NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF CIVIL ENGINEERING

THE IMPACT OF SHEAR WALLS ON SEISMIC PERFORMANCES AND SOFT STORY BEHAVIOR IN REINFORCED CONCRETE BUILDINGS

M.Sc. THESIS

AHMED ADEN YASIN

Nicosia

June 2024

AHMED ADEN YASIN

THE IMPACT OF SHEAR WALLS ON SEISMIC PERFORMANCES AND SOFT STORY BEHAVIOR IN REINFORCED CONCRETE BUILDINGS

MASTER THESIS

2024

NEAR EAST UNIVERSITY
INSTITUTE OF GRADUATE STUDIES
DEPARTMENT OF CIVIL ENGINEERING

THE IMPACT OF SHEAR WALLS ON SEISMIC PERFORMANCES AND SOFT STORY BEHAVIOR IN REINFORCED CONCRETE BUILDINGS

M.Sc. THESIS

AHMED ADEN YASIN

Supervisor
PROF. DR. KABIR SADEGHI

Nicosia
June 2024

Approval

We certify that we have read the thesis submitted by **Ahmed Aden Yasin** titled "**THE IMPACT OF SHEAR WALLS ON SEISMIC PERFORMANCES AND SOFT STORY BEHAVIOR IN REINFORCED CONCRETE BUILDINGS**" and that in our combined opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Educational Science.

Examining Committee	Name-Surname	Signature
Head of the Committee:	Assoc. Prof. Dr. Rifat Reşatoğlu	....
Committee Member:	Assoc. Prof. Dr. Fatemeh Nouban	....
Supervisor:	Prof. Dr. Kabir Sadeghi	Prof. Dr. Kabir Sadeghi ....

Approved by the Head of the Department

.30../.01../2024

Prof. Dr. Kabir Sadeghi

Prof. Dr. Kabir Sadeghi

Head of Civil Engineering Department.

Approved by the Institute of Graduate Studies

NEAR EAST UNIVERSITY INSTITUTE OF GRADUATE STUDIES 1988

....../....../2024

Prof. Dr. Kemal Hüsnü Can Başer

Head of the Institute of Graduate Studies.

Declaration

I hereby declare that all information, documents, analysis and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of Institute of Graduate Studies, Near East University. I also declare that as required by these rules and conduct, I have fully cited and referenced information and data that are not original to this study.

Ahmed Aden Yasin

27/06/2024

Acknowledgments

I want to thank my parents for their prayers and encouragement. Several people have been a backbone to complete and without their help and guidance, this thesis would have not been completed. I would like to express our deepest gratitude for helping us during our years as engineering students.

Prof. Dr. Kabir Sadeghi**,** my supervisor has been guiding me through every step of this thesis; he has overseen the progress of the thesis, modeling, and proper implementation of design codes. In addition, he was making sure that I was on the right track from the very beginning to the very end of the thesis. Thank you for giving us the delight of working as engineers, and being patient for supporting us to achieve the thesis. Thank you for your time and effort.

I would like to express my gratitude to the professors and teachers at Near East University for disseminating knowledge and providing genuine and invaluable assistance during the course.

Also, I want to thank everyone who had a hand in providing us with what I needed to complete the work from outside the university in different domains, and of course, our families who stood by us all the time and applied all the effort to help us reach where I am now.

Ahmed Aden Yasin

Abstract

The Impact of Shear Walls on Seismic Performances and Soft Story Behavior in Reinforced Concrete Buildings

Ahmed Aden Yasin

Prof. Dr. Kabir Sadeghi

M.Sc., Department of Civil Engineering

June 2024, 59 pages

Severe earthquakes can cause significant damage or the complete collapse of buildings. Past studies have demonstrated that seismic events are responsible for substantial displacement due to structural damage. Shear walls in structures protect against horizontal forces, ensuring safety. As a result, the use of shear walls in buildings can effectively mitigate significant displacement and reduce associated damages. The most recent catastrophic earthquake resulted in significant damage to numerous buildings due to inadequate design. Among the damaged buildings, some structures had shear walls. This study delves into the seismic performance and soft-story behavior of RC buildings, emphasizing the role of shear walls. Employing ETABS for 3D modeling, it examines ten-story RC buildings with various span lengths and a constant story height. The investigation encompasses three model variations: without shear walls, with full-story shear walls, and with shear walls from the second story upward. We design the buildings with specified concrete strengths and reinforcing steel bars. The focus is on the ductility reduction factor (R_μ), the elastic stiffness factor, and the R-factor. The goal is to learn more about seismic resilience and help find the best shear wall configurations for better performance in reinforced concrete structures. The results indicate that the elastic stiffness factor for models with full shear walls increased significantly, from 149.27 kN/mm at a 5 m span to 174.84 kN/mm at a 7 m span. Additionally, the ductility reduction factor for models without shear walls decreased by approximately 20%, while models with full shear walls showed an increase of about 17.7%. These results underline the critical role of shear walls in enhancing the seismic performance and resilience of RC buildings.

Keywords: soft story, pushover analysis, response modification factor, shear wall, ductility reduction factor, elastic stiffness factor, reinforced concrete.

Özet

Betonarme Binalarda Perde Duvarların Sismik Performansa ve Yumuşak Kat Davranışına Etkisi

Ahmed Aden Yasin

Prof. Dr. Kabir Sadeghi

Yüksek Lisans, İnşaat Mühendisliği Bölümü

Haziran 2024, 59 sayfa

Şiddetli depremler binaların ciddi hasar görmesine veya tamamen çökmesine neden olabilir. Geçmiş çalışmalar, sismik olayların yapısal hasara bağlı önemli yer değiştirmelerden sorumlu olduğunu göstermiştir. Yapılardaki perde duvarlar yatay kuvvetlere karşı koruma sağlayarak güvenliği sağlar. Sonuç olarak, binalarda perde duvarların kullanılması önemli yer değiştirmeleri etkili bir şekilde azaltabilir ve buna bağlı hasarları azaltabilir. En son yıkıcı deprem, yetersiz tasarım nedeniyle çok sayıda binanın ciddi hasar görmesine neden oldu. Hasar gören binaların bazılarında perde duvarlar vardı. Bu çalışma, betonarme binaların sismik performansını ve yumuşak kat davranışını inceleyerek perde duvarların rolünü vurgulamaktadır. 3D modelleme için ETABS'ı kullanarak, çeşitli açıklık uzunluklarına ve sabit kat yüksekliğine sahip on katlı betonarme binaları inceliyor. Araştırma üç model varyasyonunu kapsamaktadır: perde duvarsız, tam kat perde duvarlı ve ikinci kattan itibaren perde duvarlı. Binaları belirlenen beton dayanımlarına ve donatı çelik çubuklarına göre tasarlıyoruz. Odak noktası süneklik azaltma faktörü (R_μ), elastik sertlik faktörü ve R faktörüdür. Amaç sismik dayanıklılık hakkında daha fazla bilgi edinmek ve betonarme yapılarda daha iyi performans için en iyi perde duvar konfigürasyonlarını bulmaya yardımcı olmaktır. Sonuçlar, tam perde duvarlı modeller için elastik sertlik faktörünün, 5 m açıklıkta 149,27 kN/mm'den 7 m açıklıkta 174,84 kN/mm'ye önemli ölçüde arttığını göstermektedir. Ek olarak, perde duvarsız modellerin süneklik azaltma faktörü yaklaşık %20 azalırken, tam perde duvarlı modellerde yaklaşık %17,7 artış görülmüştür. Bu bulgular, betonarme binaların sismik performansının ve dayanıklılığının arttırılmasında perde duvarların kritik rolünün altını çizmektedir.

Anahtar Kelimeler: yumuşak kat, itme analizi, tepki modifikasyon faktörü, perde duvar, süneklik azaltma faktörü, elastik sertlik faktörü, betonarme.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ASCE: American Society of Civil Engineering

ACI: American Concrete Institute

SW: Shear Wall

RC: Reinforced Concrete

RMF: Response Modification Factor

ESF: Elastic Stiffness Factor

Rμ: Ductility Reduction Factor

UBC: Uniform Building Code

CHAPTER 1

Introduction

1.1 General

In civil engineering, seismic performance for buildings is such an important aspect, particularly in areas that experience earthquakes. The destruction of infrastructural facilities leads to significant loss of life and disrupts economic and social activities. Ensuring seismic resiliency in structures is a crucial priority for safeguarding the safety and welfare of communities. This thesis title is "The Impact of Shear Walls on Seismic Performances and Soft Story Behaviors in Reinforced Concrete Buildings." The goal is to investigate how shear walls improve the seismic resistance of reinforced concrete (RC) structures by reducing the vulnerability of soft-story behaviors.

Shear walls are vertical components with significant resistance and rigidity in a structure, allowing buildings to withstand horizontal forces caused by seismic activity. Therefore, the walls function as support in the building's structure, significantly minimizing sideways movements and keeping the building from collapsing in the case of an earthquake. By effectively incorporating the shear wall into the design of buildings using RC, we can minimize damage by seismic forces, thereby improving the stability and safety of the building structure.(Shamasti, 2023)

One cannot overstate the importance of applying shear walls in areas with high seismic activity. For example, Bhat and Azam (Bhat, 2020) Emphasize that the purpose of these walls is to manage gravity loads in conjunction with lateral forces, thereby mitigating lateral drifts and inter-story displacements. Both imparted functions make it an element whose existence is essential in tall buildings and more so in earthquake-prone areas. Shear walls can have a significant or negative impact on buildings' structural integrity and seismic performance, making them an essential element in modern seismic design.

Weak stories are an essential problem that is frequent among reinforced concrete buildings. In the field of architecture, we refer to a building's floor as a "soft story" when it shows a noticeable, gentle difference from the floors above it. Typically, these rooms consist of expansive windows, such as those found in lobbies, commercial spaces, and parking garages. The earthquake causes the building to explode as a result of significant internal deformation, primarily due to its low lateral stiffness. Because weak segments fail, the entire structure may eventually fail, posing a significant challenge to seismic design.

This study will implement shear walls to improve an RC building's shear resistance. The purpose of the study "The Impact of Shear Walls on Seismic Performances and Soft Story Behavior in Reinforced Concrete Buildings" is to shed light on the evaluation methods employed to improve seismic behaviors in connection to damages caused by earthquakes.

Both ductility and elastic stiffness reductions are seismic performance indicators. It can make buildings in earthquake-prone regions safer by considering seismic performance while choosing between various shear wall designs. The proposed design techniques can only be effectively used for this specific purpose. All of these components can be utilized to calculate the building's seismic load response modification factor. This parameter is defined as the object's elastic stiffness factor in relation to lateral loads. This parameter defines the object's elastic stiffness factor concerning lateral loads. Therefore, we can evaluate a building using the ductility reduction factor and the response modification factor based on its ability to handle stresses and their distribution without failure. In order to achieve efficient seismic design, it is necessary to have a thorough comprehension of the interaction between shear walls and soft stories.

An extensive study has demonstrated that a well-constructed shear fence enhances the structural integrity and rigidity of structures, thereby increasing their ability to withstand seismic forces. However, more studies are needed to determine the correlation between various shear wall designs and the overall structural behaviors of buildings with vulnerable ground floors. The goal is to rectify this need for more understanding by evaluating various arrangements and their influence on the seismic resilience of ten-story reinforced concrete structures. One of the research methods employed is the use of the ETABS software for nonlinear static (pushover) analysis.

The software enables comprehensive modeling and analysis of buildings' structures, specifically under seismic loading conditions. This study examines different configurations and arrangements of shear walls, encompassing no-shear walls, full-height shear walls, and partial-shear walls starting from the second story and upwards. The primary goal is to determine the best shear wall arrangement to improve seismic performance and reduce the vulnerability of soft-story structures.

Providing strong design solutions for earthquake protection and guaranteeing excellent structural integrity of buildings are highly required in today's environment. Reinforced concrete buildings with shear walls are better able to withstand earthquakes because they reduce the impact of potentially weak stories. This study provided valuable insights into the optimal use of shear walls in seismic design, enabling the construction of earthquake-resistant structures with high resilience to failure. This paper demonstrates the impact of various shear wall and soft-story designs on overall seismic performance. It improves comprehension of seismic behaviors, which will aid in the development of earthquake-resistant building designs in the future.

