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Behavior of RC Buildings Response to Earthquakes: Nonlinear Static Analysis Considering Varying Soil Types and Seismic Codes

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M.Sc. THESIS

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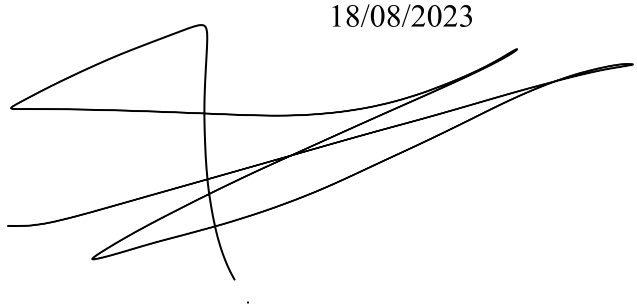
18/08/2023



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With all love and respect, I would love to thank and shout to everyone who was there for me. Starting from the best of the best, my mother and my father who guided me to the path of principles and morals, who did not criticize any of my goals and achievements, who did not laugh at any of my mistakes or weaknesses, who taught me how to share, help, guide, and love. Continuing with my seven siblings, whose existence was enough for me to feel safe, proud, strong, and not alone. Moving to my teacher Assoc.Prof.Dr. Rifat Reşatoğlu, who was part of this work and who advised me and guided me to do the right, who was always there when I asked, and who did not hesitate to spend all that time trying to make this work better and better. Ending with all the friends and mates who shared with me all moments of laughing, failing, frustrating, trying, passing, and achieving. No lies or compliments. You are all part of this work. I just wanted to say, Thank You!

AMER YASSIN

Abstract

Behavior of RC Buildings Response to Earthquakes: Nonlinear Static Analysis Considering Varying Soil Types and Seismic Codes

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Code regulations are the master reference for the design, and each code works to improve and provide new versions. This study targets to evaluate the differences between three earthquake codes: Northern Cyprus Seismic Code 2015 (NCSC-2015), Eurocode 8 (EC 8), and Turkish Buildings Earthquake Code 2018 (TBEC-2018). In addition, the study compares the earthquake analysis of the MRF system and MRF+SW system RC structures with different elevations in regular and irregular form for two selected locations with two different soil classes. Furthermore, the Pushover Analysis Method has been used to obtain the base shear, displacement, story drift, and plastic hinges behavior using ETABSv18. The results represented that regularity helped the structures to resist and stand longer than irregularity, where shear walls increased the resistance of regular and irregular buildings against earthquake loads. Also, the findings indicated that the soil class is a significant factor affecting the results between the codes. Finally, there were not always variations in the results among the codes. However, EC 8 and TBEC-2018 seemed more conservative most of the time, while TBEC-2018 is more adapted to the advanced technologies and considers the parameters in a more detailed method.

Key Words*:* soil types, seismic codes, pushover analysis method, earthquake, reinforced concrete

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List of Abbreviations

NCSC-2015: North Cyprus Seismic Code 2015

EC 8: Eurocode 8

TBEC-2018: Turkish Building Earthquake Code 2018

PGA: Peak Ground Acceleration

CHAPTER I
Introduction

1.1 General:

Reinforced concrete structures are commonly used around the world due to the high capacity they can carry, and the high number of floors they can consist of with the lowest possible costs. Therefore, the design of the reinforced structures must be studied carefully because any failure in one of the mechanisms or joints may cause the collapse of the whole structure and that leads to the death of a high amount of people. Therefore, considering earthquake loads in the design of reinforced concrete structures became a major phenomenon due to the high amount of mortality in earthquakes.

In general, codes are providing requirements that must be followed to ensure the resistance ability of the structure. In addition, code standards need to be updated periodically for the earthquake-resistant design of buildings while the Turkish code updates include the entire subject of the standard and are taking a long period to be updated. (Aksoylu et al, 2020).

This study aims to compare low, mid, and high-rise buildings' performance during earthquakes using NCSC-2015, EC 8, and TBEC-2018 to evaluate the advantages and disadvantages of each code. Recently, four advanced methods for analyzing are available, all these methods are good to use for estimating the resistance of the progressive collapse in the structure, while the nonlinear dynamic analysis is the best method to use, and it is a promising method to estimate the resistance of the progressive collapse. Nevertheless, it is a waste of time to use this method because of the many inputs it needs. Therefore, in this study, the nonlinear static analysis will be used.

The intended area is Cyprus which is a divided island in the middle sea and two codes are dominating each part of this small area Eurocode 8, and NCSC-2015, and both codes are following different earthquake requirements. Recently, considering earthquake loads in reinforced concrete structures became a major phenomenon and this leads to the importance of providing reasonable costs for designing buildings to resist earthquakes (Reşatoğlu & Atiyah, 2016). Finally, Seismic movement can be described as a complex and incomprehensible load. Therefore, it is necessary to apply the loads and analysis correctly in order to estimate the structural behavior. (Kocer et al, 2021).

1.2 Background about Earthquakes:

It is impossible to guarantee the safety of structures, but following the regulations of earthquake codes makes the buildings safer. Unfortunately, the last earthquake that happened in Turkey proves that many of the code's requirements have been neglected, and as a result, the consequences exceeded expectations.

Earthquake movements are classified according to movement grades, the first one doesn't cause damage and is called a low movement grade, the second one may cause non-structural damage and is called a moderate movement grade, and the third one causes structural and non-structural damage and called intensive movement grade. (Yassin & Sadeghi, 2023).

A glance at the types of collapse mechanisms should be taken into consideration to understand the way the collapse is and the first spot for the failure to happen. A pancake collapse is common and occurs in the soft story due to damage to columns, both the load and the failure are lateral. As a consequence, the zipper collapse happens and it occurs in the upper region of the damaged column while the load is laterally, and the collapse occurs vertically. To conclude, the connections between columns and beams fail first on the first floor and that leads to a horizontal collapse of that floor which leads to a vertical collapse of the whole structure, and that is the most expected failure mechanism.

1.3 Problem Statement

The intended area in this study is Northern Cyprus, which has a direct border with Southern Cyprus and that means both areas have similarities in the geographical nature, soil type, and environmental factors, and are surrounded by two fault lines coming from the East Anatolian Fault.

According to this study, both of the areas, are following different earthquake regulations, different design codes, also different considerations for some designing parameters. Additionally, the Northern part of the island imports some materials from Turkey, which means these materials are prepared according to regulations of a different code, while many studies are available in the literature review related to the comparison between different earthquake codes, limited studies are available related to the NCSC-2015. Therefore, there is a need to compare these three codes NCSC-2015, EC 8, and TBEC-2018, to define the resistance of the buildings under earthquake loads at each code and to define the advantages and disadvantages, weaknesses points, and strong points of each code. Moreover, Nicosia (the Gonyeli region) and Yeni Iskele (Long Beach region) were selected in this study due to the population growth in both areas and the different soil types properties of each location, whereas, the importance of soil properties observed after the last earthquake that struck Southern Turkey and Northern Syria on the 6th of February 2023 measured a magnitude of 7.7 and followed by another earthquake measured a magnitude of 7.6, with more than 9000 aftershocks, where some locations of Southern Turkey has alluvial soil, which significantly amplifies the shaking of the ground during earthquakes (Büyüksaraç et al, 2014), whereas, in Cyprus, the long beach region has the same soil type, which is listed as the softest soil type of all the three codes.

1.4 Objective of The Study

The main objective of this study is to compare the analysis results of three seismic codes, NCSC-2015, EC 8, and TBEC-2018, following these objectives:

- To evaluate the seismic analysis by performing the static nonlinear analysis method (Push Over) of a three-dimensional (3D) regular and irregular moment-resisting frame systems, and regular and irregular moment-resisting frame with shear walls (MRF+SW) systems using ETABSv18 Software.
- To compare the obtained results of the seismic design such as base shear, story shear, and displacement.
- To overview the deformation of the plastic hinges to observe the weakest joints of the building.

CHAPTER II
Literature Review

2.1 Overview

This chapter represents several investigations related to the earthquake codes, different location specifications, different building specifications, pushover analysis methods, and analysis results.

The distribution of the peak ground acceleration with expected 0.3g and 0.4g ground motion values is predicting a return period for a rock condition earthquake of 475 years which indicates a high hazard for Cyprus especially across the southern coastline, where the rest of Cyprus is characterized by less values. This is mentioned by Cagnan & Tanircan, 2010. The results stated that the approximation of the uniform hazard spectra in the Turkish Earthquake Code that is in use in the northern part of the island is inadequate with the Eurocode 8 that is in use in the southern part of the island.

A study about a case located in Cyprus using both the Turkish Earthquake Code 2007 and Eurocode 8 was demonstrated by Safkan, 2012. In this study, the analysis is applied to a non-exist structure that consists of 5 stories RC frames and is located in two sites, one in Nicosia the capital, and the other one in Famagusta, in accordance with the used ground acceleration is 0.3g according to the Turkish code for both locations and 0.2g, 0.25g according to the Eurocode 8 for Nicosia, and Famagusta, respectively. In addition, the results showed that both the cities have the same base shear for all soil types in the Turkish code section while in the Eurocode section was in Famagusta higher than the one in Nicosia according to the bigger ground acceleration value, also same results for the base columns moment, and in all results Eurocode has bigger values than the Turkish code. However, this article suggests that the use of Eurocode 8 in the northern part of Cyprus might be a solution.

Another study was carried out by Pednekar et al, 2015. 3D models without infill walls, having an area of 20*12 m, and having a different number of stories G+4, G+5, and G+6 defining gradual decrease in the base shear 1026 kN, 999 kN, and 980 kN, respectively. While gradual increase occurred in the displacement of 19 cm, 22 cm, and 26 cm, respectively. Finally, a gradual increase happened in the maximum time period of 1.98 s, 2.38 s, and 2.8 s, respectively.

An evaluation study was done by Reşatoğlu & Atiyah, 2016 using three to seven-story structures to compare the Turkish 2007 code and Eurocode 8, while the same materials, and cross-sections, also the codes data are the same with minor differences. The structures were analyzed using STA4-CAD Software and it shows that the ductility of the Turkish code provides a higher ductility reduction factor which effect the base shear of the structure.

Another study on RC MRF buildings consisting of 12 stories and were located in Cairo during the 1992 earthquake was carried out by Abd-Elhamed & Mahmoud, 2016. This study has stated clearly that the nonlinear dynamic analysis method is the most accurate method among all analyzing methods, but it is expensive and time consuming. Therefore, in this study, the Nonlinear static analysis method has been used which can be defined as the pushover method to evaluate the strength and the earthquake performance of the structure. The studied structures' status were varying from repairable damage to fully collapsed, and the conclusion of the study stated that those structures could perform well if they were designed properly considering seismic loads.

One more study about the pushover analysis for a non-existing 10-story RC building located in seismic zone 3 was studied by Daniel & John, 2016. The pushover analysis loads were applied as vertical loads followed by incremental lateral loads in both y and x directions. In addition, the author during the analysis stage gave the software 1200 steps of incremented displacement to achieve a clear perception of the incremental occurrence of plastic hinges. As a consequence, the software showed 205 and 288 incremental steps in both y and x, respectively. However, the results showed that the structure is safe in terms of base shear capacity.

A comparative study between two Seismic design codes was carried out by Reşatoğlu & Hamed, 2019. The results of Eurocode 8 and Northern Cyprus Seismic Code 2015 showed similar values for base shear and axial force in columns.

According to the irregular structures, a study was carried out by Naveen et al, 2019. 54 irregular configurations have been analyzed in this study. The results showed that the irregularity affects the seismic response of structure which concludes that some factors like location, degree of irregularity, and type need to be taken into account.

A study done by Atmaca & Atmaca, 2019 mentioned that there are two new analysis methods in the Turkish building earthquake code 2018 and these methods are not available in the Turkish earthquake code 2007. These methods are Nonlinear and Linear earthquake analysis methods, also the Turkish 2018 code has more advantages because it specifies the site of the earthquake and the type of structure's soil in that site, also considers the long and short period of acceleration coefficients, and it has six soil classes instead of four. Finally, the results of this study show that the 2018 code is more conservative than the old code.

A study using the pushover analysis to analyze RC structures with a different number of stories by Ferraioli, 2019 shows the importance of the external columns over the internal columns for the earthquake design of the structure. In addition, the scenario of the removal of an external column seemed to be much more critical than the internal column while the collapse load factor will increase adding an increase in the displacement. Regardless, following earthquake regulations in the design reveals enough capacity to avoid both of the removal scenarios' collapses. Finally, it seemed to be that the number of bays or stories is not a crucial parameter for the resistance to the progressive collapse.

A comparison study using the new Turkish earthquake code for many locations in Turkey having different seismic properties was investigated by Isık, et al, 2020. The selected plan area is 25*25 m applied for three-story structures and six-story structures. The obtained base shear for 3 stories and 6 stories were around 8400 kN, and 8900 kN, respectively. While the displacements were around 35 cm, and 36 cm, respectively.

Another study carried out by Ruggieri & Uva, 2020 defines the base shear of regular and irregular 2 stories RC Buildings with only 2 bays in the X, and Y direction considering different load profiles. The results obtained for the base shear in the X direction are between 900 kN – 1100 kN for all load profiles, and in the Y direction are between 800 kN – 1000 kN.

A study carried out by Aksoylu et al, 2020 compares TBEC-2018, ASCE 7-16 and TEC-2007 using the linear equivalent method to analyze RC buildings with a different number of stories. The results show that the ultimate base shear force is achieved at TEC-2007 for buildings of 3 and 5 stories, and the ultimate base shear force is achieved at TBEC-2018 for buildings of 7 and 9 stories. The higher increment is predicted in the design forces at TEC-2007 for weak soils, and at TBEC-2018 for strong soils. The displacement calculations showed that the cracked sections are 34% more in TBEC-2018 with respect to TEC-2007, also the TBEC-2018 in high-rise buildings has less displacement with respect to TEC-2007. In the last stage of this study, the pushover analysis was applied and showed more close results between the codes, and it revealed that the ductile behavior occurred in all structural systems, and the first occurrence of plastic hinges was obtained in the beams.

Another extensive study related to all five versions of Turkish codes was carried out by Işık, 2021 illustrating that these codes were developing starting from 1968 up to 2018. While, the Earthquake renaissance was in 2007, and in 2018 some major improvements were added like the ability to use a specific design spectrum according to the location. In addition, this study investigated a 4-story structure to be analyzed under the minimum requirement of each code for example the concrete grade is C12, C14, C16, C20, and C25 in a raw starting from 1968 code to 2018 code. Finally, the results of the base shear in the last code version were almost between two to three times more than the rest of the codes including the 2007 code.

The effectiveness of using shear walls in the structure is explained by Resatoglu & Jkhsi, 2022. 96 models were analyzed using the Pushover analysis to illustrate the effect of the location and thickness of shear walls on the ductility of the structure. The results showed a reduction in the ductility when there is an increase in the shear wall thickness and when the shear walls are located in the mid-span. In addition, Mid-span shear walls increase the ultimate displacement, yield displacement, and the maximum base shear force.

CHAPTER III
Seismicity of Cyprus

3.1 Plates and Fault Lines

475 years is the predicted period for the return of a rock condition earthquake. The Anatolian plate, the African plate, and the Arabian plate, all these plates are surrounding the studied area (Cyprus). The fault lines between these three plates are passing across Turkey, Syria, Cyprus, Lebanon, Palestine, and Jordan as shown in Fig 1.

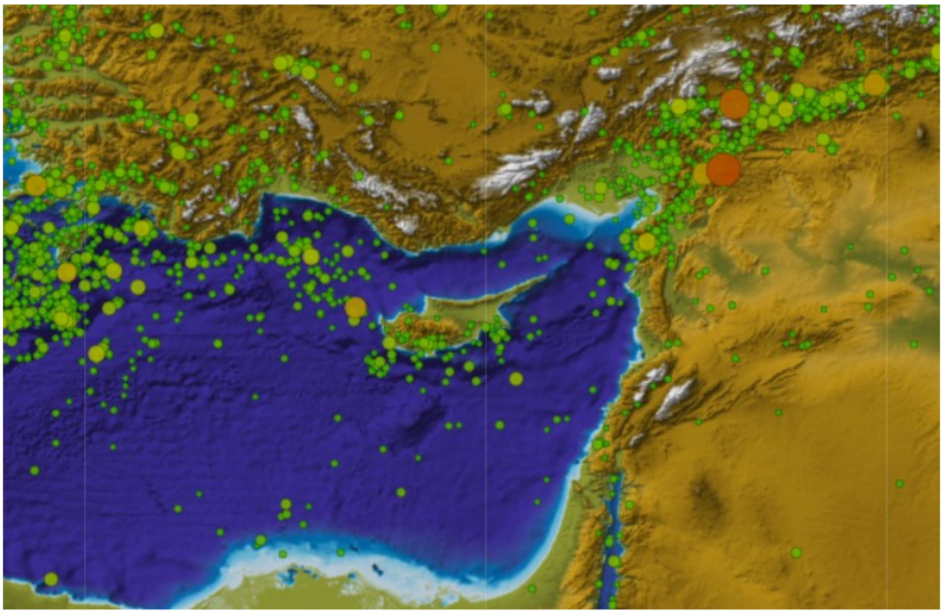
Figure 1

The Fault Lines Between the Anatolian Plate, Arabian Plate, and African Plate (Elhadidy. 2021)

These fault lines are causing periodical earthquakes in the area, especially in the east Anatolian fault, which is too close to the location of the last two earthquakes that struck Sothern Turkey and Northern Syria on the 6th of February with Mw=7.5 and Mw=7.8, see Fig 2.

Figure 2

Seismic Portal of Magnitude Mw=+4 Earthquakes in The Area (www.seismicportal.eu)



Two fault lines are crossing through Cyprus coming from the East Anatolian Fault, where the island is located near the boundaries of the African plate which is moving northward, the Arabian plate is also moving northward but faster, and the Anatolian Subplate is moving westward. Besides, a suggestion by previous studies indicates that the East Anatolian Fault has had two active extensions to the south and the north of Cyprus. (Cagnan et al. 2010). On the other hand, recent studies revealed the same conclusion as previous studies, while some recent studies indicate that the only active extension is in the south of Cyprus (Elhadidy. 2021; Khawaja. 2020) as shown in Fig 3 and Fig 4 below.

Figure 3

Map Showing the Principal Tectonic Elements of The North Eastern Mediterranean Region. (Zehra Cagnan, 2010)

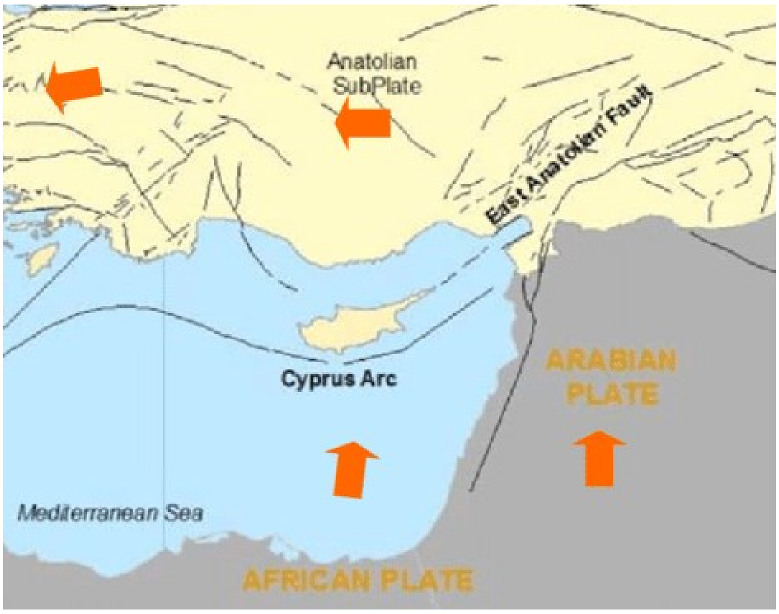
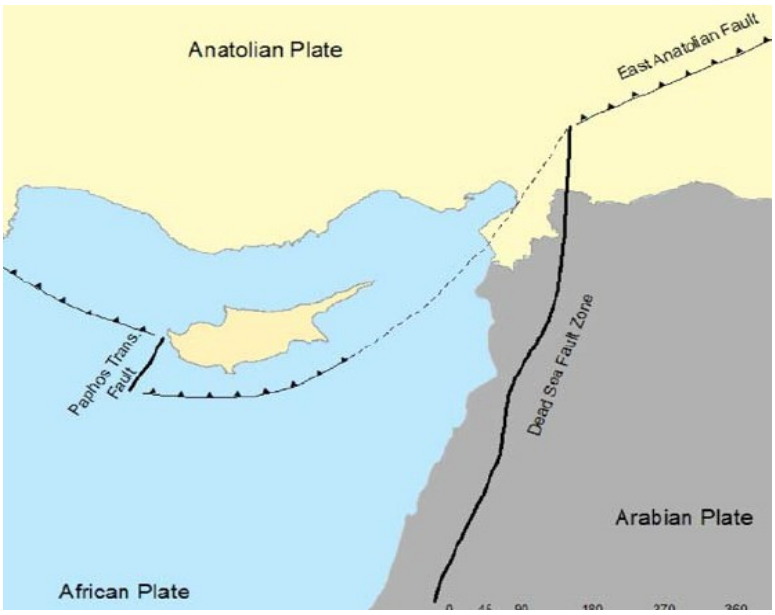


Figure 4

Proposed Plate Boundary in The Eastern Mediterranean Area. (Zehra Cagnan, 2010)



In general, active fault lines are those that have created recent movements of the earth's crust, and they could create major or minor earthquakes. On the other hand, inactive fault lines are those that haven't shown any historical movement signs of the earth's crust, but there is a possibility for these fault lines to be awakened again. However, in Cyprus, the activity of the northern fault line is not guaranteed, but the activity of the southern fault is guaranteed.

3.2 Cyprus Earthquakes History

Rock condition earthquakes have been occurring in the area for centuries, and Cyprus has been exposed to many earthquakes, where the magnitude of the largest earthquake stroke in the country was Mw=6.8 of 68 hits in 1996. Additionally, three of the most powerful earthquakes have occurred in the 21st century as shown in Table 1.

Table 1

Largest Earthquakes That Hit Cyprus (Geological Survey Department)

Year	Magnitude
1953	6.5
1961	5.7
1995	5.7
1996	6.8
1997	5.7
1999	5.6
2012	5.5
2015	5.6
2022	6.5

3.3 Topography of Cyprus

The percentage of construction of new buildings is increasing in Cyprus. While there are still old buildings in use and that refers to some people are already living in hazards.

There are three important Earthquake parameters to consider for Cyprus which are soil types, buildings age, and peak ground acceleration.

3.3.1 Soil Types

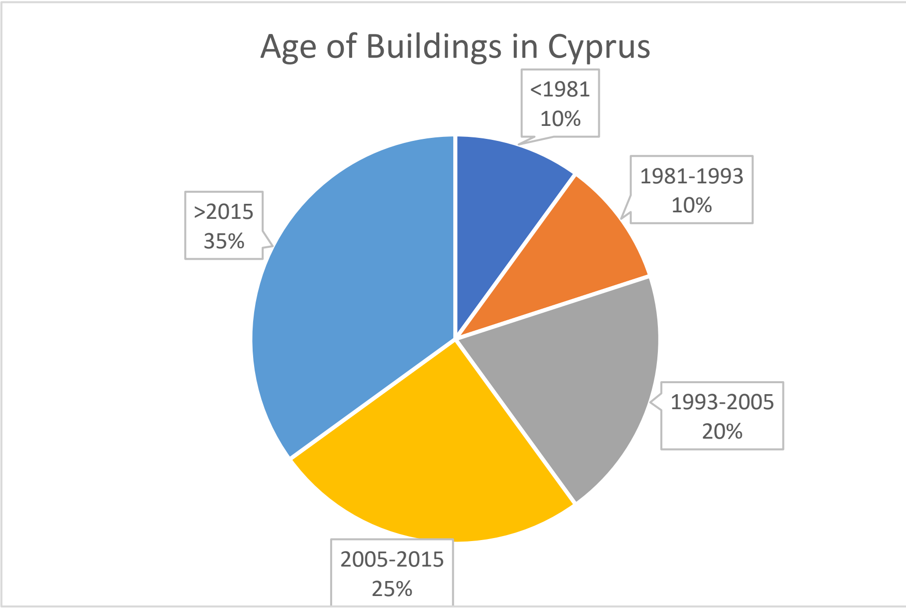
The massive earthquake that occurred in Southern Turkey and Northern Syria on the 6th of February 2023 caused a huge loss in the structures and that leads to a huge loss of lives, while one of the main experienced problems was caused by the Alluvial soils which are the thin sandy soils that drifted from the mountains to the sea by the streams and are considered among the riskiest soils in terms of earthquakes due to their liquefaction risk that causes the loss in the strength of the structure. The point of similarity here is that Alluvial soils are concentrated in Cyprus in the long beach region and Tuzla region. In this study, two soil types of structures are studied, one in the long beach region in Yeni Iskele and the other one in Gonyeli region in the Capital Nicosia. In addition, previous studies concluded that the soil of the long beach region is susceptible to liquefaction up to a depth of 6 m after taking samples and applying a standard penetration test (Ekinci, 2021).

3.3.2 Buildings Age

Around 65% of the current buildings in North Cyprus were built after 2015 (the date of launching the NCSC-2015), while around 10% of the current buildings in North Cyprus were built before 1981 (the date of launching the first code that considered horizontal loads). In other words, around 10% of the buildings and population are at real risk during an earthquake as shown in Fig 5. (Earthquake committee meetings of the presidency of TRNC, presented by General Secretary of Chamber of Civil Engineers)

Figure 5

Buildings Age in Cyprus (Earthquake committee meetings of the presidency of TRNC)



In addition, the number of buildings is increasing incredibly on the island as shown in the previous figure, and that reflects how important to consider earthquake design in future building works.

3.3.3 Peak Ground Acceleration

The Peak Ground Acceleration factor is considered in each code regulation. While Northern Cyprus is independent and follows the regulations of the Northern Cyprus Seismic Code 2015 (NCSC-2015) and Southern Cyprus is independent and follows the regulations of Eurocode 8 (EC 8), each code has specific data related to its regulations and a specific Seismic Zoning map as shown in Fig 6 and Fig 7.

