Evaluation and Comparison of Different Structural Systems According to Earthquake Loads

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ABSTRACT

To a certain extent, the performance of seismic analysis and design requirements for a building is considered as a substantial subject amongst Civil Engineers. In general, the lateral force resisting system is the structural system that resists against lateral forces in a reinforced concrete structure while the structures are under seismic excitation. Therefore, the structural system consisting of different lateral force resisting systems, such as the shear walls, coupled shear walls and stiffened coupled shear walls are used in majority of the tall buildings. On the other hand, the tunnel formwork is one of the common structural types in regions prone to high seismic risk due to the inherent earthquake resistance of buildings.

This study attempts to introduce the safest and the most economical system using different lateral force resisting structural systems of a reinforced concrete structure. These different structural systems are tested with different story levels for the purposes of predicting the safest and the most economical system. With this objective in mind, a parametric study was carried out based on the modeling of different structural systems of a reinforced concrete structure such as the flat slab-beam, the shear wall, the coupled shear wall, the stiffened coupled shear wall and the tunnel formwork system, with seven different story levels (i.e. 2, 5, 10, 15, 20, 25 and 28). These structural systems were considered as case studies that were subjected to seismic excitation loading by using the STA4-CAD software. Turkish Earthquake Code-2007 and the Turkish Standards-500 were used with a linear performance analysis method to obtain the structural design of each case study.

Out of the five currently available structural systems, the flat slab-beam and the shear wall systems were proved to be appropriate for different story levels. The safest and the most economical systems were those with up to 5 stories. The tunnel formwork system was proved to be appropriate for different story levels with 10, 15, 20, 25 and 28 story levels. The analytical results of that system are in parallelism with the results of other structural systems in terms of finding the safest system. Also, the results of the tunnel formwork system indicate that as the most economical solution when compared with the total construction cost of others structural systems.

Keywords: coupled shear wall, stiffened coupled shear wall, shear wall, tunnel formwork and Turkish Earthquake Code-2007.

ÖZ

Deprem analizi ve tasarımı konuları inşaat mühendislerinin hep ilgisini çekmiştir. Genel olarak deprem etkilerine karşı koyması için betonarme sistemlerde çeşitli yapısal sistemler kullanılmaktadır. Bu sistemler sırasıyla perde duvar, bağ kirişli perde duvar ve güçlendirilmiş bağ kirişli perde duvar sistemleridir. Ayrıca tünel kalıp sistemleri deprem riskinin yüksek olduğu bölgelerde yüksek katlı binalar için tercih edilmektedir.

Bu çalışma betonarme yapının yapısal sistemlere direnen farklı yanal kuvvetini kullanarak en güvenli ve en ekonomik sistemi tanıtmayı hedeflemektedir. Bu farklı yapı sistemleri en güvenli ve en ekonomik sistemin tahmin edilmesi amacıyla farklı kat seviyeleri ile kullanılır. Bu çalışma kapsamında betonarme çerçeve, perde duvar, bağ kirişli perde duvar, güçlendirilmiş perde duvar ile tünel kalıp yapısal sistemler yedi farklı kat sayısı için (ör. 2, 5, 10, 15, 20, 25 ve 28) karşılaştırılmıştır. Bu yapısal sistemler, STA4-CAD bilgisayar yazılımı kullanılarak sismik uyarma yüküne tabi tutulan vaka çalışmaları olarak kabul edilmiştir. Her bir vaka çalışmasının yapısal tasarımını elde etmek için doğrusal performans analizi yöntemi ile Türk Deprem Yönetmeliği 2007 ve Betonarme Yapıların Hesap Kuralları TS500 kullanılmıştır.

Mevcut beş yapı sisteminden farklı kat seviyeleri için betonarme çerçeve ve perde duvar sistemlerinin uygun olduğu kanıtlanmıştır. En güvenli ve en ekonomik sistemin 5 kata kadar olanlar olduğu gözlemlenmiştir. Bu çalışmada farklı beş kat seviyesi için (10, 15, 20, 25, 28 kat) tünel kalıp sistemi kullanılmıştır. Analitik sonuçlar güvenli ve ekonomik bir yapısal sistemin sonuçlarıyla uygundur. Ayrıca, perde duvar, bağ kirişli perde duvar ve güçlendirilmiş bağ kirişli perde duvar sonuçları bu yapısal sistemlerin tünel kalıp sistemine kıyasla daha pahalı bir sonuç olduğunu göstermiştir.

Anahtar Kelimeler: perde duvar, bağ kirişli perde duvar, güçlendirilmiş perde duvar, tünel kalıp, Türk Deprem Yönetmeliği 2007 (TDY-2007).

DEDICATION

To my husband who was always with me and supported me through my study.

I wish him success in his study and in his life.

To my lovely children.

With love to my parents.

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At first, I thank Allah, Almighty for his blessing, good health and especially for giving me the opportunity to continue my higher education.

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LIST OF ABBREVIATIONS

TEC	Turkish Earthquake Code
TS	Turkish Standards
RC	Reinforced Concrete
IO	Immediate Occupancy
LS	Life Safety
CP	Collapse Prevention
C	Collapse
RU	Ready for Usage
PC	Pre- Collapse
MN	Minimum Damage Limit
SF	Safety Limit
CL	Collapse Limit
ERTF	Easy Rapid Tunnel Formwork
TRTF	Tower Reinforcement Tunnel Formwork
NLTF	No Later Tunnel Formwork
HRTF	High Rise Tunnel Formwork

LIST OF SYMBOLS

R	Structural behavior factor
I	Building importance factor
F_{ck}	Characteristic compressive cylinder strength of concrete [N/mm^2]
F_{yk}	Characteristic yield strength of longitudinal reinforcement [N/mm^2]
β	Coefficient use to determine lower limits of response quantities
W	Total weight of the building [kN/m^3]
G	Dead load [kN/m^2]
Q	Live load [kN/m^2]
E	Earthqakuake load [kN/m^2]
C	Coefficient of later force
S	Snow load [kN/m^2]
ℓ_n	Clear span of beam between column and wall [m]
A_0	Effective ground acceleration coefficient
A(T)	Spectral acceleration coefficient
Hbi	Torsional irregularity factor defined at i'th storey
T_A, T_B	Spectrum characteristic periods [sec]
S(T)	Spectrum coefficient [m/sec^2]
T	Building natural vibration period [sec]
Z_1, Z_2, Z_3 and Z_4	Local Site Classes
V	Shear force with the earthquake direction [kN]

F_{cd}	Compressive strength of the concrete [N/mm^2]
b_w	Width of the beam web [m]
$f_{\mathbf{ctm}}$	Tensile strength of the existing concrete [N/mm^2]
d	Effective beam height [m]
V_{kol}	Shear forces at above or below the loop [kN]
Bj	Smaller of the distances measured from the vertical centerline of beam to the edges of column [m]
h	Column cross section dimension in the earthquake
ρ	Tension reinforcement ratio at the top and bottom of beam support section
ρ\`	Compression reinforcement ratio
ρ_b	Balance reinforcement ratio
A_{s1}	Total area of tension reinforcement placed on side of beam-column loop that is used to resist the negative moment [m^2]
A_{s2}	Total area of tension reinforcement placed on the other side of the beam- column [m^2]
N	Total number of stories of building from the foundation level
V_e	Shear force [kN]
ℓ_{Wall}	Length of wall fill in plan [m]
$h_{\mathbf{ji}}$	Story height of the j'th column and curtain in i'th story [m]
$h_{\mathbf{wall}}$	Height of wall fill [m]
δji	Effective storey drift of the j'th vertical element at i'th story
R	Ratio of exposure/capacity
N	Live load participation factor
$F_{\mathbf{c}}$	Concrete pressure stress in coated concrete [N /mm^2]
A_c	Gross section area of column or wall end zone [m^2]

Chapter 1

INTRODUCTION

1.1 General

The high rise building type of the 19th century is a technological innovation which provides space in urban areas where land is not readily available to meet the increasing demand for business and residential space.

The economic growth, technological advancements, innovations in structural systems, desire for aesthetics in urban settings and human aspiration in order to build higher buildings and making investments in urban development are not only the reasons for urban densification, but also for prestige (Balkaya and Kalkan, 2004a) (ULR 1).

The high rise buildings can be constructed with different structural systems, namely the shear wall system, the coupled shear wall system, the stiffened coupled shear wall system and the tunnel formwork system.

Shear wall systems are one of the most commonly used lateral-load resisting systems in high-rise buildings. They represent a structurally efficient solution to support a building's structural system as the main function of a shear wall is to increase the rigidity of the lateral load resistance (Ravikanth and Ramancharla, 2014).

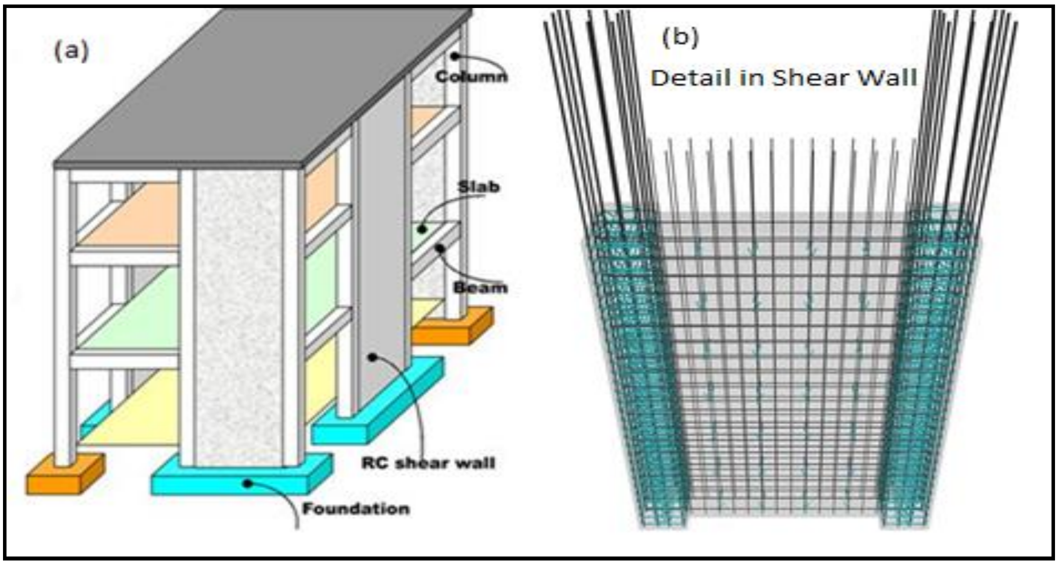

Figure 1.1: Shear Wall System in Building with Detail in Shear Wall (URL11)

Figure 1.1a illustrates the shear wall system in the building and Figure 1.1b illustrates details in a shear wall system. In this study, the shear wall system will be tested through seven different story levels (i.e. 2, 5, 10, 15, 20, 25 and 28).

The structures with coupled shear wall systems comprises of two shear walls on a single plane which are connected by beams at each floor level (Hindi and Hassan, 2004).

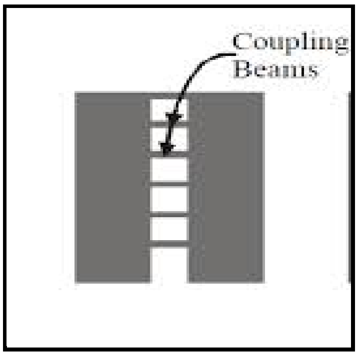

Figure 1.2: Coupled Shear Wall Systems (URL12)

Figure1.2: shows two shear walls connected intermittently by beams along the height.

The coupled shear wall systems with conventional reinforced coupling beams are used to resist the lateral-load resulting from earthquakes in high-rise buildings.

Coupling beams are crucial structural elements in seismic design due to their ability to reduce bending moments and to dissipate energy from the earthquake.

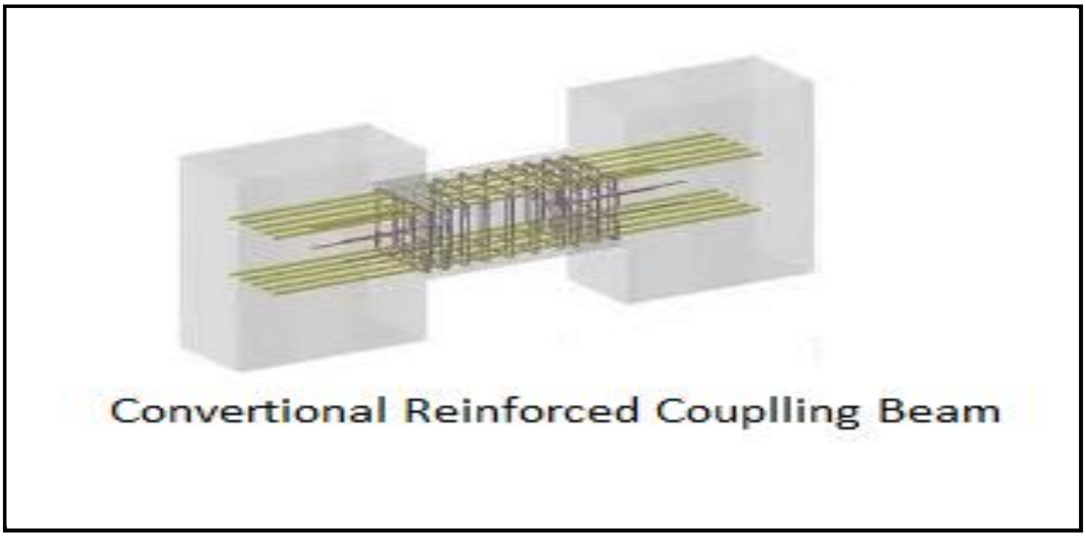

Figure 1.3: Details of a Beam in Coupled Shear Wall System (URL12)

Figure 1.3 illustrates the details of a beam in the coupled shear wall systems, which demonstrates a conventional reinforced coupling beam. The coupled shear wall structures can be made in a way that they would possess all the desirable features of an effective earthquake-resistant structure (El-Tawil et al., 2010).

In this study, the coupled shear wall system and the stiffened coupled shear wall systems will be tested with 10, 15, 20, 25 and 28 story levels.

The stiffened coupled shear wall system is made of coupled shear walls whose endurance is significantly increased by the addition of a stiffer beam (Figure 1.4).

The stiffened coupled shear wall system can be used, but the difference is that the stiffened coupled shear wall system has stiffening beams.

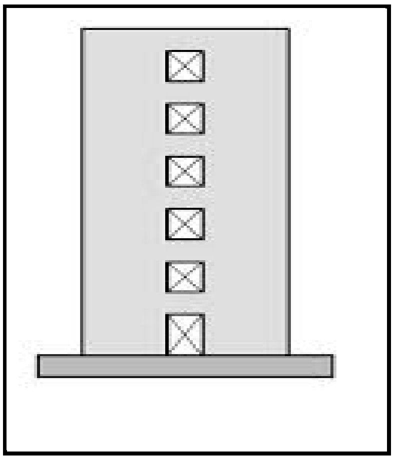

Figure 1.4: Stiffened Coupled Shear Wall System (URL12).

This system is used when the structure needs more resistance in the external lateral loads from the earthquake. Some of the external moment is resisted by the couple formed by the axial forces in the walls due to the increase in the stiffness of the coupled system by the addition of a stiffer beam (Jackson and Scott, 2010) (Figure 1.5).

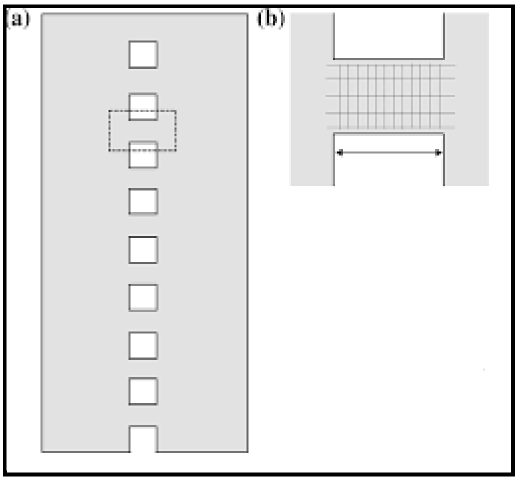

Figure 1.5: Details of a Beam in Stiffened Coupled Shear Wall System (URL12).

The tunnel formwork system is a multi-story reinforced concrete tunnel form. The main components of this system is fixed onto the steel reinforcement and positioned by the walls and slabs where concrete is poured together. When the concrete hardens, the tunnel forms are removed and then, positioned for the next day's work. Therefore, this procedure may require a team of 20-30 workers who can complete 500 m^2 of residential units, so that the building can be built timely. For this reason, tunnel formwork is an appealing system for medium to high-rise buildings. This system was developed by astute developers to get the shortest construction time, low cost, good quality and protection against earthquakes (Tavafoghi and Eshghi, 2008).

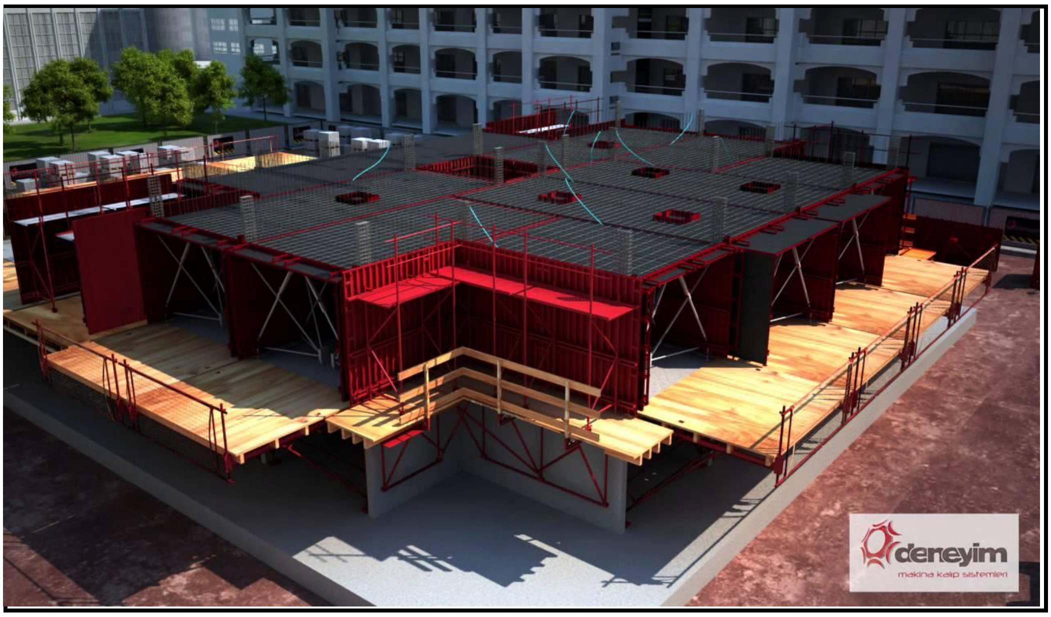

Figure 1.6: Tunnel Formwork System (URL9)

Figure 1.6 illustrates the tunnel formwork system. Recent studies show that the tunnel formwork systems had resisted against the high magnitude earthquakes in Turkey; in 1999 in Izmit and in 2003 in Bingol. The other cases reported from Romania 1977, 1986 and 1990 also showed that the tunnel formwork system can resist against high magnitude the earthquakes (Balkaya and Kalkan, 2004b). The tunnel formwork system is constructed in many countries such as USA, UAE, China, Japan, Italy, Turkey and many other countries.

The flat slab-beam system is a traditional system which is mainly used in low rise buildings, but also in medium to high-rise buildings. This system needs shear walls to resist the lateral-load (Apostolska et al., 2008). For this reason, in this study, the flat slab-beam system will be tested with three different story levels (2, 5 and 10).

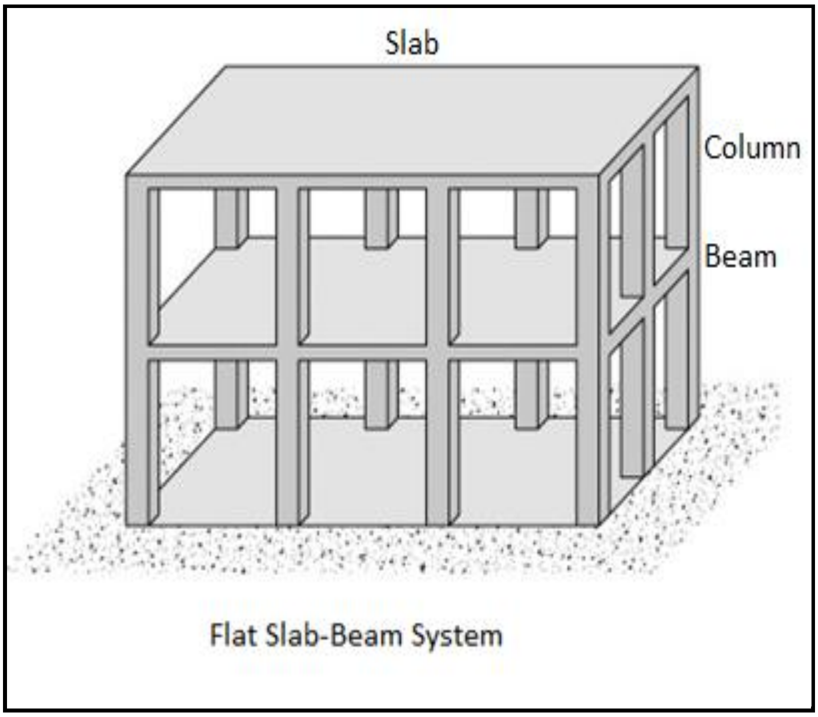

Figure 1.7: Flat Slab-Beam System (URL12)

Figure 1.7 illustrates the flat slab-beam system, consisting of beams, columns and slabs.


Figure 1.8: Existing Buildings from Istanbul (URL7)

This study focuses on the plan of an existing building in Istanbul, as illustrated in Figure 1.8. This architectural plan is used for all case studies and the structural design of each case study will include the linear performance analysis method from the Turkish Earthquake Code-2007 and TS-500.

There are five different systems:

- The flat slab-beam system will be tested with (2, 5 and 10) stories, but 15, 20, 25 and 28 stories are excluded from this system as this system needs shear walls for medium to high-rise building to resist the lateral-load.
- The shear wall system will be tested with (2, 5, 10, 15, 20, 25 and 28) stories.
- The coupled shear wall system will be tested with (10, 15, 20, 25 and 28) stories, but 2 and 5 stories are excluded from this system as the rooms which are provided with the shear wall have more space in the wall to put windows.

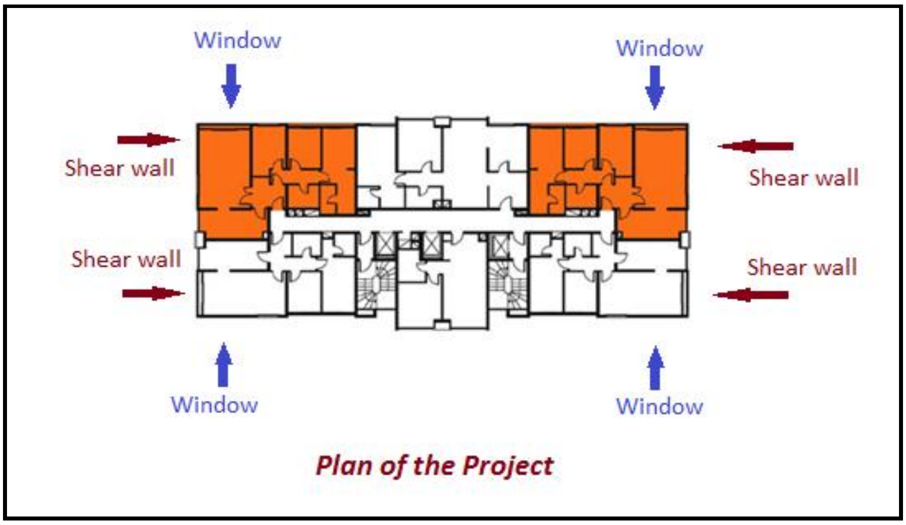

Figure 1.9: Plan of the Existing building in Istanbul (URL7)

Figure 1.9 illustrates the location of shear walls on the plan of the project and the rooms which provided the shear walls to have more space on the walls to put windows. In this study, the buildings which have 2 and 5 stories provided the shear wall at this location. The length and the thickness of the shear wall system depend on the building height to provide the support for the structure. Hence, in this study, the high-rise buildings need more shear walls to resist the lateral-load.

- The stiffened coupled shear wall system will be tested with 10, 15, 20, 25 and 28 stories, but 2 and 5 stories are not included in this as shown in Figure 1.9. The location of shear walls are demonstrated on the plan of the project.
- The tunnel formwork system will be tested with 2, 5, 10, 15, 20, 25 and 28 stories.

This study involves a total of 27 different case studies with the aim of finding the safest and the most economical system.

1.2 Previous Works Done

This study evaluates and compares different lateral force resisting systems. There are many studies previously conducted similar to this study. These studies focused on comparisons between different structural systems. For example, Balkaya and Kalkan (2004a) studied two types of building structures which used the tunnel formwork system and the shear wall system at seven different stories 5, 10, 12, 15, 18, 20 and 25. They compared these buildings to determine which system has a more realistic, more economical and safer behaviour. Their study showed that the tunnel formwork system is more economical and safer than the shear wall system.

Tavafoghi and Eshghi (2008) worked on multistory buildings with the shear wall system and multistory buildings with the tunnel formwork system. This study consisted of 10 different plans of different heights from 5 to 25 stories. The aim was to determine the most economical system. The results showed that the tunnel formwork system is very good for medium to high-rise buildings with identical floor layout, with a low cost and less construction time.

Balkaya and Kalkan (2004b) conducted a research on high rise buildings, specifically on those using tunnel formwork buildings with varying stories levels from 5 to 25. The dynamic behavior characteristic of the tunnel formwork system was evaluated and compared with the shear wall system in terms of different aspects, including the impacts of wall to wall as in the shear wall system and the impacts of wall to slab as in the tunnel formwork system. The conclusion of the performance evaluation of tunnel formwork buildings suggested that tunnel formwork buildings are economically better for practical uses.

Musmar (2013) conducted a study on different sizes of openings (windows) in the shear wall. The aim was to determine the effect of the size of the openings on the behavior of the reinforced concrete shear walls. The study was about the analysis of five shear wall models with different opening sizes. A sixth model of a solid shear wall was also presented to compare the analysis results. The high window ranges were different and they were between 0.5 m, 1.0 m, 1.5 m, 2.0 m and 3.0 m. After the analysis, it was found that the size of windows in the shear wall was 1.0 m × 1.0 m. This was seen as a positive result because the capacity of a shear wall structure is similar to that of a coupled shear wall. On the other hand, when openings are large enough, which were 1.0 m x 3.0 m in this study, the capacity of the structure is reduced by 70% with respect to the capacity of the structure of the solid shear wall. The capacity of the structure was represented by a displacement for building in (x, y) direction.

Tuna and Ilerisoy (2013), also, conducted a study on buildings with nine models with 6, 12, 18, 24, 30, 36, 42, 48 and 54 stories and these models were studied by using two different systems, the tunnel formwork system and the shear wall system. In this study, the plan was the same and the cost of each project was calculated. As a result, it was found that, the tunnel formwork system is not economical for low rise buildings but rather, for the high rise buildings.

Isler (2008) studied the buildings with shear wall system ranging from 4 to 10 stories. However, there was no shear wall around the stair walls and around the elevator. The shear walls of this building were located on the outer edges of the building however; the stair walls and the elevator wall without the shear walls could not resist the earthquake loads.

Kumbhare and Saoji (2012a) studied a building with 11 stories and they carried out the study on five different shear wall locations. The plan had the same dimensions with the section of beams, columns, walls and slabs. The results suggested that the shear wall system should be put at the corners on each side of these locations so that it could give the best results from all different positions.

Anshuman et al., (2011) studied the high rise buildings and conducted a research to examine the solution of shear wall located in the building. This case study had a symmetrical and rectangular plan. Also, the building consisted of 15 stories. The aim of this study was to find the suitable location for the shear wall in the building and to analyze the location it moseyed to reach the allowed deflection. It was found that, when the shear wall was located in the weak direction, it was defined as a small dimension in (x or y) direction on the plan layout building to resist the horizontal loads after the earthquake, when the deflection of the building was reduced.

Shahzad and Umesh (2013) carried out a study on the lateral displacement of a structure, with shear walls located in different places in the building. The obtained results showed that the shear wall can affect the seismic behavior of the frame structure when the shear walls were located on the outer edges of the building. This is because the location of shear walls on the outer edges increases the strength and stiffness of the structure.

Kumbhare and Saoji (2012b) also conducted a study about five different models and the building had 25 stories. The study aimed to compare different buildings with and without shear walls.

The case study with shear wall had a different location. The first model was without a shear wall and the other model had a shear wall which was located around the center. In one model, the shear wall was placed around the center and on the outer edge in x direction. In the other model, the shear wall was placed around the center and on the outer edge in y direction. In the last model, the shear wall was put around the center and on the outer edge in two directions x and y, aiming all four corners of the building. The results showed that the last model, where the shear wall was put around the center and in the four corners of the building in two directions, was more resistant compared to the others.

Alfa and Rasikan, (2013) presented a study where the evaluation and comparison of different structures of two different buildings were carried out. One of the buildings had a shear wall system and the second building did not have a shear wall system. The first model was with 15 stories and the second model was with 20 stories. The objective of this study was to analyze the behaviour of the building when subjected to wind loading. In conclusion, the displacement that occurred in the structures with shear wall system because of the wind was less than the displacement that occurred in the structures without the shear wall.

Himalee and Satone (2013) carried out a study on a building with a basement and 5 stories. The plan of the building was symmetric and the study was on different locations for shear wall and the relative effects of shear wall on the building. The result showed that the shear wall that was placed as a box at the stairs of the building gave a better result compared to the other structures.

Chandurkar and Pajgade (2013) studied a building with a basement and 10 stories in different zones such as 2, 3, 4 and 5. The displacement of the building with and without a shear wall was investigated after the earthquake has happened. The results demonstrated that the shear wall system provided better results and the deflection of the building was reduced.

Ashraf et al. (2008) had a study about multi-story building investigation in which the location of the shear walls was changed to see the effects of the forces on the building. In conclusion, it was found that the best location of the shear wall is the furthest point from the centroid of the building.

In a study by Humar and Yavari (2002), the relationship between the shapes of shear walls was analyzed in terms of the shear wall with a square shaped wall and the shear wall with L shaped. It was found that the square shaped shear wall was more effective than the L shaped shear wall.

Romy and Prabha (2011) undertook a study using a building with a height of more than 25 m and compared the symmetrical and unsymmetrical buildings in order to find the one with better resistance. They found that the symmetric building is more resistant than the unsymmetrical building in reducing the torsion in buildings.

Apostolska et al. (2008) presented, evaluated and compared six different structure models, comprised of a flat slab-beam system, a flat-slab with no beams, a flat- slab with no beams and different sizes of slab, a flat-slab with perimeter beams, a flat-slab with no beams but with shear walls and finally a flat slab with beams and shear walls. The building that was studied consisted of a basement and 7 stories.

In this study, it was aimed to find sustainability of a building without collapsing.

In conclusion, the model 1 flat slab-beam system had big displacements from other structures and collapsed. The best behavior was observed in model 6. The displacements of model 6 were less than model 1 by about 40%, meaning that the system acted better when it consisted of a flat slab with beams and shear walls.

It can be concluded that the buildings up to 8 stories with the flat slab-beam system need the shear walls to resist the lateral-load, especially in areas with high risk of earthquake.

1.3 Objectives and Scope

The aim of this study is to carry out a comparison among five different structural systems: the flat slab-beam system, the shear wall system, the coupled shear wall system, the stiffened coupled shear wall system and the tunnel formwork system. These different structural systems have their own projects with seven different stories; 2, 5, 10, 15, 20, 25 and 28. The economic analysis was carried out along with the analysis of seismic performance of these different structural systems.

Finally, the study aims to choose the most economical system and the safest within the range allowed as specified by the TEC-2007.

1.4 Organization of the Thesis

This thesis consists of six chapters:

- Chapter 1: Introduction

  This chapter involves an introduction to the different structural systems, the background information about the assessment procedures, and the objectives and scope of this study.

- Chapter 2: Lateral Force Resisting System

This chapter provides the definitions of different structural systems. Moreover, the advantages and disadvantages which have been studied are summarized. The method of pouring the concrete in form and the types of the tunnel formwork system are also given.

- Chapter 3: Seismic Performance Assessment Using TEC-2007

  Information regarding the assessment methods according to the Turkish Earthquake Code-2007 are described and the seismic performance assessment analysis procedures are explained.

- Chapter 4: Methodology

  Information regarding the limitations, dimensions of the structural elements according to the Turkish Earthquake Code-2007 is given. The design of the case studies and seismic performance checks are also provided.

- Chapter 5: Case Studies

  Detailed modeling of each case study is given separately for 27 different case studies. There are five different systems such as flat slab-beam system, shear wall system, coupled shear wall system, stiffened coupled shear wall system and tunnel formwork system. For each system, there are different buildings with 2, 5, 10, 15, 20, 25 and 28 stories.

  In this chapter, the analysis and result of every case study are also discussed separately. For each case study, there is a table illustrating the quantity of concrete (m^3), formwork (m^2), reinforcement (ton), building wall (m^2), plaster (m^2), cost of project in Turkish Lira (TL) for the case studies, displacement for the building (m) for two directions (x, y) and the analysis of seismic performance for the case studies.

In the end, the summary of all projects are illustrated in a table and a chart according to the total cost of each project, the displacement of the building in two directions (x, y) after earthquakes and the analysis of seismic performance for each case study.

- Chapter 6: Conclusion and Recommendation

  Conclusions along with recommendations for future research are provided.

Chapter 2

LATERAL FORCE RESISTING SYSTEM

2.1 Introduction

This chapter deals with the definition of the different structural systems that will be applied in this study. In addition, the advantages and disadvantages for each structural system based on their definitions will be discussed.

The method of pouring the concrete in the form and the type of the tunnel formwork system is also described. Issues regarding the location and the reason of the shear wall systems being located symmetrically with the different structural systems which will be applied in this study are also explained.

2.2 Structural System

2.2.1 Flat Slab-Beam System

2.2.1.1 General Information

This system is a traditional system consisting of beams, columns and slabs supporting the space between the beams.

The flat slab-beam system is mostly used in low-rise buildings, but also in medium to high-rise buildings. This system needs shear wall to resist the lateral-load. According to a study by Apostolska et al. (2008), the flat slab-beam system is used in buildings with up to 8 stories, but also in high-rise buildings. The flat slab-beam system needs the shear wall to resist the lateral-load, especially in areas of high earthquake risk.

This system is an economical system and it is easy to build. Thus, it will be used in buildings with 2, 5 and 10 stories as part of this study.

This system is usually used in many low rise buildings because the flat slab-beam systems can be used at construction sites with no restrictions and it can minimize the floor-to-floor heights when there is no requirement for a deep false ceiling. This can have benefits for the height of lower buildings and can reduce the total cost of the building (Ravikanth, 2014).

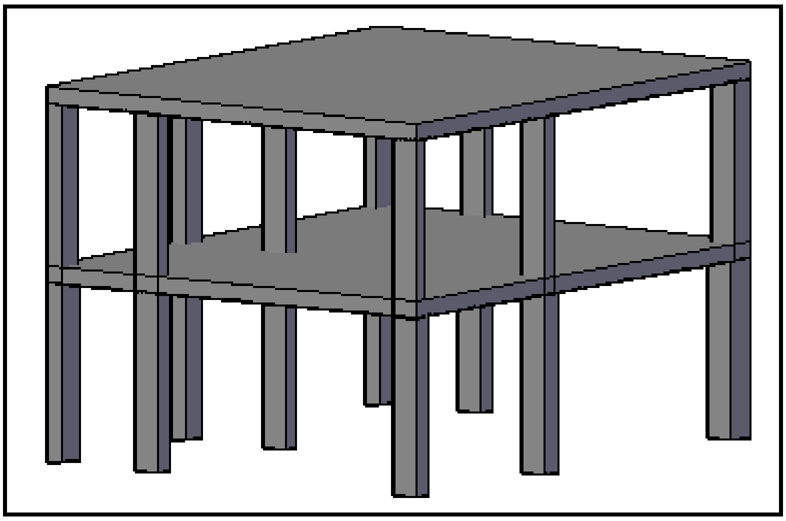

Figure 2.1: Flat Slab-Beam System (URL10)

The Figure 2.1 shows the flat slab-beam system consisting of columns, beams and slabs as a traditional system.

2.2.1.2 Advantages of Flat Slab-Beam System

The advantages of this system are given below:

1) Flexibility in the size of room design.
2) The placement of the reinforcement is easy to put and the reinforcement specification of this system is very simple.
3) Ease of frame appliance as the sizes are standard.

4) The time of construction is short (URL10).

2.2.1.3 Disadvantages of Flat Slab-Beam System

The disadvantages of the flat slab-beam system are given below:

1) The span length is not long, it has a medium length.
2) The capacity of the frame to resist the lateral load is limited.
3) This system needs a column of a larger size which will reduce the shear.
4) This system is not appropriate for heavy loads (URL10).

2.2.2 Shear Wall System

2.2.2.1 General Information

The shear wall system is one of the most commonly used lateral-load resisting systems in medium to high-rise buildings. The shear wall represents a structurally efficient solution to support a building's structural system, because the main function of a shear wall is to increase the rigidity for lateral load resistance. This system is appropriate for both loads, the vertical load and the horizontal load, in terms of resistance. The frame of the shear wall system is in the shape of a rectangle to a parallelogram, given in Figure 2.2.

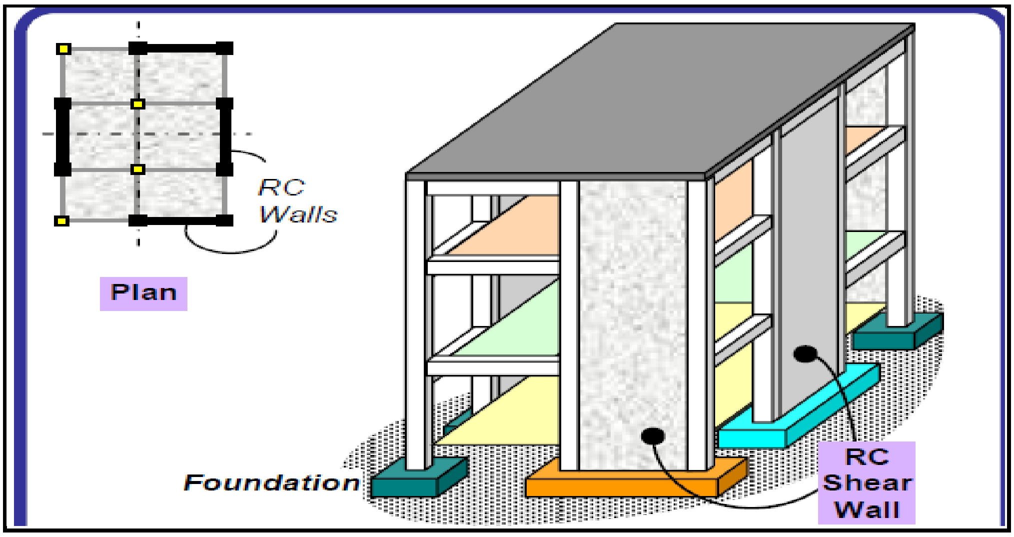

Figure 2.2: Shear Wall System Symmetrical on Both Sides (URL11).

Lateral load is the force applied laterally to a building derived from earthquakes which caused shear and moments in walls (Kumbhare et al,. 2012).

2.2.2.2 Advantages of Shear Wall System

1) The shear wall system in the building can resist strong earthquakes because the shear wall system causes less damage in the structure as a result of an earthquake (Alfa and Rajendran, 2013).
2) Shear walls are efficient in medium to high rise buildings, both in terms of economical construction cost and effectiveness in minimizing structural damage after an earthquake (Chandurkar and Pajgade, 2013).
3) Shear walls are easy to construct in low to medium rise buildings because reinforcement detailing of the walls is relatively straightforward and therefore they can easily be implemented at the site (URL11).

2.2.2.3 Disadvantages of Shear Wall System

The disadvantages of a shear wall system are given as follows:

1) Difficulty to have windows and doors.
2) It is difficult to apply on-site and needs intensive work in high-rise buildings.
3) Expensive compared to other buildings, especially to high-rise buildings (Ravikanth and Ramancharla, 2014) (URL8) (URL11).

2.2.2.4 Location of Shear Walls

Shear wall is one of the most ideal means of providing earthquake resistance to multi-story reinforced concrete buildings. Structural design of such buildings for seismic loading is primarily concerned with the structural safety during major earthquakes in high-rise buildings. The provision of shear wall in buildings has been found effective in achieving rigidity. When the shear walls are situated in advantageous positions, they can form an efficient lateral force resisting system.

The best locations for shear walls in a building are given below:

1) Shear walls in buildings must be symmetrically located in the plan to reduce the torsion in buildings (Romy and Prabha, 2011).
2) Shear walls are more effective when located in outer edges of the building (Shahzad and Umesh, 2013).
3) Shear walls in buildings should be located in the shape of a box around the stairs (Himalee and Satone, 2013).
4) The best location for the shear wall is when it is located symmetrically in the weak direction (Anshuman et al, 2011).
5) The shear walls should be located symmetrically in the corner on each side (Kumbhare and Saoji, 2012).
6) Shear walls are more effective when located around the stair walls and around the elevator (Isler, 2008).

2.2.2.5 Reasons Why the Shear Walls are Located Symmetrically

Shear walls in buildings must be symmetrically located on the plan. This is the aspect of symmetry, which has a bearing on whether torsional effects will be produced or not.

It has been noticed that there are shear walls in both directions, which is a more realistic situation, because earthquake forces need to be resisted in both directions.

Figure 2.2 shows two shear walls that are symmetrical as symmetry is preferred to avoid torsional effects (Romy and Prabha, 2011).

2.2.3 Coupled Shear Wall System

2.2.3.1 General Information

Door or window openings can be provided in shear walls, but their size must be small to ensure the least amount of interruption in order to force flow through walls. Therefore, special design checks are required to ensure that the net cross-sectional area of a wall at an opening is sufficient to carry the horizontal earthquake force. Moreover, openings should be symmetrically located.

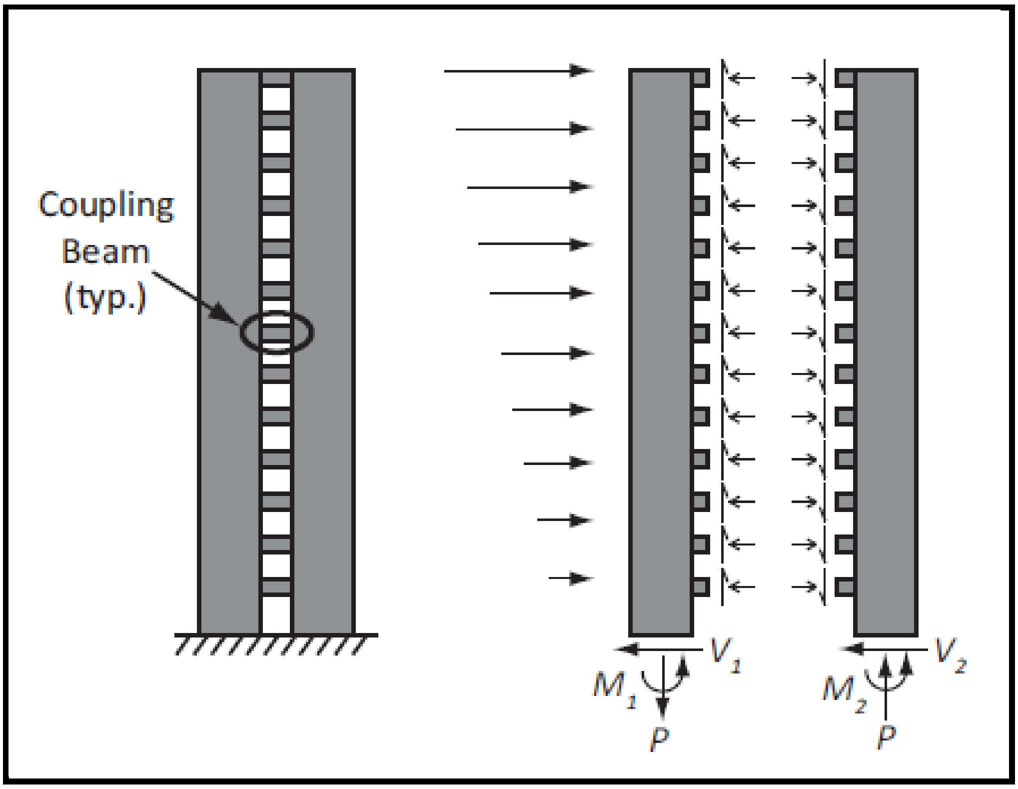

Figure 2.3: Coupled Shear Wall System (Smith and Coull, 1991)

Sometimes the shear walls need to be perforated in the wall with openings for doors and windows. These openings are typically equal in size, as shown in Figure 2.3. In every respect, the superior performance of the structure containing conventionally reinforced beams is established.

The use of conventionally reinforced coupling beams enabled a considerable portion of the total energy to be dissipated by the coupling beams (Smith and Coull, 1991).

2.2.3.2 Size of Openings in a Coupled Shear Wall System

When the design requires an opening within the shear wall such as doors or windows, they have to be controlled with the size of the windows. The interior windows smaller in size are always better. This is because a small opening is made within the wall to ensure low interruption in order to force flowing out of the wall (Musmar, 2013).

Musmar (2013) conducted a study on different size openings (window) in the shear wall, and he investigated the effects of the response of the coupled shear walls on the stress flow with small openings and found that the effect on the load was neglected by changing the size of the opening. After the analysis, it was found that the size of windows in the shear wall of 1.0 m × 1.0 m is the best opening. In this study, the size of windows in the shear wall will be 1.0 m × 1.0 m.

2.2.3.3 Symmetrical Openings in Coupled Shear Wall System

Openings within the shear wall, such as windows and doors, have to be symmetrically located to have a bearing on whether torsional effects will be produced.

It has been noticed that there are coupled shear walls in both directions, which is a more realistic situation because earthquake forces need to be resisted in both directions. This is because symmetry is preferred to avoid torsional effects (Romy and Prabha, 2011).

2.2.4 Stiffened Coupled Shear Wall System

2.4.1 General Information

Stiffened coupled shear wall system is a coupled shear wall system used in places where it is sometimes inevitable to have openings within the shear walls, such as windows, doors and other types of opening.

Stiffened coupled shear wall system is usually used when the structure needs more resistance to the external lateral loads from the earthquake, by increasing the stiffness of beams via connecting diagonally reinforced coupling beams (Smith and Coull, 1991) (Jackson and Scott, 2010).

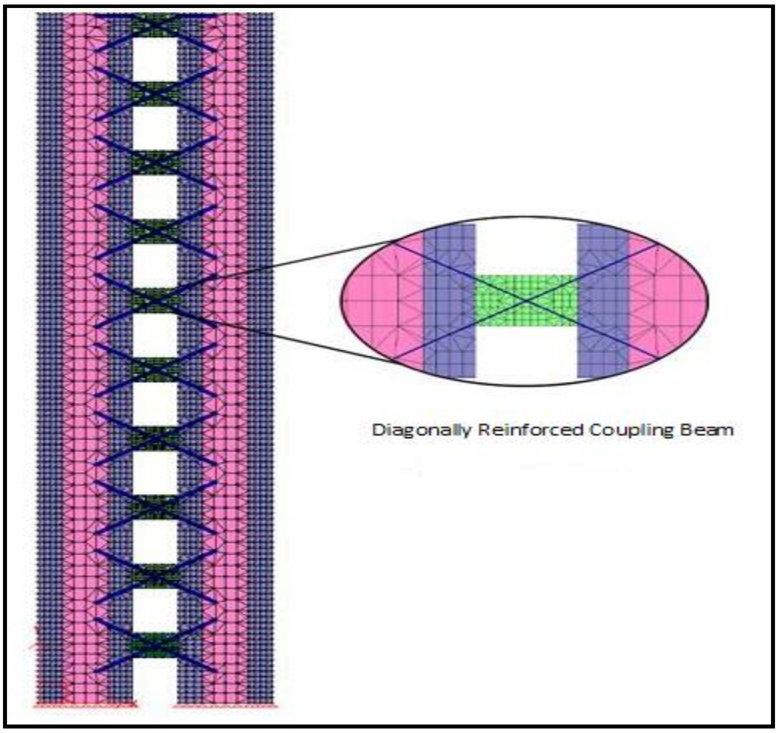

Figure 2.4: Stiffened Coupled Shear wall with Details of a Beam (URL12)

Door or window openings can be provided within shear walls, but their size must be small to ensure the least amount of interruption to force flow through walls.

Moreover, openings should be symmetrically located and in equal sizes, as shown in Figure 2.4. This established the optimum performance of the structure containing diagonally reinforced beams. The use of diagonally reinforced coupling beams enabled a considerable portion of the total energy which is dissipated by the coupling beams (Smith and Coull, 1991) (Jackson and Scott, 2010).

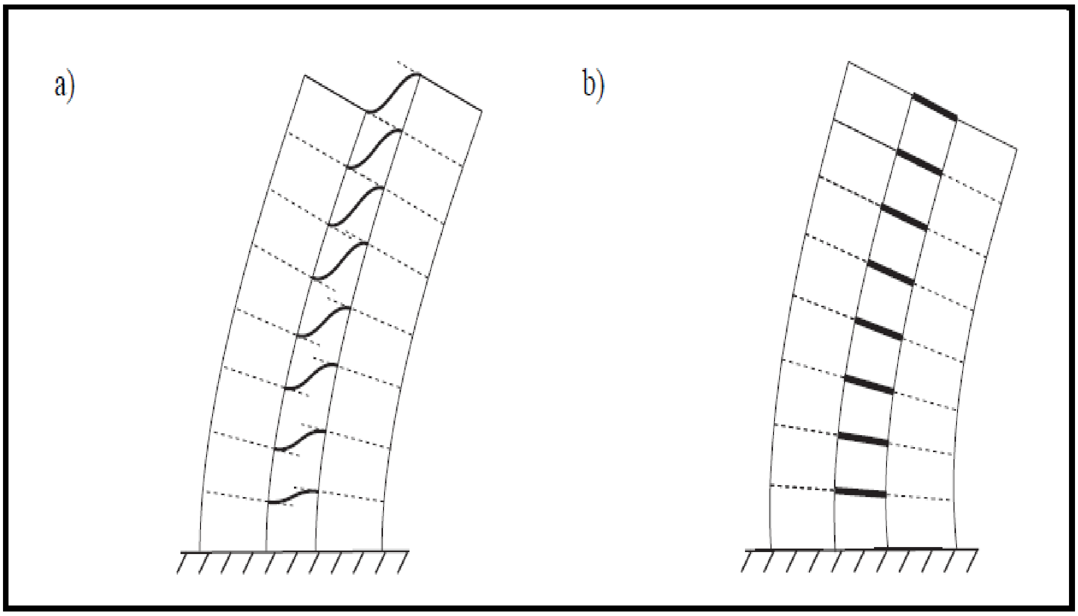

Figure 2.5: Coupled Shear Wall and Stiffened Coupled Shear Wall (Smith and Coull, 1991)

The stiffened coupled shear wall system is a coupled shear wall system, which has openings within the shear walls, such as windows and doors. However, the difference of the stiffened coupled shear wall is that it has increased stiffness of beams. When the coupled shear wall structure deforms horizontally during an earthquake, the walls rotate and this leads to the deformation in the beam, as shown in Figure 2.5a (Smith and Coull, 1991).

Nevertheless, the stiffened coupled shear wall system is a better solution than the coupled shear wall system as the walls do not rotate, as shown in Figure 2.5b (Smith and Coull, 1991).

2.2.4.2 Size of Openings in Stiffened Coupled Shear Wall System

The stiffened coupled shear wall system and the coupled shear wall system should have small sized openings because small openings in the wall ensure low interruption of force that flows out of the wall.

Torki et al., (2011) had a study about the size of the opening in the stiffened coupled shear wall and found the relative behaviour of this system.

The result of the study showed that the number of floors and the height of the beam had an effect on the behaviour of this system in high rise-buildings of the size of 0.50 m × 1.00 m. In this study, the size of windows in the shear wall will be 0.50 m × 1.00 m.

2.2.4.3 Symmetrical Openings in Stiffened Coupled Shear Wall System

Stiffened coupled shear wall system and the coupled shear wall system should have symmetrically located openings in the shear walls to have a bearing on whether torsional effects will be produced. This is because earthquake forces need to be resisted in both directions. The symmetry is preferred to avoid torsional effects (Romy and Prabha, 2011).

2.2.5 Tunnel Formwork System

2.2.5.1 General Information

The tunnel formwork system is a modern building method which enables building of the slabs and walls simultaneously. This system was developed by astute developers to get a shorter construction time at low construction costs, good quality and protection against earthquakes.

This type of buildings are widely available in urban areas, that are densely populated, where small lands are available for development (Tuna and Ilerisoy, 2013).
This system is very appealing for medium to high-rise buildings with repetitive plans due to satisfactory performance during the previous earthquake.

This system already has a familiar use in the industry; it saves cost and construction time. One building of the tunnel formwork system usually has about 15 stories which can be increased up to 40 or 50 stories and is very easy to construct (Tavafoghi and Eshghi, 2008). This type of structural system can be rapidly constructed. High rise buildings with tunnel formwork system have been used in Turkey since 1970. This system showed resistance against earthquakes. The Tunnel formwork system resisted against various earthquakes in Turkey in 1999 in Izmit and in 2003 in Bingol. These systems have the ability to resist the forces resulting from the earthquakes. Moreover, other cases reported from Romania in 1977, 1986 and 1990 also showed that the tunnel formwork system can resist high magnitude earthquakes (Balkaya and Kalkan, 2004b).

2.2.5.2 Method of Pouring Concrete for the Tunnel Formwork System

At first, it must be made sure that poured concrete is used at high strength concrete construction.

Figure 2.6: Half Tunnel (URL9)

The tunnel formwork system consists of inverted L-shaped half-tunnel forms as shown in Figure 2.6. When a room is created, it fitted two half-tunnels together.

Figure 2.7: Half Tunnel with Door (URL9)

Figure 2.7 illustrates the place of doors in the half-tunnel.

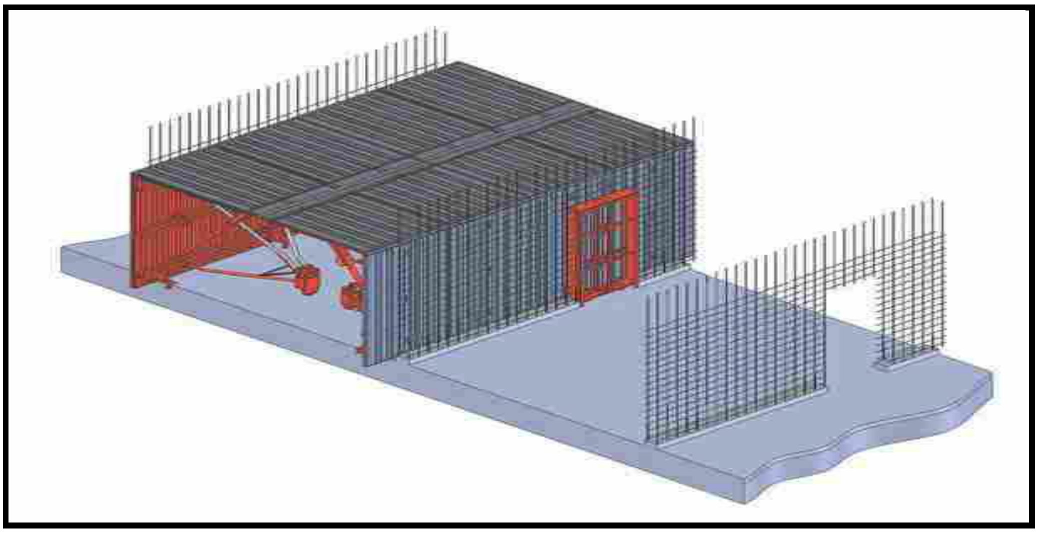

Figure 2.8: Puts the Reinforcement in the Side (URL5).

Figure 2.8 illustrates the way how to put the reinforcing steel for the walls on the side and how to put two half-tunnels together, how to create a room and how to create a door in this room.

Figure 2.9: Form the Rooms (URL9)

Figure 2.9 illustrates how to put two half tunnels together to create a full tunnel formwork, and thus how to form the rooms.