1.2 Problem statement

Several RC buildings have either fallen or suffered significant damage in previous years because of the earthquake and its various aftershocks. If properly designed, many of these buildings might still be standing today. For earthquake resistance and general strengthening, RC buildings can benefit from the shear wall approach. Nevertheless, there needs to be more research on the efficacy of various shear wall layouts for soft-story buildings. This article examines the impact of different shear wall configurations in 10-story reinforced concrete buildings on seismic performance, aiming to derive relevant design principles for safer and more robust structures in seismically active areas. The walls differ in their span lengths.

1.3 Objective and scope

The main purpose of the study is to evaluate the seismic performance of the reinforced concrete building structure in relation to various shear wall arrangements. This study presents an estimation of the elastic stiffness factor, ductility reduction factor, and R-factor. The values used in his study fall between 5.0 and 7.0 meters, whereas the height of the story remains constant at 3.3 meters, as determined by nonlinear static pushover analysis. Therefore, the project aims to make a substantial contribution to the development and construction of safer reinforced concrete structures in regions prone to earthquakes. This objective will be accomplished by conducting a comprehensive analysis of the impact of different shear wall configurations on specific seismic parameters.

1.4 Hypothesis

This research is based on the premise that different configurations of shear walls will yield different earthquake-resistance properties. The configuration of shear walls in a typical reinforced concrete structure is one of the critical features that influence its seismic performance, especially in buildings with vulnerable stories. More research into validity will be conducted utilizing ETABS modeling. All shear walls will be of the same thickness, reinforced with RC buildings that have a compressive strength of 35 MPa and a yield strength of 500 MPa. This study aims to determine how the placement and design of shear walls affect the seismic resistance of RC buildings. To achieve this, we will contrast buildings with and without soft floors.

1.5 Significance of the study

This study sheds light on how various shear wall configurations affect the seismic resilience of reinforced concrete buildings, particularly those with lower stories, and hence, is of paramount importance. The study will unveil a crucial aspect of seismic design, significantly assisting in building resilience in earthquake-prone areas. Therefore, these findings should influence the refinement of seismic design approaches, resulting in more secure and efficient structural systems that can endure seismic shocks.

CHAPTER 2

Literature review

2.1 General

This chapter summarized earlier research and efforts related to the topic. Shear walls are mentioned in the referenced paper as lateral load-resistance structures.

2.2 Soft story and shear wall

Design and construction features of L-shaped shear walls, which are vital in making buildings more resistant to seismic forces. A shear wall is a vertical structural element capable of withstanding moments, shear, and axial loads caused by both gravity and lateral (seismic) forces. A soft story is typically a structurally deficient story that needs more rigidity or flexibility to withstand the seismic forces generated by an earthquake. Lower levels of buildings typically house soft stories, and failure in these areas can lead to the entire structure failing. In such situations, installing a shear wall is an excellent solution to address this issue. Shear walls provide significant stiffness in their plane but minimal stiffness in a perpendicular direction.

According to ASCE/SEI 7-16 (Loads & Structures, 2017)a soft story is defined as a story in a building where the lateral stiffness is either less than 70% of the stiffness in the story above it or less than 80% of the average stiffness of all three stories above it.

As the population continues to increase rapidly, there is a growing trend towards constructing apartment and high-rise structures to modify land use and accommodate the large population. These structures change their land use by utilizing the ground floor to create profitable parking and retail areas. At this level, a soft story emerges.

(Ozkul et al., 2019) The study "Effect of shear wall on seismic performance of RC frame buildings" examined the role of shear walls in mitigating earthquake-induced damage in reinforced concrete (RC) buildings. This study scrutinizes two reinforced concrete (RC) structures that underwent demolition after the 2011 Van earthquake in Turkey. The non-linear time history analysis will be performed using SAP 2000. We will assess the efficacy of shear walls in mitigating structural damages by comparing the original structures with their upgraded counterparts, where the material quality and shear wall design comply with the Turkish Seismic Code 2007. Multiple studies have shown that using well-designed and appropriate-quality materials for the shear walls of a structure can significantly reduce the amount of damage in reinforced concrete (RC) constructions. This occurs even when little ductility is present in other structural components, such as columns. Properly designed shear walls, as demonstrated by the findings of this study significantly improve the seismic resilience of buildings.

The academic paper called “Impact of Position and Quantity of Shear Walls in Buildings on Seismic Performance’’ by (Khelaifia et al., 2024) The optimal positioning and proportion of shear walls in reinforced concrete buildings in relation to floor space are examined. Nonlinear calculations were performed on an eight-story building located in a high seismic zone and it was discovered that seismic performance is significantly improved by centrally orienting shear walls compared to placing them in peripheral locations. Emphasis is placed on the finding that as the shear wall-floor area ratio increases, structural rigidity is enhanced, and inter-story drift is better controlled. It is demonstrated that a ratio of 1.0% is the most optimal in terms of performance and economic efficiency. Consequently, the study contributes to bridging the information gap regarding the efficient integration of shear walls in the structural design of earthquake-resistant structures.

(Ozkul et al., 2019)study, "Seismic Analysis of Multi-Storied RCC Buildings with Shear Walls," Evaluated how well reinforced concrete shear walls withstand seismic forces in buildings. It has been used different methods, such as equivalent static and response spectrum approaches, as described in IS 1893-2002 (Part I), to do seismic analysis by several analytical models with different shear wall placements. The findings indicate that the existence of shear walls has a substantial impact on the primary natural period, lateral stiffness, and the requirement for reinforcing columns. Essentially, this improved the building’s ability to withstand sideways forces caused by an earthquake. Determined the importance of shear walls in enhancing the seismic resilience of multi-story buildings after considering various arrangements.

In their 2017 study, "An Examination of Multi-Storied RCC Buildings with and Without Shear Walls,"(Axay Thapa & Sajal Sarkar, 2017) investigated the seismic performance of multi-story RCC buildings with various shear wall designs. The study used static and dynamic analysis methods to examine models of varying heights, including those with and without shear walls. The emphasis is on fundamental features such lateral displacement, tale drift, and base shear. The studies showed that adding shear walls to a building increases its lateral stiffness. Displacements are finally reduced, and seismic performance is improved. The utmost importance of shear walls in the seismic design of multi-story buildings is highlighted by the current study. It is indicated by the previous discussion that the buildings are composed of reinforced concrete (RCC).The research paper titled "Seismic Performance of L-Shaped RC Shear Walls" by (Ghoul et al., 2024) Detailed information is provided on the behavior of L-shaped reinforced concrete shear walls under seismic excitation. It is demonstrated that these walls exhibit nonlinear characteristics. Loading is in progress. Finite element modeling is employed in this study to thoroughly examine the stress distribution, ductility capacity, and stiffness of walls subjected to varying axial and lateral loads. The main objective is to evaluate the seismic performance of these walls. Moreover, important insights are provided into the behavior of these walls under seismic conditions.

Discussed in the article "Study of behavior of the Soft Stories at Different Locations in the Multi-Story Building," (Pavithra & Prakash, 2018) The effects of soft stories on seismic damage in multi-story buildings were tested in the literature. Several soft-story designs in a 15-story reinforced concrete (RCC) skyscraper were evaluated using response spectrum analysis conducted with ETABS. It is suggested by the research findings that earthquake response is substantially greater in lower-level soft stories compared to those in upper levels, implying the significant impact of earthquake energy. It is shown that soft stories at higher levels mitigate the structural reaction of the building. Therefore, the importance of strategically placing soft stories to reduce seismic hazards is highlighted by the study.

(Abidi et al., 2020) literature review, "Review on Shear Wall for Soft Story High-Rise Buildings," focused on the significant role shear walls play in reducing the seismic susceptibility of tall buildings with soft stories at lower levels. Upon consideration of this evaluation, it was found that both the sensitive design and the appropriate placement of shear walls enhanced by structure's stability, simultaneously reducing the seismic risk. Instability. This study presented a critical analysis of various approaches and studies related to the configuration of shear walls. The focus is on these walls' effectiveness in reducing the amount of significant devastation that results from seismic events.

(Mahmoud et al., 2016) were studied the dynamic properties of reinforced concrete frame constructions designed to withstand resistance moments.

The dataset of this document includes constructions both with and without infill walls, as well as soft-story buildings of varying heights. Dynamic time-history analysis was used in the current study to assess seismic performance. The outcomes obtained using this approach are expected to demonstrate the effectiveness of the masonry infill walls unequivocally. A major effect on the structural reaction will be observed. The majority of these infill walls were found to have a significant effect on the distribution of lateral forces and significantly improve the structure's stiffness and durability, boosting its ability to withstand seismic activity. The study also demonstrates the significant influence of soft flooring on variable characteristics. Structural weaknesses in reinforced concrete buildings are revealed during seismic occurrences. A comprehensive and enlightening analysis of the planning process involved in creating a reinforced concrete (RC) building is provided in the essay. It is emphasized that, when dealing with earthquake-prone areas, the infill impact must be taken into account during the design phase. The effects of unstable flooring on the stability of wall construction are examined.

Engineers can strengthen their skills and minimize the chance of failure by gaining a thorough understanding of these topics. Furthermore, this objective will be achieved by ensuring that buildings are designed with the necessary resilience to withstand earthquakes effectively. Ultimately, a more fortified and reliable infrastructure will be established in regions susceptible to earthquakes.

In the article "Open Ground Story in Properly Designed Reinforced Concrete Frame Buildings with Shear Walls," (Ak, 2020), were employed nonlinear structural models to estimate the seismic response, allowing for a thorough evaluation of the impact of shear walls on reducing soft-story vulnerability and enhancing building resilience. The lateral rigidity of buildings was increased by shear walls, resulting in a more even distribution of seismic forces and reduced ground-level movements. Resistance to large seismic forces was enhanced in structures by shear walls, as they increased strength against horizontal stress. The results mitigated the potential for collapse hazards. The findings provide critical information on the efficient planning and construction of reinforced concrete structures. The incorporation of shear walls into building designs has been undertaken with the specific aim of enhancing resistance to seismic stresses. Otherwise, the weak parts of the structure have the potential to fail under seismic forces. Safety protocols will be enhanced, and the lifespan of structures susceptible to seismic stress will be prolonged.

(Hejazi et al., 2011) conducted a study on the "Effect of Soft Story on Structural Response of High-Rise Buildings." This study aimed to analyze the seismic impact that soft stories have on high-rise buildings. The research mainly discussed how buildings with soft floors are prone to the effects of earthquakes, especially on the low-level floors of the building. The present research examines various bracing retrofitting strategies to mitigate the deteriorating effect of soft stories on building stability under seismic excitation. Therefore, the focus of this research is earthquake resilience—namely, the optimal seismic response of structures through the execution of proper design and retrofitting strategies.

Adeel Zafar's 2009 work, titled “Response Modification Factor of Reinforced Concrete Moment Resisting Frames in Developing Countries", focuses on the R factors for RC MRFs in developing countries, with Pakistan serving as a case study. The study has highlighted the insufficiency of directly adopting seismic design standards from well-established US or European norms in countries that have substantial differences in seismic hazards, construction methodologies, and material properties. Zafar asserts that constructional quality, material strengths, and building procedures differ across developed and developing countries. Therefore, a specific seismic design plan is required. A comprehensive study was conducted to analyze Pakistan's RC MFR R factors thoroughly.

This was achieved by replicating real seismic events using local ground motion records and implementing incremental dynamic analysis. It has been demonstrated through an extensive study that the specific attributes of a building's geometry, such as its height, symmetry, mass, and stiffness, significantly influence R factors. The seismic performance of materials is determined by the structural qualities of the materials employed, specifically the type and classification of concrete and steel. However, it is not considered practical to rely solely on the R factor from seismic design standards of foreign nations, as overly cautious designs or potentially hazardous constructions could result. This occurs because the unique circumstances specific to developing countries are not taken into account. The construction of structures specifically designed to withstand and minimize the impact of seismic activity in a specific geographical location is referred to as local seismic design.

