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M.Sc. in Civil Engineering

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UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

INFLUENCE OF OPENINGS IN SHEAR WALL ON LATERAL LOAD CARRYING CAPACITY OF RC FRAME SYSTEMS

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IN

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BY

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Influence of Openings in Shear Wall on Lateral Load Carrying Capacity of RC Frame Systems

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Supervisor

Assoc. Prof. Dr. Esra METE GÜNEYİSİ

by

Pshdar Rasul ISMAEL

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This is to certify that we have read this thesis and that in our consensus opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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Pshdar Rasul ISMAEL

ABSTRACT

INFLUENCE OF OPENINGS IN SHEAR WALL ON LATERAL LOAD CARRYING CAPACITY OF RC FRAME SYSTEMS

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M.Sc. in Civil Engineering
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Shear walls are specially designed as structural walls included in the buildings to withstand horizontal forces induced by wind and earthquake. Among the factors which affect the capacity of seismic response of reinforced concrete (RC) shear walls, an important role is played by openings. In many shear walls, a regular pattern of openings has to be provided due to various functional requirements such as windows in external walls, doors, corridors in internal walls and service ducts. The scope of the present study was to investigate the influence of the various size of openings in the shear wall on the nonlinear static and dynamic responses of RC buildings. For this, as a case study, the three-dimensional (3D) model and analysis of the 5 story RC shear wall buildings with 3 bays in x-direction and 5 bays in y-direction were carried out by using ETABS 2015 software. The comparative results were obtained in terms of capacity curve, displacement, storey drift, displacement time history, and base shear time history. Results revealed that openings with an area up to 11.1% of the wall area yielded minor effects on the seismic response of RC wall-frame structural systems but higher opening ratios eventually resulted in reducing the overall performance of the case study structures.

Keywords: Opening; Reinforced concrete building; Shear wall; Static analysis; Time history analysis.

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ÖZET

BETONARME ÇERÇEVE SİSTEMLERİN YANAL YÜK TAŞIMA KAPASİTESİNE PERDE DUVAR BOŞLUKLARININ ETKİSİ

ISMAEL, Pshdar Raul
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Danışman: Doç. Dr. Esra METE GÜNEYİSİ
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Perde duvarlar, rüzgar ve deprem kaynaklı yatay kuvvetlere dayanacak şekilde binalarda bulunan ve özel olarak tasarlanmış yapısal duvarlardır. Betonarme perde duvarlarının sismik tepki kapasitesini etkileyen faktörlerden birisi olan duvardaki boşluk miktarı perde duvarın davranışında önemli bir rol oynamaktadır. Pek çok perde duvarda, dış duvarlardaki pencereler, kapılar, iç duvarlardaki koridorlar ve servis kanalları gibi çeşitli fonksiyonel gereklilikler nedeniyle düzenli bir boşluğa ihtiyaç duyulmaktadır. Bu çalışma kapsamında, betonarme binaların doğrusal olmayan statik ve dinamik tepkileri üzerinde perde duvarındaki çeşitli boşlukların etkisi araştırılmaktadır. Yapıların üç boyutlu (3D) modeli ve analizi ETABS 2015 yazılımı kullanılarak gerçekleştirildi. Karşılaştırmalı sonuçlar, kapasite eğrisi, yer değiştirme, kat ötelemesi, zamand bağlı yerdeğiştirme ve zamana bağlı taban kesme kuvveti açısından elde edilmiştir. Sonuçlar, duvar alanının % 11.1 'e kadar bir alana sahip boşlukların betonarme duvar çerçeve sistemlerin sismik tepkisini az etkilediğini, ancak daha yüksek boşluk oranlarında yapıların performansının olmsuz yönde etkilediğini göstermiştir.

Anahtar Kelimeler: Boşluk; Betonarme bina; Perde duvar; Statik analiz; Zaman tanım alanında analiz.

To My Parents

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First praise is to Allah, the Almighty, on whom ultimately we depend for sustenance and guidance. I am ever grateful to God, the Creator and the Guardian, and to whom I owe my very existence.

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TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

LIST OF SYMBOLS/ABBREVIATIONS

ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
ATC	Applied Technology Council
CP	Collapse Prevention
FEMA	Federal Emergency Management Agency
g	Acceleration of Gravity
IO	Immediate Occupancy
IS	Indian Standard
LFEM	Introduction to Finite Element Methods
LS	Life Safety
PBEE	Performance Based Earthquake Engineering
P-M-M	Axial Force-Biaxial Moment Hinges
RC	Reinforced Concrete
UBC	Uniform Building Code
LATBSDC	Los Angeles Tall Building Structural Design Council

CHAPTER 1

1. INTRODUCTION

The main purpose of all types of RC frame systems used in the building type of structures is to support gravity loads like dead load, live load and snow load. In addition, RC buildings are also exposed to lateral loads caused by earthquake and wind load. The structure should have sufficient strength, ductility and stiffness so they can react satisfactorily to these loads (Akis, 2004).

An earthquake is a sudden motion or shaking of the Earth's crust, caused by the abrupt release of slowly accumulated strain stored in the rocks below the earth surface. Generally, an earthquake is an oscillating motion produced due to release of strain energy beneath or within the crust of earth surface (Mo and Kuo, 1998). Recent earthquakes have caused severe social disruption in the vicinity of the epicenter, particularly due to structural failures causing damage to the people in urban area where the structures are concentrated (Seo et al., 2015).

The disastrous effects of past earthquakes on life have increased the requirement for a close review of the lateral load resisting systems and to adopt innovative and modified lateral load resisting systems for effective and efficient mitigation of earthquake forces (Rajesh and Prasad, 2014). Lateral forces generated either by the wind blowing against the building or by the inertial forces caused by ground shaking which tend to snap the building into shear and push it into bend. These types of forces can be resisted by using shear wall system, which is one of the most efficient methods to ensure the lateral stability of tall buildings (Wahid, 2007).

Shear walls are especially designed structural walls included in the buildings to withstand horizontal forces induced in the plane of the wall by wind, earthquake and other forces. Shear wall has high stiffness and strength which can be used to simultaneously resist large horizontal loads and support gravity loads (Chittiprolu and Kumar, 2014). When a high rise RC Structure is designed without shear wall the beam and column sizes are large and so many problems occur at the joints and due to this, it is difficult to place and vibrate the concrete at such places. Shear walls commonly start at the foundation level and are continuous throughout the building height. They are generally provided along both length and width of the building and are located at the sides of the buildings or arranged in the form of core (Aarthi and Kumar, 2015).

Among the factors which effect the capacity of seismic energy dissipation of reinforced concrete shear walls, an important role is played by openings. In many shear walls a regular pattern of openings has to be provided due to various functional requirements such as windows in external walls or doors ways or corridors in internal walls and service ducts (Merin, 2013).

The opening sizes, locations and shapes of openings influence their seismic performance by reducing the stiffness and the strength of the shear wall. The size of openings may vary depending on purposes of the openings. In most buildings, size of openings in shear wall are made without considering of their effect on the structural behavior of the building (Husain, 2011; Kim and Lee, 2003). However, the opening sizes have an adverse effect on seismic responses of frame shear wall structures. It is seen that small opening in shear walls do not have much effect on the strength, stiffness, lateral deflections as well as its deformation capacity, whereas larger openings produce larger effects (Sharma and Amin, 2015). Relative stiffness of shear walls is important since lateral forces are distributed to the individual shear wall according to their relative stiffness. Simplified methods for stiffness of shear walls with openings are recommended in several design guidelines. For a safe design, it is necessary to know the effects of openings sizes and configurations in shear wall on stiffness, strength and behavior of structural system so that a suitable configuration of openings in shear walls can be made (Rokhgar, 2014).

1.1 Objectives of the Thesis

The main objective of this study is to investigate the influence of various size of openings in shear wall on the nonlinear static and dynamic responses of RC frame systems with five different size of openings in shear wall are considered, such as, (a) opening (0.5m x 0.5m), (b) opening (1m x 1m), (c) opening (1.5m x 1.5m), (d) opening (2m x 2m) and (e) opening (2.2m x 2.2m). The three dimensional (3D) model of the structures were performed by using finite element analysis software ETABS. The results of the analyses were obtained in terms of capacity curve, displacement, storey drift, displacement time history, base shear time history, etc. The results of the shear wall with openings are compared with the solid shear wall.

1.2 Outline of the Thesis

Chapter 1-Introduction: The aim and scope of the thesis were presented.

Chapter 2-Literature review: Previous studies based on the scope of the study have been reviewed and maintained. For this, the research and development on the nonlinear behavior of the reinforced concrete buildings in the literature were given. Reinforced concrete shear wall, especially reinforced concrete shear walls with different size of openings were outlined.

Chapter 3-Case study: This chapter provided an explanation of the analytical modeling of the reinforced concrete frame system. Furthermore, the methodology for the analysis and design of the structures was summarized.

Chapter 4-Results and discussion: Results obtained from the nonlinear static analysis and nonlinear dynamic analysis for the RC frame system with different size of openings in shear wall were given. Discussion on the results of the analysis was described in this chapter.

Chapter 5-Conclusions: The conclusions built on the results or these comparative investigations were provided in this section.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Reinforced concrete frame building

In many countries, reinforced concrete (RC) buildings are considered as one of the most general buildings due to the availability of raw materials of reinforced concrete (cement, sand, steel and water), and easy in construction (Nilson, 1997). Reinforced concrete is a composite material includes of concrete and steel. Concrete has high compressive strength and low tensile strength while steel reinforcement provides the tensile strength lacking in the concrete. Also, steel reinforcing is capable of resisting compression forces and is used in columns. However, it is used mainly to improve the tensile strength of the structural members. Concrete is the most popular materials utilized to construct buildings that can be formed in different shapes and desired cross-sections. There are several advantages of using reinforced concrete for building construction (McCormac and Brown, 2015). For example, reinforced concrete has high compressive strength, great resistance to the actions of water and fire, very rigid and low-maintenance material compared with other construction materials. RC structure has a very long service life. In addition, RC structures can be used indefinitely without decreasing their carrying capacity. It is economical material that can be used to cast into variety of shapes from slabs, beams, columns, arches, and shells. In most parts of the world, reinforced concrete benefits from low-cost local materials (sand, gravel and water) and needs relatively small amounts of cement and steel. In recent decades extensive studies have been carried out on the seismic performance of multi-storey structures. However, little is known about the seismic behavior of structures in areas with low seismicity. Low to medium strength RC structures built in most of these regions are designed primarily for combinations of gravity and wind loads. Thus, throughout an unexpected seismic excitation, seismic qualifications of the building have become highly important, thus nonlinear properties of each component of the structure should be determined to design reinforced concrete structures for resisting earthquake (Kuang and Atanda, 2005). Some examples of RC buildings are given in Figures 2.1-2.3.

Figure 2.1 NCNB Tower in Charlotte, North Carolina, completed 1991 (McCormac and Brown, 2015)

Figure 2.2 Trump Tower of Chicago (MacGregor et al., 1997)

Figure 2.3 Tunnel form construction technique and its special formwork system (Balkaya and Kalkan, 2004)

In fact, after strong earthquakes, in many buildings occur different degrees of damage and some collapse. One of the most difficult tasks or the post-earthquake inspection is to assess and quantify the seismic damage or to assess the seismic safety and further usability of the remaining building stock. The classification of the damages, empirically at their base, differs from one country to another or from an engineering school to another. The necessity for a reliable way to mitigate the hazards to life and property during and in the aftermath of an earthquake. Thus, a better understanding of various degrees of damage and control of such damage by accurate design of structures becomes an essential task to the engineering community (Reinhorn, 1992).

Numerous numerical models and techniques for the analysis and design of reinforced concrete structures have been developed and there are numerous examples of their implementation and application in the literature. On the other hand, the advent of powerful computers, as well as microcomputers with parallel processing, with an exciting perspective for the development of an interactive design system, offers the possibility that such techniques can be used efficiently to solve complex practical problems. Though, it is proper to say that the numerical capability is nowadays in advance of the knowledge of concrete constitutive behaviour (Bicanic and Mang. 1990).

2.2 Nonlinear response of reinforced concrete building

Elastic analysis is commonly used in designing buildings for seismic resistance, at the same time it would experience significant inelastic deformations under severe earthquakes. The purpose of the realistic behavior of the building structures are explained in recent performance based design procedures. It is paramount important to have the knowledge of building structure response beyond elastic range to obtain many vital features which control the seismic performance of building structures in large earthquakes. During the nonlinear analysis, strength, structure capacity, performance levels, hinge properties, and failure mechanism are established (Vecchio and Balopoulou, 1990).

Vecchio and Balopoulou (1990) studied experimentally by using large-scale reinforced concrete frames to determine which factors were effecting the nonlinearity of reinforced concrete frame under short-term loading condition. The test results showed that frame behavior greatly influenced by second-order such as geometric nonlinearities, material nonlinearities, shear deformation, membrane action, concrete shrinkage, and torsion stiffening effects. Also for further improvement, it was necessary to consider another aspect of behavior such as failure mechanism, deflection response, and ultimate capacity. In their study, a large-scale one-span, two-story plane frame with span 3500 mm center to center, 2000 mm height of the story, the frames members were 300 mm wide and 400 mm deep with heavy reinforced concrete base. The material properties (concrete and longitudinal reinforcement in their study experimentally determined as shown in Figures 2.4 standard cylinder tests of 150 mm x 300 mm dimensions were taken, from the above stress-strain relation curve, the compressive strength of the concrete was 29 MPa tested by the test machine using a stroke rate of 6.67 x 10^{-3} mm/s after curing 25 days for the concrete. Reinforcement rebar of 20 mm diameter used as longitudinal reinforcement for all members with yield stress of 418 MPa, ultimate stress of 596 MPa, and have modulus of elasticity of 192600 MPa. The test observations showed that frame nonlinear behavior depended on the material nonlinearities and geometric nonlinearities.

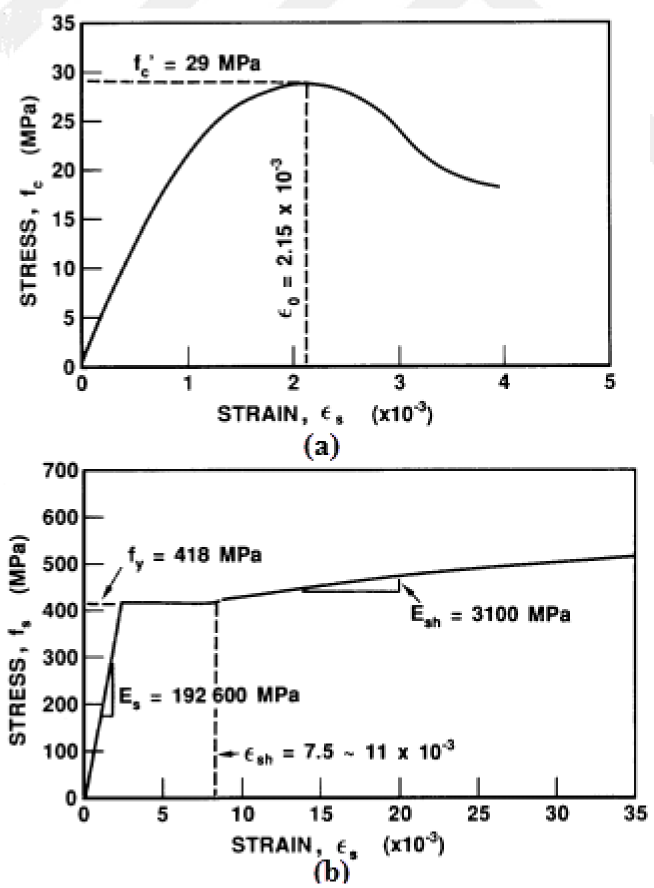


Figure 2.4 Material properties: (a) concrete and (b) longitudinal reinforcement (Vecchio and Balopoulou, 1990)

Gergana (2016) studied nonlinear analysis of a RC frame to study the structural behavior under earthquake of a RC frame. Two commonly used performance based earthquake engineering (PBEE) procedures are considered incremental dynamic analysis and static pushover analysis. Furthermore, the analyses are carried out taking different variable loading. Finally, the two methods were compared so as to outline the advantages of them and to estimate their capability in the modern structural design. The results predicted that the target displacement in pushover analysis is obtained when the building is subjected to a loading which is two times smaller than the one predicted by incremental dynamic analysis. The final conclusion that The pushover analysis appears to give accurate results compared to the incremental dynamic analysis in the elastic stage.

Duan and Hueste (2012) investigated on a typical 5-story reinforced concrete frame building conferring to the requirements of the present Chinese seismic code (GB50011- 2010). Seven earthquake acceleration records were adapted for conformity with the accepted design spectrum. Nonlinear dynamic time history and nonlinear static analysis were estimated for the frame structure. In their study, results showed that the building frame designed by GB50011-2010 provided the post-yield behavior and response projected by the code and contented the story drift and maximum plastic rotation limits recommended by ASCE 41-06. On the other hand, the pushover analysis revealed the potential for the first story mechanism under substantial lateral demands.

Bansal (2011) studied the non-linear response of four-storied RC frame using finite element SAP2000 tool. The loading was carried out with the aim of taking into account the relative importance of some factors in the nonlinear analysis of RC structures. The structure tested in their study was an existing office building. The part had certain eccentricities and symmetric in the plan as shown in Figure 2.5. Furthermore, the frame sections along the floor were changed as in the case of the original reality structure. In their study observed that the rapid degradation has been occurred in joints of the RC frame structure. Moreover, the storey deflections rapidly increased in nonlinear zone. Severe damage to the joints in the lower floors have occurred while moderate damage has been detected on the first and second floors. Small damages were observed on the roof level. It has been detected that the top storey experienced major damages in this case opposite to the case of frame.

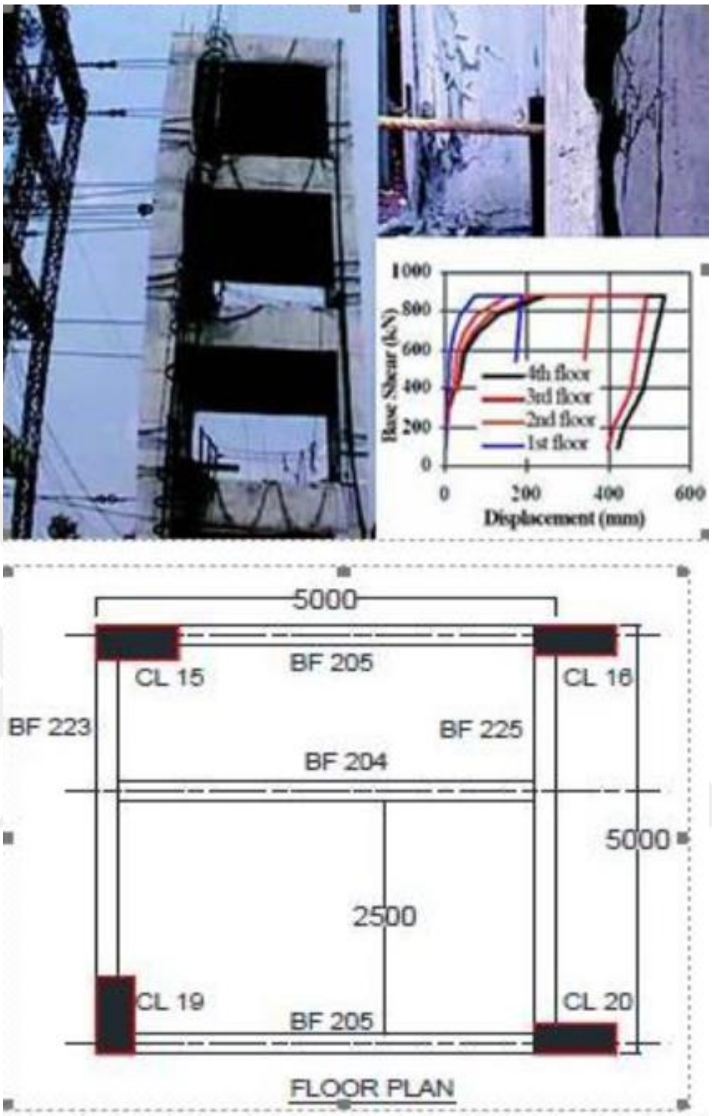


Figure 2.5 Roof plan and elevation of the structure (Bansal, 2011)

2.3 Reinforced concrete shear wall

Shear walls are deep relatively thin vertically reinforced concrete elements. Generally, they are used in the structures to withstand the effects of gravity loads and storey shears. Reinforced concrete shear walls are vertical structural members in the lateral force resisting system that transmit lateral loads from the diaphragm above to the foundation (Borra et al., 2015).

Chandurkar and Pajgade (2013) studied seismic performance of four 10-stories reinforced concrete building with and without shear wall to estimate effectiveness of shear wall. One model is a bare frame structure and other three models are dual-type structure system are generated using software ETABS. Buildings subjected to a seismic load situated in zone II, zone III, zone IV, and zone V. Some parameters such as lateral displacement and story drift are calculated. In their study, it is appropriate that the shear wall is economical in high-rise RC buildings. Also, it is shown that providing shear walls at sufficient locations significantly decreases the displacements caused by seismic loads.

Azam and Hosur (2013) studied seismic response assessment of six-storey, twelve-story, twenty-four-story, and thirty-six story moment resist RC frame buildings with shear walls with the plans of 30 mx 20 m. Bay length is 5m in both longitudinal and transverse directions and floor height of 3m are considered in their study. The structural configurations of the shear walls are shown in Figure 2.6. The finite element ETABS software was used for the analysis using pushover analysis and response spectrum analysis. In their study, results observed that the shear walls have significant effect on lateral strength whereas it has less influence on lateral stiffness in tall buildings. On the other hand, providing shear walls have substantial effect on lateral stiffness whereas it has less effect on lateral strength in buildings of shorter height.

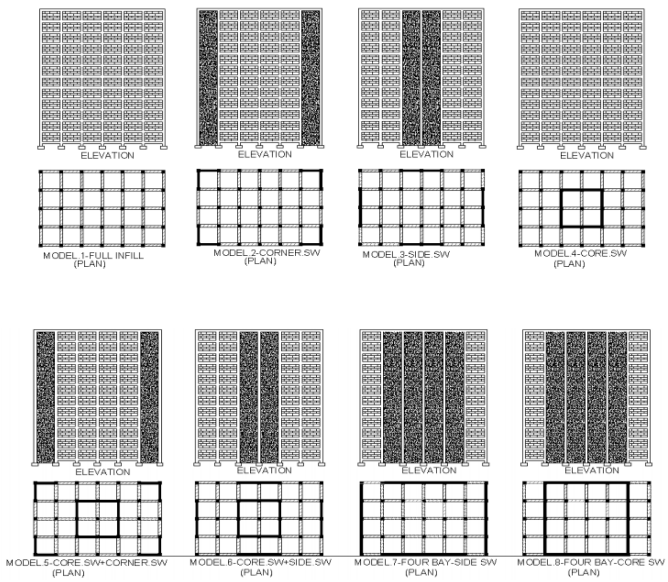


Figure 2.6 Structural configurations of the frame and shear walls (Azam and Hosur, 2013)

Anshuman et al. (2011) prepared a paper to conclude the shear wall position in multistory building based on the elastic and elasto-plastic behaviour. A seismic load is applied to a fifteen stories RC building situated in seismic zone IV. SAP2000 and STAAD Pro software were used to analysis both of the Elastic and Elasto-Plastic. Bending moment, shear forces, and story drift were calculated, and the position of the shear wall was determined based on the above divisions. Figure 2.7 shows the plan of the building without shear wall which has been considered to perform their study.

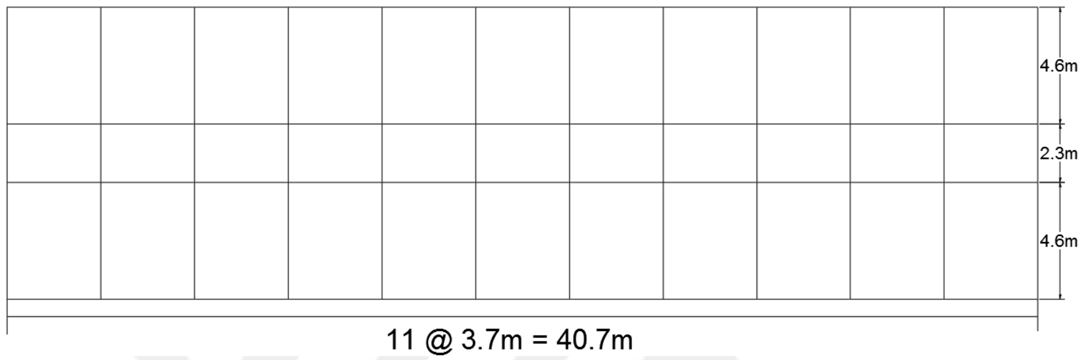


Figure 2.7 Plan of the building (Anshuman et al., 2011)

The study forwarded by Anshuman et al., (2011) indicates position of the shear wall, which is based on elastic and inelastic analyzes. In their study, after the shear wall was provided in the shorter direction, it was illustrated that the top deflection was decreased and was reached within the allowable deflection.

Kumar et al. (2014) investigated the improvement of RC shear walls and their behavior against lateral loads. In their research, the application of cyclic load tests and the behavior of different kinds of shear walls in the cyclical use of loads was carried out. Previous investigators studied various parameters such as stiffness, story drift, development forces in RC buildings, and detect perfect location of shear wall position in RC buildings. Results from their research shown that the tall buildings can be affected by lateral forces like earthquake. Thus, shear walls can be used for resisting lateral load and also for retrofitting of structures. On the other hand, the results indicate that internal shear walls are more efficient than external shear walls.

Suresh and Ananth (2015) examined the optimum location of shear wall in high rise reinforced concrete buildings under lateral loading. In their study, the optimum location of shear wall has been investigated by analyzing three different models.

Model1 is bare frame structural system and other two models are dual type RC structural system with central core wall and corner shear wall. An earthquake load is calculated as per IS 1893 (PART-1)-2002 and applied to irregular plan of building (G+20) reinforced concrete building on medium (ZONE-II) and severe (ZONE-V). ETABS software is used for the analysis of structure by Equivalent Static Lateral Force Method. Results showed that the plan without shear wall gives more displacement and more drift compare to plan with shear wall. Furthermore, providing shear wall along four edges can reduce storey displacement, storey drift, storey shear, and also can increase strength and stiffness of the structure. Therefore, they concluded that by providing shear wall along four edges is found to be optimum position of shear wall.

Seo and Davaajamts (2015) studied the seismic response of a twelve-storey reinforced concrete moment resisting frame structure with shear walls situated in zone IV according to such seismic design guidelines as (FEMA) and seismic building codes including (LATBSDC) code. Finite element software SAP2000 was used for create the 3D model of the RC structure. Response spectrum and time-history analysis method were used for the structure seismic analysis and calculate displacement and storey drift ratios of the RC frame structure. Results revealed that the maximum displacements increased throughout the height of the building as the story height of the building was higher for both methods. On the other hand, the distributions of story drift ratios for both methods are considerably different from maximum displacements because story drift ratios differ depending on story displacements and heights. As a consequence, from their study, the time history analysis provided higher values in maximum displacements and story drift ratios compared to the response spectra analysis method.

Rahangdale and Satone (2013) studied influence of shear wall location of six storey RC building situated in zone IV. Some preliminary examinations, which are analyzed by changing the different position of the shear wall, are presented. The analysis and modeling is done by using software STADD-pro. It is observed that creating shear walls damages due to effect of lateral forces due to earthquake and high winds can be decreased. Shear walls construction will provide higher stiffness to the buildings there by reducing the damage to structure and its contents.

Chittiprolu and Kumar (2014) prepared a paper on a high-rise RC building with and without shear wall to recognize the lateral displacement, story drifts, and torsion effects on the buildings. A high-rise building of 16-story having the plan dimension of 24.38 m x 25.98 m with a typical floor height 3m is used for the analysis. The superstructure is modelled using standard software package ETABS. From the results in their study, it is concluded that shear walls are more resistant to wind and earthquake loads in a high rise structures. In addition, shear walls can be used to decrease the effects of torsion of the buildings.

Akil and Mohd (2015) made a study to consider the influence of shear wall in RC frame structures, by comparing the different results for the building designed as per Indian codes for the frame with shear wall and frame having no shear wall. Also, the study has been made to know the behavior of nonlinear layered shear wall when it is in the structure and without the structure and its performance point is estimated. The buildings were designed by using SAP 2000 software tool. From their study, it has been predicted that shear wall increases the lateral load carrying capacity of the frame structure in comparison to the frame without shear wall. It has been also showed that the shear walls reduced the displacement of the frame structure compared to the frame with having no shear wall.

2.4 Shear wall with opening

There are many cases in which RC buildings need to provide openings in shear walls for different purposes. Most of the time, it is predictable to have shear walls with openings. These openings may be required for architectural purposes such as windows and doors, or for mechanical, electrical and plumbing reasons. For a safe design it is essential to know the influences of openings in RC shear wall on strength, stiffness, in addition to seismic responses of structural frame system (Merin Mathews, 2013).

Satpute and Kulkarni (2013) studied seismic performance of 10-story reinforced concrete shear wall building with different sizes of the openings and without openings. The analysis of the buildings was carried out by two nonlinear approaches (time history analysis and pushover analysis method). All procedures include concepts based on performance pay more attention to damage control. The analysis of reinforced concrete shear wall buildings with various size of openings was performed by using

SAP2000 software. In their study, the assessment of the models has been presented for different parameters in terms of displacement, story drift, and base shear. Results revealed that the values of seismic performance with respect to base shear, story displacement, and story drift for these methods are found to be increasing by increasing opening sizes in the RC shear wall. It is also indicated that the difference in the top displacement increase by increasing opening size in the RC shear wall for the both methods compared to model with having no openings.

Sharma and Amin (2015) studied the influences of the 30 storey RC buildings with various size of openings in shear walls to study the seismic responses of the multi-storey buildings. The plan of the RC building is shown in Figure 2.8. The lateral displacements and storey drift of the buildings with periphery shear wall and shear wall having different size of openings are calculated, for two cases (i) without including the reduced volume/area of the shear wall opening (ii) the volume of shear wall reduced due to opening is incorporated in the adjacent boundary elements by increasing the dimension of boundary elements. The results thus achieved are compared with bare frame to evaluate the effects of openings on the overall responses of buildings. The analyses of buildings are carried out using software E-TABS using response spectrum and time history analysis method. Results observed that the provisions of openings in RC shear walls without including the volume of the shear wall reduced because of opening, losses the stiffness and strength of the building in lateral direction and in turn the displacement and storey drift of the building increases. It was detected that displacement and drift are not only dependent on the size of opening, but shape of opening also plays a major role when the aspect ratio is large. The overall lateral displacement of the frame and inter-storey drift increases due to the provisions of different size of openings in shear walls as compared to frames without openings in shear walls. It has also indicated that in which volume of shear wall reduced due to opening is incorporated by increasing the size of the adjacent boundary elements, stiffness tends to increase compared to the first case. Therefore, the overall displacement and storey drift of the buildings decreases as compared to first case.

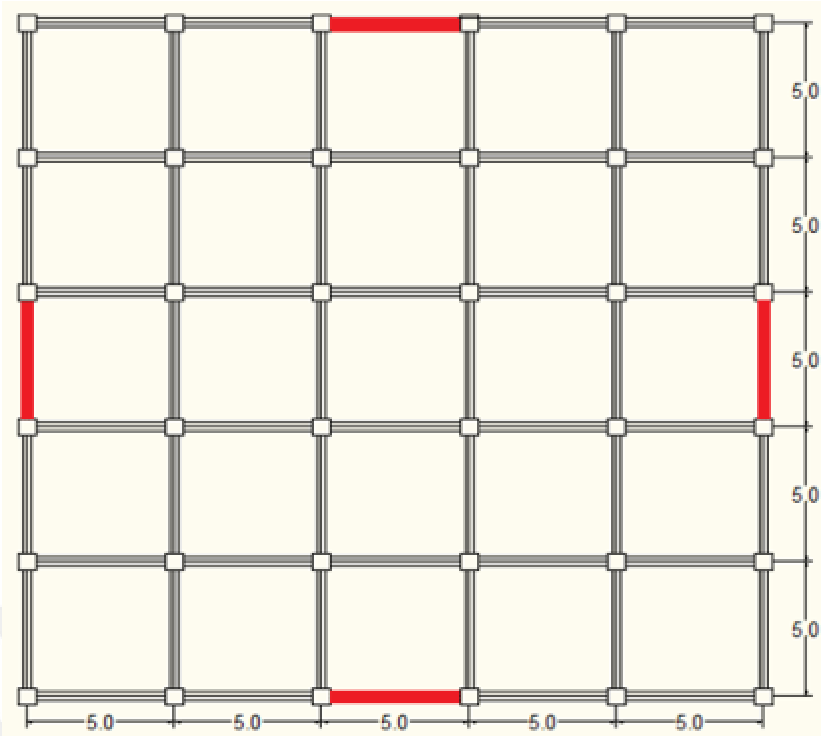


Figure 2.8 Building Plan (Sharma and Amin, 2015)

Gupta and Pande (2014) studied influence of location of shear wall and openings on behavior of RC structural frames. 10 storey reinforced concrete building with floor height 3m subjected to seismic loading located in Zone II, III, IV, and V has been considered. STAAD Pro software has been used as a tool to model and analysis of the building. Displacements, bending moments, and axial forces were observed for six different columns to observe the effect of the position and openings in the shear wall. The results showed that the shear wall significantly reduces the lateral displacements in the structures. Shear walls must be brought in both directions since a shear wall in one direction can influence in an increase in a moment in the transverse direction. The provision of additional shear walls above the optimum requirement cannot be suitable for the limitation of displacements. However, it can affect higher costs and unwanted gravitational forces. There is a slight reduction in the lateral displacement when the shear walls are extended beyond the floor to the foundation level. It has also been shown that with the increase in openings in the shear wall will cause the lateral displacement to increase.

Rajesh and Prasad (2014) modeled a six-storey reinforced concrete wall building by using 2D idealization and analyzed using SAP2000 pushover analysis capability on layered shell elements. Various parameters such as aspect ratio, reinforcement detailing aspects and presence of openings are chosen to study the seismic performance of RC walled buildings, as seen in Figure 2.9. In their study, results showed that combination of ductile detailing in the form of boundary element significantly increases the seismic performance of RC walls specially the displacement ductility of the wall and the effects are more pronounced when the bottom storeys are strengthened with boundary elements. Furthermore, it has also observed that modeling of RC wall elements using layered shell elements is accurate method in pushover analysis. Incorporation of ductile detailing in the form of boundary elements improves the base shear capacity and displacement ductility of the structures. Increase presence of openings in the RC wall decreases the lateral load carrying capacity of the shear wall.

