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SEISMIC RETROFITTING OF G+10 SOFT STOREY R.C.C. BUILDING

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SUBMITTED BY:

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UNDER THE SUPERVISION OF

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CANDIDATE'S DECLARATION

I, Amit Malik (2K20/STE/501), student of M.Tech (Structural Engineering), hereby declare that the project Dissertation titled "S**EISMIC RETROFITTING OF G+10 SOFT STOREY R.C.C. BUILDING**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the project Dissertation titled “S**EISMIC RETROFITTING OF G+10 SOFT STOREY R.C.C. BUILDING**” which is submitted by submitted by Amit Malik (2K20/STE/501) to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

Soft-floor buildings, characterized by open spaces on the first floor, pose challenges to seismic performance. To address this, braces and shear walls are commonly employed to reduce displacement and improve seismic resilience. Shear walls and braces enhance lateral stiffness, minimize displacement, and ensure safety. This study investigates the seismic response of soft-floor RCC buildings, considering parameters such as soft floor height, shear wall placement, and brace types and arrangements. The goal is to enhance structural safety without extensive alterations. Analysis is conducted in three phases: soft-storey analysis, shear wall implementation, and brace integration. Shear walls are assessed at the center and corners, while different brace arrangements are examined. Results reveal the effectiveness of shear walls in enhancing stiffness and reducing displacement. Incorporating bracing systems improves overall building performance. Cost-effective strategies for strengthening soft-floor structures are identified, with findings summarized based on seismic response.

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LIST OF ABBREVIATIONS

RCC	Reinforced cement concrete
IO	Immediate occupancy
LS	Life safety
CP	Collapse prevention
U	Poisson's ratio
α	Co-efficient of thermal expansion
G	Shear modulus
E	Modulus of Elasticity
fck	Compressive strength
fy	Yield stress
Z	Seismic zone
IS	Indian Standard
DBE	Design based Earthquake
G+	Including Ground
D.L	Dead load
L.L	Live load
E.L	Earthquake load
I	Importance factor
Sa/g	Response acceleration coefficient
T	Fundamental time period
SMRF	Special moment resisting frame
SS	Soft storey
C_eSW	Centre shear wall
C_oSW	Corner shear wall
X-MB	Cross bracing at mid-bay
X-CB	Cross bracing at corner bay
V-MB	V-type bracing at mid-bay
V-CB	V-type bracing at the corner bay
RSA	Response spectrum analysis

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Earthquakes are devastating natural disasters caused by the sudden release of underground energy, making them one of the most destructive forces that impact both living and non-living elements on the Earth's surface. These seismic events generate vibrations that propagate through the ground, leading to the loss of life and structural damage. The intensity and magnitude of earthquakes vary, making it crucial to investigate the seismic behavior of RCC structures under different parameters such as shear forces at the base and displacement. Dynamic analysis is necessary to ensure the safety of structures and understand their response characteristics during seismic events. It is also essential to determine the maximum response to base excitation.

Structures experience lateral loads during earthquakes in addition to gravity loads, causing dynamic fluctuations. Compared to high-rise buildings, low-rise buildings tend to exhibit lower levels of displacement. However, as urban areas undergo industrial and economic growth, accompanied by changes in inhabitants' lifestyles, there is an increasing demand for taller buildings that are susceptible to lateral loads. When a structure is designed to withstand horizontal loads, it is more likely to exhibit significant deflection. To reduce displacement, bracings and structural walls are commonly employed as lateral load-bearing systems.

Designing seismic structures involves considering the design basis earthquake (DBE); however, the actual forces acting on the structure often exceed the DBE forces. The primary objective of seismic design is to provide ductility, allowing structures to withstand seismic forces. Structural engineers employ various techniques such as moment-resistant frames, diaphragms, braces, and shear walls to counteract lateral forces and achieve the necessary stiffness. Among these systems, shear walls are particularly effective for resisting earthquake loads and providing the stiffness and strength required by structures, especially in high-rise buildings and elevator housings.

1.2 SOFT STOREY

Many high-rise buildings incorporate an open floor known as a "soft storey" to accommodate parking lots, retail spaces, conference rooms, and other amenities. The presence of a soft storey, as depicted in Figure 1.1, poses a significant challenge for civil engineers and designers in the field. The inclusion of a soft storey in high-rise buildings introduces structural irregularities, particularly in terms of strength and stiffness. Consequently, when predicting the seismic performance of these structures, it becomes crucial to understand the specific requirements associated with soft storeys and their impact on the overall building behavior. This research aims to investigate the effects of modifying the bracing arrangement in buildings with a soft storey by conducting a parametric analysis on both bare frame and shear wall systems.

Figure 1.2 Buildings failure due to soft storey [5]

The specifications related to the soft storey are outlined as follows:

i. **According to IS1893 (Part 1): 2002:** A soft floor is characterized by having a lateral stiffness that is less than 70% of the stiffness of the floor immediately above or less than 80% of the average lateral stiffness of the three floors above. An extremely soft floor is defined as having a lateral stiffness that is less than 60% of the stiffness of the floor above or less than 70% of the average lateral stiffness of the three floors above.

ii. **According to IS1893 (Part 1)2016** defines the lateral stiffness of a soft floor as being less than the lateral stiffness of the floor directly above it. The seismic lateral stiffness represents the combined stiffness of all the elements that resist seismic forces and mitigate the lateral vibrations induced by seismic activity in the specified direction.

iii. **According to IS13920: 2016**, a shear wall is described as a vertical planar element designed to primarily withstand lateral forces, including axial loads, shear forces, and bending moments, acting within its own plane.

1.3 SHEAR WALL

A shear wall is a structural system composed of shear panels that serve to mitigate the impact of lateral loads on a building. Its primary objective is to enhance the overall rigidity and lateral load resistance of the structure by providing the necessary stiffness and strength. Shear walls, which are wide, vertically oriented beams incorporated into reinforced concrete (RCC) structures, are employed to counteract the effects of lateral loads imposed on buildings. These walls are integrated with slabs, beams, and columns to impart the required rigidity, particularly in residential construction. Given the increased vulnerability of buildings, especially high-rise structures, to lateral loads and forces, shear walls play a crucial role.

In high-rise structures, the size of beams and columns is relatively larger, and the reinforcement at beam-column joints is significantly heavier, leading to congestion in these areas. Shear walls serve as an effective solution to address these practical challenges by providing the necessary stiffness.

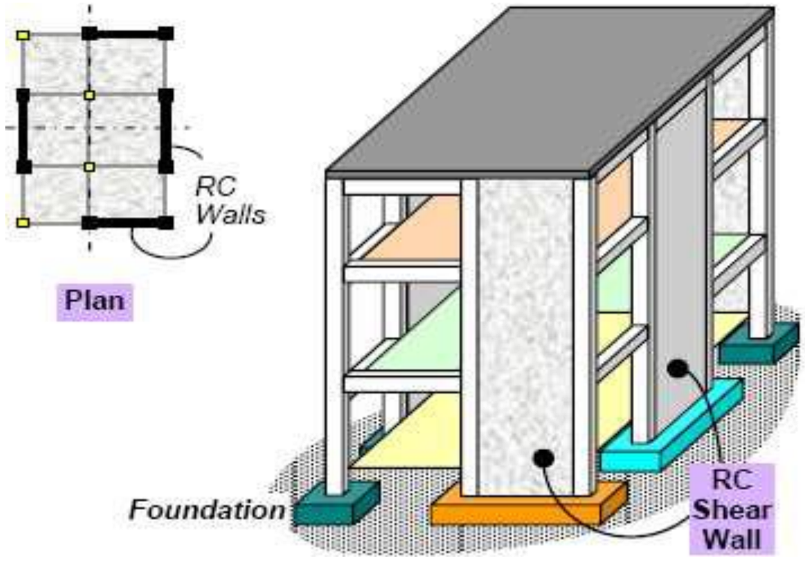


Figure 1.3. Typical plan & elevation view of shear wall building

(Source: IITK-BMTPC Earthquake Tip 23)

1.3.1 Shear wall geometry and location

Shear walls are constructed using various cross-sectional shapes, including rectangular and irregular shapes such as L, T, C, and U. The rectangular cross-section, with one dimension significantly larger than the other, is commonly employed as an irregular shape. These different cross-sectional configurations are chosen based on their ability to withstand seismic forces, as the shape and positioning of shear walls significantly influence the behavior of the building.

The placement of shear walls in the structure plays a crucial role in establishing an effective lateral resistance system that minimizes lateral displacement caused by seismic loads. Therefore, careful consideration is given to the precise location of these walls. To ensure structural efficiency, shear walls are strategically placed symmetrically to minimize the impact of torsion and promote a balanced distribution of forces throughout the building. This symmetrical arrangement helps to optimize the overall seismic performance of the structure.

1.3.2 Purpose of constructing Shear walls

Shear walls are not only designed to support vertical, or gravity loads but also to resist lateral loads caused by seismic or wind forces. These walls are statically connected to the roof, floor, and other vertically aligned side walls, providing three-dimensional stability to the building. The shear wall system offers a higher level of stability compared to the RCC skeleton structure, primarily due to the relatively large load-bearing area in relation to the total floor area of the structure.

In addition to withstanding vertical loads, shear walls are specifically designed to counter uplift forces induced by wind and resist shear forces. These walls effectively resist the lateral force exerted by the wind, preventing it from pushing the wall away from the building. One notable advantage of constructing shear walls is the speed at which they can be built. The chosen construction method often involves using formwork to pour concrete panels, facilitating efficient and rapid construction.

Shear-bearing walls offer a high degree of precision, eliminating the need for plastering and additional finishing. This feature saves both time and resources, as no extra plaster or finishing work is required once the walls are in place. The inherent strength and stability of shear walls make them a reliable choice for enhancing the overall performance and durability of buildings subjected to lateral loads.

1.4 Bracings

Bracing the frame structure to resist wind loads is a highly effective and cost-efficient method. The brace system consists of regular columns and beams that primarily carry gravity loads, along with diagonal braces. These diagonal braces are strategically connected to form a vertical cantilever truss, which provides resistance against horizontal forces. The effectiveness of braces lies in the axial tension experienced by the diagonals.

Different types of braces are utilized based on their intended application and the connection points to the columns and beams. The braces can be classified as follows:

1.4.1 Material-Based:

i. **RC Brace:** These braces are constructed using reinforced concrete beams or columns. They exhibit high compression strength due to the inherent strength of concrete in compression. However, they are not commonly used due to their inability to sustain repeated earthquake excitations, making them relatively expensive.

ii. **Steel Brace:** Steel braces are fabricated using steel profiles such as angle sections, U sections, or tube sections. They are capable of withstanding high tensile forces but may buckle under extreme loads. One advantage of steel braces is their reusability after damage, and they are generally more cost-effective than RC braces.

1.4.2 Based on Connections to Frames:

i. **Concentric:** These braces are connected directly to the beams or columns. Examples of concentric brace configurations include the K-type, V-type, and X-type braces.

ii. **Eccentric**: These braces are connected to a different location within the specified section. The connection points transfer energy from plastic drift caused by seismic activity. Eccentric braces enhance lateral stiffness and increase energy dissipation. In frame structures with eccentric braces, the lateral stiffness depends on the bending deformation of the braces.

Implementing the appropriate brace type and connection configuration is crucial for optimizing the structural performance and resilience of buildings subjected to lateral loads. The selection of bracing systems must consider factors such as material properties, cost-effectiveness, reusability, and their ability to provide the required lateral stiffness and energy dissipation capabilities.

To investigate the impact on the behavior of the building, X-bracing and V-bracing systems were implemented in both the corner and middle bays of the structure with a soft storey. This arrangement allows for a comprehensive examination of how the presence of these bracing systems influences the structural response. By strategically placing X-bracing and V-bracing in these specific locations, the study aims to analyze their effectiveness in enhancing the overall stability and resistance of the building against lateral forces. Through careful observation and analysis, valuable insights can be gained regarding the contribution of these bracing systems to mitigating the adverse effects of seismic or wind loads on the structure.