Seismic adaptation refers to the deliberate modification of a structure to effectively withstand and accommodate the distinct seismic conditions present in a particular place. The primary goals of this program are to improve the ability of structures to withstand earthquakes and to increase their ability to resume normal operations following an earthquake quickly. The report emphasized the importance of conducting research at the regional level and implementing seismic design methods that accurately replicate the behavior of buildings in less developed countries. This reduces superfluous design elements while improving It ensures the stability and long-lasting quality of the structure, thereby decreasing construction expenses. Zafar's study lays the groundwork for future research and policy efforts focused on improving earthquake safety in low-income countries, thereby fostering the resilience and sustainability of cities.

2.3 The elastic stiffness factor

In their 2020 paper, "Study of Elastic Stiffness Factor of Steel Structures under Various Lateral Load Resisting Systems," (Sarhan & Raslan, 2020), Thoroughly examined the impact of the elastic stiffness factor K on steel structures under lateral loads, such as earthquakes and wind events. Prioritizing stability and durability is the only way to guarantee lateral stiffness in building construction. In the past investigation, the elastic stiffness factor, represented by K, quantifies the building's ability to withstand externally applied stress without forming plastic hinges. This characteristic has been playing a crucial role in determining the natural lifespan of buildings. Structural analysis helps designers understand a building's ability to endure different loads and determine the exact load categories that could potentially lead to its collapse.

Similar to Hook's spring equation, the K factor can also be used to determine the displacement caused by specific loads. In this scenario, the building is considered as the spring, while the base shear is regarded as the load. The focus of this work is placed on performing pushover analysis on steel structural models that employ various bracing strategies and exhibit a variety of characteristics. This study demonstrated that increasing the number of tales negatively impacts the K value; however, increasing the span length has a beneficial impact.

Bracing systems, especially the X-bracing system, have a big effect on the K value. This implies that earthquakes are less likely to damage the structure due to its increased rigidity. The current study provides a significant advancement in comprehending the methods by which steel Structures are modified and restored to enhance their resistance to seismic activity and ensure safety.

2.4 Response modification factor

The article Seismic Response Modification Factors by (Hall et al., 1997), emphasized the crucial importance of response modification factors, denoted as R, in the seismic design of American buildings. As a result, it is critical to provide a solid technological foundation for R-values in order to ensure earthquake-resistant structures' reliability. The study defined R as a combination of redundancy, ductility, and reserve strength in buildings. These elements are crucial for accurately predicting or modeling the inelastic behavior of buildings during earthquakes. The authors provide a first formulation of R, supported by both analytical and experimental evidence, in order to establish a more coherent approach to seismic design. The importance of regularly evaluating these components is highlighted, emphasizing the need for accurate determination of R-values across various earthquake-prone regions and building types. The author's key argument critiques the limitations of conventional static-elastic methods, particularly their failure to account for non-elastic responses inherent in building systems.

The researchers propose an improved method for representing buildings' behavior under seismic loads. This method incorporated time-dependent parameters for ductility and strength, as well as the redundancy factor, into the parameter R. Its approach to upgrading seismic design regulations is innovative and focused on strengthening the safety and resilience of structures. The research focuses on the impact of response-modifying features on seismic design and its components. The main objective of this study is to improve the performance and safety of structures during seismic events by improving the dependability of seismic design methods. A more technical and rigorous foundation for the R-values is being established, reflecting the need for precision and adaptability in seismic design standards.

2.5 Ductility reduction factor and the overstrength factor

The "Effect of Building Configuration on Strength Factor and Ductility Factor" study aims to investigate the impact of various building configurations on the over-strength and ductility factors of a reinforced concrete structure. Thirty-six models varying in the number of stories, bays, and bay lengths were analyzed using nonlinear pushover analysis to investigate this relationship. (Configuration, 2021).

This research showed that the over-strength factor decreases with the number of stories. This is because the growth in yield strength is less than the increase in design base shear. An increased bay length will reduce the over-strength factor, as seismic weight increases without affecting stiffness while the number of bays remains unaffected. The increase in the number of stories in the building led to a reduction in displacement ductility and the ductility factor.

This observation indicates that buildings with fewer stories tend to exhibit relatively low ductility factor values. Lengthening the bay is suggested as a means to reduce the displacement ductility ratio, thereby lowering the ductility factor. Similarly, increasing the number of bays enhances stiffness, producing comparable effects. These findings underscore the importance of carefully considering specific building layouts in seismic design, not only to ensure safety but also to achieve cost-effectiveness. Moreover, the potential inadequacy of relying on a single value for these parameters in design codes highlights the critical need for a nuanced understanding of these design variables.

CHAPTER 3

Methodology

3.1 Introduction

This chapter explains the building models, including their sections, dimensions, and material properties. The second section focuses on the seismic method employed in this study and the parameters that were evaluated. 15 3D models were created using ETABS software. A consistent thickness was assigned to the shear walls, which were placed in different configurations to assess the response modification factor (RMF) and ductility reduction factor (R).

3.2 Models and Geometry

All buildings were developed as 3D models, each consisting of ten stories. The ETABS software employs a grid model for modeling purposes. The structure is composed of five spans in the X direction and five spans in the Y direction. The spans are designed with lengths of 5.0 m, 5.5 m, 6.0 m, 6.5 m, and 7.0 m. A height of 3.3 meters is assigned to each story.

3.3 Sections (frames and shear wall)

Various models are used for different portions, depending on their independence. Frames are used to model beams and columns, with properties like as cross-sectional dimension, reinforcing information, and material type assigned. The link between beams and columns is assumed to be rigid. The slabs are represented as shells, whereas the shear walls are described as layered or nonlinear shell sections. Beams and columns are represented using frames. All structural elements on the first floor are firmly secured.

Table 1

Thicknesses and sections of beams, columns, slabs, and shear walls

Building elements	Sections/thicknesses
Beams	0.3x0.5m
Columns	0.5x0.5m
Slabs	0.15m
Shear walls	0.3m

3.4 Materials (steel reinforcement, concrete)

The software incorporated the ACI code database to select the parameters of the concrete and reinforcing bars. The compressive strength of the concrete is assumed to be 35 MPa. Table 2 indicates that we determined the yield strengths of the steel reinforcing bars to be 500 MPa.

Table 2

Materials properties

Materials properties	**Values**
Compressive strength of concrete (f'_c)	35 Mpa
Concrete's modulus of elasticity (E_c)	27805.57 Mpa
Yield strength of steel (F_y)	500 MPa
Steel's modulus of elasticity (E_s)	200,000 MPa
Unit weight of concrete	25 kN/m^3

Table 3

The project will discuss the models.

Models type	Model 1: Base model (no shear wall)	Model 2: Partial shear wall soft story model (second to tenth story)	Model 3: full shear wall (all stories)
Span lengths (m)	5, 5.5, 6, 6.5, 7	5, 5.5, 6, 6.5, 7	5, 5.5, 6, 6.5, 7

3.5 Building information

This study has examined the structures of three stories. Each level is 3.3 meters high, and there are a total of 5 spans in the X direction and 5 spans in the Y direction. The span lengths examined were 5 m, 5.5 m, 6 m, 6.5 m, and 7 m. The kind of model determines the placement of the shear walls, positioning them in the centre of the spans.

Figure 1

Plan view for a 5 m span length without shear building.

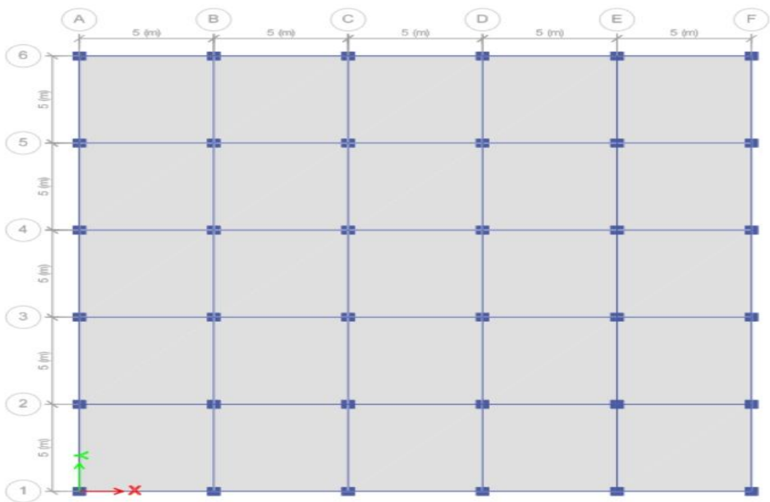


Figure 2

Plan view for a 5 m span length with a shear wall building.

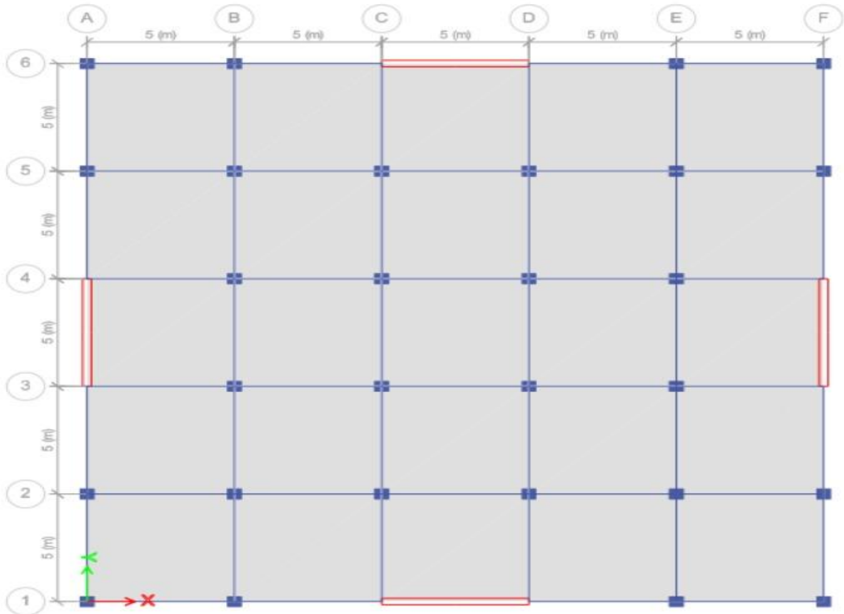


Figure 3

Three-dimensional perspective of a 10-story building without a shear wall

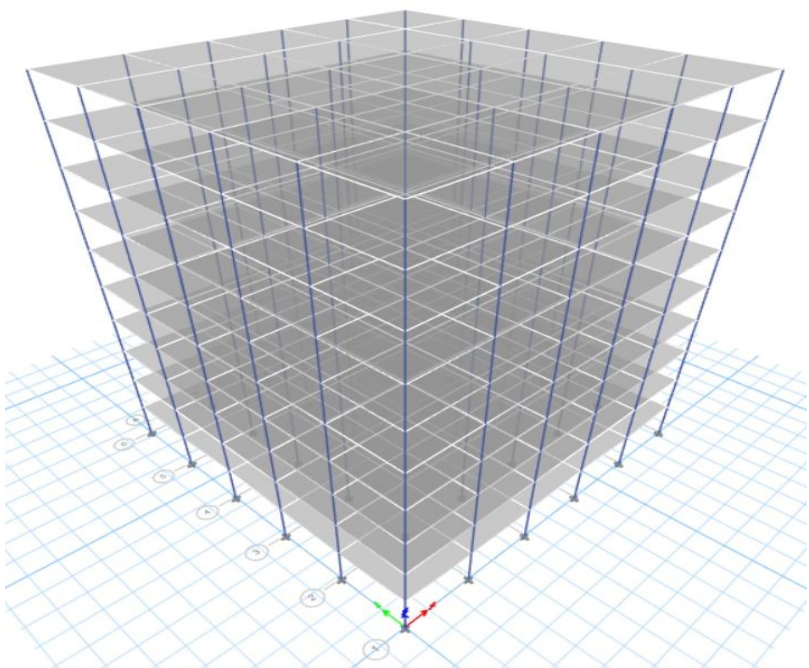


Figure 4

Three-dimensional perspective of a 10-story building with soft stories.

