T. R.
VAN YÜZÜNCÜ YIL UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES
CIVIL ENGINEERING DEPARTMENT

THE STUDY ON BEHAVIOR OF CONCRETE SHEAR WALL WITH DIFFERENT PERCENTAGES AND POSITION OF OPENING

M. Sc. THESIS

PREPARED BY: Zahra Rashid TAHA
SUPERVISOR: Assoc. Prof. Dr. Murat MUVAFIK

VAN-2018

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THESIS ACCEPTANCE AND APPROVAL PAGE

This thesis entitled “THE STUDY ON BEHAVIOR OF CONCRETE SHEAR WALLS WITH DIFFERENT PERCENTAGE AND POSITION OF OPENING” presented by Zahra Rashid TAHA under the supervision of Doç.Dr. Murat MUVAFIK in the Department of Civil Engineering has been accepted as a Master Thesis according to the rules of Higher Education Instruction of Republic of Turkey on 26/07/2018 with unanimity the member of jury.

Chair: Assoc. Prof. Dr. Murat MUVAFIK

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Member: Assoc. Prof. Dr. Murat Emre KARTAL

This thesis has been approved by the committee of The Institute of Natural and Applied Science on 03/08/2018 with decision number 2018/36 I

Prof Dr. Suat ŞENSOY
Director of Institute

THESIS STATEMENT

All information presented in the thesis obtained in the frame of ethical behavior and academic rules. In addition, all kinds of information that does not belong to have been cited appropriately in the thesis prepared by the thesis writing rules.

2018
Zahra Rashid TAHA

ABSTRACT

THE STUDY ON BEHAVIOR OF CONCRETE SHEAR WALL WITH DIFFERENT PERCENTAGES AND POSITION OF OPENING

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Concrete shear walls (one of the moment-resisting systems against earthquake load), owing to their favorable performance against lateral loads, have been widely utilized in moderate and high-rise buildings. Structures in quite a lot of cases require openings with different dimensions in order to satisfy architectural considerations. Openings dimension, position, and their number in walls are of the most important factors affecting the resistance and seismic behavior of the shear walls. In this study, displacements, drifts, and stresses that occur in structures and shear walls due to earthquake forces have been evaluated by ETABS software. Also the effect of openings dimension and position on the behavior of shear walls has been studied. In this regard, 3 groups of buildings with 5, 10, and 15 stories with different percentages and geometry of openings in shear wall were modeled and analyzed by time history analysis and the results were compared with those of moment-resisting frames as an alternative lateral load-resisting system. The buildings are loaded under the loading of the time history of the earthquake acceleration. The results revealed that as the openings percentage increases in the 10-story building, the displacement and drift increase as well. The minimum amount of drift and displacement were for the building without openings. Additionally, the minimum and maximum base shear happened in the case with moment-resisting frame in the 15-story building and in the building with shear wall without openings, respectively. Overall, the buildings seismic capacity in the cases with openings decreased.

Keywords: Different percentages of openings, Drift, Earthquake acceleration, Opening, Shear wall, Time history analysis.

ÖZET

BOŞLUKLU PERDELİ YAPI SİSTEMLERİNDE PERDE BOŞLUK ORANLARININ VE BOŞLUK KONUMLARININ YAPI DAVRANIŞINA ETKİSİNİN ARAŞTIRILMASI

TAHA, Zahra Rashid
Yüksek Lisans Tezi, İnşaat Mühendisliği
Tez Danışmanı: Assoc. Prof. Dr. Murat MUVAFIK
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Yanal yüklere karşı olumlu performansları nedeniyle, (deprem yüküne karşı moment dirençli sistemlerinden biri olan) beton perde duvarları, orta ve yüksek katlı binalarda yaygın olarak kullanılmaktadır. Pek çok durumda yapılar, mimari ihtiyaçları karşılamak için farklı boyutlarda boşluklar gerektirmektedir. Duvarlardaki boşlukların boyutu, konumu ve sayıları perde duvarlarının direnci ve sismik davranışını etkileyen en önemli faktörlerdir. Bu çalışmada, yapılarda ve perde duvarlarında yer değiştirme, yanal kayma ve mevcut gerilmeler ETABS yazılımı ile değerlendirilmiştir. Ayrıca boyut ve konumun perde duvarlarının davranışına etkisi incelenmiştir. Bu bağlamda, 5, 10 ve 15 katlı 3 bina grubu perde duvarlarında farklı yüzde ve geometrili boşluklar ile modellenmiş ve zaman tanım alanı analizi ile analiz yapılmıştır. Sonuçlar, alternatif bir yanal yük-dirençli sistem olan moment dirençli çerçevelerin sonuçlarıyla karşılaştırıldı. Binalar, deprem ivmesinin zaman tanım alanı yüklenmesiyle yüklenmiştir. Sonuçlar, 10 katlı binanın boşluk yüzdesi arttıkça, yer değiştirme ve kaymanın da arttığını ortaya koymuştur. Minimum yanal kayma ve yer değiştirme miktarı boşluksuz bina için elde edilmiştir. Ayrıca, moment-dirençli çerçeve durumunda minimum ve maksimum taban kesme kuvveti sırası ile 15 katlı binada ve boşlukları olmayan binada meydana gelmiştir. Genel olarak, boşluklar bulunan binalarda deprem direnç kapasitesi azalmıştır.

Anahtar kelimeler: Boşluk, Deprem ivmesi , Kayma, Perde duvar, Zaman tanım alanı analizi.

FOREWORDS

I wish to express my sincere and deepest appreciation to my supervisor Assoc. Prof. Dr. Murat MUVAFIK for the guidance, advice and idea during this thesis, without his help, this work would not have been easily finished. My best regards also to all other members of the Department of Civil Engineering. This thesis is dedicated to my lovely mother and sister. I'm so grateful for their encouragement and support during this journey, I feel very fortunate to be a part of this family.

2018
Zahra Rashid TAHA

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SYMBOLS AND ABBREVIATIONS

Along with a description of some symbols and abbreviations used in this study are presented below:

Symbols	**Explanation**
σ_x	Stress
N	Axial force
mm	Millimeter
kn	Kilo Newton
g	Gravity
δ	deflection
MP	Mega Pascal

Abbreviations	**Explanation**
ADRS	Acceleration Displacement Response Spectra
CQC	Complete Quadratic Combination
CSI	Computers and Structures, Inc
ETABS	Extended three dimensional analysis of building system
MDOF	Multi degree of freedom
PRC	Pushover Result Combination
Sa	Spectral Acceleration
Sd	Spectral Displacement
SDOF	Single degree of freedom
SRSS	Square-Root-of-Sum-of-Squares

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1. INTRODUCTION

Since behavior of structures in an earthquake is random, the lateral load-resisting system has to keep the damage within acceptable limits which guarantees inhabitants' safety. Therefore, the structure should enjoy sufficient ductility in order to resist large forces and deformations without collapsing.

Structural design should provide three fundamental requirements: firstly, the basic need of any structure is strength, which is necessary to prevent the early collapse of structures; second, structures require enough stiffness to prevent collapse of non-structural elements by controlling effect of displacements in the event of minor earthquakes; and finally, structures have to be safe during strong earthquakes by providing enough ductility and absorbing the energy released by earthquakes. For this purpose, moment-resisting frames, concrete shear walls, and dual frame-wall systems can be utilized.

Using shear walls is one of the different methods so as to resist the earthquake load. They play such a substantial role in creating lateral stiffness in concrete structures that almost the whole strength of structure against lateral loads which are mostly earthquake loads in many areas is provided by shear walls. Studying the behavior of these structural members, therefore, has been a matter of high importance for engineering (Naveed, 2002).

Moment-resisting frames, owing to their high ductility, perform very good in absorbing the energy of an earthquake. However, as the number of stories in this system increase, apart from the fact that large deformations will cause failure in non-structural elements, it also will not have enough stiffness. Studies have shown that shear walls contain higher stiffness and therefore can be used in short spans too. Dual frame-concrete shear walls, on the other hand, do not behave as well as moment-resisting frames in absorbing energy. Walls by carrying most of the loads applying on structures prevent the frame from absorbing energy, which the frame absorbs almost no energy. The wall itself does not behave much well in absorbing energy in lower floors where materials starts to be inelastic (Tasnimi, 2001).

Shear walls have a very strong in-plane stiffness; they behave the same as a vertical and deep cantilever beam, giving buildings lateral stability that resist shear forces as well as bending moments resulting from lateral loads. This system is an essential part of tall reinforced concrete structures, and a suitable member for short reinforced concrete structures. Additionally, stiffness of shear walls reduces large deformations of structures, while frames alone are not enough for this purpose even in tall building. Using moment-resisting frames as the resisting system against lateral loads, especially earthquake loads, requires particular details to provide sufficient ductility for the frame.

These details are very difficult to implement and their execution is guaranteed only when the execution process and monitoring in the workshop has excellent quality. In most cases, therefore, systems with shear walls are more economical than systems with moment-resisting frames. Buildings with frame and reinforced concrete shear wall systems have less architectural restrictions in comparison with moment-resisting reinforced concrete frames, since they do not need large scale frame elements, which reduces stories height and provides more spaces for openings.

In regions with high seismic risk, shear walls have to be designed based on special seismic consideration. Because the lateral earthquake load has a dynamic nature, the damping quality of the resisting elements against this force has the utmost importance. Accordingly, the building codes specify special reinforcing conditions to design reinforced concrete members, which requires structural elements to have ductile behavior.

Boundary elements or edge elements in shear walls are those parts of shear walls which are located at the edges of the walls, or at the edges of openings which are reinforced specifically with longitudinal and transverse reinforcements. These elements may have more thickness than the walls. However, there is no obligation to consider the boundary elements thicker than the walls. When the wall is located between two columns of one frame, columns can be reinforced as the boundary elements of the walls, whereas if the wall is not located between the columns, the wall has separate elements and the column will act only as a structural member in the frame

The forces obtained from severe earthquakes are much greater than the figures that codes specify in the equivalent static lateral force method. In addition, designing structures based on their elastic behavior in earthquakes, except in some special structures, is not cost-effective, and gives very big sections. Therefore, considering the ductility concept and understanding the nature of earthquake load in design process is important. Ductility is a type of retaining capacity and ability of absorbing energy—which it’s prerequisite is ability of the structure for large deformations without considerable loss in strength, or without failure.

1.1. Problem Definition

It is common to use shear walls in concrete buildings as a dual lateral load-resisting system. Shear walls have high in-plane stiffness, so they carry the most portions of the shear forces imposed by earthquake or wind load. Moreover, shear walls increase the ductility and decrease drift of the buildings. In some buildings, however, architectural and construction installations such as door, windows and installation ducts needs require using openings in shear walls. Opening in a wall changes the behavior of the wall, which is a whole continuous structure, to two separate shear walls on both sides of the opening.

Usually, not widely, walls of the buildings contain openings. They are used in the web or wing of walls. Their width and height has to be determined with an engineering judgment in a way that these dimensions should not be so small that they would be ignored in design, nor should they be so big that they would have an undesirable effect on shear and flexural strength. It is clear that in order to avoid this undesirable effect, calculating the strength and reinforcing details must be precise. For this purpose, shear walls have to be evaluated in both with and without openings cases (Tasnimi, 2001).

Shear walls, by considering openings, are categorized into monolithic (solid) and perforated (with regular and irregular patterns) shear walls (Figure 1.1). Monolithic shear walls either have openings or have small openings that can be ignored. Pierced walls have openings that are not placed perpendicularly. These walls, which sometimes are called frame-shear walls, are composed of horizontal as well as vertical wall segments with regular patterns.

Coupled shear wall is a specific type of perforated shear walls in which adjacent openings are connected with coupling beams (spandrels) and piers. Normally the walls are connected directly to the foundations, however, in some cases where the lateral loads are relatively small and there is no appreciable dynamic effects, then they can be supported on columns connected by a transfer beam to provide a clear space. These types of walls are called discontinuous shear walls. The interaction of wall with frames or its adjacent walls, especially discontinuous walls and the elements of other axes of the building should be determined. In coupled and perforated walls, vertical and horizontal components between openings are also called piers and coupling beams (connecting beams or spandrels), respectively. These aforementioned elements are called wall segment as well (Tasnimi, 2001).

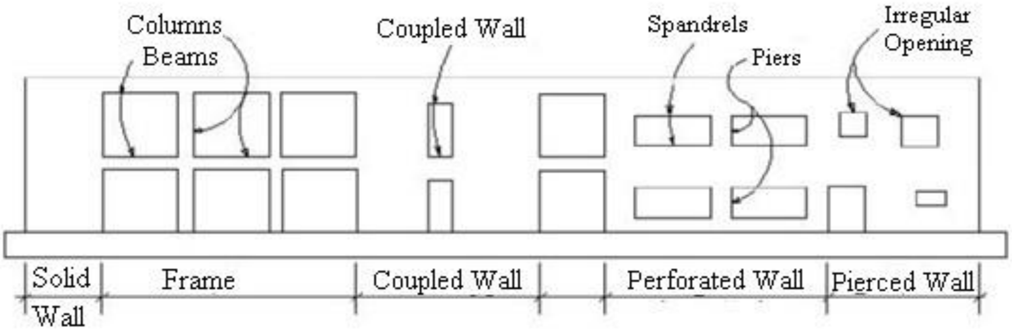

Figure 1.1. Frame and wall components, and shear walls with opening.

In this study, owing to shear forces and bending moments' being great in the shear walls with openings, the effect of dimension and position of opening on the behavior of shear walls has been evaluated.

1.2. Importance and Necessity of the Research

Utilizing shear walls is one of the most economical and reasonable ways to decrease drift and increase stiffness as well as strength of the buildings. In designing the buildings with shear walls, placing the walls in the plan, the distance between walls and the center of the mass of the building, and the symmetry of shear walls in the plan are of considerable importance. In many cases sticking to these principles is not possible, however. In buildings with moderate height, shear walls due to architectural and construction installations considerations are placed around the elevator and the staircase. In high-rise buildings, because of the considerable length of the shear walls required in the orthogonal directions, shear walls are usually placed at the perimeter of the buildings. In many cases, however, adhering to these rules is not possible. Therefore in both moderate and high-rise buildings using openings in shear walls in order to have daylight in interior spaces, or to have entrance and exit doors, are quite likely.

According to the above-mentioned issues, existing opening in shear walls is a matter that all the civil engineers will be faced with in design and implementation. Unfortunately, there are no criteria regarding determination of the integrated, separate, or coupled performance of shear walls with openings in ACI. (ACI-318, 2008) Therefore, studying the effect of dimension and position of opening on the behavior of shear walls is very important.

1.3. Research Objectives

One of the main purposes of this study is evaluating the effect of the position and dimensions of openings in concrete shear walls on behavior of the walls in concrete buildings, and comparing shear walls with opening with moment-resisting frames as an alternative lateral load-resisting system.

Other objectives can be outlined as follow:

1- Determine the effect of the percent of openings on the performance of shear walls and buildings.

2-Determine the effect of the position of openings on performance of shear walls and buildings.

3- Drawing a comparison between the effect of openings in short, moderate, and high-rise buildings.

4- Evaluating the seismic performance of shear walls with and without openings, and comparing the results with those of moment-resisting frames as an alternative lateral load-resisting system.

1.4. Research Assumptions

- The analysis will be performed 3-D in ETABS Software.
- Time history analyses will be used.
- The seismic force will be applied and studied in the X-direction
- The shear walls in all stories in X-direction will be placed in the first and last spans.

1.5. Definitions

- Short shear walls:

If the shear wall has a low height, that is, if the ratio between height to length is less than 2 or 3, the wall is considered short and can be used in short buildings. In some cases, in order to strengthen the buildings against lateral loads, short shear walls are used in tall buildings in some spans of ground floor or between spans in a continuous manner above the foundation. There are numerous variations between the behavior of short shear walls and that of tall buildings. Most research on these walls is conducted by Park and Paulay in New Zealand. They recommend that reinforcing in these types of walls should be as uniform as possible, and be more concentrated toward the vertical edges.

- Tall shear walls:

These walls have a high ratio of height to length, which their dominant behavior unlike their names is flexural. As mentioned earlier, these types of walls have a very effective role in carrying seismic loading and absorbing its energy in moderate and high-rise buildings. Geometric shape of their sections have a dramatic effect on their flexural behavior. Furthermore, different changes pertaining to structural or architectural considerations in their length and thickness in height will affect their behavior (Park and Paulay, 1975).

- Types of shear walls based on their section shape:

Shear walls are implemented as two or three-dimensional. The walls that have wings at their both ends (wing sections) contain more stability as well as ductility in comparison with the walls without wings. Therefore, it has been suggested that these sections should be used. Figure (1.2), shows eleven shear wall sections, in which the section (A) is used in a two-dimensional shear wall and the other ten are wing sections.

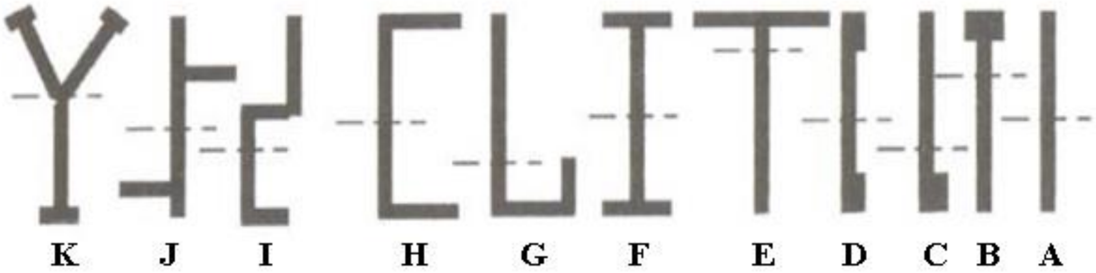

Figure 1.2. Common sections used in shear walls.

As it’s illustrated in the sections (E) and (H), some wing sections have a great length. In designing these sections, the whole wing cannot be considered in carrying loads (Seifi and Hadizadeh, 2010).

2. LITERATURE REVIEW

Seismic behavior of the buildings toward dynamic loading is dependent on the lateral load-resisting systems. Choosing a system that can behave well in the event of an earthquake is a matter of high importance. Structural walls are one of the systems which are very appropriate to resist against lateral loadings. Since these walls absorb the major part of the lateral forces acted on and the shear forces created in the structures, they are called shear walls. Placing shear walls along with moment-resisting frames can bring about a good performance in carrying dynamic forces.

In general, there are two perspectives: geometric and behavior-based. ACI code follows behavior-based perspective in designing columns and walls, so this code doesn’t specify a certain range for the column to wall transformation ratio. For bending moment and axial force, considering the slenderness, similar equations can be applied, but the design procedure for shear force is different from columns; and that’s because the behavior of columns under shear force is like the behavior of beams, while the effect of out-of-plane shear on the walls is similar to slabs. Recent earthquakes have revealed that shear walls in which shear force is dominant have limited application, due to their limited ductility and brittle failure.

It has been observed that several buildings have the same number and particular types of failures in their structural members during earthquakes. Having short columns (generally, short elements, which contains walls too), caused the columns which are of the very essential elements of stability of a building to fail. In these structural systems, this problem mostly occurs because of using shear walls with openings, deep beams, and very stiff concrete walls in the terrace. Figure (2.1), shows this problem in deep beams.

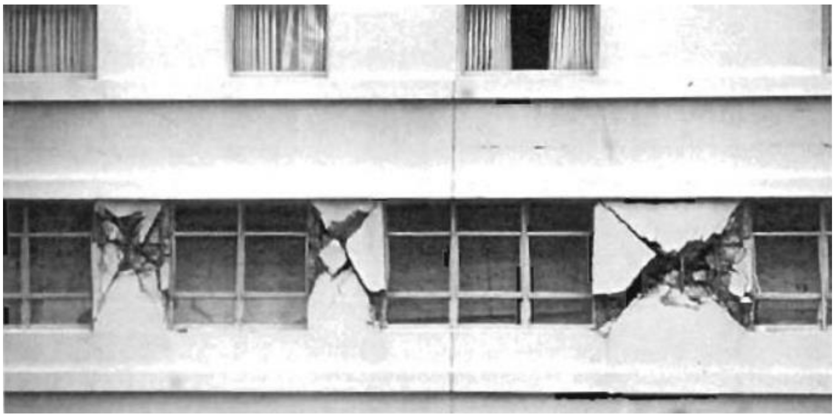

Figure 2.1. Failure of short column and shear wall, the Northridge earthquake.

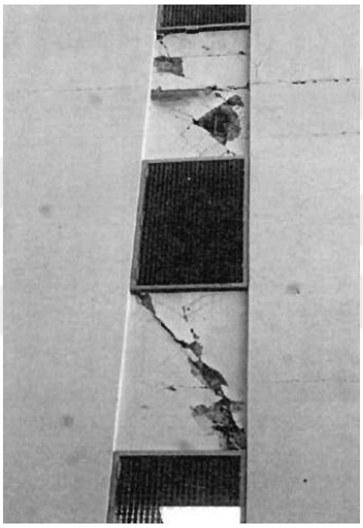

Figure 2.2. Failure of a short beam, the Northridge earthquake.

Finally, the short members of these structures (Figure 2.2), due to non-confinement conditions and also lack of necessary transverse reinforcements for favorable ductility (and also with considering other factors, like torsion, that might cause this type of failure) collapse, and sometimes cause the building to develop into the level which is prone to destruction (choosing the destruction of the building by the owner). It should be noted that in all the studied cases it is obvious that these structures due to their high stiffness reduce the inter-story displacements; and because of that, structural and non-structural damage of other structural members has been significantly reduced. Although the shear walls suffered damages during these earthquakes, the structure did not lose its overall performance. In all cases, the reinforcement maintained the overall cohesion of the shear wall, and prevented its failure (Fintel, 1995).

2.1. Thematic Review

Paulay and Binnay (1974), for the first time recommended diagonal reinforcements to improve the ductility of coupling beams and walls, and presented an equation so as to calculate the beam capacity by ignoring the effect of longitudinal and transvers bars. They build samples of coupling beams with diagonal reinforcements under cyclic loadings, and showed that these samples have a great energy absorption as well as ductility capacity which they can show a ductile behavior by dissipating and absorbing earthquake energy. The only demerit of these samples could be buckling of diagonal reinforcements (Paulay and Binney, 1974).

Tassios et al. (1995), studied effect of the type of reinforcements and beam spans on the behavior of shear walls with openings. For this purpose, they built beams with 5 types of reinforcements (Figure 2.3), and the ratios of span to height for beams were equal 1 and 1.66, and evaluated their behavior under cyclic loadings. The sample A reinforced with usual flexural and shear reinforcements and sample B was reinforced with crosscut reinforcement. The sample C in addition to the reinforcements used in the sample A was reinforced with bent bars (Figure 2.3.C). Apart from the usual reinforcements, the samples D and E also were reinforced with long and short connecting bars in the middle of the height, respectively. All the samples were of the half dimensions of a real sample.

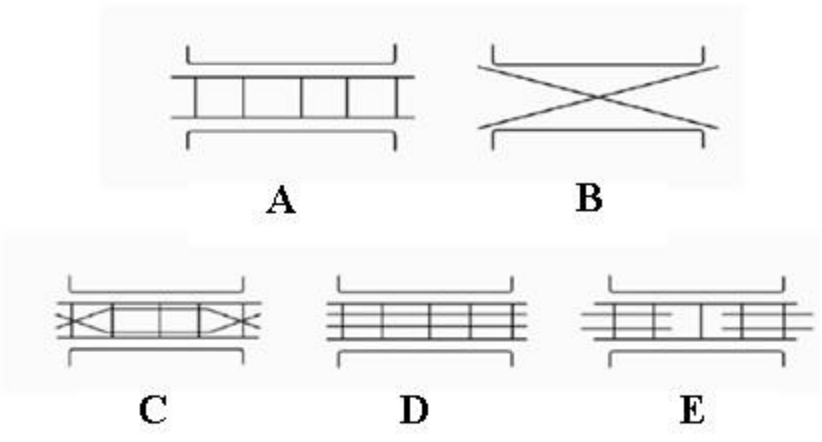

Figure 2.3. Walls reinforcements.

The samples with usual reinforcements showed less plastic displacements. In addition, their strength and stiffness decreased significantly during the experiment. It was proved that the performance of the samples with crosswise inserted bars were great as well. The overall performance of the sample C was better than the sample A. The bent bars have increased the ultimate shear capacity of this sample by 20%. The overall performance of the sample D was better than the sample E too. The advantage of this type of reinforcing is keeping the bond between steel and concrete in the end section (Tassios et al., 1995).

Shahrooz et al. (1992), in Ohio University conducted a series of experiments and evaluated the effect of compressive and tensile stresses acting perpendicularly on the boundary element of walls, and also studied the effect of the vertical bars welded to the wings of the steel link beam where it was embedded. For this purpose, they experimented 3 full-scale plate girders along with the walls of one story under cyclic loading. The first specimen was built in a way that the compressive and tensile stresses acting on boundary elements of walls were equal. The second and third samples were loaded in a way that the tensile stresses acting on the boundary element were always less than compressive stresses. The difference between the second and third samples were that in the third sample some bars were welded to the wings of beam. After experiment, it was observed that all the three samples were damaged in a similar fashion. The damage inflicted to the samples were cracking as well as concrete being detached from the top and bottom part of the beams where they are connected to the walls.

The difference is that the cracks appeared in the samples 2 and 3 were less than the sample 1 and they were hairline cracks. Hysteresis loops are spindle-shaped. Although the sample 1 and 3 were tested under the same loading, the bars welded to beam wings in the sample 3 decreased the effect of the tensile stresses on the stiffness of the connections and therefore their hysteretic loops became more symmetric. In terms of the stiffness of the walls, the first sample has the least stiffness. Weight forces increased the fixedness of the beam, which increased its stiffness by 33%. The combined effect of weight forces and the bars welded to the wings of the beam in sample 3 increased its stiffness by 47% compared to the sample 1. In these samples, 65, 70, and 80 percent of the dissipated energy in walls of the samples 1, 2, and 3 happened in their beams, respectively. In other words, contribution of the connected area in the dissipated energy was small, and most of the energy was dissipated in the free span of the beams during plastic hinge formation (Shahrooz et al., 1992).

Choo and Li (1997), proposed a method to analyze coupling shear walls with stiffening beams under lateral static loads. By placing stiffening beams in coupling shear walls, drifts from shear forces in coupling beams and the bending moment at the base of walls can be reduced significantly. They also concluded from numerical studies that the most effective positions for the stiffeners were at 40 and 25-50 percent of the height of the walls for walls with one and two middle stiffeners, respectively. Placing the stiffening beam in the lowest floor changes the base deformations in the walls placed on the soft foundation (Choo and Li, 1997).

Sarabi et al. (2016), studied the effect of the shapes and dimensions of openings in concrete shear walls by means of nonlinear static analysis. The effect of opening position on performance of shear walls were evaluated by finite element method. For this purpose, 4 walls without and with openings in top, middle, and the bottom of the walls were modeled in Abaqus software. Generally, the best case for energy dissipation is using shear walls with no openings. Next priority is to create openings in the bottom parts of the walls. In other words, energy dissipation and ductility in walls with openings in top parts of the walls is more than the case in which openings are in the middle part. In addition, walls with opening in the middle have a better performance in energy dissipation than the walls with openings in the bottom. In walls without openings, the greatest stress happen in the lower part of the walls due to occurrence of the maximum shear and bending moment in this area. Additionally, comparing pushover diagrams in different walls reveals that for a specific displacement, walls without opening, walls with opening in top, walls with opening in the middle, and finally walls with opening in the bottom carry more base shear, respectively (Sarabi et al., 2016).

Paulay (2001), by considering a perfectly elastoplastic model, in order to determine the deformation after yielding in coupling beams with usual as well as diagonal reinforcements, and also in order to evaluate their ductility, proposed some equations. He determined the yield displacement of the coupling beam with usual reinforcement based on the yield strain of the longitudinal bars (Paulay, 2001).

Balkaya and Kalkan (2004), in a study which was intended for evaluation of the effect of openings on the behavior of shear walls, made use of diagonal form of bars in the coupling beam. They determined the bearing capacity and stress distribution around the openings by means of time history analysis in 2-D and 3-D cases, and then presented the results in terms of openings length and width as the resisting moment diagram as well as load-displacement diagram (Bakaya and Kalkan, 2004).

Chai and Anderson (2005), by conducting experiments on a short shear wall with lightweight concrete, plotting lateral force-deformation, and recording stresses and strains, evaluated cracking pattern around openings. They observed that by increasing the lateral force, firstly, minor cracks appeared, and then minor oblique cracks in the area of door and window opening developed. As the force increased, the first cracks appeared in the beams at top of the door opening, and big cracks in the window corners. Finally, as the footing started lifting up from the ground, the experiment was stopped (Chai and Anderson, 2005).

To find the effect of boundary elements on shear walls, hongmei et al. (2007), examined three walls with different boundary elements under cyclic pseudo static loading. These experiments considered parameters such as failure modes, lateral bearing capacity, ductile displacements ratio, stiffness reduction and energy dissipation capacity. As a result, considering reasonable boundary elements not only can provide the ability to diagnose plastic failure areas, but also increases the lateral bearing capacity and energy dissipation of the earthquake considerably. In a more precise way, the longitudinal reinforcements ratio of the boundary elements has a direct influence on improving the seismic performance of the wall (Zhang et al., 2007).

In an experiment, Young hoon et al. (2002), observed that the way in which boundary elements are reinforced has an impact upon increasing ductility capacity of the wall as well as the parameters such as ductile displacements and energy dissipation of earthquakes. For instance, at the boundary areas of shear walls, using transvers reinforcements which provide the minimum requirements of the columns confined by ties has a considerable effect on confining the concrete of the boundary areas. As a result of this, concrete in these areas can withstand the compression forces of dead loads as well as overturning moment of earthquakes (Young et al., 2002).

Rezapour et al. (2013), in a research work evaluated the macro-modeling of concrete shear walls with symmetric openings. They, by using multiple vertical line element mode (MVLEM), tried to achieve a better result in less time. Modeling concrete shear walls without openings by means of MVLEM brings about favorable results. However, if a number of openings due to architectural restrictions is considered in a concrete shear wall, the precision of these elements will reduce. The reason for this, is improper modeling of the coupling beam in the concrete wall with openings. In this study, a concrete shear wall with symmetric openings was modeled in Abaqus software by using 3-D micro elements. Afterwards, the aforementioned wall was modeled by using MVLEM in Abaqus, and the results in both pushover as well as cyclic loading cases were evaluated and then compared to one another. In order to be precise enough in modeling concrete shear walls with openings, one should pay a critical attention to the coupling beam. Therefore, the most important objective of this research was determining a MVLEM, based on elastic behavior and generalizing it to the plastic behavior, for the coupling beam of a concrete shear wall. The main purpose of using this model in macro-modeling of the concrete shear wall with openings was to have a similar behavior in the modeled shear wall to the shear wall modeled with micro elements (Rezapour et al., 2013).

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3. MATERIALS AND METHODS

In addition to be being stable against gravity loads, buildings must maintain their stability against lateral forces. The shear walls with high stiffness can resist lateral loads and the resulting moments. In many buildings, architectural considerations require creating openings in the shear walls, which reduces the walls stiffness against applied loads. In this study, the effect of dimensions and positions of openings on the shear wall has been evaluated. The results demonstrate drifts and deformations exponential variation with increase in opening area. Concentration as well as magnitude of stresses have been evaluated in addition.

3.1. The Study Type

Regarding the objective, applied studies, and modeling, this research was performed using ETABS 2015 software. A research was undertaken in order to gather information, then the computer modeling was carried out.

3.2. Methodology

In this research, drawing, modeling, and analysis of an assumed structural geometry form was fulfilled in ETABS 2015 software. In this method, the effect of openings on the seismic behavior of the buildings with opening have been evaluated. In other words, the following cases were considered:

1- A concrete shear wall without openings.

2- A shear wall with regular openings in all stories.

3- A number of shear walls have openings (stories have openings alternately).

4- Effect of openings position (openings are created in a zigzag pattern in the stories)

5- The effect of openings shape (in this case, two different dimensions of shear walls were considered).

6- Moment-resisting systems without shear walls.