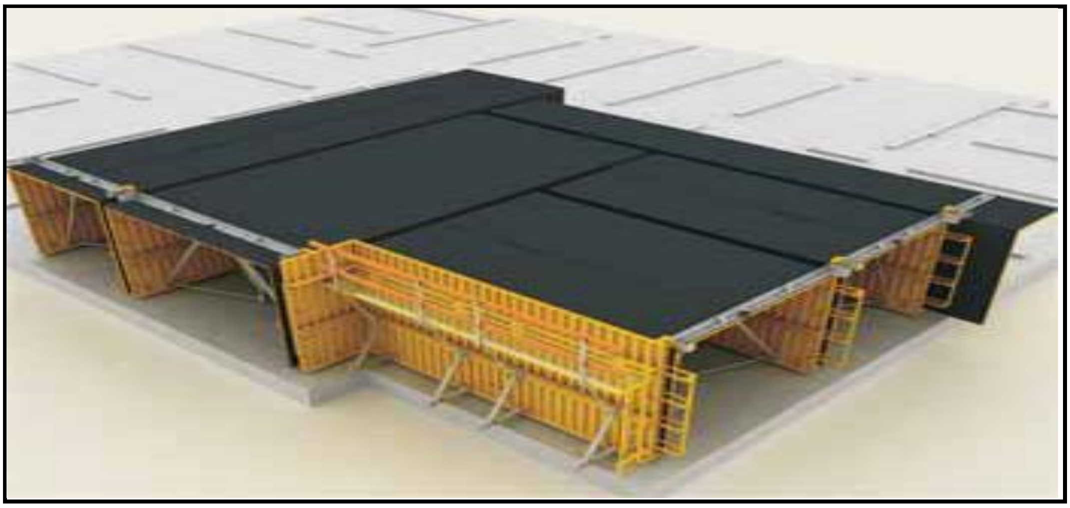

Figure 2.10: Formworks are Placed in their Locations (URL9)

Figure 2.10 illustrates the tunnel formworks placed in their locations ready to finish the first story.

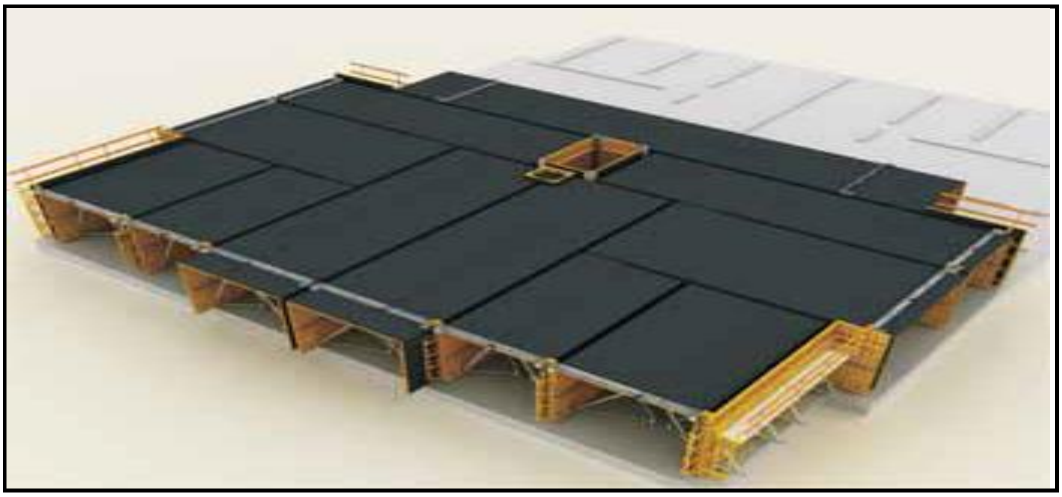

Figure 2.11: Completion of the Installation of Formwork (URL9)

Figure 2.11 illustrates the installation of the formwork and the formation of the first story.

Figure 2.12: Installation the Reinforcement on the Formwork (URL9)

Figure 2.12 illustrates the alignment of reinforcing steel on the formwork completed, reinforcing steel for the slabs of the first story before concrete pouring.

Figure 2.13: The Axle Stands and Brackets are Closed (URL9)

Figure 2.13 illustrates the last stage before the casting of the concrete into the tunnel formwork, the axle stands and brackets are closed**.**

Figure 2.14: Concrete Casting (URL 9)

Figure 2.14 illustrates the completed preparations and the poured concrete.

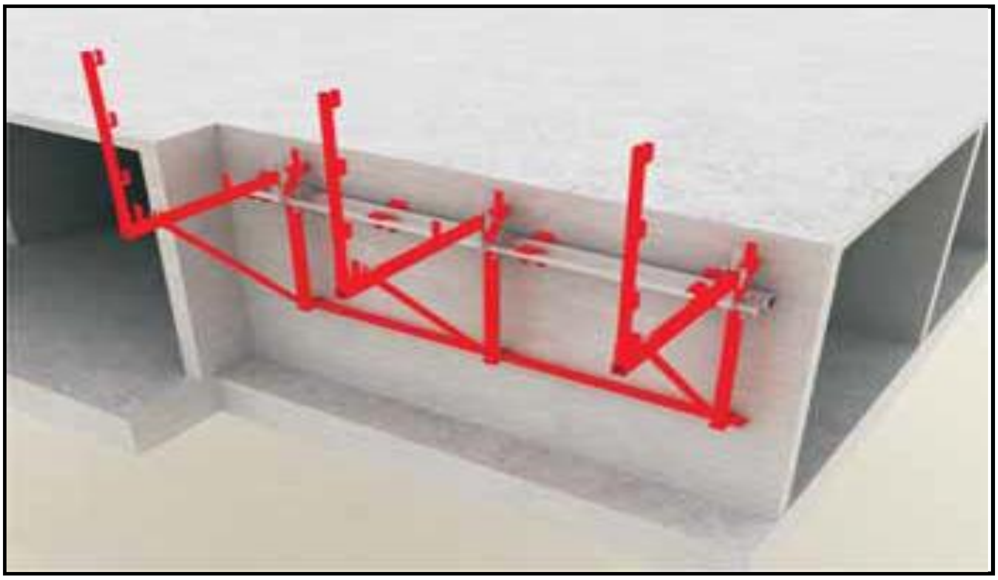

Figure 2.15: Position of the Hanger Apparatus (URL9)

Figure 2.15 illustrates the later stage after the completion of the first story, when the hanger apparatus is put to start exterior scaffolds for the second story and repeat the previous phases.

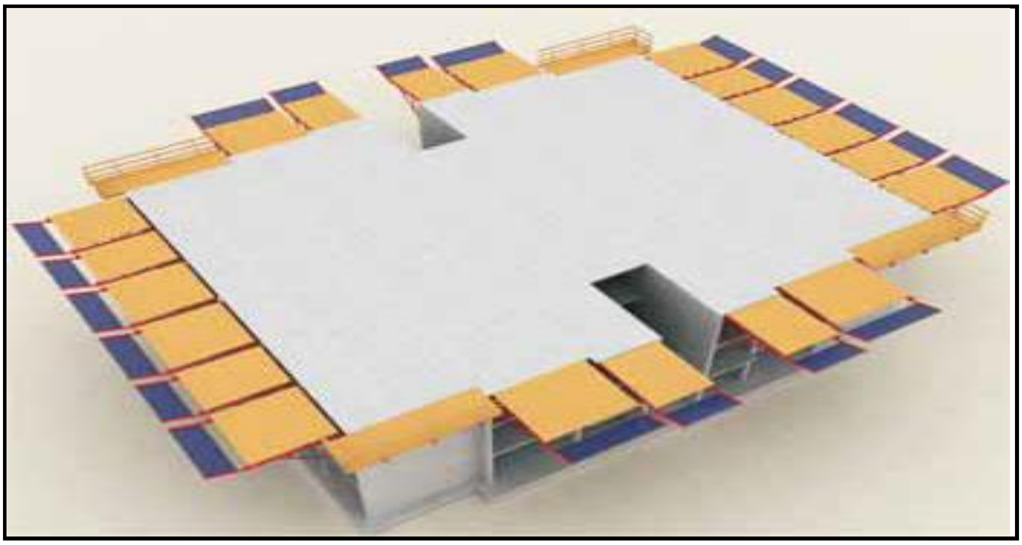
Figure 2.16: Exterior Scaffolds Prepared (URL9)

Figure 2.16 illustrates how to put the exterior scaffolds to start put the formwork in the second story of the project.

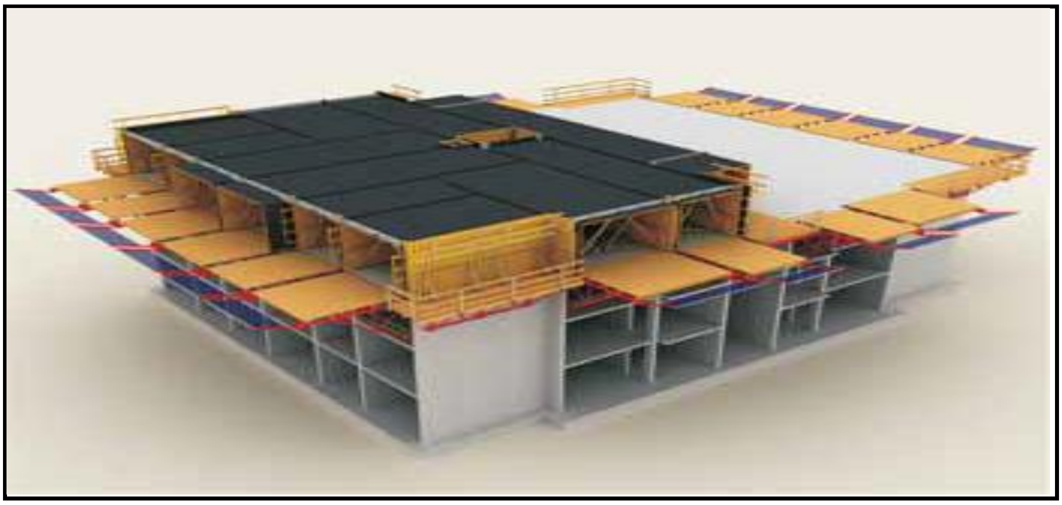
Figure 2.17: New Story (URL9)

Figure 2.17 illustrates a new story. During the tunnel formwork construction process, a structural tunnel is created by pouring concrete into steel formwork to make the slab and walls within one monolithic process. Every 24 hours, the formwork is moved so that another tunnel can be formed. When a story is completed, the process is repeated for the next story. A strong, monolithic structure is thus constructed that can reach up to 40 or more stories (Jayachandran, 2009).

2.2.5.3 The Tunnel Formwork is an Economical System

The Tunnel formwork system is an economical system because the floors and the rooms are repeated and the project takes a short time to be finished. There are many previous studies focusing on the comparison between the shear wall system and the tunnel formwork system in high-rise buildings. The results showed that the tunnel formwork system is generally a more economical and time saving construction method. (Tavafoghi and Eshghi, 2008) (Balkaya and Kalkan, 2004a)

The Tunnel formwork system in high rise buildings can be used to form about approximately 1000 recycling on each floor and room. This frame can be continued to be used in order to finish several projects. During the construction, one story can be finished in one day. This means that groups of 26-31 laborers can complete 500 m^2 in one day. All of these benefits prove the tunnel formwork as an economical system (URL2) (URL3).

2.2.5.4 The Dimensions of Tunnel Formwork System

The dimension of the width of the tunnel formwork system is between 9 m to 12 m and the length of the tunnel formwork system is between 12 m to 16 m.

The smallest size of the room in the tunnel formwork system is 2.10 m^2 (URL4).

2.2.5.5 Types of Mold of the Tunnel Form

2.2.5.5.1 ERTF-Tunnel Form Modular of System

ERTF Easy Rapid Tunnel Formwork

Figure 2.18: ERTF Tunnel Formwork (URL5).

Figure 2.18 illustrates the easy, rapid tunnel formwork. This system is fast and high quality to build in a short time and it may need less construction workers and provide an easy formwork to apply to the construction project. It also improves the quality.

2.2.5.5.2 TRTF-Classic Model of the Tunnel Formwork

TRTF Tower Reinforcement Tunnel Formwork is a classic model of the tunnel formwork system as shown in Figure 2.19. It is a simpler and lighter weight system and this system has a lower exploitation rate than other types of tunnel formwork thus, it can save construction cost and time.

This system is simpler than the other system and the building can use the form 100 times, which reduces the cost of the project. This system, also, increases the quality of the building (URL5).

Figure 2.19: TRTF Tunnel Formwork (URL5).

2.2.5.5.3 NLTF-Tunnel Form of Modular System

NLTF No Later Tunnel Formwork of modular system is shown in Figure 2.20. Its range is expanded with this modular, the design is unique and the system can serve for a big project (URL5).

This system has the following advantages:

1- The vertical panel jacks are easy to replace.

2- The joint between two half tunnels is reduced to zero.

Figure 2.20: NLTF Tunnel Formwork (URL5)

2.2.5.5.4 HRTF-Tunnel Form of Modular System

HRTF High Rise Tunnel Formwork of module system is shown in Figure 2.21. It is a requirement in the U.S.A and it is designed to serve for the project. This strong modular system can be used for different structure types to build one housing to a high rise building (URL5).

Figure 2.21: HRTF Tunnel Formwork (URL5)

2.2.5.6 Advantages and Disadvantages of Tunnel Formwork

2.2.5.6.1 Advantages of Tunnel Formwork System

There are many advantages of this system such as the following:

1) Formwork cost per m^2 (or per housing unit) can be reduced by using formwork up to 8 hundred times.
2) It can be completed within a period of one to three days. Therefore, the project can be finished in a short time compared to the other systems.
3) As the project can be finished in a short time, the effects of climatic conditions are also minimized.
4) Due to smooth surfaces like walls and slabs, no additional finishing such as plaster is needed.
5) Early completion of project provides financial opportunities such as rental incomes (URL5) (URL6).

2.2.5.6.2 Disadvantages of Tunnel Formwork System

The tunnel formwork system has disadvantages as well which can be listed as follows:

1) Investment cost of formwork system increases the formwork cost per m^2 if the project is small sized.
2) A continuous and fast cash flow that complies with the speed of production is essential.
3) Skilled labour force is needed compared to the traditional systems. Equipment costs are relatively higher due to the cranes needed by each block (URL5) (URL6).

Chapter 3

SEISMIC PERFORMANCE ASSESSMENT USING TURKISH EARTHQUAKE CODE-2007

3.1 Introduction

Different case study samples with different heights were designed by adapting a basic architectural design that was selected from Istanbul. Then, the structural design process took place according to the corresponding codes as explained earlier. In this study, the plan of all case studies was established by using the Linear Response Spectrum Analysis and then; the Linear Performance Analysis which were both carried out for assessment purposes.

This chapter deals with the information about the performance of minimum building targets expected at different earthquake levels. The method of analysis for linear performance with the target spectral acceleration A(T) was derived from the consideration of the effective ground acceleration A_0, the building importance factor (I), the spectrum coefficient S(T) and the spectrum characteristic periods (T_A, T_B). The target performance levels of the buildings during an earthquake are also explained in this chapter.

This study will make use of each case study in order to find the percentage of the limits and areas of damage in structure elements and the linear performance elastic calculation method will be carried out in order to find the type of damage on the elements.

3.2 Determine Performance for Objectives

The general basis of the design for the earthquake resistance is to limit the damage to the structural elements of buildings at low intensity earthquakes. It aims to avoid the collapsing of the structure at high intensity earthquakes. On the other hand, one of the main aim behind the code based seismic design is to avoid the loss of life. Performance criteria is based on the evaluation and strengthening of the design of buildings. The Building Importance Factor of $I = 1$ is shown in (Table 3.4).

For the new buildings, the acceleration spectrum is defined for the earthquakes with 10% probability of being exceeded within the next 50 years.

In addition to this earthquake level, two different seismic intensity levels are given below to evaluate the design of buildings and to be utilized in strengthening:

a) The coordinates of the acceleration spectrum of the earthquakes with the probability of exceeding within 50 years (approximately half of the coordinates of the spectrum is previously defined, i.e. 50%).
b) The coordinates of the acceleration spectrum of the earthquakes with the probability of exceeding within 50 years (2% is decided to be taken as the basis which is approximately 1.5 times of the coordinates of the spectrum that were previously defined).

Table 3.1: Performance of minimum building targets expected for different earthquake levels (TEC-2007)

The usage purpose and the type of building	The probability of the earthquake to be exceeded		
	50 % in 50 years	10 % in 50 years	2 % in 50 years
Buildings that should be used after earthquakes: Hospitals, dispensaries, heath facilities, fire stations, communications, energy facilities and transportation stations etc	-	RU	LS
Buildings that people stay in for a long time period: Schools, accommodations, dormitories, posts etc	-	RU	LS
Buildings that people visit densely and stay for a short time period: Cinemas, theatres, concert halls and sports facilities.	RU	LS	-
Buildings containing hazardous materials: Buildings containing flammable, explosive materials and buildings where the mentioned materials are stored.	-	RU	PC
Other buildings: Buildings that dose not fit the building definitions given above (houses, offices, hotels etc	-	LS	-

Note that: LS: Life Safety, RU: Ready for Usage and PC: Pre-Collapse

In this study, Other buildings: (Buildings that dose not fit the building definitions given (houses, offices, hotels etc)) is select. The acceleration spectrum is constructed by adapting the intensity level with 10% exceedance probability in the next 50 years.

3.3 Seismic Performance Analysis Methods

The buildings can be assessed by the linear elastic and nonlinear evaluation methods. The definition of these two methods are provided below:

- Linear performance analysis (equivalent seismic load method and mode superposition method)
- Nonlinear performance analysis (pushover analysis and time history analysis).

3.3.1 Linear Performance Analysis

The linear performance analysis methods can be regarded as an extension of the method used for the design of a new building and existing buildings. However, in the design of a new building and existing buildings, the capacity ratio of the cross sections are given in the code to evaluate and compare their limiting values.

After the earthquake has happened, the linear elastic performance calculation methods are used to obtain the seismic performances of the building.

The dynamic analysis method is applied to all buildings without any restrictions. The equivalent seismic load method is also applied to the buildings that do not exceed 25 m in height. When eight stories having $\eta bi < 1.4$ buckling disorder which is calculated without considering the joint eccentricity the ηbi is the torsional irregularity factor defined at i'th story of the building.

3.3.1.1 The Information Levels Coefficients for Buildings

Usually there are three information levels which are given in Table 3.2 and each information level has a different safety coefficient.

Table 3.2: Information level coefficient (TEC-2007)

Information level	Safety coefficient based on TEC-2007
Limited	0.75
Moderate	0.90
Comprehensive	1.00

1) Limited Information Level

By field studies, several structural data of the plan on the walls and the member's location are gathered through the inspection of the foundation system. The identified reinforcement details should be inspected visually 10% from the columns and 5% from the beams for each floor after removing the cover concrete in accordance with the Turkish Earthquake Code-2007.

2) Moderate Information Level

In general, this level is similar to the limited information level. The reinforcement should be inspected visually 20% from the columns and 10% from the beams at each floor after removing the concrete cover. At least three samples were taken from the concrete and the total minimum number of concrete samples is nine (TEC-2007).

3) Comprehensive Information Level

The comprehensive information level requirement is the details of structural plans of the foundation system that are gathered through inspection, the reinforcement details, the concrete material properties and the existing steel strength all of which should be verified by taking specimens from the buildings (TEC-2007).

3.3.1.2 Spectral Acceleration Coefficient

The elastic seismic load can be calculated by using the Spectral Acceleration A(T), which can be found from the Equation 3.1.

$$A(T) = A_0 \, I \, S(T) \tag{3.1}$$

where:

A(T): Spectral Acceleration

A_0: Effective Ground Acceleration coefficient

I: Building Importance Factor

S(T): Spectrum Coefficient [m/sec^2]

3.3.1.3 Effective Ground Acceleration Coefficient

The Effective Ground Acceleration Coefficient, A_0 in the Equation 3.1, has different values due to different seismic zone. They are shown sequentially below in Table 3.3.

Table 3.3: Ground Acceleration Coefficient (A_0) (TEC-2007)

Seismic Zone	A_0
1	0.40
2	0.30
3	0.20
4	0.10

3.3.1.4 Building Importance Factor

The Building Importance Factor, (I), which is given in Table 3.4, is based on different building occupancy.

Table 3.4: Structure Importance Factor (I) (TEC-2007)

Purpose of occupancy or type of building	Importance Factor (I)
1. Buildings 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, firefighting buildings, transportation stations and telecommunication facilities, etc). b) Building containing or storing toxic, flammable and explosive materials, etc.	1.5
2. Intersively and long-term occupied buildings and buildings preserving valuable goods: a) Schools, other educational buildings and dormitories. b) Museums.	1.4
3. Intensively but short-term occupied buildings: Cinemas, theatres, concert halls and sports facilities, etc.	1.2
4. Other buildings: Buildings other than above-defined buildings (Residential, offices and hotels, etc).	1.0

3.3.1.5 Spectrum Coefficient

The Spectrum Coefficient S(T) is determined by the Equation 3.2, which depends on the Figure 3.1.

$$S(T) = 1+1.5\,(T/T_A) \qquad (0 \le T \le T_A) \qquad (3.2)$$

$$S(T) = 2.5 \qquad (T_A < T \le T_B)$$

$$S(T) = 2.5\,(T_B/T)^{0.8} \qquad (T_B < T)$$

The soil related Spectrum Characteristic Periods T_A and T_B are specified in Table 3.5 which depend on Local Site Classes to be considered as the basis of determination of soil conditions of design of new buildings to be enhanced in seismic zones.

where:

S(T): The Spectrum Coefficient [m/sec^2]

T_A, T_B: The Spectrum Characteristic Periods [sec]

T: The Buildings Natural Vibration Period [sec]

Z_1, Z_2, Z_3 and Z_4: Local Site Classes.

Table 3.5: Spectrum Characteristic Periods (T_A, T_B) (TEC-2007)

Local Site Class	T_A Second	T_B Second
Z_1	0.10	0.30
Z_2	0.15	0.40
Z_3	0.15	0.60
Z_4	0.20	0.90

3.2.1.6 Special Design Acceleration Spectra

The local seismic zone details as well as Code Specified Spectral Acceleration Coefficients from the Figure 3.1 were used. The Spectrum Coefficient S(T) from the Equation 3.1 and from Table 3.5 represent the specific period range where the peak Spectral Acceleration is expected.

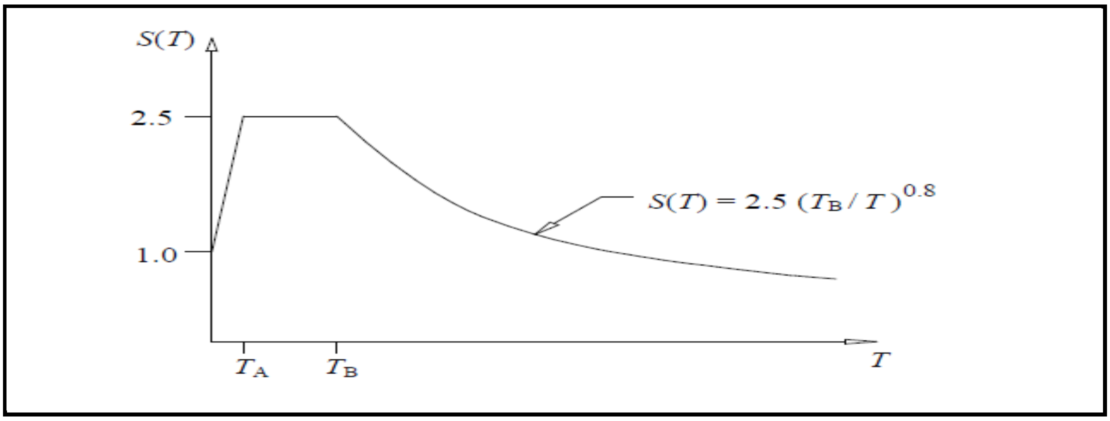

Figure 3.1: Spectral Acceleration Coefficients (TEC2007).

3.3.1.7 Considering the Displacement Components and the Application of Seismic Loads

In the structure where story behaves as a rigid lateral overlay, two horizontal displacement components and rotation of the vertical axis, should be taken into account at each story level. In other words, the eccentricity should be considered at each storey level.

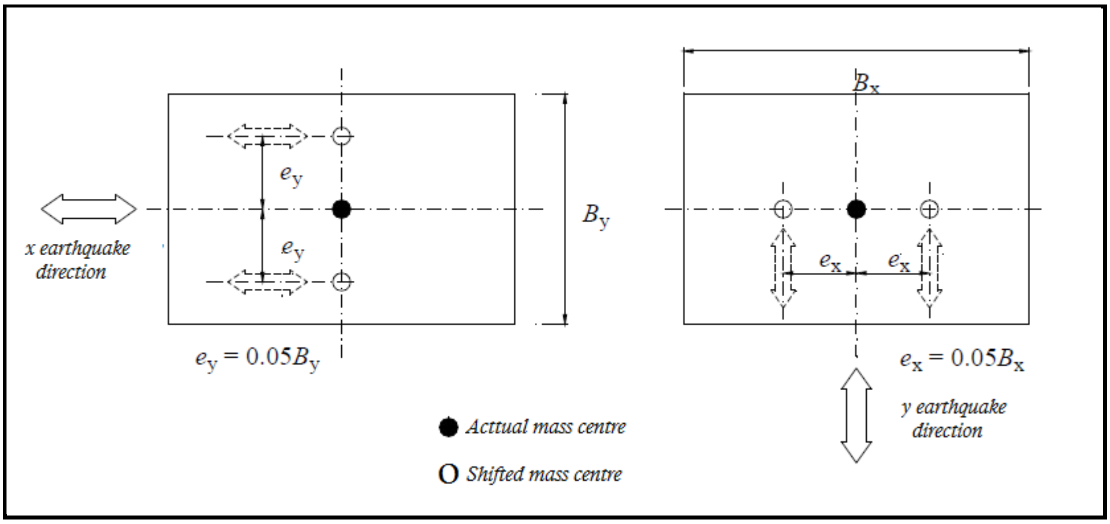

Figure 3.2: Earthquake Loading Having X or Y Direction (TEC-2007).

Figure 3.2 illustrates the plan, where there are two lateral displacement components with x or y directions the building rotates around the vertical axis during an earthquake loading. In order to consider the eccentricity effect, at each floor, equivalent seismic loads, determined in accordance with the points obtained by shifting the actual mass center by + 5% or - 5% times the floor length in the perpendicular direction to the earthquake direction, are considered for story mass center.

3.4 Seismic Performance Level

The level of performance has four levels:

i. Immediate occupancy (IO).

ii. Life Safety (LS).

iii. Collapse Prevention (CP).

iv. Collapse (C).

After the building is defined, it analyzed for performance by STA4-CAD. The performance levels of buildings, wherever applicable, are defined below with respect to the estimated damage levels in earthquakes.

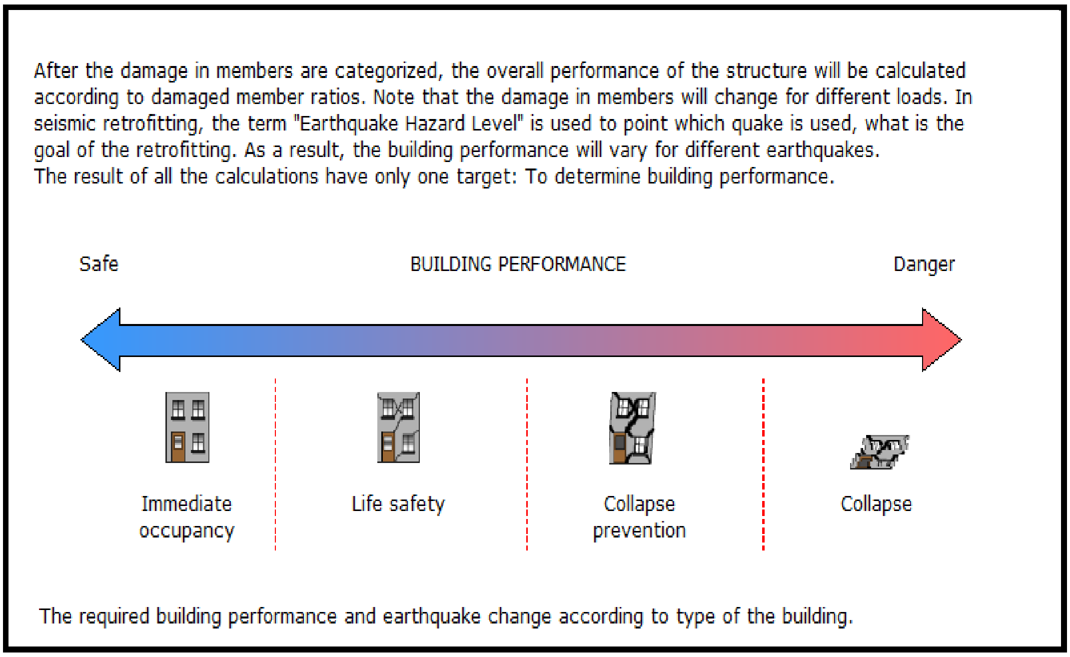

Figure 3.3: Levels of Building Performance for Different Earthquakes (STA4-CAD Handbook)

The performance levels of buildings are shown in Figure 3.3.

3.4.1 Immediate Occupancy (IO)

After the earthquake hits, the damage affecting the beams on any floor is 10% of the beams at most and this is considered as a small damage.

3.4.2 Life Safety (LS)

The buildings that satisfy the conditions mentioned below can be considered as having Life Safety (LS) standards. The Life Safety Performance Level according to TEC-2007 can be divided into four sections:

1) After the earthquake hits, the damage affecting the beams on each floor is 30% at most which is the ratio of the number of the beams damaged on any floor to the total number of all beams on that floor.

2) After the earthquake hits, the damage affecting the columns on each floor should not exceed 20% which is the ratio of the number of the column damaged on any floor to total number of all columns on that floor.

3) The roof story V_c ratio is for each floor on the top floor, the ratio of the total shear forces of the columns on the floor to the total shear forces of all the columns on that floor can be 40% at most.

4) The columns including plastic hinge V_c ratio have the shear forces borne by of the columns which both in upper and lower sections. For any floor, it should not be more than 30% for all columns of the shear force borne by all columns which is the joint columns over minimum damage shear force distribution.

3.4.3 Collapse Prevention (CP)

The Collapse Prevention Performance Level according to TEC-2007 can be provided for all components that are brittle to damage as follows:

1) The damage of beam is 20% at most on any floor.

2) The columns including plastic hinge have the shear forces borne by the columns which are both in upper and lower sections. For any floor, it should not be more than 30% of the shear force borne by all columns of that floor.

3) Usage of the building under these circumstances poses threats towards life safety.

3.4.4 Collapse (C)

1) If the building does not satisfy the Collapse Prevention (CP), it is categorized as a Collapse Case (CC).
2) Usage of the building under these circumstances poses threats towards life safety.

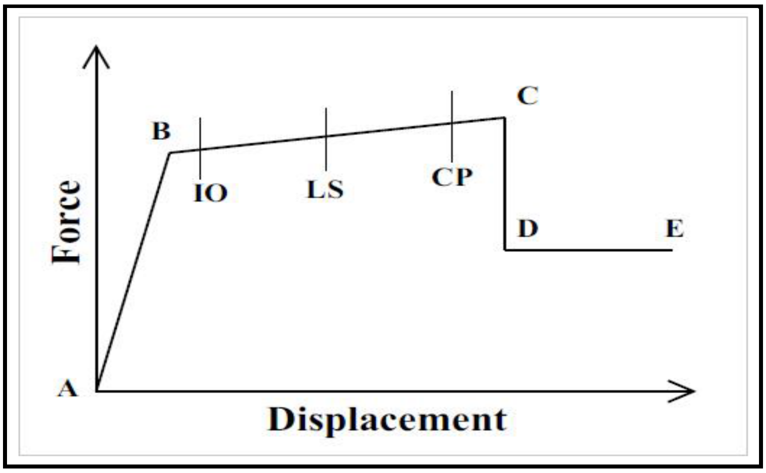

Figure 3.4: The Level of Performance (Fardis, 2003).

From Figure 3.4, it can be seen that the level of damage increases with the increasing force. If the displacement reaches the point C, then, the system is expected to collapse.

3.5 Limits and Areas of Damage in Structure Elements

3.5.1 Limits of Damage in Cross Section

There are three limits whose conditions are defined based on the cross sectional elements in the building.

3.5.1.1 Minimum Damage Limit (MN)

Minimum Damage Limit describes a performance condition of the damage that occurs in buildings and in their elements during an earthquake when the damage is very limited. In this condition, the building can be fixed in a few days.

3.5.1.2 Safety Limit (SF)

Safety Limit describes a performance condition where limited damage is permitted in buildings and in their elements during an earthquake. In this condition, the building can be expected to be fixed in short term (a few weeks or months).

3.5.1.3 Collapse Limit (CL).

Collapse Limit describes a performance condition where extensive damage occurs in buildings and in their elements during an earthquake to the point of collapse. In this case, the buildings can be fixed in long term.

3.5.2 Areas of Damage in Cross Section

The Minimum Damages State, given in Figure 3.5, illustrates the region of the elements when this element reaches the critical sections, just before MN.

The Significant Damage State is the region of the element between MN and SF.

The Extreme Damage State is the region of the element between SF and CL.

The Collapsing State is the region of the element after CL.

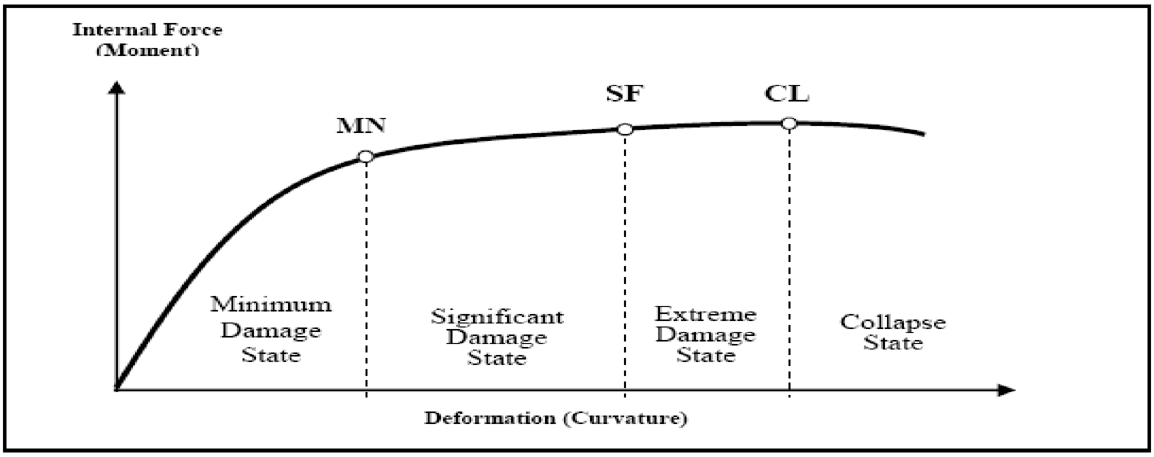

Figure 3.5: Performance Levels and Ranges (TEC-2007)

3.5.3 Definitions of Damage in Cross Sections and Elements

By using the linear performance analysis method, the damage limitations are adapted and corresponding damages are identified, as given in Figure 3.5.

3.6 Damage Level in the Structural Elements with Linear Elastic Methods

The damage description of the elements, are calculated by linear performance elastic calculation method. The (r) is the numerical value, which will be used for the ratios of capacity column, beams, and wall of strengthening in walls.

3.6.1 Effects of Capacity Ratios (r) in Concrete Elements

It decides the damage zone of the element by comparing the effect of capacity ratio for wall, column, and beam sections and the strengthened full of walls. The values of (r) are in Tables 3.6, 3.7, 3.8 and 3.9, which are used besides the damage to reinforced concrete beams.

Table 3.6: Effect the capacity ratios (r) of the damage to reinforced concrete beams (TEC-2007)

Ductile Beams			**Damage Boundary**		
$\frac{\rho - \rho`}{\rho b}$	**Coating**	$\frac{V}{bw\ d\ fctm}$	**MN**	**SF**	**CL**
≤ 0.0	Available	≤ 0.65	3	7	10
≤ 0.0	Available	≥ 1.30	2.5	5	8
≥ 0.5	Available	≤ 0.65	3	5	7
≥ 0.5	Available	≥ 1.30	2.5	4	5
≤ 0.0	Not available	≤ 0.65	2.5	4	6
≤ 0.0	Not available	≥ 1.30	2	3	5
≥ 0.5	Not available	≤ 0.65	2.5	4	6
≥ 0.5	Not available	≥ 1.30	1.5	2.5	4

where;

V: The shear force that should be calculated with the earthquake direction [kN]

The ratio of reinforcement in beams is defined as:

$$\frac{\rho - \rho`}{\rho_b} \qquad (3.3)$$

where;

ρ : The tension reinforcement ratio.

$\rho`$: The compression reinforcement ratio.

ρ_b : The balance reinforcement ratio.

From the Equation 3.3, if the section of the beam is $\rho - \rho` < \rho_b$. Therefore, this Equation 3.3 is a factor related with the ductility of the sections. When the values of ductility increase, the r_{limit} decreases.

where;

bw : width of beam web, thickness of wall web [m]

d : an effective beam height [m]

f_{ctm} : The tensile strength of the existing concrete [N/mm^2]

Table 3.7: Effect of the capacity ratios (r) of the damage to reinforced concrete columns (TEC-2007)

Ductile Columns			**Damage Boundary**		
$\frac{N}{Ac\, fc}$	**Coating**	$\frac{V}{bw\, d\, fctm}$	**MN**	**SF**	**CL**
≤ 0.1	Available	≤ 0.65	3	6	8
≤ 0.1	Available	≥ 1.30	2.5	5	6
≥ 0.4	Available	≤ 0.65	2	4	6
≥ 0.4	Available	≥ 1.30	2	3	5
≤ 0.4	Not available	≤ 0.65	2	3.5	5
≤ 0.1	Not available	≥ 1.30	1.5	2.5	3.5
≥ 0.4	Not available	≤ 0.65	1.5	2	3
≥ 0.4	Not available	≥ 1.30	1	1.5	2

where;

N : The axial force [kN]

Ac : The cross section area of a column or a wall end zone [m^2]

*f*c : The concrete pressure stress in coated concrete [N/mm^2]

V:Shear force that should be calculated in accordance the earthquake direction [kN]

bw : The width of the beam web, thickness of web wall [m]

d : The effective beam height [m]

f_{ctm} : The tensile strength of the existing concrete [N/mm^2]

For both column and beam sections, if the shear demand increases, the behave section behaves like brittle. Hence, when this value increases, the ductility and r_{limit} reduce. Moreover, as N/A_cf_c increases, the curvature ultimate capacity reduces. For this reason, the values of r_{limit} reduce when the values of N/A_cf_c increase (TEC-2007). The shear force in column and beam joints, in the along direction of an earthquake, will be calculated in Equation 3.4:

$$V_e = 1.25\ f_{yk}\ (A_{S1} + A_{S2}) - V_{kol} \tag{3.4}$$

The shear force V_e should be not exceeding the limits, as defined in the Equations 3.3 and 3.4. If the shear force V_e exceedes the limits, as defined in the Equations 3.5 and Equation 3.6 below, the cross section of beam and column should be increased.

In confined joints $\quad Ve \leq 0.60\ bj\ h\ fcd \quad$ (3.5)

In unconfined joints $\quad Ve \leq 0.45\ bj\ h\ fcd \quad$ (3.6)

where;

As_1: Total area of tension reinforcement placed on one side of the beam-column loop at the top that is used to resist the negative beam moment [m^2]

As_2: Total area of tension reinforcement placed on the other side of the beam-column loop with respect to As1 at the bottom to resist negative beam moment [m^2]

V_{kol} : The smallest of shear forces at above or below the loop [kN]

f_{yk} : The characteristic yield strength of longitudinal reinforcement [N/mm^2]

fcd : The design compressive strength of the concrete [N/mm^2]

bj : The smallest of the distances measured from the vertical centerline of beam to the edges of column [m]

h : The column cross section dimension in the earthquake direction considered [m^2]

Table 3.8: Effect of the capacity ratios (r) of the damage to reinforced concrete walls (TEC-2007)

Ductile Walls	**Damage Boundary**		
Coating	**MN**	**SF**	**CL**
Available	3	6	8
Not available	2	4	6

Table 3.9: Effect of the capacity ratios (r) the damage for reinforced full of walls and ration of the relative floor drift (TEC-2007)

Ratio range of ℓ_{Wall} / h_{wall} 0.5 – 2.0	**Damage Boundary**		
	MN	**SF**	**CL**
Effect / Capacity Ratios(r)	1	2	-
Ratios of Relative Storey Drift	0.0015	0.0035	-

where;

ℓ_{Wall} : Length of filling wall in plan [m]

r : The ratio of exposure/capacity

h_{wall} : The height of filling wall [m]

Table 3.10: Boundaries of relative floor drift (TEC-2007)

The ratio of relative floor drift	Damage Boundary		
	MN	SF	CL
δ_{ji} / h_{ji}	0.01	0.03	0.04

where;

hji : The storey height of the j'th column or curtain on i'th story [m]

δji : Effective story drift of the j'th vertical element on i'th story

In the linear performance elastic methods for each earthquake direction, the relative floor drifts on each floor of the structure shall not exceed the values given in Table 3.10.

Chapter 4

METHODOLOGY

4.1 Introduction

This Chapter explains the designing process of the different structural systems with different stories. The architectural design was selected from Istanbu which was then, used for structural design by considering the limitations specified in the TEC-2007 and TS-500.

These limitations will be explained later in this chapter. In total, there are seven different numbers of story categories. These are 2, 5, 10, 15, 20, 25 and 28 stories.

So, this study deals with 27 different models, including different numbers of stories with different structural systems, such as the flat slab beam system, the shear wall system, the coupled shear wall system, the stiffened coupled shear wall system and the tunnel formwork system. The modeling procedure in STA4-CAD will be explained.

4.2 Limitations Specified in Elements of Structures by Turkish Earthquake Code-2007.

4.2.1 Limitations Specified in Column Design

The cross section of the column requires the following:

i. Rectangular section, the shortest dimension should not be less than 25 cm and the area of the section should not be less than 750 cm^2.

ii. Circular section, the diameter of the section should not be less than 30 cm.

iii. Whole structure is constructed on seismic zones, the strength of the concrete to be used in construction should not be less than C20.

iv. The strength of the reinforcing steel to be used in construction at seismic zones must be equal to or more than S420. It can also be used in an apartment slab, in external of the walls of basements, especially with shear wall system.

4.2.2 Limitations Specified in Beam Design

The cross section of the beam requires the following:

i. Width of the beam should not be less than 25 cm, the width should not exceed the sum of the beam height and the width of the supporting column in the perpendicular direction to the beam axis.

ii. The beam height should not be less than 3 times the slab thickness and should not be less than 30 cm.

iii. The beam height should not be more than 1/4 of the clear span. See Figure 4.1.

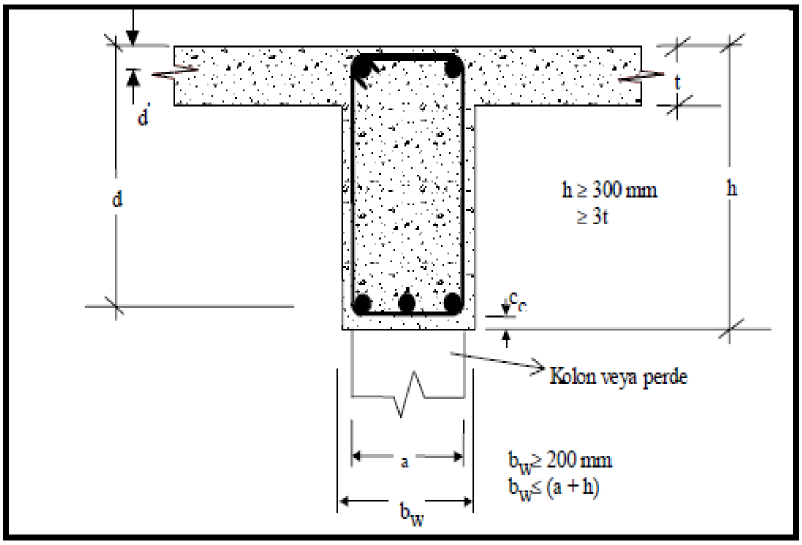

Figure 4.1: Cross Section of the Beam (TS-500)

4.2.3 Limitations Specified in Slab Design

The cross section of the slab requires the following:

i. The height of the slab should not be less than 1/20 of the height of the story.

ii. The height of the slab should not be less than 1/35 a bigger distance between the column and another column L_n and the height of the slab should not be less than 14 cm i.e. $h \geq (L_n / 35)$ and $h \geq 14$ cm, as shown in Figure 4.2.

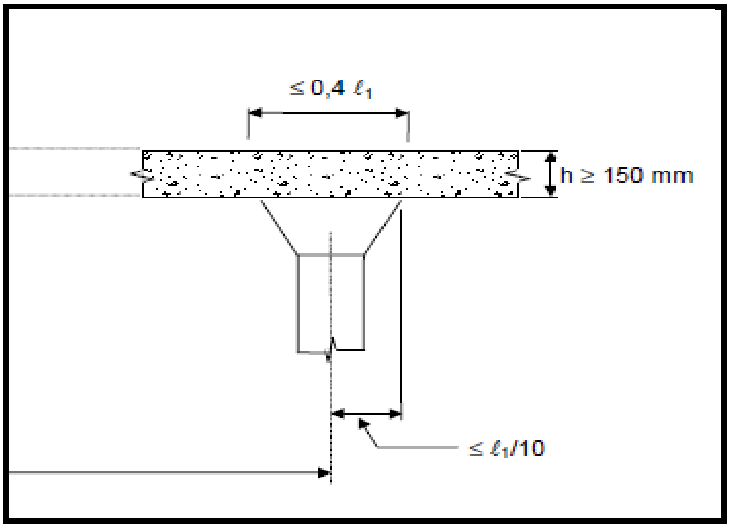

Figure 4.2: Cross Section in the Slab (TS-500)

iii. The length dimensions for the slab should not exceed 17 m, which should be followed by a gap of at least 30 mm.

4.2.4 Limitations Specified in Shear Walls Design

The cross section of the shear wall requires the following:

i. The length of the shear wall is the ratio of length to thickness; it must be equal to at least 7.

ii. The thickness of the wall should not be less than 1/20 of the highest story and 15 cm.

iii. The length of the walls in lateral direction should be equal to 1/5 of the story length, on the condition that it does not exceed 6 m.

iv. The wall thickness of the basement should be equal to 30 cm or should be less than 1/20 of the horizontal length.

4.3 Type of Structural System in STA4-CAD

4.3.1 Flat Slab-Beam in STA4-CAD

This system consists of the column, the beam and the slab. The selection is made from the tool for data input in STA4-CAD.

4.3.2 Types of Shear Walls in STA4-CAD

There are three types of shear walls in the STA4-CAD program.

4.3.2.1 Rectangular Shear Wall

The rectangular columns are used to resist the total lateral load that is distributed between the shear wall based areas associated with each wall on a purely geometrical basis, as shown in Figure 4.3.

4.3.2.2 Polygonal Shear Wall

The polygonal shear walls, where the wall thickness varies along the wall path, can be designed in any shape such as L shape, as given in Figure 4.3.

4.3.2.3 Panel Elements

A panel element is defined in terms of boundary node arrangement and intended for using in efficient static and dynamic analysis of shear wall. The panel members form only the body part of the shear walls. Also, the shear wall system allows defining the openings on panels. Figure 4.3 illustrates the three types of the shear walls.

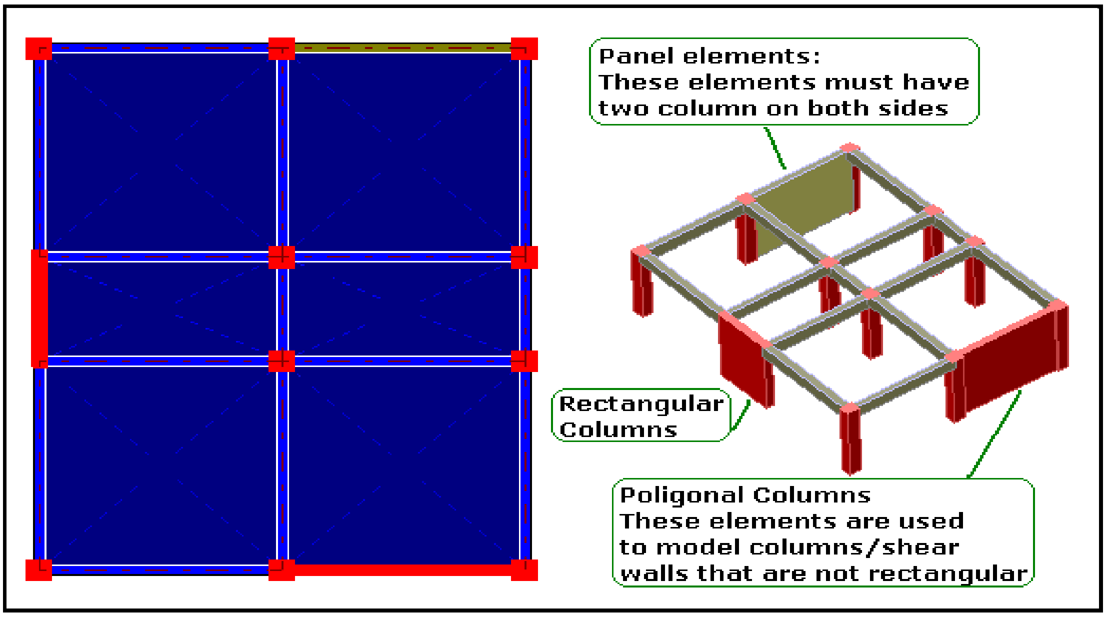

Figure 4.3: Types of Shear Wall (STA4-CAD Handbook)

4.3.3 Coupled Shear Wall in STA4-CAD

The shear wall system allows defining the openings on panel elements. When the building needs openings such as windows or doors, the discontinuity of rigidity occurs. Architectural design usually demands such situations and it is called coupled shear wall system.

4.3.4 Stiffened Coupled Shear Wall in STA4-CAD

The shear wall system allows defining the openings on panel elements. When the building needs openings such as windows or doors, the discontinuity of the rigidity occurs.

Similar to the coupled shear wall system, this system has openings on the shear wall, but the beam is increased significantly by the addition of a stiffer beam.

4.3.5 Tunnel Formwork in STA4-CAD

The panel elements are used in the tunnel formwork system.

4.4 Design the Case Studies

The case study selected for this thesis consists of only architectural structures from existing buildings in Istanbul (ULR7). The dimension of elements of this case study is different from the existing buildings. See Figures 4.4 and 4.5 for comparison.

Figure 4.4: The Existing Building (URL7)

Figure 4.5: Plan of the Existing Building (URL7)

STA4-CAD Program was used for the design and the analysis of this case study. This program is an integrated package of software, which is able to carry out the three dimensional analysis and draw the multi-storey reinforced concrete building.

4.4.1 The Plan Layout of Case Studies

The plan layout of case studies by the computer program STA4-CAD is as shown in Figure 4.6. These case studies have same plan.

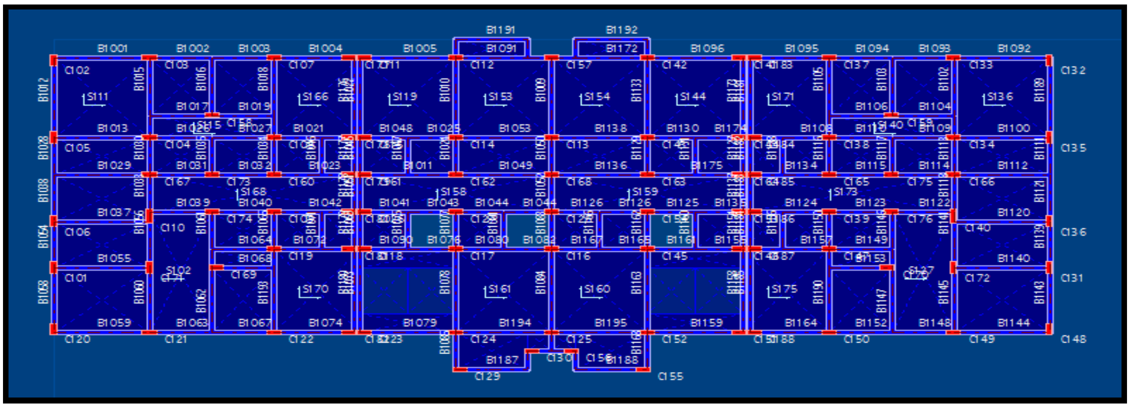

Figure 4.6: Plan Layout of the Case Study with STA4-CAD

The expansion joints were employed at two locations in the case studies as the length of the plan is 41.6 m. This length is very long to continue the slab without space because the slabs need some space when the building is exposed to higher temperatures. According to TEC-2007, the length of slabs should not exceed 17 m. Therefore, the length of the plan in this study was 41.6 / 3 =13. 86 m. Thus, it would separate the building into three blocks. That means there is a 3.5cm distance maintained between two blocks. As for the width of the building of 14m, this distance was necessary for the expansion of joint.

4.4.2 Modeling the Case Studies

In this study, properties of materials and structural members have been identified.

Input definition of the STA4-CAD program has been prepared by story application principle. Entering data input for every story is separate. Similarly, the data between story, in story and in symmetrical structures could be easily copied.

4.4.2.1 The Element Dimensions of Different Models

Input data design rules were adapted by using the program STA4-CAD. The dimensions of the columns, beams, slabs and walls are illustrated in the Table 4.1 below.

Table 4.1: Dimension of elements of different systems in this Study.

No Story	Column cm × cm	Beam cm × cm	Slab cm	Wall Cm	Shear wall cm × cm	Coupled shear wall cm × cm	Stiffened coupled shear wall cm × cm	Tunnel formwork cm × cm
2	25 × 60	25 × 50	20	25	25 × 200	-	-	25 × 100 25 × 60
5	25 × 60	25 × 50	20	25	25 × 200	-	-	25 × 100 25 × 60
10	25 × 60	25 × 50	20	25	25 × 200 25 × 300	25 × 200 25 × 300	25 × 200 25 × 300	25 × 100 25 × 60
15	30 × 60	30 × 50	20	25	30 × 200 30 × 300	30 × 200 30 × 300	30 × 200 30 × 300	30 × 100 30 × 60
20	30 × 60 30 × 30	30 × 50	20	25	30 × 200 30 × 300	30 × 200 30 × 300	30 × 200 30 × 300	30 × 100 30 × 60
25	35 × 60	35 × 50	20	25	35 × 200 35 × 300	35 × 200 35 × 300	35 × 180 35 × 175	35 × 100 35 × 60
28	35 × 60	35 × 50	20	25	35 × 200 35 × 300	35 × 200 35 × 300	35 × 200 35 × 300	35 × 100 35 × 60

4.4.2.2 Modeling Types of Different Structures in STA4-CAD

4.4.2.2.1 Flat Slab-Beam System

This system is used for 2 and 5 stories only because it causes more damage at the higher story categories. The dimension of the columns are 25 cm × 60 cm and the dimension of the beams are 25 cm × 50 cm.

4.4.2.2.2 Shear Wall System

Shear wall system is used for 2 and 5 stories, as there are only four walls in the corners, with short distances. It was found that this provides weak earthquake resistance in taller case studies. On the other side, the case study models with 10 stories require about eight shear walls. However, with 15, 20, 25 and 28 stories, there are 14 walls. Otherwise, the seismic performance criteria does not match.

The case studies with 2, 5 and 10 stories are modeled with the columns with a section of 25 cm × 60 cm, the beams with a section of 25 cm × 50 cm and the shear walls with a section of 25 cm × 200 cm. Nevertheless, for 15 and 20 stories, the section of the columns is 30 cm × 60 cm, the section of the beams is 30 cm × 50 cm and the section of shear walls in short direction is 30 cm × 200 cm whereas; for long direction, it is 30 cm × 300 cm. On the other hand, for 20 and 28 stories, the section of columns is 35 cm × 60 cm, the section of beams is 35cm × 50 cm and the section of shear walls in short direction is 35 cm × 200 cm whereas; for long direction, it is 35 cm × 300 cm.

4.4.2.2.3 Coupled Shear Wall System

The coupled shear wall with 10, 15, 20, 25 and 28 stories have four openings on walls due to the architectural design where the size of the windows is 1.00 m × 1.20 m.

However, 10 stories require eight shear walls and 15, 20, 25 and 28 stories require 14 shear walls. Otherwise the earthquake demand is not satisfied.

