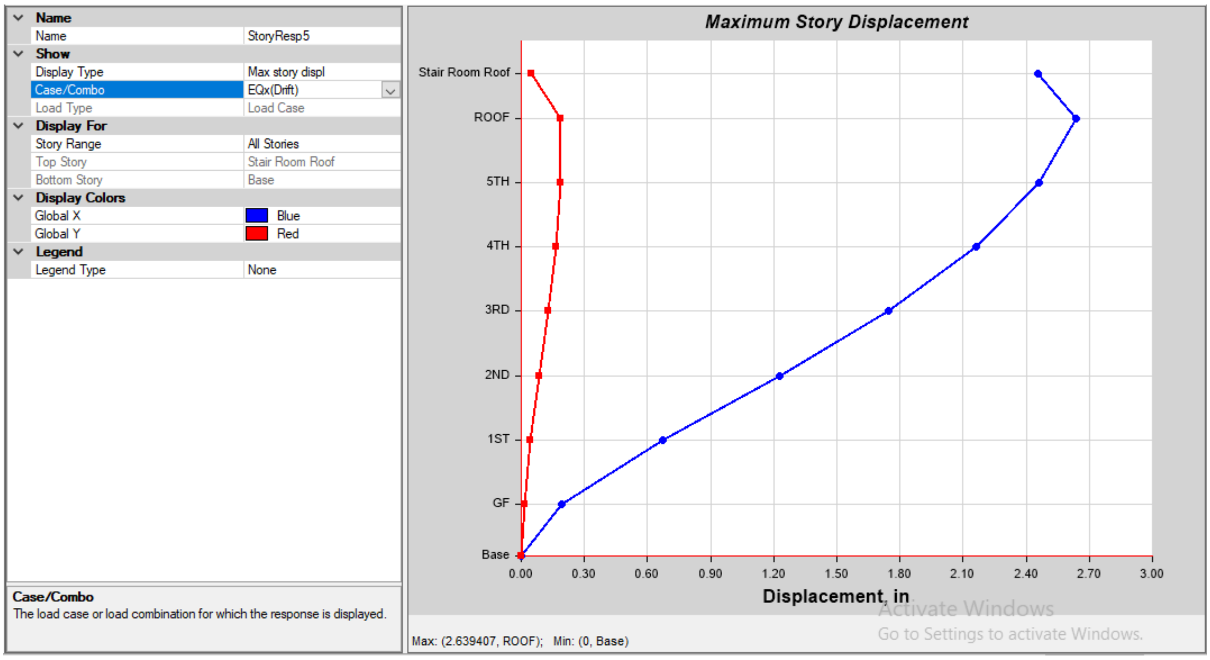
Name	
Name	StoryResp4
Show	
Display Type	Max story drifts
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.002834, 2ND); Min: (0, Base)

Figure 4.26: Maximum Story Drift With Retrofitting (EQy)

4.4.4 For Soil Type: SC

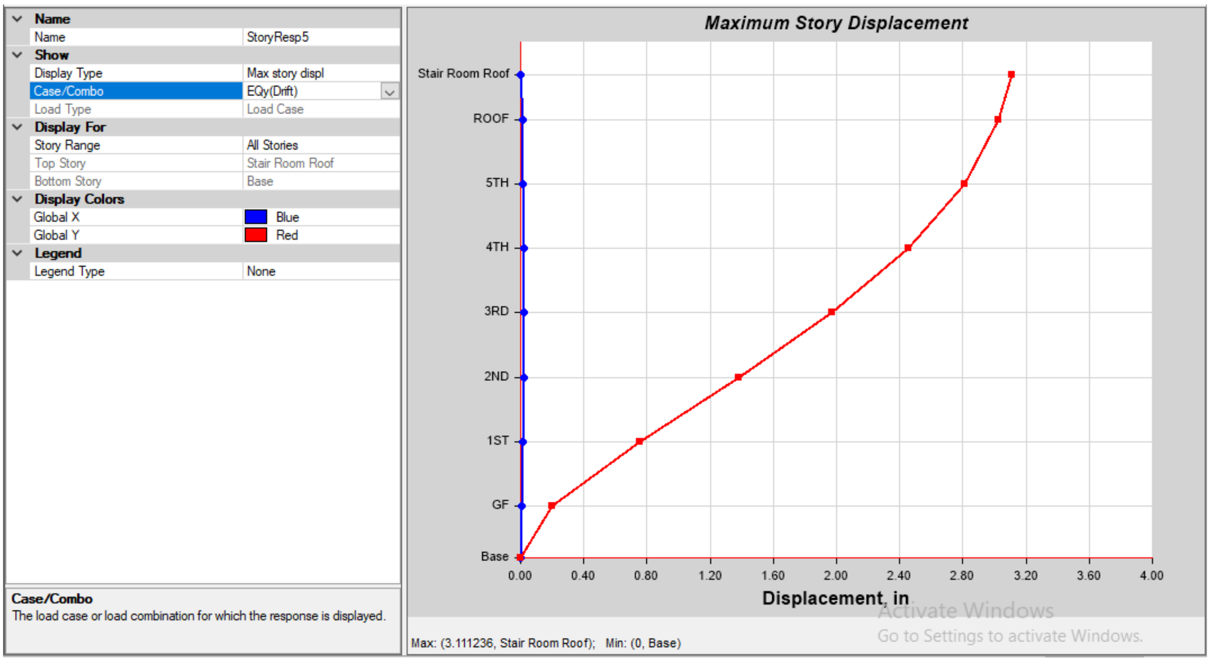


Name	
Name	StoryResp5
Show	
Display Type	Max story displ
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (2.639407, ROOF); Min: (0, Base)

Figure 4.27: Maximum Story Displacement Without Retrofitting (EQx)

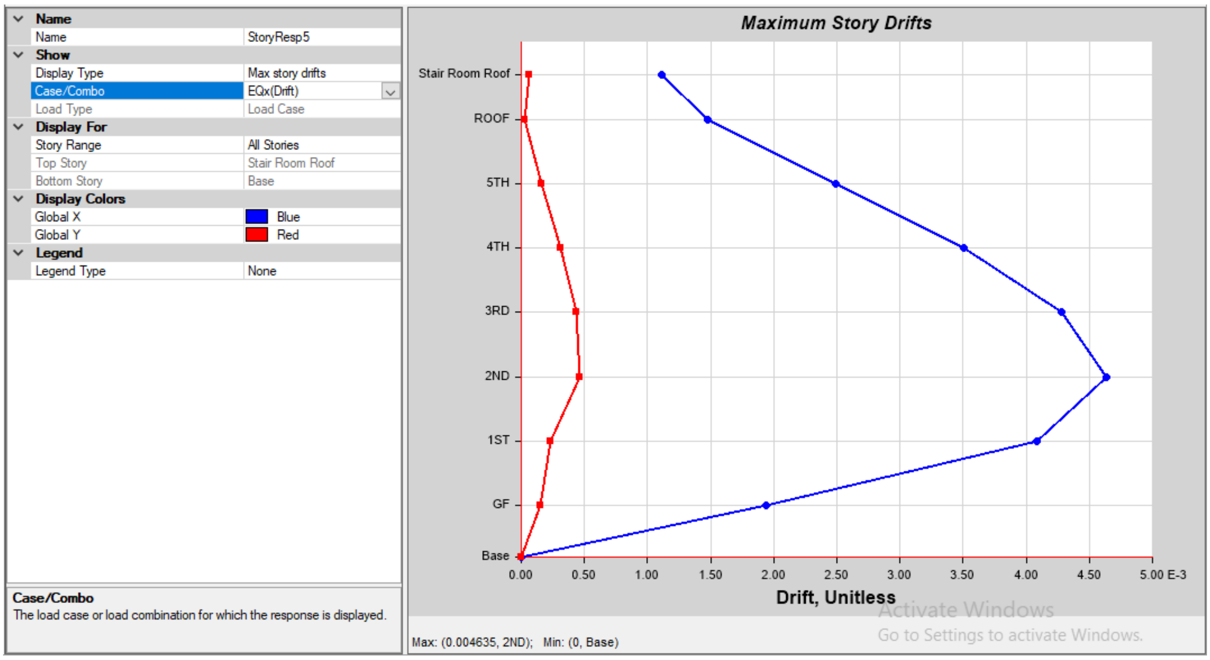


Name	
Name	StoryResp5
Show	
Display Type	Max story displ
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (3.111236, Stair Room Roof); Min: (0, Base)

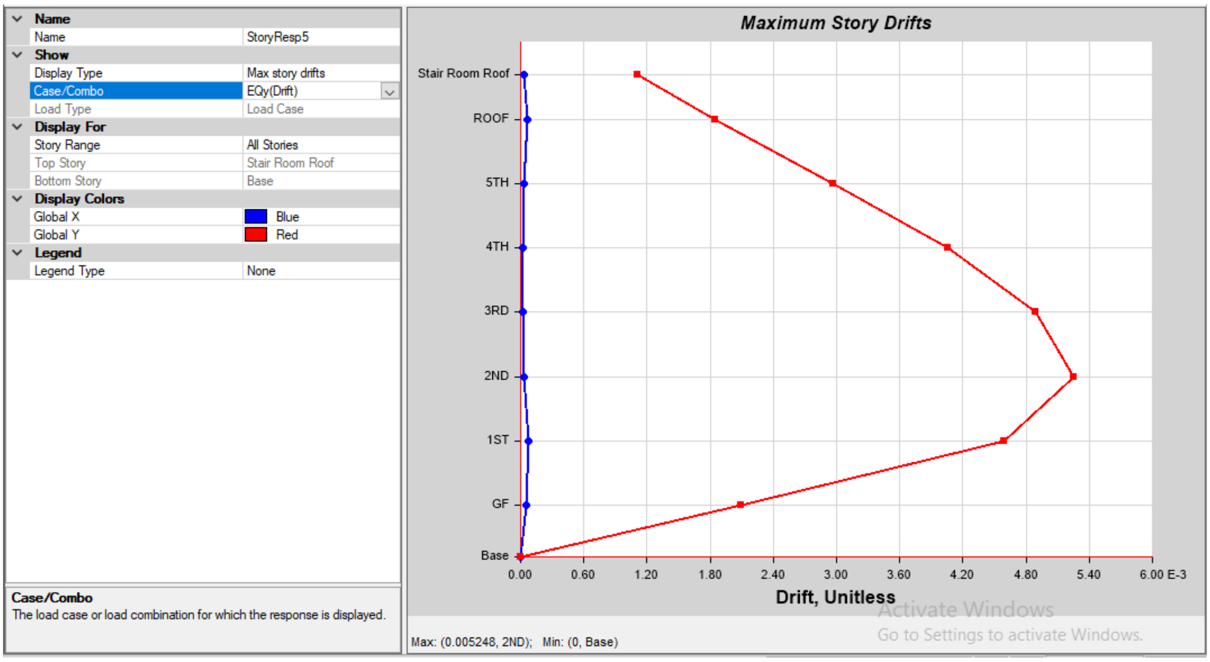
Figure 4.28: Maximum Story Displacement Without Retrofitting (EQy)