7- Afterwards, the effect of seismic behavior in every cases mentioned above on the floors displacement as well as drift was evaluated, and also stress distribution in shear walls were analyzed. The next step in order to evaluate and analyze the issue more precisely was analyzing different percentages of openings from 0% (no shear wall) to 100% (moment-resisting frames) of openings area and the cases in between in addition.

8- Evaluating the effect of distribution of base shear (internal force) based on the type of the shear walls.

3.3. ETABS Software

CSI ETABS is a special software for analysis and design of buildings structures. All the elements of buildings are defined in this software. All the design processors of the software are perfect, which all types of buildings elements can be designed in it. This software is designed for buildings systems. Designing buildings using softwares was introduced 35 years ago. Engineers' using of nonlinear static and dynamic analysis practically urged the need for engineering softwares such as ETABS. Additionally, the advent of today's powerful computers has enabled structural engineers to make use of more extensive and complicated models.

The most important analytic capabilities of ETABS software are as follows:

- Recognizing the buildings and floor elements
- Calculating the mass and center of mass automatically
- Transferring gravity forces from floors to beams
- Defining and assigning lateral forces between stories level
- Modeling shell elements and ramps

Capabilities of CSI ETABS software are as follows:

- Steel frames design

- Concrete frames design
- Shear walls design
- Composite beams design

3.4. Analysis Methods

3.4.1. Equivalent Linear Static Analysis

This method is one of the most common methods of seismic analysis, which is presented in most seismic codes with minor differences. In this method the building base shear, which is a percent of the building weight, is applied to the building through a coefficient which is called seismic coefficient and with a certain pattern, mostly triangular, in the direction of the building height. Then, the building will be analyzed under load combinations of a specific code. Afterwards, assuming the material behavior is elastic, maximum forces and displacements are extracted. Finally, the building will be designed.

- ✓ Loading pattern in equivalent linear static analysis

As mentioned in the previous section, in equivalent linear static analysis, lateral loads are applied on structures according to a specific pattern. This pattern in most earthquake codes, including standard No. 2800 code, has a triangle shape and is based on the first mode of the structure. In essence, deformation of a structure under lateral forces is dependent on the type of the structure. This deformation is a combination of flexural and shear cases. Shear deformations are in a way that the relative displacement in each story is greater in comparison to the floor below, which the structure goes through a cantilever deformation. The major displacement of moment-resisting frames are shear deformations. Structures with braces and shear walls, on the other hand, have bending deformations. In seismic codes, a combination of three modes of above-mentioned displacements which are linear is recommended. In some codes, more complete patterns that try to use a load pattern corresponding to dynamic characteristics of the structure, including period and first mode shape, in a more realistic way have been presented as follow (Moghaddam, 2009)

$$F_i = \frac{w_i h_i^k}{\sum_{j=1}^{N} w_i h_i^k} V \tag{3.1}$$

Where;

Fi = applied lateral force at level i, Wi = story weight, hi = story height k = Stiffness, V = Design based shear, N = Number of story

Different patterns will be gained based on different amounts k:

1- Triangular load pattern $k = 1$ (Figure 3.1)

2- Rectangular load pattern $k = 0$ (base shear is distributed in the structure only corresponding to stories mass) (Figure 3.1)

3- Triangle and rectangular combination

4- Whipping load pattern

5- Parabolic load pattern

6- Second order parabolic load pattern

7- Modified rectangular load pattern

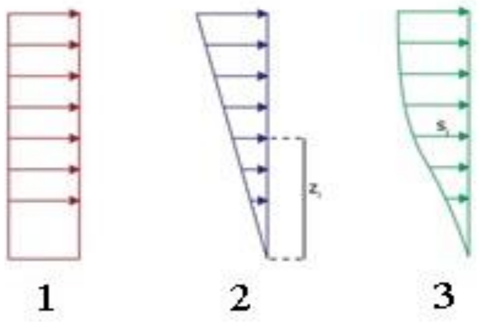

Figure 3.1. Equivalent Linear Static load pattern.

3.4.2. Modal Dynamic Analysis

In this method, similar to the equivalent linear static analysis, material behavior is elastic. The only difference is that dynamic characteristics of structures such as period and mode shapes are involved in the structural analysis. In this method, dynamic characteristics of the structure in each mode such as mode shapes and period are calculated at first. Then, the acceleration response of each mode according to its period and based on the earthquake response spectrum or design spectrum is determined. Afterwards, other structural responses based on this acceleration such as base shear, relative displacement of the stories, internal forces of members, and so forth are determined based on the dynamic characteristics of that mode. Next, the total response is determined by combining these effects with one of the statistics methods such as the root sum squared method. This method is one of the most appropriate and widely used methods which is based—based on the standard 2800 code— mandatory for regular buildings higher than 50 meters above the base elevation as well as irregular buildings with more than 5 stories, or higher than 50 meters (Standing committee, 2007).

3.4.3. Linear time history analysis

Material behavior similar to the previous method is considered to be linear as well. In this method, the structures foundation is analyzed under the seismic accelerogram of a specific earthquake using structural dynamic analysis equations. Next, the structural responses are recorded in consecutive time steps, and then a set called response history is determined. Finally, the design engineer based on engineering judgment and by relying on her or his experience decides to how apply the responses in order to appropriately design the structures.

3.4.4. Nonlinear time history analysis

In this type of analysis, the structural behavior is studied within the both linear and nonlinear behavior under the accelerogram of the desired earthquake. In order to obtain favorable results, it is necessary that the nonlinear characteristics of the members such as strength, stiffness, ductility, and their complete hysteretic behavior which all are modeled by the software have to be compatible with their real behavior. These characteristics are usually determined by means of the built specimens in a laboratory (Guideline, 2003).

The ground acceleration and velocity upon reaching the structures are often accentuated. The accentuated motion can create forces and displacements that are beyond the structures capacity. There are three methods used in analysis and design of buildings against earthquakes which are the dynamic analysis, pseudo-dynamic analysis, and equivalent linear static analysis. In the following sections, these methods are evaluated in concrete buildings with moment-resisting frames, and the process of choosing as well as scaling the accelerograms in order to use in the time history analysis are discussed. For this purpose, three types of concrete buildings with 5, 10, and 15 stories are considered and the earthquake force distribution in their stories is evaluated in different cases.

The analytical solution of the dynamic response of the structures within the nonlinear limits is not possible even if the time changes are a function of a simple excitation, and therefore the principal method to analyze these systems is numerical methods, including the central difference and Newmark methods.

In this method, in every analysis step, the stiffness of the structure is modified and the response of that step is determined based on the modified stiffness. Recoding every single response results in the history of the real response of the structure. In order to analyze the structure with this method, it is necessary that the place of recoding the used accelerogram is as close as possible to place of the desired site (Sasaki et al., 1998).

The motion equation for the system in the form of matrix could be written as;

$$[m]\{\ddot{x}\}+[c]\{\dot{x}\}+[k]\{x\}=mg(t) \qquad (3.2)$$

Where,

$[m]$ = mass matrix $\{\ddot{x}\}$ = incremental vectors of acceleration

$[c]$= damping matrix $\{\dot{x}\}$ = incremental vectors of velocity

$[k]$ = stiffness matrix $\{x\}$ = incremental vectors of displacement

Mg (t) = increment in the horizontal ground acceleration

In this study, the Kobe earthquake has been used for the analysis. In order to analyze the structure with this method, it is necessary that the place of recoding the used accelerogram is as close as possible to place of the desired site. In order to scale the accelerogram based on the 2800 code, the selected accelerogram have to be scaled according to the following method:

a) All the accelerograms are to be scaled to their maximum value, that is, the maximum acceleration of all the accelerograms should be equal to g.

b) The response spectrum of every scaled accelerogram should be determined by considering 5 percent damping.

c) The response spectrum of every accelerogram should be combined with each other using the root sum squared method (SRSS), and a unit combined spectrum for every couple has to be made.

In this study, the Kobe earthquake has been used for the analysis. The Kobe earthquake with a magnitude of 7.3 on the Richter scale shook and destroyed the Kobe city of Japan for 20 seconds in 1994. This earthquake was one of the worst natural disasters ever happened in japan, causing severe damages to the most of the bridges and other structures. The focus of this earthquake was at a depth of 14 kilometers in the coastal waters of the Kobe city. Japanese officials attributed the severity of the damage to the type of the earthquake, which happened almost beneath the region vertically.

3.4.5. Incremental nonlinear static analysis

The general methodology of this procedure which is called pushover analysis too is that a lateral load according to a certain loading pattern is applied to the structure incrementally, which deforms the structure to a point called target displacement. Then, the seismic requirements of the desired structure are studied. In this method the behavior of a system with multi degrees of freedom by a system with single degree of freedom evaluated.

The main relationship between these two systems in the static analysis is stablished by the modal contribution coefficient of the principal mode of the system with multi degrees of freedom; which is:

$$\Gamma = \frac{\{\Phi\}^T.M.\{1\}}{\{\Phi\}^T.M.\{\Phi\}} \tag{3.3}$$

In which, Φ and M are the principal shape vector and the mass matrix of the system with multi degrees of freedom, respectively.

After calculating the coefficient Γ, the force and deformation of the system with one degree of freedom are determined by equations 3-3 and 3-4, respectively:

$$d_{SDOF} = \frac{d_{MDOF}}{\Gamma} \tag{3.4}$$

$$F_{SDOF} = \frac{F_{MDOF}}{\Gamma} \tag{3.5}$$

The equations above are the roof displacement and its base shear in the corresponding system with multi degrees of freedom. Therefore, the capacity diagram of the equivalent single degree of freedom system, which is usually as force against displacement, can be determined.

3.4.6. Multi-Mode Method of Pushover Analysis

In this method as shown in Figure (3.2), structures are analyzed according to loaded mode shapes with different patterns separately. The capacity diagrams of every analysis are converted to ADRS coordinates, and plotted along with the desired spectrum in a coordinate system. Afterwards, the critical case according the designer’s opinion is selected and based on that the appropriate decision is made (Sasaki et al., 1998).

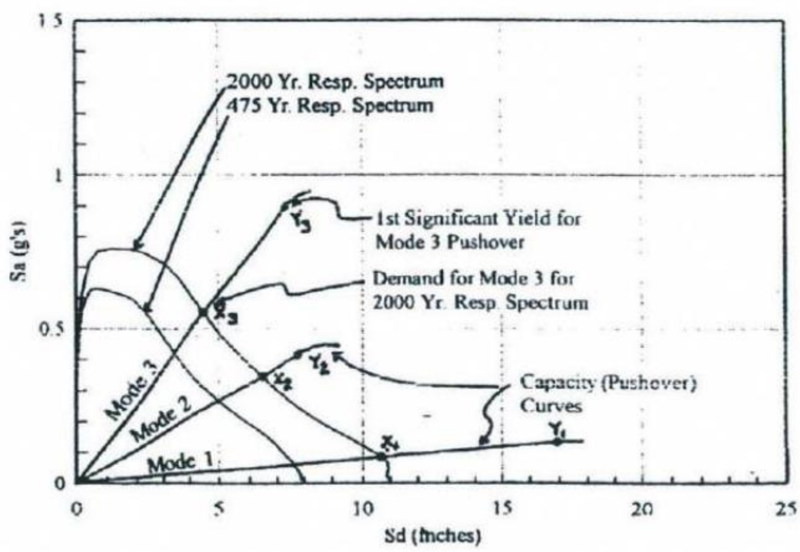

Figure 3.2. Multimodal approach.

Another method is the PRC method presented by Moghadam and Tesu, which based on this method the results obtained from the multimodal approach are combined according the equation (3.5) and the final response is calculated.

$$R = \sum_{i=1}^{N} \beta_i R_i \tag{3.6}$$

In which, β_i, R, and R_i are the modal participation coefficient, the structure response under pushover analysis with i^{th} mode pattern, respectively (Chopra and Goel, 2002).

3.4.7. Adaptive pushover analysis (APA)

When applying the lateral load to the structure in the nonlinear incremental static analysis (Figure 3.3), the members—especially at connections—deform beyond the linear limit and enter into the plastic area. By calculating the instantaneous stiffness of the members and then obtaining the total stiffness matrix in each step, it was observed that the structure matrix decreases. This decrease causes a change in the structure response to the ground motion, and the distributed forces in the structure will be different from the previous state as well.

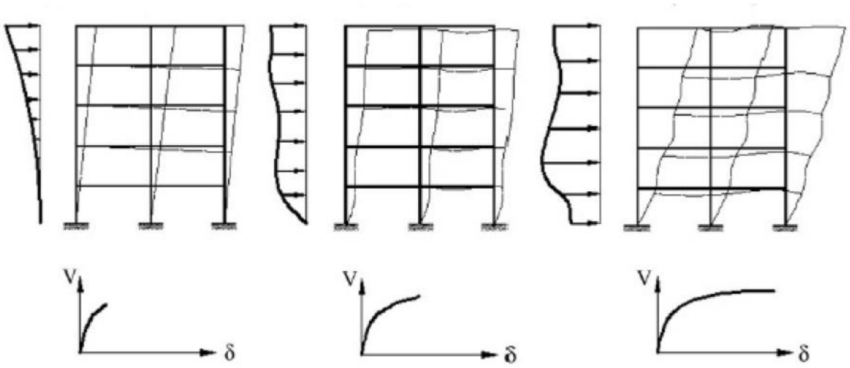

Figure 3.3. The loading stages in the adaptive pushover analysis.

3.5. Failure modes of the shear walls with openings

Basically, there could be three failure modes in the reinforced concrete shear walls. These modes depend on the coupling beams geometry and walls, bars, concrete, and the interaction between the beams and the walls (Abdelbaky, 2008).

These modes are:

a) Flexural failure

b) Shear or diagonal failure

c) Combined failure

3.5.1. Flexural failure

This mode happens in the shear walls with rather small height and bars. The structure, as shown in (Figure 3.4), when applying the lateral load—deforms along with forming flexural cracks in the tensile walls (Tasnimi, 2001).

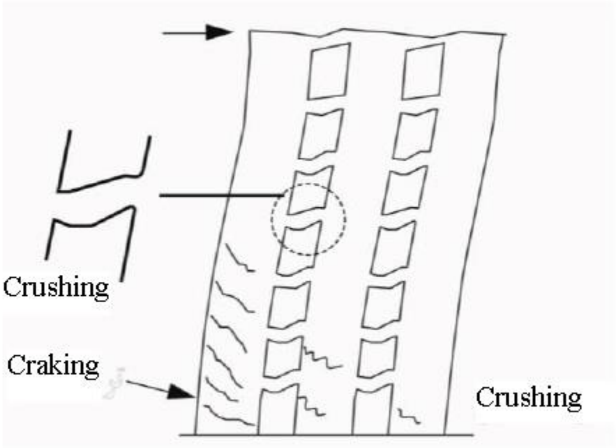

Figure 3.4. Flexural failure of the shear wall.

The beams deform with a double curvature and an infection point in the center. The forces resulted from these displacements are presented in (Figure 3.5). The shear force resulted in the inflection point creates a bending moment in the supports, which propagates the flexural cracks in the beams. As the lateral force increases, the bending moment increases and the cracks widen more crushing the concrete in the compression area. Consequently, the beam fails (Subedi, 1991).

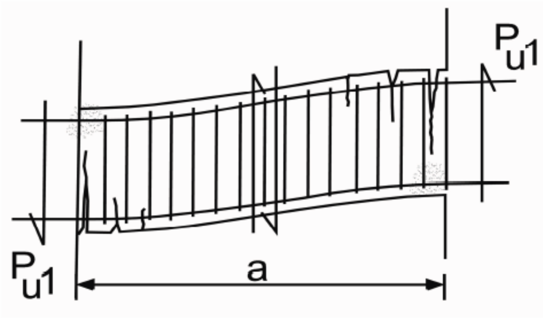

Figure 3.5. The flexural deformation of the beam.

The flexural cracks were created in the tensile walls too, and a few cracks propagated along the height of the wall. Finally, the failure of the wall happens due to the crushing of the compression wall which the maximum stress happens at the corners (Subedi, 1991).

3.5.2. Shear or diagonal failure mode

This mode happens in the coupled shear walls with a rather great height and a balanced amount of steel. The failure usually begins by forming flexural cracks in the tensile walls, and the diagonal cracks at the center of the diameter propagate in the transverse direction as the lateral load increases. The net shear deformation and the reactions created in the beams are shown in (Figure 3.6). The net shear deformation is equivalent to the whole upper and bottom area of the beam’s being in tension. In this case, a compressive force along the direction of the diameter AC and a tensile force along the direction of the diameter BD are created, which one element of the beam close to the center of the span is under 2 axis tension-compression stress state. When the tensile stress in the concrete and the diameter BD reaches the ultimate tensile strength of the concrete, the concrete fails. As the load increases, flexural cracks in the tensile walls increases and some new cracks were appeared along the height of the walls. The wall failure, in this case, is accompanied by crushing the concrete in the compressive wall at the point of the maximum stress. In this case, the diagonal crack in all the coupled beams are completed simultaneously (Subedi, 1991).

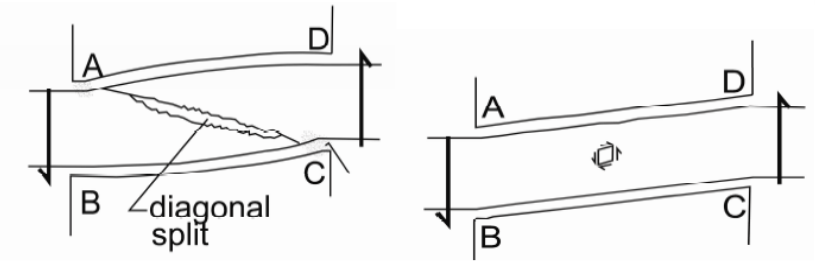

Figure 3.6. The shear deformation of the beam.

3.5.3. Combined failure mode

This mode happens in the walls with coupled beams with great height. The flexural deformations which cause the beam to have double curvature, and to be under tension at the middle of the cross section of the beam, are converted into the compression at the middle of the cross section of the beam and are combined with shear deformations which cause tension in both surfaces. This behavior can be explained as following (Figure 3.7):

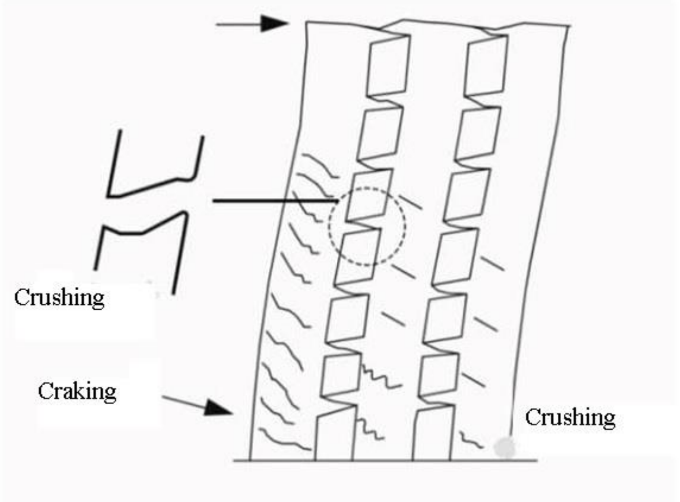

Figure 3.7. Combined failure of the shear walls.

1- In the first stages of loading, the beam has flexural deformation, as shown in figure 3.8. In this case, the beam has a double curvature with an inflection point at center of the span. After this stage, when the shear forces are great enough to form flexural cracks, the flexural behavior of the beam changes.

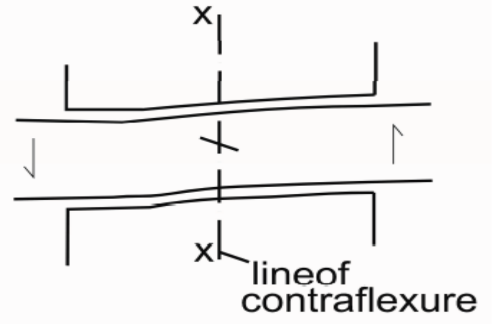

Figure 3.8. The first stage of the combined bending-shear performance.

2- By widening the cracks due to increment in the effect of diagonal tension-compression, the outer concavity part of the curvature in the upper and lower surfaces of the beam are transferred outward gradually. This behavior is equivalent to change in the inflection point in the bars from their original position at center to the supports in opposite directions. Figure (3.9), shows that the inflection line has a counter clockwise rotation with development of diagonal cracks from outside to the center.

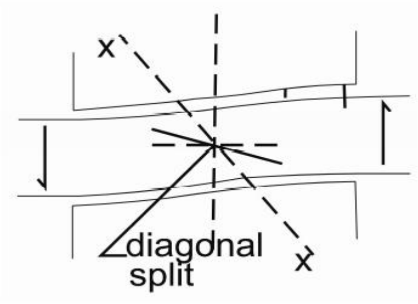

Figure 3.9. Diagonal failure and rotation of the inflection line.

3- Change in the position of the inflection point stops in the bars near to the beam supports, and in this area intertwining the required deformations for flexural and shear reactions causes twist and torsion in the bars (Figure 3.10). In this stage, the concrete is damaged mainly by diagonal cracks, and the bars located at the top and bottom are under tension along their entire length.

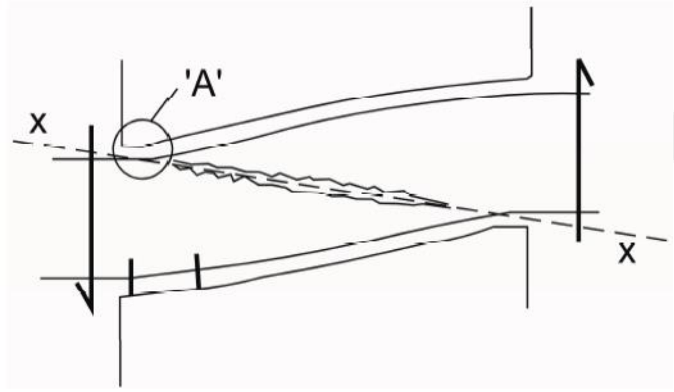

Figure 3.10. The final stage of failure.

4- When a small part of concrete at the corners crushes under pressure, the beam reaches its ultimate bearing capacity. In this stage, quite a lot of cracks develop along the height of the wall (Tasnimi, 1997).

3.6. Relative lateral displacements of the stories

The relative lateral displacements of stories—known as drift among engineers is defined as the difference between the lateral displacement of the center of mass of the upper and lower floors of a specific story. Drift control of a structure is one of the important issues related to the structural design, which most of the time can impact the design and should not be more than a specified value mentioned in the code.

In the following lines, after evaluating the philosophy of the relative lateral displacements of stories (drift) and the related issues, the method of controlling the relative lateral displacements of buildings (drift control in ETABS) is presented. The actual relative lateral displacements of stories can be determined only by means of nonlinear analysis of structures; however, it can be calculated with a good approximation with following equation:

$$\Delta_M = C_d \Delta_{eu} \tag{3.7}$$

In which, C_d, Δ_{eu}, and Δ_M are the deflection amplification factor ,the relative lateral displacement of the story under the design earthquake, the nonlinear relative lateral displacement of the story or the actual relative lateral displacement of the story, respectively. Δ_M in buildings up to 5 stories, is $0.025h$ and in other buildings is $0.02h$ - which h is the story height.

The Figure (3.11), illustrates the drift concept exactly:

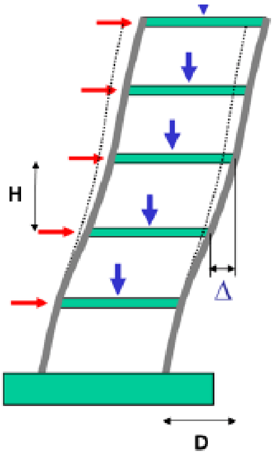

Figure 3.11. The drift concept.

D → absolute story displacement

Δ → reletative story displacement (drift)

Δ/H → Drift ratio

3.7. Shear stresses of the shear walls

In this method, as shown in Figure (3.12), distribution of the wall stress in different sections is determined for bending moments M_1, M_2, and the axial force N. Strength of material principles were applied to calculate the stresses. The stress in the section was determined by combining the bending and axial stress (Cuoll et all, 1987).

$$\sigma = \frac{MC}{I} \tag{3.8}$$

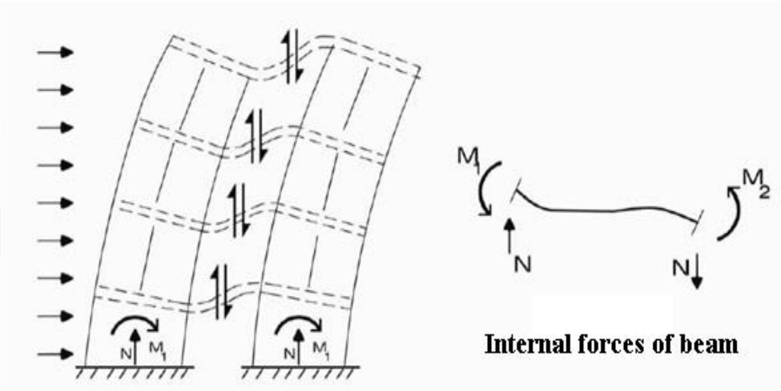

Figure 3.12. The shear wall behavior under the lateral load.

In this method, distribution of the real stress, which includes uniform axial stresses and linear bending stress for each wall, is determined by combining two hypothetical stress distribution. At first, it’s assumed that the wall behavior is as a combined unit cantilever and the neutral axis is at the center of the two walls (Figure3.13).

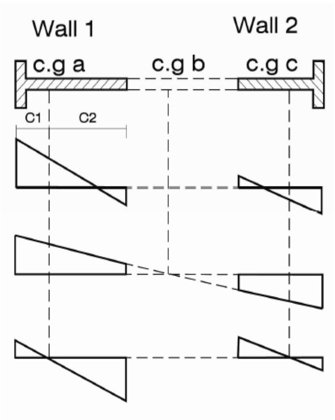

Figure 3.13. Combination of independent cantilever and compound stresses in order to determine the real stress of the walls.

Therefore, a stress distribution is obtained. Then, two linear stress distributions are determined according to this assumption that the wall behavior is as a completely independent cantilever and that the neutral axis is at the center of each wall.

4. RESULTS

Earthquake resistant buildings must have a resisting system against seismic and gravity loads acting on them. These systems should be able to transfer applied loads on the structure to the foundation. Shear walls, owing to their high in-plane rigidity, are amongst the most important resisting components against lateral loads. Sometimes architectural considerations require using openings in shear walls or using very slender shear walls. Building shear walls in both high-rise and moderate buildings and even in short buildings increase the building strength significantly. In addition, they apart from being the best method to control drifts are more economical in comparison to moment-resisting frames. Nowadays, shear walls along with moment-resisting frames are used in order for buildings to be more soft, resistant, and ductile. Openings effect the behavior of shear walls considerably. Such factors sometimes reduce the stiffness and rigidity of shear walls substantially. In this chapter, the effects of creating different openings in shear walls on the seismic performance as well as stresses and deformations of shear walls are discussed.

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4.1. Problem Definition and Solution

In this research, the effect of openings on the seismic performance of shear walls has been studied. In other words, the following cases regarding shear walls have been considered:

1- Concrete shear walls without openings

2- Shear walls with regular openings in all stories

3- Some of the shear walls in the building height have openings (stories have openings alternately)

4- Effect of openings position (openings are created in a zigzag pattern in the stories)

5- The effect of openings shape (in this case, two different dimensions of openings in a horizontal and a vertical pattern were considered).

6- Moment-resisting system without shear walls.

7- The next step in order to evaluate and analyze the issue more precisely was analyzing different percentages of openings from 0% (shear wall) to 100% (moment-resisting frames) of openings area and the cases in between in addition. Afterwards, the effect of seismic behavior in every cases mentioned above on the floors displacement as well as drift was evaluated, and also stress distribution in shear walls were analyzed.

8- Evaluating the effect of distribution of base shear (internal force) based on the type of the shear walls.

4.2. General Properties and Assumptions

All the cases mentioned in 2-4 were considered for 5, 10, and 15-story buildings which had a floor to ceiling height of 3 meters and the dimensions 12×16m in plan view. They have 4 longitudinal and 3 transverse spans of 4 meters. The positions of the shear walls in the stories were in the first and last longitudinal spans. Modeling and analysis were performed through finite element method using ETABS software.

- ✓ Shear walls thickness were assumed to be 250 mm.
- ✓ All the other beams and columns dimensions were considered to be $250\times 500\ mm$.
- ✓ The slab thickness was assumed to be 150 mm.
- ✓ Horizontal openings dimensions in cases 2 to 5 (horizontal) were considered to be 1×1.34 m.
- ✓ Vertical openings dimensions in the case 5 (vertical) was considered to be 1×1.8 m.

All the models in order to achieve more accurate results were meshed meticulously.

4.3. Model Geometry

Shear walls like other types of walls can be analyzed through one of the approximate or exact methods. Approximate methods are faster and therefore would be easier for manual calculations. However, they are used only for regular and quasi-regular structures and loads. Exact methods are capable of analyzing regular structures and complicated loadings, which in order to use these methods the aid of computers is necessary. Usually the analysis method is chosen based on the structural shape as well as the degree of accuracy. In this study, in order to sketch the geometric model according to the information given in the previous section, 21 models of buildings were considered in ETABS software. In Figures 1 to 3, three models of the 21 sketched models have been considered.

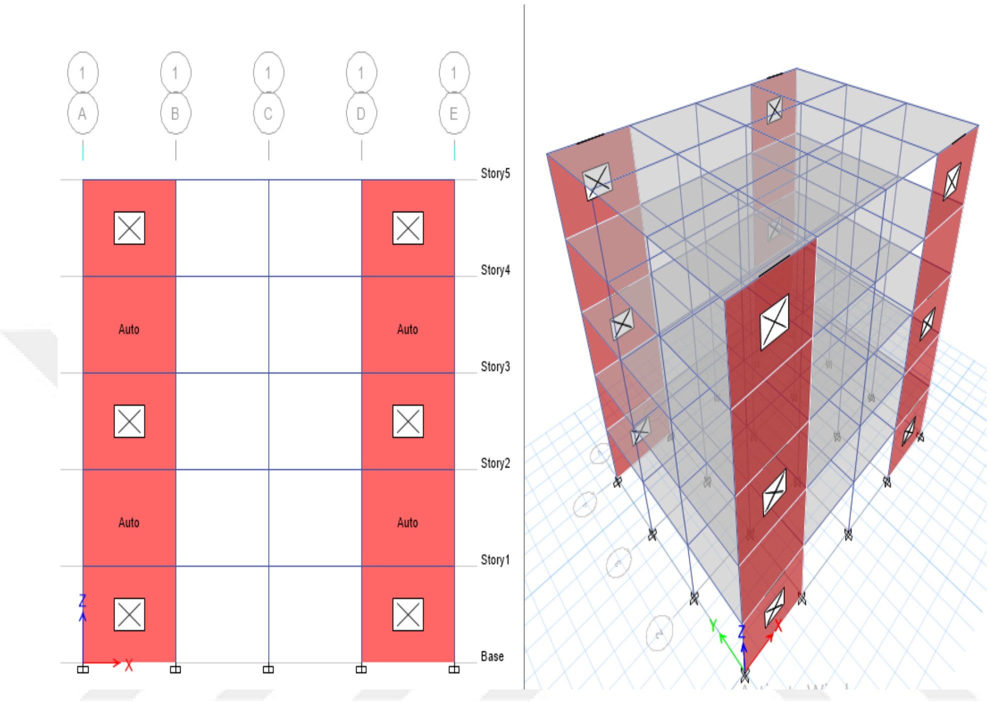

Figure 4.1. Geometric model of the 5-story building with alternately openings.