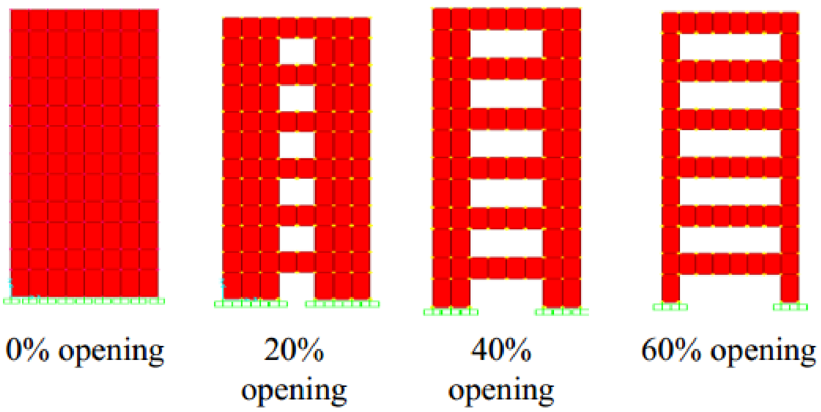


Figure 2.9 RC walls with different percentage of openings (Rajesh and Prasad, 2014)

Chowdhury et al. (2012) studied on six story RC frame shear wall buildings having opening to assess the influence of opening sizes and arrangements in shear wall on stiffness, strength, as well on the seismic performance of the buildings so that a appropriate arrangement of openings in the shear walls can be performed. Linear elastic analysis has been done by using finite element software ETABS under earthquake loads. The results in their study demonstrated that the stiffness, strength, as well seismic responses of the structures is affected by the size of the openings and their positions in the shear wall. It is also observed that more the area of opening more the displacements of the RC building and this increases with increasing building height. Moreover, it is obviously showed that the openings in shear walls located in plane of loading is more critical than that of openings placed out of plane of loading.

Taleb et al. (2012) studied four specimen of RC structural walls having various opening sizes and different locations were created and tested under lateral reversed cyclic loading. Three of these specimens (S1, M1, L1) were with eccentric openings and one specimen (N1) with having no openings in shear wall. The opening ratios were 30%, 34% and 46% for S1, M1, and L1 specimen as shown in Figure 2.10. The aim of their experimental tests were to assess the shear performance and to identify the effect of opening sizes on the shear strength and cracks distribution of the RC structural walls. A 2D analysis was carried out to simulate the performance of the four specimens. It was noted that the shear strength obtained during the loading side of the opening is greater than that obtained from the opposite side. Also, it is recommended to carefully evaluate this phenomenon through other tests and should be considered in the future design standard. The shear strength of sample S1 with an opening ratio of 30% was higher than that of samples M1 and L1 with 34% and 46% opening ratio, respectively.

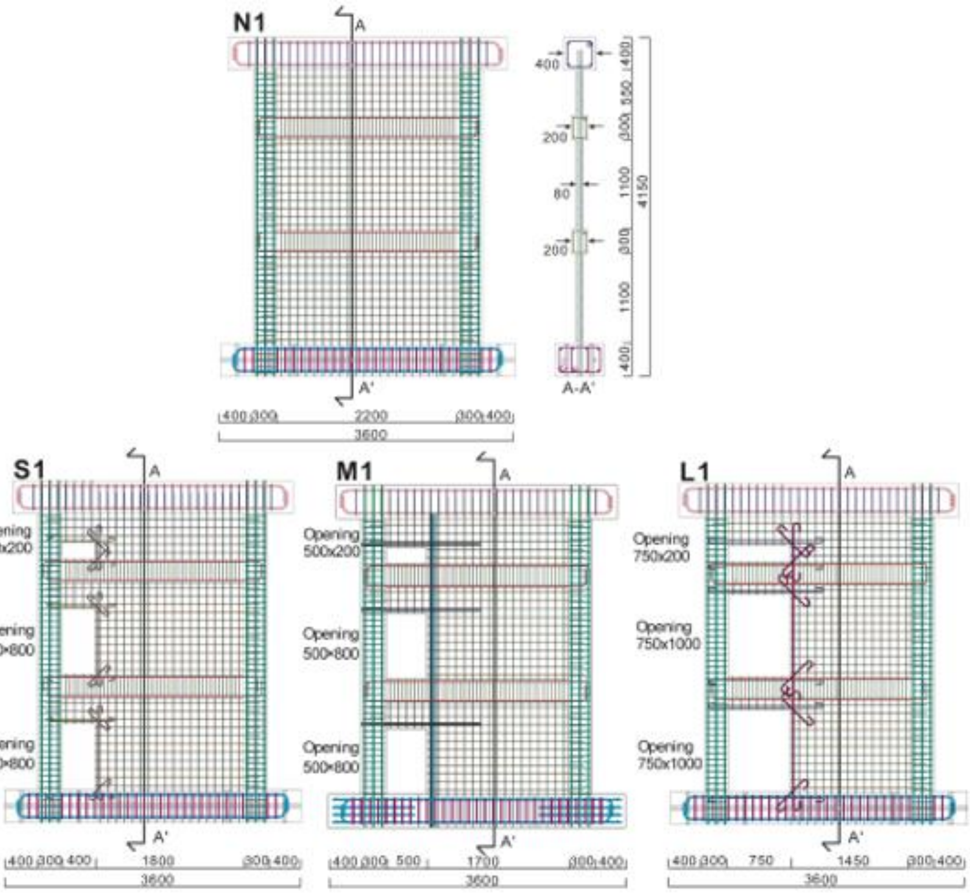


Figure 2.10 Specimen configurations (Taleb et al., 2012)

Gopalarathnam and Kumar (2013) studied nonlinear dynamic response of reinforced concrete shear wall with and with having no openings, subjected to ELCentro seismic load. The RC shear wall with dimensions of 3.6 m height, 3.6 m width, and 0.2 m thickness were considered. Three different opening sizes are shown: (a) a shear wall with an opening ratio 11.1%, (b) a shear wall with an opening ratio 22.2%, and (c) a shear wall with an opening ratio 44.4% of the wall area. In their present study, the results were detected that the increase size of openings cause to severe stresses and displacements on the shear wall.

Lin and Kuo (1988) studied both numerical analysis and experimental work to investigate the strength and stiffness of reinforced concrete shear wall with openings affected by lateral load. The test program illustrated the shear behavior of RC shear walls with various opening sizes and reinforcing designs around the openings, as shown in Figure 2.11. The test results in their study showed that the shear strength donated by diagonal steel reinforcement around opening reached 40% of its yield strength, whereas the shear strength donated by rectangular arrangement reached 20% of its yield strength. Furthermore, it was observed that lateral load resistant of the sections is affected by both width and height of the opening.

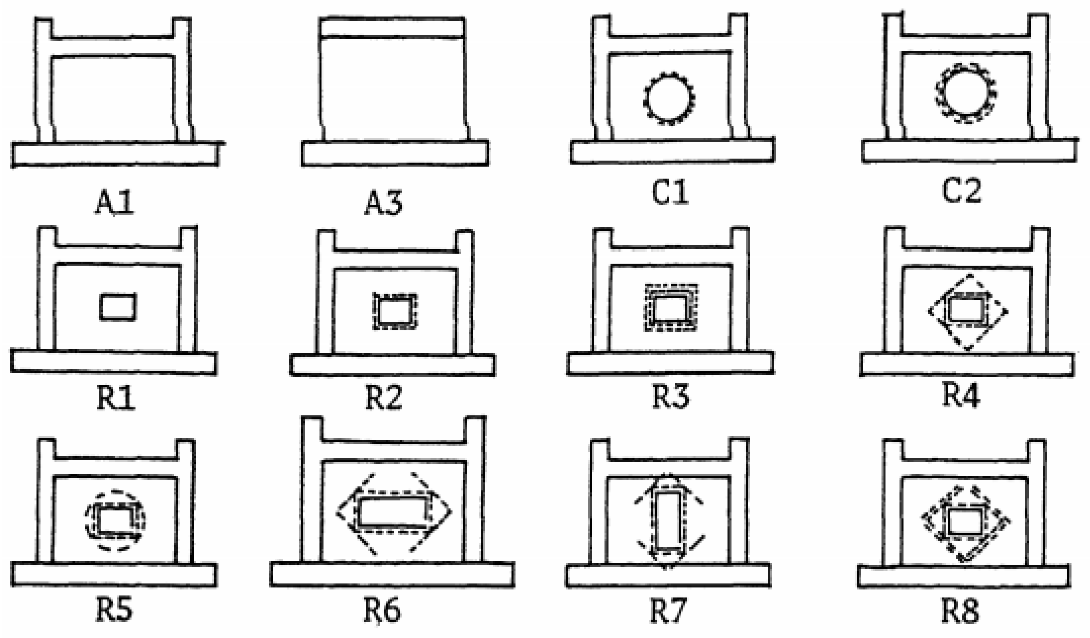


Figure 2.11 Test specimens (Lin and Kuo, 1988)

Musmar (2013) adopted nonlinear finite element analysis using solid65 element to study influence of the size of openings on the behavior of the reinforced concrete shear wall structures. The finite element analysis involves both geometric and material nonlinearities. ANSYS software has been used to provide solid65, it is also allows entering three reinforcement bar materials corresponding to the x, y, and z directions in the concrete. Five shear wall models with various opening sizes are studied. The models have openings of 1m width and variable heights starting from 0.5m to 3.0m of 0.5m increments. A sixth model of a solid shear wall is also presented to compare the analysis results. Their study observes that the shear walls considered in the study, openings up to 1x1m in size produce minor effects on the lateral load capacity of shear walls, flexural stresses, cracking pattern, and maximum drifts. In case of small openings, the shear walls perform as coupled shear walls. The ductility is relatively high without decreasing the load capacity of the shear walls. The larger the size of the opening is the greater is the stress flow within the shear wall. In case of shear wall with having no openings, the initial cracking occurs at discrete locations near to the base of the wall in the regions where the concrete tensile strength is exceeded. When the opening size exceeds that of a small opening, the initial cracking starts at locations close to base of the shear wall and also appears at the opposite corners of the opening. When openings are large enough, the initial cracking occurs at the joint between the upper lintel of the opening and the sidewalls.

Itwar and kalwane (2015) investigated the effects of opening sizes and arrangements in shear wall on seismic performance of RC frame structures. In their study, 6 and 12 storied 7x3 bays apartment buildings with floor plan of 35mx15m and floor height of 3m were modeled in the structural analysis program STAAD pro software tool. An equivalent static analysis for models of the RC buildings was performed as per IS 1893 (part 1): 2002. The results of their study reveal that for opening area up to 20% of shear wall area, the stiffness and strength of the shear wall structure is more affected by the opening sizes than their arrangement in the shear walls. On the other hand, for opening area beyond 20% of shear wall area, the stiffness and strength of the system is significantly affected by the openings arrangement in shear walls.

Ashok et al. (2016) compared seismic performance of 15 Storey RC building with openings in shear wall situated in seismic zone V. Four models are prepared in their study as model 1: bare frames, model 2: frames with core shear wall, model 3: frames with core and internal shear wall, and model 4: frames with internal and external shear wall. Linear finite element analysis of RC buildings by changing location of shear wall with opening is carried out for different storey levels. The size and shape of openings in shear wall is changed. Seismic coefficient method and response spectrum method are used for seismic analysis by using SAP2000 software. Location of shear wall by changing the sizes and shape of the openings in shear wall for all models is determined. Comparison is made between many parameters with respect column moment and axial force. In their study, results demonstrated that the presence of openings in shear wall reduces the strength, stiffness, and rigidity of the wall. The axial force and column moment increase as sizes of opening increase because stiffness and strength of shear wall with openings decreases. As length of shear wall in plan increases the opening effect is reduced. Size of openings is affected more than their locations in the shear walls on the stiffness, strength, and response of the frame structure.

Kim and Lee (2003) proposed an analysis technique that can be used irrespective of the size, number, and location of the openings. As seen in Figure 2.12, static analyses of specimen structures with different type of size, number, and location of openings were carried out to check the accuracy of the analysis method. Example structures were analyzed by using a computer code MIDAS. The results revealed that the suggested method is a suitable method for analysis of a shear wall with different size of openings.

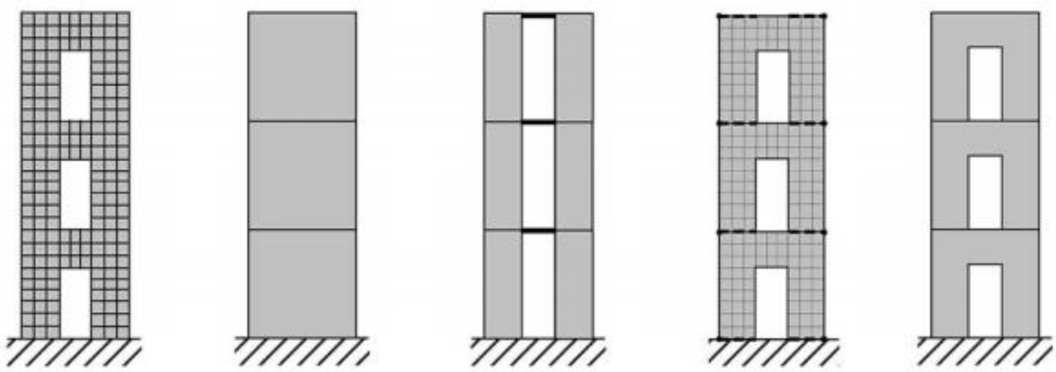


Figure 2.12 Type of specimens (Kim and Lee, 2003)

Guan et al. (2010) investigated the non-linear layer finite element method to investigate the efficiency of the technique in expecting the failure characteristics of 7 concrete walls with door and window openings and without openings. The load deflection responses, deflected shapes, and crack patterns expected by the non-linear layer finite element method were compared to the experimental observations. Furthermore, their approach carried out three studies to study the effect of opening size, width and height on the deflection of the wall panels, in one-way and two-way as predicted in Figure 2.13. Outcomes of their study presented that the openings reduce the axial strength ratio for one-way and two-way walls.

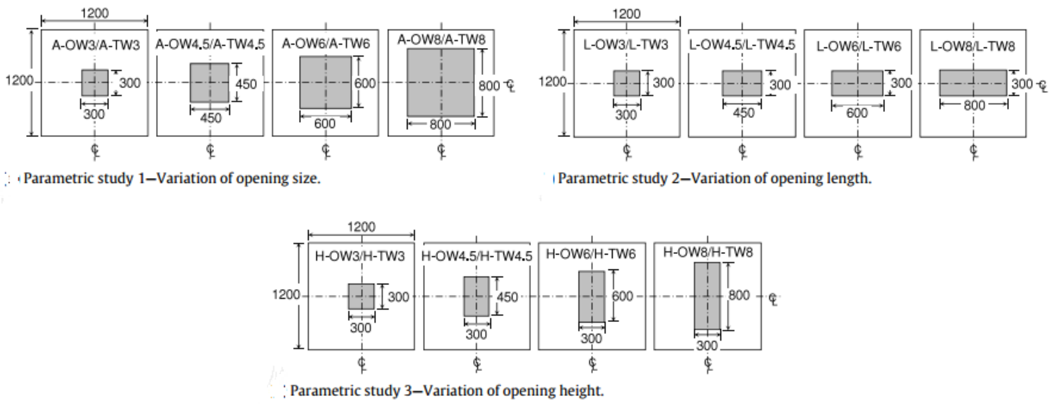


Figure 2.13 Models layout (dimensions in mm) (Guan et al., 2010)

Masood el at. (2012) investigated the behavior of planar and box type shear wall with varying percentages of base opening and compared to that of a shear wall with having no opening. An attempt is made to establish the range of base opening that can be permitted without significantly affecting the strength and stiffness of the shear wall. Shear wall has been modeled by using finite element package ANSYS. Three parametric ratios such as deflection ratio, maximum shear stress ratio, and maximum flexural stress ratio have been considered. An investigation is also performed to express how the degradation of the stiffness of the planar shear wall with base opening can be compensated using an additional portion of the shear wall. It is detected that the rate of decrease of stiffness and strength is relatively low for up to 60% base opening. More than this limit, strength and stiffness degradations are excessive. In accordance of their study, it is recommended that in the case of high-rise buildings the provision of a base opening of up to 50% of the wall length can be considered as a feasible option.

Li et al. (2016) studied the flange effects on seismic response evaluation of reinforced concrete squat shear walls with regular or irregular openings to study the effects of arrangement and size, of the openings on the seismic performance of the reinforced concrete shear walls. Six models of RC flanged walls for both regular and irregular openings were tested under quasit-static cyclic lateral loading. From their results, it is found that openings may detrimentally affect stiffness and strength of the walls of any kind with regular and irregular openings. The openings located near to the boundary or edge of shear walls may more reduce the strength and stiffness of the wall.

Harcheganiua el at. (2012) examined the effects of different geometric parameters on the relative flexural behaviour of coupled shear walls were examined with the purpose of calculate the flexural independent and conjugate behaviors specifically. 384 models were analyzed, and designed in ETABS, and each parameter was different in a number of models. From each model, story drifts and the lateral displacements of the four key points on the shear wall were extracted. For middle openings, in addition to the alpha parameter, the relative bending behavior of pillars in middle buildings can be predicted according to the thickness-to-length ratio of the coupling beam and the ratio of the coupling beam length to the pier length; But in high-rise buildings it is always conjugated. For corner openings, the alpha parameter must be changed with respect to the number of projectiles.

Marius (2013) studied seismic performance of RC shear walls with regular and staggered openings during the earthquakes in Italy (2009), Chile (2010), Turkey (2011), New Zealand (2011), and Japan (2011). The main aims of their study is to show the mechanism of failures documented throughout the earthquakes among 2009 and 2011, to define the failure modes on the basis of the last recordings of the seismic wave, the records on the ground floor and on the bearing sections of the RC buildings and the analysis of the benefits of the RC constructions with staggered openings exposed to seismic loads act on the location of the openings in the shear wall. In their research new information were provided on the seismic behavior of the RC walls with staggered openings with comparisons to the specimens used were: one a solid wall, one with regular openings, and three staggered openings wall. Data achieved from the theoretical investigation were compared to the data obtained from the experiments by using the BIOGRAF program. The results indicated that the walls with regular openings have higher top displacement than RC shear walls with staggered openings. Furthermore, the shear walls with staggered openings have lesser values of the relative displacement compared to the shear wall with regular openings. the shear walls with regular openings had a brittle failure, where the shear walls with staggered openings had a ductile failure.

Wu and Li (2003) studied RC walls with irregular openings to consider the influence of critical parameters on the performances of these walls subjected to seismic loadings. In their study, the program UC-WIN/MESH & UC WIN/WCOMD was used. The corresponding load paths were analyzed and the strut-and-tie method was applied to explain the effects of the parameters. The effects of flanges, axial load and the arrangement and size of openings were focused upon in this study. Analytical results illustrate that the arrangement and size of openings may exert an effect on the walls with low aspect ratios when it was subjected to the actions of axial loading and reversed cyclic lateral loading, respectively. Walls with small size openings can carry out better than walls with greater openings. Because of the influence of axial loading, the opening should not be arranged adjacent to the boundary. Strengthening the walls along the load paths could improve their performances.

Pooja and SV (2014) studied on shear wall with base openings, focusing on comparing the load carrying capacity with respect to that of shear wall with having no opening. Nonlinear static method used as the analysis method in their research. A 5-story reinforced concrete building frame with shear wall, located in seismic zone IV, has been considered for the analysis of the building. The lateral loads are generally resisted by the RC shear wall. The lateral force at each floor level is calculated using equivalent static method. The shear wall is isolated from the structural elements and further analysis is performed for the considered shear wall. Finite element ANSYS software is used for modeling and analysis the building. A non-linear static analysis is performed for two parameters a) the percentage area of base opening for the shear wall and b) location of the base opening. On the basis of the study carried for shear wall with and with having no base opening following conclusions were made:

1. Load carrying capacity is higher for shear wall with having no opening in comparison to the shear wall with opening.
2. Load carrying capacity of shear wall with symmetric opening is higher compared to that of shear wall with eccentric opening. Therefore, eccentricity in the base opening must be avoided as far as possible.

3. Load carrying capacity for solid shear wall and up to opening sizes 50% area of that of solid shear wall at ground floor are relatively close and above this the load carrying capacity values are about 75% and less than that of solid shear wall.
4. Thus the percentage of base opening greater than 50% of shear wall area must be avoided.

Warashina et al. (2008) studied the shear behavior of multi-stage RC shear walls with eccentric openings. The static load test was performed on four samples on a 40% scale. Sample configuration was determined from a typical six-storey building in Japan. From the experimental results, the shear strength of the samples was evaluated using the existing codes and the reduction factors. It was shown that the shear strengths of the samples were assessed to combine the shear strength of the shear walls with having no openings and the Ono reduction factor. The computer method used simulated the results of the tests. It has been proved that the process can be applied to structural walls having an opening ratio of less than 0.46. Then, a 2D of finite element method analysis model was made to simulate the behavior observed in the experiment. The well simulated lateral load model - drift angle relationships and damage distribution of wall panels.

Arvind and Parikh (2015) presented a paper on influence position of shear wall with openings in RC irregular building subjected to blast load and seismic load to understand the lateral loads, torsion effects and story drifts. Their study based on the modeling and analysis of irregular RC building having plan irregularities which has G+ 6 stories. The analysis carried out using ETABS software. The basic parameter of their analysis is time history and pressure history analysis. Therefore, the purpose of their study is analysis of shear wall by past earthquake history to decrease the effect of earthquake on the irregular building. Optimum position of building is found, then apply the blast history for finding the influence of blast on the building. The regular opening size is 2x1m at the corner of shear wall. From their outcomes it is concluded that the optimum shear walls are further resistant to blast load and seismic load in an irregular structure.

Mosoarca (2014) presented a paper to study the failure analysis of reinforced concrete shear walls having staggered openings under the effect of earthquake loads. Comparison between the failure mode of a wall with regular vertical openings, three walls with staggered openings and a shear wall with having no openings subjected to seismic loads have been considered as shown in Figure 2.14. Their behavior is presented in the elastic and post-elastic stage until they reach the failure point. All these models have been reinforced with the equal amount of rebars, having the same dimensions and the same concrete class. The failure modes determined theoretically by pushover analysis, were compared to the experimental failure modes laboratory obtained. In their study results showed that the shear walls having staggered openings are more stiff, rigid, and greater bearing capacity compared to the shear walls with ordered openings. Also, the shear walls having staggered openings fail at levels of seismic loads and at horizontal displacements higher than the forces and the horizontal displacements recorded with regular openings.

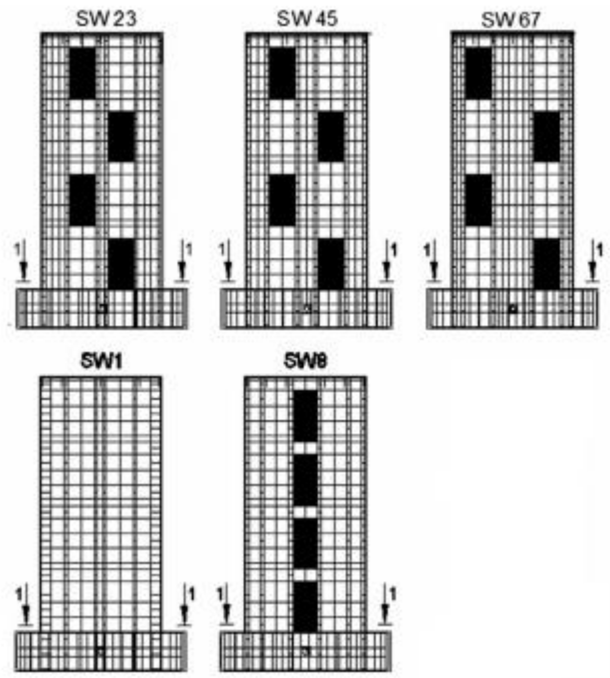


Figure 2.14 Experimental models (Mosoarca, 2014)

Merin Mathews (2013) presented a work on nonlinear behavior of a RC shear wall under lateral seismic load. Six storied RC structure has been considered as shown in Figure 2.15. The nonlinear behavior of the shear walls is then studied by nonlinear static pushover analysis using the general purpose FE-program ANSYS. From the analysis results a study of steel stresses, initial cracks, tension, compression, and crushing cracks has been showed. An attempt is then made to assess crack width to reflect the extent of damage.

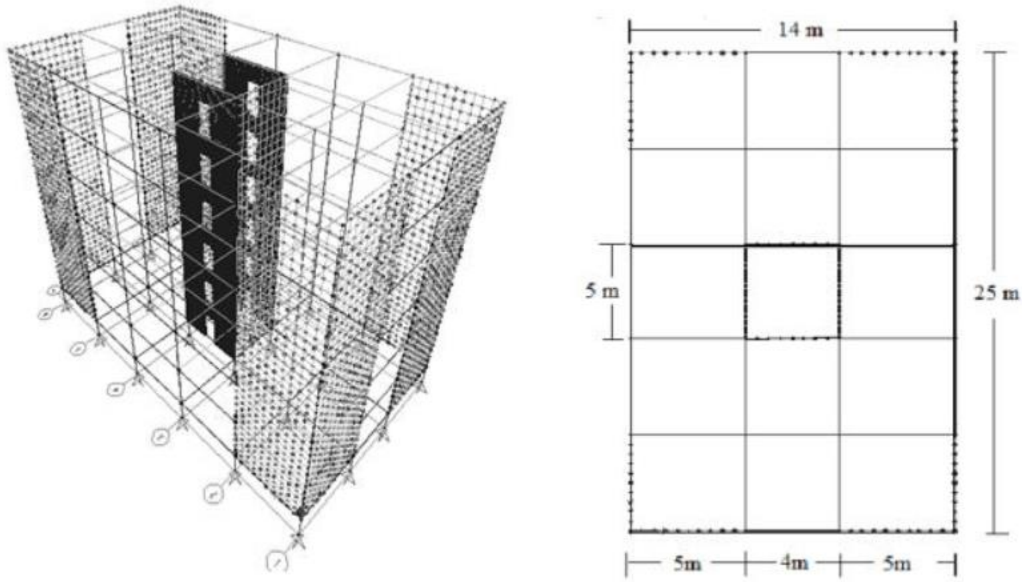


Figure 2.15 Building model (Merin Mathews, 2013)

Khatami et al. (2012) presented a paper on influences of openings in reinforced concrete shear walls under near-fault ground motions. For this, two near-fault earthquakes were used from different records of past earthquakes: Loma Prieta and Taiwan. Three models of ten-story three dimensional building were modeled with three types of shear wall: shear walls with having no openings, shear walls having quadrangular opening in the center and shear wall having opening at right end side as shown in Figure 2.16. Lateral displacements and basal shears were selected as the comparative quantities in a first study of the buildings by using SAP2000 software. The final ultimate resisting lateral force and the top lateral displacement were selected in a second study of almost square panel models by using ANSYS. Results of their investigation revealed a considerable decrease in strength of the shear walls with openings compared to the shear walls with having no openings. The model with having opening in the center of the wall, the maximum lateral displacement was up to 8% less than the maximum lateral displacement of the model with having opening on the right side; Whereas for the shear wall with having no opening, this decrease was up to 17% less.

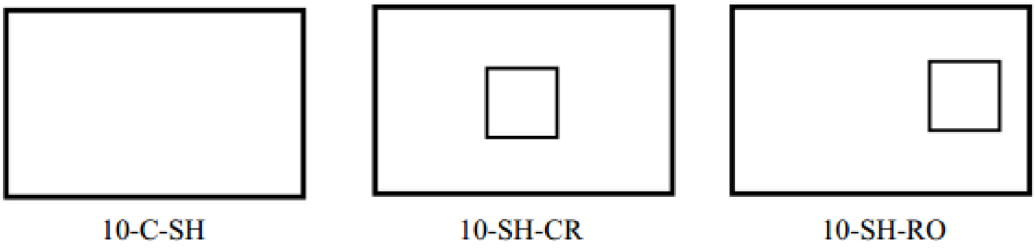


Figure 2.16 Three different shapes of opening (Khatami et al., 2012)

Aarthi Harini and Kumar (2015) presented a paper about performance of RC shear wall having staggered openings under earthquake loads. Their study is carried out on a 7-storey frame shear wall building: with no openings, with vertical openings, and with having staggered openings, by linear elastic analysis, with the aid of finite element ETABS. Figure 2.17 shows elevation of the shear wall frame building with vertical and staggered openings. Results in their study indicated that the base shear, displacement, drift, stress distribution, and the whole seismic performance of the building is influenced by the position of openings in the shear walls. Staggered openings in shear wall provided better lateral resistance than shear walls with vertical openings.

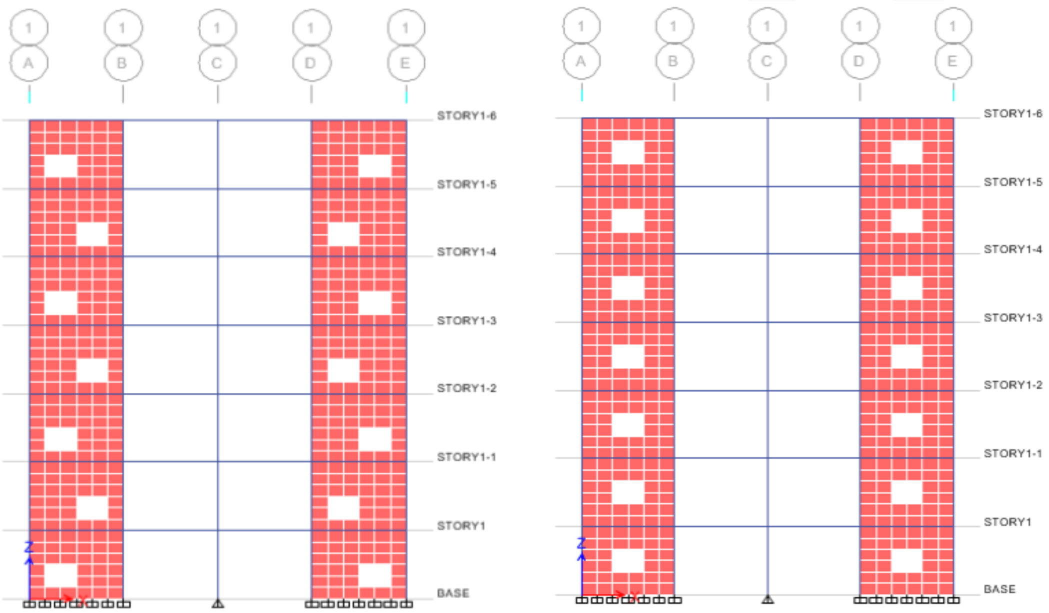


Figure 2.17 Elevation of the shear wall building with vertical and staggered openings (Aarthi Harini and Kumar, 2015)

Abd-el-rahim and Farghaly (2010) studied the cases of openings of the well-known architected requirements to achieve the ideal case that will serve as earthquake and architectural necessities. Five three dimensional models of different arrangements of the openings as shown in Figure 2.18 are chosen and compared to the model with having no opening in shear wall. The 3D model of each case with variable thickness is studied with a finite element program SAP2000 and the loading is considered using time history with a maximum ground acceleration 0.25g provided in the new Egyptian code (ECOL, 2008) for seismic loads on buildings. The results exposed that installation of openings in the shear walls can effect on the top displacements of the buildings and it is related with openings configuration. The staggered openings and away distance openings give the top displacement which agreed quit well with that induced in shear walls without openings. On the other hand, the staggered openings have minor influence on the resulting lateral load carrying capacity in the shear walls compared with that induced in the shear walls without openings.

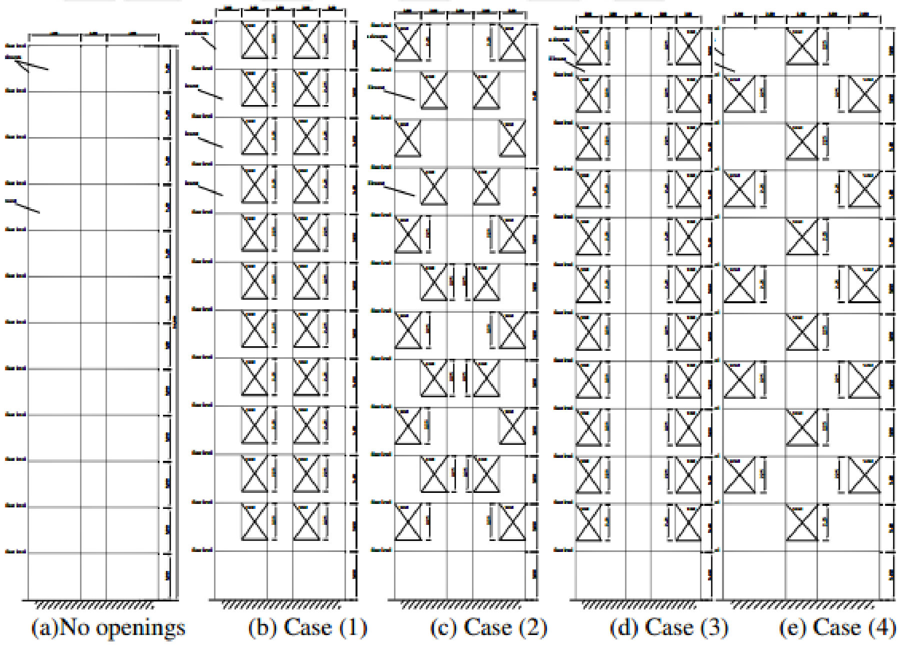


Figure 2.18 Openings-arrangement cases (Abd-el-rahim and Farghaly, 2010)

Satpute and Kulkarni studied seismic performance of 10-story reinforced concrete shear wall building with openings and with having no opening. They prepared five models and analyzed by using time history analysis method. Rectangular shear walls were modeled and analyzed using SAP2000 nonlinear software tool. The software is able to predict the dynamic loadings and the geometric nonlinear behavior of space frames, taking into account both material inelasticity and geometric nonlinearity. The software accepts dynamic actions and has the capability to carry out nonlinear dynamic analyses. For their study, the ratio of openings in the exterior face of the wall-frame buildings was gone up to 0%, 14%, 25%, 33%, and 42% for all models. It has concluded that the values of seismic responses are found to be increasing by increasing opening size.

Husain (2011) presented a paper on the elastic analysis three models of shear wall with different opening sizes by using brick elements to study the influence of the openings on the performance of the shear wall. Also, another three models of shear wall with openings of different locations were performed to study the influence of opening locations. The method used in their paper gave an accurate analysis for the shear walls with openings and presented a study of the effect of opening locations on the behavior of the shear wall. In his study, finite element models were developed using brick element by using SAP2000 software. Results of the analyses revealed that lateral displacements obtained from the brick element model increased for the large openings. Moreover, lateral displacements through the height of the shear wall obtained from the brick element for the center opening case were smaller than those obtained from the left and right opening cases.

Marius and Valeriu (2012) presented a paper on comparison between the dissipated seismic energy determined by experimental tests and theoretical studies. Experimental tests carried out on 5-lamellar RC walls: one with having no openings, one with vertically openings, and three with staggered openings, separated by the location of the openings. Post elastic behavior analysis of RC shear walls at lateral loads was carried out using the software program. The results observed in their article confirm the capacity of shear walls having staggered openings to dissipate seismic energy, in function of the vertical locating of the door openings, lacking special reinforcing measures. Furthermore, from the point of view of the locating of the openings, the capacity of energy dissipation is reduced by placing the openings near to the wall boundaries.