Name
Name: StoryResp5
Show
Display Type: Max story drifts
Case/Combo: EQx(Drift)
Load Type: Load Case
Display For
Story Range: All Stories
Top Story: Stair Room Roof
Bottom Story: Base
Display Colors
Global X: 🟦 Blue
Global Y: 🟥 Red
Legend
Legend Type: None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.004635, 2ND); Min: (0, Base)

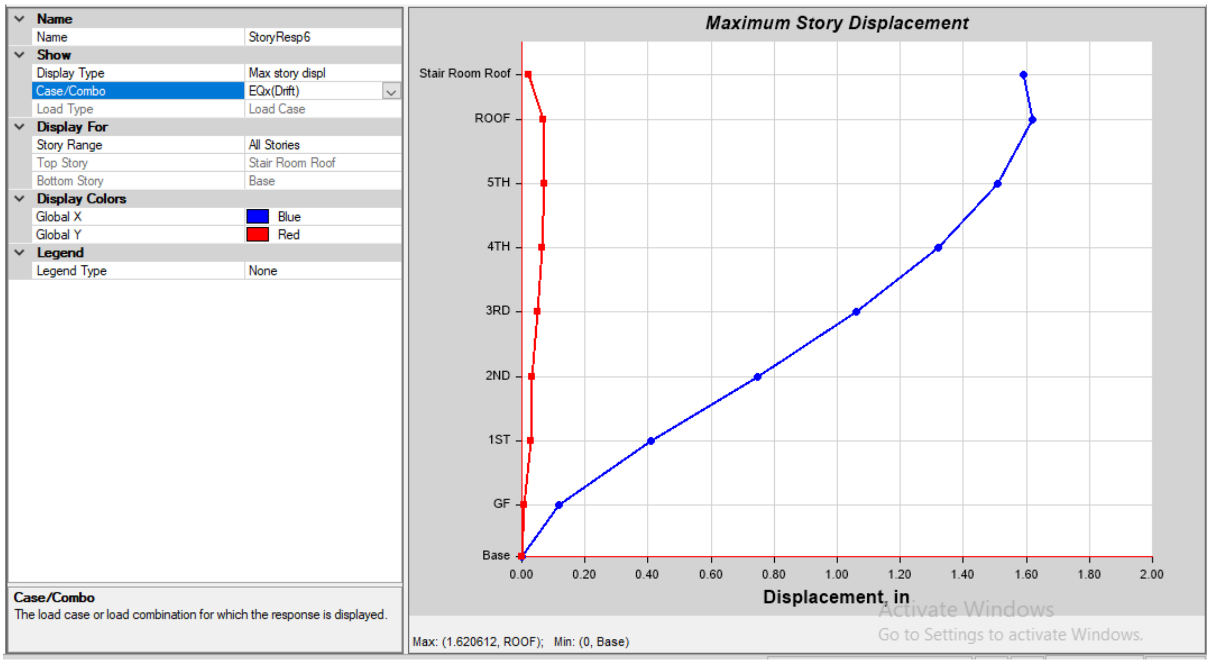
Figure 4.29: Maximum Story Drift Without Retrofitting (EQx)


Name
Name: StoryResp5
Show
Display Type: Max story drifts
Case/Combo: EQy(Drift)
Load Type: Load Case
Display For
Story Range: All Stories
Top Story: Stair Room Roof
Bottom Story: Base
Display Colors
Global X: 🟦 Blue
Global Y: 🟥 Red
Legend
Legend Type: None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.005248, 2ND); Min: (0, Base)

Figure 4.30: Maximum Story Drift Without Retrofitting (EQy)



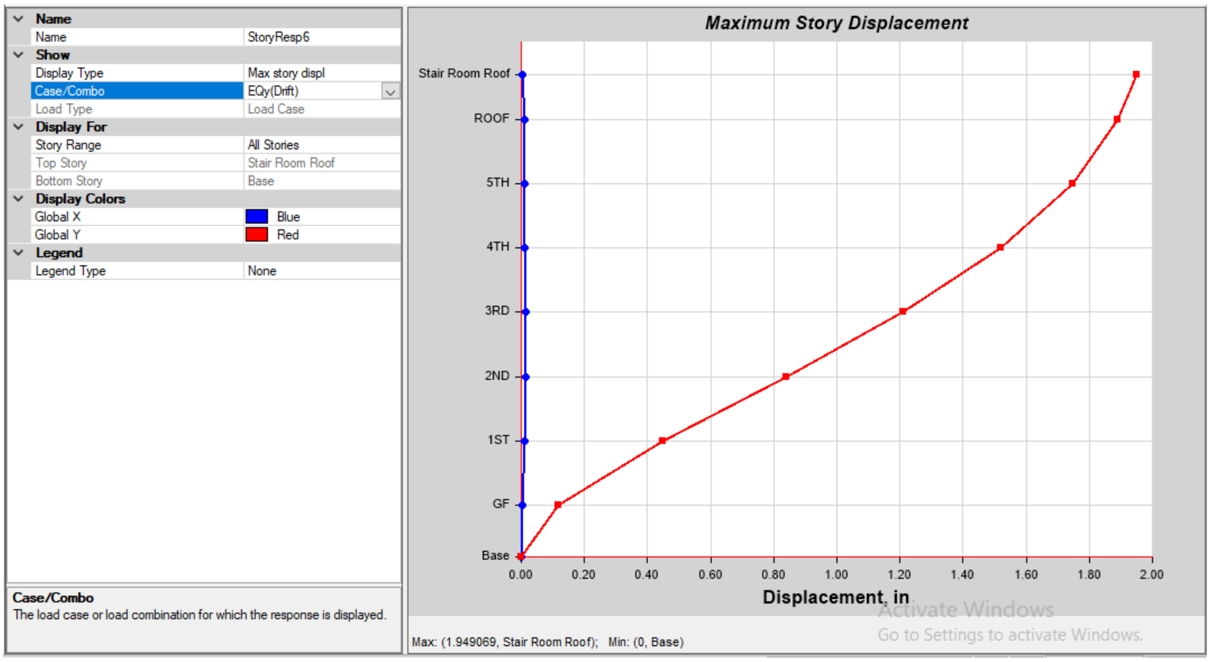
Name	
Name	StoryResp6
Show	
Display Type	Max story displ
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo

The load case or load combination for which the response is displayed.

Max: (1.620612, ROOF); Min: (0, Base)

Figure 4.31: Maximum Story Displacement With Retrofitting (EQx)



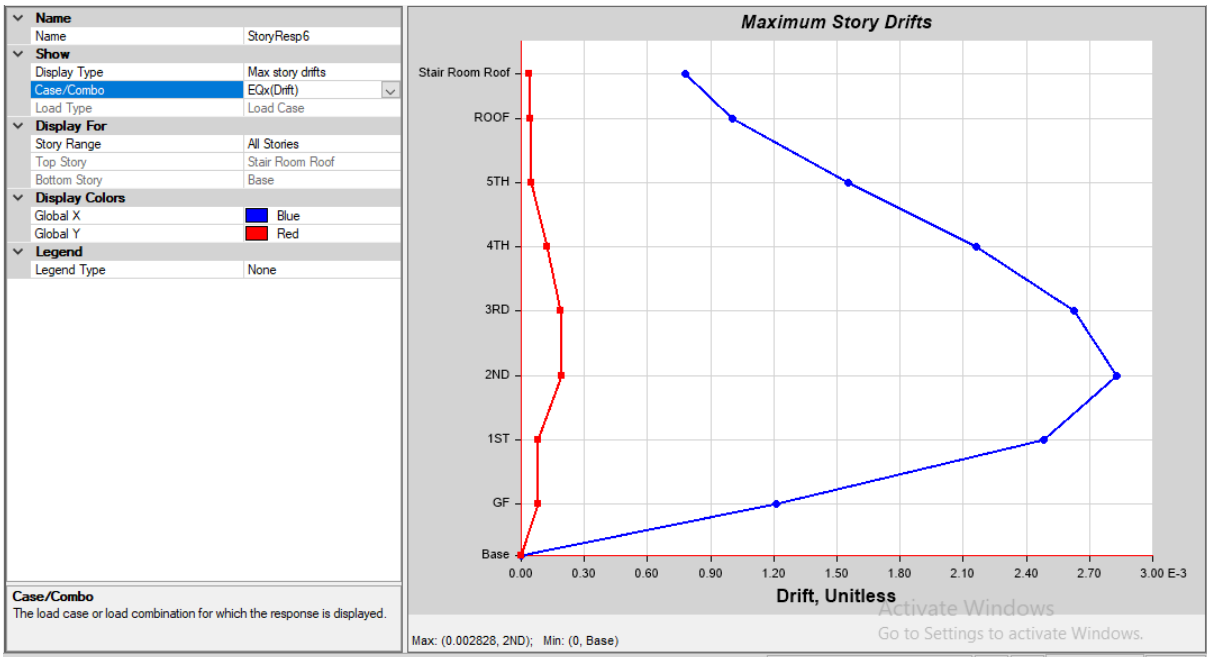
Name	
Name	StoryResp6
Show	
Display Type	Max story displ
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo

The load case or load combination for which the response is displayed.

Max: (1.949069, Stair Room Roof); Min: (0, Base)

Figure 4.32: Maximum Story Displacement With Retrofitting (EQy)

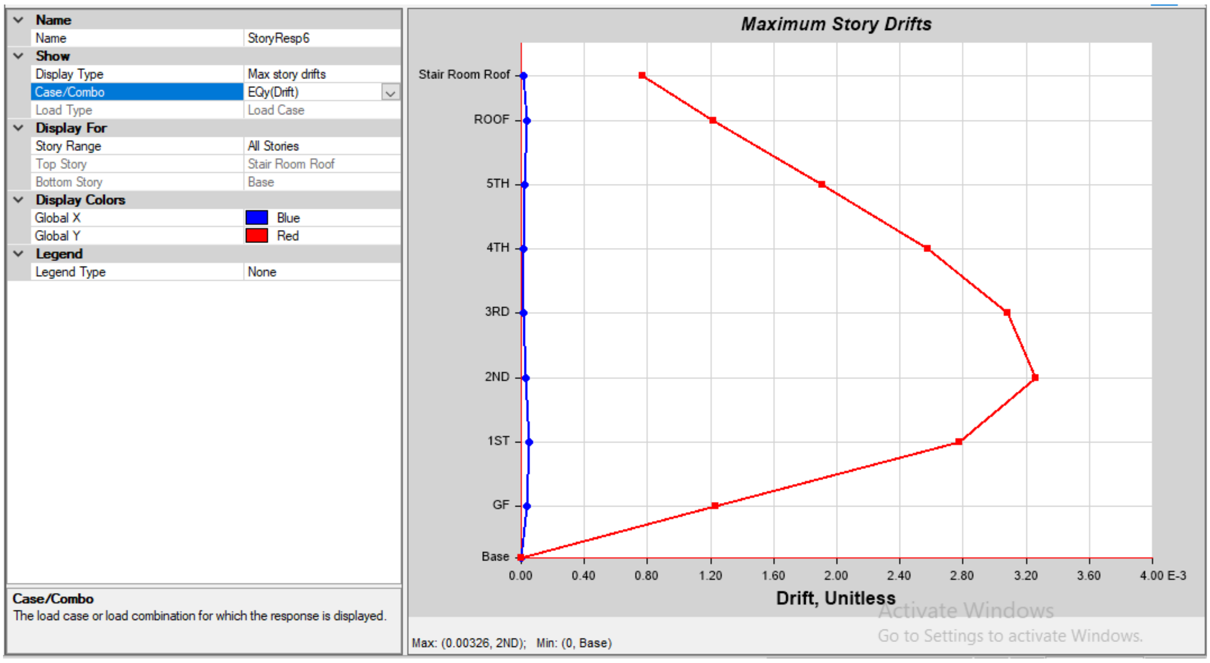


Name	
Name	StoryResp6
Show	
Display Type	Max story drifts
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.002828, 2ND); Min: (0, Base)