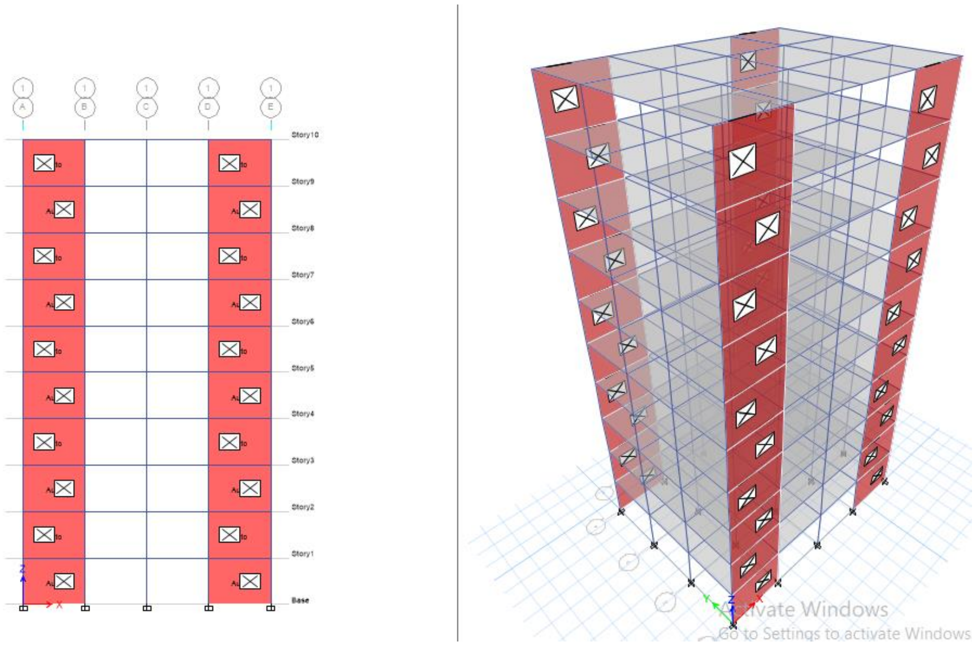

Figure 4.2. Geometric model of the 10-story building with zigzag openings.

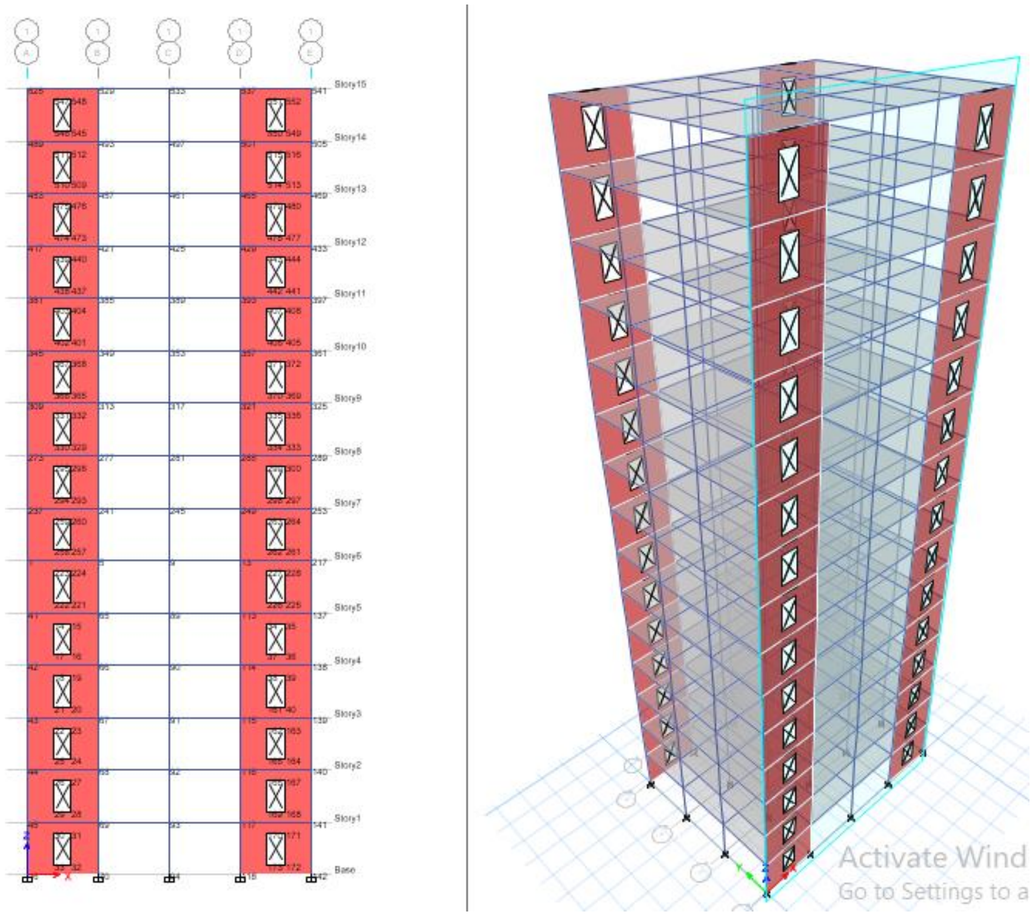

Figure 4.3. Geometric model of the 15-story building with vertical regular openings.

4.4. Assigning the Material and Meshing

The material properties in the buildings were defined according to table 4.1:

Table 4.1. Material Properties.

Material Feature	Value
Type	Concrete
Directional Symmetry Type	Isotropic
Weight per Unit Volume (kN/m^3)	23.5631
Mass per Unit Volume (kg/m^3)	2402.77
Modulus of Elasticity, (E) (MPa)	24855.58
Poisson's Ratio, (U)	0.2
Coefficient of Thermal Expansion, (A) (1/C)	0.0000099
Shear Modulus, G (MPa)	10356.49

4.5. Loading

In this research, in order to have seismic loading type, Kobe earthquake accelerogram was used. This accelerogram was applied to the buildings in the X direction. The acceleration-time graph of this accelerogram is shown in Figure 4.4.

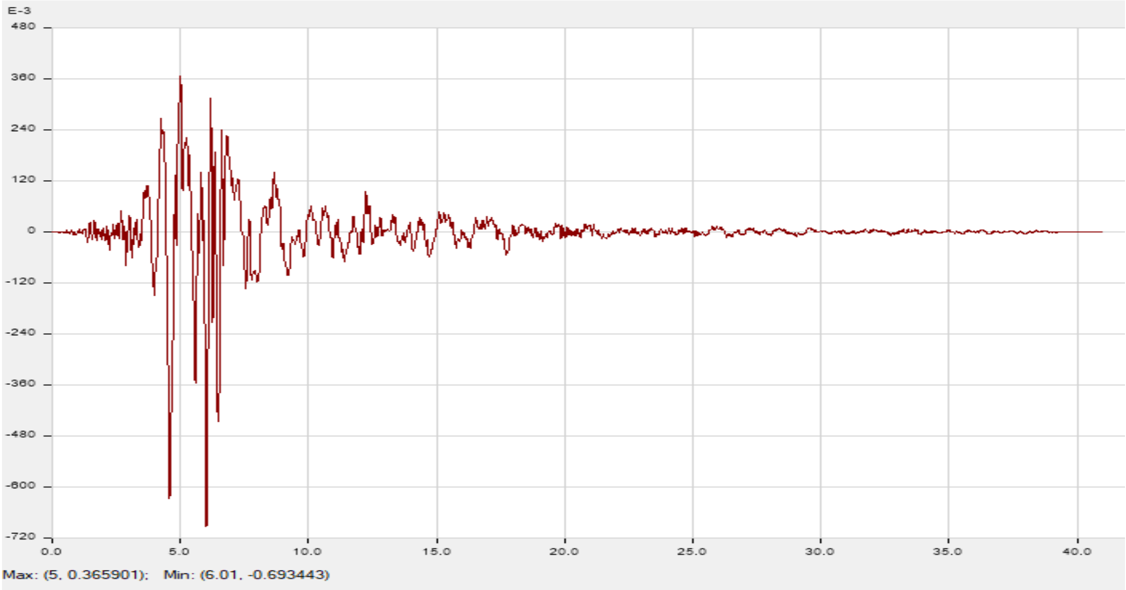

Figure 4.4. Kobe earthquake accelerogram.

4.6. Analysis Type

In this study, time history analysis in order to evaluate the behavior of the buildings was used. In this, method, the buildings are loaded under the loading of the time history of the earthquake acceleration, and then the structures are analyzed completely and responses are determined as time histories. In the time history analysis, the effect of the higher modes as well as variations in inertia loading pattern due to the buildings ductility during the earthquake are considered automatically. In this method, the maximum total displacement which is applied to the structure by a certain accelerogram is determined, and there is no need to estimate this parameter based on empirical-theoretical equations. This type of analysis is very sensitive to such changes as accelerogram properties and nonlinear hardening behavior of the desired elements. Therefore, scaling the accelerogram and the applied method has a direct impact on the analysis results.

4.7. Analysis results

After sketching the geometry and assigning the materials, meshing and defining the properties such as shear walls and openings positions based on the software assumptions, and finally after defining seismic function in the analysis portion of the software, the models were analyzed. The results are evaluated afterwards.

4.7.1. Displacement, Drift, and Stress Contours

After analyzing the models, the results of shear walls displacements in the buildings height were determined. The shifting of each point of the structure in the X and Y direction in relation to its initial position due to seismic waves is called displacement. Additionally, the drift (relative displacement) of the models and the stress contours in the shear walls are presented hereunder.

4.7.2. Case 1 Shear wall without openings

- Model 1; the 5-story building without openings

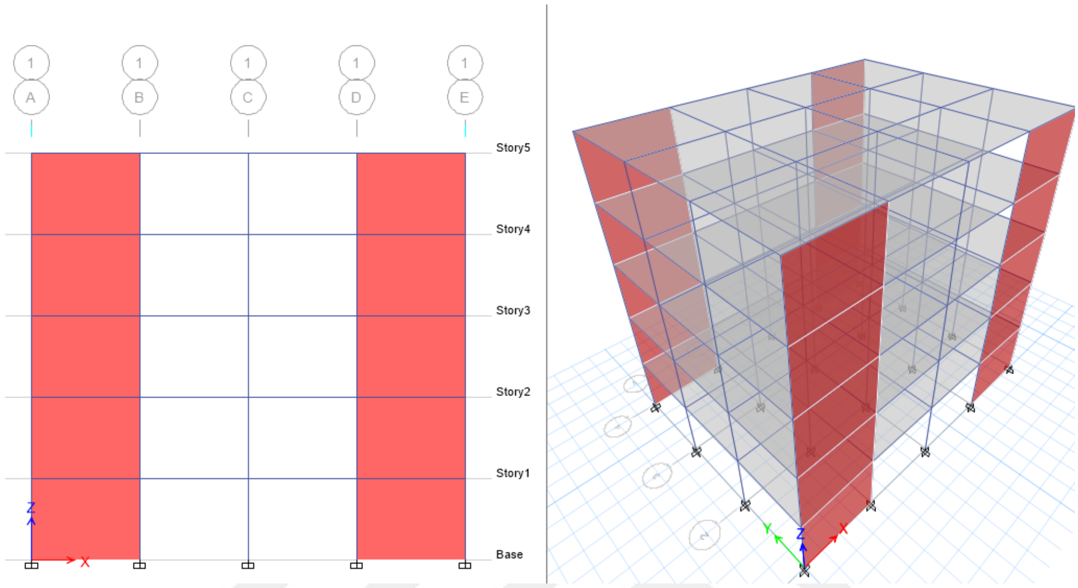

Figure 4.5. The 5-story building with concrete shear walls and without openings.

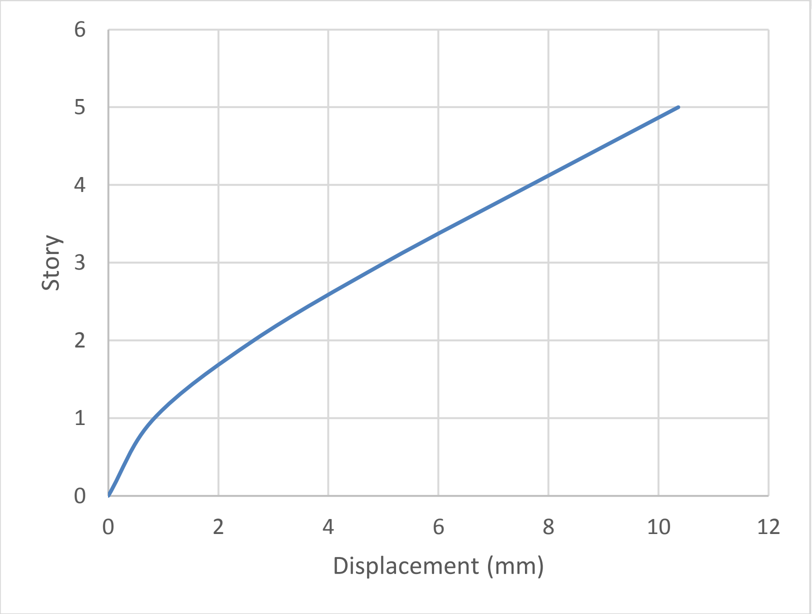

Figure 4.6. Displacement diagram in the X direction for the 5 story building.

The displacement of the fifth story is 10.36 mm, which is more than the other stories, as shown in (Figure 4.6) With regard to the slope of this diagram, the displacement is more in the top stories.

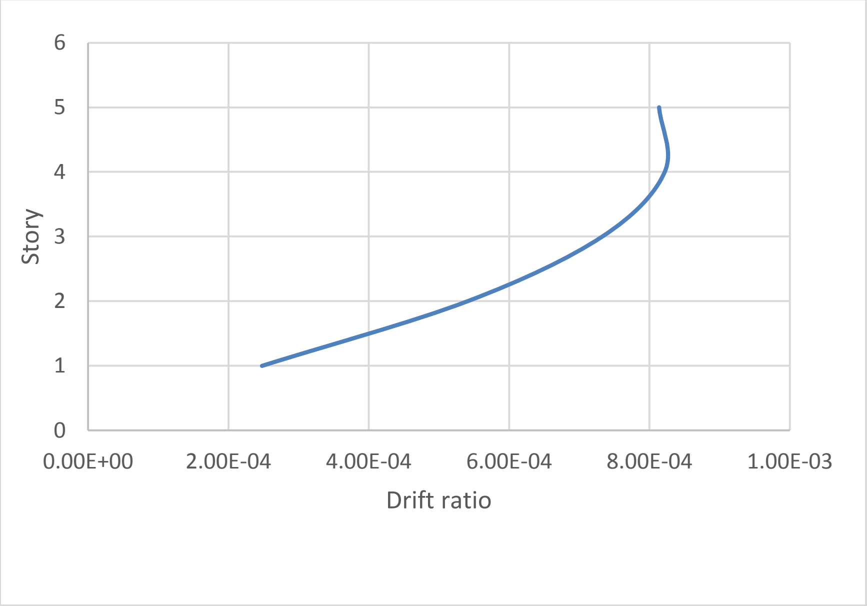

Figure 4.7. Drift diagram in the X direction for the 5 story building.

As illustrated in (Figure 4.7), the drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 8.22e-4, which happened in the fourth story.

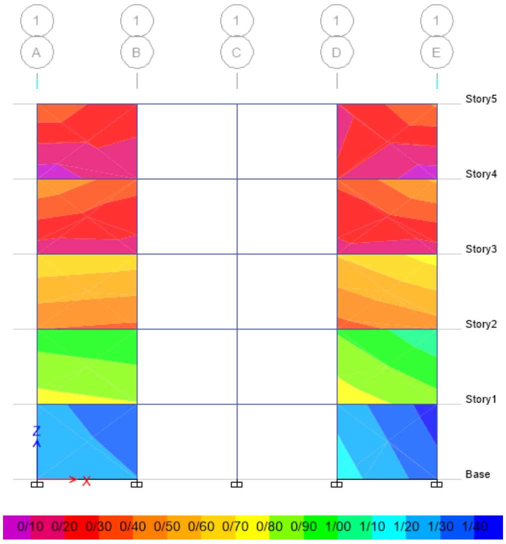

Figure 4.8. Stress contours in the shear walls(σ_x) MPa for the 5 story building.

- Model 2; the 10-story building without openings

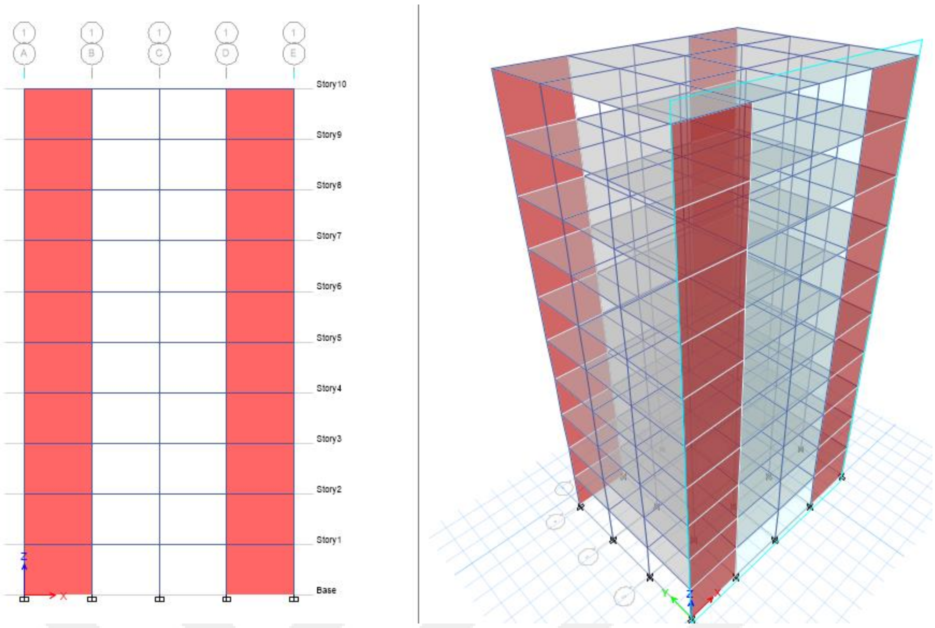

Figure 4.9. The 10-story building with concrete shear walls and without openings.

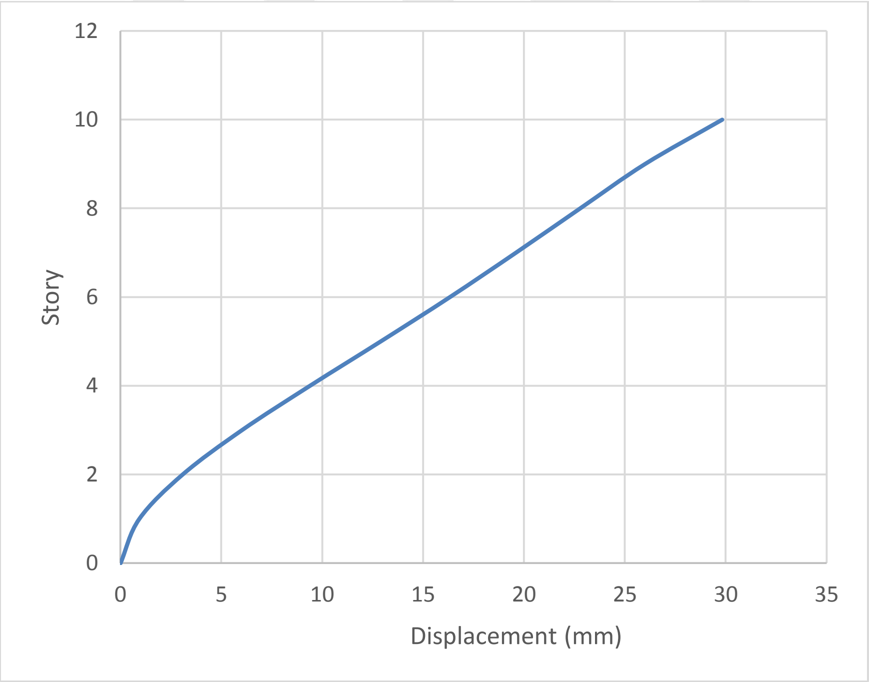

Figure 4.10. Displacement diagram in the X direction for the 10 story building.

The tenth story displacement is 29.83 mm, and is more than the other stories. With regard to the slope of this diagram, the displacement is more in the top stories (Figure 4.10).

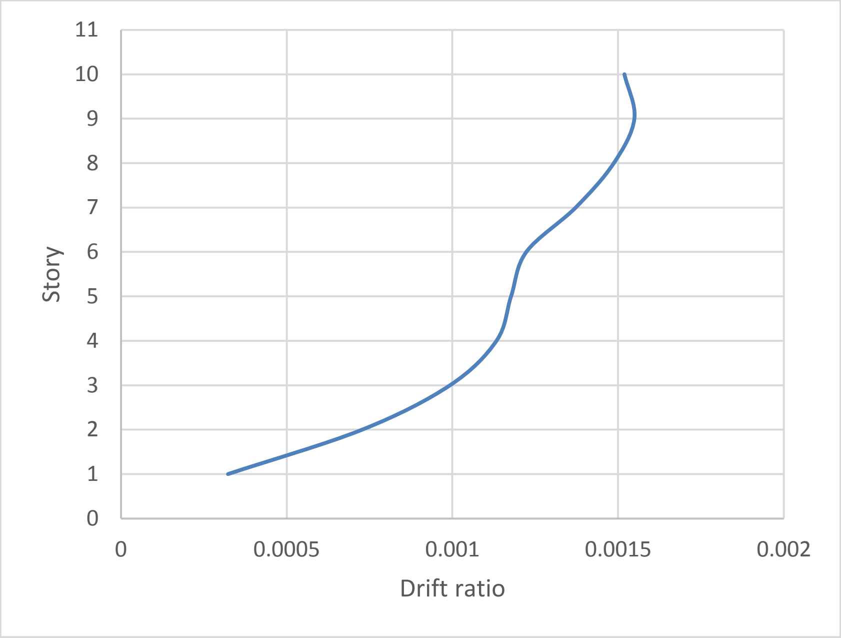

Figure 4.11. Drift diagram in the X direction for the 10 story building.

As shown in (Figure 4.11), the drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 0.00155, which happened in the ninth story.

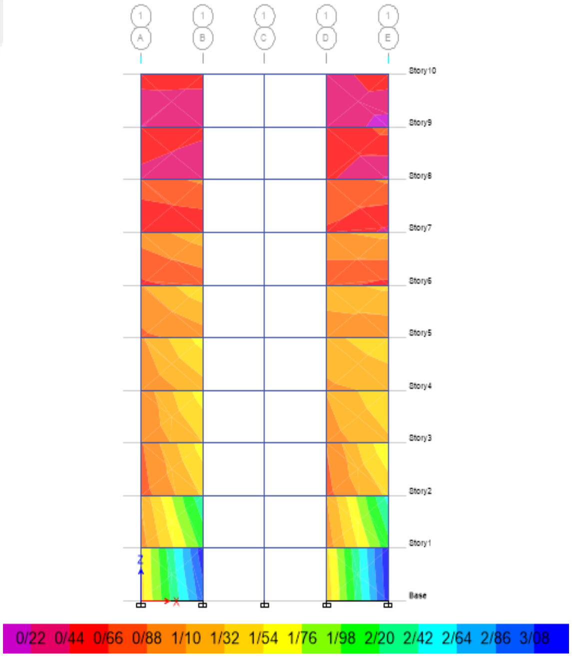

Figure 4.12. Stress contour in the shear walls(σ_x) MPa, for the 10 story building.

- Model 3; the 15-story building without openings

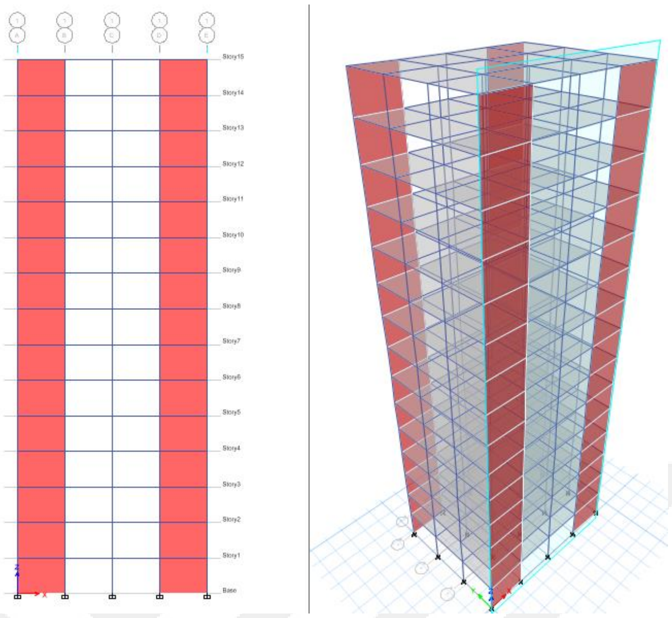

Figure 4.13. The 15-story building with concrete shear wall and without openings.

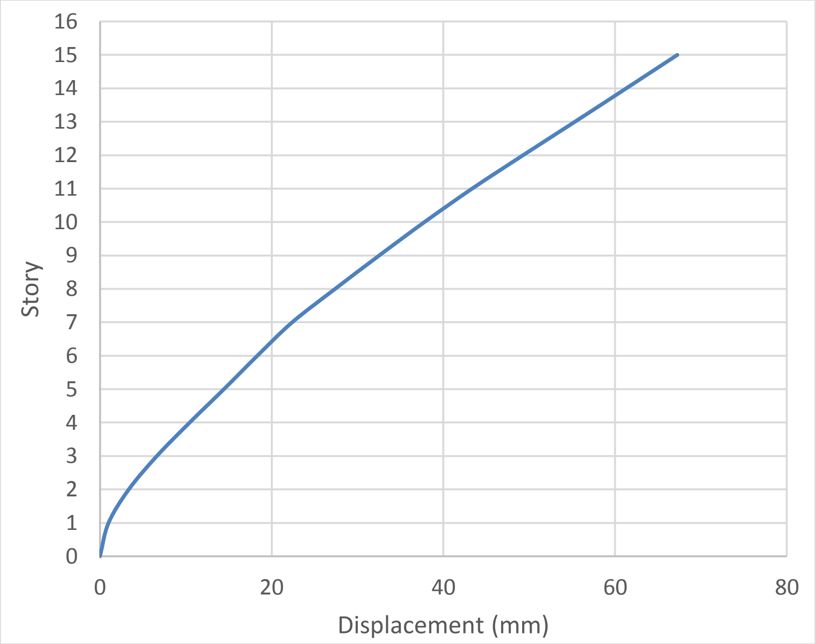

Figure 4.14. Displacement diagram in the X direction for the 15 story building.

As depicted in (Figure 4.14), the fifteenth story displacement is 67.25 mm, and is more than the other stories. With regard to the slope of this diagram, the displacement in the eighth story to the fifteenth story has changed with a constant slope.

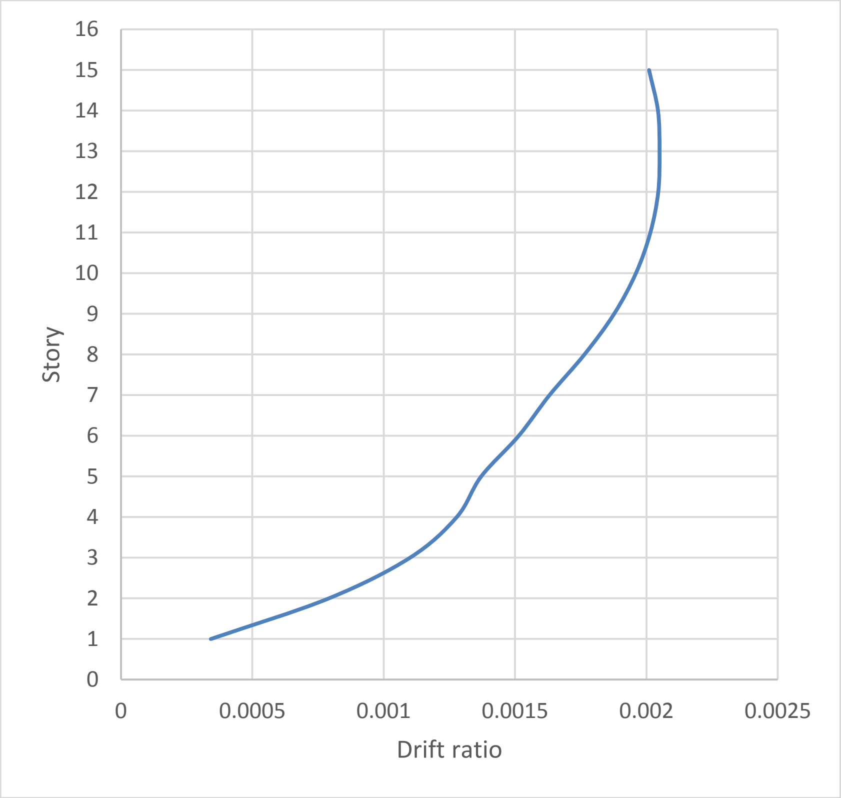

Figure 4.15. Drift in the X direction for the 15 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 0.00205, which happened in the 13th story (Figure 4.15).

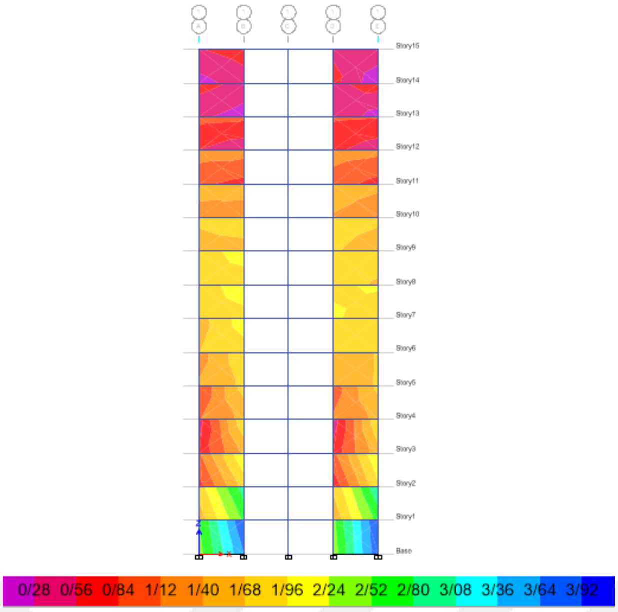

Figure 4.16. Stress contours in the shear walls (σ_x) MPa, for the 15 story building.

4.7.3. Case 2 Shear wall with alternately openings in stories

- Model 4; the 5-story building with openings in odd stories

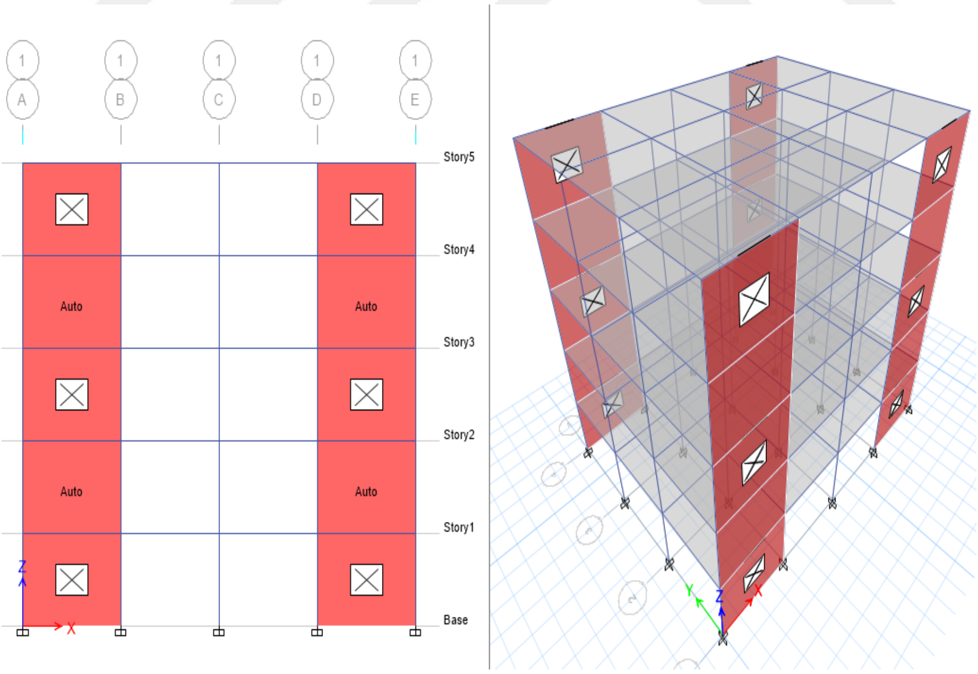

Figure 4.17. The 5-story building with concrete shear walls and with openings in odd stories.