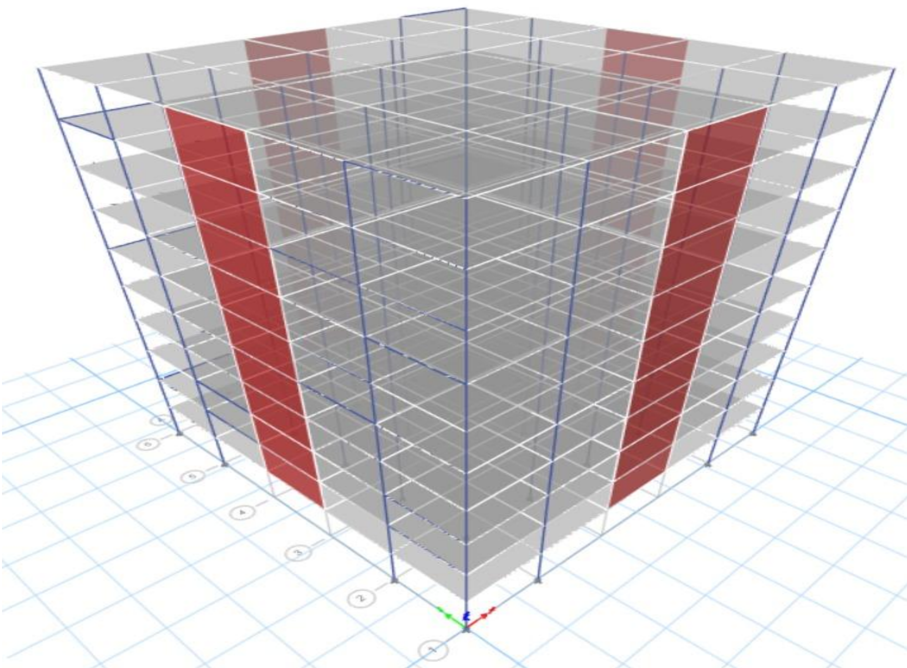


Figure 5

Three-dimensional perception of a 10-story shear wall building

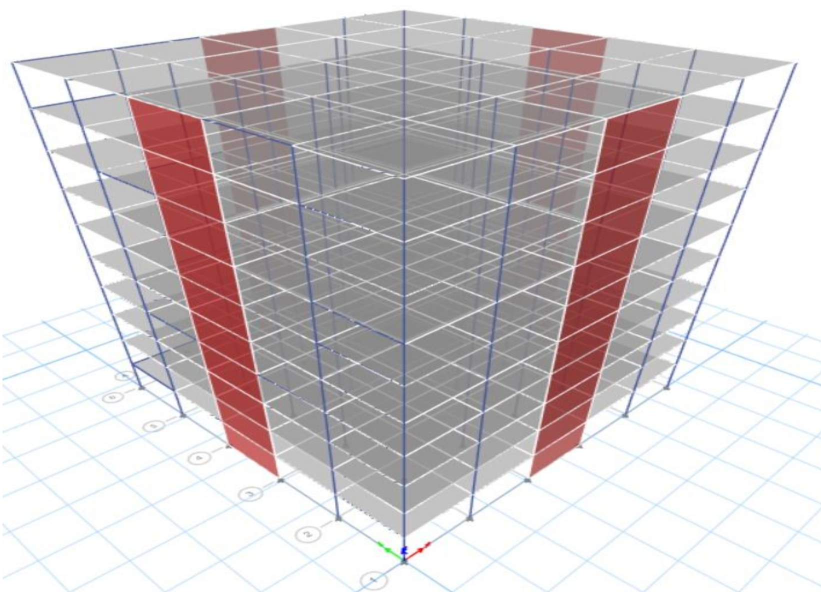


Figure 6

Two-dimensional perception of a 10-story, non-shear building

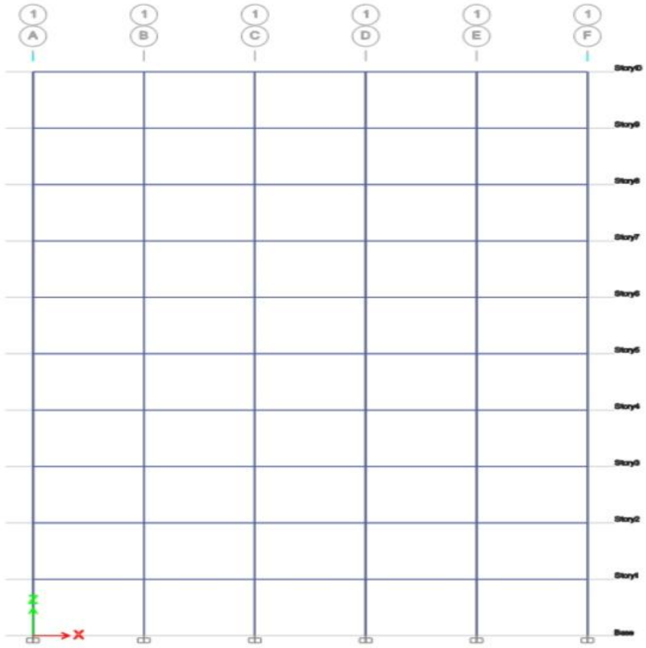


Figure 7

Two-dimensional perspective of a 10-story building with soft stories.

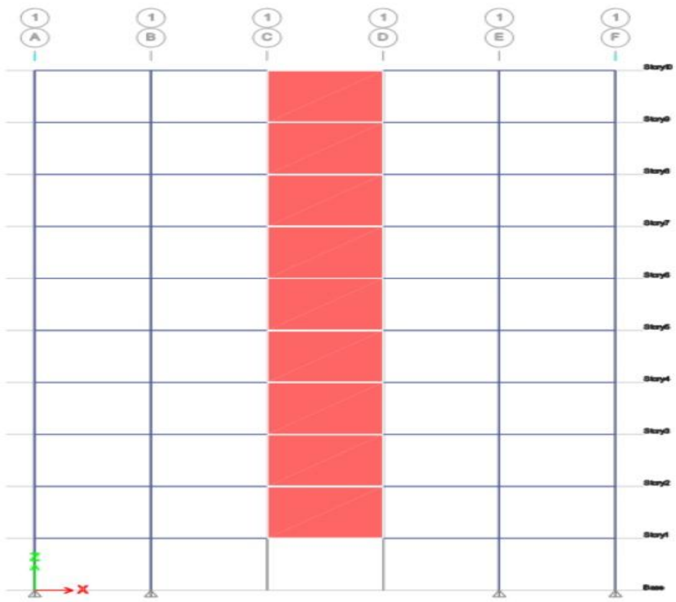
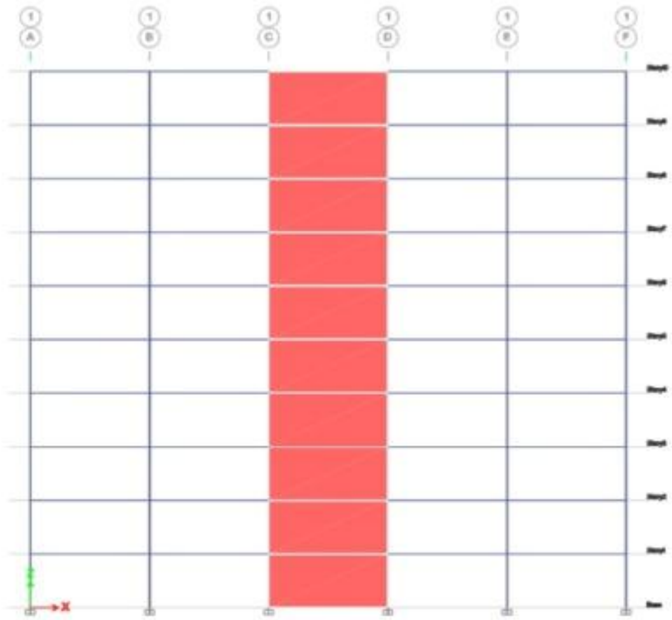


Figure 8

Two-dimensional perception of a 10-story shear wall building.



3.6 Loads

The ASCE/SEI 7-16 standards guided the selection of the loads imposed on frames and slabs. The sub-sections below detail the applied loads for all residential models.

3.6.1 Dead load

The task of accounting for the self-weight (dead load) of structural elements falls to the software Etabs.

3.6.2 Super dead load

The super dead load refers to the external load acting on a structural element, excluding its own weight. This study applied a floor-finished load of 1.352 kN/m^2 to the floor slab. An additional dead load of 12.608 kN/m, for wall load, was assigned to the beams.

3.6.3 Live load

According to ASCE/SEI 7-16, Table 4.3-1, all of the building's floors have applied a live load magnitude of 1.92 kN/m^2 and 0.96 kN/m^2 for the roof.

3.6.4 Lateral loads

According to (UBC97-V2 Structural Engineering Design Provisions.Pdf, n.d.) assigned lateral loads due to earthquakes, take into account necessary parameters such as soil profile type, seismic zone factor, overstrength factor, and importance factors in the X and Y directions. Assigned wind loads in accordance with ASCE/SEI 7-16, considering factors like exposure type and wind speeds of 105 mph.

3.7 Structural irregularities

Plan irregularities and vertical irregularities are the two main categories of irregularities in buildings. These irregularities vary based on the location and scope of the construction. In this chapter, will been discussed and explain the vertical irregularities.

3.7.1 Vertical irregularities

Buildings have historically suffered damage or collapse as a result of numerous significant earthquakes. Studies have revealed that structures with regular shapes perform better in an earthquake. The presence of structural irregularities results in an uneven distribution of loads across different components of a building. An unbroken pathway is necessary for the transmission of these inertial forces from the ground to the building. A discontinuity in this gearbox path leads to structural failure at that specific spot. Researchers have conducted multiple studies on building irregularities, including the assessment of torsional response in multi-story buildings using equivalent static eccentricity, the development of a three-dimensional damage index for RC buildings with planar irregularities (Jeong & Elnashai, 2006), and the evaluation of mass, strength, and stiffness limits in regular buildings specified by UBC.

This chapter focused on analyzing the behavior of 10-story plane frames under lateral stresses, specifically considering anomalies in mass and stiffness in the building's elevation. Modifying the characteristics of individuals involved in the examined narrative leads to these anomalies. Several anomalies were present, such as story drift, excessive weights on the top floor, floating columns, and an unusually tall first story. The study focused on the effects of story-shear forces, tale drift, and beam deflection on the story.

3.7.2 Stiffness-soft story irregularity

Stiffness-soft story irregularity refers to a structural issue when there is a notable decrease in the lateral stiffness of one floor in comparison to the floors located above it. More precisely, were detected this anomaly when the lateral stiffness of a certain level falls below 70% of the stiffness of the floor directly above it, or below 80% of the average stiffness of the three floors above it.

In structural engineering, lateral stiffness refers to a building's ability to resist and withstand lateral forces, such as those caused by wind or seismic activity, without experiencing significant deformation or failure. A soft story is a level in a building that has more flexibility and less resistance to sideways forces compared to other levels. In this case, the lack of stiffness can lead to significant horizontal displacements at that particular level during an earthquake, which are highly likely to cause substantial stress concentrations and potential failure.

Soft-story abnormalities pose a significant risk because they can lead to a structurally deficient building that is unable to bear lateral pressures or heavy loads. This vulnerable area becomes a focal point for distortions due to seismic activity, resulting in a phenomenon known as "soft story collapse." Buildings with soft-story abnormalities have previously demonstrated inadequate seismic performance, frequently experiencing partial or complete collapse. Identifying and correcting the stiffness-softness abnormality during the design and retrofitting of structures will enhance their ability to withstand seismic activity.

3.7.3 Stiffness-extreme soft story irregularity

Stiffness-extreme soft story irregularity has a higher severity than stiffness-soft story irregularity. Existence is the condition under which a building's lateral stiffness is less than 60% of the stiffness of the story directly above it, or less than 70% of the average stiffness of the three stories above.

The substantial decrease in lateral stiffness signifies a notable vulnerability in the building's structural structure. This can significantly reduce the building's ability to resist lateral stresses, rendering it highly susceptible to extensive damage or complete collapse during an earthquake. Particularly pliable narratives suggest a blue narrative, when a story exhibits greater flexibility compared to other sections of the structure. This could lead to significant shifts between narratives and increase the likelihood of catching the structure off-guard.

Structures that exclusively use the first level for parking or commercial purposes sometimes display significant anomalies in their structural layout. The absence of appropriate shear walls or other wall bracing elements leads to a notable insufficiency of lateral stiffness. To reduce extreme abnormalities in soft-story buildings, architects may increase lateral stiffness by purposely incorporating structural features like shear walls or braced frames.