Figure 6

Seismic Zoning Map of Cyprus According to EC 8 (Cyprus National Annex, Eurocode 8)

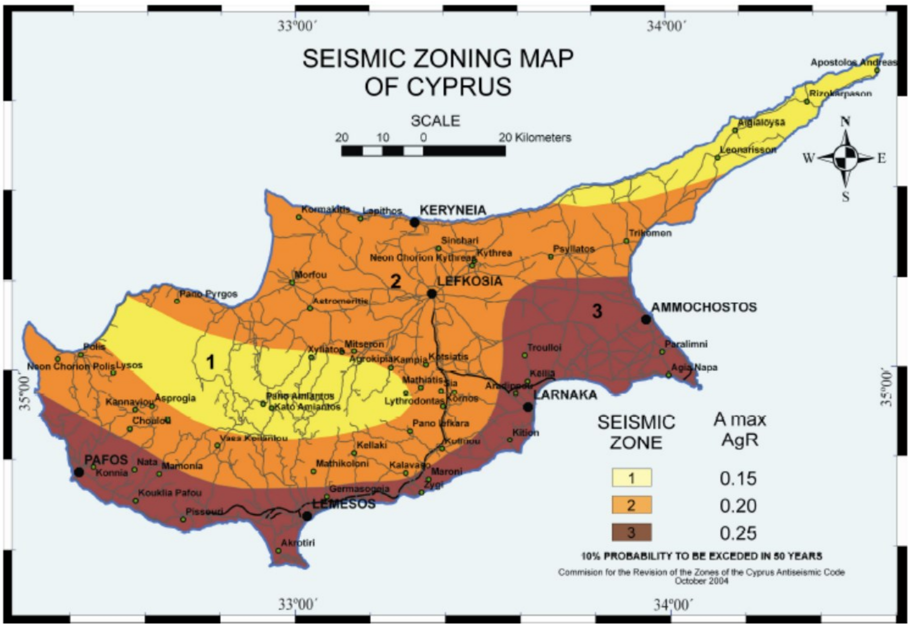
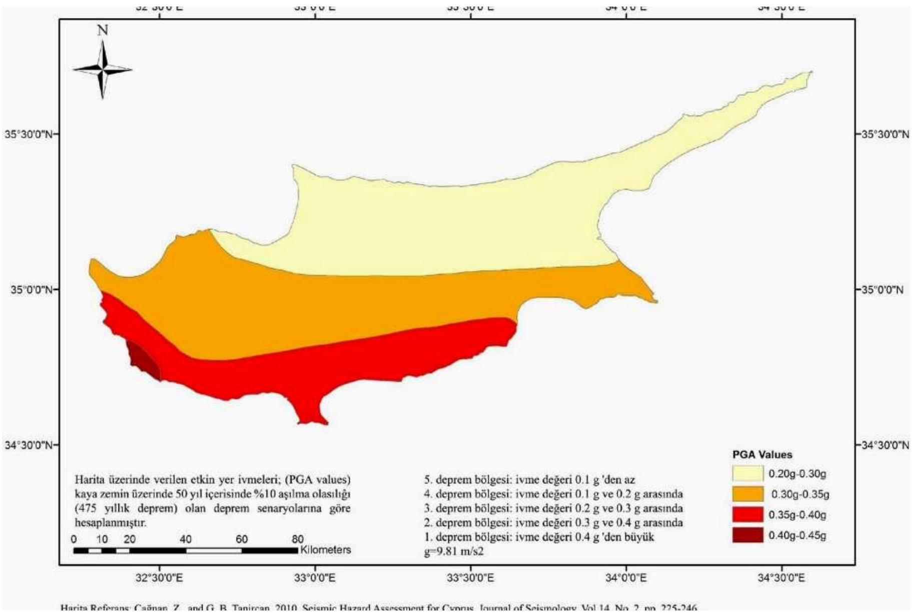


Figure 7

Seismic Zoning Map of Cyprus According to NCSC-2015 (NCSC-2015)



CHAPTER IV
Seismic Design Codes

4.1 Overview

Codes are the columns that illustrate the design regulations, and they should be studied and updated with time in order to evolve. Earthquake codes are not new in the civil engineering world, while the first era of earthquake codes in Turkey was in 1940, and the last one was in 2018 which is the 10^{th} version (Işık, 2021). These codes were improving, and with each new code, some regulations changed. However, unfortunately, the last earthquake that happened on the 6^{th} of February 2023 was totally destructive and confirms that these regulations are not followed as needed, and it is necessary to update them continuously. On the other hand, there are ten design Eurocodes, while Eurocode 8 is used for designing in seismic zones. (Cutia & Țurcan, 2020).

Finally, this island is divided into two parts so it uses two different codes with different earthquake zone maps, different peak ground acceleration values, and different number of soil types, these codes are North Cyprus Seismic Code 2015, and Eurocode 8. (Reşatoğlu & Hamed. 2019).

4.2 Turkish Codes Revolution

Northern Cyprus Seismic Code 2015 quoted from the Turkish Earthquake Code 2007. Therefore, the Turkish Codes revolution is considered in this part.

The Italian Building Instruction for Construction in Earthquake Region 1940 was the first used code in Turkey, then the codes have been continuously updated by taking into account all improvements in the technology of engineering (Işık. 2021). Thus far, ten different codes have been used in Turkey, and only two of them are in the 21st century (Işık, 2021). The following are the last five Turkish codes:

4.2.1 Specification for Structures to Be Built in Disaster Areas 1968

Some protection suggestions have been added to this code, but the main improvement in this code is that this code added to the RC buildings some earthquake rules and the analysis became more detailed. In addition, this code has three ground types but they have not been made in accordance with any parameter.

4.2.2 Specification for Structures to Be Built in Disaster Areas 1975

Earthquake zones have been added in this code, dividing Turkey into four earthquake zones. Also, earthquake forces are depending on many parameters to make them more accurate like the acceleration spectrum coefficients, buildings importance level, and live load reduction factors. The earthquake analysis considers more details, and it became compulsory to use vibrators to mix the concrete in the casting. In addition, the first use of the ductile design expression.

4.2.3 Specification for Structures to Be Built in Disaster Areas 1998

The capacity design was considered carefully to result in achieving a very safe design method by following other developed countries' regulations and standards. This code has four different ground types similar to the previous one but with considering more parameters like penetration, stiffness, and pressure strength.

4.2.4 Turkish Earthquake Code 2007

This code is the first column in this study, while North Cyprus Seismic Code is quoted from this code and was obtained from this code as well. The aim of adding this code came after the massive earthquake that arises in Izmit city with Mw=7.6 in 1999 and took three years of preparation. This code is named exactly according to its content which is an earthquake. While it is the first time to use the non-linear method, and the first time to contain earthquake-resistant regulations for RC structures, Steel structures, and masonry structures, also it has four ground types similar to both previous codes. In addition, it was the first code to mention rules for retrofitting existing structures. Finally, it became mandatory in RC buildings to use ready-mixed concrete.

4.2.5 Turkish Building Earthquake Code 2018

This code is the second column in this study and the last code in the Turkish code series. This code has been added due to the earthquake that happened in 2011 in Van City. This code has a main amendment which is the usage of design spectra for a specific location using the Turkish Earthquake Hazard Map instead of defining seismic zones like the previous codes. In addition, it was the first time to use both the horizontal and the vertical elastic design spectra which helps to obtain more accurate results. Finally, it was the first time to include six different ground types.

4.3 North Cyprus Seismic Code 2015 (NCSC-2015)

4.3.1 Overview

This code is a copy of the Turkish earthquake code 2007 and has been accredited in Northern Cyprus. The purpose of establishing this code was after the earthquake with Mw=7.6 magnitude and Mw=7.2 that happened in 1999 in Izmit and in Düzce, respectively. This copy started to be prepared in 2004 and in 2007 it came into force, while the major difference in this code from the previous code can be defined by the name which is the first code that includes only the regulations for buildings in earthquake zones. Moreover, this code contains earthquake-resistant regulations for RC structures, Steel, and Masonry, and it was the first code to make the use of ready-mixed concrete mandatory in RC buildings. Also, this code classifies the ground types into four different types similar to the previous code (Işık. 2021). Additionally, this code uses a limited yield strength in the upper reinforcement steel in order to increase the ductility while the ductility increases with the decrease of yield strength (Safkan, 2012). Finally, in accordance with this study, this code is using a specific seismic zone map for Cyprus and specific peak ground acceleration values. (Reşatoğlu & Hamed. 2019).

4.3.2 Soil Types

NCSC-2015 has 4 ground types which are less than the other two codes as shown in table 2.

Table 2

Ground Types According to The Regulations of NCSC-2015 (K.K.T.C. DEPREM BÖLGELERİNDE YAPILACAK BİNALAR HAKKINDA YÖNETMELİK 2015)

Ground Type	Soil Description	Vs30 (m/s)
A	1. Massive. volcanic. rocks, unweathered sound. metamorphic. rocks, stiff. cemented sedimentary. rocks	> 1000
	2. Very. dense. sand, gravel	> 700
	3. Hard. clay. and silty. Clay	> 700
B	1. Soft. volcanic. rocks. such as tuff and. agglomerate. weathered. cemented sedimentary. rocks with planes of. discontinuity	700-1000
	2. Dense. sand,. gravel	400-700
	3. Very. stiff. clay, silty. clay	300-700
C	1. Highly. weathered. soft. metamorphic. rocks and cemented. sedimentary. rocks. with planes of. discontinuity.	400-700
	2. Medium dense. sand and. gravel	200-400
	3. Stiff .clay and. silty clay	200-300
D	1. Soft, deep alluvial. layers with. high. Groundwater level	<200
	2. Loose. sand	<200
	3. Soft. clay and. silty. clay	<200

4.3.3 Seismic Zones

Figure 6 in chapter 3 demonstrates all four seismic zones of Cyprus according to the NCSC-2015, while the northern part is considered a low seismic zone, then moderate and high seismic zones from the middle to the deep south, respectively, and a very small area of the island in the very south point is very high seismic zone. These seismic zones have different Peak Ground Acceleration values as shown in table 3.

Table 3

Seismic Zones (K.K.T.C. DEPREM BÖLGELERİNDE YAPILACAK BİNALAR HAKKINDA YÖNETMELİK 2015)

Seismic Zone	**PGA**
1	0.40-0.45
2	0.35-0.40
3	0.30-0.35
4	0.20-0.30

4.3.4 Reduction Factor

The seismic Load Reduction Factor, R, divides the elastic seismic loads in order to consider the nonlinear behavior of buildings during earthquake movements. The reduction factor can be determined by using the following equations:

$$Ra(T) = 1.5 + (R - 1.5)\frac{T}{T_A} \qquad FOR \quad 0 \leq T \leq T_A \qquad (4.3.1)$$

$$Ra(T) = R \qquad FOR \quad T_A \leq T \qquad (4.3.2)$$

Reduction factor values for natural vibration period T and various structural systems are defined in table 4.

Table 4

Structural System Behaviour Factors (R) for Reinforced Concrete Buildings (K.K.T.C. DEPREM BÖLGELERİNDE YAPILACAK BİNALAR HAKKINDA YÖNETMELİK 2015)

BUILDING STRUCTURAL SYSTEM	**Systems of Nominal Ductility Level**	**Systems of High Ductility Level**
Buildings in which seismic loads are fully resisted by frames	4	8
Buildings in which seismic loads are fully resisted by coupled structural walls	4	7
Buildings in which seismic loads are fully resisted by solid structural walls	4	6
Buildings in which seismic loads are jointly resisted by frames and solid and / or coupled structural walls	4	7

Systems of Nominal Ductility Level is referred to RC structures where seismic loads are resisted by only MRF. On the other hand, Systems of High Ductility Level is referred to RC structures where seismic loads are resisted by MRF+SW.

4.3.5 Importance Factor

Importance factor, I, is divided into four types according to the purpose of occupancy as shown in table 5.

Table 5

Building Importance Factor (K.K.T.C. DEPREM BÖLGELERİNDE YAPILACAK BİNALAR HAKKINDA YÖNETMELİK 2015)

Purpose of Occupancy or Type of Building	**I**
1. Buildings required to be utilized after the earthquake and buildings containing hazardous materials a) Buildings required to be utilized immediately after the earthquake (Hospitals, dispensaries, health wards, fire fighting buildings and facilities, PTT and other telecommunication facilities, transportation stations and terminals, power generation and distribution facilities; governorate, county and municipality administration buildings, first aid and emergency planning stations) b) Buildings containing or storing toxic, explosive and flammable materials, etc	1.5
2. Intensively and long-term occupied buildings and buildings preserving valuable goods a) Schools, other educational buildings and facilities, dormitories and hostels, military barracks, prisons, etc. b) Museums	1.4
3. Intensively but short-term occupied buildings Sport facilities, cinema, theatre and concert halls, etc.	1.2
4. Other buildings Buildings other than above defined buildings. (Residential and office buildings, hotels, building-like industrial structures, etc.)	1

4.4 Eurocode 8 (EC 8)

4.4.1 Overview

This seismic code is specified for earthquake resistance design and is used in the European Union (EU) and some affiliated countries. Its first version was in 1971 till the last version was published in 2007 which is the fifth version of the Serie (Cutia & Țurcan, 2020).

This code is general for all the United European countries; hence, it's expected from each country to issue its own national annex.

4.4.2 Soil Types

There are Seven ground types to be considered according to EC 8. To determine the soil type depending on Shear wave velocity, standard penetration test blow-count and undrained shear strength of soil as shown in table 6.

Table 6

Ground Types (CYPRUS NATIONAL ANNEX)

Ground type	Description of stratigraphic profile	Vs,30 (m/s)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	>800
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360-800
C	Deep deposits of dense or mediumdense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180-360
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	<180
E	A soil profile consisting of a surface alluvium layer with vs values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with vs > 800 m/s.	
S1	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index (PI > 40) and high water content	<100 (indicative)
S2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S1	

4.4.3 Seismic Zones

Seismic zones are divided by the national authorities according to the hazard of the area, and the reference peak ground acceleration value is chosen for any seismic zone. According to EC 8, the elastic response spectrum is called for the earthquake movements at any certain point on the studied surface area due to the elastic earth acceleration response spectrum as shown in figure 8.

The Peak Ground Acceleration (PGA) values in accordance with Cyprus are divided in the table 7.

Figure 8

Elastic Response Spectrum (CYPRUS NATIONAL ANNEX)

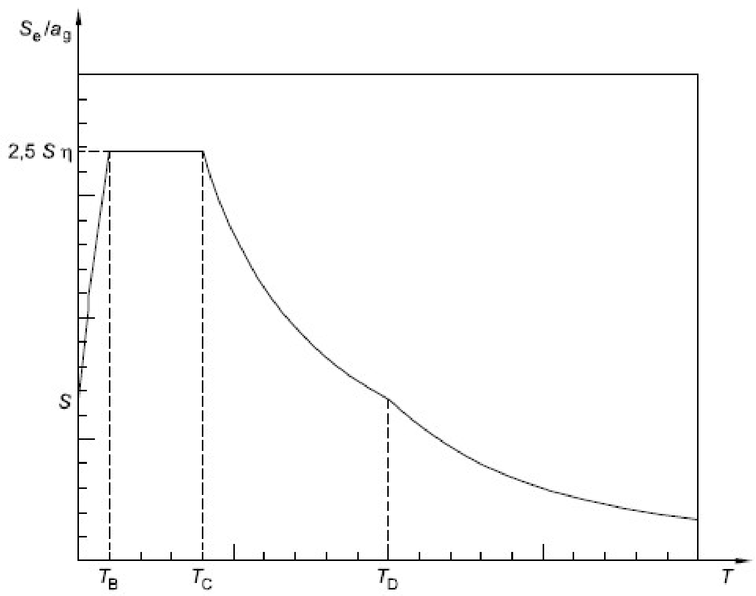


Table 7

Seismic Zones (CYPRUS NATIONAL ANNEX)

Seismic Zone	PGA
1	0.15
2	0.2
3	0.25

4.4.4 Behavior Factors for Horizontal Seismic Actions

Inserting the behavior factor (q) reduces the response spectrum, and the behavior factor is used in the elastic analysis when the viscous damping equals 5% and according to the ductility levels. Higher ductility classes (DCH) structural systems and medium ductility classes (DCM) structural systems. The behavior factor (q) values for DCM, and DCH are given in table 8.

Table 8

Behaviour Factor (q) Value (Eurocode 8)

Type of Structure	**DCM**	**DCH**
Uncoupled wall system	3	4 $\alpha u/\alpha 1$
Torsional flexible system	2	3
Inverted pendulum system	1.5	2
Frame system, dual system, coupled wall system	3 $\alpha u/\alpha 1$	4.5 $\alpha u/\alpha 1$

$\alpha u/\alpha 1$ can be defined using the following table 9 and table 10.

Table 9

αu /α1 Values for Frames or Frame-Equivalent Dual Systems (Eurocode 8)

Frames or frame-equivalent dual systems	**$\alpha u/\alpha 1$**
One-storey buildings	1.1
Multistorey, one-bay frames	1.2
Multistorey, multi-bay frames or frame-equivalent dual structures	1.3

Table 10

αu/α1 Values for Wall or Wall-Equivalent Dual Systems (Eurocode 8)

Wall or wall-equivalent dual systems	**αu/α1**
wall systems with only two uncoupled walls per horizontal direction	1
other uncoupled wall systems	1.1
wall-equivalent dual, or coupled wall systems	1.2

Where:

αu multiplier of horizontal seismic design action at formation of global plastic mechanism

α1 multiplier of horizontal design seismic action at formation of first plastic hinge in the system

4.4.5 Importance Factor

The importance factor, γI is divided into four types according to the importance of the structure as shown in table 11.

Table 11

Building Importance actor (Eurocode 8)

Importance factor	**Buildings**	**Importance Value**
I	Buildings of minor importance for public safety, e.g. agricultural buildings, etc	0.8
II	Ordinary buildings, not belonging in the other categories.	1
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc.	1.2
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc	1.4

4.5 Turkish Building Earthquake Code 2018 (TBEC-2018)

4.5.1 Overview

This version came after the 2011 Van earthquake with Mw=7.6 magnitude and started to be prepared in 2018 and in January 2019 it came into force. The major change and advantage in this code was the ability to use a specific design spectrum according to the location instead of using seismic zones. Moreover, it has six different ground types. Additionally, this code added both horizontal and vertical elastic designs while the previous version has only the horizontal elastic design. Also, this code added the mixed-function, and wooden structures design regulations (Işık, 2021**).**

4.5.2 Soil Types

There are six ground types to be considered in TBEC-2018. In order to determine the soil type depending on Shear wave velocity, standard penetration test blow-count and undrained shear strength of soil as shown in table 12.

Table 12

Ground Types (TBDY-2018)

Ground Type	Soil Description	Vs30 (m/s)
ZA	Solid, Hard rocks	>1500
ZB	Less weathered, moderately strong rocks	760-1500
ZC	Very tight layers of sand, gravel and hard clay or weathereed, highly fractured weak rocks	360-760
ZD	Medium firn-firm sand, gravel or very solid clay layers	180-360
ZE	Loose sand, gravel or soft-solid clay layers or profiles with a total thickness of more than 3 meters of soft clay layer (cu < 25 kPa) satisfying PI > 20 and w > 40%	<180
ZF	Grounds that require site-specific research and evaluation: 1) Soils with the risk of collapse and potential collapse under the effect of earthquakes (liquefiable soils, highly sensitive clays, collapsible weakly cemented soils, etc.), 2) Clays with a total thickness of more than 3 meters of peat and/or high organic content, 3) High plasticity (PI > 50) clays with a total thickness of more than 8 meters, 4) Very thick (> 35 m) soft or medium solid clays.	

4.5.3 Seismic Zones

The seismic zone methodology has the biggest change in this code as mentioned previously, while this code provides the ability to find all needed parameters like the Peak Ground Acceleration and the Peak Ground Velocity for each Province of Turkey as shown in table 13.

Table 13

Earthquake Parameters (Işik, 2020)

Province	Earthquake Parameters					
	Ss	**S1**	**PGA**	**PGV**	**Fs**	**F1**
Balikesir	0.88	0.219	0.372	21.591	1.2	1.5
Bilecik	0.566	0.177	0.238	15.616	1.274	1.5
Bursa	0.854	0.228	0.356	21.807	1.2	1.5
Çanakkale	0.713	0.216	0.3	19.51	1.215	1.5
Edirne	0.424	0.132	0.18	11.663	1.3	1.5
İstanbul	0.977	0.27	0.4	24.668	1.2	1.5
Kırklareli	0.387	0.128	0.165	11.085	1.3	1.5
Kocaeli	1.633	0.444	0.668	55.648	1.2	1.5
Sakarya	1.581	0.433	0.643	51.11	1.2	1.5
Tekirdağ	0.956	0.263	0.391	24.542	1.2	1.5
Yalova	1.477	0.392	0.603	42.287	1.2	1.5

Where:

$$S_{DS} = S_S . F_S \quad (4.5.1)$$

$$S_{D1} = S_1 . F_1 \quad (4.5.2)$$

$$T_B = S_{D1}/S_{DS} \quad (4.5.3)$$

$$T_A = 0.2 \, . T_B \quad (4.5.4)$$

S_S Spectral acceleration coefficient for short period of time

S_1 Spectral acceleration coefficient for 1 second period of time

F_S Soil effect coefficient for short period of time

F_1 Soil effect coefficient for 1 second period of time

The previous table is not used in this study because the study case is in Cyprus, but it is important to mention the advanced used technologies in this code.

S_S, S_1, F_S, *and* F_1 these parameters are shown in table 14 and table 15.

Table 14

Soil Effect Coefficient (Fs) for Short Period (TBDY-2018)

Ground type	**Ground effect coefficient for short period Fs**					
	Ss<=0.1	**Ss=0.50**	**Ss=0.75**	**Ss=1.00**	**Ss=1.25**	**Ss>=1.50**
ZA	0.8	0.8	0.8	0.8	0.8	0.8
ZB	0.9	0.9	0.9	0.9	0.9	0.9
ZC	1.3	1.3	1.2	1.2	1.2	1.2
ZD	1.6	1.4	1.2	1.1	1	1
ZE	2.4	1.7	1.3	1.1	0.9	0.8
ZF	A Special ground behaviour analysis should be carried out					

Table 15

Ground Effect Coefficient (F1) for 1 Second Period (TBDY-2018)

Ground type	**Ground effect coefficient for 1 second period F1**					
	S1<=0.1	**S1=0.20**	**S1=0.3**	**S1=0.4**	**S1=0.5**	**Ss>=0.6**
ZA	0.8	0.8	0.8	0.8	0.8	0.8
ZB	0.8	0.8	0.8	0.8	0.8	0.8
ZC	1.5	1.5	1.5	1.5	1.5	1.5
ZD	2.4	2.2	2	1.9	1.8	1.7
ZE	4.2	3.3	2.8	2.4	2.2	2
ZF	A Special ground behaviour analysis should be carried out					

4.5.4 Ductility Levels of Structural Systems:

The Structural Behavior Factor (R) and Overstrength Factor (D) can be obtained from several tables according to the ductility structure system of the building in this code according to different cases. The used case here is cast-in-place reinforced concrete building systems, and the values can be obtained from table 16.

Table 16

Structural Behavior Factor (R) and Overstrength Factor (D) for High Ductile Structural Systems (TBDY-2018)

Building Structural System	**Structural Behavior Factor (R)**	**Overstrength Factor (D)**
Buildings in that earthquake loads are fully resisted by moment transmitting high ductile frames	8	3
Buildings in that earthquake loads are fully resisted by high ductile coupled structural walls	7	2.5
Buildings that earthquake loads are fully resisted by high ductile solid structural walls	6	2.5
Buildings in that earthquake loads are resisted together by moment transmitting high ductile reinforced concrete frames and coupled structural walls	8	2.5
Buildings in that earthquake loads are resisted together by moment transmitting high ductile reinforced concrete frames and solid structural walls	7	2.5
Earthquake loads are resisted by single storey	3	2

4.5.5 Importance Factor

Importance factor, I, is divided into three types according to the purpose of occupancy as shown in table 17.

Table 17

Building importance factor (TBDY-2018)

Building type	Purpose of Occupancy	I
1	Buildings that need to be used after an earthquake, long-term and intense buildings where valuables are stored buildings and buildings containing hazardous materials a) It should be used immediately after an earthquake buildings (Hospitals, dispensaries, health centers, fire brigade buildings and facilities, PTT, and other communication facilities, transportation stations, terminals, energy production and distribution facilities, province, district governorship and municipal administration buildings, first aid, and disaster planning stations) b) Schools, other educational buildings and facilities, dormitories and dormitories, military barracks, prisons, etc. c) Museums d) Toxic, explosive, flammable, etc. with features where substances are found or stored in b	1.5
2	Intensively but short-term occupied buildings Shopping centers, sports facilities, cinemas, theatres, concert halls, places of worship, etc.	1.2
3	other buildings Buildings that are not related into first or second type like: other buildings (Houses, workplaces, hotels, building type industry structures, etc.)	1

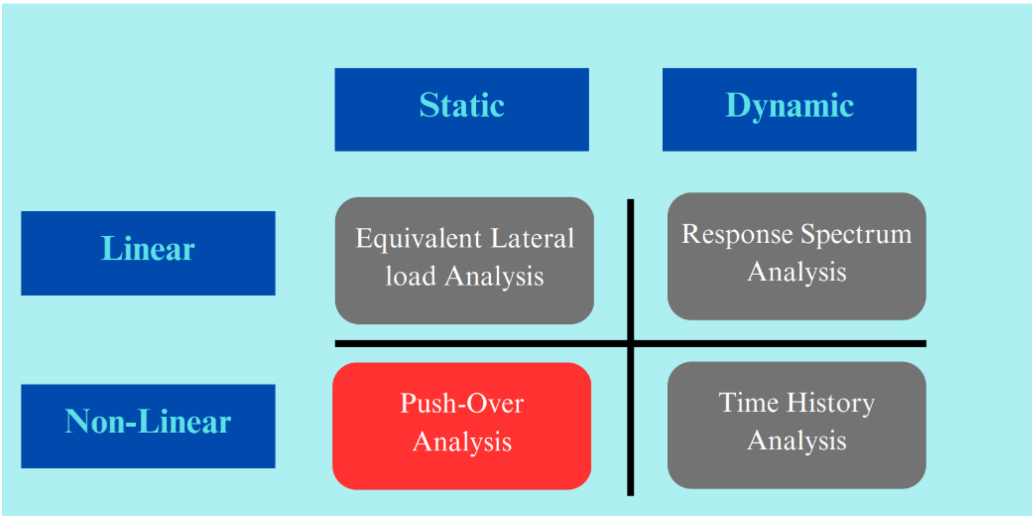
CHAPTER V
Seismic Analysis Methods

5.1 Overview

Earthquakes are unpredictable and random events. In the earthquake design of structures, four different methods can be used to evaluate the seismic behavior of the structures show below in Fig 9. This chapter is describing briefly the Seismic Analysis Methods and is describing the Nonlinear Static Method in detail.