The sections of the models for 10 stories are as follows: The section of columns is 25 cm × 60 cm, the section of beams is 25 cm ×50 cm and the section of shear walls is 25 cm × 200 cm.

For 15 and 20 stories, the section of columns is 30 cm × 60 cm, the section of beams is 30 cm × 50 cm and the section of shear walls in short direction is 30 cm × 200 cm whereas; for long direction, it is 30 cm × 300 cm.

Furthermore, for the models with 20 and 28 stories, the section of columns is 35 cm × 60 cm, the section of beams is 35 cm × 50 cm and the section of shear walls in short direction is 35 cm × 200 cm whereas; for long direction, it is 35 cm × 300 cm.

4.4.2.2.4 Stiffened Coupled Shear Wall System

The stiffened coupled shear wall system is similar to the coupled shear wall system. For 10, 15, 20, 25 and 28 stories, the architectural design requires an opening in four walls, but the difference is the size of the windows which is 0.50 m × 1.20 m.

The dimensions of elements of stiffened coupled shear wall system are similar to the coupled shear wall system.

4.4.2.2.5 Tunnel Formwork System

The Tunnel formwork system molds to build the slab and the wall in a single process. So, the section of the columns increases as the seismic demand is not satisfied by small sections. Therefore, the section of the columns is 100 cm × 25 cm and the section of beams is 50 cm × 25 cm. This dimension is for the 2, 5 and 10 stories but it changes and the section of columns becomes 100 cm × 30 cm and the section of beams becomes 30 cm × 50 cm for 15 and 20 story models.

The section of columns is 100 cm × 35cm and the section of beams is 35 cm × 50 cm for 25 and 28 story models.

4.4.2.3 Modeling the Foundation

In this study, there are three types of foundation used; continuous foundation for 2 and 5 stories, mat foundation for 10 stories, mat foundation and pile foundation for 15, 20, 25 and 28 stories.

4.4.2.3.1 Continuous Foundation

The definition of the continuous foundation is not much different than the beams. The difference is that the foundation can be connected to more than one column (at least two). Figure 4.7 illustrates the data of the details in the section of continuous foundation. This type of foundation was used for 2 and 5 stories in this study.

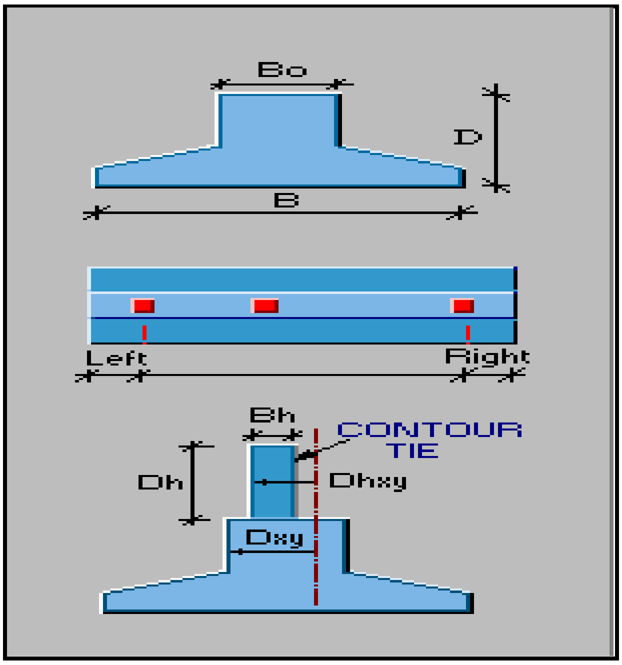

Figure 4.7: Section of Continuous Foundation (STA4-CAD Handbook)

4.4.2.3.2 Mat Foundation

In this study, the mat foundation was used for the models 10, 15, 20, 25 and 28 stories. The Figure 4.8 illustrates the mat foundation. In case of soils having low bearing capacity, heavy structural loads are usually supported by providing mat foundations.

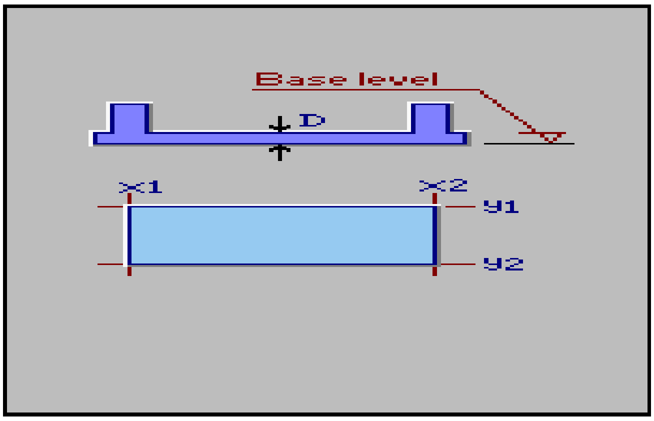

Figure 4.8: Section in Mat Foundation (STA4-CAD Handbook)

Mat Foundations provide an economical solution to difficult site conditions, where pile foundation cannot be used and independent continuous foundations becomes impracticable.

4.4.2.3.3 Pile Foundation

Pile foundations are used when soil safety pressure exceeds or the settlement limits are expected to exceed the safety limit.

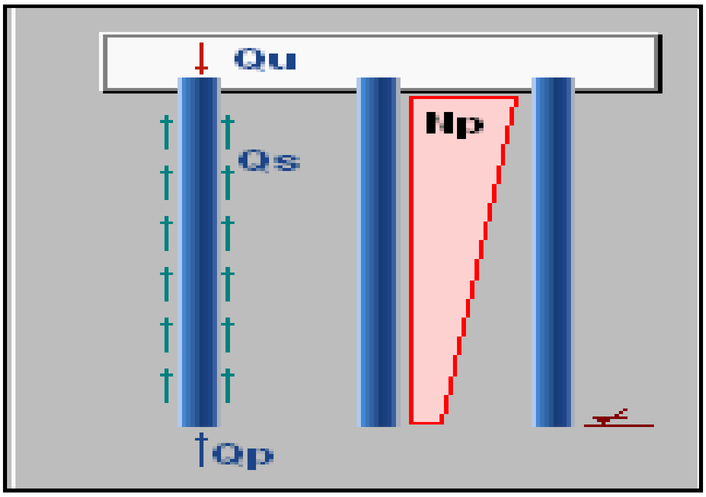

Figure 4.9: Sections in Pile Foundation (STA4-CAD Handbook)

In this study, this type of foundation was used for the models 15, 20, 25 and 28 stories. The pile diameter is 20cm for 15, 20 stories and the pile diameter is 40 cm for 25, 28.

4.5 Check for the Seismic Performance

After designing the case studies, the seismic performance has to be checked for each case study following the design analysis. This is done in order to determine the safest case study model after an earthquake and the different structural systems should be evaluated and compared for every number of stories. Then, the case study should be compared to find the safest system among different systems.

In this study, Other buildings: (Buildings that dose not fit the building definitions given (houses, offices, hotels etc)). The Acceleration Spectrum is constructed by adapting the intensity level with 10% exceedance probability in the next 50 years, is given in Table 3.1.

4.6 The Cost of Building Material

In this study, different structural systems are evaluated and compared with different number of stories, where cost estimation is conducted. In addition, the comparison of the estimated cost was carried out in order to select a more economic system for corresponding story levels.

The amount of concrete, formwork, reinforcement and building wall for every case study and the total cost were calculated and the cost details of the main items are presented in Table 4.8.

The building material prices were gathered from the Northern Cyprus Ministry of Public Works and Transport Planning, 2015. The unit prices were in Turkish Lira (TL), as shown in Table 4.2. The data for a unit cost of building materials are given in Appendix B.

Table 4.2: Cost of building materials (Appendix B)

Description	**Unit Price (TL)**
Reinforcements (ton)	2030
Concrete (m^3)	137
Formwork (m^2)	20
Wall to be built with bricks in 25 cm (m^2)	65
Wall to be built with bricks in 10 cm (m^2)	37
Plaster surface concrete (m^2)	33

Chapter 5

CASE STUDIES

5.1 Introduction

Chapter 5 provides a general information about the case studies. The main classification of the case studies is performed according to the number of stories. These categories consist of different structural systems for 2, 5, 10, 15, 20, 25 and 28 story models. Also, the models for 10, 15, 20, 25 and 28 stories are modeled with a basement.

There are 27 case study models in total with different structural systems. These are the flat slab beam system, the shear wall system, the coupled shear wall system, the stiffened coupled shear wall system and the tunnel formwork system.

For each case study, there is an associated table to illustrate the cost of concrete (m^3), formwork (m^2), reinforcement (ton), building walls (m^2) and plaster (m^2). The total cost of each case study is presented in Turkish Lira (TL) and the cost of each case study was calculated. The displacement results in (x, y) directions due to an earthquake analysis are presented for all case studies. The seismic performance damage of the elements is also illustrated.

5.2 Design of the Case Studies

The plan of the case studies is the same for all case studies involved in this study.

The general building information is explained in Table 5.1

Table 5.1: General buildings information in this study

Type of structure	Reinforced concrete
Height of each floor	3.00 m
Area of each floor	632 m^2
Intended purpose	Residential
Concrete class	C20
Steel class	S420

The different structural system that will be applied in this thesis having five different systems are listed below:

1. The flat slab-beam system.
2. The shear wall system.
3. The coupled shear wall system.
4. The stiffened coupled shear wall system
5. The tunnel formwork system.

These different systems are expected to be tested at different levels of story, i.e. 2, 5, 10, 15, 20, 25 and 28.

5.2.1 Parameters of the Case Studies

In this study, parameters of all case studies are the same, however; the behavior factors (R) are different due to the various systems used in each case study. The Table 5.2 illustrates the different value of (R) corresponding to a different system where the behavior factors for the flat slab-beam system is R=8, the shear wall system, coupled shear wall system and stiffened coupled shear wall system having same behavior facts is R=7 and the tunnel formwork system have the behavior factor of R=6.

Table 5.2: The Behavior Factors (R) high ductile structural systems (TEC-2007)

Different system	Behavior Factors (R)
Buildings in which seismic loads are fully resisted by frames.	8
Buildings in which seismic loads are fully resisted by coupled structural walls.	7
Buildings in which seismic loads are fully resisted by solid structural walls.	6
Buildings in which seismic loads are jointly resisted by frames and solid and / or coupled structural walls	7

All the live load participation factor n= 0.30 selected from Table 5.3, for all the case studies for this thesis is same.

Table 5.3: Live load participation factor (n) (TEC-2007)

Purpose of Occupancy of Building	n
Store, warehouse, etc.	0.80
School, dormitory, sport facility, shop, cinema, theatre, car park, concert hall, restaurant, etc.	0.60
Residential, hotel, office, hospital, etc.	0.30

The design parameters for the case study buildings are obtained from Turkish Earthquake Code-2007, as shown in Table 5.4.

Table 5.4: General building data in this study

Importance Factor (I)	1
Live load participation factor (n)	0.30
The Behavior Factors (R)	8 or 7 or 6
Characteristic compressive cylinder strength of concrete (f_{ck})	20 N/mm^2
Characteristic yield strength of longitudinal reinforcement (f_{yk})	420 N/mm^2

The parameter of the earthquake obtained from Turkish Earthquake Code-2007, for the investigated buildings, as shown in Table 5.5.

Table 5.5: Parameter of earthquake in this study

Seismic Zone Coefficient (A_0)	0.3
Spectrum Characteristic Period (T_A/T_B)	0.15/0.4
Seismic analysis min force ratio (ß)	0.8 (for regular building)
Design method	TS-500 ultimate design method

5.2.2 The Applied Loads for the Study

Dead loads live loads and horizontal loads on structures are placed in the equilibrium equations before they are multiplied by characteristic load factors. According to the reinforced concrete analysis option, they are multiplied by these factors in order to find maximum unfavorable values, as shown in Table 5.6.

Table 5.6: Load Combinations (TEC-2007)

TEC-2007
0.90 G ± 1.00 CE
1.00 G + 1.00 Q + 1.00 Cs ± 1.00 E
1.40 G + 1.60 Q
1.40 G + 1.60 Q + 1.60 Cs
1.40 G
1.00 G + 1.00 Q ± 1.00 CE
1.00 G + 1.30 Q ± 1.30 Cw
1.00 G + 130 Q + 1.00 Cs ± 130 Cw
0.90 G ± 1.30 Cw
0.90 G + 0.90 Cs ± 1.30 Cw

where;

G: Dead load (kN/m^2)

Q: Live load (kN/m^2)

E: Earthquake load (kN/m^2)

C: Coefficient of later force

S: Snow load (kN/m^2)

W: Weigh of the building (kN/m^3)

5.3 Modeling the Case Studies with Selected Systems

5.3.1 The First Case Study-Two Story Building with Selected Systems

In the first case, different structures with 2 stories will be illustrated

1- Flat slab beam system.

2- Shear wall system.

3- Tunnel formwork system.

These 3 case studies will be built, modeling in STA4-CAD. The coupled shear wall system and the stiffened coupled shear wall system are excluded in this case because 2 stories do not require more wall of a shear wall, as illustrated in Figure 5.3.

5.3.1.1 Flat Slab-Beam System

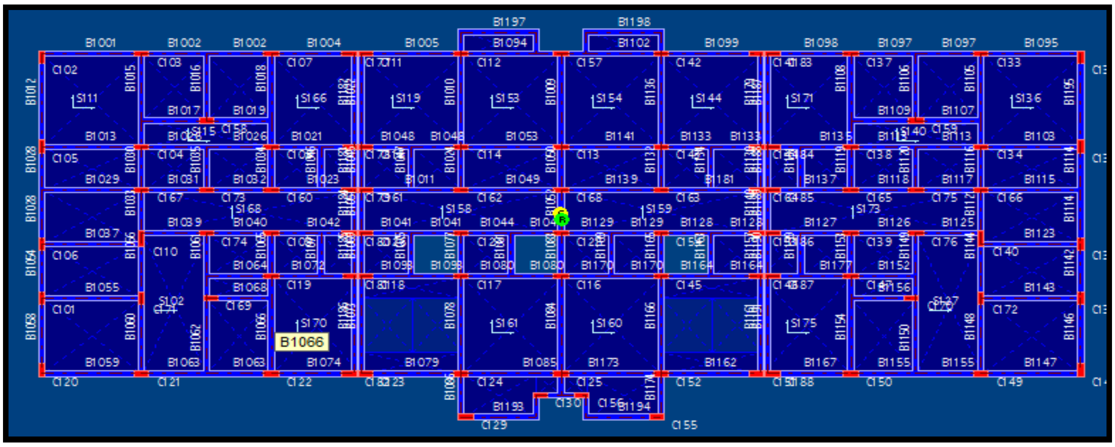

Figure 5.1: Plan of Two Stories with Flat Slab-Beam System

The Figure 5.1 illustrates the plan of the case study. The mass center connects to the other point with small displacement from the building center, when the earthquake is rotating the building.

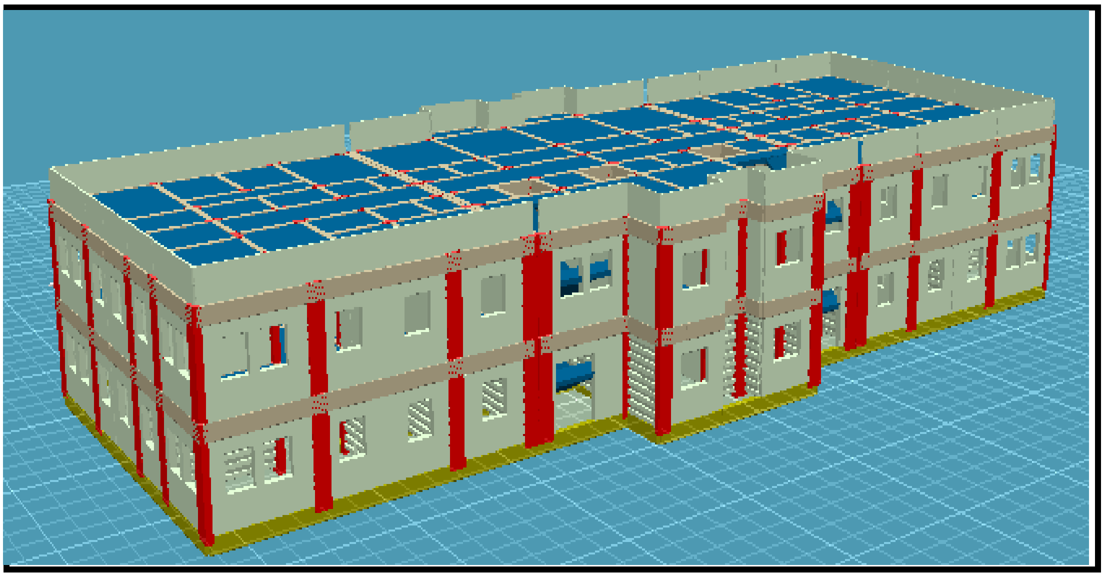

Figure 5.2: The 3D View of Two Stories with Flat Slab-Beam System

The Figure 5.2 illustrates the 3D view of two stories with flat slab-beam system.

5.3.1.2 Shear Walls System

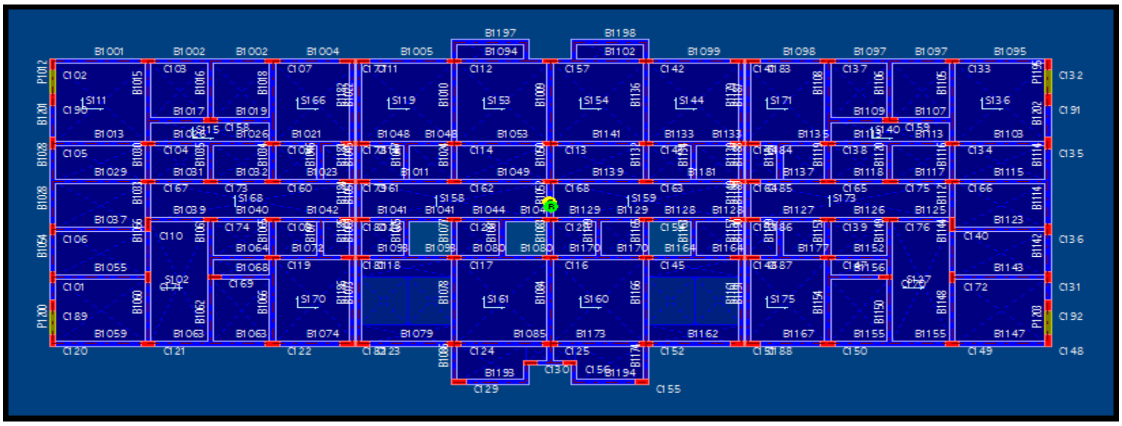

Figure 5.3: Plan of Two Stories with Shear Wall System

The Figure 5.3 illustrates the plan of the case study. The mass center connects to the other point with small displacement from the building center, when the earthquake is rotating the building.

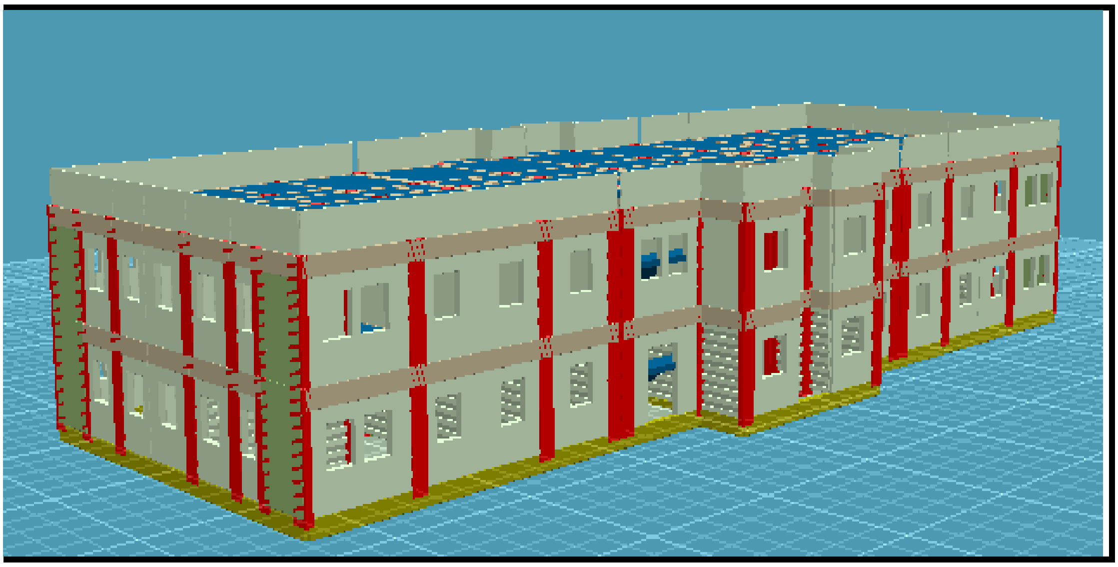

Figure 5.4: The 3D View of Two Stories with Shear Wall System

The Figure 5.4 illustrates the 3D view of 2 stories with shear wall system.

5.3.1.3 Tunnel Formwork

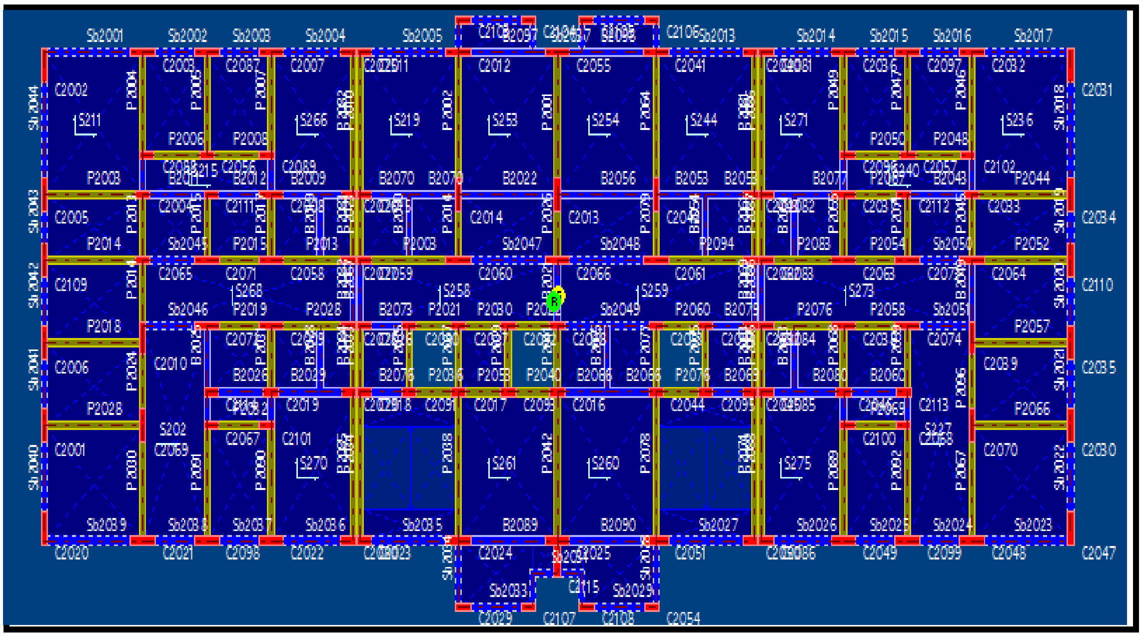

Figure 5.5: Plan of Two Stories with Tunnel Formwork System

The Figure 5.5 illustrates the plan of the case study. The mass center connects to the other point with small displacement from the building center, when the earthquake is rotating the building.

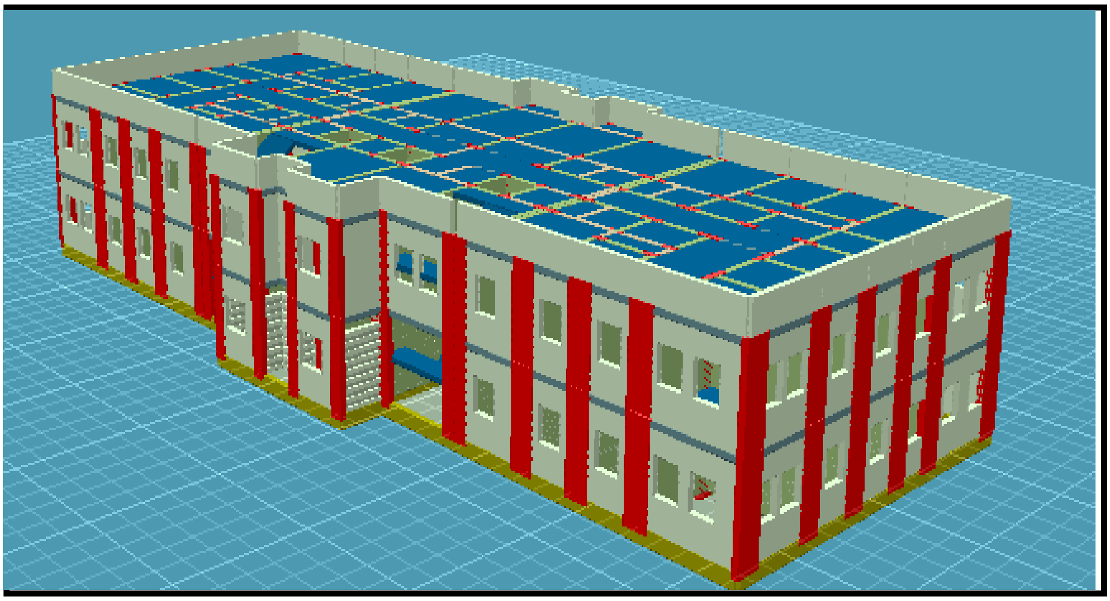

Figure 5.6: The 3D View Two Stories with Tunnel Formwork System

The Figure 5.6 illustrates the 3D view of two stories with tunnel formwork system.

5.3.1.4 Results of Analysis for the First Case Study with Two Stories

It decides the capacity ratio of the plastic hinge of the columns for the best system by comparing the capacity ratio of the plastic hinge of the columns of the other systems. The number of damaged columns at each story and the total number of columns in that story are shown in Tables 5.10, 5.11, and 5.12. The plastic hinge ratio is zero for the tunnel formwork, which means (IO), also observed for shear wall and flat slab-beam, are in respectively 0.8 and 2.2. Hence, the number of damaged columns at any story to be damaged in seismic regions is zero, as shown in Appendix D. Therefore, it is similar to the assumption in the analytical studies performed under seismic excitation loading. The result of analysis all case studies is shown in Table 5.13.

Table 5.7: Shear wall system

```
BUILDING PERFORMANCE RESULTS:

Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.0<=%20 ✓),(CC=%0 ✓)
Roof Story Vc ratio=(CP=%0.0<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%0.8<=%30 ✓,(CC=%0 ✓)
```

Table 5.8: Flat slab-beam system

```
BUILDING PERFORMANCE RESULTS:

Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.0<=%20 ✓),(CC=%0 ✓)
Roof Story Vc ratio=(CP=%0.0<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%2.2<=%30 ✓,(CC=%0 ✓)
```

Table 5.9: Tunnel formwork system

```
BUILDING PERFORMANCE RESULTS:
Beams Immediate Occupancy Damage Ratio=%0.0<=%10 Immediate Occupancy ✓
```

Table 5.10: Shear wall with 2 stories.

Percentage of damaged beam and column of the system on each story				
Story	X- direction		Y- direction	
No	Beam	Column	Beam	Column
2	0/74 (0 %)	0/96 (0%)	0/77 (0%)	0/96 (0%)
1	0/74 (0 %)	0/96 (0%)	0/77 (0%)	0/96 (0%)

Table 5.11: Flat slab beam with 2 stories.

Percentage of damaged beam and column of the system on each story				
Story	X- direction		Y- direction	
No	Beam	Column	Beam	Column
2	0/74 (0 %)	0/88 (0%)	0/77 (0%)	0/88 (0%)
1	0/74 (0 %)	0/88 (0%)	0/77 (0%)	0/88 (0%)

Table 5.12: Tunnel formwork with 2 stories

Percentage of damaged beam and column of the system on each story				
Story	X-direction		Y- direction	
No	Beam	Column	Beam	Column
2	0/53 (0%)	0/203 (0%)	0/36 (0%)	0/203 (0%)
1	0/50 (0%)	0/208 (0%)	0/34 (0%)	0/203 (0%)

Table 5.13: Results of analysis with 2 stories

Kind of compare	The Analysis of STA4-CAD	Shear wall	Flat-slab beam	Tunnel formwork
Amount	Concrete (m^3)	672.1	656.2	1,968.6
	Formwork (m^2)	3,330.6	3,266.6	6,352
	Reinforce (ton)	50.6	40.7	120
	Wall Building (m^2)	1,876.3	1,887.55	560
	Plaster of all buildings (m^2)	6,799.5	6,823.1	1,120
Total	Cost (TL)	607,750.7	585,705.5	713,698.2
Displacement	X (m)	0.00072	0.00071	0.00005
	Y (m)	0.00080	0.00113	0.00002
Seismic performance	Beam damage ratio < 30%	0.0 %	0.0 %	0.0 %
	Column damage ratio < 20%	0.0 %	0.0 %	0.0 %
	Roof story V_C ratio < 40%	0.0 %	0.0 %	0.0 %
	Columns include plastic hinge Vc ratio < 30% [LS+ CP +CC]	0.8 % LS	2.1 % LS	0.0 % IO

5.3.1.4.1 Quantity of Each Case Study

Table 5.10 illustrates the quantity of each case study in respectively. Figure 5.7, 5.8, 5.9 show that the tunnel system requires larger amount in order of concrete, formwork and reinforcement. In addition, Figure 5.10 shows that the tunnel system requires smaller amount in order to build walls and plaster. Moreover, Figure 5.11 shows that the total cost of the tunnel system is high. However, the displacement of the case studies with two directions (x, y), as shown in Figure 5.12, demonstrates that the tunnel system causes the least displacement and seismic performance. Figure 5.13 shows that all systems satisfy the safety criteria.

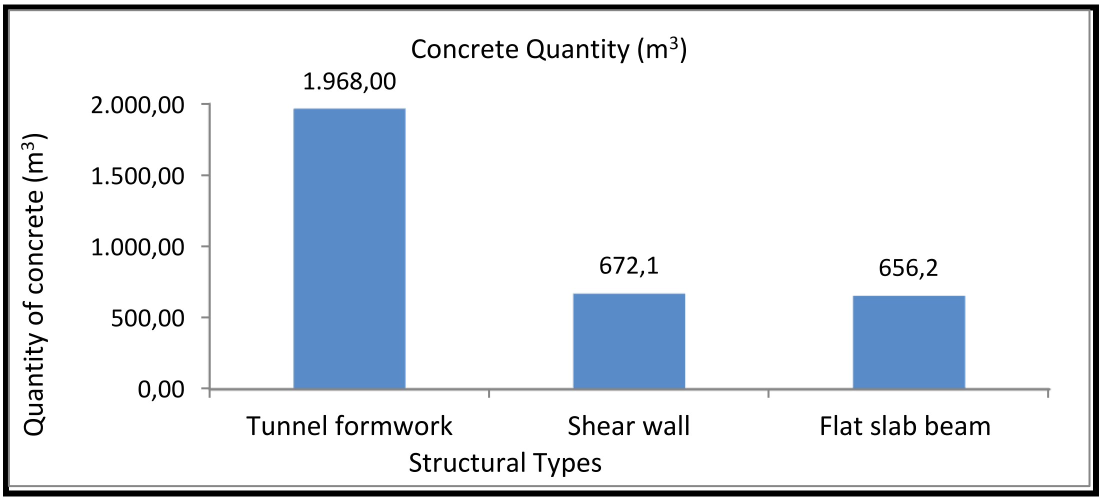

Figure 5.7: Quantity of Concrete in Buildings with Two Stories

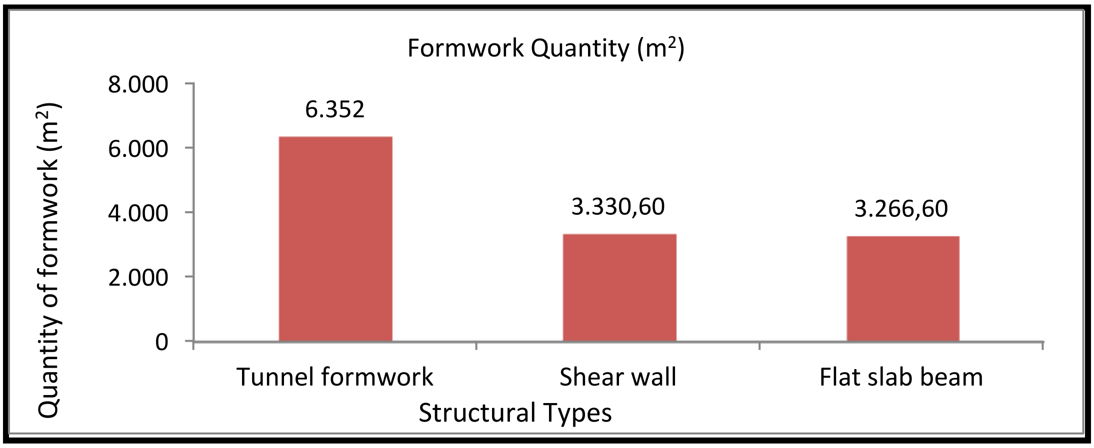

Figure 5.8: Quantity of Formwork in Buildings with Two Stories

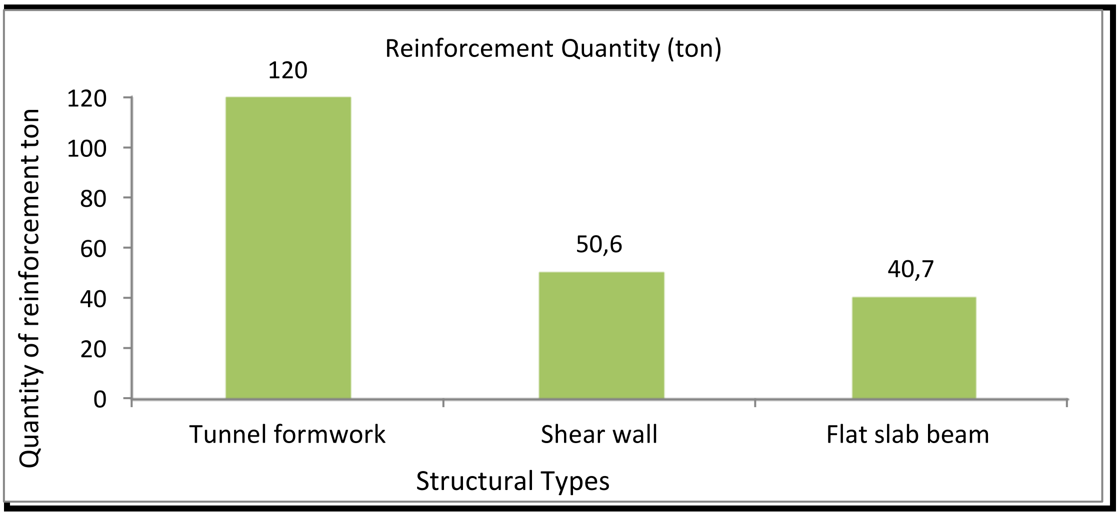

Figure 5.9: Quantity of Reinforcement in Buildings with Two Stories

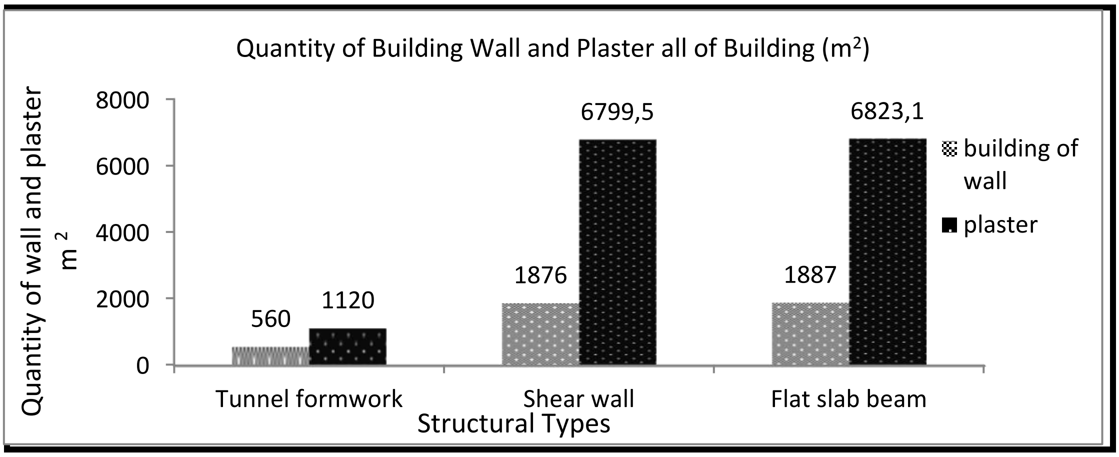

Figure 5.10: Quantity of Wall and Plaster in Buildings with Two Stories

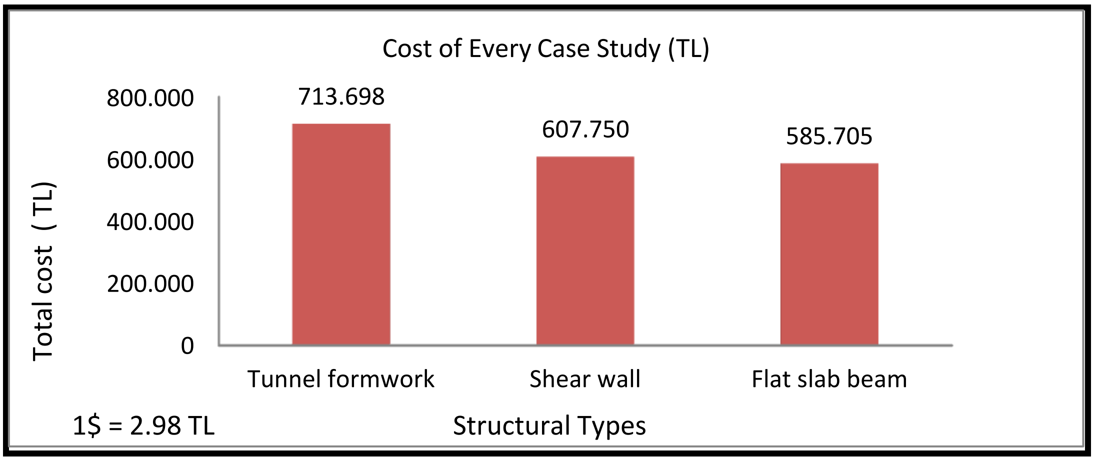

Figure 5.11: Total Costs of the Case Studies in Buildings with Two Stories

5.3.1.4.2 Displacement of the Case Studies in X and Y Directions

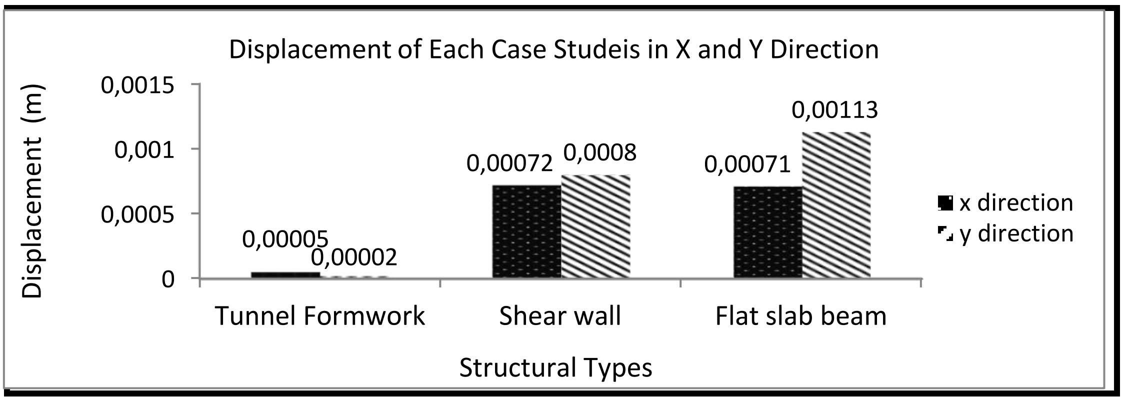

Figure 5.12: Displacement of Each Case Study in Buildings with Two Stories

5.3.1.4.3 Performance

The chart below explains the percentage of damage occurred on beam and column of different systems after the performance analysis.

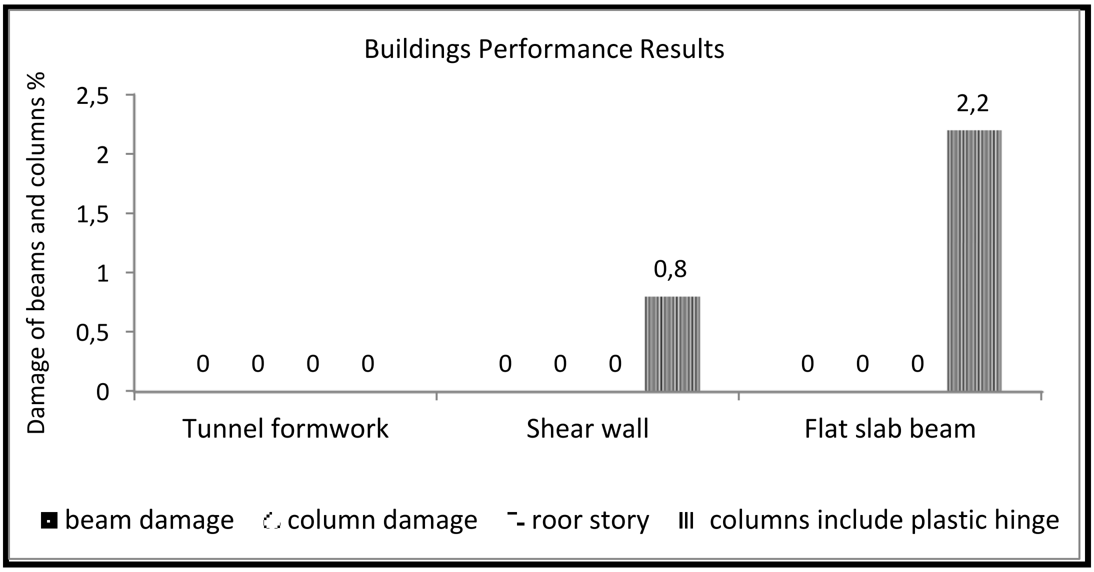

Figure 5.13: Damage of Beams and Columns in Buildings with Two stories

The seismic performance in Figure 5.13 shows all systems which satisfy the safety criteria. The tunnel formwork is not cheap. The flat slab beam system is an economical system.

5.3.2 The Second Case Study- Five Stories Building with Selected Systems

The second case will illustrate different structures with 5 stories

1- The flat slab-beam system.

2. The shear wall system.

3. The tunnel formwork system.

These 3 case studies will be building by modeling in STA4-CAD. The coupled shear wall system and the stiffened coupled shear wall system are excluded in this case because 5 stories do not require more shear walls, as shown in Figure 5.16.

5.3.2.1 Flat Slab-Beam System

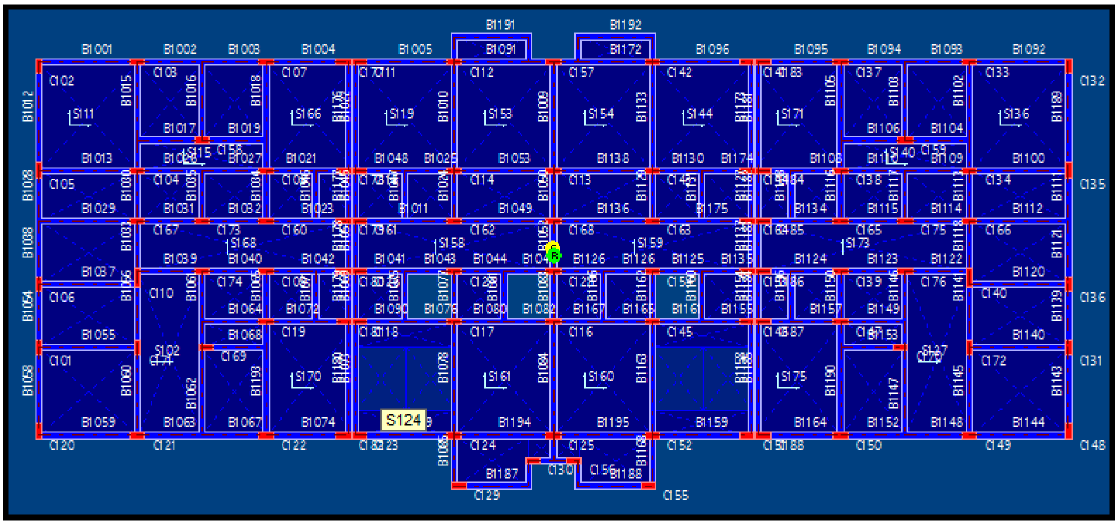

Figure 5.14: Plan of Five Stories with Flat Slab-Beam System

The Figure 5.14 illustrates the plan of the case study. The mass center connects to the other point with small displacement from the building center, when the earthquake is rotating the building.

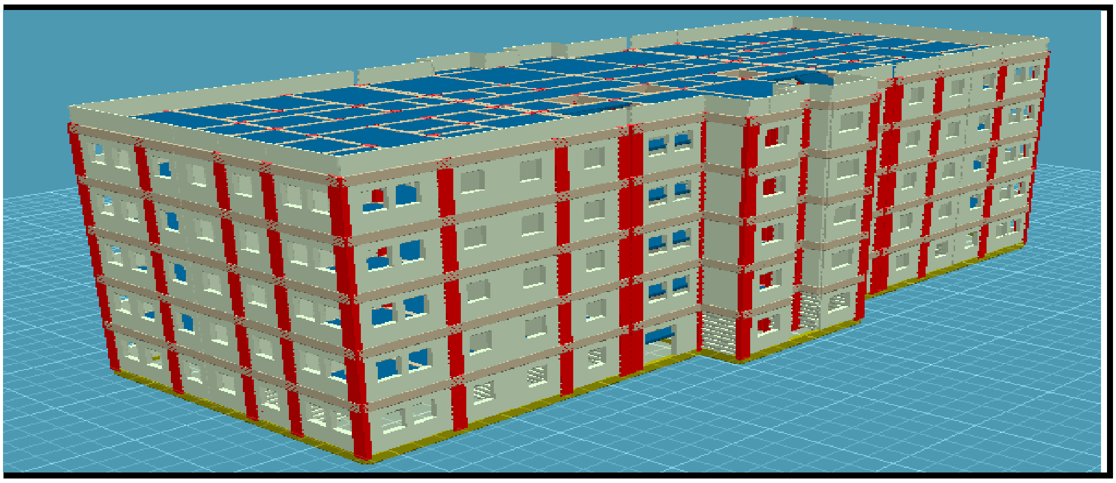

Figure 5.15:The 3D View of Buildings with Five Stories and Flat Slab-Beam System

Figure 5.15 illustrates the 3D view of Buildings with 5 stories and flat slab-beam system.

5.3.2.2 Shear Wall System

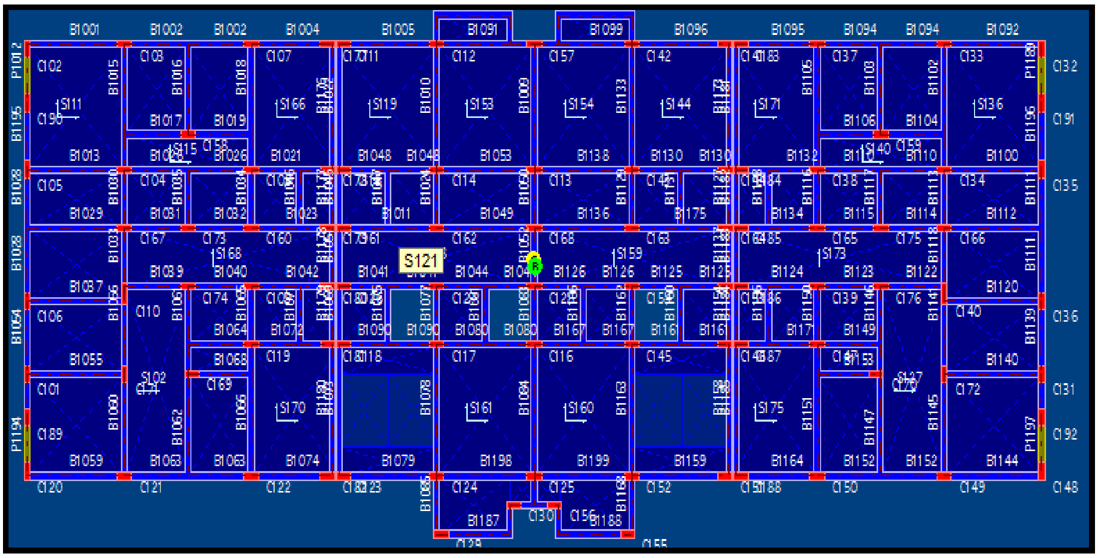

Figure 5.16: Plan of Buildings with Five Stories and Shear Wall System

The Figure 5.16 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

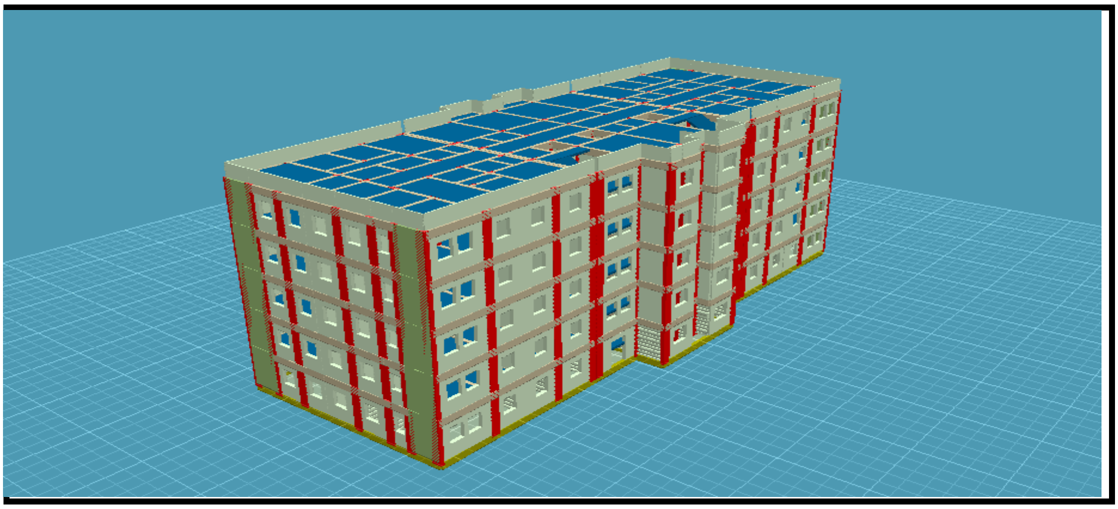

Figure 5.17: The 3D View of Buildings with Five Stories and Shear Wall System

The Figure 5.17 illustrates the 3D view of buildings with 5 stories and shear wall system.

5.3.2.3 Tunnel Formwork System

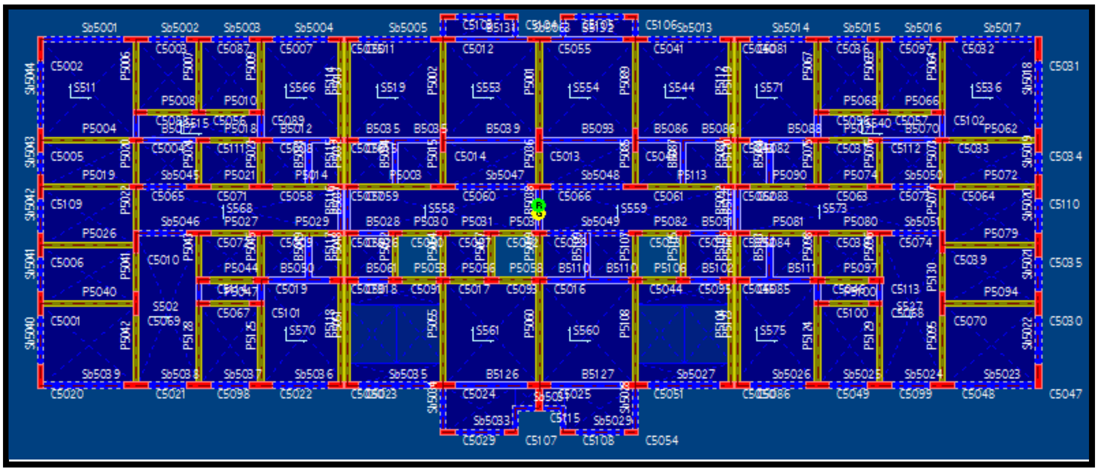

Figure 5.18: Plan of Buildings with Five Stories and Tunnel Formwork System

The Figure 5.18 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

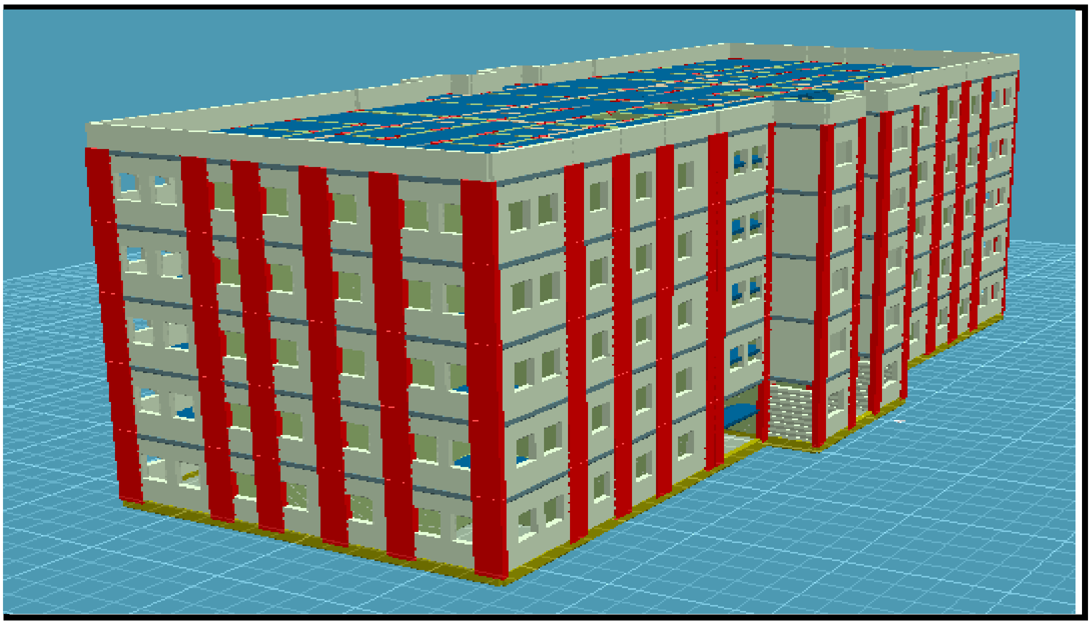

Figure 5.19: The 3D View of Buildings with Five Stories and Tunnel Formwork

Figure 5.19 illustrates the 3D view for 5 stories with the tunnel formwork system.

5.3.2.4 Results of Analysis the Second Case Study with Fives Stories

It decides the capacity ratio of the plastic hinge of the columns for the best system by comparing the capacity ratio of the plastic hinge of the columns of other systems. Therefore, the number of damaged columns at each story and the total number of columns in that story are shown in Tables 5.17, 5.18, and 5.19. The plastic hinge ratios are zero for the tunnel formwork, that means (IO), also observed for shear wall and flat slab-beam are in 0.6 and 9.8 respectively. Hence, the number of damaged columns at any story to be damaged in seismic regions is zero. As shown in Appendix D. Therefore, it was assumed in the analytical studies performed under seismic excitation loading. Also, the result of analysis for all case studies is shown in Table 5.17.

