NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF CIVIL ENGINEERING

THE EFFECT OF SHEAR WALL THICKNESSES ON THE SEISMIC PERFORMANCES OF REINFORCED CONCRETE FRAME SYSTEMS

MSc. THESIS

JACQUES MULONDWA FATAKI

Nicosia

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MASTER THESIS

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Approval

We certify that we have read the thesis submitted by Jacques Mulondwa Fataki titled "The Effect of Shear Wall Thicknesses on the Seismic Performances of Reinforced Concrete Frame Systems" and that in our combined opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Educational Sciences.

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Declaration

I hereby declare that all information in this document has been obtained and presented according to the academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Jacques Mulondwa Fataki
22/06/2023

Acknowledgments

Foremost, I would like to thank God for helping me to succeed in all evaluations and difficulties I passed through. Secondly, I would like to thank my parents who supported, believed, and encouraged me during my studies.

I would like to express my sincere acknowledgments to my supervisor Prof. Dr. Kabir Sadeghi for the knowledge I got from him, the trust he has put in me during my master’s studies, and his assistance during this thesis work. Further, I would like also to thank all the members of the civil engineering department at Near East University, especially Assoc. Prof. Dr. Rifat Reşatoğlu, and Assoc. Prof. Dr. Fatemeh Nouban. Finally, my thanks go to all my classmates and friend for their support during the research.

Jacques Mulondwa Fataki

Abstract

The Effect of Shear Wall Thicknesses on the Seismic Performances of Reinforced Concrete Frame Systems

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June 2023, 70 pages

An earthquake is a rapid release of energy through the ground, and disasters are enormous. Therefore, buildings need to be designed in order to withstand these loads. Shear walls (SW) are among the best structural elements that provide sufficient lateral resistance force against lateral loads. Structures provided with shear walls have been found to be more resistant to the effect of earthquakes compare to those without shear walls or those with bracing systems. However, the focus study on the shear wall thickness's impact on the seismic parameters has not deeper evaluated throughout the literature. In this manner, an assessment of shear wall thickness on the elastic stiffness factor (ESF), the ductility reduction factor (R_u), and the response modification factor (RMF) are going to be done in this study considering some variations in the building geometry. Reinforced concrete (RC) buildings with low-, mid-, and high-rise are modeled by using Etabs software and designed according to the ACI-318-14 code. Various span lengths, number of stories, and two (2) concrete's compressive strengths f_c' have been considered in this study. Additionally, the non-linear static analysis also known as the Pushover analysis is conducted on 96 three-dimensional models to determine the seismic parameters. Further, a discussion is done on the findings and a comparison is made to the values found in the literature and those suggested by the Uniform Building (UBC) Code 1997. Overall, it has been noticed a positive contribution in the increase of shear wall thicknesses on the seismic parameters assessed.

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

Ozet

Perde Kalınlıklarının Betonarme Çerçeve Sistemlerin Sismik Performanslarına Etkisi

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Haziran 2023, 70 sayfa

Deprem, yerden hızlı bir enerji salınımıdır ve felaketler çok büyüktür. Dolayısıyla binaların bu yüklere dayanacak şekilde tasarlanması gerekmektedir. Perde duvarlar, yanal yüklere karşı yeterli yanal dayanım kuvveti sağlayan en iyi yapı elemanları arasındadır. Perde duvarlı yapıların, perdesiz veya çapraz sistemli yapılara göre deprem etkisine karşı daha dayanıklı olduğu görülmüştür. Bununla birlikte, perde duvar kalınlığının sismik parametreler üzerindeki etkisine yönelik odak çalışması, literatür boyunca derinlemesine değerlendirilmemiştir. Bu şekilde, bu çalışmada, bina geometrisindeki bazı değişimler dikkate alınarak, elastik rijitlik faktörü (ESF), süneklik azaltma faktörü ve davranış değiştirme faktörü (RMF) üzerinde perde duvar kalınlığının bir değerlendirmesi yapılacaktır. Az katlı, orta katlı ve yüksek katlı betonarme (BS) binalar Etabs ortalamasıyla modellenmiş ve ACI-318-14 koduna göre tasarlanmıştır. Bu çalışmada farklı açıklık uzunlukları, kat sayısı ve betonun iki basınç dayanımı dikkate alınmıştır. Ayrıca, sismik parametreleri belirlemek için 96 adet üç boyutlu model üzerinde doğrusal olmayan statik (itme) analizi yapılmıştır. Ayrıca bulgular üzerinde bir tartışma yapılmış ve literatürde bulunan değerler ile 1997 Tekdüzen Bina (UBC) Kodu tarafından önerilen değerlerle bir karşılaştırma yapılmıştır. Genel olarak, kesme kuvveti artışında olumlu bir katkı olduğu fark edilmiştir duvar kalınlıkları üzerinde sismik parametreler değerlendirildi.

Anahtar Kelimeler: perde duvar, elastik rijitlik faktörü, süneklik, davranış değiştirme faktörü, betonarme, itme analizi.

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List of Abbreviations

ACI: American Concrete Institute

ASCE: American Society of Civil Engineering

ESF: Elastic Stiffness Factor

Rμ: ductility reduction factor

RC: Reinforced concrete

RMF: Response Modification Factor

SW: Shear Wall

UBC: Uniform Building Code

CHAPTER 1
Introduction

1.1 General

Years ago, in Nepal (Katmandou-2005), chili(bio-bio-2010), Haiti-2010, Japan (Kobe-1995, Tohoku-2011), Indonesia (Sumatra-2004), China (Shaanxi-1556) and so many other seismic events have cost loss of life of people and also several damages of structures have been observed. Seismic activity continues to occur throughout the world. Following these tragic experiences, the building must be designed to be resistant to the effects brought on by earthquake excitation (Mallesh et al, 2019). Turkey is one of the most countries affected by earthquakes overall in the world (Okzul et al, 2019). Several seismic activities have hit the county (Erzincan in 1992, Kocaeli and Ducze in 1999, Bingol in 2003, and Van Earthquakes in 2011). Additionally, the last devastating earthquake which occurred in February 2023 with a magnitude of 7.8 causing building collapse and loss of life. At the end of the day, it was observed that many buildings that have not collapsed during the main earthquake. They collapsed because of the aftershocks. Along the same line, the main shock is found to provide a higher significance of damage accumulation effect for irregular structures when compared to the regular structure (R. Oyguc et al, 2018). From these tragic events, structures must be revised in the way they are designed for carrying lateral loads such as wind loads and earthquake loads. However, the moment-resisting frame itself is not providing suitable and sufficient stiffness to the structure. Therefore, shear walls and bracing systems are provided in the buildings to increase their lateral stiffness (F. Aliakbari & H. Shariatmadar, 2019).

Shear walls have been found to provide poor performance when they are very tall before improvement in material modeling and computer allowed to model and test the large size of shear walls (Rasoolinejad and Bažant, 2019). In addition, it was discovered that to guarantee the shear wall's capacity to withstand seismic loads, the low RC SW needs have adequate lateral reinforcement (Miao et al, 2022).

High-rise lateral loadings often refer to wind and seismic loadings. On the one hand, from the standpoint of structural engineering, wind loading often becomes dominant as building height increases. However, many communities have increased the degree of their seismic fortification to reduce the possibility of a loss of life and property after an earthquake (Zhen Wang et al, 2020).

Due to the fast population expansion, the expensive price of land, and the space constraints in metropolises, the demand for high-rise structures are continuously growing. As a building's height rises, horizontal forces brought on by earthquake and wind loads take precedence. Raising the structure's stiffness or expanding the building's capacity to resist lateral loads to endure lateral loads brought on by seismic loads and wind loads. The rigidity, resilience, and weight distribution of the construction at the time of an earthquake are the main factors that determine how it will behave. Building components such as shear walls and steel braces are used to reduce the impact of seismic loads (Amru and Dhyani, 2018).

The characteristics of seismic shear walls influence the reaction of structures, consequently, it is critical to evaluate the seismic endurance of the SW effectively (Akansha & Tyagi, 2020). Due to their excellent performance in resisting earthquake loads, RC SWs are most frequently used in RC structures, whereas steel braces are frequently used in steel buildings because they are particularly effective and efficient ways to support horizontal loads in a frame construction. (Amru and Dhyani, 2018).

Shear walls in structures are often symmetrical to reduce the damaging consequences of twists. A shear wall (SW) is one of the common structural elements used to carry lateral loads such as wind force and earthquake forces. They offer great strength and stiffness because of their rigidity, bearing capacity, and high ductility, allowing them to withstand significant horizontal loads, and therefore enabling them to be utilized in many instances in structural engineering. Openings in shear walls may be necessary due to municipal or renovation concerns, comparable to elevators, windows, doors, and staircase positioning (Saeed et al, 2022).

Much earlier research focused on the comparison between the shear wall and other lateral load-resisting systems like bracing, while in this study, a focus is taken to the shear wall itself considering its thickness. Dampers are as well used to carry lateral loads in a building. When the reaction is primarily influenced by resonance, the addition of passive dampers is completely appropriate (Mohamed et al, 2018). Because of their significant lateral stiffness and strength, RC SWs are commonly utilized in structures to withstand horizontal forces and successfully limit the structure's sideways movements. For structures to effectively increase their seismic resilience, shear walls must be planned and constructed with the necessary rigidity, strength, and distortion tolerance. They are generally built so that If they are exposed to powerful earthquakes, they will experience ductile flexural damage. (Wei et al, 2021). Steel plate shear walls have been created in a variety of ways to meet the demands of architectural and structural purposes owing to their benefits in terms of lighter weight, increased initial stiffness, improved deformation performance, and quicker construction (Jiang et al, 2022).

Response modification factor (R-factor) is a crucial component in the seismic analysis of buildings, furthermore, it indicates the structure’s ability to release energy through the inelastic behavior. This decrease increases the structure's capacity to disperse and absorb energy, and seismic codes depend on reserve strength and ductility to justify it (Nasr et al, 2021). This parameter has been studied by many researchers, and as the code and literature state, in line with the IBC (2000), R-factor should be used to assess the design of structures with lower seismic forces, and the deflection amplification factor (Cd) should be used to transform elastic sideways movements into total sideways movements. Additionally, according to NEHRP (2000), The R factor is suggested to explain the ductility R_u, the overstrength Ω, and the energy release through the mechanism of soil foundation (Abdi et al., 2019).

Using an inelastic energy dissipation system, a slew of structural and non-structural flaws may be analyzed to effectively reach a structural design that prioritizes safety to a great degree. Most seismic regulations recommend that structures have high levels of extra strength (overstrength) and dispersion of energy ability (ductility R_μ), which permits a reduction in design loads. RMF incorporates these aspects into the structural design (Kim and Choi, 2005). Therefore, through this study, these seismic parameters are going to be assessed according to different shear wall thicknesses. Additionally, discussions according to the code and literature are going to be made.

1.2 Problem Statement

The use of a shear wall as a structural element to withstand lateral loads is common in many buildings. However, the effect of variation in its thickness is not deeper investigated. Therefore, seismic performances of 3D reinforced concrete frames strengthened with shear walls having different thicknesses and considering variations in span length and story numbers are investigated. This thesis considers the concrete's two compressive strengths as well as the steel reinforcing bars' one yield strength.

1.3 Objective and Scope

Through a nonlinear static analysis to be conducted, seismic parameters such as the elastic stiffness factor, the ductility reduction factor (R_μ), and the R-factor of 3D reinforced concrete models are going to be assessed by variating the thicknesses of the shear wall. In addition, span length and story height (low-, medium-, and high-rise). This study is done by the mean of the commercial software Etabs.

1.4 Hypothesis

To reach the goal of this thesis, frames considered for RC are 3D frames. The number of spans (5), and the height of the stories (3.4 m) are going to be considered as mentioned. The two compressive strengths of concrete considered are 25 MPa and 30 MPa. Furthermore, the yield strength of the reinforcing steel bars considered is 420 MPa.

The shear wall thicknesses for the assessment are 25 cm, 30 cm, and 35 cm.

Three numbers of stories are considered for the investigation, 5 for the low-rise, 10 for the middle-rise, and 15 for the high-rise building.

The study and method applied are done using the software ETABS.

1.5 Significance of the Study

The study seeks to assess the impact of increasing the thicknesses of a SW in a building as a lateral load-resisting element. And to make the study more reasonable, 3D RC structures are going to be modeled. In addition, as long as there are factors that influence the behavior of a building during a seismic event, the variation in span length and the number of stories will be taken into account. Finally, to help understand deeper the seismic behaviors of buildings, the following parameters are going to be the object of the research: the elastic stiffness factor, the ductility reduction factor (R_μ), and the R-factor.

1.6 Organization of the Thesis

This present thesis study is broken down into six (6) main chapters.

- The first chapter offers a quick introduction related to this study, objectives of this study, and importance of this study, and the description of parameters that are going to be investigated in this study;
- chapter 2 presents earlier findings about this study, referred to as the literature review;
- chapter 3 gives the methodology used to reach the goal of this study, the formulations, methods, and code to be applied;
- chapter 4 provides outcomes and discussion; and the last chapter,
- chapter 5 presents a discussion between the main findings in this study and those in the literature.
- Chapter 6 concludes with recommendations.

CHAPTER 2

Literature review

2.1 General

This chapters eeks to provide past research and work done related to this study. The research mentioned down here explained finding about the use of the shear walls as lateral load-resisting systems, and others compare the shear wall with bracings in various situations, for both RC and steel structures.

2.2 Shear wall

An analysis was carried out by Shaligram and Parikh (2018) to ascertain which systems in high-rise structures will withstand earthquake and wind effects. According to the literature research they utilized, it is advised to utilize steel bracing for structures with 10- to 20-story since shear walls are quite heavy and are not economically advantageous for structures with fewer than fifteen-story. As a result, shear walls may be employed in structures of 20- to 35-story. The adoption of a diagrid system would also be the most practical and cost-effective for structures with more than 35-story, at which point it is regarded as the most ideal for resisting lateral stress.

To determine the impact of shear walls on composite structures and reinforced cement concrete under an earthquake load in zone IV, (Dwivedi and Tyagi, 2020) analyzed buildings with and without SWs. Using the ETABS 17 program, four distinct models were created: an RCC structure without a shear wall, an RCC structure with a shear wall, a structure with composite columns and a shear wall, and a composite column structure without a shear wall. Story displacement, story drift, stiffness, lateral force, and base shear were all factors considered for the G+19 structures that were the subject of the study. The results indicated that shear walls enhance the rigidity of structures and those composite columns are more effective for all 20-story buildings. As a result, it may be argued that composite column buildings with shear walls resist seismic force better than other varieties. Furthermore, compared to structures with RCC columns, the drift is more significantly decreased, down to 25%. Shear walls also had the effect of reducing displacement, which at the top was decreased by around 40%.

A study is carried out (Saeed et al, 2022) to determine a seismic parameter for G+13-story with and without the shear walls. Openings have been considered on the shear walls as well. And it has been concluded that a system with a shear wall presents less displacement than a system without a shear wall. In the aftermath of that, the result about the effect of opening concluded that the opening type (regular or staggered) has a slight impact on the behaviors of the shear walls.

Okzul et al, (2019) have studied the damage distribution using shear walls on two buildings, located in Turkey, which have been damaged because of the event of the *Van 2011 earthquake* that hit the country. Several damages have been recorded from this event. To reach the goal of their study, SAP2000 software was used for modeling frames and the Turkish seismic code 2007 for designing structures' components and shear walls. Applying the nonlinear time history analysis, It was found that shear walls enhance building performance and have a substantial impact on the seismic performance of RC buildings.

Miao et al, (2022) studied the effect of the two important parameters that need to be evaluated when using shear walls as a lateral load-resisting element, and these two parameters are the shear-span ratio and vertical reinforcement ratio. To guarantee the best performance of the shear wall during seismic activities, factors like shear span ratio, axial compression ratio, width-to-thickness ratio, boundary componante, lateral reinforcement ratio, and vertical reinforcement ratio have to be evaluated. Therefore, in this study, the output showed that as the shear span ratio increases, the failure mechanism of SW shifts from shear to bending. In addition, as the shear span ratio increases, the shear capacity of the SW drops and ductility improves, resulting in a diminution of the size effect. The SW's shear capacity is slightly increased by raising the vertical reinforcement ratio, although this has little effect on ductility and the size effect.

Resatoglu & Shahram (2022) assessed the shear wall thickness effect on the ductility values for RC structures. Using SAP2000, 2D models have been modeled, and static non-linear analysis has been applied to reach the goal of the study. It is found that ductility coefficients drop as shear wall thickness increases. In addition to that, a reduction in ductility coefficients also occurs when the SW's location shifts from edge to middle.