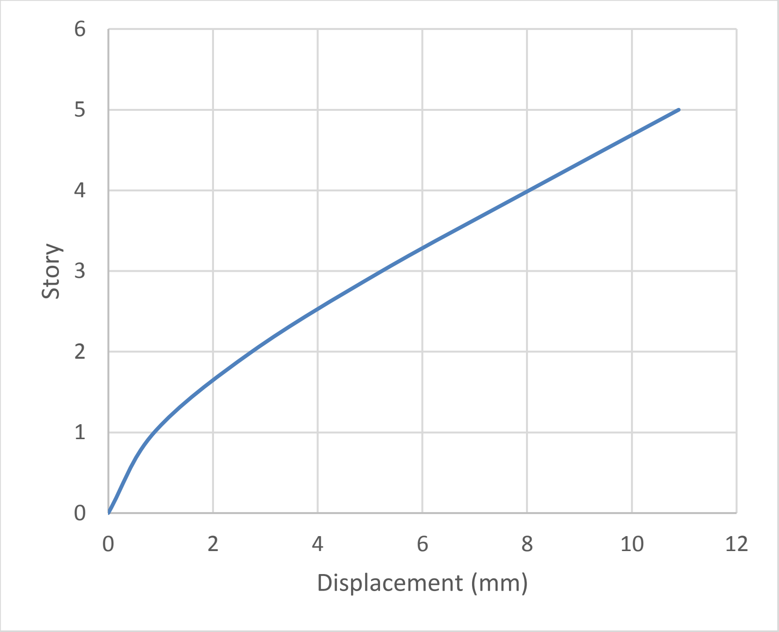

Figure 4.18. Displacement diagram in the X direction for the 5 story building.

The fifth story displacement is 10.9 mm which is more than the other stories. With regard to the slope of this diagram, the displacement is more in the top stories (Figure 4.18).

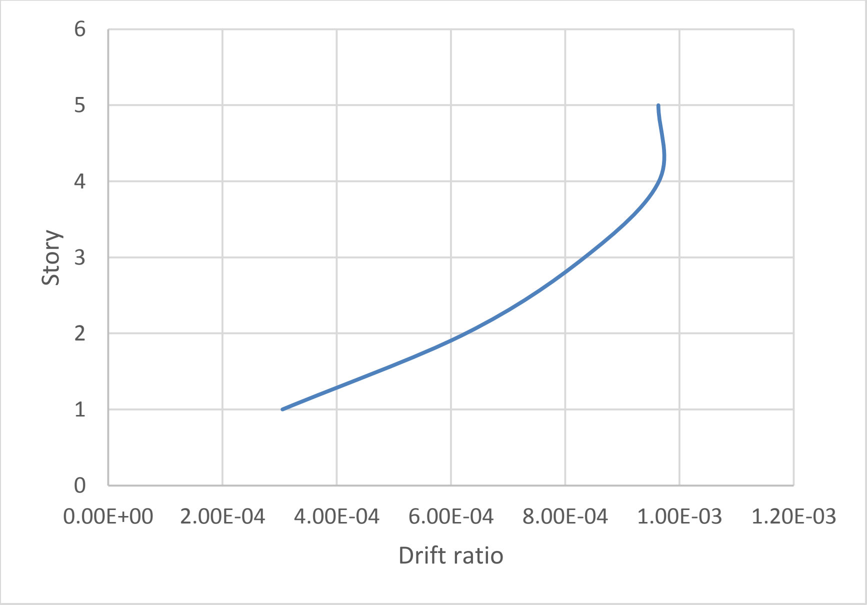

Figure 4.19. Drift diagram in the X direction for the 5 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift ise-4, which happened in the fourth story (Figure 4.19).

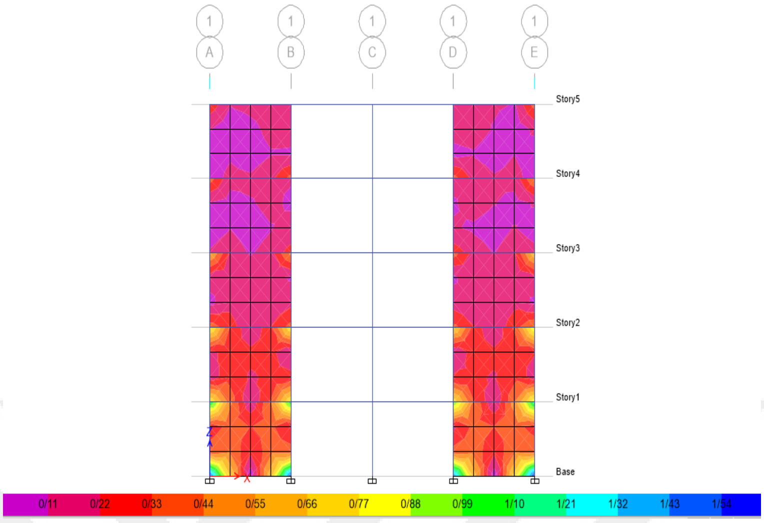

Figure 4.20. Stress contours in the shear walls (σ_x) MPa, for the 5 story building.

- Model 5; the 10-story building with openings in the odd stories

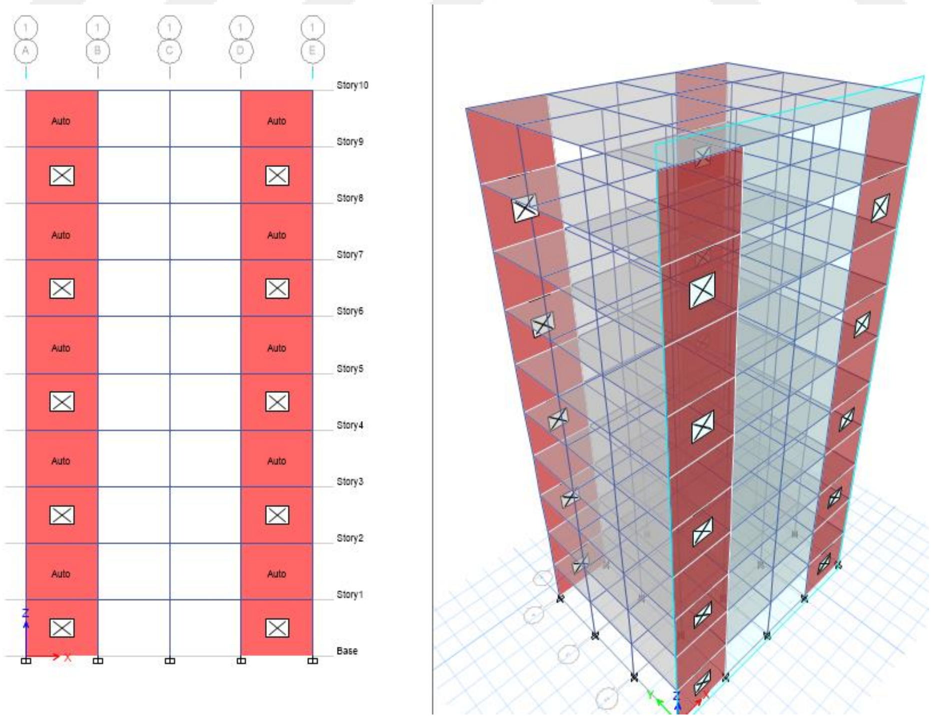

Figure 4.21. The 10-story building with concrete shear wall and with openings in the odd stories.

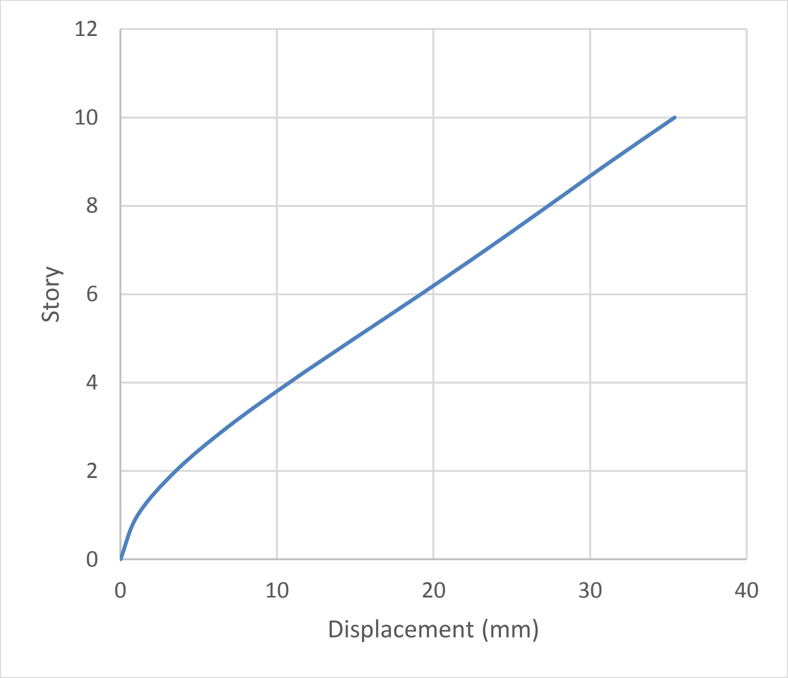

Figure 4.22. Displacement diagram in the X direction for the 10 story building.

The tenth story displacement is 35.41 mm which is more than the other stories. With regard to the slope of this diagram, the displacement is more in the top stories (Figure 4.22).

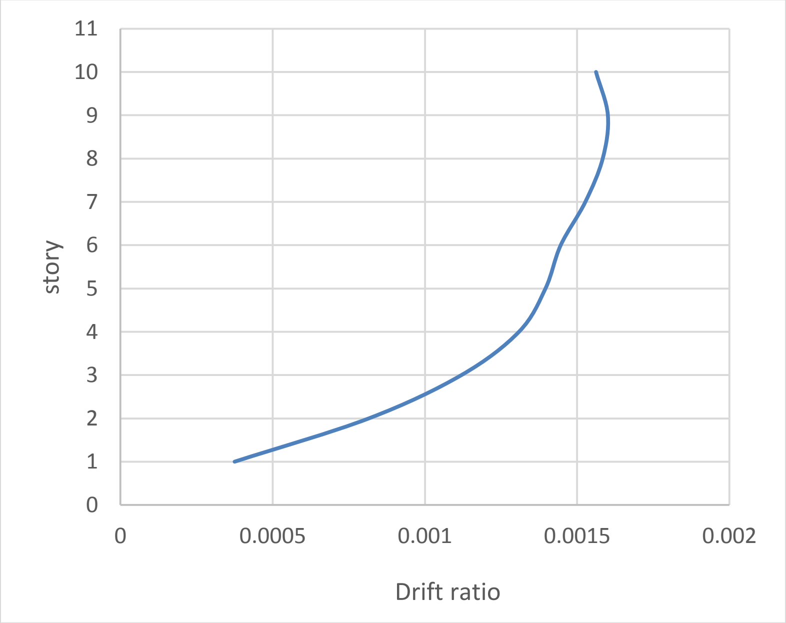

Figure 4.23. Drift diagram in the X direction for the 10 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 0.0016, which happened in the ninth story (Figure 4.23).

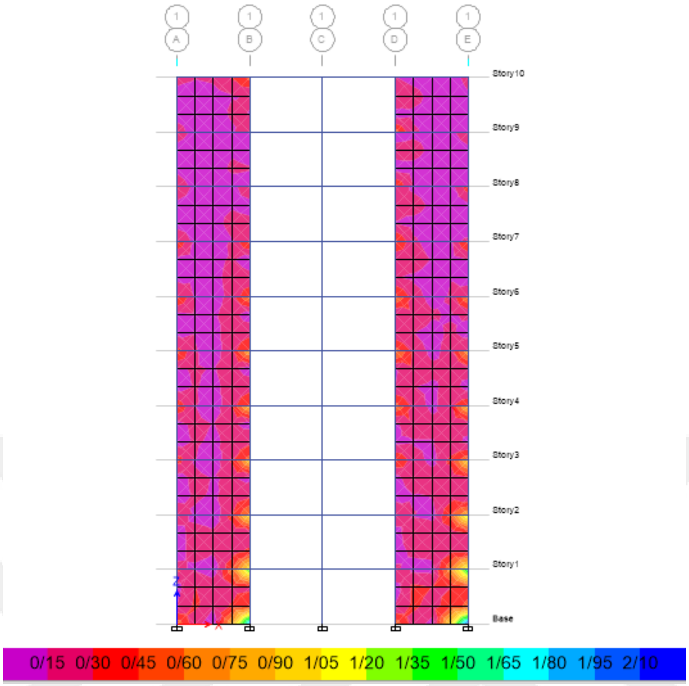

Figure 4.24. Stress contours in the shear walls (σ_x) MPa, for the 10 story building.

- Model 6; the 15-story building with openings in the odd stories

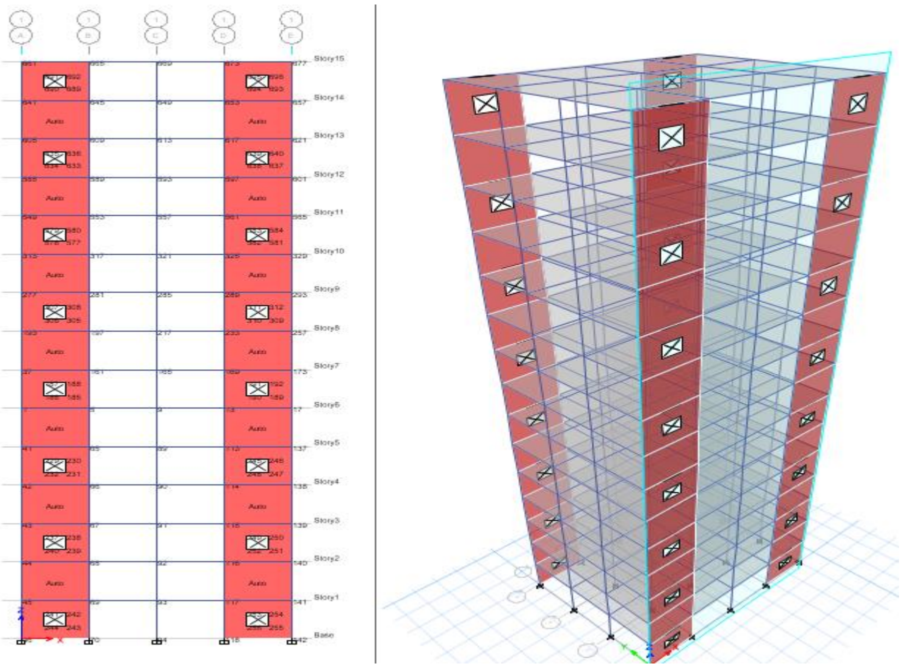

Figure 4.25. The 15-story building with concrete shear wall and with openings in the odd stories.

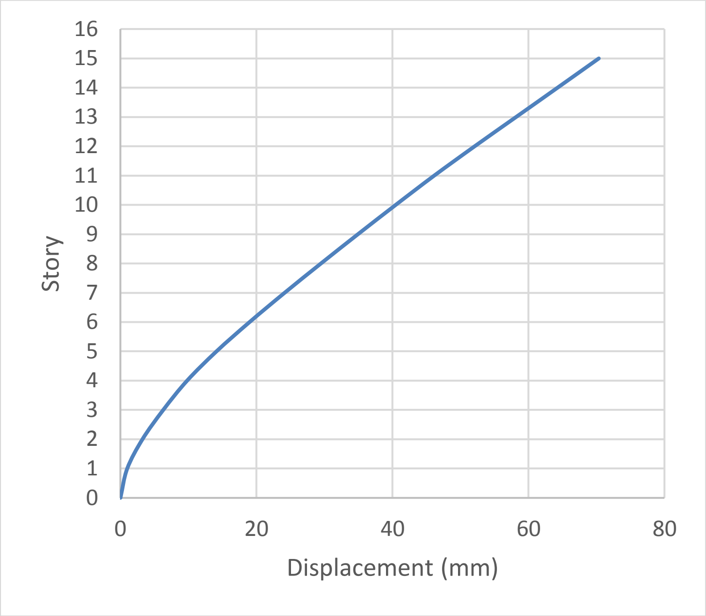

Figure 4.26. Displacement diagram in the X direction for the 15 story building.

The fifteenth story displacement is 70.33 mm which is more than the other stories. With regard to the slope of this diagram, the displacement is more in the top stories and from the ninth story to the top it has changed with a constant slope (Figure 4.26).

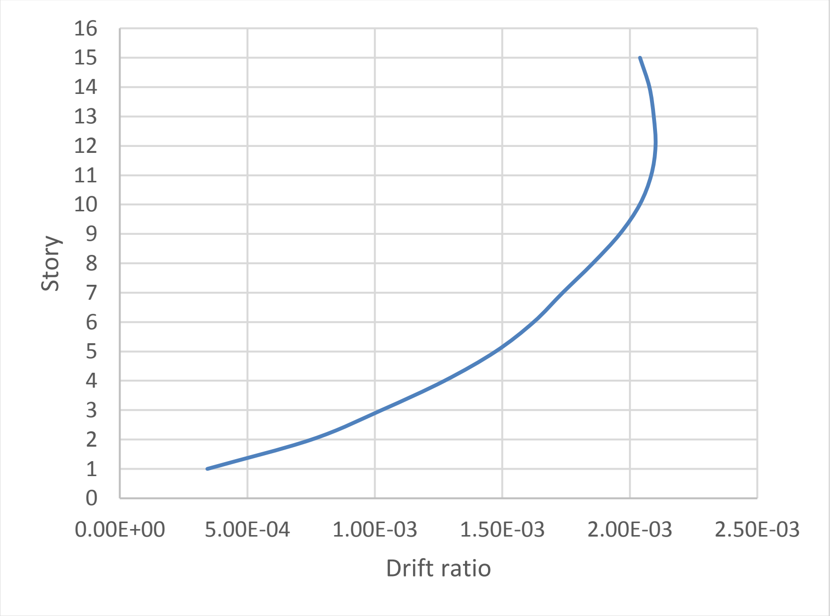

Figure 4.27. The drift diagram in the X direction for the 15 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 2.10e-3 mm, which happened in the 12th story (Figure 4.27).

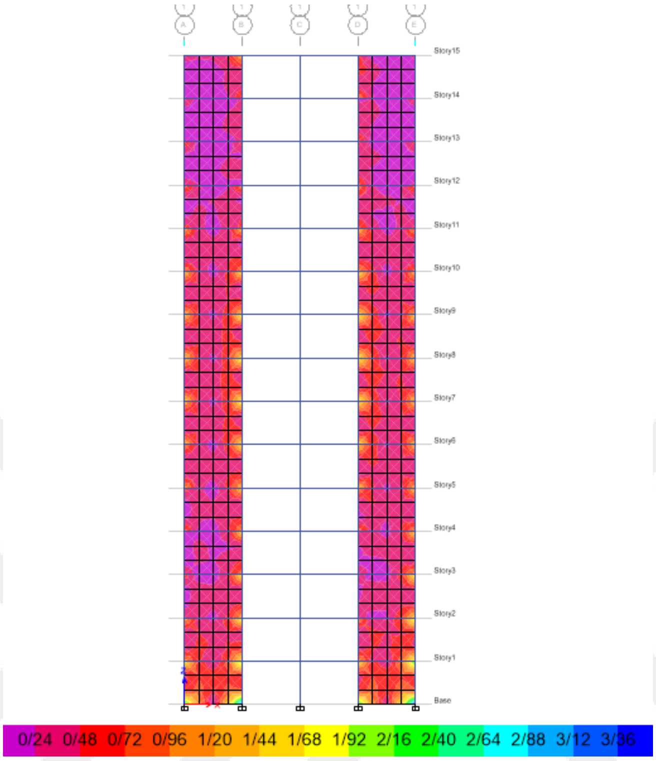

Figure 4.28. Stress contours in the shear walls (σ_x) MPa, for the 15 story building.

4.7.4. Case 3 Shear wall with openings in a zigzag pattern

- Model 7; the 5-story building with zigzag openings

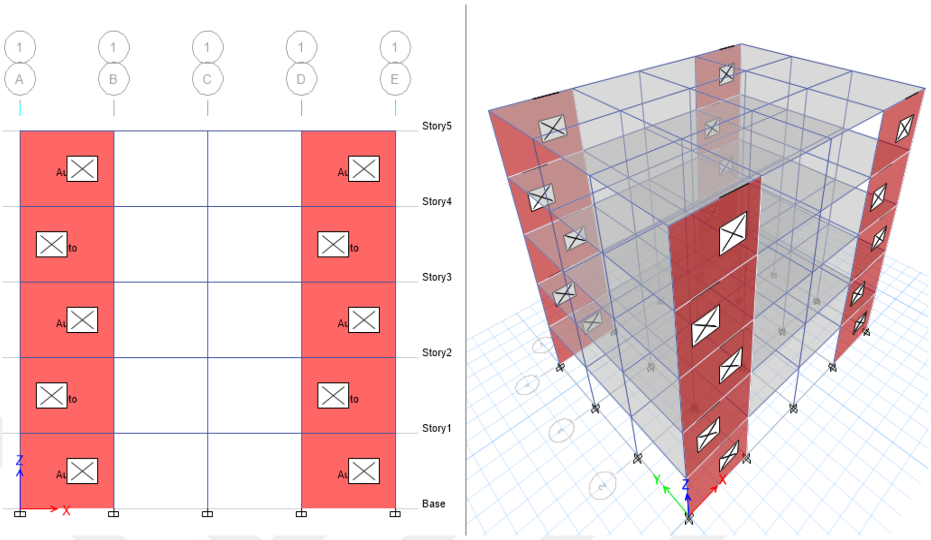

Figure 4.29. The 5-story building with concrete shear walls and with zigzag openings.

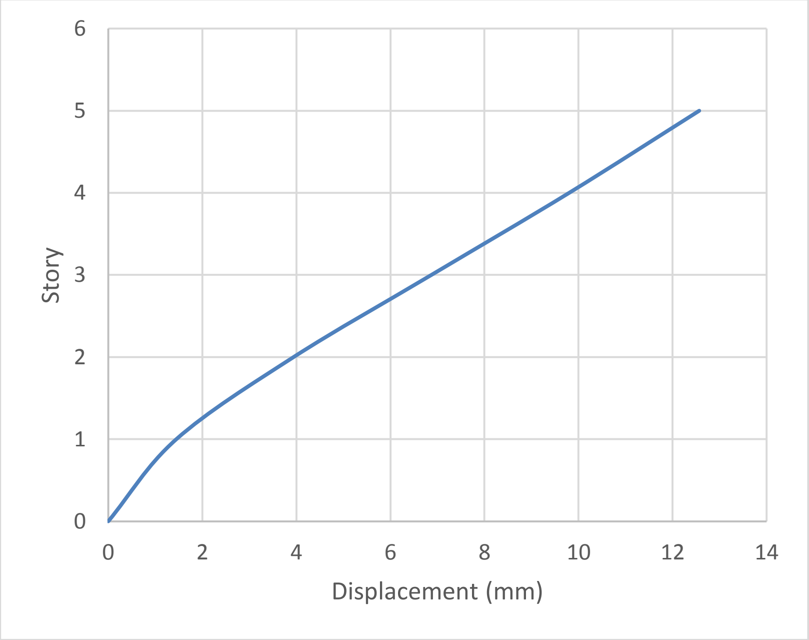

Figure 4.30. Displacement diagram in the X direction for the 5 story building.

The fifth story displacement is 12.57 mm which is more than the other stories. With regard to the slope of this diagram, the displacement is more in the top stories (Figure 4.30).

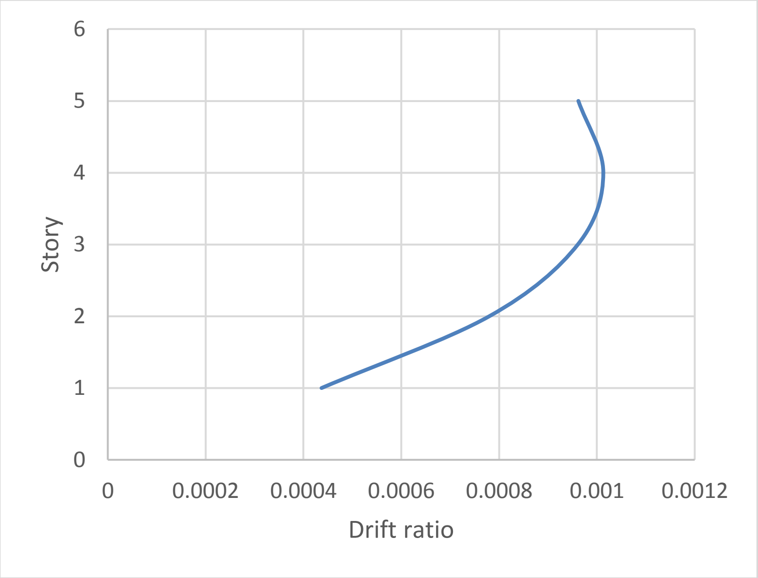

Figure 4.31. Drift diagram in the X direction for the 5 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 0.001, which happened in the fourth story (Figure 4.31).

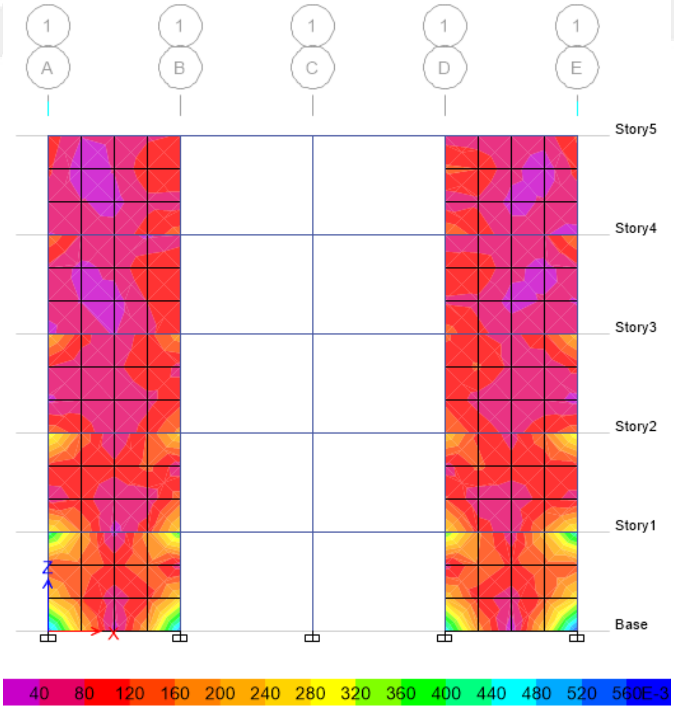

Figure 4.32. Stress contours in the shear walls (σ_x) MPa, for the 5 story building.

- Model 8; the 10-story building with zigzag openings

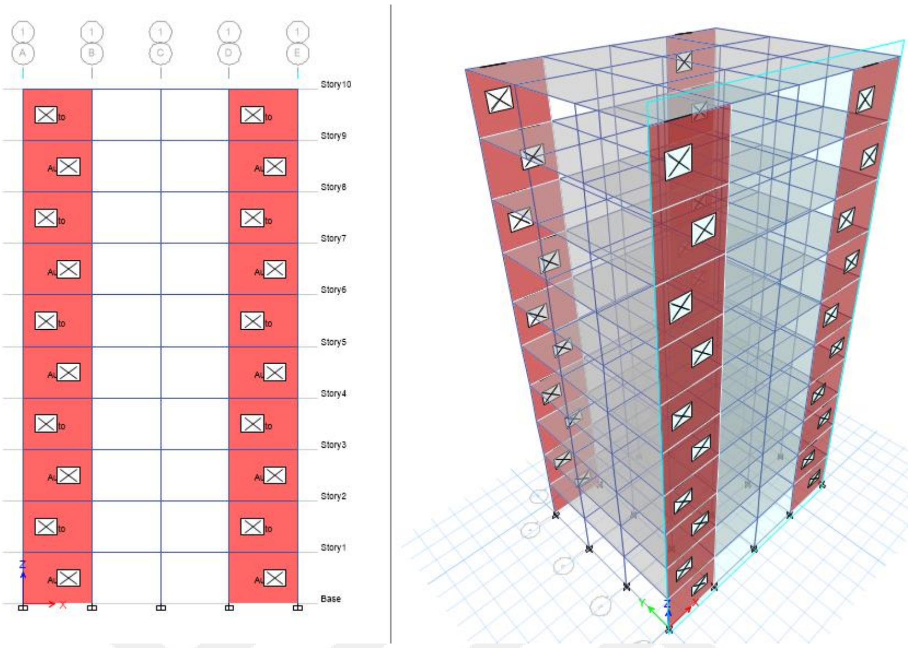

Figure 4.33. The 10-story building with concrete shear walls and with zigzag openings.

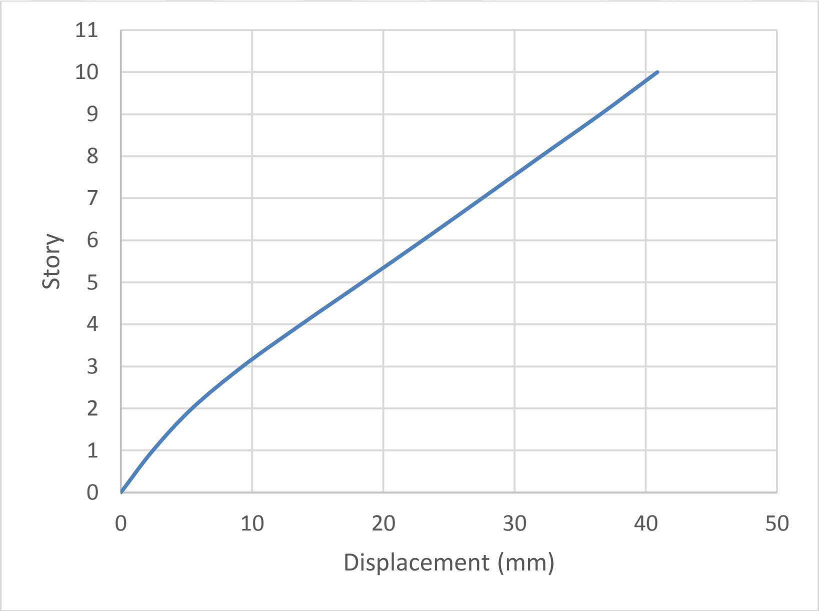

Figure 4.34. Displacement diagram in the X direction for the 10 story building.

The tenth story displacement is 40.88 mm, and is more than the other stories. With regard to the slope of this diagram, the displacement in the eighth story to the tenth story has changed with a constant slope (Figure 4.34).

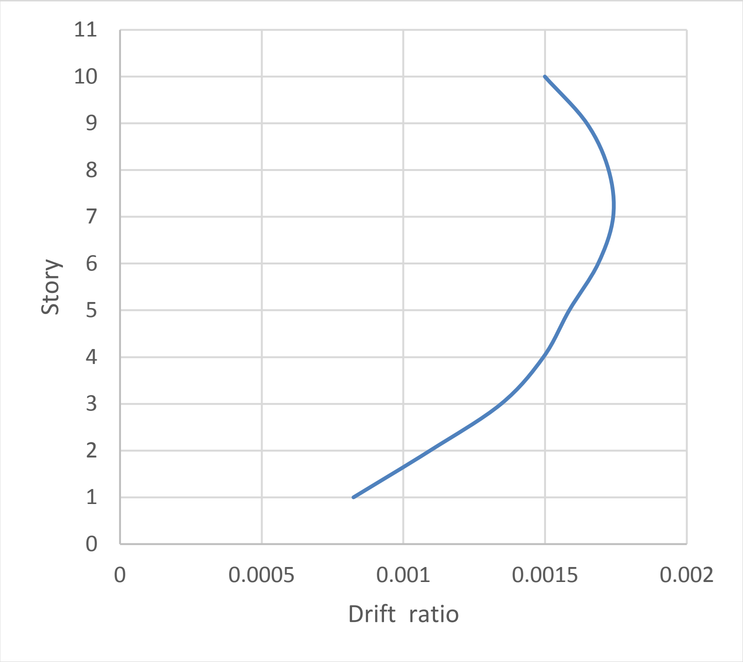

Figure 4.35. Drift diagram in the X direction for the 10 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 0.00174, which happened in the seventh story (Figure 4.35).