Table 5.14: Shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.0<=%20 ✓),(CC=%0 ✓)
Roof Story Vc ratio=(CP=%0.0<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%0.6<=%30 ✓,(CC=%0 ✓)
```

Table 5.15: Flat slab-beam

```
BUILDING PERFORMANCE RESULTS:

Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.0<=%20 ✓),(CC=%0 ✓)
Roof Story Vc ratio=(CP=%0.0<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%9.8<=%30 ✓,(CC=%0 ✓)
```

Table 5.16: Tunnel formwork system

BUILDING PERFORMANCE RESULTS:

Beams Immediate Occupancy Damage Ratio=%0.0<=%10 Immediate Occupancy ✓

Table 5.17: Shear wall in buildings with 5 stories

Percentages of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
5	0/73(0 %)	0/96(0%)	0/76(0 %)	0/96(0%)
4	0/73(0 %)	0/96(0%)	0/76(0%)	0/96(0%)
3	0/73(0 %)	0/96(0%)	0/76(0 %)	0/96(0%)
2	0/73(0 %)	0/96(0%)	0/76(0 %)	0/96(0%)
1	0/73(0 %)	0/96(0%)	0/76(0 %)	0/96(0%)

Table 5.18: Flat slab-beam in buildings with 5 stories

Percentages of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
5	0/96(0%)	0/88(0%)	0/84(0%)	0/88(0%)
4	0/96(0%)	0/88(0%)	0/84(0%)	0/88(0%)
3	0/96(0%)	0/88(0%)	0/84(0%)	0/88(0%)
2	0/96(0%)	0/88(0%)	0/84(0%)	0/88(0%)
1	0/96(0%)	0/88(0%)	0/84(0%)	0/88(0%)

Table 5.19: Tunnel formwork in buildings with 5 stories

Percentages of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
5	0/50(0.0%)	0/208(0%)	0/34(0%)	0/208(0%)
4	0/50(0.0%)	0/208(0%)	0/34(0%)	0/208(0%)
3	0/50(0.0%)	0/208(0%)	0/34(0%)	0/208(0%)
2	0/50(0.0%)	0/208(0%)	0/34(0%)	0/208(0%)
1	0/50(0.0%)	0/208(0%)	0/34(0%)	0/208(0%)

Table 5.20: Results of analysis of Buildings with 5 stories

Kind of comparison	The Analysis of STA4-CAD	Shear wall	Flat slab beam	Tunnel formwork
Amount	Concrete (m^3)	1,477.8	1,451.2	4,353.0
	Formwork (m^2)	7,556.4	7,331.8	13,023.8
	Reinforce (ton)	108.6	90.1	270.0
	Wall Building (m^2)	4,194	4,218	1,400
	Plaster of all buildings (m^2)	15,479.6	16,029.0	2,800.0
Total	Cost (TL)	1,356,126	1,331,480	1,588,321
Displacement	X (m)	0.00134	0.00135	0.00022
	Y (m)	0.00149	0.00185	0.00012
Seismic performance	Beam damage ratio < 30%	0.0 %	0.0%	0.0%
	Column damage ratio < 20%	0.0%	0.0%	0.0%
	Roof story V_C ratio < 40%	0.0%	0.0%	0.0%
	Columns include plastic hinge Vc ratio < 30%	0.6% LS	9.8% LS	0.0% IO

5.3.2.4.1 Quantity of Building Material for Each Case Study

Table 5.14 illustrates the quantity of each case study in Figure 5.20, 5.21, 5.22, respectively. It shows that the tunnel system requires a larger amount in of concrete, formwork and reinforcement. Also, Figure 5.23 shows that the tunnel system requires a small amount in order to build walls and plaster. In addition, Figure 5.24 shows the total cost of the tunnel system is high. However, the displacement of the case studies with two directions (x, y) in Figure 5.25 shows the tunnel system which has the least displacement and seismic performance. Figure 5.26 shows that all systems satisfy the safety criteria.

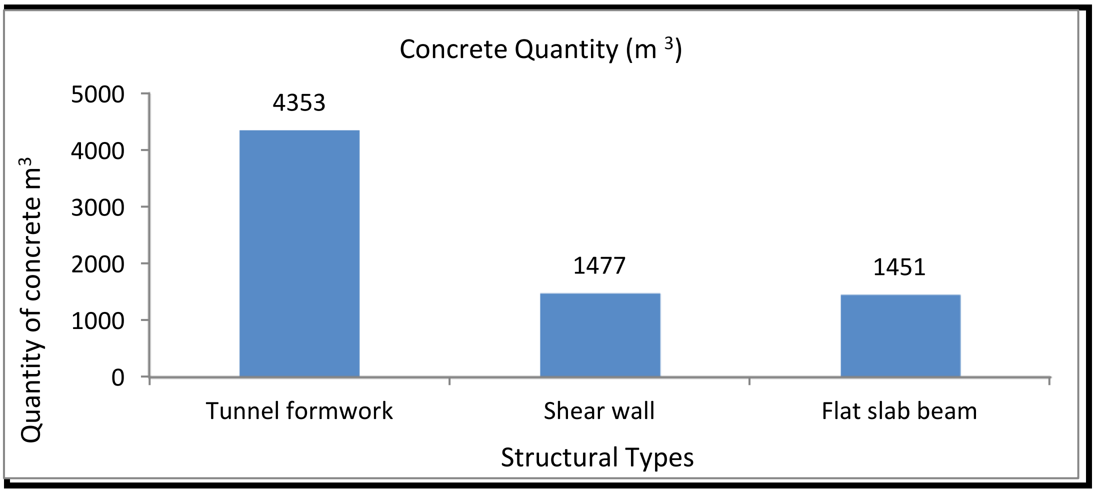

Figure 5.20: Quantity of Concrete in Buildings with Five Stories.

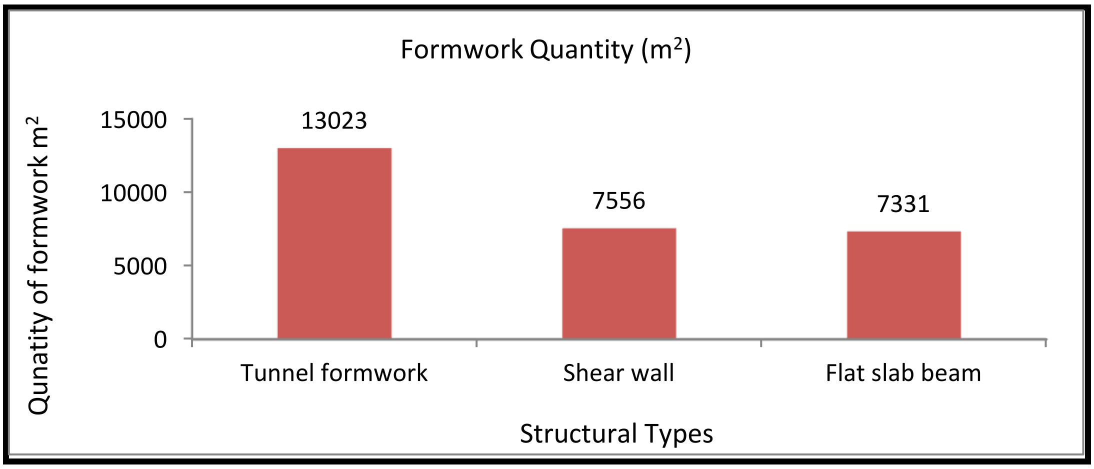

Figure 5.21: Quantity of Formwork in Buildings with Five Stories.

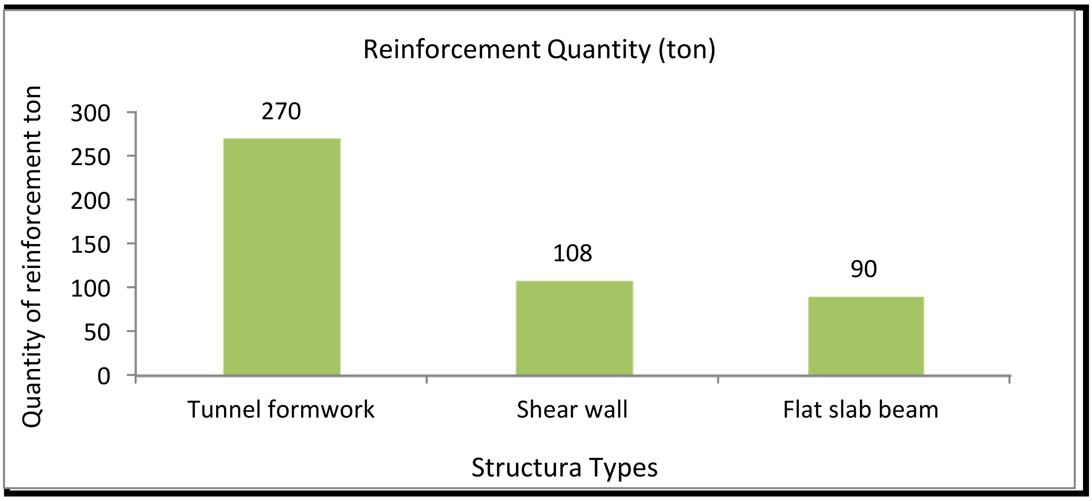

Figure 5.22: Quantity of Reinforcement in Buildings with Five Stories.

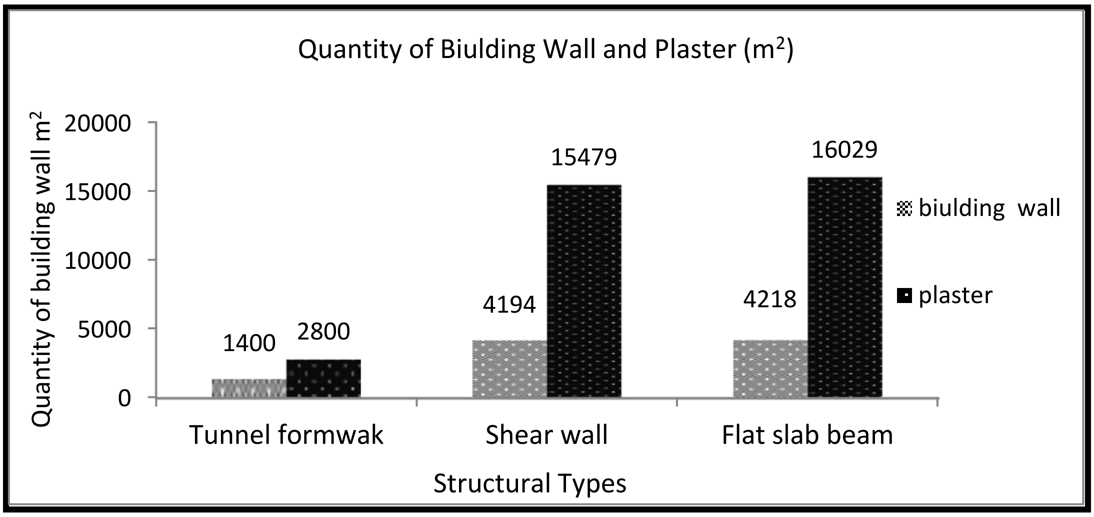

Figure 5.23: Quantity of Building Wall and Plaster in Buildings with Five Stories.

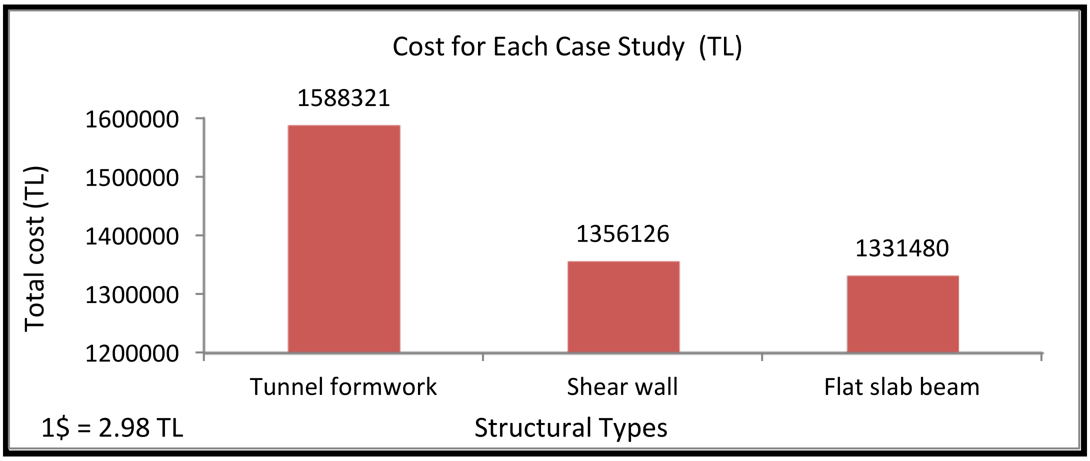

Figure 5.24: Total Costs of the Case Studies in Buildings with Five Stories.

5.3.2.4.2 Displacement of Each Case Study in X and Y Directions

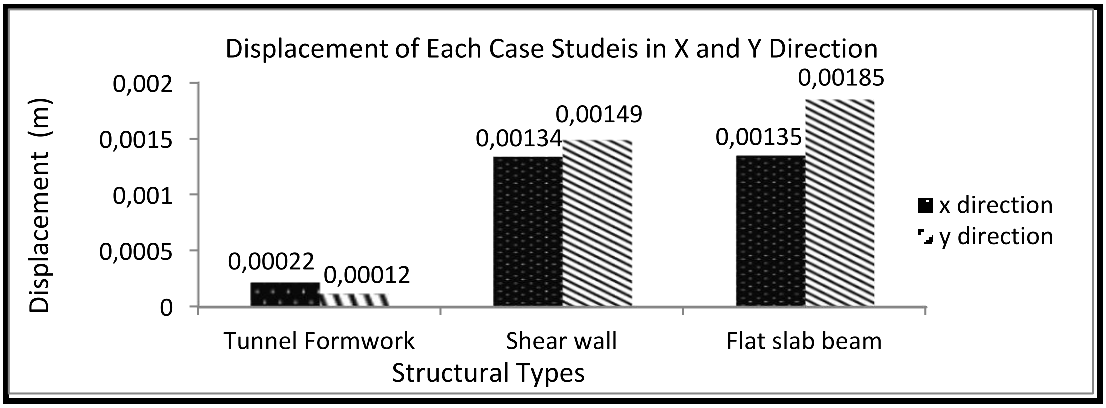

Figure 5.25: Displacements of the Case Studies in Buildings with Five Stories.

5.3.2.4.3 Performance

The Chart below explains the percentage of damaged beam, column, roof story and column including plastic hinges of different structures after the analysis result.

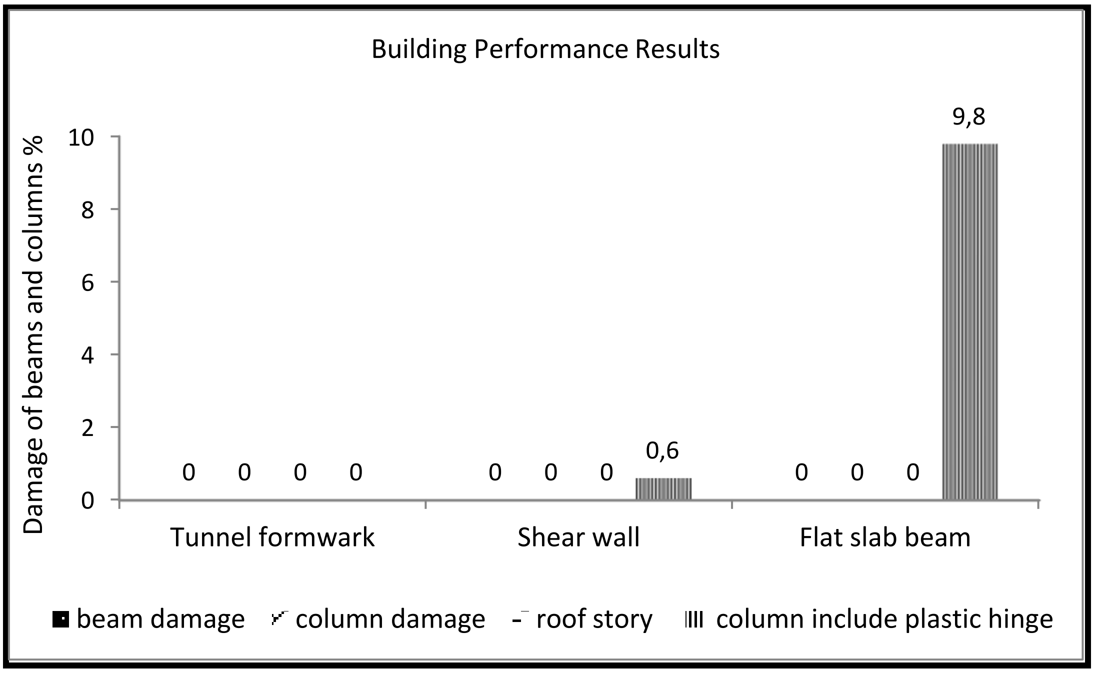

Figure 5.26: Damage of Beams and Columns in Buildings with Five Stories

By the analysis results, the seismic performance in Figure 5.26 shows all systems satisfy the safety criteria. The shear wall system and the flat slab-beam are economic systems.

5.3.3 The Third Case Study-Ten Story Building with Selected System

The third case illustrates different structures with 10 stories

1- The flat slab-beam system.

2. The shear wall system.

3. The coupled shear wall system.

4. The stiffened coupled shear wall system

5. The tunnel formwork system.

These 5 case studies will be built by modeling STA4-CAD.

5.3.3.1 Flat Slab-Beam System in Buildings with Ten Stories.

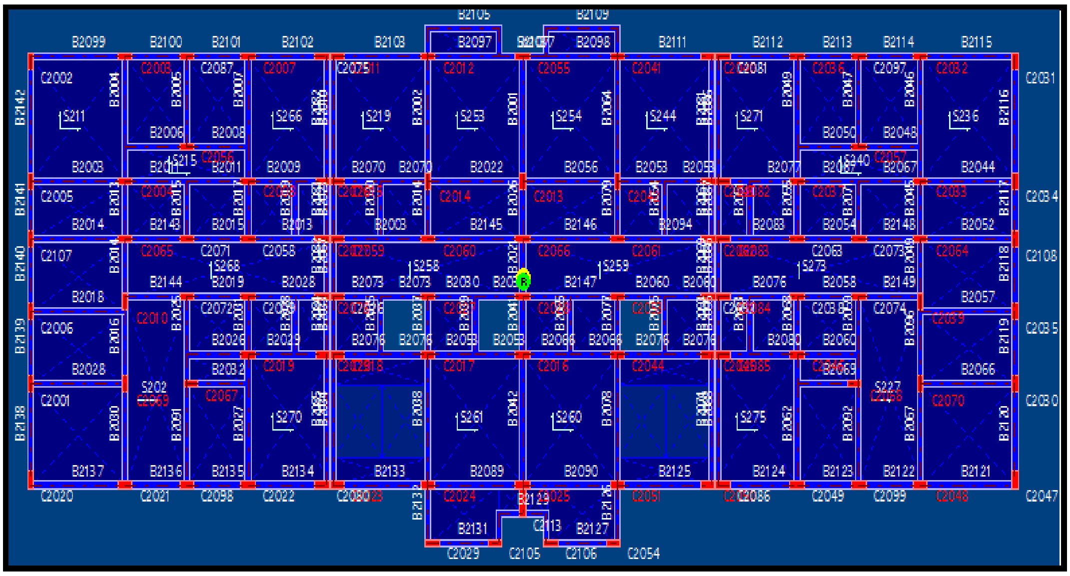

Figure 5.27: Plan of Buildings with Ten Stories and Flat Slab-Beam System

The Figure 5.27 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

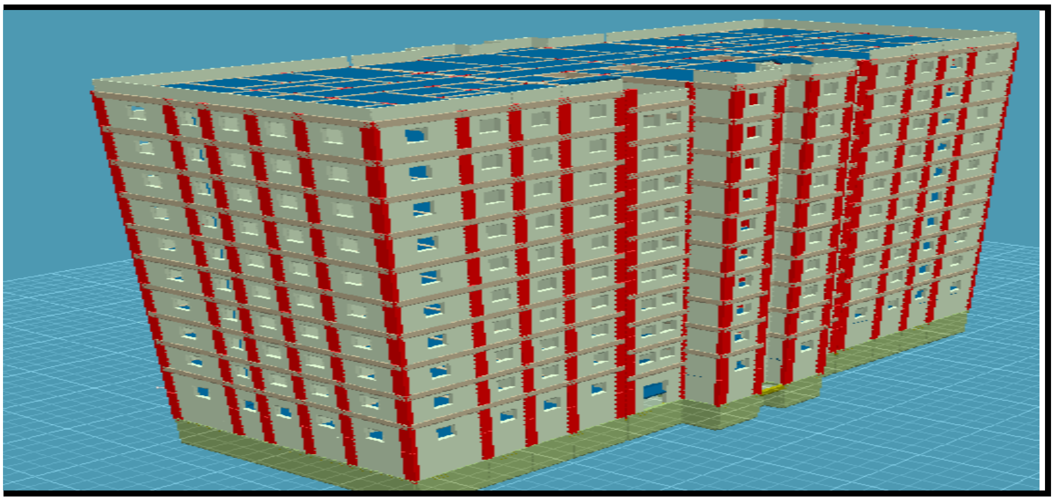

Figure 5.28: The 3D View of Buildings with Ten Stories and Flat Slab-Beam System

The Figure 5.28 illustrates the 3D view of buildings with 10 stories and flat slab beam system.

5.3.3.2 Shear Wall System

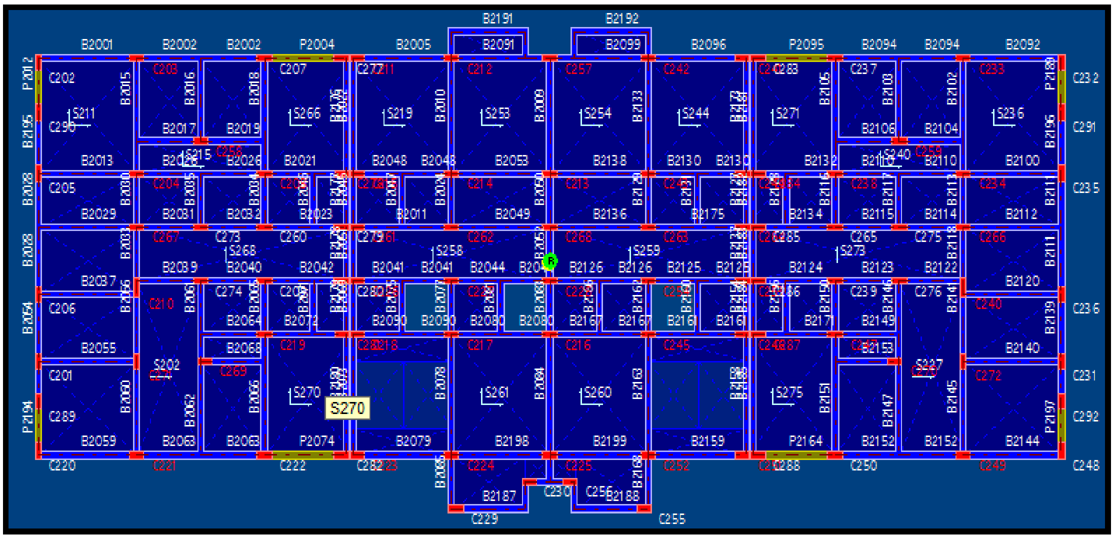

Figure 5.29: Plan of Buildings with Ten Stories and Shear Wall System

The Figure 5.29 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

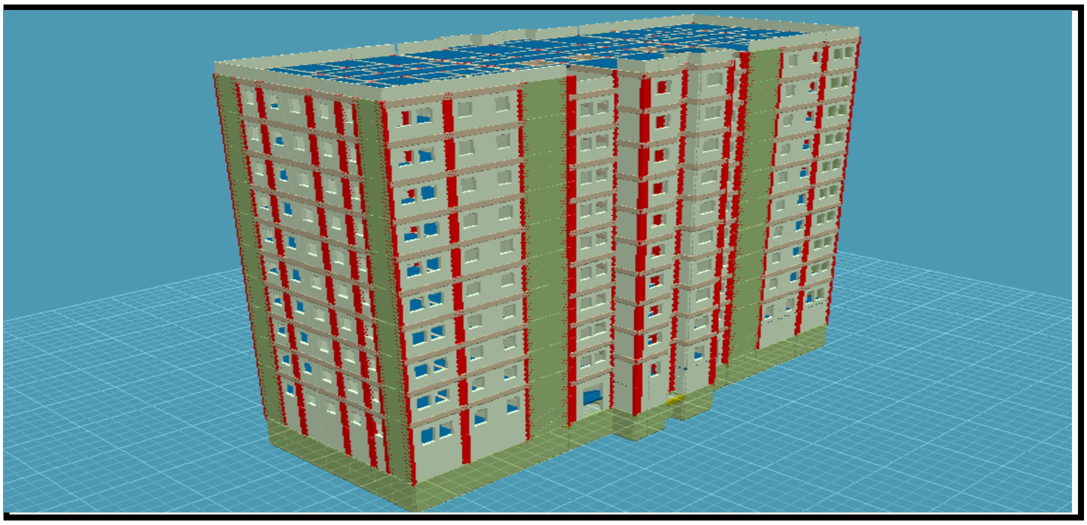

Figure 5.30: The 3D View of Buildings with Ten Stories and Shear Wall System

The Figure 5.30 illustrates the 3D view of buildings with 10 stories and shear wall system.

5.3.3.3 Coupled Shear Wall System

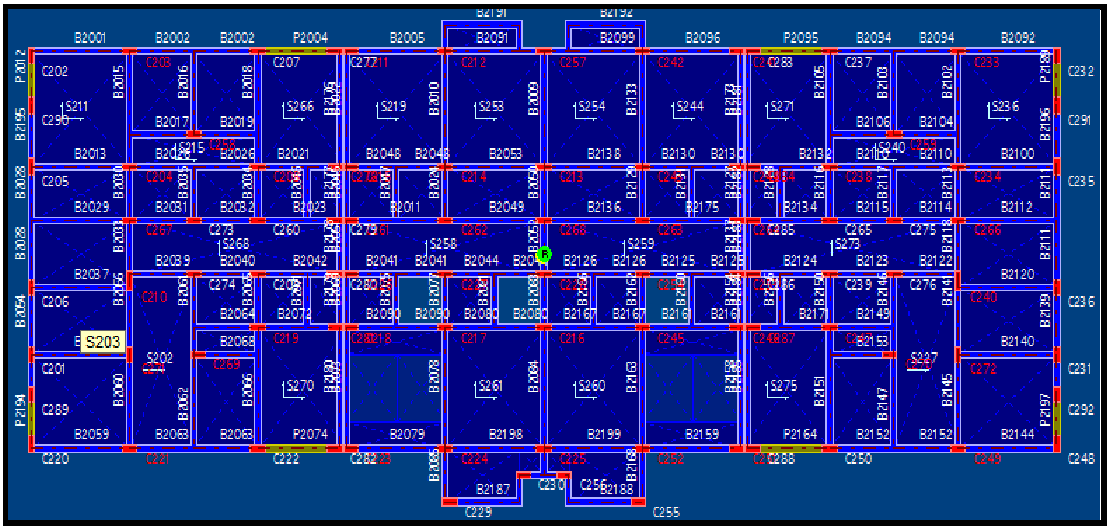

Figure 5.31: Plan of Buildings with Ten Stories and Shear Wall System

The Figure 5.31 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

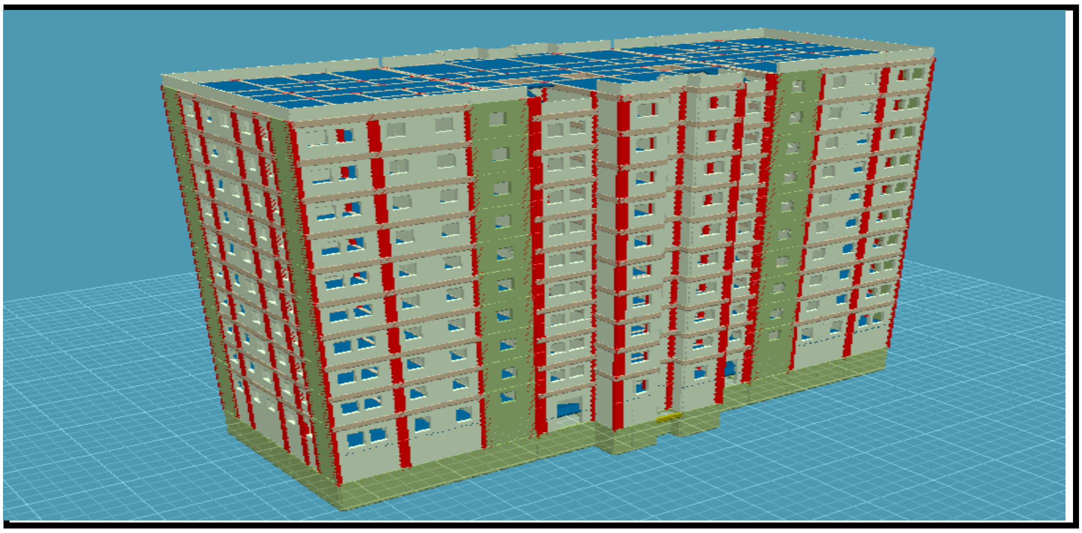

Figure 5.32: The 3D View of Buildings with Ten Stories and Coupled Shear Wall

The Figure 5.32 illustrates the 3D view of buildings with 10 stories and coupled shear wall system.

5.3.3.4 Stiffened Coupled Shear Wall System

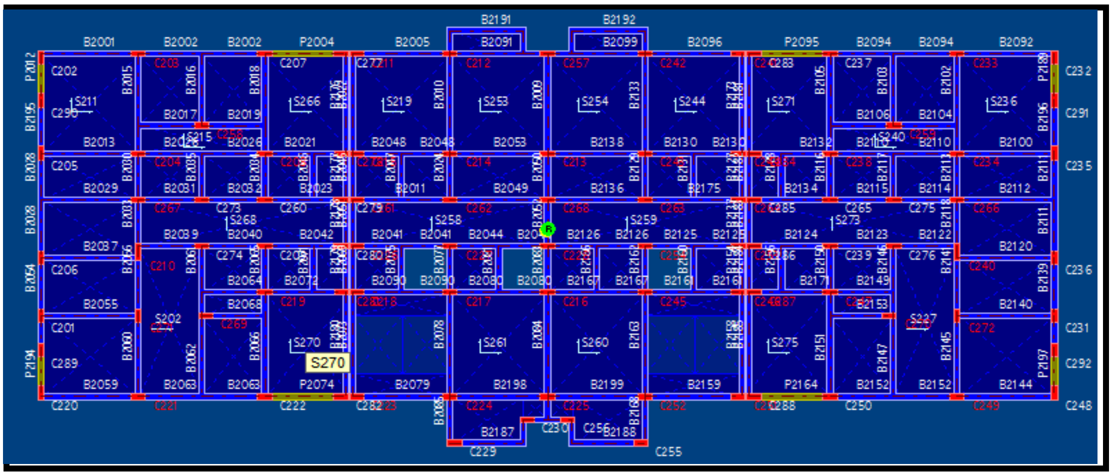

Figure 5.33: Plan of Buildings with Ten Stories and Stiffened Coupled Shear Wall

The Figure 5.33 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

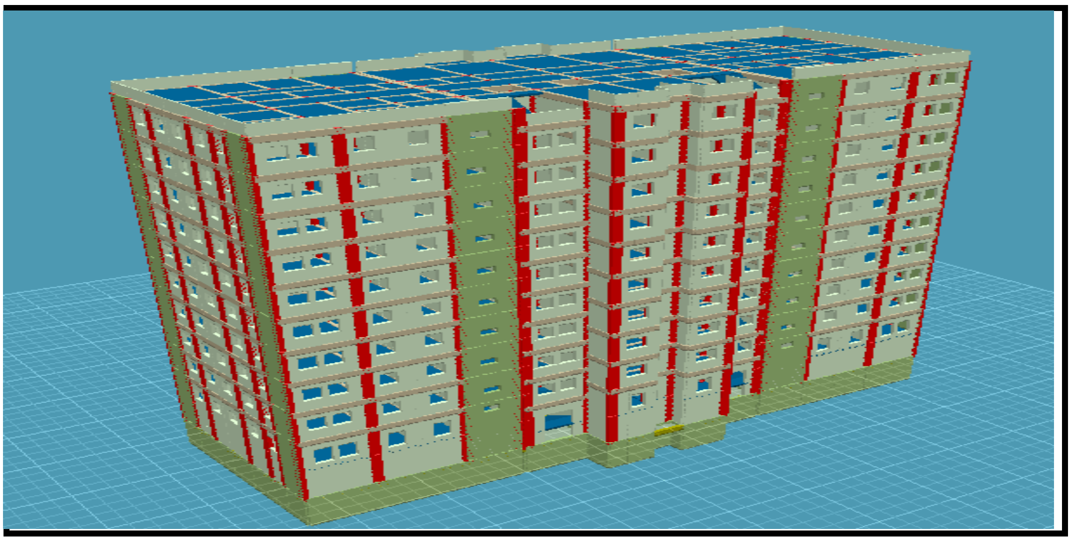

Figure 5.34: The 3D View of Buildings with Ten Stories and Stiffened Coupled Shear Wall System

The Figure 5.34 illustrates the 3D view of buildings with 10 stories and stiffened coupled shear wall system.

5.3.3.5 Tunnel Formwork System

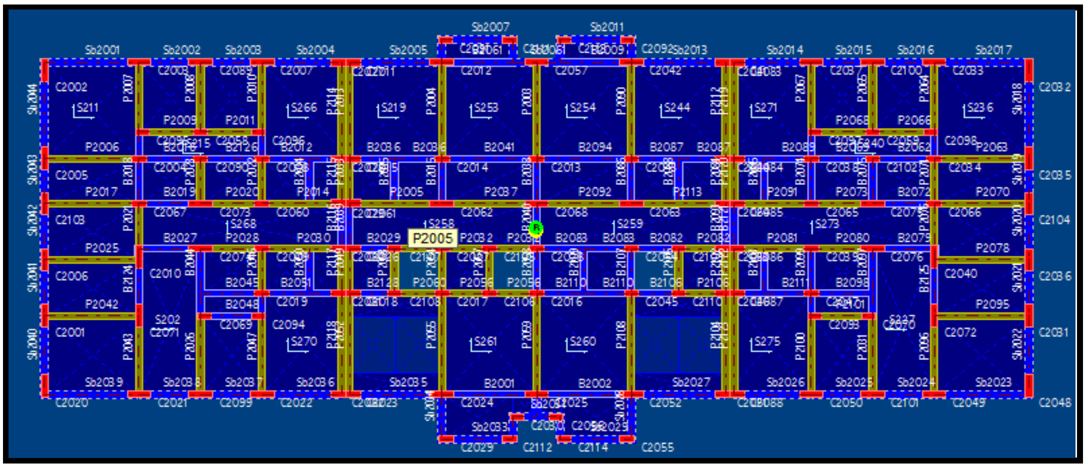

Figure 5.35: Plan of Buildings with Ten Stories and Tunnel Formwork System

The Figure 5.35 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

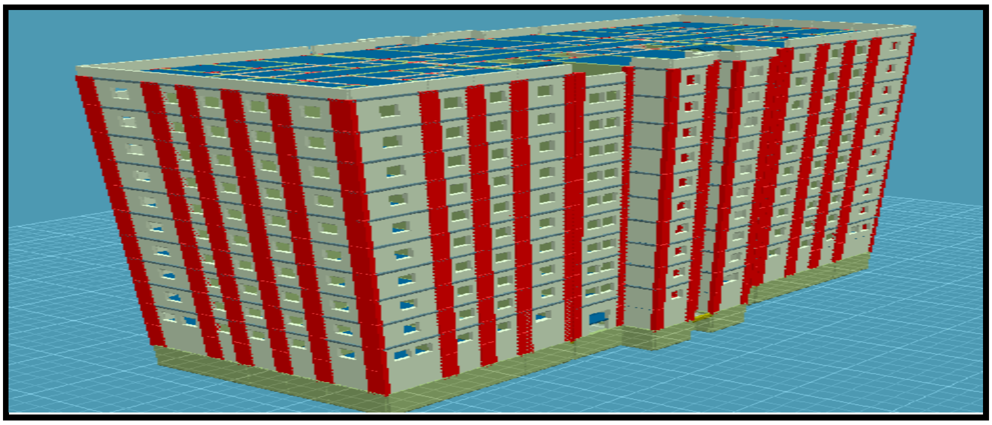

Figure 5.36: The 3D View of Buildings with Ten Stories and Tunnel Formwork

The Figure 5.36 illustrates the 3D view of buildings with 10 stories and tunnel formwork system.

5.3.3.6 Results of Analysis the Third Case Study with Ten Stories

It decides the capacity ratio of the plastic hinge of the columns for the best system by comparing the capacity ratio of the plastic hinge of the columns of other systems. Therefore, the number of damaged columns at each story and the total number of columns on that story are shown in Tables 5.26, 5.27, 5.28 ,5.29, and 5.30. The plastic hinge ratio is 0.7 for the tunnel formwork. Also, the observed ratio for shear wall, coupled shear wall and stiffened coupled shear wall are 2.3, 2.3 and 2.4 respectively. Hence, the number of damaged columns on any story to be damaged in seismic regions for the tunnel formwork is zero. Moreover, the observed ratio for shear wall, coupled shear wall and stiffened coupled shear wall is equal to the number of damaged columns, which is 5. The total number of columns is 2,594, as shown in Appendix D. The flat slab-beam provided unsatisfactory results against earthquake forces. Therefore, it was assumed that the analytical studies were performed under seismic excitation loading. The result of analysis of all case studies is shown in Table 5.31.

Table 5.21: Shear wall system.

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.3<=%20 ✓),(CC=%0.2 ✓)
Roof Story Vc ratio=(CP=%0.3<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%2.3<=%30 ✓,(CC=%0 ✓)
```

Table 5.22: Coupled shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.4<=%20 ✓),(CC=%0.2✓)
Roof Story Vc ratio=(CP=%0.3<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%2.3<=%30 ✓,(CC=%0 ✓)
```

Table 5.23: Stiffened coupled shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓), (CC=%0 ✓)
Colums Damage Ratio=(CP=%0.2<=%20 ✓) ,(CC=%0.2✓)
Roof Story Vc ratio=(CP=%0.1<=%40 ✓) ,(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%2.4<=%30 ✓,(CC=%0 ✓)
```

Table 5.24: Flat slab-beam

```
BUILDING PERFORMANCE RESULTS:
Buiding horizontal loads capacity ratio 3. story : Vr/Ve=886.88/716.28=1.238
Columns include Plastic Hinge Vc ratio=%49.7>%30 ✗
Collapse case, shall need Resistance. Life Safety ✗

Collapse Prevention case, sufficiency check:
Beams Collapse Prevention Damage Ratio=%0.0<%20 ✓
Columns include Plastic Hinge Vc ratio=%49.7>%30 ✗,(CC=49.7>%0 ✗)
```

Table 5.25: Tunnel formwork system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.0<=%20 ✓),(CC=%0 ✓)
Roof Story Vc ratio=(CP=%0.0<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%0.7<=%30 ✓,(CC=%0 ✓)
```

Table 5.26: Shear wall in buildings with 10 stories

Percentage of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
10	0/69(0%)	1/100(1%)	0/76(0%)	2/100(2%)
9	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
8	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
7	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
6	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
5	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
4	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
3	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
2	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
1	0/69(0%)	0/100(0%)	0/76(0%)	2/100(2%)
Basement	0/69(0%)	0/297(0%)	0/76(0%)	0/297(0%)

Table 5.27: Coupled shear wall in buildings with 10 stories

Percentage of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
10	0/69(0%)	1/100(1%)	0/76(0%)	2/100(2%)
9	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
8	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
7	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
6	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
5	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
4	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
3	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
2	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
1	0/69(0%)	0/100(0%)	0/76(0%)	2/100(2%)
Basement	0/69(0%)	0/297(0%)	0/76(0%)	0297(0%)

Table 5.28: Stiffened coupled shear wall in buildings with 10 stories

Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
10	0/69(0%)	1/100(1%)	0/76(0%)	2/100(2%)
9	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
8	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
7	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
6	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
5	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
4	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
3	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
2	0/69(0%)	0/100(0%)	0/76(0%)	0/100(0%)
1	0/69(0%)	0/100(0%)	0/76(0%)	2/100(2%)
Basement	0/69(0%)	0/297(0%)	0/76(0%)	0/297(0%)

Table 5.29: Flat slab beam in buildings with 10 stories

Percentage of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
10	0/76(0%)	0/95(0%)	0/74(0%)	5/95(5.3%)
9	0/76(0%)	0/95(0%)	0/74(0%)	3/95(3.2%)
8	0/76(0%)	0/95(0%)	0/74(0%)	1/95(1.1%)
7	0/76(0%)	0/95(0%)	0/74(0%)	1/95(1.1%)
6	0/76(0%)	0/95(0%)	0/74(0%)	1/95(1.1%)
5	0/76(0%)	0/95(0%)	0/74(0%)	1/95(1.1%)
4	0/76(0%)	0/95(0%)	0/74(0%)	3/95(3.2%)
3	0/76(0%)	0/95(0%)	0/74(0%)	3/95(3.2%)
2	0/76(0%)	0/95(0%)	0/74(0%)	3/95(3.2%)
1	0/76(0%)	0/95(0%)	0/74(0%)	0/95(0%)
Basement	0/76(0%)	0/95(0%)	0/74(0%)	0/95(0%)

Table 5.30: Tunnel formwork in buildings with 10 stories

Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
10	0/53(0%)	0/191(0%)	0/36(0%)	0/191(0%)
9	0/53(0%)	0/191(0%)	0/36(0%)	0/191(0%)
8	0/53(0%)	0/191(0%)	0/36(0%)	0/191(0%)
7	0/53(0%)	0/191(0%)	0/36(0%)	0/191(0%)
6	0/53(0%)	0/191(0%)	0/36(0%)	0/191(0%)
5	0/53(0%)	0/191(0%)	0/36(0%)	0/191(0%)
4	0/53(0%)	0/191(0%)	0/36(0%)	0/191(0%)
3	0/53(0%)	0/191(0%)	0/36(0%)	0/191(0%)
2	0/53(0%)	0/191(0%)	0/36(0%)	0/191(0%)
1	0/53(0%)	0/191(0%)	0/36(0%)	0/191(0%)
Basement	0/53(0 %)	0/315(0%)	0/36(0%)	0/315(0%)

Table 5.31: Results of analysis of buildings with 10 stories

The Analysis of STA4-CAD	Shear wall	Coupled shear wall	Stiffened coupled shear wall	Flat slab beam	Tunnel formwork
Concrete (m^3)	3,503.3	3,347.3	3,504.3	1,723.0	4,569.0
Formwork (m^2)	19,571.3	18,302.6	19,570.0	17,518.1	26,010.8
Reinforce (ton)	254.6	252.9	257.5	109.1	300.0
Building wall (m^2)	10,319.5	10,319.5	10,319.5	10,381.5	2,800
Plaster of all building (m^2)	38,912.0	38,912.0	38,912.0	39,998.0	5,600.0
Cost (TL)	3,343,079	3,292,882	3,349,077	2,802,414	2,121,969
X (m)	0.00148	0.00149	0.00148	0.00222	0.00048
Y (m)	0.00192	0.00192	0.00191	0.00286	0.00052
Beam damage ratio < 30%	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Column damage ratio < 20%	0.3 %	0.4 %	0.2 %	5 %	0.0 %
Roof story V_C ratio < 40%	0.3 %	0.3 %	0.1 %	2 %	0.0 %
Columns including plastic hinge Vc ratio [LS+CP+CC] < 30%	2.3 % LS	2.3 % LS	2.4 % LS	49.7 % CC	0.3 % LS

5.3.3.6.1 Quantity of Each Case Study

Table 5.20 illustrates the quantity of each case study respectively in Figure 5.37, 5.38, 5.39. It shows that the tunnel system requires a larger amount of concrete, formwork and reinforcement. Also, Figure 5.40 shows the tunnel system requires a small amount in order to build walls and plaster. In addition, Figure 5.41 shows that the total cost of the tunnel system is low. However, the displacement of the case studies with two directions (x, y) in Figure 5.42 shows that the tunnel system has the least displacement and seismic performance. Figure 5.43 shows that all systems satisfy the safety criteria.

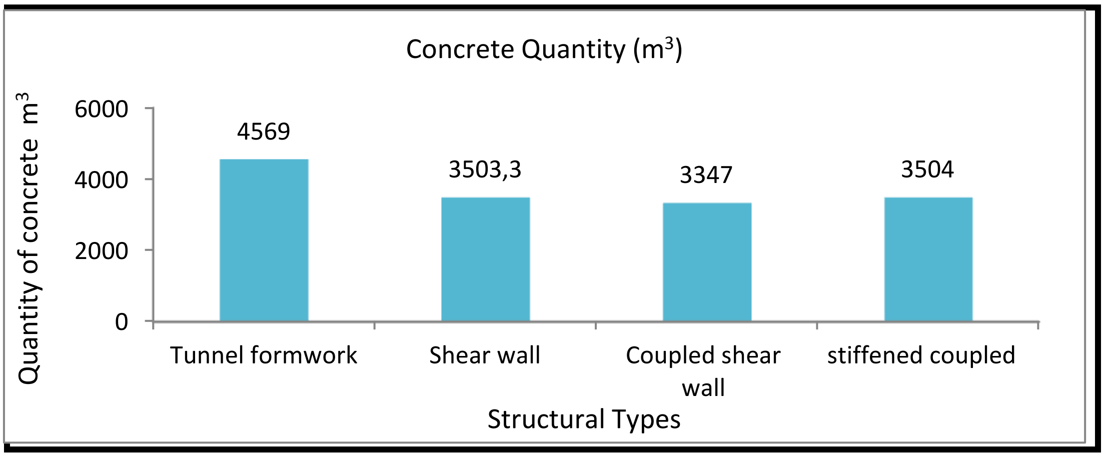

Figure 5.37: Quantity of Concrete in Buildings with Ten Stories.

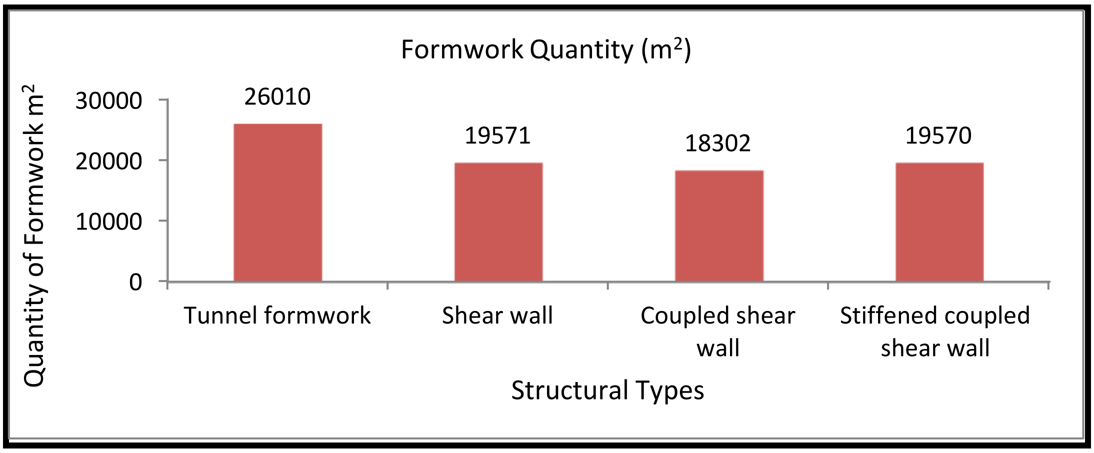

Figure 5.38: Quantity of Formwork in Buildings with Ten Stories.

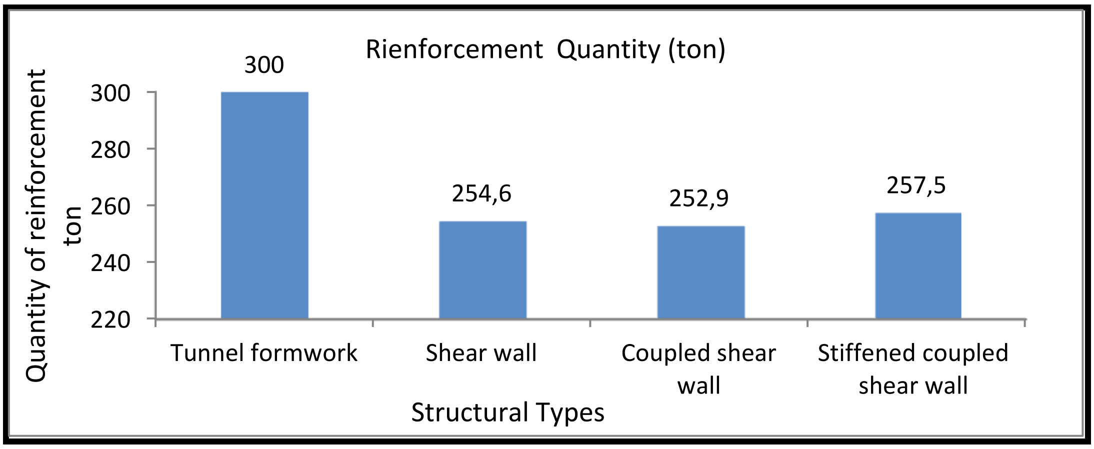

Figure 5.39: Quantity of Reinforcement in Buildings with Ten Stories.

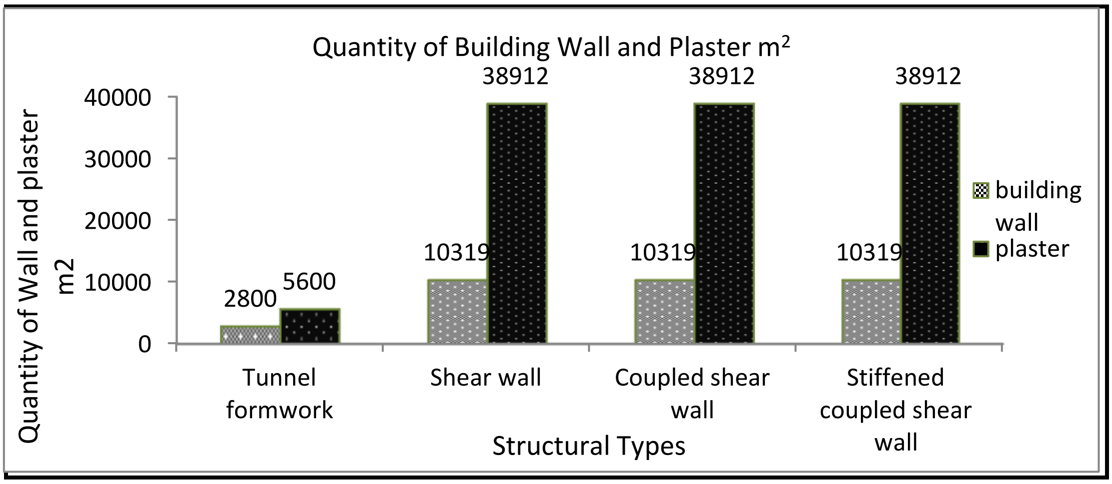

Figure 5.40: Quantity of Wall and Plaster in Buildings with Ten Stories.

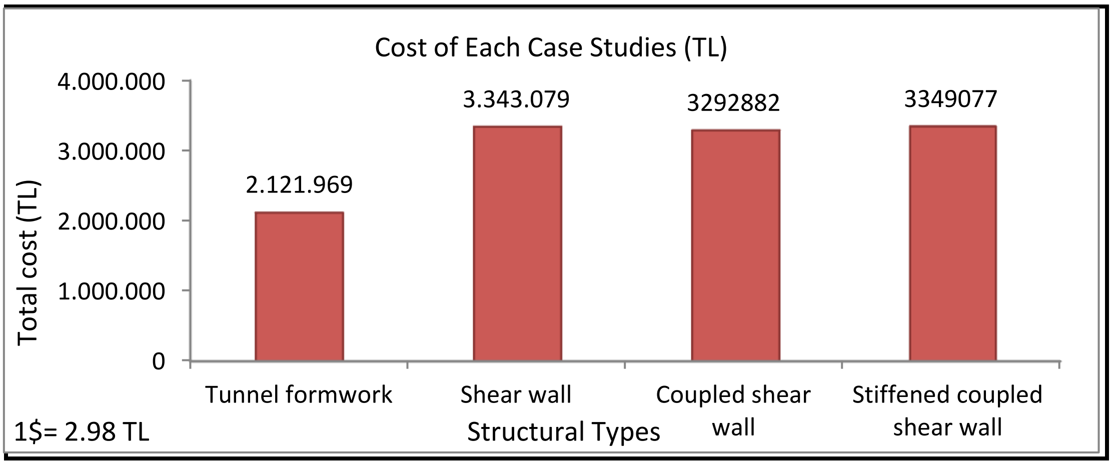

Figure 5.41: Total Costs of Case Studies in Buildings with Ten Stories.

5.3.3.6.2 Displacement of Case Studies in X and Y Directions

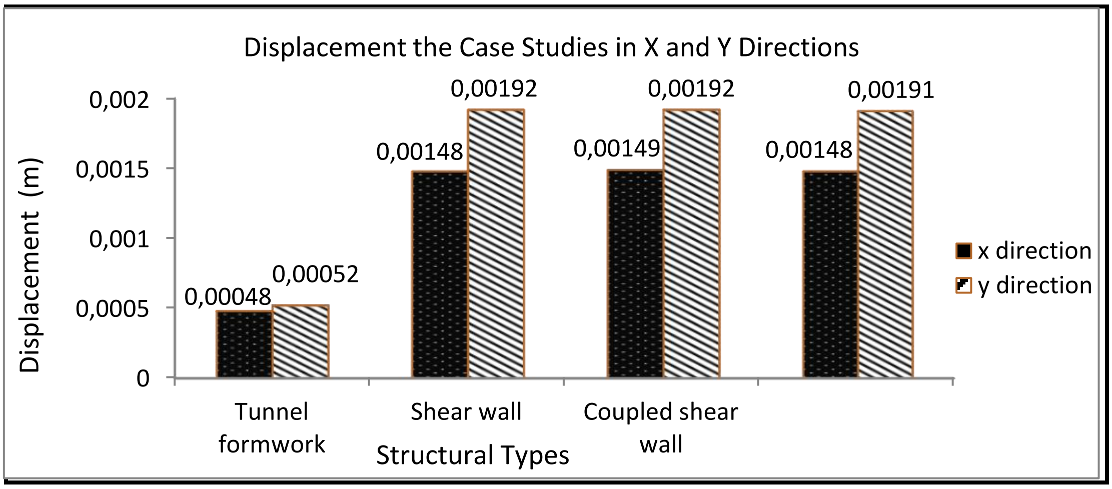

Figure 5.42: Displacement Building of Each Case Study in Buildings, Ten Stories

5.3.3.6.3 Performance

The chart below in Figure 5.43 explains the percentage of the damage beam, column, roof story and the column included in the damage of different structures after the analysis of results.

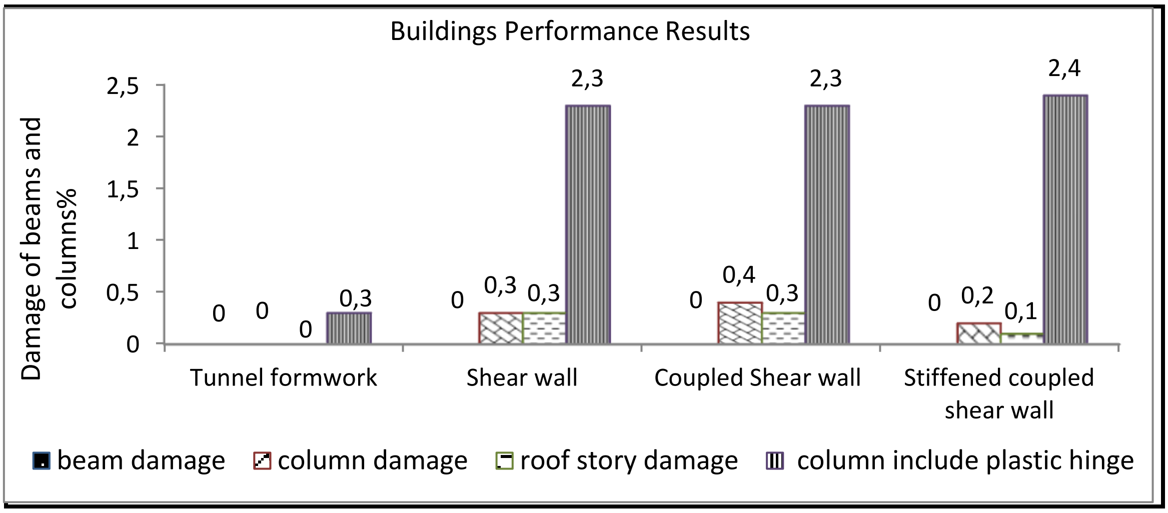

Figure 5.43: Damage of Beams and Columns of Buildings with Ten Stories.

The seismic performance in Figure 5.43 shows all systems satisfy the safety criteria. It also shows that the tunnel formwork system is an economic system.

5.3.4 The Fourth Case Study-Fifteen Story Building with the Selected System

The fourth case illustrates a different system in a building with 15 stories. In this case, there are 4 case studies with different systems**,** but the flat slab-beam system excluded from this different structur, because it gives unsatisfactory results against earthquake forces. These different systems are:

1. The shear wall system.

2. The coupled shear wall system.

3. The stiffened coupled shear wall system.

4. The tunnel formwork system.

5.3.4.1 Shear Wall System

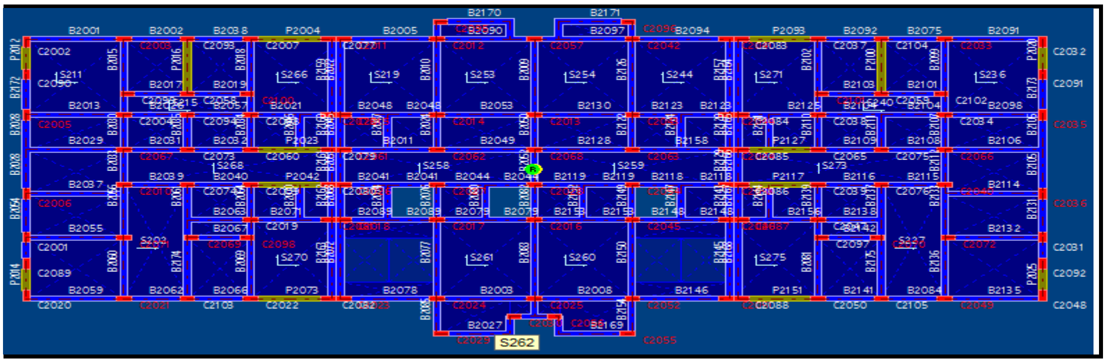

Figure 5.44: Plan of Fifteen Stories, Shear Wall System

The Figure 5.44 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

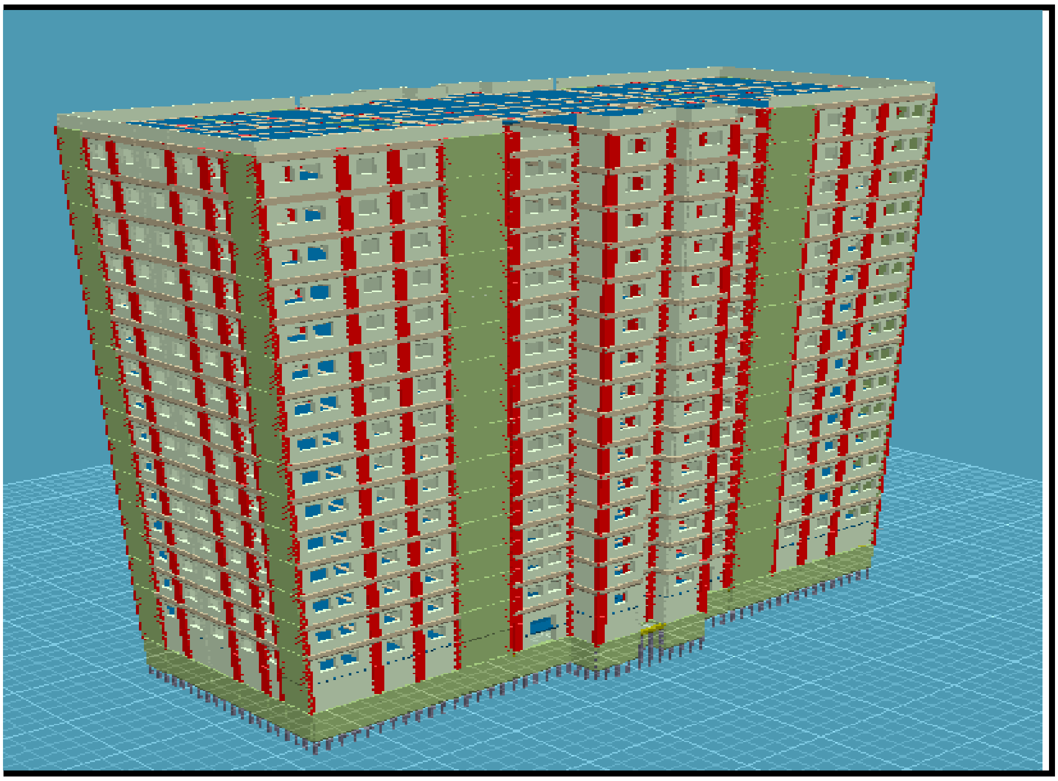

Figure 5.45: The 3D View of a Building with Fifteen Stories and Shear Wall System

The Figure 5.45 illustrates the 3D view of a building with 15 stories and shear wall system.

5.3.4.2 Coupled Shear Wall System

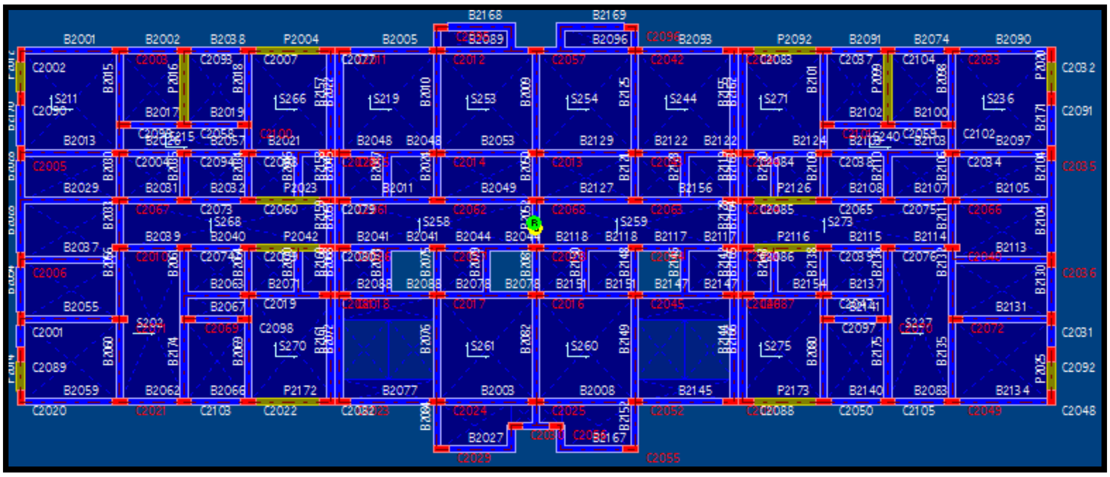

Figure 5.46: Plan of a Building with Fifteen Stories and Coupled Shear Wall System

The Figure 5.46 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

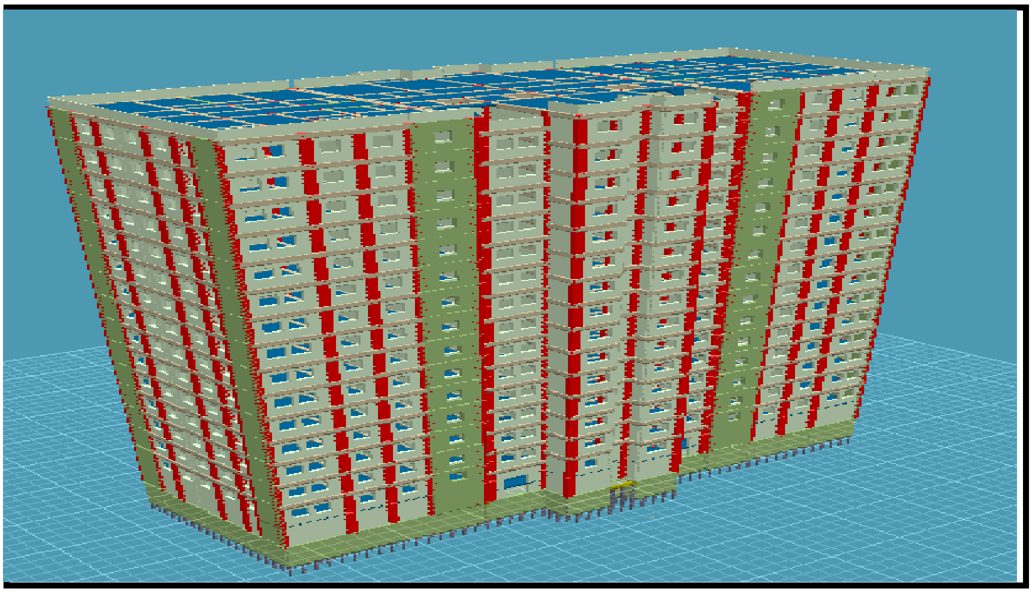

Figure 5.47: The 3D View of a Building with Fifteen Stories and Coupled Shear Wall

The Figure 5.47 illustrates the 3D view a building with 15 stories and coupled shear wall system.

5.3.4.3 Stiffened Coupled Shear Wall System

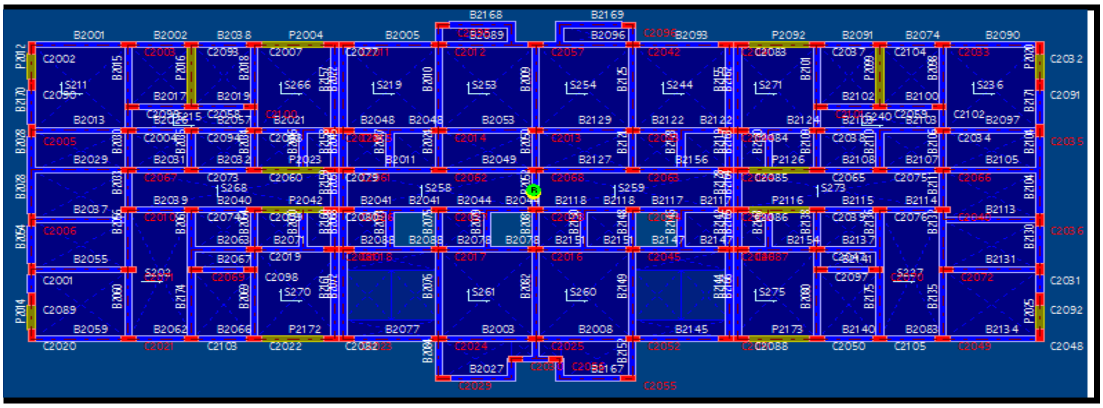

Figure 5.48: Plan of a Building with Fifteen Stories and Stiffened Coupled Shear Wall

The Figure 5.48 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

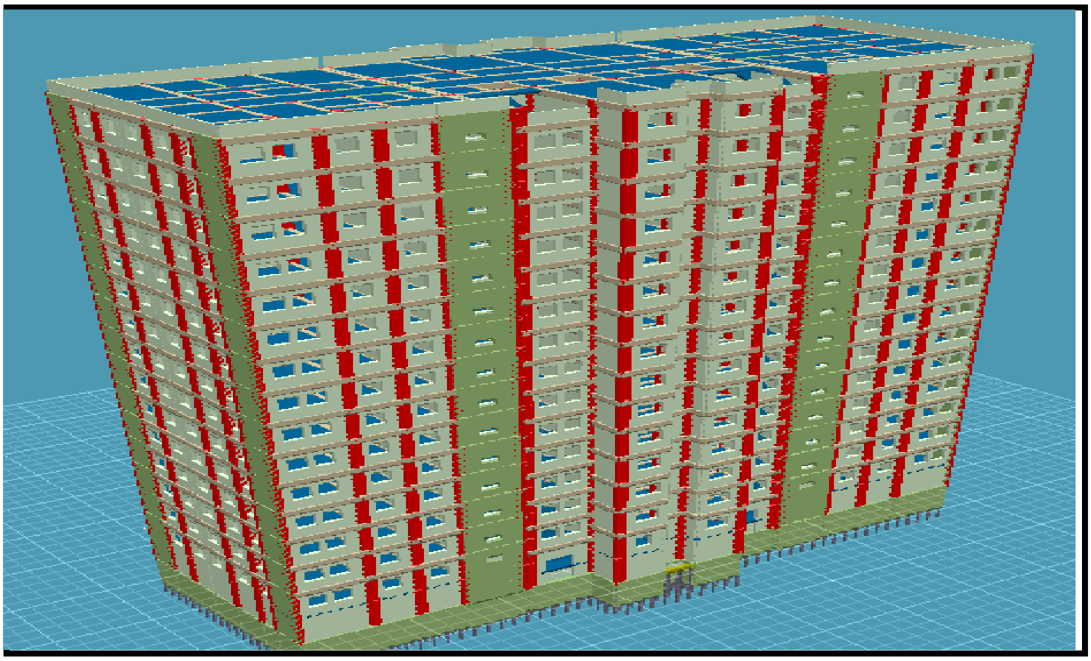

Figure 5.49: The 3D View of a Building with Fifteen Stories and Stiffened Coupled Shear Wall System

Figure 5.49 illustrates the 3D view of a building with 15 stories and stiffened coupled shear wall.

5.3.4.4 Tunnel Formwork System

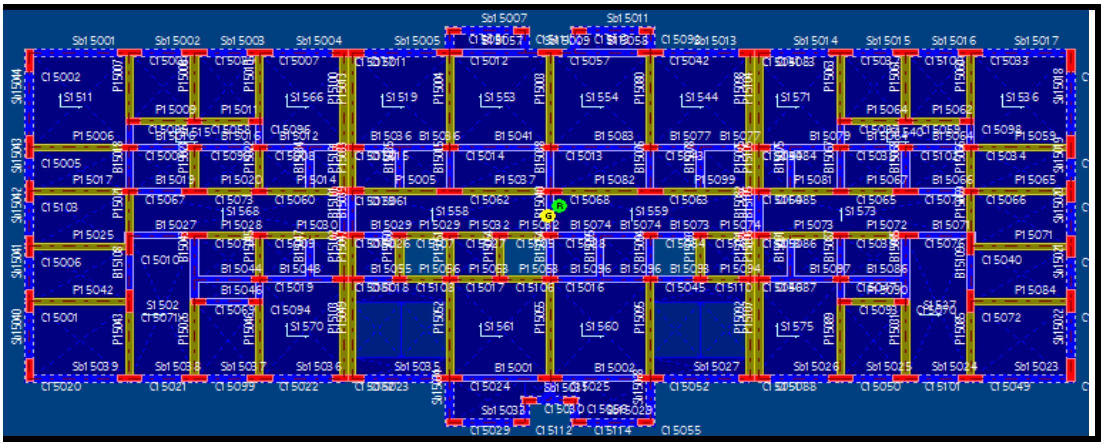

Figure 5.50: Plan of Fifteen Stories and Tunnel Formwork System

The Figure 5.50 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

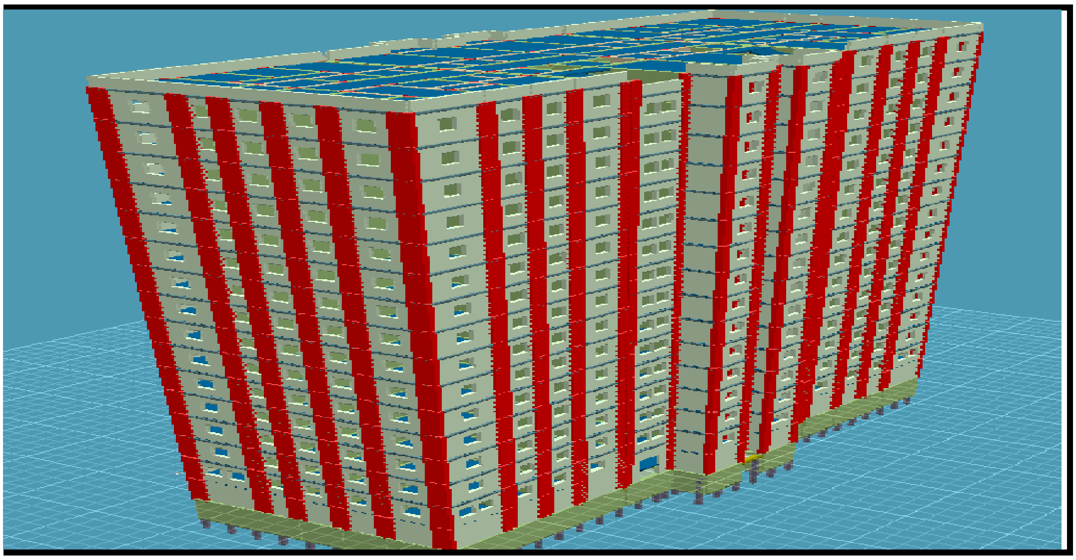

Figure 5.51: The 3D view of a Building with Fifteen Stories and Tunnel Formwork

The Figure 5.51 illustrates the 3D view of a building with 15 stories and the tunnel formwork system.

5.3.4.5 Results of Analysis the Fourth Case Study with Fifteen Stories

It decides the capacity ratio of the plastic hinge of the columns for the best system by comparing the capacity ratio of the plastic hinge of the columns of other systems. Therefore, the number of damaged columns on each story and the total number of columns on that story are shown in Tables 5.36, 5.37, 5.38, and 5.39. The plastic hinge ratio is 0.8 for the tunnel formwork, also the observed ratio for shear wall; coupled shear wall and stiffened coupled shear wall are 2.5, 2.5 and 2.5 respectively. Hence, the number of damaged columns is 49 columns and the total number of columns to be damaged in seismic regions for the tunnel formwork is 4,200 columns. Also, the observed number of damaged columns for shear wall, coupled shear wall and stiffened coupled shear wall are 52, 54, and 50 respectively. The total number of columns is 4,220 columns, as shown in Appendix D. Therefore, it was assumed that the analytical studies were performed under seismic excitation loading. The result of analysis of all case studies is shown in Table 5.40.

Table 5.32: Shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.7<=%20 ✓),(CC=%0.1 ✓)
Roof Story Vc ratio=(CP=%0.1<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%2.5<=%30 ✓,(CC=%0 ✓)
```