Figure 4.33: Maximum Story Drift With Retrofitting (EQx)



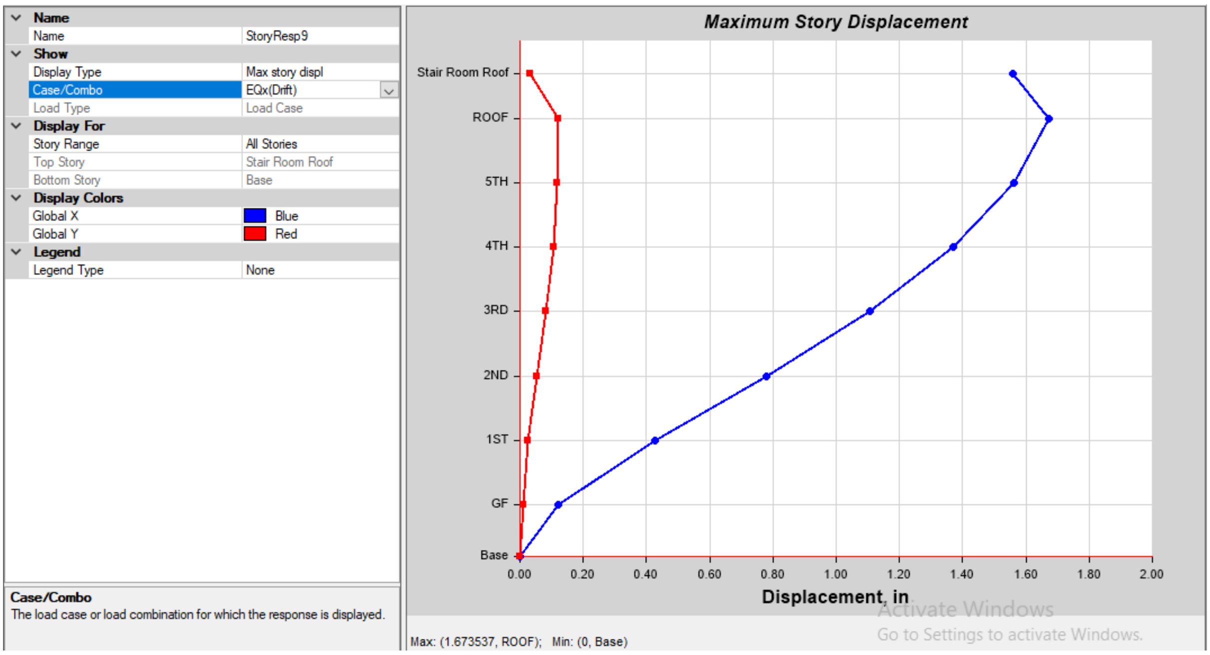
Name	
Name	StoryResp6
Show	
Display Type	Max story drifts
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.00326, 2ND); Min: (0, Base)

Figure 4.34: Maximum Story Drift With Retrofitting (EQy)

4.4.5 For Soil Type: SE

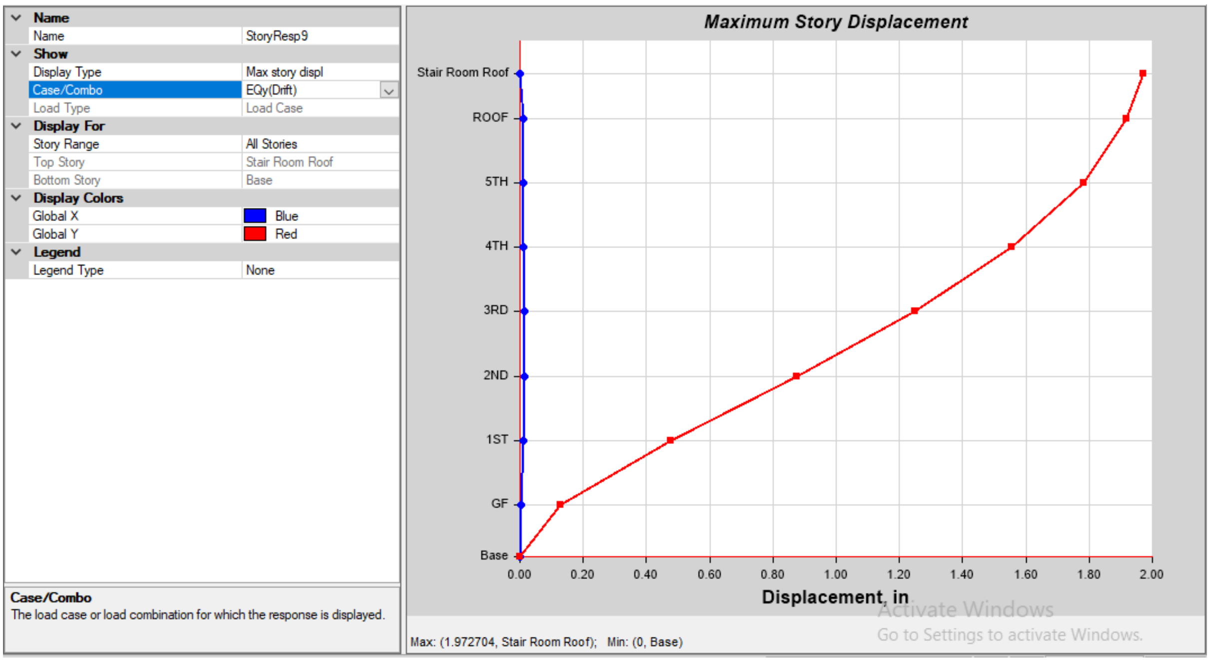


Name	
Name	StoryResp9
Show	
Display Type	Max story displ
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (1.673537, ROOF); Min: (0, Base)

Figure 4.35: Maximum Story Displacement Without Retrofitting (EQx)

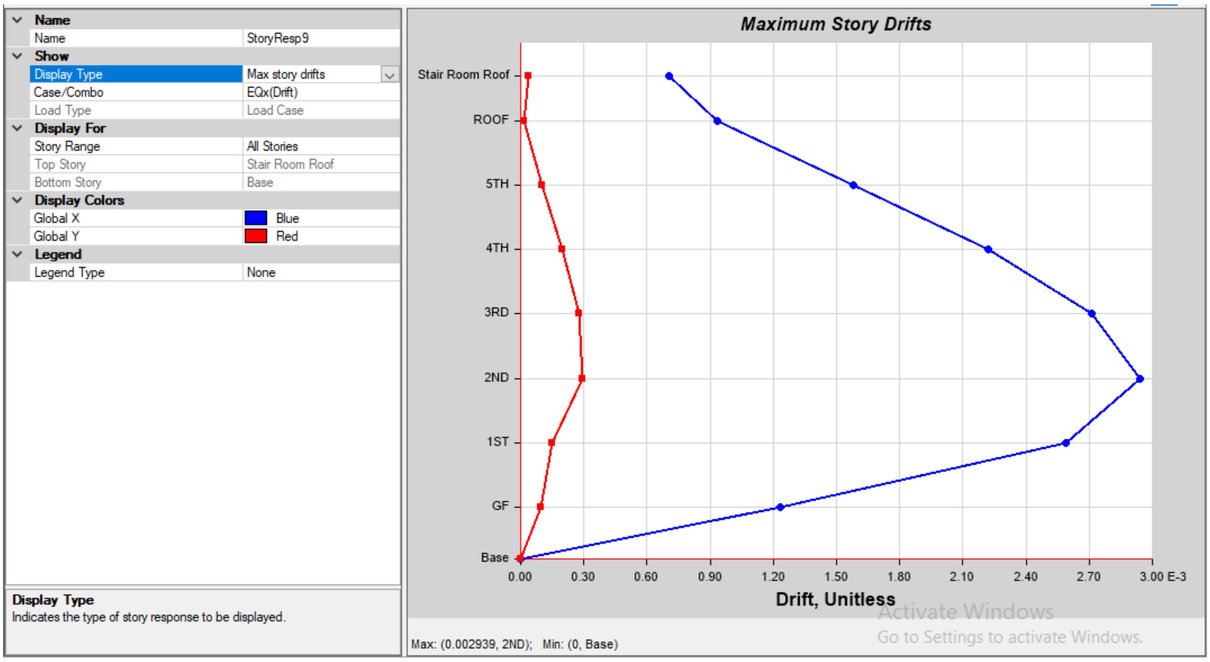


Name	
Name	StoryResp9
Show	
Display Type	Max story displ
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (1.972704, Stair Room Roof); Min: (0, Base)

Figure 4.36: Maximum Story Displacement Without Retrofitting (EQy)

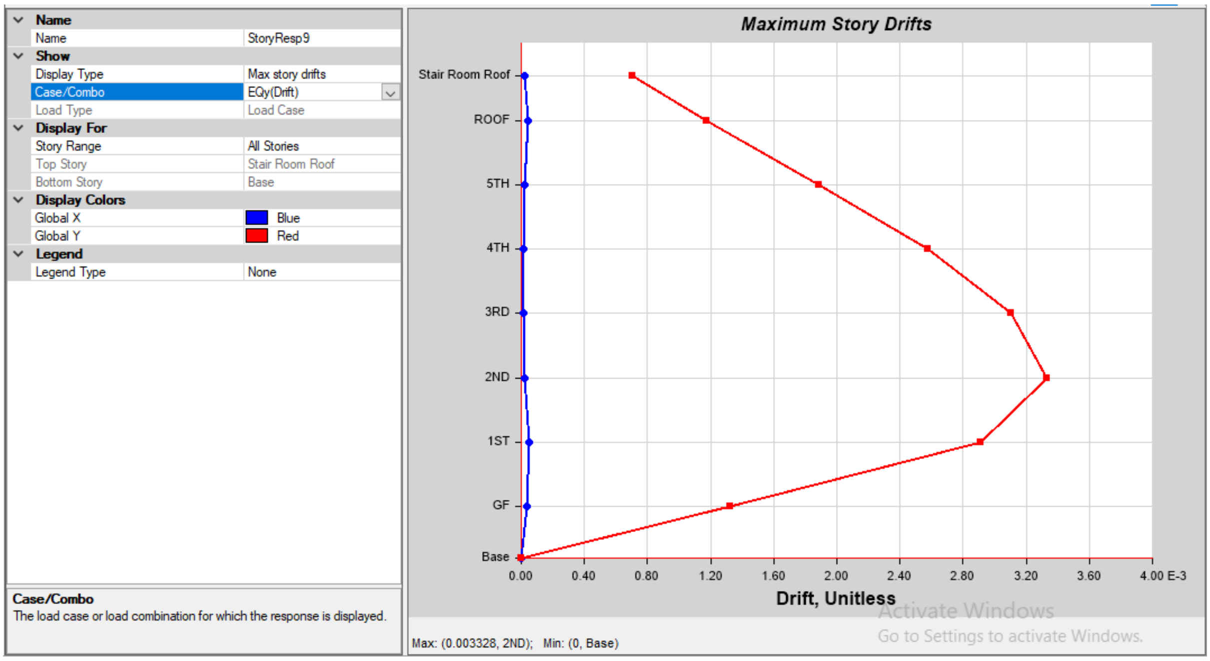


Name	
Name	StoryResp9
Show	
Display Type	Max story drifts
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Display Type
Indicates the type of story response to be displayed.