Thakre et al., (2020) evaluated the effect of opening in SW areas in a high-rise building. The opening in the shear wall is aimed for architectural purposes on one hand and for structural engineering purposes on the other hand. RC Being a costly material, a reduction in area for RC shear walls may be advantageous to make an economic structure. The finding in this study was that the rigidity of the structure will be reduced and the structural elements will collapse if the opening is used excessively beyond a 20% limit.

Feng Wei et al, (2021) focused on the ratio’s shear span of SWs, being one of the key factors to consider for shear walls that affect the seismic behavior of a structure. Models of shear walls with a shear span ratio of 0.5, 0.75, and 1.0 have been fabricated after that suggested to a horizontal low-cycle repeated load. And it has been concluded that the amount of shear distortion during the ultimate specimens’ failure rapidly dropped as the SSR went from 0.5 to 1.0, and the failure mechanism switched from shear failure to shear-bending failure.

2.1.Response modification factor

S Sharifi and Toopchi Nezhad. (2018) evaluated the Seismic RMF of RC-frame structures. The frames particularly assessed in the study were the special reinforced concrete and ordinary frames. In addition, the limit state design method has been used. The values obtained were compared to those prescribed in other codes. It was noticed that the story’s and bay’s number have an effect on the R-factor, as well as the displacement value prescribed by the user, as long the static nonlinear pushover analysis is carried out. The maximum lateral displacement applied on the structure during the pushover analysis was 2% of the height of the structure, as prescribed by Standard 2800-91. The number of bays did not impact the R-factor, while for the structure with the lowest number of stories, larger R-factor values were observed. Additionally, it was concluded that the non-linear analysis should be carried out to evaluate the R-factor to be assigned to a building. And considering ordinary and special RC structures in this study, the R-factors were observed to be around 3 and 7 respectively.

To evaluate the seismic RMF, the overstrength, and the ductility of steel slit panel frames, Aliakbari and Shariatmadar (2019) applied the nonlinear pushover analysis, the linear dynamic analysis, and the nonlinear incremental dynamic analysis. Using the Abaqus software to perform the analyses, different story heights of structures with a span length of 5m have been modeled and the design has been performed in line with the Iranian Earthquake Code and Iranian National Standard. Results showed that the R-factor obtained from the pushover analysis was slightly smaller than the one obtained from the nonlinear incremental dynamic analysis. For the overstrength factor, it was observed that it decreases up to 6-story and then remains constant when the number of stories is increasing. While for the RMF, the value is decreasing as well as the story number is increasing.

The RMF and the displacement amplification factor are among the principal elements to assess in a seismic design, Shen Li et al, 2022 analyzed the K-shaped eccentrically braced high-strength steel frames to evaluate them. Applying the pushover analysis and an increment dynamic analysis (IDA), the R-factor and the displacement amplification factor (Cd) were found. The different number of stories and the link length were designed. Models considered were designed through the performance-based seismic design method, by which the target drift and the expected mode of failure are first determined.

Nasr et al, 2022 studied the impact of openings in shear walls on the response modification factor by considering the height and width of shear walls, and by applying the pushover analysis through the commercial software Etabs. After reviewing the literature on this topic, a numerical study is then conducted on two buildings of 8- and 16-story. The main finding of this study was that by increasing the opening area, the R-factor was decreasing as well. And this effect is due majorly to the height of the opening. As well as the stories' number are increasing, the percentage of reduced R-factor values is increasing though. Therefore, opening in the shear wall need to be placed in areas where its impact on the overall structure resistance will be maintained safely.

The impact of change in the thicknesses of shear walls to assess the story drift, the story shear, and the deflection of G+24-story building in a seismic zone III has been monitored using SAP2000 and Etabs software. To reach the goal of the study, the location of shear walls has been taken fixed for all models. At the corner and in the middle of the structure, the shear walls have been placed to do the study. For every five-story, the thickness was changing, until the total number of stories was reached. It was found that shear walls placed at the corner reduce the displacement and the lateral drift due to the earthquake excitation. Furthermore, the increase in thickness rises the rigidity of the building, while the increase in height will decrease the deflection (Shinde and Raut, 2016).

Studies carried out to assess the RMF for steel structures on the one hand and for RC structures on the other hand with dampers devices have been presented respectively by (Abdi et al, 2015) and (Keykhosravi and Aghayari, 2017). building dampers by partially absorbing and dissipating input energy, structural reaction is reduced. For both studies, the nonlinear statical analysis was performed and results showed that structures equipped with dampers provided higher values of RMF compared to the structures without dampers devices.

2.3 Ductility reduction factor and overstrength factor

The ductility reduction factor (R_μ) and the overstrength factor (Rs) are important factors to assess in a seismic study, and they are used to calculate the RMF which is used in the design for an economic design purpose. Calculating the R_μ factor involves dividing the base shear at the elastic design level by the yield strength level. While the base shear at the yield level to the base shear at the first major yield level is how the R_S factor is determined (Bohara, 2022).

Structural overstrength (Rs) is caused by the approximations of the design, the overstrength of the material, and lateral load system redundancies. It was found that the quantity of perimeter reinforcement and axial load impact the displacement ductility and overstrength factor. The influence of the other characteristics (ratio of the wall aspect, the wall thickness, and the ratio of the horizontal steel) was shown to be negligible. This study done to investigate the ductility and overstrength took into consideration a shape-memory-alloy RC SWs as it was discovered that they reduced seismic residual deformations while rising the seismic inelastic deformations (Abraik and Youssef, 2021).

A staggered wall providing the advantage of allowing wider open space was studied to evaluate its seismic behavior factors. Through this study, the overstrength, the R_μ, and the R-factor have been evaluated. To this end, variation in the number of stories has been considered, and the non-linear static analysis, as well as the dynamic analysis, were carried out. It was found that the buildings constructed with medium-level seismic force showed out to have lesser overstrength factors than those planned with the low-level seismic load. On the other hand, the ductility factors appeared to be uniform regardless of the height of the model structures. Furthermore, the response modification factor is going to reduce as the stories' number is increasing (Kim et al., 2016).

2.4 Elastic stiffness factor

(Krekar, 2018) evaluated the effect of providing a lateral load-resisting system into 2D steel frame systems on the ESF. different bracing systems and shear walls have been utilized during the study, and it was found that among all bracing types, the X-bracings were increasing the rigidity of the structure. Additionally, the shear walls are stiffer than other bracing types utilized. According to the parameter considered, the story height, the span length and the number of spans impact the stiffness of the structure. While in the other hand, the time period has been assessed as well, and providing a lateral load-resisting system is decreasing its value. Which is better for a structure when experiencing an earthquake.

Similarly, to the previous study cited above, by applying the pushover analysis on 12 two-dimensional RC frames, the ESF is investigated by Ahmad (2021). To avoid the formation of plastic hinges, non-linear analysis is carried out, so that the behavior of the structure in the inelastic range can be assessed. Results showed the positive contribution of the shear walls to the ESF of the buildings. Additionally, parameters like story height and span length have an impact on this value.

CHAPTER 3
Methodology

3.1 Introduction

The building models are described in this chapter in terms of their dimensions, sections, and material properties. The second part of this chapter will focus on the explanation of the seismic method used in this study, and the parameters assessed. In total, 96 3D models have been modeled using ETABS software considering different thicknesses of shear walls to assess the response modification factor (RMF), ductility reduction factor (Rμ), and elastic stiffness factor (K). Variations in span length and the number of stories. ACI 318-14 and ASCE 7-10 codes were used for the design and analysis.

3.2 Model and Geometry

All buildings designed were 3D models, with five-story, ten-story, and fifteen-story. Using the grid model for modeling in the ETABS software, 5 spans in both directions X and Y, having 5.0 m, 5.5 m, 6.0 m, 6.5 m, and 7.0 m. The story height is 3.4 m.

3.3 Section (frames, shear wall)

Depending on the specific type of section, different models are used for the various sections. Beams and columns are modeled as frames, and Cross-sectional sizes, reinforcing information, and material type are the attributes that need to be assigned. The beams-columns' connection are assumed to be rigid. Although the slabs are modeled as shells, and shear walls as layered/nonlinear shell sections. The shear wall is made up of different layers having different thicknesses. The beams and columns are modeled as frames. The first floor's structural components are all fixed.

Table 1

Sections and thicknesses of beams, slabs, and shear walls

Elements	Section and thickness
Beam	30 cm × 50 cm
Slab	18 cm
Shear wall	25 cm
	30 cm
	35 cm

Table 2

Sections of columns

Number of Stories	Story level	sections
5-story	1-5	35cm×35cm
10-story	1-5	55cm×55cm
	6-10	35cm×35cm
15-story	1-5	75cm×75cm
	6-10	55cm×55cm
	10-15	35cm×35cm

3.4 Buildings description

In this study, three numbers of stories buildings have been considered. Each story's height is 3.4 m and the number of spans is equal to five. The span lengths considered were 5 m, 5.5 m, 6 m, 6.5 m, and 7 m. The position of the shear walls is fixed, they have been placed in the middle.