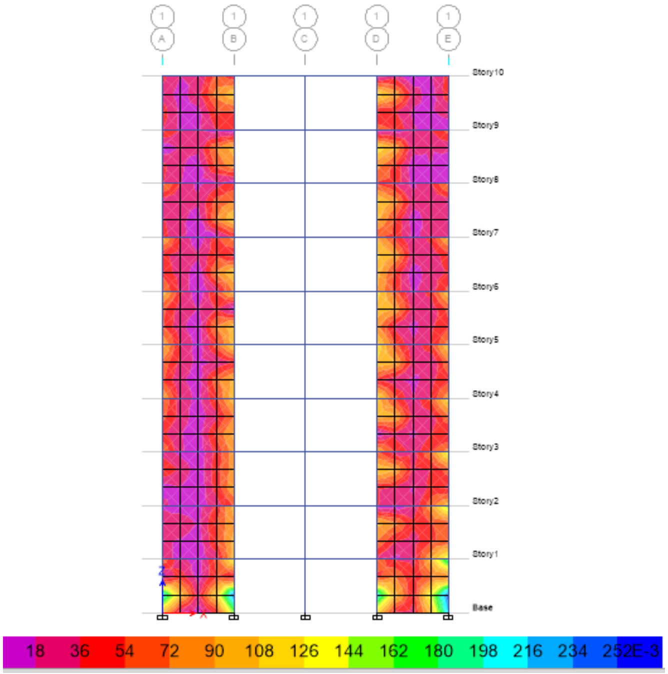

Figure 4.36. Stress contours in the shear walls (σ_x) MPa, for the 10 story building.

- Model 9; the 15-story building with zigzag openings

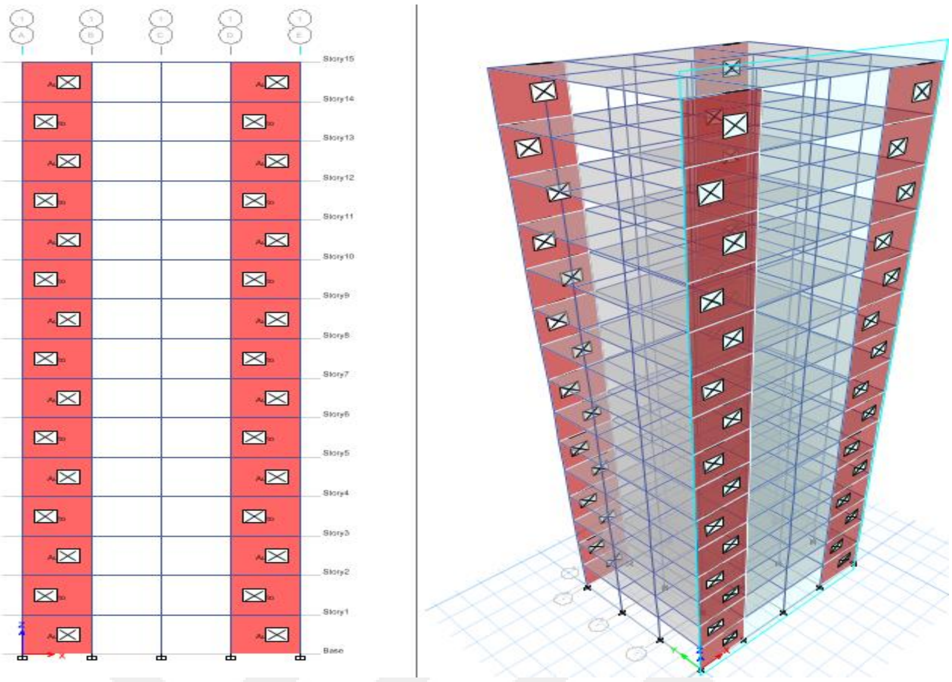

Figure 4.37. The 15-story building with concrete shear walls and with zigzag openings.

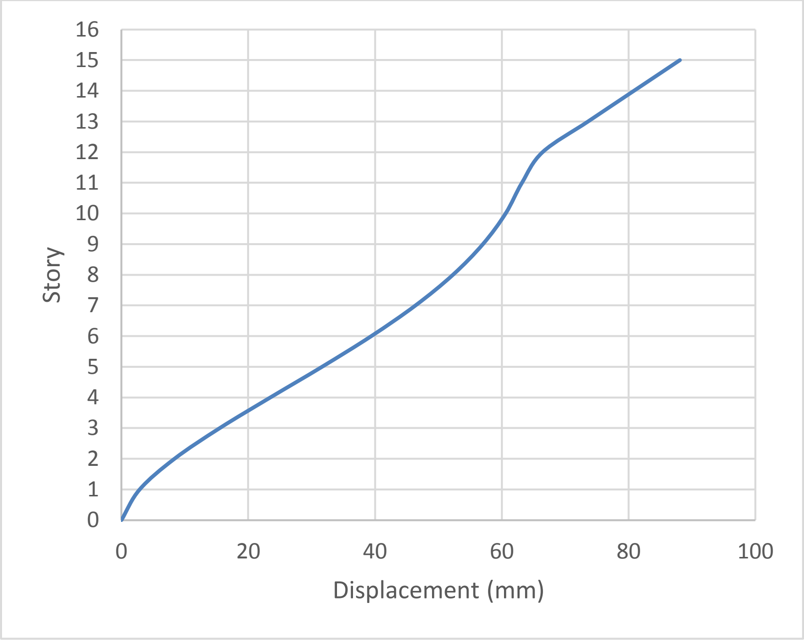

Figure 4.38. Displacement diagram in the X direction for the 15 story building.

The fifteenth story displacement is 88.10 mm which is more than the other stories (Figure 4.38).

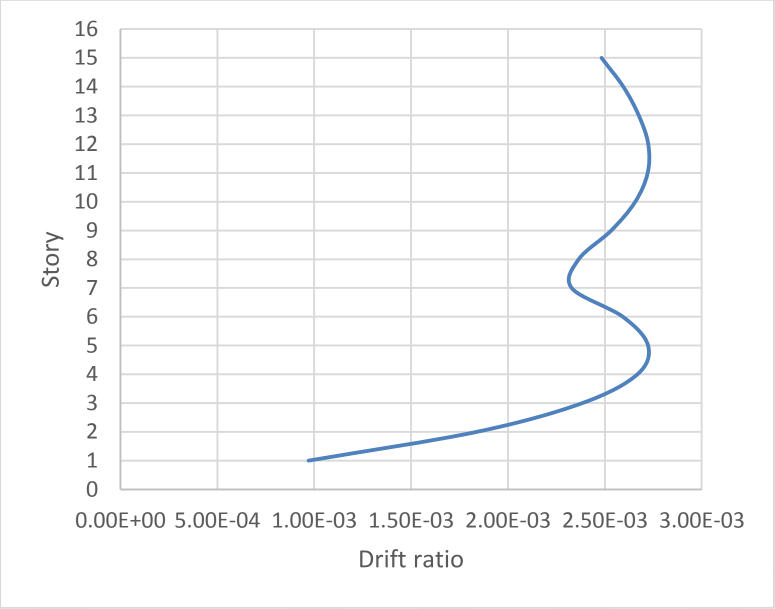

Figure 4.39. Drift diagram in the X direction for the 15 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 0.0027, which happened in the stories from 12th (Figure 4.39).

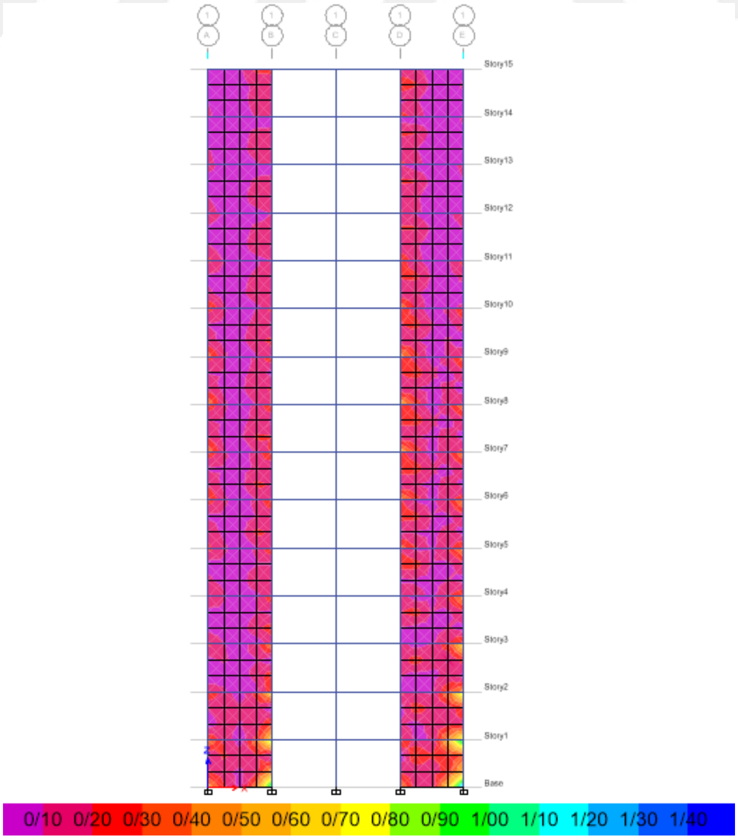

Figure 4.40. Stress contours in the shear walls (σ_x) MPa, for the 15 story building.

4.7.5. Case 4 Shear wall with regular horizontal openings

- Model 10; the 5-story building with horizontal openings

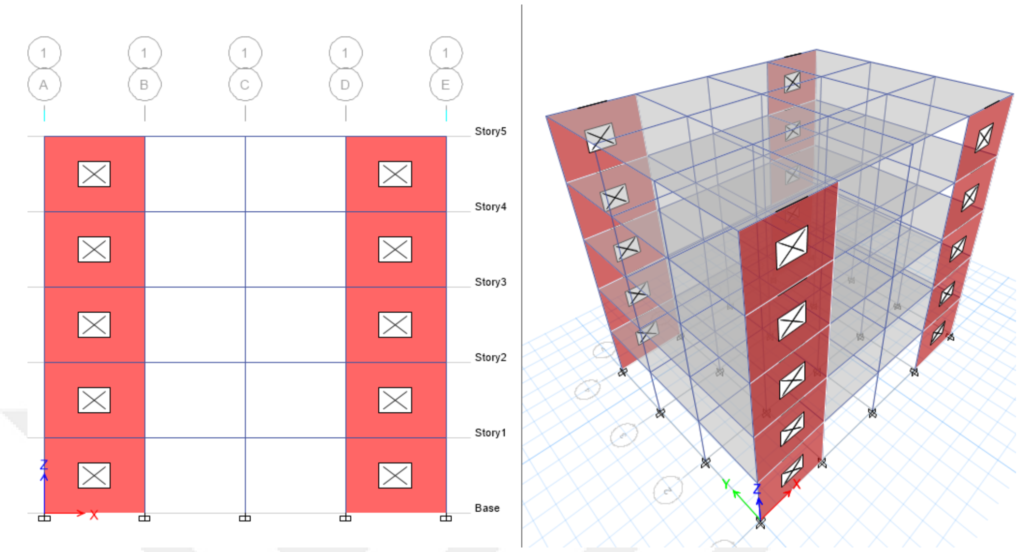

Figure 4.41. The 5-story building with concrete shear walls and with horizontal openings.

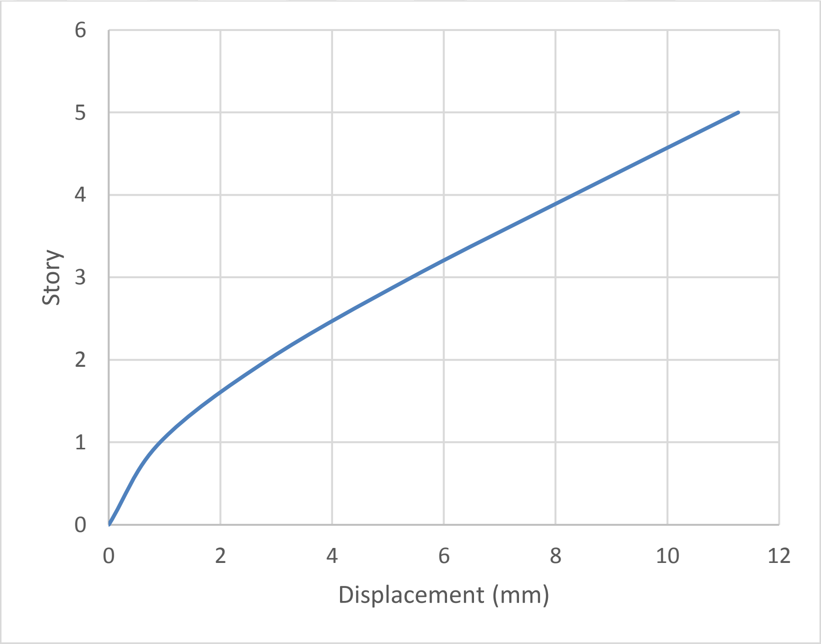

Figure 4.42. Displacement diagram in the X direction for the 5 story building.

The fifth story displacement is 11.27 mm which is more than the other stories. With regard to the slope of this diagram, the displacement is more in the top stories (Figure 4.42).

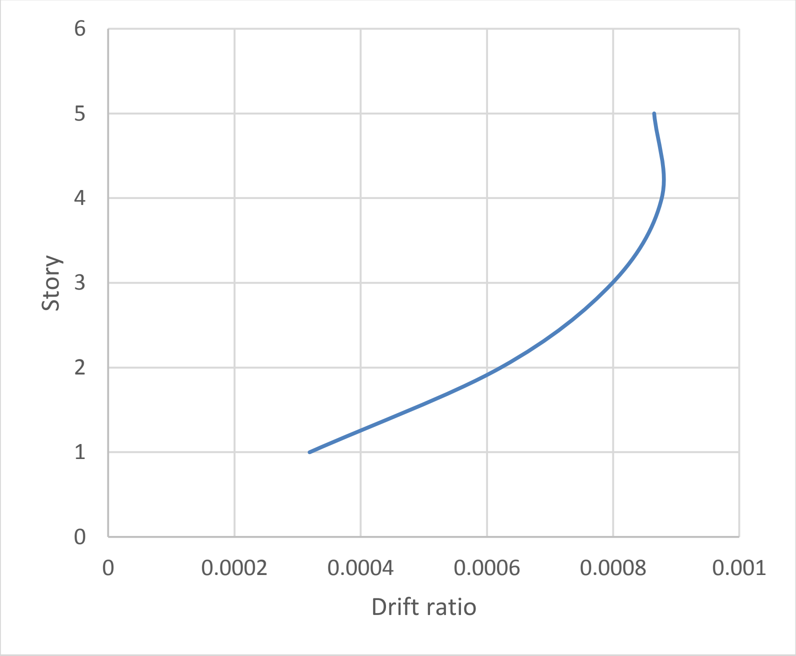

Figure 4.43. Drift diagram in the X direction for the 5 story building.

As illustrated in Figure 4.43, the drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 0.00088, which happened in the fourth story.

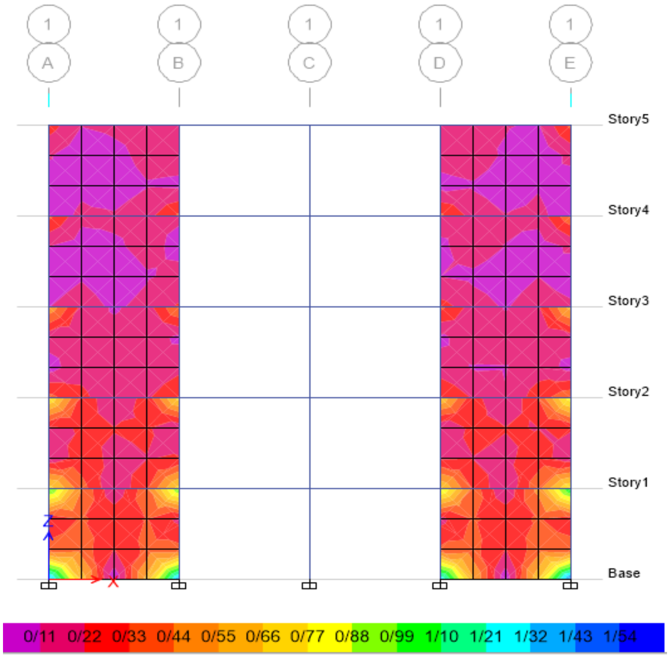

Figure 4.44. Stress contours in the shear walls (σ_x) $MPa,$ for the 5 story building.

- Model 11; the 10-story building with horizontal openings

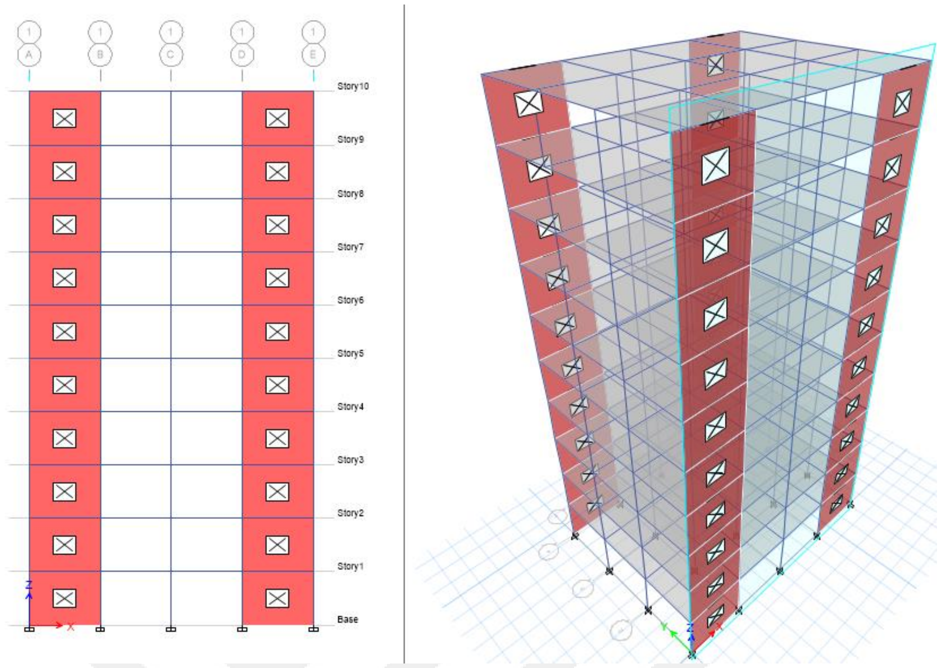

Figure 4.45. The 10-story building with concrete shear wall and with horizontal openings.

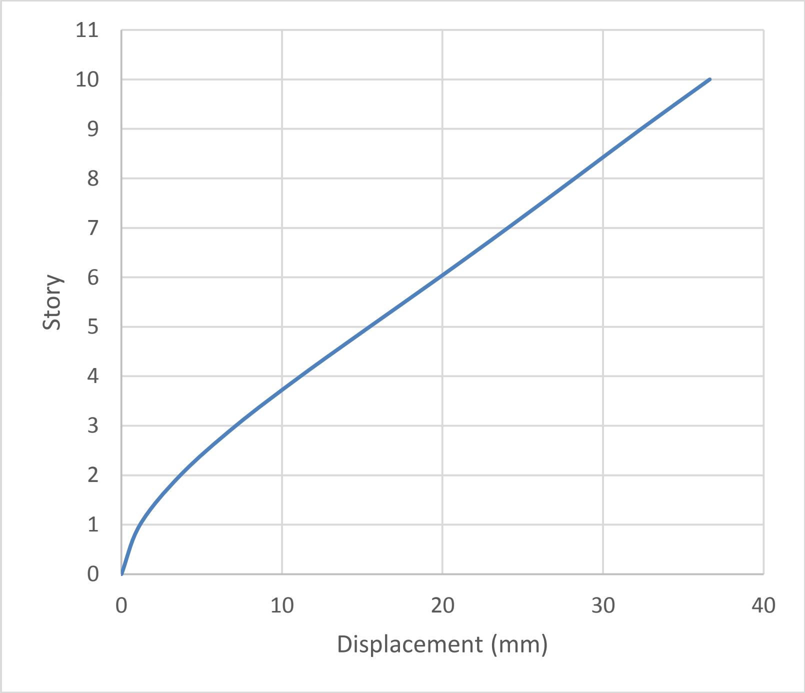

Figure 4.46. Displacement diagram in the X direction for the 10 story building.

As shown in Figure 4.46, the displacement in the tenth story is 36.65 mm, which is more than that of the other stories.

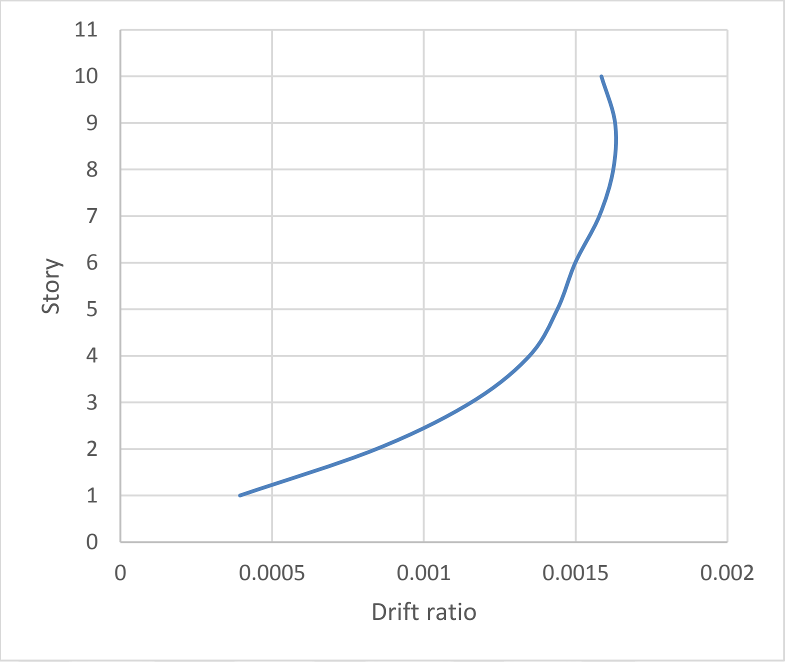

Figure 4.47. Drift diagram in the X direction for the 10 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 0.00163, which happened in the ninth story (Figure 4.47).

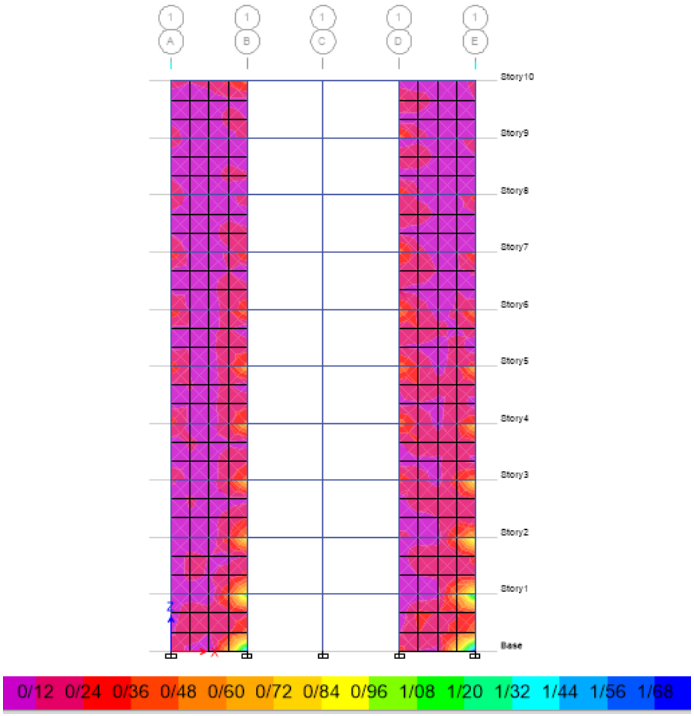

Figure 4.48. Stress contours in the shear walls (σ_x) MPa, for the 10 story building.

- Model 12; the 15-story building with horizontal openings

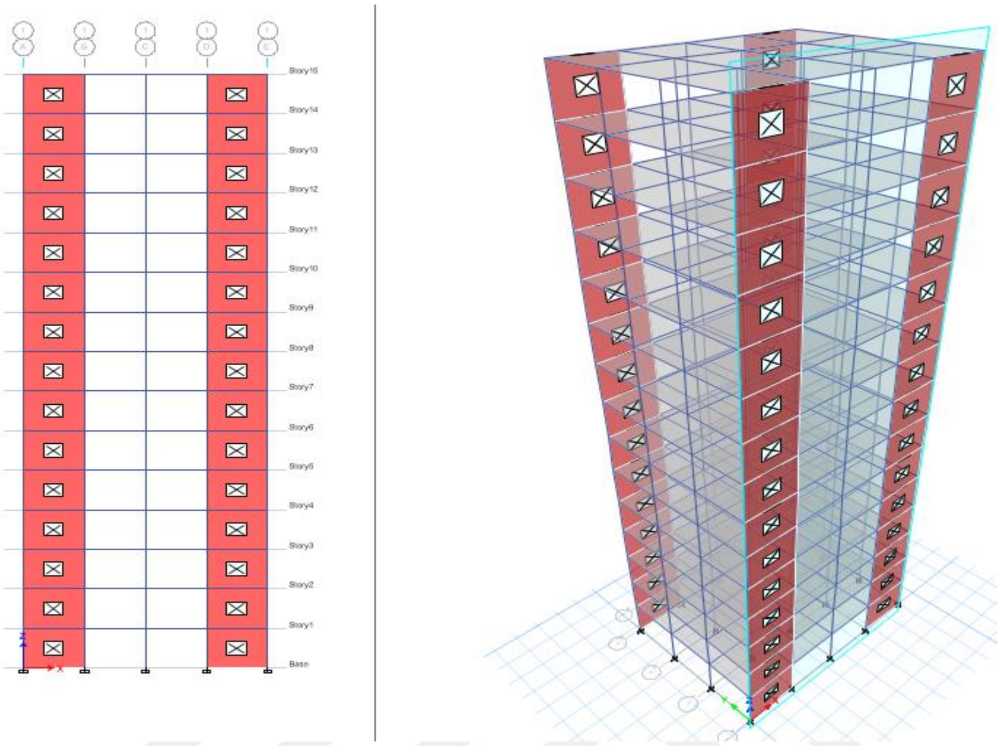

Figure 4.49. The 15-story building with concrete shear walls and with horizontal openings.

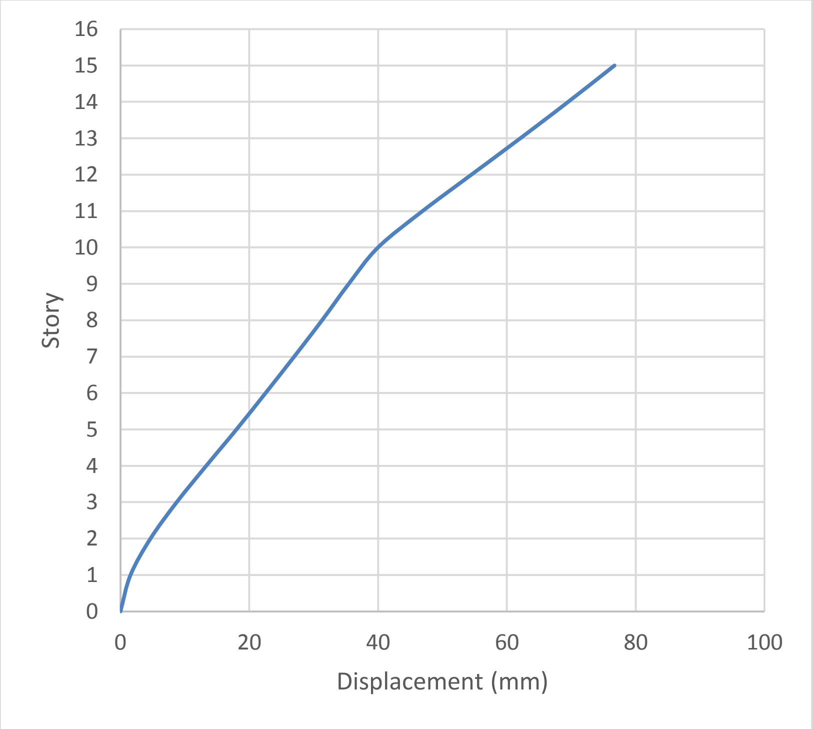

Figure 4.50. Displacement diagram in the X direction for the 15 story building.

The fifteenth story displacement is 76.71mm which is more than that of the other stories (Figure 4.50).

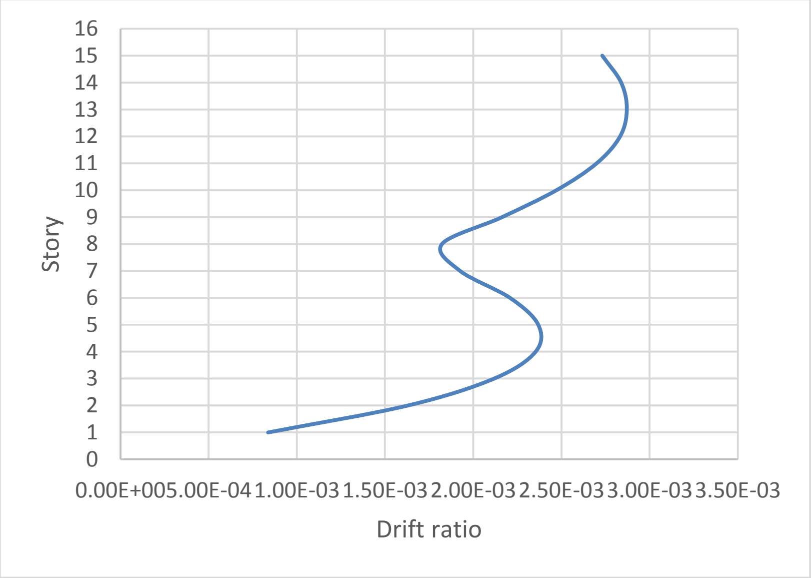

Figure 4.51. Drift diagram in the X direction for the 15 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 2.87e-3, which happened in the 13th story (Figure 4.51).

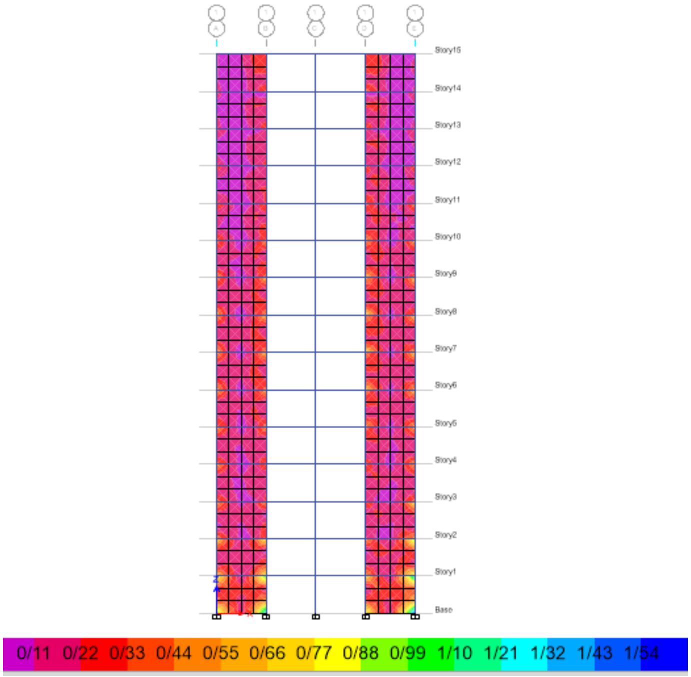

Figure 4.52. Stress contours in the shear walls (σ_x) MPa, for the 15 story building.