Max: (0.002939, 2ND); Min: (0, Base)

Figure 4.37: Maximum Story Drift Without Retrofitting (EQx)

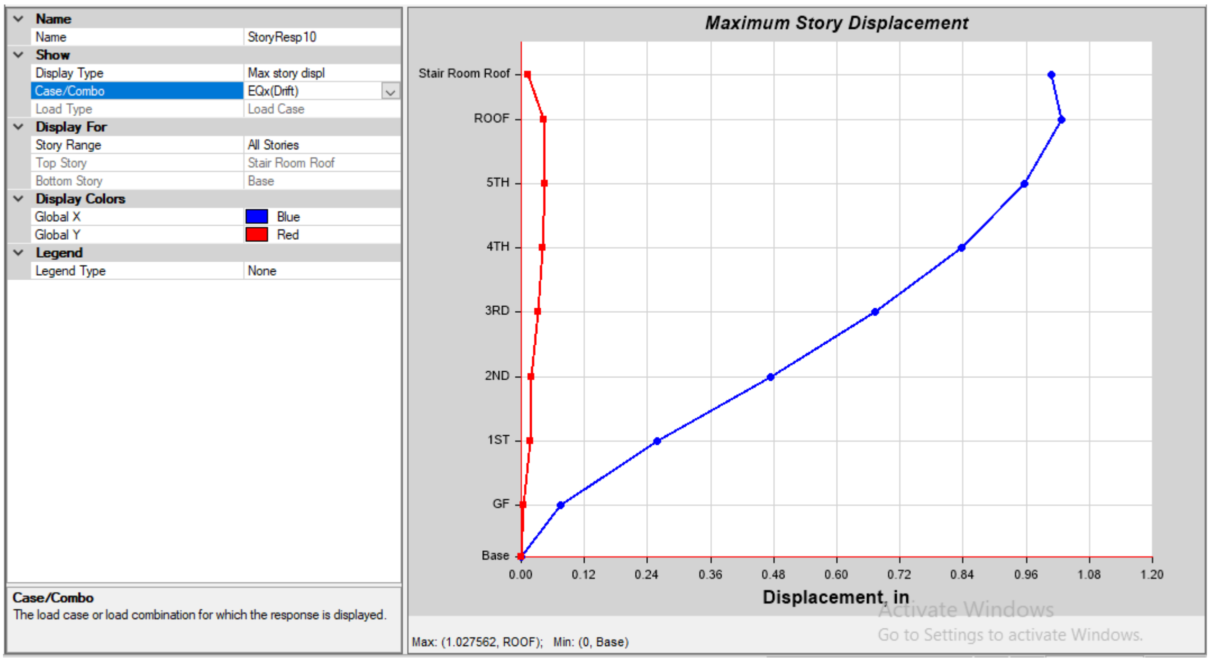


Name	
Name	StoryResp9
Show	
Display Type	Max story drifts
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.003328, 2ND); Min: (0, Base)

Figure 4.38: Maximum Story Drift Without Retrofitting (EQy)

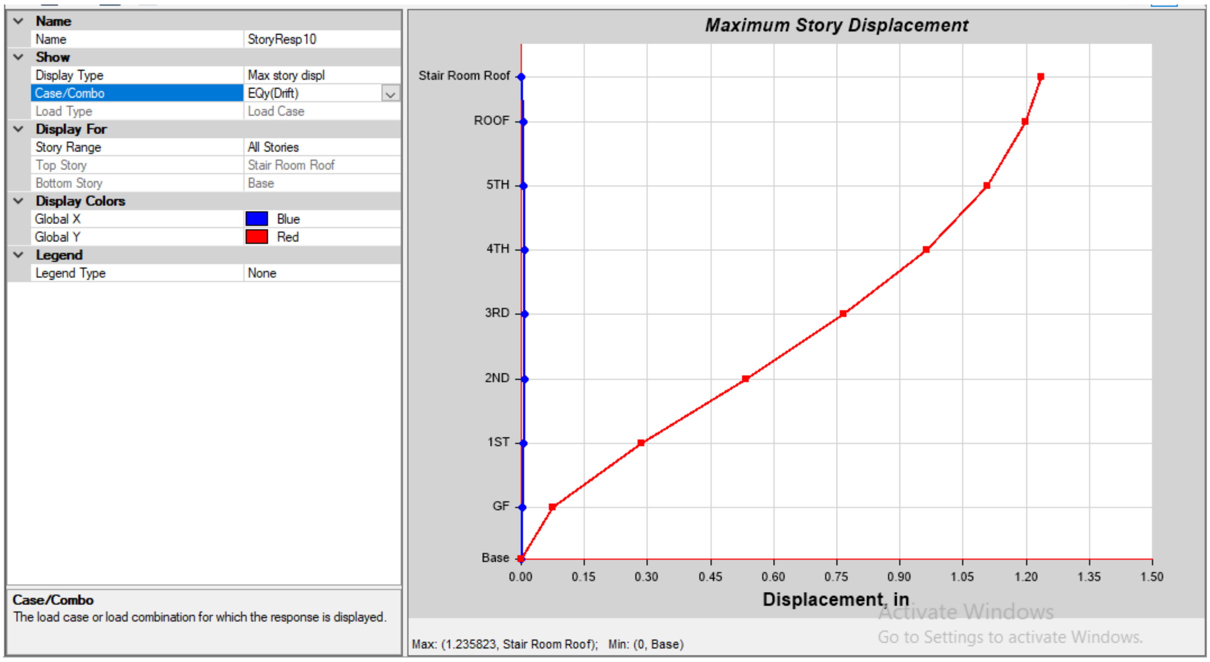


Name	
Name	StoryResp10
Show	
Display Type	Max story displ
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (1.027562, ROOF); Min: (0, Base)

Figure 4.39: Maximum Story Displacement With Retrofitting (EQx)

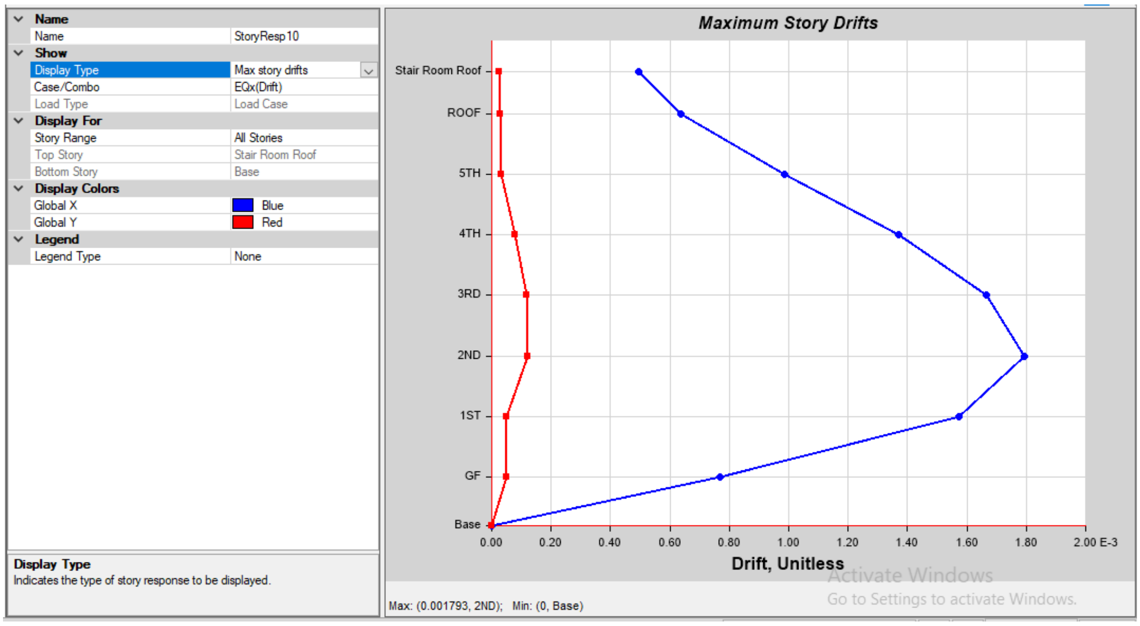


Name	
Name	StoryResp10
Show	
Display Type	Max story displ
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (1.235823, Stair Room Roof); Min: (0, Base)

Figure 4.40: Maximum Story Displacement With Retrofitting (EQy)

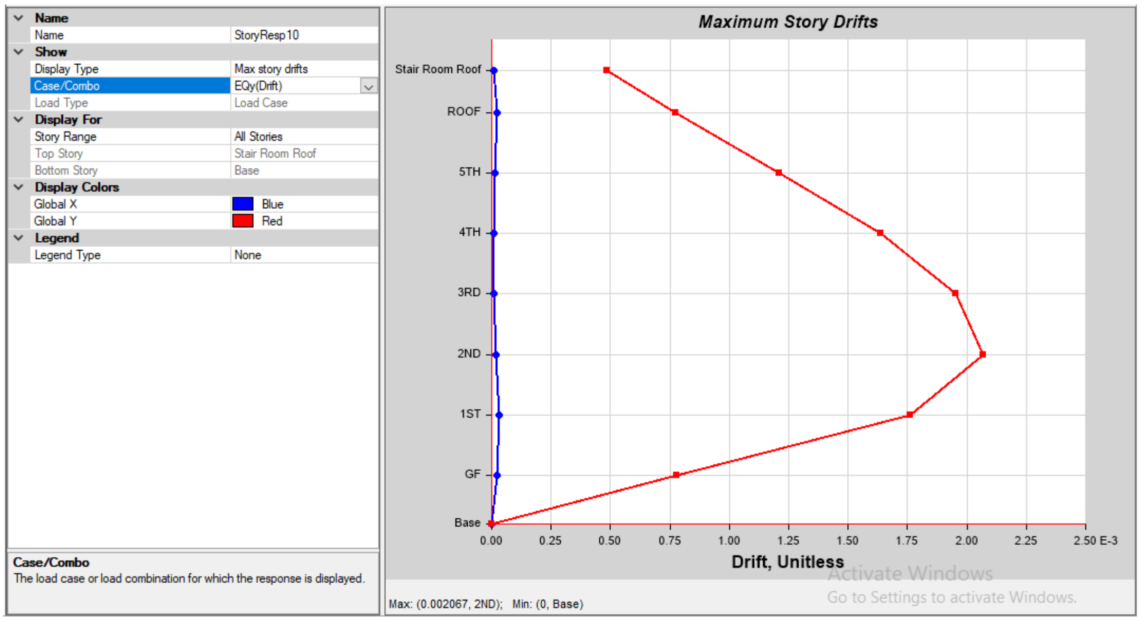


Name	
Name	StoryResp10
Show	
Display Type	Max story drifts
Case/Combo	EQx(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Display Type
Indicates the type of story response to be displayed.