Figure 9

Seismic Analysis Methods



In general, all these four methods can be taken into account to evaluate the seismic analysis where the Time History Analysis is the most accurate method as well as the most complicated one. In this study, the Push-Over Analysis method is used.

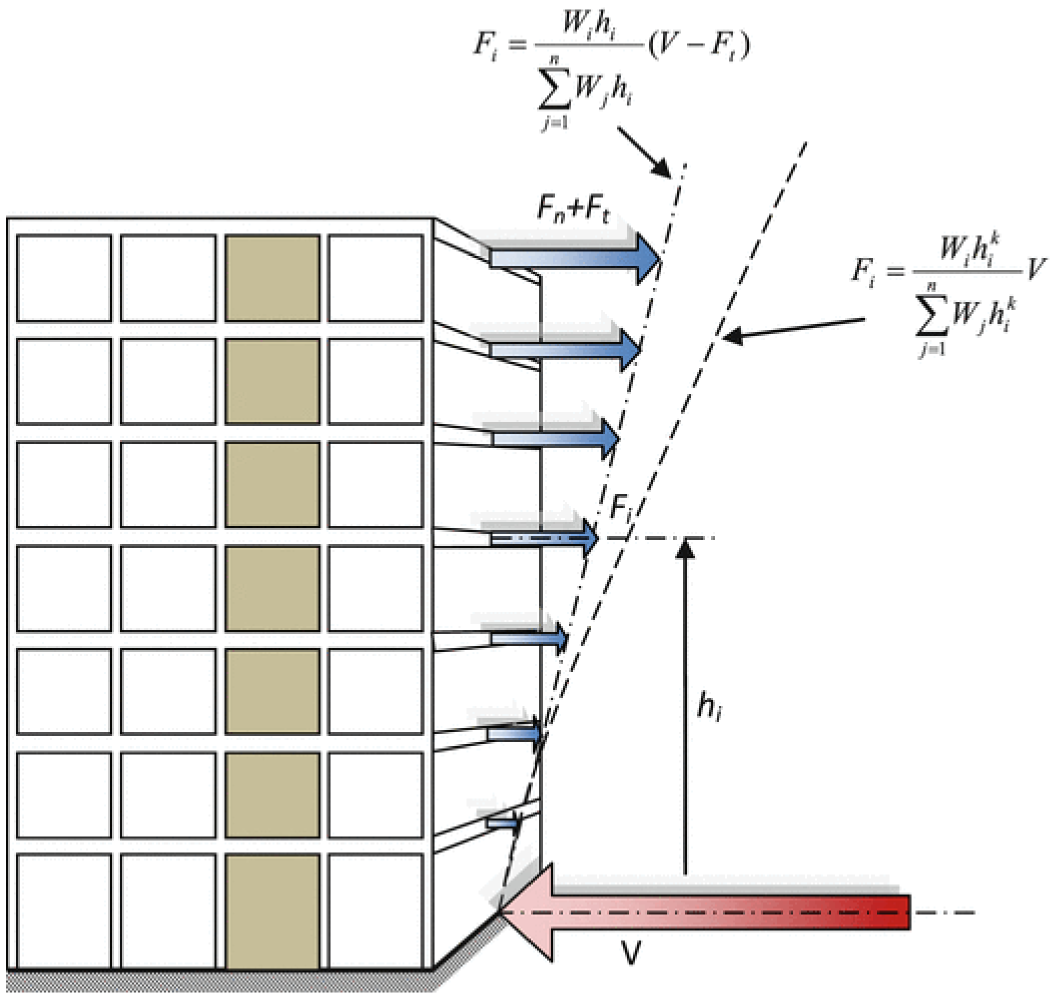
5.2 Linear Static Analysis (Equivalent Lateral Load):

This method can be defined as a simplified technique that distributes the static forces laterally on a building after substituting these forces from the affection of dynamic forces. (Bourahla, 2014)

This method is common and can be applied to most regular buildings, also it's the fastest method due to the simple practical way it uses and its availability in the codes. While, it uses a simple formula for stiffness and mass to calculate the total base shear, followed by distributing the obtained base shear along the building heights as shown in Fig 10. (Hamed, 2018)

Figure 10

Equivalent Static *Analysis of Structure Subjected to Seismic Actions (Hamed, 2018).*

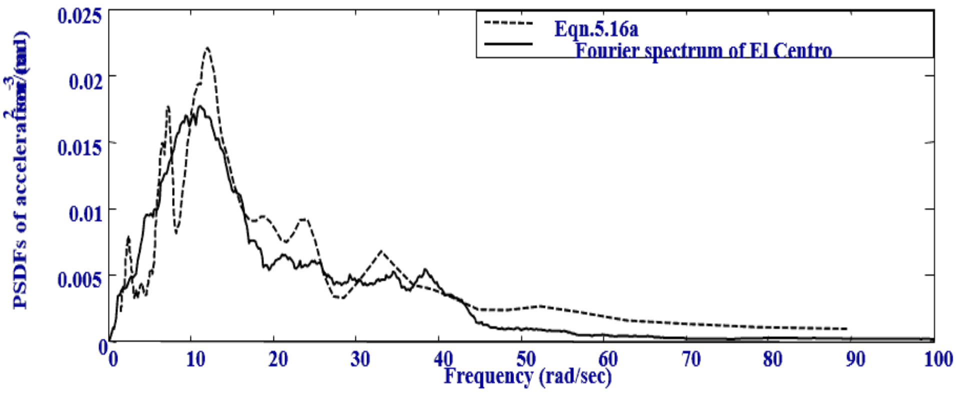


5.3 Linear Dynamic Analysis Method (Response Spectrum Analysis)

This method can be defined as response spectrum curves between maximum response and frequency of SDOF subjected to earthquake motion to obtain the developed lateral forces in a building due to earthquake, and any response of the linear system can be picked up from the natural oscillation of the plot (Hamed, 2018), as shown in Fig 11.

Figure 11

Response Spectrum Analysis Curve (Hamed, 2018)



Two important parameters to consider in the response spectrum:

5.3.1 Natural Time Period:

The needed time to finish one complete cycle of vibration considering the mass and the stiffness of the structure.

If the mass increases the period increases, and if the stiffness increases the period decreases. Therefore, short buildings vibrate faster and they are stiffer than tall buildings.

5.3.2 Acceleration:

The acceleration is the response of the structure to an earthquake and is measured by the relative displacement to get the shear force.

5.4 Nonlinear Static Analysis Method (Pushover)

Previous studies provided multiple definitions for the nonlinear static analysis method such as:

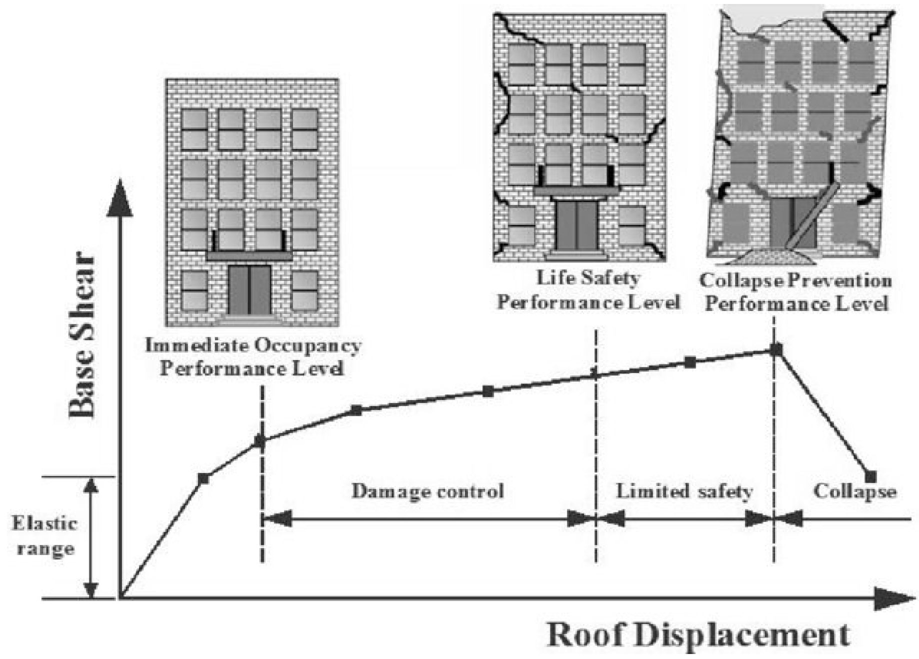
- Pushover method is defined as the magnitude of the incremental force in the horizontal direction to evaluate the seismic analysis of the structure and is described as a curve that compares the displacement of the structure versus the base shear. In other words, pushover analysis is the consideration of the vertical loads followed by the gradual increase in horizontal loads in both the x and the y directions (Daniel & John, 2016)

- This method works on pushing the structure up to failure; thus, it estimates ductility capacity and the collapse load. (Abd-Elhamed & Mahmoud, 2016**)**

In this study, the pushover analysis is the used method, so it is substantial to cover all aspects of this method. Therefore, the pushover analysis method is defined as the method that aims to push the structure till it reaches the maximum resistance, accordingly, the building either reaches a collapsed state or reaches the maximum limit without collapsing according to the applied earthquake properties such as PGA, soil type, spectral acceleration, etc. Furthermore, the structure does not need to collapse, so if the applied earthquake properties reached their maximum and the building didn't show any critical hinges and didn't reach a collapsed state so this structure is safe according to these earthquake properties and from the maximum point the base shear and displacement can be obtained, but if the building collapsed so it means the applied earthquake properties pushed the building till it collapsed. Finally, this method evaluates the real strength and structure seismic performance as shown in Fig 12.

Figure 12

Capacity Curve of Structures with Demonstration of Damage State and Building Performance Level (Abd-Elhamed & Mahmoud, 2016)



Regardless the first Elastic limit, this figure induces four levels as shown in the table 18.

Table 18

Seismic Performance of Building Levels and Description

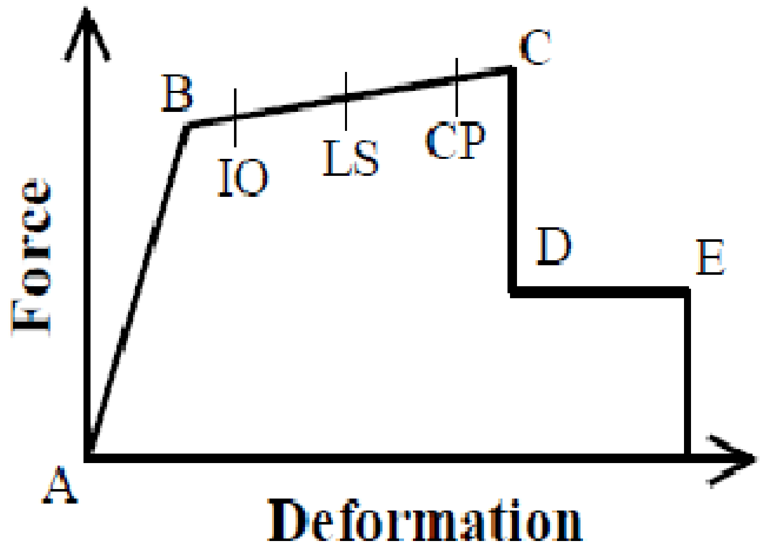
Level	Description
Operational	Temporary drift, very little damage, the structure retains original strength and stiffness, and all systems are normal
Immediate occupancy	Temporary drift, little damage, the structure retains its original strength and stiffness, fire protection still works, and the elevator can be restarted
Life safety	Some permanent drift, Fair damage, some residual strength and stiffness left, damage to partition, and the building may be beyond economical repair
Collapse prevention	Large displacement, Severe damage, little residual stiffness and strength while loading bearing column and wall function, the building is close to collapse

5.4.1 Performance Levels (Acceptance Criteria)

In the pushover analysis, the Plastic hinge describes a concrete member undergoing a large deformation in a stage called post-yield, and it's an assumed point that describes the entire deformation. The plastic hinge is labeled in five points considering the three points labeled IO, LS, and CP to define the acceptance criteria (Abd-Elhamed & Mahmoud, 2016) as shown in Fig 13.

Figure 13

The pushover Curve with Different 5 Stages of Plastic Hinge Formation (Abd-Elhamed & Mahmoud, 2016)



This figure induces the five labeled points A, B, C, D, and E these points define different deformation behavior of forces, and the three points labeled IO, LS, and CP are used to define as shown in table 19.

Table 19

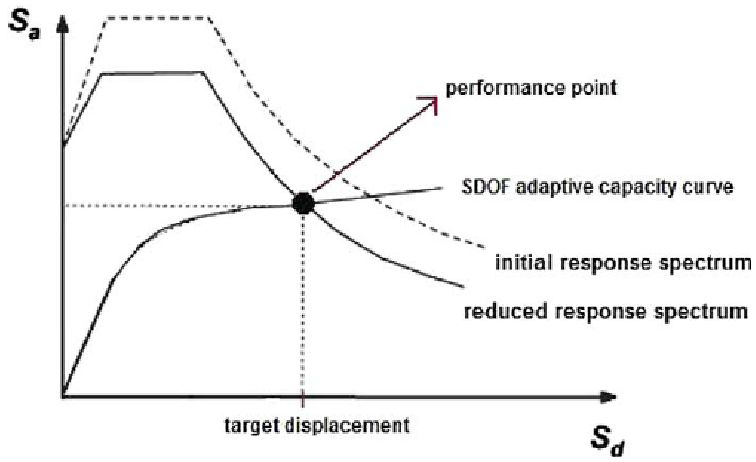
Different Deformation Behaviour of Plastic Hinges and Description

Point	Description
A	The origin point
B	The yield point
C	The ultimate point
D	Displacement capacity and residual strength
E	Displacement capacity and residual strength

Moreover, pushover targets to find a link between the seismic response spectrum which represents the imposes of earthquake according to a certain location, with the capacity curve which represents the structure performance in a point called the performance point, as shown in Fig 14.

Figure 14

Response spectrum curve and capacity curve linked with the performance point (Bento & Bhatt, 2014)



As shown in the previous figure, the performance point is the intersection between the response spectrum curve and capacity curve which represents the maximum base shear and target displacement for a certain building according to a specific earthquake ground motion.

5.4.2 Plastic Hinges Concept

Plastic hinges occur when the bending strength of a member has been reached and all the materials reach their plastic limits, and if the members remain stable at that point, then they will start rotating without an increase in the resisting moment. For example, if a beam has a bending capacity of 1000 kN.m then after the beam hits 1000 kN.m it will start rotating in a plastic state without increase in this moment. In other words, plastic hinges are visualization hinges that are placed in the corners of beams and columns (the locations of the most common collapse scenario during earthquakes) to evaluate and define the occurrence of the first plastic hinge.

In addition, all loads are transferred to the foundations by the columns. Therefore, columns should be more rigid than beams in order to form the plastic hinges (Hama & Sadeghi, 2023)

5.5 Nonlinear Dynamic Analysis Method (Time History Analysis)

This method is the most accurate and reliable method where it provides the response and the displacement history at all joints of the structure. On the other hand, the analysis procedure is complex in this method where it uses numerical analysis methods such as integration, and the analysis can be done in steps procedure. Firstly, determine the time-step value and apply the analysis. Secondly, repeating the analysis for each time interval.

Finally, the other methods are more common and more used in the current time due to the complexity of this method and the less conservative design solutions.

5.6 The differences between Seismic Analysis methods

The main differences (Advantages, Disadvantages) between Seismic Analysis methods can be described in table 20.

Table 20

The Advantages and Disadvantages of Seismic Analysis Methods (Čada & Máca, 2017)

Method	Advantages	Disadvantages
Equivalent lateral load	Simplest method Most conservative method Used for simple regular structures Can be done with hand calculations	The only material behaviour is linear
Response Spectrum	Suitable for more complicated structures Common in the practice work	Not suitable for structure with oversized members
Pushover	The best method for reconstructions or designing new structures Considered fast despite the nonlinearity	Less Accurate than time-history
Time-history	Suitable for the analysis for already known earthquakes	Complicated
	The most accurate method	Time consuming

CHAPTER VI
Methodology

6.1 Overview

In this chapter, case studies were analyzed according to NCSC-2015, EC 8, and TBEC-2018 using ETABSv18 computer software for analyzing and performing the non-linear static pushover analysis.

6.2 Structure Configurations

In this study, regular and irregular floorplan structures were selected, where for each selected plan, the ground story height is 3.2 m, whereas the remaining stories' heights are 3 m with considering the basements as fixed. Additionally, Plastic hinges were added at 10% and 90% of the length of each column and beam, to achieve more accurate results while applying the pushover analysis method and observing plastic hinges occurrence, which is practical to predict the first member to fail.

Two locations were chosen for the study: Yeni Iskele (Long Beach region) and Nicosia (Gönyeli region). The two different places have different types of soil. The ground surveys conducted against earthquakes in the country stated that the coast of the Long Beach region has the lowest bearing capacity, where it has a liquefaction potential (Selcukhan & Ekinci, 2023). At all events, these two locations were selected due to the noticeable increase in the population and urbanization as shown below in Fig 15 and Fig 16.

Figure 15

Nicosia City, Gonyeli region satellite view, a)2012, b)2023 (earth.google.com)

a)

b)

Figure 16

Yeni Iskele City, Long Beach region satellite view, a)2012, b)2023 (earth.google.com)

a)

b)

The analyzed models in this study are MRF system and MRF+SW system with two different SW span lengths of 5m and 1.5m in regular form for low, mid, and high-rise buildings and in irregular form for only high-rise buildings. In addition, the member sizes are kept the same between the three selected codes at each structure with the same story to strengthen the comparison.

6.2.1 Regular Structures

The regular structure is the structure that has no significant discontinuities in the plan. Also, it can be defined as a structure that has continuities in plan and vertical configurations (Naveen et al, 2019).

A regular typical plan was selected as a residential building with 3 different story configurations (G+3, G+7, and G+11), having the dimensions 25m on the X axis and 25m on the Y axis, consisting of 5 bays with a 5m bay length in each direction.

- Moment-Resisting Frame (MRF) in regular form as shown in Fig 17 and Fig 18.

Figure 17

Floor Flan for Moment-Resisting Frame (MRF) in Regular Form

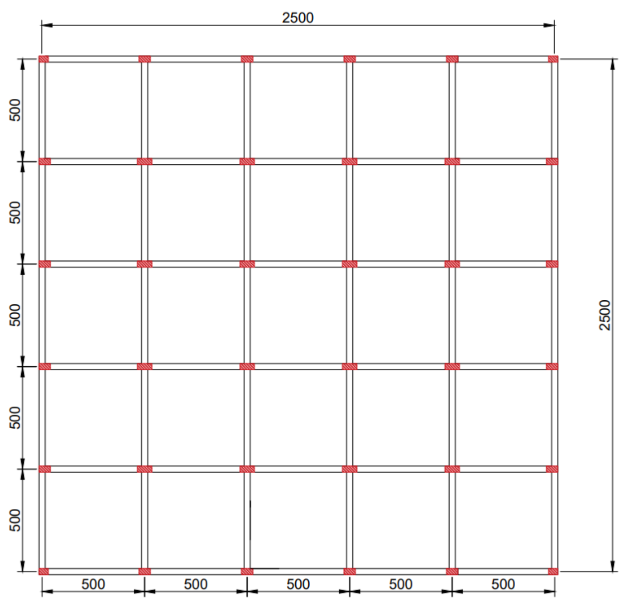
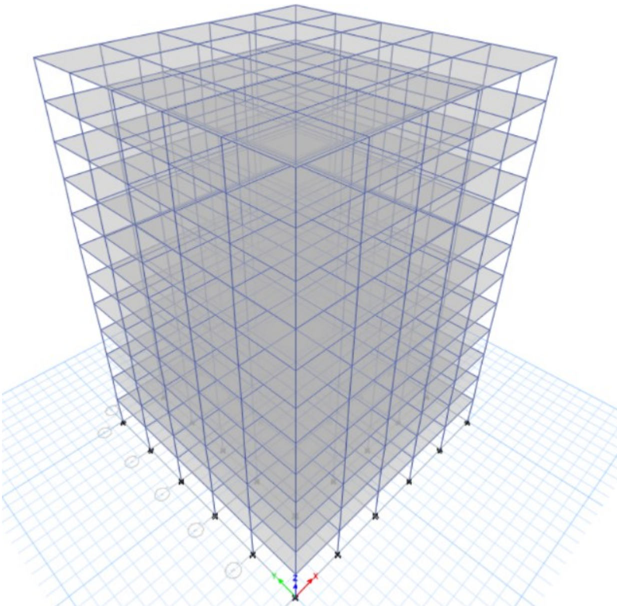


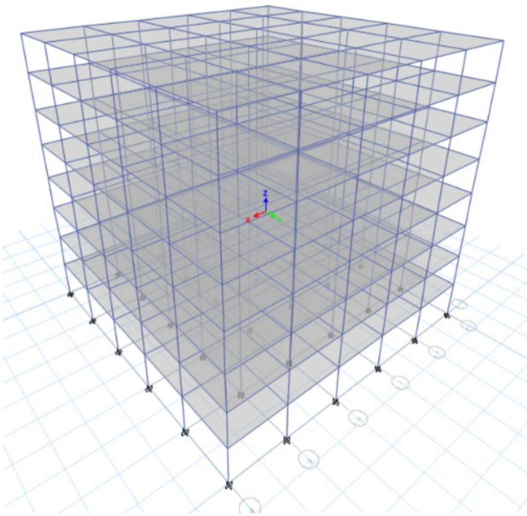
Figure 18

The 3D dimensional view for moment resisting frames (MRF) in regular form. a) G+3 Stories, b) G+7 Stories, c) G+11 Stories

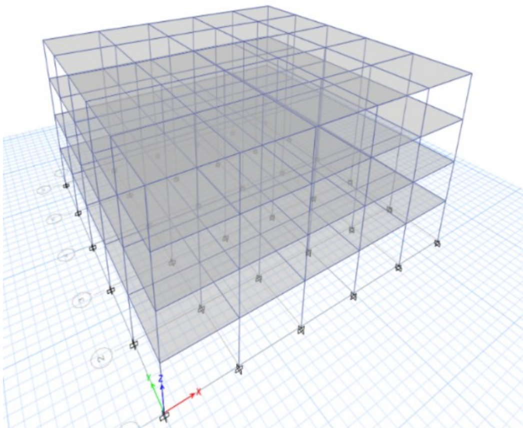
a)



b)



c)



- Moment-Resisting Frame with Shear Walls (MRF+SW) in regular form as shown in Fig 19 and Fig 20.

Figure 19

Floor Plan for Moment-Resisting Frame with Shear Walls (MRF+SW) in Regular Form with 5 m Shear Walls Span Length.

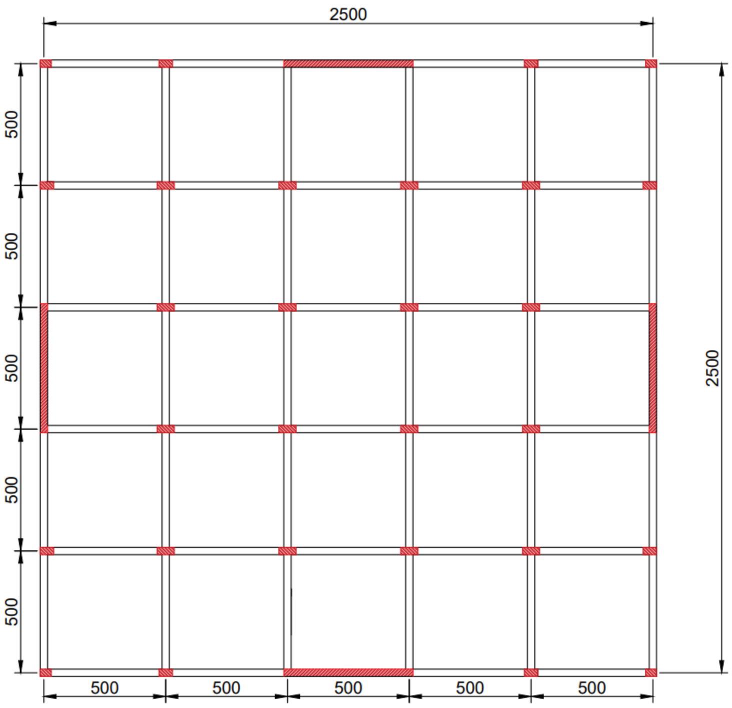
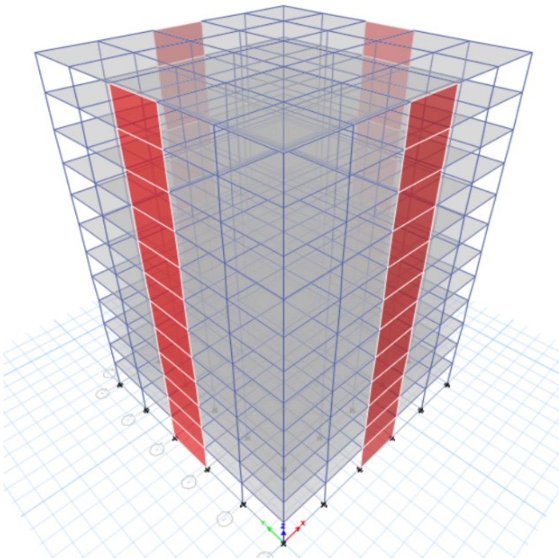


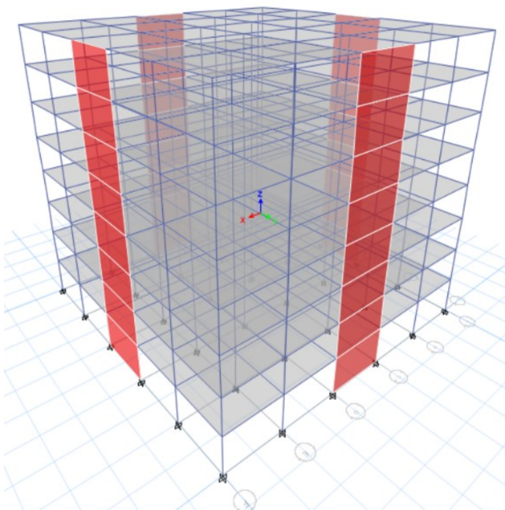
Figure 20

The 3D dimensional view for (MRF+SW) in regular form with 5 m shear walls Span Length. a) G+3 Stories, b) G+7 Stories, c) G+11 Stories

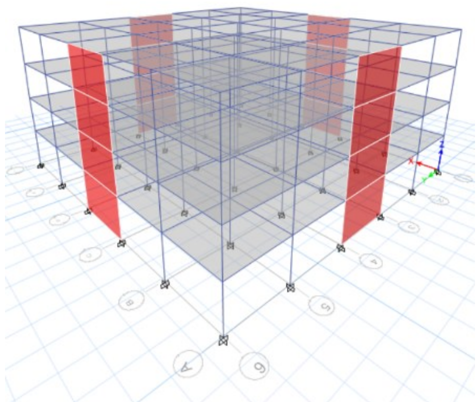
a)



b)



c)



In general, comparative studies focus on the comparison without considering the realism of the selected floor plans. Accordingly, as shown in the previous figures, the selected shear walls' span length is 5 meters which is difficult to apply in reality. Therefore, another floor plan was selected with 1.5 m shear walls span length to make the study more real and achieve more accurate results as shown in Fig 21 and Fig 22.