1.5 OBJECTIVE

i. Assessing the seismic response of soft-floor RC buildings: The main objective could be to investigate and understand the behavior of structures with soft floors under seismic loading conditions. and analyze their behavior under earthquake conditions using response spectrum and pushover analysis.
ii. Evaluating the effectiveness of shear walls and bracings: The aim could be to study the impact of incorporating shear walls and bracings in mitigating the adverse effects of soft floors, such as reducing displacement and drift, increasing stiffness, and improving base shear values.
iii. Investigating the influence of different parameters: The objective might be to analyze the effects of various factors, such as soft floor heights, shear wall positions, and bracing types and arrangements, on the seismic performance of the structures.
iv. The effectiveness of incorporating shear walls in buildings with a soft story will be investigated to determine their contribution to structural stability and seismic resistance.

v. Comparing analysis methods: The aim could be to compare the results obtained from linear dynamic analysis (response spectrum) and pushover analysis methods to determine their effectiveness in assessing soft story conditions.

vi. Providing design guidance: The objective might be to offer design engineers insights and recommendations for addressing soft floor deficiencies in their structural designs, considering the findings and observations from the study.

1.6 SCOPE OF PROJECT

i. This study focuses solely on multi-storey frames, excluding other types of structures.

ii. Plan irregularities are not considered in the analysis.

iii. Shear walls and bracings are incorporated into the framework to facilitate dynamic and pushover analysis of the structures.

iv. Dynamic analysis utilizes the response spectrum method to predict the actual performance of RC shear wall frames subjected to lateral loads. Additionally, pushover analysis is conducted on specific structures.

v. The buildings under investigation undergo strengthening measures through the implementation of various brace systems.

vi. The aim is to evaluate the effectiveness of these brace systems in improving the seismic performance and overall structural integrity of the buildings.

1.7 NEED FOR RESEARCH.

i. It is important to acknowledge that structural irregularities are inherent in real-world buildings, and it is crucial for designers to evaluate their implications during seismic events.

ii. The assessment of irregularities and their effects on the structural behavior under earthquake conditions is a necessary aspect of structural design.

iii. Further research is required to identify cost-effective and efficient methods for enhancing the lateral stiffness system in areas prone to seismic activity.

iv. The objective is to develop strategies that can effectively mitigate the vulnerabilities of structures in seismically active regions while ensuring economic viability.

v. This research aims to provide valuable insights into improving the seismic performance of structures through the development of innovative approaches to address irregularities and enhance lateral stiffness.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

The literature review provides a comprehensive overview of the existing knowledge and research in a particular field. It serves as a foundation for understanding the current state of the subject matter and identifying gaps that need further investigation. In this context, the literature review explores various scholarly articles, books, and research papers relevant to the research topic. It critically analyzes and synthesizes the findings, methodologies, and theories presented in these sources**.** By reviewing and evaluating the literature, researchers can contextualize their own work, identify research questions, and justify the significance and novelty of their study. Following papers are helpful during this project: -

Suresh Kannan (2023) conducted a comprehensive study on the behavior of a soft storey structure with different bracing systems in seismic zones IV and V, which are very severe in terms of seismic activity according to IS 1893. The study involved adjusting the soft storey at various levels and analyzing seismic characteristics such as storey displacement, base shear, and storey drift. Based on the analysis, the shear wall demonstrated better earthquake resistance compared to the steel bracings in soft-story buildings[2]. The shear wall exhibited superior performance in terms of base shear and earthquake resistance, especially in highly seismic areas. On the other hand, steel bracings were found to be effective in lower-risk areas with less seismic activity.

Sawsan Yaseen Khudhair (2019) [3] conducted a study that examined the impact of shear wall's location on the stiffness and behavior of the structure under lateral loads, specifically seismic effects. The study provided insights into the importance of shear wall location, their impact on the building's response to lateral loads, and the significance of stiffness enhancement in mitigating the effects of seismic activity.

Dhiraj D Ahiwale, Rushikesh R Khartode (2020) conducted a pushover analysis on a twelve-storied RC frame building with an open ground storey retrofitted using different strengthening systems, namely infill, steel bracing, and shear wall[5]. The analysis was performed using SAP 2000. Work focused on evaluating the performance of different retrofitting techniques in enhancing the seismic performance of an RC frame building with an open ground storey. The findings emphasized the superior performance of shear walls compared to infill walls and steel bracing in terms of base shear carrying capacity and displacement control. The study aimed to provide insights into the effectiveness of various strengthening systems for deficient buildings and to identify the optimal retrofitting strategy for achieving the desired seismic performance.

Kashif Ahmer, Sharat. S. Chouka (2020) conducted a project that involved the analysis of different models with shear walls at various locations in a building. Work focused on analyzing the behavior of different models with shear walls at various locations in terms of storey displacement, drift, base shear, stiffness, time period, and the comparison between ESA and RSA [6]. The findings highlight the benefits of placing shear walls at the corner for reducing displacement, drift, and increasing stiffness, ultimately improving the overall seismic performance of the building structure.

Hema Mukundan, S. Manivel (2015) In this study, Response Spectrum Analysis (RSA) was conducted on ten multi-storey buildings in Zone IV using Etabs software. The study compared models with and without reinforced concrete structural walls to evaluate their effects on displacements, shear forces, modal shapes, and drifts[7]. The researchers also investigated the impact of irregularities such as openings and changes in the depth of the concrete structural walls. The findings revealed that the inclusion of shear walls in the structure resulted in a reduction in column moments and a significant decrease (50%) in maximum displacement. These results emphasize the effectiveness of shear walls in enhancing the structural performance and seismic resistance of the buildings analyzed.

Vidhya K (2021) In this study, the non-linear static behavior of a structural wall with and without openings, such as doors and windows, was investigated. A G + 9 structure was modeled, and a pushover analysis was conducted using ETABS software considering soil type II according to IS 1893: 2002. Three cases were considered: the first case had shear walls in the corners without openings, while the second and third cases had structural walls with mid and zigzag openings in the corners [8]. The results indicated that the structure with corner walls without openings exhibited greater shear resistance and better seismic performance compared to the models with central and zigzag openings in the corner walls. Therefore, the first case demonstrated superior seismic performance in terms of shear resistance.

Yaseer Alashkar, Sohaib Nazar, Mohammad Ahmed (2015) In this study, a relative seismic retrofit investigation was conducted on a ten-storey RCC frame structure located in Zone III. The analysis focused on comparing the performance of a steel brace system and a shear wall system, considering the position of concrete walls within the structure. The analysis was performed using SAP2000 software. Six different models were created, incorporating core and boundary shear walls, as well as X and V braces in the corner and core of the structure. The results were compared in terms of displacement, story drift, moments, and shear in beam-columns [9]. The findings indicated that the shear wall located at the core of the building outperformed the one at the boundary. Additionally, the cross brace configuration demonstrated greater effectiveness compared to the V brace configuration.

S. Arun Kumar, Dr. G. Nandini Devi (2016) In this study, a pushover analysis was conducted on a ten-storey RC structure with a soft storey on the ground floor using Etabs software. The analysis considered Seismic Zone III and Soil Type II according to the IS Code. The study included the presence of shear walls and cross braces to reinforce the soft storey. The results provided information on maximum base shear, displacement, storey drift, shear, and overturn moment [12]. It was observed that the structure with shear walls exhibited minimal drift, and the presence of a structural wall at the soft storey led to improved performance compared to other configurations.

Dr. Rakesh Kumar Pandya, Abhishek Kumar Singha (2020) In this study, the author has conducted a study on the performance of reinforced concrete frames using pushover analysis, evaluating factors such as fundamental time period, nonlinear behavior, and hinge distribution[13].

Shaik Akhil Ahamad, K.V. Pratap (2020) In this study, the author focuses on investigating the use of shear walls at various locations in a 21-story multi-story structure across different earthquake zones. Response spectrum analysis is employed to understand the behavior of seismically exposed structures. The investigation includes analyzing storey drift, shear, permissible displacement, and twisting irregularities in multi-story buildings [14]. Structural investigation and modeling using Etabs software are conducted for all earthquake zones as per the IS 1893 code. The goal of the study is to compare the behavior of multi-story structures with and without shear walls, as well as analyze the results across all seismic zones. The findings indicate that the four-ended shear wall configuration yields better results in terms of displacement, drift, and shear at the base.

Akash Malik, Akshay Kumar, Vishwas Malik, Arun Kumar, Mohammad. Amir Khan, Fahimul Islam Kirman (2023) This study focuses on assessing the seismic behavior of staggered shear wall models and staggered X bracing models using nonlinear time history analysis in ETABS software [15]. staggered shear walls offer improved performance in terms of displacements and drift reductions, while staggered X bracing structures exhibit lower shear forces and a longer fundamental time period.

Anwar Jabar, Halmat Ahmed (2022) In this study, the seismic performance of buildings with shear wall and steel bracing were evaluated. To this, a nine-storey reinforced concrete (RC) building having a square plan with five bays in both directions and identical story height was considered. The building consists of typical beam-column frames. RC shear walls and concentric steel bracings were used to improve the seismic behavior of the structure [16]. A total of five building cases were considered as the existing building and those upgraded with the shear wall, X-bracing, inverted-V bracing, and diagonal bracing. The nonlinear static pushover and nonlinear time history analyses were performed through ETABS Software.

Shaik Kamal Mohammed Azam et al., (2013) A well designed system of shear walls in a building frame improves its seismic performance significantly. The configurations of RC moment resisting framed building structure with different arrangements of shear walls are considered for evaluation of seismic performance, so as to arrive at the suitable arrangement of shear wall in the structural framing system for better seismic resistance.

Satpute S G et al., (2013), study seismic responses of the ten storey RC shear wall building with and without opening. Developed mathematical modeling and analyzed the reinforced concrete shear wall building by using different nonlinear methods (time history and pushover method). These methods differ in respect to accuracy, simplicity, transparency, and clarity of theoretical background. Non-linear static procedures were developed with the aim of overcoming the insufficiency and limitations of linear methods, whilst at the same time maintaining a relatively simple application. All procedures incorporate performance-based concepts paying more attention to damage control.

S C Pednekar, H S Chore and S B Patil, (2015) study gives an effect of increase in number of storey on seismic responses by performing pushover analysis. Reinforced concrete structures of G+4, G+5 and G+ 6 storey have been modeled and analyzed using ETABS 9.7.4 software. Comparison of seismic responses of the structure in terms of base shear, time period and displacement has been done by performing nonlinear static pushover analysis. From analysis results it has been observed that base shear and spectral acceleration is reduced, whereas displacement, time period, spectral displacement is increased as the number of storey increases. Analysis also shows location of plastic hinges at performance point of the structures with different number of storey.

2.2 LITERATURE GAPS

i. The Indian Standard IS 1893: 2002 specifies guidelines for studying structures with open first-story conditions, considering a multiplying factor of 2.5 to account for stiffness irregularity in the absence of considering the stiffness of infill. However, engineers have found that using a multiplying factor of 2.5 is often unrealistic for low-rise structures.

ii. The design procedures outlined in IS codes for strengthening techniques are inadequate, lacking sufficient detail and steps. The code and research papers provide more comprehensive coverage of theoretical aspects and case studies, but there is a lack of emphasis on the design aspect.

iii. The placement and shape of shear walls are commonly investigated to determine their optimal location in various studies. However, there is a lack of literature exploring the effects of varying the percentage of shear wall presence in each principal direction.

iv. Detailed provisions for pushover analysis are currently absent in the Indian standard code and require further inclusion and elaboration.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

The study process for determining seismic forces within structures involves several steps to ensure accuracy and reliability i.e., Defining the research problem and establishing the research objective. Conducting a comprehensive review of existing literature on the subject. Selecting the relevant parameters and software tools for the study. Developing numerical models and performing dynamic analysis and pushover analysis, considering the following aspects: Incorporating moment resisting frames in the structure. Introducing a soft storey on the ground floor. Adding shear walls at strategic locations, such as corners and the core, throughout the height of the building. Implementing retrofitting measures by introducing bracing in both mid and corner bays throughout the building height. Analyzing and discussing the obtained results in detail. Formulating conclusions based on the findings and analysis. Documenting the entire research process, including methodologies, results, discussions, and conclusions. By following these steps, the study aims to provide valuable insights into the seismic behavior of structures and the effectiveness of different retrofitting techniques in enhancing their seismic resistance.