Max: (0.001793, 2ND); Min: (0, Base)

Figure 4.41: Maximum Story Drift With Retrofitting (EQx)



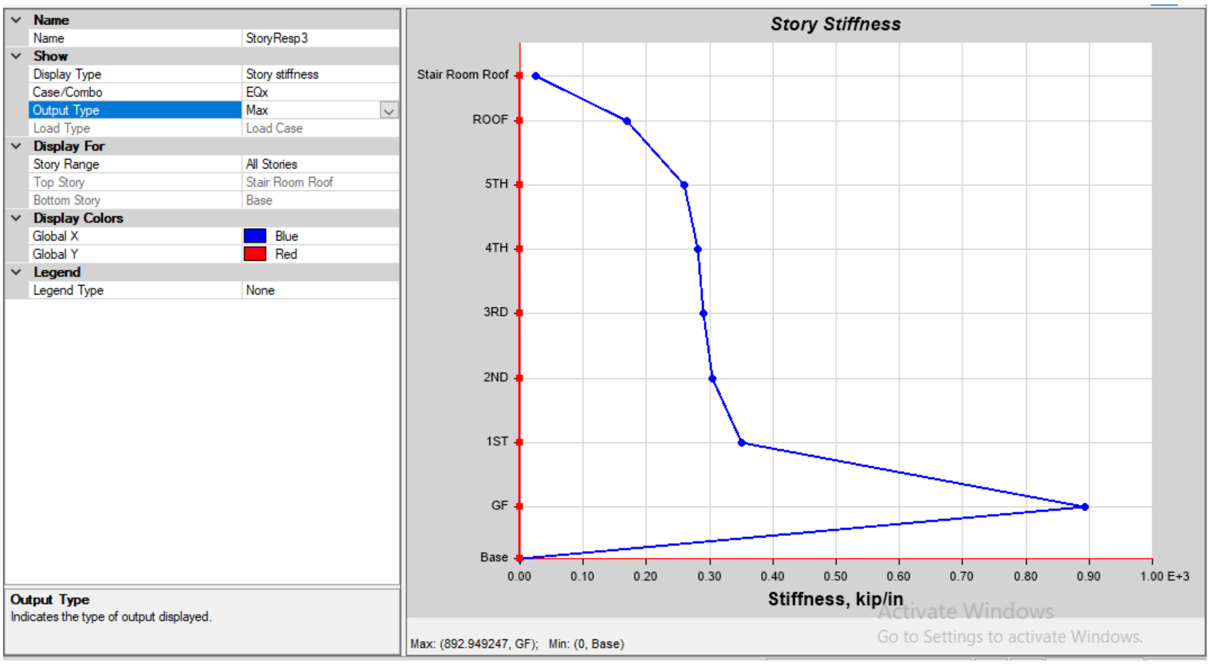
Name	
Name	StoryResp10
Show	
Display Type	Max story drifts
Case/Combo	EQy(Drift)
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (0.002067, 2ND); Min: (0, Base)

Figure 4.42: Maximum Story Drift With Retrofitting (EQy)

Representative story drift and displacement graphs are presented in this chapter to illustrate the seismic behavior of the structure. Detailed results for all load combinations and soil conditions are provided in the Appendix to avoid redundancy and to maintain clarity in result interpretation.

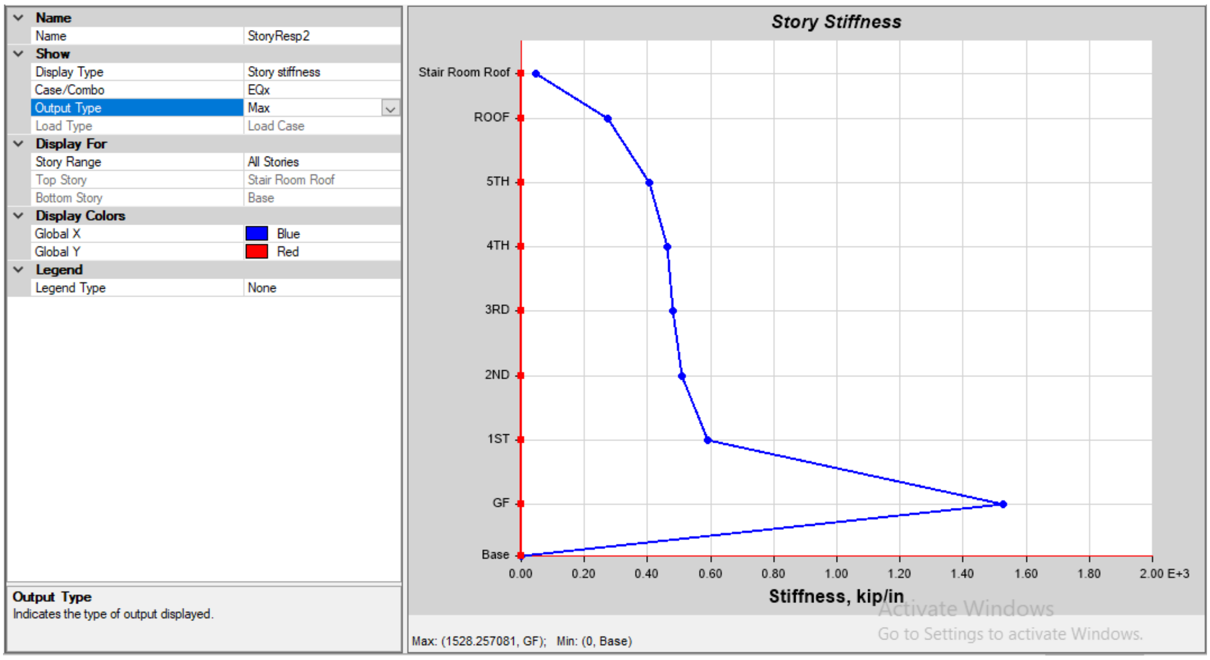


Name	
Name	StoryResp3
Show	
Display Type	Story stiffness
Case/Combo	EQx
Output Type	Max
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Output Type
Indicates the type of output displayed.

Max: (892.949247, GF); Min: (0, Base)

Figure 4.43: Stiffness Irregularity without Steel Retrofitting X Direction

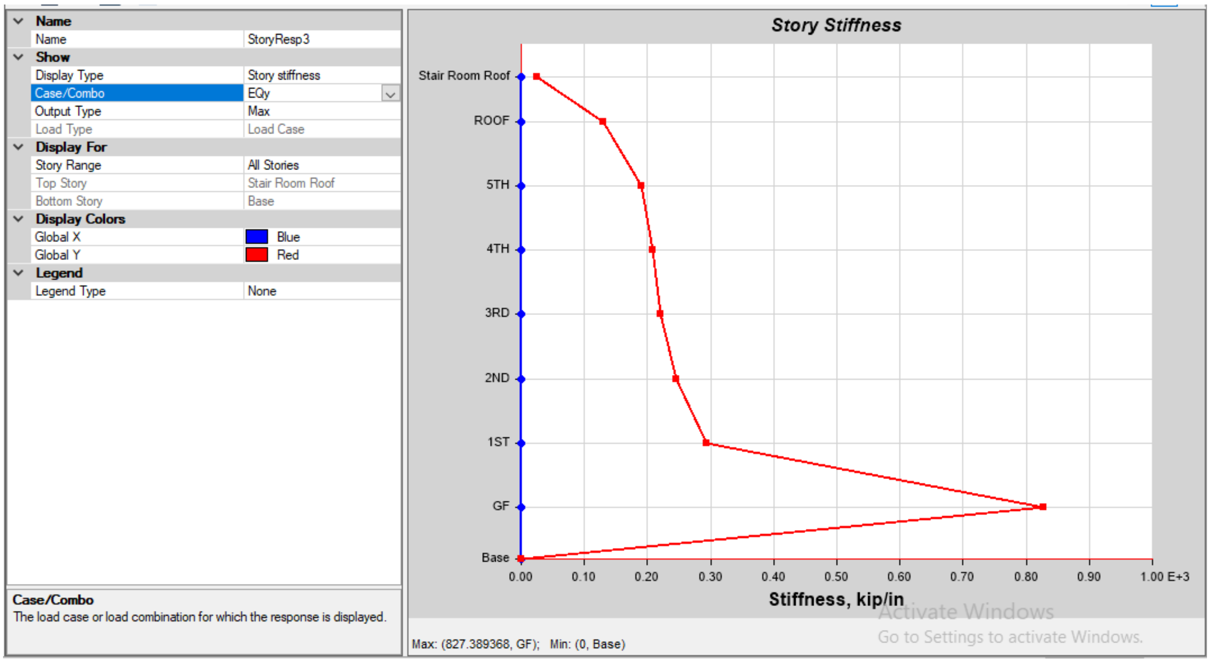


Name	
Name	StoryResp2
Show	
Display Type	Story stiffness
Case/Combo	EQx
Output Type	Max
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Output Type
Indicates the type of output displayed.

Max: (1528.257081, GF); Min: (0, Base)

Figure 4.44: Stiffness Irregularity with Steel Retrofitting X Direction

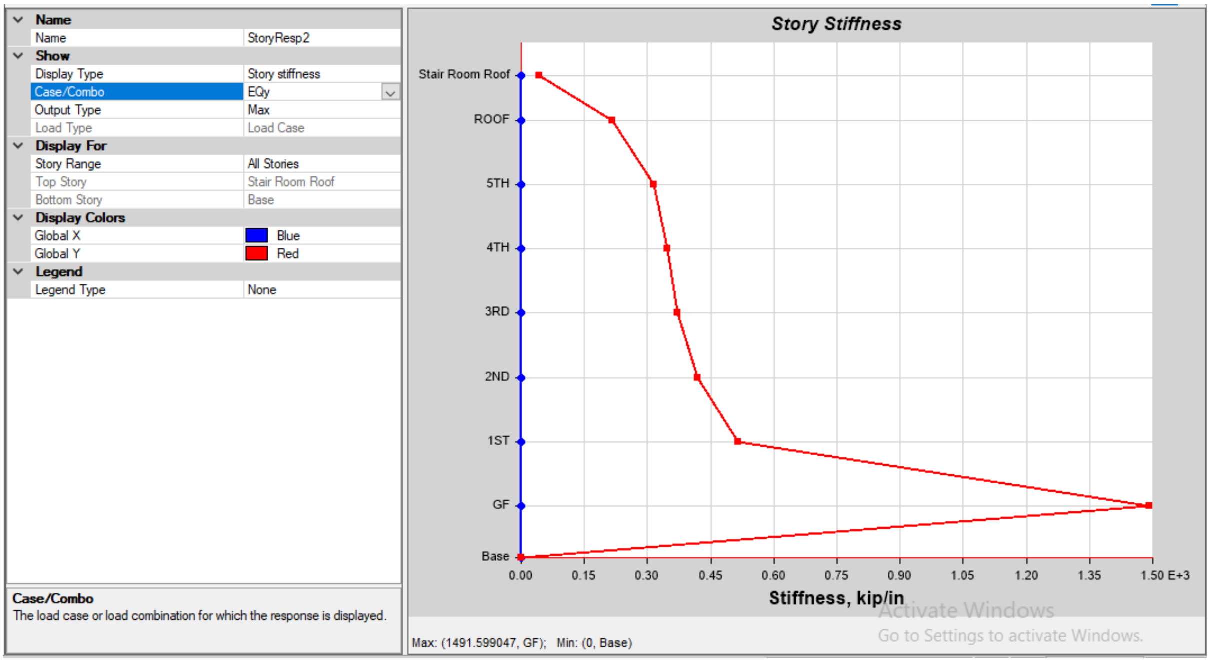


Name	
Name	StoryResp3
Show	
Display Type	Story stiffness
Case/Combo	EQy
Output Type	Max
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (827.389368, GF); Min: (0, Base)

Figure 4.45: Stiffness Irregularity without Steel Retrofitting Y Direction



Name	
Name	StoryResp2
Show	
Display Type	Story stiffness
Case/Combo	EQy
Output Type	Max
Load Type	Load Case
Display For	
Story Range	All Stories
Top Story	Stair Room Roof
Bottom Story	Base
Display Colors	
Global X	🟦 Blue
Global Y	🟥 Red
Legend	
Legend Type	None

Case/Combo
The load case or load combination for which the response is displayed.