Sakurai et al. (2008) investigated a static load test of RC shear walls with openings that were performed to study the influence of the different number and arrangement of the openings. All specimens have the same ratio of openings, that is 0.4 as shown in

Figure 2.19. The results indicated that the shear strength, failure mode, and deformability of RC shear walls with openings were considerably affected by the difference of the number and arrangement of the openings. A two-dimensional non-linear FEM analysis was also conducted for all specimens. The analytical model is studied to investigate the stress transfer mechanism of RC Shear wall with multi-openings, and good agreement between experimental and analytical results was achieved.

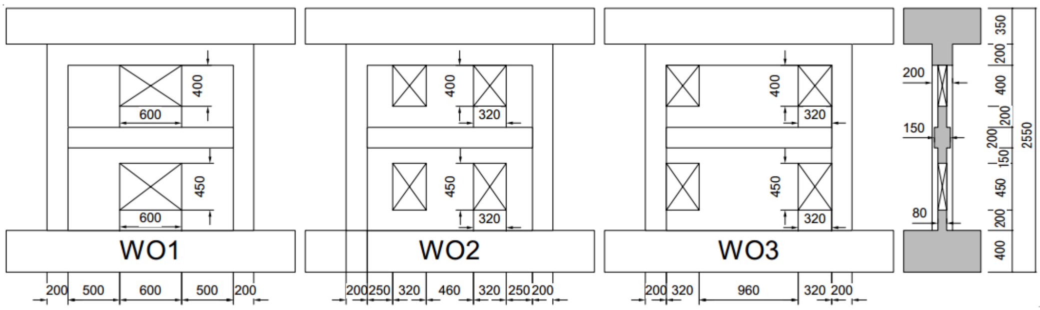


Figure 2.19 Test Specimens (Sakurai et al., 2008)

Mohammed and Mouli (2015) prepared a paper on analyze the RC shear wall building with openings and with no openings as shown in Figure 2.20. Modeling and analyzing the RC shear wall building by using ETABS software program. It was indicated that shear wall is very effective to resist lateral loads coming from earthquake. The maximum lateral displacement at the top story was in control and in limitations. Shear wall is very effective to decrease the peak story drift of the structure. Also, there was not significant difference in drift and displacement provision of 20 % opening considered in the shear wall.

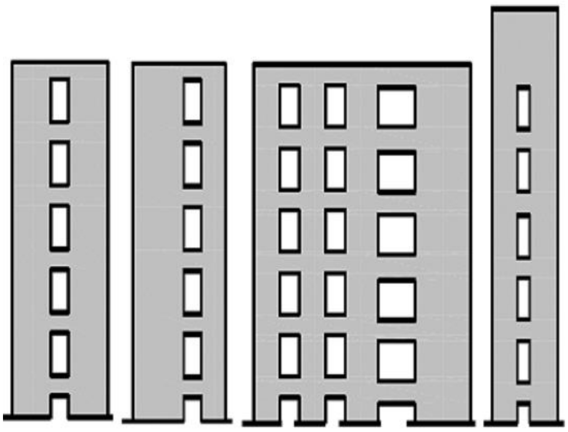


Figure 2.20 Shear wall with opening (Mohammed and Mouli, 2015)

2.5 Nonlinear static and time history analysis

2.5.1 Nonlinear static pushover analysis

Pushover analysis is the basic nonlinear analysis procedures used for seismic performance evaluation of buildings. Though, pushover analysis consists of certain approximations that the reliability and the accuracy of the technique should be recognized. For this purpose, investigators studied various features of pushover analysis to identify the limitations of the procedure and proposed improved pushover procedures that consider the effects of lateral load patterns, higher modes, and failure mechanisms (Oğuz, 2005).

Raut and Prasad (2014) prepared a paper to assess the behavior of 4-story RC frame exposed to seismic loads in zone II. The RC structures are analyzed by nonlinear pushover analysis using SAP2000 software. The analysis provides a better understanding and a more accurate seismic performance of buildings of the damage or failure of the structure. The building was designed and created using IS-456-1978 and the revised code IS- 1893- 2000. The results obtained with respect to capacity spectrum, pushover demand, and plastic hinges. Hinges have evolved in the beams and columns, which show the three stages of immediate occupancy, life safety, and collapse prevention.

Mwafy and Elnashai (2001) carried out a series of pushover analyses on twelve RC buildings to study the validity and the applicability of pushover analysis. As shown in Figure 2.21, twelve RC buildings like, four 8-story irregular building, four 8-story dual frame wall building, and four 12-story regular building were used for the study. Nonlinear dynamic analysis using four artificial earthquakes and four natural records were performed on detailed 2D models of the RC structures in view of local and global collapse limits. Then, complete pushover curves in the form of lower and upper reaction envelopes were achieved for each RC building by carrying out regression analysis using the outcomes of non-linear dynamic analyses method. Moreover, pushover analysis using triangular, uniform, and multimodal load patterns were performed and pushover results were achieved. The results detected by the researchers showed that the triangular load pattern consequences were in good correlation with dynamic analysis outcomes and a conservative estimate of capacity and a reasonable assessment of deformation were gained by using triangular load pattern. Also, results illustrated that the pushover analysis is more suitable for low rise building and short period buildings and triangular loading is acceptable to expect the reaction of such buildings. Additional developments on accounting the inelasticity of lateral loads which would allow more exact analysis of high rise and highly irregular buildings were mentioned.

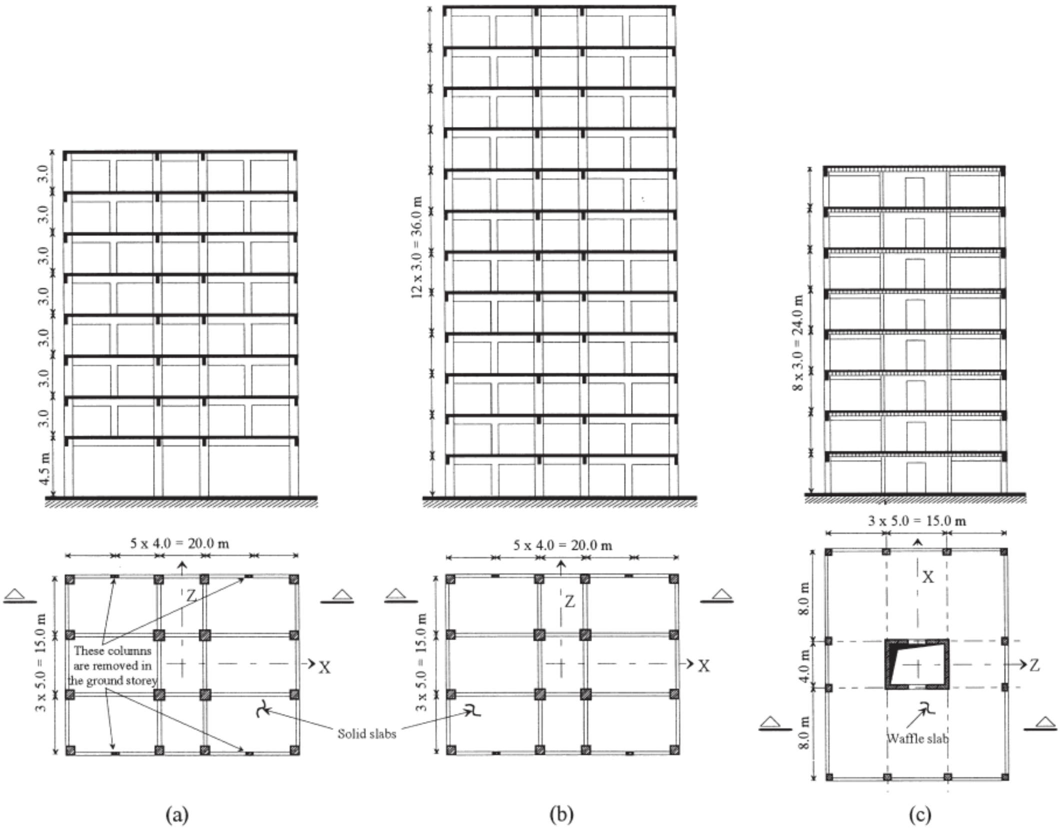


Figure 2.21 Plane and elevation of the buildings (a) 8-storey irregular buildings, (b) 12-storey regular buildings and (c) 8- storey regular buildings with shear wall (Mwafy and Elnashai , 2001)

Rana et al. (2004) conducted a study on nineteen story RC shear wall building. Lateral system of the RC building included of shear walls. A plan view of the building is shown in Figure 2.22. The building was designed according to 1997 Uniform Building Code. The life safety performance confirmed using pushover analysis. The researchers showed in their study that the pushover analysis was an effective method to consider inelastic behavior of structures, however it was more complex than traditional elastic analysis, but it was essential less amount of data than nonlinear time history, also pushover analysis requires inferior application. The results of this analysis on 19-story RC building presented some modifications were made to the original code-base design so as to predict life safety performance under earthquake design.

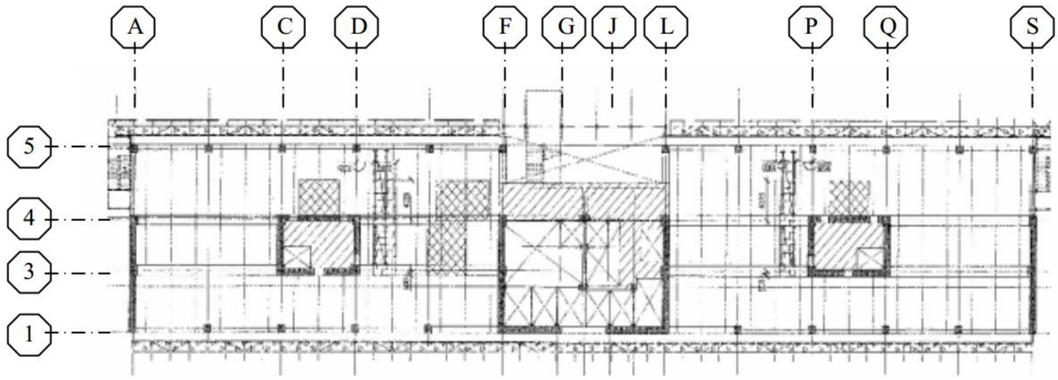


Figure 2.22 Typical floor plan and wall arrangement (Rana et al., 2004)

2.5.2 Nonlinear time history analysis

Time history analysis is the most accurate technique to conclude the seismic performance of buildings. In accordance to this method the buildings is subjected to actual ground motion which is the demonstration of the ground acceleration versus time. The structural response is calculated at every time to know its time history and the peak value of this time history is chosen to be design demand (Seo et al., 2015).

Inel and Ozmen (2006) applied the interior frames of 4-story, and 7-story buildings to show low and medium rise reinforced concrete building nonlinearities. Nonlinear time history and pushover analyses were performed to determine nonlinear behavior of the reinforced concrete frames. Columns and beams were formed with default and defined hinge properties so as to determine the difference between them in analyses which observed at displacement points equivalent to global yielding and ultimate displacement. The researchers found that user-defined hinges and default hinges for different plastic hinge length and transverse reinforcement spacing for two models had similar base shear capacity. It estimated that the base shear didn't depend on whether the user-defined hinges or default hinge were used. The displacement of the frames influenced by the plastic hinge length, about 30% variation in displacement because of plastic hinge length, the displacement depended on amount of reinforcement at the possible hinge part; therefore, increasing amount of reinforcement improved the displacement. Reducing the reinforcement layout from 200 mm to 100 mm, the displacement increased up to 40%, at the same time as reducing the layout from 200 mm to 150 mm gave an increase of 12% for 4-story building. The study showed that the user-define hinge model was better than default-hinge model for demonstrating nonlinear behavior.

CHAPTER 3

3. CASE STUDY

3.1 Description of RC shear wall buildings

In this investigation, the influence of various size of openings in shear wall on the earthquake performance of RC wall-frame systems were studied. For this purpose, the 5 story reinforced concrete (RC) frame system having the similar height of 3 m at each story with 3 bays in x-direction and 5 bays in y-direction of different spacing was studied. The model consists of frame elements as beam and column, the nonlinear properties for columns are assumed to be a plastic P-M-M hinge and for the beams as plastic moment hinge. The plastic hinges are defined according to ASCE 41-13 with the designed rebar distribution. Rectangular shear walls building with and without opening were modeled using shell elements. For the parametric study, the percentage of centered opening in the external shear walls of the buildings were increased from 2.7%, 11.1%, 25%, 44.4%, and 53.7% model. The models have been considered in Table 3.1.

Table 3.1 Building description

Opening in shear wall		
Model	Opening	Opening %
1	Solid shear wall	0
2	Opening of 0.5m x 0.5m is provided centrally in shear wall	2.7
3	Opening of 1m x 1m is provided centrally in shear wall	11.1
4	Opening of 1.5m x 1.5m is provided centrally in shear wall	25.0
5	Opening of 2m x 2m is provided centrally in shear wall	44.4
6	Opening of 2.2m x 2.2m is provided centrally in shear wall	53.7

The cross-section of the frame elements such as beam, column, shear wall and slab are summarized in Table 3.2.

Table 3.2 Member dimensions of the buildings

Member	Dimension (mm)
Columns	250 x 600
Beams	250 x 500
Slab thickness	150
Shear walls	3000 x 250

Shear wall was represented as a thin shell element and slab was represented as a thin membrane element. Concrete compressive strength of 20 MPa was used for all the RC frame structures, the modulus of elasticity and yield stress of the steel bar were 200 GPa and 350 MPa, respectively.

Gravity loads on the floors of the building are considered. The dead load and live load from the tributary slab areas are applied as distributed loads on the wall, consisting in 4.75 kN/m dead wall, 2.3 kN/m roof dead wall, 1.6 kN/ m^2 super dead load, 4 kN/ m^2 live load and 2 kN/ m^2 roof live load. During this design development, ETABS2015 was utilized which has standard usage in the design of reinforced concrete building because of the feasibility. The 2D view of the buildings are given in Figures 3.1. The location of shear wall with various size of openings in the 3D view of the structures are given in Figures 3.2 to 3.7.

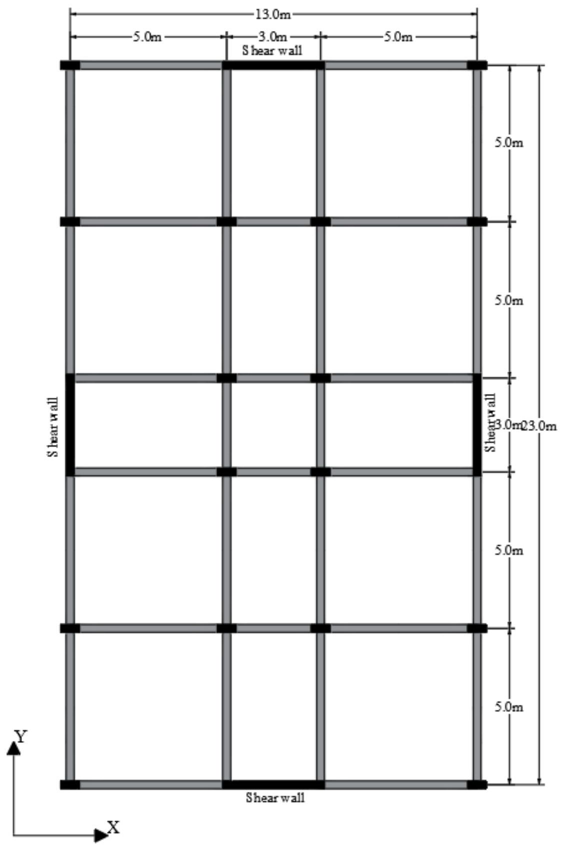


Figure 3.1 Plan view of the five story reinforced concrete building

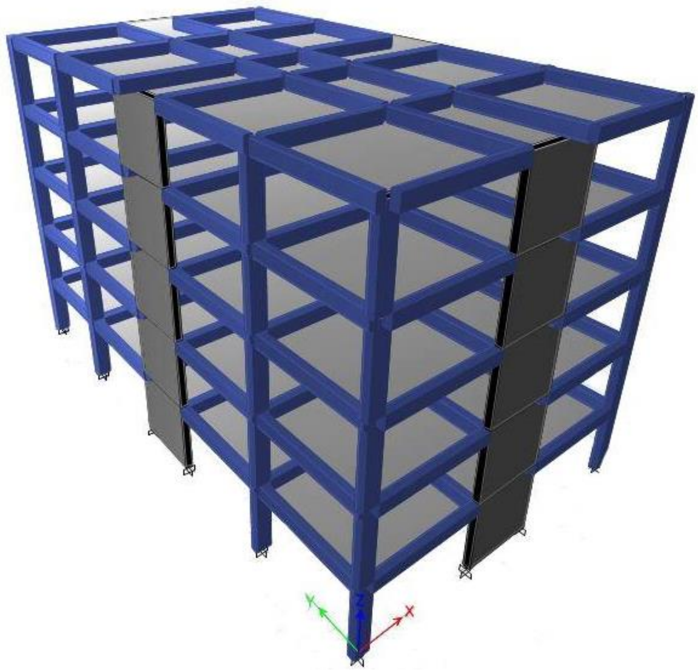


Figure 3.2 3D view of the five story reinforced concrete building with solid shear wall (Model 1)

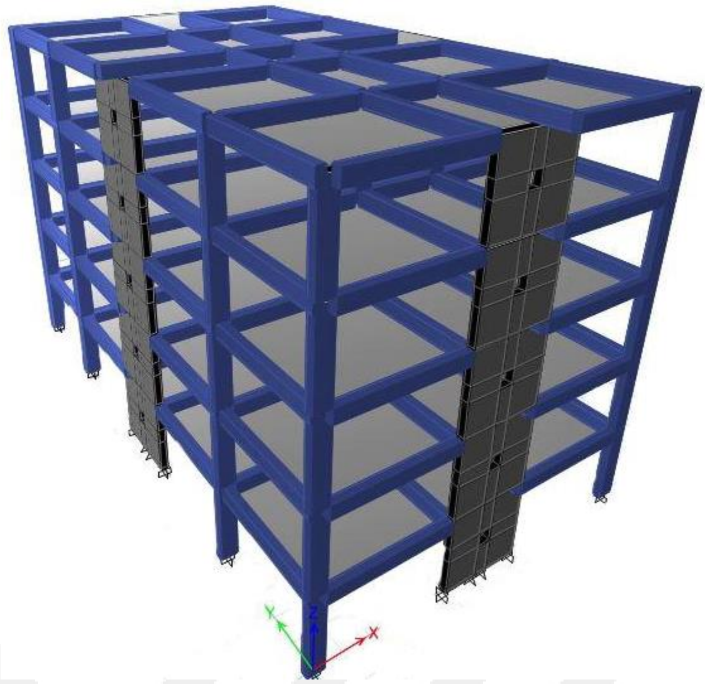


Figure 3.3 3D view of the five story reinforced concrete building with opening (0.5m x0.5m) in shear wall (Model 2)

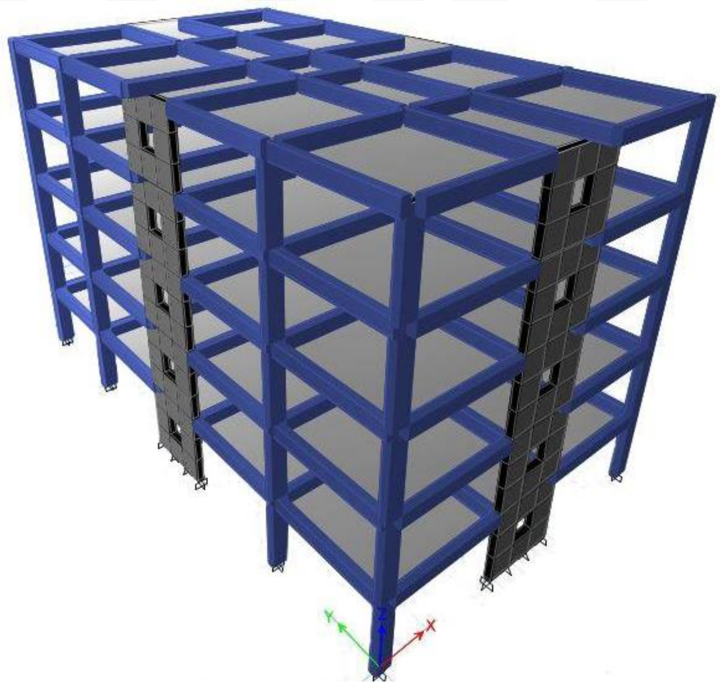


Figure 3.4 3D view of the five story reinforced concrete building with opening (1m x 1m) in shear wall (Model 3)

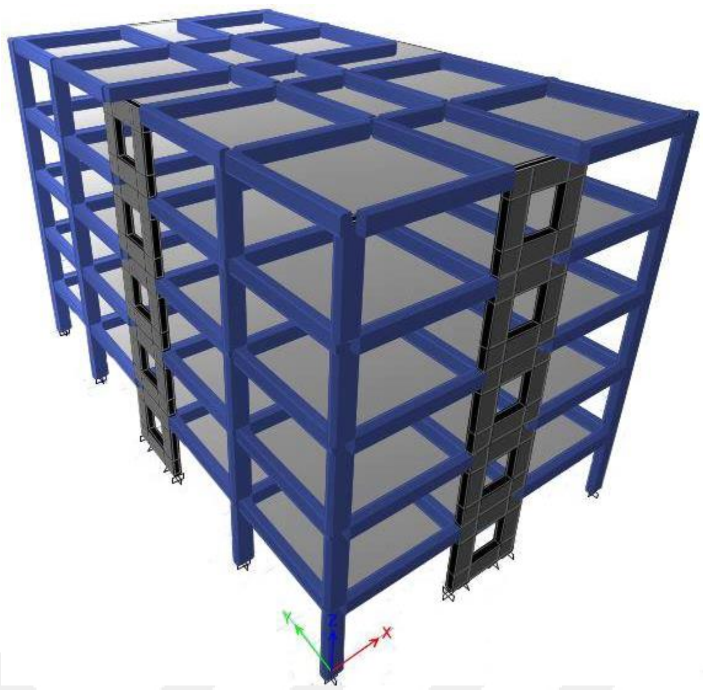


Figure 3.5 3D view of the five story reinforced concrete building with opening (1.5m x 1.5m) in shear wall (Model 4)

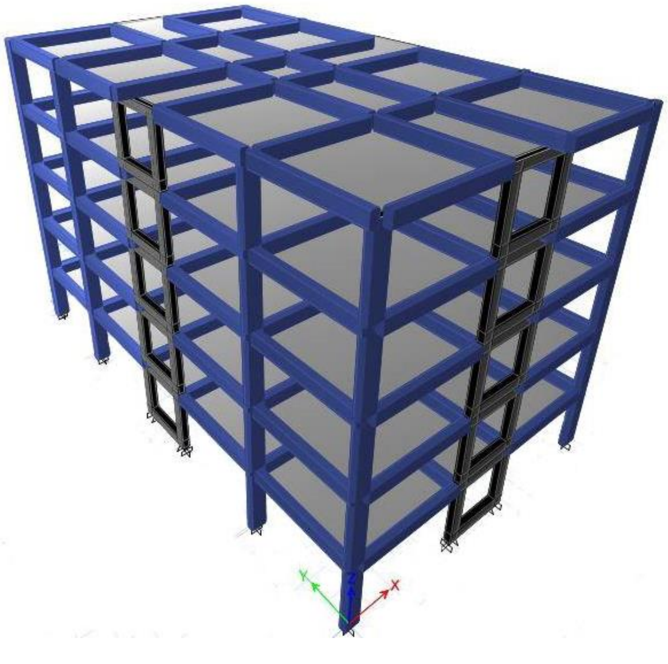


Figure 3.6 3D view of the five story reinforced concrete building with opening (2m x 2m) in shear wall (Model 5)

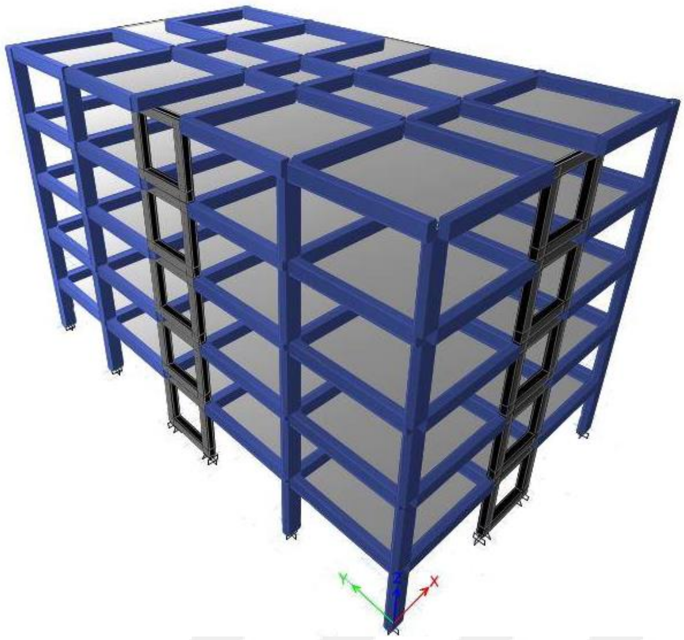


Figure 3.7 3D view of the five story reinforced concrete building with opening (1m x 1m) in shear wall (Model 6)

3.2 Nonlinear methodologies

3.2.1 Nonlinear static pushover analysis

Nonlinear pushover analysis is performed for assessing the structural seismic response. In pushover analysis, the structure is subjected to incrementally increasing lateral forces with a uniform height-wise distribution until a target displacement is reached (Kadid and Boumrkik, 2008). The base shear and roof displacement could intend to create the pushover curve. It provided an indication of the maximum base shear that the structure was capable of resisting at the time of the earthquake. For regular buildings, it could provide a rough idea about the global stiffness of the building. The ATC-10 and FEMA 356 documents have established modeling techniques, analysis procedures, and acceptance criteria for pushover analysis. These documents refer to force-deformation criteria for hinges used in pushover analysis pronounced the acceptance criteria depending on the plastic hinge rotations by considering different performance levels. Each plastic hinge is designed as a separate point binge. All plastic deformation is displacement or rotation, develops within the point hinge (Nel and Ozmen, 2006). Five points considered A, B, C, D, and E describe the force deflection behavior of the hinge as shown in Figure 3.8.

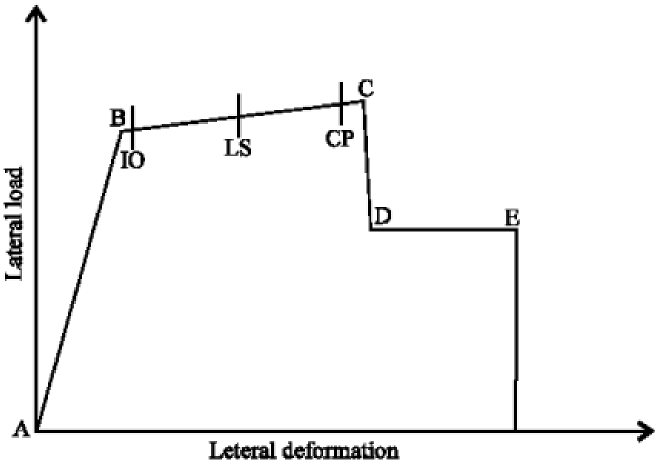


Figure 3.8 The curve of force vs. deformation (Bansal, 2011)

Point A refers to unloaded state and point B represents yielding of the element. The ordinate at C corresponds to nominal strength and D corresponds to the deformation at which substantial strength degradation starts. Three points termed LO, LS, and CP represented immediate occupancy, life safety, and collapse prevention, respectively. The principles for assigning values for each of these points differ liable on the form and type of member such many other parameters defined in the ATC-10 and FEMA-356 documents (Bansal, 2011). In this study, the steps in performing the static nonlinear pushover analysis of a five-story three-dimensional building model in ETABS2015 as tool for performing the pushover analysis procedure as follow:

1. The properties of five-story building were created and assigned in ETABS2015, and then properties and acceptance criteria for the pushover hinges were defined.
2. The pushover hinges on the model was localized by assigning two hinges to each beams and columns with deformation properties based on an assumed hinge length.
3. The pushover load case was defined using gravity load and then subsequent lateral pushover load cases were specified to start from the final conditions of the gravity pushover.
4. From this analysis, the capacity curves and performance level of each structure were established.

3.2.2 Nonlinear dynamic time history analysis

Time history analysis of the structure has been successfully used to analyze the structure. Even though time history analysis consumes time, it is the only method capable of giving results closer to the actual one. In the time history analysis, the loads are applied over a period of time and the response is obtained at different time intervals (Muthukumar and Kumar, 2014). Nonlinear time history analysis was carried out on the same analytical models with the same hinge properties so as to estimate the actual nonlinear behavior of the structural systems. In the dynamic analysis, LACC_NOR-2.TH record was used as a ground motion. Figure 3.9 shows the acceleration time plot of the earthquake.

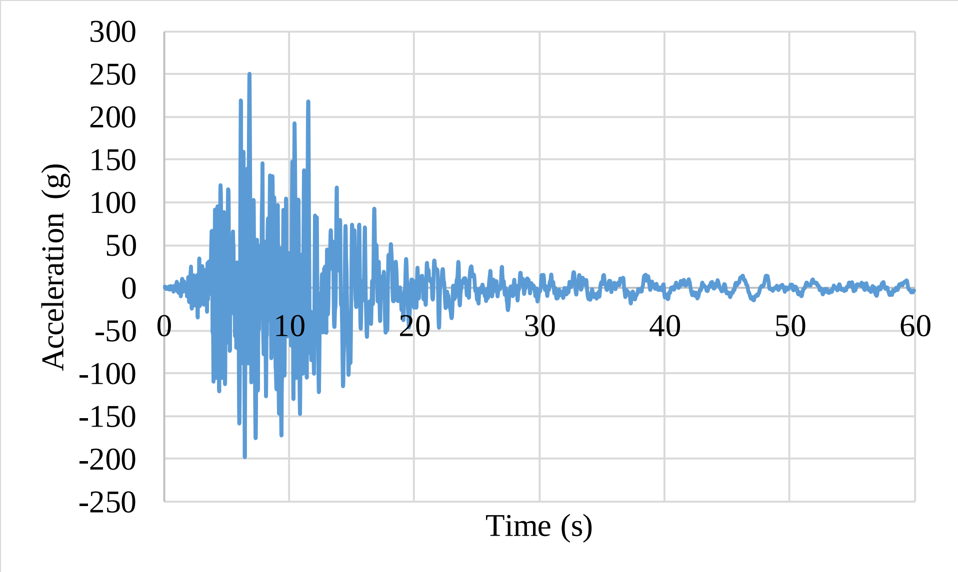


Figure 3.9 Acceleration time plot of the earthquake ground motion

CHAPTER 4

4. RESULTS AND DISCUSSION

This chapter presents the results of analysis of RC frame system. The nonlinear static pushover analysis and nonlinear time history analysis were carried out using ETABS2015. Five story RC shear wall building with and without opening were analyzed. Since the main model, loading and position of openings are all unsymmetrical, the results will be different in both x and y directions. Therefore, all of the results displayed in both directions of the structure. All of the parameters stay the same and the only parameter which changes at each step is the dimension of opening. From the analysis, modal periods, capacity curves, story drift and story displacements were obtained for each model.

4.1 Modal Periods

Since the fundamental period of a structure is in relation with stiffness of the structure and openings can affect the total stiffness of RC frame system, it can be considered that the modal periods are also subjected to change as opening ratios increase. Comparison of the modal periods show how much a structure is influenced by increasing openings in shear wall. From Table 4.1, it is observed that fundamental period is increased as the opening size increased. The first fundamental period of model 1 is 0.637 s is increased to 0.658 s, 0.671 s, 0.704 s, 0.793 s, and 0.858 s for the model 2, 3, 4, 5, and 6, respectively. Results clearly show that the openings are playing a major role in the modal periods of the structure. Also, it is indicated that in cases where the ratios of the openings are higher, the impact that opening have on stiffness and natural period must be considered and cannot be ignored.

Table 4.1 Fundamental period of the building studied

Building models	Opening size	T_1(s)	T_2(s)	T_3(s)
Model 1	solid shear wall (0%)	0.637	0.549	0.427
Model 2	0.5m x 0.5m (2.7%)	0.658	0.567	0.437
Model 3	1m x 1m (11.1%)	0.671	0.577	0.446
Model 4	1.5m x 1.5m (25%)	0.704	0.602	0.469
Model 5	2m x 2m (44.4%)	0.793	0.664	0.535
Model 6	2.2m x 2.2m (53.7%)	0.858	0.704	0.584

4.2 Evaluation of RC shear wall buildings with and without opening using nonlinear static analysis

4.2.1 Pushover curve

The basic outcome of the pushover analysis is the force-displacement relationship. Various pushover cases are considered such as Push-x (loads are applied in x-direction) and Push-y (loads are applied in y-direction). Figure 4.1 illustrates the comparison of pushover curves for the original building having no opening in the x-direction and y-direction. It is observed that the lateral displacement is more and the base shear is less in the y-direction by comparing with the x-direction. This is because of the lateral dimension of columns, so as to x-axis is the longitudinal axis, and the y-axis is the transverse axis, as a result the lateral stiffness and strength of the frame system is comparatively less in the y-direction.