3.2 METHODS ADOPTED FOR ANALYSIS.

i. Response Spectrum Analysis
ii. Non Linear Static Analysis

3.2.1 Response Spectrum Analysis

Response Spectrum Analysis is a widely used method in structural engineering for evaluating the seismic response of structures. It is a dynamic analysis technique that considers the effect of a range of ground motion records, representing different seismic events, on the structure.

In Response Spectrum Analysis, the ground motion records are converted into response spectra, which depict the maximum structural response at different natural frequencies. These response spectra are obtained by analyzing the structure's dynamic properties, such as its mass, stiffness, and damping, along with the input ground motion.

The analysis involves calculating the structure's response at each frequency in the response spectrum, considering the modes of vibration. By combining the responses from all modes, the overall response of the structure to seismic excitation can be determined.

Response Spectrum Analysis provides valuable information about the structural behavior, including maximum displacements, accelerations, and forces experienced during an earthquake. It helps engineers in designing structures that can withstand specific seismic events by assessing their performance under various ground motion scenarios.

The results obtained from Response Spectrum Analysis aid in optimizing the design, selecting appropriate structural systems, and implementing necessary measures to ensure the safety and reliability of the structure against seismic forces.

3.2.2 Non-Linear Static Analysis

Nonlinear static analysis, also known as pushover analysis, is a computational method used in structural engineering to assess the behavior and response of a structure under nonlinear conditions. Unlike linear static analysis, which assumes linear behavior of the structure, nonlinear static analysis considers the nonlinear properties of materials and the geometric nonlinearity of the structure.

In nonlinear static analysis, the structure is subjected to incremental or monotonic loading until it reaches its ultimate capacity or a predetermined limit state. The analysis involves applying a series of load patterns, gradually increasing the magnitude of the loads, and evaluating the corresponding displacements, internal forces, and deformations of the structure at each step.

The main objective of nonlinear static analysis is to determine the structural capacity, identify potential failure mechanisms, and assess the redistribution of forces within the structure. It allows engineers to understand the nonlinear behavior of the structure, including the development of plastic hinges, yielding of materials, and the formation of cracks.

By analyzing the response of the structure under nonlinear conditions, engineers can evaluate the structural performance, identify weak points, and make informed decisions regarding retrofitting or strengthening measures. Nonlinear static analysis provides valuable insights into the behavior of structures during extreme events, such as earthquakes, and helps ensure their safety and resilience.

Overall, nonlinear static analysis is a powerful tool for assessing the structural response beyond the limitations of linear analysis and plays a crucial role in the design and evaluation of structures subjected to significant nonlinear effects.

3.2.3 Advantages of Nonlinear static analysis

Nonlinear static analysis and response spectrum analysis are two different methods used in structural engineering to evaluate the behavior of structures under seismic loads. While both approaches have their merits, nonlinear static analysis offers several advantages over response spectrum analysis in certain situations.

i. Capturing Nonlinear Behavior: Nonlinear static analysis considers the nonlinear response of the structure, accounting for material yielding, plastic deformation, and redistribution of forces. This allows for a more accurate representation of the actual structural behavior, especially in systems with significant nonlinearities such as yielding elements or large displacements.

ii. Localized Damage Assessment: Nonlinear static analysis can identify and localize areas of potential damage within the structure, such as plastic hinge formations or high-stress concentrations. This information is valuable for assessing the structural integrity and planning targeted retrofitting or strengthening measures.

iii. Nonlinear Load-Displacement Relationship: Nonlinear static analysis provides a realistic representation of the load-displacement relationship, considering the effects of stiffness degradation and energy dissipation. This enables engineers to assess the structure's response beyond elastic limits and understand its performance under extreme loading conditions.

iv. Consideration of Strength and Ductility: Nonlinear static analysis allows for a direct assessment of the strength and ductility of structural elements, which is crucial for evaluating their capacity to withstand seismic forces. It provides insights into the potential for structural collapse or excessive deformation, facilitating more informed design decisions.

v. Customized Load Patterns: Nonlinear static analysis offers flexibility in applying customized load patterns that simulate the actual seismic response of the structure. Engineers can tailor the loading sequence and magnitude to capture specific characteristics of the seismic event, resulting in a more accurate representation of the structural behavior.

vi. Detailed Assessment of Retrofitting Strategies: Nonlinear static analysis is particularly useful for evaluating retrofitting strategies and assessing their effectiveness in improving the seismic performance of existing structures. It enables engineers to simulate the behavior of retrofitted elements and evaluate the overall impact on the structural response.

While nonlinear static analysis provides these advantages, it typically requires more computational effort and expertise compared to response spectrum analysis. The choice between the two methods depends on the complexity of the structure, the level of accuracy required, and the specific objectives of the analysis.

3.3 INTRODUCTION OF ETABS SOFTWARE

Etabs is a extensively used software program for structural analysis and design of structures. Developed by Computers and Structures, Inc. (CSI), Etabs stands for" Extended 3D Analysis of Building Systems." It offers a comprehensive suite of tools and features that enable masterminds to efficiently model, dissect, and design colorful types of structures, including high- rise structures, islands, and artificial structures. Etabs provides a stoner-friendly interface that allows masterminds to produce 3D models of structures using a range of structure factors similar as shafts, columns, crossbeams, walls, and braces. These factors can be fluently defined and customized to directly represent the figure and parcels of the factual structure. The software supports colorful analysis styles, including static, dynamic, and nonlinear analyses, allowing masterminds to assess the structure under different lading conditions. It can perform response diapason analysis, time history analysis, and pushover analysis, among others, to estimate the seismic response and stability of the structure. With its important logical capabilities, Etabs can calculate and induce results for important structural parameters similar as deportations, forces, moments, stresses, and design conditions. These results aid in optimizing the design, relating implicit structural sins, and icing compliance with applicable structure canons and norms. Etabs also offers advanced features for designing colorful structural rudiments, including sword and concrete members. The software can induce detailed design reports, delineations, and attestation to grease the construction and perpetration of the structural design. Overall, Etabs provides masterminds with a robust platform for effective and accurate structural analysis and design. Its capabilities, versatility, and stoner-friendly interface make it a precious tool in the field of civil and structural engineering.

3.3.1 Features and benefits of Etabs

Etabs offers a range of features that facilitate the analysis of structures with shear walls and bracing. Some of the key features include:

i. Shear Wall Modeling: Etabs allows for the easy and accurate modeling of shear walls within the structural system. Engineers can define the properties, dimensions, and material characteristics of shear walls, including their locations and orientations within the building.

ii. Bracing Modeling: The software enables the modeling of different types of bracing systems, such as X-bracing and V-bracing. Engineers can define the bracing elements, specify their properties, and arrange them at desired locations along the height of the structure.

iii. Nonlinear Analysis: Etabs supports nonlinear analysis capabilities, which are essential for accurately capturing the behavior of shear walls and bracing systems under seismic loads. It can perform pushover analysis, considering the inelastic behavior of the structure, and capture the response beyond the linear range.

iv. Response Spectrum Analysis: Etabs includes response spectrum analysis methods, allowing engineers to evaluate the dynamic response of the structure to seismic loads. This analysis considers the effects of various ground motion records and provides insights into the structure's performance, including displacements, accelerations, and inter-story drifts.

v. Design Optimization: The software offers design optimization tools specifically tailored for structures with shear walls and bracing. Engineers can perform automatic optimization routines to find the optimal distribution and sizing of shear walls and bracing elements, considering factors such as material utilization, stability, and performance criteria.

vi. Code Compliance Checks: Etabs incorporates built-in design codes and standards, including provisions from international seismic design codes such as IS 1893, ASCE 7, Eurocode, etc. The software performs code compliance checks for shear walls and bracing elements, ensuring that the design meets the required strength and stability criteria.

vii. Visualization and Reporting: Etabs provides comprehensive visualization capabilities, allowing engineers to visualize the structural response, deformations, and member forces. It also generates detailed reports and documentation, including design calculations, drawings, and graphical representations of the analyzed structure.

These features in Etabs enable engineers to accurately model, analyze, and design structures with shear walls and bracing systems, ensuring their safety and performance under seismic loads.

3.4 MODEL SPECIFICATIONS

This research focuses on the seismic analysis of a G + 10-story reinforced concrete building with a regular plan shape in Zone V. The study is conducted in three phases, each exploring different structural configurations. Initially, the building is modeled with a soft storey on the ground floor. In the second phase, shear walls are introduced in two positions, the center and the corner, to determine the optimal location. The third phase incorporates different types of X and V brace arrangements in the central and corner spans along the building's height. The construction plan can be seen in Figure below. The analysis data of the building is provided below:

A 10-story RC frame structure with a soft story and a floor plan measuring 30x30m is selected as the model structure for this study. The building models are developed in three phases to investigate the impact of different retrofitting strategies.

i. In the first phase, the initial model is created with a soft story in the ground floor, simulating the vulnerable condition commonly observed in buildings.

ii. The second phase involves incorporating shear walls into the structure while still maintaining the soft story on the ground floor. This allows for evaluating the effectiveness of shear walls in improving structural performance.

iii. In the third phase, the model is modified to include bracings along with the soft story on the ground floor. This enables the assessment of the impact of bracings as a retrofitting measure for enhancing structural stability.

Shear walls are incorporated into the building at different locations, including the corners and the core of the structure where the soft story is present. This allows for a comparative evaluation of the effectiveness of shear walls in reducing the structural response. Shear walls have been provided on different locations- Corner and at the core of the building with soft storey. Various bracing arrangements, such as X and V-type bracings, are implemented in the corner and mid-bays throughout the height of the building. This facilitates the examination of the bracing system's impact on structural performance. The seismic analysis of the structure is conducted using ETABS software version 18.0.2, following the guidelines specified in IS 1893:2016. Both linear dynamic response spectra analysis and nonlinear static pushover analysis are performed to assess the structural behavior under seismic loads. By conducting these analyses and comparisons, the study aims to provide comprehensive insights into the performance of the structure with different shear wall and bracing configurations, aiding in the selection of appropriate retrofitting measures for enhancing the seismic resilience of buildings with soft stories.

Figure 3.4 Plan of G+10 storey RCC building

3.4.1 General Data of the Model:

a) Concrete grade	:	M25.
b) f_y	:	415 N /mm^2
c) Poisson ratio	:	0.2
d) Type	:	SMRF regular plan
e) Plan dimension	:	30m x 30m
f) No. of stories	:	G +10
g) Floor height Bottom	:	Typical storey 3.0m, storey: 5m
h) Slab depth	:	150mm
i) Beam size	:	300mm × 600mm
j) Column size	:	600mm × 600mm
k) Bay no (X-axis)	:	5
l) Bay no (Y-axis)	:	5
m) width of bay both directions	:	6m
n) Live load	:	2 KN/m^2
o) Floor and partition	:	1.5 KN /m^2

p) Wall load	:	14 KN /m
q) Masonry thickness	:	230mm
r) Shear wall thickness	:	200mm
s) concrete density	:	25 KN/m^3
t) Masonry unit weight	:	19 KN/m^3
u) Soil type	:	II
v) Equivalent lateral loads	:	According to Indian standard 1893 part1
w) Seismic zone	:	V
w) Damping of structure	:	5%
x) Support conditions	:	Fixed
y) Response reduction factor	:	5(SMRF)
z) Importance factor	:	1.2