Table 5.33: Coupled shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.8<=%20 ✓),(CC=%0.1 ✓)
Roof Story Vc ratio=(CP=%0.1<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%2.5<=%30 ✓,(CC=%0 ✓)
```

Table 5.34: Stiffened coupled shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.6<=%20 ✓),(CC=%0.1 ✓)
Roof Story Vc ratio=(CP=%0.1<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%2.5<=%30 ✓,(CC=%0 ✓)
```

Table 5.35: Tunnel formwork system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.0<=%20 ✓),(CC=%0 ✓)
Roof Story Vc ratio=(CP=%0.0<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%0.8<=%30 ✓,(CC=%0 ✓)
```

Table 5.36: Shear wall of the building with 15 stories

Percentage of damaged beams and columns of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
15	0/72(0%)	1/127(0.8%)	0/80(0%)	2/127(1.6%)
14	0/72(0%)	0/119(0%)	0/80(0%)	2/119(1.6%)
13	0/72(0%)	1/119(0.8%)	0/80(0%)	1/119(0.8%)
12	0/72(0%)	1/119(0.8%)	0/80(0%)	3/119(2.5%)
11	0/72(0%)	1/119(0.8%)	0/80(0%)	2/119(1.7%)
10	0/72(0%)	0/119(0%)	0/80(0%)	3/119(2.5%)
9	0/72(0%)	0/119(0%)	0/80(0%)	5/119(4.2%)
8	0/72(0%)	1/119(0.8%)	0/80(0%)	5/119(4.2%)
7	0/72(0%)	0/119(0%)	0/80(0%)	8/119(6.7%)
6	0/72(0%)	0/119(0%)	0/80(0%)	8/119(6.7%)
5	0/72(0 %)	0/119(0%)	0/80(0%)	8/119(6.7%)
4	0/72(0 %)	0/119(0%)	0/80(0%)	0/119(0%)
3	0/72(0 %)	0/119(0%)	0/80(0%)	0/119(0%)
2	0/72(0 %)	0/119(0%)	0/80(0%)	0/119(0%)
1	0/72(0 %)	0/127(0%)	0/80(0%)	0/127(0%)
Basement	0/72(0%)	0/309(0%)	0/80(0%)	0/309(0%)

Table 5.37: Coupled shear wall of the building with 15 stories

Percentage of damaged beams and columns of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
15	0/72(0%)	1/127(0.8%)	0/80(0%)	2/127(1.6%)
14	0/72(0%)	0/119(0%)	0/80(0%)	2/119(1.6%)
13	0/72(0%)	1/119(0.8%)	0/80(0%)	1/119(0.8%)
12	0/72(0%)	1/119(0.8%)	0/80(0%)	3/119(2.5%)
11	0/72(0%)	1/119(0.8%)	0/80(0%)	2/119(1.7%)
10	0/72(0%)	0/119(0%)	0/80(0%)	3/119(2.5%)
9	0/72(0%)	0/119(0%)	0/80(0%)	5/119(4.2%)
8	0/72(0%)	1/119(0.8%)	0/80(0%)	5/119(4.2%)
7	0/72(0%)	0/119(0%)	0/80(0%)	8/119(6.7%)
6	0/72(0%)	0/119(0%)	0/80(0%)	8/119(6.7%)
5	0/72(0 %)	1/119(0.8%)	0/80(0%)	8/119(6.7%)
4	0/72(0 %)	0/119(0%)	0/80(0%)	0/119(0%)
3	0/72(0 %)	1/119(0.8%)	0/80(0%)	0/119(0%)
2	0/72(0 %)	0/119(0%)	0/80(0%)	0/119(0%)
1	0/72(0 %)	0/127(0%)	0/80(0%)	0/127(0%)
Basement	0/72(0%)	0/309(0%)	0/80(0%)	0/309(0%)

Table 5.38: Stiffened coupled shear wall in buildings with 15 stories

Percentage of damaged beams and columns of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
15	0/72(0%)	1/127(0.8%)	0/80(0%)	2/127(1.6%)
14	0/72(0%)	0/119(0%)	0/80(0%)	2/119(1.6%)
13	0/72(0%)	1/119(0.8%)	0/80(0%)	1/119(0.8%)
12	0/72(0%)	1/119(0.8%)	0/80(0%)	3/119(2.5%)
11	0/72(0%)	1/119(0.8%)	0/80(0%)	0/119(0%)
10	0/72(0%)	0/119(0%)	0/80(0%)	3/119(2.5%)
9	0/72(0%)	0/119(0%)	0/80(0%)	5/119(4.2%)
8	0/72(0%)	1/119(0.8%)	0/80(0%)	5/119(4.2%)
7	0/72(0%)	0/119(0%)	0/80(0%)	8/119(6.7%)
6	0/72(0%)	0/119(0%)	0/80(0%)	8/119(6.7%)
5	0/72(0 %)	0/119(0%)	0/80(0%)	8/119(6.7%)
4	0/72(0 %)	0/119(0%)	0/80(0%)	0/119(0%)
3	0/72(0 %)	0/119(0%)	0/80(0%)	0/119(0%)
2	0/72(0 %)	0/119(0%)	0/80(0%)	0/119(0%)
1	0/72(0 %)	0/127(0%)	0/80(0%)	0/127(0%)
Basement	0/72(0%)	0/309(0%)	0/80(0%)	0/309(0%)

Table 5.39: Tunnel formwork in buildings with 15 stories

Percentage of damaged beams and columns of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
15	0/45(0%)	0/191(0%)	0/45(0%)	0/191(0%)
14	0/45(0%)	0/191(0%)	0/45(0%)	0/191(0%)
13	0/45(0%)	0/191(0%)	0/45(0%)	0/191(0%)
12	0/45(0%)	0/191(0%)	0/45(0%)	0/191(0%)
11	0/45(0%)	2/191(1.0%)	0/45(0%)	0/191(0%)
10	0/45(0%)	4/191(2.1%)	0/45(0%)	1/191(0.5%)
9	0/45(0%)	4/191(2.1%)	0/45(0%)	1/191(0.5%)
8	0/45(0%)	4/191(2.1%)	0/45(0%)	2/191(1.0%)
7	0/45(0%)	4/191(2.1%)	0/45(0%)	2/191(1.0%)
6	0/45(0%)	4/191(2.1%)	0/45(0%)	2/191(1.0%)
5	0/45(0%)	0/191(0%)	0/45(0%)	0/191(0%)
4	0/45(0%)	0/191(0%)	0/45(0%)	4/191(2.1%)
3	0/45(0%)	0/191(0%)	0/45(0%)	5/191(2.6%)
2	0/45(0%)	0/191(0%)	0/45(0%)	5/191(2.6%)
1	0/45(0%)	0/191(0%)	0/45(0%)	5/191(2.6%)
Basement	0/45(0%)	0/315(0%)	0/45(0%)	0/315(0%)

Table 5.40: Results of analysis of buildings with 15 stories

The Analysis from STA4-CAD	Shear wall	Coupled shear wall	Stiffened coupled shear wall	Tunnel formwork
Concrete (m^3)	5,581.2	5,505.8	5,585.8	7,763.1
Formwork (m^2)	28,754.1	28,541.3	28,750.0	41,722.2
Reinforce (ton)	449.0	440.0	450.8	551.0
Building wall (m^2)	15,100.4	15,100.4	15,100.4	4,480
Plaster of all buildings (m^2)	54,944.1	54,944.1	54,944.1	8,960.0
Cost (TL)	5,045,585	5,013,001	5,050,059	3,603,399
X (m)	0.00155	0.00155	0.00154	0.00064
Y (m)	0.00222	0.00221	0.00221	0.00075
Beam damage ratio < 30%	0.0 %	0.0 %	0.0 %	0.0 %
Column damage ratio < 20%	0.7 %	0.8 %	0.6 %	0.0 %
Roof story VC ratio < 40%	0.1 %	0.1 %	0.1 %	0.0 %
Columns including plastic hinge Vc ratio [LS+CP+CC]< 30%	2.5 % LS	2.5 % LS	2.5 % LS	0.8 % LS

5.3.4.5.1 Quantity of Each Case Study

Table 5.25 illustrates the quantity of each case study respectively in Figure 5.52, 5.53, 5.54. It shows that the tunnel system requires a larger amount of concrete, formwork and reinforcement. Also, Figure 5.55 shows the tunnel system requires a small amount in order to build walls and plaster. Figure 5.56 shows the total cost of the tunnel system is low. However, the displacement of the case studies with two directions (x, y) in Figure 5.57 shows the tunnel system has the least displacement and seismic performance. Figure 5.58 show all systems satisfy the safety criteria.

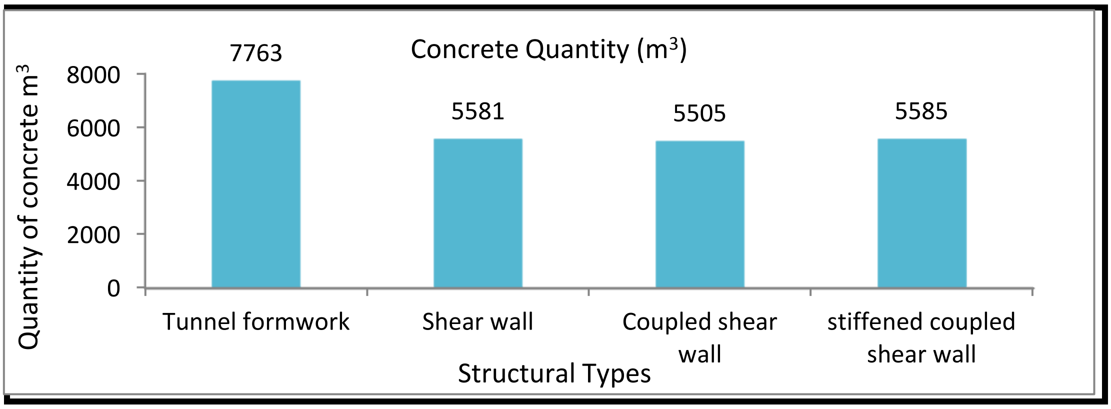

Figure 5.52: Quantity of Concrete in Buildings with Fifteen Stories.

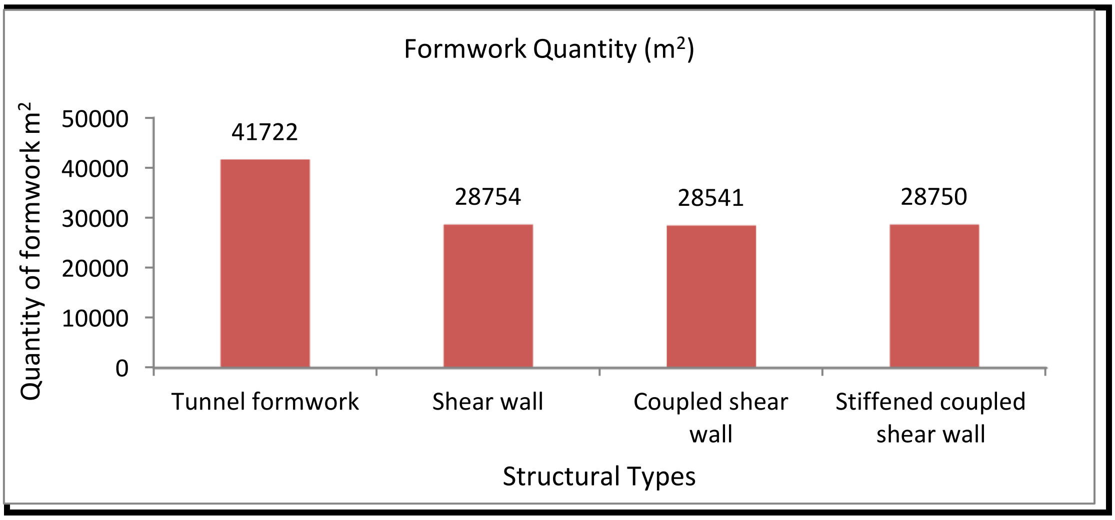

Figure 5.53: Quantity of Formwork in Buildings with Fifteen Stories

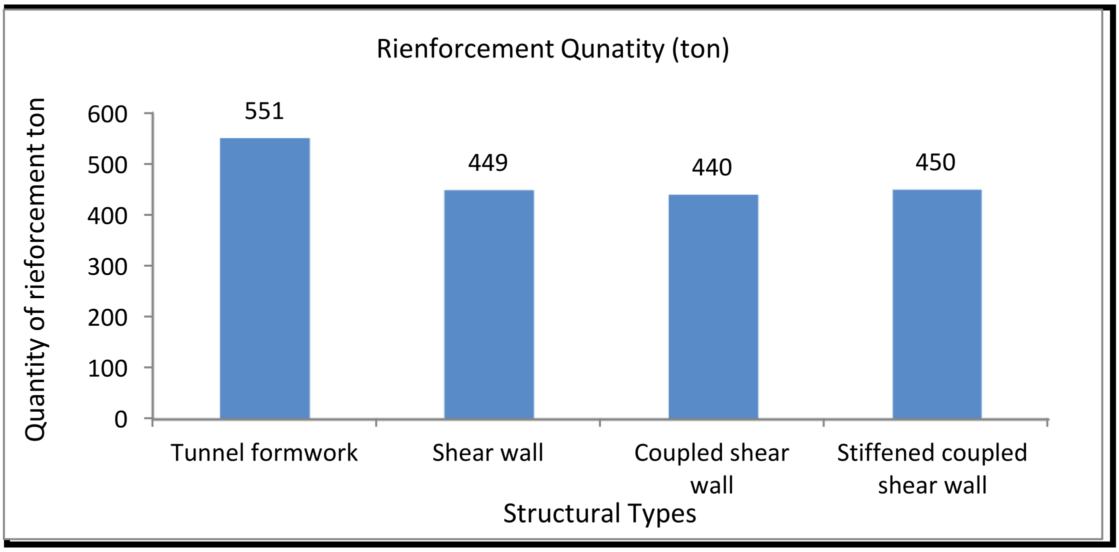

Figure 5.54: Quantity of Reinforcement in Buildings with Fifteen Stories.

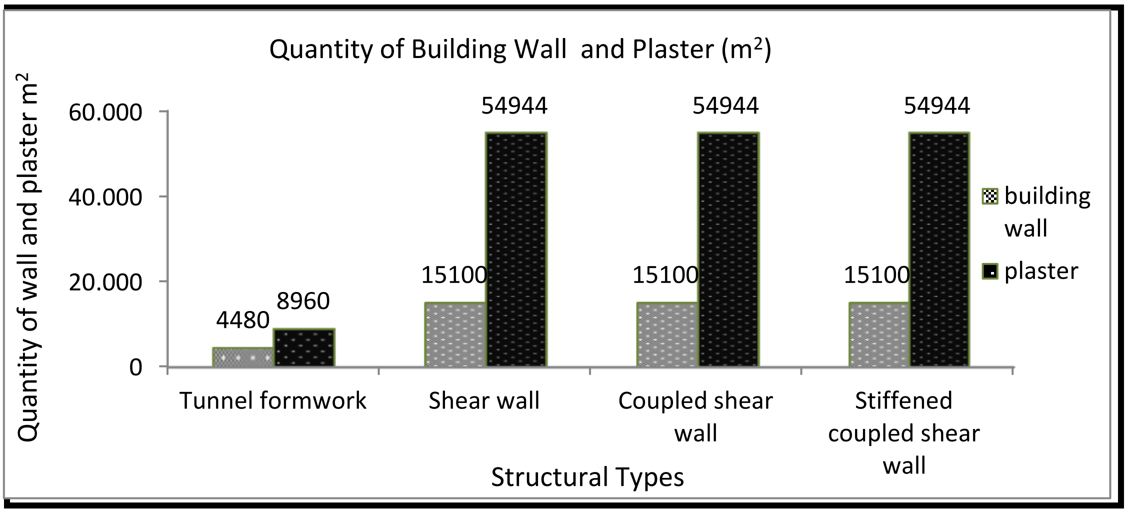

Figure 5.55: Quantity of Building Walls and Plaster in Buildings with Fifteen Stories

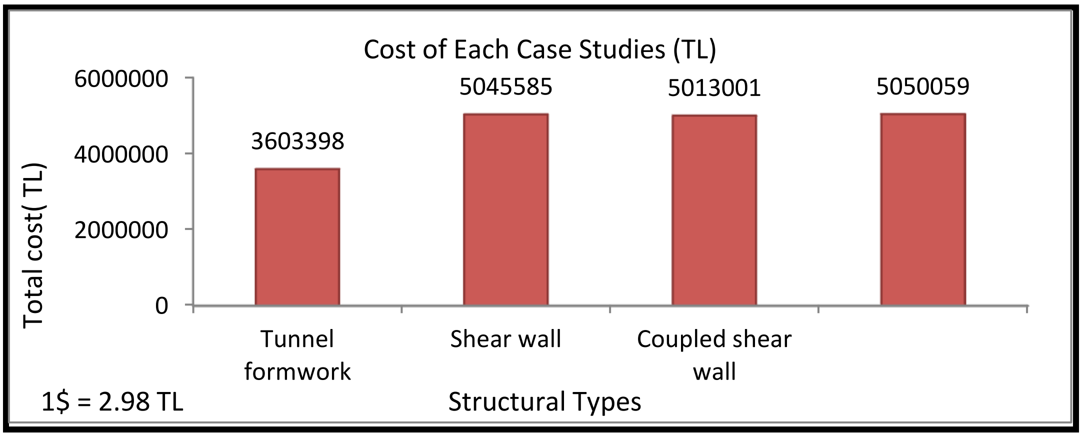

Figure 5.56: Total Costs of the Case Studies in Buildings with Fifteen Stories.

5.2.4.5.2 Displacement of Each Case Study in X and Y Directions

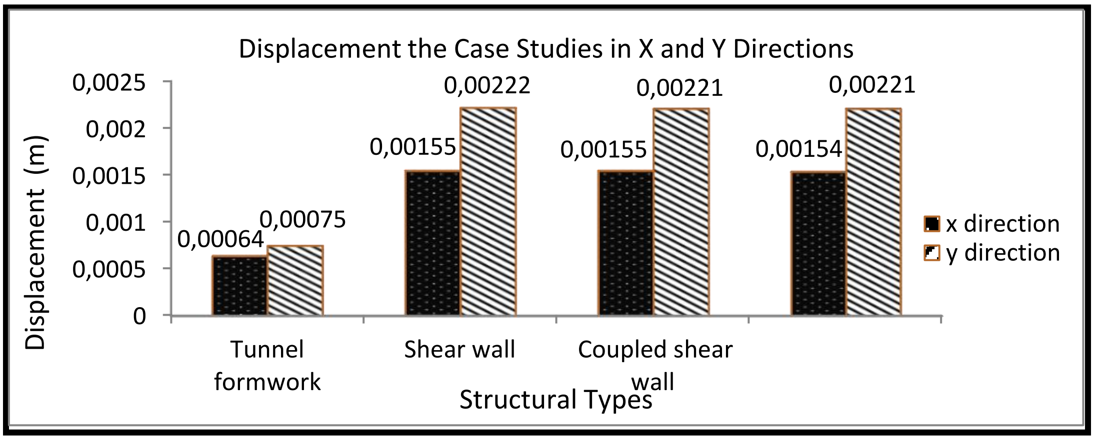

Figure 5.57: Displacement of Each Case Study in Buildings with Fifteen Stories

5.3.4.5.3 Performance

The chart below Figure 5.58 explains the percentage of damaged beam, column, roof story and the column including the damage of different systems after analysis of result performance.

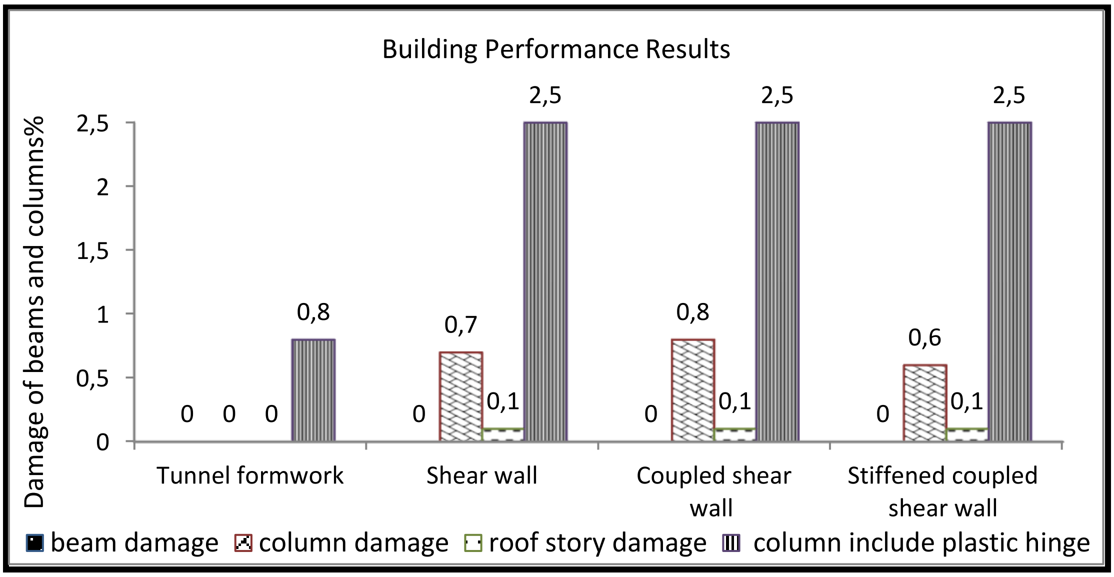

Figure 5.58: Damage of Beams and Columns in Buildings with Fifteen Stories.

The seismic performance in Figure 5.58 shows all systems satisfy the safety criteria. The tunnel formwork system is cheap according to the total cost of each case study.

5.3.5 The Fifth Case Study-Twenty Story Building with Selected System

The fifth case illustrates the different systems in buildings with 20 stories

In this case, there are 4 case studies with different systems, but the flat slab-beam system is excluded from these different systems because this system is not used in high rise buildings.

1. The shear wall system.
2. The coupled shear wall system.
3. The stiffened coupled shear wall system
4. The tunnel formwork system.

5.3.5.1 Shear Wall System

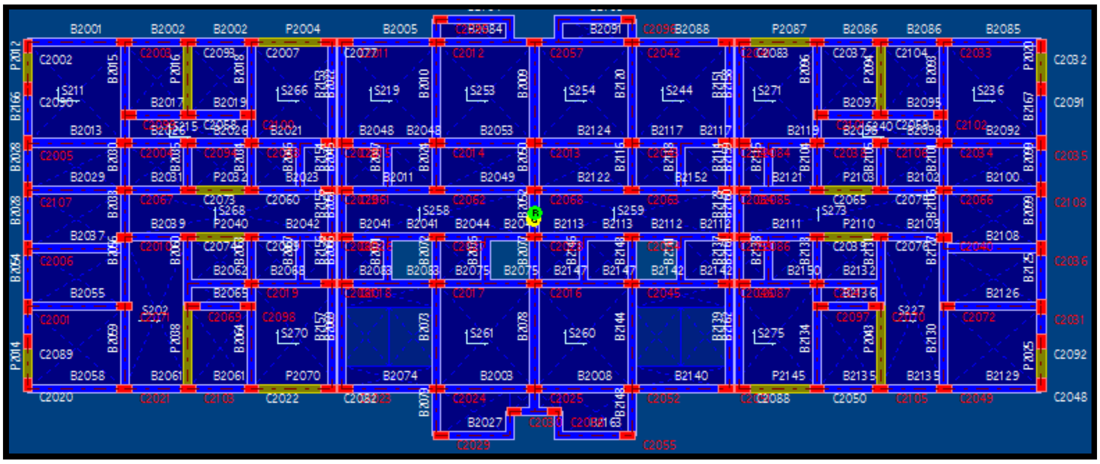

Figure 5.59: Plan of Twenty Stories and Shear Wall System

The Figure 5.59 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

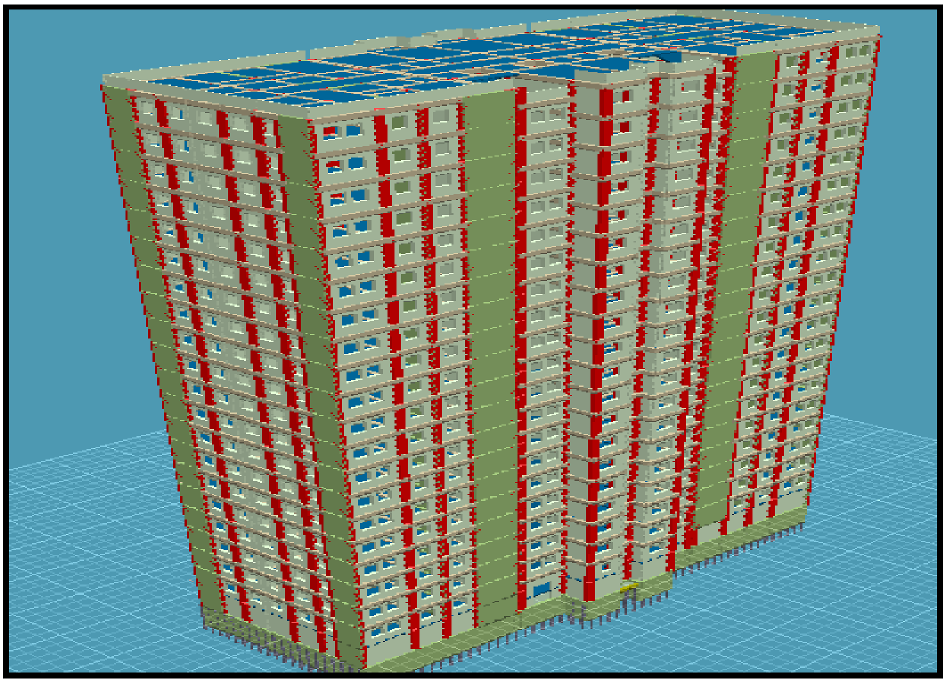

Figure 5.60: The 3D View of Twenty Stories with Shear Wall System

The Figure 5.60 illustrates the 3D view of a building with 20 stories and shear wall system.

5.3.5.2 Coupled Shear Wall System

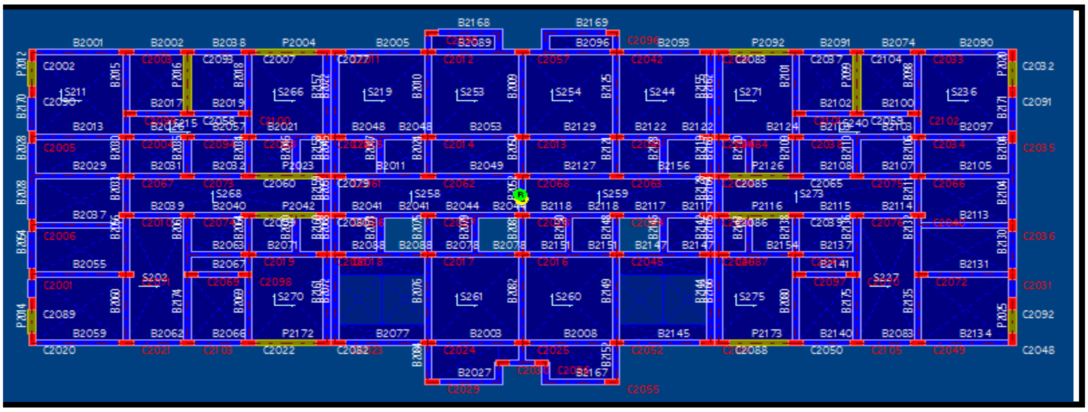

Figure 5.61: Plan of Twenty Stories and Coupled Shear Wall System

The Figure 5.61 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

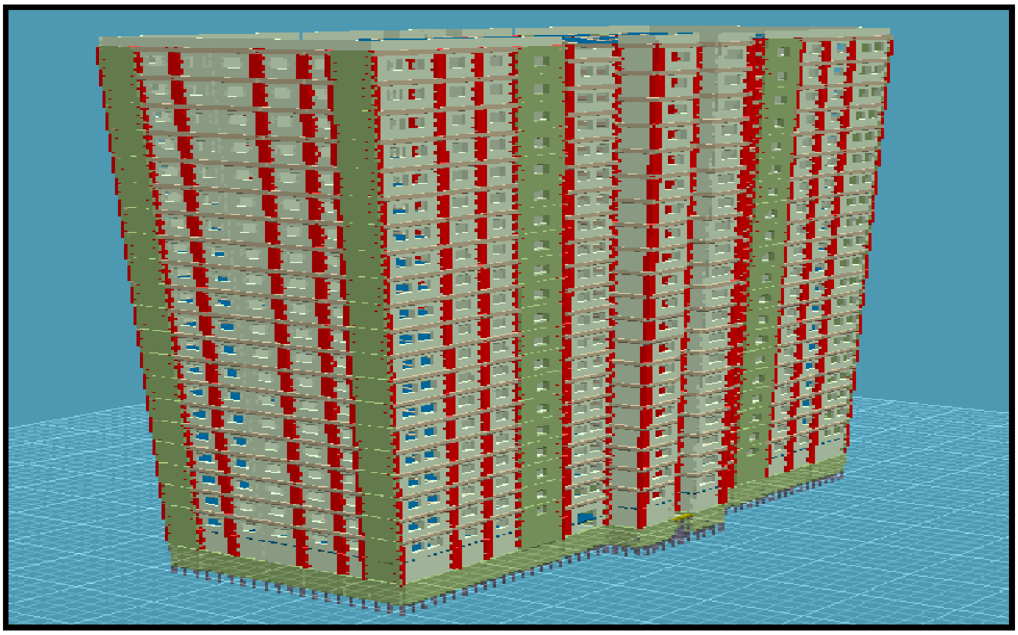

Figure 5.62 the 3D View of a Building with Twenty Stories and Coupled Shear Wall

Figure 5.62 illustrates the 3D view a building with 20 stories.

5.3.5.3 Stiffened Coupled Shear Wall System

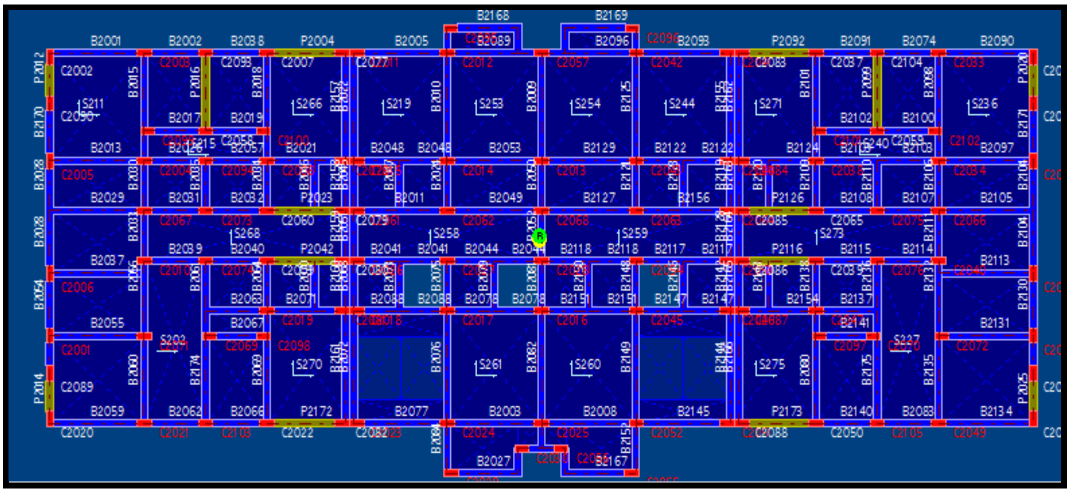

Figure 5.63: Plan of Twenty Stories and Stiffened Coupled Shear Wall System

The Figure 5.63 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

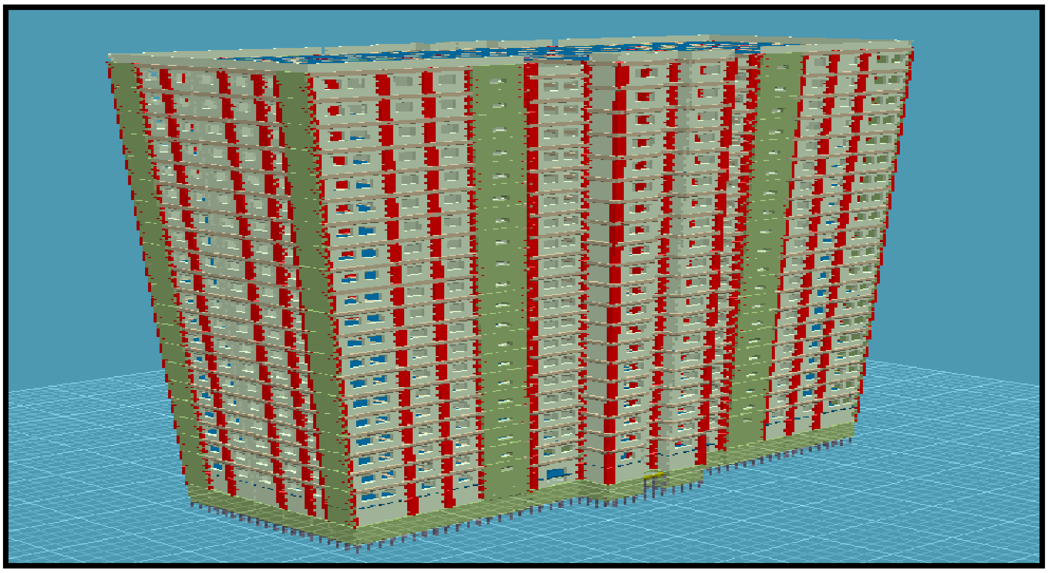

Figure 5.64: The 3D view a building with Twenty Stories and Stiffened Coupled Shear Wall System

Figure 5.64 illustrates the 3D view of a building with 20 stories.

5.3.5.4 Tunnel Formwork System

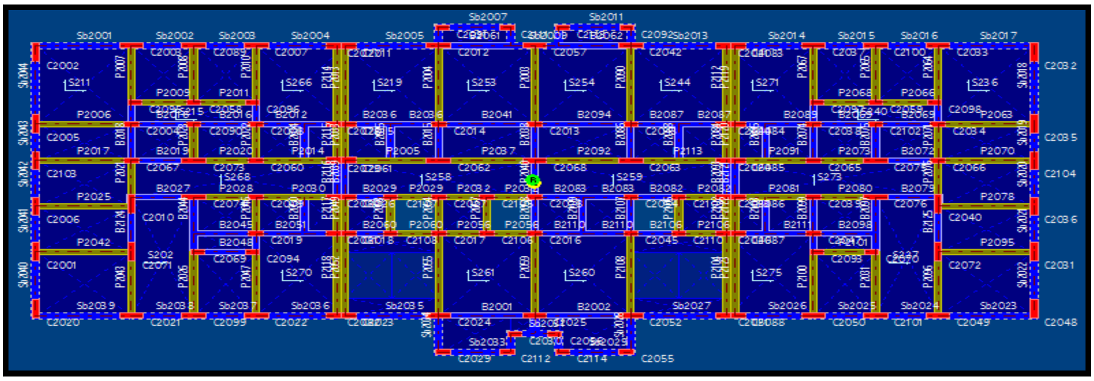

Figure 5.65: Plan of Twenty Stories and Tunnel Formwork System

The Figure 5.65 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

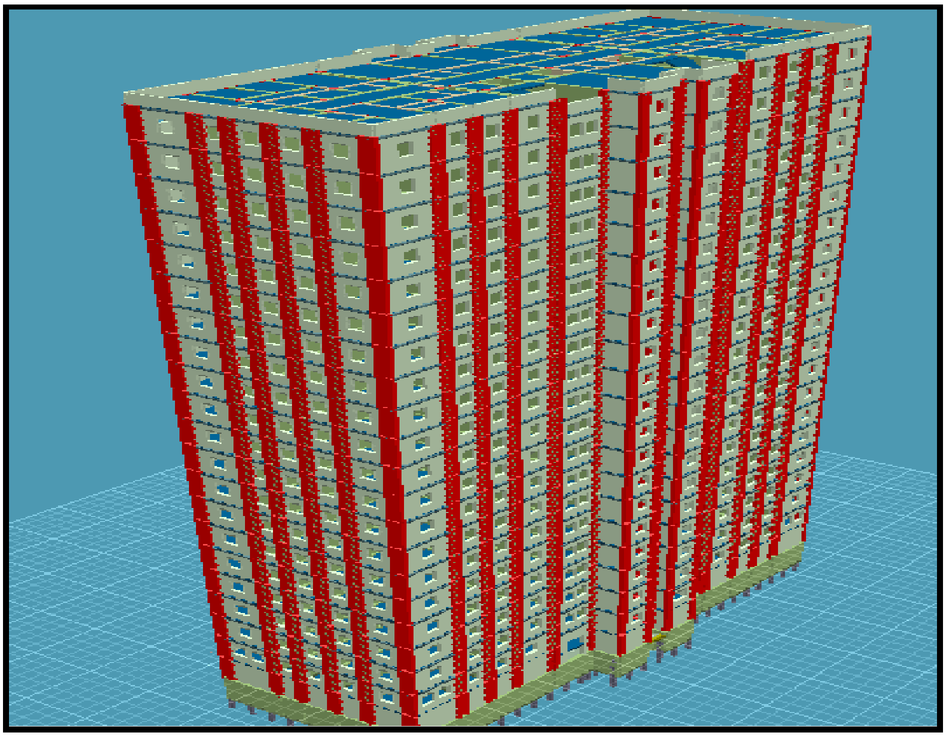

Figure 5.66: The 3D View of Twenty Stories and Tunnel Formwork

Figure 5.66 Illustrates, the 3D view of a building with 20 stories

5.3.5.5 Results of Analysis the Fifth Case Study with Twenty Stories

It decides the capacity ratio of the plastic hinge of the columns for the best system by comparing the capacity ratio of the plastic hinge of the columns of other systems. Therefore, the number of damaged columns on each story and the total number of columns on that story are shown in Tables 5.45, 5.46, 5.47 and 5.48. The plastic hinge ratio is 0.8 for the tunnel formwork. Also, the observed ratio of shear wall, coupled shear wall and stiffened coupled shear wall are 2.6, 2.8 and 2.7 respectively. Hence, the number of damage columns is 121 columns and the total number of columns to be damaged in seismic regions for the tunnel formwork is 5,390 columns. Moreover, the observed number of damaged columns for shear wall, coupled shear wall and stiffened coupled shear wall are 216, 219, 201 respectively. The total number of columns is 5,410 columns, as shown in Appendix D. Therefore, it is assumed that the analytical studies are performed under seismic excitation loading. The result of analysis all case studies is shown in Table 5.49.

Table 5.45: Shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.5<=%20 ✓),(CC=%0.4 ✓)
Roof Story Vc ratio=(CP=%0.2<=%40 ✓),(CC=%0.1 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%2.6<=%30 ✓,(CC=%0 ✓)
```