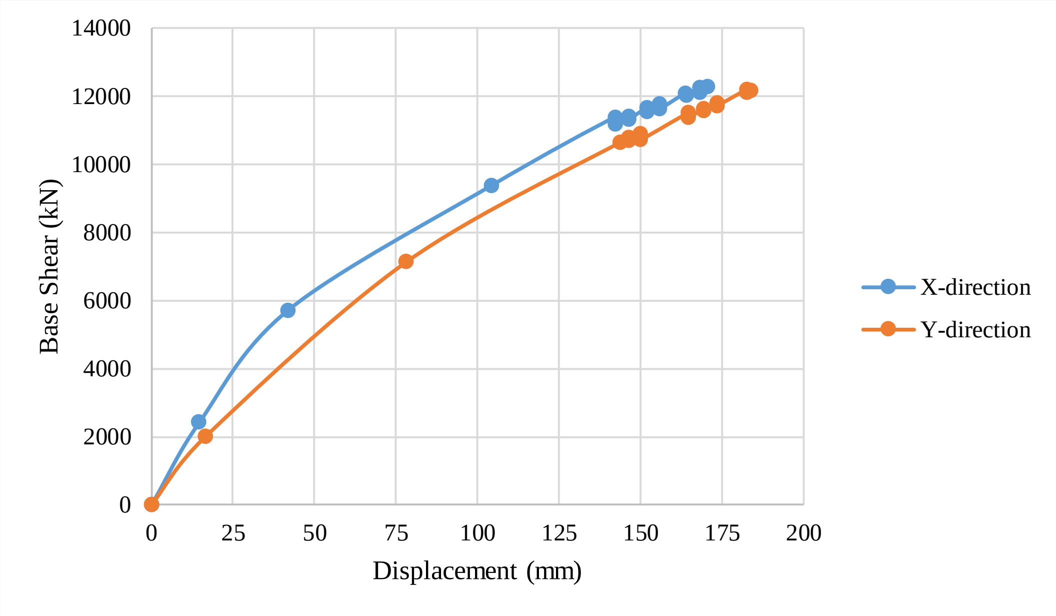


Figure 4.1 Pushover curve of the original building with shear wall having no opening (Model 1) for seismic force acting along X-direction and Y-direction

Pushover curve is a function of the point of application of the resultant of lateral load as well as the nonlinear structural characteristics. It is expected that reduced stiffness and strength results into less lateral load carrying capacity of the structural system. The result of pushover analysis (capacity curve) in the form of base shears-displacement is illustrated in Figures 4.2 and 4.3 for x and y direction, respectively. The curve clearly shows along x-direction that the original building with shear wall having no opening behaved linearly up to the yield point at 2426.7 kN after that the building stated to have nonlinear behavior. In the nonlinear part of the curve, the original building has reached a maximum base shear of 12284.5 kN. It is reduced to 12218.4 kN, 12007.0 kN, 11363.6 kN, 9691.3 kN, and 8457.4 kN for the model 2, 3, 4, 5, and 6, respectively. Although similar trends are observed in y-direction, in the nonlinear part of the curve, the original building has reached a maximum base shear of 12221.4 kN. It is reduced to 12206.8 kN, 11977.3 kN, 11428.2 kN, 9992.3 kN, and 9019.0 kN for the model 2, 3, 4, 5, and 6, respectively. Here it is evident that increased presence of openings in shear wall reduces the lateral load carrying capacity of the structural system. However, as observed in Figures 4.4 and 4.5, it can be seen that the maximum lateral load carrying capacity from the peak roof drift ratio about 1.14 for original building. There was a significant decrease in lateral load carrying capacity and increase in roof drift ratio to 1.15, 1.18, 1.21, 1.27, and 1.27 for the model 2, 3, 4, 5, and 6, respectively along x-direction. Similarly, when conducting the pushover analysis in the y-direction, the maximum lateral load carrying capacity from the peak roof drift ratio about 1.22 for original building. There was decrease in lateral load carrying capacity and increase in roof drift ratio to 1.25, 1.27, 1.34, 1.5, and 1.62 for the model 2, 3, 4, 5, and 6, respectively. As also indicated in these figures, the first three models are moving very close to each other in the graphs indicating that opening ratios up to 11.1% in this structural system, do not make a remarkable effect. However, openings beyond 11.1% start to show results that are considerably different which will affect lateral load carrying capacity more severely and appropriate considerations are required. Moreover, openings with higher ratios can severely reduce the stiffness and strength of shear walls and entire frame systems.

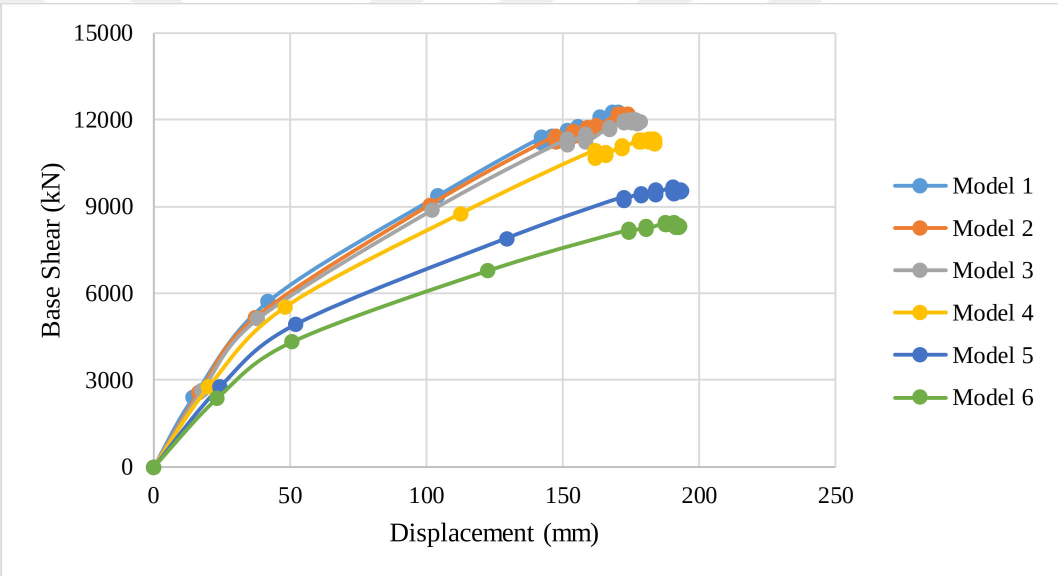


Figure 4.2 Lateral displacement vs. base shear in X-direction for different models based on the pushover analysis

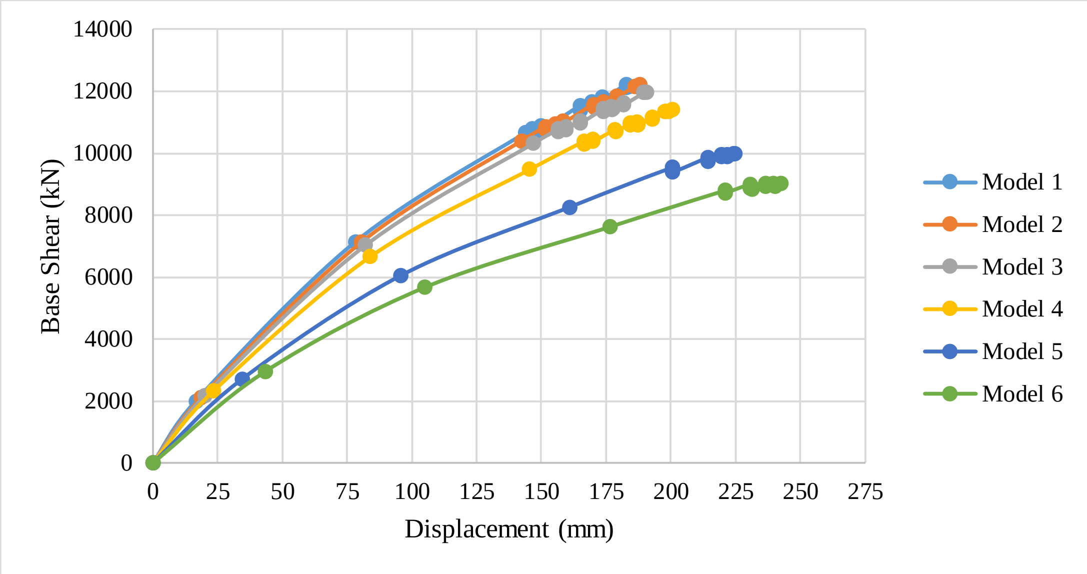


Figure 4.3 Lateral displacement vs. base shear in Y-direction for different models based on the pushover analysis

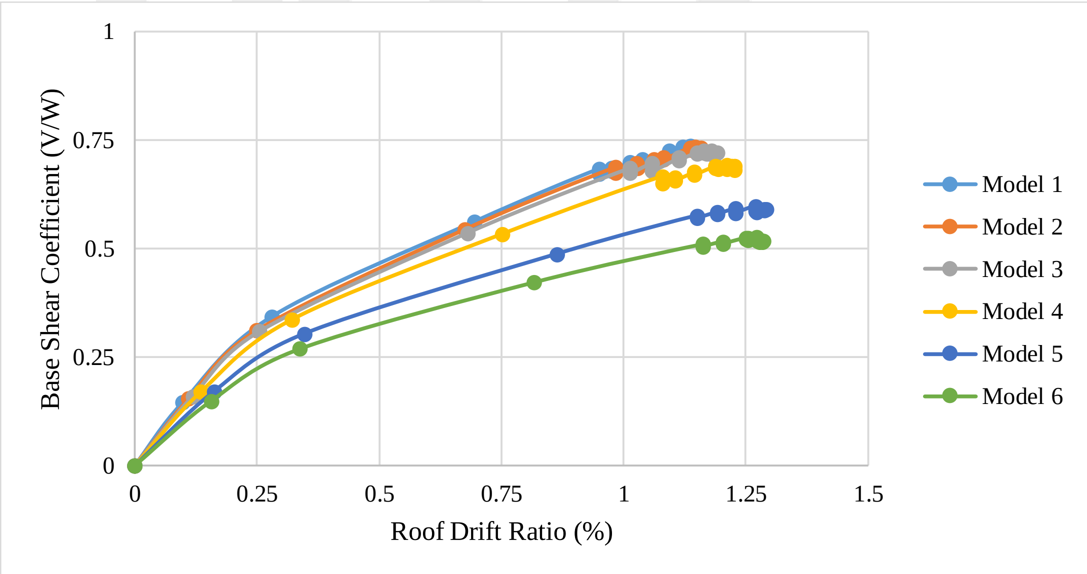


Figure 4.4 Represention of base shear coefficient-roof drift relationship in X-direction

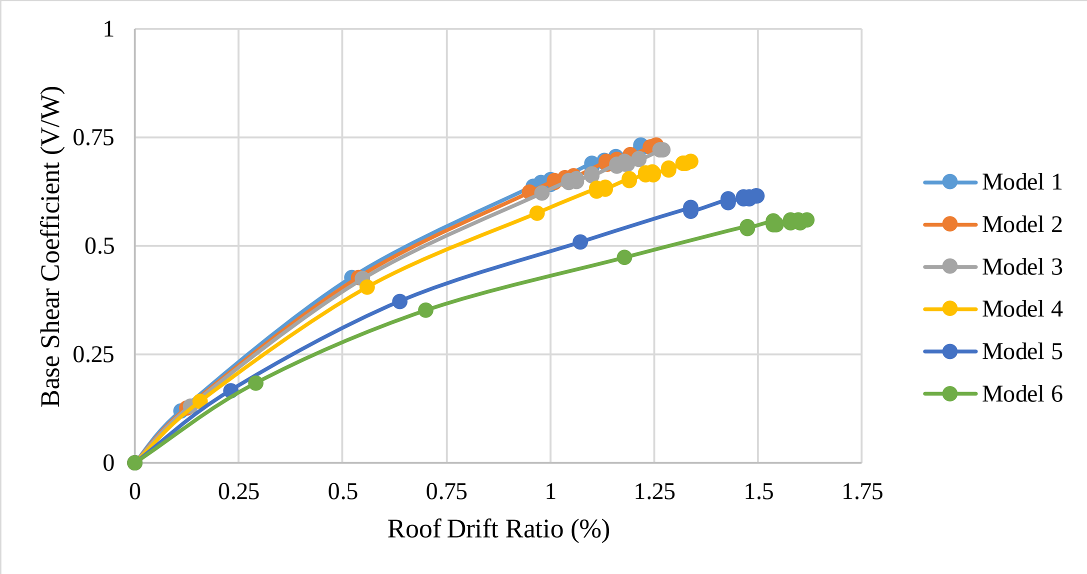


Figure 4.5 Represention of base shear coefficient-roof drift relationship in Y-direction

4.2.2 Lateral displacement demands at mechanisms

The displacement refers to the distance that points on the ground are moved from their original locations through the seismic waves. As the opening size increases, the stiffness and strength of the shear walls decreases and become less result in higher lateral displacements. Maximum story displacement is always one of the most important considerations in design and it is very important to consider how much openings in shear walls can play a role in the lateral displacement of frame systems. In this case study, the models are analyzed for different opening sizes and the results of maximum roof displacement demands at mechanisms are summarized in Table 4.2.

Table 4.2 Maximum roof displacement demands for the frame systems at mechanisms

Building models	Opening size	Roof displacement (mm) X-direction	Increase percentage (%)	Roof displacement (mm) Y-direction	Increase percentage (%)
Model 1	solid shear wall (0%)	170.7	0	183.8	0
Model 2	0.5m x 0.5m (2.7%)	173.9	1.9	188.1	2.3
Model 3	1m x 1m (11.1%)	178.7	4.7	190.5	3.6
Model 4	1.5m x 1.5m (25%)	184.0	7.8	200.7	9.2
Model 5	2m x 2m (44.4%)	193.9	13.6	224.7	22.3
Model 6	2.2m x 2.2m (53.7%)	193.1	13.1	242.7	32.0

Roof displacements shown in the table above observed that the roof displacement of models 2, 3, 4, 5, and 6 is increased to 1.9%, 4.7%, 7.8%, 13.6%, and 13.1%, respectively which is considerable when compared to the values of original building along x-direction. At the same time, the roof displacement of models 2, 3, 4, 5, and 6 is increased to 2.3%, 3.6%, 9.2%, 22.3%, and 32.0%, respectively which is significant when compared to the values of original building along y-direction. It is clear that the displacements in the y-direction are greater than the x-direction. This is because of lesser lateral stiffness due to lesser column dimension in the y-direction. Figures 4.6 and 4.7 show the story displacement graph in both x-direction and y-direction, respectively.

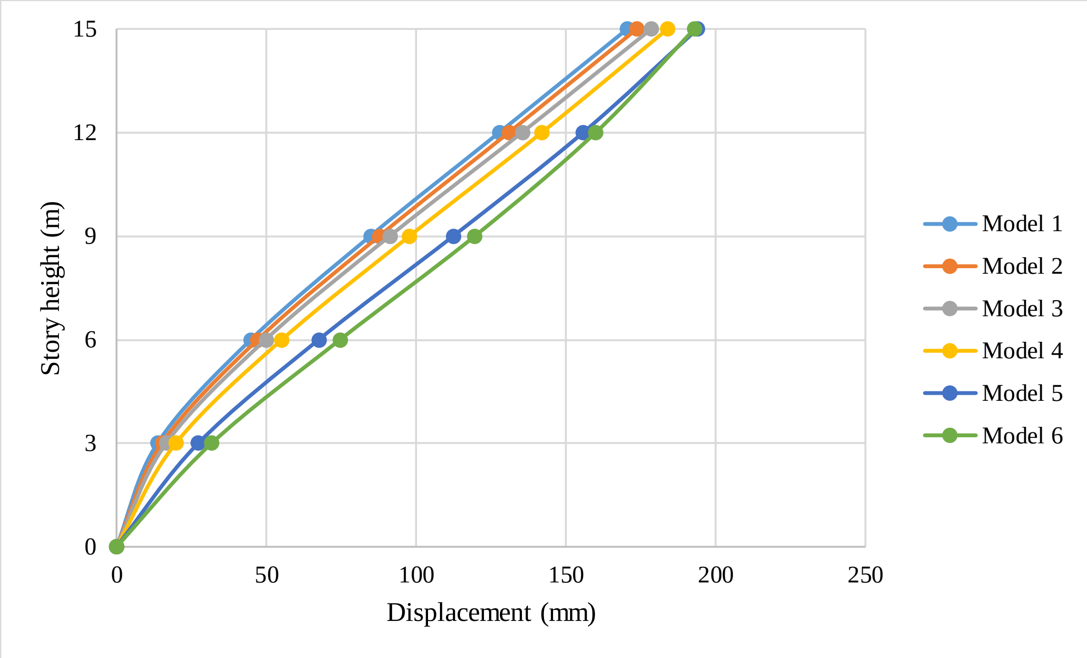


Figure 4.6 Comparison of storey height and displacement curves for all the models in X-direction at mechanisms

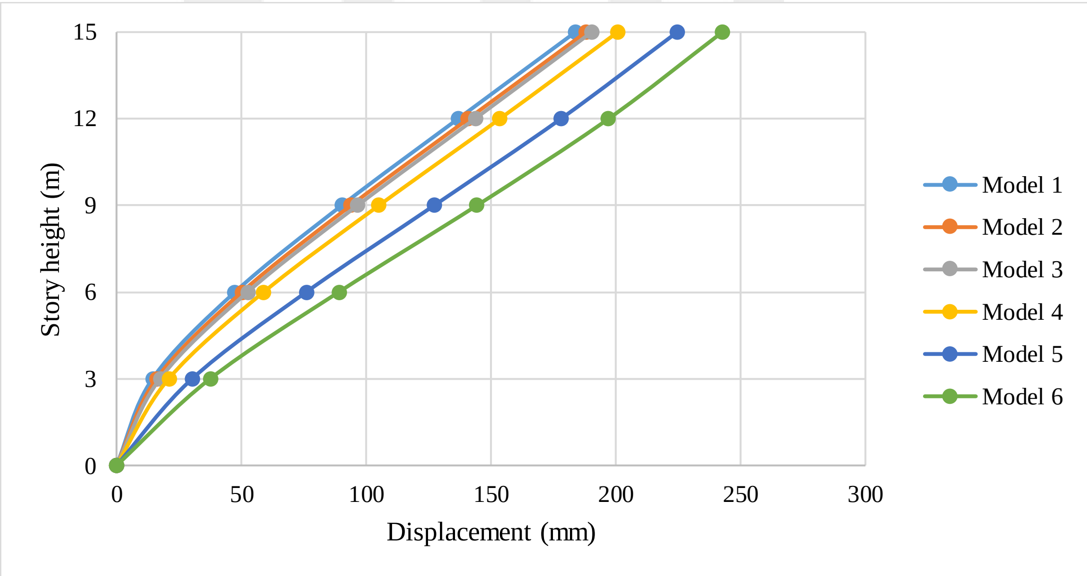


Figure 4.7 Comparison of storey height and displacement curves for all the models in Y-direction at mechanisms

The graphs shown above agree with the general idea that increased opening ratio can cause a higher lateral displacement. It is obvious in these figures that the first few lines which represent no openings, 2.7% and 11.1% opening of shear wall area along both directions are very close to each other in every level. It can be concluded that opening ratios less than 11.1% of shear wall area, may not have a significant effect on lateral displacement and stiffness of the frame system. However, opening ratios more than 11.1% of shear wall area displayed more undesirable effects on lateral displacement and stiffness of the frame system. It is obvious from the results that increasing the area of opening has the strong influence on the displacement response by the frame system and this trend increases with story height. Hence, it could be advisable to avoid large openings in the shear wall for better structural response.

4.2.3 Story drift demands at mechanisms

The other important parameter in the lateral analysis which is similar to displacement is drift in each story. Storey drift is the displacement of one level relative to the other level above or below. Drift also vary according to each direction. According to UBC 97, the story drift for buildings is limited to 0.020 times the story height, which was not exceeded in this analytical study for all six models. Values of peak story drifts and different story height for each model are provided in Table 4.3 along x-direction and Table 4.4 along y-direction.

Table 4.3 Story drift demand along X-direction

Story drift (mm)						
Story	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1	13.7	15.2	16.6	19.8	27.3	31.8
2	31.2	32.0	33.2	35.4	40.2	42.9
3	39.9	40.6	41.5	42.6	44.9	45.0
4	43.1	43.3	44.2	44.2	43.4	40.4
5	42.8	42.8	43.2	42.0	38.1	33.0

Table 4.4 Story drift demand along Y-direction

Story drift (mm)						
Story	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1	14.4	16.0	17.4	20.9	30.3	37.5
2	33.0	34.2	35.1	38.0	45.7	51.5
3	42.8	43.7	44.1	46.2	51.3	55.4
4	46.6	47.0	47.2	48.4	50.8	52.7
5	47.0	47.1	46.8	47.2	46.6	45.6

As seen in the tables above, the results along x-direction shown that the peak story drift is 43.1 mm for original building without opening in shear wall. It is increased to 43.3 mm, 44.2 mm, 44.2 mm, 44.9 mm, and 45 mm for the models 2, 3, 4, 5, and 6, respectively. On the other hand, the results along y-direction observed that the peak story drift is 47 mm for original building with shear wall having no opening. It was gone up to 47.1 mm, 47.2 mm, 48.4 mm, 50.8 mm, and 55.4 mm for the models 2, 3, 4, 5, and 6, respectively. The story drift in y-direction is comparatively higher than the story drift in x-direction. This is due to the fact that the lateral stiffness is less in the y-direction. Figures 4.8 and 4.9 demonstrate the story drift demand corresponding to the story height in x-direction and y-direction, respectively.

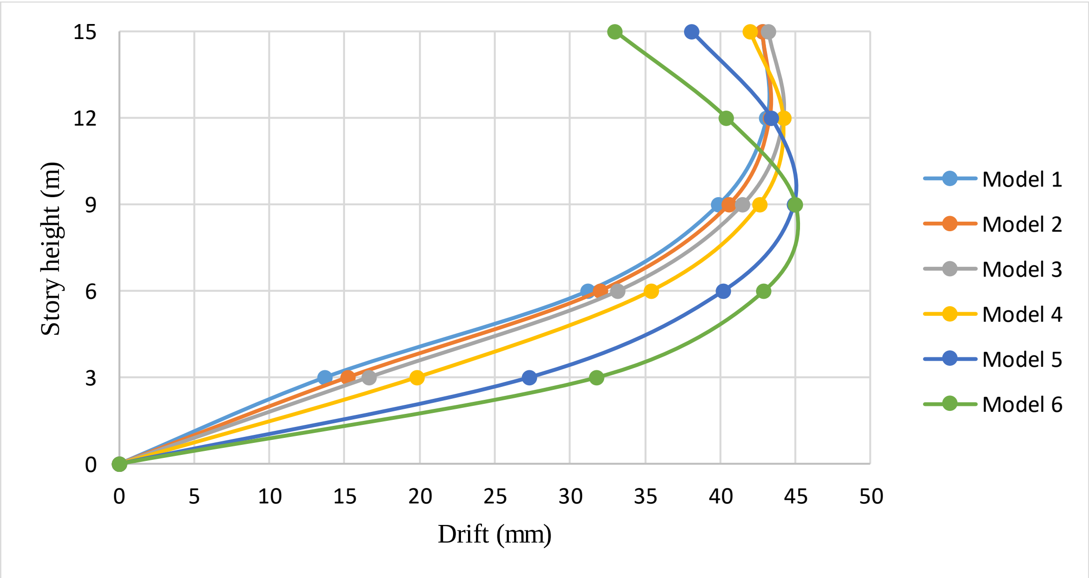


Figure 4.8 Comparison of storey height and storey drift curves for all the models in X-direction at mechanisms

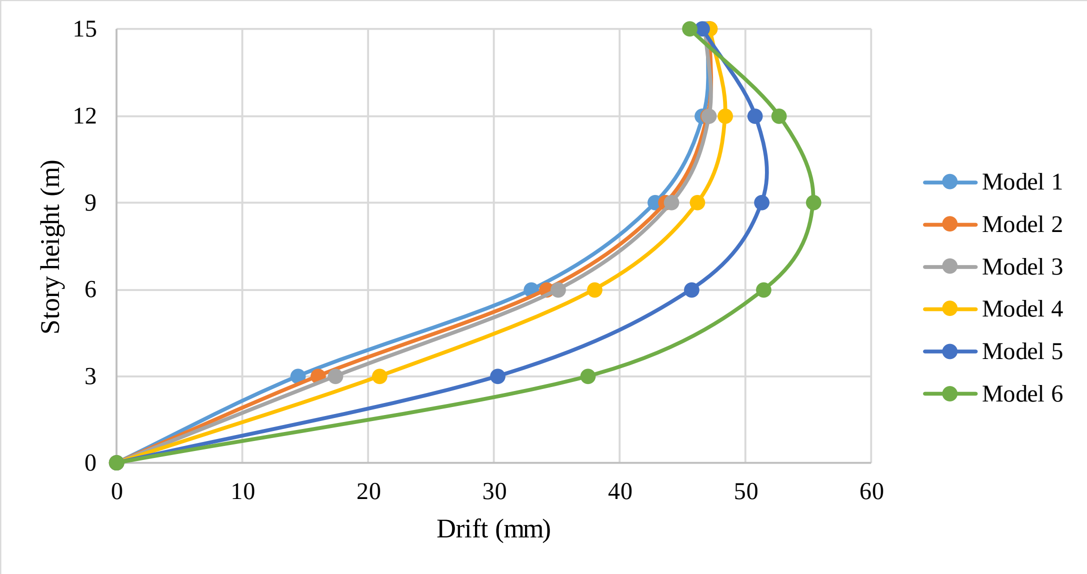


Figure 4.9 Comparison of storey height and storey drift curves for all the models in Y-direction at mechanisms

As presented in the above graph of the maximum story drift, the first three lines which represent model 1, model 2, and model 3 are very close to each other through story height. It can be concluded that opening ratios of up to about 11.1% of shear wall area may not have a substantial effect on story drift and flexibility of the frame system. However, opening ratios greater than 11.1% of shear wall area showed much higher story drifts and the walls behavior to be more flexible. The overall trend indicates that the more openings in the shear wall are causing larger drift values and the higher these opening ratios, the larger the story drifts and more flexibility of the walls.

4.3 Evaluation of RC shear wall buildings with and without opening using nonlinear time history analysis

The time history method is used when it is important to display inelastic response characteristics or to consider time dependent effects in the calculation of the structural dynamics. The earthquake ground motion which is used in the time-history analysis of the structure is for both x-direction and y-direction. The results were discussed below.

4.3.1 Lateral displacement

Maximum story displacement is always one of the most important considerations in design and it is very important to consider how much openings in shear walls can play a role in the lateral displacement of frame systems under actual earthquake record. The results of maximum roof displacements are summarized in Table 4.5 along x-direction and Table 4.6 along y-direction.

Table 4.5 Maximum roof displacement for frame systems in X-direction

Building models	Opening size	Roof displacement (mm) (+) X-direction	Increase percentage (%)	Roof displacement (mm) (-) X-direction	Increase percentage (%)
Model 1	solid shear wall (0%)	14.6	0	23.9	0
Model 2	0.5m x 0.5m (2.7%)	15.7	7.5	25.7	7.5
Model 3	1m x 1m (11.1%)	16.4	12.3	26.5	10.9
Model 4	1.5m x 1.5m (25%)	17.4	19.2	28.3	18.4
Model 5	2m x 2m (44.4%)	21.1	44.5	31.7	32.6
Model 6	2.2m x 2.2m (53.7%)	23.1	58.2	32.9	37.7

It can be seen from the table that the overall lateral displacement of the buildings increased to 7.5%, 12.3%, 19.2%, 44.5%, 58.2% for the models 2, 3, 4, 5, and 6, respectively which is significant compared to the values of building without openings in shear walls along positive x-direction. At the same time, the overall lateral displacement of the buildings was gone up to 7.5%, 10.9%, 18.4%, 32.6%, and 37.7% for the models 2, 3, 4, 5, and 6, respectively which is considerable when compared to the values of building without openings in shear walls along negative x-direction. It should be noted that the displacement in negative direction is more than in positive direction but the variation of the displacement in positive direction more than in negative direction.

Table 4.6 Maximum roof displacement for frame systems in Y-direction

Building models	Opening size	Roof displacement (mm) (+) Y-direction	Increase percentage (%)	Roof displacement (mm) (-) Y-direction	Increase percentage (%)
Model 1	solid shear wall (0%)	19.8	0	32.0	0
Model 2	0.5m x 0.5m (2.7%)	21.6	9.1	33.2	3.8
Model 3	1m x 1m (11.1%)	22.4	13.1	33.5	4.7
Model 4	1.5m x 1.5m (25%)	24.0	21.2	34.4	7.5
Model 5	2m x 2m (44.4%)	33.9	71.2	34.5	7.8
Model 6	2.2m x 2.2m (53.7%)	42.9	116.7	35.3	10.3

Results illustrated in Table 4.6 observed that the roof displacement of the models 2, 3, 4, 5, and 6 is increased to 9.1%, 13.1%, 21.2%, 71.2%, and 116.7%, respectively which is considerable when compared to the values of original building along positive y-direction. meanwhile, along negative y-direction the roof displacement of the models 2, 3, 4, 5, and 6 was gone up to 3.8%, 4.7%, 7.5%, 7.8%, and 10.3%, respectively which is significant compared to the values of original building. As seen in results displacement and variation percentage displacement in positive direction more than in negative y-direction. It is also indicating that the lateral displacements are greater in the y-direction compared to the x-direction. This is because of less lateral stiffness in the y-direction. Figures 4.10 and 4.11 infers the story displacement graph in both x-direction and y-direction respectively.

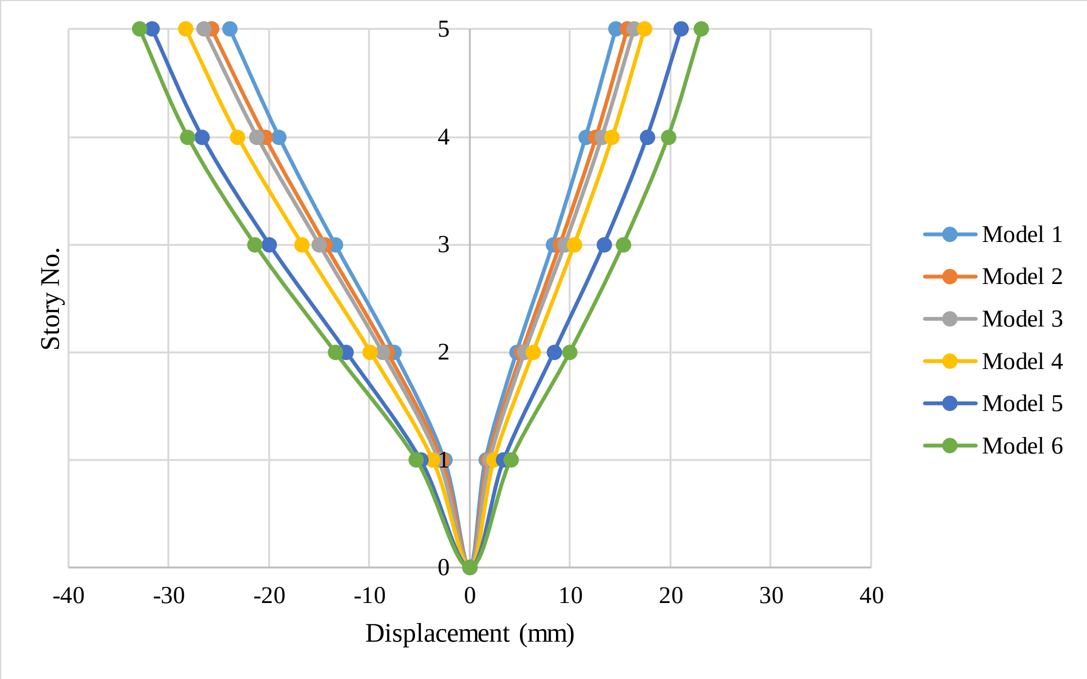


Figure 4.10 Variation of displacement with story number for all the models in X-direction from time history analysis

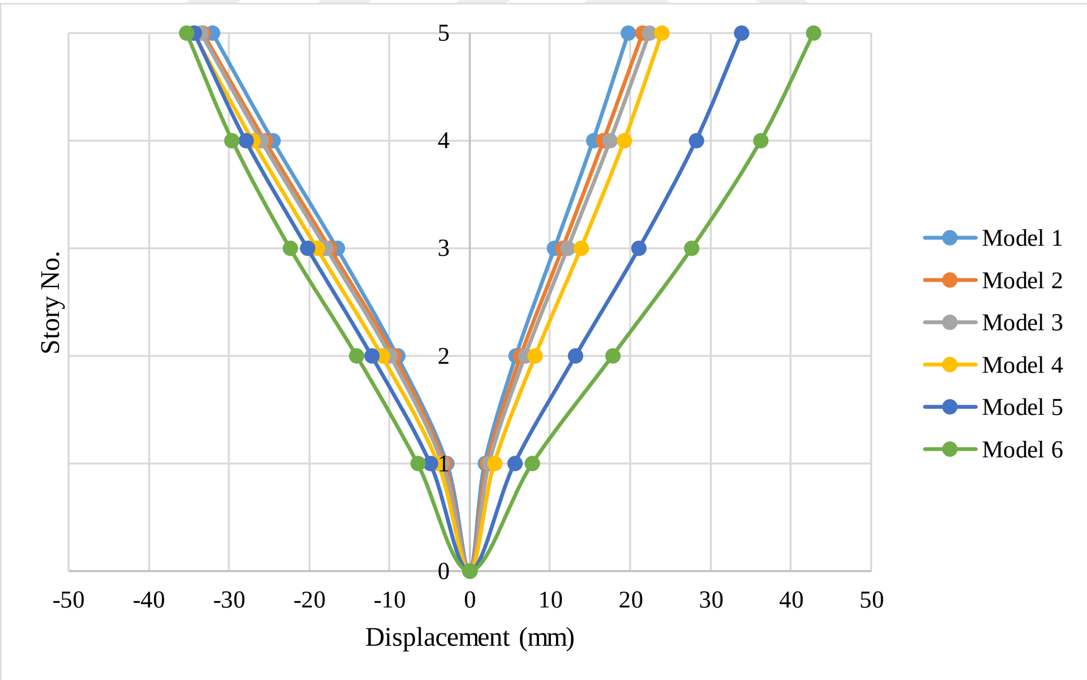


Figure 4.11 Variation of displacement with story number for all the models in Y-direction from time history analysis

The graphs demonstrated above that increased opening ratio can cause a higher lateral displacement. Based on the graph of maximum displacements in both directions, the first few lines which represent no openings, 2.7% and 11.1% opening along positive and negative x-direction, also, the first few lines which represent no openings, 2.7% and 11.1% opening along positive and negative y-direction are very close to each other in every story compared to other three lines which represent 25%, 44%, and 53.7% opening. It can be concluded that opening ratios of up to about 11.1% of shear wall area did not have a remarkable influence on lateral displacement and stiffness of the frame systems. Therefore, it can be safely ignored in analysis of the structure. However, opening ratios more than 11.1% of shear wall area displayed more undesirable effects on lateral displacement and stiffness of the frame systems and it may not be safe to ignore their influence. As a consequence, it is noted that more the area of opening more the displacements conceded by the building and this trend increases with increasing story number.

4.3.2 Story drift

Storey drift is the displacement of one level relative to the other level above or below. Drift also vary according to each direction. According to UBC 97, the story drift for buildings is limited to 0.020 times the story height, which was not exceeded in this analytical study for all six models. Tables 4.7 and 4.8 present the predicted story drift at different story height for each model along x-direction and y-direction.

Table 4.7 Story drift along positive X-direction

Story drift (mm)						
Story	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1	1.6	1.8	2.0	2.4	3.4	4.1
2	3.1	3.4	3.5	3.9	5.0	5.9
3	3.6	3.8	4.0	4.1	5.0	5.3
4	3.3	3.6	3.7	3.8	4.3	4.5
5	3.0	3.1	3.2	3.2	3.4	3.3

Table 4.8 Story drift along negative X-direction

Story drift (mm)						
Story	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1	2.5	2.8	3.1	3.7	4.9	5.3
2	5.0	5.4	5.6	6.2	7.4	8.1
3	5.9	6.2	6.3	6.8	7.7	8.0
4	5.6	6.0	6.2	6.4	6.7	6.7
5	4.9	5.3	5.3	5.2	5.0	4.8

Results along positive x-direction shows that the peak story drift is 3.6 mm for original building with having no openings in shear wall. It was gone up to 3.8 mm, 4.0 mm, 4.1 mm, 5.0 mm, and 5.9 mm for the models 2, 3, 4, 5, and 6, respectively. Also, along negative x-direction results shown the that peak story drift is 5.9 mm for building without opening in shear wall. It is increased to 6.2 mm, 6.3 mm, 6.8 mm, 7.7 mm, and 8.1 mm for models 2, 3, 4, 5, and 6, respectively. Results indicate that story drift in negative direction is more than in positive direction.