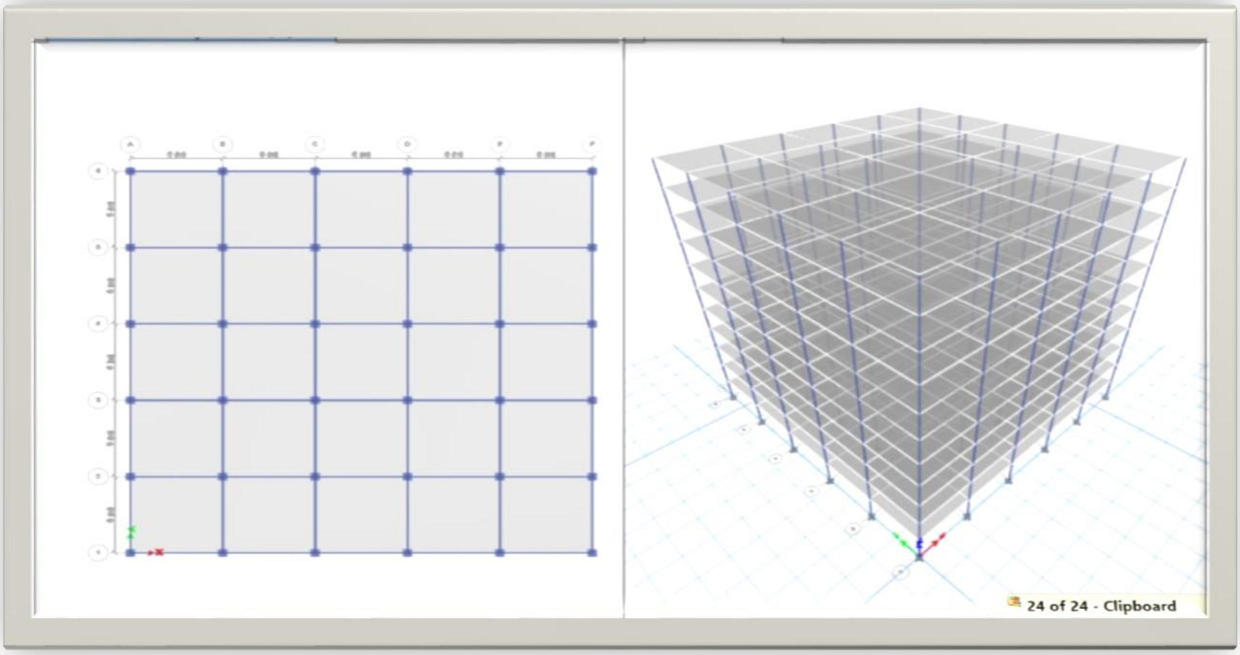


Figure 3.4.1 Model plan and elevation

3.5 GEOMETRY OF MODEL

i. **Concrete:** The concrete properties utilized in this thesis are derived from the data presented in the Table of Properties of Concrete.

Particular	**Properties**
Material	Isotropic
Specific weight Density	25 KN/m^3
Specific Mass Density	2548 kg/m^3
U	0.2
α	0.0000055 $1/^0c$
G	10416.67 MPa
E	25000MPa
fck	25

Table 3.5.1 Table of Concrete

ii. **Reinforcement:** The Reinforcement properties utilized in this thesis are derived from the data presented in the Table of Properties of Reinforcement.

Particular	**Properties**
Material	Isotropic
Specific weight density	76.97 kN/m^3
Specific mass density	7850 kg/m^3
U	0.3
α	0.0000117 $1/^0c$
G	80769.23 MPa
E	210000 Mpa

Table 3.5.2 Table of Reinforcement

iii. Non-linear properties: The compression and tension strain properties of steel and concrete, as presented in the table below, are employed to incorporate their non-linear behavior.

Table 3.5.3 Non-linear properties of Concrete

	Strain in tension	Strain in compression
I O	0. 01	- 0. 005
L S	0. 02	- 0. 01
C P	0. 05	- 0. 02

Table 3.5.4 Non-linear properties of steel

	Strain in tension	Strain in compression
I O	0. 01	- 0. 003
L S	0. 02	- 0. 006
C P	0. 05	- 0. 015

3.6 LOADS

3.6.1 Dead Load (D.L.)

Dead load refers to the self-weight of structural elements and any permanent loads applied to the structure, such as the weight of walls, floors, roofs, and other permanent components. Dead load is an important factor to consider in structural analysis and design as it contributes to the overall load on the structure. In ETABS, dead load can be assigned to different elements and members based on their respective weights and properties.

3.6.2 Live Load (L.L.)

Live load refers to the transient or variable loads that are applied to a structure, such as the weight of people, furniture, equipment, and other movable objects. Live loads are not permanent and can change over time.

In ETABS, live loads can be applied to specific areas or elements of the structure based on the expected usage and occupancy. Live loads can be defined as uniform loads, line loads, or point loads, depending on the distribution and nature of the load. These loads are considered in the analysis to evaluate the structural response and ensure that the structure can safely support the expected live load conditions.

Various load combinations were:

1.5 (D. L+L.L)

1.2 (D. L+ L.L ± ELX)

1.2 (D. L+ L.L ± ELY)

1.5 (D.L ± ELX)

1.5 (D.L ± ELY)

0.9 D. L ± 1.5EL X

0.9 D.L ±
1.5ELY

E.L: - Earthquake Load in X And Y.

3.6.3 Earthquake Load

IS 1893 is utilized as a seismic load calculation method to assess the effects of earthquakes on structures in both the x and y directions. There are two commonly employed approaches for resolving seismic loads: manual analysis and computer calculations.

The static equivalence method is a technique used to estimate a structure's load-bearing capacity. In this study, we will apply the IS code 1893:2016 to determine the basic shear and evenly distribute the load throughout the structure.

The base and lateral shear are determined by the mass distribution, which corresponds to the seismic weight of the structure. The code provides specific zones for different geographical locations, denoted by the terms I, Z, and R.

The estimation of base shear follows the guidelines outlined in the Indian standard. As per the IS code, the base shear (Vb) can be calculated as Ah multiplied by the seismic weight (w) of the structure under consideration.

Here, Ah represents the horizontal seismic coefficient.

The design of the horizontal seismic coefficient considers various parameters, including the zone coefficients (Z), the importance factor (I), the response reduction factor (R), and the acceleration coefficient (Sa/g). The fundamental time period (T) is also considered.

For RCC frame design, the value of Ta (the approximate fundamental time period) is calculated as 0.075 multiplied by the building height (h) multiplied by 0.75. In the case of moment resisting frames, Ta is computed as 0.09 multiplied by the building height (h) divided by the square root of the deflection parameter (d).

3.7 LATERAL DISTRIBUTION OF BASE SHEAR FORCE

The calculation of the base shear force is influenced by the elevation of the structure. The base shear on each floor is determined based on factors such as floor height, concentrated mass, and the overall shape of the building.

The determination of the lateral force at the soil node involves the following steps:

i. Evaluating the distribution of stiffness along the entire height of the structure.
ii. Assessing the nodal displacement at the specified locations.
iii. Considering the mass of each floor to account for its contribution to the lateral forces.

3.8 CHECKING OF SOFT STOREY

To determine if the ground floor qualifies as a soft floor, the stiffness of the first and second storeys is calculated. The stiffness of the ground floor is determined by evaluating the stiffness of the floor columns using the formula K = 12EI/L^3, where E represents the elastic modulus of the concrete, I represent the column inertia, and L represents the column height.

For the concrete grade M25E, the elastic modulus E is calculated as 25000×10^3 KN/m^2. The moment of inertia I is calculated as 0.0108 m^4. The ground floor consists of 36 columns, all of the same size with a height of 5 m.

The stiffness of the ground floor is computed as 933120 KN/m. The stiffness of the first floor, which also consists of 36 columns of the same size and a height of 3 m, is calculated as 4320000 KN/m. The stiffness of the ground floor is found to be 21.6% of the first floor's stiffness, indicating a stiffness irregularity as per the IS 1893:2016 code.

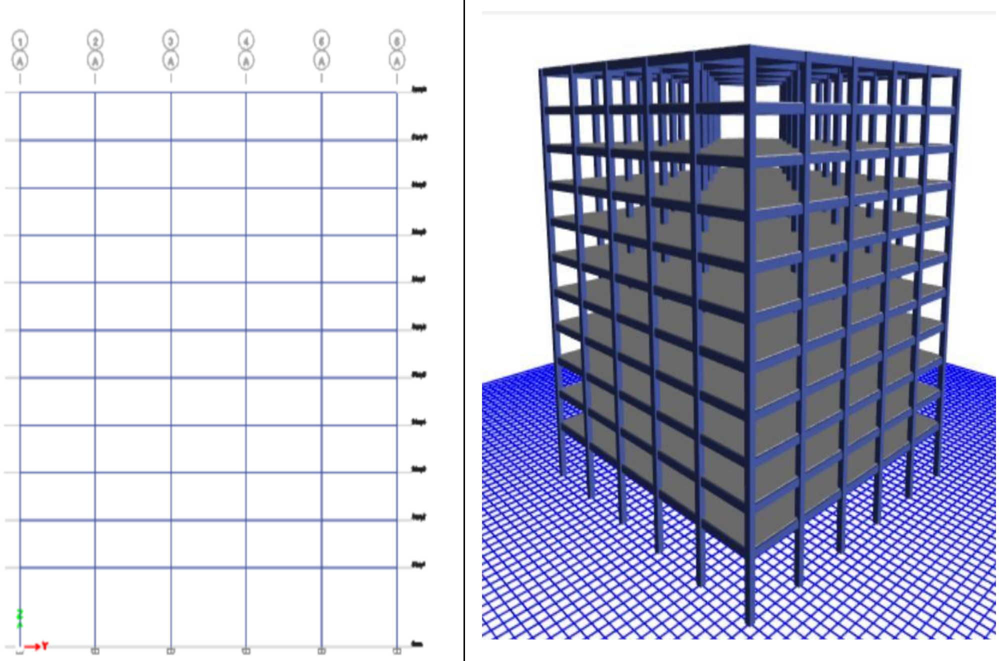
3.9 Models

The G+10 reinforced concrete skeleton building is modeled and analyzed using the ETABS 18.0.2 software, following the specifications provided by the IS 1893:2016 code. The analysis is conducted in three phases, and the results obtained from each model are compared.

In the first case, the building is analyzed with a soft storey on the ground floor. In the second case, shear walls are introduced in two different scenarios. The first scenario includes four shear walls, two located in the left corner and two in the opposite right corner, arranged in a way that two walls are positioned along the X-direction and two along the Y-direction, ensuring equal stiffness in both directions. In the second scenario, a shear wall is positioned at the core of the structure. In the third case, two types of bracing arrangements, X and V type, are implemented in the mid and corner bays along the height of the building.

3.9.1 Case 1: Soft story in Ground floor

In Case 1, we investigate the presence of a soft story in the ground floor of a building. A soft story refers to a floor level that exhibits lower stiffness or resistance to lateral forces compared to the floors above it. This condition can pose significant challenges to the structural integrity and overall performance of the building, particularly during seismic events. The objective of this study is to analyze the behavior of the building with a soft story in the ground floor under various loading conditions, including earthquake forces. By examining this case, we aim to gain insights into the potential vulnerabilities and identify effective strategies to enhance the seismic resilience of buildings with soft stories.



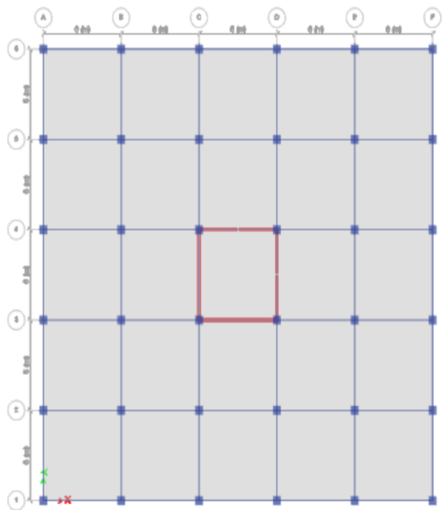
Elevation view

Rendered view

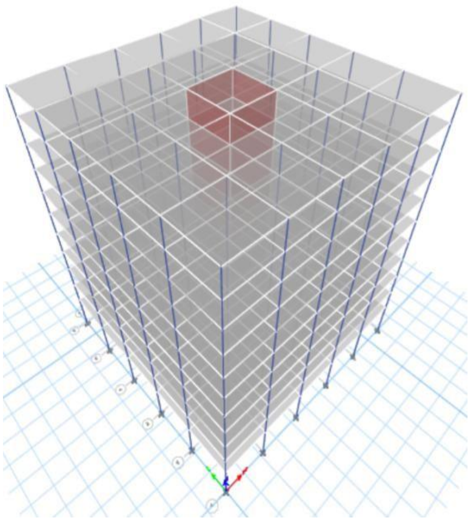
Figure 3.9.1. Building having soft storey in Ground floor

3.9.2 Case 2: Core Shear wall in building with soft story

In Case 2, we focus on the addition of a core shear wall to a building with a soft story. A core shear wall is a vertical structural element designed to resist lateral forces and provide stiffness to the building. By introducing a shear wall in the core area of the structure, we aim to improve its overall stability and mitigate the effects of a soft story. This study aims to analyze the behavior of the building with a combination of a soft story and a core shear wall, particularly under seismic loads. By examining this case, we seek to understand the influence of the shear wall on the structural response and identify the optimal configuration for enhancing the building's seismic performance. The findings from this analysis will contribute to the development of effective strategies for retrofitting or designing buildings with soft stories to ensure their safety and resilience during seismic events.