Figure 21

Floor Plan for Moment-Resisting Frame with 1.5m Span Length Shear Walls (MRF+SW) in Regular Form

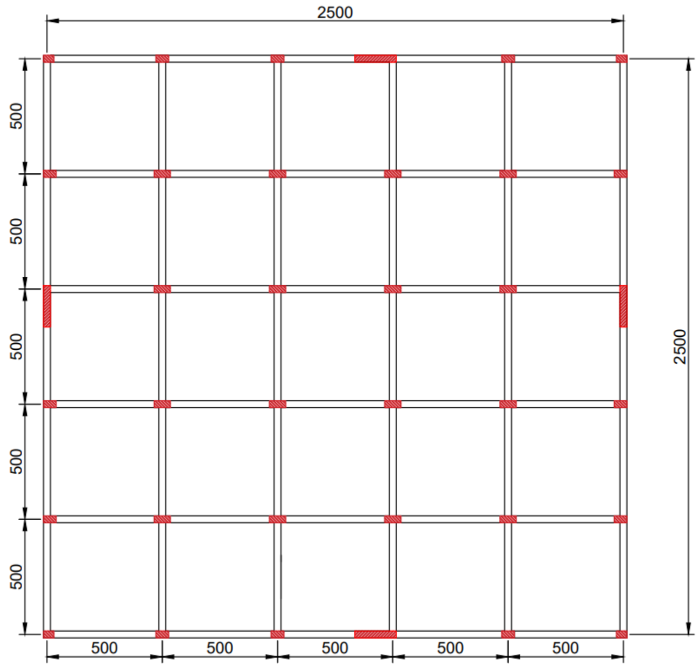
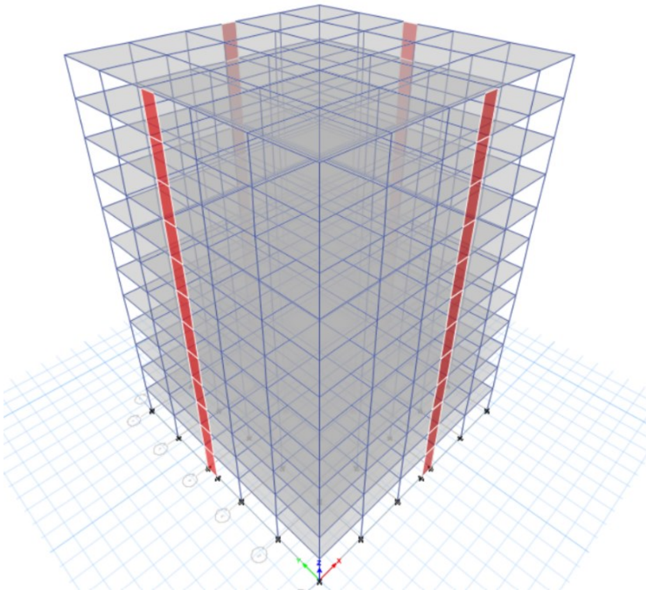


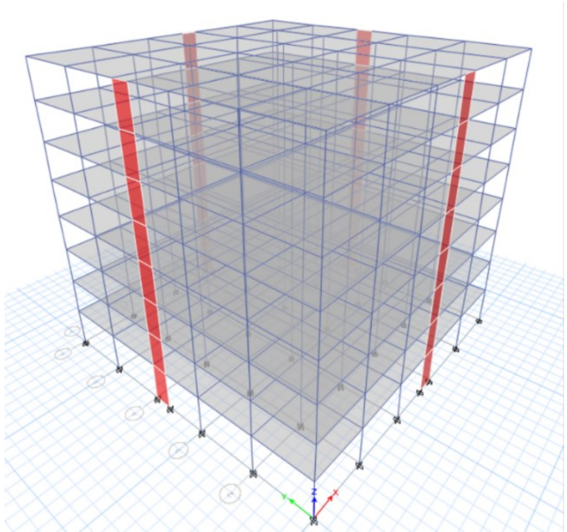
Figure 22

The 3D Dimensional View for (MRF+SW) in Regular Form with 1.5m Shear Walls Span Length. a) G+3 Stories, b) G+7 Stories, c) G+11 Stories

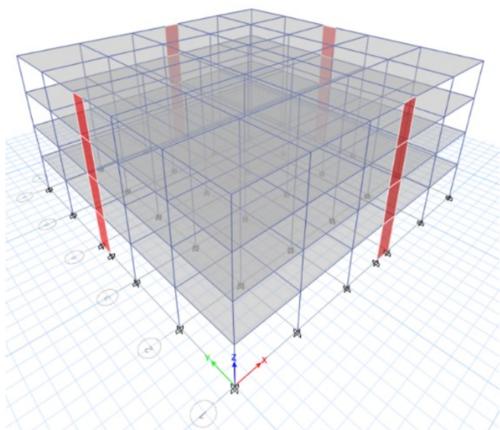
a)



b)



c)



6.2.2 Irregular Structures

An irregular structure is a structure that has discontinuities in either plan or vertical configurations or both and that affect the structure's performance when it's subjected to seismic loads. (Naveen et al, 2019).

An irregular plan was selected as a residential building consisting of G+11 stories, having the dimensions 25m in the X axis and 25m in the Y axis, consisting of discontinuous 5 bays with a 5m length of each bay.

- Moment-Resisting Frame (MRF) in irregular form as shown in Fig 23 and Fig 24.

Figure 23

Floor Plan for Moment-Resisting Frame (MRF) in Irregular Form

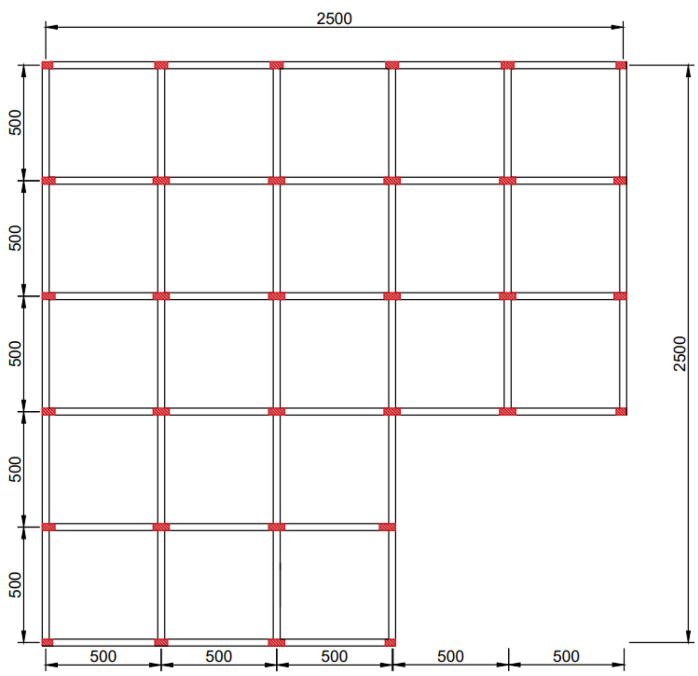
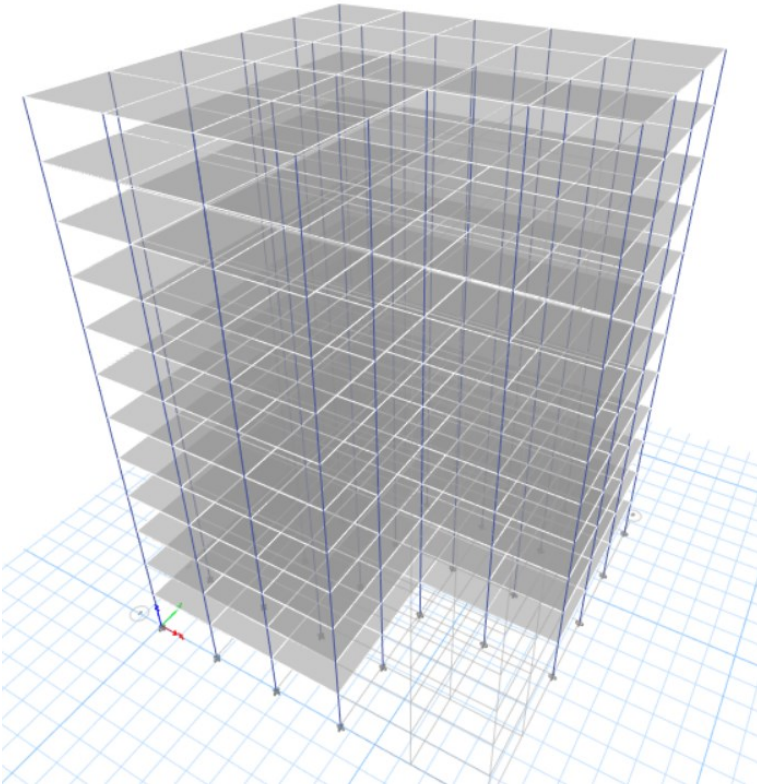


Figure 24

The 3D Dimensional View for (MRF) in Irregular Form



- Moment Resisting Frame with Shear walls (MRF+SW) in irregular form with 5m SW length span as shown in Fig 25 and Fig 26.

Figure 25

Floor plan for Moment-Resisting Frame with Shear Walls (MRF+SW) in Irregular Form with 5m SW Span Length

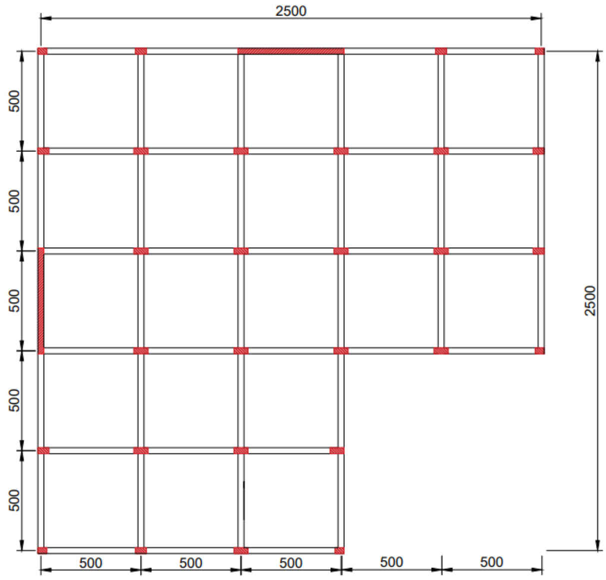
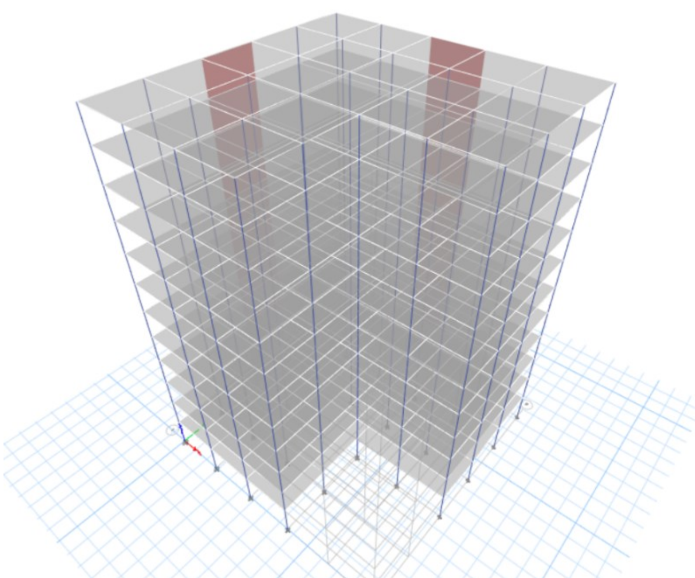


Figure 26

The 3D Dimensional View for (MRF+SW) in Irregular Form with 5m SW Span Length



This case also has been applied for a 1.5m SW length span as shown in Fig 27 and Fig 28.

Figure 27

Floor Plan for Moment-Resisting Frame with Shear Walls (MRF+SW) in Irregular Form with 1.5m SW Span Length

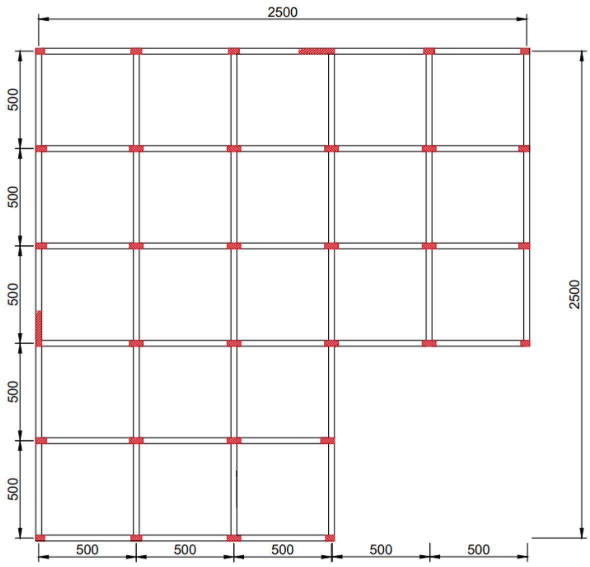
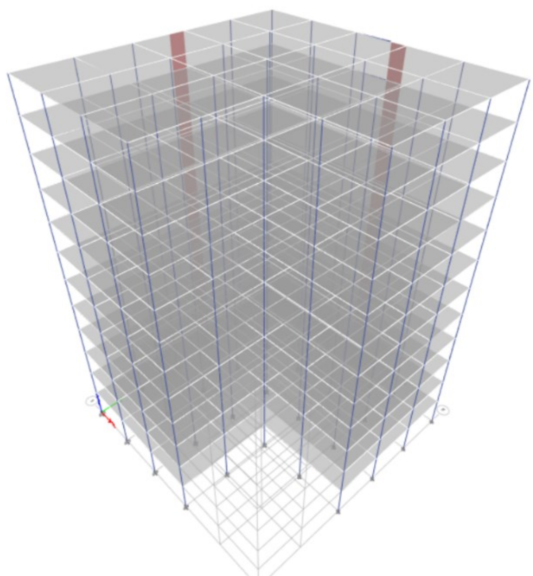


Figure 28

The 3D Dimensional View for (MRF+SW) in Irregular Form with 1.5m SW Span Length



6.3 Design Criteria

The targeted models were analyzed by applying the nonlinear static analysis (Pushover Analysis) using ETABSv18 software. Furthermore, the same loads were applied for all codes, such as dead load, super dead load, and live load. On the other hand, earthquake loads were selected according to the parameters of each code (see 6.3.4).

6.3.1 Material Properties:

The used materials for concrete and steel reinforcement for all cases are given in table 21.

Table 21

Material Properties of Steel, Concrete and Clay

Parameter	Value
Compressive Strength ($f'c$)	30 MPa
Unit weight of Concrete	30 kN/m^3
Concrete Modulus of Elasticity	25743 MPa
Yield Stress (Fy)	420 MPa
Minimum Tensile Strength (Fu)	520 MPa
Unit weight of Steel	78.5 kN/m^3
Steel Modulus of Elasticity	210000 MPa
Unit weight of Brick walls	16 kN/m^3

6.3.2 Section Properties

Regular and Irregular models were selected for the analyzed structures consisting of solid slabs, beams, clay brick walls, shear walls, and columns as shown in the following tables:

Table 22

Layout of Slab, Shear Wall ,Internal, and External Walls for The Residential Buildings.

Stories	Type	Thickness (mm)
All stories	Solid Slab	180
All stories	Shear Wall	250
All stories	Internal Walls	200
All stories	External Walls	250

Table 23

Layout of Beams for The Residential Buildings

Stories	Type	Carrying	Cross-Section (mm)
All Stories	Beam	Internal walls	500*250
All Stories	Beam	External walls	500*250

Table 24

Layout of Columns for G+3 Stories Residential Buildings

Stories	Type	Dimensions (mm)
G	Corner Column	300*400
	External Column	300*500
	Internal Column	300*600
1,2, and 3	Corner Column	300*300
	External Column	300*400
	Internal Column	300*500

Table 25

Layout of Columns for G+7 Stories Residential Buildings

Stories	**Type**	**Dimensions (mm)**
G	Corner Column	300*450
	External Column	300*550
	Internal Column	300*700
1,2, and 3	Corner Column	300*350
	External Column	300*450
	Internal Column	300*600
4,5,6, and 7	Corner Column	300*300
	External Column	300*400
	Internal Column	300*500

Table 26

Layout of Columns for G+11 Stories Residential Buildings

Stories	Type	Dimensions (mm)
G	Corner Column	300*600
	External Column	300*700
	Internal Column	300*800
1,2, and 3	Corner Column	300*500
	External Column	300*600
	Internal Column	300*700
4,5, and 6	Corner Column	300*400
	External Column	300*500
	Internal Column	300*600
7,8, and 9	Corner Column	300*350
	External Column	300*400
	Internal Column	300*500
10, and 11	Corner Column	300*300
	External Column	300*350
	Internal Column	300*400

6.3.3 Load Properties

Some of the applied loads are constant in the code standards according to the type of the building, whereas the rest can be taken according to the unit weight of the loads. Table 27 shows all loads details:

Table 27

Applied Loads on The Residential Buildings

Load Pattern	Value
Live load	2 kN/m^2
Super Dead load	2.5 kN/m^2
External wall	12 kN/m
Internal wall	9.6 kN/m

6.3.4 Earthquakes Properties

Earthquake properties are considered according to the requirements of each code, and the studied locations mentioned in this study.

The properties are shown in the following tables:

Table 28

NCSC-2015 Earthquake Regulations for Both Selected Locations in The Study

Property		Nicosia (Gönyeli region)	Yeni Iskele (Long beach region)
Seismic Zone		1	1
Peak Ground acceleration (PGA)		0.3	0.3
Ground type		C	D
Behaviour factor (R)	**MRF**	8	8
	MRF+SW	7	7
Importance factor (I)		1	1

In Eurocode 8, the behavior factor is calculated in this code according to the regularity and irregularity in the elevation of the structure and can be calculated using the following equations:

For MRF structures:

$q = 4.5\ \alpha u / \alpha 1 \ * 0.8$ ➔ $q = 4.5 * 1.3$ ➔ $q = 5.85$

For MRF+SW structures:

$q = 4.5\ \alpha u / \alpha 1 \ * 0.8$ ➔ $q = 4.5 * 1.2$ ➔ $q = 5.4$

Table 29

EC 8 Earthquake Regulations for Both Selected Locations in the Study

Property		Nicosia (Gönyeli region)	Yeni Iskele (Long beach region)
Seismic Zone		2	2
Peak Ground acceleration (PGA)		0.2	0.2
Ground type		C	E
Soil Factor		1.15	1.4
Importance factor (I)		1	1
Lower limit of the period (TB)		0.2	0.15
Upper limit of the period (TC)		0.6	0.5
The beginning of the constant displacement (TD)		2	2
Behaviour Factor q	**MRF**	5.85	5.85
	MRF+SW	5.4	5.4
Correction Factor		1	1

In TBEC-2018 is providing specific details about each location in Turkey, while the investigated study is focusing on Northern Cyprus. Therefore, some calculations have to be done to obtain the earthquake properties.

According to the seismic zoning Map of Cyprus in NCSC-2015, the peak ground acceleration for the two locations is equal to PGA=0.3 Therefore, the spectral acceleration of a short period can be obtained using the following formula (Lubkowski & Aluisi, 2012)

$\frac{S_S}{PGA} = 2.265$ ➔ $\frac{S_S}{0.3} = 2.265$ ➔ $S_S = 0.6795$

Also, the spectral acceleration of 1 second period can be obtained using the following formula (Lubkowski & Aluisi, 2012)

$\frac{S_1}{PGA} = 0.753$ ➔ $\frac{S_1}{0.3} = 0.753$ ➔ $S_1 = 0.2259$

Note: For more information regarding these equations, check Appendix F.

Table 30

TBEC-2018 Earthquake Regulations for Both Selected Locations in The Study

Property		**Nicosia (Gönyeli region)**	**Yeni Iskele (Long beach region)**
Spectral Acceleration for short period (Ss)		0.6795	0.6795
Spectral Acceleration for 1 second (S1)		0.2259	0.2259
Long-Period Transition Period		8	8
Site Class		ZC	ZE
Response Modification (R)	**MRF**	8	8
	MRF+SW	7	7
System Overstrength (D)	**MRF**	3	3
	MRF+SW	2.5	2.5
Importance factor (I)		1	1

6.4 Targeted Outcomes

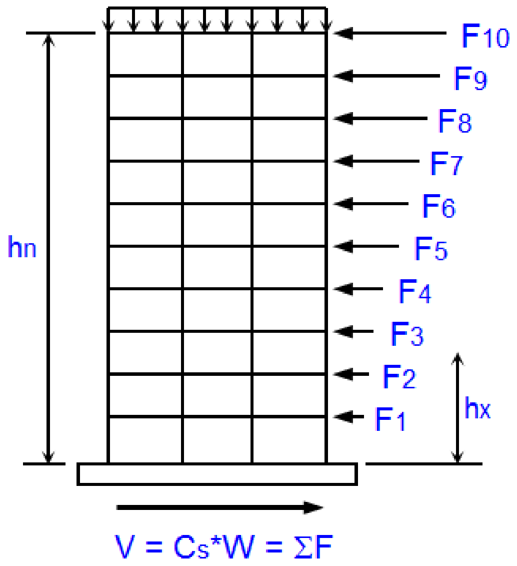
In this study, the intended goal is to achieve an accurate comparison between the three used codes and to illustrate the advantages and disadvantages of each code by comparing the following outcomes:

6.4.1 Base Shear

Base shear is the reaction at the base that supports the summation of all lateral loads acting on the whole building as shown in the figure 29. The obtained graph from the pushover analysis shows the required design base shear which is always less than the yielding base shear value.

Figure 29

Illustration of The Concept of Base Shear

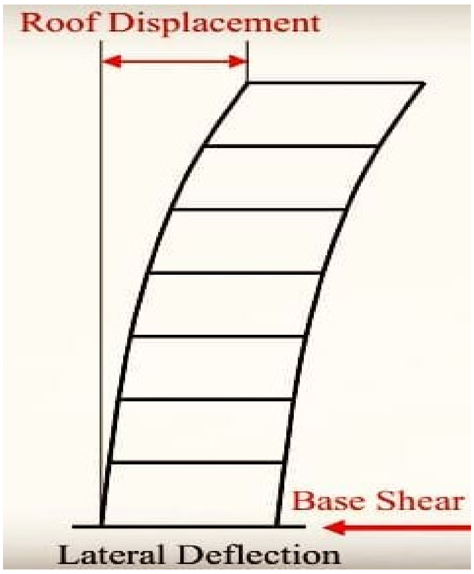


6.4.2 Displacement

Displacement is the estimation of the top seismic displacement of the structure when it's exposed to lateral earthquake forces (A. Ismail, 2014) In other words, the displacement of each story with respect to the base of the structure. Therefore, displacement and base shear have a positive relationship, and they can be obtained from the pushover curve. In addition, as mentioned previously the base reaches its peak at the base, where the displacement reaches its peak at the top as shown in Fig 30.

Figure 30

Illustration of The Concept of Displacement (Marabi & Marsono, 2016)

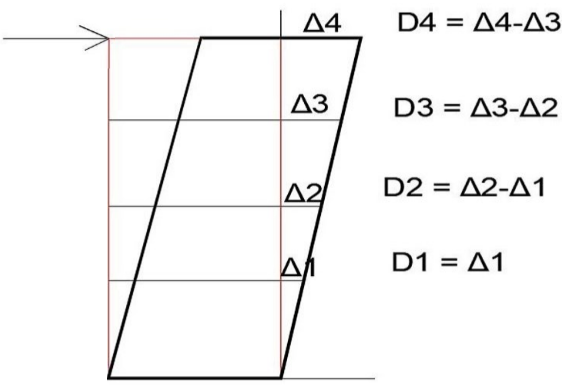


6.4.3 Story Drift

The story drift is the lateral displacement of a story with respect to the story below. In other words, story drift is a ratio that equals the drift of the story over the height of the story. This means, story drift and displacement have the same target but the only difference is that story drift expresses the displacement as a ratio in each story independently as shown in Fig 31.

Figure 31

Illustration of The Concept of Story Drift

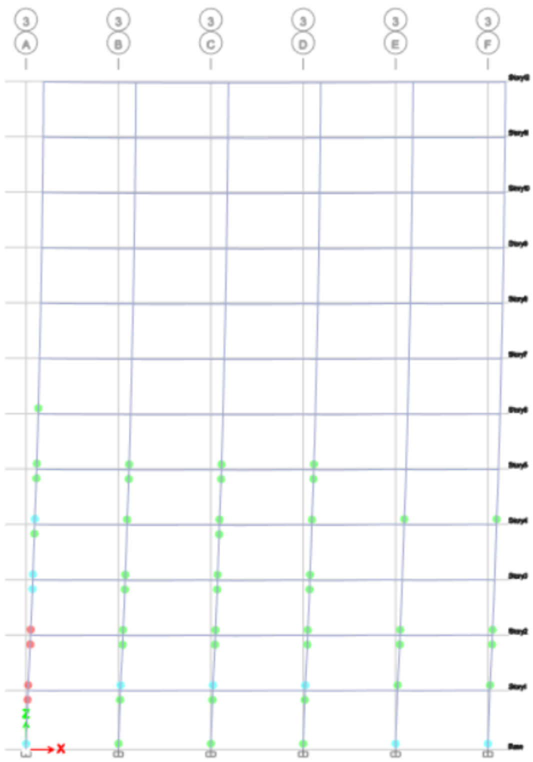


6.4.4 Plastic Hinges

Plastic hinges are the hinges that are placed at 10% space of each member's corner, and they are important to define the behavior of each member during earthquake loads. In addition, those hinges are located at the corners of the members because the connections between columns and beams are always the weakest locations of the building, and generally the collapse occurs due to the failure of one of these connections. The following figure shows the formation of plastic hinges.