Figure 1

Floor plan for 5 m span length building

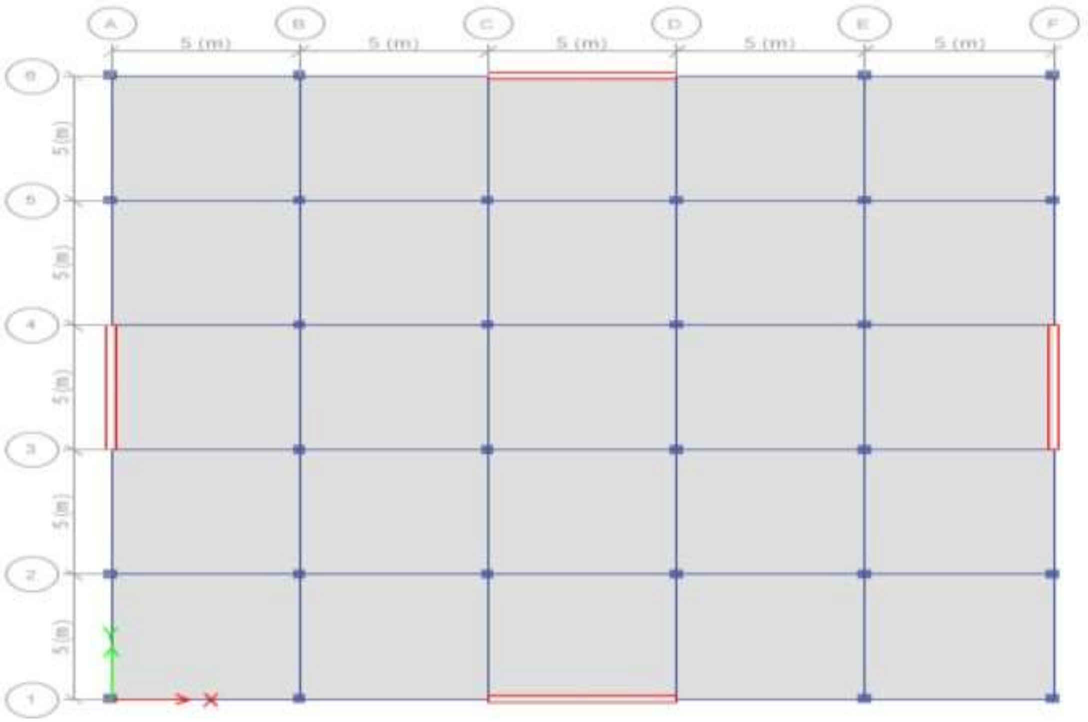


Figure 2

Three-dimensional perceptive of 5-story building

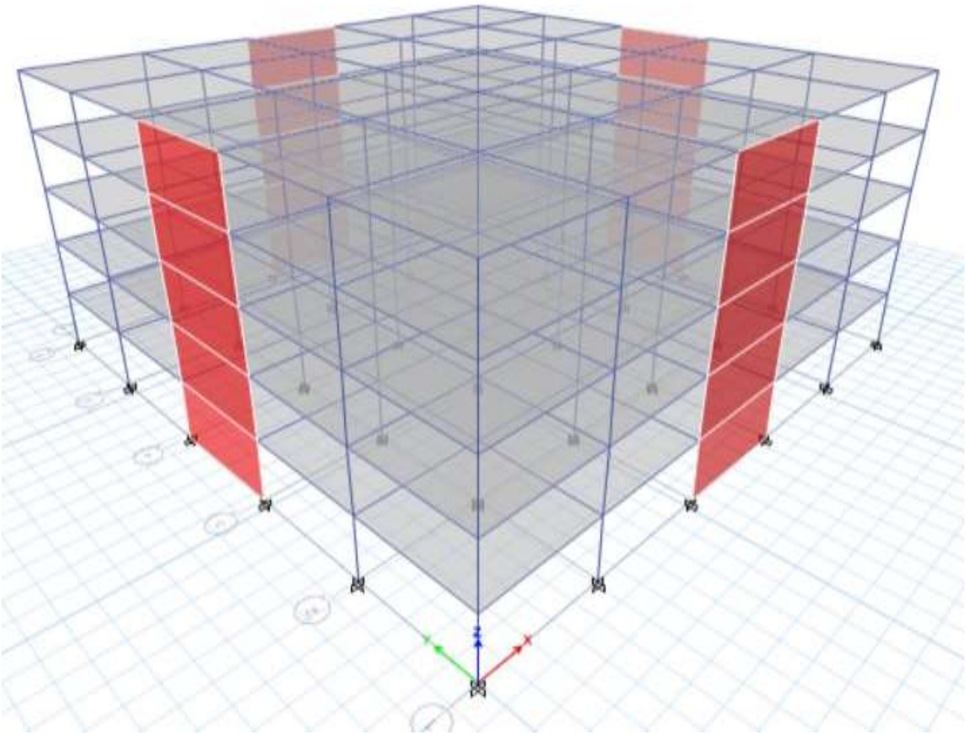


Figure 3

Three-dimensional perceptive of 10-story building

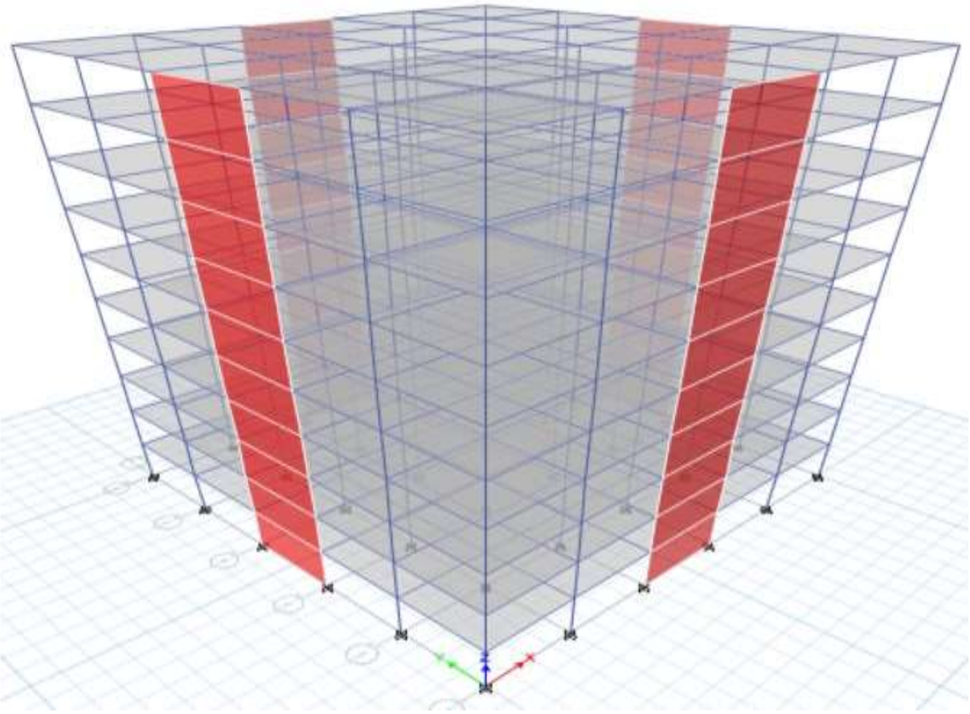


Figure 4

Three-dimensional perceptive of 15-story building

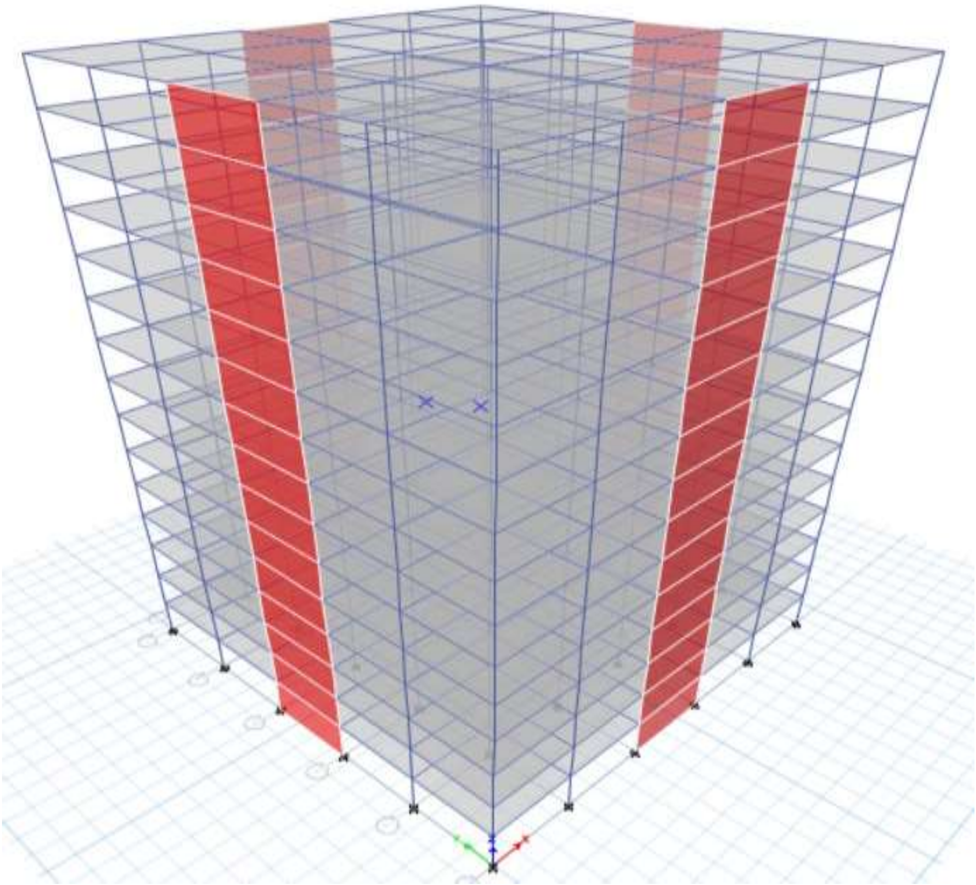


Figure 5

Two-dimensional perceptive of 5-story building

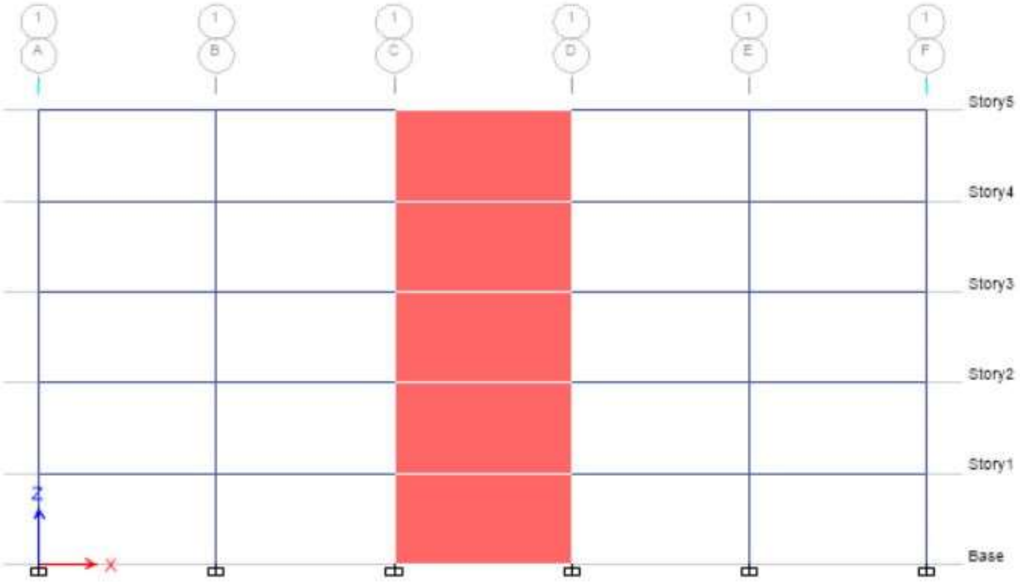


Figure 6

Two-dimensional perceptive of 10-story building

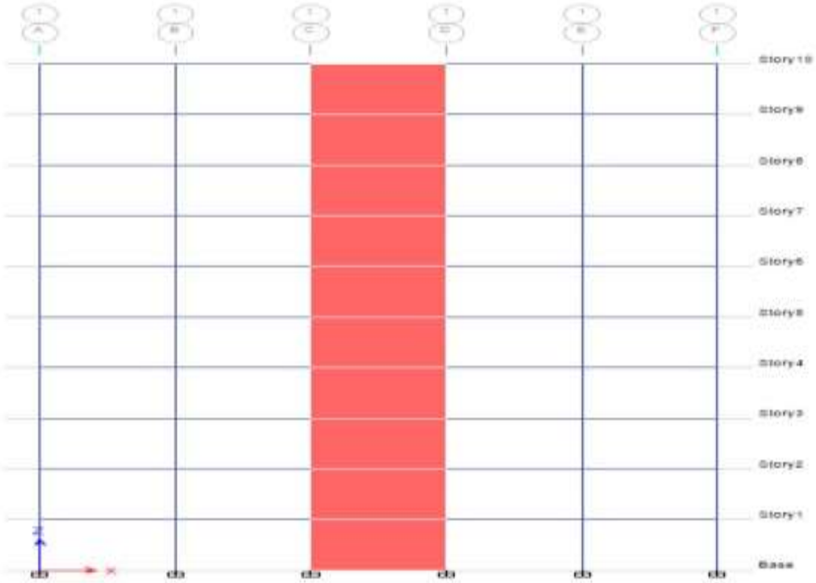
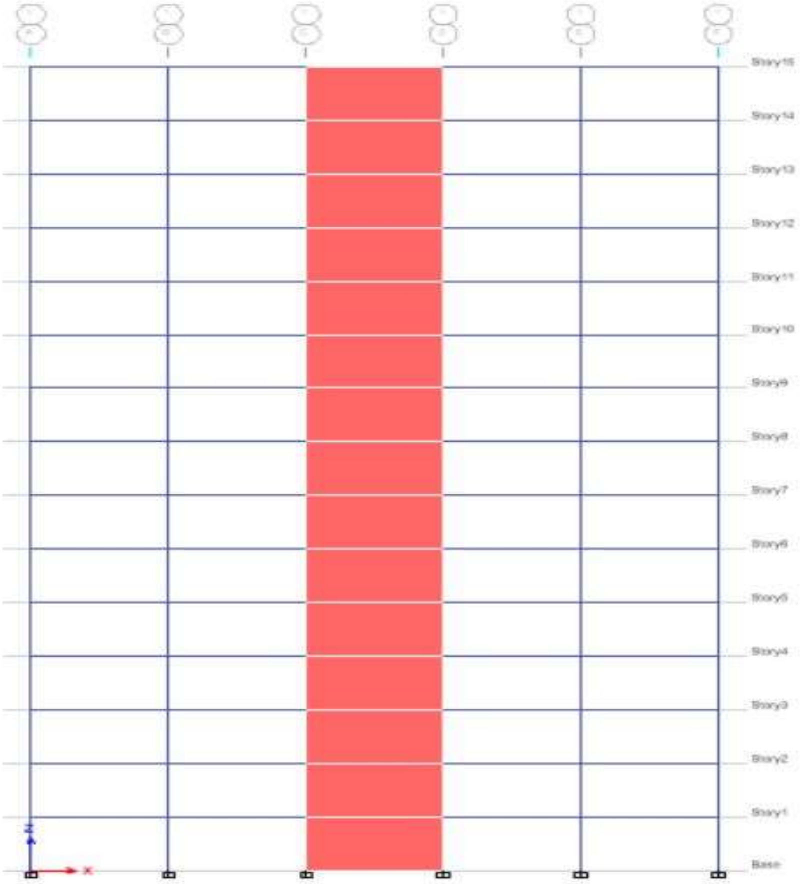


Figure 7

Two-dimensional perceptive of 15-story building



3.5 Loads

The loads applied to frames and slabs were chosen according to the UBC-1997. All models being residential, the applied loads are discussed in the sub-sections below.

3.5.1 Dead load

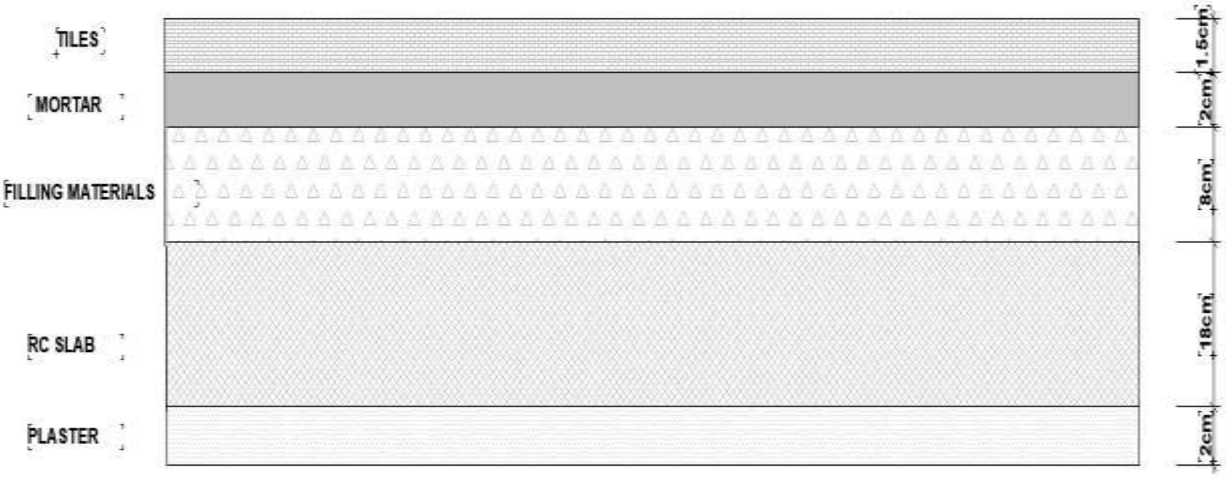
It has been assigned to the software Etabs to consider the self-weight (dead load) of structural members. An additional dead load of 11 kN/m, for wall load, was assigned to the beams.

3.5.2 Super dead load

The super dead load is the load that does not include the self-weight of the structural element as shown in Figure 8. It has been considered in this study SDL for the current floor slab and the roof slab equal to 2.6 kN/m^2 and 3.45 kN/m^2.

Figure 8

Cross-section of ceiling composition



3.5.3 Live load

The live loads have been assigned to slabs. The current floor slab and the roof slab's live loads applied have a magnitude of 2 kN/m^2 and 3 kN/m^2 respectively, according to UBC-1997, Table 16.A (Appendix A)

3.5.4 Lateral loads

The lateral loads imposed to the models were the wind load and the earthquake load. According to the IBC-2012 in section 1609, buildings and structures shall be designed to wisthand the minimum wind load. In addition, the type of opening protection necessary, the ultimate design wind speed, and the exposure category for a location is permitted to be determined by this section. The wind load direction is assumed to be a horizontal direction, and it shall be assumed to act normally to the surface. Thereby, with a basic wind speed of V=125 km/h, an equivalent load of 1 kN/m^2 is obtained.

The earthquake load in both X and Y directions has been assigned as acceleration type until the target displacement is reached, as per IS-code:1983-2002. And depending on the ground motion, the seismic design category (SDC) for the structure is permitted to be determined by IBC-2012, section 1613.

3.6 Materials (concrete, steel reinforcement)

Concrete and reinforcement bars properties are chosen from the ACI code database integrated into the software. The compressive strengths of concrete considered were 25 MPa and 30 MPa. While for the steel reinforcing bars, the yield strengths were considered to be 420 MPa (Table 3)

Table 3

Materials properties

Materials properties	Values
F_y of steel reinforcing bars	420 MPa
Compressive strength of concrete (f_c')	25 MPa and 30 MPa
Concrete’s modulus of elasticity (E_c)	23,500 MPa and 25,742.96 MPa
Steel’s modulus of elasticity (E_s)	200,000 MPa
Unit weight of concrete	25 kN/m^3

3.7 Non-linear properties

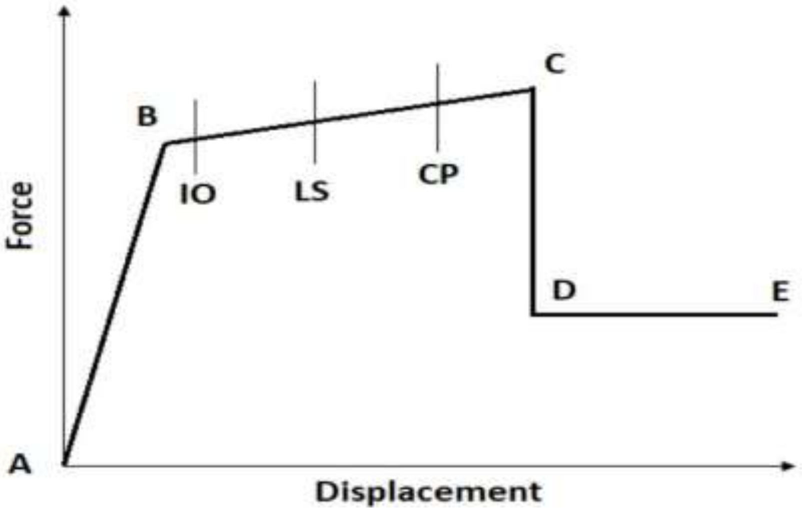
3.7.1 Plastic hinge

As the buildings are subjected to undergo lateral forces and the non-linear analysis is to be performed, the components responsible to carry lateral forces should be designed in a nonlinearity manner. Therefore, plastic hinges are assigned to members. The definition of the plastic hinges varies according on the type of section.

A plastic deformation curve is created while defining hinges to characterize the behavior of the hinge at various deformation levels. Five points are found on each curve, and they stand for the various stages of the hinge situation. Figure 9 illustrates a such kind of curve.

Figure 9

Performance level of hinges



Point A stands for the unstressed point and the origin of the curve. From point A to point B, a linear behavior between force and displacement is observed. Point B stands for the yield point and the end of the elastic stage. The pushover analysis's carrying capacity is attained when the hinge reaches point C. Point D denotes the pushover analysis's remaining strength, while point E denotes the hinge's complete failure. Further, point E can be considered as the yield point in designing if it is not desired for hinges to occur like that. Additionally, it is observed three points, named performance points, between point B and point C. These points are IO, LS, and CP, respectively immediate occupancy, life safety, and collapse prevention. Finally, to divide the components and ultimately produce superior outcomes, hinge overwrites are allocated to each hinge. (Computers & Structures Inc, 2017).

3.7.2 Shear wall

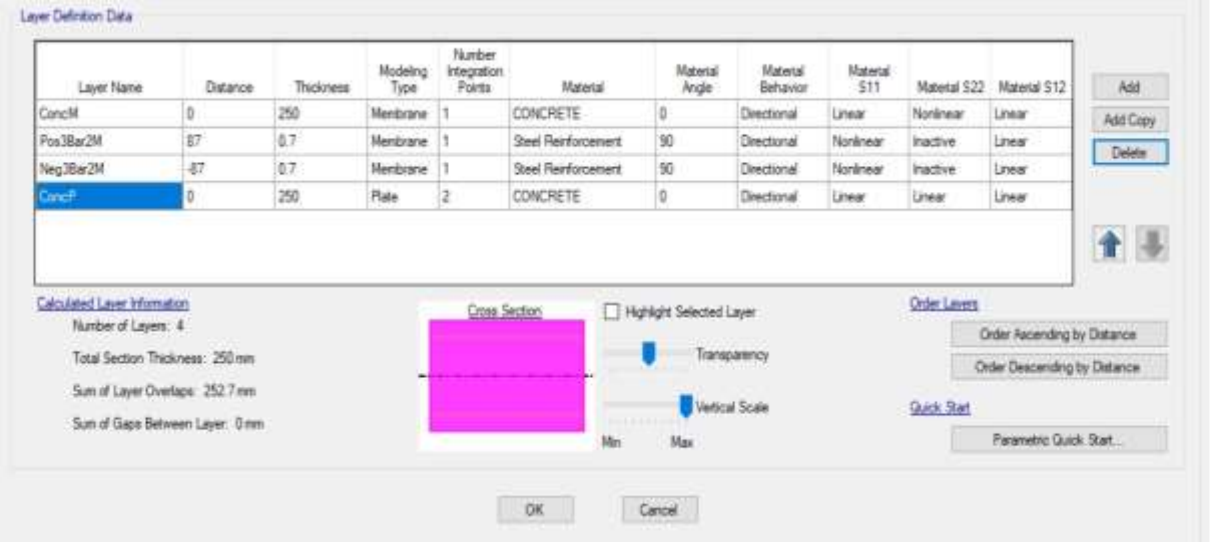
As layered/nonlinear shell sections, shear walls are defined. This kind of shell section enables the definition of several wall layers as well as the determination of the linearity and nonlinearity of the various layers and directions. Membrane and plate behavior are combined in a shell segment in Etabs. In most cases, the shell section should be used (Computers & Structures Inc, 2017).