Plan view

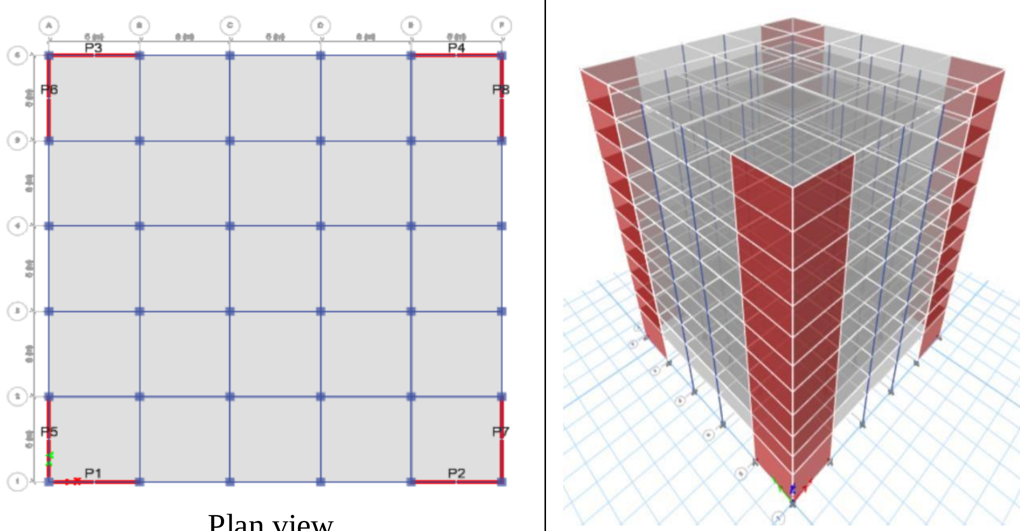


3-D view

Figure 3.9.2. Core Shear wall in building with soft story

3.9.3 Case 3: Corner Shear wall in building with soft story

In Case 3, we investigate the introduction of a corner shear wall in a building with a soft story. A corner shear wall is a structural element located at the corners of the building designed to provide additional stiffness and resist lateral forces. The purpose of this study is to analyze the behavior of a building with both a soft story and corner shear walls, specifically under seismic conditions. By incorporating corner shear walls, we aim to improve the overall stability and performance of the structure during earthquakes. This case study aims to explore the influence of the corner shear walls on the structural response and determine the optimal placement of these shear walls to enhance the building's seismic resilience. The findings from this analysis will contribute to the development of effective strategies for retrofitting or designing buildings with soft stories, ensuring their ability to withstand seismic events and protect occupants.



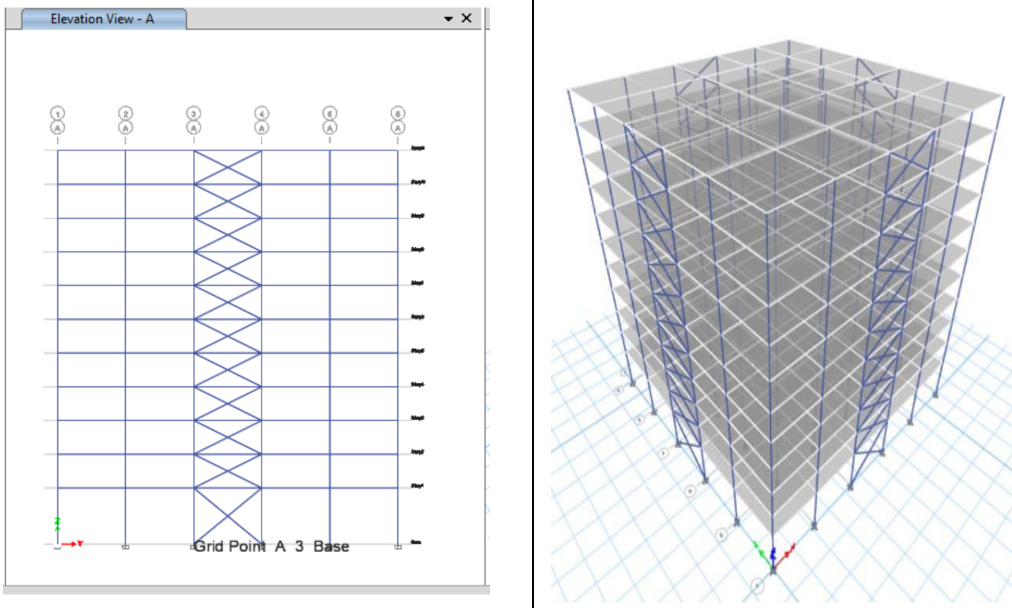
Plan view

3-D view

Figure 3.9.3. Corner Shear wall in building with soft story

3.9.4 Case 4: Cross bracing at mid bay

In Case 4, we focus on the introduction of cross bracing at mid bays in a building. Cross bracing is a structural system that uses diagonal members to enhance the lateral stability and stiffness of the structure. The objective of this study is to analyze the behavior of a building with cross bracing at mid bays, particularly in the context of a seismic event. By incorporating cross bracing, we aim to improve the overall structural integrity and resistance to lateral forces.



Elevation view | 3-D view

Figure 3.9.4. Cross Bracing at mid bay

3.9.5 Case 5: Cross bracing at corner bay

In Case 5, our focus shifts to the implementation of cross bracing at corner bays in a building. Cross bracing is a structural system that utilizes diagonal members to enhance the lateral stability and stiffness of a structure. The objective of this study is to investigate the behavior of a building with cross bracing at corner bays, specifically under seismic conditions. By introducing cross bracing at the corners, we aim to improve the overall structural integrity and resistance to lateral forces, particularly during earthquakes. This case study aims to examine the impact of corner bracing on the building's response to seismic forces and evaluate its effectiveness in enhancing the building's performance. The findings from this analysis will contribute to a better understanding of the behavior of buildings with corner bracing and provide valuable insights for the design and retrofitting of structures to enhance their seismic resilience.

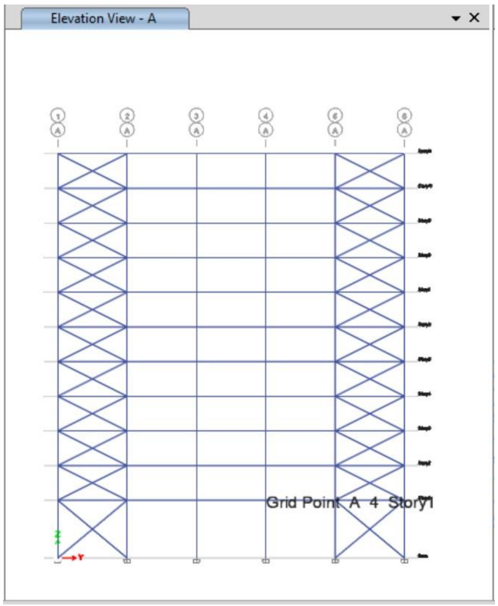
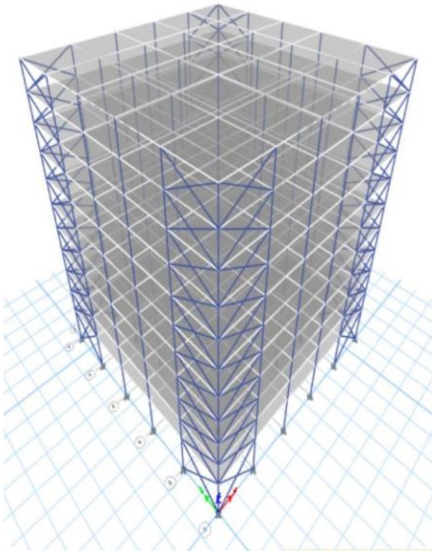
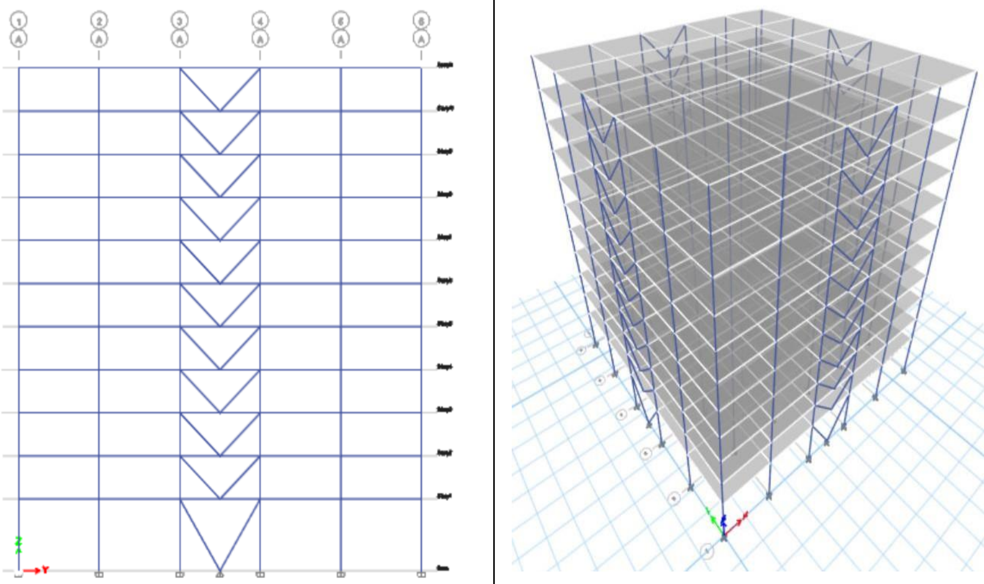
 Elevation view	 3-D view

Figure 3.9.5. Cross bracing at corner bays

3.9.6 Case 6: V-type bracing at mid bay.

In Case 6, we explore the application of V-type bracing at mid bays in a building. V-type bracing is a common structural system used to improve the lateral stability and resistance of buildings against seismic forces. The primary objective of this study is to investigate the behavior of a building with V-type bracing at mid bays under seismic conditions. By incorporating V-type bracing, we aim to enhance the building's overall structural integrity and mitigate the effects of lateral loads, particularly during earthquakes. This case study aims to analyze the response of the building to seismic forces, assess the effectiveness of V-type bracing in improving its performance, and provide insights for the design and retrofitting of structures to enhance their seismic resilience. The findings from this analysis will contribute to a deeper understanding of the behavior of buildings with V-type bracing and inform future practices in structural engineering and seismic design.



Elevation view | 3-D view

Figure 3.9.6. V- type Bracing at mid bay

3.9.7 Case 7: V-type bracing at corner bay.

Case 7 focuses on the implementation of V-type bracing at the corner bays of a building. V-type bracing is a widely used structural system employed to enhance the lateral stability and resistance of structures against seismic forces. This case study aims to investigate the behavior and performance of a building with V-type bracing specifically applied at the corner bays. The primary objective is to assess the effectiveness of this bracing configuration in improving the overall structural integrity and mitigating the effects of lateral loads, particularly during seismic events. By analyzing the building's response to seismic forces, this study aims to provide valuable insights into the behavior of structures with V-type bracing at corner bays and contribute to the advancement of seismic design and engineering practices. The findings will help inform future building design and retrofitting strategies to enhance the seismic resilience of structures.