4.7.6. Case 5 Shear wall with regular vertical openings

- Model 13; the 5-story building with vertical openings

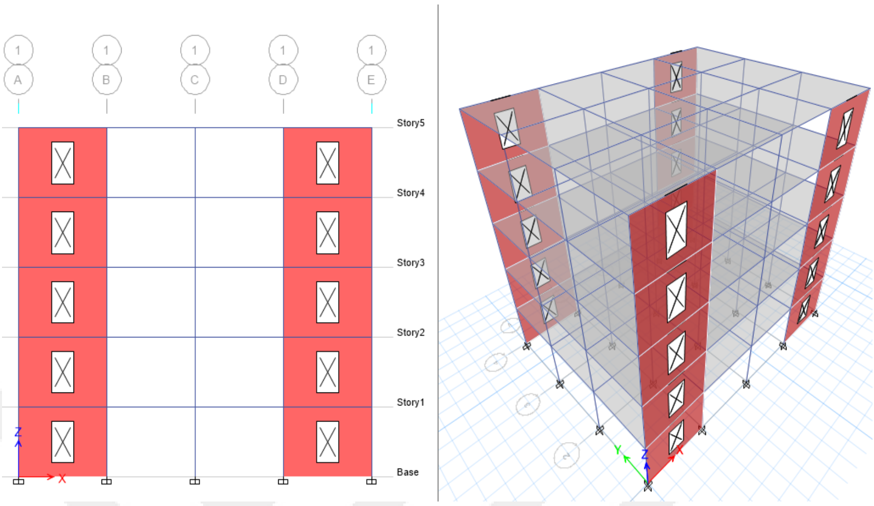

Figure 4.53. The 5-story building with concrete shear walls and with vertical openings.

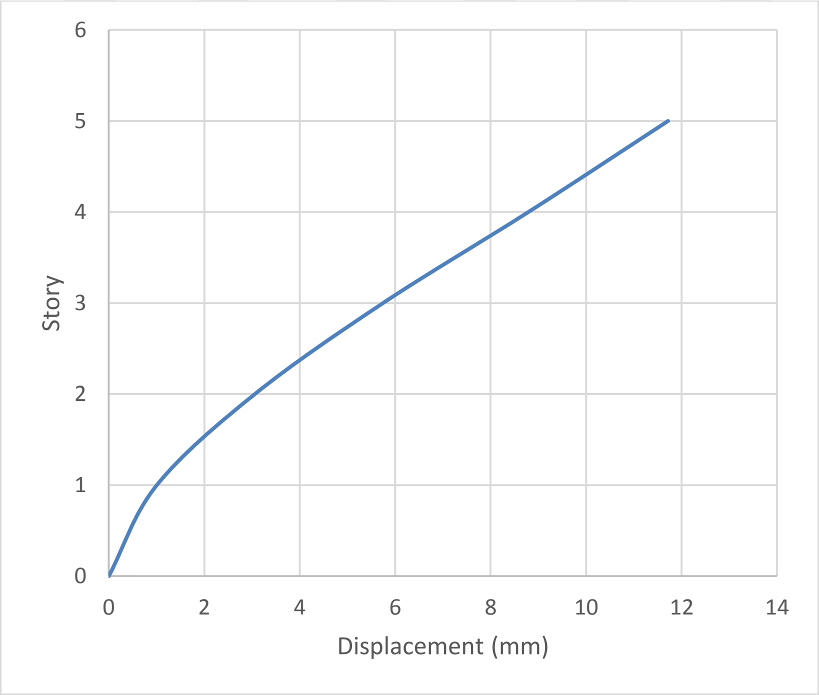

Figure 4.54. Displacement diagram in the X direction for the 5 story building.

The fifth story displacement is 11.72 mm which is more than that of the other stories (Figure 4.54).

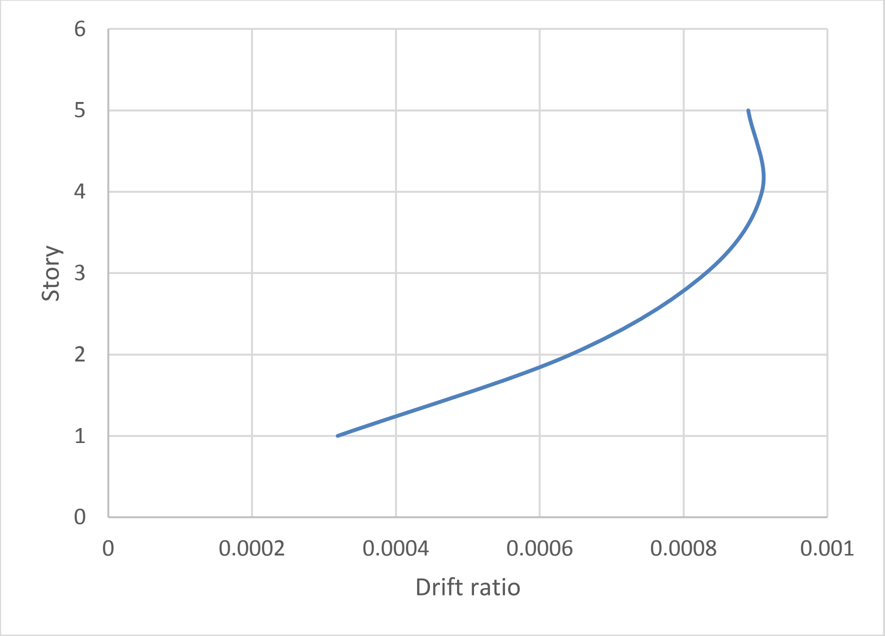

Figure 4.55. Drift diagram in the X direction for the 5 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 0.00091, which happened in the fourth story (Figure 4.55).

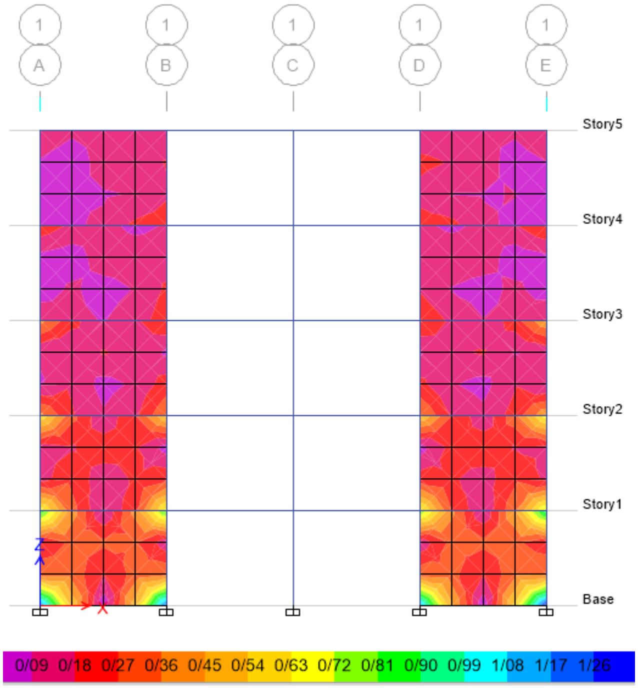

Figure 4.56. Stress contours in the shear walls (σ_x) MPa, for the 5 story building.

- Model 14; the 10-story building with vertical openings

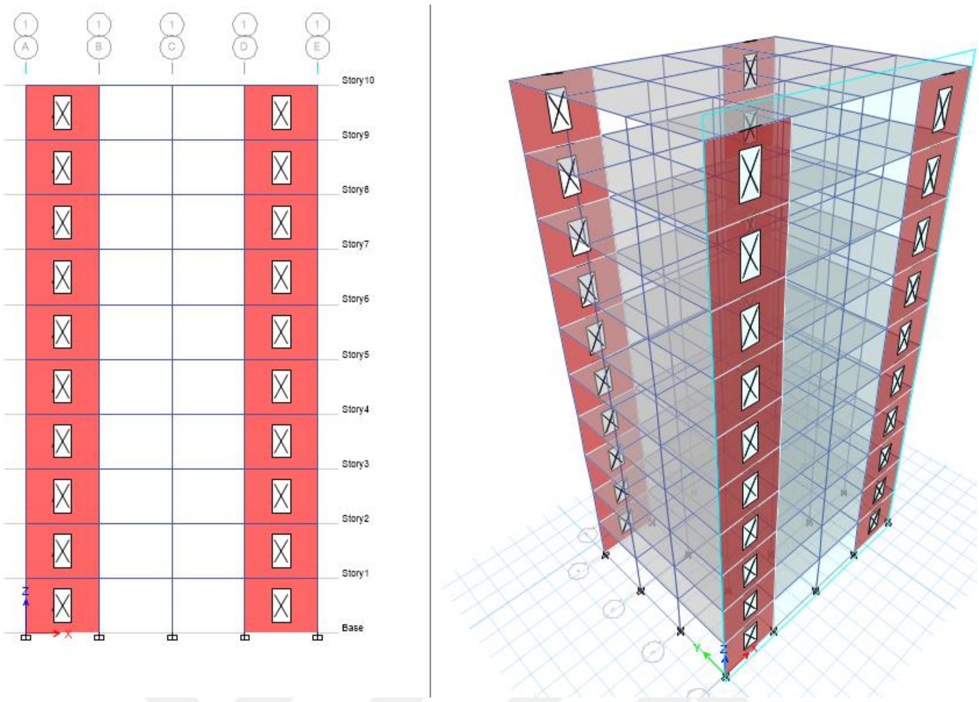

Figure 4.57. The 10-story building with concrete shear walls and with vertical openings.

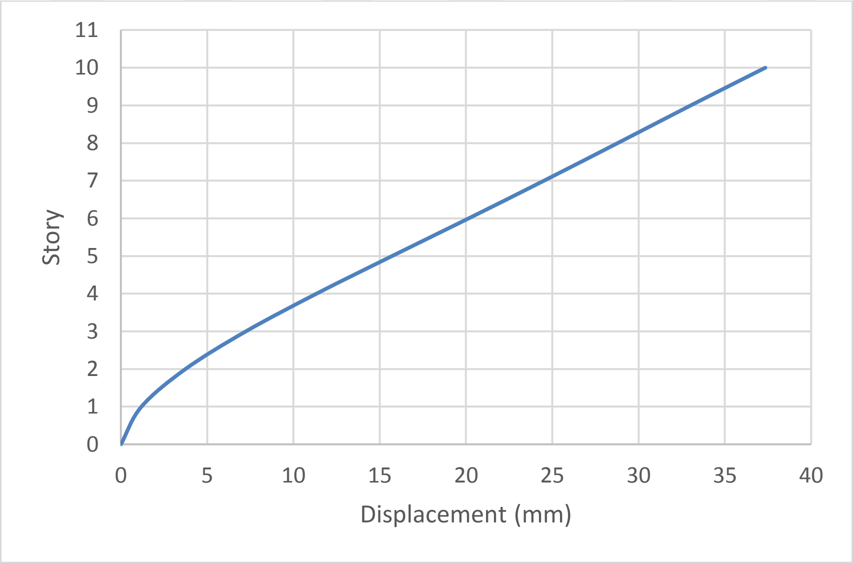

Figure 4.58. Displacement diagram in the X direction for the 10 story building.

The tenth story displacement is 37.35 mm which is more than that of the other stories (Figure 4.58).

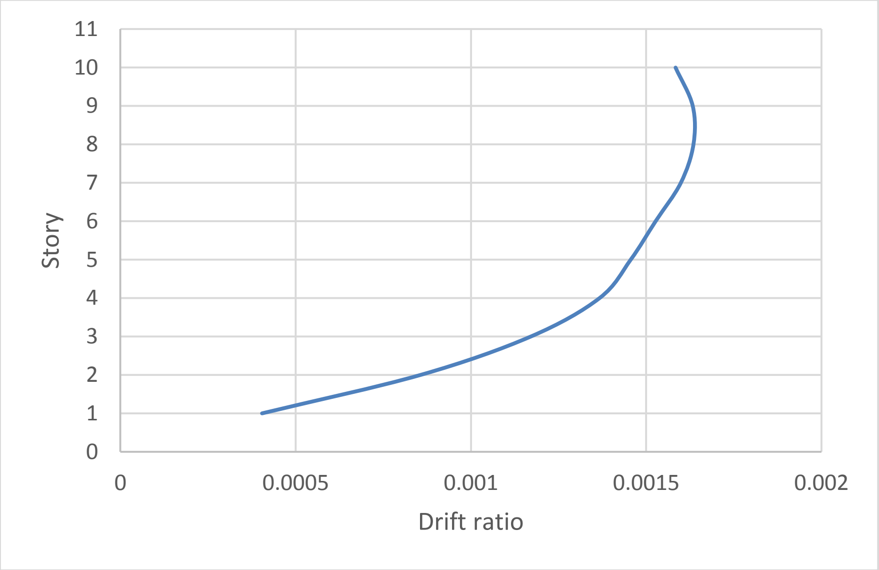

Figure 4.59. Drift diagram in the X direction for the 10 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 0.001635, which happened in the eighth story (Figure 4.59).

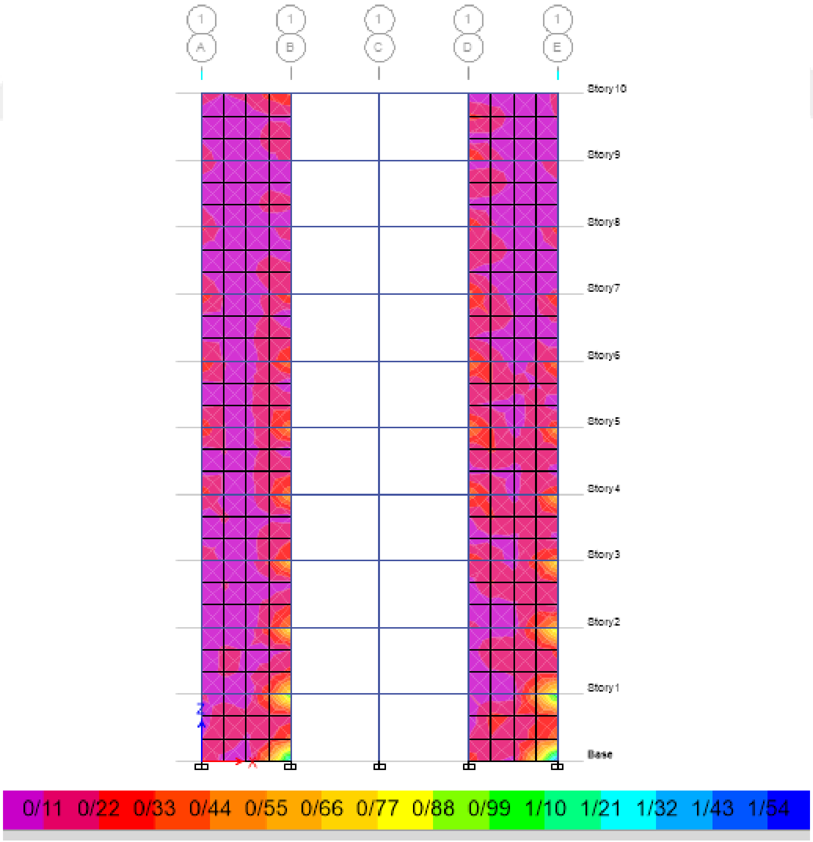

Figure 4.60. Stress contours in the shear walls (σ_x) MPa, for the 10 story building.

- Model 15; the 15-story building with vertical openings

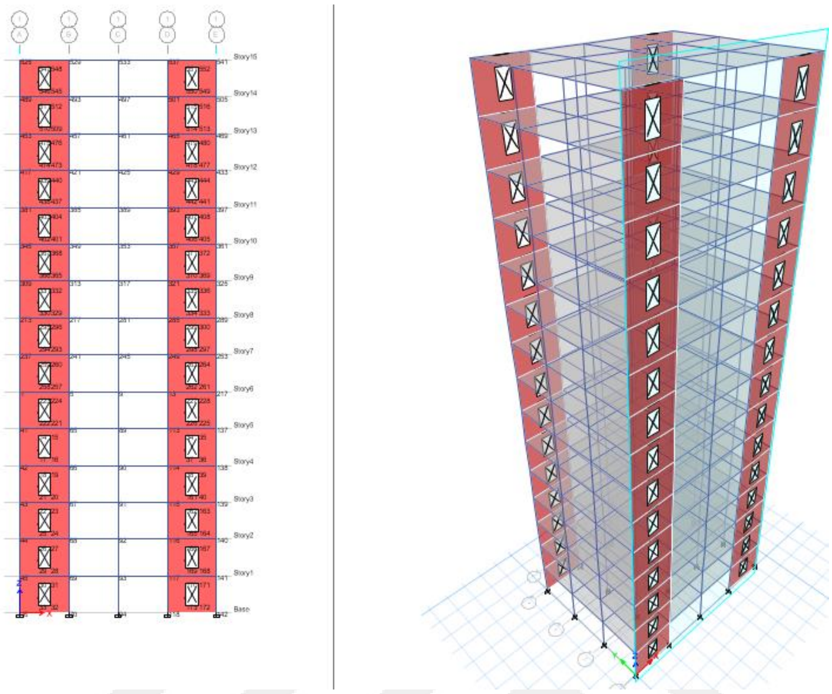

Figure 4.61. The 15-story building with concrete shear walls and with vertical openings.

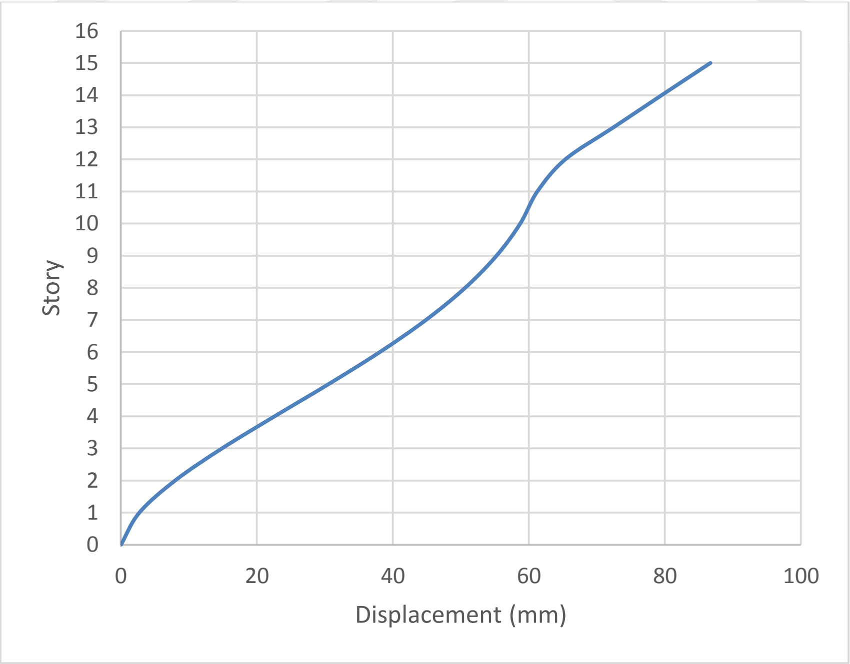

Figure 4.62. Displacement diagram in the X direction for the 15 story building.

The fifteenth story displacement is 86.69 mm which is more than that of the other stories (Figure 4.62).

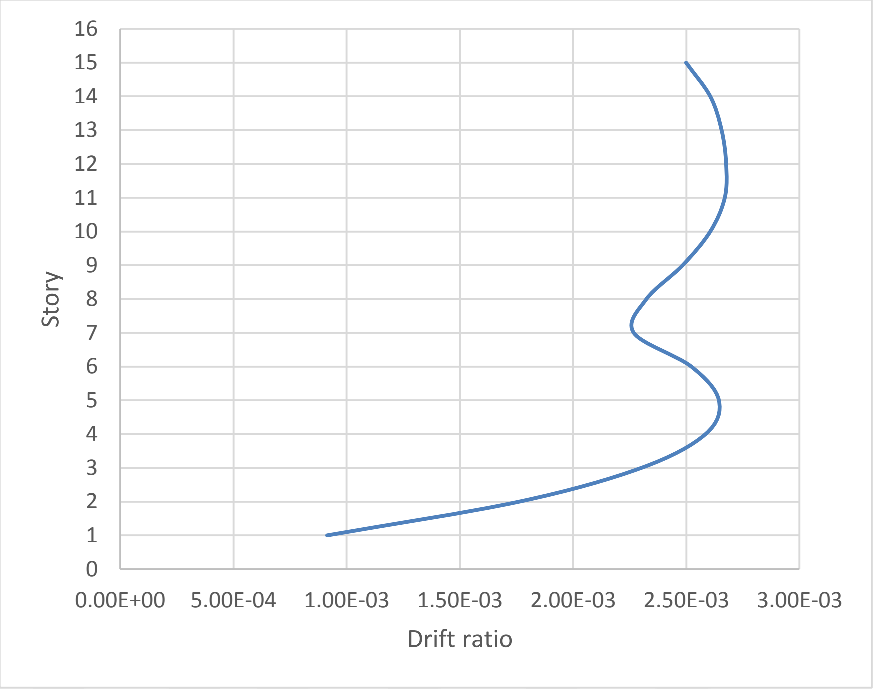

Figure 4.63. Drift diagram in the X direction for the 15story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 2.68e-3, which happened in the 12th story (Figure 4.63).

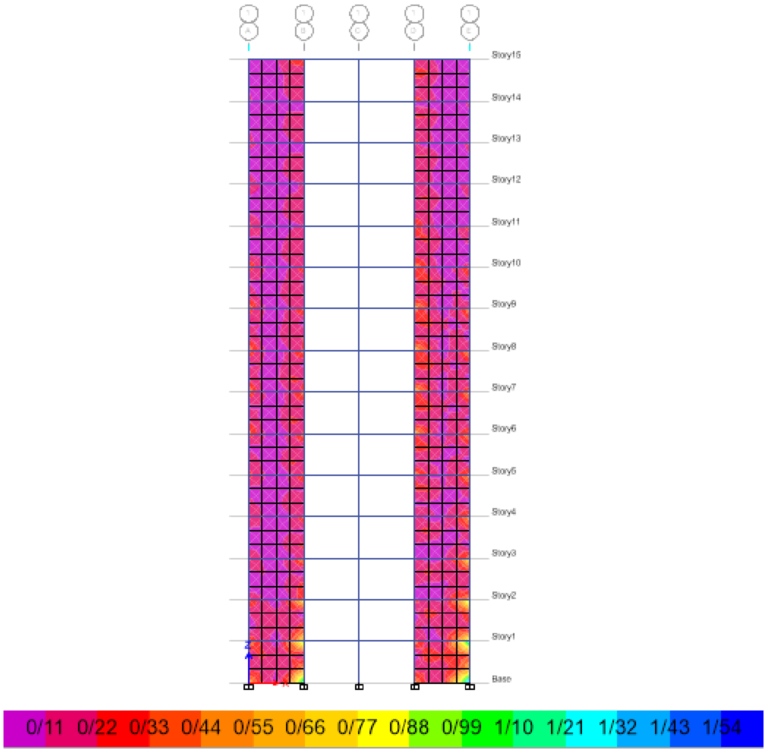

Figure 4.64. Stress contours in the shear walls (σ_x) MPa, for the 15 story building.

4.7.7. Case 6 Moment –Resisting system without shear wall

- Model 16; the 5-story building with moment-resisting frame and without shear walls

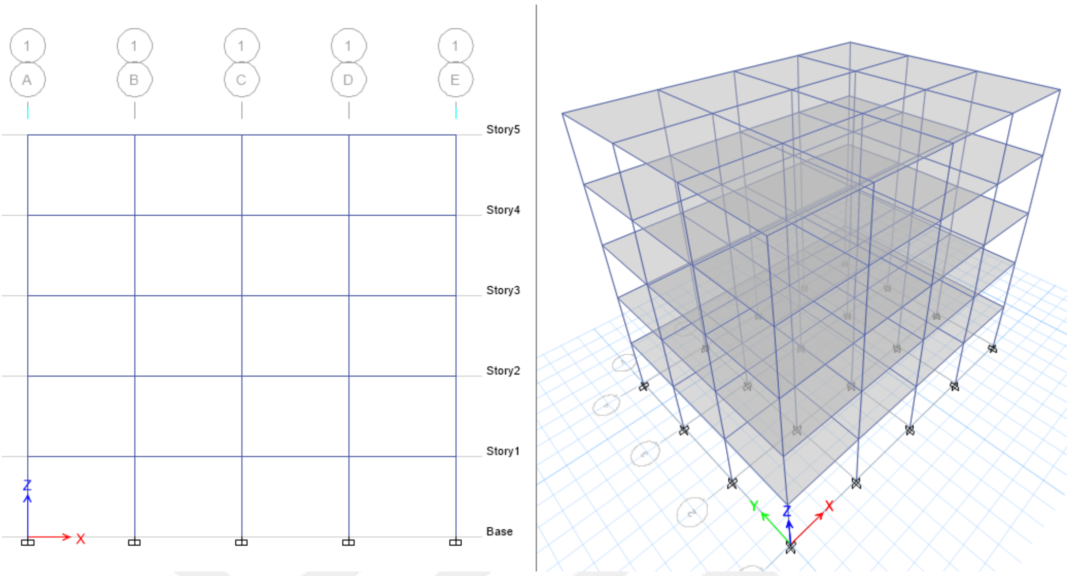

Figure 4.65. The 5-story building with moment-resisting frame and without shear walls.

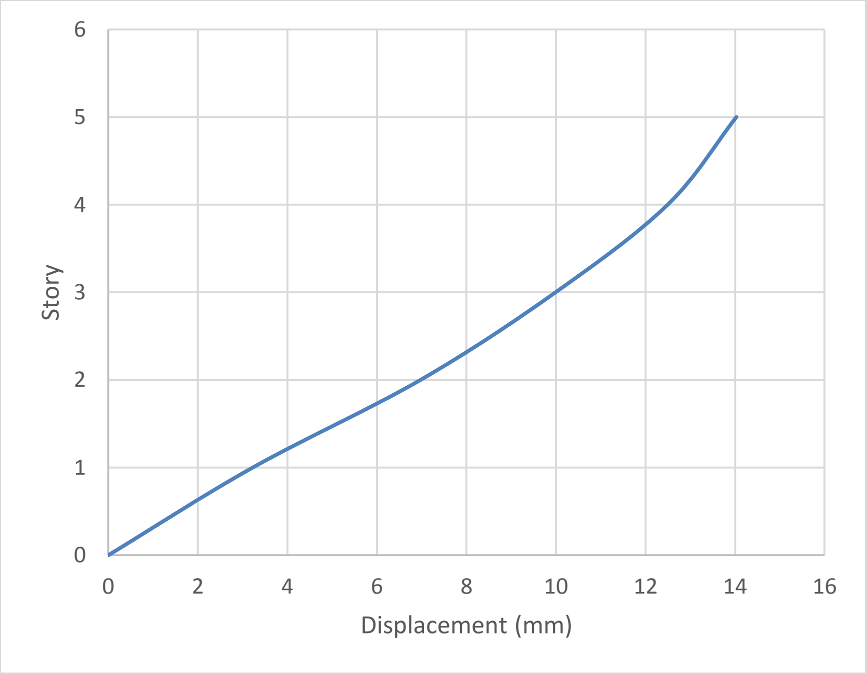

Figure 4.66. Displacement diagram in the X direction for the 5 story building.

The fifth story displacement is 14.03 mm which is more than the other stories. With regard to the slope of this diagram, the displacement is more in the top stories (Figure 4.66).

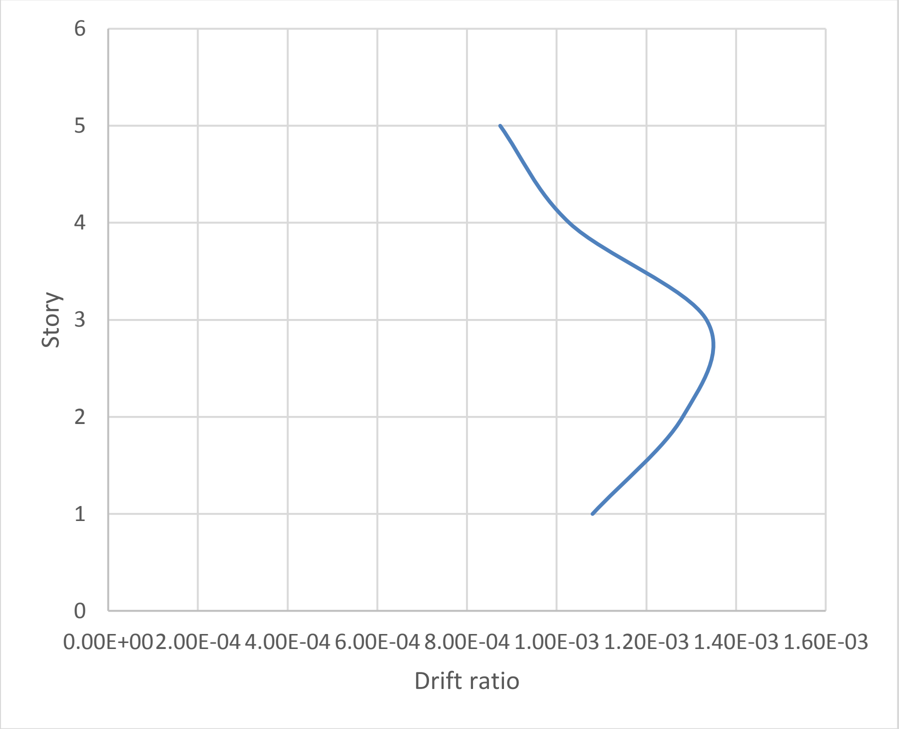

Figure 4.67. Drift diagram in the X direction for the 5 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 1.33e-3, which happened in the third story (Figure 4.67).

- Model 17; the 10-story building with moment-resisting frame and without shear walls

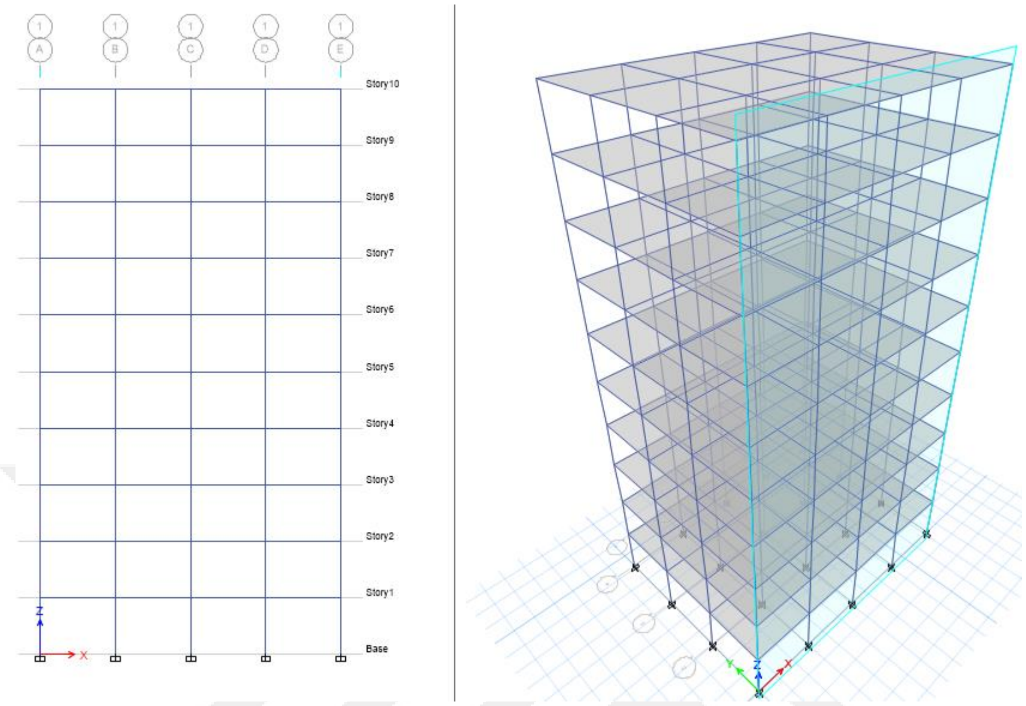

Figure 4.68. The 10-story building with moment-resisting frame and without shear walls.