Figure 32

The Formation of Plastic Hinges at The Corners of The Members



The green hinge refers that the state of the hinge being between IO and LS, the blue hinge refers to the state between LS and CP, and the red hinge refers to a state exceeding CP. These symbols have been described briefly in Chapter 5.

CHAPTER VII

Results and Discussion

7.1 Overview

In this chapter, all obtained results from the Non-linear Static Analysis method such as base shear, displacement, story drift, and plastic hinges occurrence were presented and explained as graphs and compared according to regular and irregular structures. The results were prepared in order of buildings type as follows:

7.2 MRF in Regular Form

The results such as base shear, displacement, story drift, and plastic hinges formation for MRF in regular form were obtained according to two soil types, three codes, and three different story structures with different numbers of stories.

7.2.1 Base Shear and Displacement

The pushover curve that shows the base shear forces and displacement for MRF residential buildings in regular form with different number of stories, different codes, and soil classes are shown below in Fig 33 and 34, respectively.

Figure 33

Pushover Curves for MRF structure in regular form, medium soil class

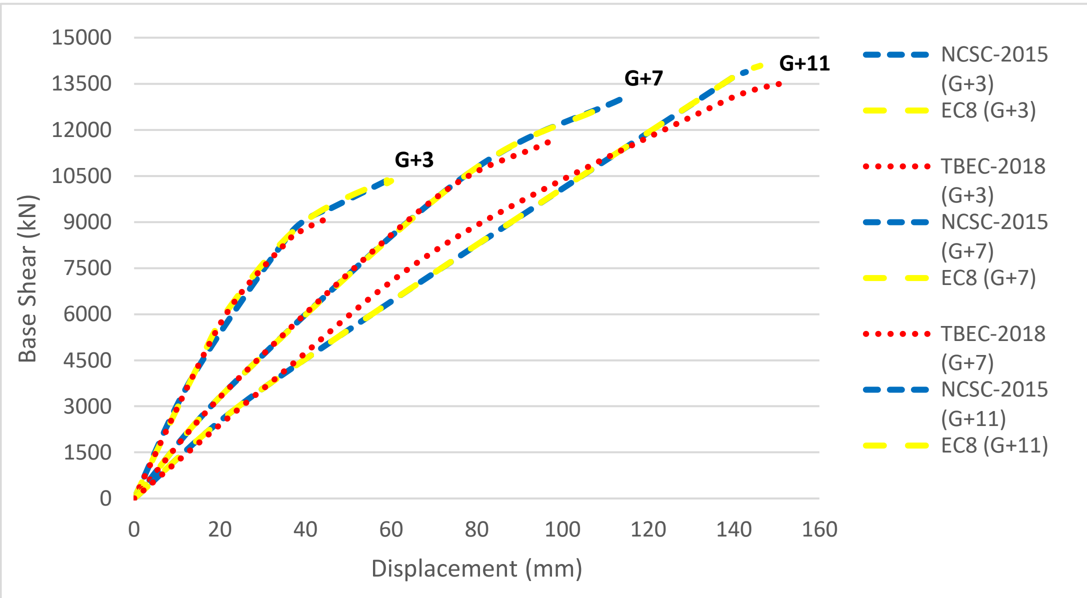
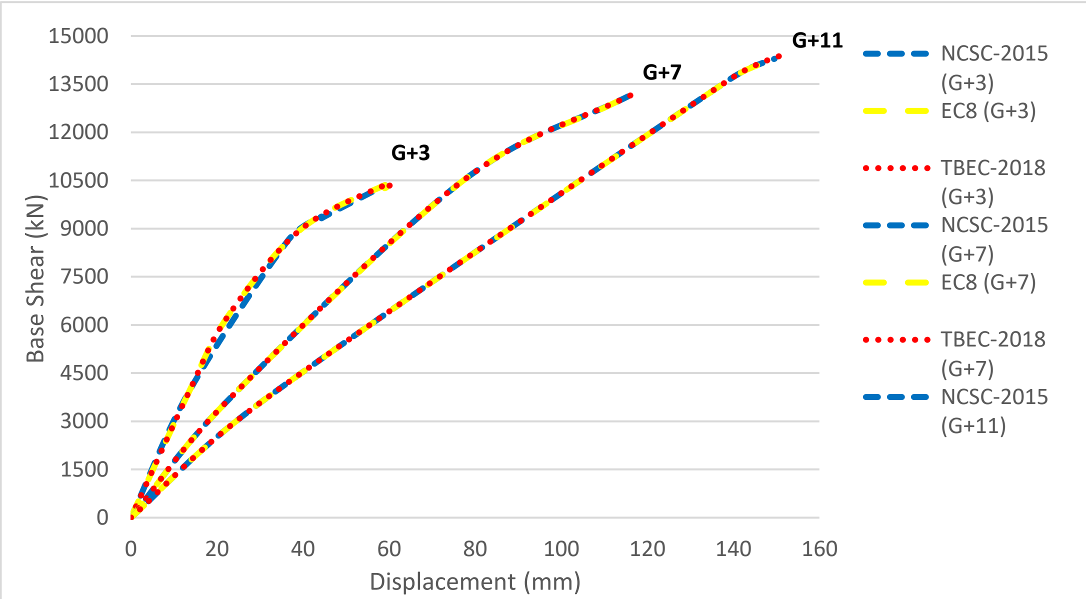


Figure 34

Pushover Curves for MRF structure in regular form, soft soil class



As shown in these two graphs the base shear and displacement have increased for both soil classes gradually with the increase in the number of stories. TBEC-2018 observed an increase in the results from medium to soft soil in all cases, wherein low-rise buildings the base shear and displacement increased by 14% and 23%, respectively, and for mid-rise buildings, the increase was 12% and 18%, respectively, while for high-rise buildings the increase was only in the base shear of 6%. On the other hand, the increase from medium to soft soil class in NCSC-2015 and EC 8 was tiny and didn't exceed 5% for all cases. However, TBEC-2018 seemed more conservative in the medium soil class, where the results were almost the same between the codes for the soft soil class.

The same results given above are shown differently as column charts in Appendix H.

7.2.2 Story Drift

The story drifts were evaluated as shown below in Fig 35 and 36, respectively.

Figure 35

Story Drift for MRF structure in regular form, medium soil class

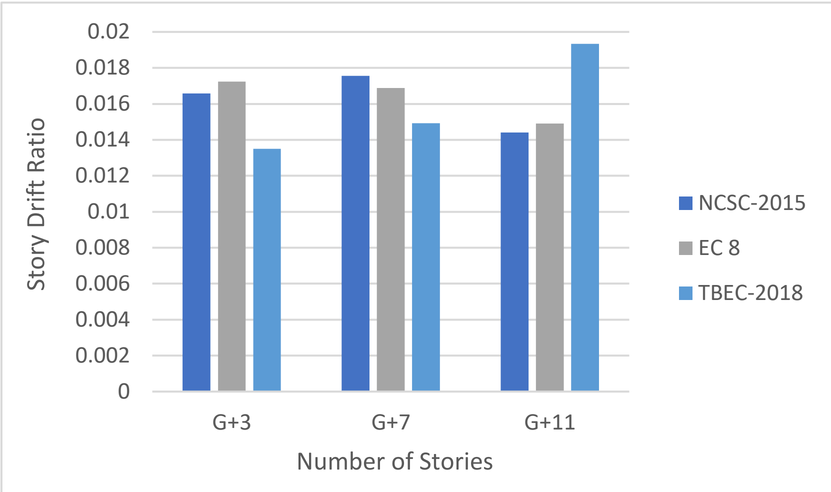
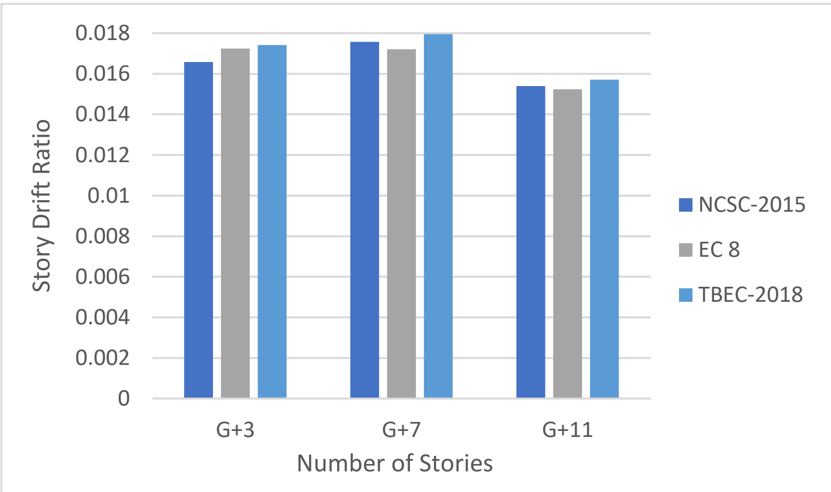


Figure 36

Story Drift for MRF structure in regular form, soft soil class



Generally, the maximum story drift ratio occurs in one of the first three stories and in the Y-direction. In this case, maximum story drift occurred for low-rise buildings on the first floor, whereas for mid and high-rise buildings on the second floor. TBEC-2018, the story drift increased from medium to soft soil by 23% and 17% for low and mid-rise buildings, respectively, whereas it decreased by 20% for high-rise buildings. NCSC-2015 showed around 6% increase from medium to soft soil only for high-rise buildings, while EC 8 has not shown any increase or decrease.

7.2.3 Plastic Hinges

The occurrence of plastic hinges helps to define if the building is going to stay standing or collapse during earthquakes. In these cases, plastic hinges occurred in many spots of the buildings, where some of them exceeded CP state were located in the ground and first story. In other words, all those structures in the selected areas are in danger and not lucky to stay standing during earthquakes.

7.2.4 Summary

The selected MRFs in regular form are unsafe in the mentioned earthquake locations. In this case, the majority of results increased in soft soil type, where some results decreased or stayed the same, and this means that the results don't need to increase always because the structure may collapse earlier in soft soil compared to medium soil. In addition, plastic hinges always occur in the first three stories, which means those structures are in real danger because any failure in one of those plastic hinges may cause the collapse of the whole structure. However, EC 8 and NCSC-2015 showed similar or near results, whereas TBEC-2018 showed more realistic results.

7.3 MRF+SW In Regular Form (5m SW)

The results such as base shear, displacement, story drift, and plastic hinges formation for MRF+SW in regular form with a 5m SW span length were obtained according to two soil types, three codes, and three different story structures with different numbers of stories.

7.3.1 Base Shear and Displacement

The pushover curve that shows the base shear forces and displacement for MRF+SW residential buildings with 5m SW span length in regular form with different number of stories, different codes, and soil classes are shown below in Fig 37 and 38, respectively.

Figure 37

Pushover Curves for MRF+SW structures for 5m SW length span in regular form, medium soil class

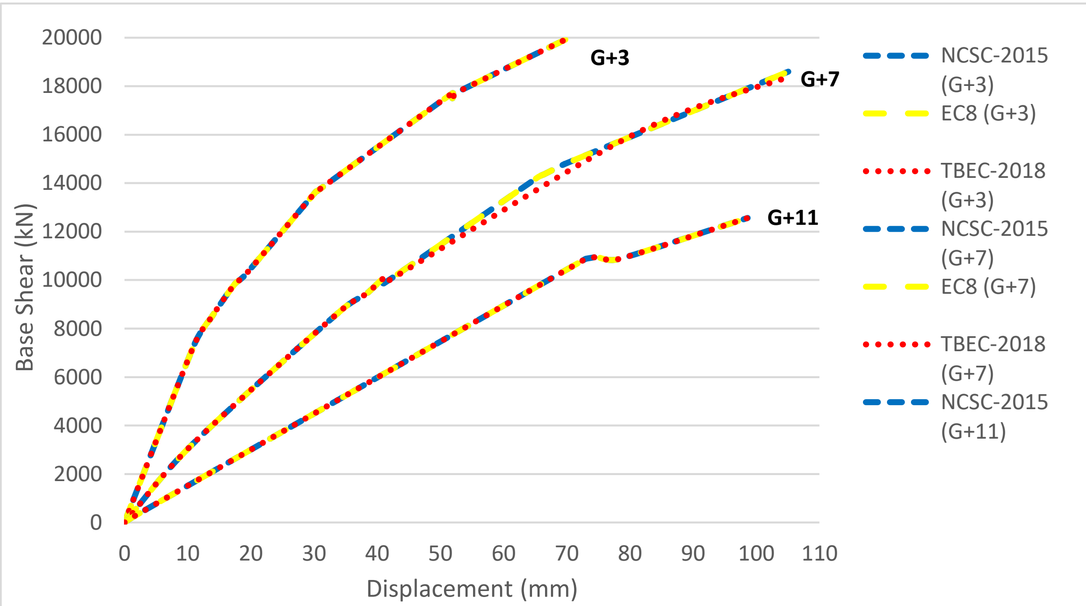
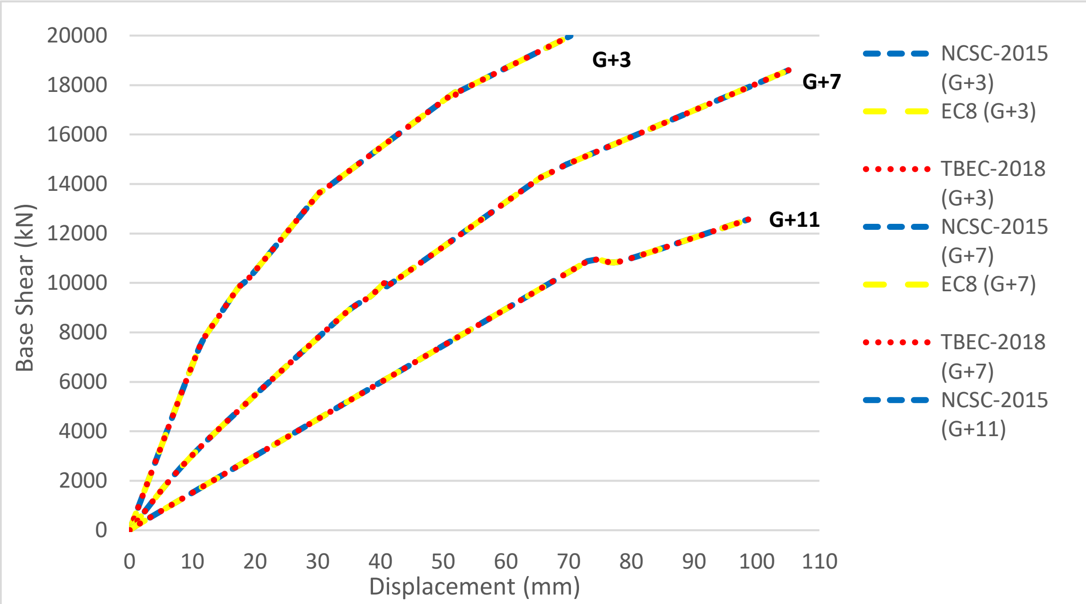


Figure 38

Pushover Curves for MRF+SW structures for 5m SW length span in regular form, soft soil class



In all cases, the base shear and displacement did not show differences between medium and soft soil. In addition, the base shear decreased gradually from low to high-rise buildings, where the displacement increased from low to mid-rise buildings and then decreased again in high-rise buildings. However, there was no difference between medium and soft soil because of the applied wide shear walls. Therefore, another length span of shear walls was applied in this study.

The same results given above are shown differently as column charts in Appendix H.

7.3.2 Story Drift

The story drifts were evaluated as shown below in Fig 39 and 40, respectively.

Figure 39

Story Drift for MRF+SW structures for 5m SW length span in regular form, medium soil class

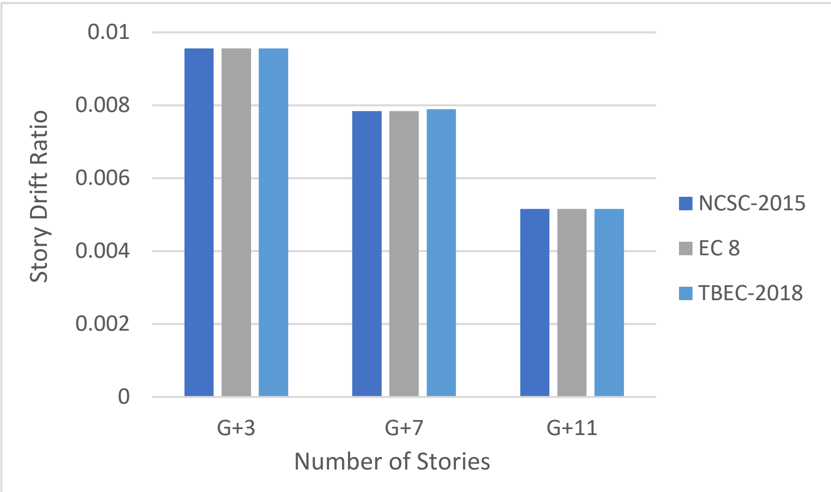
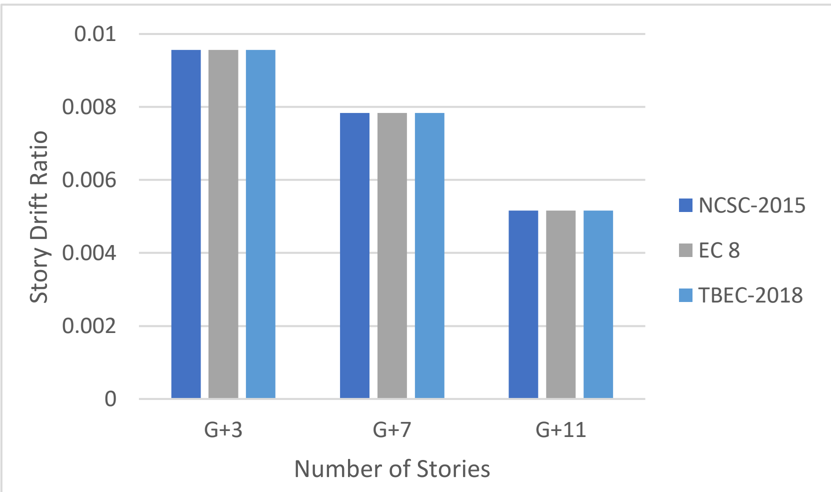


Figure 40

Story Drift for MRF+SW structures for 5m SW length span in regular form, soft soil class



As shown in the previous figures, for all codes, the story drift ratio is reduced when the building has a higher altitude. Moreover, the second story has the highest drift value in low-rise buildings, while the third story has the highest drift value in mid and high-rise buildings. However, for all cases, the results didn't show any difference between medium and soft soil.

7.3.3 Plastic Hinges

In low-rise buildings, some plastic hinges exceed the CP state occurred in the top story, whereas in mid-rise buildings some plastic hinges with the LS and CP state occurred, while in high-rise buildings no plastic hinges occurred. Therefore, those shear walls have affected the behavior of the structure, especially in mid and high-rise buildings.

7.3.4 Summary

According to the previous models, shear walls are effective, especially in high-rise buildings, where they minimize the risk of earthquakes and even eliminate the risk in some cases. In addition, all codes showed similar results because of the wide span length SW. Finally, it is crucial to mention that this span length of shear walls is used only for theoretical study and is not common in reality. Therefore, the same models were analyzed again but with only a 1.5m SW length span.

7.4 MRF+SW In Regular Form (1.5m SW)

The results such as base shear, displacement, story drift, and plastic hinges formation for MRF+SW in regular form with a 1.5m SW span length were obtained according to two soil types, three codes, and three different story structures with different numbers of stories.

7.4.1 Base Shear and Displacement

The pushover curve that shows the base shear forces and displacement for MRF+SW residential buildings with 1.5m SW span length in regular form with different number of stories, different codes, and soil classes are shown below in Fig 41 and 42, respectively.

Figure 41

Pushover Curves for MRF+SW structures for 1.5m SW length span in regular form, medium soil class

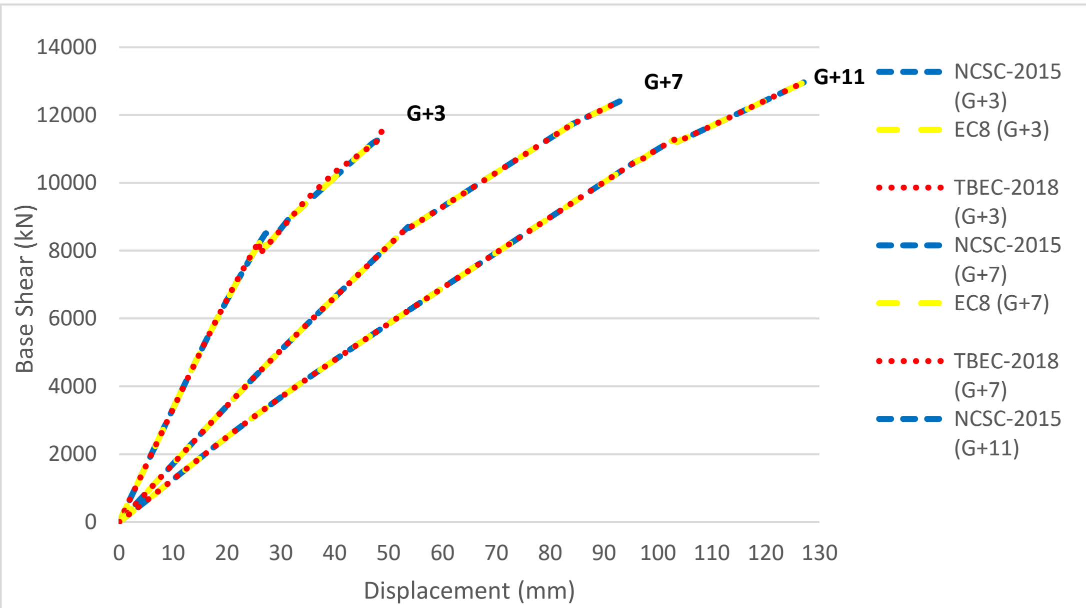
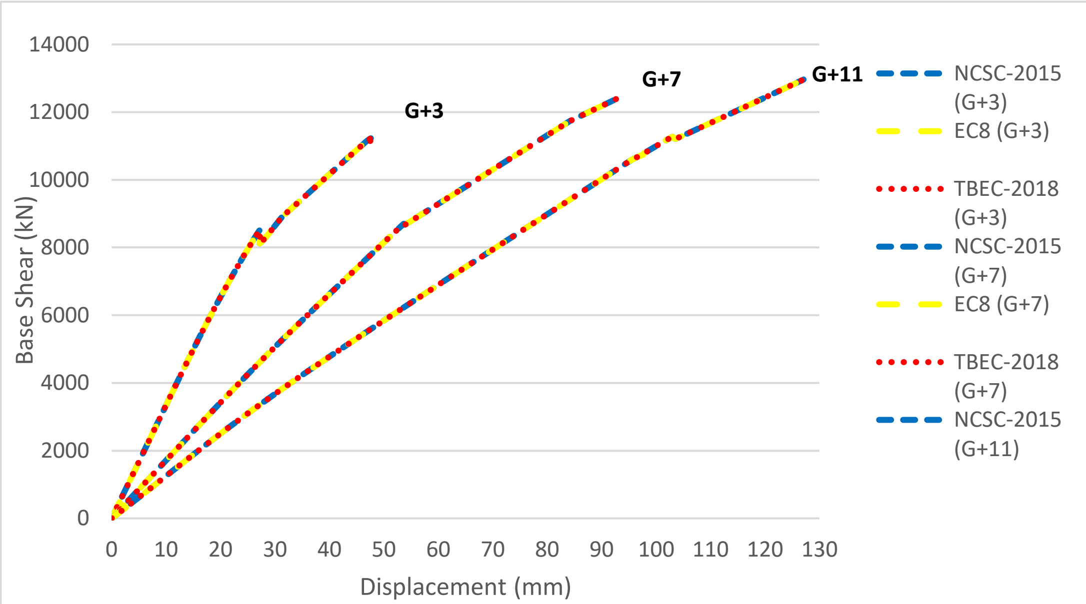


Figure 42

Pushover Curves for MRF+SW structures for 1.5m SW length span in regular form, soft soil class



According to the previous figures, the base shear increased slightly and the displacement increased dramatically from low to high-rise buildings. The results seemed the same for the base shear and displacement except for TBEC-2018 in low-rise buildings there was a 5% decrease in base shear and displacement from medium to soft soil, because the only critical hinge appeared in this case were in low-rise buildings with soft soil class, while mid and high-rise buildings appeared safe.

The same results given above are shown differently as column charts in Appendix H.

7.4.2 Story Drift

The story drifts were evaluated as shown below in Fig 43 and 44, respectively.

Figure 43

Story Drift for MRF+SW structures for 1.5m SW length span in regular form, medium soil class

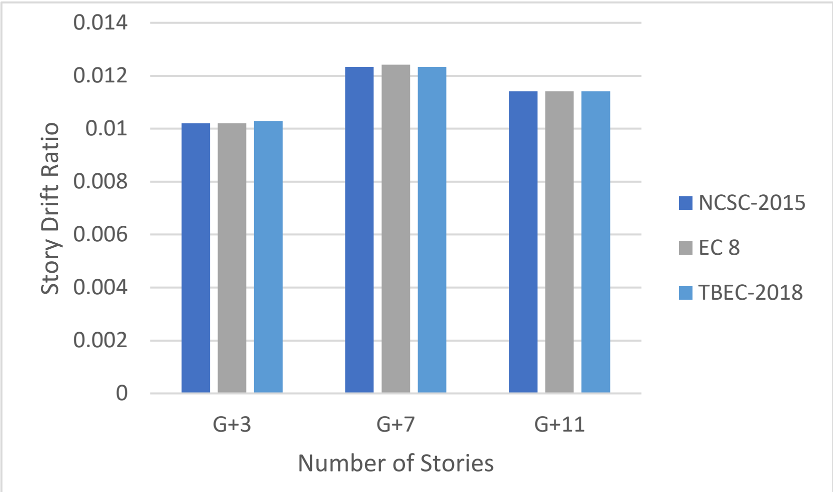
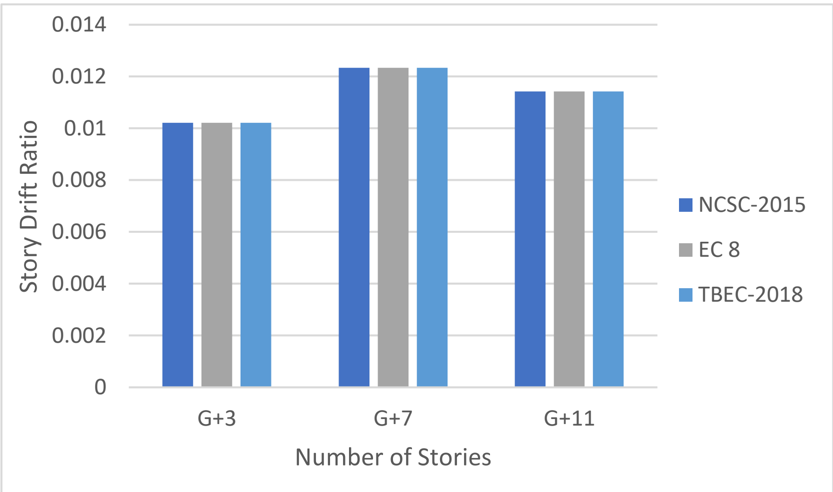


Figure 44

Story Drift for MRF+SW structures for 1.5m SW length span in regular form, soft soil class



The maximum story drift ratio is located on the second story for all cases. Additionally, the maximum drift ratio has no considerable difference from low to high-rise buildings and from medium to soft soil. However, the peak story drift shown in mid-rise buildings.