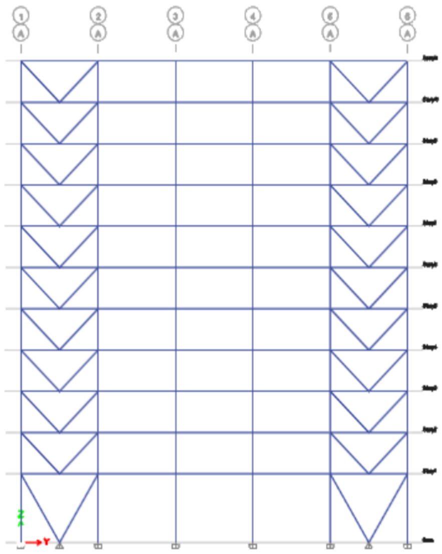
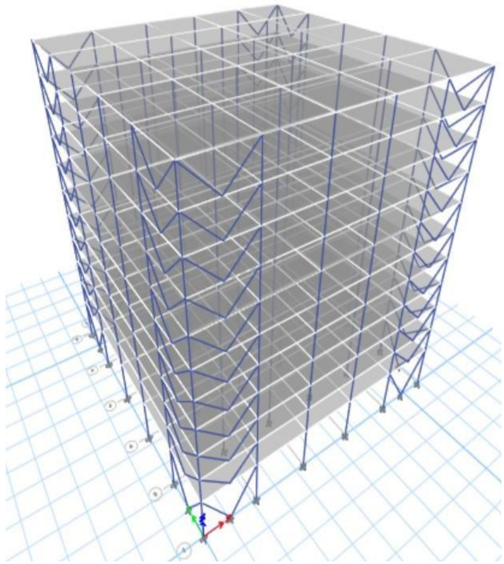
 Elevation view	 3-D view

Figure 3.9.7. V-type Bracing at corner bays

CHAPTER 4

RESULTS

4.1 RESPONSE SPECTRUM ANALYSIS

During the analysis phase I constructed various models of RCC frames and performed a range of assessments. The obtained results from the response spectrum analysis encompass several findings:

4.1.1 Storey displacement

		Centre bracing		corner bracing		Centre shear wall	Corner shear wall
		X-type	V-type	X-type	V-type		
Story 11	46.28	39.02	40.08	35.60	36.72	33.02	28.55
Story 10	45.14	37.18	38.31	33.47	34.65	30.49	25.85
Story 9	43.17	34.73	35.94	30.86	32.14	27.52	23.02
Story 8	40.37	31.74	33.06	27.87	29.25	24.33	20.08
Story 7	36.87	28.33	29.75	24.59	26.06	20.98	17.07
Story 6	32.82	24.60	26.11	21.10	22.65	17.55	14.06
Story 5	28.34	20.65	22.24	17.50	19.10	14.12	11.11
Story 4	23.55	16.59	18.25	13.88	15.52	10.79	8.31
Story 3	18.54	12.54	14.23	10.35	11.99	7.65	5.73
Story 2	13.36	8.61	10.27	7.01	8.61	4.83	3.48
Story 1	7.96	4.87	6.34	3.94	5.35	2.44	1.66

The top storey consistently exhibited the highest displacement values in all cases. Under earthquake load, the maximum displacement recorded was 46.28 mm, which occurred in the soft story model. Conversely, the structure with a corner shear wall had the lowest displacement value of 28.55 mm among all model types at top storey. Comparatively, the X-type bracing resulted in smaller displacement values than the V-type bracing. Additionally, when the shear wall was positioned at all four corners, it yielded lower displacement values compared to when placed at the core. It is important to note that the displacement of all models remained within the permissible limit prescribed by IS 1893-2016, which is less than 0.004H (140 mm in the selected building model).

4.1.2 Storey shear

		Centre bracing		corner bracing		Centre shear wall	Corner shear wall
		X-type	V-type	X-type	V-type		
Story 11	603.33	774.76	738.11	891.29	835.51	1107.82	1304.35
Story 10	1398.28	1795.45	1710.02	2065.73	1936.32	2573.19	3039.60
Story 9	2054.59	2636.31	2510.93	3032.47	2842.72	3778.37	4466.21
Story 8	2585.85	3314.94	3157.61	3811.85	3573.77	4748.86	5614.45
Story 7	3005.64	3848.95	3666.80	4424.20	4148.53	5510.14	6514.57
Story 6	3327.53	4255.93	4055.27	4889.85	4586.05	6087.68	7196.80
Story 5	3565.16	4553.47	4339.79	5229.13	4905.38	6506.92	7691.37
Story 4	3732.12	4759.16	4537.14	5462.36	5125.63	6793.32	8028.49
Story 3	3842.06	4890.60	4664.14	5609.86	5265.88	6972.31	8238.39
Story 2	3908.56	4965.36	4737.66	5691.93	5345.34	7069.33	8351.24
Story 1	3945.94	5001.95	4775.59	5729.93	5387.16	7111.38	8399.48

The model with a corner shear wall exhibits the highest storey shear, measuring 8399.48 KN, among all six models. Conversely, the model with a soft story has the lowest storey shear at 3945.94 KN on the Ground Floor. When bracings are placed in the corner bays instead of the mid-bays, the storey shear is higher. Additionally, the X-type bracing shows greater storey shear compared to the V-type bracing. Placing shear walls at all four corners results in higher shear values compared to placing the shear wall at the core of the structure.

4.1.3 Story stiffness

		Centre bracing		corner bracing		Centre shear wall	Corner shear wall
		X-type	V-type	X-type	V-type		
Story 11	545689.25	443424.09	438987.72	435087.88	422661.81	429739.18	503148.88
Story 10	545689.56	443424.16	438987.79	435087.82	422661.31	429739.11	503148.08
Story 9	734547.54	756744.62	750305.59	814777.23	792565.59	885367.32	1096297.24
Story 8	734547.59	756744.82	750305.32	814777.69	792565.48	885367.00	1096297.35
Story 7	764746.32	913825.57	899050.54	1042666.10	1007185.66	1229201.05	1552143.26
Story 6	773103.21	1005773.28	984590.38	1192083.67	1146089.62	1487162.46	1908443.60
Story 5	776987.85	1067201.91	1040568.94	1301092.38	1245435.20	1696511.25	2208782.15
Story 4	779646.93	1116060.64	1083670.21	1392901.41	1326704.08	1888278.99	2491785.80
Story 3	781819.55	1163297.25	1123691.45	1483714.56	1404279.09	2092235.53	2797910.31
Story 2	783125.07	1217612.78	1167687.16	1588291.12	1490277.54	2345203.49	3181372.73
Story 1	780843.67	1288046.98	1219982.78	1725216.00	1597931.28	2706771.41	3735459.52

The model with a corner shear wall exhibits a higher storey stiffness of 503148.38 KN/m at top storey compared to the other six models. The highest storey stiffness observed at corner shear wall at storey 1. Placing bracings in the corner bays instead of the mid-bays increases the storey stiffness. Moreover, the X-type bracing demonstrates greater stiffness than the V-type bracing. When shear walls are placed at all four corners, the stiffness of the structure is higher compared to placing the shear wall at the core. By placing shear walls on all four corners, the soft story irregularity is completely reduced, resulting in the maximum stiffness value on the ground floor.

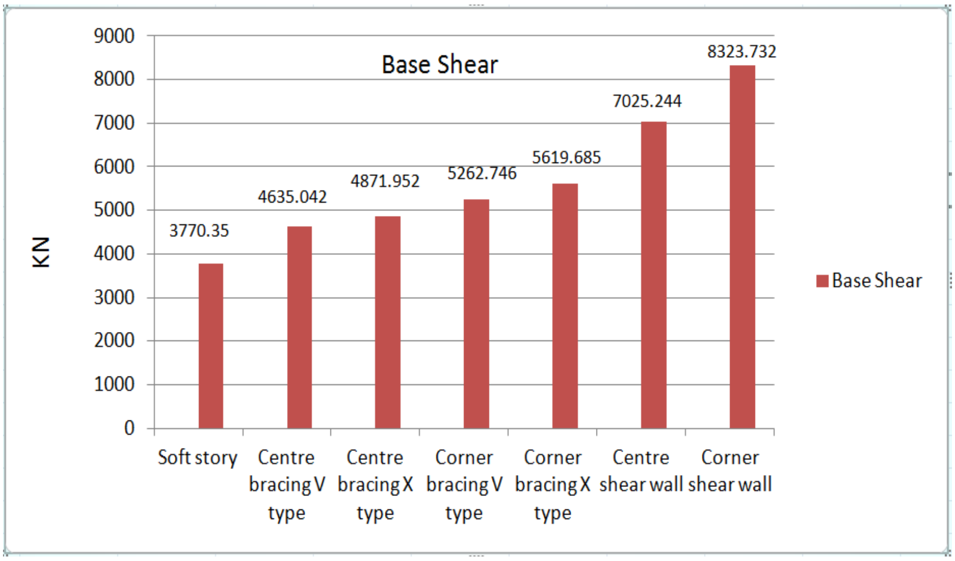
4.1.4 Story drift

		Centre bracing		corner bracing		Centre shear wall	Corner shear wall
		X-type	V-type	X-type	V-type		
Story 11	0.001556	0.001135	0.001212	0.000909	0.000975	0.000978	0.000895
Story 10	0.001683	0.001129	0.001202	0.000901	0.000973	0.000976	0.00886
Story 9	0.001550	0.001229	0.001224	0.001057	0.001060	0.000929	0.000839

Story 8	0.001550	0.001221	0.001221	0.001057	0.001071	0.000925	0.000812
Story 7	0.001477	0.001200	0.001217	0.001086	0.001078	0.000992	0.000810
Story 6	0.001373	0.001197	0.001175	0.001081	0.001066	0.001035	0.000808
Story 5	0.001232	0.001125	0.001100	0.001043	0.001023	0.001024	0.000804
Story 4	0.001046	0.001018	0.000991	0.000974	0.000951	0.000995	0.000800
Story 3	0.000910	0.000875	0.000889	0.000875	0.000850	0.000942	0.000795
Story 2	0.000837	0.000798	0.000873	0.000847	0.000821	0.000870	0.000788
Story 1	0.000859	0.000792	0.000812	0.000795	0.000800	0.000793	0.000783

The maximum drift under earthquake load is recorded as 0.001683, which is highest in the structure with a soft story model. However, the structure with a corner shear wall exhibits the minimum drift value among all model types, measuring 0.000783 mm. Placing bracings in the corner bays rather than the mid-bays results in lower drift values, and the V-type bracing shows lesser drift compared to the X-type bracing. When shear walls are placed at all four corners, the drift value decreases compared to when they are placed at the core. It is important to note that the storey drift of all models falls within the allowable limit of less than 0.004, as prescribed by the IS 1893-2016 code.

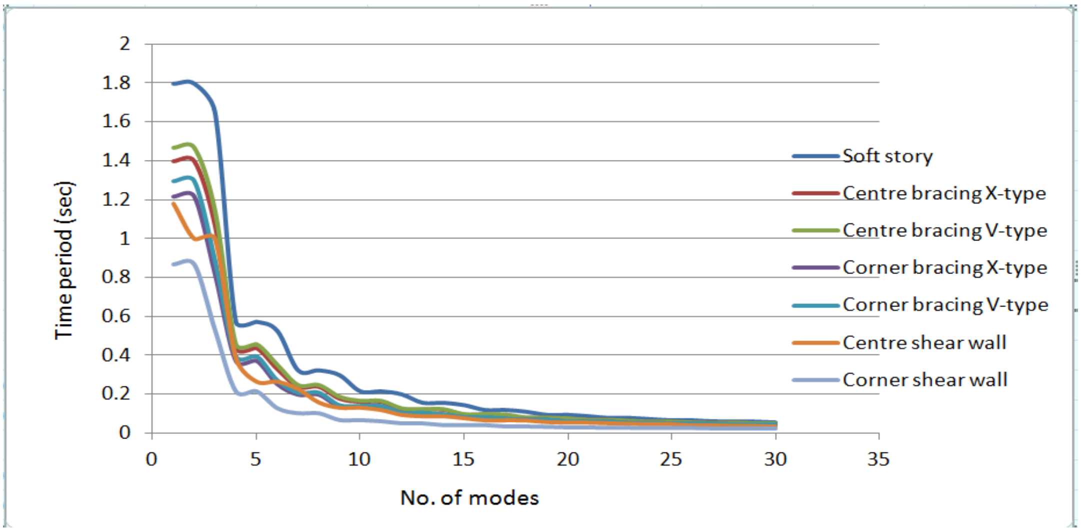
4.1.5 Base shear



The figure above displays the base shear values in ascending order.