Table 4.9 Story drift along positive Y-direction

Story drift (mm)						
Story	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1	1.9	2.2	2.4	3.1	5.6	7.8
2	3.9	4.2	4.5	5.1	7.6	10.0
3	4.8	5.2	5.3	5.7	7.9	9.9
4	4.8	5.1	5.3	5.4	7.1	8.6
5	4.4	4.9	4.9	4.7	5.7	6.6

Table 4.10 Story drift along negative Y-direction

Story drift (mm)						
Story	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1	2.8	3.1	3.4	3.9	4.9	6.5
2	6.2	6.3	6.5	7.0	7.3	7.6
3	7.5	8.0	8.0	8.1	8.0	8.3
4	8.0	8.1	8.1	8.0	7.7	7.2
5	7.5	7.7	7.5	7.4	6.6	5.7

On the other hand, results along positive y-direction shows that the peak story drift is 4.8 mm for original building with having no openings in shear wall. There is a slight increase in story drift to 5.2 mm, 5.3 mm, 5.7 mm, 7.9 mm, and 10.0 mm for models 2, 3, 4, 5, and 6, respectively. Also, along negative y-direction results observed that peak story drift is 8 mm for original building with having no openings in shear wall. There is a slight increase in story drift to 8.1 mm, 8.1 mm, 8.1 mm, 8.0 mm, and 8.3 mm for the models 2, 3, 4, 5, and 6, respectively. The story drift identical in y-direction is comparatively higher than the story drift in x-direction for both positive and negative values. This is because lateral stiffness is lesser in the y-direction. Figures 4.12 and 4.13 shows the story drift corresponding to the story number in x-direction and y-direction separately.

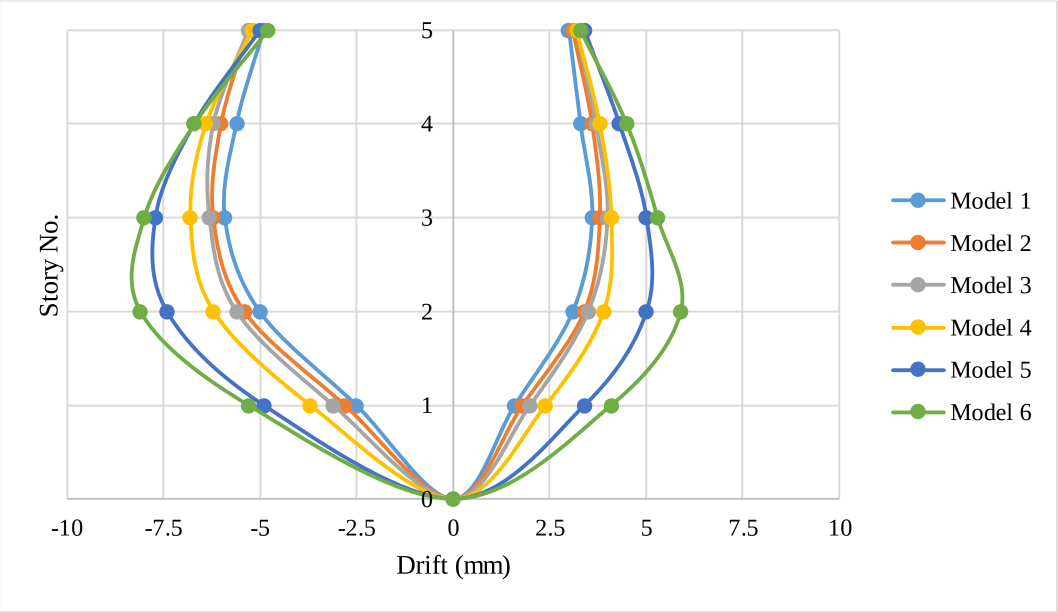


Figure 4.12 Comparison of storey number and storey drift curves for all the models in X-direction

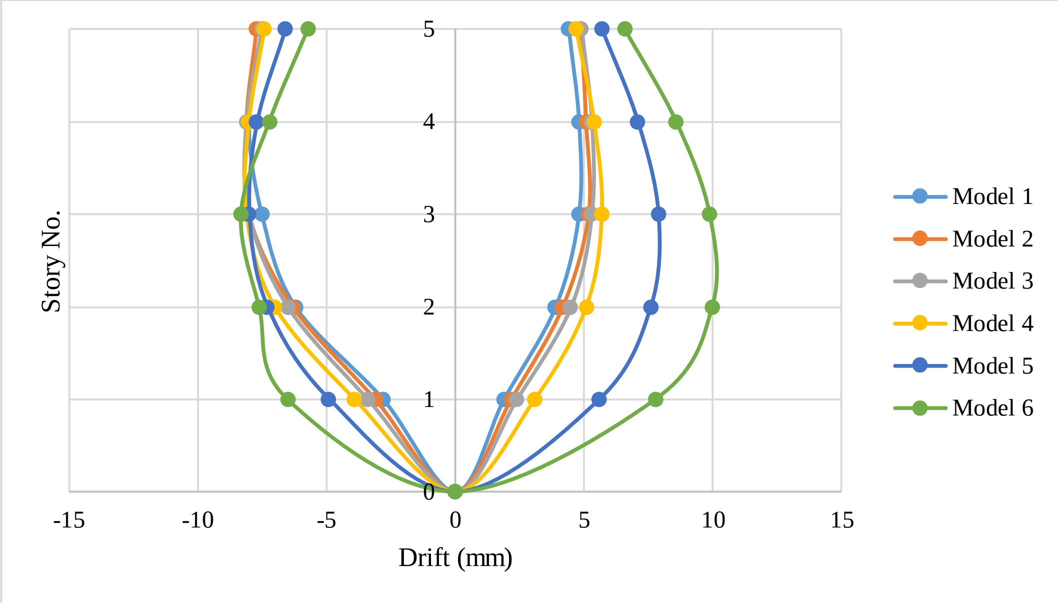


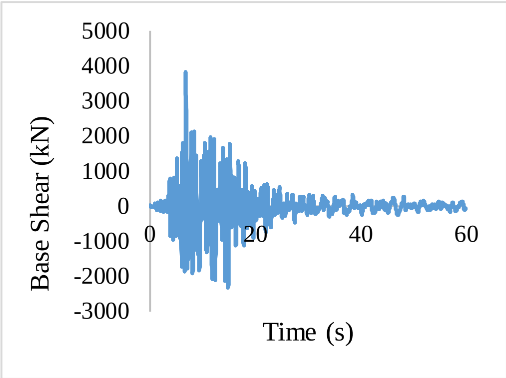
Figure 4.13 Comparison of storey number and storey drift curves for all the models in Y-direction

The graphs depicted above agree with the general idea that increased opening ratio can cause increase story drift. It can be seen from the graph of maximum story drift, the first three lines which represent model 1, model 2, and model 3 for both x and y directions are very close to each other in every story compared to other three lines with represent model 4, model 5, and model 6. It can be concluded that opening ratios of up to about 11.1% of shear wall area, may not have a significant effect on drift story. However, opening ratios beyond 11.1% of shear wall area displayed more undesirable effects on lateral story drift and the walls behavior to be more flexible. Again, the overall trend indicates that the more openings in the shear wall are causing larger drift values and the higher these opening ratios, the larger the story drifts and more flexibility of the walls.

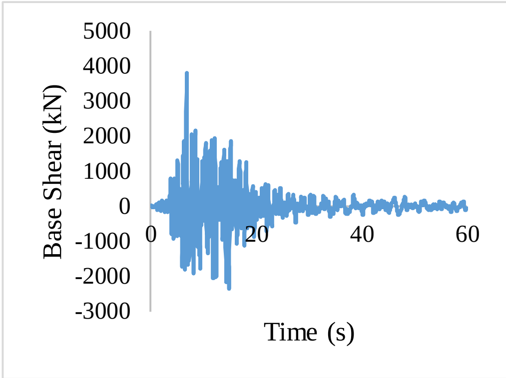
4.3.3 Time history plots for base shear and displacement

Figures 4.14 and 4.15 demonstrate the base shear time history variation for all of the investigated models. According to the analysis of the results in x-direction, it was indicated that the base shear of the original building with shear wall having no opening was 3838.0 kN but it was significantly decreased to 3816.0 kN, 3811.5 kN, 3698.3 kN, 3321.5 kN, and 2990.4 kN for the model 2, 3, 4, 5, and 6, respectively. It was also evident from results in y-direction that the base shear of the original building with shear wall having no opening was 3436.4 kN but it was significantly decreased to 3283.2 kN, 3181.1 kN, 2949.8 kN, 2408.0 kN, and 2328.2 kN for the model 2, 3, 4, 5, and 6, respectively. Again, results indicated that Presence of openings in a RC wall decreases the lateral load carrying capacity of the frame system.

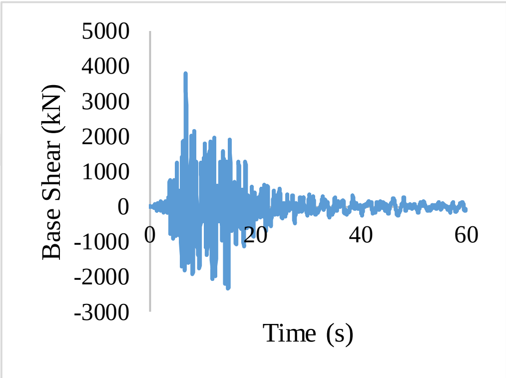
The nonlinear time history of displacements shown in Figures 4.16 to 4.25 indicate a general fluctuation of top lateral displacement responses for all of the models in both directions. According to the analysis of the results in x-direction, the maximum lateral displacement of the original building with shear wall having no opening was 14.6 mm at the instant of 14.9 s whereas the maximum roof displacement of the models 2, 3, 4, 5, and 6 was increased to 15.7 mm, 16.4 mm, 17.4 mm, 21.1 mm, and 23.1 mm, respectively. In addition, it was also observed from results in y-direction that the maximum lateral displacement of the original building with shear wall having no opening was 19.8 mm at the instant of 14.4 seconds whereas the maximum roof displacement of the model 2, 3, 4, 5, and 6 was gone up to 21.6 mm, 22.4 mm, 24.0 mm, 33.9 mm, and 42.9 mm, respectively.



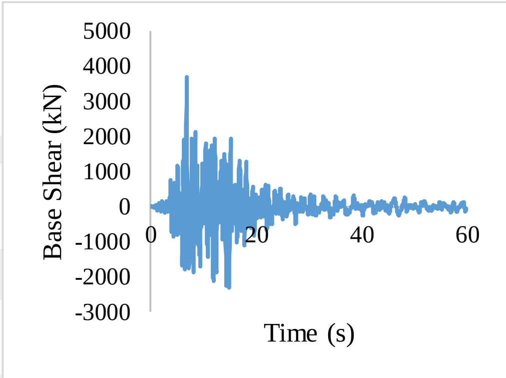
Model 1



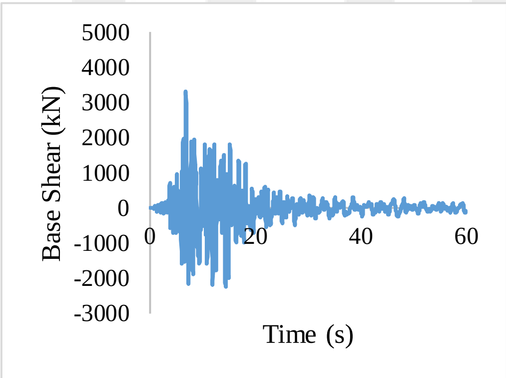
Model 2



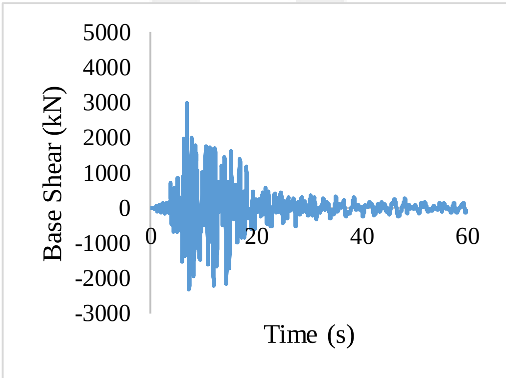
Model 3



Model 4



Model 5



Model 6

Figure 4.14 Base shear time history variations for all the models in X-direction

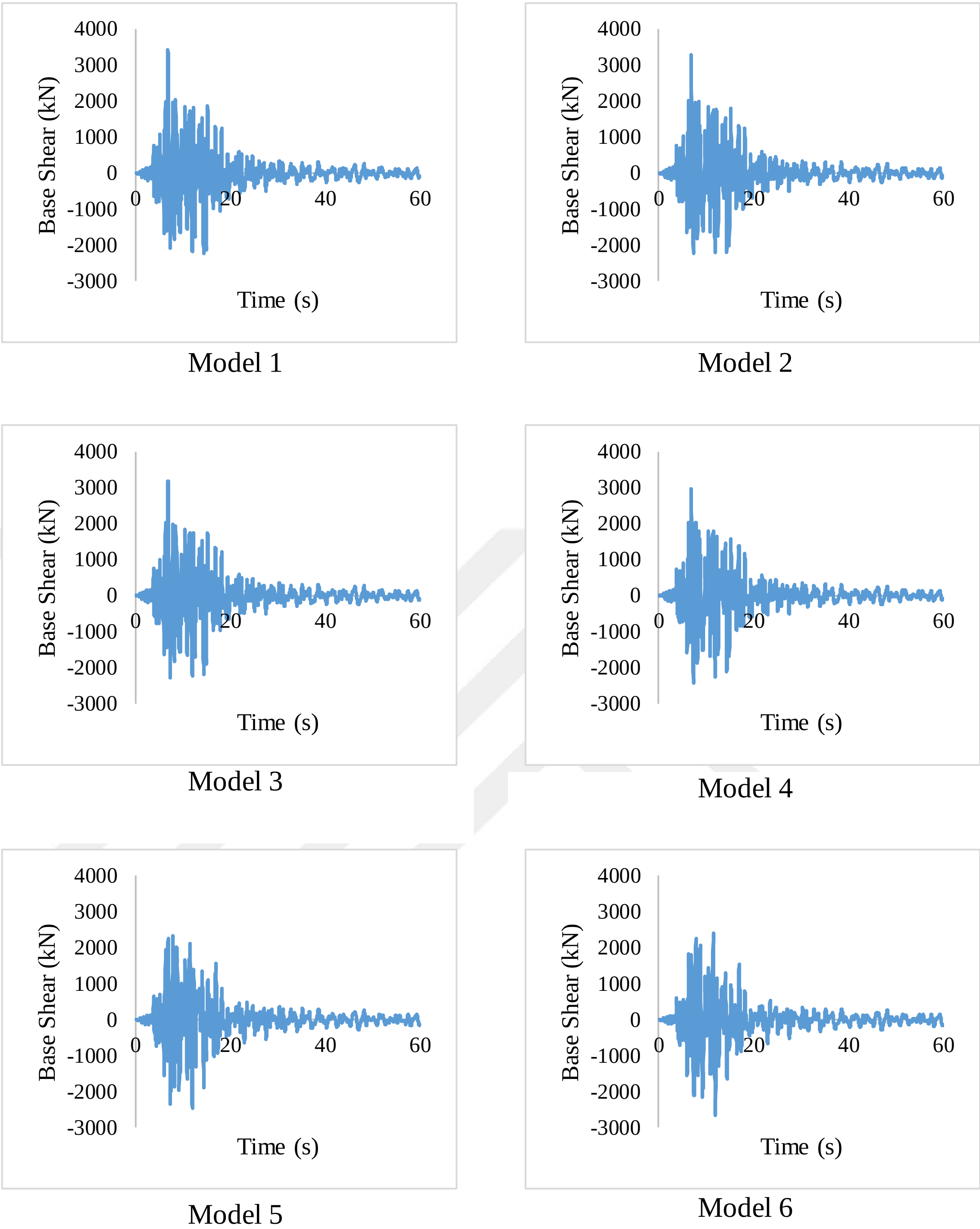
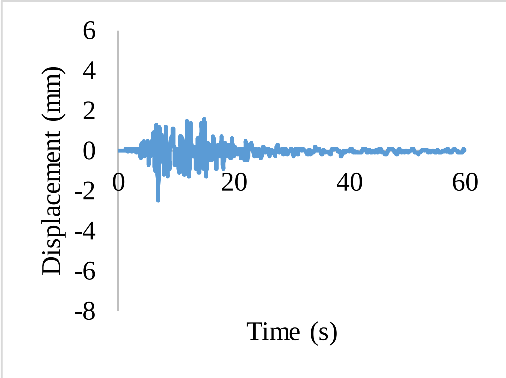
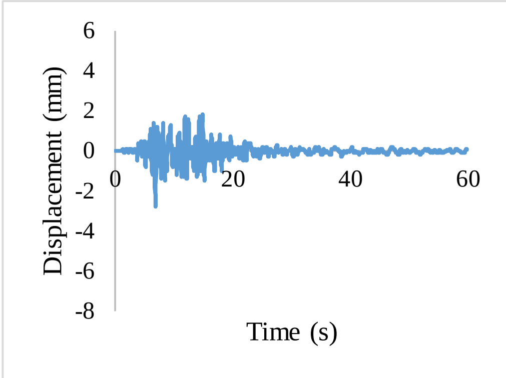


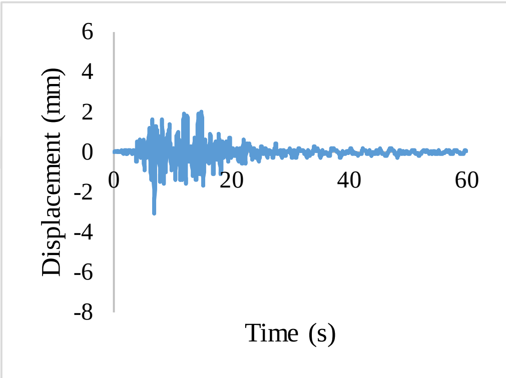
Figure 4.15 Base shear time history variations for all the models in Y-direction



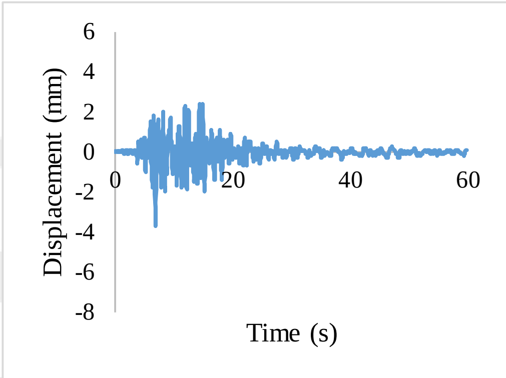
Model 1



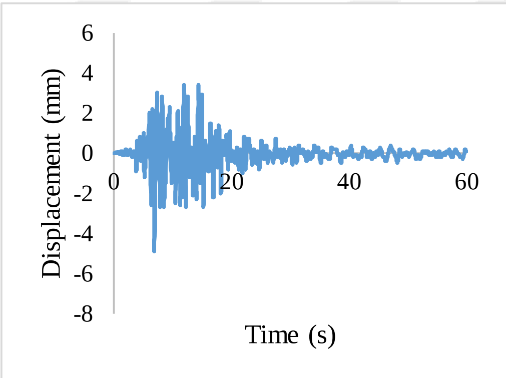
Model 2



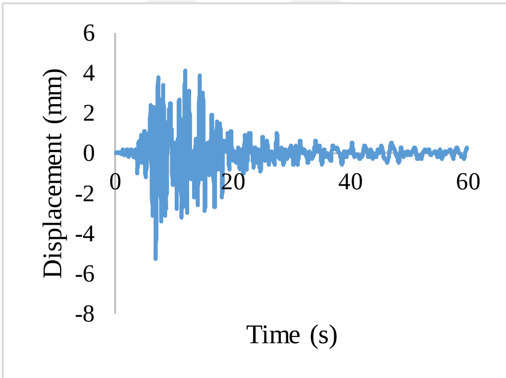
Model 3



Model 4

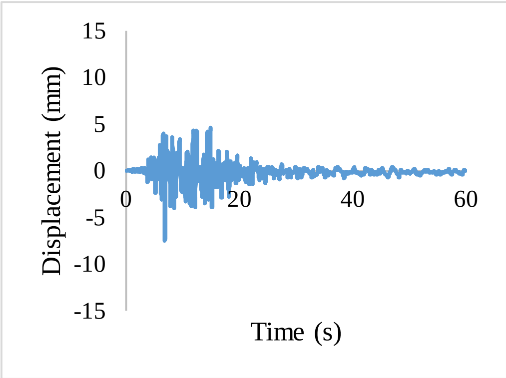


Model 5

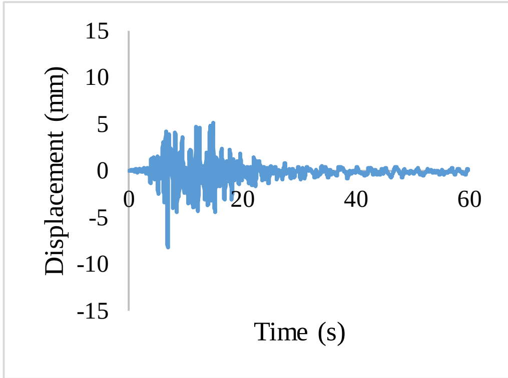


Model 6

Figure 4.16 1st story displacement time history variations for all the models in X-direction



Model 1



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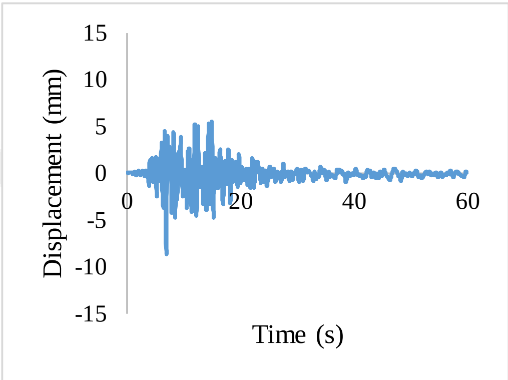
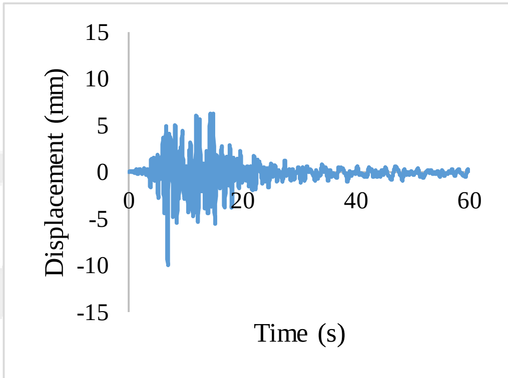


Model 3



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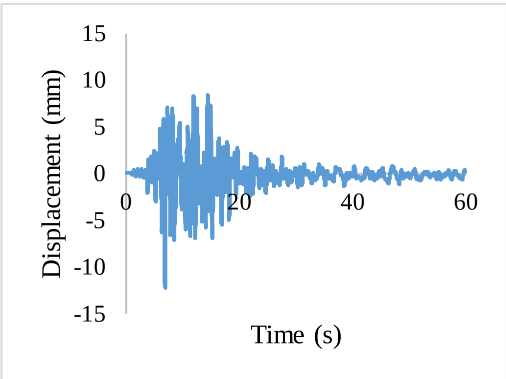
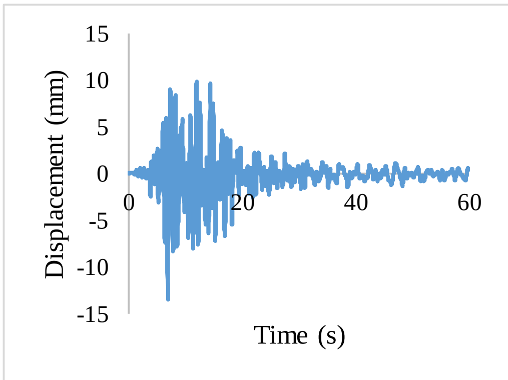


Model 5



Model 6

Figure 4.17 2nd story displacement time history variations for all the models in X-direction

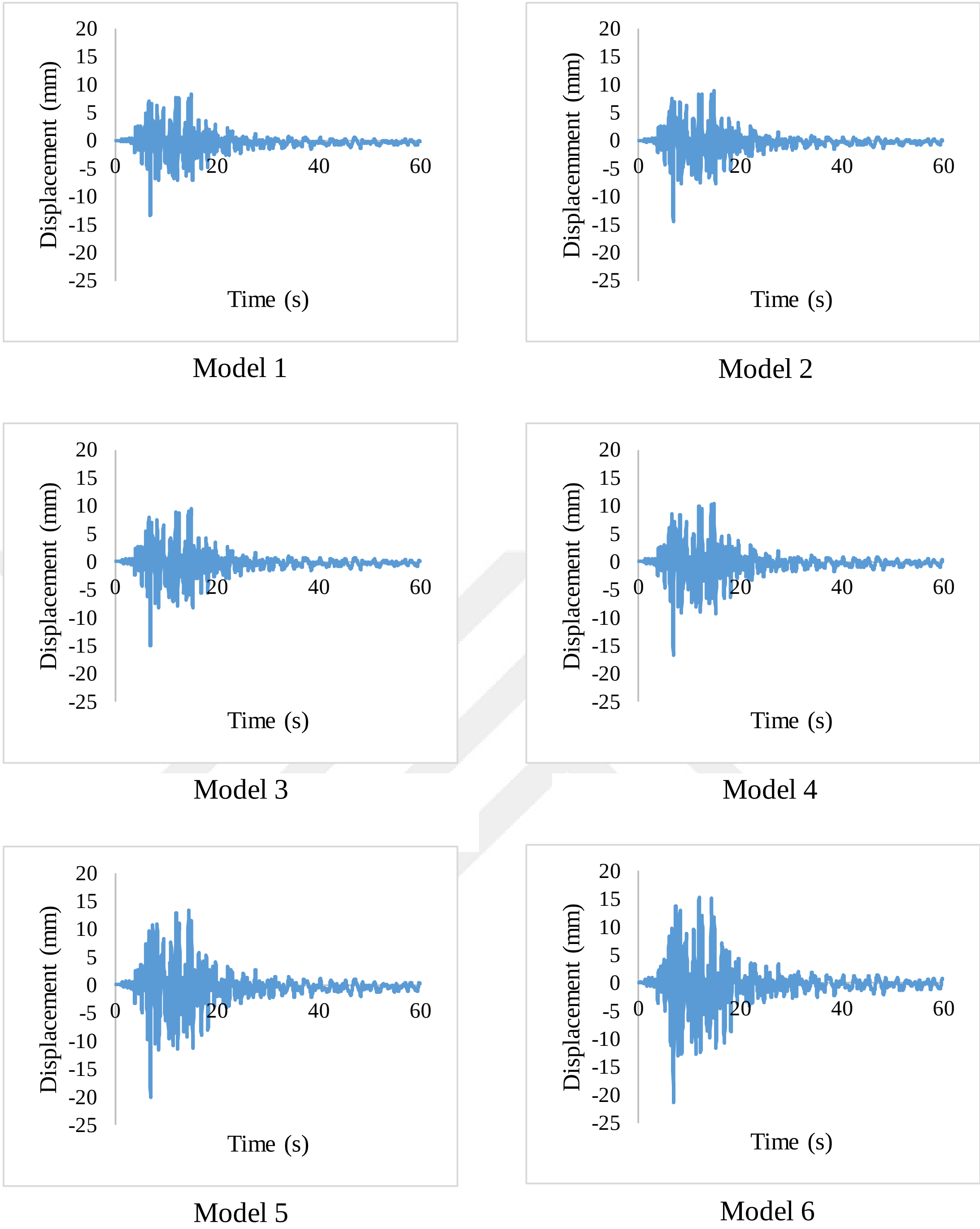
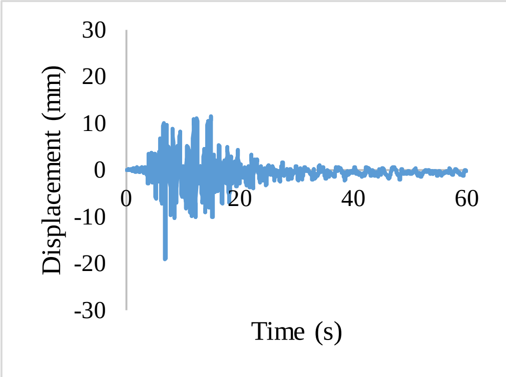
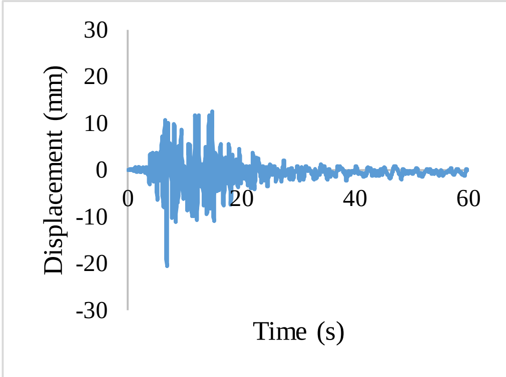


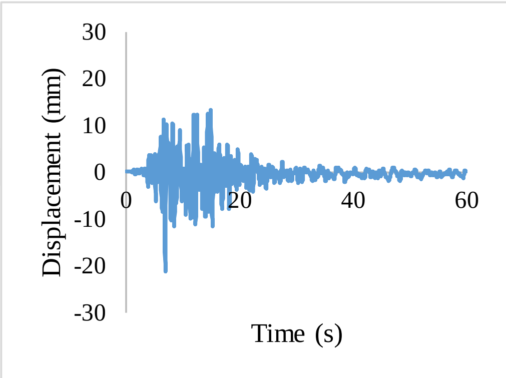
Figure 4.18 3rd story displacement time history variations for all the models in X-direction



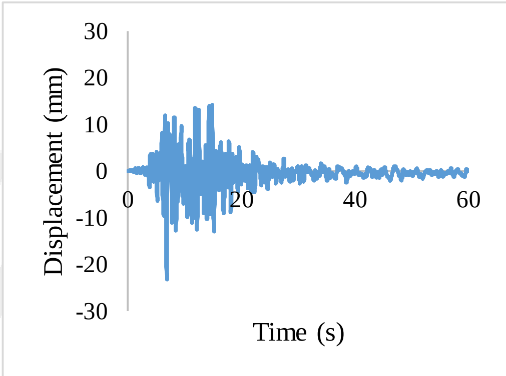
Model 1



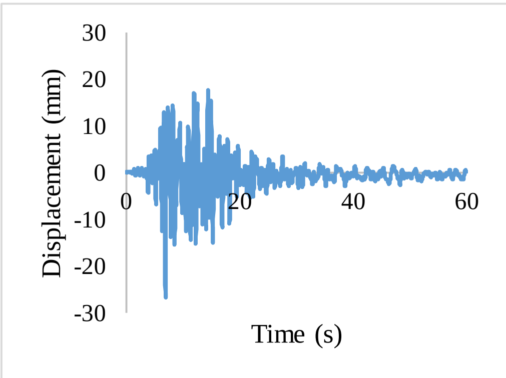
Model 2



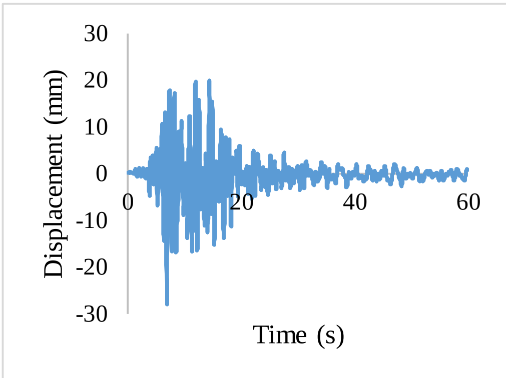
Model 3



Model 4

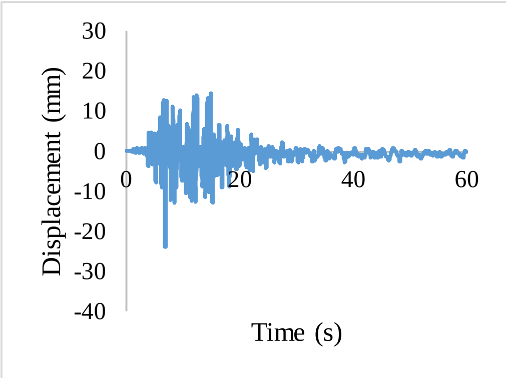


Model 5

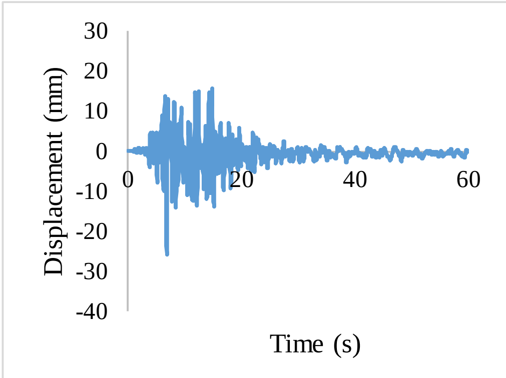


Model 6

Figure 4.19 4th story displacement time history variations for all the models in X-direction



Model 1



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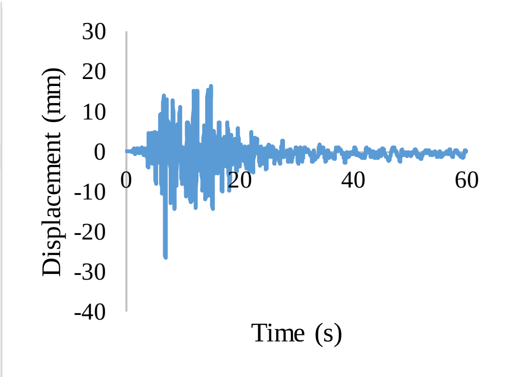