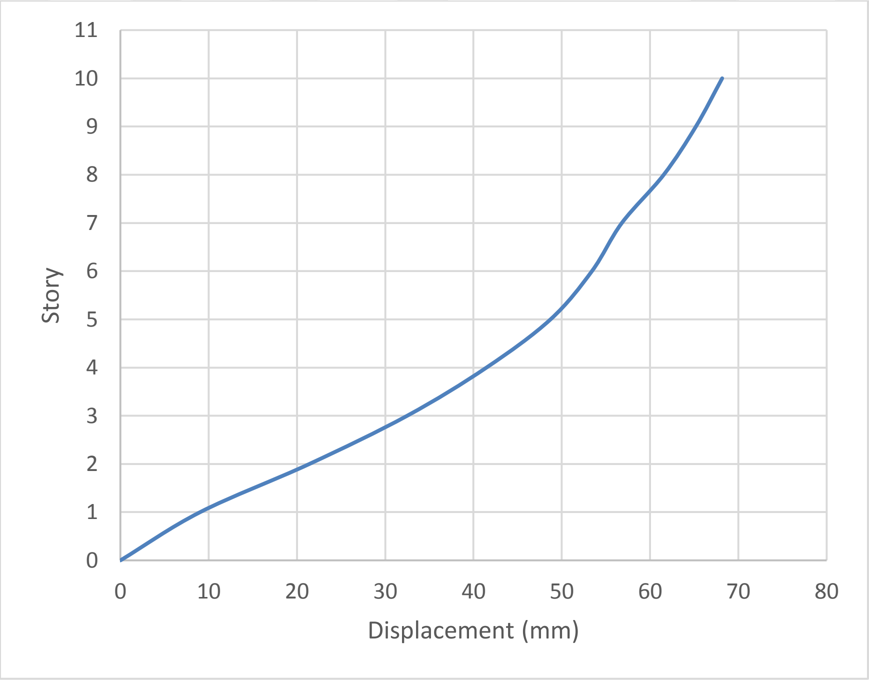

Figure 4.69. Displacement diagram in the X direction for the 10 story building.

The tenth story displacement is 68.17 mm which is more than the other stories. With regard to the slope of this diagram, the displacement is more in the top stories (Figure 4.69).

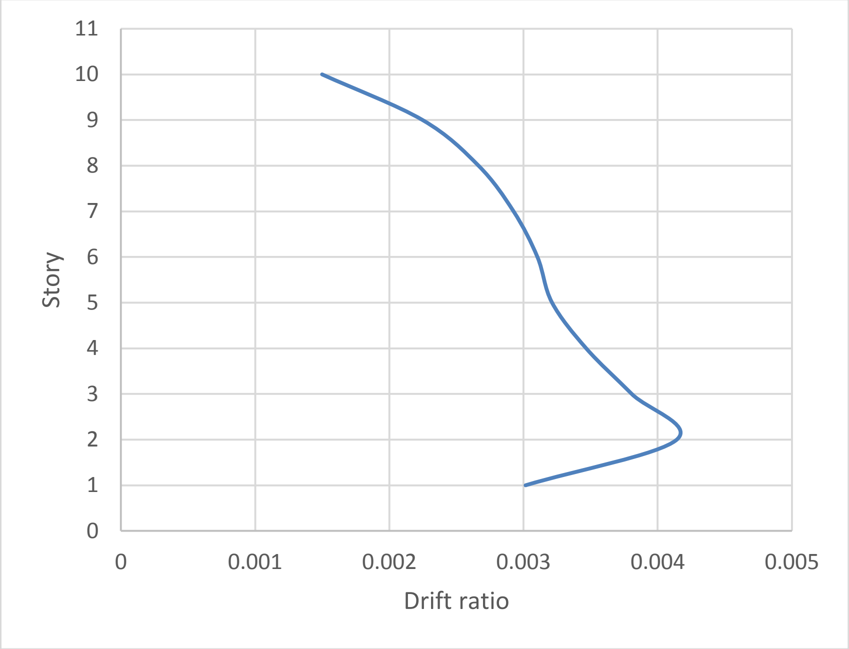

Figure 4.70. Drift diagram in the X direction for the 10 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 0.0041 mm, which happened in the 2th story (Figure 4.70).

- Model 18; the 15-story building with moment-resisting frame and without shear walls

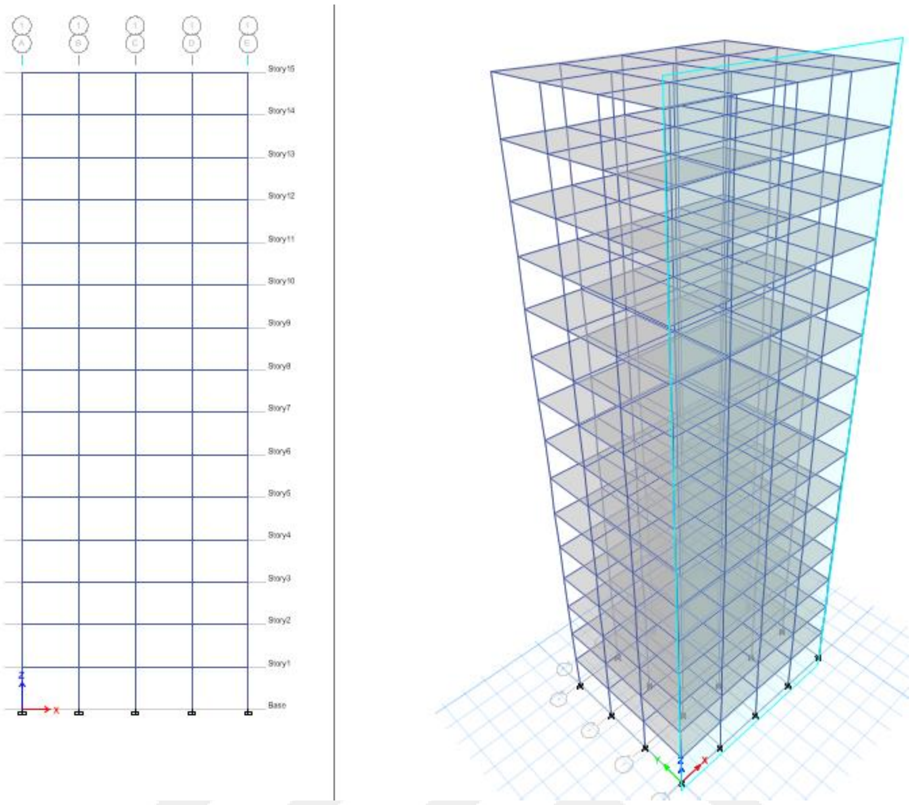

Figure 4.71. The 15-story building with moment-resisting frame and without shear walls.

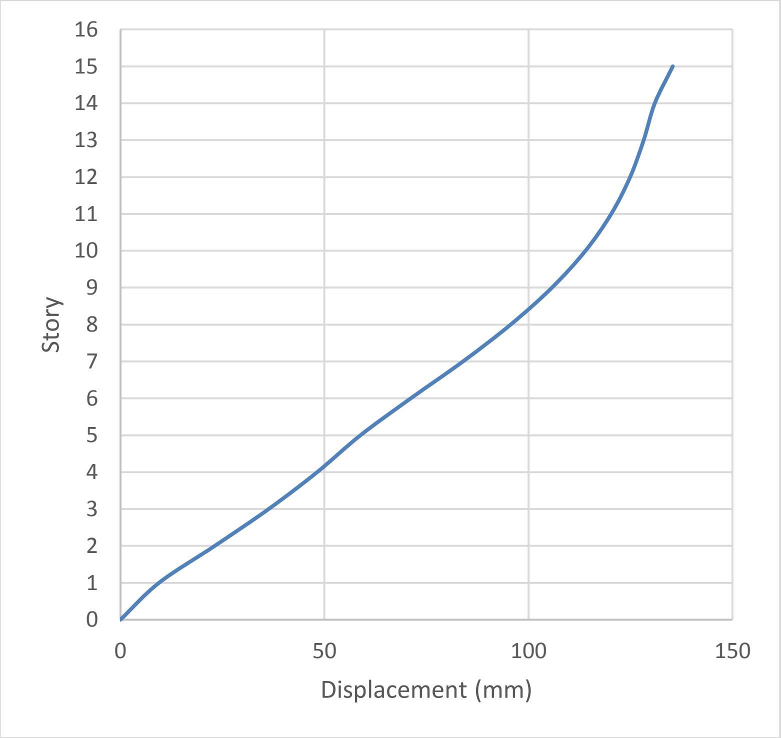

Figure 4.72. Displacement diagram in the X direction for the 15story building.

The fifteen story displacement is 135.38 mm which is more than the other stories. With regard to the slope of this diagram, the displacement is more in the top stories (Figure 4.72).

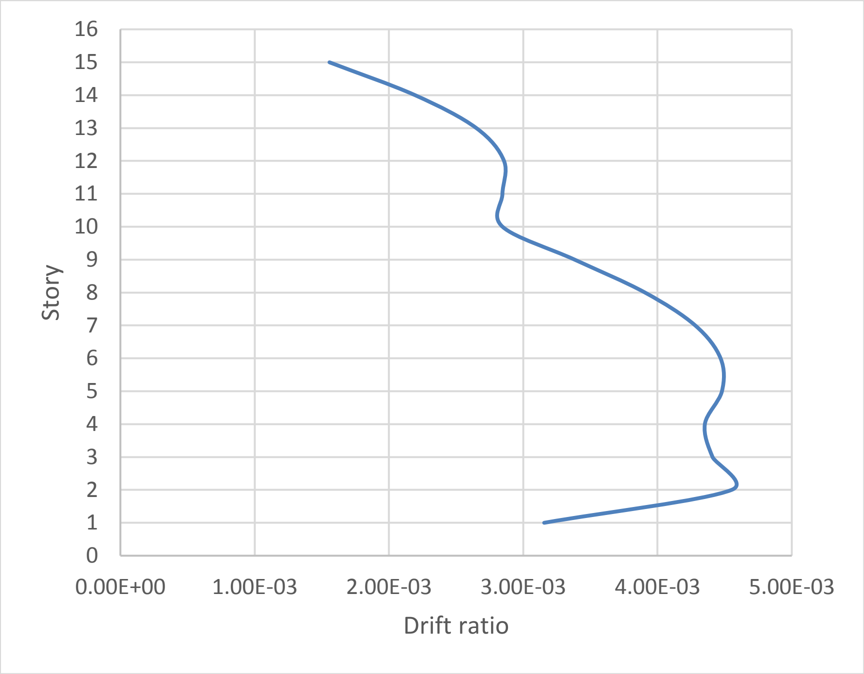

Figure 4.73. Drift diagram in the X direction for the 15 story building.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 4.55e-3 mm, which happened in the 2th story (Figure 4.73).

4.8. The Effect of Different Openings Percentage on the Performance of the Shear Walls of the 10-Story Building

As mentioned in the 4-7 sections, the effect of openings on the performance of the shear walls in different cases in the 5, 10, and 15-story buildings were evaluated. For instance, in the horizontal opening in the 5, 10, and 15-story buildings, this opening with the dimensions $1\times 1.34\,m$ were created in the shear wall with the dimension $3\times 4\,m$ in each story equivalent to 11 percent of the area of the shear walls and analyzed. In addition, in the vertical opening in the 5, 10, and 15-story buildings, this opening with the dimensions $1\times 1.8\,m$ were created in the shear wall with the dimension $3\times 4\,m$ in each story equivalent to 15 percent of the area of the shear walls and analyzed.

Now, by evaluating the 10-story building more exactly, we change the aforementioned percentages in order to study the effect of openings percentages on the performance of the shear walls, the displacements as well as the drifts, in the shear walls more precisely. According to the table below, different percentages of openings are used and analyzed in the buildings.

Table 4.2. Different cases of openings percentages used in the shear walls of the 10-story building

The 10-story building	Case 1	Case 2	Case 3	Case 4	Case 5
The opening dimensions ($m\times m$)	0	1.5×1.5	2×3	2.5×3.4	Moment-resisting frame
The shear wall dimensions	3×4	3×4	3×4	3×4	3×4
Percentage (%)	0	18.75	50	71	100

Among the presented cases in the table 4.2, the cases 1, 5 are studied in the previous sections. The cases 2 to 4 are evaluated in the following sections.

- Case 2- the 10-story building with the opening with the dimensions $1.5\times 1.5\,m$

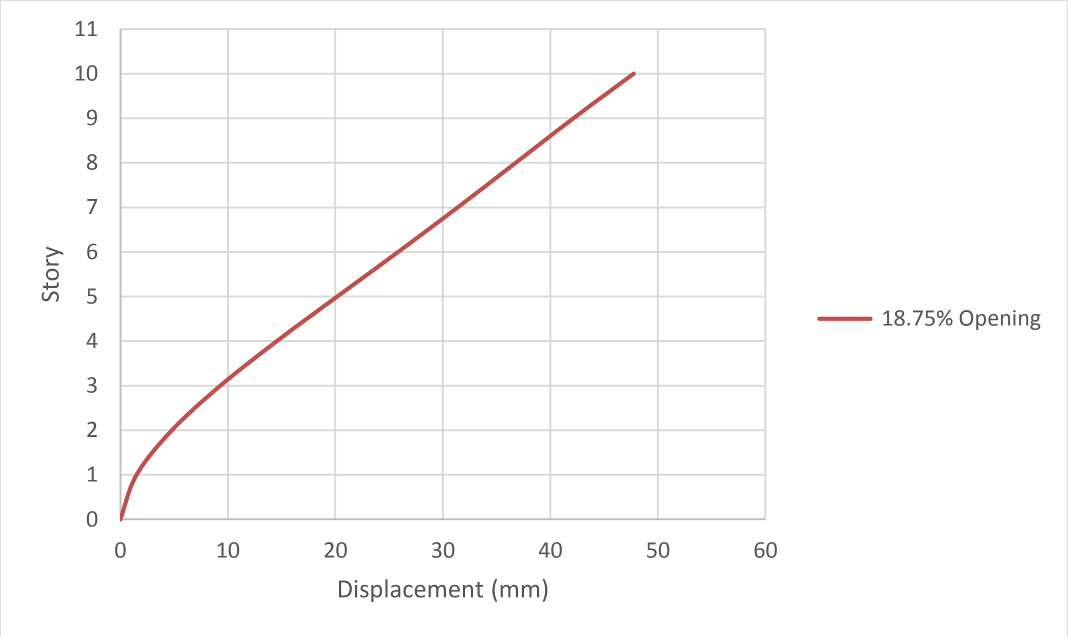

Figure 4.74. The displacement diagram in the X direction.

As shown in Figure 4.74, the tenth story displacement is 0.00589 mm which more than that of other stories is.

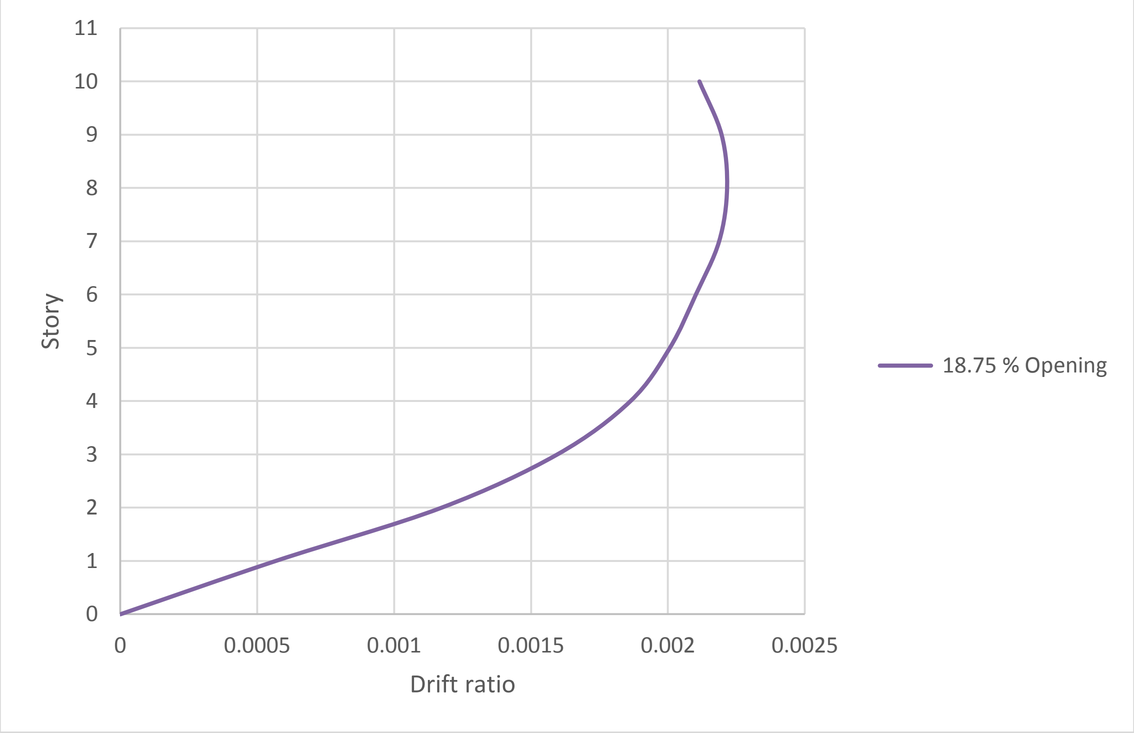

Figure 4.75. The drift diagram in the X direction.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 0.0022, which happened in the eighth story, as shown in (Figure 4.75).

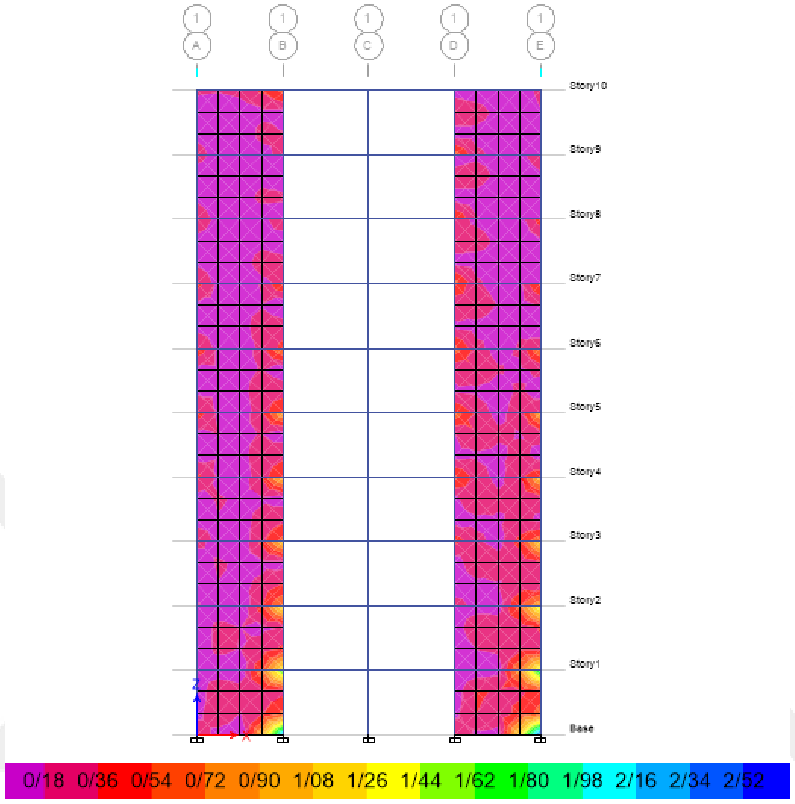

Figure 4.76. Stress contours in the shear walls (σ_x) MPa, for18.75 % opening.

- Case 3- the 10-story building with the opening with dimension $3 \times 2\ m$

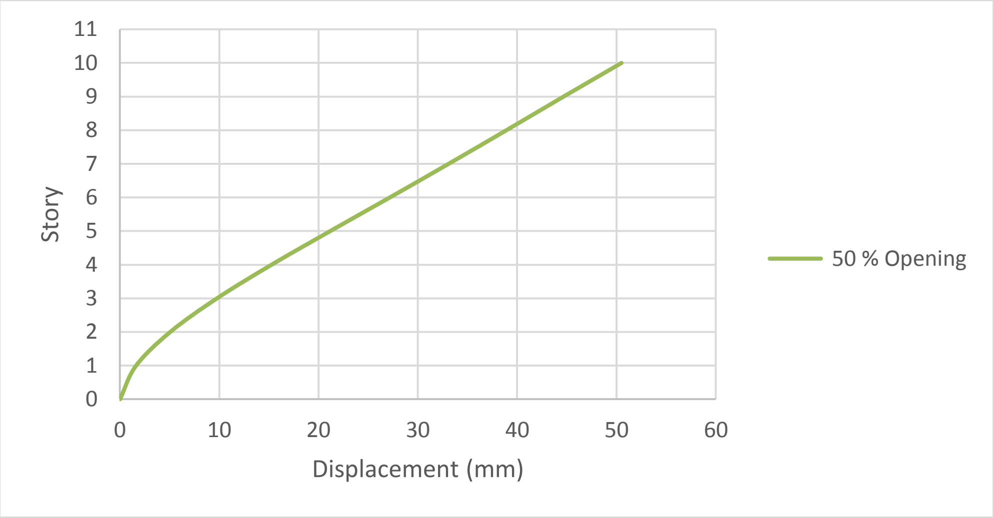

Figure 4.77. The displacement diagram in the X direction.

As illustrated in (Figure 4.77), the displacements in the stories have an increasing trend. The maximum displacement is 50.59 mm, which happened in the tenth story.

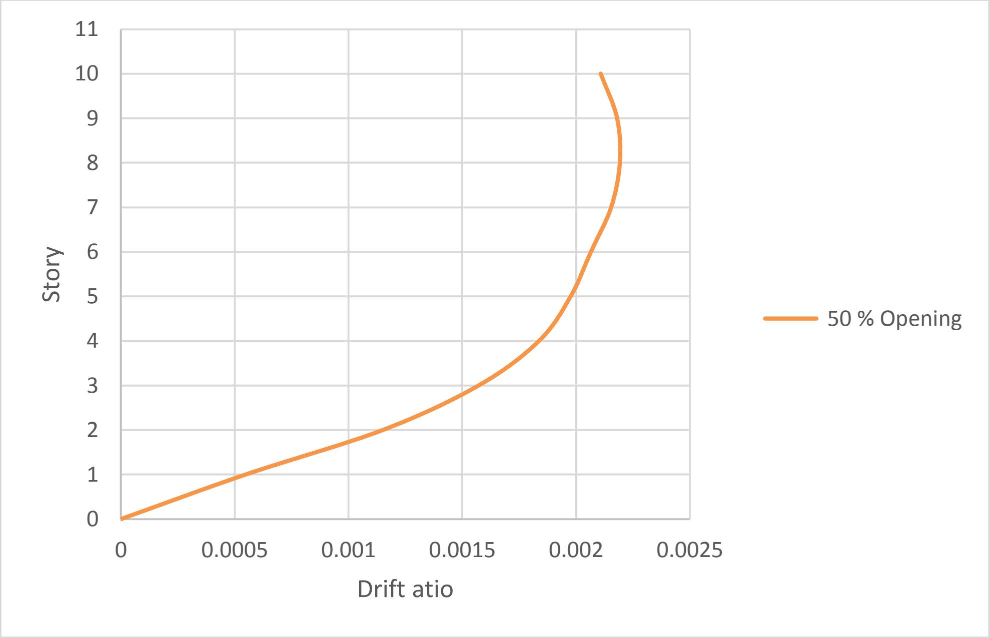

Figure 4.78. The drift diagram in the X direction.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 2.19e-3 mm, which happened in the sixth (Figure 4.78).

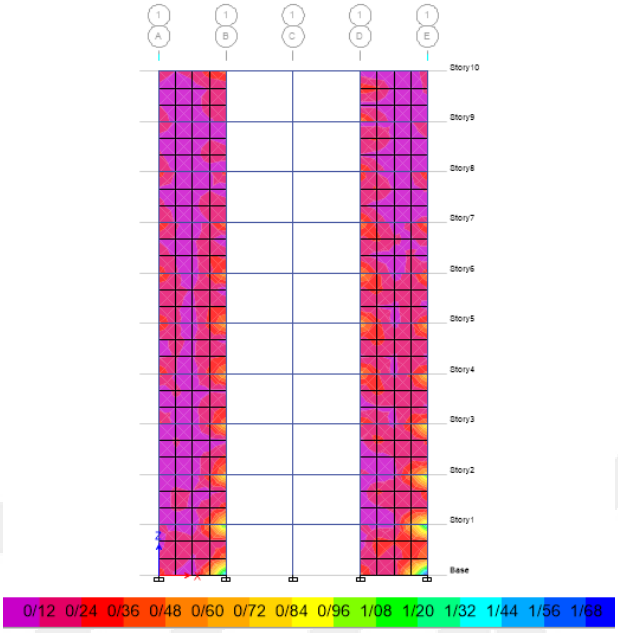

Figure 4.79. Stress contours in the shear walls (σ_x) MPa, for50 % opening.

- Case 4- The 10-story building with opening with the dimensions $2.5 \times 3.4\ m$

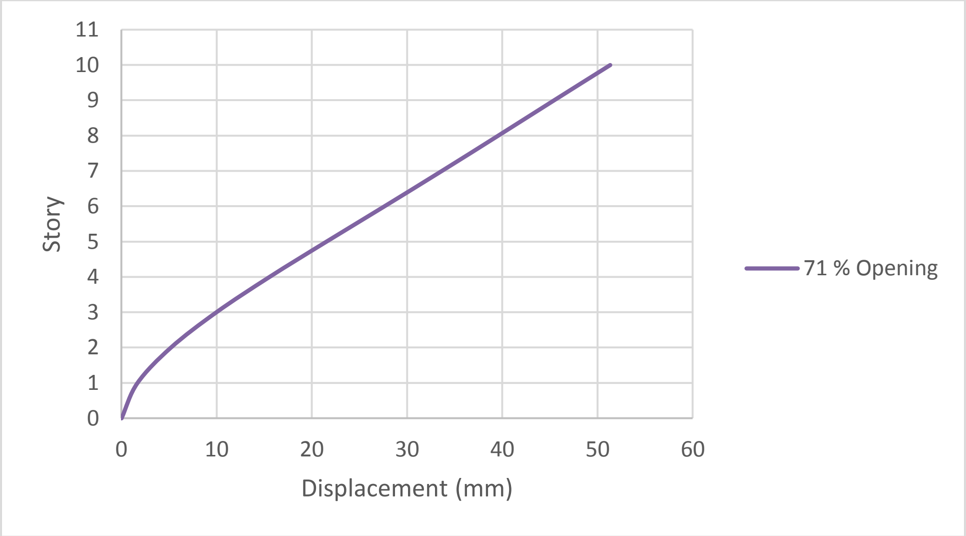

Figure 4.80. The displacement diagram in the X direction.

The displacements in the stories have an increasing trend, as show in (Figure 4.80). The maximum displacement is 51.35 mm, which happened in the tenth story.

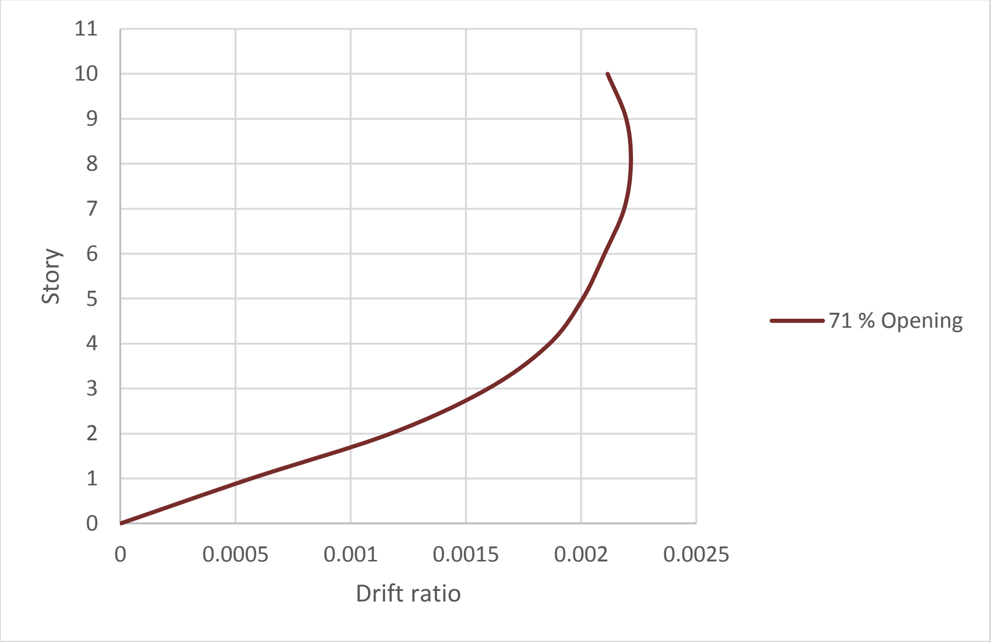

Figure 4.81. The drift diagram in the X direction.

The drifts in the stories increase at first, and then decrease afterwards. The maximum drift is 0.00222 mm, which happened in the eighth story (Figure 4.81).

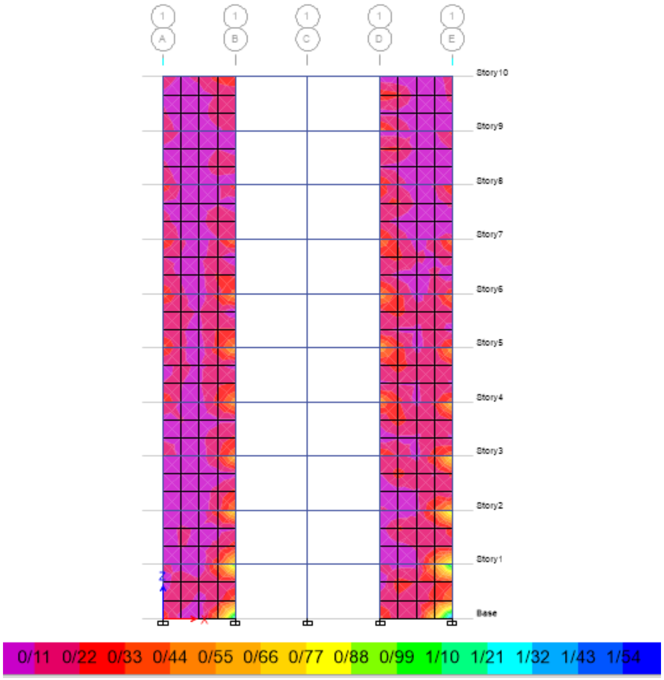

Figure 4.82. Stress contours in the shear walls (σ_x) MPa, for71 % opening.

5. CONCLUSION

One type of shear walls is the shear walls with openings, which are used in the walls due to architectural and construction installation considerations. These openings make changes in the ultimate strength, the distribution of forces, and stories displacements as well as drifts. In the chapter four, 21 structural models with different dimensions and openings position under the seismic loading of the Kobe earthquake accelerogram were analyzed. Furthermore, buildings displacements in the height, the stories drifts, and the stress variations in and around the shear walls were plotted. Now, in this chapter, by comparing analysis outputs, the displacements, stresses, and drifts are compared to one another through comparison diagrams.