Among all the model types, the RCC frame model with shear walls located at all four ends exhibits the highest value of base shear.

4.1.6 Time period



On each building model, the time period value decreases as the mode number increases. The model with a corner shear wall exhibits the shortest vibration period of 0.86 seconds under seismic loads, while the model with a soft story has the longest vibration period of 1.81 seconds. Placing bracings in the corner bays results in a shorter time period compared to placing them in the mid-bays, and the X-type bracing generally has a shorter time period than the V-type bracing. When shear walls are positioned at all four corners, the time period is reduced compared to when they are placed at the core.

4.2 Results from pushover analysis

The RCC frame modeling process and its subsequent analysis have been concluded, yielding a range of results from the pushover analysis.

4.2.1 Storey displacement

		Centre bracing		corner bracing		Centre shear wall	Corner shear wall
		X-type	V-type	X-type	V-type		
Story 11	23.64	6.85	14.51	8.19	16.69	14.04	9.91
Story 10	23.28	6.70	14.26	8.01	16.51	13.67	8.99
Story 9	21.64	5.94	12.86	6.93	14.44	11.19	7.71
Story 8	21.60	5.61	12.66	6.69	14.21	10.01	7.06
Story 7	20.29	5.35	11.79	6.18	13.09	9.65	6.54
Story 6	18.58	4.68	10.56	5.34	11.59	8.06	5.35
Story 5	16.51	3.92	9.17	4.43	9.96	6.43	4.15
Story 4	14.07	3.10	7.64	3.46	8.21	4.80	2.97
Story 3	11.27	2.22	5.98	2.45	6.37	3.22	1.84
Story 2	8.11	1.30	4.22	1.43	4.48	1.75	1.27
Story 1	4.57	0.35	2.34	0.41	2.54	0.45	0.38

In all cases, the top storey recorded the highest displacement value during the pushover analysis, with a maximum value of 23.64 mm this maximum displacement was observed in the structure with a soft story configuration, while the structure with corner shear wall exhibited the lowest displacement value of 0.38 mm among all model types. Comparatively, the X-type brace resulted in a smaller displacement value compared to the V-type brace. Furthermore, when the shear wall was positioned at all four corners, it yielded a smaller displacement value than when placed at the core. It is important to note that the displacement of all models remained within the allowable limit prescribed by IS 1893-2016, which is less than 0.004H (140 mm in the selected building model).

4.2.2 Storey shear

		Centre bracing		corner bracing		Centre shear wall	Corner shear wall
		X-type	V-type	X-type	V-type		
Story 11	31.58	59.78	128.93	104.37	192.17	257.50	268.48
Story 10	68.98	184.75	367.73	313.26	543.13	719.62	757.70
Story 9	106.48	309.85	606.79	522.26	894.33	1181.75	1246.90
Story 8	144.08	435.05	846.11	731.35	1245.75	1643.85	1736.05
Story 7	106.48	309.85	606.79	522.26	894.33	1181.75	1246.90
Story 6	144.08	435.05	846.11	731.35	1245.75	1643.85	1736.05
Story 5	181.78	560.36	1085.68	940.52	1597.36	2105.88	2225.13
Story 4	219.57	685.75	1325.48	1149.74	1949.16	2567.80	2714.08
Story 3	257.46	811.20	1565.50	1358.99	2301.12	3029.54	3202.87
Story 2	295.43	936.68	1805.71	1568.23	2653.21	3491.02	3691.44
Story 1	333.47	1062.17	2046.10	1777.42	3022.83	3952.16	4179.72

In the case of the model with a corner shear wall, the storey shear is higher, measuring 4179.72 KN, compared to the other six models. Conversely, in the model with a soft story, the storey shear is lower, measuring 31.58 KN. The storey shear is maximized when bracings are positioned in the corner bays rather than the mid-bays, and it is greater in V-type bracing compared to X-type bracing. Additionally, placing the shear wall at all four corners results in a higher shear value compared to when it is placed at the core.

4.2.3 Story stiffness

		Centre bracing		corner bracing		Centre shear wall	Corner shear wall
		X-type	V-type	X-type	V-type		
Story 11	426558.34	341532.98	380501.68	392031.31	381284.36	349076.28	466106.65
Story10	584660.97	602643.78	661623.17	743786.93	719844.24	749004.96	1027187.15
Story 9	609207.54	744271.75	803941.48	963693.16	923557.94	1051832.29	1460442.47

Story 8	614325.94	831945.45	888193.08	1109950.54	1059231.81	1283376.26	1800679.00
Story7	615881.16	892702.85	944452.10	1218330.96	1157855.94	1475785.83	2089920.34
Story 6	616716.61	942104.76	988274.53	1310691.17	1239474.79	1655062.55	2364042.27
Story 5	617408.34	990451.92	1029115.35	1402807.94	1318062.99	1847677.91	2661728.92
Story 4	617876.25	1046366.84	1073708.68	1509557.12	1405304.14	2087630.97	3035278.36
Story 3	617343.03	1119333.12	1125427.11	1650258.71	1512490.04	2431917.14	3576540.33
Story 2	611583.13	1215737.15	1156714.52	1843011.14	1599712.83	3010845.18	4509605.18
Story 1	421752.76	932783.93	736997.06	1471621.51	1512490.04	3027470.64	4790003.07

Storey stiffness is more i.e., 4790003.07 KN/m in case of model having corner shear wall as compared to other six models Storey stiffness increases when bracings are placed in corner bays rather than mid-bays and was greater in X-type bracing as compared to V-type bracing. Shearing wall when placed at all four corners gives higher stiffness as compared to wall placed at core. Soft story irregularity was reduced totally when shear wall is introduced in both corner and at core giving to a maximum value of stiffness in ground floor.

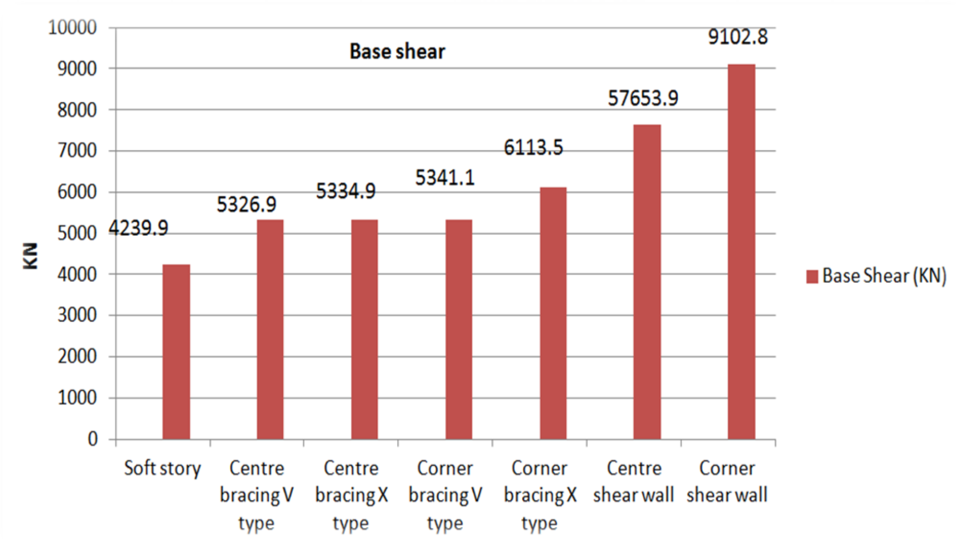
4.3.4 Story drift

		Centre bracing		corner bracing		Centre shear wall	Corner shear wall
		X-type	V-type	X-type	V-type		
Story 11	0.000545	0.000102	0.000182	0.000150	0.000302	0.000419	0.000330
Story 10	0.000933	0.000127	0.000236	0.000184	0.000338	0.000452	0.000348
Story 9	0.001325	0.000156	0.000290	0.000212	0.000390	0.000476	0.000362
Story 8	0.001660	0.000185	0.000346	0.000241	0.000442	0.000500	0.000375
Story 7	0.001929	0.000214	0.000402	0.000268	0.000492	0.000520	0.000385
Story 6	0.002137	0.000241	0.000455	0.000291	0.000537	0.000531	0.000388
Story 5	0.002290	0.000264	0.000503	0.000311	0.000575	0.000530	0.000382
Story 4	0.002399	0.000283	0.000545	0.000324	0.000605	0.000515	0.000365

Story 3	0.002474	0.000295	0.000581	0.000329	0.000623	0.000479	0.000333
Story 2	0.002544	0.000306	0.000633	0.000326	0.000665	0.000420	0.000283
Story 1	0.002235	0.000260	0.000640	0.000273	0.000623	0.000280	0.000175

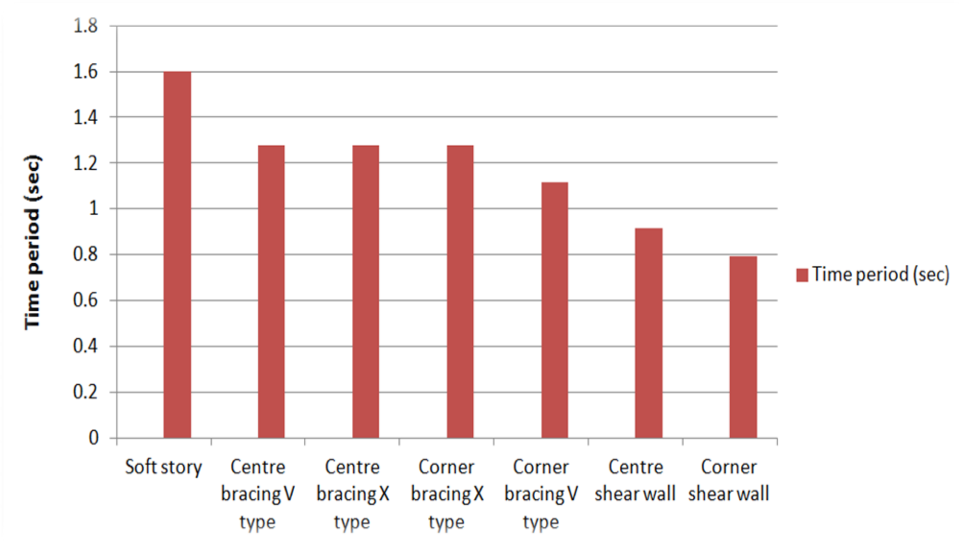
The maximum drift observed under the pushover load is 0.002235, which is highest in the soft story model and lowest in the structure with cross bracings at the center, measuring 0.000102 mm. The drift value is minimized when bracings are positioned in the corner bays rather than the mid-bays, and X-type bracing exhibits lower drift compared to V-type bracing. Additionally, placing a shear wall at all four corners results in a reduced drift compared to placing it at the core. Importantly, the storey drift of all models remains within the allowable limit of less than 0.004 as specified by IS 1893-2016.

4.2.5 Base shear



The figure above illustrates the base shear values in ascending order. Among all the model types, the RCC frame with shear walls positioned at all four ends exhibits the highest base shear value.

4.2.6 Time period



The model with a corner shear wall has the shortest vibration period of 0.79 seconds, whereas the model with a soft story has the longest vibration period of 1.60 seconds. The placement of bracings in corner bays results in a shorter time period compared to mid-bays, and the X-type bracing exhibits a shorter time period than the V-type bracing. Additionally, when shear walls are positioned at all four corners, a shorter time period is observed compared to when they are placed at the core.

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4.3 COMPARATIVE RESULTS OF RESPONSE SPECTRUM AND PUSHOVER ANALYSIS

4.3.1 Base shear comparison

Model type		Base shear (KN)	
		Response spectrum	Pushover analysis
Soft story		3770.35	4239.9485
Centre bracing	X-type	4871.952	5334.98
	V-type	4635.042	5326.9284
Corner bracing	X-type	5619.685	6113.5851
	V-type	5262.746	5341.164
Centre shear wall		7025.244	7653.9342

Corner shear wall	8323.732	9102.8918

In Response Spectrum Analysis the RC frame model with shear walls placed at four ends exhibits the maximum base shear value of 8323.732 KN. When compared to this reference model, the base shear increases by 86% and 120% when shear walls are located at the core and at four corners, respectively. Similarly, the base shear increases by 29% and 49% when cross bracings are placed at mid and corner bays. Lastly, when V-type bracings are placed at mid and corner bays, the base shear increases by 22.9% and 39.5%. In pushover Comparison, the RC frame model with shear walls placed at four ends shows a maximum base shear value of 9102.8 KN. When shear walls are located at the core and at four corners, the base shear increases by 80% and 114%, respectively. Additionally, the base shear increases by 25.8% and 44% when cross bracings are placed at mid and corner bays. Lastly, placing V-type bracings at mid and corner bays leads to a base shear increase of 25% and 26%. The results demonstrate the significant influence of the placement of shear walls and bracings on the base shear values of the RC frame models. The variations in base shear values highlight the importance of these structural elements in redistributing and resisting lateral forces, thereby improving the seismic performance of the analyzed models.