3.7.4 Weight (mass) irregularity

Mass irregularity arises when a narrative's effective mass exceeds 150% of that of the story next to it. The effective mass is the total gravity of the floor, partitions, and equipment, excluding any other elements. Excessive mass can increase lateral inertial forces, reduce ductility in vertical load-resisting components, and raise the risk of collapse.

Deviations from uniform mass distribution in both vertical and horizontal planes can cause non-uniform reactions and complex dynamics. Heavy loads on upper levels shift the center of gravity above the base, resulting in considerable bending moments.

3.7.5 Vertical geometric irregularity

Geometric irregularity occurs when the horizontal dimension of a lateral force system in one story exceeds 150% of the horizontal dimension in the adjacent story. A vertical concave corner is another way to illustrate the setback. The most effective way to address a setback issue is to incorporate complete seismic isolation into the building's construction, allowing certain areas to shake separately.

3.8 Non-linear properties

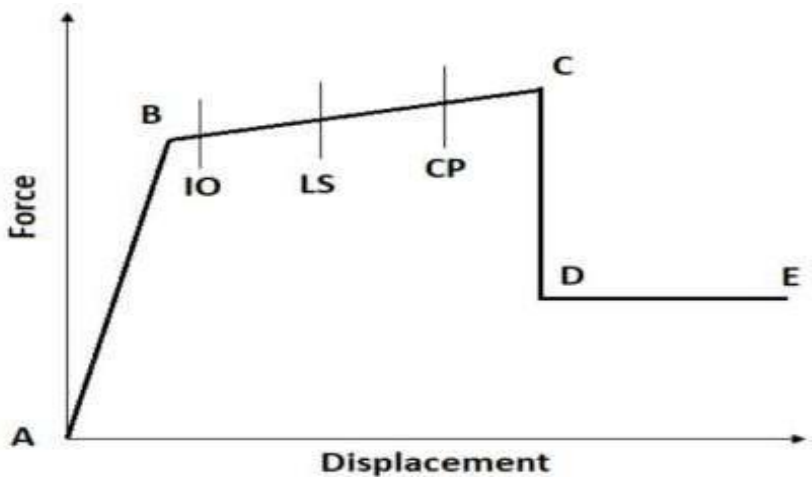
3.8.1 Plastic hinge

It is necessary to design the components responsible for carrying these forces in a nonlinear manner because structures are subject to lateral stresses and require nonlinear analysis. Consequently, we designate plastic hinges for the members. The exact meaning of plastic hinges varies depending on the section's specific characteristics.

A plastic deformation curve was constructed to illustrate the behaviors of hinges at various levels of deformation. These curves typically consist of five points representing different stages of hinge behaviors. Figure 9 provides an example of such a curve.

Figure 9

Performance level of hinges



Point A represents the starting point of the curve, indicating that there is no stress on the hinge. Moving from point A to point B, there is a linear relationship between force and displacement, representing the elastic stage, with point B marking the yield point. In pushover analysis, point C represents the carrying capacity, point D denotes the remaining strength, and point E signifies complete hinge failure. If such hinge failure is undesirable, Point E can serve as a yield point in the design. Additionally, three performance points, IO, LS, and CP, lie between points B and C, representing immediate occupancy, life safety, and collapse prevention, respectively.

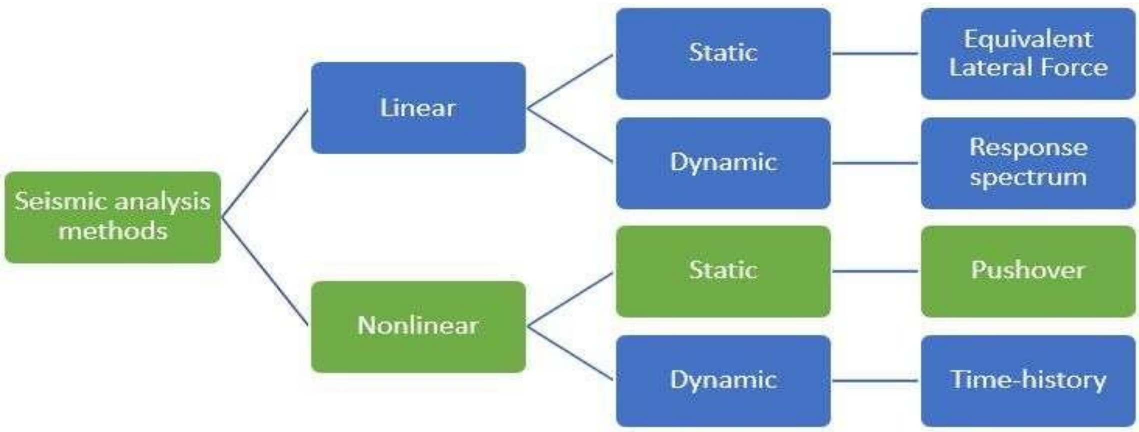
Lastly, we assign hinge overwrites to each hinge to facilitate component division and achieve better outcomes.

3.9 Analysis methods

The lateral forces exerted on a building directly influence the formation of plastic hinges. According to (Sarhan & Raslan, 2020), The "plastic-hinge evaluation approach" is employed to allow for an accurate depiction of structural behavior, particularly under significant displacement. These lateral forces, primarily including wind and seismic loads, are accounted for as they can cause damage to a structure. Therefore, it is considered crucial that every building be engineered to endure these lateral forces. Four seismic analysis techniques are outlined below for studying a building's response to seismic events. An overview of these seismic analysis methods is provided in Figure 10.

Figure 10

The overall scheme for seismic analysis methods.



- Linear analysis showed a direct relationship between applied force and displacement. This sort of analysis is utilized for structural issues with stresses that fall within the linear elastic range. As a result, investigating plastic hinges is not acceptable. Prior to performing the pushover investigation, the structural models are created and developed using a linear static approach.
- Nonlinear dynamic analysis, or time-history analysis, utilized ground motion data and a structural model to produce precise results. Nonlinear pushover analysis is much faster to carry out than time-history analysis.

- Nonlinear static analysis, also known as pushover analysis, involved applying a series of loads on a structural model. This technique considered nonlinear components such as steel yielding. When steel frames are concentrically braced, earthquakes can be tolerated as long as the bracing parts can withstand several cycles of inelastic deformations, such as stretching and buckling. A graph, popularly known as the pushover curve, is created to show the relationship between overall shear force and displacement. Pushover analysis is used to examine a structure's behavior under a variety of horizontal forces. This study is based on the structure's performance and can be applied to both existing and previously constructed structures. Weights are incrementally raised until the structure reaches its peak response.

3.9.1 Maximum base shear

The term "maximum base shear" refers to the maximum amount of external force that a building is capable of withstanding before it experiences a full failure, such as the collapse of the entire structure. The maximum base shear of the first plastic hinge is the load limit at which the building suffers plastic deformation, which ultimately fails in the building near its location. When it comes to precisely determining whether or not a structure is capable of withstanding seismic events like earthquakes, it is essential to conduct a study of the maximum base shear.

3.9.2 Lateral displacement

There is a positive correlation between lateral displacement and the stiffness of the building. When a building is less rigid, it will experience increased displacement and movement. It is crucial to consider this parameter throughout the design phase, as every structure must maintain a certain degree of flexibility to prevent structural failure. Controlling the displacement, on the other hand, is necessary in order to avoid serviceability issues and the possibility of collisions with adjacent buildings.

3.9.3 Response modification factor

Most seismic codes require structures to be able to withstand significant deformation without damage and dissipate energy effectively (ductility). In addition, structures should possess a significant surplus of strength, known as overstrength. The response modification factor, as explained by Abdi et al. (2015), incorporates these considerations into the structural design. The methodology for calculating the response modification factor takes into account the important factors of strength, stiffness, and ductility, which are crucial in inelastic analysis. The pushover analysis produces a pushover curve that demonstrates the correlation between base shear and displacement. Using the bilinearization curve derived from software, engineers determine yield capacity and ultimate capacity. Ve represents elastic design, Vy denotes the equivalent yield force corresponding to the yield displacement (Δy), and Vd represents the design force. Calculated by the R-factor using Equation 3.

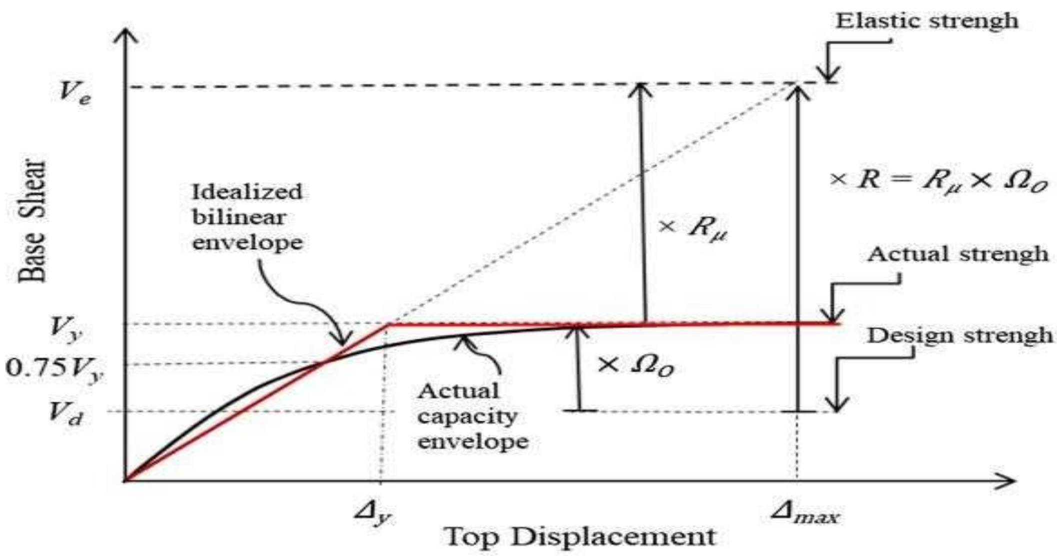
The overstrength factor, RS=Vy/Vs, (1)

The ductility reduction factor, $R\mu = Ve/Vy$, (2)

The response modification factor, $R = Rs * R\mu$, (3)

Figure 11

The pushover curve's bilinearity.



To calculate the design force, the response modification factor 'R' determines the reduction of the earthquake-induced lateral force on a building. It is a specific characteristic of each structure. Consequently, the greater the building's ability to release energy during its plastic phase, the greater its R-value will be. In addition, the design will be completely elastic, with a response modification factor of 1, resulting in a very costly construction

3.9.4 The over-strength factor

A building's maximum lateral strength typically exceeds its design strength, which is influenced by several factors that are not always apparent to many design professionals. Moreover, structures located in regions with lower seismic activity may have different overstrength coefficients compared to those in higher seismic zones due to varying gravitational and seismic forces. Variations in real building processes and differences between actual and nominal material strengths influence the strength factor value similarly but in unexpected ways (ATC-19).

To determine the overstrength factor in static nonlinear (pushover) analysis, follow these steps:

- During the pushover analysis, show a graph depicting how base shear relates to roof displacement.
- Using the bi-linearized curve, find the base shear at the structure's yield point (Vy), and determine the base shear (Vs) at the onset of the first hinge formation.
- Finally, use the formula in equation 1 to determine the overstrength value.

3.9.5 The ductility factor (Rμ)

The ductility of a building depends on structural attributes such as damping, the fundamental vibration period, and the properties of ground motion experienced during an earthquake. R is the ratio of the base shear at the elastic design level to the base shear at the yield strength level. Equation 2 defines R. Another method of explanation is to express it as the ratio between the highest drift displacement and the yield displacement. Suppose the maximum base shear, maximum displacement, yield force, and yield displacement are known. In that case, the overstrength factor, ductility reduction factor, elastic stiffness factor, and response modification factor can be calculated.