Max: (1491.599047, GF); Min: (0, Base)

Figure 4.46: Stiffness Irregularity with Steel Retrofitting Y Direction

4.5 Earthquake Response (Moment Magnitude Limit) on Seismic Zones

- Calculation for Moment Magnitude Scale of Earthquake (For Seismic Zone 2)

$$\mathrm{M} = \frac{2}{3}\log 10\ \ \mathrm{M}_0 - 10.7$$

Here,

$\mathrm{M}_0 = \mu\mathrm{AD}$

$\mathrm{M}_0 =$ Earthquake moment in dyne cm

$\mu =$ Modulus of rigidity

$\mathrm{A} =$ Total affected area (seismic zone district area)

$\mathrm{D} =$ Allowable Drift

Modulus of rigidity was found by hooks law,

$\mathrm{E} = 2\mathrm{G}(1 + \nu)$

$\mathrm{G} = 0.5\mathrm{E}/(1 + \nu)$

Here,

$\mathrm{E} =$ Modulus of Elasticity

$\mathrm{G} =$ Modulus of Rigidity

$\nu =$ Poisson's ratio

For,

$\mathrm{E} =$ Modulus of Elasticity

Modulus of elasticity (Rebar) = 29000000 lb./in^2= 2x10^{11} N/m^2

Modulus of elasticity (CC) =$57000\sqrt{\mathrm{fc}} = 57000\sqrt{3500}$ = 3372165 lb./in^2

= $2.3\mathrm{x}10^{10}\ \mathrm{N/m^2}$

Modulus of elasticity (Steel) =2.0x10^{11} N/m^2

Modulus of elasticity (Without Steel) =1.77x10^{11} N/m^2

Modulus of elasticity (With Steel) =3.77x10^{11} N/m^2

Poisson's Ratio $\approx$ 0.3 [with and without steel]

Now,

$G = 0.5E/(1 + \nu)$

Modulus of Rigidity (Without Steel) $= 6.8x10^{10}$

Modulus of Rigidity (With Steel) $= 1.45x10^{11}$

Now,

$M_0 = \mu AD$

$D = \text{Allowable Drift} - \text{Found maximum Drift}$

$\mu = \text{Modulus of rigidity}$

$A = \text{Area of selected seismic zone} = 1530 \text{ km}^2 = 1530000000 \text{ m}^2$

Without Steel Jacketing ,

$M_0 = 6.8x10^{10} * 1530000000 * (0.06096 - 0.09877)$

$= 3.933x10^{18} \text{ Nm} = 3.933x10^{18} x10^7$

$= 3.933x10^{25} \text{ dyne.cm } (1 \text{ Nm} = 10^7 \text{ dyne.cm})$

With Steel Jacketing ,

$M_0 = 1.45x10^{11} * 1530000000 * (0.06096 - 0.05911)$

$= 4.370x10^{17} \text{ Nm} = 4.370x10^{17} x10^7$

$= 4.370x10^{24} \text{ dyne.cm } (1 \text{ Nm} = 10^7 \text{ dyne.cm})$

Now,

$M = \frac{2}{3}\log 10 \text{ Mo} - 10.7$

Without Steel Jacketing,

$M = \frac{2}{3}\log 10\ (3.933x10^{25}) - 10.7$

$M = 17.063 - 10.7 = 6.36$

With Steel Jacketing,

$$M = \frac{2}{3}\log10\ (4.370x10^{24}) - 10.7$$

$$M = 16.426 - 10.7 = 5.72$$

Table 4.18: Earthquake Moment Magnitudes

Structure Type	Seismic Zone	Soil Type	Area of Seismic District	Earthquake Moment	Reduction %
Without Steel Jacketing	Seismic Zone 2	SD	1530 km^2	6.36	10.1 %
With Steel Jacketing	Seismic Zone 2		1530 km^2	5.72	
Without Steel Jacketing	Seismic Zone 2	SA	1530 km^2	6.01	8.2 %
With Steel Jacketing	Seismic Zone 2		1530 km^2	5.52	
Without Steel Jacketing	Seismic Zone 2	SB	1530 km^2	6.06	6.4 %
With Steel Jacketing	Seismic Zone 2		1530 km^2	5.67	
Without Steel Jacketing	Seismic Zone 2	SC	1530 km^2	6.24	1.0 %
With Steel Jacketing	Seismic Zone 2		1530 km^2	6.18	
Without Steel Jacketing	Seismic Zone 2	SE	1530 km^2	6.47	1.1 %
With Steel Jacketing	Seismic Zone 2		1530 km^2	6.40	

4.6 Discussion of the Found Results

The ETABS 17 analysis clearly shows a significant improvement in seismic performance after retrofitting with steel jacketing. In the un-retrofitted condition, several stories, especially the lower and mid-level floors, exceeded the allowable drift limits prescribed by BNBC 2020. The maximum drift values at the 2nd, 3rd, and 4th stories were well beyond the permissible 0.020hsx, which indicates that the building, as originally designed, was highly vulnerable to seismic excitation. This confirms the concern that structures built under earlier codes such as BNBC 1993/2006 may not satisfy the updated drift control requirements.

A quantitative comparison between the original and retrofitted structures indicates a significant improvement in seismic performance due to steel jacketing. The maximum inter-story drift of the building was reduced by approximately 40–45%, depending on soil condition and seismic direction (EQx and EQy). This reduction confirms that the retrofitted structure satisfies the BNBC 2020 drift limitation of 0.020h, whereas the original structure approached or exceeded the allowable limit in several stories. The results clearly demonstrate the effectiveness of steel jacketing in controlling lateral deformation under seismic loading.

After applying 8 mm thick Grade 50 steel jacketing to the columns and beams, the maximum drift values across all stories were reduced to within BNBC 2020 limits. The improvement was particularly noticeable at the critical lower stories, where drift values decreased by nearly 40–45% compared to the un-retrofitted model. This indicates that the retrofitting enhanced the stiffness and ductility of the structure, preventing large deformations and ensuring better energy dissipation under seismic loading.

The base shear analysis further supports this conclusion. The maximum base shear demand remained around 161.82 kip, but the retrofitted structure demonstrated increased capacity to resist this demand. This implies that although the seismic forces themselves do not change, the ability of the structure to withstand those forces improves significantly with steel jacketing.

In terms of structural safety, the visual failure patterns in the un-retrofitted model indicated potential collapse at the lower columns and beams due to excessive drift. After retrofitting, the failure patterns disappeared, and the structure remained stable under both wind and earthquake load combinations. This validates the effectiveness of steel jacketing as a strengthening method.

❖ Discussion of the Earthquake Moment Magnitude

"The moment magnitude of the structure reduces from 6.36 before retrofitting to 5.72 after steel jacketing, indicating that the retrofit significantly lowers the seismic response and potential damage during an earthquake."

4.7 Summary

The case study showed that the original structure failed to meet BNBC 2020 drift requirements, with excessive inter-story drift in lower stories indicating high seismic vulnerability. After retrofitting with 8 mm Grade 50 steel jacketing, drift values were reduced within allowable limits, with about 40% - 45% improvement in the lower stories. The base shear demand remained unchanged, but member capacity increased, eliminating critical failure patterns. Importantly, the calculated moment magnitude decreased from 6.36 before retrofitting to 5.72 after retrofitting, confirming that the retrofit significantly lowered seismic demand and enhanced structural safety. Overall, steel jacketing proved to be an effective technique for upgrading existing RC buildings to modern seismic standards.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This study aimed to evaluate the effectiveness of steel jacketing as a seismic retrofitting technique for reinforced concrete (RC) columns and beams in existing buildings in Bangladesh, using ETABS 17 and in accordance with BNBC 2020 provisions. Through detailed modeling and analysis of a case study building, the research compared the seismic performance of the original and retrofitted structures in terms of inter-story drift, base shear, and displacement control. This chapter summarizes the key findings, draws conclusions, acknowledges limitations, and offers recommendations for future research and practical implementation.

5.2 Conclusions

This study investigated the seismic performance of a mid-rise reinforced concrete (RC) building before and after retrofitting with steel jacketing, using ETABS 17 and evaluating results against BNBC 2020 provisions. The major conclusions are:

- Buildings designed under BNBC 1993/2006 may not satisfy the drift and base shear requirements of BNBC 2020, particularly in lower stories where drift demand is critical.
- Without retrofitting, several stories of the analyzed building exceeded allowable drift limits, demonstrating significant seismic vulnerability.
- Retrofitting with 8 mm thick Grade 50 steel jacketing improved confinement, axial and flexural capacity, and significantly reduced inter-story drift, bringing all stories within BNBC 2020 allowable limits.
- Base shear capacity of the retrofitted structure increased compared to the original model, indicating enhanced overall seismic resistance.
- The study confirms that steel jacketing is an effective and practical retrofit technique for vulnerable RC buildings in Bangladesh, offering strength, ductility, and compliance with modern seismic codes.

5.3 Limitations of the Study

Despite its useful findings, the study has some limitations:

- Software Constraints – ETABS 17 does not directly incorporate BNBC 2020 seismic parameters. Load patterns and combinations were adapted from ASCE 7-05, which may introduce approximations.
- Analytical-Only Approach – The research was limited to numerical modeling. No experimental validation of steel-jacketed members was performed.
- Single Case Study Building – Only one 7-storied residential building located in Seismic Zone II (Dhaka) was analyzed, which restricts generalization of the results.
- Cost and Construction Aspects Excluded – The study focused solely on structural performance (drift and base shear). Practical issues such as construction feasibility, workmanship, corrosion protection, and cost analysis were not included.
- Simplified Material Properties – Standard code values for steel and concrete were assumed. The effects of material aging, variability, and construction defects were not considered.

5.4 Recommendations for Future Work

Based on the above limitations and findings, the following recommendations are proposed for future studies:

- Expand Case Studies – Analyze multiple building types in different seismic zones of Bangladesh, including irregular and high-rise structures, to obtain more generalized conclusions.
- Experimental Validation – Perform laboratory testing of steel-jacketed RC members under cyclic and dynamic loading to compare with ETABS simulations.
- Comparative Retrofitting Methods – Evaluate alternative retrofit techniques such as FRP wrapping, concrete jacketing, or hybrid systems, and compare them with steel jacketing in terms of effectiveness and cost.