Table 5.42: Coupled shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.5<=%20 ✓),(CC=%0.4 ✓)
Roof Story Vc ratio=(CP=%0.1<=%40 ✓),(CC=%0.1 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%2.8<=%30 ✓,(CC=%0 ✓)
```

Table 5.43: Stiffened coupled shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.4<=%20 ✓),(CC=%0.3 ✓)
Roof Story Vc ratio=(CP=%0.1<=%40 ✓),(CC=%0.1 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%2.7<=%30 ✓,(CC=%0 ✓)
```

Table 5.44: Tunnel formwork system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.0<=%20 ✓),(CC=%0.1 ✓)
Roof Story Vc ratio=(CP=%0.0<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%0.8<=%30 ✓,(CC=%0 ✓)
```

Table 5.45: Shear wall in buildings with 20 stories

Percentage of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
20	0/80(0%)	1/127(0.8%)	0/80(0%)	0/127(0%)
19	0/80(0%)	5/119(4.2%)	0/80(0%)	1/119(0.8%)
18	0/80(0%)	5/119(4.2%)	0/80(0%)	3/119(2.5%)
17	0/80(0%)	5/119 (4.2%)	0/80(0%)	3/119(2.5%)
16	0/80(0%)	5/119(4.2%)	0/80(0%)	5/119(4.2%)
15	0/80(0%)	4/119(3.3%)	0/80(0%)	2/119(1.5%)
14	0/80(0%)	4/119(3.3%)	0/80(0%)	3/119(2.5%)
13	0/80(0%)	4/119(3.3%)	0/80(0%)	4/119(3.3%)
12	0/80(0%)	4/119(3.3%)	0/80(0%)	6/119 (5.0%)
11	0/80(0%)	4/119(3.3%)	0/80(0%)	6/119(5.0%)
10	0/80(0%)	4/119(3.3%)	0/80(0%)	5/119(4.2%)
9	0/80(0%)	6/119(5.0%)	0/80(0%)	5/119(4.2%)
8	0/80(0%)	7/119(5.9%)	0/80(0%)	5/119(4.1%)
7	0/80(0%)	5/119(4.2%)	0/80(0%)	6/119(5.0%)
6	0/80(0%)	3/119(2.5%)	0/80(0%)	7/119 (5.8%)
5	0/80(0%)	3/119(2.5%)	0/80(0%)	6/119(5.0%)
4	0/80(0%)	7/119(5.9%)	0/80(0%)	5/119(4.2%)
3	0/80(0%)	4/119(3.3%)	0/80(0%)	6/119(5.0%)
2	0/80(0%)	4/119(3.3%)	0/80(0%)	7/119 (5.9%)
1	0/80(0%)	10/127(7.87%)	0/80(0%)	12/127(9.4%)
Basement	0/80(0%)	12/309(3.88%)	0/80(0%)	12/309 (3.8%)

Table 5.46: Coupled shear wall of buildings with 20 stories

No	Beam	Column	Beam	Column
20	0/80(0%)	1/127(0.8%)	0/80(0%)	0/127(0%)
19	0/80(0%)	5/119(4.2%)	0/80(0%)	4/119(3.3%)
18	0/80(0%)	5/119(4.2%)	0/80(0%)	3/119(2.5%)
17	0/80(0%)	5/119 (4.2%)	0/80(0%)	3/119(2.5%)
16	0/80(0%)	5/119(4.2%)	0/80(0%)	5/119(4.2%)
15	0/80(0%)	4/119(3.3%)	0/80(0%)	2/119(1.5%)
14	0/80(0%)	4/119(3.3%)	0/80(0%)	3/119(2.5%)
13	0/80(0%)	4/119(3.3%)	0/80(0%)	4/119(3.3%)
12	0/80(0%)	4/119(3.3%)	0/80(0%)	6/119 (5.0%)
11	0/80(0%)	4/119(3.3%)	0/80(0%)	6/119(5.0%)
10	0/80(0%)	4/119(3.3%)	0/80(0%)	5/119(4.2%)
9	0/80(0%)	6/119(5.0%)	0/80(0%)	5/119(4.2%)
8	0/80(0%)	7/119(5.9%)	0/80(0%)	5/119(4.1%)
7	0/80(0%)	5/119(4.2%)	0/80(0%)	6/119(5.0%)
6	0/80(0%)	3/119(2.5%)	0/80(0%)	7/119 (5.8%)
5	0/80(0%)	3/119(2.5%)	0/80(0%)	6/119(5.0%)
4	0/80(0%)	7/119(5.9%)	0/80(0%)	5/119(4.2%)
3	0/80(0%)	4/119(3.3%)	0/80(0%)	6/119(5.0%)
2	0/80(0%)	4/119(3.3%)	0/80(0%)	7/119 (5.9%)
1	0/80(0%)	10/127(7.87%)	0/80(0%)	12/127(9.4%)
Basement	0/80(0%)	12/309(3.88%)	0/80(0%)	12/309 (3.8%)

Table 5.47: Stiffened coupled shear wall of buildings with 20 stories

Percentage of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
20	0/80(0%)	1/127(0.8%)	0/80(0%)	0/127(0%)
19	0/80(0%)	0/119(0%)	0/80(0%)	1/119(0.8%)
18	0/80(0%)	0/119(0%)	0/80(0%)	3/119(2.5%)
17	0/80(0%)	0/119 (0%)	0/80(0%)	3/119(2.5%)
16	0/80(0%)	5/119(4.2%)	0/80(0%)	5/119(4.2%)
15	0/80(0%)	4/119(3.3%)	0/80(0%)	2/119(1.5%)
14	0/80(0%)	4/119(3.3%)	0/80(0%)	3/119(2.5%)
13	0/80(0%)	4/119(3.3%)	0/80(0%)	4/119(3.3%)
12	0/80(0%)	4/119(3.3%)	0/80(0%)	6/119 (5.0%)
11	0/80(0%)	4/119(3.3%)	0/80(0%)	6/119(5.0%)
10	0/80(0%)	4/119(3.3%)	0/80(0%)	5/119(4.2%)
9	0/80(0%)	6/119(5.0%)	0/80(0%)	5/119(4.2%)
8	0/80(0%)	7/119(5.9%)	0/80(0%)	5/119(4.1%)
7	0/80(0%)	5/119(4.2%)	0/80(0%)	6/119(5.0%)
6	0/80(0%)	3/119(2.5%)	0/80(0%)	7/119 (5.8%)
5	0/80(0%)	3/119(2.5%)	0/80(0%)	6/119(5.0%)
4	0/80(0%)	7/119(5.9%)	0/80(0%)	5/119(4.2%)
3	0/80(0%)	4/119(3.3%)	0/80(0%)	6/119(5.0%)
2	0/80(0%)	4/119(3.3%)	0/80(0%)	7/119 (5.9%)
1	0/80(0%)	10/127(7.87%)	0/80(0%)	12/127(9.4%)
Basement	0/80(0%)	12/309(3.88%)	0/80(0%)	12/309 (3.8%)

Table 5.48 Tunnel formwork of buildings with 20 stories

Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
20	0/54 (0 %)	0/191(0%)	0/45(0%)	0/191(0%)
19	0/54 (0 %)	0/191(0%)	0/45(0%)	0/191(0%)
18	0/54 (0 %)	0/191(0%)	0/45(0%)	0/191(0%)
17	0/54 (0 %)	0/191(0%)	0/45(0%)	0/191(0%)
16	2/191(1.0%)	2/191(1.0%)	0/45(0%)	1/191(0.5%)
15	2/191(1.0%)	2/191(1.0%)	0/45(0%)	1/191(0.5%)
14	2/191(1.0%)	2/191(1.0%)	0/45(0%)	1/191(0.5%)
13	0/54 (0 %)	4/191(2.1%)	0/45(0%)	2/191(1.0%)
12	0/54 (0 %)	4/191(2.1%)	0/45(0%)	2/191(1.0%)
11	0/54 (0 %)	4/191(2.1%)	0/45(0%)	3/191(1.6%)
10	0/54 (0 %)	4/191(2.1%)	0/45(0%)	3/191(1.6%)
9	0/54 (0 %)	4/191(2.1%)	0/45(0%)	3/191(1.6%)
8	0/54 (0 %)	4/191(2.1%)	0/45(0%)	4/191(2.1%)
7	0/54 (0 %)	4/191(2.1%)	0/45(0%)	5/191(2.6%)
6	0/54 (0 %)	4/191(2.1%)	0/45(0%)	5/191(2.6%)
5	0/54 (0 %)	4/191(2.1%)	0/45(0%)	5/191(2.6%)
4	0/54 (0 %)	4/191(2.1%)	0/45(0%)	5/191(2.6%)
3	0/54 (0 %)	4/191(2.1%)	0/45(0%)	5/191(2.6%)
2	0/54 (0 %)	4/191(2.1%)	0/45(0%)	4/191(2.1%)
1	0/54 (0 %)	3/191(1.6%)	0/45(0%)	3/191(1.6%)
Basement	0/54 (0 %)	6/315(1.9%)	0/45(0%)	6/315(1.9%)

Table 5.49: Results of analysis of buildings with 20 stories

The Analysis from STA4-CAD	Shear wall	Coupled shear wall	Stiffened coupled shear wall	Tunnel formwork
Concrete (m^3)	7,067.5	7,002.8	7,080.0	9,938.6
Formwork (m^2)	36,741.5	36,577.4	36,579.0	53,180.3
Reinforce (ton)	646.7	643.0	648.0	694.2
Building wall (m^2)	19,701.15	19,701.15	19,701.15	5,985.2
Plaster of all building (m^2)	75,766.8	75,766.8	75,766.8	11,970.4
Cost (TL)	6,796,747.9	6,777,100.7	6,797,859.1	4,618,481.4
X (m)	0.00204	0.00198	0.00197	0.00084
Y (m)	0.00242	0.00240	0.00241	0.00100
Beam damage ratio < 30%	0.0 %	0.0 %	0.0 %	0.0 %
Column damage ratio < 20%	0.5 %	0.5 %	0.4 %	0.0 %
Roof story VC ratio < 40%	0.2 %	0.1 %	0.1 %	0.0 %
Columns including plastic hinge Vc ratio [LS+CP+CC] < 30%	2.6 % LS	2.8 % LS	2.7 % LS	0.8 % LS

5.3.5.5.1 Quantity of Each Case Study

Table 5.30 illustrates the quantity of each case study respectively in Figure 5.67, 5.68, 5.69. It shows that the tunnel system requires a larger amount of concrete, formwork and reinforcement. Also, Figure 5.70 shows the tunnel system requires a small amount in order to build walls and plaster. In addition, Figure 5.71 shows the total cost of the tunnel system is lower; however, the displacement of the case studies with two directions (x, y) in Figure 5.72 shows the tunnel system has the least displacement and seismic performance. Figure 5.73 shows all system satisfy the safety criteria.

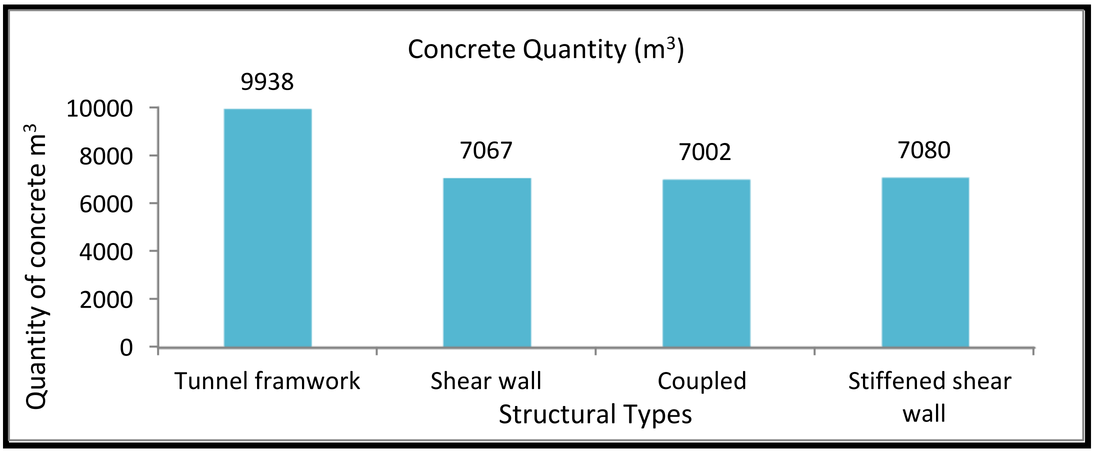

Figure 5.67: Quantity of Concrete in Buildings with Twenty Stories

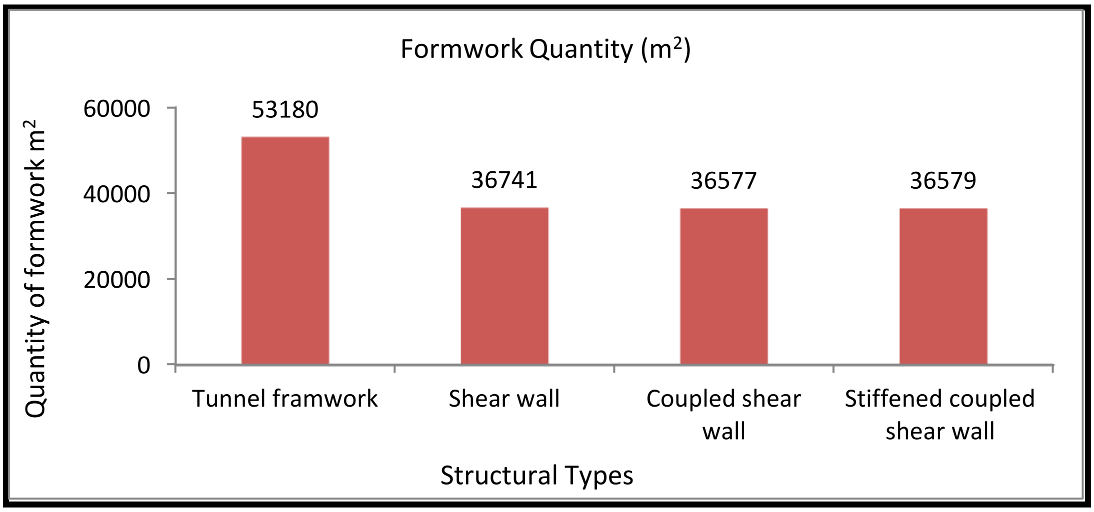

Figure 5.68: Quantity of Formwork in Buildings with Twenty Stories

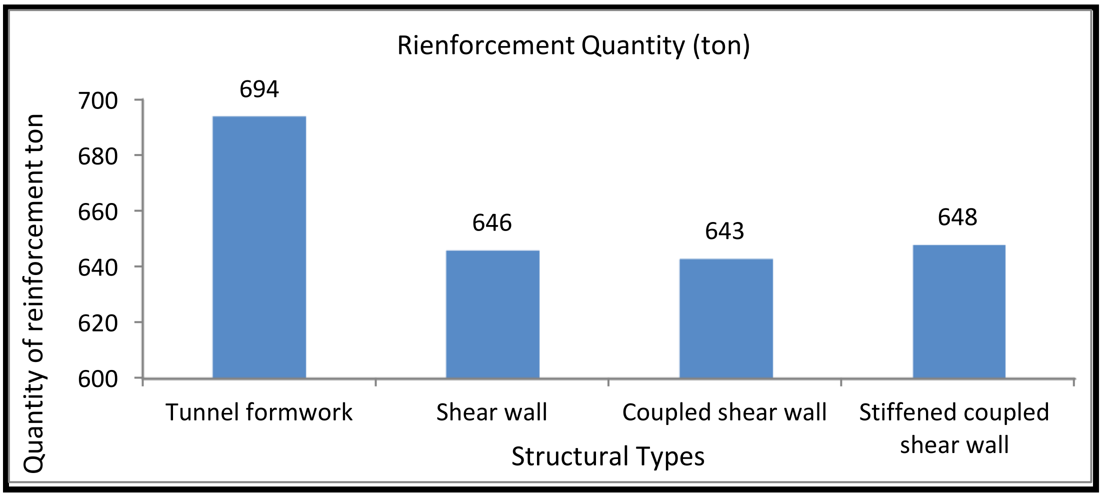

Figure 5.69: Quantity of Reinforcement in Buildings with Twenty Stories

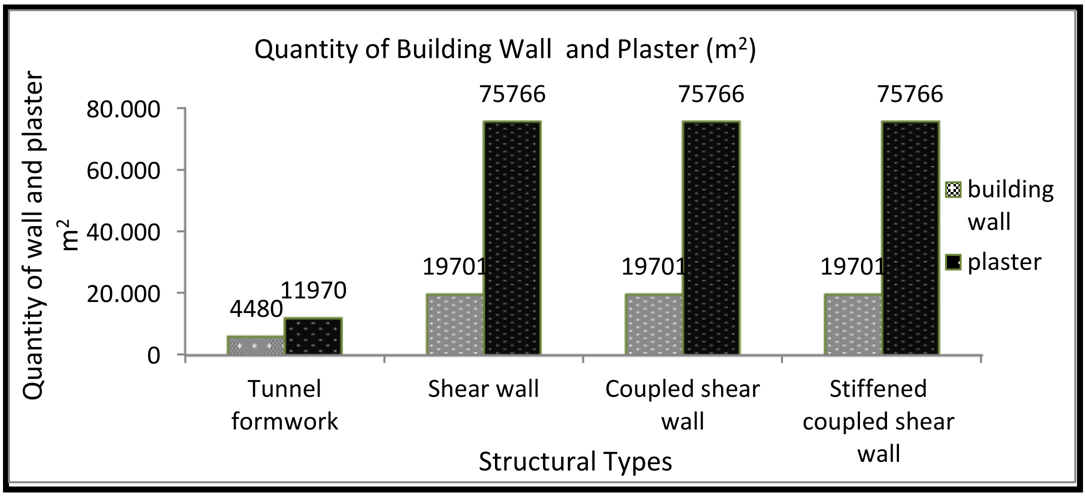

Figure 5.70: Quantity of Building Wall and Plaster in Buildings with Twenty Stories

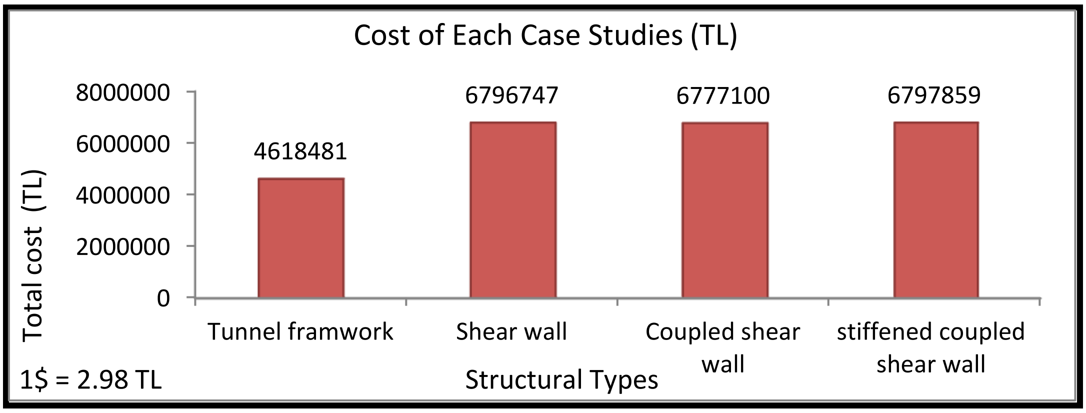

Figure 5.71: Total Costs of the Case Studies in Buildings with Twenty Stories

5.3.5.5.2 Displacement of Case Studies in X and Y Directions

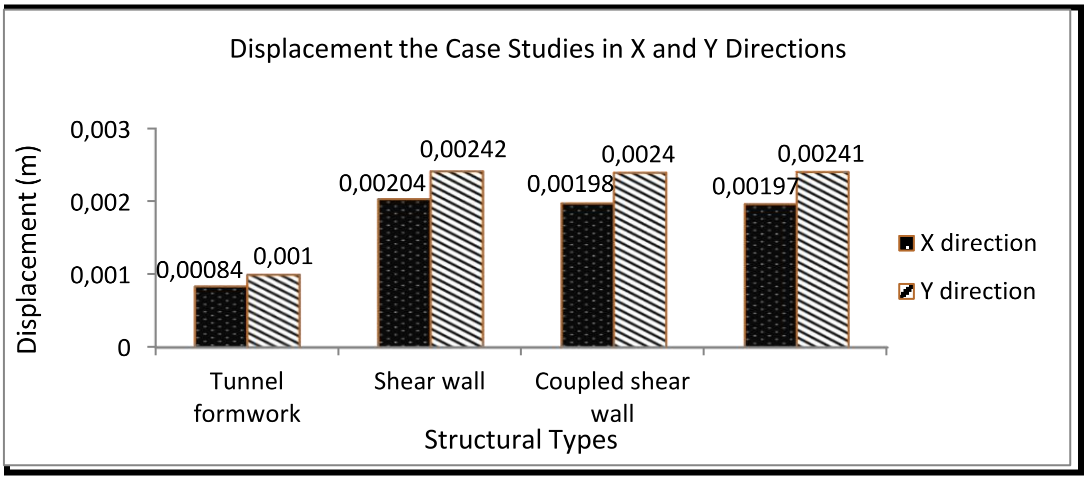

Figure 5.72: Displacement Building of Each Case Study in Buildings, Twenty Stories

5.3.5.5.3 Performance

The chart below Figure 5.73 explains the percentage of the damaged beam, column, roof story and the column including different systems after the analysis of result performance.

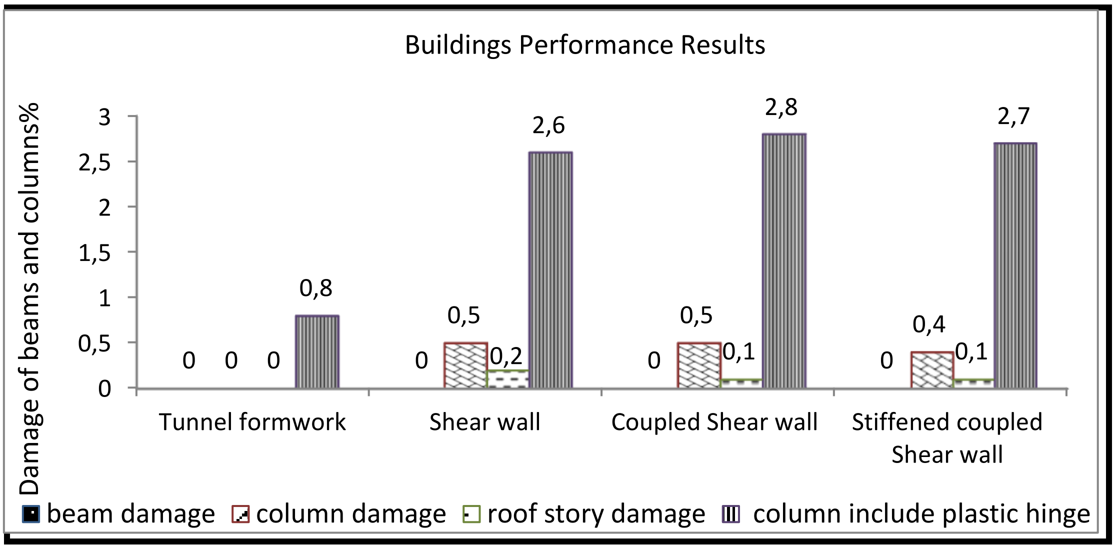

Figure 5.73 Damage of Beams and Columns in Buildings with Twenty Stories.

The seismic performances in Figure 5.73 shows all system are satisfy the safety criteria. From the analysis results the tunnel formwork is cheap cost.

5.3.6 The Sixth Case Study- Twenty Five Story Building with Selected System

In the sixth case it will illustrate the different structure with 25 stories.

In this case there are 4 case studies, with a different system, the flat slab-beam system, exclude these different structure because this system does not use in high rise building.

1. The shear wall system.
2. The coupled shear wall system.
3. The stiffened coupled shear wall system.
4. The tunnel formwork system.

5.3.6.1 Shear Wall System

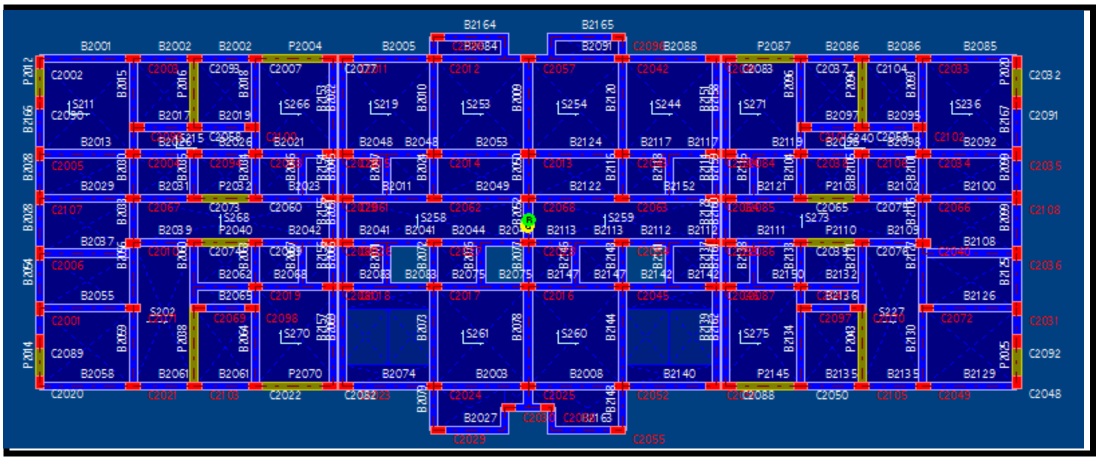

Figure 5.74: Plan of Twenty Five Stories and Shear Wall System

The Figure 5.74 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

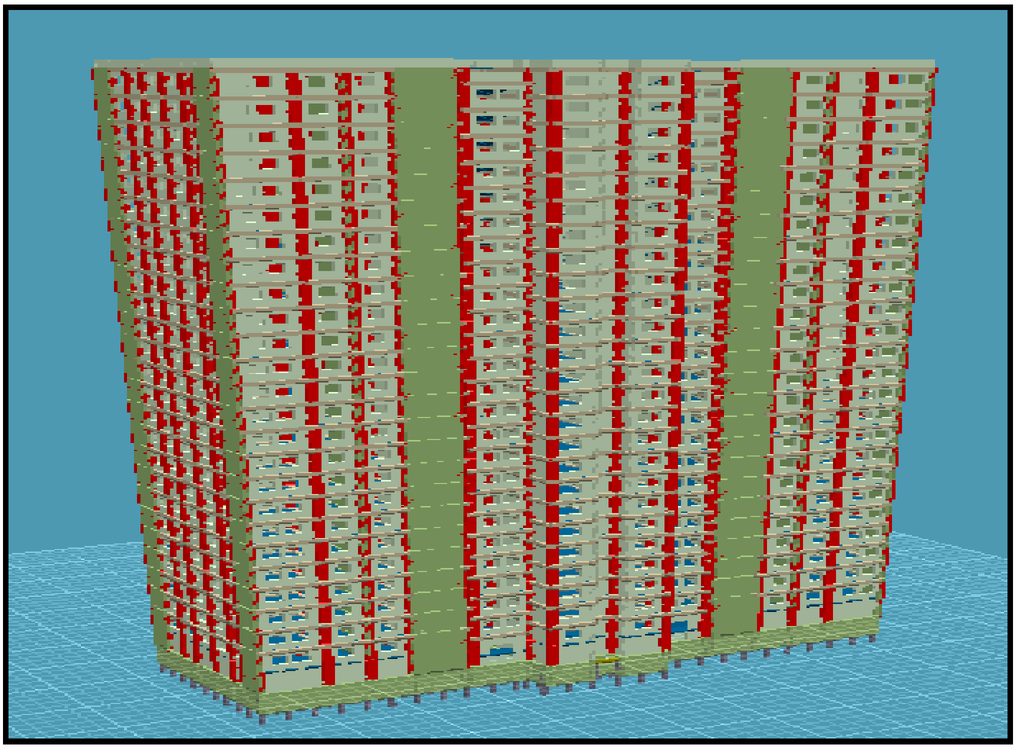

Figure 5.75: The 3D View Twenty Five Stories Shear Wall System

The Figure 5.75 illustrates, the 3D view 25 stories, with shear wall system.

5.3.6.2 Coupled Shear Wall System

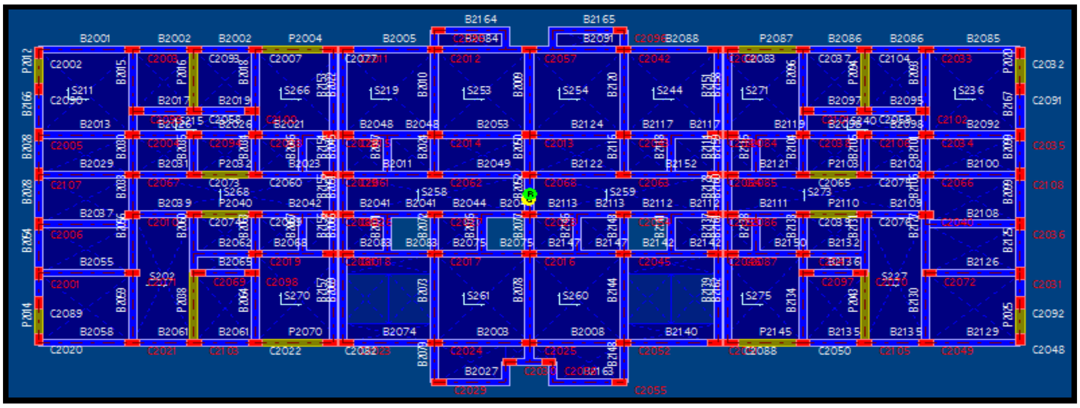

Figure 5.76: Plan Twenty Five Stories the Coupled Shear Wall System

The Figure 5.76 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

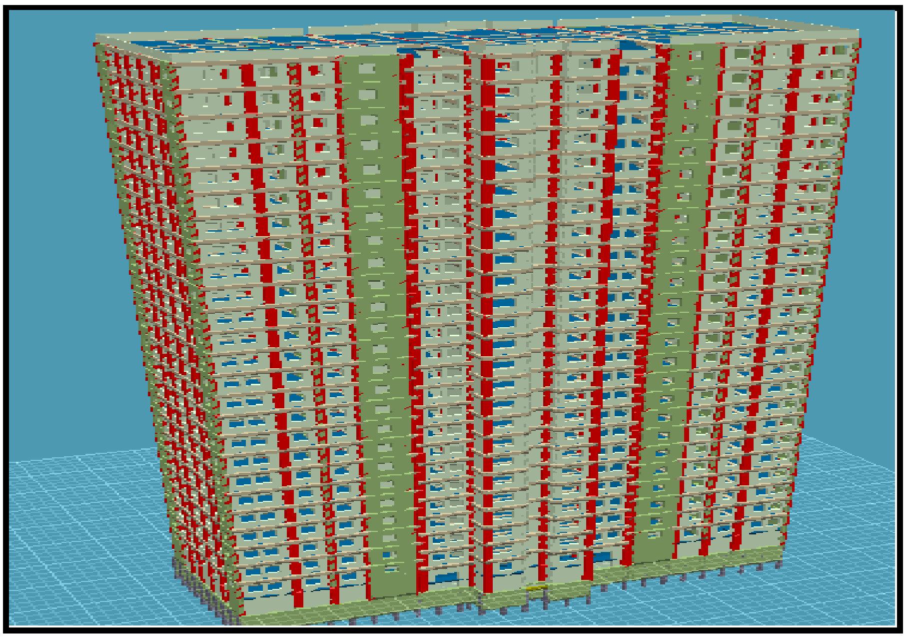

Figure 5.77: The 3D view of a building with Twenty Five Stories and Coupled Shear Wall System

The Figure 5.77 illustrates the 3D view of a building with 25 stories.

5.3.6.3 Stiffened Coupled Shear Wall System with Twenty Five Stories

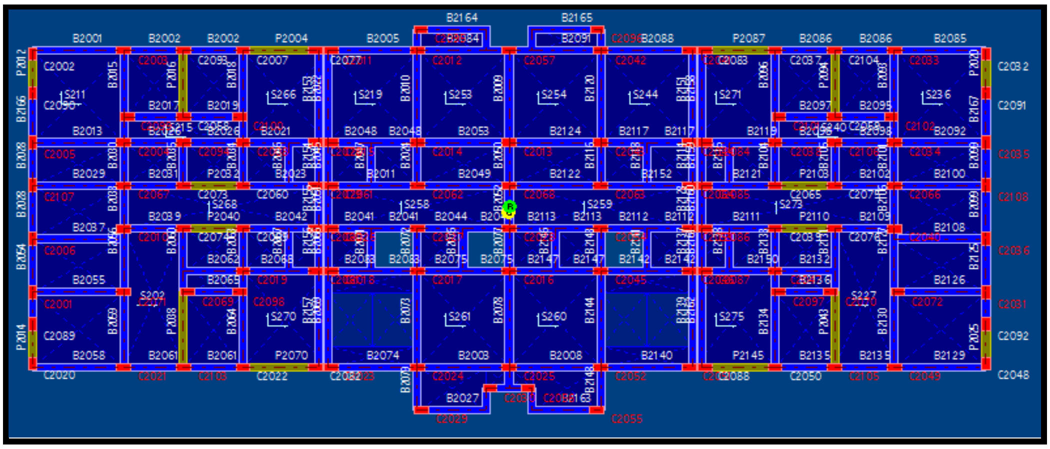

Figure 5.78: Plan of Twenty Five Stories and Stiffened Coupled Shear Wall System

The Figure 5.78 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

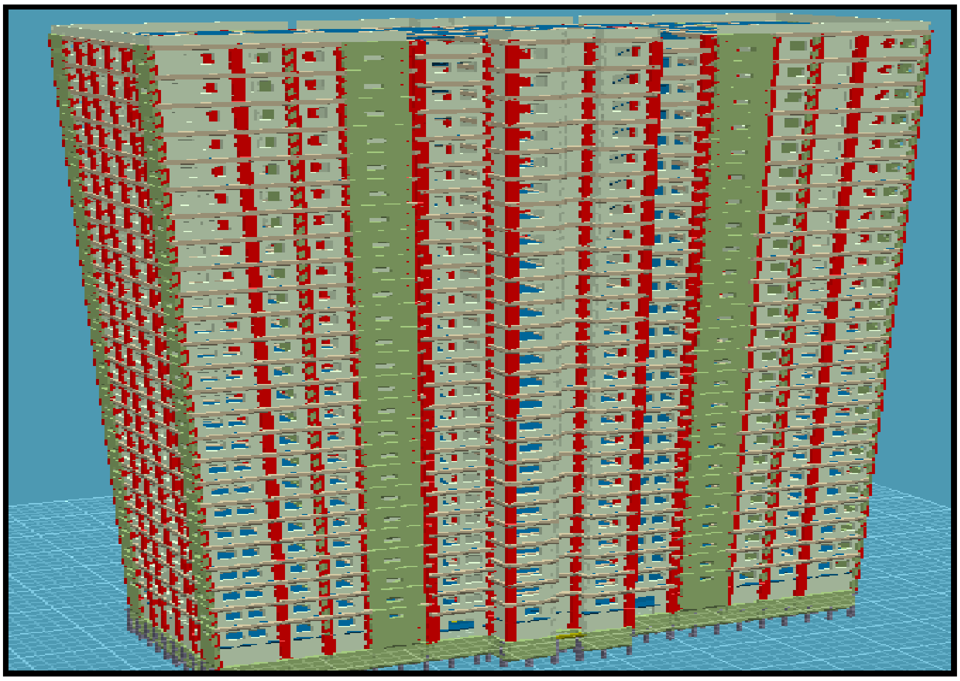

Figure 5.79: The 3D View of Twenty Five Stories and Stiffened Coupled Shear Wall

The Figure 5.79 illustrates the 3D view of a building with 25 stories.

5.3.6.4 Tunnel Formwork System

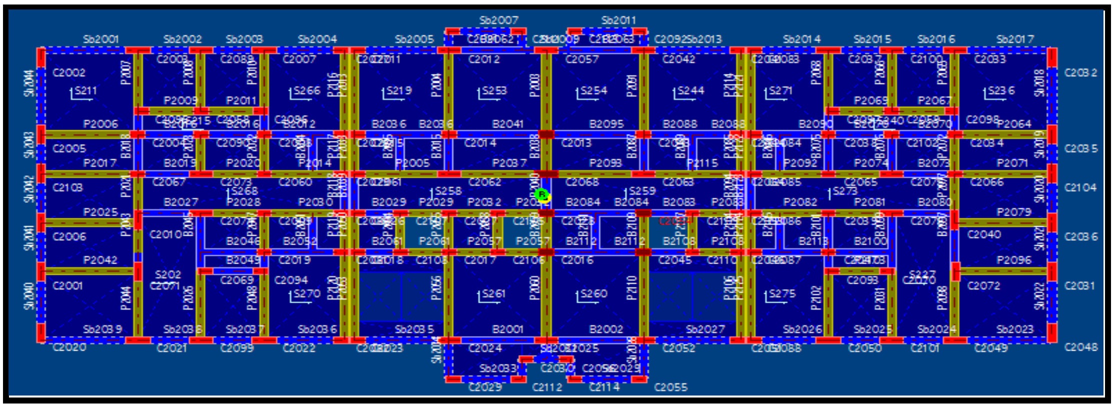

Figure 5.80: Plan of Twenty Five Stories and Tunnel Formwork System

The Figure 5.80 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

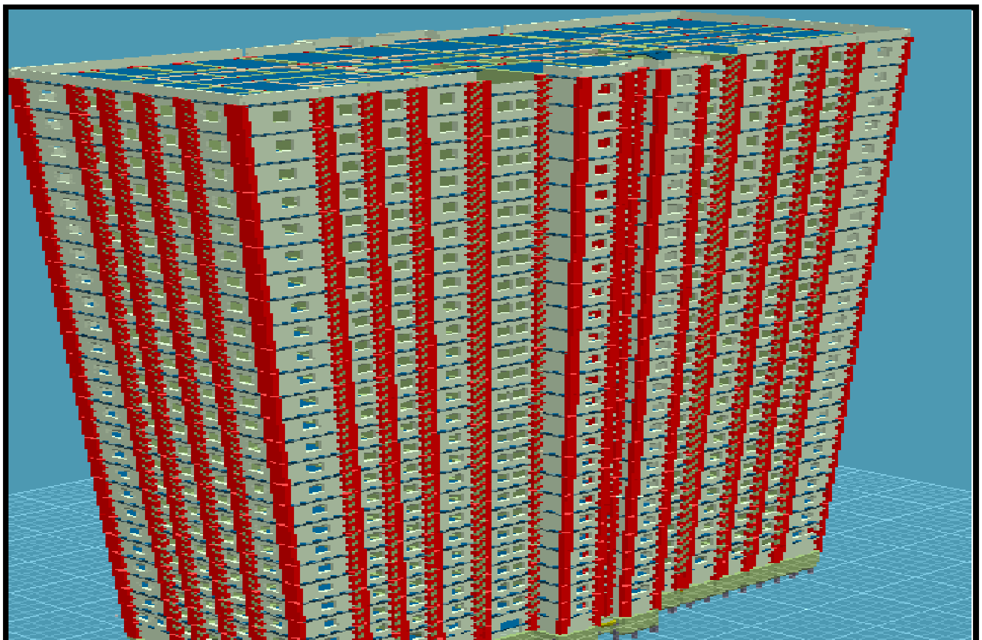

Figure 5.81: The 3D View of Twenty Five Stories and Tunnel Formwork System

The Figure 5.81 illustrates the 3D view of a building with 25 stories.

5.3.6.5 Results of Analysis the Sixth Case Study with Twenty Five Stories

It decides the capacity ratio of the plastic hinge of the columns for the best system by comparing the capacity ratio of the plastic hinge of the columns of other systems. Therefore, the number of damaged columns on each story and the total number of columns on that story are shown in Tables 5.54, 5.55, 5.56, 5.34, and 5.57. The plastic hinge ratio is 0.9 for the tunnel formwork. Also, the observed ratio for shear wall, coupled shear wall and stiffened coupled shear wall are 1.8, 1.9 and 1.7 respectively. Hence, the number of damaged columns is 251 columns and the total number of columns to be damaged in seismic regions for the tunnel formwork is 10,388. In addition, the observed number of damaged columns for shear wall, coupled shear wall and stiffened coupled shear wall are 279, 270, 260 respectively. The total number of columns is 6,856, as shown in Appendix D. Therefore, it is assumed that the analytical studies are performed under seismic excitation loading. The result of analysis all case studies is shown in Table 5.58.

Table 5.50: Shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.6<=%20 ✓),(CC=%0.4 ✓)
Roof Story Vc ratio=(CP=%0.1<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%1.8<=%30 ✓,(CC=%0 ✓)
```

Table 5.51: Coupled shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.5<=%20 ✓),(CC=%0.3 ✓)
Roof Story Vc ratio=(CP=%0.2<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%1.9<=%30 ✓,(CC=%0 ✓)
```

Table 5.52: Stiffened coupled shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.3<=%20 ✓),(CC=%0.2 ✓)
Roof Story Vc ratio=(CP=%0.1<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%1.7<=%30 ✓,(CC=%0 ✓)
```