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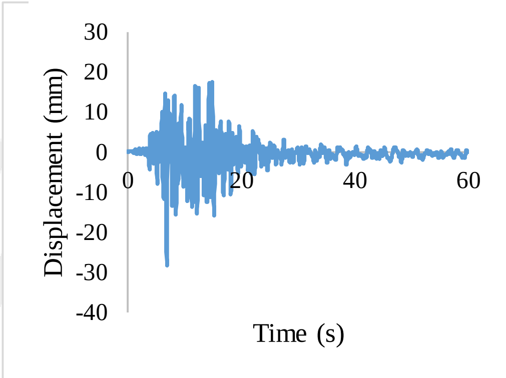
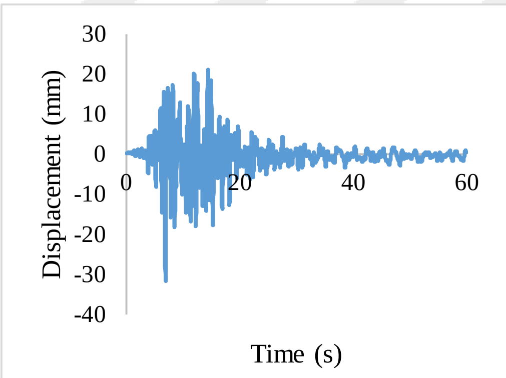


Model 4



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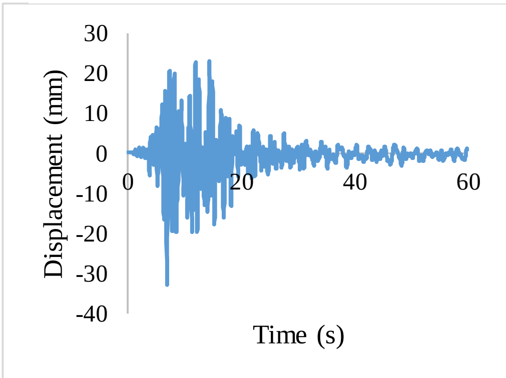
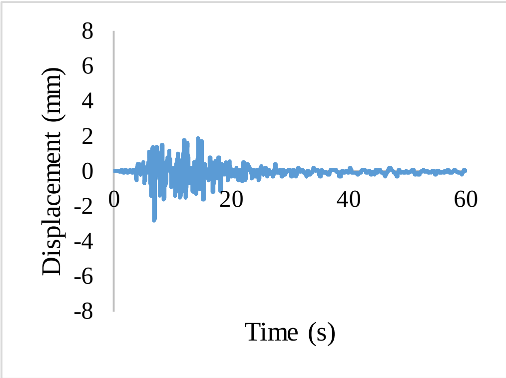
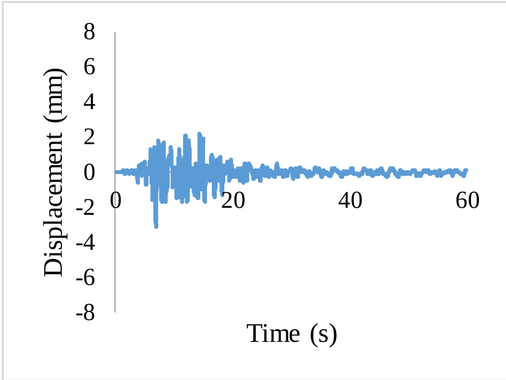


Model 6

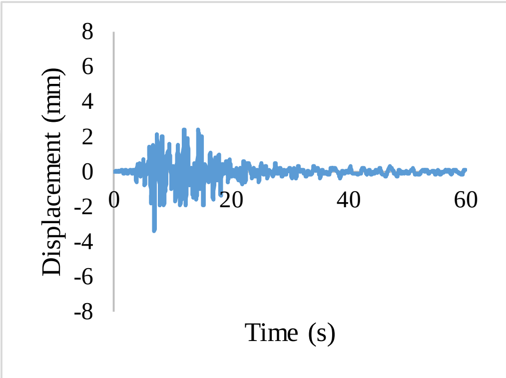
Figure 4.20 5th story displacement time history variations for all the models in X-direction



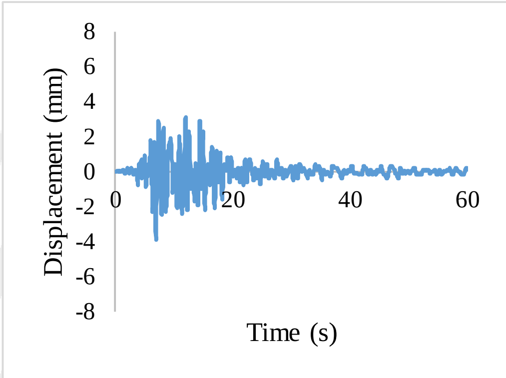
Model 1



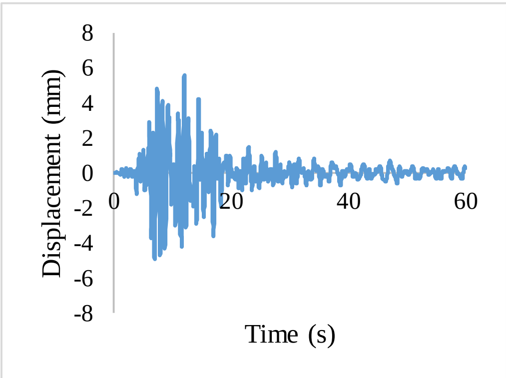
Model 2



Model 3



Model 4



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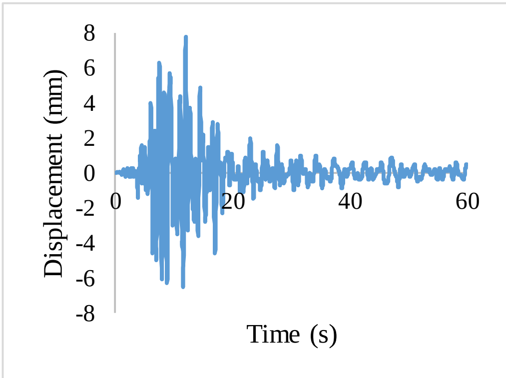
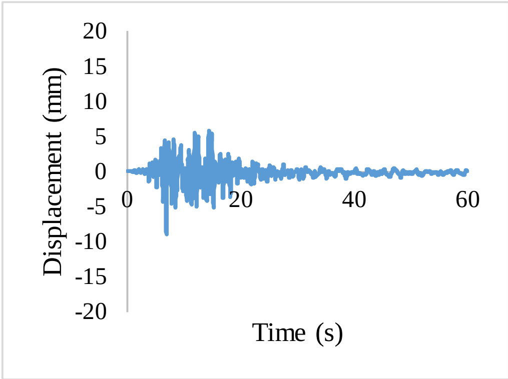
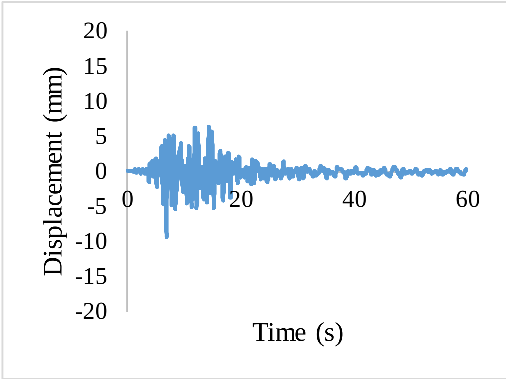


Model 6

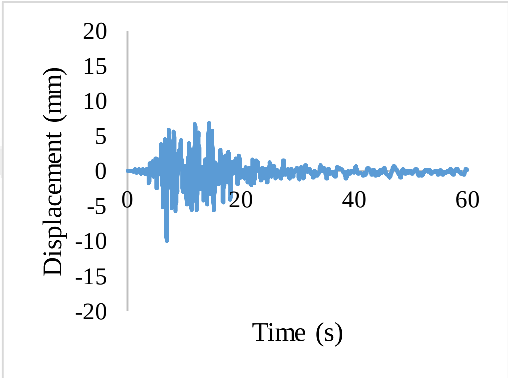
Figure 4.21 1st story displacement time history variations for all the models in Y-direction



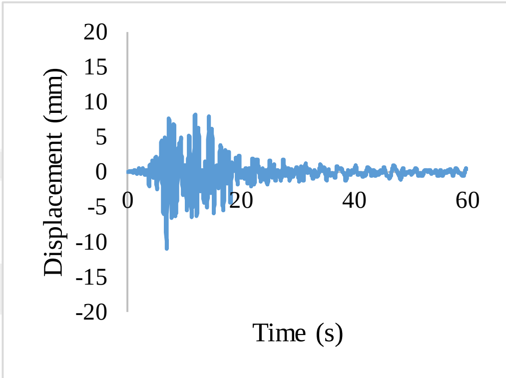
Model 1



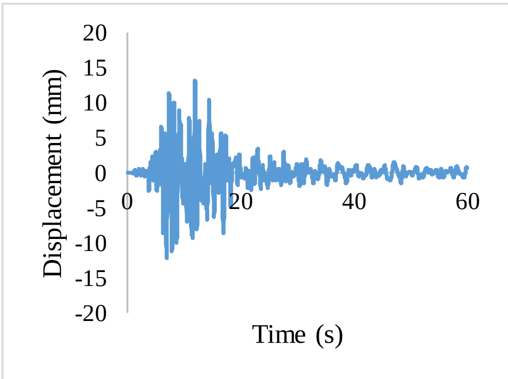
Model 2



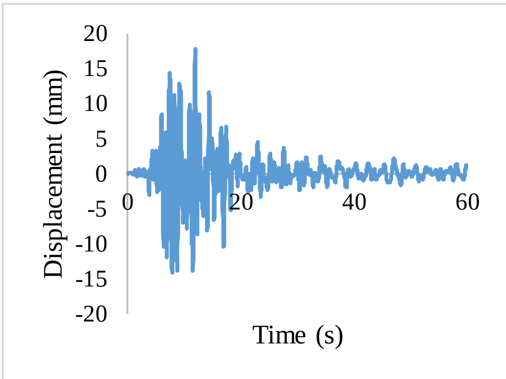
Model 3



Model 4

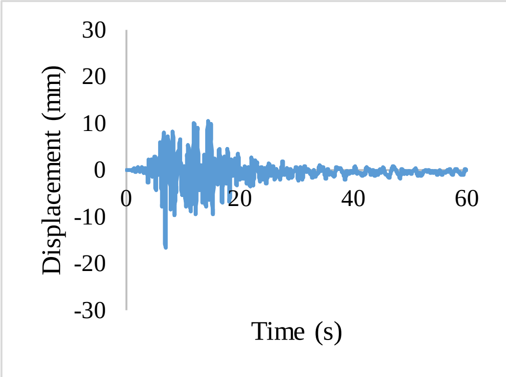


Model 5

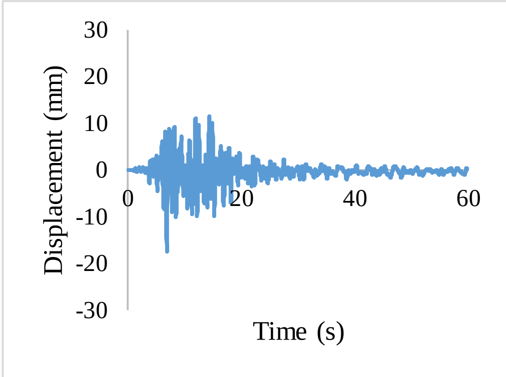


Model 6

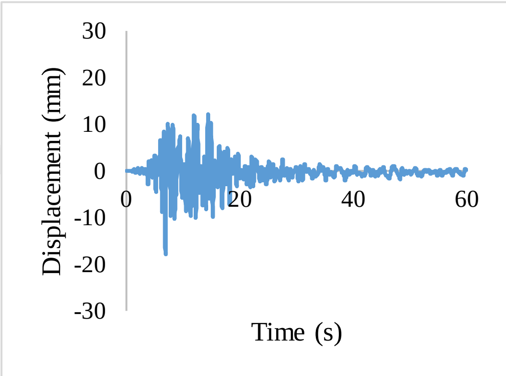
Figure 4.22 2nd story displacement time history variations for all the models in Y-direction



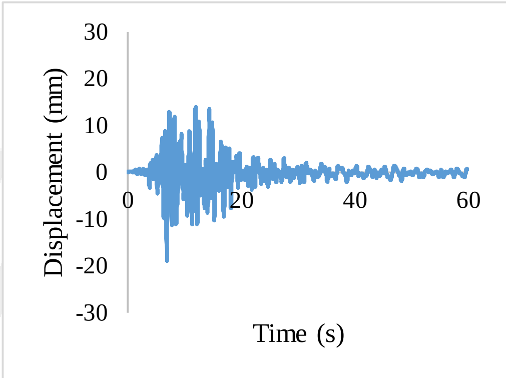
Model 1



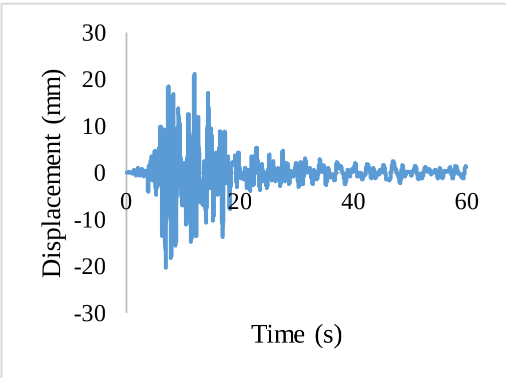
Model 2



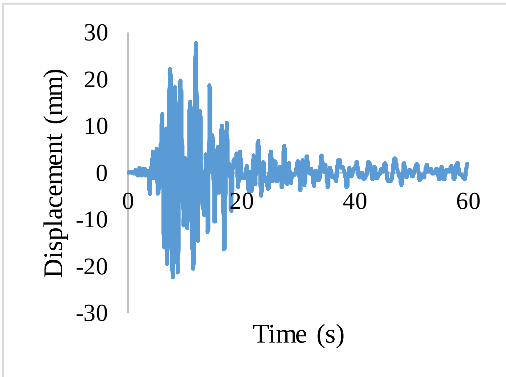
Model 3



Model 4

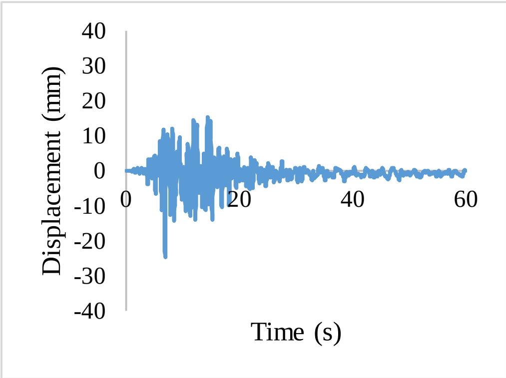


Model 5

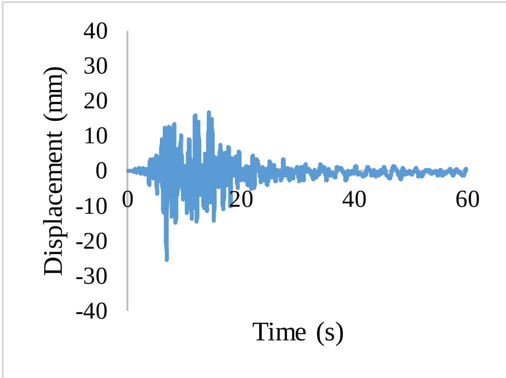


Model 6

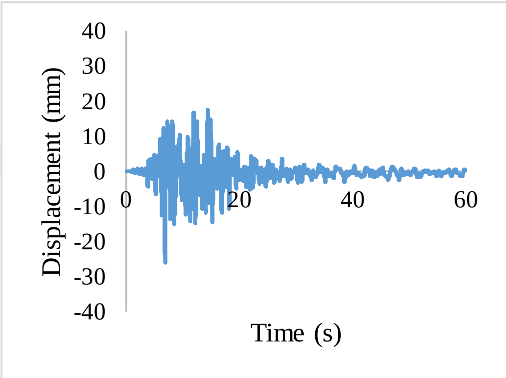
Figure 4.23 3rd story displacement time history variations for all the models in Y-direction



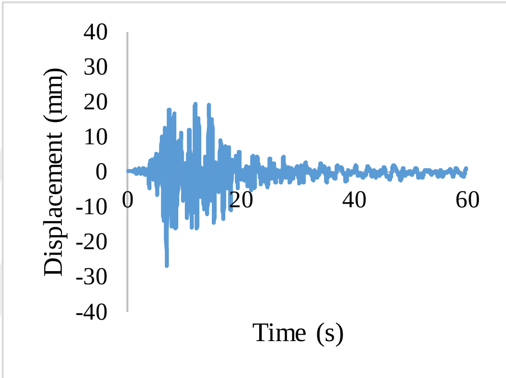
Model 1



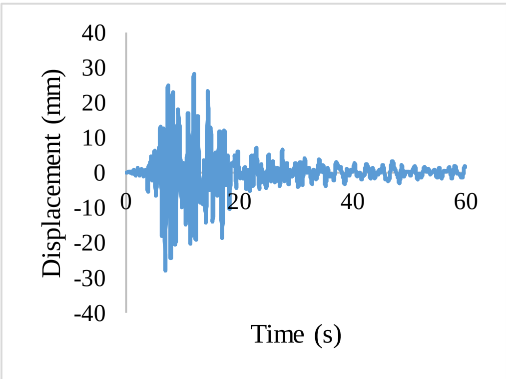
Model 2



Model 3



Model 4



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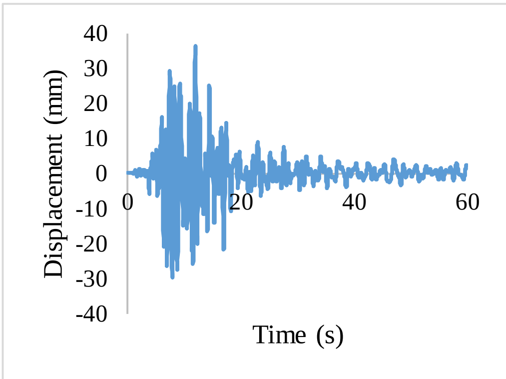
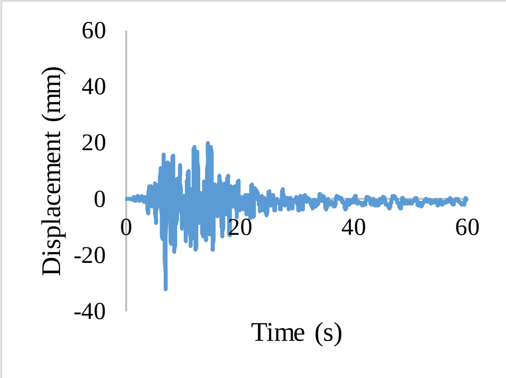
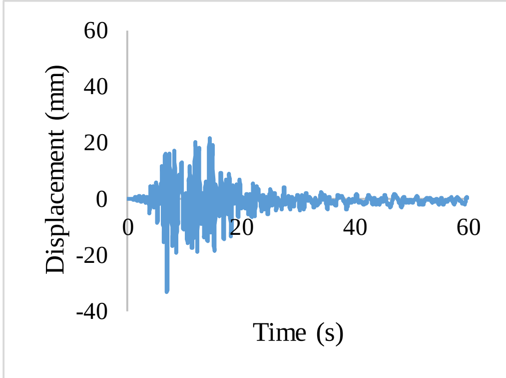


Model 6

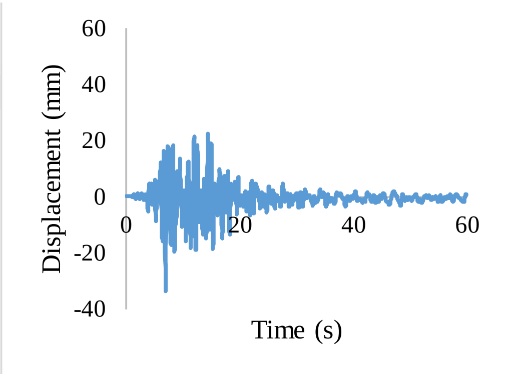
Figure 4.24 4th story displacement time history variations for all the models in Y-direction



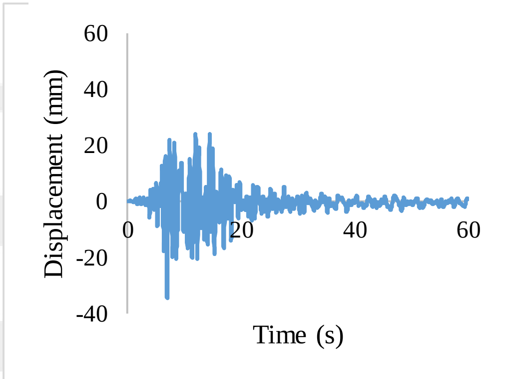
Model 1



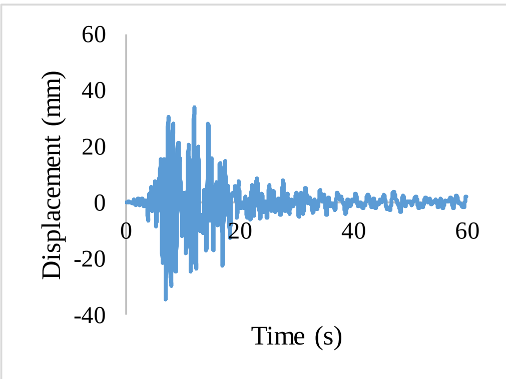
Model 2



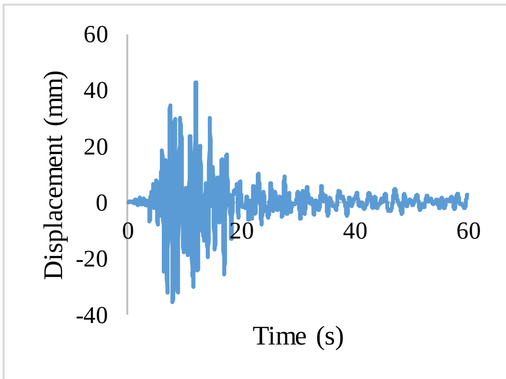
Model 3



Model 4



Model 5



Model 6

Figure 4.25 5th story displacement time history variations for all the models in Y-direction

CHAPTER 5

5. CONCLUSIONS

In this work, the effect of various size of openings in shear wall on the seismic performance of RC wall-frame systems was studied by nonlinear static and nonlinear dynamic method. The 3D model and analysis of RC shear walls with openings building was carried out using the finite element analysis software ETABS2015. The following conclusions can be extracted on the basis of the numerical results:

- It was observed that the fundamental period increased when the shear wall opening size was increased. Openings are playing a major role in modal periods of the structure. Also, where ratios of openings are higher, the impact that opening have on natural period should be considered and cannot be ignored.
- The results indicated that increasing presence of openings in shear wall reduced considerably the lateral load carrying capacity of the structural system.
- It was pointed out that the base shear, displacement, drift, and the overall seismic response of the structure was affected by the size of openings in shear wall.
- Increasing the presence of openings in shear walls reduce the stiffness and strength of structure in general but this reduction varied from negligible to significant depending on size of the openings. Furthermore, increasing the presence of openings increased the flexibility of the structural system.
- Based on the results, it could be concluded that in this study small openings up to a ratio of 11.1% of the shear wall did not have a significant influence on base shear, displacement, drift and the overall lateral stiffness and strength of the structure. These openings which may be required for architectural reasons or mechanical, electrical or plumbing purposes can be safely ignored in analysis of the structure. However, openings with higher ratios can severely effect on the base shear, displacement, drift and the overall lateral stiffness and strength of the structural frame system. The opening ratios higher than 11.1% of shear wall area

displayed more detrimental effects and it may not be safe to ignore their influence.

- Roof displacement of the models 2, 3, 4, 5, and 6 (with various opening size) increased to 1.9%, 4.7%, 7.8%, 13.6%, and 13.1%, respectively along x-direction, in comparison to the model 1 (no opening). Furthermore, the roof displacement of the models 2, 3, 4, 5, and 6 increased to 2.3%, 3.6%, 9.2%, 22.3%, and 32.0%, respectively along y-direction as compared to values of original building (model 1) in the pushover analysis.
- The overall lateral displacement of the buildings rised to 7.5%, 12.3%, 19.2%, 44.5%, and 58.2% for the models 2, 3, 4, 5, and 6, respectively along positive x-direction. At the same time, the overall lateral displacement of the buildings went up to 7.5%, 10.9%, 18.4%, 32.6%, and 37.7% for the models 2, 3, 4, 5, and 6, respectively along negative x-direction which was considerable when compared to the values of building with having no openings in shear walls in the time history analysis.
- Roof displacement of the models 2, 3, 4, 5, and 6 increased to 9.1%, 13.1%, 21.2%, 71.2%, and 116.7%, respectively along positive y-direction. Meanwhile, along negative y-direction, the roof displacement of the models 2, 3, 4, 5, and 6 extended to 3.8%, 4.7%, 7.5%, 7.8%, and 10.3%, respectively which is significant compared to the values of the original building in the time history analysis.
- The distribution of the story drift ratio over the frame height was observed to become non uniform based on the results of both analysis methods.
- It is recommended for designers to avoid openings in shear walls as much as possible. It is advisable to say that before introducing opening in shear wall proper analysis should be made.

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APPENDIX

Appendix A: Deflected shapes

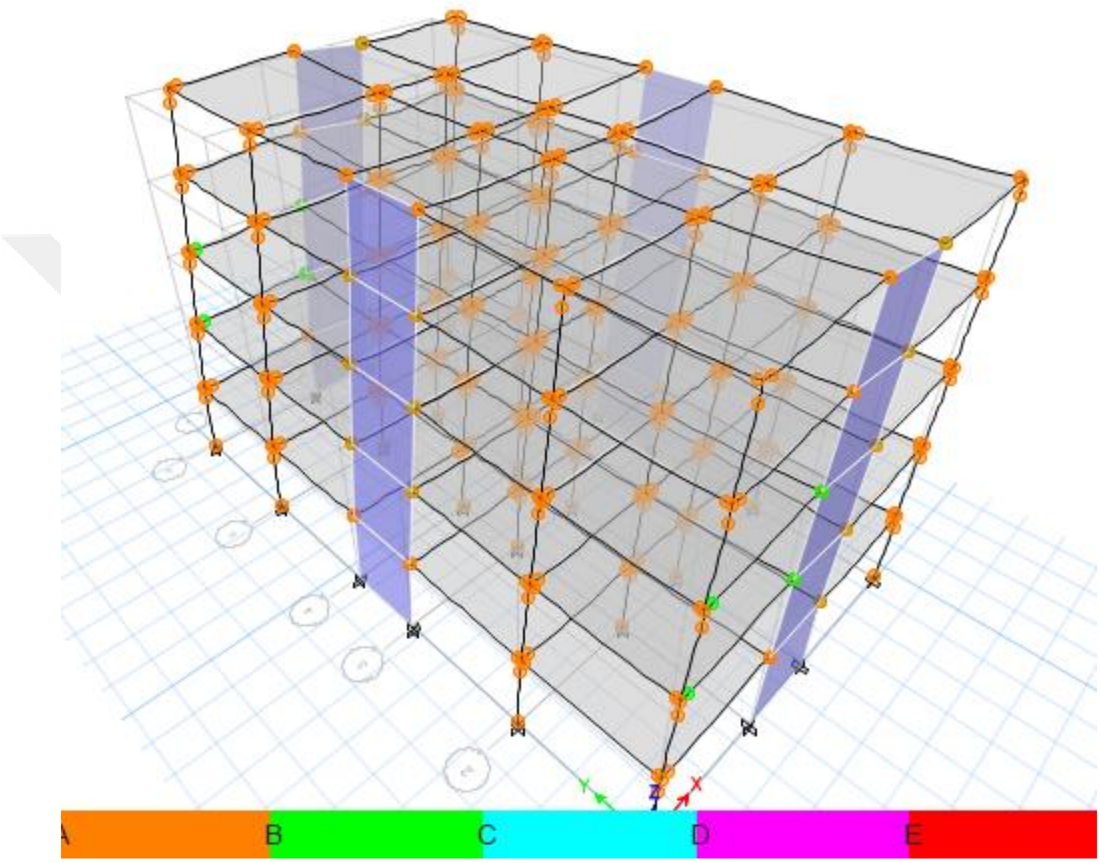

Figure A1. 3D view of hinge formation of the model 1 under the earthquake in +X direction

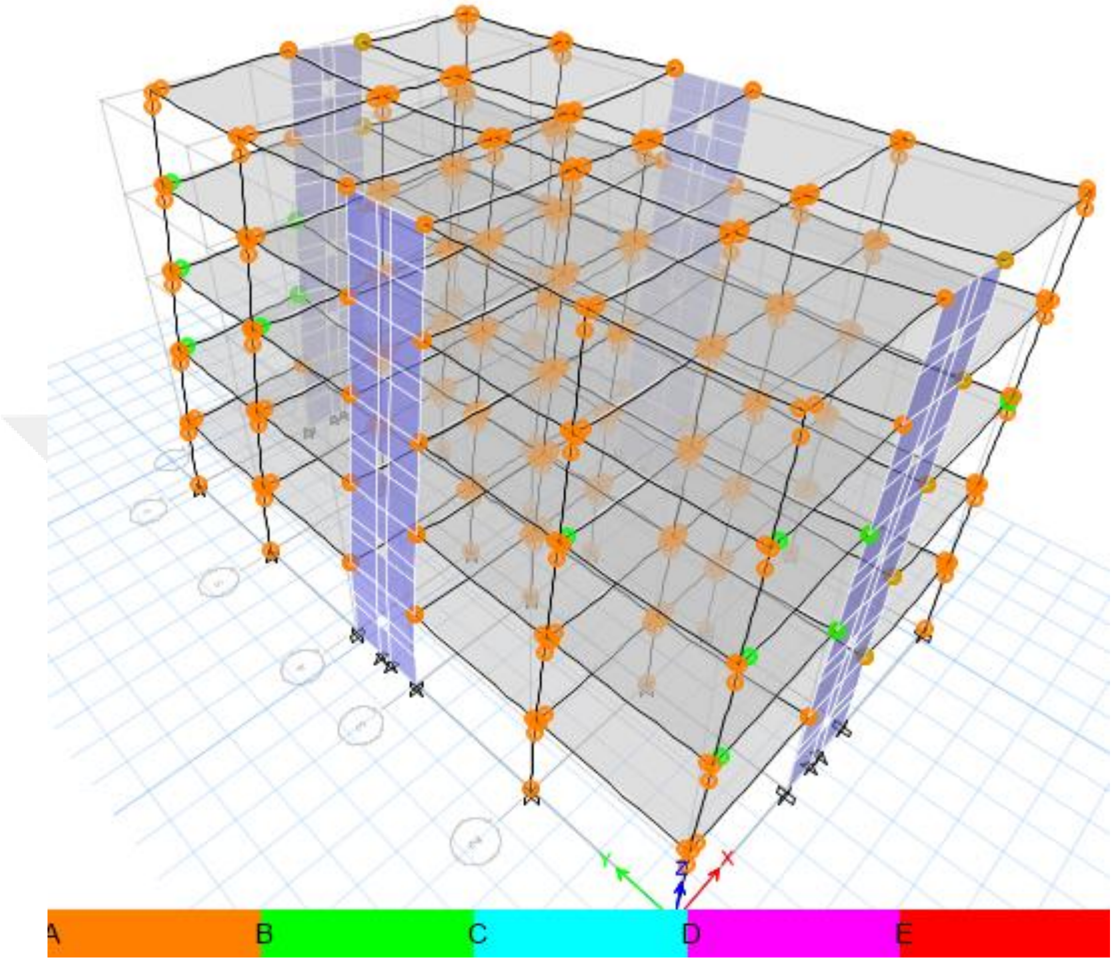

Figure A2. 3D view of hinge formation of the model 2 under the earthquake in +X direction

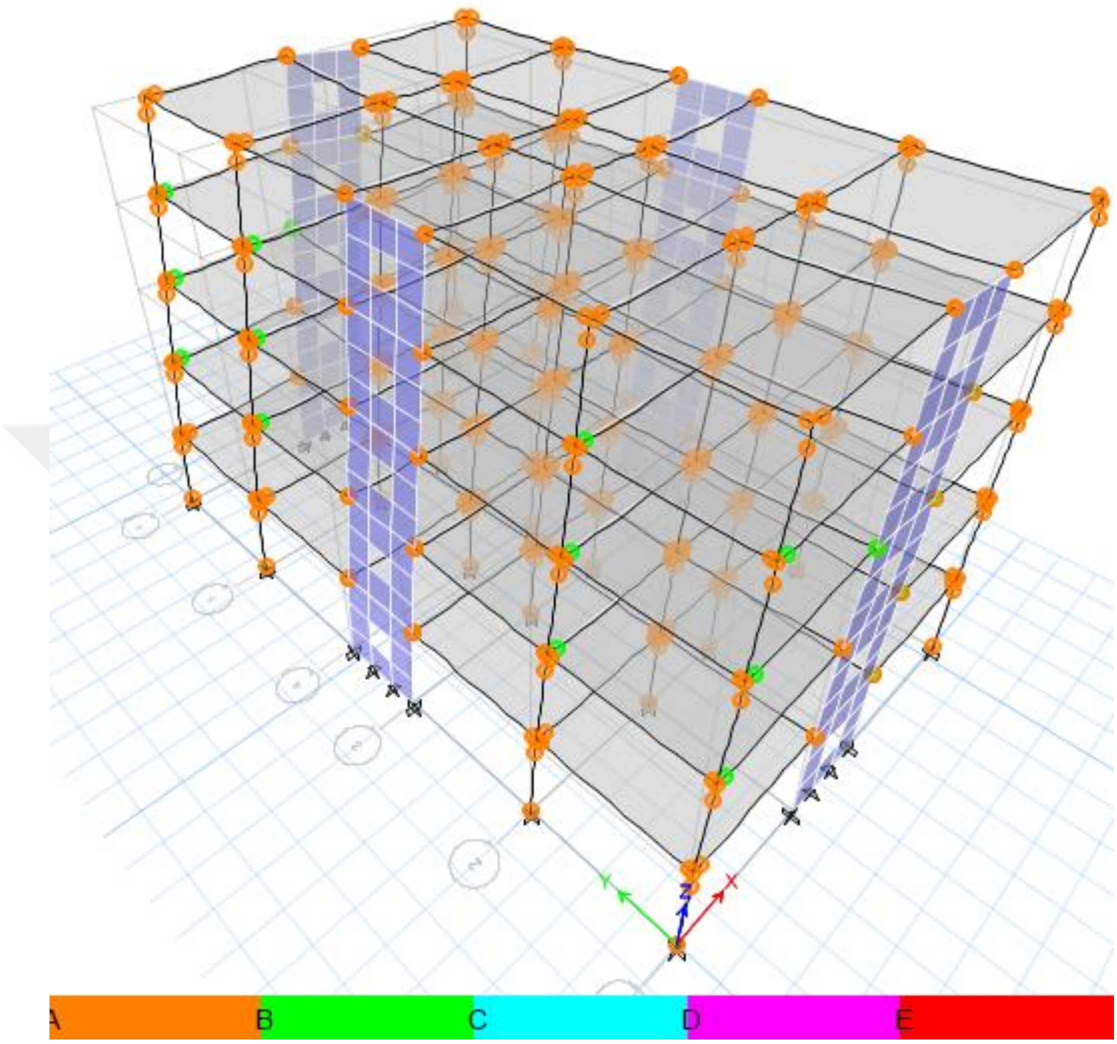

Figure A3. 3D view of hinge formation of the model 3 under the earthquake in +X direction