3.9.6 The elastic stiffness factor K

As the following statement explains, the elastic stiffness factor, denoted by the letter K, is the ratio of the base shear that occurs at the time of the first hinge to the displacement that corresponds to it. This element establishes a structure's ability to sustain applied loads without developing plastic hinges. It can be used to determine the natural period (T) of buildings, giving architects and designers a better understanding of the building's load capacity as well as the processes required for its collapse. Additionally, you can use the K factor to determine the displacement under a specific load. Hooke's law, which uses the structure as a spring and the base shear to represent the load, is comparable to this. The equation is summarized as follows:

$$\mathbf{K} = Vs/\mathrm{Ds} \tag{4}$$

Where:

Vs: The base shear at the occurrence of the first plastic hinge.

Ds: The displacement at the point where the first plastic hinge occurs

K: The elastic stiffness factor

3.9.7 Pushover Analysis Procedure

Pushover analysis was performed using the displacement control method, which caused the structures to fracture at the top joint. The following methods were also undertaken to identify the pushover curve, from which the factors evaluated in this thesis were derived.

Generate three-dimensional models and assign materials and section attributes to elements.

1. Specify and assign load patterns to segments.
2. To enable nonlinear analysis, use the ETABS programs to designate hinges for beams and columns and specify shear walls as layered.
3. Define the nonlinear dead load, considering 100% of the dead load, the super dead load, and 25% of the live load.

Define the pushover pattern, beginning from the endpoint of the nonlinear dead load, and assign a direction to it, considering the acceleration pattern for the lateral load.

4. Perform the analysis and plot the base shear-displacement curve.

CHAPTER 4

Findings and discussion

4.1 Introduction

This chapter will cover the findings obtained when analyzing the seismic performance of reinforced concrete buildings with different configurations of shear walls. The key parameters of importance include the elastic stiffness factor K, the ductility reduction factor R_μ, and the response modification factor R. Carefully analyzed the results, displaying the impact of various span lengths on each parameter and comparing them to the existing literature.

4.2 The elastic stiffness factor

Finally, K is the elastic stiffness factor, which represents a measure of the building's capacity to resist loads prior to the formation of plastic hinges. Higher values mean greater rigidity and less displacement sensitivity under seismic loading.

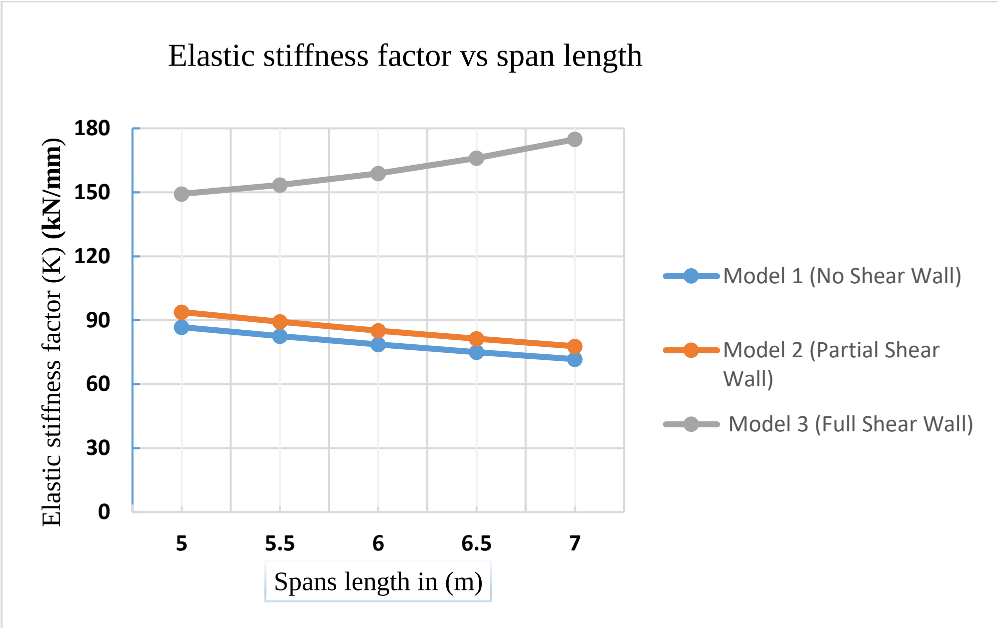
Table 4

The elastic stiffness factor values for all models

Span length (m)	Model 1 (no shear wall) (kN/mm)	Model 2 (partial shear wall) (kN/mm)	Model 3 (full shear wall) (kN/mm)
5	86.77	93.86	149.27
5.5	82.47	89.32	153.38
6	78.56	85.13	158.9
6.5	74.99	81.31	165.99
7	71.73	77.8	174.84

Figure 12

Elastic stiffness factor vs. span length



4.2.1 The effect of span length variation on the elastic stiffness factor

This study evaluated the ESF for three different models: no shear wall, partial shear wall, and full shear wall. In the absence of a shear wall, the ESF decreases from 86.77 kN/mm to 71.73 kN/mm for Model 1 as the span increases from 5 m to 7 m. This happened because no shear walls can provide lateral stiffness and resist deformation. As the span length increases, the behavior of structural elements without shear walls weakens their effectiveness against lateral loads and, therefore, reduces stiffness. Similar to Model 1 in Model 2, it is also partially shear-walled; the ESF decreases from 93.86 kN/mm at a 5 m span down to 77.80 kN/mm at a 7 m span. Although partial shear walls offer some resistance, their size is insufficient to counterbalance the increase in span length, leading to a reduction in lateral stiffness. Conversely, Model 3—Full Shear Wall—gives an ESF increasing from 149.27 kN/mm at a span of 5 meters to 174.84 kN/mm at a span of 7 meters, which reflects increased stiffness with longer spans. Throughout their existence, the shear walls have seen notable improvements in the structure's lateral stiffness, maintaining and even increasing stiffness as the span length increases.

The entire shear walls' full-scale lateral resistance effectively counteracts the impacts of increased span length, resulting in a stiffer structural system.

4.3 Ductility reduction factor

The ductility reduction factor Rμ represented the potential of a building to undergo inelastic deformations without losing its load-carrying capacity. The higher the value, the more a building is capable of absorbing and deforming energy.

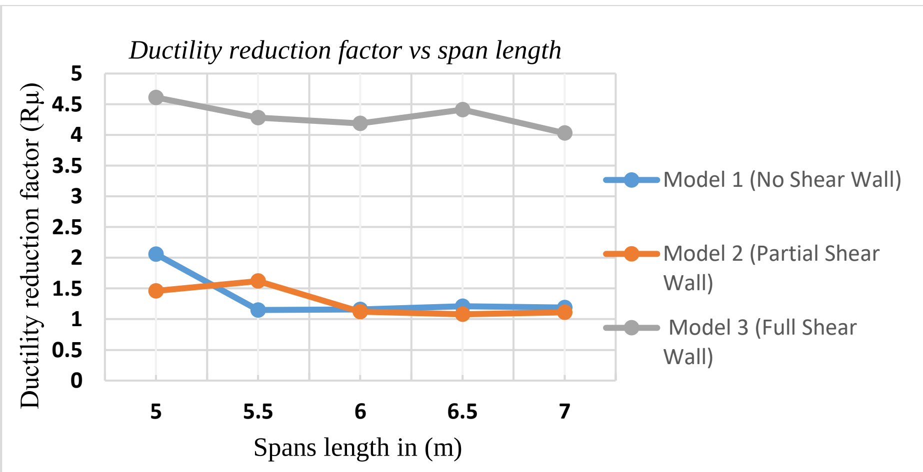
Table 5

All models' ductility reduction factor values

Span length (m)	Model 1 (no shear wall) (Rμ)	Model 2 (partial shear wall) (Rμ)	Model 3 (full shear wall) (Rμ)
5	2.06	1.46	4.61
5.5	1.15	1.62	4.28
6	1.16	1.12	4.19
6.5	1.21	1.08	4.41
7	1.19	1.11	4.03

Figure 13

Ductility reduction factor vs. span length



4.3.1 The effect of span length variation on the ductility reduction factor

This paper investigated the effect of different span lengths on the reduction factor of ductility. Analysis of three different models has been done: one with no shear wall, one with a partial shear wall, and the last with an entire shear wall. As depicted by model 1, when there is no shear wall, an increase in span length from 5 to 7 meters reduces the ductility reduction factor by about 20%. Model 2 shares the same geometry as the partial shear wall, but it reduces ductility by approximately 18%. On the other hand, Model 3, completely applied with shear walls, maintained increasing span lengths and had a corresponding increase of about 17.7% of its reduction factor for ductility. Shear walls improve the structural ductility, enabling it to undergo more considerable deformation due to increased span lengths. The obtained results reveal that the presence of shear walls in a reinforced concrete building significantly enhances the efficiency of span lengthening. This is due to the enhancement of flexibility and the prevention of rupture.

4.4 Response modification factor

The response modification factor (R) represents the building's ability to reduce seismic forces through inelastic behavior and overstrength. Higher values indicate better seismic performance.

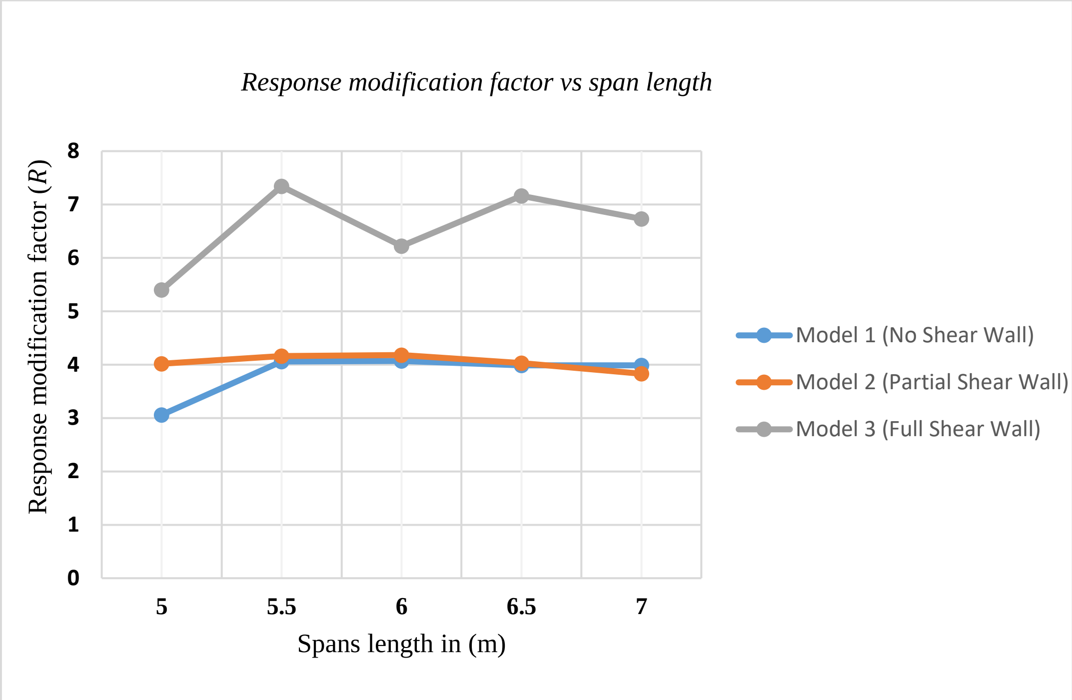
Table 6

The response modification factor values for all models

Span length (m)	**Model 1 (no shear wall)**	**Model 2 (partial shear wall)**	**Model 3 (full shear wall)**
5	3.06	4.02	5.4
5.5	4.06	4.16	7.34
6	4.07	4.18	6.22
6.5	3.99	4.03	7.16
7	3.99	3.83	6.73

Figure 14

Response modification factor vs. span length



4.4.1 The effects of span length variation on response modification factor

This study focused on how varying span lengths affect three different models of the response modification factor: model 1, no shear wall; model 2, partial shear wall; and model 3, complete shear wall. An increase in the span length from 5 m to 7 m in model 1, without a shear wall, precipitates a decrease of around 25.7% in RMF. The decrease may indicate that seismic performance is deteriorating. With partial shear walls, Model 2 drops by about 22.5%. This suggests that partial shear walls provided some benefit, but the spans are incredibly long. On the other hand, incorporating the entire shear wall would lead to a 20% increase in the RMF. Any increase in the span lengths of a building's shear walls significantly boosts the overall structure's resiliency by enhancing its seismic energy dissipation capacity.