With the help of the quick start tool, the layers are specified. For the stress component, nonlinear behavior The membrane layer, an in-plane element component, exhibits behavior that is specified in S22. It is only necessary to specify one concrete plate layer because the behavior of the out-of-plane element component is linear.

Furthermore, after the definition of these parameters, the quick start tool suggests multiple levels of the shell componante. All lateral layers are deleted, as are the layers below the concrete plate layer that have linear characteristics. Four layers are defined in this case: a concrete membrane, two layers of vertical rebars, and a concrete plate. This process of defining the shear wall as a nonlinear element has been done for all three thicknesses of 25 cm, 30 cm, and 35 cm.

Figure 10

25 cm shear wall layers definition in Etabs



Layer Definition Data

Layer Name	Distance	Thickness	Modeling Type	Number Integration Points	Material	Material Angle	Material Behavior	Material S11	Material S22	Material S12
ConcM	0	250	Membrane	1	CONCRETE	0	Directional	Linear	Nonlinear	Linear
Pos3Bar2M	87	0.7	Membrane	1	Steel Reinforcement	90	Directional	Nonlinear	Inactive	Linear
Neg3Bar2M	-87	0.7	Membrane	1	Steel Reinforcement	90	Directional	Nonlinear	Inactive	Linear
ConcP	0	250	Plate	2	CONCRETE	0	Directional	Linear	Linear	Linear

Calculated Layer Information

Number of Layers: 4

Total Section Thickness: 250 mm

Sum of Layer Overlaps: 252.7 mm

Sum of Gaps Between Layer: 0 mm

☐ Highlight Selected Layer

3.8 Pushover analysis

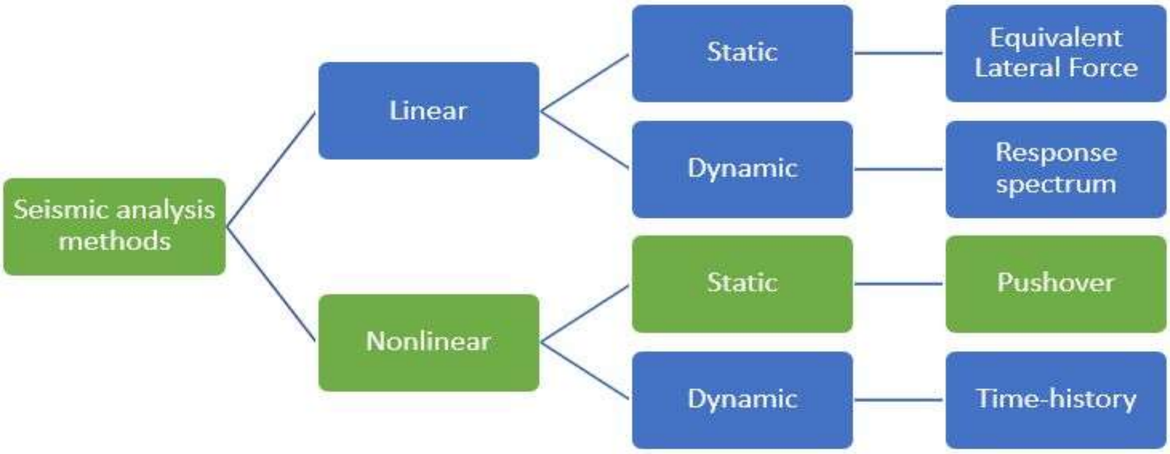
As the analysis to be conducted is nonlinear, the nonlinearity is due to the geometry nonlinearity, and the material nonlinearity. Therefore, the P-delta effect is going to be considered in the analysis due to the geometry nonlinearity. Further, the static nonlinear load case is defined. The nonlinear dead load case’s final state serves as the beginning condition for the pushover analysis. As a result, the dead load case has to be characterized as nonlinear static.

The load type automatically suggested in the software are mode load type and acceleration load type. Choosing the acceleration load type means that relative to the ground, the displacements, velocities, and accelerations are calculated. This capability allows the program to compute acceleration loads automatically in all directions. The total sum is calculated for the entire structure and equals the element mass's negative value. Each joint and component are subjected to this load. The lateral loads are delivered in a way that produces the specific mode shape for the mode load type. The results of the modal analysis indicate the importance of the mode shape for each direction. (Computers & Structures Inc, 2017). In this study, earthquake load has been assigned in an acceleration load type. Additionally, the target displacement taken as 4% of the height of the structure, is the limit displacement that the construction is prone to experiencing during the seismic design (FEMA, 1997).

After the earthquake load is to be defined and assigned, the structure has to go through the analysis. There are 4 methods to do a seismic analysis. For this present study, the simplified non-linear static analysis (pushover) has been performed.

Figure 11

Seismic design methods



3.8.1 Response modification factor

The majority of seismic regulations stipulate that structures have the capacity to sustain significant deformation without suffering damage and the flexibility to disperse energy (ductility). Further structures possess as well a substantial reservoir of strength (overstrength). These parameters are included in a structural design by the response modification factor (Abdi et al, 2015). The formulation used to find the response modification factor contains terms of strength, stiffness, and ductility. These are the three main parameters to consider in an inelastic analysis. Through the pushover analysis, a curve called the pushover curve is obtained. The link between base shear and displacement is shown by this curve. With the bi-linearization curve obtain from the software, a determination is made of the yield capacity and the ultimate capacity. V_e is the elastic design, V_y is the equivalent yield force corresponding to Δ_y the yield displacement, and V_d is the design force, the R-factor is obtained using equation-3.

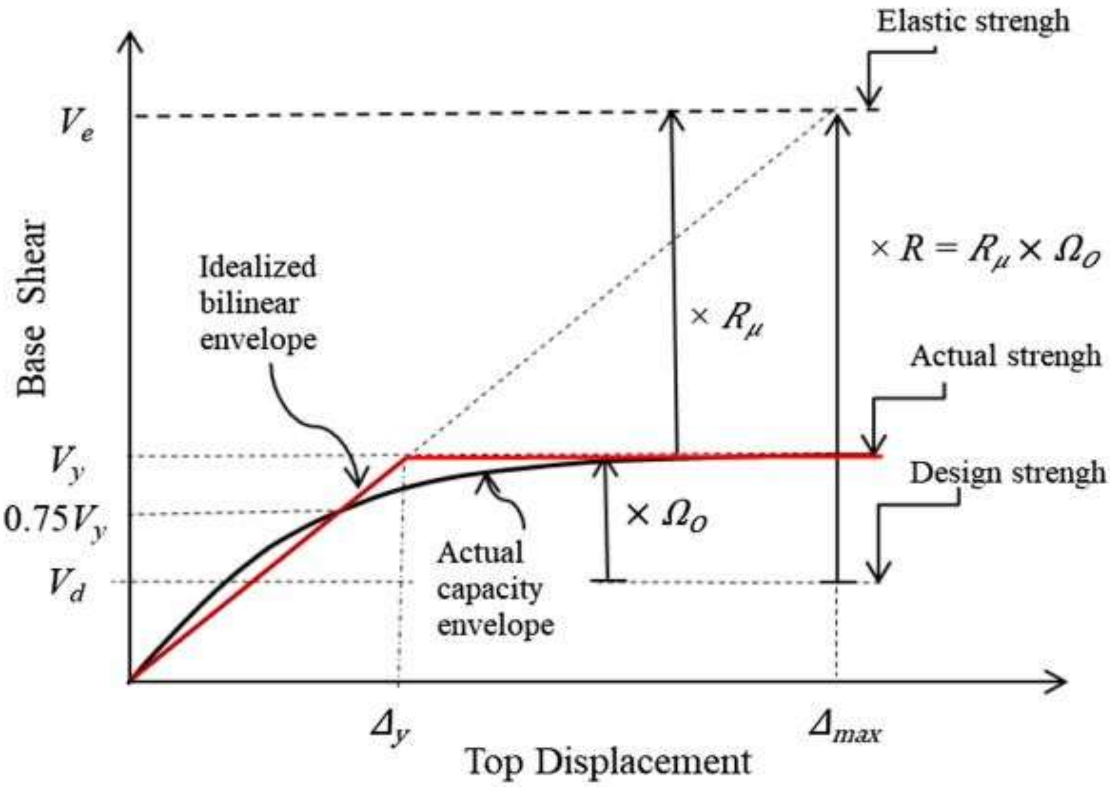
$R_S = \frac{Vy}{Vs}$, the overstrength factor (1)

$R_\mu = \frac{Ve}{Vy}$, the ductility reduction factor (2)

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

Figure 12

The bilinear curve of the pushover curve



The response modification factor 'R' is, therefore, the amount by which the lateral force (earthquake) acting on the building will be reduced so that the design force can be calculated. So, R is characteristic of a structure. This means that the more the building can dissipate energy in its plastic stage, the higher its R-value is going to be. Additionally, the design will be purely elastic for a response modification factor taken as 1, which leads to a structure extremely expensive.

3.8.2 Overstrength factor

A building's maximum lateral strength typically surpasses its design strength. Several factors that are not immediately obvious to many design experts affect the strength factor. Also, Structures in low seismically active areas are probable to have varying overstrength coefficients from those in higher seismic regions because to the divergent gravity and seismic forces, resulting in zone-dependent values for the strength factor. The strength factor's value is similarly impacted by variations in real building techniques and between actual and nominal material strengths but in unanticipated ways (ATC-19).

From the static nonlinear (pushover) analysis, these steps are followed to calculate the overstrength factor:

- Display the base shear–roof displacement relationship curve from the pushover analysis
- Determine the base shear at the yield point of the structure (V_y) obtained with the bi-linearization of the curve, and the base shear at the start point where the 1st hinge start occurring (V_s).
- Finally, calculate the overstrength value using the expression of the equation (1).

3.8.3 The ductility factor (R_μ)

The ductility is a factor that will depend on the structural properties like damping, the basic period of vibration, as well as the features of the ground motion during an earthquake. Equation 2 defines R as the base shear ratio at the elastic design level and yield strength level. As well it can be defined as the ratio of maximum drift and yield displacements. Knowing the maximum base shear, the maximum displacement, the yield force, and the yield displacement, the overstrength factor, the ductility reduction factor, the elastic stiffness factor, and the response modification factor are calculated.

3.8.4 The elastic stiffness factor K

The elastic stiffness factor expresses the ratio of the base shear when the 1st hinge occurs to its equivalent displacement, as shown in the following expression:

$$K = \frac{Vs}{Ds} \tag{4}$$

3.8.5 Pushover analysis steps

The pushover analysis has been run by considering the displacement control method, and the structures have been propelled up to a fractured displacement at the top joint of the structures. The following steps have been applied to get the pushover curve, then factors evaluated in this thesis have been calculated from the curve.

1. create 3D models; define and assign materials and section properties to the elements.
2. define and assign load patterns to sections

3. Assign hinges for beams and columns and define the shear walls as layered so that Etabs software will analyze walls as nonlinear analysis.
4. Non-linear dead load is defined by considering 25% of the live load, 100% of the dead load, and the super dead load.
5. Then the pushover pattern is defined, starting from the endpoint of the non-linear dead load. This pushover has a direction assigned to it, and the acceleration pattern is taken into account for the lateral load pattern.
6. After running the analysis, the base shear-displacement curve is plotted.

CHAPTER 4

Findings and Discussions

In this chapter, results and discussions are presented and made in graphs and tables, including parameters assessed. Those parameters are the elastic stiffness factor, the R_μ factor, and the RMF. Considering the variation in the span lengths, the concrete's compressive strength, and the number of stories, discussions are made. The principal parameter assess in this present study is the thickness of the SWs. Therefore, this chapter is divided into three sections, as three factors to evaluate. The first section will focus on the impact of the variations in span length, the number of stories, and compressive strength on the ESF. the second part will focus on the variation of the parameters listed above on the ductility. And finally, the third part will focus on the effect of the variation of these parameters on the RMF. All the discussion will be done considering the three thicknesses considered.

Global results of ESF, ductility reduction factors, and response modification factors are presented in Table 4, Table 5, and Table 6 respectively.

Table 4

Elastic stiffness factor values for all models

5-story			Span lengths		
f'_c : 25 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	332.08	316.15	343.97	567.61	528
SW30cm	426.11	333.23	590.22	665.77	739.62
SW35cm	473.4	399.85	608.57	771.53	849.79
f'_c : 30 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	381.4	333.99	446.66	631.64	724.07
SW30cm	466.37	377.32	652.74	745.48	827.71
SW35cm	518.34	382.1	675.12	855.49	964.04
10-story			Span lengths		
f'_c : 25 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	103.93	109.4	102.16	147.81	113.35

SW30cm	110.54	117.94	118.57	115.2	120.87
SW35cm	116.66	124.99	127.2	140.04	150
f'_c : 30 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	110.9	121.43	112.19	116.94	127.34
SW30cm	112.89	129.45	131.43	128	121.71
SW35cm	119.02	137.2	141.11	140.04	148.83
15-story			Span lengths		
f'_c : 25 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	61.75	67.93	70.39	108.97	73.25
SW30cm	65.34	72.45	70.32	109.48	78.27
SW35cm	67.73	72.59	74.63	116.1	79.65
f'_c : 30 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	71.89	76.37	75.96	114.24	84.66
SW30cm	71.75	78.52	79.09	106.03	89.54
SW35cm	74.46	75.34	83.29	125.28	87.14

Table 5

Ductility reduction factor values for all models

5-story			Span lengths		
f'_c : 25 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	6.43	8.92	5.77	9.14	8.33
SW30cm	8.75	8.77	9.99	11.39	12.11
SW35cm	6.71	10.57	10.41	10.11	10.61
f'_c : 30 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	7.36	8.1	7.02	9.69	10.35
SW30cm	11.83	8.83	9.76	11.62	11.66
SW35cm	11.32	9.76	9.04	8.91	10.19
10-story			Span lengths		
f'_c : 25 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	4.65	2.56	4.36	4.6	4.81
SW30cm	3.69	5.09	4.96	5.09	4.89

SW35cm	4.44	5.62	5.62	5.55	5.73
f'_c : 30 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	5.2	3.73	4.25	4.24	4.85
SW30cm	4.58	5.2	5.61	4.61	7.47
SW35cm	5.07	6.62	5.98	5.54	3.25
15-story			Span lengths		
f'_c : 25 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	2.43	2.74	2.8	2.68	8.37
SW30cm	4.58	2.96	2.56	2.92	5.05
SW35cm	2.88	2.7	2.86	4.14	3.18
f'_c : 30 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	2.86	2.8	2.66	2.83	5.43
SW30cm	2.64	2.9	3.1	2.13	2.97
SW35cm	3.23	2.25	3.15	4.34	7.48

Table 6

Response modification factor values for all models

5-story			Span lengths		
f'_c : 25 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	8.49	13.73	8.07	11.72	11.38
SW30cm	14.62	12.48	13.72	14.75	14.56
SW35cm	18.96	15.43	11.23	13.59	13.13
f'_c : 30 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	8.38	13.09	9.07	11.69	11.64
SW30cm	10.1	12.01	13.5	14.55	14.14
SW35cm	22.18	9.83	10.44	12.51	12.54
10-story			Span lengths		
f'_c : 25 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	6.64	2.86	5.07	4.95	4.84
SW30cm	3.79	5.8	8.31	4.9	4.9
SW35cm	5.67	6.6	9.52	5.7	7.12

f'_c : 30 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	7.86	5.03	5.02	4.36	5.03
SW30cm	5.3	6.93	9.42	5.02	4.49
SW35cm	6.3	8.05	9.87	5.7	8.23
15-story	Span lengths				
f'_c : 25 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	2.39	3.37	3.49	4.61	8.21
SW30cm	4.86	3.55	3.37	3.65	3.58
SW35cm	3.47	3.13	3.39	4.1	2.86
f'_c : 30 MPa, f_y : 420 MPa	**5 m**	**5.5 m**	**6 m**	**6.5 m**	**7 m**
SW25cm	3.33	3.23	3.39	3.84	8.32
SW30cm	2.92	3.24	3.19	2.34	6.83
SW35cm	3.47	2.28	3.21	4.17	2.86

4.1 Elastic stiffness factor

Some parameters affect the elastic stiffness factor, besides the change in the shear wall thicknesses assessed in this study. Those parameters are going to be evaluated in this section and discussions are going to be made. In this section, the impact of span length, the stories' number, and the reinforced concrete compressive strength f'_c are going to be evaluated to seek their effect on the elastic stiffness factor, considering 25 cm, 30 cm, and 35 cm of shear wall.