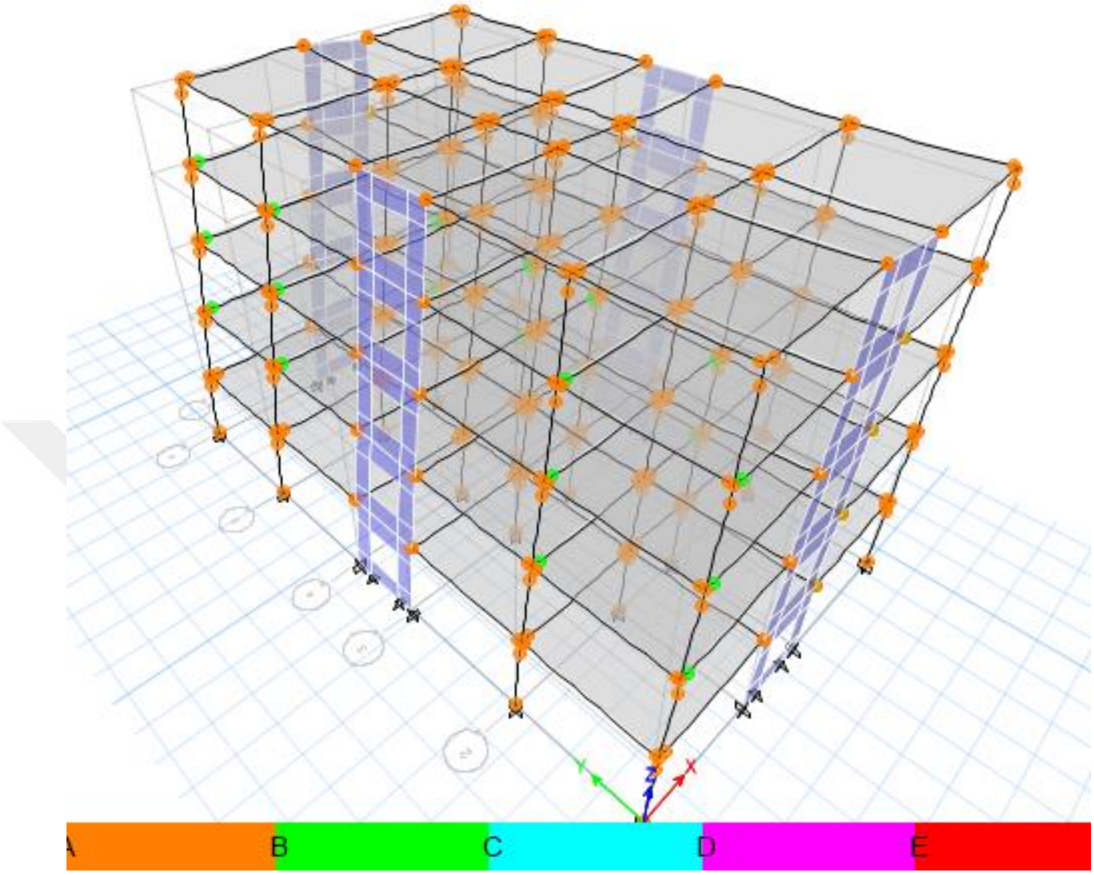

Figure A4. 3D view of hinge formation of the model 4 under the earthquake in +X direction

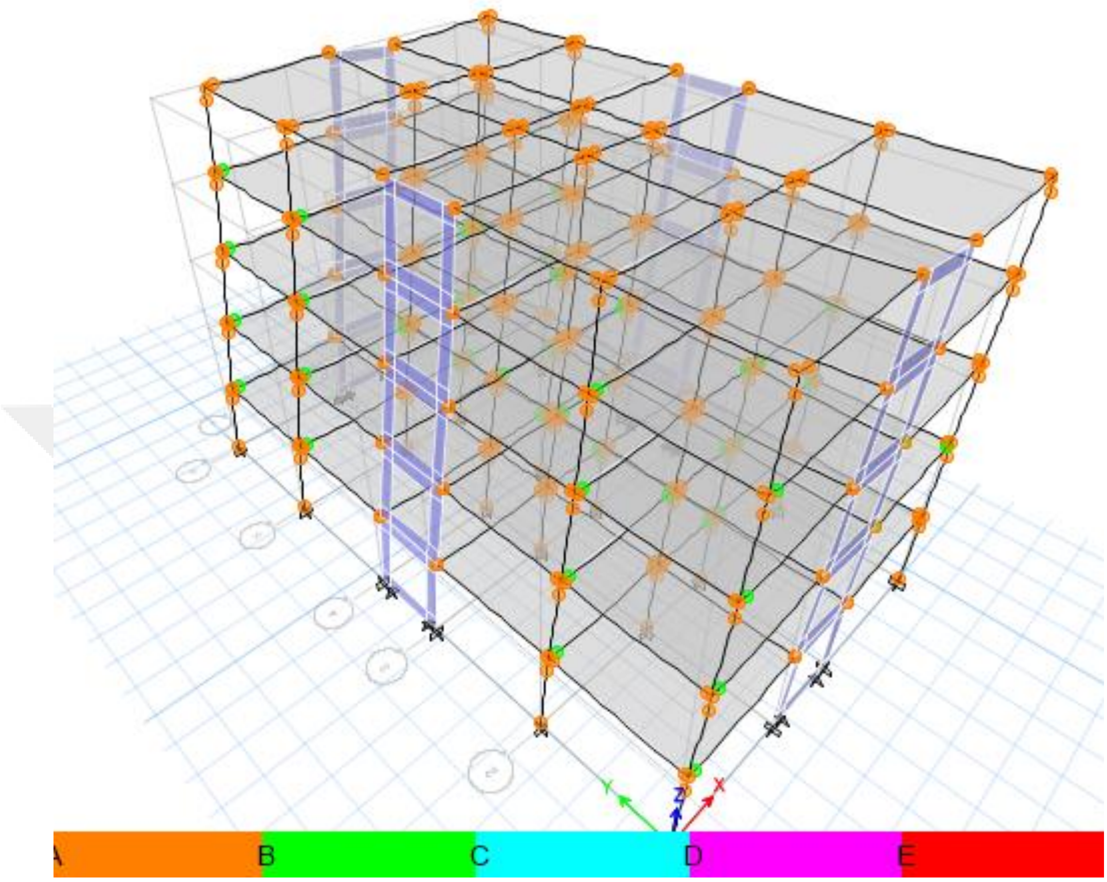

Figure A5. 3D view of hinge formation of the model 5 under the earthquake in +X direction

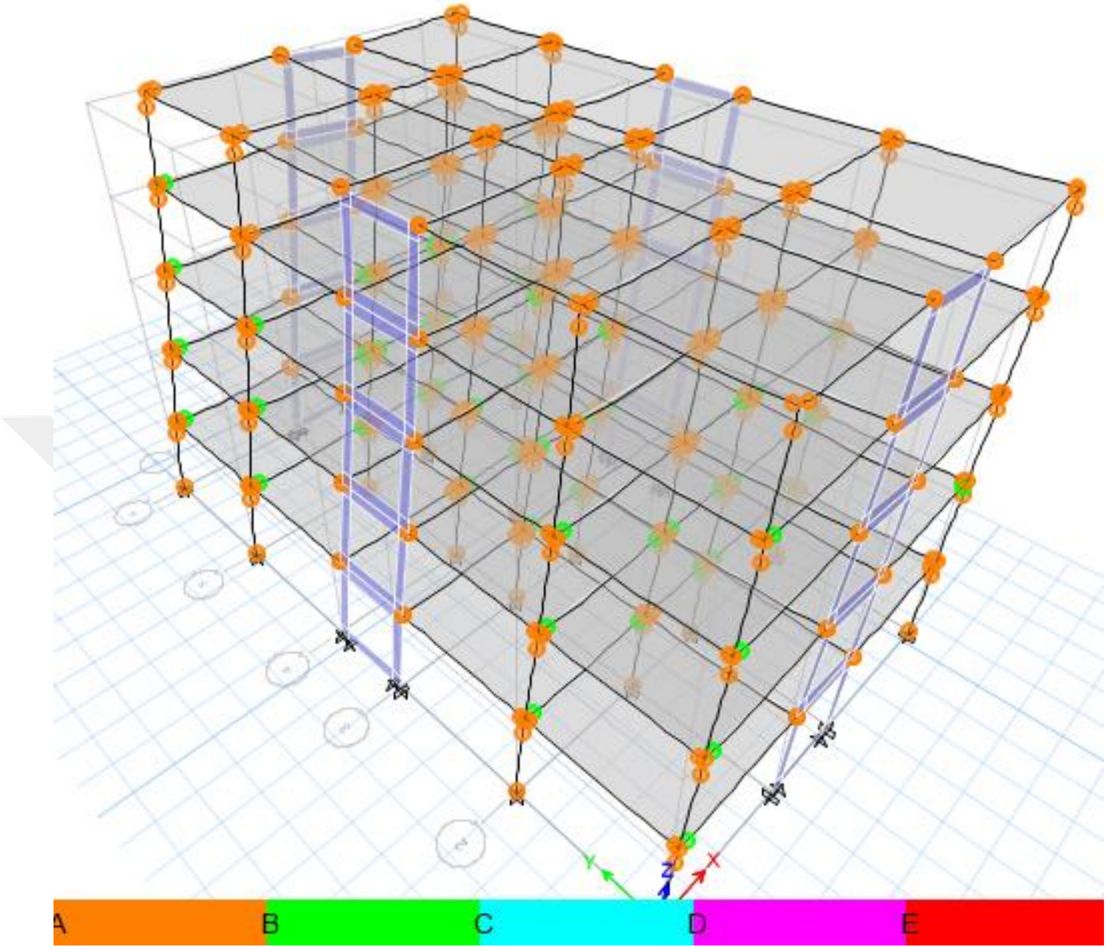

Figure A6. 3D view of hinge formation of the model 6 under the earthquake in +X direction

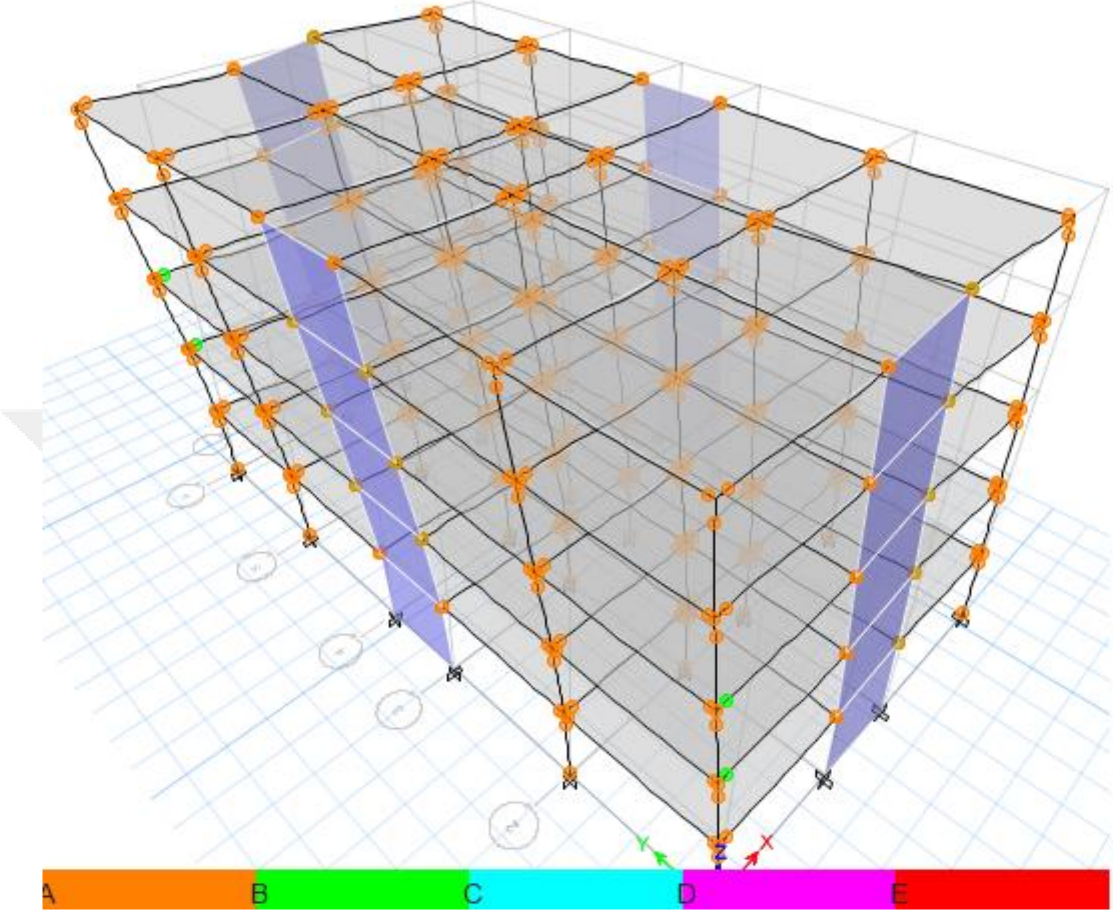

Figure A7. 3D view of hinge formation of the model 1 under the earthquake in -X direction

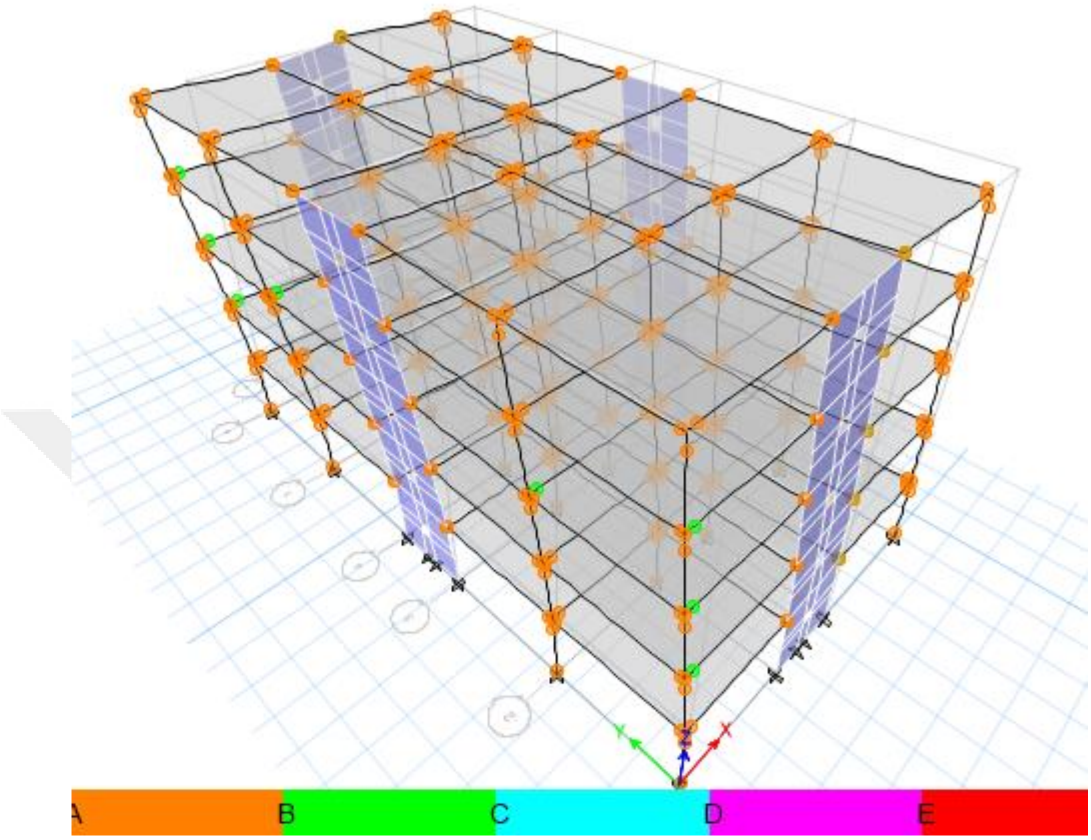

Figure A8. 3D view of hinge formation of the model 2 under the earthquake in -X direction

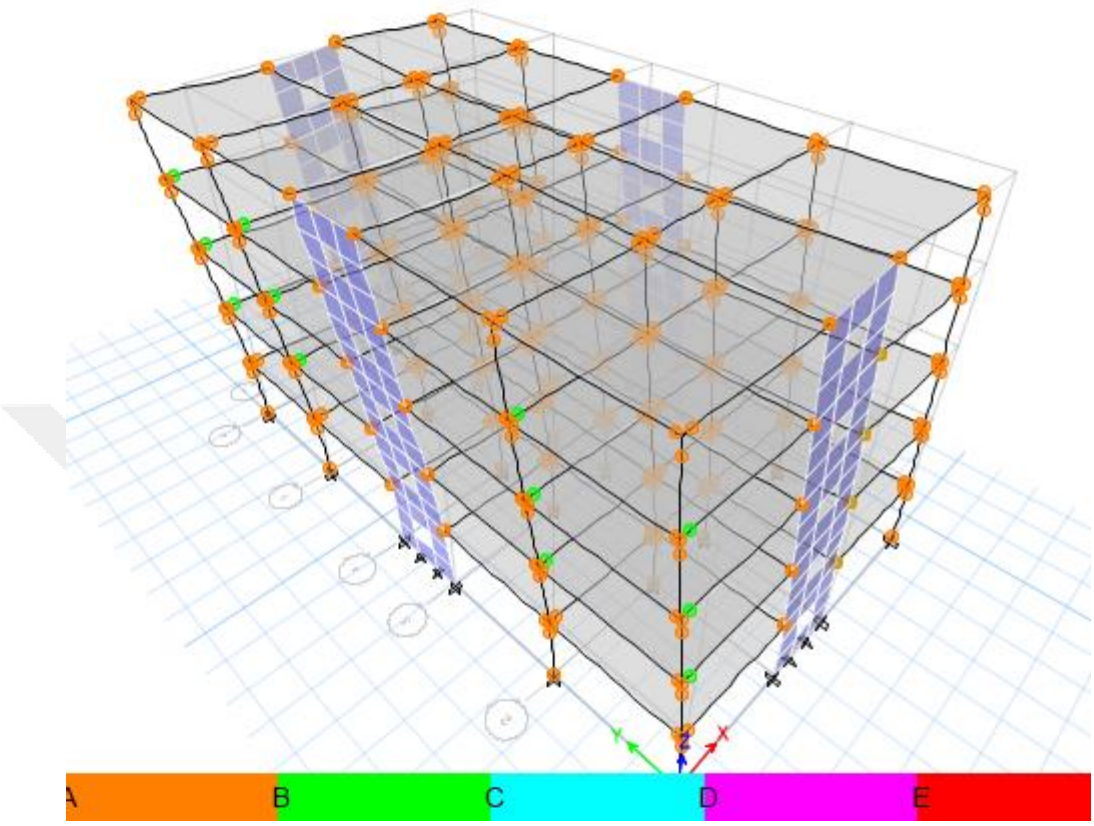

Figure A9. 3D view of hinge formation of the model 3 under the earthquake in -X direction

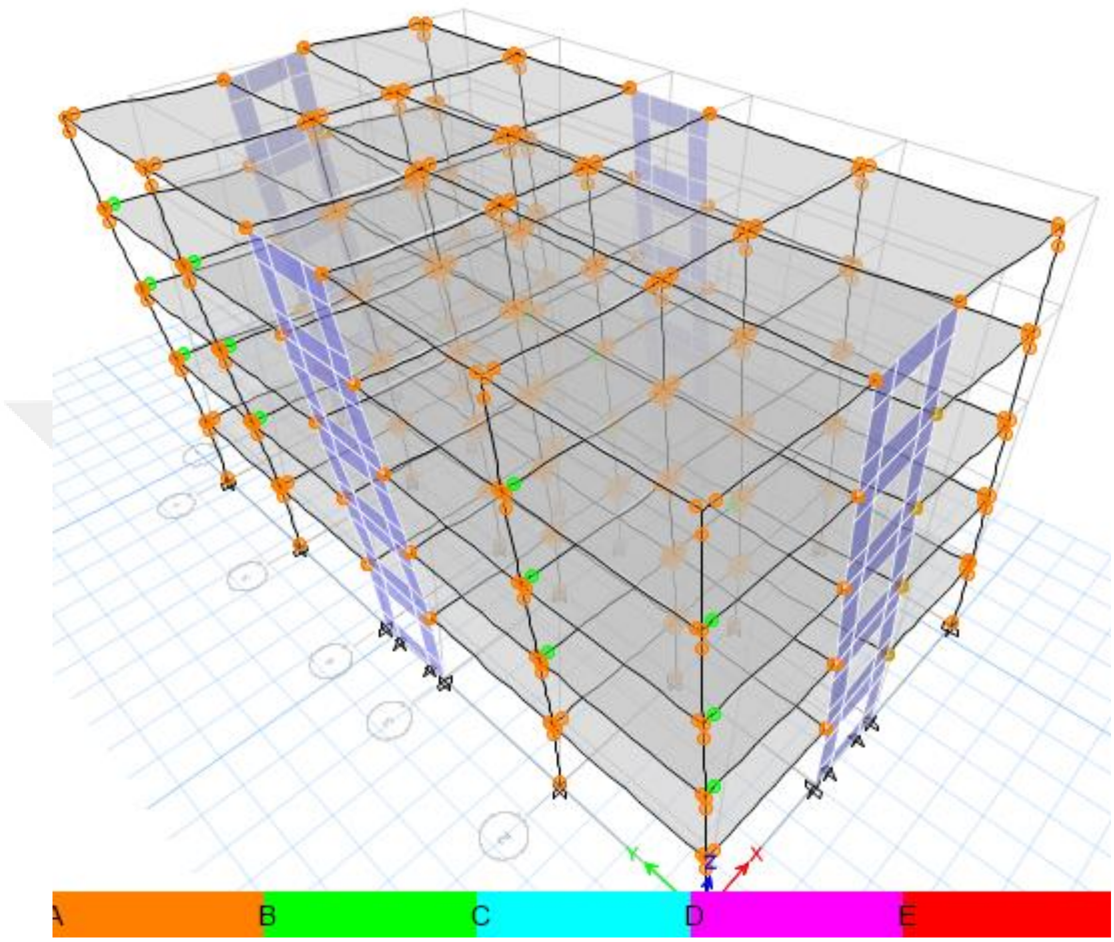

Figure A10. 3D view of hinge formation of the model 4 under the earthquake in -X direction

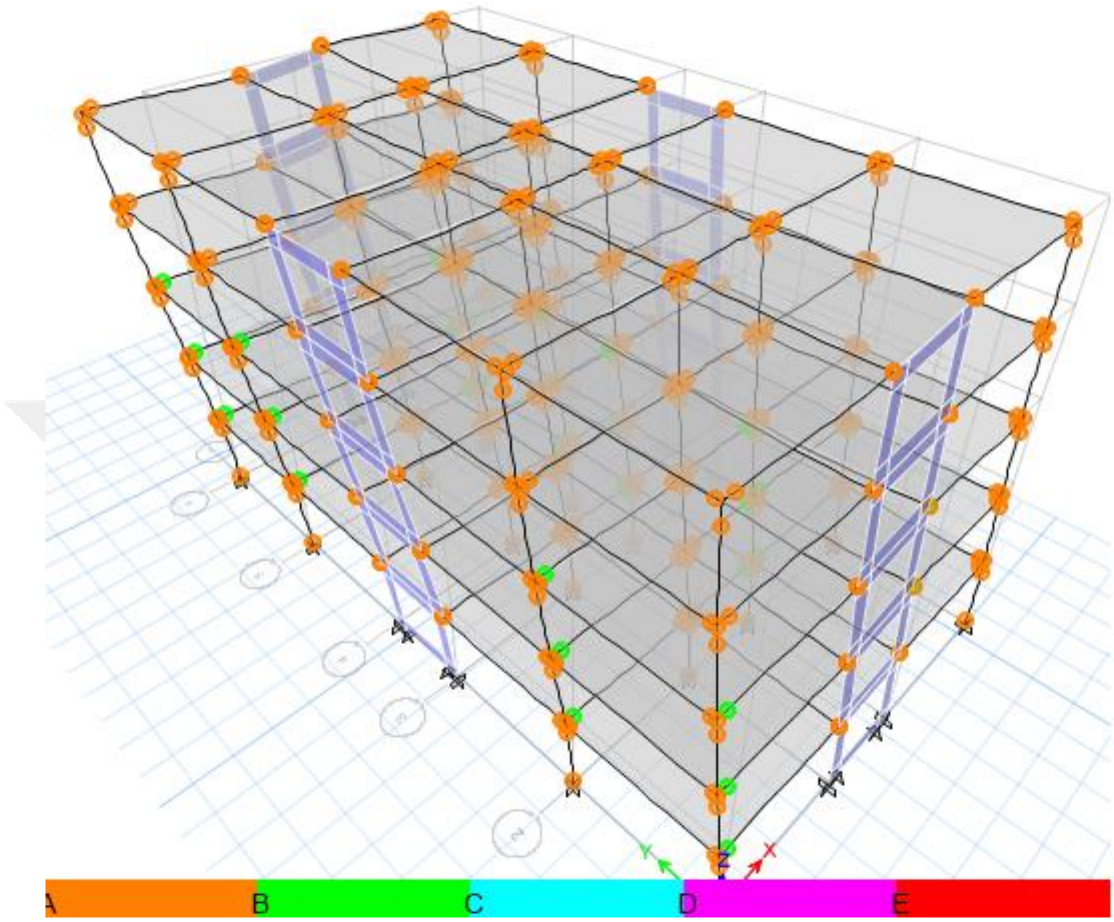

Figure A11. 3D view of hinge formation of the model 5 under the earthquake in -X direction

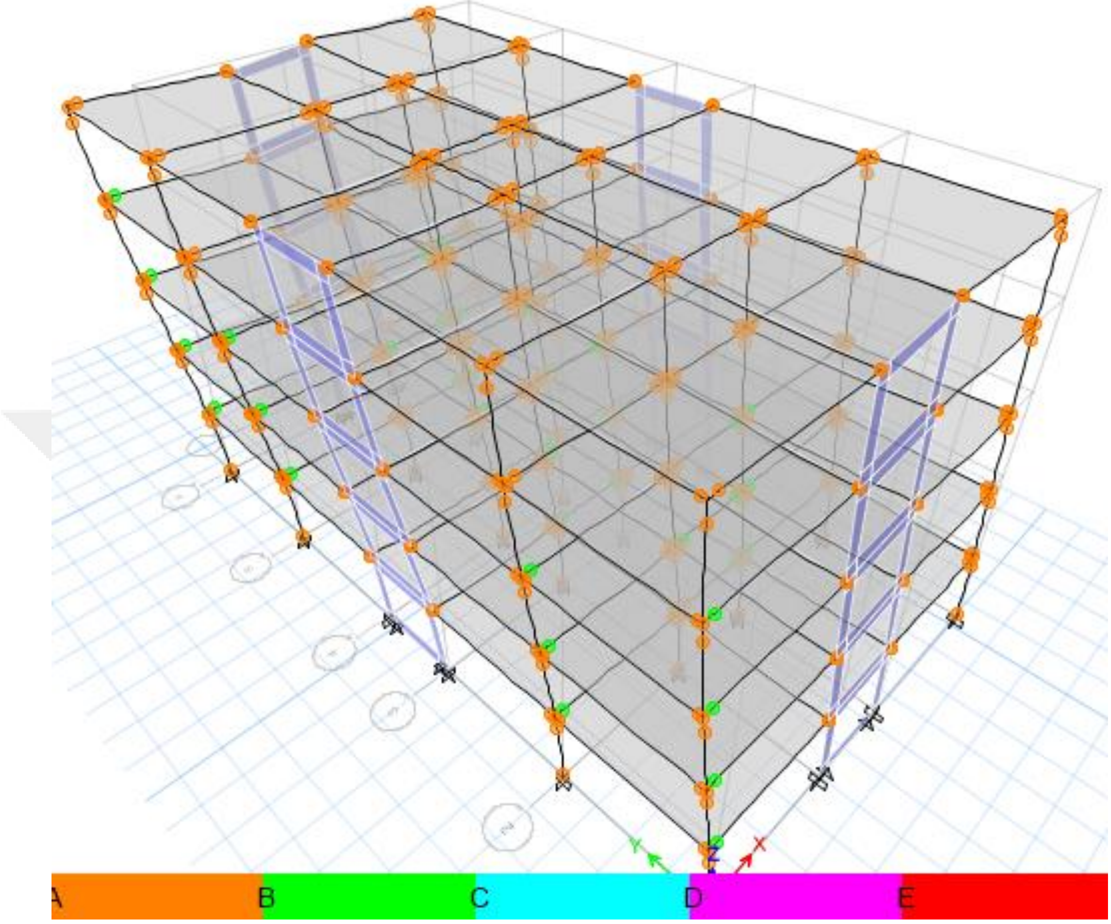

Figure A12. 3D view of hinge formation of the model 6 under the earthquake in -X direction

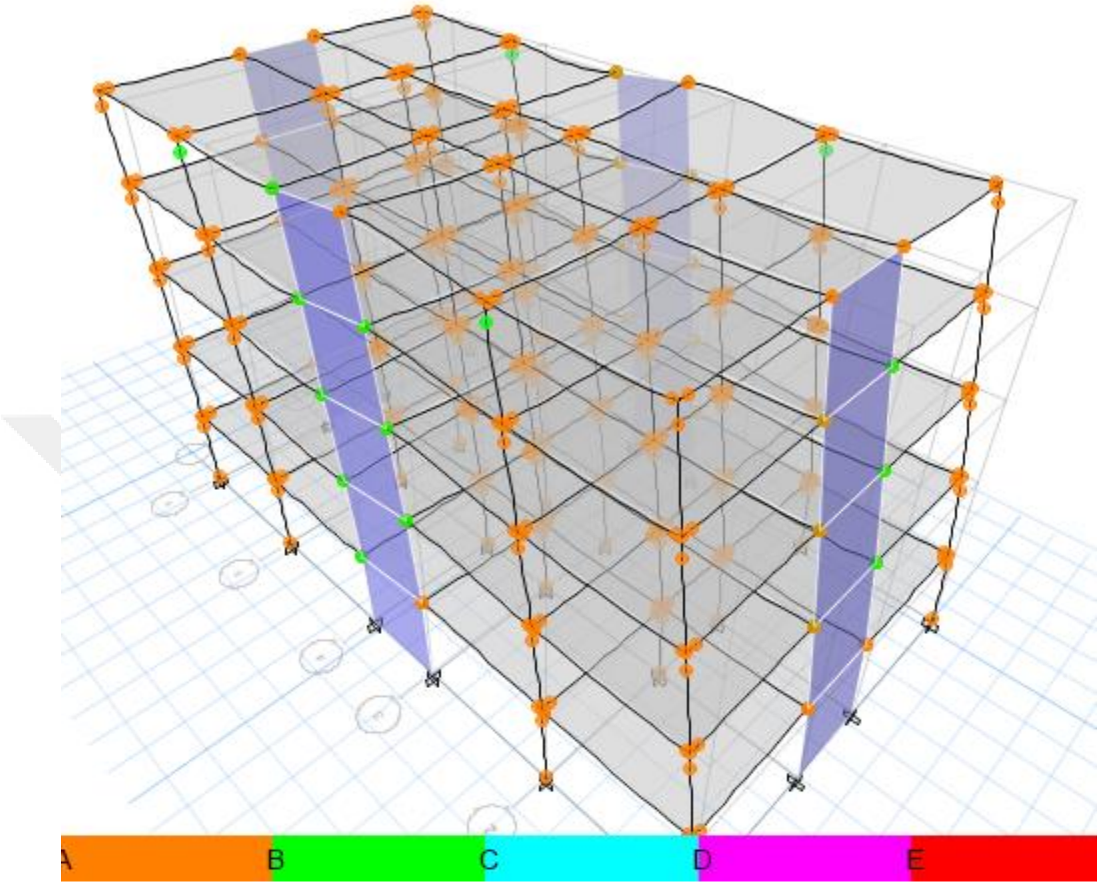

Figure A13. 3D view of hinge formation of the model 1 under the earthquake in +Y direction

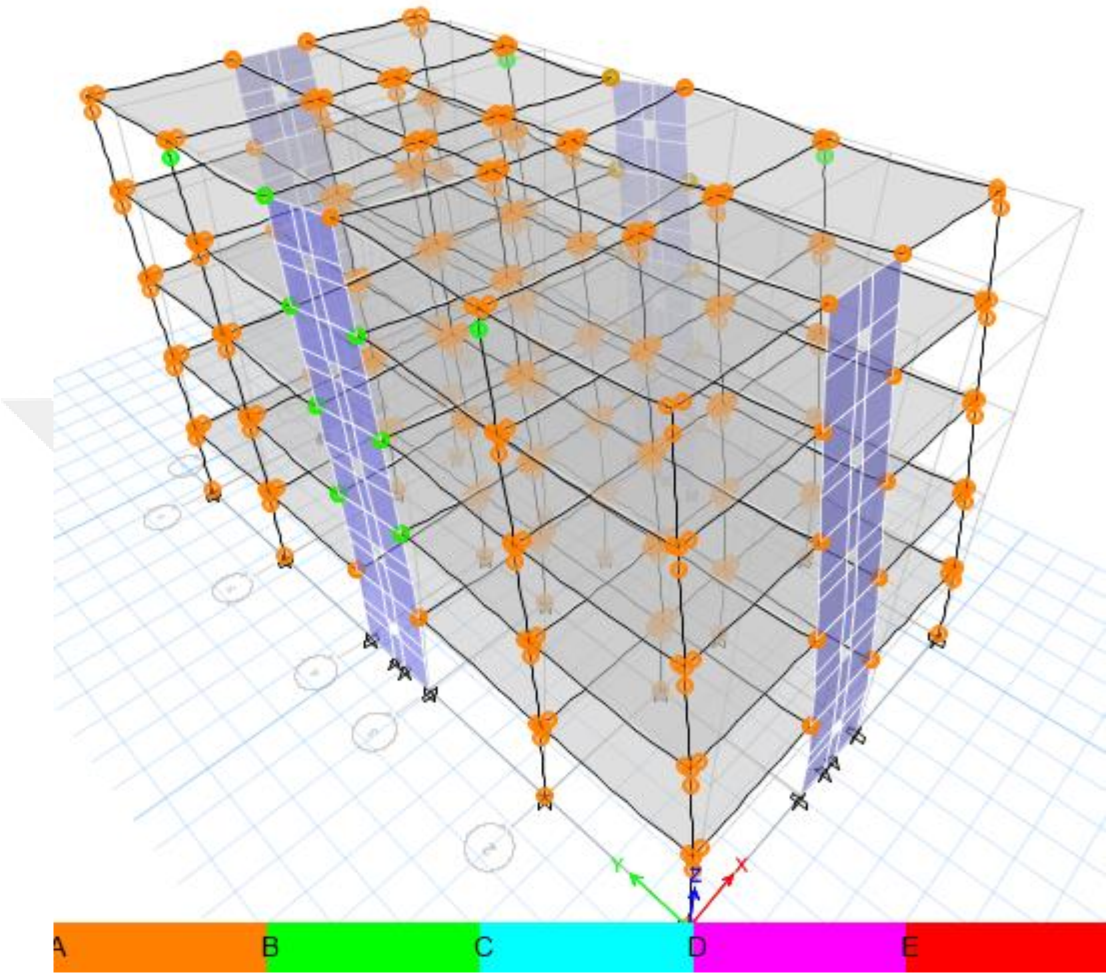

Figure A14. 3D view of hinge formation of the model 2 under the earthquake in +Y direction