Table 5.53: Tunnel formwork system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.0<=%20 ✓),(CC=%0 ✓)
Roof Story Vc ratio=(CP=%0.0<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%0.9<=%30 ✓,(CC=%0 ✓)
```

Table 5.54: Shear wall of buildings with 25 stories

Percentage of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
25	0/73(0%)	1/132(0%)	0/80(0%)	2/132(1.6%)
24	0/73(0%)	0/124(0%)	0/80(0%)	1/124(0.8%)
23	0/73(0%)	0/124(0%)	0/80(0%)	1/124(0.8%)
22	0/73(0%)	0/124(0%)	0/80(0%)	1/124(0.8%)
21	0/73(0%)	0/124(0%)	0/80(0%)	0/124(0%)
20	0/73(0%)	1/124(0.8%)	0/80(0%)	0/124(0%)
19	0/73(0%)	2/124(1.6%)	0/80(0%)	2/124(1.6%)
18	0/73(0%)	3/124(2.4%)	0/80(0%)	2/124(1.6%)
17	0/73(0%)	3/124(2.4%)	0/80(0%)	2/124(1.6%)
16	0/73(0%)	4/124(3.2%)	0/80(0%)	3/124(2.4%)
15	0/73(0%)	4/124(3.2%)	0/80(0%)	4/124(3.2%)
14	0/73(0%)	4/124(3.2%)	0/80(0%)	4/124(3.2%)
13	0/73(0%)	5/124(4.0%)	0/80(0%)	4/124(3.2%)
12	0/73(0%)	7/124(5.6%)	0/80(0%)	4/124(3.2%)
11	0/73(0%)	8/124(6.5%)	0/80(0%)	4/124(3.2%)
10	0/73(0%)	8/124(6.5%)	0/80(0%)	5/124(4.0%)
9	0/73(0%)	8/124(6.5%)	0/80(0%)	6/124(4.5%)
8	0/73(0%)	7/124(5.6%)	0/80(0%)	8/124(6.5%)
7	0/73(0%)	7/124(5.6%)	0/80(0%)	8/124(6.5%)
6	0/73(0%)	6/124(4.8%)	0/80(0%)	10/124(8.1%)
5	0/73(0%)	8/124(6.5%)	0/80(0%)	10/124(8.1%)
4	0/73(0%)	8/124(6.5%)	0/80(0%)	11/124(8.9%)
3	0/73(0%)	7/124(5.6%)	0/80(0%)	10/124(8.1%)
2	0/73(0%)	2/124(1.6%)	0/80(0%)	9/124(7.3%)
1	0/73(0%)	5/132(3.8%)	0/80(0%)	8/132(6.5%)
Basement	0/73(0%)	0/312 (0%)	0/80(0%)	2/312 (0.6%)

Table 5.55: Coupled shear wall in buildings with 25 stories

Percentage of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
25	0/73(0%)	1/132(0%)	0/80(0%)	2/132(1.6%)
24	0/73(0%)	0/124(0%)	0/80(0%)	1/124(0.8%)
23	0/73(0%)	0/124(0%)	0/80(0%)	1/124(0.8%)
22	0/73(0%)	0/124(0%)	0/80(0%)	1/124(0.8%)
21	0/73(0%)	0/124(0%)	0/80(0%)	0/124(0%)
20	0/73(0%)	1/124(0.8%)	0/80(0%)	0/124(0%)
19	0/73(0%)	2/124(1.6%)	0/80(0%)	2/124(1.6%)
18	0/73(0%)	3/124(2.4%)	0/80(0%)	2/124(1.6%)
17	0/73(0%)	3/124(2.4%)	0/80(0%)	2/124(1.6%)
16	0/73(0%)	4/124(3.2%)	0/80(0%)	3/124(2.4%)
15	0/73(0%)	4/124(3.2%)	0/80(0%)	4/124(3.2%)
14	0/73(0%)	4/124(3.2%)	0/80(0%)	4/124(3.2%)
13	0/73(0%)	5/124(4.0%)	0/80(0%)	4/124(3.2%)
12	0/73(0%)	7/124(5.6%)	0/80(0%)	4/124(3.2%)
11	0/73(0%)	8/124(6.5%)	0/80(0%)	4/124(3.2%)
10	0/73(0%)	8/124(6.5%)	0/80(0%)	5/124(4.0%)
9	0/73(0%)	8/124(6.5%)	0/80(0%)	6/124(4.5%)
8	0/73(0%)	7/124(5.6%)	0/80(0%)	8/124(6.5%)
7	0/73(0%)	7/124(5.6%)	0/80(0%)	8/124(6.5%)
6	0/73(0%)	6/124(4.8%)	0/80(0%)	10/124(8.1%)
5	0/73(0%)	8/124(6.5%)	0/80(0%)	10/124(8.1%)
4	0/73(0%)	8/124(6.5%)	0/80(0%)	11/124(8.9%)
3	0/73(0%)	7/124(5.6%)	0/80(0%)	10/124(8.1%)
2	0/73(0%)	2/124(1.6%)	0/80(0%)	9/124(7.3%)
1	0/73(0%)	5/132(3.8%)	0/80(0%)	8/132(6.5%)
Basement	0/73(0%)	0/312 (0%)	0/80(0%)	2/312 (0.6%)

Table 5.56: Stiffened coupled Shear wall in buildings with 25 stories

Percentage of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
25	0/73(0%)	1/132(0%)	0/80(0%)	2/132(1.6%)
24	0/73(0%)	0/124(0%)	0/80(0%)	1/124(0.8%)
23	0/73(0%)	0/124(0%)	0/80(0%)	1/124(0.8%)
22	0/73(0%)	0/124(0%)	0/80(0%)	1/124(0.8%)
21	0/73(0%)	0/124(0%)	0/80(0%)	0/124(0%)
20	0/73(0%)	1/124(0.8%)	0/80(0%)	0/124(0%)
19	0/73(0%)	2/124(1.6%)	0/80(0%)	2/124(1.6%)
18	0/73(0%)	3/124(2.4%)	0/80(0%)	2/124(1.6%)
17	0/73(0%)	3/124(2.4%)	0/80(0%)	2/124(1.6%)
16	0/73(0%)	4/124(3.2%)	0/80(0%)	3/124(2.4%)
15	0/73(0%)	4/124(3.2%)	0/80(0%)	4/124(3.2%)
14	0/73(0%)	4/124(3.2%)	0/80(0%)	4/124(3.2%)
13	0/73(0%)	5/124(4.0%)	0/80(0%)	4/124(3.2%)
12	0/73(0%)	7/124(5.6%)	0/80(0%)	4/124(3.2%)
11	0/73(0%)	8/124(6.5%)	0/80(0%)	4/124(3.2%)
10	0/73(0%)	8/124(6.5%)	0/80(0%)	5/124(4.0%)
9	0/73(0%)	8/124(6.5%)	0/80(0%)	6/124(4.5%)
8	0/73(0%)	7/124(5.6%)	0/80(0%)	8/124(6.5%)
7	0/73(0%)	7/124(5.6%)	0/80(0%)	8/124(6.5%)
6	0/73(0%)	6/124(4.8%)	0/80(0%)	10/124(8.1%)
5	0/73(0%)	8/124(6.5%)	0/80(0%)	10/124(8.1%)
4	0/73(0%)	8/124(6.5%)	0/80(0%)	11/124(8.9%)
3	0/73(0%)	7/124(5.6%)	0/80(0%)	10/124(8.1%)
2	0/73(0%)	2/124(1.6%)	0/80(0%)	9/124(7.3%)
1	0/73(0%)	5/132(3.8%)	0/80(0%)	8/132(6.5%)
Basement	0/73(0%)	0/312 (0%)	0/80(0%)	2/312 (0.6%)

Table 5.57: Tunnel formwork in buildings with 25 stories

Percentage of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
25	0/54(0%)	0/195(0%)	0/42(0%)	0/195(0%)
24	0/54(0%)	1/195(0.5%)	0/42(0%)	0/195(0%)
23	0/54(0%)	1/195(0.5%)	0/42(0%)	0/195(0%)
22	0/54(0%)	1/195(0.5%)	0/42(0%)	0/195(0%)
21	0/54(0%)	2/195(1.0%)	0/42(0%)	0/195(0%)
20	0/54(0%)	3/195(1.5%)	0/42(0%)	1/195(0.5%)
19	0/54(0%)	3/195(1.5%)	0/42(0%)	2/195(1.0%)
18	0/54(0%)	3/195(1.5%)	0/42(0%)	3/195(1.5%)
17	0/54(0%)	3/195(1.5%)	0/42(0%)	3/195(1.5%)
16	0/54(0%)	3/195(1.5%)	0/42(0%)	3/195(1.5%)
15	0/54(0%)	3/195(1.5%)	0/42(0%)	3/195(1.5%)
14	0/54(0%)	5/195(2.6%)	0/42(0%)	3/195(1.5%)
13	0/54(0%)	6/195(3.1%)	0/42(0%)	3/195(1.5%)
12	0/54(0%)	6/195(3.1%)	0/42(0%)	5/195(2.6%)
11	0/54(0%)	6/195(3.1%)	0/42(0%)	6/195(3.1%)
10	0/54(0%)	7/195(3.6%)	0/42(0%)	6/195(3.1%)
9	0/54(0%)	7/195(3.6%)	0/42(0%)	6/195(3.1%)
8	0/54(0%)	7/195(3.6%)	0/42(0%)	7/195(3.6%)
7	0/54(0%)	7/195(3.6%)	0/42(0%)	7/195(3.6%)
6	0/54(0%)	7/195(3.6%)	0/42(0%)	7/195(3.6%)
5	0/54(0%)	8/195(4.1%)	0/42(0%)	7/195(3.6%)
4	0/54(0%)	7/195(3.6%)	0/42(0%)	7/195(3.6%)
3	0/54(0%)	7/195(3.6%)	0/42(0%)	8/195(4.1%)
2	0/54(0%)	6/195(3.1%)	0/42(0%)	7/195(3.6%)
1	0/54(0%)	5/195(2.6%)	0/42(0%)	6/195(3.1%)
Basement	0/54(0%)	0/315 (0%)	0/42(0%)	0/315(0%)

Table 5.58: Results of analysis of buildings with 25 stories

The Analysis from STA4-CAD	Shear wall	Coupled shear wall	Stiffened coupled shear wall	Tunnel formwork
Concrete (m^3)	9,134.6	9,119.0	9,140.0	13,266.8
Formwork (m^2)	45,508	45,444.0	45,488.5	64,886.0
Reinforce (ton)	902.7	887.0	926.0	950.1
Building Wall (m^2)	24,391.9	24,391.9	24,391.9	7,280
Plaster of all building (m^2)	88,896.0	88,896.0	88,896.0	14,560.0
Cost (TL)	8,513,122.7	8,477,834.0	8,560,771.5	5,997,654.6
X (m)	0.00219	0.00217	0.00216	0.00102
Y (m)	0.00223	0.00232	0.00227	0.00113
Beam damage ratio < 30%	0.0 %	0.0 %	0.0 %	0.0 %
Column damage ratio < 20%	0.6 %	0.5 %	0.3 %	0.0 %
Roof story VC ratio < 40%	0.1 %	0.2 %	0.1 %	0.0 %
Columns including plastic hinge Vc ratio [LS+CP+CC] < 30%	1.8 % LS	1.9 % LS	1.7 % LS	0.9 % LS

5.3.6.5.1 Quantity of Each Case Study

Table 5.31 illustrates the quantity of each case study respectively in Figure 5.82, 5.83, 5.84. It shows that the tunnel system requires a larger amount of concrete, formwork and reinforcement. Also, Figure 5.85 shows the tunnel system requires a small amount in order to build walls and plaster. Moreover, Figure 5.86 shows the total cost of the tunnel system is lower. However, the displacement of the case studies with two directions (x, y) in Figure 5.87 shows the tunnel system has the least displacement and seismic performance. Figure 5.88 shows all systems satisfy the safety criteria.

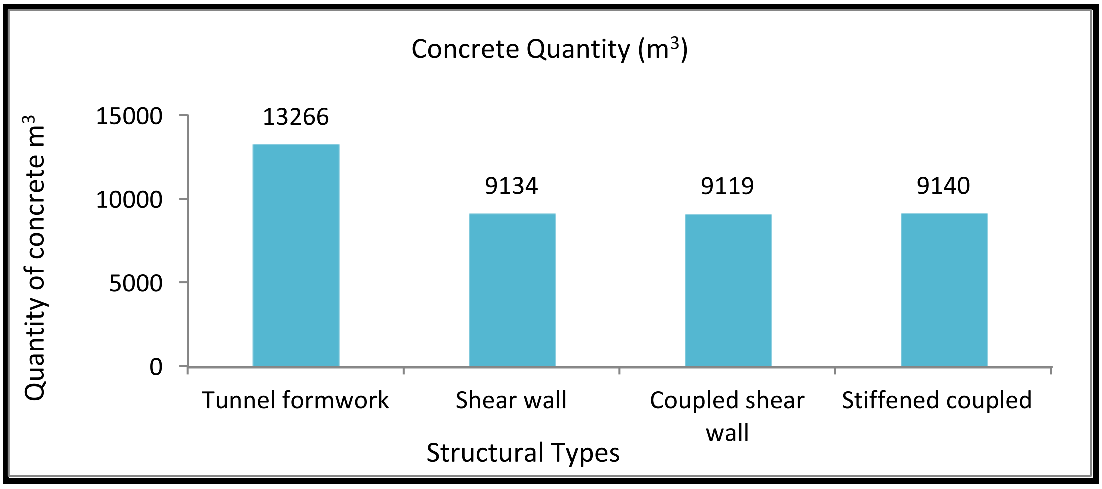

Figure 5.82: Quantity of the Concrete in Buildings with Twenty Five Stories

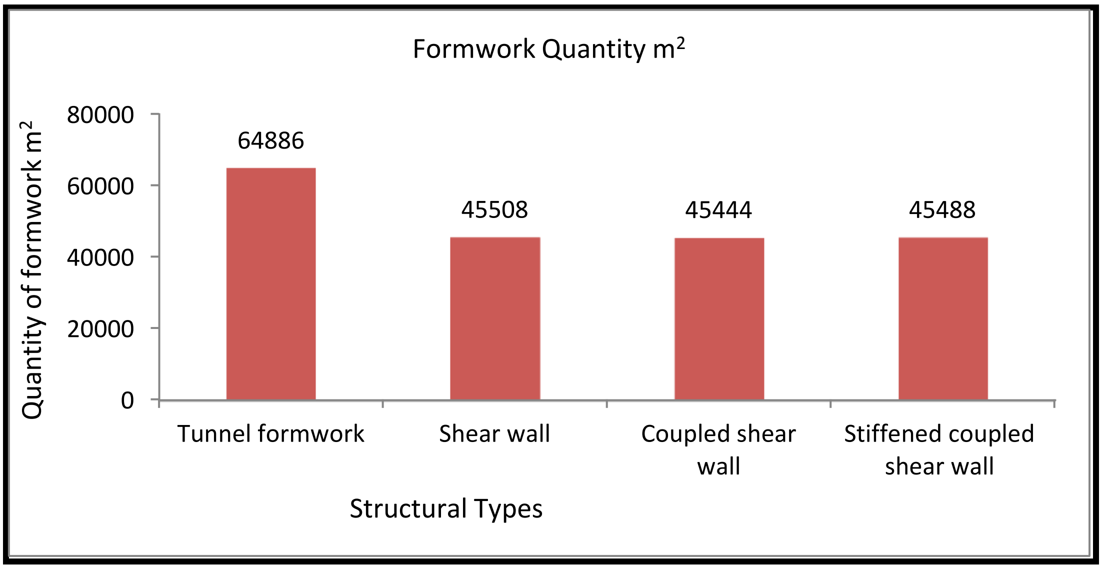

Figure 5.83: Quantity of the Formwork in Buildings with Twenty Five Stories

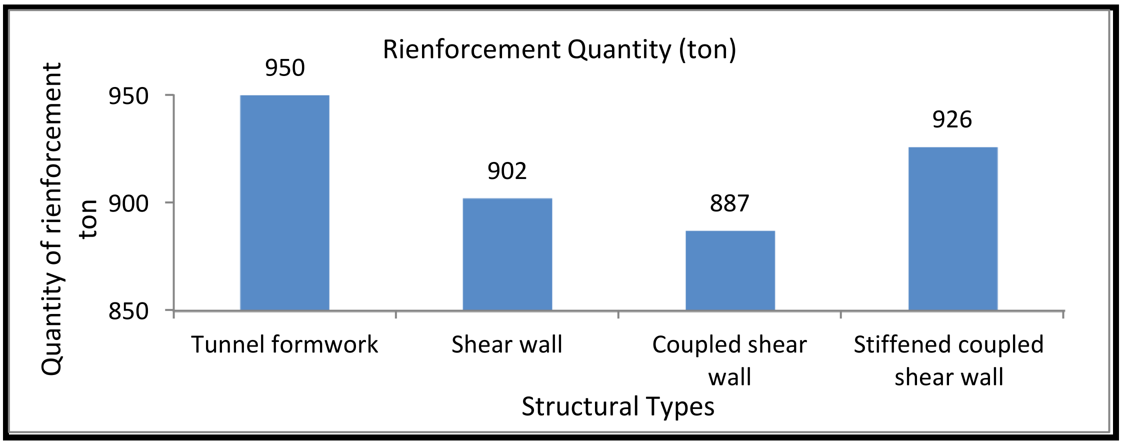

Figure 5.84: Quantity of the Reinforcement in Buildings with Twenty Five Stories

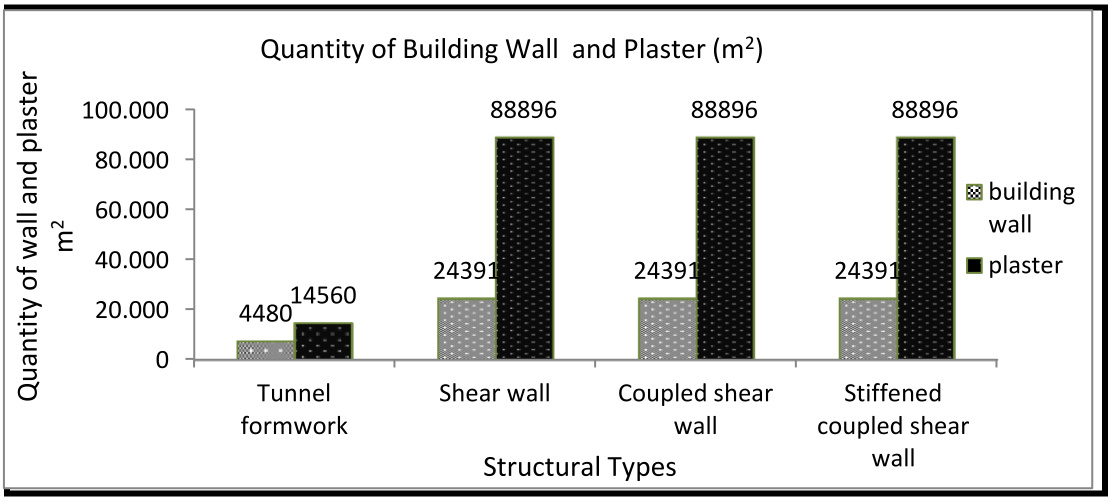

Figure 5.85: Quantity of the Building Wall and Plaster in Buildings,Twenty Five

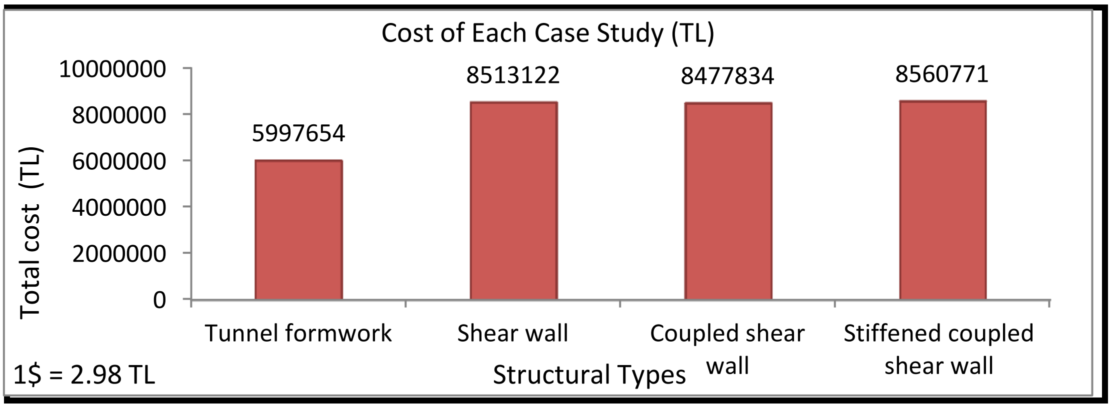

Figure 5.86: Costs of Each Case Study in Buildings with Twenty Five Stories

5.3.6.5.2 Displacement of Each Case Study in X and Y Directions

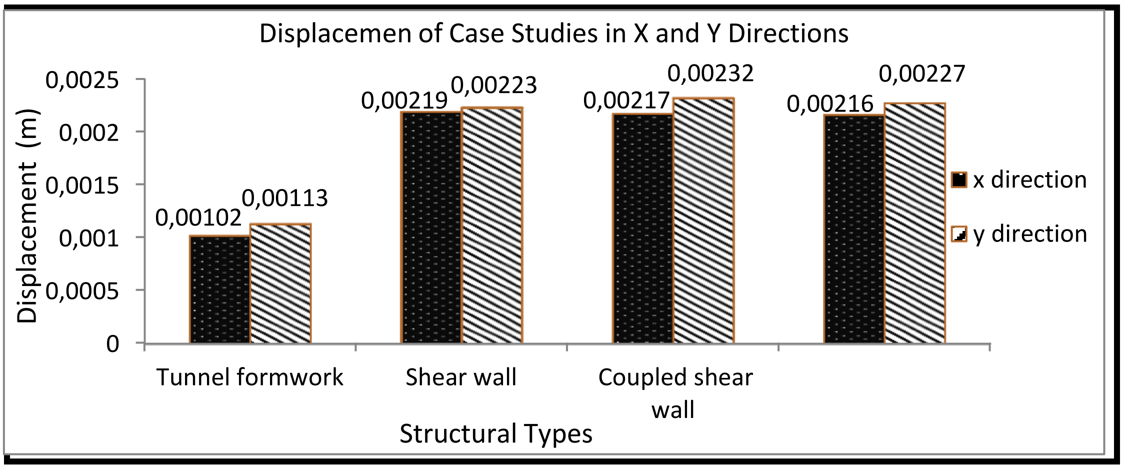

Figure 5.87: Displacement of Each Case Study in Buildings, Twenty Five Stories

5.3.6.5.3 Performance

The chart below Figure 5.88 explains the percentage of the damaged beam, column, roof story and the column including different systems after analysis of results.

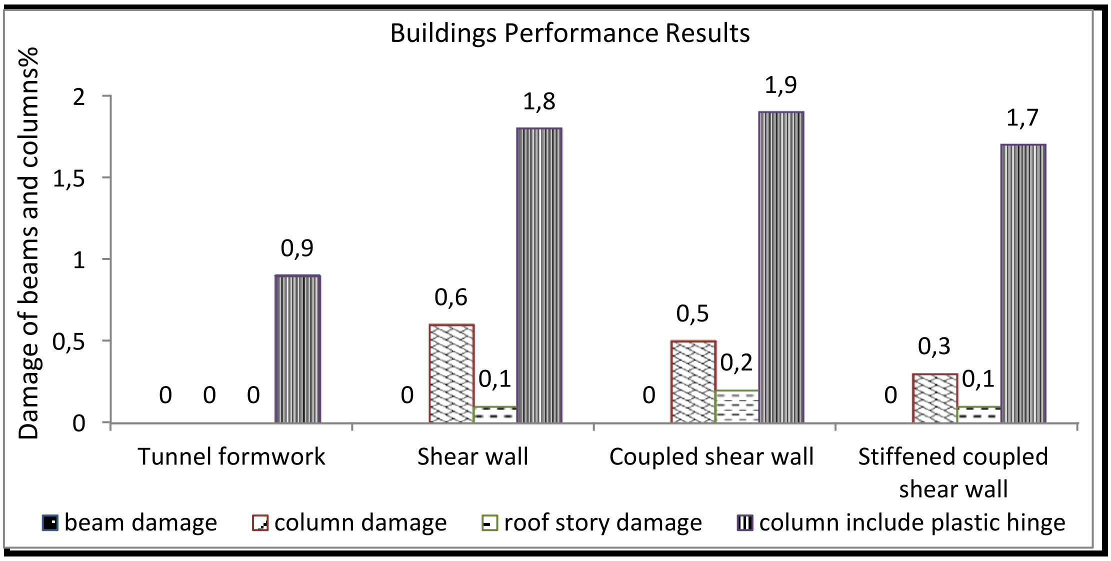

Figure 5.88: Damage of Beams and Columns in Buildings with Twenty Five Stories.

The seismic performance in Figure 5.88 shows all system satisfy the safety criteria. The tunnel formwork system is cheap.

5.3.7The Seventh Case Study-Twenty Eight Story Building with Selected System

The seventh and final case illustrates a different system with 28 stories

In this case, there are 4 case studies with different systems. The flat slab-beam system is excluded from these different structures because this system is not used in high rise buildings.

1. The shear wall system.
2. The coupled shear wall system.
3. The stiffened coupled shear wall system
4. The tunnel formwork system.

5.3.7.1 Shear Wall System

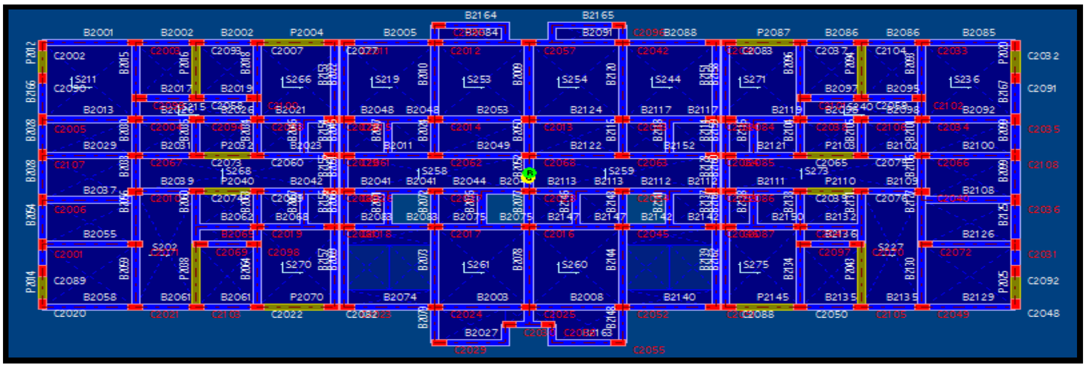

Figure 5.89: Plan of Twenty Eight Stories and Shear Wall System

The Figure 5.89 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

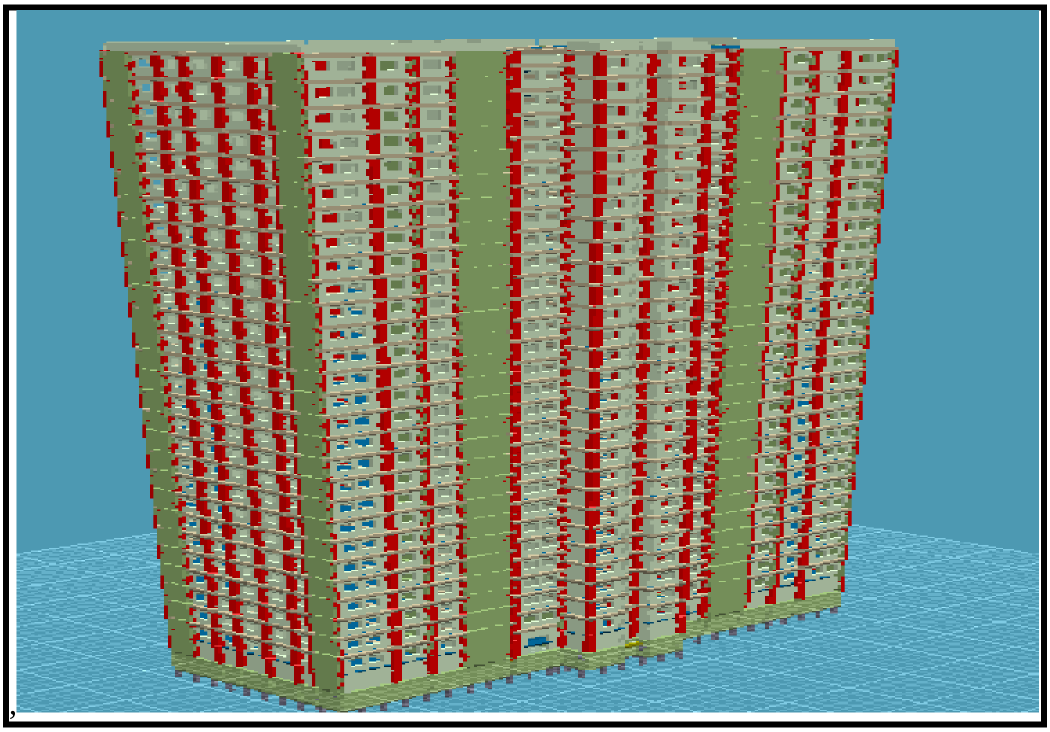

Figure 5.90: The 3D View of Twenty Eight Stories and Shear Wall System

The Figure 5.90 illustrates the 3D view of a building with 28 stories.

5.3.7.2 Coupled Shear Wall System

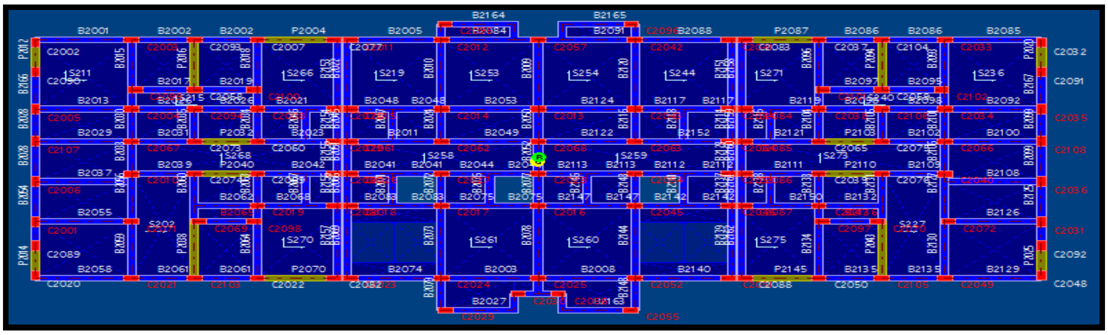

Figure 5.91: Plan of Twenty Eight Stories and Coupled Shear Wall System

The Figure 5.91 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the direction of the earthquake is rotating the building.

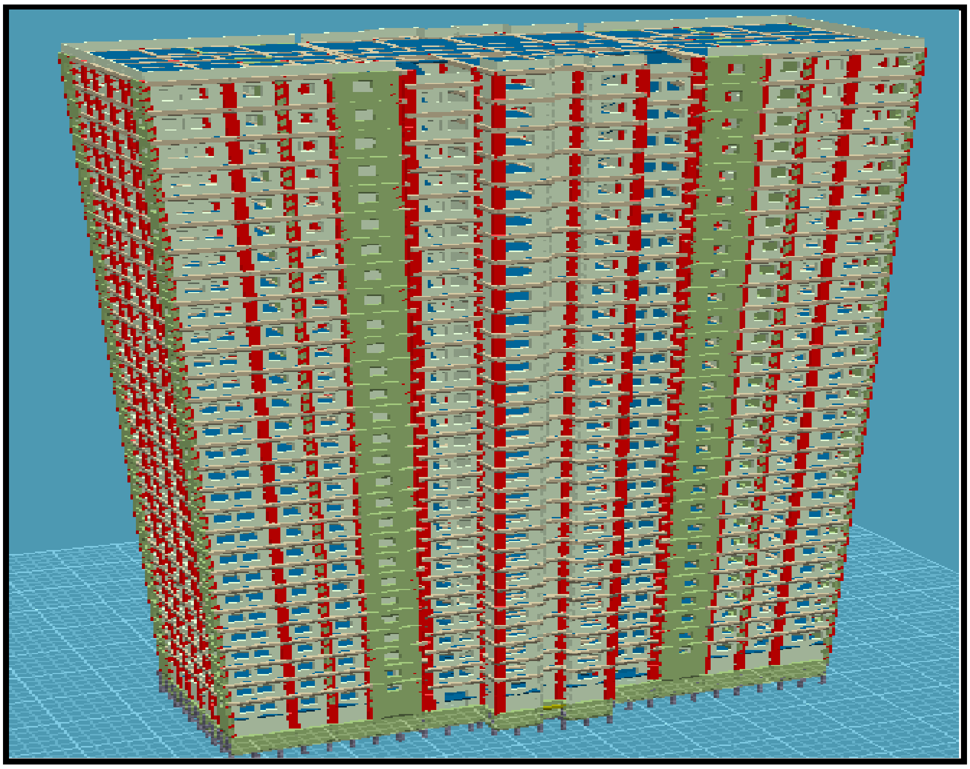

Figure 5.92: The 3D View of Twenty Eight Stories and Coupled Shear Wall System

Figure 5.92 illustrates the 3D view of a building with 28 stories.

5.3.7.3 Stiffened Coupled Shear Wall System

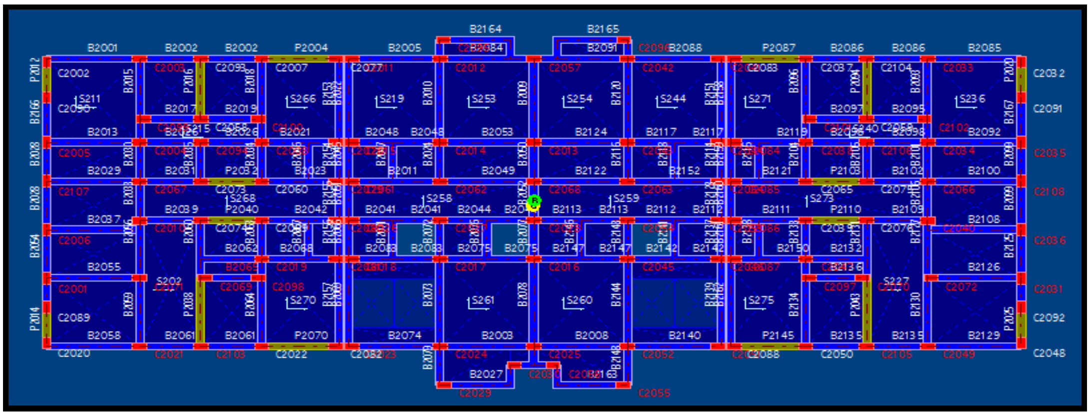

Figure 5.93: Plan of Twenty Eight Stories and Stiffened Coupled Shear Wall System

The Figure 5.93 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

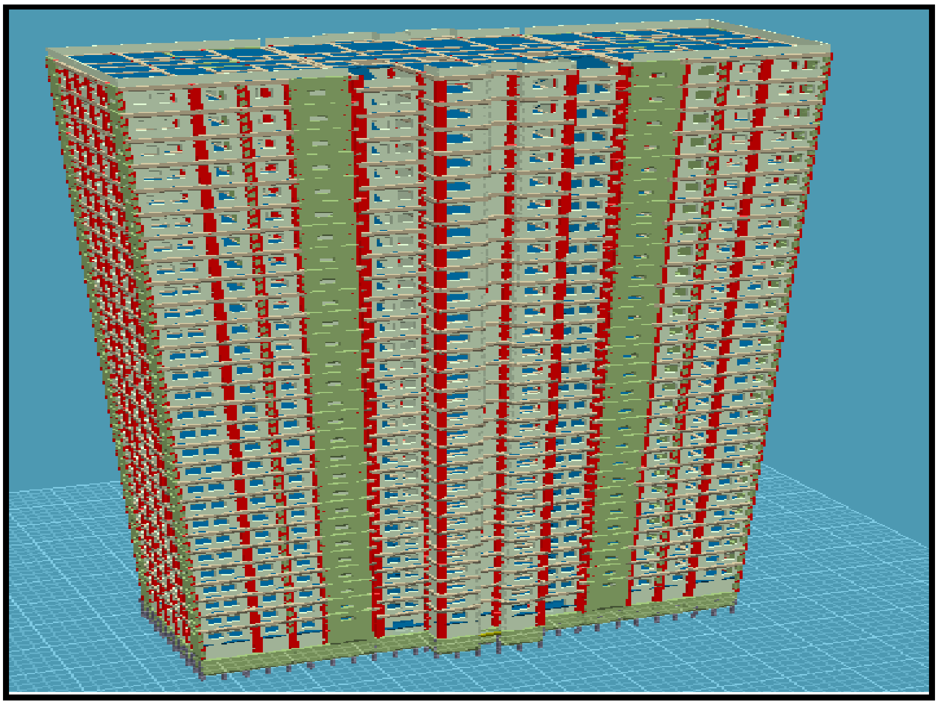

Figure 5.94: The 3D View of Twenty Eight Stories and Stiffened Coupled Shear Wall

The Figure 5.94 illustrates the 3D view of a building with 28 stories.

5.3.7.4 Tunnel Formwork System

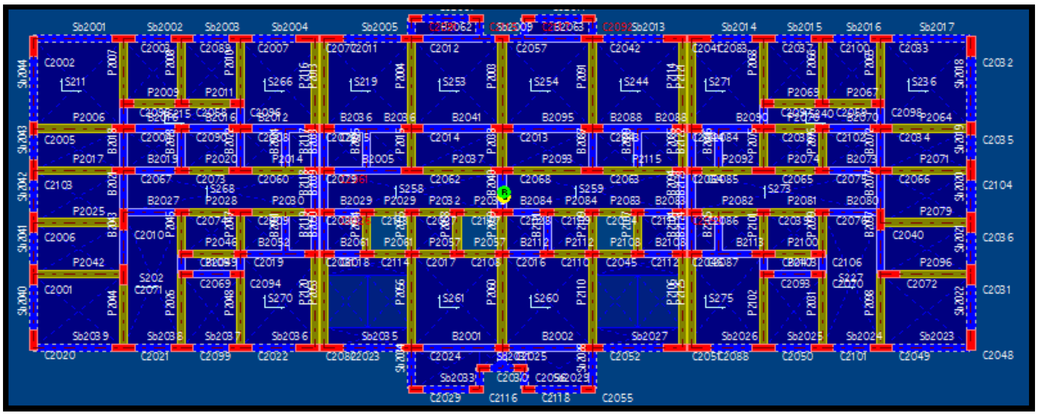

Figure 5.95: Plan of Twenty Eight Stories and Tunnel Formwork System

The Figure 5.95 illustrates the plan of the case study. The mass center connects to other point with small displacement from the building center, when the earthquake is rotating the building.

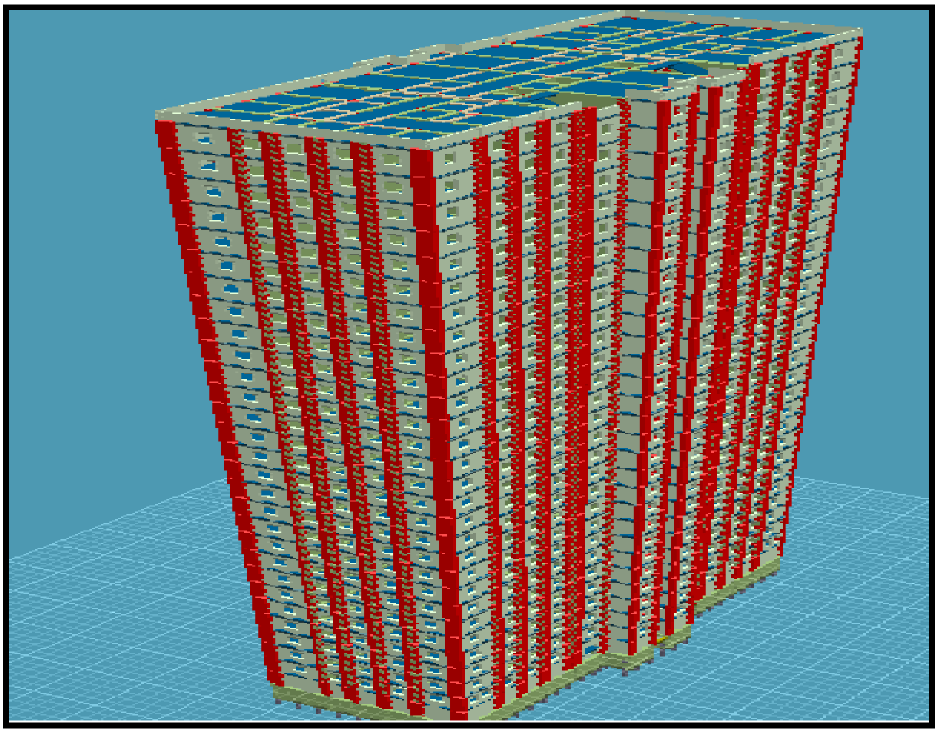

Figure 5.96: The 3D View of Twenty Eight Stories and Tunnel Formwork System

The Figure 5.96 illustrates the 3D view of a building with 28 stories.

5.3.7.5 Results of Analysis the Seventh Case Study with Twenty Eight Stories

It decides the capacity ratio of the plastic hinge of the columns for the best system by comparing the capacity ratio of the plastic hinge of the columns of other systems. Therefore, the number of damaged columns on each story and the total number of columns on that story are shown in Tables 5.63, 5.64, 5.65, and 5.66. The plastic hinge ratio is 0.9 for the tunnel formwork. Also, the observed ratio for shear wall, coupled shear wall and stiffened coupled shear wall are 1.8, 1.9 and 1.7 respectively. Hence, the number of damaged columns is 268 columns and the total number of columns to be damaged in seismic regions for the tunnel formwork is 11,558. Furthermore, the observed number of damaged columns for shear wall, coupled shear wall and stiffened coupled shear wall are 308, 318, and 296 respectively. The total number of columns is 7,600 columns, as shown in Appendix D. Therefore, it is assumed that the analytical studies are performed under seismic excitation loading. The result of analysis of all case studies is shown in Table 5.67.

Table 5.59: Shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.5<=%20 ✓),(CC=%0.3 ✓)
Roof Story Vc ratio=(CP=%0.1<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%1.8<=%30 ✓,(CC=%0 ✓)
```

Table 5.60: Coupled shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.6<=%20 ✓),(CC=%0.4 ✓)
Roof Story Vc ratio=(CP=%0.1<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%1.9<=%30 ✓,(CC=%0 ✓)
```

Table 5.61: Stiffened coupled shear wall system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.4<=%20 ✓),(CC=%0.2 ✓)
Roof Story Vc ratio=(CP=%0.1<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%1.7<=%30 ✓,(CC=%0 ✓)
```

Table 5.62: Tunnel formwork system

```
BUILDING PERFORMANCE RESULTS:


Life Safety case, not need Resistance.

Life Safety case, sufficiency check:
Beams Damage Ratio=(CP=%0.0<=%30 ✓),(CC=%0 ✓)
Colums Damage Ratio=(CP=%0.0<=%20 ✓),(CC=%0 ✓)
Roof Story Vc ratio=(CP=%0.0<=%40 ✓),(CC=%0 ✓)
Columns include Plastic Hinge Vc ratio=(LS+CP+CC=%0.9<=%30 ✓,(CC=%0 ✓)
```

Table 5.63: Shear wall in buildings with 28 stories

Percentage of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
28	0/73(0%)	1/124(0.8%)	0/88(0%)	1/124(0.8%)
27	0/73(0%)	0/124(0%)	0/88(0%)	1/124(0.8%)
26	0/73(0%)	0/124(0%)	0/88(0%)	1/124(0.8%)
25	0/73(0%)	0/124(0%)	0/88(0%)	0/124(0%)
24	0/73(0%)	0/124(0%)	0/88(0%)	0/124(0%)
23	0/73(0%)	2/124(1.6%)	0/88(0%)	0/124(0%)
22	0/73(0%)	2/124(1.6%)	0/88(0%)	2/124(1.6%)
21	0/73(0%)	3/124(2.4%)	0/88(0%)	2/124(1.6%)
20	0/73(0%)	4/124(3.2%)	0/88(0%)	2/124(1.6%)
19	0/73(0%)	5/124(4.0%)	0/88(0%)	3/124(2.4%)
18	0/73(0%)	5/124(4.0%)	0/88(0%)	3/124(2.4%)
17	0/73(0%)	5/124(4.0%)	0/88(0%)	4/124(3.2%)
16	0/73(0%)	6/124(4.8%)	0/88(0%)	4/124(3.2%)
15	0/73(0%)	6/124(4.8%)	0/88(0%)	4/124(3.2%)
14	0/73(0%)	7/124(5.6%)	0/88(0%)	4/124(3.2%)
13	0/73(0%)	7/124(5.6%)	0/88(0%)	5/124(4.0%)
12	0/73(0%)	8/124(6.5%)	0/88(0%)	6/124(4.8%)
11	0/73(0%)	9/124(7.3%)	0/88(0%)	6/124(4.8%)
10	0/73(0%)	8/124(6.5%)	0/88(0%)	8/124(6.5%)
9	0/73(0%)	9/124(7.3%)	0/88(0%)	10/124(8.1%)
8	0/73(0%)	8/124(6.5%)	0/88(0%)	10/124(8.1%)
7	0/73(0%)	9/124(7.3%)	0/88(0%)	11/124(8.9%)
6	0/73(0%)	9/124(7.3%)	0/88(0%)	11/124(8.9%)
5	0/73(0%)	9/124(7.3%)	0/88(0%)	10/124(8.1%)
4	0/73(0%)	9/124(7.3%)	0/88(0%)	10/124(8.1%)
3	0/73(0%)	9/124(7.3%)	0/88(0%)	12/124(9.7%)
2	0/73(0%)	3/124(2.4%)	0/88(0%)	10/124(8.1%)
1	0/73(0%)	6/124(4.5%)	0/88(0%)	6/124(4.5%)
Basement	0/73(0%)	0/312(0%)	0/88(0%)	2/312(0.6%)

Table 5.64: Coupled shear wall in buildings with 28 stories

Percentage of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
28	0/73(0%)	1/124(0.8%)	0/88(0%)	1/124(0.8%)
27	0/73(0%)	0/124(0%)	0/88(0%)	1/124(0.8%)
26	0/73(0%)	0/124(0%)	0/88(0%)	1/124(0.8%)
25	0/73(0%)	0/124(0%)	0/88(0%)	0/124(0%)
24	0/73(0%)	0/124(0%)	0/88(0%)	0/124(0%)
23	0/73(0%)	2/124(1.6%)	0/88(0%)	0/124(0%)
22	0/73(0%)	2/124(1.6%)	0/88(0%)	2/124(1.6%)
21	0/73(0%)	3/124(2.4%)	0/88(0%)	2/124(1.6%)
20	0/73(0%)	4/124(3.2%)	0/88(0%)	2/124(1.6%)
19	0/73(0%)	5/124(4.0%)	0/88(0%)	3/124(2.4%)
18	0/73(0%)	5/124(4.0%)	0/88(0%)	3/124(2.4%)
17	0/73(0%)	5/124(4.0%)	0/88(0%)	4/124(3.2%)
16	0/73(0%)	6/124(4.8%)	0/88(0%)	4/124(3.2%)
15	0/73(0%)	6/124(4.8%)	0/88(0%)	4/124(3.2%)
14	0/73(0%)	7/124(5.6%)	0/88(0%)	4/124(3.2%)
13	0/73(0%)	7/124(5.6%)	0/88(0%)	5/124(4.0%)
12	0/73(0%)	8/124(6.5%)	0/88(0%)	6/124(4.8%)
11	0/73(0%)	9/124(7.3%)	0/88(0%)	6/124(4.8%)
10	0/73(0%)	8/124(6.5%)	0/88(0%)	8/124(6.5%)
9	0/73(0%)	9/124(7.3%)	0/88(0%)	10/124(8.1%)
8	0/73(0%)	8/124(6.5%)	0/88(0%)	10/124(8.1%)
7	0/73(0%)	9/124(7.3%)	0/88(0%)	11/124(8.9%)
6	0/73(0%)	9/124(7.3%)	0/88(0%)	11/124(8.9%)
5	0/73(0%)	9/124(7.3%)	0/88(0%)	10/124(8.1%)
4	0/73(0%)	9/124(7.3%)	0/88(0%)	10/124(8.1%)
3	0/73(0%)	9/124(7.3%)	0/88(0%)	12/124(9.7%)
2	0/73(0%)	3/124(2.4%)	0/88(0%)	10/124(8.1%)
1	0/73(0%)	6/124(4.5%)	0/88(0%)	6/124(4.5%)
Basement	0/73(0%)	10/312(3.2%)	0/88(0%)	2/312(0.6%)

Table 5.65: Stiffened coupled shear wall in buildings with 28 stories

Percentage of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
28	0/73(0%)	1/124(0.8%)	0/88(0%)	1/124(0.8%)
27	0/73(0%)	0/124(0%)	0/88(0%)	1/124(0.8%)
26	0/73(0%)	0/124(0%)	0/88(0%)	1/124(0.8%)
25	0/73(0%)	0/124(0%)	0/88(0%)	0/124(0%)
24	0/73(0%)	0/124(0%)	0/88(0%)	0/124(0%)
23	0/73(0%)	2/124(1.6%)	0/88(0%)	0/124(0%)
22	0/73(0%)	2/124(1.6%)	0/88(0%)	2/124(1.6%)
21	0/73(0%)	3/124(2.4%)	0/88(0%)	2/124(1.6%)
20	0/73(0%)	4/124(3.2%)	0/88(0%)	2/124(1.6%)
19	0/73(0%)	5/124(4.0%)	0/88(0%)	3/124(2.4%)
18	0/73(0%)	5/124(4.0%)	0/88(0%)	3/124(2.4%)
17	0/73(0%)	5/124(4.0%)	0/88(0%)	4/124(3.2%)
16	0/73(0%)	6/124(4.8%)	0/88(0%)	4/124(3.2%)
15	0/73(0%)	6/124(4.8%)	0/88(0%)	4/124(3.2%)
14	0/73(0%)	7/124(5.6%)	0/88(0%)	4/124(3.2%)
13	0/73(0%)	7/124(5.6%)	0/88(0%)	5/124(4.0%)
12	0/73(0%)	8/124(6.5%)	0/88(0%)	6/124(4.8%)
11	0/73(0%)	9/124(7.3%)	0/88(0%)	6/124(4.8%)
10	0/73(0%)	8/124(6.5%)	0/88(0%)	8/124(6.5%)
9	0/73(0%)	9/124(7.3%)	0/88(0%)	10/124(8.1%)
8	0/73(0%)	0/124(0%)	0/88(0%)	10/124(8.1%)
7	0/73(0%)	9/124(7.3%)	0/88(0%)	11/124(8.9%)
6	0/73(0%)	9/124(7.3%)	0/88(0%)	11/124(8.9%)
5	0/73(0%)	9/124(7.3%)	0/88(0%)	10/124(8.1%)
4	0/73(0%)	9/124(7.3%)	0/88(0%)	10/124(8.1%)
3	0/73(0%)	9/124(7.3%)	0/88(0%)	12/124(9.7%)
2	0/73(0%)	3/124(2.4%)	0/88(0%)	10/124(8.1%)
1	0/73(0%)	6/124(4.5%)	0/88(0%)	6/124(4.5%)
Basement	0/73(0%)	0/312(0%)	0/88(0%)	2/312(0.6%)

Table 5.66: Tunnel formwork in buildings with 28 stories

Percentage of damaged beam and column of the system for each story				
Story	X-direction		Y-direction	
No	Beam	Column	Beam	Column
28	0/53(0%)	0/195(0%)	0/52(0%)	0/195(0%)
27	0/53(0%)	1/195(0.5%)	0/52(0%)	0/195(0%)
26	0/53(0%)	1/195(0.5%)	0/52(0%)	0/195(0%)
25	0/53(0%)	1/195(0.5%)	0/52(0%)	0/195(0%)
24	0/53(0%)	2/195(1.0%)	0/52(0%)	0/195(0%)
23	0/53(0%)	3/195(1.5%)	0/52(0%)	1/195(0.5%)
22	0/53(0%)	3/195(1.5%)	0/52(0%)	2/195(1.0%)
21	0/53(0%)	3/195(1.5%)	0/52(0%)	3/195(1.5%)
20	0/53(0%)	3/195(1.5%)	0/52(0%)	3/195(1.5%)
19	0/53(0%)	3/195(1.5%)	0/52(0%)	3/195(1.5%)
18	0/53(0%)	4/195(2.1%)	0/52(0%)	3/195(1.5%)
17	0/53(0%)	5/195(2.6%)	0/52(0%)	3/195(1.5%)
16	0/53(0%)	6/195(3.1%)	0/52(0%)	3/195(1.5%)
15	0/53(0%)	7/195(3.6%)	0/52(0%)	5/195(2.6%)
14	0/53(0%)	7/195(3.6%)	0/52(0%)	6/195(3.1%)
13	0/53(0%)	7/195(3.6%)	0/52(0%)	6/195(3.1%)
12	0/53(0%)	7/195(3.6%)	0/52(0%)	6/195(3.1%)
11	0/53(0%)	7/195(3.6%)	0/52(0%)	7/195(3.6%)
10	0/53(0%)	7/195(3.6%)	0/52(0%)	7/195(3.6%)
9	0/53(0%)	8/195(4.1%)	0/52(0%)	7/195(3.6%)
8	0/53(0%)	8/195(4.1%)	0/52(0%)	7/195(3.6%)
7	0/53(0%)	8/195(4.1%)	0/52(0%)	7/195(3.6%)
6	0/53(0%)	8/195(4.1%)	0/52(0%)	8/195(4.1%)
5	0/53(0%)	8/195(4.1%)	0/52(0%)	7/195(3.6%)
4	0/53(0%)	8/195(4.1%)	0/52(0%)	7/195(3.6%)
3	0/53(0%)	8/195(4.1%)	0/52(0%)	6/195(3.1%)
2	0/53(0%)	7/195(3.6%)	0/52(0%)	5/195(2.6%)
1	0/53(0%)	8/195(4.1%)	0/52(0%)	6/195(3.1%)
Basement	0/53(0%)	2/319 (0%)	0/52(0%)	0/319 (0%)

Table 5.67: Results of analysis in buildings with 28 stories

The Analysis from STA4-CAD	Shear wall	Coupled shear wall	Stiffened coupled shear wall	Tunnel Formwork
Concrete (m^3)	10,041.6	10,019.1	10,055.0	14,408.2
Formwork (m^2)	50,257.9	50,202.0	50,234.1	70,319
Reinforcement (ton)	1,111.7	1,099.2	1,142.2	996.7
Building wall (m^2)	27,206.35	27,206.35	27,206.35	8,120.2
Plaster of all building (m^2)	99,090.0	99,090.0	99,090.0	16,240.4
Cost (TL)	9,675,990.9	9,646,415.5	9,739,265.7	6,467,350.6
X (m)	0.00231	0.00238	0.00228	0.00121
Y (m)	0.00244	0.00245	0.00242	0.00147
Beam damage ratio < 30%	0.0 %	0.0 %	0.0 %	0.0 %
Column damage ratio < 20%	0.5 %	0.6 %	0.4 %	0.0 %
Roof story VC ratio < 40%	0.1 %	0.1 %	0.1 %	0.0 %
Columns including plastic hinge Vc ratio [LS+CP+CC] < 30%	1.8 % LS	1.9 % LS	1.7 % LS	0.9 % LS

5.3.7.5.1 Quantity of Each Case Study

Table 5.40 illustrates the quantity of each case study respectively in Figure 5.97, 5.98, 5.99. It shows the tunnel system requires a larger amount of concrete, formwork and reinforcement. Also, Figure 5.100 shows the tunnel system requires a small amount in order to build walls and plaster. In addition, Figure 5.101 shows that the total cost of the tunnel system is low. However, the displacement of the case studies with two directions (x, y) in Figure 5.102 shows that the tunnel system has the least displacement and seismic performance. Figure 5.103 shows that all systems satisfy the safety criteria.

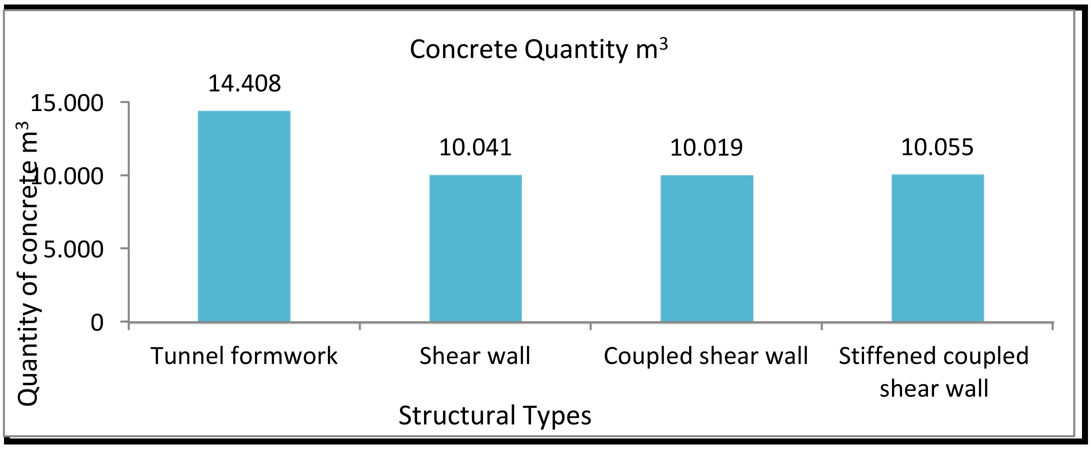

Figure 5.97: Quantity of the Concrete in Buildings with Twenty Eight Stories

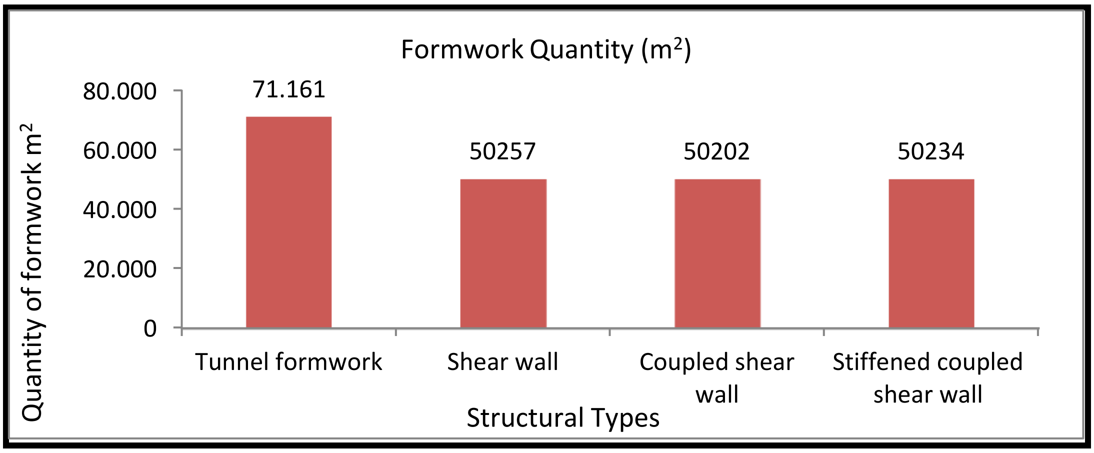

Figure 5.98: Quantity of the Formwork in Buildings with Twenty Eight Stories

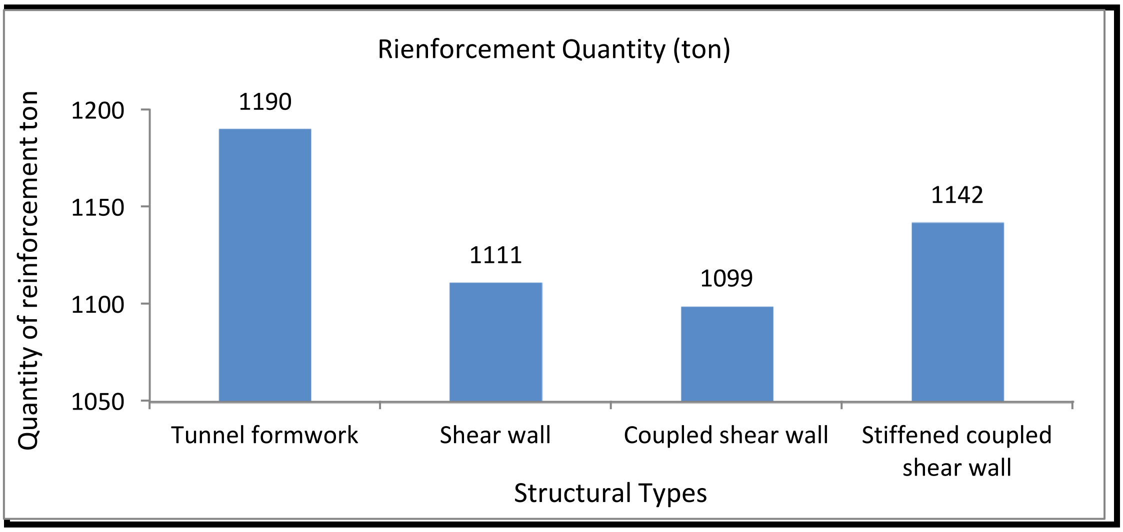

Figure 5.99: Quantity of the Reinforcement for Each Case Study in Buildings with Twenty Eight Stories

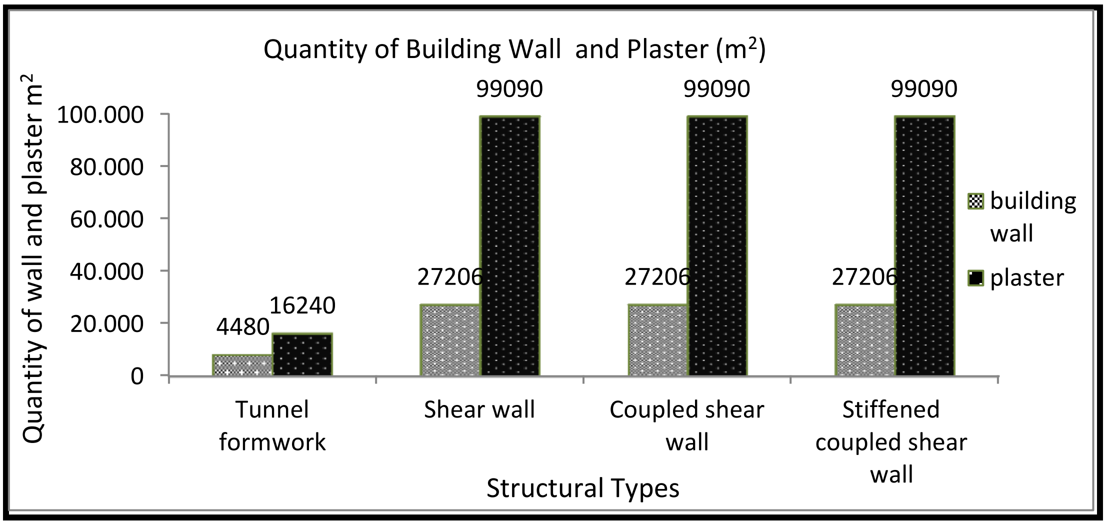

Figure 5.100: Quantity of the Wall and Plaster in Buildings, Twenty Eight Stories

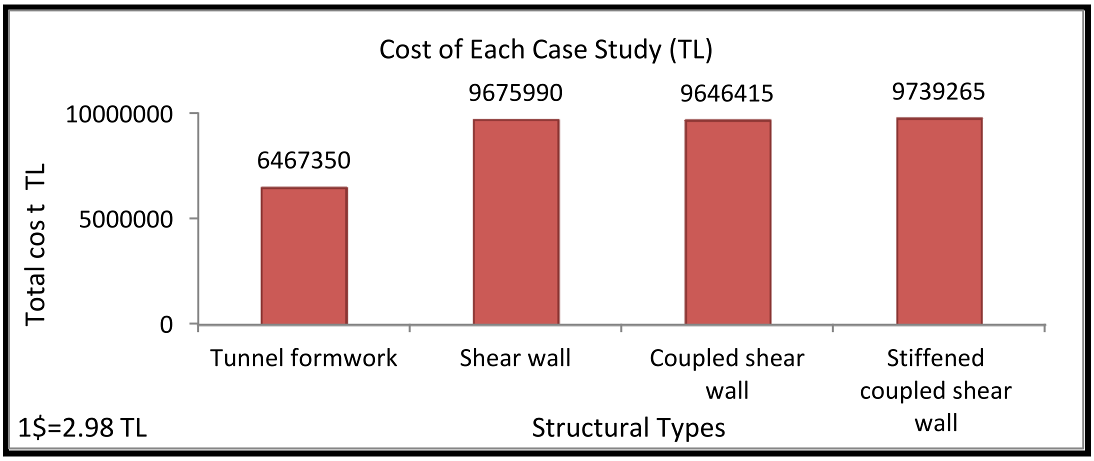

Figure 5.101: Total Costs of Each Case Study in Buildings, Twenty Eight Stories

5.3.7.5.2 Displacement of Each Case Study in X and Y Directions

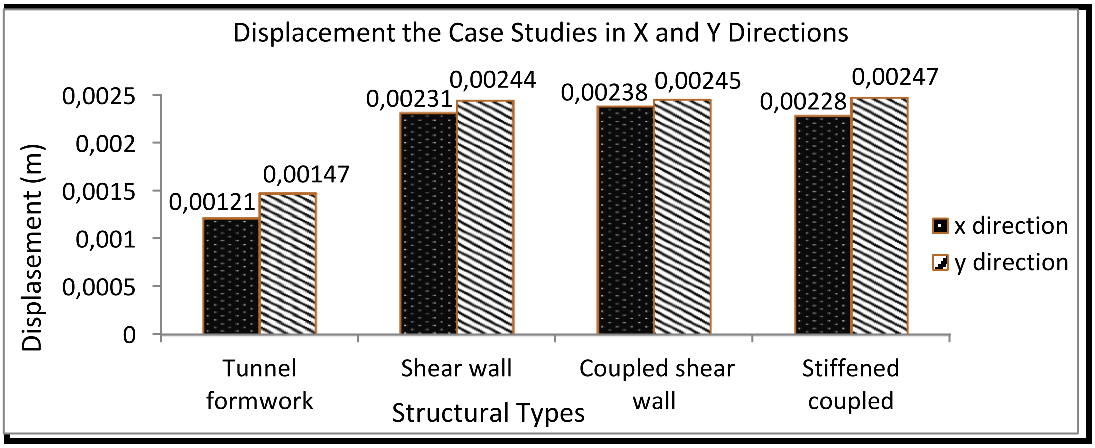

Figure 5.102: Displacement of Each Case Study in Buildings, Twenty Eight Stories

5.3.7.5.3 Performance

The chart below explains the percentage of the damage of beam, column, roof storey and the column including different structures after the analysis of results.

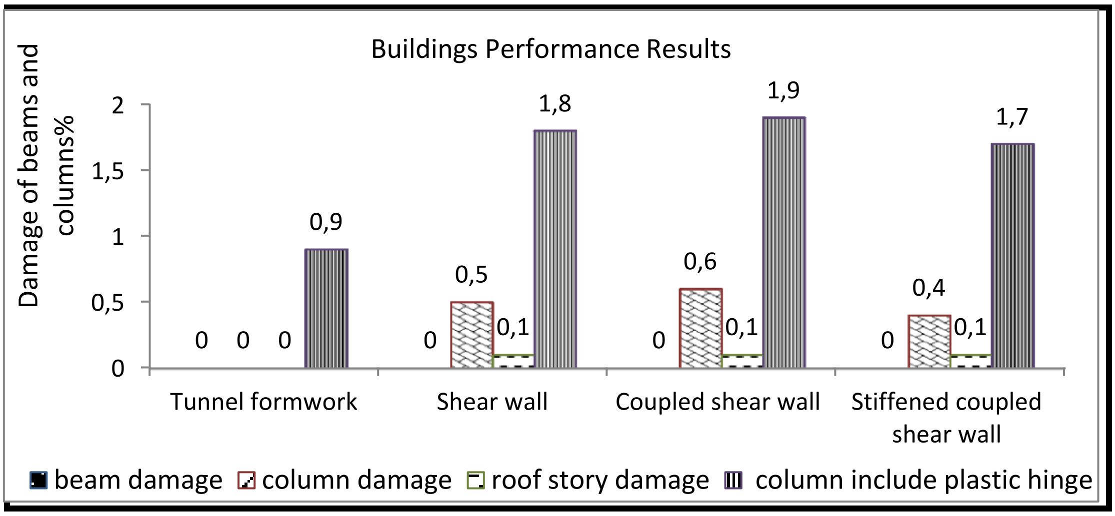

Figure 5.103: Damage of Beams and Columns in Buildings, Twenty Eight Stories.

The seismic performance in Figure 5.103 shows that all systems satisfy the safety criteria and that the tunnel formwork system is a cheap case study.

5.4 The Result Summary

After illustrating all the details of the analysis results from the program STA4-CAD, the discussion will be in four parts.

5.4.1 Construction Cost

This study has five different structure systems. These different systems are applied to different building heights, with the same plan. The Table below illustrates the total cost for all of the case studies in this study. Table 5.41 illustrates the total cost of case studies and compare the studies to find out which case study is more economic, as shown in Figure 5.104. (Note that 1$ = 2.98 TL).

Table 5.68: Total cost of all case studies

Story No	Shear wall (TL)	Coupled shear wall (TL)	Stiffened coupled shear wall (TL)	Tunnel formwork (TL)	Flat slab beam (TL)
2	607,750	-	-	713,698	585,705
5	1,356,126	-	-	1,588,321	1,331,480
10	3,343,079	3,292,882	3,349,077	2,121,969	-
15	5,045,585	5,013,001	5,050,059	3,603,398	-
20	6,796,747	6,777,100	6,797,859	4,618,481	-
25	8,543,122	8,477,834	8,560,771	5,997,654	-
28	9,695,990	9,646,415	9,739,265	6,467,350	-

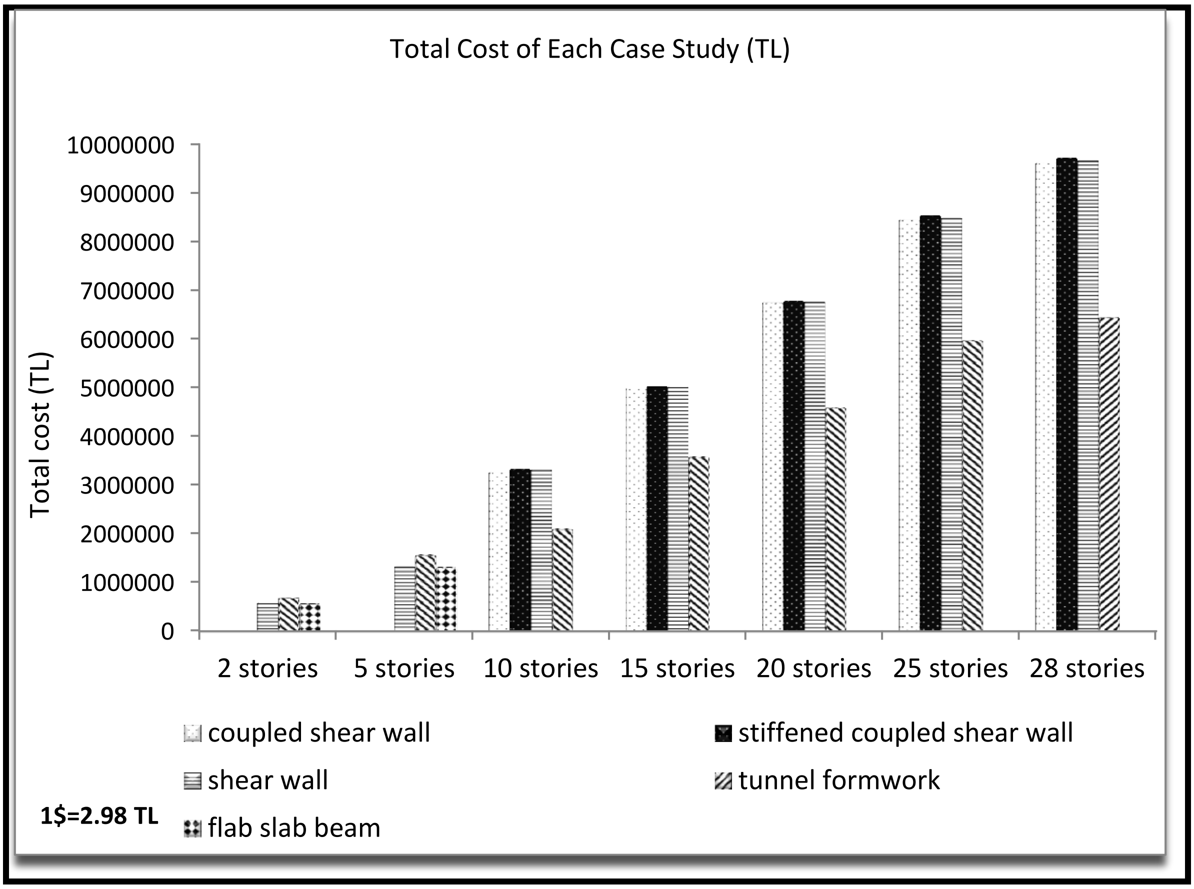

Figure 5.104: Total Cost of all Case Studies

Table 5.41 and Figure 5.104 note that the flat slab-beam and shear wall system have a lower cost for the 2 and 5 story buildings. On the other hand, the tunnel formwork system is an expensive solution for the 2 and 5 story models.