- Durability and Maintenance – Investigate long-term issues such as corrosion, bonding failures, and maintenance needs of steel jacketing in Bangladesh’s humid environment.
- Economic Analysis – Incorporate cost-benefit and life-cycle analysis to assess whether retrofitting or rebuilding is more viable for different categories of structures.
- Software Improvement – Encourage future ETABS versions or local plug-ins to integrate BNBC 2020 parameters directly, allowing more accurate modeling for Bangladesh-specific conditions.

REFERRENCES

Hossain, M. S., & Islam, M. R. (2022). Seismic performance evaluation of existing RC buildings in Dhaka city under BNBC 2020. Journal of Building Engineering, 52, 104389.

Shrestha, R., & Guragain, R. (2021). Retrofitting of RC buildings in South Asia: Lessons from Nepal earthquake 2015. Engineering Structures, 242, 112543.

Rahman, T., & Chowdhury, M. A. (2023). Comparative study of FRP and steel jacketing for seismic retrofitting of RC frames. Asian Journal of Civil Engineering, 24(6), 1187–1202.

Bangladesh National Building Code (BNBC) 2020, Part 6: Earthquake Resistant Design. Housing and Building Research Institute (HBRI), Dhaka, Bangladesh.

Mander, J. B., Priestley, M. J. N., & Park, R. (1988). Theoretical stress–strain model for confined concrete. Journal of Structural Engineering, ASCE, 114(8), 1804–1826.

Xiao, Y., & Wu, H. (2000). Seismic behavior and design of steel-jacketed reinforced concrete columns. Earthquake Engineering & Structural Dynamics, 29(7), 1021–1040.

Pampanin, S., Priestley, M. J. N., & Calvi, G. M. (2005). Seismic retrofit of RC buildings using steel jacketing. Journal of Earthquake Engineering, 9(2), 177–200.

Aboutaha, R. S., Moustafa, M., & Ghobarah, A. (1996). Strengthening of RC beams using steel plates. Engineering Structures, 18(3), 182–190.

Rahman, M. M., Alam, M. S., & Hoque, M. A. (2019). Seismic vulnerability assessment of existing RC buildings in Dhaka city. Journal of Civil Engineering Research, 9(3), 80–92.

Kabir, M. H., & Hasan, M. K. (2020). Performance evaluation of retrofitted RC frames under earthquake loading in Bangladesh. International Journal of Advanced Structural Engineering, 12(4), 255–267.

Islam, M. R., Sarker, P., & Chowdhury, M. A. (2021). Seismic retrofit strategies for RC buildings using steel jacketing: A case study in Bangladesh. Asian Journal of Civil Engineering, 22(5), 591–607.

CSI ETABS 17 Manual. Computers and Structures, Inc. (2017). ETABS: Integrated Analysis, Design, and Drafting of Building Systems. Berkeley, CA.

Mander, J. B., & Priestly, M. J. N. (1993). Seismic retrofit of concrete structures. Journal of Structural Engineering, 119(10), 3180–3200.

APPENDIX

APPENDIX A

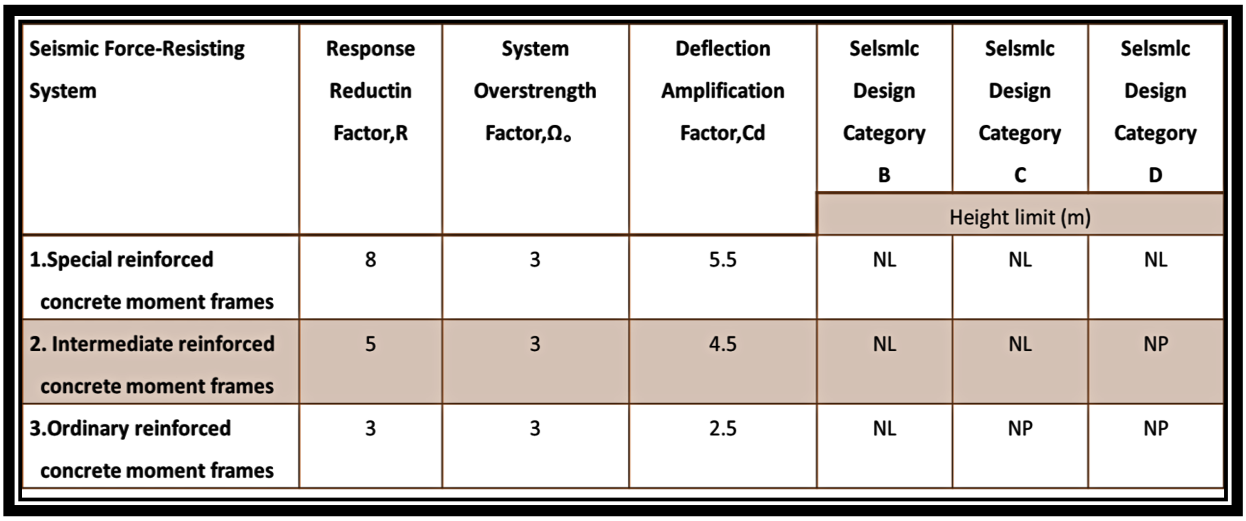
Table A1: Site Dependent Soil Factor and Other Parameters Defining Elastic Response Spectrum.

Soil Type	S	TB(S)	TC(S)	TD(S)
SA	1.0	0.15	0.40	2.0
SB	1.2	0.15	0.50	2.0
SC	1.15	0.20	0.60	2.0
SD	1.35	0.20	0.80	2.0
SE	1.4	0.15	0.50	2.0

Table A2: Importance Factors for Buildings and Structures for Earthquake Design

Occupancy Category	Importance factor I
I,II	1.00
III	1.25
IV	1.50

Table A3: Response Reduction Factor, Deflection Amplification Factor and Height Limitations for Different Structural Systems



Seismic Force-Resisting System	Response Reductin Factor,R	System Overstrength Factor,Ω_o	Deflection Amplification Factor,Cd	Selsmlc Design Category B	Selsmlc Design Category C	Selsmlc Design Category D
				Height limit (m)		
1.Special reinforced concrete moment frames	8	3	5.5	NL	NL	NL
2. Intermediate reinforced concrete moment frames	5	3	4.5	NL	NL	NP
3.Ordinary reinforced concrete moment frames	3	3	2.5	NL	NP	NP

Table A4: Load Combinations

(1) 1.4D	(9) 1.2D-1.6Wx+L+0.5Lr	(17) 1.29D + 0.3Ex - Ey + L	25) 0.81D + Ex - 0.3Ey
(2) 1.2D+1.6L+0.5Lr	(10) 1.2D+1.6Wy+L+0.5Lr	(18) 1.29D - 0.3Ex + Ey + L	26) 0.81D - Ex + 0.3Ey
(3) 1.2D+1.6Lr+L	(11) 1.2D-1.6Wy+L+0.5Lr	(19) 1.29D - 0.3Ex - Ey + L	27) 0.81D - Ex - 0.3E
(4) 1.2D+1.6Lr+0.8Wx	(12) 1.29D + Ex + 0.3Ey + L	(20) 0.9D+1.6Wx	28) 0.81D + 0.3Ex + Ey
(5) 1.2D+1.6Lr-0.8Wx	(13) 1.29D + Ex - 0.3Ey + L	(21) 0.9D-1.6Wx	29) 0.81D + 0.3Ex – Ey
(6) 1.2D+1.6Lr+0.8Wy	(14) 1.29D - Ex + 0.3Ey + L	(22) 0.9D+1.6Wy	30) 0.81D - 0.3Ex + Ey
(7) 1.2D+1.6Lr-0.8Wy	(15) 1.29D - Ex - 0.3Ey + L	(23) 0.9D-1.6Wy	31) 0.81D - 0.3Ex - Ey
(8) 1.2D+1.6Wx+L+0.5Lr	(16) 1.29D + 0.3Ex + Ey + L	24) 0.81D + Ex + 0.3Ey	(32) Envelope

Table A5: Dead Loads

Loads Name	Concentrated Load
Floor Finish Load on Floor Slab	16.40 psf
Floor Finish Load on Roof Slab	10 psf
Partition Wall Load on Floor Slab	44.70 psf
Partition Wall Load on Beam	0.51 K/ft.

Table A6: Live Loads

Loads Name	Concentrated Load
Load on Floor Slab	41.78 psf
Load on Roof Slab	60.58 psf
Stair & Exit Ways	100.27 psf

Table A7: Maximum Story Drift without Steel Jacketing Retrofitting

Story	Load Case/Combo	Max. Story Drift (in)	Status
Stair Room Roof	EQx	-0.8001345	Ok
	EQy	0.43714	Ok
ROOF	EQx	0.9154695	Ok
	EQy	1.1233585	Ok
5TH	EQx	1.535501	Ok
	EQy	1.835295	Ok
4TH	EQx	2.1513305	Ok
	EQy	2.5241095	Not ok
3RD	EQx	2.618869	Not ok
	EQy	3.0418575	Not ok
2ND	EQx	2.838627	Not ok
	EQy	3.26139	Not ok
1ST	EQx	3.46577	Not ok
	EQy	3.888896	Not ok
GF	EQx	0	Ok
	EQy	0	Ok

Table A8: Maximum Story Drift with Steel Jacketing Retrofitting

Story	Load Case/Combo	Max. Story Drift (in)	Status
Stair Room Roof	EQx	-0.1073325	Ok
	EQy	0.3052225	Ok
ROOF	EQx	0.586421	Ok
	EQy	0.7422305	Ok
5TH	EQx	0.9615045	Ok
	EQy	1.1775885	Ok
4TH	EQx	1.3340965	Ok
	EQy	1.601457	Ok
3RD	EQx	1.615229	Ok
	EQy	1.914198	Ok
2ND	EQx	1.7402385	Ok
	EQy	2.0256335	Ok
1ST	EQx	2.105378	Ok
	EQy	2.327237	Ok
GF	EQx	0	Ok
	EQy	0	Ok

Table A9: Base Shear without and with Steel Retrofitting

Condition	Base Shear
Without Retrofitting	153.64 kip For X & Y Direction
With Retrofitting	161.82 kip For X & Y Direction

Table A10: BNBC 2020 Reference Data

Parameter	Symbol	Value Used
Seismic Zone Factor	Z	0.20
Importance Factor	I	1.0
Response Modification Factor	R	8.0
Drift Limit	Δ / h	0.02