4.3.2 Maximum storey displacement comparison

Model type	Displacement (mm)	
	Response spectrum	Pushover analysis
Soft story	46.28	23.64
Centre bracing X-type	39.02	6.85
Centre bracing V-type	40.08	14.51
Corner bracing X-type	35.60	8.91
Corner bracing V-type	36.72	16.69

Centre shear wall	33.02	14.04
Corner shear wall	28.55	9.91

In Response Spectrum Analysis the displacements observed in all the analyzed models comply with the maximum limits specified in IS 1893:2016. Among the different model types, the structure with a soft story exhibits the highest maximum storey displacement of 46.28mm under earthquake load. However, by incorporating a corner shear wall in the structure, this displacement is reduced by 38.7% to a value of 28.55mm. Similarly, under pushover load, the maximum storey displacement in the structure with a soft story model is 23.64mm. However, by introducing cross bracings at the center of the structure, this displacement is reduced to 6.85mm, representing a significant decrease in displacement for this model type. Overall, the displacement values observed in all the models meet the criteria specified in IS 1893:2016, and the introduction of shear walls and bracings proves effective in reducing the maximum storey displacements, improving the structural performance.

4.3.3 Maximum storey drift comparison

Model type		Drift	
		Response spectrum	Pushover analysis
Soft story		0.001683	0.002235
Centre bracing	X-type	0.001229	0.000306
	V-type	0.001224	0.000640
Corner bracing	X-type	0.001086	0.000329
	V-type	0.001078	0.000665
Centre shear wall		0.001035	0.000531
Corner shear wall		0.000886	0.000388

In Response Spectrum Analysis the storey drifts of all the analyzed models are in accordance with the limits specified in IS 1893:2016.

Among the different model types, the structure with a soft story model exhibits the highest maximum drift of 0.001683 under earthquake load. However, by incorporating a corner shear wall in the structure, this drift is reduced by 44.3%, resulting in a minimum value of 0.000886 mm among all the model types. Similarly, under pushover load, the structure with a soft story model has the highest maximum drift of 0.002235 However, by introducing cross bracing at the center of the structure, this drift is reduced to a minimum value of 0.000338 mm, representing a significant reduction in drift compared to other model types. It is important to note that all the observed drift values meet the specified limits in IS 1893:2016. The incorporation of shear walls and bracings in the analyzed models proves effective in reducing the maximum storey drifts, contributing to improved structural performance and compliance with seismic design requirements.

4.3.4 Maximum Storey stiffness comparison

Model type		Stiffness (K N /m)	
		Response spectrum	Pushover analysis
Soft story		783125.07	617876.25
Centre bracing	X-type	1288046.98	1215737.15
	V-type	1219982.78	1156714.52
Corner bracing	X-type	1725216.00	1843011.41
	V-type	1597931.28	1599712.83
Centre shear wall		2706771.41	3027470.64
Corner shear wall		3735459.52	4790003.07

The storey stiffness is higher in the model with a corner shear wall, with a value of 5035779.586 KN/m, compared to the other six models. On the other hand, the model with a soft story has a lower storey stiffness of 783150.066 KN/m. When shear walls are placed on all four corners, the soft story irregularity is completely reduced, resulting in a maximum stiffness value in the ground floor. In Pushover analysis, the storey stiffness is higher in the model with a corner shear wall, with a value of 4790126.626 KN/m, compared to the other six models. Conversely, the model with a soft story has a lower storey stiffness of 617999.8 KN/m. soft story irregularity is completely reduced when shear walls are introduced in both the corner and core positions, resulting in a maximum stiffness value in the ground floor. The comparison shows that the presence of a corner shear wall significantly enhances the storey stiffness in the RC frame models. The model with a corner shear wall exhibits higher stiffness values compared to the other models, including the model with a soft story. The introduction of shear walls at the corner and core positions effectively reduces the soft story irregularity, leading to a substantial increase in the stiffness of the ground floor. This highlights the importance of incorporating shear walls in strategic locations to improve the overall structural stiffness and stability of the building under seismic loads.

4.3.5 Maximum Storey shear comparison

Model type		Storey shear (KN)	
		Response spectrum	Pushover analysis
Soft story		3945.94	333.47
Centre bracing	X-type	5001.95	1062.17
	V-type	4775.59	2046.10
Corner bracing	X-type	5729.93	1777.42
	V-type	5387.16	3022.83
Centre shear wall		7111.38	3952.14
Corner shear wall		8399.48	4179.72

In Response Spectrum Analysis the storey shear is maximum when bracings are placed in corner bays rather than mid-bays, and it is greater for V-type bracing compared to X-type bracing. In the case of the model with a corner shear wall, the storey shear is 8399.48 KN, which is higher than the other six models. On the other hand, the model with a soft story has a lower storey shear of 3945.94 KN. When the shear wall is placed at all four corners, it results in a higher shear value compared to when it is placed at the core. In Pushover analysis, the storey shear is also maximum when bracings are placed in corner bays rather than mid-bays, and it is greater for V-type bracing compared to X-type bracing. In the model with a corner shear wall, the storey shear is 4179.72 KN, which is higher than the other six models. Conversely, the model with a soft story has a lower storey shear of 333.47 KN. Placing the shear wall at all four corners yields a higher shear value compared to when it is placed at the core. The results indicate that the placement of bracings in corner bays and the type of bracing (V-type or X-type) significantly impact the storey shear values in the RC frame models. The highest storey shear values are observed when bracings are located in the corner bays, and the V-type bracing configuration tends to result in higher shear values compared to X-type bracing. These findings emphasize the importance of carefully considering the positioning and type of bracing elements to enhance the structural strength and stability against lateral loads.

4.3.6 Time period comparison

Model type		Time period (sec)	
		Response spectrum	Pushover analysis
Soft story		1.81	1.60
Centre bracing	X-type	1.37	1.26
	V-type	1.45	1.25
Corner bracing	X-type	1.20	1.10
	V-type	1.27	1.26
Centre shear wall		0.96	0.90
Corner shear wall		0.86	0.79

In Response Spectrum Analysis as the number of modes increased for all building model types, the time period decreased. Among the analyzed models, the one with a corner shear wall exhibits the minimum vibration period of 0.86 sec under seismic loads. On the other hand, the model with a soft story has a maximum vibration period of 1.81 sec. In pushover model with a corner shear wall has the minimum vibration period of 0.79 sec, while the model with a soft story has the maximum vibration period of 1.60 sec. It is observed that placing bracings in the corner bays rather than mid-bays results in a lower time period. Additionally, the X-type bracing exhibits a shorter time period compared to the V-type bracing. It is worth noting that the vibration periods vary among the different model types, with the presence of shear walls and bracings influencing the dynamic behavior of the structures. The obtained time periods adhere to the seismic design requirements, providing insights into the structural response and characteristics of the analyzed models.

i. The base shear values obtained from the pushover analysis were higher compared to those from the response spectrum analysis. Among all the models analyzed using both methods, the model with shear walls placed at all four corners exhibited the maximum base shear.
ii. The displacement values for all models were found to be within the maximum limits specified in IS 1893:2016. However, the pushover analysis yielded lower maximum displacement values compared to the response spectrum analysis. The models with shear walls in all four corners consistently showed the least displacement values in both analysis methods. Additionally, the models with bracings placed at mid bays had lower displacements in the pushover analysis, while the models with bracings placed at corner bays had lower displacements in the response spectrum analysis.
iii. The storey drift values obtained from the pushover analysis were lower than those from the response spectrum analysis. The models with shear

walls located at all four corners exhibited the lowest drift values in both analysis methods. When comparing the two brace types, X braces showed less drift in the pushover analysis and slightly higher values in the response spectrum analysis compared to V braces.

iv. The introduction of shear walls at both the corner and core positions resulted in the complete reduction of soft story irregularity, leading to a maximum stiffness value in the ground floor according to the pushover analysis. However, in the response spectrum analysis, full irregularity reduction was achieved only when shear walls were placed at all four corners. The storey stiffness increased when bracings were placed in corner bays rather than mid bays, with X-type bracing exhibiting greater stiffness compared to V-type bracing. Furthermore, in both analysis methods, shear walls located at all four corners provided higher stiffness values compared to those placed at the core.

v. In both the response spectrum and pushover analysis, the models with bracings placed in corner bays exhibited maximum storey shear values compared to those with bracings placed in mid bays. X-type bracing showed higher storey shear values in the response spectrum analysis but lower values in the pushover analysis compared to V-type bracing. The models with corner shear walls consistently displayed higher storey shear values among all six models, while the model with a soft story had lower storey shear values. Additionally, shear walls placed at all four corners resulted in higher shear values compared to shear walls placed at the core in both analysis methods.

vi. In both the response spectrum and pushover analysis, the model with corner shear walls exhibited the minimum vibration period, while the model with a soft story had the maximum vibration period. When bracing was placed in the corner bays instead of the mid bay, the time duration was minimized. Moreover, the X brace showed a shorter period than the V brace in both analysis methods.

CHAPTER 5

CONCLUSION

5.1 CONCLUSIONS

The following conclusions are drawn from this study: -

i. The presence of a soft floor significantly affects the stiffness of a structure.

ii. The study investigates the impact of soft floor heights, shear wall positions, and types of bracing arrangements along the height of the structure. The introduction of shear walls and bracings effectively reduces roof displacement and drift while enhancing the base shear value and overall stiffness. Placing shear walls and bracings at the building's corners yields greater effectiveness.

iii. The inclusion of a corner shear wall in the structural model results in a notable increase in base shear, indicating enhanced stiffness. The presence of shear walls significantly influences the stiffness of each storey in the building. When shear walls are strategically placed at all four corners, the stiffness value is higher compared to when they are positioned in the core of the structure. Additionally, placing bracings in the corner bays instead of the mid-bays further contributes to increased storey stiffness, with the X-type bracing demonstrating superior performance over the V-type bracing in terms of stiffness.

iv. Shear walls have demonstrated their effectiveness in addressing the irregularity of soft storeys, effectively reducing both drift and displacement. Proper placement of these shear walls enhances the overall structural performance during seismic events, mitigating the effects of ground movement caused by earthquakes. Notably, the performance of shear walls positioned at the four corners of the building surpasses that of shear walls located in the core areas.

v. Steel braces emerged as one of the most effective methods for strengthening structures with soft storeys. The X-brace system exhibits minimal displacement and time period while showcasing higher levels of stiffness and shear values compared to the V-brace system.

vi. Furthermore, the introduction of braces and shear walls to the soft storey model significantly reduces the natural time period of the structure, leading to improved dynamic characteristics and overall seismic response.

5.2 FUTURE SCOPE OF WORK

i. Time history analysis can be employed to provide a more precise evaluation of the structure's capacity and to capture a realistic demand scenario accurately.

ii. Shear walls can be constructed and analyzed in various configurations and locations within the building.

iii. Diverse types of bracing, such as diagonal and inverted V shapes, can be explored to assess their effectiveness in enhancing structural performance.

iv. Further research can be conducted on multi-storey buildings to investigate their behavior and response under seismic forces.

v. Conducting an extensive literature review will help identify existing research gaps and contribute to a comprehensive understanding of the subject.

vi. Additional investigations can be carried out to explore the impact of factors like openings in shear walls and modifications to wall thickness, as well as analyzing the behavior of structures with varying percentages of shear walls in different directions.

vii. It is important to conduct analyses under extreme seismic events to evaluate the resilience and robustness of structures in such scenarios.

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