For the 10, 15, 20, 25, and 28 story models, the shear wall, coupled shear wall and stiffened coupled shear wall system are more expensive compared to tunnel formwork. Thus, the tunnel formwork gives the best solution in terms of economy. In general, the shear wall, coupled shear wall and stiffened coupled shear wall systems give close to equal results when compared together. It can be noted that the coupled shear wall system is found to be more cheaper, especially compared to the shear wall and stiffened coupled shear shear.

5.4.2 Displacement the Case Studies in X Directions

In this study, there are five different structural systems. These different structural are applied to different stories. The Table below illustrates the displacement results of the models, for x directions of earthquake loading.

Table 5.69: Displacement of all case studies in x direction

Story No	Shear wall (m)	Coupled shear wall (m)	Stiffened coupled shear wall (m)	Tunnel Formwork (m)	Flat slab beam (m)
2	0.00072	-	-	0.00005	0.00071
5	0.00134	-	-	0.00022	0.00135
10	0.00148	0.00149	0.00148	0.00048	-
15	0.00155	0.00155	0.00154	0.00064	-
20	0.00204	0.00198	0.00197	0.00084	-
25	0.00219	0.00217	0.00216	0.00102	-
28	0.00231	0.00238	0.00228	0.00121	-

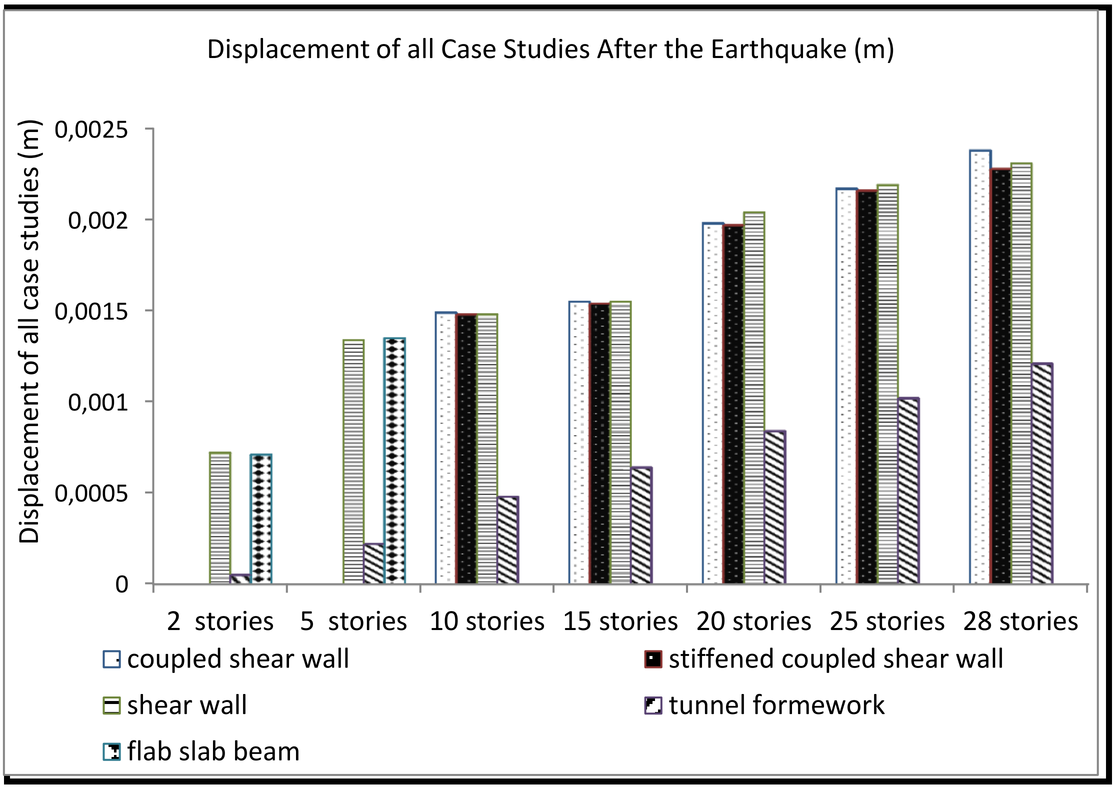

Figure 5.105: Displacement of all Case Studies in X Direction

The displacement results due to earthquake loading are presented for all models in Figure 5.105. It can be noted that the tunnel formwork system has the least displacement in buildings with 2, 5, 10, 15, 20, 25 and 28 stories. The flat slab beam and the shear wall system result in big displacements in general. On the other hand, in buildings with 10, 15, 20, 25 and 28 stories, the shear wall, coupled shear wall and stiffened coupled shear wall systems provide near equals displacements, when compared together.

5.4.3 Displacement the Case Studies in Y Directions

In this study, there are five different structural systems. These different structural are applied to different stories. The Table below illustrates the displacement results of the models, for y direction of earthquake loading.

Table 5.70: Displacement of all case studies in y direction

Story No	Shear wall (m)	Coupled shear wall (m)	Stiffened coupled shear wall (m)	Tunnel Formwork (m)	Flat slab beam (m)
2	0.00080	-	-	0.00002	0.00113
5	0.00149	-	-	0.00012	0.00185
10	0.00192	0.00192	0.00191	0.00052	-
15	0.00222	0.00221	0.00221	0.00075	-
20	0.00242	0.00240	0.00241	0.00100	-
25	0.00223	0.00232	0.00227	0.00113	-
28	0.00244	0.00245	0.00242	0.00147	-

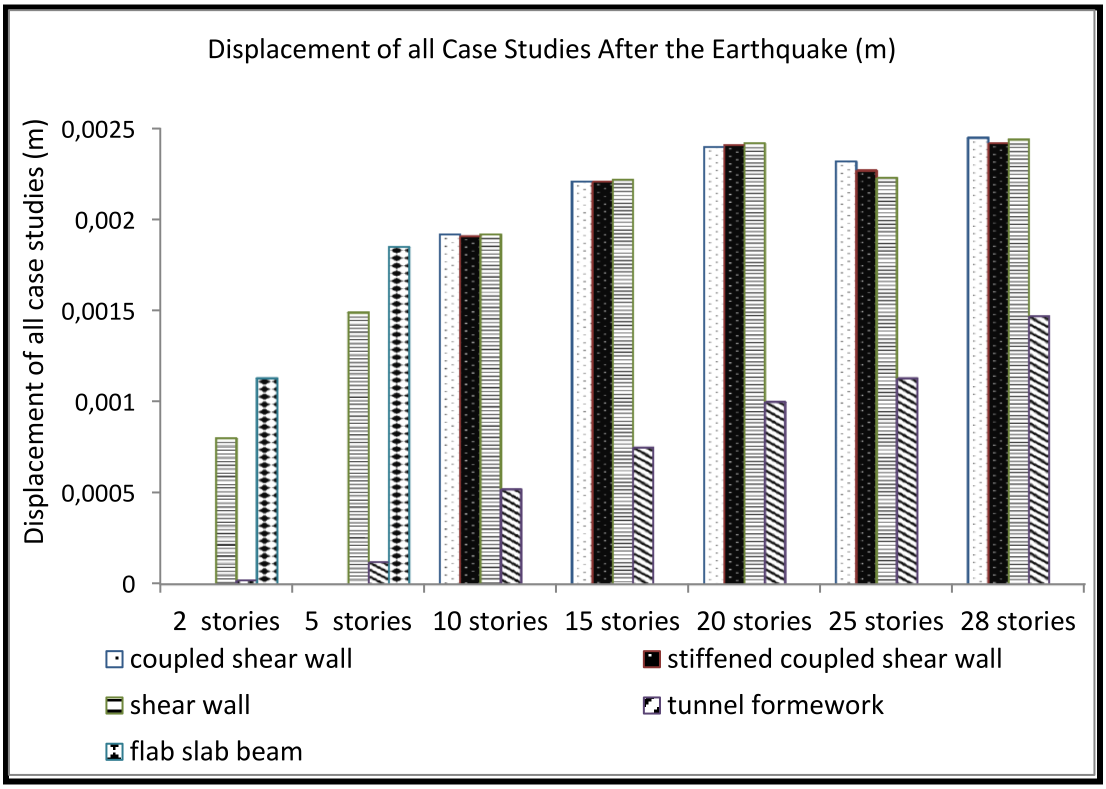

Figure 5.106: Displacement of all Case Studies in Y Direction

The displacement results due to earthquake loading are presented for all models in Figure 5.106. It shows the tunnel formwork system in buildings with 2, 5, 10, 15, 20, 25 and 28 stories in smaller displacements compared to all other systems. The flat slab beam and shear wall systems result in big displacements in general.

5.4.4 Performance of All Case Studies

The Table 5.44 below illustrates the seismic performance of buildings after the application of the earthquake loading. Here, the sum of the beam damage, column damage, roof damage and the column are considered to present the total percentage of damage for each model.

Table 5.71: Performance of all case studies

Story No	Shear wall	Coupled shear wall	Stiffened coupled shear wall	Tunnel formwork	Flat slab Beam
2	0.8 %	-	-	0.0 %	2.1 %
5	0.6 %	-	-	0.0 %	9.8 %
10	2.9 %	3 %	2.7 %	0.3 %	-
15	3.3 %	3.4 %	3.2 %	0.8 %	-
20	3.3 %	3.4 %	3.2 %	0.8 %	-
25	2.5 %	2.6 %	2.1 %	0.9 %	-
28	2.4 %	2.6 %	2.2 %	0.9 %	-

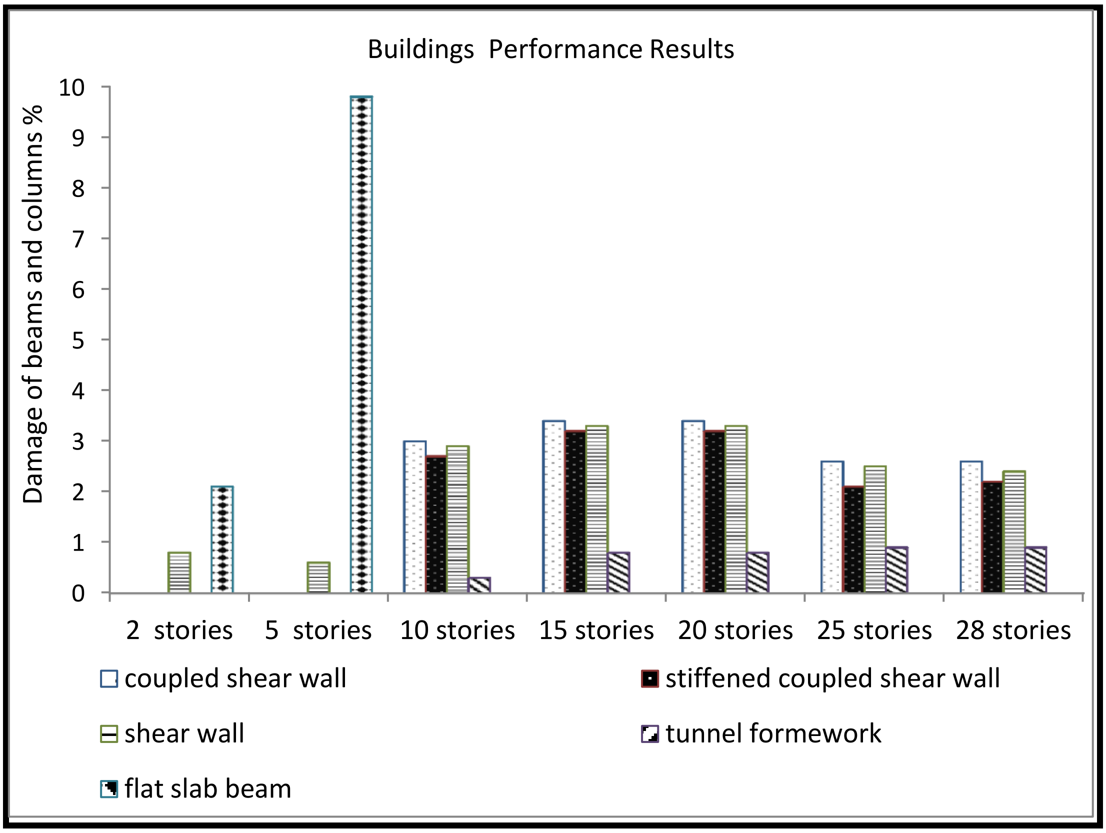

Figure 5.107: Performance of all Case Studies

The seismic damage percentage for the all models is illustrated in Figure 5.107. All the different building performance is in the range sufficient to be safe for human life, called Life Safety (LS). Except the flat slab-beam for buildings with 10 stories, it gives unsatisfactory results against earthquake forces, called Collapse Case (CC). However, the tunnel formwork for 2 and 5 story models is the best, called Immediate Occupancy (IO). The flat slab beam system is found within the range that does not highly damage 2 story buildings but for 5 story buildings, the damage is high compared to shear wall. However, it is still the Life Safety (LS) case.

Chapter 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This study is an evaluation and comparison of different reinforced concrete structures when the structures are under seismic excitation. The objective of this study was to investigate the effects of using different lateral load resisting systems, such as the flat slab beam system, the shear wall system, the coupled shear wall system, the stiffened coupled shear wall system and the tunnel formwork systems on the behavior of reinforced concrete structures. They were compared within different structural heights of 2, 5, 10, 15, 20, 25 and 28 stories, taking into account their design conditions according to the Turkish Earthquake Code-2007 and Turkish Standards-500. In addition, considering their construction cost by the building material prices, according to the Northern Cyprus Ministry of Public Works and Transport Planning, 2015 unit prices in Turkish Lira (TL) were found to be the safest and the most economic system.

During the comparison of results, significant findings were observed and the following conclusions can be drawn from those observations:

- The results of this study about the seismic performance analysis conducted on different lateral load resisting structural systems are sufficient for human life safety. They meet Life Safety (LS) standards, except the flat slab-beam for 10 stories which gave unsatisfactory results against earthquake forces, such as

Collapse Case (CC). However, the tunnel formwork was proved to be the safest for 2 and 5 stories as Immediate Occupancy (IO).

- Out of the five currently available structural systems, the flat slab-beam and the shear wall systems were to be proved appropriate for different story levels. The safe and the economical systems were those with up to 5 stories.
- Out of the five currently available structural systems, the tunnel formwork system was proved to be appropriate for different story levels of 10, 15, 20, 25 and 28 stories. The analytical results of that system are in agreement with the results of other structural systems showing it as the safest system. The analytical results of that system indicating the plastic hinge gave a low ratio compared with other structural systems, and the number of damage columns gave a low number of damage columns compared with other structural systems.
- The details of the results of the construction cost showed that the flat slab-beam and the shear wall systems are based on the low construction cost obtained for different story levels up to 5 stories which were investigated.
- The tunnel formwork system provides a low construction cost compared to other structural systems of different story levels with 10, 15, 20, 25 and 28 stories which were investigated.

Based on the investigations from this study, the tunnel formwork system provides a better seismic performance in addition to their low construction cost compared to the other lateral load resisting structural systems. This, in turn, makes them an alternative building type to the more costly buildings in seismically active regions. For this reason, the intent of this study is to bring forward the optimum performance of these structures and to identify the most economical system for practical applications.

6.2 Recommendation

In the light of these findings, it is expected that this study will be a point of reference for the buildings built using other different structural systems in the Turkish Republic of Northern Cyprus, for low to high rise buildings to become more economical and to have safer systems.

6.3 Suggestion for Further Research

The following recommendations are suggested for future research:

- Analyzing and considering high rise structures with more than 28 stories, with the tunnel formwork system, the coupled shear wall, the stiffened coupled shear wall and the shear wall system.
- This study was to be built in Famagusta and it is possible in the future for the exposure to first zones of seismic on structures, calculation in the first seismic zones to find the safest and the most economic systems with different reinforced concrete structure.
- Considering Irregular Buildings, which are high rise buildings up to 28 stories, in order to find the safest and the most economic system.

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APPENDICES

Appendix A: Quantity of Concrete (m^3) and Formwork (m^2)

Two Stories Flat slab Beam System

Story	Concrete m^3	R.C.Form m^2	Ribbed m^3
FOUNDATION	256.67	556.71	
1.sto Slabs 1.sto Beams 1.sto Columns	105.17 54.83 39.34	525.84 379.64 445.00	0.00
1.sto Total	199.33	1350.48	0.00
2.sto Slabs 2.sto Beams 2.sto Columns	105.17 55.25 39.83	525.84 382.94 450.60	0.00
2.sto Total	200.24	1359.39	0.00

Five Stories Shear Wall System

Story	Concrete m^3	R.C.Form m^2	Ribbed m^3
FOUNDATION	452.77	566.46	
1.sto Slabs 1.sto Beams 1.sto Columns	105.17 53.91 48.36	525.84 371.69 527.89	0.00
1.sto Total	207.44	1425.43	0.00
2.sto Slabs 2.sto Beams 2.sto Columns	105.17 53.91 45.32	525.84 371.69 493.59	0.00
2.sto Total	204.40	1391.13	0.00
3.sto Slabs 3.sto Beams 3.sto Columns	105.17 53.91 45.32	525.84 371.69 493.59	0.00
3.sto Total	204.40	1391.13	0.00
4.sto Slabs 4.sto Beams 4.sto Columns	105.17 53.91 45.32	525.84 371.69 493.59	0.00
4.sto Total	204.40	1391.13	0.00
5.sto Slabs 5.sto Beams 5.sto Columns	105.17 53.91 45.32	525.84 371.69 493.59	0.00

Ten Stories Tunnel Formwork System

Story	Concrete m^3	R.C.Form m^2	Ribbed m^3
FOUNDATION	734.28	517.39	
1.sto Slabs 1.sto Beams 1.sto Columns	124.74 0.00 712.58	623.68 0.00 4593.64	0.00
1.sto Total	837.32	5217.32	0.00
2.sto Slabs 2.sto Beams 2.sto Columns	104.17 8.68 256.53	520.85 45.27 1731.69	0.00
2.sto Total	369.37	2297.81	0.00
3.sto Slabs 3.sto Beams 3.sto Columns	104.17 0.00 76.86	520.85 0.00 715.80	0.00
3.sto Total	181.03	1236.65	0.00
4.sto Slabs 4.sto Beams 4.sto Columns	104.17 0.00 76.86	520.85 0.00 715.80	0.00
4.sto Total	181.03	1236.65	0.00
5.sto Slabs 5.sto Beams 5.sto Columns	104.17 0.00 76.86	520.85 0.00 715.80	0.00
6.sto Slabs 6.sto Beams 6.sto Columns	104.17 0.00 76.86	520.85 0.00 715.80	0.00
6.sto Total	181.03	1236.65	0.00
7.sto Slabs 7.sto Beams 7.sto Columns	104.17 0.00 76.86	520.85 0.00 715.80	0.00
7.sto Total	181.03	1236.65	0.00
8.sto Slabs 8.sto Beams 8.sto Columns	104.17 0.00 76.86	520.85 0.00 715.80	0.00
8.sto Total	181.03	1236.65	0.00
9.sto Slabs 9.sto Beams 9.sto Columns	104.17 0.00 76.86	520.85 0.00 715.80	0.00
9.sto Total	181.03	1236.65	0.00
10.sto Slabs 10.sto Beams 10.sto Columns	104.17 0.00 76.86	520.85 0.00 715.80	0.00
10.sto Total	181.03	1236.65	0.00
11.sto Slabs 11.sto Beams 11.sto Columns	104.17 0.00 76.86	520.85 0.00 715.80	0.00
11.sto Total	181.03	1236.65	0.00

Fifteen Stories Tunnel Formwork System

Story	Concrete m^3	R.C.Form m^2	Ribbed m^3
FOUNDATION	1035.75	435.08	
1.sto Slabs 1.sto Beams 1.sto Columns	124.74 0.00 681.73	623.68 0.00 4394.74	0.00
1.sto Total	806.47	5018.42	0.00
2.sto Slabs 2.sto Beams 2.sto Columns	104.17 18.24 438.12	520.85 97.29 2778.41	0.00
2.sto Total	560.53	3396.55	0.00
3.sto Slabs 3.sto Beams 3.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
3.sto Total	382.88	2348.01	0.00
4.sto Slabs 4.sto Beams 4.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
4.sto Total	382.88	2348.01	0.00
5.sto Slabs 5.sto Beams 5.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
6.sto Slabs 6.sto Beams 6.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
6.sto Total	382.88	2348.01	0.00
7.sto Slabs 7.sto Beams 7.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
7.sto Total	382.88	2348.01	0.00
8.sto Slabs 8.sto Beams 8.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
8.sto Total	382.88	2348.01	0.00
9.sto Slabs 9.sto Beams 9.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
9.sto Total	382.88	2348.01	0.00
10.sto Slabs 10.sto Beams 10.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
10.sto Total	382.88	2348.01	0.00

Fifteen Stories Tunnel Formwork System

11.sto Slabs	104.17	520.85	0.00
11.sto Beams	18.08	96.38	
11.sto Columns	260.62	1730.78	
11.sto Total	382.88	2348.01	0.00
12.sto Slabs	104.17	520.85	0.00
12.sto Beams	18.08	96.38	
12.sto Columns	260.62	1730.78	
12.sto Total	382.88	2348.01	0.00
13.sto Slabs	104.17	520.85	0.00
13.sto Beams	18.08	96.38	
13.sto Columns	260.62	1730.78	
13.sto Total	382.88	2348.01	0.00
14.sto Slabs	104.17	520.85	0.00
14.sto Beams	18.08	96.38	
14.sto Columns	260.62	1730.78	
14.sto Total	382.88	2348.01	0.00
15.sto Slabs	104.17	520.85	0.00
15.sto Beams	18.08	96.38	
15.sto Columns	260.62	1730.78	
15.sto Total	382.88	2348.01	0.00
16.sto Slabs	104.17	520.85	0.00
16.sto Beams	18.08	96.38	
16.sto Columns	260.62	1730.78	
[illegible]	[illegible]	[illegible]	[illegible]

Twenty Stories Tunnel Formwork System

FOUNDATION	1327.82	352.08	
1.sto Slabs 1.sto Beams 1.sto Columns	124.74 0.00 650.89	623.68 0.00 4195.85	0.00
1.sto Total	775.62	4819.53	0.00
2.sto Slabs 2.sto Beams 2.sto Columns	104.17 18.24 438.12	520.85 97.29 2778.41	0.00
2.sto Total	560.53	3396.55	0.00
3.sto Slabs 3.sto Beams 3.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
3.sto Total	382.88	2348.01	0.00
4.sto Slabs 4.sto Beams 4.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
4.sto Total	382.88	2348.01	0.00
5.sto Slabs 5.sto Beams 5.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
5.sto Total	382.88	2348.01	0.00
6.sto Slabs 6.sto Beams 6.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
6.sto Total	382.88	2348.01	0.00
7.sto Slabs 7.sto Beams 7.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
7.sto Total	382.88	2348.01	0.00
8.sto Slabs 8.sto Beams 8.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
8.sto Total	382.88	2348.01	0.00
9.sto Slabs 9.sto Beams 9.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
9.sto Total	382.88	2348.01	0.00
10.sto Slabs 10.sto Beams 10.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
10.sto Total	382.88	2348.01	0.00

Twenty Stories Tunnel Formwork System

11.sto Slabs 11.sto Beams 11.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
11.sto Total	382.88	2348.01	0.00
12.sto Slabs 12.sto Beams 12.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
12.sto Total	382.88	2348.01	0.00
13.sto Slabs 13.sto Beams 13.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
13.sto Total	382.88	2348.01	0.00
14.sto Slabs 14.sto Beams 14.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
14.sto Total	382.88	2348.01	0.00
15.sto Slabs 15.sto Beams 15.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
15.sto Total	382.88	2348.01	0.00
16.sto Slabs 16.sto Beams 16.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
16.sto Total	382.88	2348.01	0.00
17.sto Slabs 17.sto Beams 17.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
17.sto Total	382.88	2348.01	0.00
18.sto Slabs 18.sto Beams 18.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
18.sto Total	382.88	2348.01	0.00
19.sto Slabs 19.sto Beams 19.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
19.sto Total	382.88	2348.01	0.00
20.sto Slabs 20.sto Beams 20.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00
20.sto Total	382.88	2348.01	0.00
21.sto Slabs 21.sto Beams 21.sto Columns	104.17 18.08 260.62	520.85 96.38 1730.78	0.00

Twenty Five Stories Tunnel formwork System

Story	Concrete m^3	R.C.Form m^2	Ribbed m^3
FOUNDATION	1483.10	238.54	
1.sto Slabs 1.sto Beams 1.sto Columns	124.74 0.00 723.55	623.68 0.00 3976.87	0.00
1.sto Total	848.29	4600.55	0.00
2.sto Slabs 2.sto Beams 2.sto Columns	101.00 20.56 506.91	505.01 98.26 2747.98	0.00
2.sto Total	628.48	3351.25	0.00
3.sto Slabs 3.sto Beams 3.sto Columns	101.00 19.70 310.42	505.01 93.95 1770.85	0.00
3.sto Total	431.12	2369.81	0.00
4.sto Slabs 4.sto Beams 4.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
4.sto Total	429.38	2362.01	0.00
5.sto Slabs 5.sto Beams 5.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
6.sto Slabs 6.sto Beams 6.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
6.sto Total	429.38	2362.01	0.00
7.sto Slabs 7.sto Beams 7.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
7.sto Total	429.38	2362.01	0.00
8.sto Slabs 8.sto Beams 8.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
8.sto Total	429.38	2362.01	0.00
9.sto Slabs 9.sto Beams 9.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
9.sto Total	429.38	2362.01	0.00
10.sto Slabs 10.sto Beams 10.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
10.sto Total	429.38	2362.01	0.00

Twenty Five Stories Tunnel formwork System.

11.sto Slabs 11.sto Beams 11.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
11.sto Total	429.38	2362.01	0.00
12.sto Slabs 12.sto Beams 12.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
12.sto Total	429.38	2362.01	0.00
13.sto Slabs 13.sto Beams 13.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
13.sto Total	429.38	2362.01	0.00
14.sto Slabs 14.sto Beams 14.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
14.sto Total	429.38	2362.01	0.00
15.sto Slabs 15.sto Beams 15.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
15.sto Total	429.38	2362.01	0.00
16.sto Slabs 16.sto Beams 16.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
16.sto Total	429.38	2362.01	0.00
17.sto Slabs 17.sto Beams 17.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
17.sto Total	429.38	2362.01	0.00
18.sto Slabs 18.sto Beams 18.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
18.sto Total	429.38	2362.01	0.00
19.sto Slabs 19.sto Beams 19.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
19.sto Total	429.38	2362.01	0.00
20.sto Slabs 20.sto Beams 20.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
20.sto Total	429.38	2362.01	0.00

Twenty Five Stories Tunnel formwork System

21.sto Slabs 21.sto Beams 21.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
21.sto Total	429.38	2362.01	0.00
22.sto Slabs 22.sto Beams 22.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
22.sto Total	429.38	2362.01	0.00
23.sto Slabs 23.sto Beams 23.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
23.sto Total	429.38	2362.01	0.00
24.sto Slabs 24.sto Beams 24.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
24.sto Total	429.38	2362.01	0.00
25.sto Slabs 25.sto Beams 25.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00
25.sto Total	429.38	2362.01	0.00
26.sto Slabs 26.sto Beams 26.sto Columns	101.00 19.70 308.68	505.01 93.95 1763.05	0.00

Twenty Eight Stories Tunnel Formwork System

Story	Concrete m^3	R.C.Form m^2	Ribbed m^3
FOUNDATION	1592.65	273.53	
1.sto Slabs 1.sto Beams 1.sto Columns	124.74 0.00 720.72	623.68 0.00 3955.80	0.00
1.sto Total	845.45	4579.48	0.00
2.sto Slabs 2.sto Beams 2.sto Columns	100.86 20.43 510.05	504.31 95.84 2775.42	0.00
2.sto Total	631.34	3375.58	0.00
3.sto Slabs 3.sto Beams 3.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
3.sto Total	419.95	2330.84	0.00
4.sto Slabs 4.sto Beams 4.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
4.sto Total	419.95	2330.84	0.00
5.sto Slabs 5.sto Beams 5.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
6.sto Slabs 6.sto Beams 6.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
6.sto Total	419.95	2330.84	0.00
7.sto Slabs 7.sto Beams 7.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
7.sto Total	419.95	2330.84	0.00
8.sto Slabs 8.sto Beams 8.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
8.sto Total	419.95	2330.84	0.00
9.sto Slabs 9.sto Beams 9.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
9.sto Total	419.95	2330.84	0.00
10.sto Slabs 10.sto Beams 10.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
10.sto Total	419.95	2330.84	0.00

Twenty Eight Stories System Tunnel Formwork System

11.sto Slabs 11.sto Beams 11.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
11.sto Total	419.95	2330.84	0.00
12.sto Slabs 12.sto Beams 12.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
12.sto Total	419.95	2330.84	0.00
13.sto Slabs 13.sto Beams 13.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
13.sto Total	419.95	2330.84	0.00
14.sto Slabs 14.sto Beams 14.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
14.sto Total	419.95	2330.84	0.00
15.sto Slabs 15.sto Beams 15.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
15.sto Total	419.95	2330.84	0.00
16.sto Slabs 16.sto Beams 16.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
16.sto Total	419.95	2330.84	0.00
17.sto Slabs 17.sto Beams 17.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
17.sto Total	419.95	2330.84	0.00
18.sto Slabs 18.sto Beams 18.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
18.sto Total	419.95	2330.84	0.00
19.sto Slabs 19.sto Beams 19.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
19.sto Total	419.95	2330.84	0.00
20.sto Slabs 20.sto Beams 20.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
20.sto Total	419.95	2330.84	0.00

Twenty Eight Stories System Tunnel Formwork System

21.sto Slabs 21.sto Beams 21.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
21.sto Total	419.95	2330.84	0.00
22.sto Slabs 22.sto Beams 22.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
22.sto Total	419.95	2330.84	0.00
23.sto Slabs 23.sto Beams 23.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
23.sto Total	419.95	2330.84	0.00
24.sto Slabs 24.sto Beams 24.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
24.sto Total	419.95	2330.84	0.00
25.sto Slabs 25.sto Beams 25.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
25.sto Total	419.95	2330.84	0.00
26.sto Slabs 26.sto Beams 26.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
26.sto Total	419.95	2330.84	0.00
27.sto Slabs 27.sto Beams 27.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
27.sto Total	419.95	2330.84	0.00
28.sto Slabs 28.sto Beams 28.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
28.sto Total	419.95	2330.84	0.00
29.sto Slabs 29.sto Beams 29.sto Columns	100.83 20.25 298.87	504.17 94.79 1731.88	0.00
29.sto Total	419.95	2330.84	0.00

Appendix B: Unit Price of Building Material (Northern Cyprus Ministry of Public Work and Transport Planning, 2015 unit price)

KUZEY KIBRIS TÜRK CUMHURİYETİ
BAYINDIRLIK VE ULAŞTIRMA BAKANLIĞI
PLANLAMA VE İNŞAAT DAİRESİ

İNŞAAT TÜRLERİNE GÖRE M2 BİRİM FİYATLARI (KDV HARİÇ)

TARİH : 1 OCAK 2015 - 30 HAZİRAN 2015 ARASI GEÇERLİDİR

1.	Konut I. Sınıf (Yardımcı Binalar , Trafo Odası , Garaj)	835.00	TL / m2
2.	Konut II. Sınıf (3 Kata kadar olan Apt. ve 300 m2'ye kadar Konut)	1,195.00	TL / m2
3.	Konut III. Sınıf (300 m2 üzeri konut)	1,500.00	TL / m2
4.	Konut IV. Sınıf (120 m2'ye kadar konut)	925.00	TL / m2
5.	Apartman tipi konut	1,180.00	TL / m2
6.	Sendeli Dükkan	1,180.00	TL / m2
7.	Sendesiz Dükkan	945.00	TL / m2
8.	Ofis Tipi Bina(Standart)	970.00	TL / m2
9.	Ofis Tipi Bina(Özellikli)	1,235.00	TL / m2
10.	Okul	1,030.00	TL / m2
11.	Derslik	945.00	TL / m2
12.	Yurt	1,260.00	TL / m2
13.	Fabrika Atölye Tipi Binalar	830.00	TL / m2
14.	Süthane , Salhane	940.00	TL / m2
15.	Unlu mamüller tesisi	1,240.00	TL / m2
16.	Otel I	1,500.00	TL / m2
17.	Otel II	1,800.00	TL / m2
18.	Otel III	2,020.00	TL / m2
19.	Otel Deluxe	2,500.00	TL / m2
20.	Bungolow (Motel)	1,205.00	TL / m2
21.	Sinema Çok Maksatlı Salon	1,625.00	TL / m2
22.	Lokanta	1,230.00	TL / m2
23.	Benzin İstasyonu	1,160.00	TL / m2
24.	Oto Tamirevi	800.00	TL / m2
25.	Ağıl , Kümes	425.00	TL / m2
26.	Oto Park (Yanları Açık)	710.00	TL / m2
27.	Bodrum(Otopark,Depo)	870.00	TL / m2
28.	Sığınak- Sığınak amaçlı bodrum	990.00	TL / m2
29.	Arsa Altyapı Maliyeti	12,725.00	TL / Arsa
30.	Yüzme Havuzu	1,455.00	TL / m2
31.	Açık Verandalar	245.00	TL / m2
32.	Telleme	132.00	TL / mt
33.	Bahçe Duvarı	205.00	TL / mt
34.	Halı Saha	190.00	TL / m2

NOT : **Fiyatlara Müteahhit Karı Dahildir.**

SIRA NO:	İMALATIN ÇEŞİDİ:	ÖLÇÜ BİRİM	BİRİM FİYATI TL:
1.	KAZILAR:		
1.1	El ile Yapılan Serbest Kazılar:		
a-	El ile yumuşak toprak kazılması	m3	72.00
b-	El ile sert toprak kazılması	m3	84.00
2.	MAKİNE İLE YAPILAN KAZILAR:		
2.1	Makina ile toprakta serbest kazı yapılması. (Tesviye v.s)	m3	10.00
2.2	Makina ile toprakta geniş derin kazı yapılması. (Bodrum gibi)	m3	11.00
2.3	Makina ile yumuşak ve sert toprakta münferit sömel kazısı.	m3	36.00
2.4	Makina ile orta sert kayanın kazılması.	m3	44.00
2.5	Makina ile çok sert kaya kazılması.	m3	70.00

2.6	Elle beton kırma	m3	225.00
2.7	Komprosörle beton kırma	m3	195.00
3.	DOLGULAR:		
3.1	Dolguya gelmiş,serilmiş her cins kazının elle tokmaklanıp sıkıştırılması.	m3	22.00
3.2	Taşıma toprak ile dolgu yapıp tokmaklayıp sıkıştırma.	m3	29.00
3.3	Stabilize malzemesi ile dolgu yapılıp sıkıştırılması	m3	34.00
3.4	Mekanik temel	m3	36.00
3.5	Gübreli toprak	m3	55.00
4.	KUM ÇAKIL SERİLMESİ:		
4.1	Temel tabanına el ile kum-çakıl serilmesi.	m3	55.00

5.	**TAŞ İŞLERİ:**		
5.1	Blokaj dizilmesi	m3	77.00
6.	**BETONLAR:**		
6.1	C14	m3	122.00
6.2	C16	m3	127.00
6.3	C18	m3	129.00
6.4	C20	m3	132.00
6.5	C25	m3	137.00
6.6	C30	m3	144.00
6.7	Köpük beton 500 dozajlı	m3	174.00
6.8	Köpük beton 700 dozajlı	m3	180.00

7.	**BETONARME BETONU İŞLERİ: (kalıp + demir + beton)**		
7.1	C14 (bahçe duvarı vb.)	m3	445.00
7.2	C16 (bahçe duvarı vb.)	m3	450.00
7.3	C18 (bahçe duvarı vb)	m3	452.00
7.4	C20	m3	556.00
7.5	C25	m3	561.00
7.6	C30	m3	568.00
7.7	C35	m3	584.00
7.8	C40	m3	600.00
7.9	C14 Blokaj üzeri ızgaralı betonarme betonu,subasman vb.	m3	305.00
7.10	C16 Blokaj üzeri ızgaralı betonarme betonu,subasman vb.	m3	310.00

8.	**BETONARME DEMİRLERİNİN İŞLENMESİ:** (Malzeme Dahil)		
8.1	0,10 - 0 ,24mm.lik betonarme demirlerin projesine göre bükülmesi ve yerine konması.	Ton	2,030.00
	2		
9.	**KALIP İŞLERİ:**		
9.1	**Düz Yüzeyli Beton ve Betonarme Kalıbı:**		
a-	Zemin kat ve üzeri beton ve betonarme kalıbı.	m2	20.00
b-	Merdiven basamağı kalıbı.	mt	32.00
9.2	**Çıplak Yüzeyli Beton ve Betonarme Kalıbı:**		
a-	Zemin kat ve üzeri beton ve betonarme kalıbı.	m2	28.00

10.	**DUVAR İŞLERİ VE BÖLÜCÜ ELEMANLAR**		
10.1	10 cm.kalınlıkta delikli tuğla ile duvar örülmesi.	m2	37.00
10.2	20 cm.kalınlıkta delikli tuğla ile duvar örülmesi.	m2	56.00
10.3	25 cm.kalınlıkta delikli tuğla ile duvar örülmesi.	m2	65.00
10.4	Beton blok (briket) 10 cm'lik duvar örülmesi.	m2	44.00
10.5	Beton blok (briket) 15 cm'lik duvar örülmesi.	m2	48.00
10.6	Beton blok (briket) 20 cm'lik duvar örülmesi.	m2	53.00
10.7	Kırma taş (Dağtaşı) duvar örme işleri.	m3	300.00
10.8	Kesme (sarı) taş ile 20 cm'lik duvar örülmesi.	m2	65.00
10.9	Gaz beton(ytong) ile duvar örülmesi -10-20-25- cm'lik.	m2	46,00-75,00-90,00
10.10	10 cm'lik 10x39x18,5 bims duvar	m2	50.00
10.11	15 cm'lik 15x39x18,5 bims duvar	m2	62.00
10.12	20 cm'lik 19x39x18,5 bims duvar	m2	68.00

12.	**SIVALAR:**		
12.1	Çimento+kum karışımı ile 1.ci el sıva yapılması.	m2	9.50
	4		
12.2	Çimento+Kireç+Kum karışımı harçla 2 el sıva yapılması.	m2	25.00
12.3	Kireç+Kum karışımı harçla 3.cü el sıva yapılması.	m2	10.00
12.4	Çimento+Kireç+Kum karışımı harçla 3 El sıva yapılması.	m2	35.00
12.5	Çimento+Kireç+Kum karışımı harçla 3 el tavan sıvası yapılması.	m2	40.00
12.6	Püskürtme sıva (Sprit) (Beyaz çimento) iskeleli.	m2	12.00
12.7	Püskürtme sıva (Sprit) (Beyaz çimento) iskelesiz.	m2	13.00
12.8	Çıplak beton veya perdahlanmış sıva yüzüne özel sıva yapılması. (Santeks,Rolteks, v.s.)	m2	23.00
12.9	Duvar yüzeylerine çimentolu sıva yapılması.	m2	35.00
12.10	Düzgün yüzeylere alçı sıva yapılması.	m2	33.00

12.5	Çimento+Kireç+Kum karışımı harçla 3 el tavan sıvası yapılması.	m2	40.00
12.6	Püskürtme sıva (Sprit) (Beyaz çimento) iskeleli.	m2	12.00
12.7	Püskürtme sıva (Sprit) (Beyaz çimento) iskelesiz.	m2	13.00
12.8	Çıplak beton veya perdahlanmış sıva yüzüne özel sıva yapılması. (Santeks,Rolteks, v.s.)	m2	23.00
12.9	Duvar yüzeylerine çimentolu sıva yapılması.	m2	35.00
12.10	Düzgün yüzeylere alçı sıva yapılması.	m2	33.00
12.11	Alçı sıva üzerine saten alçı sıva yapılması.	m2	11.00
12.12	Hazır Sıva.	m2	32.00

Appendix C: Ministry of Labour and Social Security Building, Soil Investigation Report

Temel Zeminine Ait Mekanik Parametreler:

1. İnceleme alanı **2. Derece** deprem bölgesindedir.
2. Temel zemin grubu **(C)**
3. Yerel zemin sınıfı **(Z_2)**
4. Zeminin spekturum karakteristik periyotları **T_A=0.15sn,**
   T_B=0.40sn
5. Kayma dalgası hızı **200-400 m/s** alınabilir.
6. Deprem hesaplarında kullanılacak etkin yer ivmesi katsayısı **A_0 = 0.30** 'dur.
7. Yatak Katsayısı **K_0=2000 ton/m^3**
8. Bina önem katsayısı **I=1.4**

Hatice Kaşer

Jeoloji Yüksek Mühendisi

Appendix D: The Case Studies Performance Results

Shear wall with 2 stories

JOINTS COLUMN OVER MINIMUM DAMAGE SHEAR FORCE DISTRIBUTION

STORY	(-X)		(+X)		(-Y)		(+Y)	
NO	IO	LS+CP+CC	IO	LS+CP+CC	IO	LS+CP+CC	IO	LS+CP+CC
2	100.	0.0	100.	0.0	100.	0.0	100.	0.0
1	99.2	0.8	99.2	0.8	100.	0.0	100.	0.0
Max.	100.			0.8				

Tunnel formwork 2 stories

JOINTS COLUMN OVER MINIMUM DAMAGE SHEAR FORCE DISTRIBUTION

STORY	(-X)		(+X)		(-Y)		(+Y)	
NO	IO	LS+CP+CC	IO	LS+CP+CC	IO	LS+CP+CC	IO	LS+CP+CC
2	100.	0.0	100.	0.0	100.	0.0	100.	0.0
1	100.	0.0	100.	0.0	100.	0.0	100.	0.0
Max.	100.							

Flat slab-beam 2 stories

JOINTS COLUMN OVER MINIMUM DAMAGE SHEAR FORCE DISTRIBUTION

STORY	(-X)		(+X)		(-Y)		(+Y)	
NO	IO	LS+CP+CC	IO	LS+CP+CC	IO	LS+CP+CC	IO	LS+CP+CC
2	100.	0.0	100.	0.0	97.9	2.1	98.0	2.0
1	100.	0.0	100.	0.0	100.	0.0	100.	0.0
Max.	100.					2.1		

Shear wall with 5 stories

JOINTS COLUMN OVER MINIMUM DAMAGE SHEAR FORCE DISTRIBUTION

STORY	(-X)		(+X)		(-Y)		(+Y)	
NO	IO	LS+CP+CC	IO	LS+CP+CC	IO	LS+CP+CC	IO	LS+CP+CC
5	100.	0.0	100.	0.0	100.	0.0	100.	0.0
4	100.	0.0	100.	0.0	100.	0.0	100.	0.0
3	100.	0.0	100.	0.0	100.	0.0	100.	0.0
2	99.4	0.6	99.4	0.6	99.6	0.4	100.	0.0
1	100.	0.0	100.	0.0	100.	0.0	100.	0.0
Max.	100.			0.6				

Tunnel formwork with 10 stories

COLUMNS SHEAR PERCENTAGE

STORY	(-X)				(+X)				(-Y)				(+Y)			
NO	IO	LS	CP	CC	IO	LS	CP	CC	IO	LS	CP	CC	IO	LS	CP	CC
11	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
10	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
9	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
8	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
7	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
6	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
5	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
4	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
3	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
2	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
1	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.3	0.7	0.0	0.0	99.3	0.7	0.0	0.0
Max.	100.													0.7		

JOINTS COLUMN OVER MINIMUM DAMAGE SHEAR FORCE DISTRIBUTION

STORY	(-X)		(+X)		(-Y)		(+Y)	
NO	IO	LS+CP+CC	IO	LS+CP+CC	IO	LS+CP+CC	IO	LS+CP+CC
11	100.	0.0	100.	0.0	100.	0.0	100.	0.0
10	100.	0.0	100.	0.0	100.	0.0	100.	0.0
9	100.	0.0	100.	0.0	100.	0.0	100.	0.0
8	100.	0.0	100.	0.0	100.	0.0	100.	0.0
7	100.	0.0	100.	0.0	100.	0.0	100.	0.0
6	100.	0.0	100.	0.0	100.	0.0	100.	0.0
5	100.	0.0	100.	0.0	100.	0.0	100.	0.0
4	100.	0.0	100.	0.0	100.	0.0	100.	0.0
3	100.	0.0	100.	0.0	100.	0.0	100.	0.0
2	100.	0.0	100.	0.0	100.	0.0	100.	0.0
1	100.	0.0	100.	0.0	99.3	0.7	99.3	0.7
Max.	100.							0.7

Tunnel formwork with 15 stories

COLUMNS SHEAR PERCENTAGE

STORY	(-X)				(+X)				(-Y)				(+Y)			
NO	IO	LS	CP	CC	IO	LS	CP	CC	IO	LS	CP	CC	IO	LS	CP	CC
16	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
15	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
14	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
13	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
12	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.0	0.0	0.0	100.	0.0	0.0	0.0
11	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
10	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
9	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
8	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
7	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
6	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
5	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
4	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
3	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
2	99.8	0.2	0.0	0.0	99.9	0.1	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
1	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.3	0.7	0.0	0.0	99.2	0.8	0.0	0.0
Max.	100.		0.0					0.0						0.8		

Tunnel formwork 20 stories

JOINTS COLUMN OVER MINIMUM DAMAGE SHEAR FORCE DISTRIBUTION

STORY	(-X)		(+X)		(-Y)		(+Y)	
NO	IO	LS+CP+CC	IO	LS+CP+CC	IO	LS+CP+CC	IO	LS+CP+CC
21	100.	0.0	100.	0.0	100.	0.0	100.	0.0
20	100.	0.0	100.	0.0	100.	0.0	100.	0.0
19	100.	0.0	100.	0.0	100.	0.0	100.	0.0
18	100.	0.0	100.	0.0	100.	0.0	100.	0.0
17	100.	0.0	100.	0.0	100.	0.0	100.	0.0
16	100.	0.0	100.	0.0	100.	0.0	100.	0.0
15	100.	0.0	100.	0.0	100.	0.0	100.	0.0
14	100.	0.0	100.	0.0	100.	0.0	100.	0.0
13	100.	0.0	100.	0.0	100.	0.0	100.	0.0
12	100.	0.0	100.	0.0	100.	0.0	100.	0.0
11	100.	0.0	100.	0.0	100.	0.0	100.	0.0
10	100.	0.0	100.	0.0	100.	0.0	100.	0.0
9	100.	0.0	100.	0.0	100.	0.0	100.	0.0
8	100.	0.0	100.	0.0	100.	0.0	100.	0.0
7	100.	0.0	100.	0.0	100.	0.0	100.	0.0
6	100.	0.0	100.	0.0	100.	0.0	100.	0.0
5	100.	0.0	100.	0.0	100.	0.0	100.	0.0
4	100.	0.0	100.	0.0	100.	0.0	100.	0.0
3	100.	0.0	100.	0.0	100.	0.0	100.	0.0
2	100.	0.0	100.	0.0	100.	0.0	100.	0.0
1	100.	0.0	100.	0.0	99.2	0.8	99.2	0.8
Max.	100.							0.8

COLUMNS SHEAR PERCENTAGE

STORY	(-X)				(+X)				(-Y)				(+Y)			
NO	IO	LS	CP	CC	IO	LS	CP	CC	IO	LS	CP	CC	IO	LS	CP	CC
21	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0
20	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
19	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
18	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
17	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
16	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
15	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
14	100.	0.0	0.0	0.0	99.9	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
13	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
12	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
11	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
10	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.0	0.0	0.0	100.	0.0	0.0	0.0
9	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
8	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
7	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
6	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
5	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
4	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
3	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
2	99.8	0.1	0.0	0.1	99.8	0.2	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0
1	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.2	0.8	0.0	0.0	99.2	0.8	0.0	0.0
Max.	100.			0.1			0.0							0.8		

Tunnel formwork 25 stories

JOINTS COLUMN OVER MINIMUM DAMAGE SHEAR FORCE DISTRIBUTION

STORY NO	(-X) IO	(-X) LS+CP+CC	(+X) IO	(+X) LS+CP+CC	(-Y) IO	(-Y) LS+CP+CC	(+Y) IO	(+Y) LS+CP+CC
26	100.	0.0	100.	0.0	100.	0.0	100.	0.0
25	100.	0.0	100.	0.0	100.	0.0	100.	0.0
24	100.	0.0	100.	0.0	100.	0.0	100.	0.0
23	100.	0.0	99.9	0.1	100.	0.0	100.	0.0
22	100.	0.0	100.	0.0	100.	0.0	100.	0.0
21	100.	0.0	100.	0.0	100.	0.0	100.	0.0
20	100.	0.0	100.	0.0	100.	0.0	100.	0.0
19	100.	0.0	100.	0.0	100.	0.0	100.	0.0
18	100.	0.0	100.	0.0	100.	0.0	100.	0.0
17	100.	0.0	100.	0.0	100.	0.0	100.	0.0
16	100.	0.0	100.	0.0	100.	0.0	100.	0.0
15	100.	0.0	100.	0.0	100.	0.0	100.	0.0
14	100.	0.0	100.	0.0	100.	0.0	100.	0.0
13	100.	0.0	100.	0.0	100.	0.0	100.	0.0
12	100.	0.0	100.	0.0	100.	0.0	100.	0.0
11	100.	0.0	100.	0.0	100.	0.0	100.	0.0
10	100.	0.0	100.	0.0	100.	0.0	100.	0.0
9	100.	0.0	100.	0.0	100.	0.0	100.	0.0
8	100.	0.0	100.	0.0	100.	0.0	100.	0.0
7	100.	0.0	100.	0.0	100.	0.0	100.	0.0
6	100.	0.0	100.	0.0	100.	0.0	100.	0.0
5	100.	0.0	100.	0.0	100.	0.0	100.	0.0
4	100.	0.0	100.	0.0	100.	0.0	100.	0.0
3	100.	0.0	100.	0.0	100.	0.0	100.	0.0
2	100.	0.0	100.	0.0	100.	0.0	100.	0.0
1	100.	0.0	100.	0.0	99.1	0.9	99.1	0.9
Max.	100.							0.9

Tunnel formwork 28 stories

COLUMNS SHEAR PERCENTAGE

STORY NO	(-X) IO	(-X) LS	(-X) CP	(-X) CC	(+X) IO	(+X) LS	(+X) CP	(+X) CC	(-Y) IO	(-Y) LS	(-Y) CP	(-Y) CC	(+Y) IO	(+Y) LS	(+Y) CP	(+Y) CC
29	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.5	0.5	0.0	0.0	99.2	0.8	0.0	0.0
28	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
27	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.9	0.1	0.0	0.0
26	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
25	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.9	0.1	0.0	0.0
24	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.8	0.2	0.0	0.0	99.9	0.1	0.0	0.0
23	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.7	0.2	0.0	0.0	99.9	0.1	0.0	0.0
22	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.8	0.2	0.0	0.0	99.9	0.1	0.0	0.0
21	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.8	0.2	0.0	0.0	99.9	0.1	0.0	0.0
20	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.8	0.2	0.0	0.0	99.9	0.1	0.0	0.0
19	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.8	0.2	0.0	0.0	99.9	0.1	0.0	0.0
18	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.8	0.2	0.0	0.0	99.8	0.2	0.0	0.0
17	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.8	0.2	0.0	0.0	99.8	0.2	0.0	0.0
16	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0	99.8	0.1	0.0	0.0	99.8	0.2	0.0	0.0
15	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.8	0.1	0.0	0.0	99.8	0.2	0.0	0.0
14	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.8	0.1	0.0	0.0	99.8	0.2	0.0	0.0
13	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.8	0.1	0.0	0.0	99.8	0.2	0.0	0.0
12	100.	0.0	0.0	0.0	99.9	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.8	0.2	0.0	0.0
11	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.8	0.2	0.0	0.0
10	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.8	0.2	0.0	0.0
9	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.9	0.1	0.0	0.0
8	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	99.9	0.0	0.0	0.0
7	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
6	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
5	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.1	0.0	0.0	100.	0.0	0.0	0.0
4	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.9	0.0	0.0	0.0	100.	0.0	0.0	0.0
3	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0
2	99.7	0.3	0.0	0.0	99.7	0.2	0.0	0.0	99.9	0.1	0.0	0.0	99.9	0.1	0.0	0.0
1	100.	0.0	0.0	0.0	100.	0.0	0.0	0.0	99.1	0.9	0.0	0.0	99.1	0.9	0.0	0.0
Max.	100.							0.0		0.9	0.0					

JOINTS COLUMN OVER MINIMUM DAMAGE SHEAR FORCE DISTRIBUTION

STORY NO	(-X) IO	(-X) LS+CP+CC	(+X) IO	(+X) LS+CP+CC	(-Y) IO	(-Y) LS+CP+CC	(+Y) IO	(+Y) LS+CP+CC
29	100.	0.0	100.	0.0	99.9	0.1	100.	0.0
28	100.	0.0	100.	0.0	100.	0.0	100.	0.0
27	100.	0.0	100.	0.0	99.9	0.1	100.	0.0
26	100.	0.0	100.	0.0	100.	0.0	100.	0.0
25	100.	0.0	100.	0.0	100.	0.0	99.9	0.1
24	100.	0.0	100.	0.0	100.	0.0	99.9	0.1
23	100.	0.0	100.	0.0	99.9	0.1	99.9	0.1
22	100.	0.0	100.	0.0	99.8	0.2	99.9	0.1
21	100.	0.0	100.	0.0	99.9	0.1	100.	0.0
20	100.	0.0	100.	0.0	99.9	0.1	99.9	0.1
19	100.	0.0	100.	0.0	99.9	0.1	99.9	0.1
18	100.	0.0	100.	0.0	99.9	0.1	99.9	0.1
17	100.	0.0	100.	0.0	99.9	0.1	99.9	0.1
16	100.	0.0	100.	0.0	99.9	0.1	99.9	0.1
15	100.	0.0	100.	0.0	99.9	0.1	99.9	0.1
14	100.	0.0	100.	0.0	99.9	0.1	99.9	0.1
13	100.	0.0	100.	0.0	99.9	0.1	99.9	0.1
12	100.	0.0	100.	0.0	99.9	0.1	99.9	0.1
11	100.	0.0	100.	0.0	99.9	0.1	99.9	0.1
10	100.	0.0	100.	0.0	99.9	0.1	100.	0.0
9	100.	0.0	100.	0.0	100.	0.0	100.	0.0
8	100.	0.0	100.	0.0	100.	0.0	100.	0.0
7	100.	0.0	100.	0.0	100.	0.0	100.	0.0
6	100.	0.0	100.	0.0	100.	0.0	100.	0.0
5	100.	0.0	100.	0.0	100.	0.0	100.	0.0
4	100.	0.0	100.	0.0	100.	0.0	100.	0.0
3	100.	0.0	100.	0.0	100.	0.0	100.	0.0
2	100.	0.0	100.	0.0	100.	0.0	100.	0.0
1	100.	0.0	100.	0.0	99.1	0.9	99.1	0.9
Max.	100.					0.9		