7.4.3 Plastic Hinges

For all codes, one critical hinge exceeding CP state occurred in low-rise buildings on the ground floor, while mid and high-rise buildings showed only some hinges between IO and LS state on the first and ground floor. Therefore, the buildings in this case seemed safe but mid and high-rise buildings seemed more safe than low-rise buildings.

7.4.4 Summary

The results for all codes were the same except in TBEC-2018 for low-rise buildings. Regardless, SW is sufficient to increase the resistance of buildings against earthquake loads. However, the results did not show considerable differences according to the codes. Subsequently, MRF+SW buildings might not be considered seriously in the code regulations.

7.4 MRF In Irregular Form

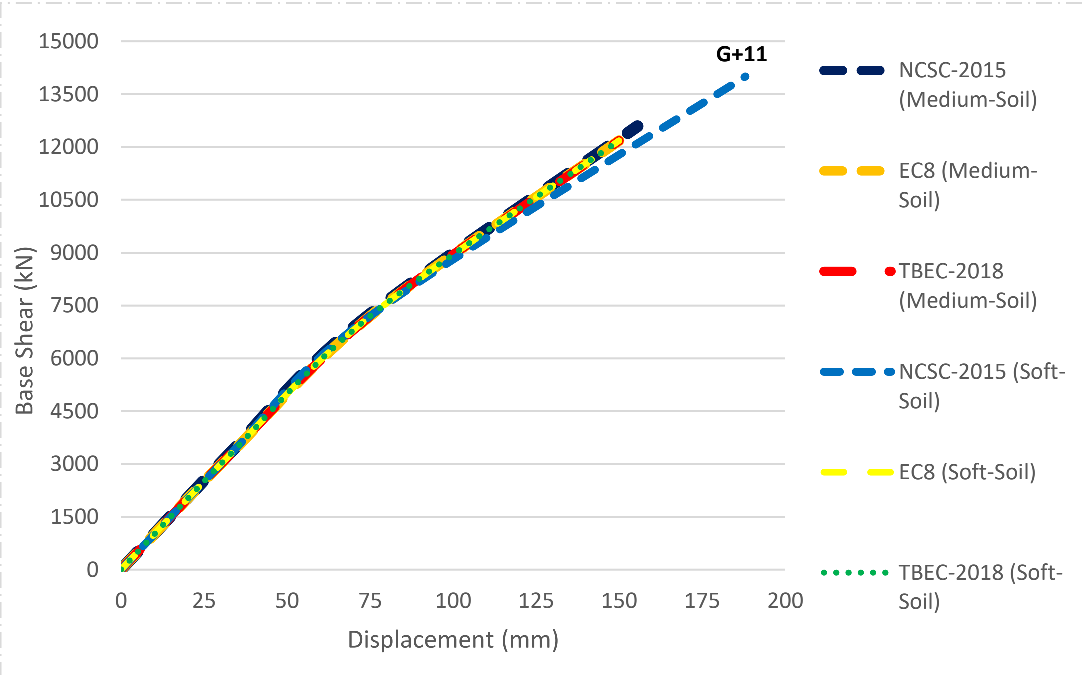
The results such as base shear, displacement, story drift, and plastic hinges formation for MRF in irregular form were obtained according to two soil types, and three codes, and for only high-rise buildings.

7.4.1 Base Shear and Displacement

The pushover curve that shows the base shear forces and displacement for high-rise MRF residential buildings in irregular form with different codes and different soil classes are shown below in Fig 45.

Figure 45

Pushover Curves for MRF in an irregular form, medium and soft soil class



NCSC-2015, the base shear, and displacement increased from medium to soft soil by 10% and 17%, respectively, and the results were higher than other codes. On the other hand, in EC 8 and TBEC-2018, the base shear and displacement were the same for both soil classes. However, the results in NCSC-2015 showed that the structure could resist more before it collapses, while other codes showed that structures for both soil classes collapsed at the same point. Nevertheless, in all cases, buildings are not safe according to the formation of plastic hinges.

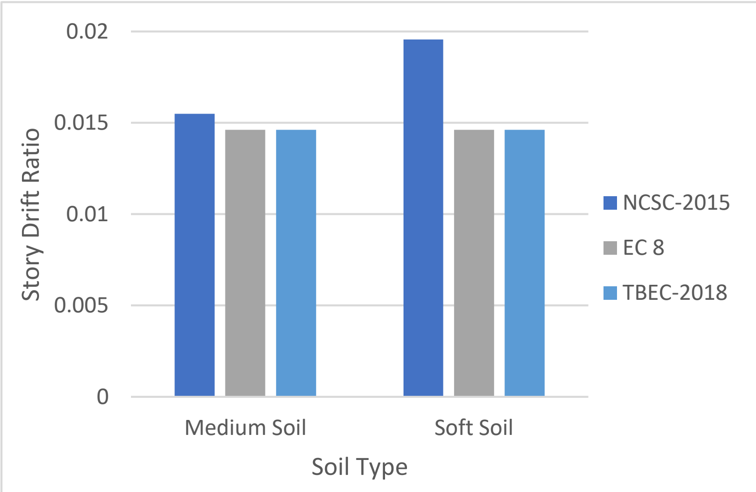
The same results given above are shown differently as column charts in Appendix H.

7.4.2 Story Drift

The story drifts were evaluated as shown below in Fig 46.

Figure 46

Story Drift for MRF in an irregular form, medium and soft soil class



The maximum story drift was in the second story for all cases. However, NCSC-2015 has the highest story drift and showed an increase from medium to soft soil by 20%, while EC 8 and TBEC-2018 showed the same results for both soil classes.

7.4.3 Plastic Hinges

All cases have plastic hinges exceeding the CP state, where in NCSC-2015, the hinges were more and located in the ground, first and second stories for soft soil, whereas medium soil has fewer hinges and the hinges were located only in the ground and first story. On the other hand, in EC 8 and TBEC-2018, the hinges occurred in the ground and first story for both medium and soft soil. However, all buildings have hinges exceeding the CP state and are unsafe.

7.4.4 Summary

All codes showed that structures are unsafe and will collapse, but EC 8 and TBEC-2018 seemed to consider the danger and the possibility of collapsing more than NCSC-2015. Furthermore, MRF in irregular form seemed to be very weak against earthquake loads, and it is necessary to provide some elements to resist earthquake loads, such as shear walls.

7.5 MRF+SW in Irregular Form (5m SW)

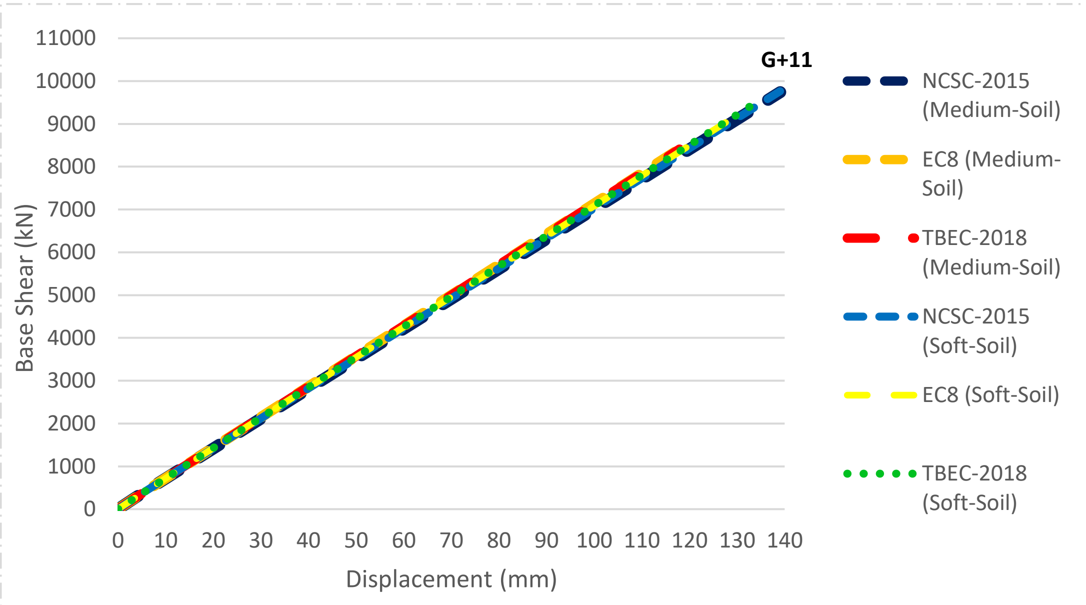
The results such as base shear, displacement, story drift, and plastic hinges formation for MRF+SW in irregular form for a 5m SW length span were obtained according to two soil types, and three codes, and for only high-rise buildings.

7.5.1 Base Shear and Displacement

The pushover curve that shows the base shear forces and displacement for high-rise MRF+SW residential buildings with 5m SW span length in irregular form with different codes and different soil classes are shown below in Fig 47.

Figure 47

Pushover Curves for MRF+SW structures for 5m SW span length in an irregular form, medium and soft soil class



TBEC-2018, the base shear, and displacement increased from medium to soft soil by 11%, while in EC8, the results increased by 10%. On the other hand, in NCSC-2015, the base shear and displacement did not show a considerable increase or decrease, but in general, the results were higher than in other codes. In any case, the formation of plastic hinges shows that all medium soil structures are safe, while all soft soil structures are unsafe.

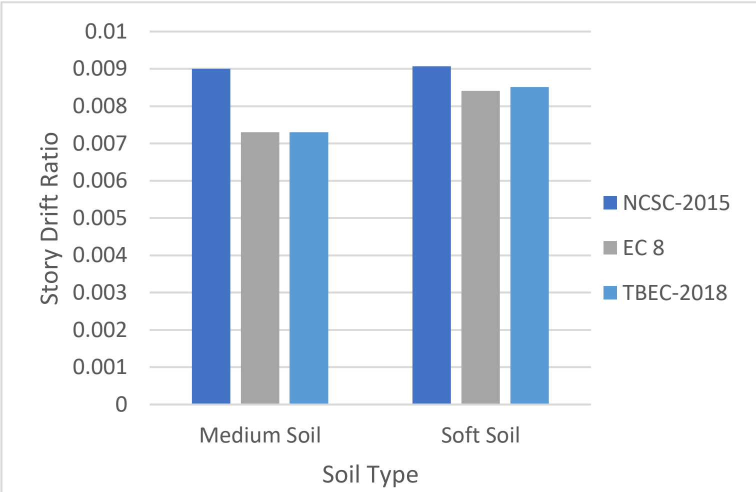
The same results given above are shown differently as column charts in Appendix H.

7.5.2 Story Drift

The story drifts were evaluated as shown below in Fig 48.

Figure 48

Story Drift for MRF+SW structures for 5m SW span length an in irregular form, medium and soft soil class



The maximum story drift occurred in the second story for all cases. NCSC-2015 shows similarity in the results between both soil classes. EC 8 and TBEC-2018 showed around a 14% increase from medium to soft soil.

7.5.3 Plastic Hinges

There was no occurrence of plastic hinges for all buildings with medium soil, while plastic hinges exceeding the CP state occurred for buildings with soft soil in the first five stories. As a result, buildings with medium soil were safe, and buildings with soft soil were unsafe. Furthermore, NCSC-2015 shows more plastic hinges exceeding CP state than other codes.

7.5.4 Summary

In all codes, medium soil structures were safe, and no plastic hinges were observed, whereas soft soil structures were unsafe, and the critical hinges were located in the first five stories. Therefore, shear walls act to distribute the earthquake loads on the stories. Regardless, EC 8 and TBEC-2018 seemed to consider the affection of soil types on the behavior of irregular structures against earthquake loads more than NCSC-2015.

7.6 MRF+SW in Irregular Form (1.5m SW)

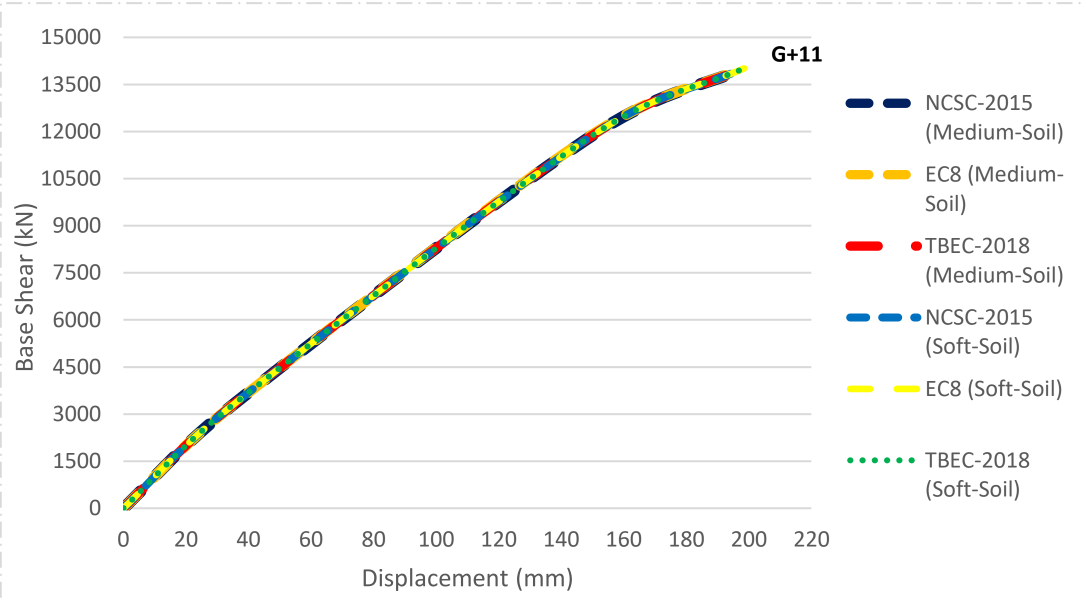
The results such as base shear, displacement, story drift, and plastic hinges formation for MRF+SW in irregular form for a 1.5m SW length span were obtained according to two soil types, and three codes, and for only high-rise buildings.

7.6.1 Base Shear and Displacement

The pushover curve that shows the base shear forces and displacement for high-rise MRF+SW residential buildings with 1.5m SW span length in irregular form with different codes and different soil classes are shown below in Fig 49.

Figure 49

Pushover Curves for MRF+SW structures with 1.5m SW length span in an irregular form, medium and soft soil



In this figure, the base shear and displacement did not increase or decrease more than 1% from medium to soft soil for all cases because the critical hinges occurred at the same positions.

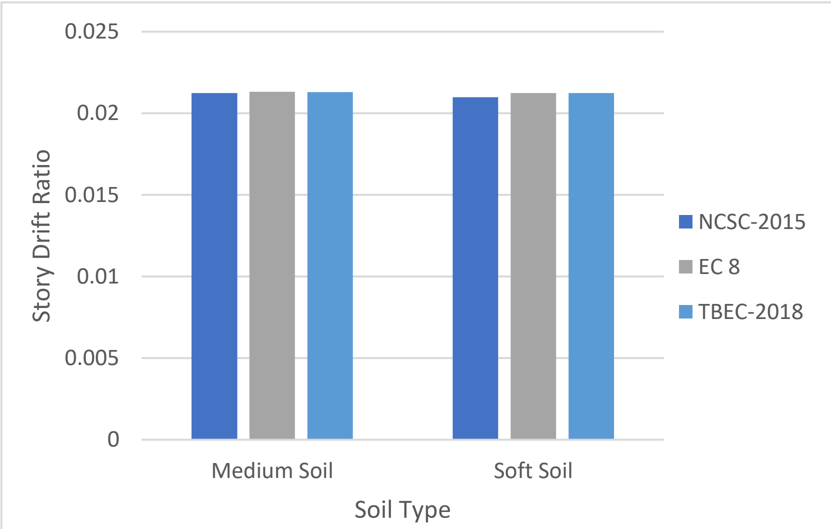
The same results given above are shown differently as column charts in Appendix H.

7.6.2 Story Drift

The story drifts were evaluated as shown below in Fig 51.

Figure 50

Story Drift for MRF+SW structures with 1.5m SW span length in an irregular form, medium and soft soil



For all codes, the maximum story drift was observed in the second story, and there was no difference between soil classes.

7.6.3 Plastic Hinges

For all codes, plastic hinges that exceed the CP state occurred in the first three stories for both soil classes. Therefore, these buildings are deemed unsafe.

7.6.4 Summary

Irregular structures are weak, and the 1.5m SW span length did not seem enough to protect the buildings against earthquake loads. In all events, the codes showed similar results and the same quantity of critical hinges located at the same locations. Therefore, all codes predicted the collapse to happen at the same point.

7.7 Discussion

TBEC-2018, NCSC-2015, and EC 8 are all used or contributing to the same area. Since its important to consider this, a few studies contributed to adding one or two of these codes in one study, where this study is the first to compare the three codes simultaneously.

Aksoylu et al, 2020 compared TBEC-2018, TEC-2007, and ASCE 7-16, and as mentioned previously, NCSC-2015 quoted from TEC-2007. The study targeted to analyze regular 6*6 bays MRF structures with 3, 5, 7, and 9 stories and for all soil types using the linear equivalent method. The results for TEC-2007 for medium and soft soil classes showed no increase in the base shear for 3 stories structure and an increase for the rest structures where this study showed no increase for G+3 and G+7, but for G+11 there was a tiny increase. On the other hand, in TBEC-2018, the base shear increased for 3 and 5 stories while nothing changed for 7 stories structure, but the base shear decreased for 9 stories structure, where this study showed an increase in all cases. However, it is hard to determine a conclusion between the codes from only MRF systems.

Reşatoğlu & Hamed, 2019 compared between NCSC-2015 and EC 8. The study aimed to analyze mid and low-rise regular and irregular buildings using Response Spectrum Method and Equivalent Lateral Force Method. EC 8 showed more conservative results compared to NCSC-2015 in the base shear results for both methods, whereas, in this study, EC 8 seemed more conservative in all cases except in low-rise regular form building results were the same between the codes.

Safkan, 2012 compared TEC-2007 and EC 8 for 5 stories MRF regular structure, using all soil types and two locations with different peak ground accelerations, the first location in Nicosia, and the other location in Famagusta. In all cases, EC 8 has higher base shear than NCSC-2015 except for only medium soil class building in Nicosia. In this study, base shear was always higher in NCSC-2015 compared to EC 8. As a result, these two studies have different conclusions.

CHAPTER VIII

Conclusions and Future Recommendations

1. MRF in the regular form:

Base shear and displacement increased from low to high-rise buildings, and all structures appeared unsafe due to the critical hinges. However, in TBEC-2018, the base shear and displacement were affected more realistically from medium to soft soil.

2. MRF+SW in the regular form with a 5m SW length span:

Base shear and displacement decreased from low to high-rise buildings, and in all codes, the structures have the same results for both soil classes due to the wide shear walls, which effecting the structures' behavior against earthquake loads. However, critical hinges occurred only in low-rise buildings. Finally, a 5m shear wall span length was used for the study but not preferable to use in reality therefore another shear wall with a 1.5m span length was applied in this study.

3. MRF+SW in the regular form with a 1.5m SW length span:

Base shear and displacement increased from low to high-rise buildings, whereas the results seemed the same for both soil classes in all codes except for TBEC-2018, there was a small decrease from medium to soft soil class for low-rise buildings. However, the structures appeared to stay safe and resist the applied earthquake loads.

4. MRF in the irregular form:

NCSC-2015, base shear and displacement increased from medium to soft soil, whereas in TBEC-2018 and EC 8, the results were the same for both soil classes. However, TBEC-2018 and EC 8 consider the occurrence of critical hinges earlier than NCSC-2015. Therefore, NCSC-2015 evaluated that the structures can resist more before collapsing. Nevertheless, all cases have critical hinges and are unsafe.

5. MRF+SW in the irregular form with a 5m SW length span

TBEC-2018 and EC 8, base shear and displacement increased from medium to soft soil, while in NCSC-2015, results have no increase or decrease. As a result, TBEC-2018 and EC 8 consider the affection of soil types more than NCSC-2015. Finally, soft soil class buildings experience critical hinges and may not be safe.

6. MRF+SW in the irregular form with a 1.5m SW length span:

For all codes, base shear and displacement were the same for both soil classes, and critical hinges occurred at the same spots. However, all buildings appeared unsafe.

7. Secondary conclusions:

- Shear Walls play a crucial role in decreasing the affection of earthquake loads.
- Regular buildings are luckier to stay standing during earthquakes compared to irregular buildings.
- Irregular buildings are much weaker compared to regular buildings.
- In general, plastic hinges occur in the first three stories, and they are the most critical stories in the building.
- Story drift is crucial to predict the floor that affects the most on the displacement.

8. Primary conclusions:

- Plastic hinges occurred at the same spots for all codes. Therefore, these codes frame the same conclusion "the building safe or unsafe".
- There was no considerable difference between the codes according to the results of MRF+SW buildings. As a result, the codes may not give much weight to this particular type of building.
- It is determined that the earthquake effect did not change much compared to the old and new regulations. However, this situation may vary according to buildings with different geometric features and soil classes.
- The most considerable change in TBEC-2018 regulation compared to NCSC-2015 is the Earthquake Hazard Map, where TBEC-2018 uses specific earthquake properties according to a map with coordinates for each provision.

- NCSC-2015 divides the island into four seismic regions with four peak ground acceleration values without regard to local site conditions. On the other hand, TBEC-2018 changes the process by introducing a seismic hazard map and providing site-specific data dependent on the building's coordinates.
- The codes stated similar results when:

1. Structures are safe, and no plastic hinges appeared.
2. Structures collapsed and could not resist the applied earthquake loads.

- TBEC-2018 seemed more comprehensive, while it is more adapted to the advanced technologies and considers the parameters in a more detailed method.
- The obtained results indicate that the soil class is a significant factor affecting the results between the codes.
- Based on the findings, there were not always variations among the codes. However, EC 8 and TBEC-2018 seemed more conservative most of the time.
- It would be desirable to study more cases before reaching definite conclusions about the behavior of reinforced concrete buildings.

Recommendations:

According to the results of this study, the following recommendations are preferred to use in future studies:

- Future studies can go for the Japanese code and compare it with the current TBEC-2018 code, which will help to understand what makes Japan more advanced in earthquake engineering.
- Further studies on different soil types might be investigated in the future.
- It would be better for studies to utilize a 3D model similar to reality, which might harden the comparison, but it is more accurate and logical
- Future studies can go through defining a new earthquake map for Cyprus with coordinates like Turkey.
- It would be better for future studies to select wisely a few models and analyze them with another seismic analysis method or two methods to obtain more accurate results.
- It would be better if Cyprus shifts to use TBEC-2018 in the area.

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Appendices

Appendix A
NCSC-2015 Regulations

- Elastic Seismic Design

The Spectral Acceleration Coefficient, A(T), is the basis for determining the seismic loads as given by the following equation:

$$A(T) = Ao.I.S(T) \tag{A.1}$$

Where:

Ao = Effective ground acceleration coefficient

I = Importance factor of the building

S(T) = Spectrum coefficient

Effective ground acceleration coefficient value can be given in table 31.

Table 31

Ao Coefficient Seismic Zones (K.K.T.C. DEPREM BÖLGELERİNDE 2015)

Seismic Zone	Ao
1	0.4
2	0.3
3	0.2
4	0.1

Elastic Spectral Acceleration, Sae (T) is the elastic acceleration spectrum Ordinator for a 5% damping rate is derived by the following equation:

$$Sae(T) = A(T).\mathrm{g} \tag{A.2}$$

Spectrum Coefficient, S(T) as shown in the previous equation is depending on the building's natural period (T) and the local site conditions as shown in the following equations:

$$S(T) = 1 + 1.5\frac{T}{TA} \qquad FOR \quad 0 \leq T \leq T_A \tag{A.3}$$

$$S(T) = 2.5 \qquad FOR \quad T_A \leq T \leq T_B \tag{A.4}$$

$$S(T) = 2.5\left(\frac{TB}{T}\right)^{0.8} \qquad FOR \quad T_B < T \qquad (A.5)$$

Where both of the periods T_A and T_B are specified depending on local site classes as shown in table 32, also the design acceleration spectra graph is shown in figure 60.

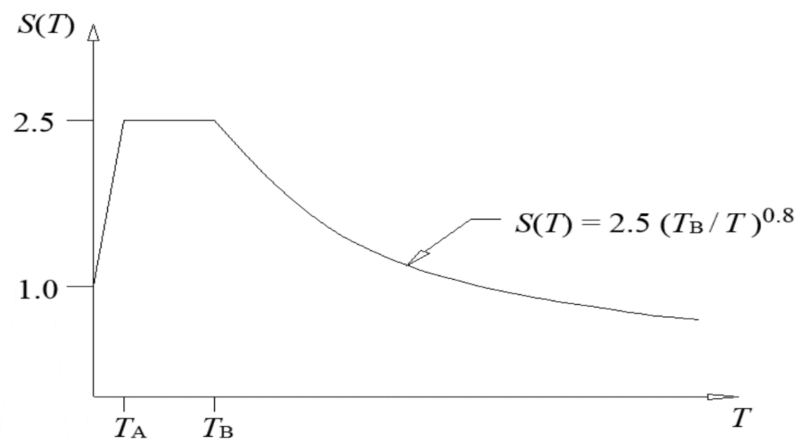
Table 32

Spectrum Periods (K.K.T.C. DEPREM BÖLGELERİNDE 2015)

Local site class	T_A (second)	T_B (second)
Z1	0.1	0.3
Z2	0.15	0.4
Z3	0.15	0.6
Z4	0.2	0.9

Figure 51

Design Acceleration Spectra (K.K.T.C. DEPREM BÖLGELERİNDE-2015)



- Base Shear Force

The total base shear, V_t, acting on the whole structure in the same direction of the earthquake is considered by using equation:

$$V_t = \frac{A(T_1)}{R_a(T_1)} \geq 0.1A_O\, I\, W \qquad (A.6)$$

Where:

W Total building weight, and can be calculated in accordance with…

$$W = \sum_{i=1}^{N} W_i \qquad (A.7)$$

W_i The story weight, and is calculated according to:

$$W_i = \mathrm{DL}_i + n\, LL_i \qquad (A.8)$$

DL_i Total dead load at story i

LL_i Total live load at story i

n Live Load Participation Factor, and is defined in table 33.