CHAPTER 5

Discussion

5.1 Discussion

The paper examined case studies on the seismic performance of different designs of shear walls in reinforced concrete structures. The new seismic code relied on two essential factors: elastic stiffness factor K and ductility reduction factor $R\mu$, as opposed to the prior response modification factor R. The previous literature review revealed the following findings regarding the importance of shear walls in increasing the seismic performance of reinforced concrete structures:

In 2021 (Ahmad, 2021) conducted a study to assess the elastic stiffness factor (ESF) of 2D RC frame systems with different parameters. Ahmad noted that the elastic stiffness generally increases as the span length increases. Additionally, frames with shear walls exhibit higher stiffness compared to those without. Furthermore, the number of floors affects stiffness, with taller structures being more likely to have greater flexibility. This is consistent with the general trend in building construction. However, it contradicts these present findings for models without or only partially incorporating shear walls, which demonstrate a reduction in stiffness as the length of the spans increases. Both investigations demonstrate that the inclusion of shear walls leads to an increase in both elasticity and stiffness. The study demonstrated that entire shear wall structures exhibited superior stiffness and performance as the span length increased. In contrast, the findings by Ahmad revealed that for each configuration, there was a constant increase in stiffness with span length. It underlines that the comparison must need design techniques to improve seismic performance in RC buildings.

Ozkul et al. (2019) showed that the shear wall has improved seismic performance by increasing the response modification factor. Hence, findings from this study are in agreement with these facts, especially about a complete shear wall, where it is obviously noticed that span length directly affects the Resisting Moment Factor. In the models of structures without or partially provided with shear walls, the RMF reduces. Therefore, in scenarios when structures do include full shear wall arrangements, they improve RMF and overall resilience to earthquakes. Ozkul et al.

(2019) proved that including shear walls in buildings drastically improves ductility and, thus, the general seismic performance according to obtained results. These data support the conclusion that, in a complete shear wall model, the ductility reduction factor rises with span length. Nevertheless, models lacking partial shear walls exhibit a reduction in the factor. It, therefore, brings out the need for complete shear wall configurations so that deforming plastically with increased distance between supports is either preserved or enhanced for a structure.

This study, contrary to the findings presented by Ahmad (2021) and Ozkul et al. (2019), demonstrates that shear walls contribute less to improving RC building performance but mainly towards resilience, ductility, and elastic stiffness enhancement. However, our study found that incorporating shear walls, particularly completely set-up configurations, hugely increased the structural integrity with varying span lengths. This highlights the importance of integrating fully constructed shear walls into the design of any reinforced concrete building to get the best possible seismic performance. These results differ from Ahmad's for both the no-shear wall and partial-shear wall models. They unequivocally demonstrate that lengthening the span without a well-designed shear wall can result in a decrease in rigidity and effectiveness. In order to attain comparable seismic resistance, it is important to strategically plan the configuration of the shear walls, taking into account the changes in the lengths of the spans.

Therefore, this research and the referenced studies suggested that shear walls significantly improve the structural performance of reinforced concrete buildings. According to reports, utilizing entire shear wall topologies not only improves stiffness and RMF but also preserves or heightens ductility as span length increases.

These findings are also crucial in terms of how they can guide future design techniques to ensure the seismic resilience of reinforced concrete (RC) buildings. Comprehensive designs that take into account variations in the span length of shear walls are critical for optimizing the seismic performance of reinforced concrete buildings in earthquake-prone areas, with the goal of improving safety and durability.

The values for RMF and overstrength. These values fail to satisfy the specified standard (Appendix B) according to UBC-79, resulting in low seismic performance according to models 1 and 2, while the model 3 full shear wall complies with the established specifications and demonstrates enhanced earthquake resilience. as a result, it is necessary to incorporate complete shear walls into the designs of reinforced concrete buildings to match or exceed the seismic performance standards for structural safety

CHAPTER 6

Conclusion and recommendations

6.1 Conclusions

This study has examined the impact of varied lengths on the elastic stiffness factor, response modification factor, and ductility reduction factor for various layouts of reinforced concrete buildings with varying numbers of shear walls. Analysis has demonstrated that including shear walls is crucial for enhancing the seismic resilience of a reinforced concrete (RC) structure.1.

- Comparison of ESF and Span Length: As the length of the span increased, the elastic stiffness factor (ESF) dropped for models that did not have shear walls and for models that had partial shear walls. Model 1 without a shear wall exhibits a decrease in strength from 86.77 kN/mm at a 5 m span to 71.73 kN/mm when the span is increased to 7 m. Similarly, Model 2, which includes a partial shear wall, demonstrates a comparable pattern: On the other hand, Model 3 (Full Shear Wall) exhibited a rise in ESF from 149.27 kN/mm for a 5 m span to 174.84 kN/mm for a 7 m span, demonstrating that the complete shear walls played a role in enhancing stiffness as the spans grew.
- The response modification factor (RMF) diminished as the span length increases for models that do not have a shear wall or a partial shear wall. Model 1 exhibited a reduction of approximately 25.7%. The presence of a partial shear wall in Model 2 resulted in a reduction of around 22.5%. Nevertheless, Model 3 exhibited a notable 20% improvement in the RMF compared to the reference model. This finding highlights the substantial role played by the complete shear walls in effectively dispersing seismic energy within the building and improving overall structural resilience.
- Influence of Span Length on the Ductility Reduction Factor: As the span length increased, the ductility reduction factor decreased for both models, one without shear walls and one with partial shear walls. Model 1, without a shear wall, saw a decrease of approximately 20%, while model 2, with a partial shear wall, experienced a decrease of about 18%. The Model 3, Full Shear Wall, demonstrated a significant increase of approximately 17.7%. This suggests that

complete shear walls play a vital role in enhancing ductility and maintaining structural integrity when dealing with larger spans.

Finally, span lengths are an important factor that influences the effectiveness of shear walls in boosting earthquake resistance. In the case of reinforced concrete buildings, the book frequently emphasizes the critical functions that shear walls can perform to increase earthquake resistance. The findings highlight the importance of architectural and structural design in the construction of shear walls to ensure stability and safety during a seismic event.

6.2 Recommendations

The research results and conclusions serve as a basis for developing methods to enhance the seismic resilience of reinforced concrete (RC) buildings.

1. Design Requirement: The mixed concrete building must include full-height shear walls to significantly improve its ability to withstand seismic forces. Position the shear walls near the center to ensure optimal structural stability.

2. Earthquake codes: Building designs must adhere to the most current and up-to-date seismic design principles. ACI 318-14 and ASCE 7-16 outline the design and placement of shear walls. By adhering to these regulations, structures can be designed that will exhibit greater resilience against seismic forces.

3. Additional investigation is necessary to study the seismic response of shear walls with different thicknesses and multiple design configurations. There are numerous avenues for conducting further research on the potential use of new materials and corresponding construction techniques to improve earthquake resistance.

4. In earthquake-prone areas, the construction of new structures with shear walls and the retrofitting of existing ones will largely depend on the strength and endurance of the buildings, as well as other infrastructure facilities. This precautionary step is implemented to mitigate potential harm or structural failure in the event of an earthquake, thereby significantly safeguarding the occupants from such catastrophes.

References

Abidi, M., N, M. M., Abidi, M., Madhuri, M., Review, N., Wall, S., Buildings, S. H., Abidi, M., & N, M. M. (2020). *Review on Shear Wall for Soft Story High-Rise Buildings To cite this version : Review on Shear Wall for Soft Story High-Rise Buildings*. *6*(1), 52–54.

Ahmad, O. (2021). *Evaluation of elastic stiffness factor of 2D reinforced concrete frame system with different parameters*. *2*(2), 26–31.

Ak, E. (2020). *Open ground story in properly designed reinforced concrete frame buildings with shear walls Open Ground Story in Properly Designed Reinforced Concrete Frame Buildings with Shear Walls Adnan Menderes University , Department of Civil Engineering , Aydın , T*. *October*. https://doi.org/10.1016/j.istruc.2019.07.003

Axay Thapa & Sajal Sarkar. (2017). Comparative Study of Multi-Storied RCC Building with and Without Shear Wall. *International Research Journal of Engineering and Technology (IRJET)*, *4*(8), 11–20.

Bhat, E. A. (2020). *Effect of Shear Wall Area on Seismic Behaviour of Multistoried Building with Soft Storey At Ground Floor*. *9*(07), 22–37.

Configuration, B. (2021). *Engineering and Technology Quarterly Reviews Effect of Building Configuration on Overstrength Factor and Ductility Factor*.

Ghoul, S., Ahmed-Chaouch, A., Saidani, M., Taleb, R., & El-Demerdash, W. E. (2024). Seismic Performance of L-Shaped RC Shear Walls of Buildings Subjected to Monotonic Lateral Loading. *International Journal of Civil Engineering*, *22*(1), 125–144. https://doi.org/10.1007/s40999-023-00889-3

Hall, B., Angeles, L., & City, R. (1997). *S r m f*.

Hejazi, F., Jilani, S., Noorzaei, J., Chieng, C. Y., Jaafar, M. S., & Abang Ali, A. A. (2011). Effect of soft story on structural response of high rise buildings. *IOP Conference Series: Materials Science and Engineering*, *17*(1). https://doi.org/10.1088/1757-899X/17/1/012034

Jeong, S., & Elnashai, A. S. (2006). *New Three-Dimensional Damage Index for RC Buildings with Planar Irregularities*. *September*, 1482–1490.

Khelaifia, A., Chebili, R., & Zine, A. (2024). Impact of the position and quantity of shear walls in buildings on the seismic performance. *Asian Journal of Civil Engineering*, *25*(1), 953–964. https://doi.org/10.1007/s42107-023-00824-w

Loads, M. D., & Structures, O. (2017). Minimum design loads and associated criteria for buildings and other structures. In *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*. https://doi.org/10.1061/9780784414248

Mahmoud, S., Genidy, M., & Tahoon, H. (2016). *Time-History Analysis of Reinforced Concrete Frame Buildings with Soft Storeys*. https://doi.org/10.1007/s13369-016-2366-1

Ozkul, T. A., Kurtbeyoglu, A., Borekci, M., Zengin, B., & Kocak, A. (2019). Effect of shear wall on seismic performance of RC frame buildings. *Engineering Failure Analysis*, *100*(February), 60–75. https://doi.org/10.1016/j.engfailanal.2019.02.032

Pavithra, R., & Prakash, T. M. (2018). Study of Behavior of the Soft Stories at Different Locations in the Multi-Story Building. *International Journal of Engineering Research & Technology (IJERT)*, *7*(06), 53–60.

Sarhan, O., & Raslan, M. (2020). *Study of the elastic stiffness factor of steel structures with different lateral load resisting systems*. *1*(2), 6–11.

Shamasti, M. F. (2023). Seismic Analysis Of Soft Storey Frame High Rise Building Using Shear Wall. *Journal of Scientific Research and Technology*, *6*, 24–28.

UBC97-V2 Structural Engineering Design Provisions.pdf. (n.d.).