4.1.1 The impact of the span length variation on the ESF

The change in span length is an important option to take into account when designing seismically a structure. The impact of the change in the span length on the ESF, considering the three main thicknesses assessed, is going to be evaluated in this section. Table-4 and Figure-13 present and illustrate the values found for the elastic stiffness factor for the low-rise building, with a compressive strength of concrete equal to 25 MPa and the steel's yield strength bars reinforcement equal to 420 MPa. It has been noticed that the increase in span length leads to a rise in the ESF consequently. In the same manner, the increase in the shear wall thickness leads to a rise in the elastic stiffness factor. Overall, for the middle and high-rise frames and the concrete's compressive strength equal to 30 MPa, it has been noticed the same behaviors. An increase in span length and shear wall thickness allows an increase in the elastic stiffness factor.

Figure 13

The relationship between the frames' elastic stiffness factor and the span lengths for various shear walls thicknesses

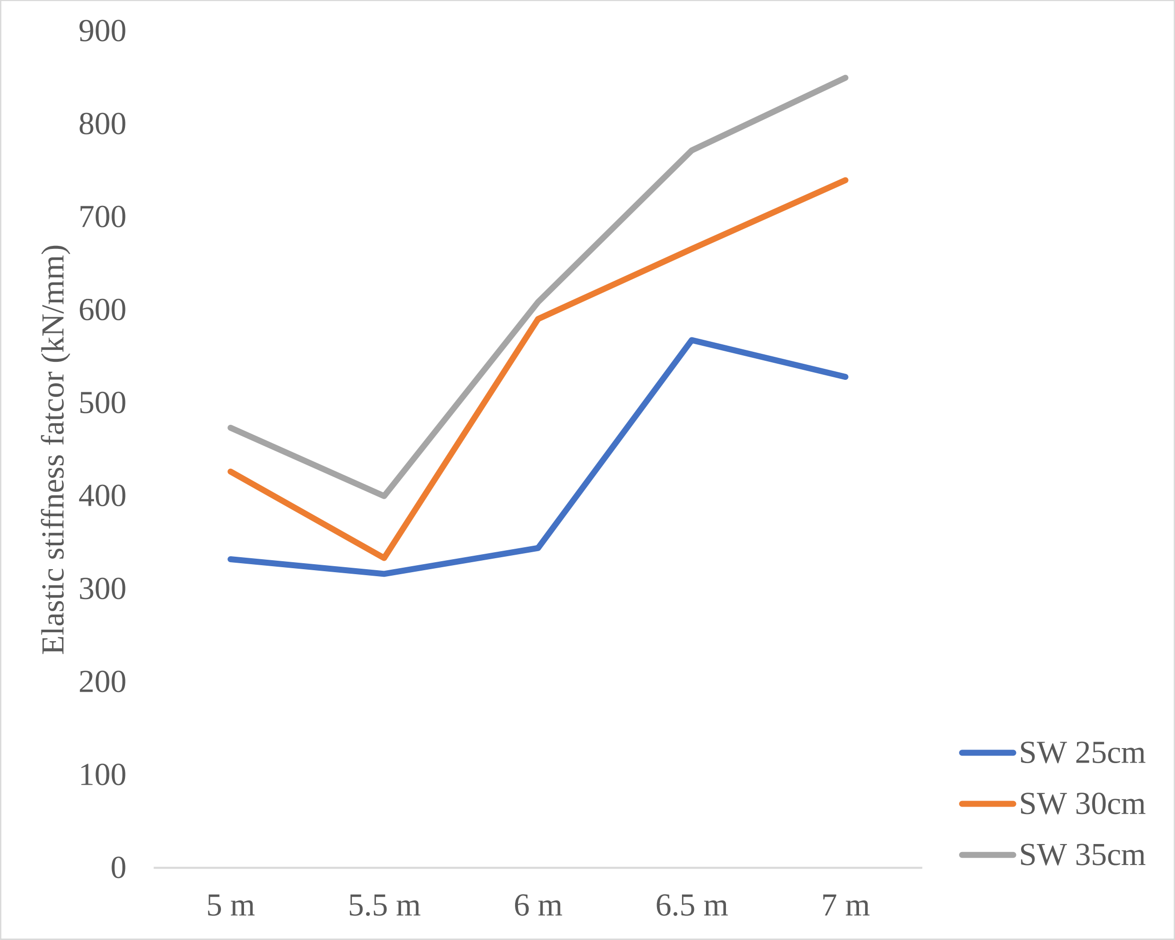


Table 7

Results of elastic stiffness factors of building with different span lengths and shear wall thicknesses

Span lengths	SW 25cm	SW 30cm	SW 35cm
5 m	332.08	426.11	473.4
5.5 m	316.15	333.23	399.85
6 m	343.97	590.22	608.57
6.5 m	567.61	665.77	771.53
7 m	528	739.62	849.79

4.1.2 The impact of the stories' number variation on the ESF

The change in the number of stories, by varying the shear wall thicknesses has an impact on the elastic stiffness factor, and this impact is going to be discussed in this section. Table-5 and figure-14 are providing found values for the ESF for different numbers of stories with 5-story (low-rise), 10-story (mid-rise), and 15-story (high-rise). Additionally, the thicknesses of the shear wall are provided in this section to assess the effect of their change. As a result, it has been found that the rise in the number of stories will decrease the ESF. While the rise in shear wall thickness will increase the stiffness for each number of stories considered. Further, a slight rise in the elastic stiffness factor is observed for the 10- and 15-story when increasing the shear wall thickness. But, a considerable increase in the elastic stiffness factor of 28.3% is noticed for the 5-story building when increasing the shear wall thickness from 25 cm to 30 cm, while this increase is 11.09% from 30 cm to 35 cm. Overall, the rise in the stories's number will lead to a decrease in the elastic stiffness factor, which has been observed for the rest of the models.

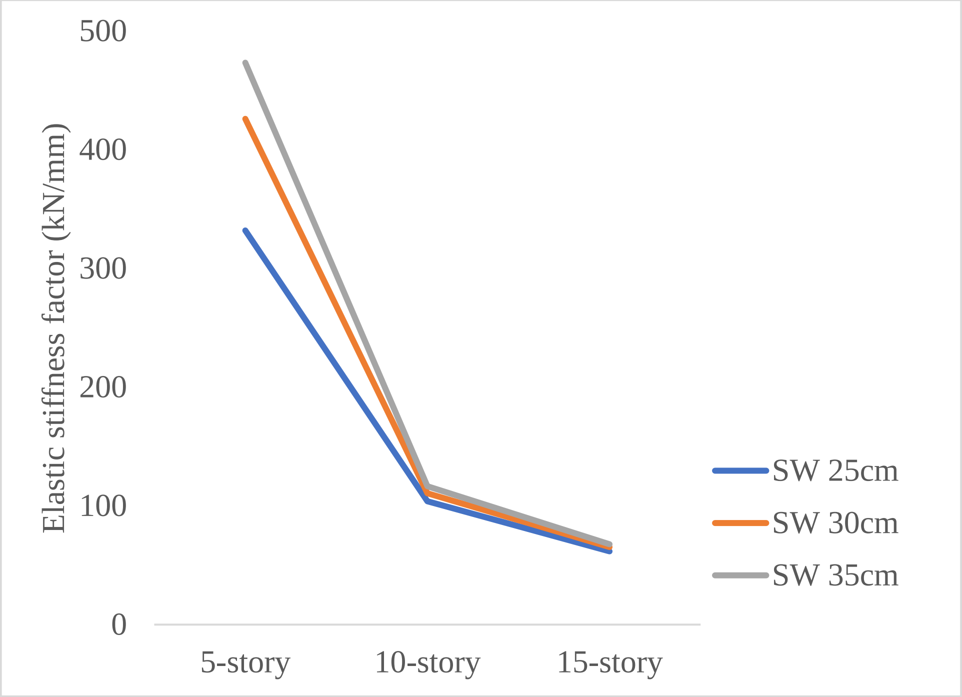
Table 8

Results of the ESF values of building with various numbers of stories and shear wall thickness

Stories	SW 25cm	SW 30cm	SW 35cm
5-story	332.08	426.11	473.4
10-story	103.93	110.54	116.66
15-story	61.75	65.34	67.73

Figure 14

The relationship between the frames' elastic stiffness factor and the number of stories for various shear walls thicknesses



4.1.3 The impact of the concrete's compressive strength variation on the elastic stiffness factor

Material characteristics are among the crucial factor to consider to design a structure, and in this study, a focus has been done on the effect of the concrete's f_c' to investigate the seismic behavior of 3D buildings. In this section, a discussion is done on the effect of the concrete's f_c' on the elastic stiffness factor, considering the three main thicknesses of shear walls. Further, Table 6 and Figure 15 are presenting values of elastic stiffness factor found for low-rise buildings (5-story) and 5 m span length. It has been found that the rise in the concrete's f_c' allows the increase in the values of elastic stiffness factors. In the same manner, the rise in the shear wall thicknesses leads to the rise of elastic stiffness factors for each compressive strength considered. 14.85%, 9.44%, and 9.49% are the increase in terms of percentages of the elastic stiffness factor for the concrete's f_c' considering respectively the thicknesses of shear walls equal to 25 cm, 30 cm, and 35 cm. Overall, the value of the elastic stiffness factor increases when the compressive strength increase. This fact has been observed for all types of buildings (low-, mid-, and high-rise).

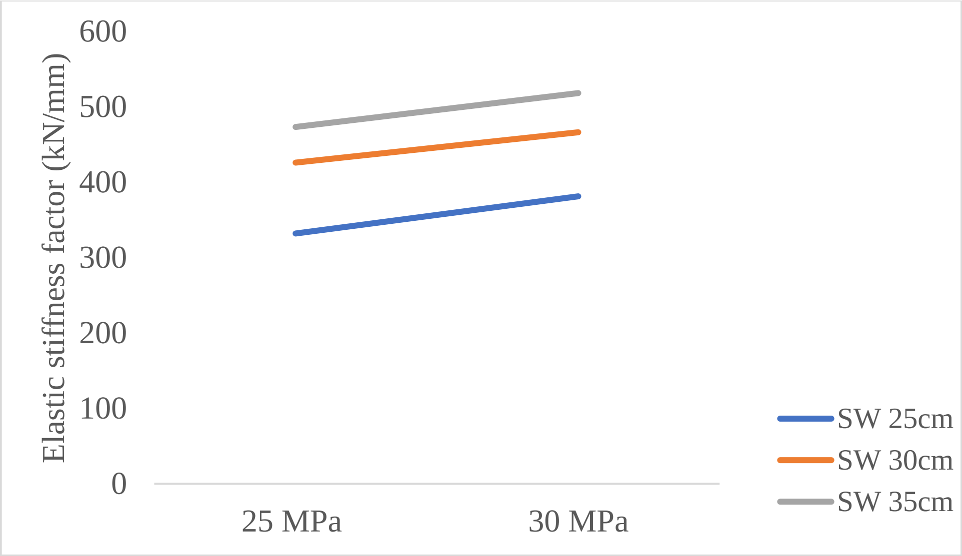
Table 9

Results of the ESF values of building with various compressive strength of concrete and shear wall thickness (low-rise building, 5 m span length).

Compressive strengths	SW 25cm	SW 30cm	SW 35cm
25 MPa	332.08	426.11	473.4
30 MPa	381.4	466.37	518.34

Figure 15

The relationship between the frames' ESF and the concrete's compressive strength for various shear walls thicknesses (low-rise building, 5 m span length)



4.2 Ductility reduction factor

In this section, the impact of SW thickness on the R_μ values is going to be evaluated. Span length, stories' number, and the f_c' of the concrete are elements that will be included in this section for the discussion. This section includes 3 parts, considering the three parameters. The first portion of the debate focuses on the impact of span length on ductility values, while the second section is concerned with the impact of the number of stories on ductility values. The impact of altering the f_c' of the concrete on the ductility value is covered in the third and final section.

4.2.1 The impact of the span length variation on the ductility reduction factor

The variation in span length affects the ductility value, and this factor is to be assessed when designing a building. Figure-16 and Table-7 are presenting ductility values obtained for the mid-rise building with compressive strength of concrete equal to 25 MPa. Figure 16 reveals that there is no meaningful relationship between the rise in the span length and the variation of the ductility reduction factor. however, for each span length consider, the increase in shear wall thickness led to an increase in the ductility reduction factor. Overall, it has been observed no significant effect of the increase in span length on the ductility values, in contrast only the impact of the SW thicknesses affected the ductility values.

Figure 16

The relationship between the frames' ductility reduction factor and the span lengths for various shear walls thicknesses

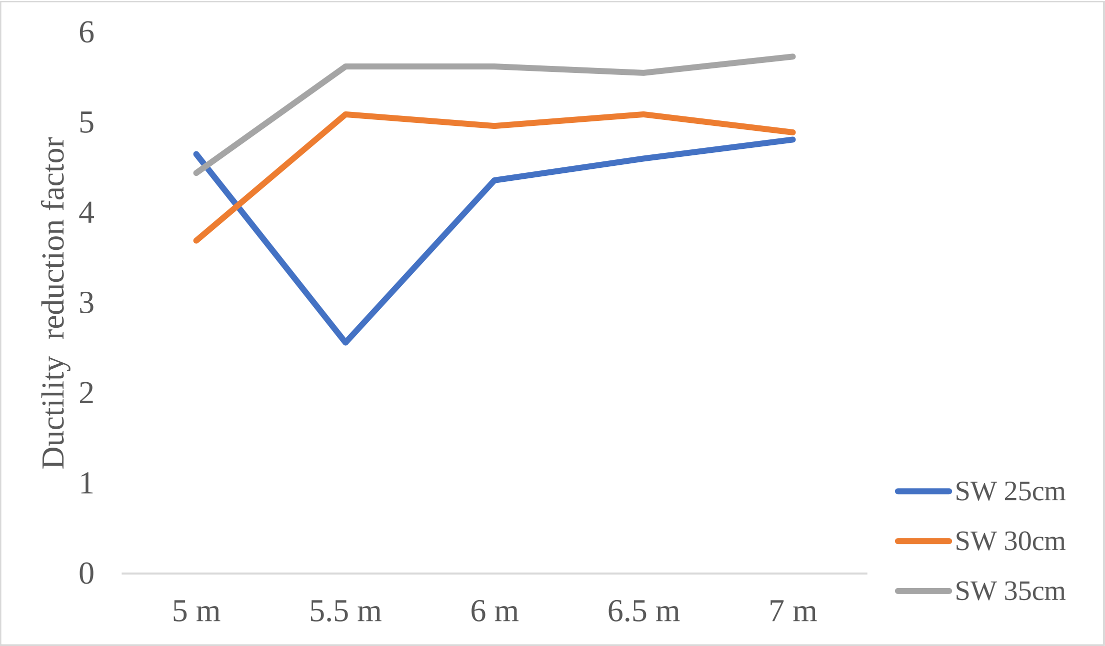


Table 10

Results of the ductility reduction factors of building with different span lengths and shear wall thicknesses

Span lengths	SW 25cm	SW 30cm	SW 35cm
5 m	4.65	3.69	4.44
5.5 m	2.56	5.09	5.62

6 m	4.36	4.96	5.62
6.5 m	4.6	5.09	5.55
7 m	4.81	4.89	5.73

4.2.2 The impact of the stories' number variation on the ductility reduction factor

The impact of the number of stories on the ductility values, considering different thicknesses of shear walls is going to be evaluated in this section. Figure-17 and Table-8 are illustrating the obtained values of ductility reduction factor for the low-, mid-, and high-rise buildings, considering span length to be equal to 6 m, and the concrete's f_c' equal to 25 MPa. The results are showing that the rise in the stories' number allows a decrease in the ductility reduction factor. While for each number of stories considered (5, 10, and 15), the increase in shear wall thickness led to a rise in the ductility reduction factor. For the case of 5 stories, the increase in ductility value is 73.1% when the SW thickness is increased from 25 cm to 30 cm. while this increase is only 4.2% when the shear wall thickness increases from 30 cm to 35 cm. On the other hand, when considering the mid-rise and the high-rise buildings, a slight increase in the ductility values in terms of percentage is observed when increasing the shear wall thickness.