Table 33

Live Load Participation Factor (n) (K.K.T.C. DEPREM BÖLGELERİNDE-2015)

Purpose of Occupancy of Building	**n**
Depot, warehouse, etc.	0.8
School, dormitory, sport facility, cinema, theatre, concert hall, car park, restaurant, shop, etc.	0.6
Residence, office, hotel, hospital, etc.	0.3

T_1 First natural vibration period of the building. It is defined by the following:

$$T_1 = \mathrm{C}_t\, H_N^{3/4} \qquad (A.9)$$

C_t = 0.07 for RC frames

H_N= Total height of building from top foundation level

N Total number of stories

If the building has more than 13 stories excluding the basement, the natural period shouldn't be more than:

$$T_1 = 0.1\, N \qquad (A.10)$$

The equivalent seismic load distributed to stories can be expressed as:

$$F_t = (V_t - \Delta F_N)\frac{w_i H_i}{\sum_{j=1}^{N} w_j H_j} \qquad (A.11)$$

Where:

w_i, w_j Story weights

$H_i H_j$ Story heights

ΔF_N The additional equivalent seismic load acting at the i'th story, and can be defined by the following equation:

$$\Delta F_N = 0.0075\ N\ V_t \qquad (A.12)$$

Appendix B
EC 8 Regulations

- Elastic Seismic Design

In general, the non-linear range allows the design to resist seismic forces that are smaller than those corresponding to a linear elastic response. The behavior factor q is used to accomplish the reduction in the response spectrum. Moreover, the q factor can be used in the elastic analysis if the structure was completely elastic with only 5% viscous damping, also this factor may differ according to the horizontal directions of the structure, though the classification of ductility shall be the same.

The elastic response spectrum for horizontal seismic movements can be defined by the following expressions:

$$S_e(T) = a_g.\mathrm{S}.[1 + \frac{T}{T_B}.(\eta.2{,}5 - 1) \qquad For \quad 0 \leq T \leq T_B \qquad (B.1)$$

$$S_e(T) = a_g.\mathrm{S}.\eta.2{,}5 \qquad For \quad T_B \leq T \leq T_C \qquad (B.2)$$

$$S_e(T) = a_g.\mathrm{S}.\eta.2{,}5\left[\frac{T_C}{T}\right] \qquad For \quad T_C \leq T \leq T_D \qquad (B.3)$$

$$S_e(T) = a_g.\mathrm{S}.\eta.2{,}5\left[\frac{T_C T_D}{T^2}\right] \qquad For \quad T_D \leq T \leq 4_S \qquad (B.4)$$

$S_e(T)$ The elastic response spectrum;

T The vibration period of a linear single-degree-of-freedom system;

a_g The design ground acceleration on type A ground (ag = γI.agR);

T_B The lower limit of the period of the constant spectral acceleration branch;

T_C The upper limit of the period of the constant spectral acceleration branch;

T_D The value defining the beginning of the constant displacement response range of the spectrum;

S is the soil factor;

η is the damping correction factor with a reference value of η = 1 for 5% viscous damping.

There are two different types of spectrum shapes according to the seismicity conditions. If the magnitude of the surface wave (Ms < 5.5) it's recommended to use the second type (Schott, C., & Schwarz). Elastic response spectrum shape described the soil factor values S as shown in Figure 61 and Figure 62. While, the periods T_B, T_C, T_D according to the two types as shown in table 34, and table 35.

Table 34

The Values for The First Spectrum Type (Eurocode 8)

Ground Type	S	T_B(s)	T_C(s)	T_D(s)
A	1,0	0,15	0,4	2,0
B	1,2	0,15	0,5	2,0
C	1,15	0,20	0,6	2,0
D	1,35	0,20	0,8	2,0
E	1,4	0,15	0,5	2,0

Table 35

The Values for The Second Spectrum Type (Eurocode 8)

Ground Type	S	T_B(s)	T_C(s)	T_D(s)
A	1,0	0,05	0,25	1,2
B	1,35	0,05	0,25	1,2
C	1,5	0,10	0,25	1,2
D	1,8	0,10	0,30	1,2
E	1,6	0,05	0,25	1,2

Figure 52

Elastic Response Spectrum for Ground Types of The First Spectrum Type (Eurocode 8)

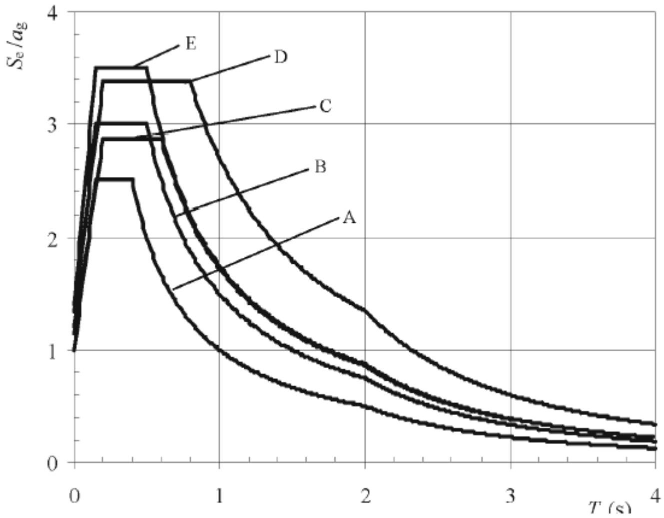
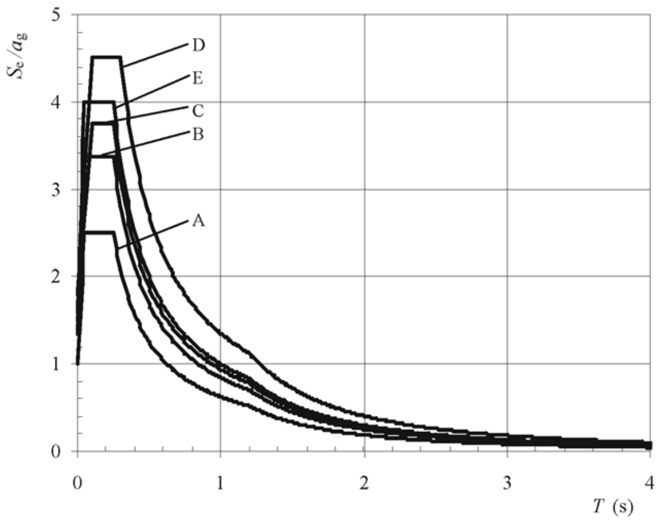


Figure 53

Elastic Response Spectrum for Ground Types of The Second Spectrum Type (Eurocode 8)



The damping correction factor η can be obtained by using the following expression:

$$\eta = \sqrt{\frac{10}{(5+\xi)}} \geq 0{,}55 \qquad (B.5)$$

where ξ is the structure's viscous damping ratio.

The elastic displacement response spectrum $S_{De}(\mathrm{T})$ shall be obtained by the elastic acceleration response spectrum $\mathrm{S}_e(\mathrm{T})$ as shown in the following expression:

$$S_{De}(\mathrm{T}) = \mathrm{S}_e(\mathrm{T})[\frac{T}{2\pi}]^2 \qquad (B.6)$$

The following expressions are for the horizontal seismic action components of the design spectrum, $S_d(\mathrm{T})$:

$$S_d(T) = a_g.\mathrm{S}.[\frac{2}{3} + \frac{T}{T_B}.\left(\frac{2.5}{q} - \frac{2}{3}\right) \qquad For \quad 0 \leq T \leq T_B \qquad (B.7)$$

$$S_d(T) = a_g.\mathrm{S}.\frac{2.5}{q} \qquad For \quad T_B \leq T \leq T_C \qquad (B.8)$$

$$S_d(T) = a_g.\mathrm{S}.\frac{2.5}{q}\left[\frac{T_c}{T_B}\right] \geq \beta.a_g \qquad For \quad T_C \leq T \leq T_D \qquad (B.9)$$

$$S_d(T) = a_g.\mathrm{S}.\frac{2.5}{q}\left[\frac{T_c T_D}{T^2}\right] \geq \beta.a_g \qquad For \quad T_D \leq T \qquad (B.10)$$

Where:

$S_d(T)$ The design spectrum;

q The behaviour factor;

β The lower bound factor for the horizontal design spectrum. (The recommended value is 0,2)

- Base Shear Force

The base shear force Fb, represents the seismic force for each horizontal direction and can be defined using the expression:

$$F_b = S_d(T_1).m.\lambda \qquad (\mathrm{B}.11)$$

Where:

$S_d(T_1)$ Design spectrum at period T1

T_1 The fundamental period of vibration in the considered direction

m The total mass of the building

λ The correction factor (λ = 0,85 if T1 < 2 TC and the building has more than two stories, or λ = 1,0 otherwise)

Unfortunately, there is an expression for buildings with heights up to 40m not more, and the cases in this study have some structures with more than 40m. Therefore, the following expression cannot be used to all structures:

$$T_1 = C_t . H^{\frac{3}{4}} \qquad (B.12)$$

Where:

C_t 0,075 for moment-resistant space concrete frames

H The height of the building from the basement.

Appendix C
TBEC-2018 Regulations

- Elastic Seismic Design

Horizontal Elastic Design spectral acceleration, $S_{ae}(T)$, which are the ordinates for any seismic ground motion of the horizontal elastic design acceleration, as shown in figure 63. All equations are defined depending on the natural vibration period as shown in the following:

$$S_{ae}(T) = \left(0.4 + 0.6\frac{T}{T_A}\right) S_{DS} \qquad FOR \quad 0 \leq T \leq T_A \qquad (C.1)$$

$$S_{ae}(T) = S_{DS} \qquad FOR \quad T_A \leq T \leq T_B \qquad (C.2)$$

$$S_{ae}(T) = \frac{S_{D1}}{T} \qquad FOR \quad T_B \leq T \leq T_L \qquad (C.3)$$

$$S_{ae}(T) = \frac{S_{D1}\, T_L}{T^2} \qquad FOR \quad T_L \leq T \qquad (C.4)$$

Where:

S_{DS} The design spectral acceleration coefficient

S_{D1} The design spectral acceleration coefficient

T The natural vibration period.

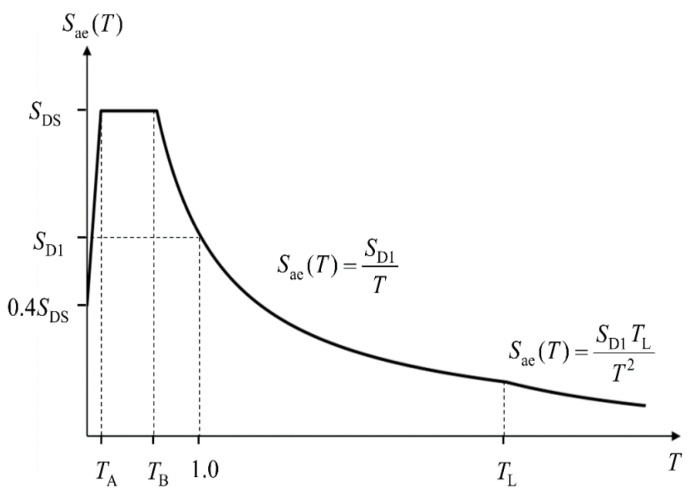
$$T_A = 0.2\frac{S_{D1}}{S_{DS}} \qquad (C.5)$$

$$T_B = \frac{S_{D1}}{S_{DS}} \qquad (C.6)$$

T_L The transition period to fixed displacement and fixed value of 6 seconds.

Figure 54

Design Horizontal Acceleration Spectral (TBDY-2018)

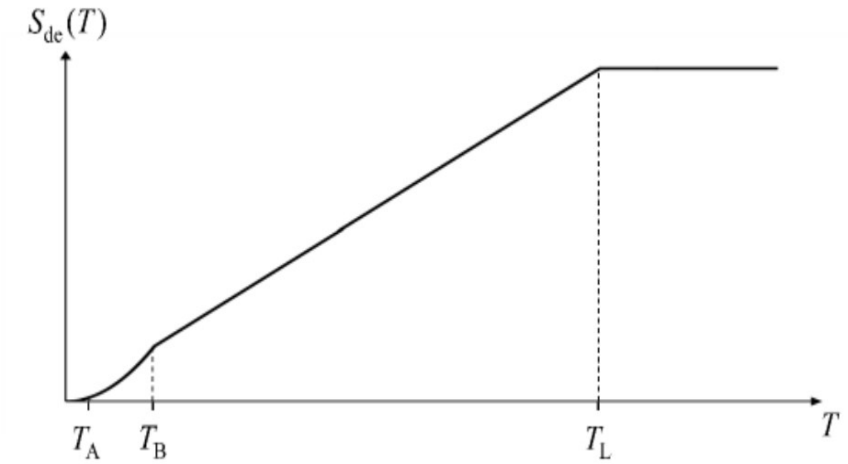


The horizontal elastic design spectral displacement, $S_{de}(T)$, which are the ordinates for any seismic ground motion of the horizontal elastic design displacement, as shown in Figure 64 The equation is defined depending on the natural vibration period as shown in the following:

$$S_{de}(T) = \frac{T^2}{4\,\pi^2}\,g\,S_{ae}(T) \qquad (C.7)$$

Figure 55

Design Displacement Spectral (TBDY-2018)



The vertical elastic design spectral acceleration, $S_{aeD}(T)$, which are the ordinates for any seismic ground motion of the vertical elastic design displacement, as shown in Figure 65. The equations are defined depending on the natural vibration period and the short-period design acceleration coefficient as shown in the following:

$$S_{aeD}(T) = \left(0.32 + 0.48\frac{T}{T_{AD}}\right)S_{DS} \qquad FOR \quad 0 \leq T \leq T_{AD} \qquad (C.8)$$

$$S_{aeD}(T) = 0.8\,S_{DS} \qquad FOR \quad T_{AD} \leq T \leq T_{BD} \qquad (C.9)$$

$$S_{aeD}(T) = 0.8\,S_{DS}\frac{T_{BD}}{T} \qquad FOR \quad T_{BD} \leq T \leq T_{LD} \qquad (C.10)$$

Where:

T_{AD} The vertical spectrum corner periods

T_{BD} The vertical spectrum corner periods

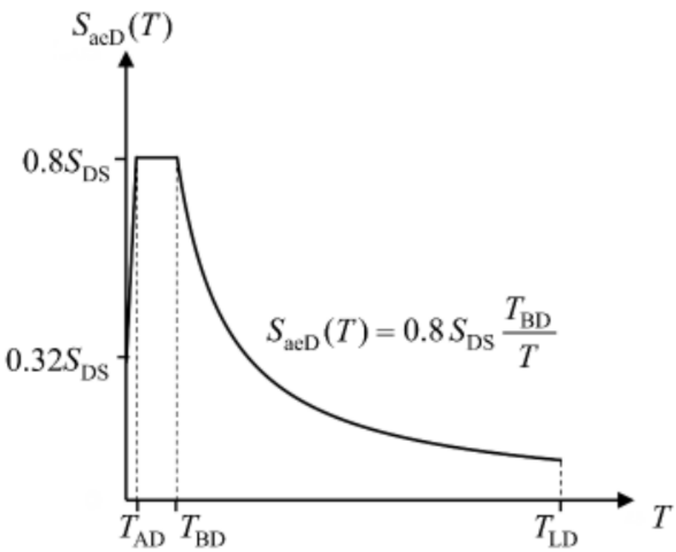
$$T_{AD} = \frac{T_A}{3} \qquad (C.11)$$

$$T_{BD} = \frac{T_B}{3} \qquad (C.12)$$

$$T_{LD} = \frac{T_L}{2} \qquad (C.13)$$

Figure 56

Design vertical acceleration spectral (TBDY-2018)



- Base Shear Force

The total base shear, V_t, acting on the whole structure in the same direction of the earthquake is considered by using equation:

$$V_{tE}^{(X)} = m_t\, S_{aR}\, (T_p^{(X)}) \geq 0.04 m_t\, I\, S_{DS}\, \text{g} \qquad (C.14)$$

Where:

m_t Total building weight, and can be calculated in accordance with…

$$m_t = \sum_{i=1}^{N} m_i \qquad (C.15)$$

m_i The story weights

$S_{aR}\,(T_p^{(X)})$ Reduce design spectral acceleration

$$S_{aR}\,(T) = \frac{S_{ae}(T)}{R_a(T)} \qquad (C.16)$$

Where $R_a(T)$ The load reduction coefficient

In TBEC-2018 the load reduction value depends on the ductility of the building and there are specific tables to obtain this coefficient value.

$T_p^{(X)}$ The dominant natural vibration period of the building during an earthquake in X direction and can be defined using the expression:

$$T_p^{(X)} = 2\pi(\frac{\sum_{i=1}^{N} m_i d_{fi}^{(X)2}}{\sum_{i=1}^{N} F_{fi}^{(X)} d_{fi}^{(X)}})^{\frac{1}{2}} \qquad (C.17)$$

Where:

$F_{fi}^{(X)}$ The fictitious load acting on i-th floor and is defined in the next expression

$$F_{fi}^{(X)} = (V_{tE}^{(X)} - \Delta F_{NE}^{(X)}) \qquad (C.18)$$

$\Delta F_{NE}^{(X)}$ The equivalent earthquake load acting on the top floor and is determined by using the equation:

$$\Delta F_{NE}^{(X)} = 0.0075\, N\, V_{tE}^{(X)} \qquad (C.19)$$

The dominant natural vibration period value, $T_p^{(X)}$, shouldn't exceed 1.4 times T_{pA}

$$T_{pA} = C_t\, H_N^{3/4} \qquad (C.20)$$

$C_t = 0.1$ For RC Frames buildings

$C_t = 0.07$ For all other buildings.

Appendix D
Live and Dead Loads

- In this study, the applied Live load was 2.5kN/m^2, which is selected to be more than the minimum required live load in ASCE 7: American Society of Civil Engineers, Minimum Design Loads for Buildings and Other Structures as shown in Fig 66.

Figure 57

Minimum Live Loads (ASCE 7)

TABLE 4-1 — continued
MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_O, AND MINIMUM CONCENTRATED LIVE LOADS

Occupancy or Use	Uniform psf (kN/m^2)	Conc. lbs (kN)
Grandstands (see stadium and arena bleachers)		
Gymnasiums, main floors, and balconies	100 (4.79) Note (4)	
Handrails, guardrails, and grab bars	See Section 4.4	
Hospitals		
Operating rooms, laboratories	60 (2.87)	1000 (4.45)
Private rooms	40 (1.92)	1000 (4.45)
Wards	40 (1.92)	1000 (4.45)
Corridors above first floor	80 (3.83)	1000 (4.45)
Hotels (see residential)		
Libraries		
Reading rooms	60 (2.87)	1000 (4.45)
Stack rooms	150 (7.18) Note (3)	1000 (4.45)
Corridors above first floor	80 (3.83)	1000 (4.45)
Manufacturing		
Light	125 (6.00)	2000 (8.90)
Heavy	250 (11.97)	3000 (13.40)
Marquees and canopies	75 (3.59)	
Office buildings		
File and computer rooms shall be designed for heavier loads based on anticipated occupancy		
Lobbies and first floor corridors	100 (4.79)	2000 (8.90)
Offices	50 (2.40)	2000 (8.90)
Corridors above first floor	80 (3.83)	2000 (8.90)
Penal institutions		
Cell blocks	40 (1.92)	
Corridors	100 (4.79)	
Residential		
Dwellings (one- and two-family)		
Uninhabitable attics without storage	10 (0.48)	
Uninhabitable attics with storage	20 (0.96)	
Habitable attics and sleeping areas	30 (1.44)	
All other areas except stairs and balconies	40 (1.92)	
Hotels and multifamily houses		
Private rooms and corridors serving them	40 (1.92)	
Public rooms and corridors serving them	100 (4.79)	
Reviewing stands, grandstands, and bleachers	100 (4.79) Note (4)	
Roofs	See Sections 4.3 and 4.9	

(continued)

Minimum Design Loads for Buildings and Other Structures 13

- The Dead load was considered as self-weight from the software

Appendix E
Earthquake tables from ETABS

- The following figures show the applied seismic load patterns in ETABS software for each code. These tables had some changes between MRF and MRF+SW structure and according to the soil type as well. However, the following figures show the differences between the tables for each code.

Figure 58

NCSC-2015 Seismic load pattern according to ETABS software.

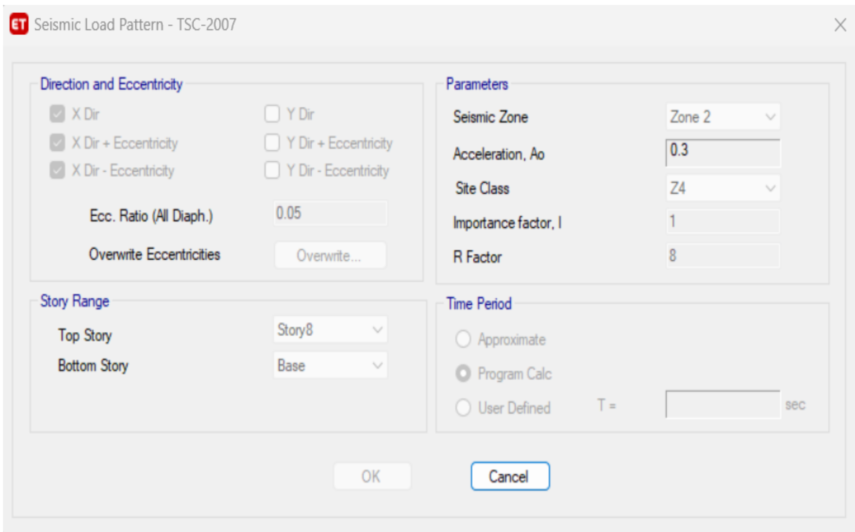


Figure 59

EC 8 Seismic load pattern according to ETABS software.

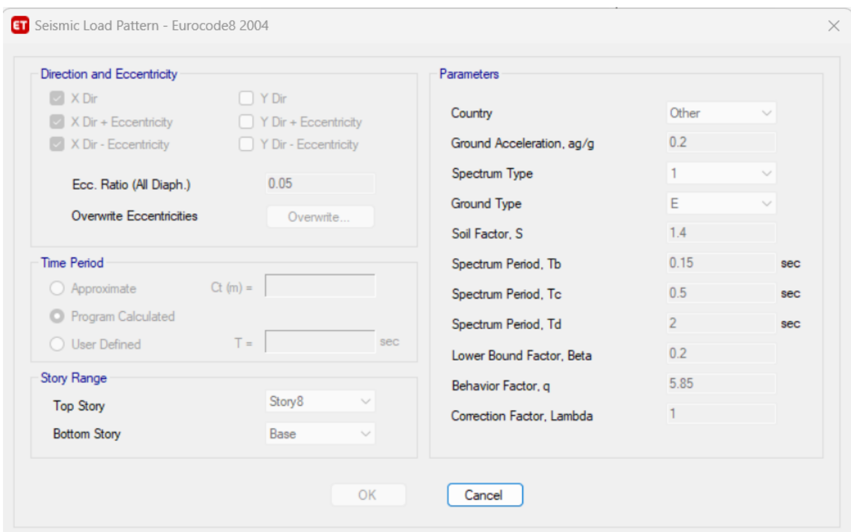
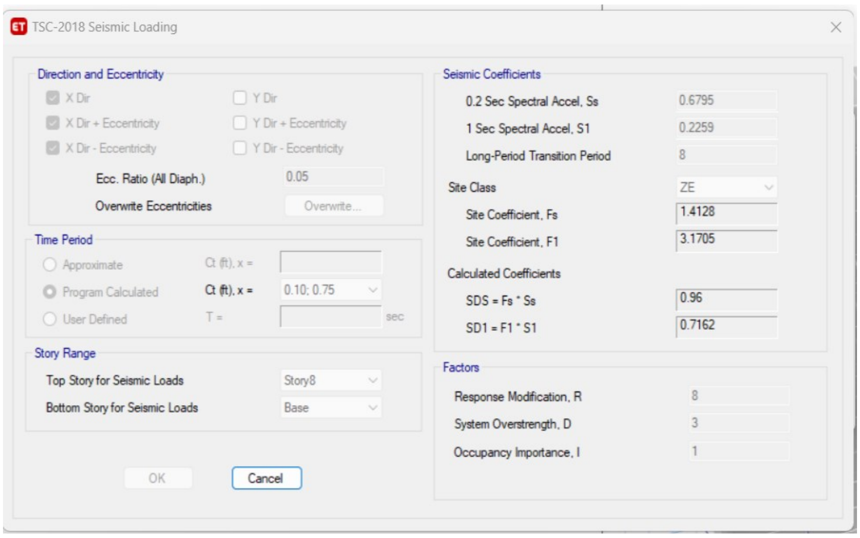


Figure 60

TBEC-2018 Seismic load pattern according to ETABS software.



Note: the previous tables are an example of how earthquake parameters were applied in the software while there are more tables having differences in some parameters such as soil class, overstrength factor, and response factor or behavior factor.

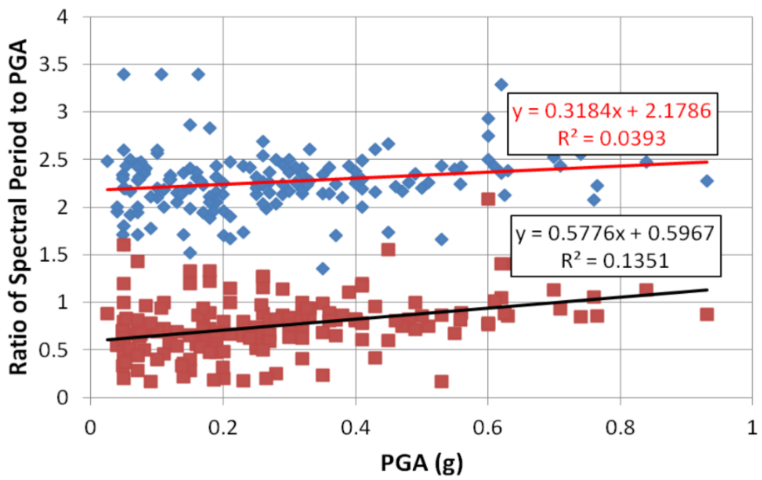
Appendix F
The Ratio of Spectral Acceleration to PGA

The average time interval for the occurrence of earthquakes in a specific region at a certain magnitude or greater is called the return period. For example, Nicosia and Famagusta have a PGA of 0.3g represents a 10% for 50 years return period. In other words, 100% for 475 years return period.