Appendices

Appendix A- Uniform and concentrated loads from ASCE/SEI 7-16 code

Table 4.3-1. *(Continued)* Minimum Uniformly Distributed Live Loads, L_o, and Minimum Concentrated Live Loads

Occupancy or Use	Uniform, L_o psf (kN/m²)	Live Load Reduction Permitted? (Sec. No.)	Multiple-Story Live Load Reduction Permitted? (Sec. No.)	Concentrated lb (kN)	Also See Section
Penal institutions					
Cell blocks	40 (1.92)	Yes (4.7.2)	Yes (4.7.2)		
Corridors	100 (4.79)	Yes (4.7.2)	Yes (4.7.2)		
Recreational uses					
Bowling alleys, poolrooms, and similar uses	75 (3.59)	No (4.7.5)	No (4.7.5)		
Dance halls and ballrooms	100 (4.79)	No (4.7.5)	No (4.7.5)		
Gymnasiums	100 (4.79)	No (4.7.5)	No (4.7.5)		
Residential					
One- and two-family dwellings					
Uninhabitable attics without storage	10 (0.48)	Yes (4.7.2)	Yes (4.7.2)		4.12.1
Uninhabitable attics with storage	20 (0.96)	Yes (4.7.2)	Yes (4.7.2)		4.12.2
Habitable attics and sleeping areas	30 (1.44)	Yes (4.7.2)	Yes (4.7.2)		
All other areas except stairs	40 (1.92)	Yes (4.7.2)	Yes (4.7.2)		
All other residential occupancies					
Private rooms and corridors serving them	40 (1.92)	Yes (4.7.2)	Yes (4.7.2)		
Public rooms	100 (4.79)	No (4.7.5)	No (4.7.5)		
Corridors serving public rooms	100 (4.79)	Yes (4.7.2)	Yes (4.7.2)		
Roofs					
Ordinary flat, pitched, and curved roofs	20 (0.96)	Yes (4.8.2)	—		4.8.1
Roof areas used for occupants	Same as occupancy served	Yes (4.8.3)	—		
Roof areas used for assembly purposes	100 (4.70)	Yes (4.8.3)			
Vegetative and landscaped roofs					
Roof areas not intended for occupancy	20 (0.96)	Yes (4.8.2)	—		
Roof areas used for assembly purposes	100 (4.70)	Yes (4.8.3)	—		
Roof areas used for other occupancies	Same as occupancy served	Yes (4.8.3)	—		
Awnings and canopies					
Fabric construction supported by a skeleton structure	5 (0.24)	No (4.8.2)	—		
Screen enclosure support frame	5 (0.24) based on the tributary area of the roof supported by the frame member	No (4.8.2)	—	200 (0.89)	
All other construction	20 (0.96)	Yes (4.8.2)	—		4.8.1
Primary roof members, exposed to a work floor					
Single panel point of lower chord of roof trusses or any point along primary structural members supporting roofs over manufacturing, storage warehouses, and repair garages				2,000 (8.90)	
All other primary roof members		—	—	300 (1.33)	
All roof surfaces subject to maintenance workers		—	—	300 (1.33)	
Schools					
Classrooms	40 (1.92)	Yes (4.7.2)	Yes (4.7.2)	1,000 (4.45)	
Corridors above first floor	80 (3.83)	Yes (4.7.2)	Yes (4.7.2)	1,000 (4.45)	
First-floor corridors	100 (4.79)	Yes (4.7.2)	Yes (4.7.2)	1,000 (4.45)	
Scuttles, skylight ribs, and accessible ceilings				200 (0.89)	
Sidewalks, vehicular driveways, and yards subject to trucking	250 (11.97)	No (4.7.3)	Yes (4.7.3)	8,000 (35.60)	4.15
Stairs and exit ways	100 (4.79)	Yes (4.7.2)	Yes (4.7.2)	300 (1.33)	4.16
One- and two-family dwellings only	40 (1.92)	Yes (4.7.2)	Yes (4.7.2)	300 (1.33)	4.16
Storage areas above ceilings	20 (0.96)	Yes (4.7.2)	Yes (4.7.2)		
Storage warehouses (shall be designed for heavier loads if required for anticipated storage)					
Light	125 (6.00)	No (4.7.3)	Yes (4.7.3)		
Heavy	250 (11.97)	No (4.7.3)	Yes (4.7.3)		

Appendix B- Uniform and concentrated loads from UBC-1997 code

TABLE 16-N—STRUCTURAL SYSTEMS[1]

BASIC STRUCTURAL SYSTEM[2]	LATERAL-FORCE-RESISTING SYSTEM DESCRIPTION	R	Ω_o	HEIGHT LIMIT FOR SEISMIC ZONES 3 AND 4 (feet) × 304.8 for mm
1. Bearing wall system	1. Light-framed walls with shear panels			
	a. Wood structural panel walls for structures three stories or less	5.5	2.8	65
	b. All other light-framed walls	4.5	2.8	65
	2. Shear walls			
	a. Concrete	4.5	2.8	160
	b. Masonry	4.5	2.8	160
	3. Light steel-framed bearing walls with tension-only bracing	2.8	2.2	65
	4. Braced frames where bracing carries gravity load			
	a. Steel	4.4	2.2	160
	b. Concrete[3]	2.8	2.2	—
	c. Heavy timber	2.8	2.2	65
2. Building frame system	1. Steel eccentrically braced frame (EBF)	7.0	2.8	240
	2. Light-framed walls with shear panels			
	a. Wood structural panel walls for structures three stories or less	6.5	2.8	65
	b. All other light-framed walls	5.0	2.8	65
	3. Shear walls			
	a. Concrete	5.5	2.8	240
	b. Masonry	5.5	2.8	160
	4. Ordinary braced frames			
	a. Steel	5.6	2.2	160
	b. Concrete[3]	5.6	2.2	—
	c. Heavy timber	5.6	2.2	65
	5. Special concentrically braced frames			
	a. Steel	6.4	2.2	240
3. Moment-resisting frame system	1. Special moment-resisting frame (SMRF)			
	a. Steel	8.5	2.8	N.L.
	b. Concrete[4]	8.5	2.8	N.L.
	2. Masonry moment-resisting wall frame (MMRWF)	6.5	2.8	160
	3. Concrete intermediate moment-resisting frame (IMRF)[5]	5.5	2.8	—
	4. Ordinary moment-resisting frame (OMRF)			
	a. Steel[6]	4.5	2.8	160
	b. Concrete[7]	3.5	2.8	—
	5. Special truss moment frames of steel (STMF)	6.5	2.8	240
4. Dual systems	1. Shear walls			
	a. Concrete with SMRF	8.5	2.8	N.L.
	b. Concrete with steel OMRF	4.2	2.8	160
	c. Concrete with concrete IMRF[5]	6.5	2.8	160
	d. Masonry with SMRF	5.5	2.8	160
	e. Masonry with steel OMRF	4.2	2.8	160
	f. Masonry with concrete IMRF[3]	4.2	2.8	—
	g. Masonry with masonry MMRWF	6.0	2.8	160
	2. Steel EBF			
	a. With steel SMRF	8.5	2.8	N.L.
	b. With steel OMRF	4.2	2.8	160
	3. Ordinary braced frames			
	a. Steel with steel SMRF	6.5	2.8	N.L.
	b. Steel with steel OMRF	4.2	2.8	160
	c. Concrete with concrete SMRF[3]	6.5	2.8	—
	d. Concrete with concrete IMRF[3]	4.2	2.8	—
	4. Special concentrically braced frames			
	a. Steel with steel SMRF	7.5	2.8	N.L.
	b. Steel with steel OMRF	4.2	2.8	160
5. Cantilevered column building systems	1. Cantilevered column elements	2.2	2.0	35[6]
6. Shear wall-frame interaction systems	1. Concrete[8]	5.5	2,8	160
7. Undefined systems	See Sections 1629.6.7 and 1629.9.2	—	—	—

N.L.—no limit

[1]See Section 1630.4 for combination of structural systems.

[2]Basic structural systems are defined in Section 1629.6.

[3]Prohibited in Seismic Zones 3 and 4.

[4]Includes precast concrete conforming to Section 1921.2.7.

[5]Prohibited in Seismic Zones 3 and 4, except as permitted in Section 1634.2.

[6]Ordinary moment-resisting frames in Seismic Zone 1 meeting the requirements of Section 2211.6 may use a R value of 8.

[7] Total height of the building including cantilevered columns.

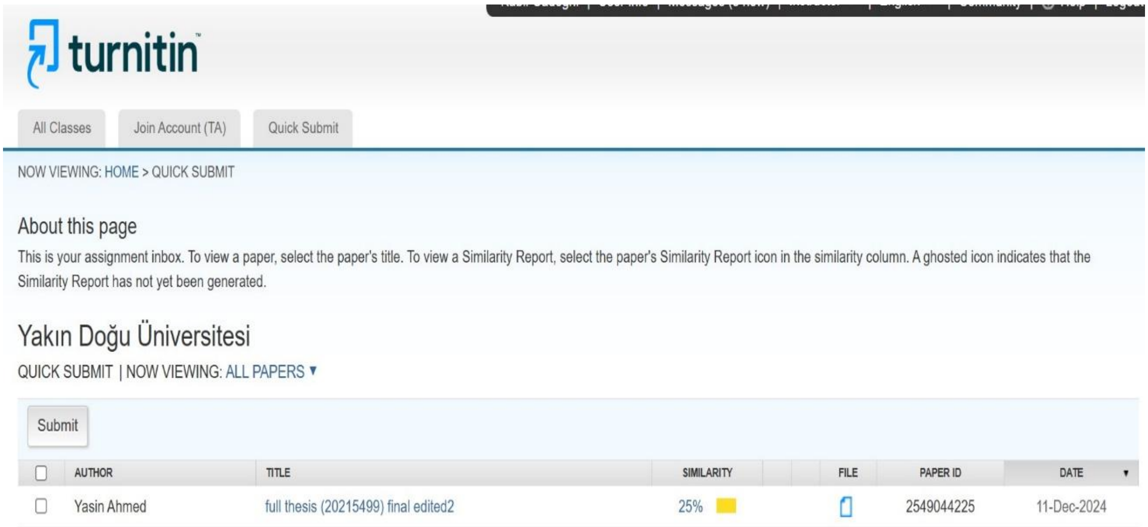
[8]Prohibited in Seismic Zones 2A, 2B, 3 and 4. See Section 1633.2.7.

Appendix C- Risk category of buildings and other structures

TABLE 1604.5
RISK CATEGORY OF BUILDINGS AND OTHER STRUCTURES

RISK CATEGORY	NATURE OF OCCUPANCY
I	Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to: • Agricultural facilities. • Certain temporary facilities. • Minor storage facilities.
II	Buildings and other structures except those listed in Risk Categories I, III and IV
III	Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to: • Buildings and other structures whose primary occupancy is public assembly with an occupant load greater than 300. • Buildings and other structures containing elementary school, secondary school or day care facilities with an occupa load greater than 250. • Buildings and other structures containing adult education facilities, such as colleges and universities, with an occupant load greater than 500. • Group I-2 occupancies with an occupant load of 50 or more resident care recipients but not having surgery or emergency treatment facilities. • Group I-3 occupancies. • Any other occupancy with an occupant load greater than 5,000[a]. • Power-generating stations, water treatment facilities for potable water, waste water treatment facilities and other public utility facilities not included in Risk Category IV. • Buildings and other structures not included in Risk Category IV containing quantities of toxic or explosive materials that: Exceed maximum allowable quantities per control area as given in Table 307.1(1) or 307.1(2) or per outdoor control area in accordance with the *International Fire Code*; and Are sufficient to pose a threat to the public if released [b].
IV	Buildings and other structures designated as essential facilities, including but not limited to: • Group I-2 occupancies having surgery or emergency treatment facilities. • Fire, rescue, ambulance and police stations and emergency vehicle garages. • Designated earthquake, hurricane or other emergency shelters. • Designated emergency preparedness, communications and operations centers and other facilities required for emergency response. • Power-generating stations and other public utility facilities required as emergency backup facilities for Risk Category IV structures. • Buildings and other structures containing quantities of highly toxic materials that: Exceed maximum allowable quantities per control area as given in Table 307.1(2) or per outdoor control area in accordance with the *International Fire Code*; and Are sufficient to pose a threat to the public if released [b]. • Aviation control towers, air traffic control centers and emergency aircraft hangars. • Buildings and other structures having critical national defense functions. • Water storage facilities and pump structures required to maintain water pressure for fire suppression.

Appendix D-Turnitin similarity report



Appendix E- Ethical certificate

YAKIN DOĞU ÜNİVERSİTESİ

NEAR EAST UNIVERSITY

February 2, 2024,

Nicosia

ETHICS EVALUATION

Dear AHMED ADEN YASIN

Your application titled "The impact of shear walls on seismic performances and soft story behavior in reinforced concrete buildings" has been evaluated as a secondary category. You can start your research on the conditions that you will abide by the information provided in your application.

This evaluation has been done by me because you do have not to use a questionnaire and no need for data collection from the people, and your work will be based on analytical calculations and the application of the software.

Sincerely yours

Prof. Dr. Kabir Sadeghi

Prof. Kabir Sadeghi, Ph.D., P.E.

Head of Civil Engineering Department-Postgraduate Program

Institute of Graduate Studies/Faculty of Civil and Environmental Engineering

Near East University, Near East Boulevard, ZIP: 99138, Nicosia/TRNC, Mersin 10 - Turkey