Table 11

Results of the ductility reduction factor values of building with distinctive numbers of stories and shear wall thicknesses

Stories	SW 25cm	SW 30cm	SW 35cm
5-story	5.77	9.99	10.41
10-story	4.36	4.96	5.62
15-story	2.8	2.56	2.86

Figure 17

The relationship between the frames' ductility reduction factor and the number of stories for various shear walls thicknesses

4.2.3 The impact of the concrete's compressive strength variation on the ductility reduction factor

The impact of the concrete's compressive strength on the ductility values for the models considered in this study is going to be evaluated in this section. The values obtained and presented in this section are those found for the model with 10-story and a span length to be equal to 5.5 m. Additionally, a discussion is going to be made on the impact of increasing the SW thickness, which is the main factor to be assessed in this study. Figure-18 and Table-9 are presenting values obtained for the mid-rise building with a span length considered equal to 5.5 m. It has been found through the analysis of this model that the increase in the concrete's f_c' tends to increase the ductility reduction factor as well. In the same vein, an increase in the shear wall thickness led to a rise in the ductility value. When considering the thickness of the shear wall is equal to 25 cm, an increase of 45.7% is observed when increasing the concrete's compressive strength from 25 MPa to 30 MPa. When the shear wall thickness is equal to 30 cm and 35 cm, a slight increase in the ductility values is noticed, less than 20%. Therefore, the rise in the concrete's f_c' and the increase of the shear wall thicknesses are directly proportional to the rise of the ductility reduction factor for this model. Overall, this behavior has been observed in many models.

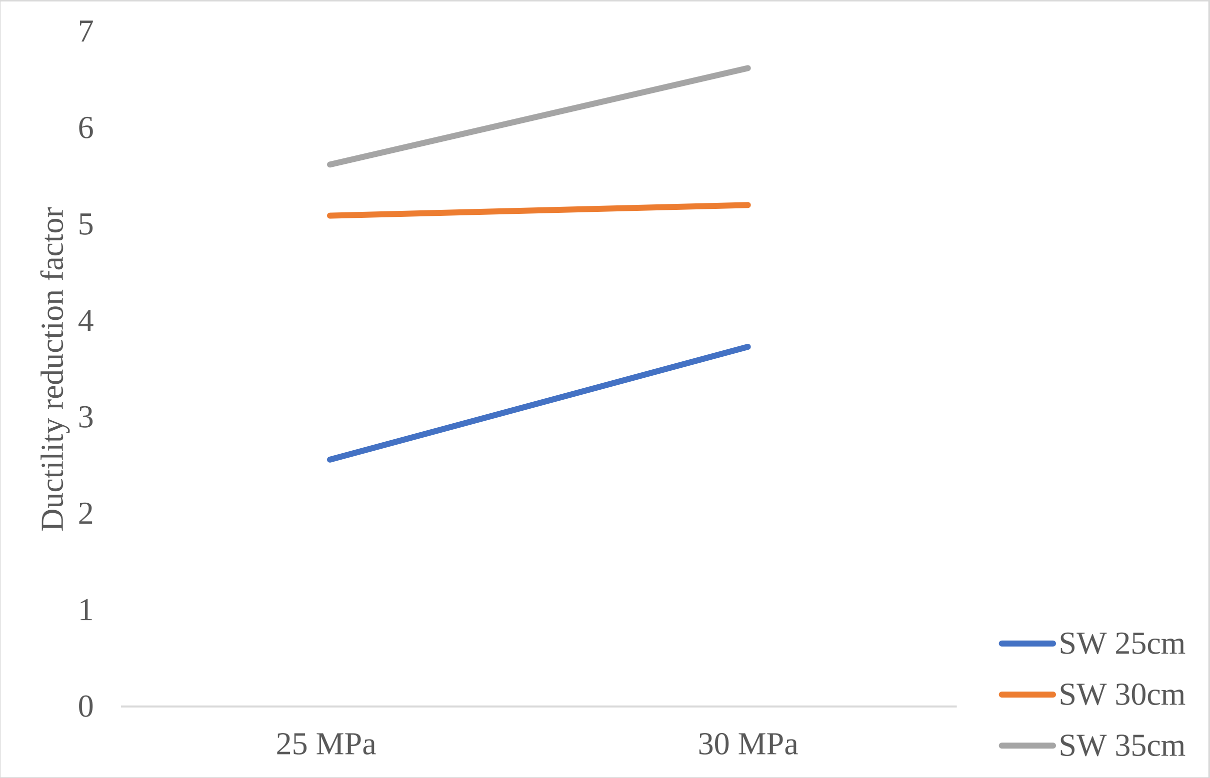
Table 12

Results of the ductility reduction factor values of building with distinctive compressive strength of concrete and shear wall thickness (mid-rise building, 5.5m span length).

Compressive strength	SW 25cm	SW 30cm	SW 35cm
25 MPa	2.56	5.09	5.62
30 MPa	3.73	5.2	6.62

Figure 18

The relationship between the frames' ductility reduction factor and the compressive strength of concrete for various shear walls thicknesses (mid-rise building, 5.5 m span length)



4.3 Response modification factor

In this section, the RMF for the models considered is going to be assessed, considering the effect of the span lengths, the number of stories, and the compressive strengths of concrete. The principal parameter evaluated in this present study is the thickness of the SW impact, all the discussions will focus on that parameter for each sub-section. This section is divided into three sub-sections, which are the effect of span length on the R-factor, secondly, the impact of the stories' number will be evoked, and finally, in the third part, the effect of the concrete's compressive strength on the R-factor is going to be discussed.

4.3.1 The impact of the span length variation on the RMF

The results obtained when evaluating the effect of span length on the R-factor are going to be presented in this section. The shear wall thickness effect will be assessed as well in this section, and a discussion is going to be done. The results presented in this section are those obtained for the low-rise building model with the concrete's compressive strength equal to 25 MPa. Figure-19 and table-10 are presenting results obtained for the R-factor when considering the number of stories equal to 5 (low-rise), and the f_c' of concrete 25 MPa. The results reveal that the increase in span length is not following any fixed pattern. Therefore, no meaningful relationship between the RMF and the span length has been found. However, a rise in the shear wall thickness seems to have an impact on the R-factor. For the overall models assessed, an increase in the R-factor has been noticed when increasing the shear wall thickness.

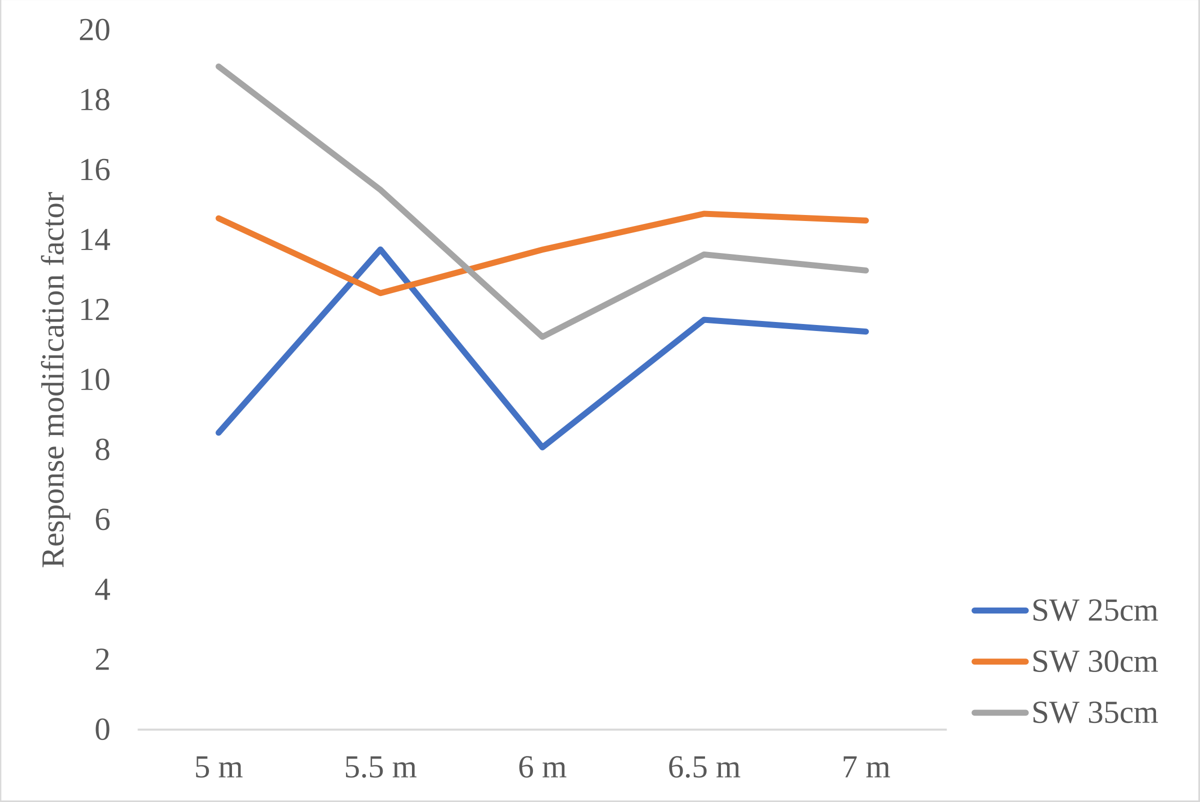
Table 13

Results of response modification factors of building with different span lengths and shear wall thicknesses

Span lengths	SW 25cm	SW 30cm	SW 35cm
5 m	8.49	14.62	18.96
5.5 m	13.73	12.48	15.43
6 m	8.07	13.72	11.23
6.5 m	11.72	14.75	13.59
7 m	11.38	14.56	13.13

Figure 19

The relationship between the frames' response modification factor and the number of spans for various shear walls thicknesses



4.3.2 The impact of the stories' number variation on the Response modification factor

The RMF assessed in this study has been obtained by multiplying the overstrength value by the ductility reduction factor value. Therefore, due to the overstrength value, it has been observed that the RMF obtained for the models do not follow any fixed pattern when evaluating each story. Overall, a rise in the stories' number leads to a decrease in the response modification factor. Figures (20 and 21) and Tables (11 and 12) are presenting values obtained of the R-factor respectively when the span length is equal to 5 m and 6 m, for the low-rise building (5-story). For the model with a span length equal to 5 m and SW 25 cm, a decrease of 21.7% is noticed when the stories' number rises from 5 to 10. Additionally, this decrease is about 64% when the stories' number increases from 10 to 15.

On the other hand, in the model with SW30cm, a decrease of 74.07% is noticed when the story number shifts from 5 to 10. Further, an increase in the R-factor of 28% is noticed when the stories' number passes from 10 to 15.

Finally, the R-factor decreases by about 70% when the thickness is 35 cm and when the number of stories passes from 5 to 10. Additionally, the R-factor is decreasing by 38.8% when the stories' number moves from 10 to 15, for the shear wall thickness considered to be 35cm.

From this discussion, it may be said that the R-factor is inversely proportional to the number of stories.

Figure 20

The relationship between the frames' response modification factor and the number of stories for various shear walls thicknesses, span length 5 m

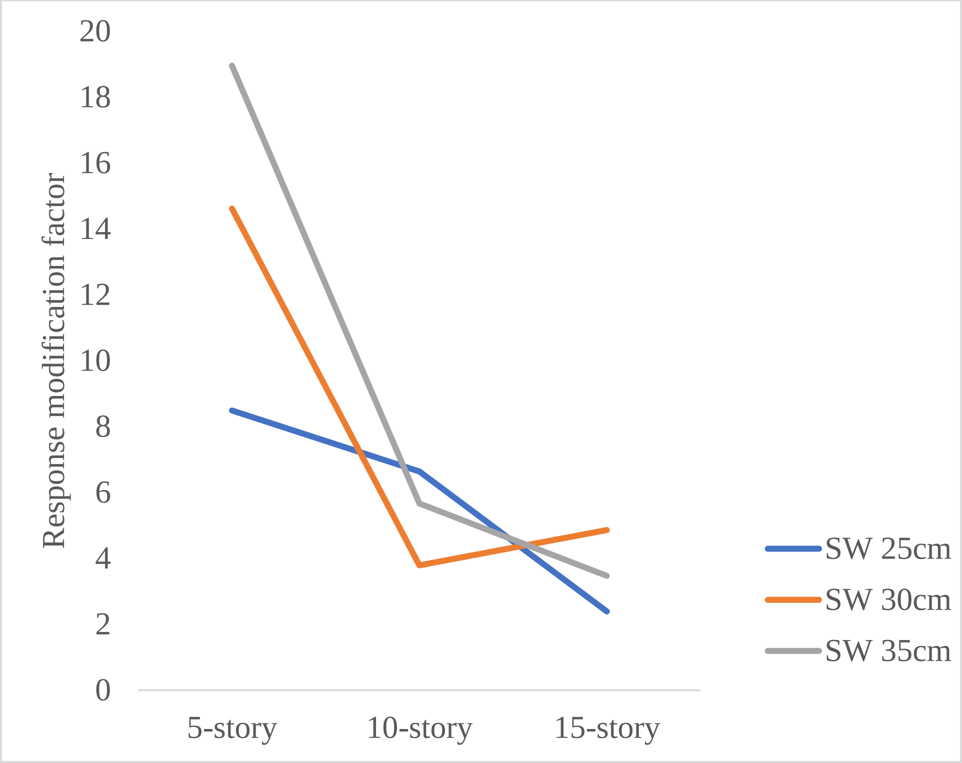


Table 14

Results of response modification factor values of building with different numbers of stories and shear wall thickness, span length 5m

Stories	SW 25cm	SW 30cm	SW 35cm
5-story	8.49	14.62	18.96
10-story	6.64	3.79	5.67
15-story	2.39	4.86	3.47

Figure 21

The relationship between the frames' response modification factor and the number of stories for various shear walls thicknesses, span length 6 m

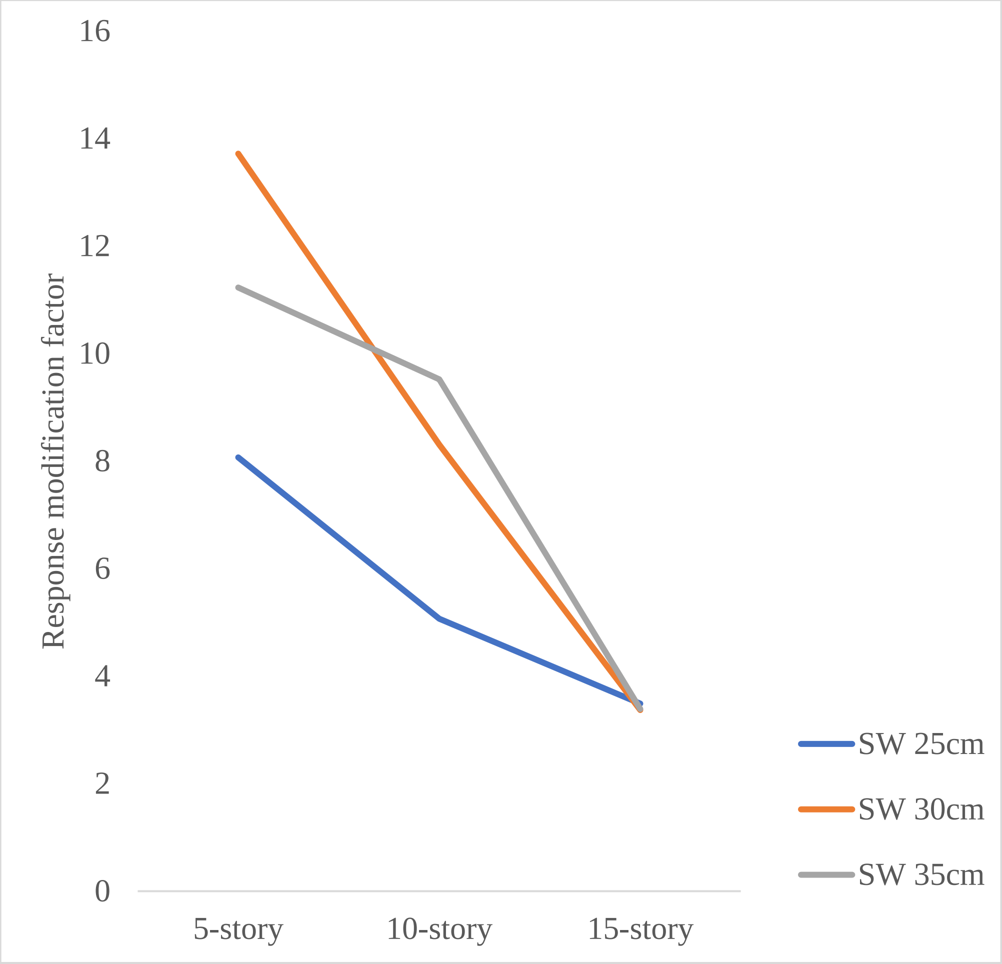


Table 15

Results of response modification factor values of building with different numbers of stories and shear wall thickness, span length 6m

Stories	SW 25cm	SW 30cm	SW 35cm
5-story	8.07	13.72	11.23
10-story	5.07	8.31	9.52
15-story	3.49	3.37	3.39

4.3.3 The impact of the concrete’s compressive strength variation on the response modification factor

The concrete’s compressive strength effect on the R-factor has been assessed in this study, and the discussion of the findings is going to be done in this section. Figures (22, 23, and 24) and Tables (13, 14, and 15) are presenting values obtained for the response modification factors for 5-story, 10-story, and 15-story respectively. Additionally, the span length for the models presented in this section is equal to 5.5 m.