TBEC-2018 is not using the PGA accelerations value anymore and is using short-period spectral acceleration (Ss) and long-period spectral acceleration (S1) instead. In order to obtain the ratio of spectral acceleration to PGA see Fig 61, which represents the ratio between spectral acceleration and PGA of return periods ranging from 100 to 1000 from the database of more than 50 studies. (Lubkowski & Aluisi, 2012)

Figure 61

The Ratio of Spectral Period to PGA from Seismic Hazard Database (Lubkowski & Aluisi, 2012)



Blue diamonds represent the ratio between Ss and PGA, while the ratio can be considered 2.265. Therefore, Ss can be obtained from one of these two equations:

$\frac{S_S}{PGA} = 2.265$ $\qquad$ $\frac{S_S}{PGA} = 0.3386\ PGA + 2.1696$

On the other hand, red squares represent the ratio between S1 and PGA, while the ratio can be considered 0.753. Therefore, S1 can be obtained from one of these two equations:

$\frac{S_1}{PGA} = 0.753$ $\qquad$ $\frac{S_1}{PGA} = 0.5776\ PGA + 0.5967$

Appendix G

Base Shear and Displacement Results

Figure 62

Base shear for MRF structure in regular form, medium soil class

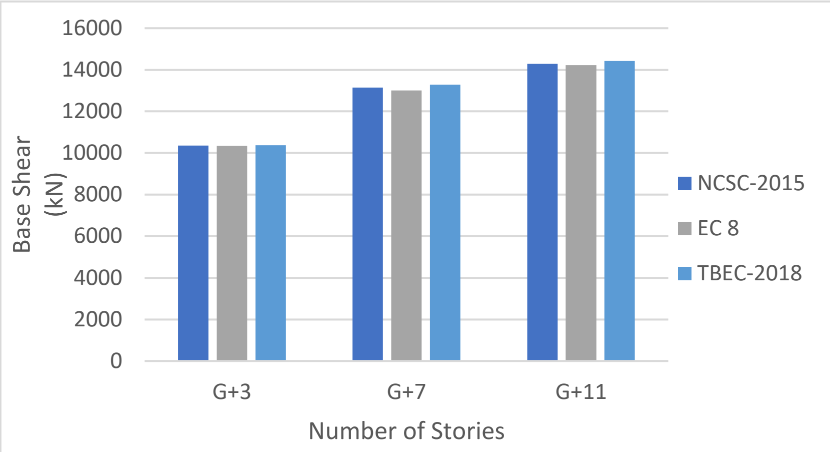


Figure63

Base shear for MRF structure in regular form, soft soil class

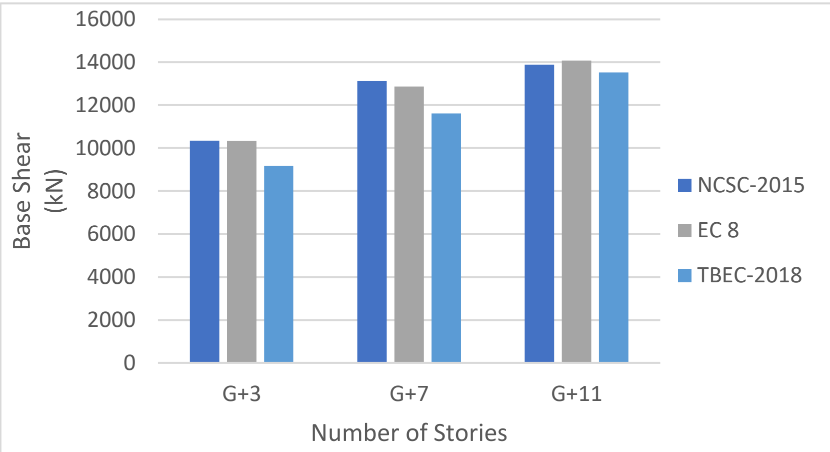


Figure64

Displacement for MRF structure in regular form, medium soil class

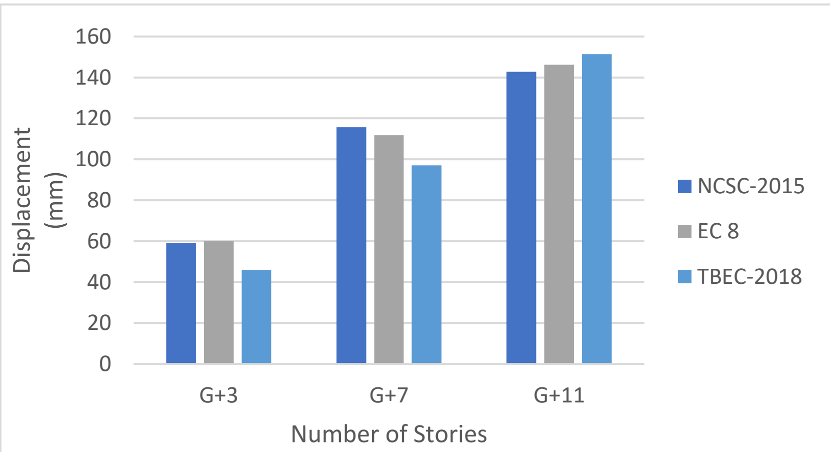


Figure65

Displacement for MRF structure in regular form, soft soil class

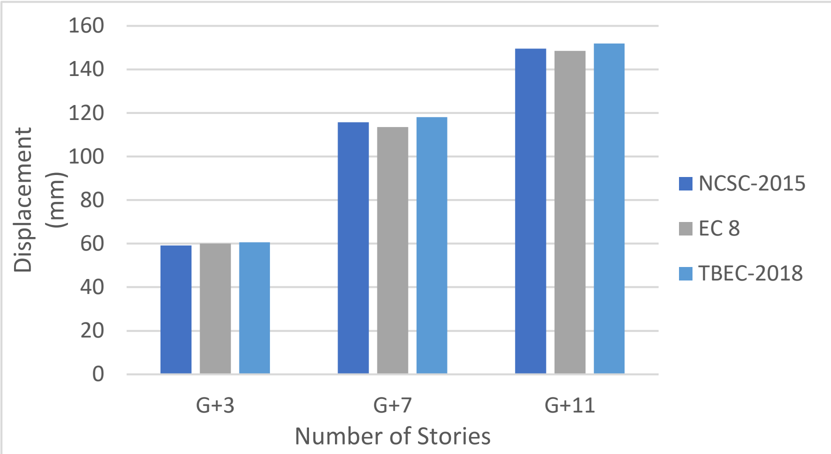


Figure 66

Base shear for MRF+SW structures for 5m SW length span in regular form, soft soil class

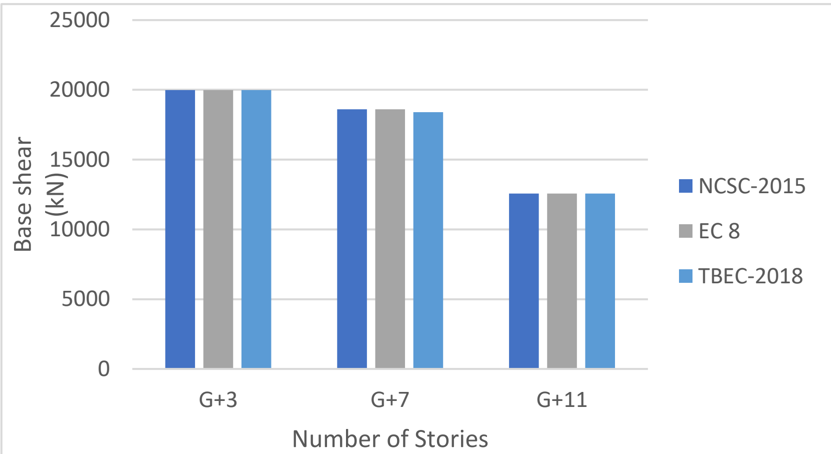


Figure67

Base shear for MRF+SW structures for 5m SW length span in regular form, medium soil class

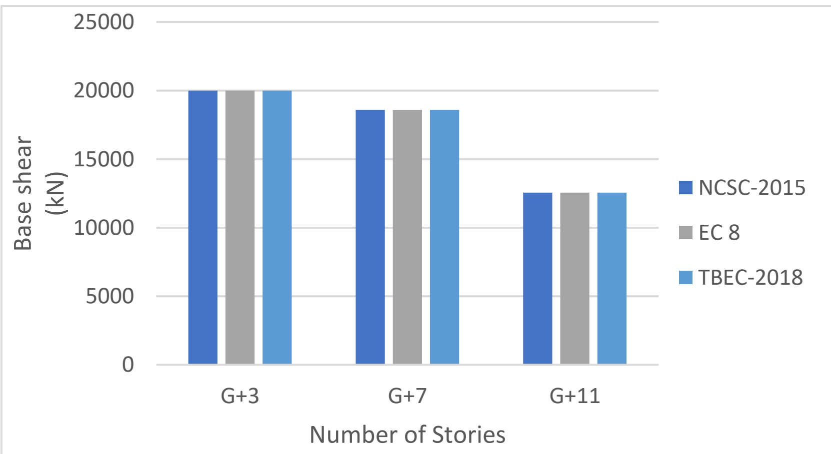


Figure68

Displacement for MRF+SW structures for 5m SW length span in regular form, medium soil class

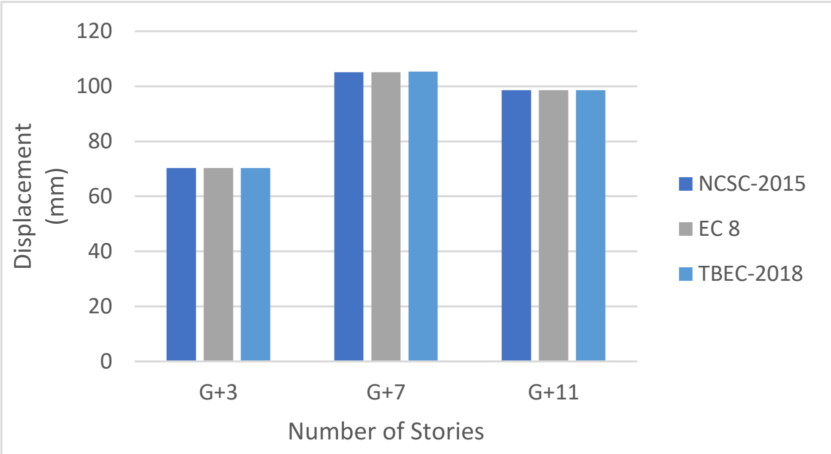


Figure69

Displacement for MRF+SW structures for 5m SW length span in regular form, soft soil class

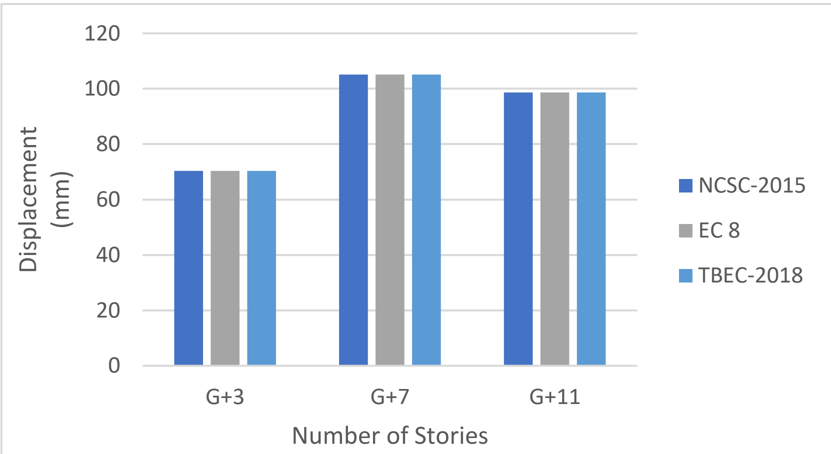


Figure70

Base shear for MRF+SW structures for 1.5m SW length span in regular form, medium soil class

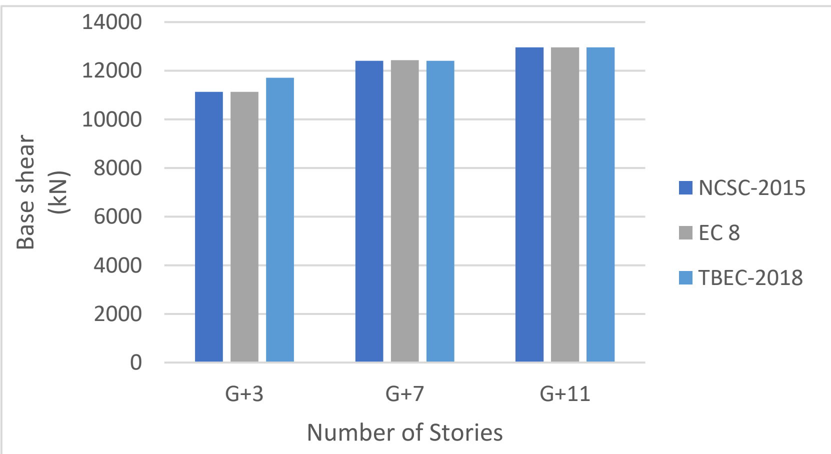


Figure71

Base shear for MRF+SW structures for 1.5m SW length span in regular form, soft soil class

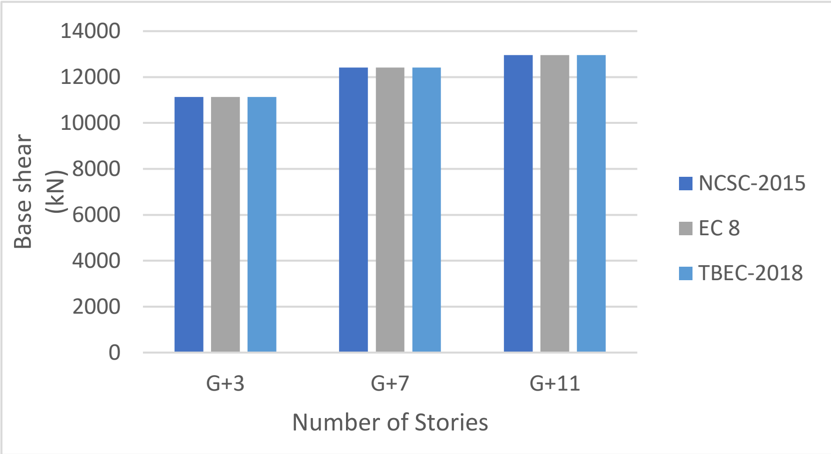


Figure72

Displacement for MRF+SW structures for 1.5m SW length span in regular form, medium soil class

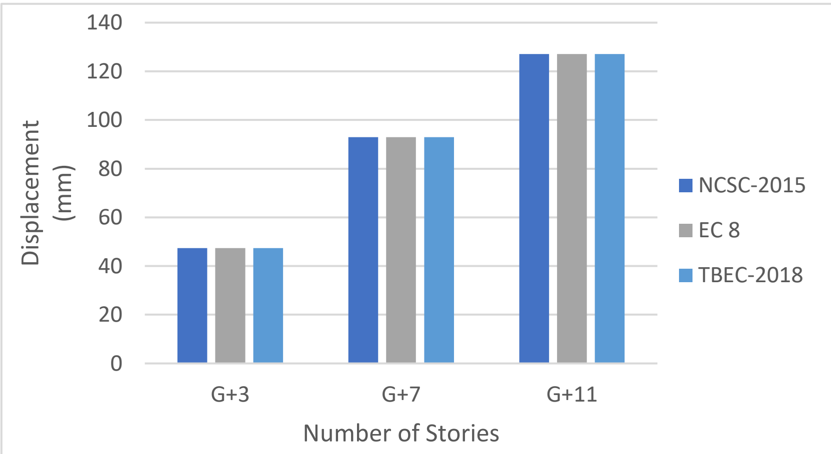


Figure73

Displacement for MRF+SW structures for 1.5m SW length span in regular form, soft soil class

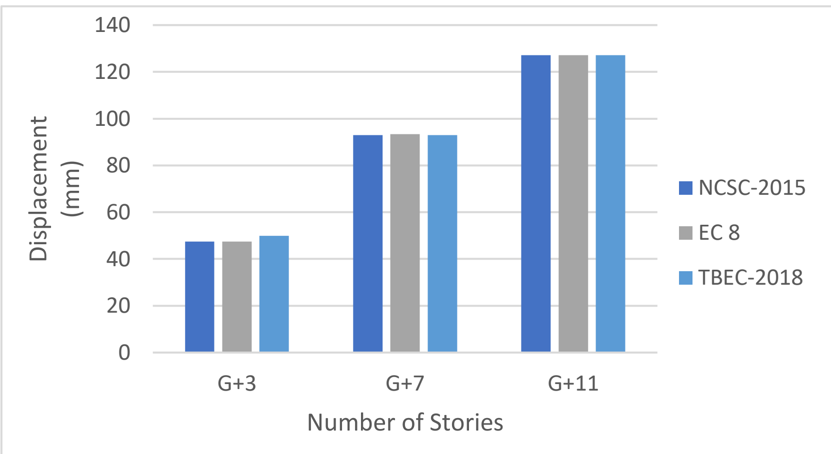


Figure74

Base Shear for MRF in an irregular form, medium and soft soil class

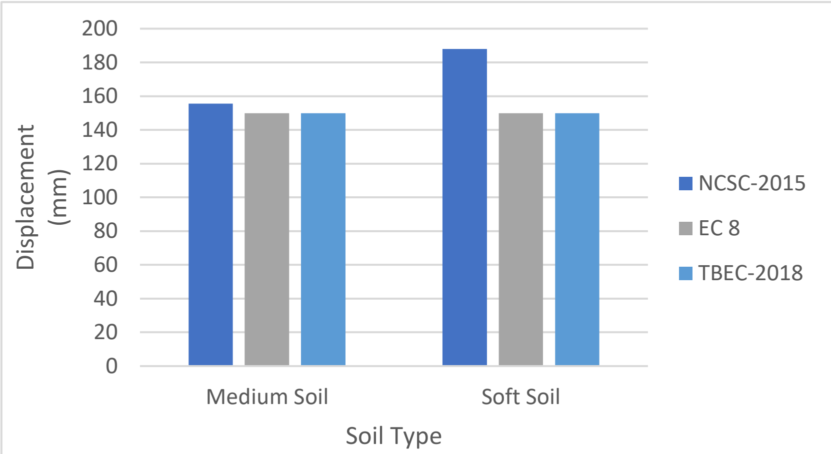


Figure75

Displacement for MRF in an irregular form, medium and soft soil class

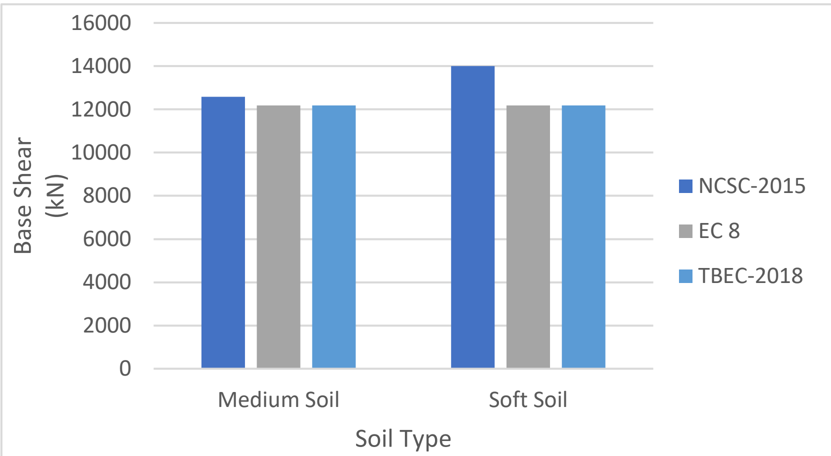


Figure76

Base shear for MRF+SW structures for 5m SW span length in an irregular form, medium and soft soil class

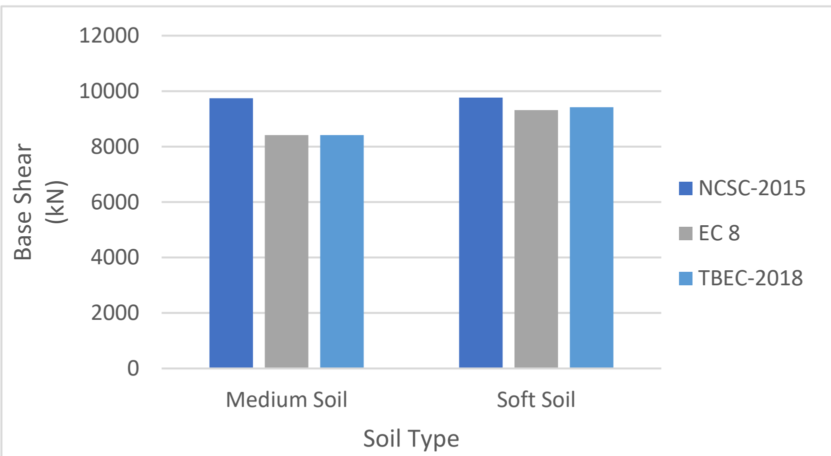


Figure77

Displacement for MRF+SW structures for 5m SW span length in an irregular form, medium and soft soil class

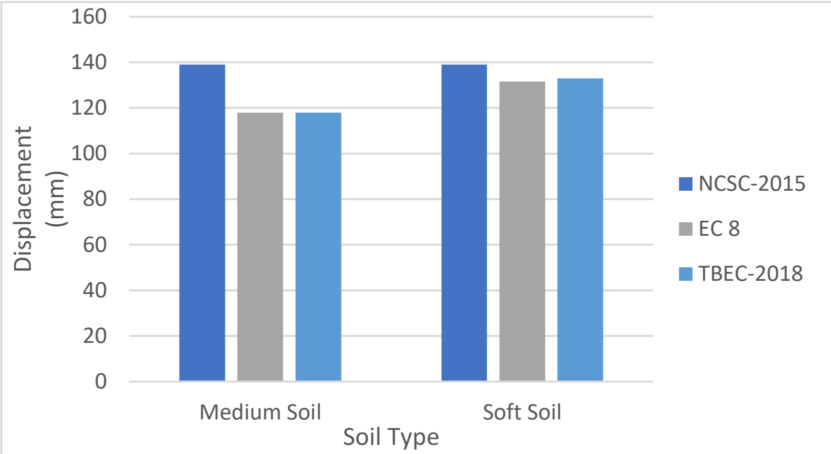


Figure78

Base shear for MRF+SW structures with 1.5m SW length span in an irregular form, medium and soft soil

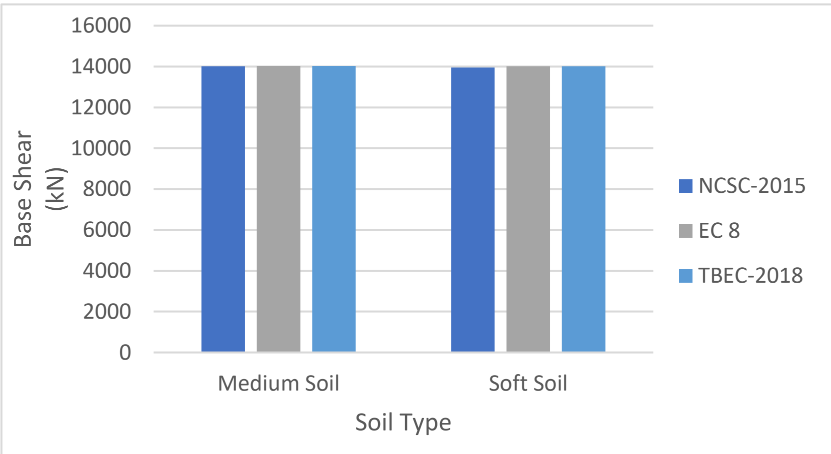
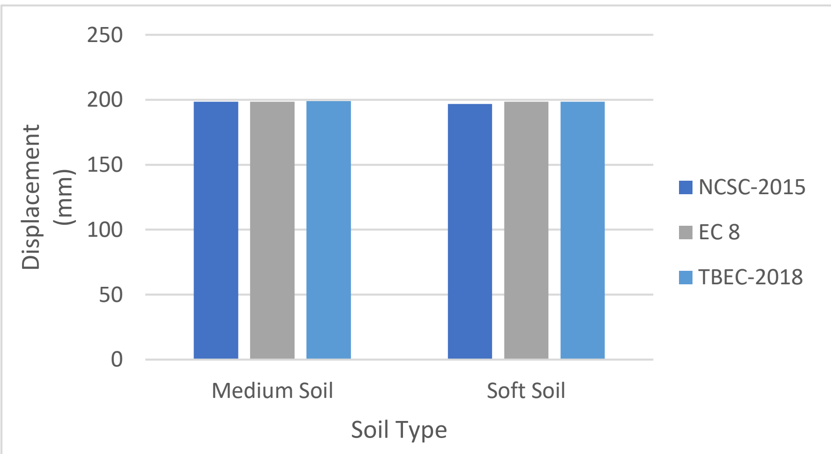


Figure79

Displacement for MRF+SW structures with 1.5m SW span length in an irregular form, medium and soft soil



Appendix H
Ethical Certificate

31.07.2023

ETHICS LETTER

TO GRADUATE SCHOOL OF APPLIED SCIENCES

REFERENCE: AMER YASSIN (Std. No.: 20215184)

The aforementioned candidate is one of the MSc. students in the field of Civil Engineering. He is working on a thesis under my supervision, entitled **"**Behavior of RC Buildings Response to Earthquakes: Nonlinear Static Analysis Considering Varying Soil Types and Seismic Codes**".**

The work is based on modelling MRF and MRF+SW systems in regular and irregular-form residential buildings using ETABS v18. The study compares three earthquake codes: NCSC-2015, EC 8, and TBEC-2018.

Sincerely yours,

Assoc. Prof. Dr. Rifat RESATOGLU
(Supervisor)
Civil Engineering Department,
Faculty of Civil and Environmental Engineering

Appendix I
Turnitin Similarity Report

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