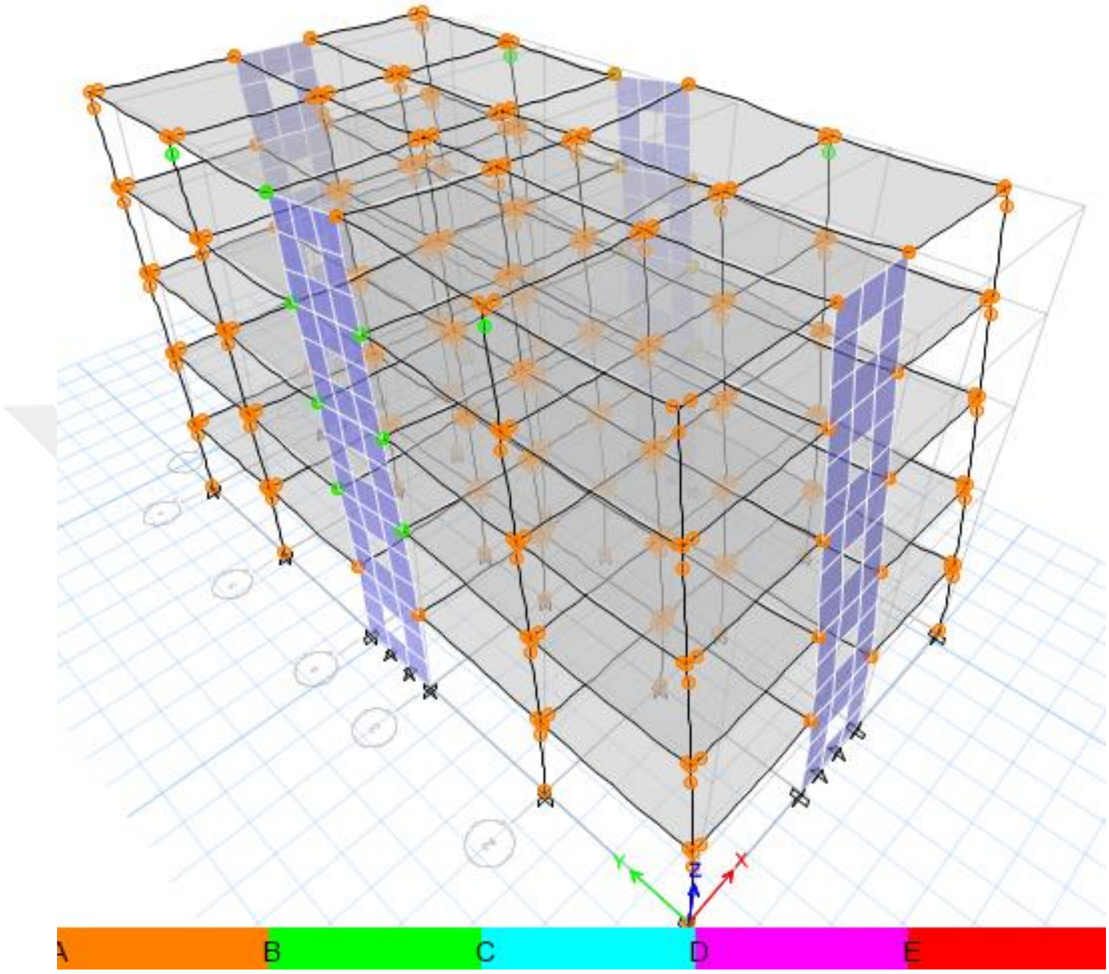

Figure A15. 3D view of hinge formation of the model 3 under the earthquake in +Y direction

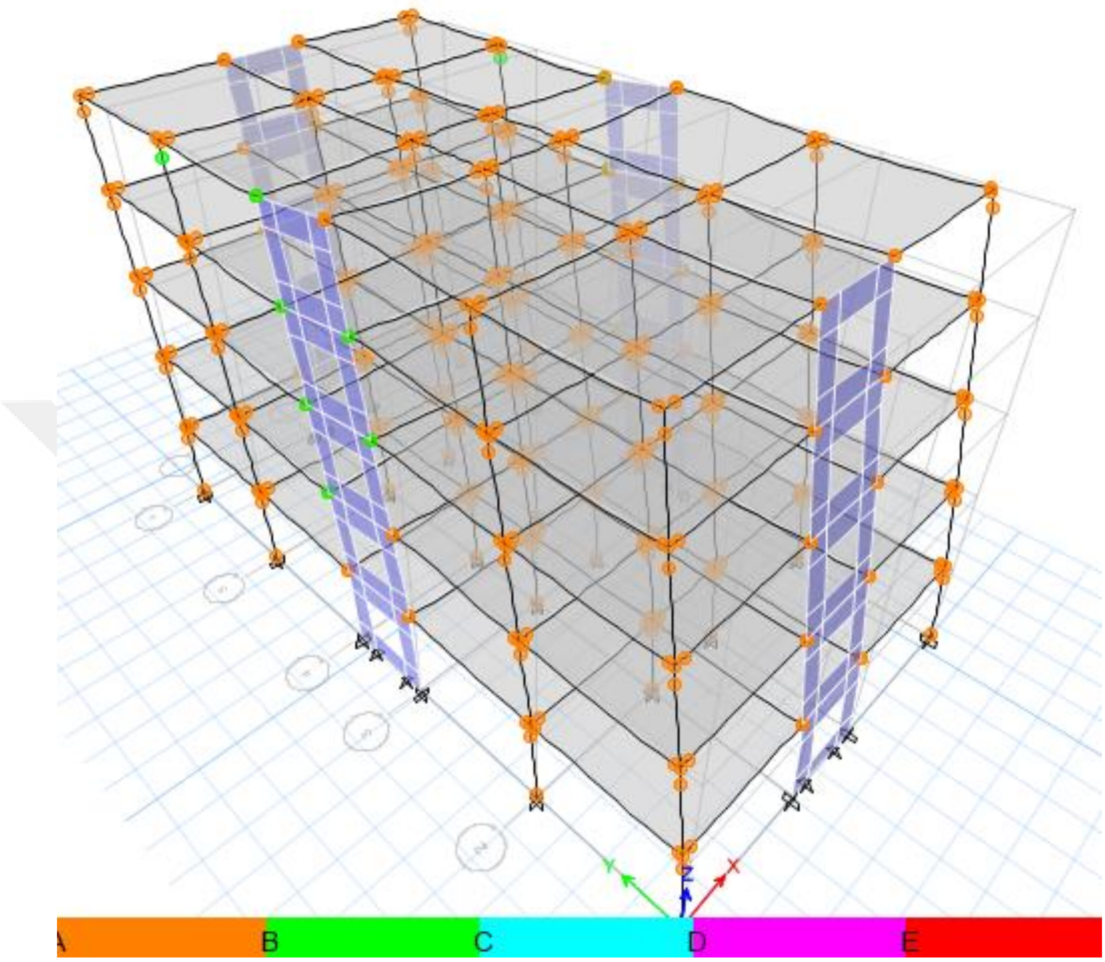

Figure A16. 3D view of hinge formation of the model 4 under the earthquake in +Y direction

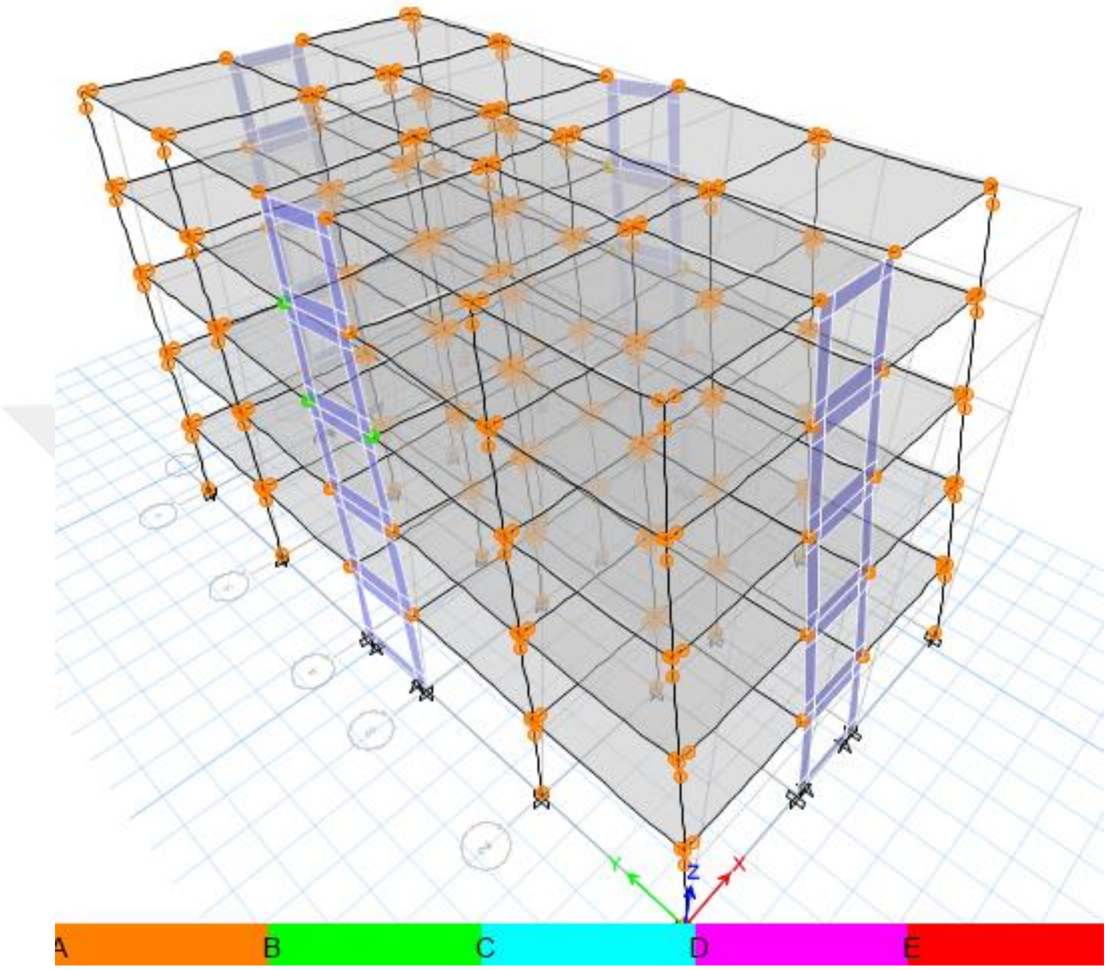

Figure A17. 3D view of hinge formation of the model 5 under the earthquake in +Y direction

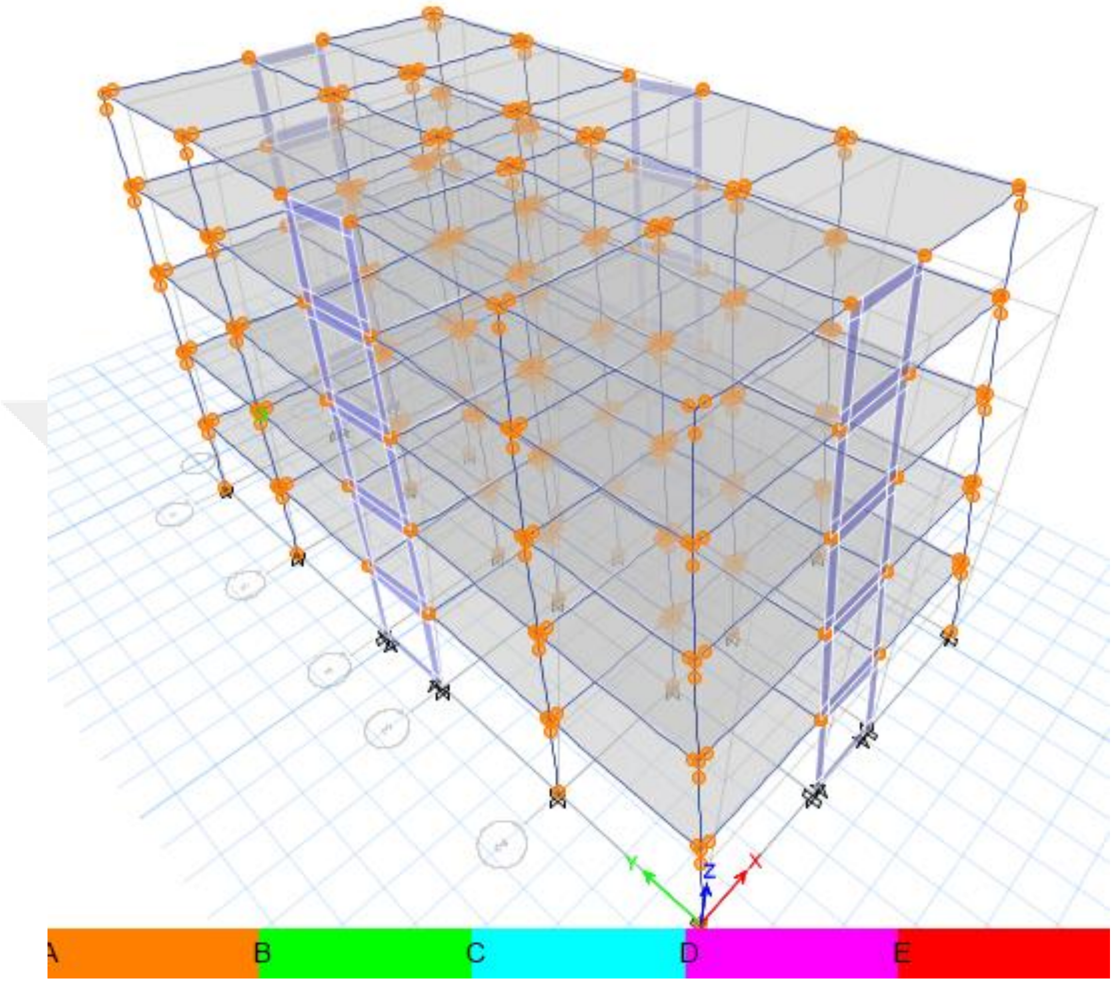

Figure A18. 3D view of hinge formation of the model 6 under the earthquake in +Y direction

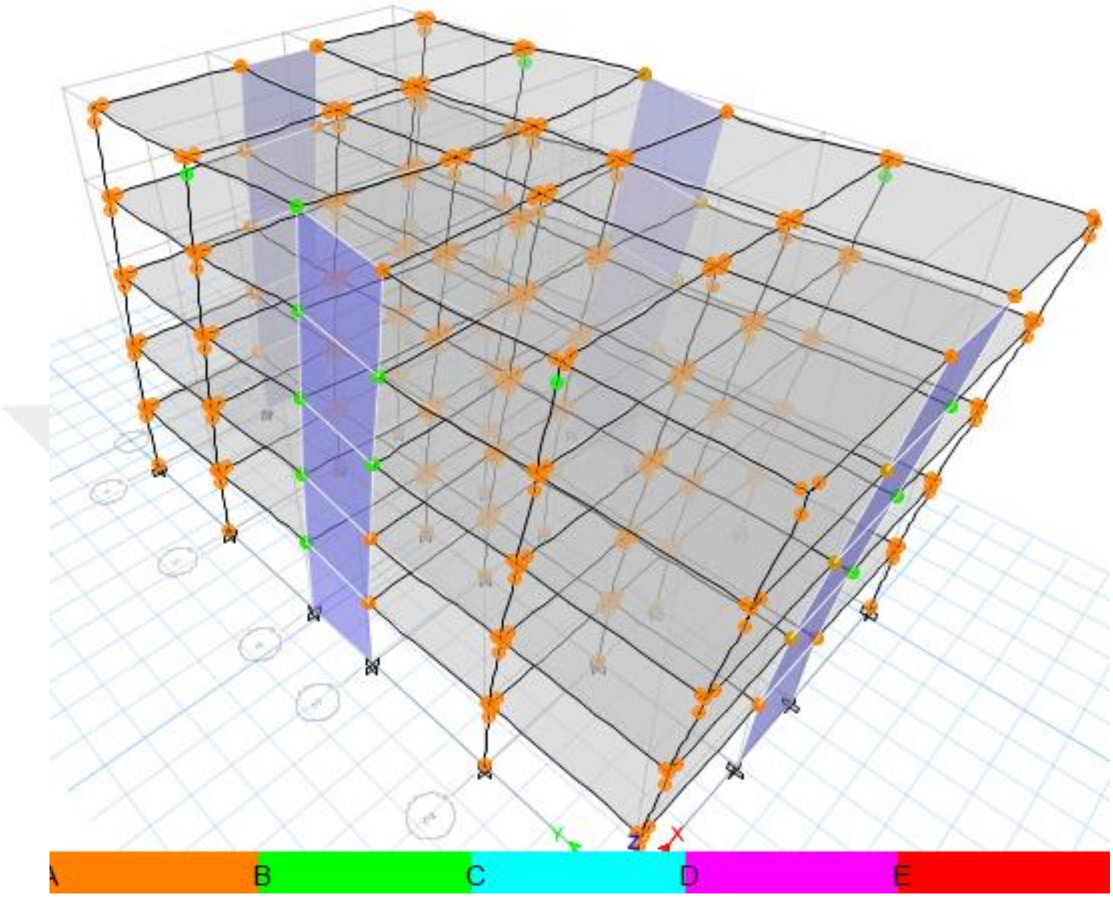

Figure A19. 3D view of hinge formation of the model 1 under the earthquake in -Y direction

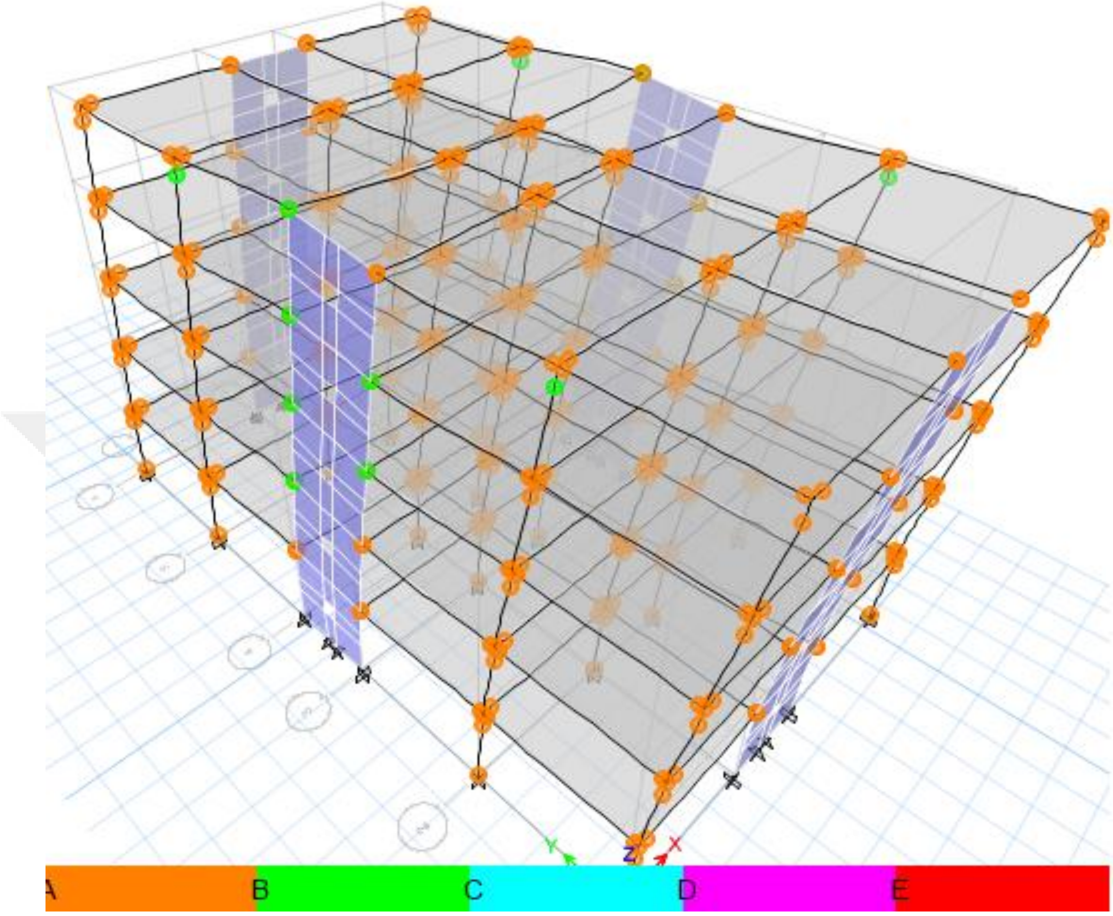

Figure A20. 3D view of hinge formation of the model 2 under the earthquake in -Y direction

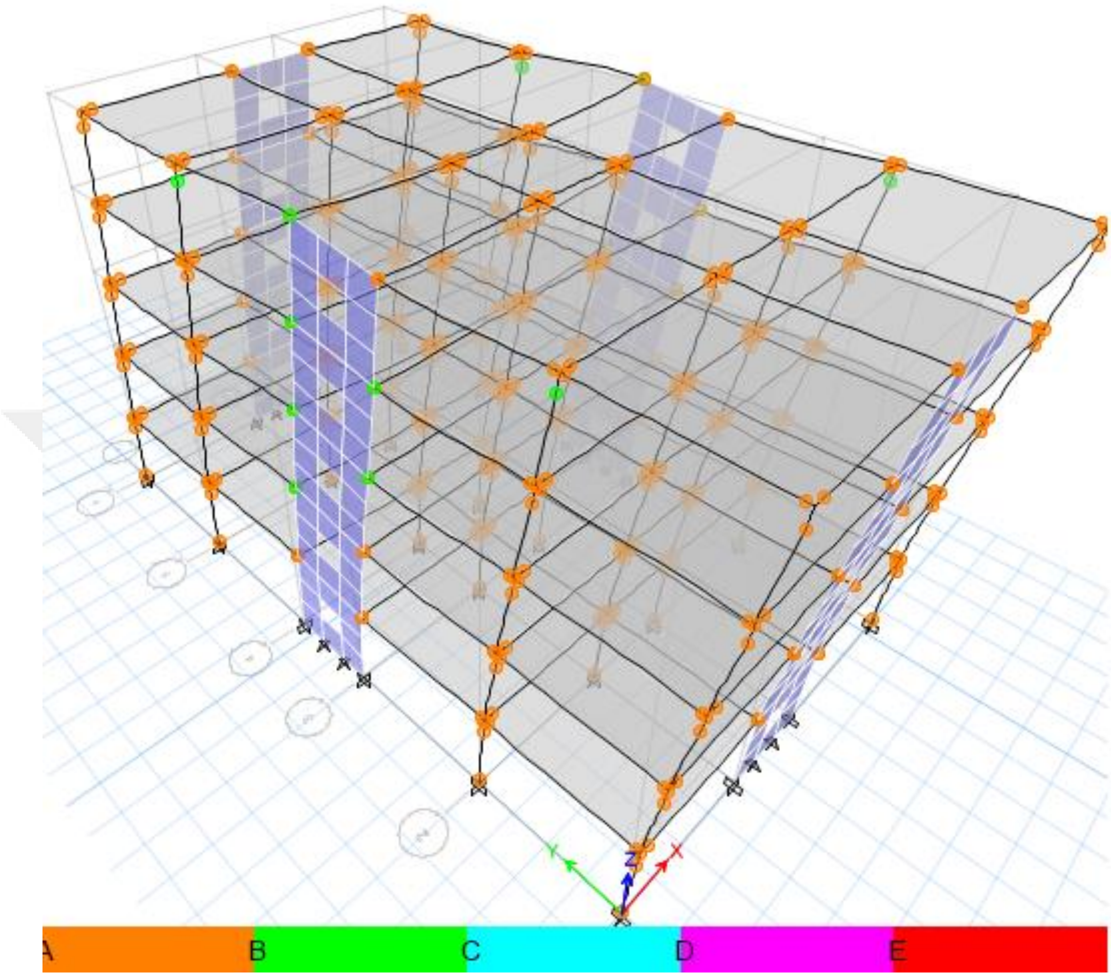

Figure A21. 3D view of hinge formation of the model 3 under the earthquake in -Y direction

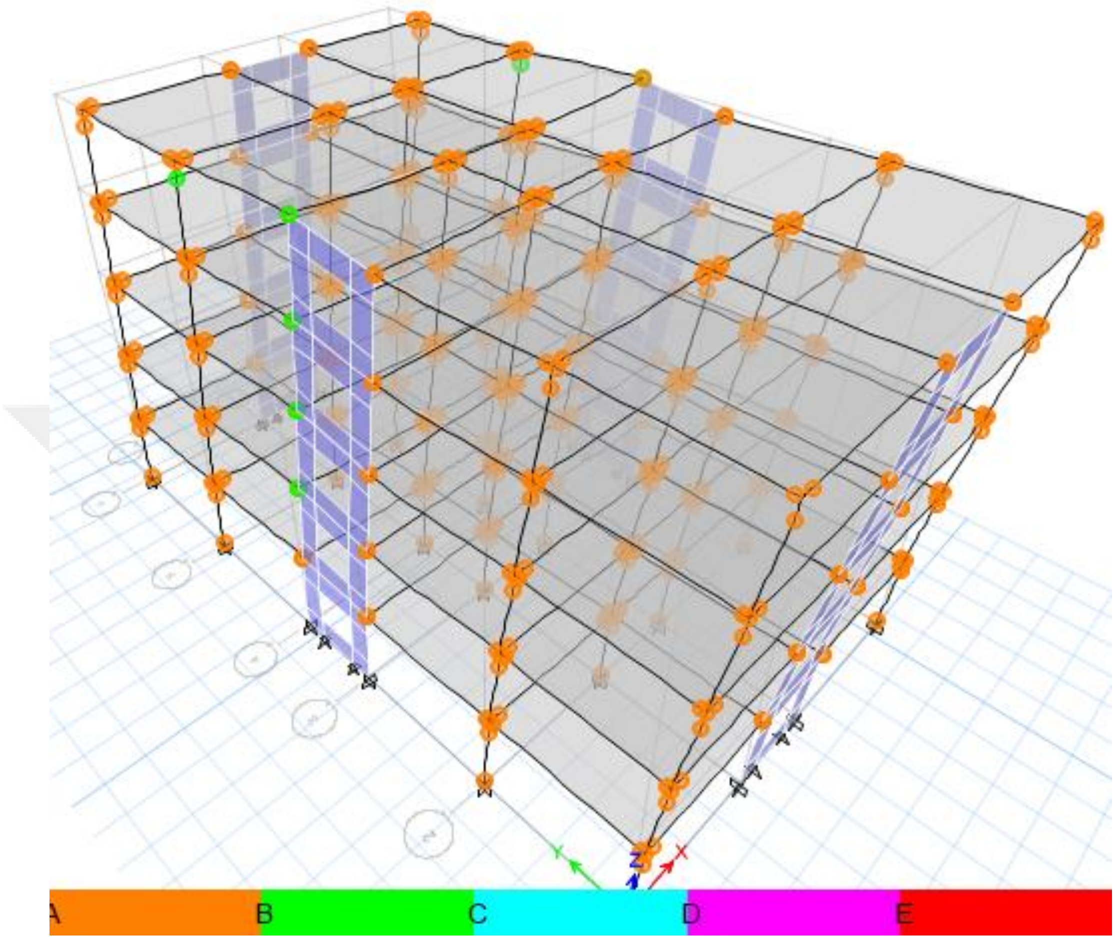

Figure A22. 3D view of hinge formation of the model 4 under the earthquake in -Y direction

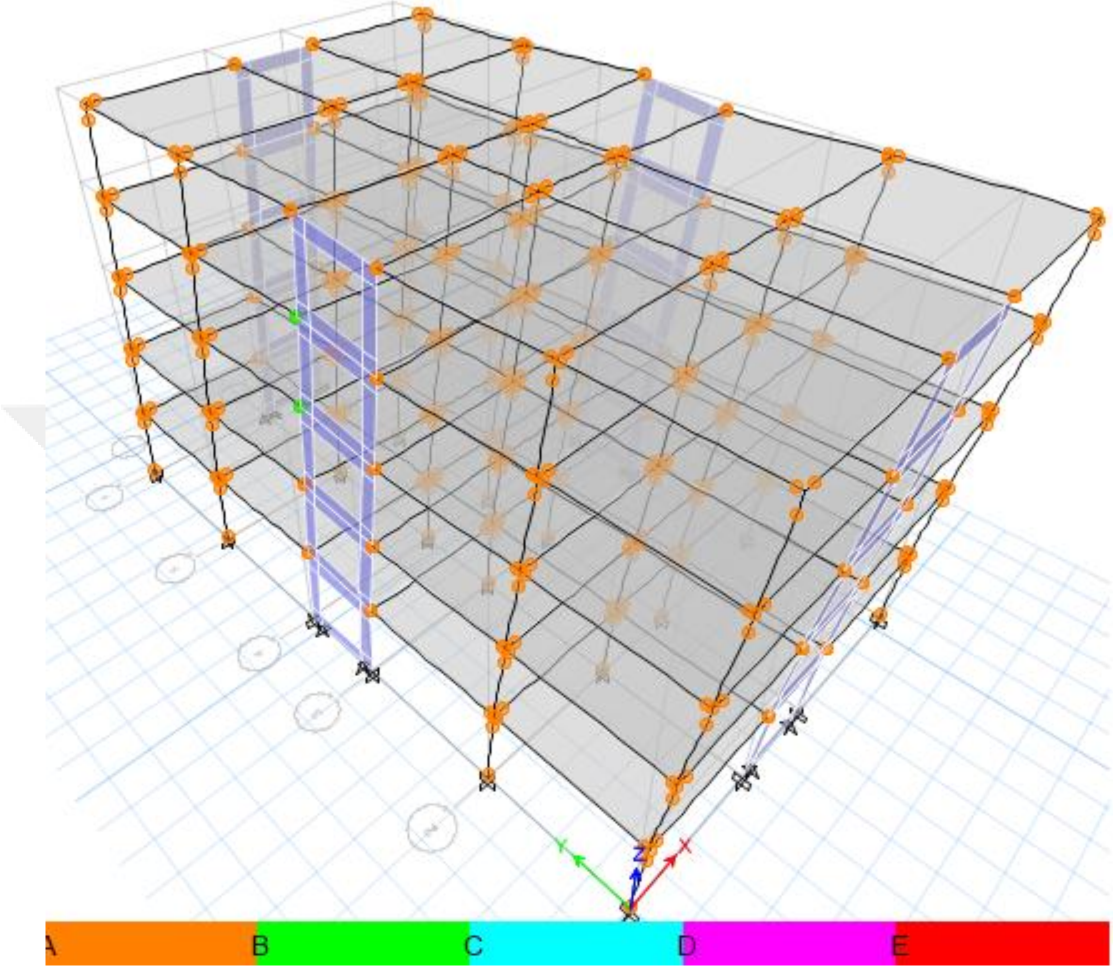

Figure A23. 3D view of hinge formation of the model 5 under the earthquake in -Y direction

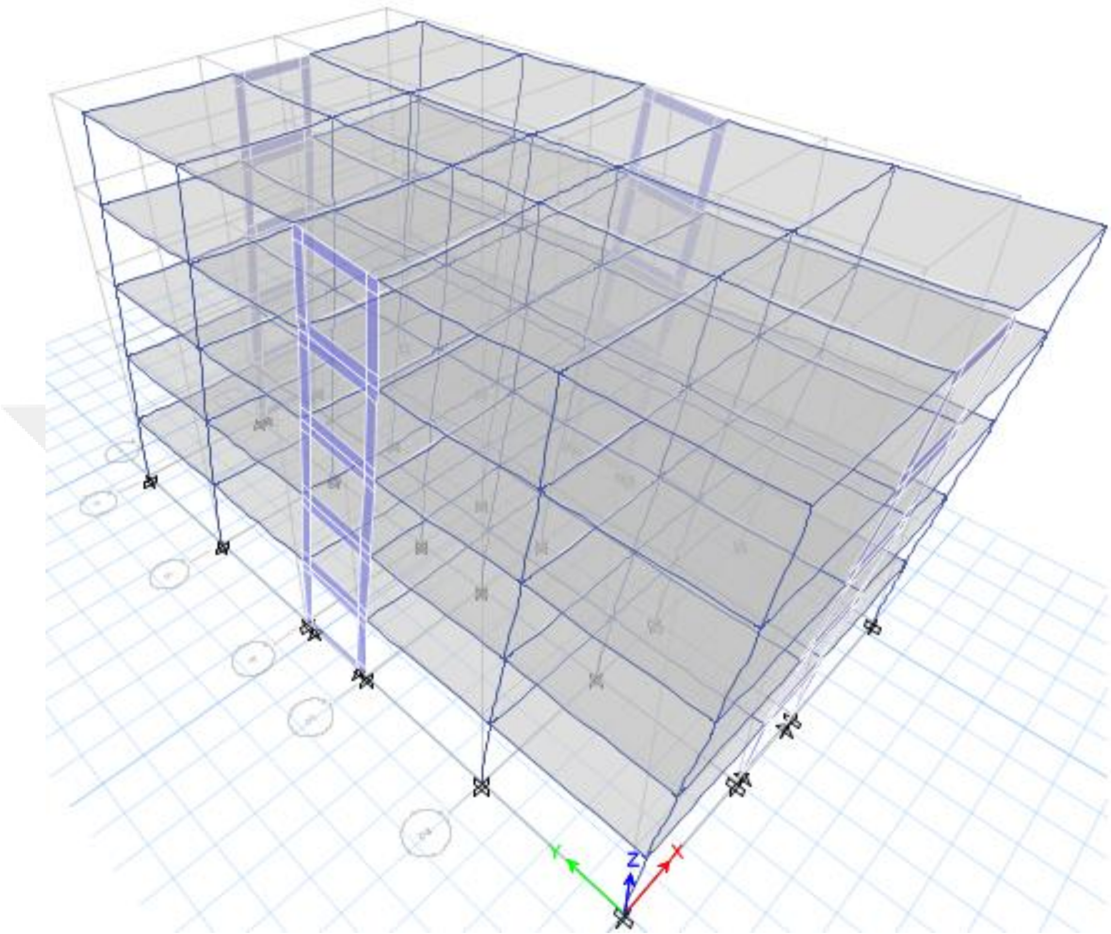

Figure A24. 3D view of hinge formation of the model 6 under the earthquake in -Y direction