It has been observed that a rise in the concrete’s f_c' leads to a decrease in the R-factor when the low-rise building is assessed. On the other side, for the mid-rise and high-rise buildings, an increase in the concrete’s compressive strength led to an increase in the R-factor as well. While there is no meaningful relationship between the increase in shear wall thickness and the R-factor. For the other model, there is no fixed behavior noticed for the impact of the concrete’s f_c' on the R-factor.

Figure 22

The relationship between the frames’ response modification factor and the compressive strength of concrete for various shear walls thicknesses (low-rise building, 5.5 m span length)

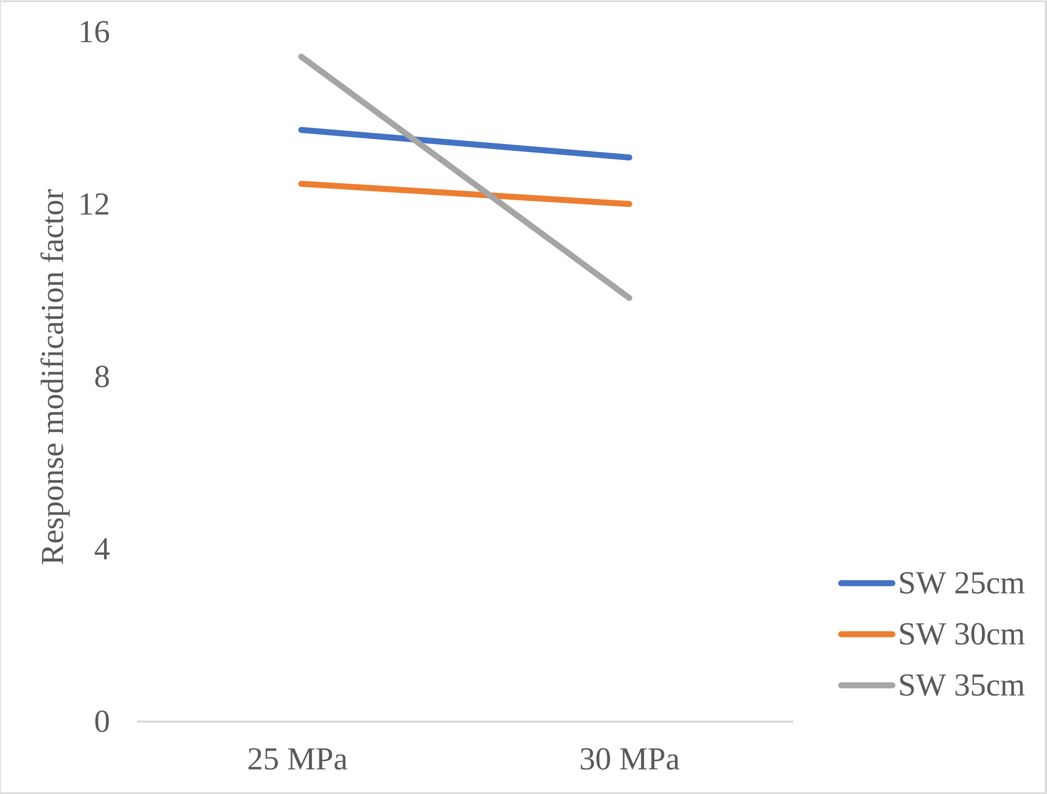


Table 16

Results of response modification factor values of building with different compressive strength of concrete and shear wall thickness (low-rise building, 5.5m span length).

Compressive strength	SW 25cm	SW 30cm	SW 35cm
25 MPa	13.73	12.48	15.43
30 MPa	13.09	12.01	9.83

Figure 23

The relationship between the frames' response modification factor and the compressive strength of concrete for various shear walls thicknesses (mid-rise building, 5.5 m span length)

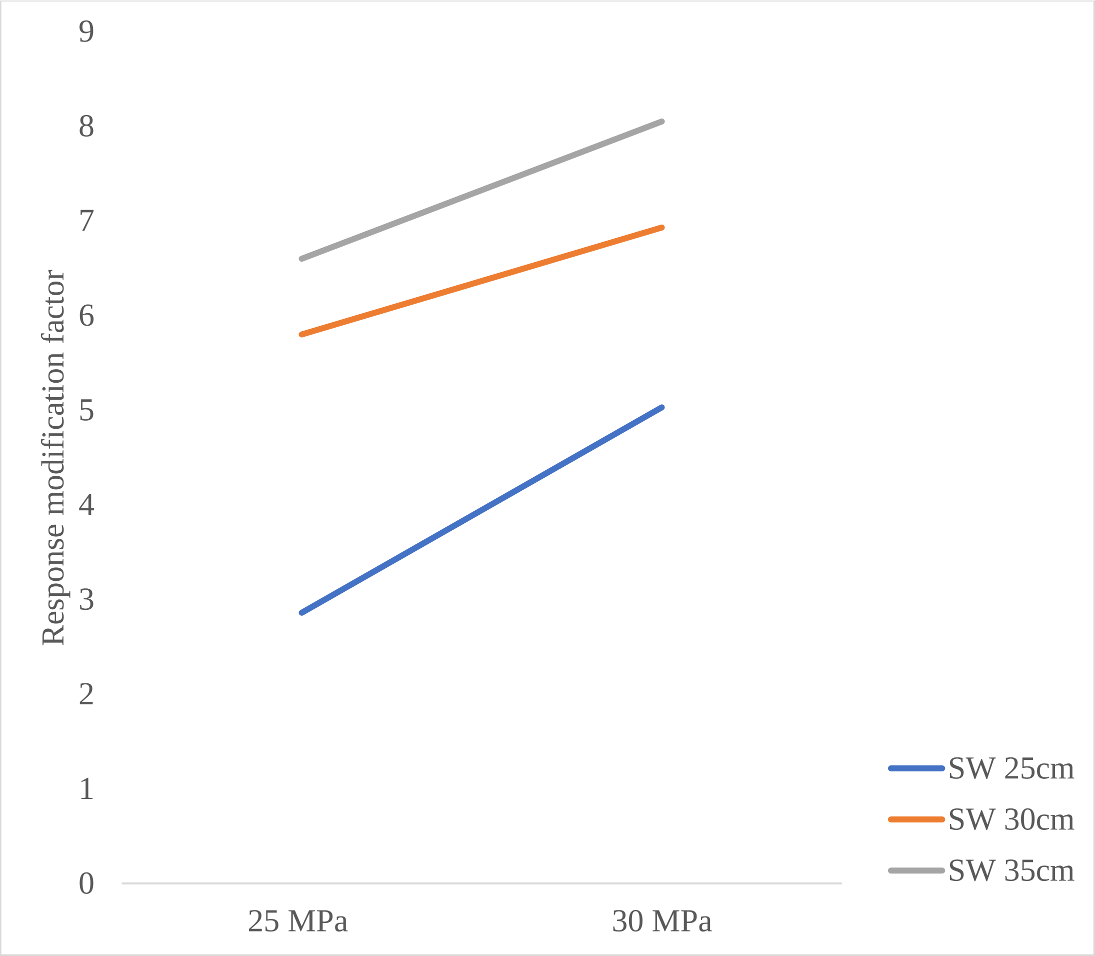


Table 17

Results of response modification factor values of building with different compressive strength of concrete and shear wall thickness (mid-rise building, 5.5m span length).

Compressive strength	SW 25cm	SW 30cm	SW 35cm
25 MPa	2.86	5.8	6.6
30 MPa	5.03	6.93	8.05

Figure 24

The relationship between the frames' response modification factor and the compressive strength of concrete for various shear walls thicknesses (high-rise building, 5.5 m span length)

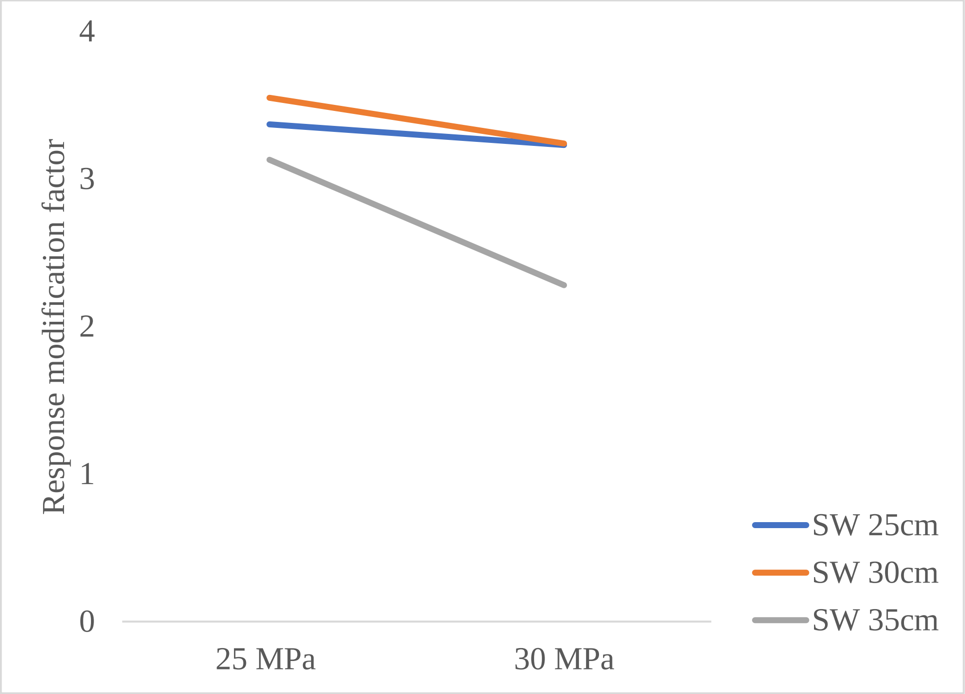


Table 18

Results of response modification factor values of building with different compressive strength of concrete and shear wall thickness (high-rise building, 5.5m span length)

Compressive strengths	SW 25cm	SW 30cm	SW 35cm
25 MPa	3.37	3.55	3.13
30 MPa	3.23	3.24	2.28

CHAPTER 5

Discussion

5.1 Overview

Studies according to this subject have been done previously. In this study, a discussion about the findings of this study and the findings in the previous is going to be done. Additionally, the values of the parameters assessed prescribed by the code and those found in this study are going to be compared.

5.2 Discussion

O. Ahmad (2021) conducted a study on 2D reinforced concrete models to assess the ESF by varying the number of stories and the span lengths by using Etabs software. All models were provided with and without shear walls. He mentioned that the rise in the stories' number was decreasing the ESF. Additionally, the rise in span length was leading to an increase in ESF. Further, the buildings with SWs were stiffer than those without SWs. Even though his study was done on 2D models, the findings are matching with those of 3D models done in this study. The same findings have been noticed by Krekar (2018) when assessing the ESF on 2D steel frame systems.

R. Reşatoğlu and J. Shahram (2022) stated that a rise in the SW thickness conducts to a decrease in the ductility coefficient and a decrease in the ductility value will also happen when the position of the SW moves from the edge to the middle. Additionally, they found that the increase in the stories' number led to a rise in ductility values. Findings that are opposite to those in this study. For both studies, dual systems have been considered. however, 2D models have been models for their study, while 3D models have been models for this study. Further, different positions of shear walls have been considered for that study.

In the same manner, the following study is going to provide matched findings according to the ductility reduction factor. In 2021, Sharifi and Hamid found that the increase in the number of stories was decreasing the ductility reduction factor. Additionally, buildings with a lower number of stories were found to have larger values of RMF. This finding is matching with those in this study. Let us mention that no meaningful relationship has been noticed between the R-factor and the number of bays within the frame structures. While in this study no meaningful relationship between the response modification factor and the span length has been found. This finding has been noticed as well by S. B. Talaeitaba et al. (2014) for the detached shear wall considered. However, an increase in the shear wall thickness seems to have an impact on the R-factor.

The UBC-1997 provides values of RMF and the overstrength (Appendix B). The RMF values found for the 5-story frame systems seem to be far greater than the value prescribed by the code. Frames with 10-story seemed to provide RMF close to the one provided in the UBC-1997 code, and the frames with 15-story were provided with RMF values lesser than the one provided by the code. While the value of 2.8 for the overstrength is found to be overestimated.

CHAPTER 6

Conclusion and Recommendations

6.1 Conclusions

In this study, the effect of shear wall thicknesses on the seismic performances of reinforced concrete frame systems has been evaluated. 3D models have been considered for the analysis, and in total, 96 three-dimensional buildings have been modeled using Etabs 2020 software. The static non-linear pushover analysis has been run, and the factor analyzed were the elastic stiffness factor, the ductility reduction factor, and the response modification factor. Different story categories (low-rise, mid-rise, high-rise), span lengths (5 m, 5.5 m, 6 m, 6.5 m, 7 m), and compressive strength of concrete (25 MPa and 30 MPa) have been taken into account for a wide view of results. Finally, the thicknesses of the shear wall considered for the assessment in this study were 25 cm, 30 cm, and 35 cm. After running analysis and discussions, it has been found that:

- When the span length is increasing, it is observed that the values of the elastic stiffness factor are increasing. Parallelly, when the shear wall thickness is increasing, the fact conducts to an increasing of the elastic stiffness factor. Overall, for the middle and high-rise frames and the f_c' of concrete equal to 30 MPa, it has been noticed the same behaviors. An increase in span length and shear wall thickness allows a rise in the ESF values.
- the increase in the number of stories will decrease the elastic stiffness factor. While the increase in shear wall thickness will increase the stiffness for each number of stories considered. Further, a slight increase in the elastic stiffness factor is observed for the 10- and 15-story when increasing the shear wall thickness. Overall, when the story's number increase, this conducts in a decrease of the elastic stiffness factor values, which has been observed for the rest of the models.
- Overall, the value of the elastic stiffness factor increases when the compressive strength increase. This fact has been observed for all the assessed buildings.
- there is no meaningful relationship between the increase in span length and the variation of the ductility reduction factor. however, for each span length consider, the increase in shear wall thickness led to an increase in the ductility reduction factor. Overall, it has

been observed no significant effect of the increase in span length on the ductility values, in contrast only the impact of SW thicknesses affected the ductility values.

- When increasing the story's number, it is observed a reduction in the ductility reduction factor. While for each number of stories considered (5, 10, and 15), the increase in shear wall thickness led to a rise in the ductility reduction factor. For the case of 5-story, the increase in ductility value is 73.1% when the shear wall thickness is increased from 25 cm to 30 cm. while this increase is only 4.2% when the shear wall thickness increases from 30 cm to 35 cm. On the other hand, when considering the mid-rise and the high-rise buildings, a slight increase in the ductility values in terms of percentage is observed when increasing the shear wall thickness.
- the increase in f_c' of concrete and the increase of the shear wall thicknesses are directly proportional to the increase of the ductility reduction factor.
- no meaningful relationship between the response modification factor and the span length has been found. However, an increase in the shear wall thickness seems to have an impact on the R-factor. For the overall models assessed, an increase in the R-factor has been noticed when increasing the shear wall thickness.
- the R-factor was inversely proportional to the stories' number.
- A rise in the concrete's compressive strength conducts to a reduction in the R-factor when the low-rise building is assessed. On the other side, for the mid-rise and high-rise buildings, an increase in the f_c' of concrete led to a rise in the R-factor as well. While there is no meaningful relationship between the increase in shear wall thickness and the R-factor. For the other model, there is no fixed behavior noticed for the impact of the f_c' of concrete on the R-factor.

6.2 Recommendations

In this study, three-dimensional models have been assessed. In addition, the yield strength of the steel reinforcement bar has been taken equal to 420 MPa in this study. For further study, the impact of steel yield strength, and the impact of opening in addition to the thickness can be investigated.

Additionally, in this study, the static non-linear pushover analysis is applied to assess the seismic parameters. Moreover, the others type of seismic analysis can be studied and a comparison of results can be made.