APPENDIX B

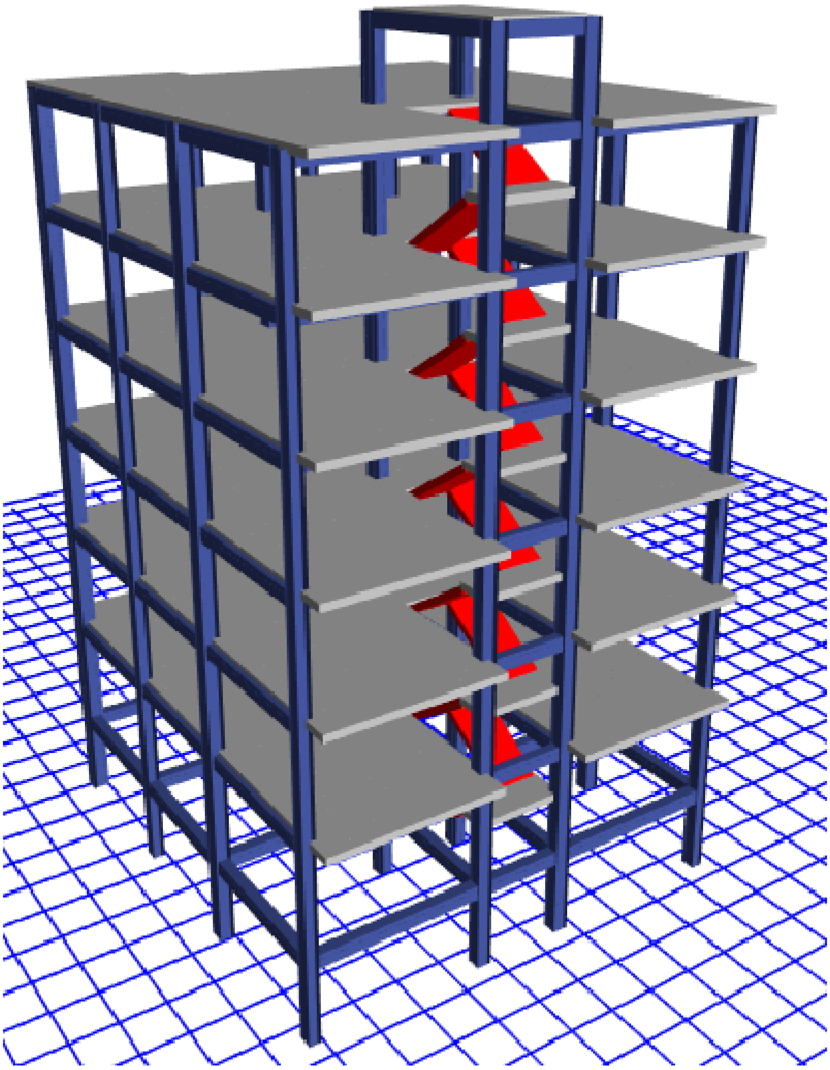


Figure B3: ETABS 3D Modeling

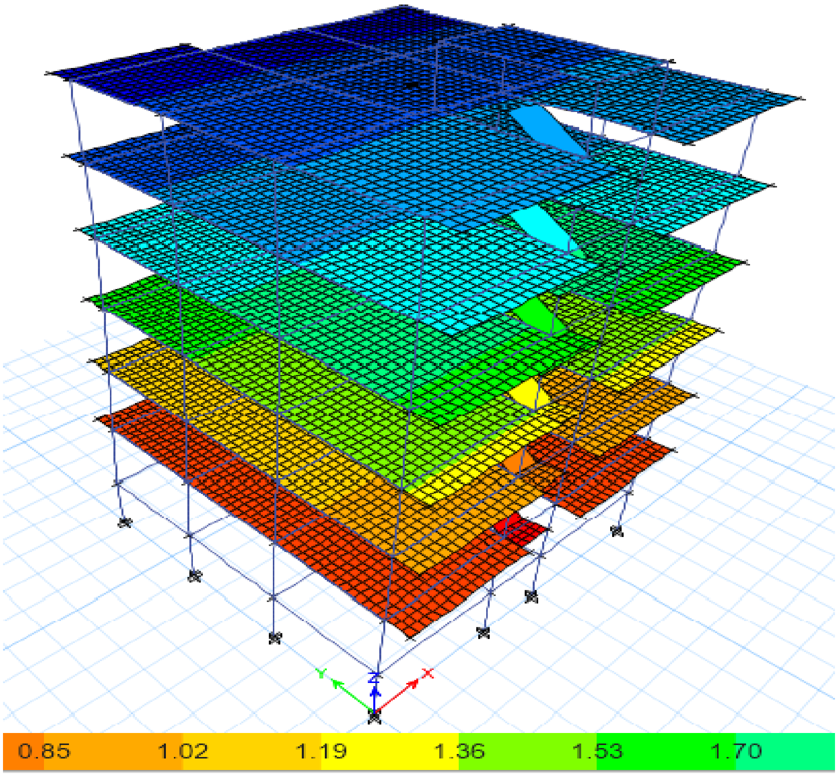


Figure B2: Deformed Shape under Seismic Load (EQx) Without Retrofitting

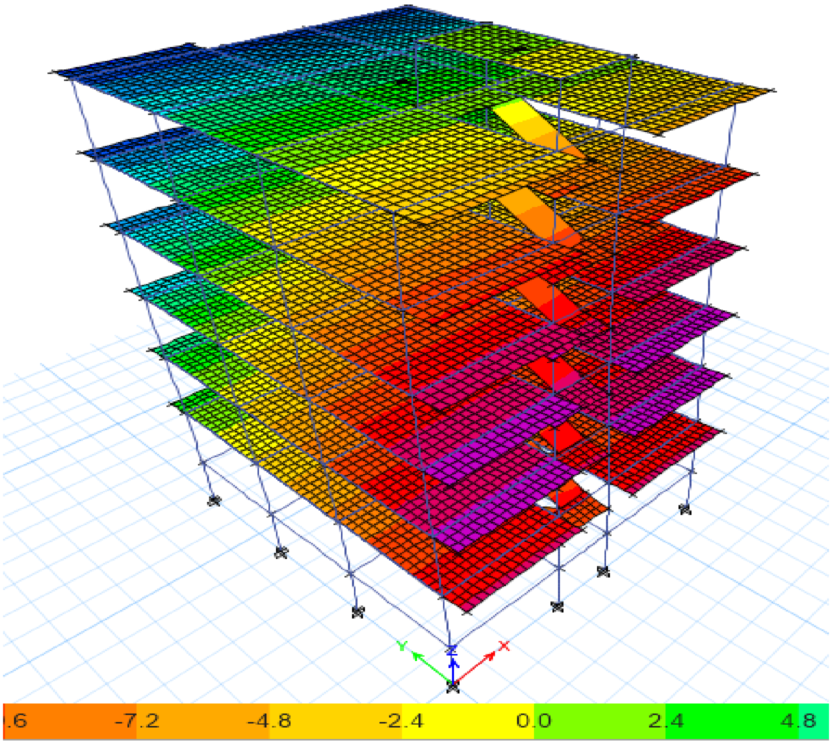


Figure B3: Deformed Shape under Seismic Load (EQy) Without Retrofitting

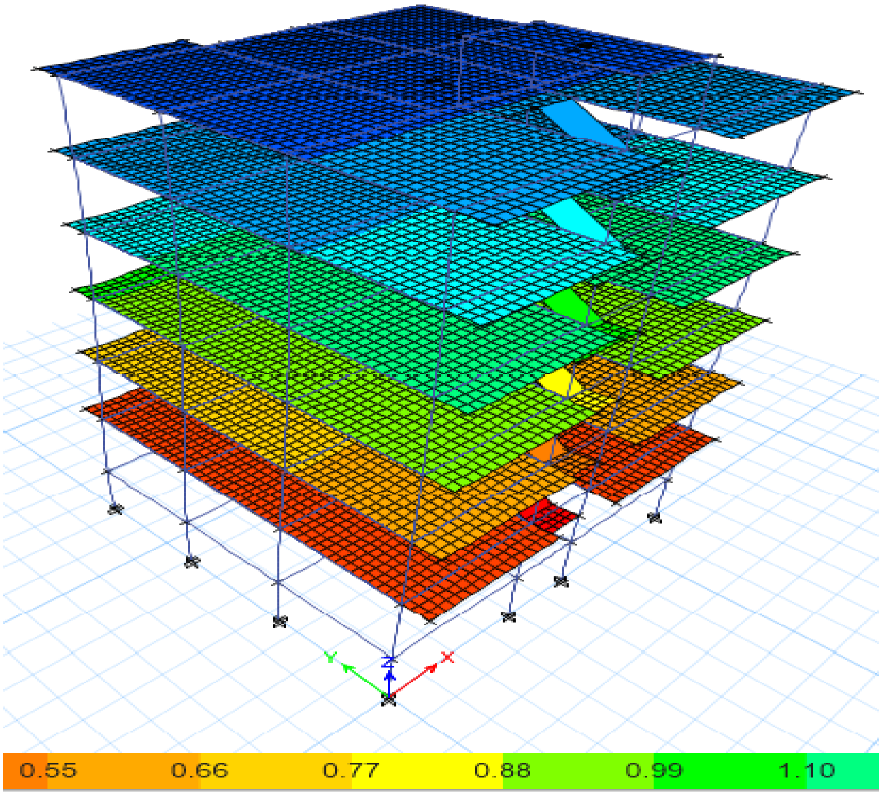


Figure B4: Deformed Shape under Seismic Load (EQx) With Retrofitting

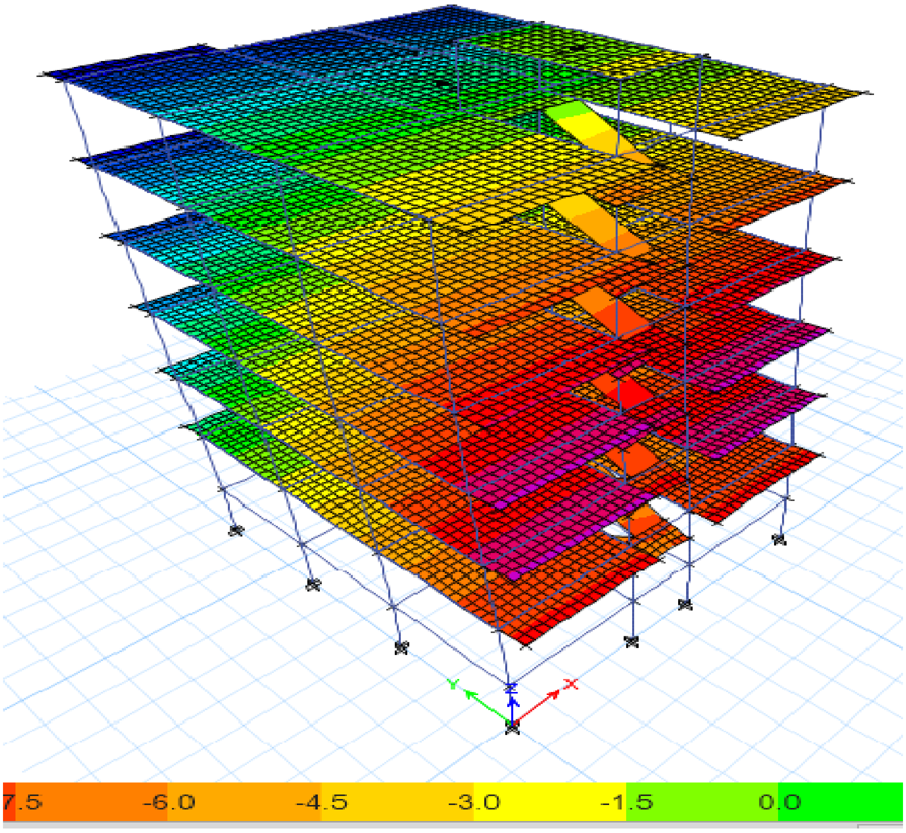


Figure B5: Deformed Shape under Seismic Load (EQy) With Retrofitting