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APPENDICES

Appendix A
Uniform and concentrated loads from UBC-1997 code

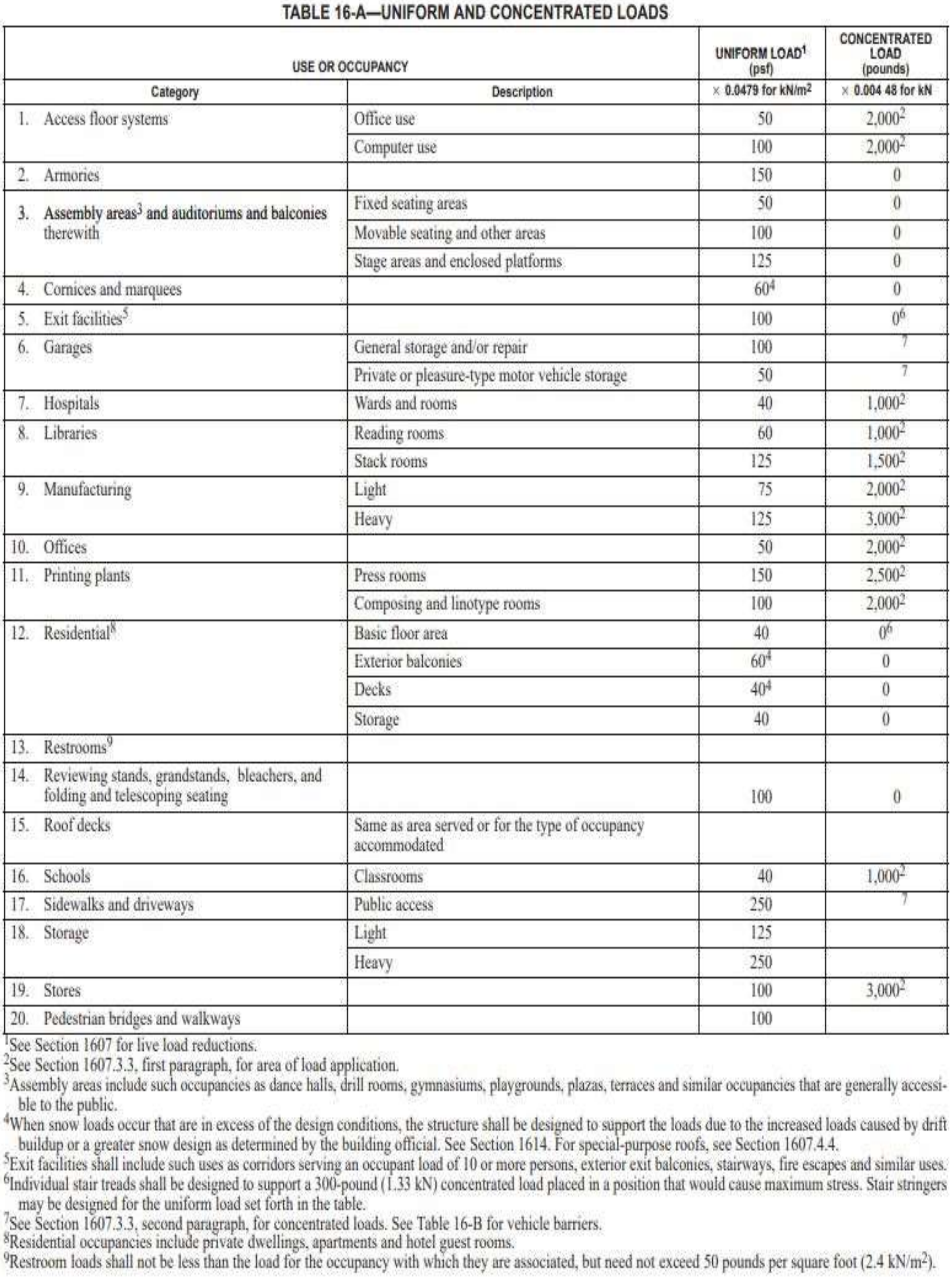


TABLE 16-A—UNIFORM AND CONCENTRATED LOADS

USE OR OCCUPANCY		UNIFORM LOAD[1] (psf)	CONCENTRATED LOAD (pounds)
Category	Description	× 0.0479 for kN/m^2	× 0.004 48 for kN
1. Access floor systems	Office use	50	2,000[2]
	Computer use	100	2,000[2]
2. Armories		150	0
3. Assembly areas[3] and auditoriums and balconies therewith	Fixed seating areas	50	0
	Movable seating and other areas	100	0
	Stage areas and enclosed platforms	125	0
4. Cornices and marquees		60[4]	0
5. Exit facilities[5]		100	0[6]
6. Garages	General storage and/or repair	100	[7]
	Private or pleasure-type motor vehicle storage	50	[7]
7. Hospitals	Wards and rooms	40	1,000[2]
8. Libraries	Reading rooms	60	1,000[2]
	Stack rooms	125	1,500[2]
9. Manufacturing	Light	75	2,000[2]
	Heavy	125	3,000[2]
10. Offices		50	2,000[2]
11. Printing plants	Press rooms	150	2,500[2]
	Composing and linotype rooms	100	2,000[2]
12. Residential[8]	Basic floor area	40	0[6]
	Exterior balconies	60[4]	0
	Decks	40[4]	0
	Storage	40	0
13. Restrooms[9]			
14. Reviewing stands, grandstands, bleachers, and folding and telescoping seating		100	0
15. Roof decks	Same as area served or for the type of occupancy accommodated		
16. Schools	Classrooms	40	1,000[2]
17. Sidewalks and driveways	Public access	250	[7]
18. Storage	Light	125	
	Heavy	250	
19. Stores		100	3,000[2]
20. Pedestrian bridges and walkways		100	

[1] See Section 1607 for live load reductions.

[2] See Section 1607.3.3, first paragraph, for area of load application.

[3] Assembly areas include such occupancies as dance halls, drill rooms, gymnasiums, playgrounds, plazas, terraces and similar occupancies that are generally accessible to the public.

[4] When snow loads occur that are in excess of the design conditions, the structure shall be designed to support the loads due to the increased loads caused by drift buildup or a greater snow design as determined by the building official. See Section 1614. For special-purpose roofs, see Section 1607.4.4.

[5] Exit facilities shall include such uses as corridors serving an occupant load of 10 or more persons, exterior exit balconies, stairways, fire escapes and similar uses.

[6] Individual stair treads shall be designed to support a 300-pound (1.33 kN) concentrated load placed in a position that would cause maximum stress. Stair stringers may be designed for the uniform load set forth in the table.

[7] See Section 1607.3.3, second paragraph, for concentrated loads. See Table 16-B for vehicle barriers.

[8] Residential occupancies include private dwellings, apartments and hotel guest rooms.

[9] Restroom loads shall not be less than the load for the occupancy with which they are associated, but need not exceed 50 pounds per square foot (2.4 kN/m^2).

Appendix B
RMF and Overstrength values from UBC-1997 code

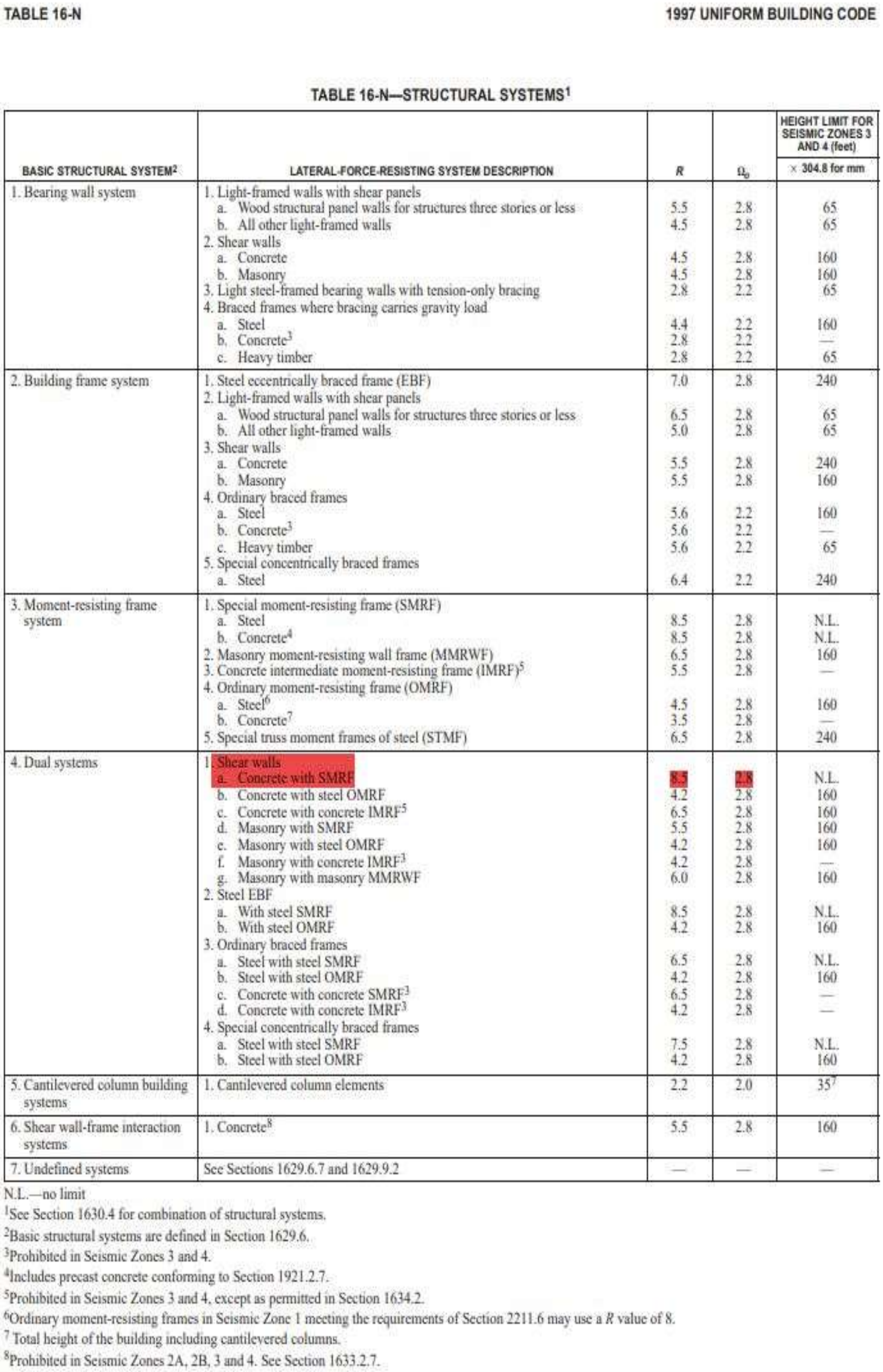


TABLE 16-N 1997 UNIFORM BUILDING CODE

TABLE 16-N—STRUCTURAL SYSTEMS[1]

BASIC STRUCTURAL SYSTEM[2]	LATERAL-FORCE-RESISTING SYSTEM DESCRIPTION	R	Ω_0	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[7]
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

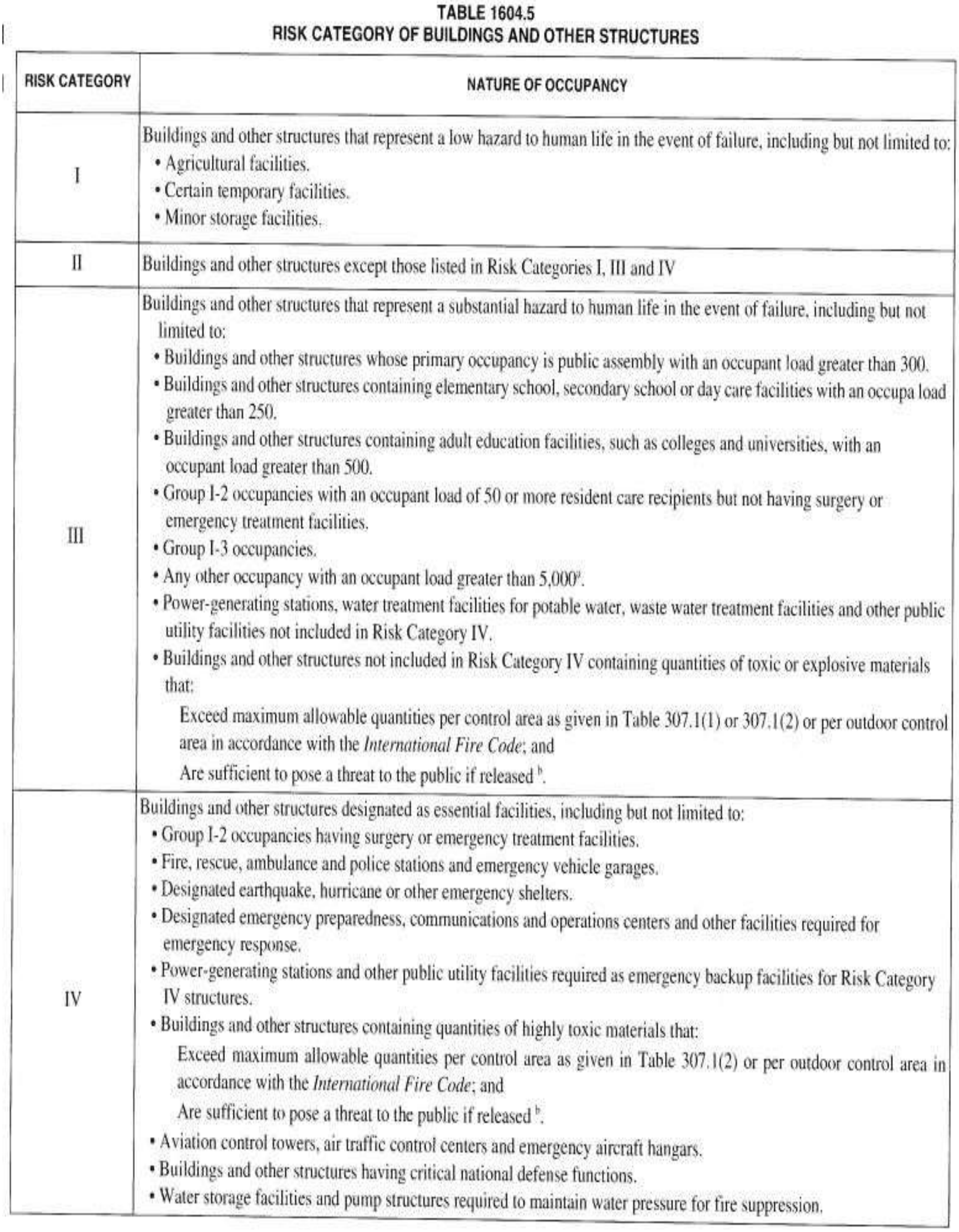
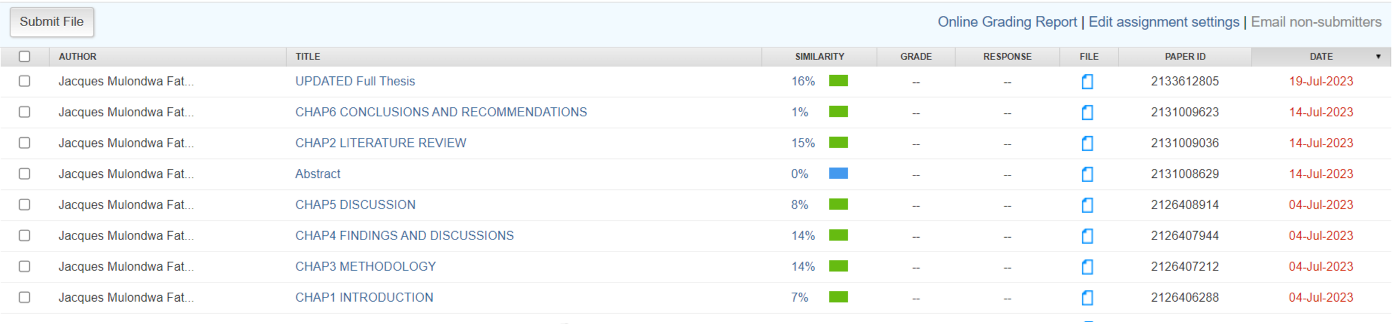


TABLE 1604.5
RISK CATEGORY OF BUILDINGS AND OTHER STRUCTURES

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

Similarity check report



☐	AUTHOR	TITLE	SIMILARITY	GRADE	RESPONSE	FILE	PAPER ID	DATE ▾
☐	Jacques Mulondwa Fat...	UPDATED Full Thesis	16% 🟩	--	--		2133612805	19-Jul-2023
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☐	Jacques Mulondwa Fat...	CHAP1 INTRODUCTION	7% 🟩	--	--		2126406288	04-Jul-2023

Prof. Dr. Kabir Sadeghi

Appendix E

Ethical approval letter

YAKIN DOĞU ÜNİVERSİTESİ
NEAR EAST UNIVERSITY

February 2, 2023,
Nicosia

ETHICS EVALUATION

Dear Jacques Mulondwa FATAKI

Your application titled “The effect of shear wall thicknesses on the seismic performances of reinforced concrete frame systems” has been evaluated by me (instead of the Scientific Research Ethics Committee) and granted approval. 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 have not to use a questionnaire and there is no need for data collection from the people, and your work will be based on analytical calculations and the application of the software.

Sincerely,

Prof. Kabir Sadeghi, Ph.D., P.E.
Head of Civil Engineering Department-Postgraduate Program

Institute of Graduate School/Faculty of Civil and Environmental Engineering
Near East University, Near East Boulevard, ZIP: 99138, Nicosia/TRNC, Mersin 10 - Turkey

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