5.1. Results and Conclusion

By plotting the comparison diagram of the 5-story buildings displacement, we obtain:

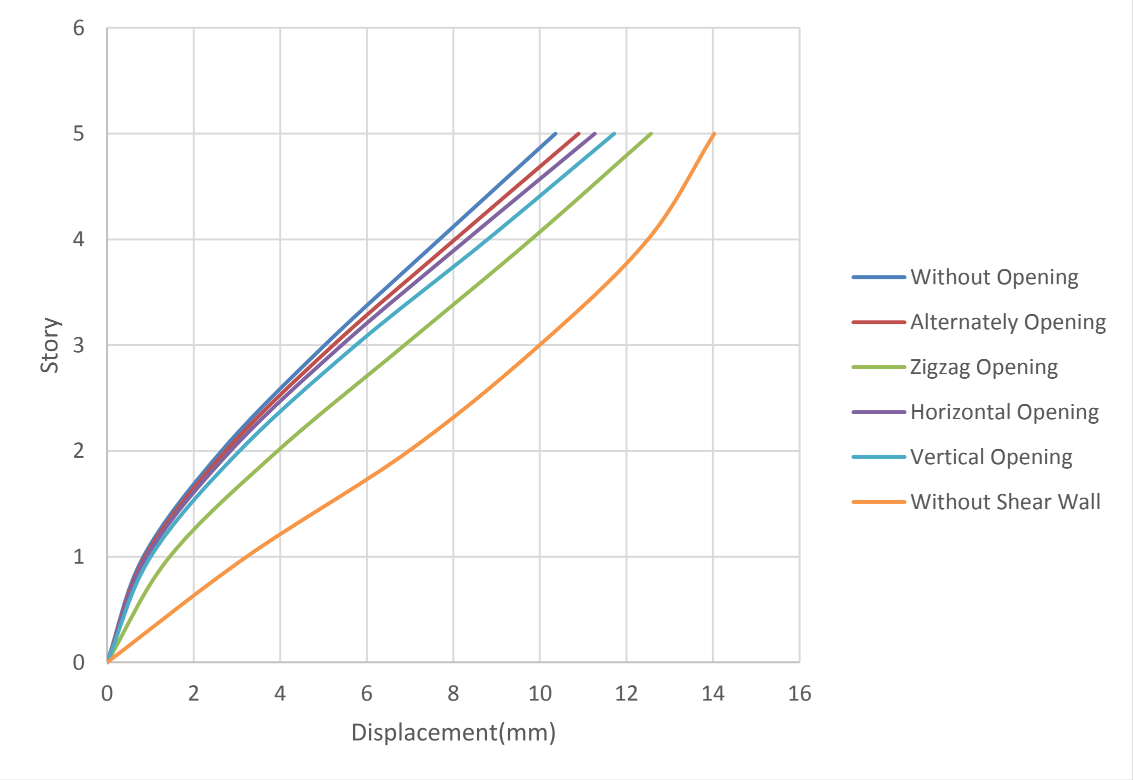

Figure 5.1. Comparison diagram of the displacement in the X direction for the 5 story building.

As shown in Figure 5.1, the effect of existing shear walls in comparison to the case only with moment-resisting frames is very considerable. Shear walls are effective in improving the seismic behavior of structures. The shear wall with zigzag opening compared to the vertical and horizontal openings have a greater contribution in the buildings displacement in the X direction. Additionally, the buildings without openings in comparison with the buildings with zigzag, vertical, and horizontal and alternately openings have a less displacement.

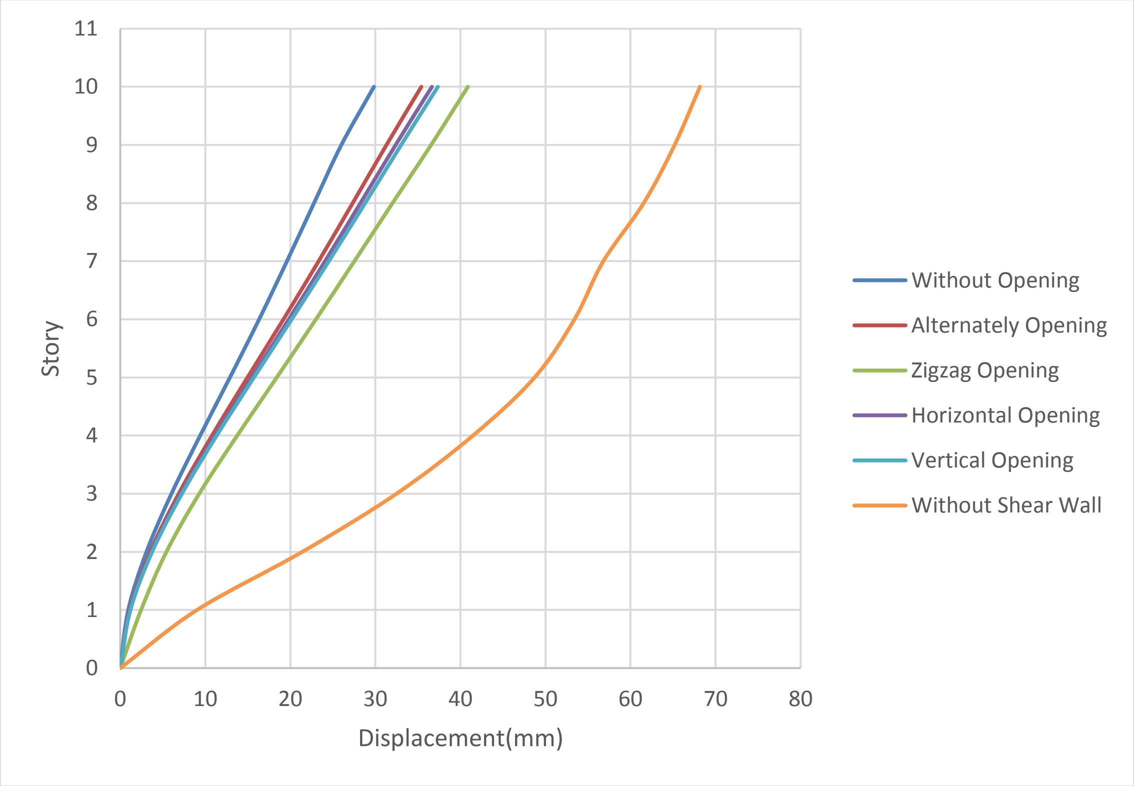

Figure 5.2. Comparison diagram of the displacement in the X direction for the 10-story building.

As shown in (Figure 5.2), the effectiveness of shear walls in improving the seismic behavior of the buildings is obvious. The effect of existing openings in the 10-story building with shear walls and openings has caused changes in the buildings behavior as well. The effect of existing shear walls in comparison to the case only with moment-resisting frames is very considerable (Figure 5.2). Shear walls are effective in improving the seismic behavior of structures. The vertical openings compared to the horizontal openings has a greater contribution in the buildings displacement in the X direction. In addition, the buildings without openings compared to the buildings with zigzag, vertical, and horizontal openings have a less displacement. The shear walls without openings had the least displacement.

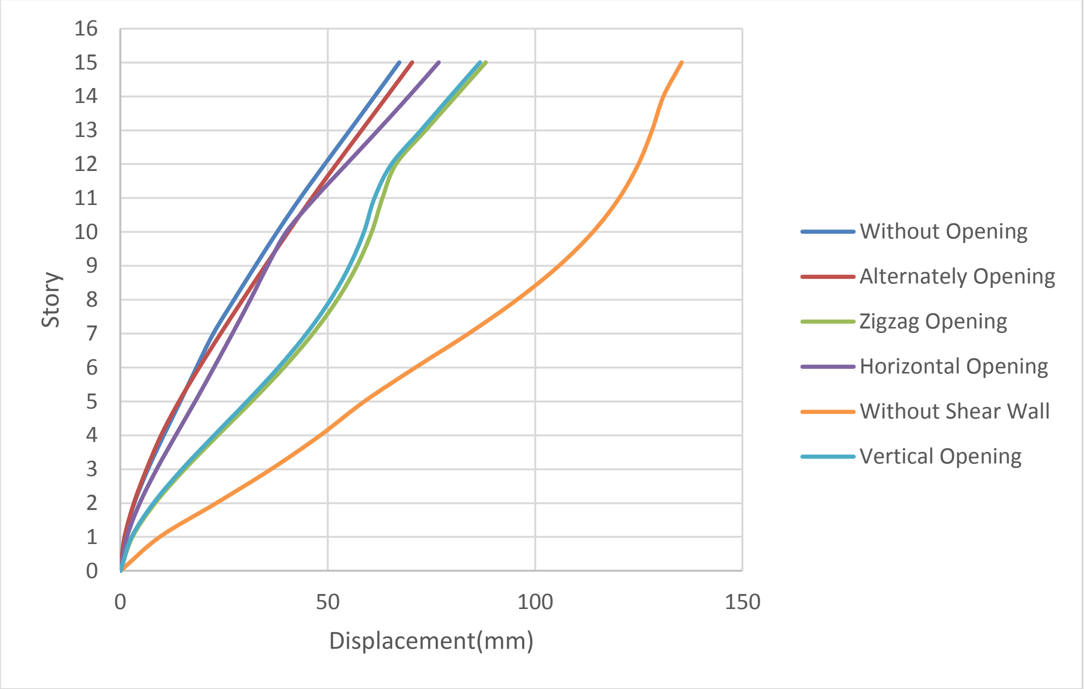

Figure 5.3. Comparison diagram of the displacement in the X direction for the 15-story building.

As it is seen from (Figure 5.3), the shear walls are effective in improving the displacement of the buildings. The effect of existing openings in the 15-story building with shear walls has caused changes in the buildings behavior as well. The shear walls in comparison to the case with only moment-resisting frame have been more effective in reducing the displacement and increasing the seismic capacity of the buildings, as shown in (Figure 5.3). The least displacement is for the case in which shear walls have no openings. The other cases with the least displacement in ascending order of displacement are: the building with alternately openings, horizontal openings, vertical openings, zigzag openings, and finally the moment-resisting frame without openings.

- Comparison diagram of the buildings Drift:

- The 5-story-buildings

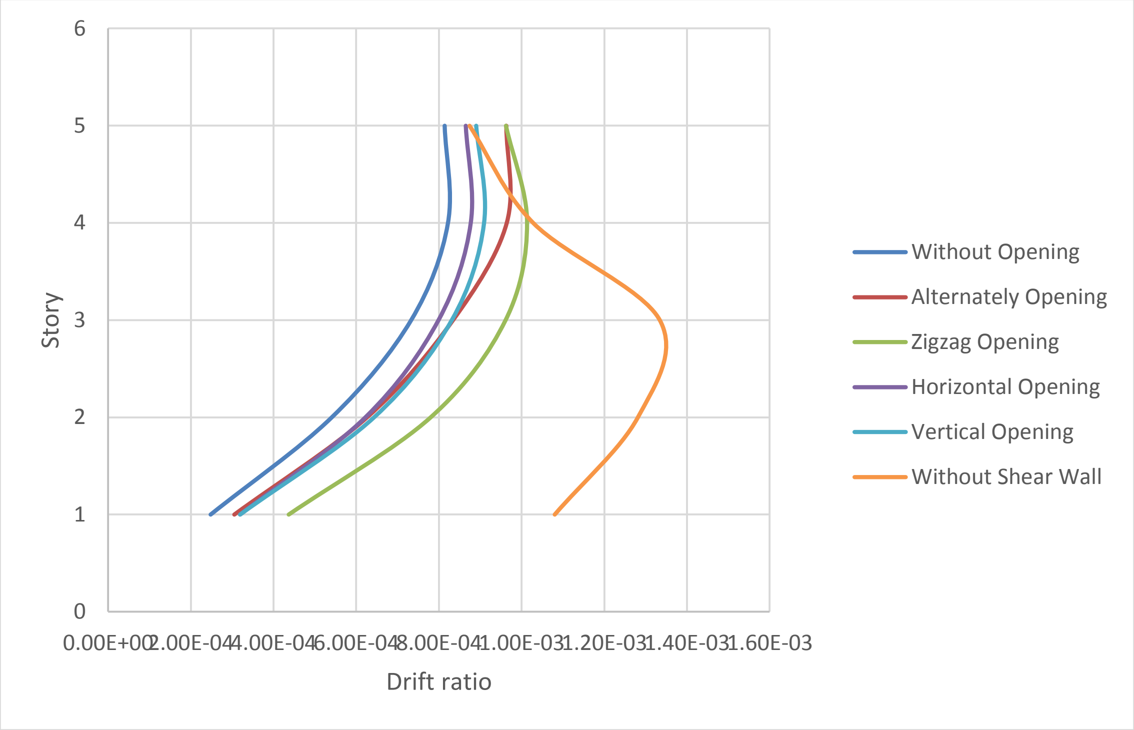

Figure 5.4. Comparison diagram of the buildings drift in the X direction for the 5-story building.

The least drift is for the building without openings. The other cases with the least drift in ascending order of drift are: the building with alternately openings, horizontal openings, vertical openings, zigzag openings, and finally the moment-resisting frame without openings (Figure 5.4).

- The 10-story-buildings

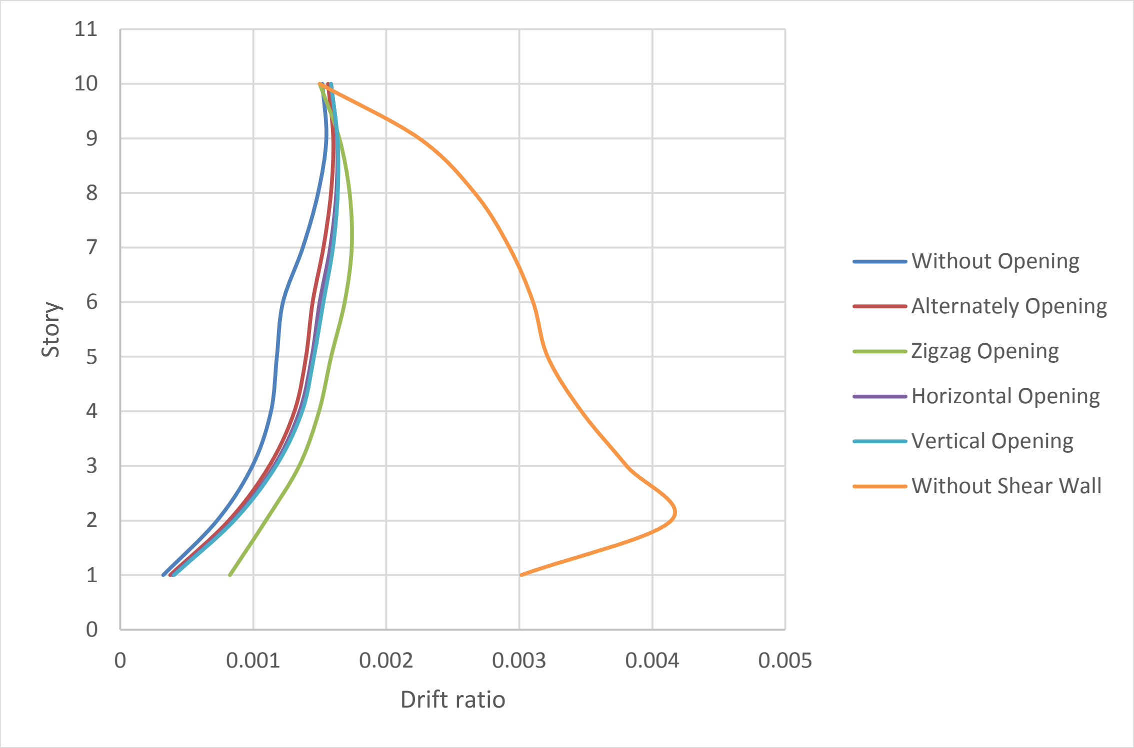

Figure 5.5. Comparison diagram of the buildings drift in the X direction for the 10-story building.

The least drift is for the case in which shear walls have no openings. The other cases with the least drift in ascending order of displacement are: the building with alternately openings, horizontal openings, vertical openings, zigzag openings, and the moment-resisting frame without openings (Figure 5.5).

- The 15-story-buildings

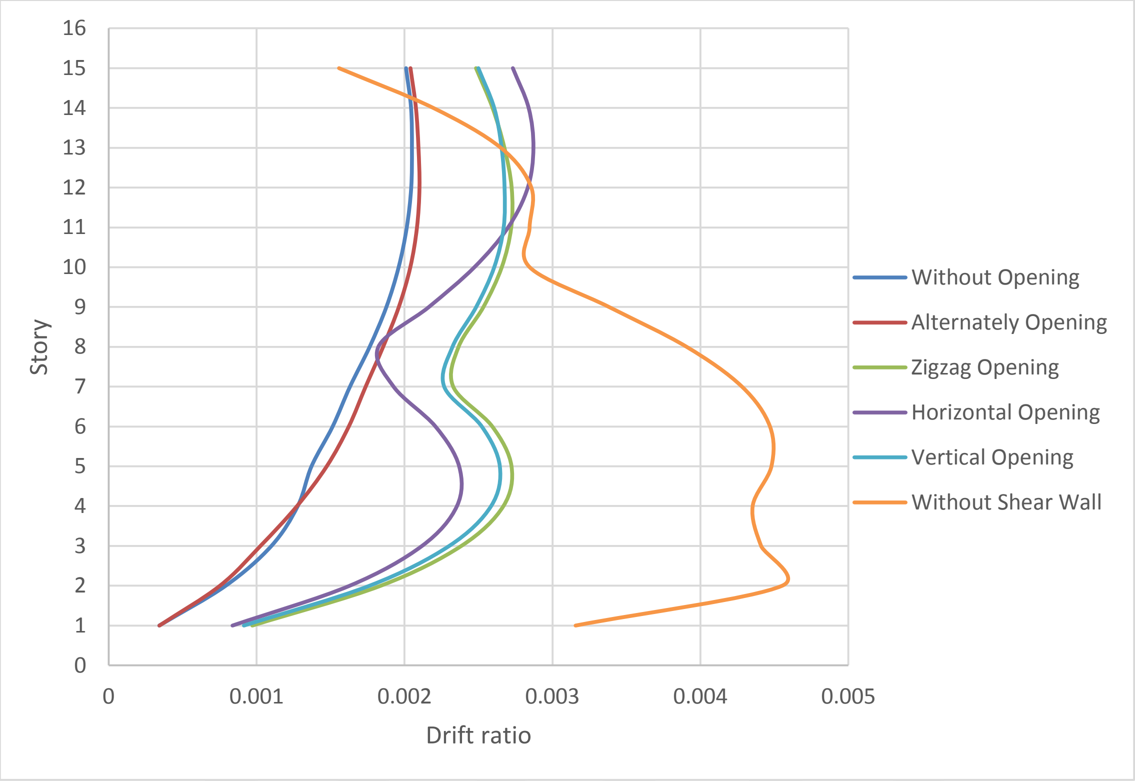

Figure 5.6. Comparison diagram of the buildings drift in the X direction for the 15-story building.

The least drift is for the case in which shear walls have no openings. The other cases with the least drift in ascending order of drift are: the building with alternately of openings, horizontal openings, vertical openings, zigzag openings, and the moment-resisting frame without openings (Figure 5.6).

- Evaluating the effect of distribution of Base Shear based on the type of the shear walls:
- The 5-story buildings

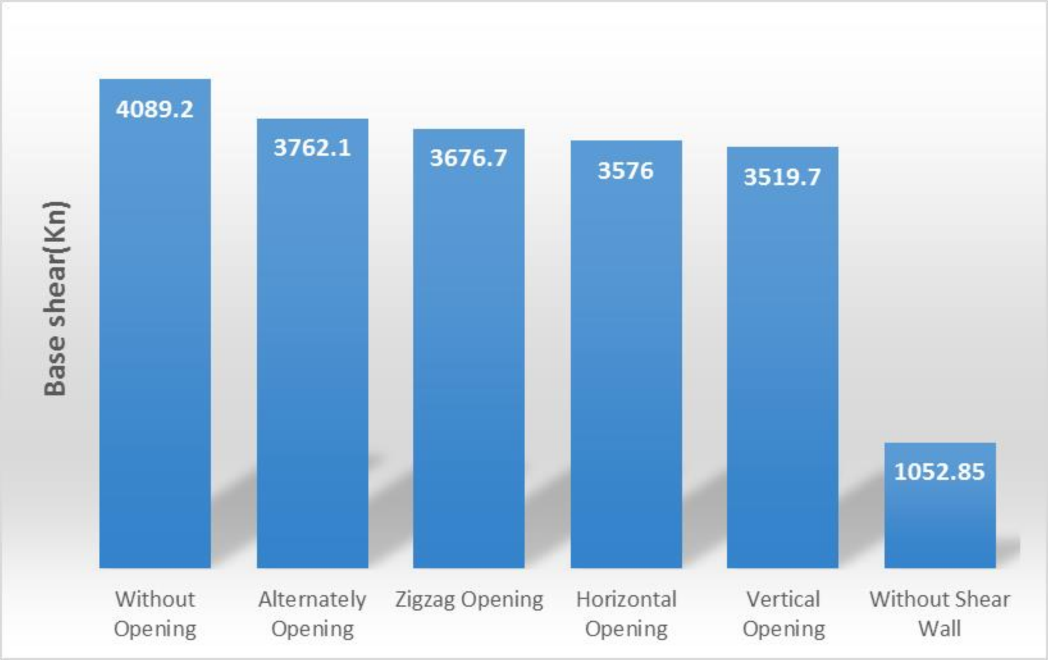

Figure 5.7. Shear base of the 5-stoty buildings based on the type of the shear walls.

- The 10-story buildings

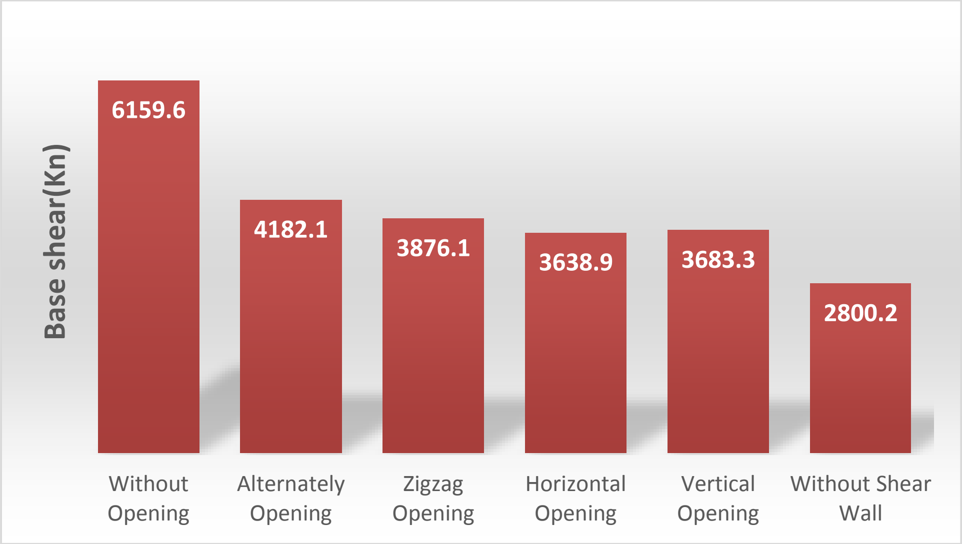

Figure 5.8. Shear base of the 10-stoty buildings based on the type of the shear walls.

- The 15-story buildings

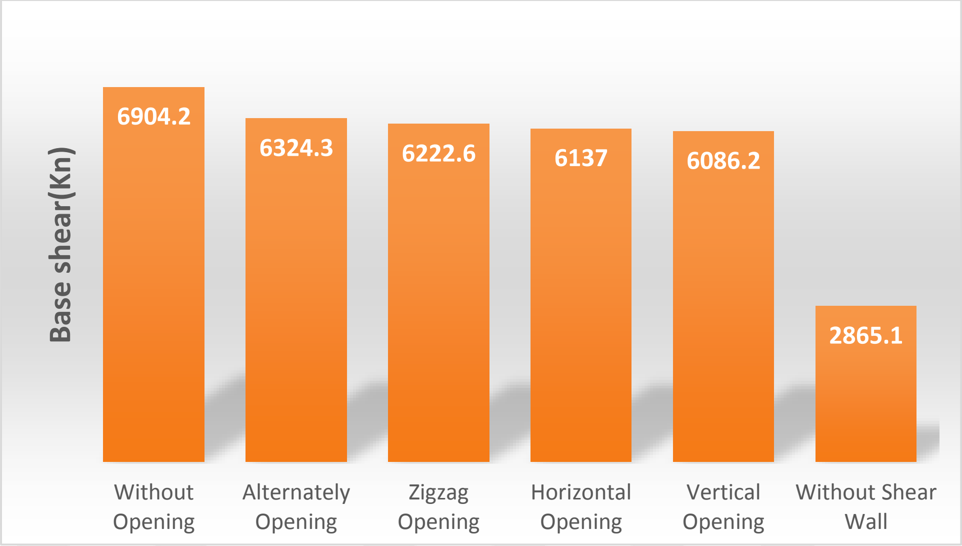

Figure 5.9. Shear base of the 15-stoty buildings based on the type of the shear walls.

The type of the openings (zigzag, horizontal, vertical and alternately openings) and not having openings and without shear walls (moment-resisting frames) each case have their own effect on the distribution of the base shear, as shown in Figure 5.8, 5.7, and 5.9. The 5, 10, and 15-story buildings, without openings have created the maximum base shear. Among other cases, the one with the alternately openings has the maximum base shear after the cases without openings. The minimum base shear in the buildings with shear walls happened in the cases without shear wall. As a result, openings increase the buildings base shear force.

- Evaluating the effect of openings in the 10-story buildings in five different cases

In this section, the results of analysis of the 10-story buildings in five different percentages of openings have been plotted for displacement and drift values comparatively.

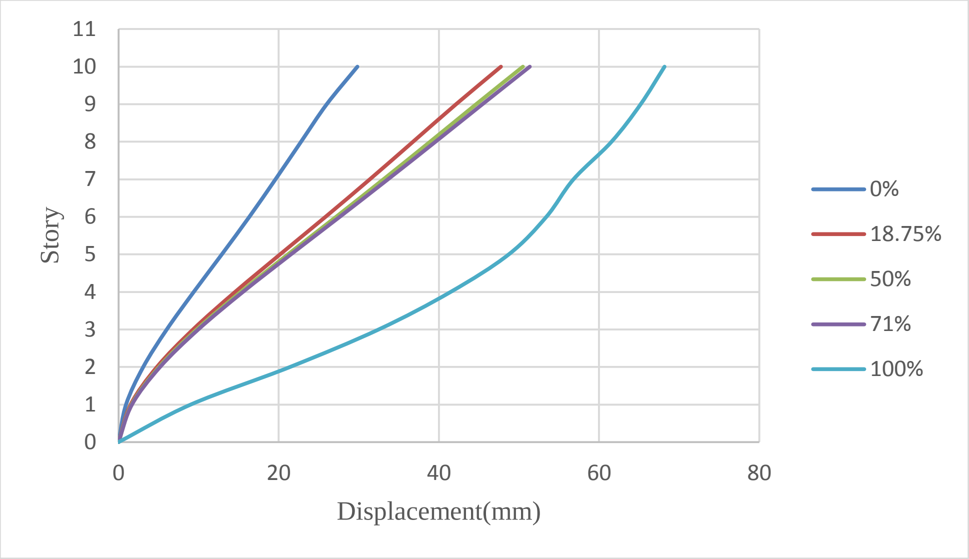

Figure 5.10. Comparative displacement of the 10-story building for different openings percentages.

As the openings percentage increases, stories displacements after analysis increase which in all the stories this increment is obvious. The minimum variation in the displacements is for the case without openings (0% opening) by value of (29.83 mm). The maximum variation in the displacements is for the case without shear walls (i.e. 100% openings), which in this case the maximum displacement is 68.17 mm for the tenth stories (Figure 5.10).

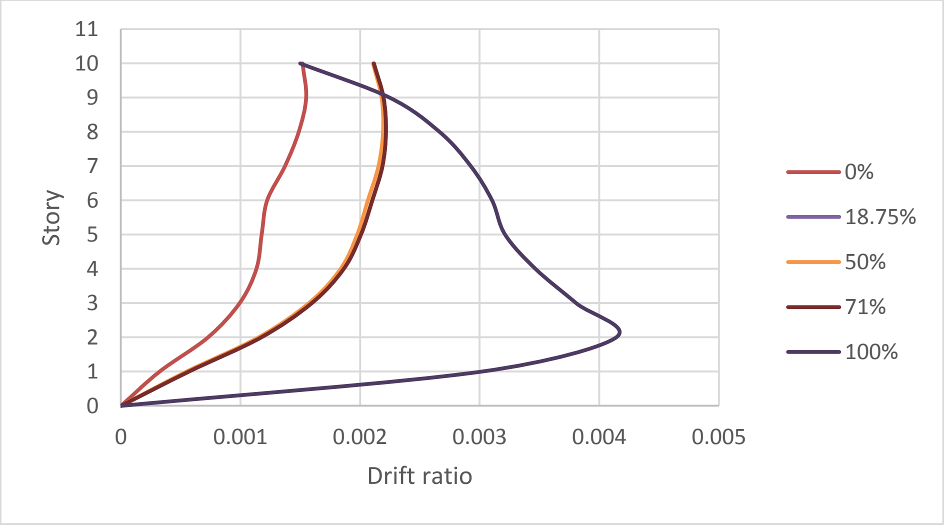

Figure 5.11. Comparative drift of the 10-story building for different openings percentages.

As shown in Figure (5.11), by increasing the openings percentage of the shear walls, the stories drift increase which these variations in all stories are at first happen in an increasing fashion, and then decrease afterward. The minimum variation in the drifts is for the case without openings (0 % opening), which in this case the maximum drift ratio is $1.55\ e-3$ for the ninth story. The maximum variation in the drift ratio is for the case without shear walls (i.e. 100% openings), which in this case the maximum drift ratio is $4.14e-3$ for the 2nd story.

- Evaluating the effect of distribution of Base Shear based on the percentage of opening:

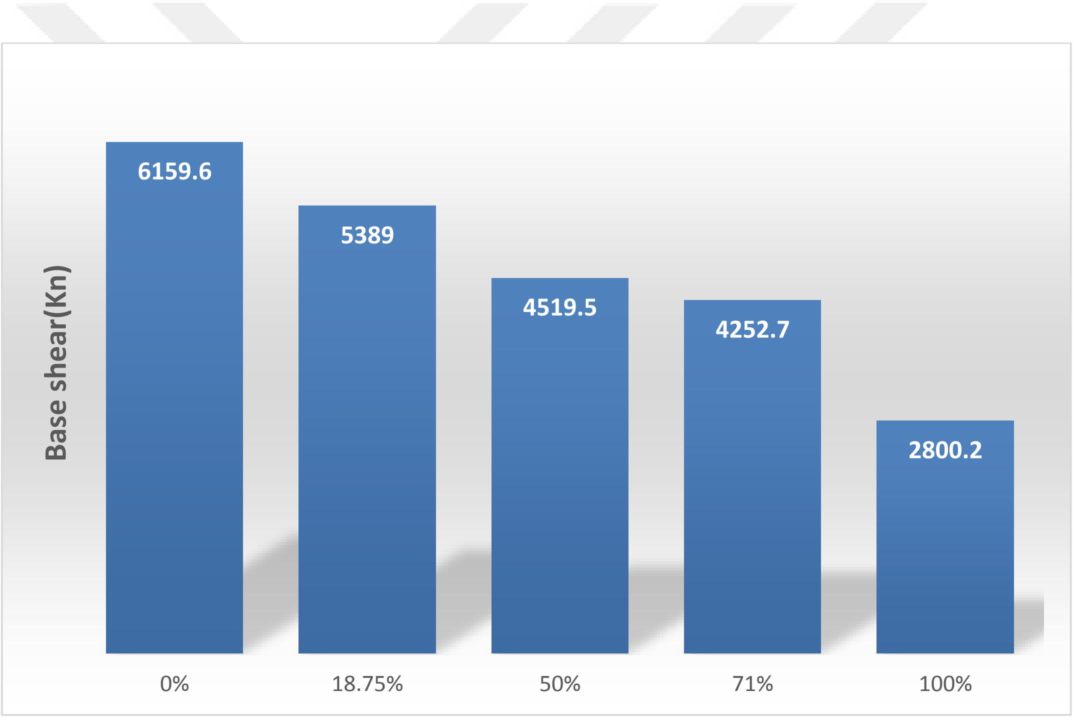

Figure 5.12. Shear base of the 10-stoty buildings based on percentage of opening.

Table 5.1. Increase percentage of story displacement for different cases of opening, compared with the case without opening.

Opening Case	**5-Story**	**10-Story**	**15-Story**
Alternately	5.21 %	15.76 %	4.38 %
Horizontal	8.07 %	18.61 %	12.33 %
Vertical	11.60 %	20.13 %	22.39 %
Zigzag	17.58 %	27.03 %	23.67 %
Moment Resisting F	26.16 %	56.24 %	50.33 %

Using shear wall greatly reduces lateral displacements in structures due to application of earthquake forces. As shown in Table (5.1), the minimum variation in the displacements is for the case alternately openings, which in this case the percentage of displacement is 5.21 % for 5 story building and maximum displacement percentage is for the case moment resisting frame that is 56.24 % for 10 story building rated by without opening cases for each structures. The least displacement percentages in ascending order of displacement are: the building with alternately of openings, horizontal openings, vertical openings, zigzag openings, and the moment-resisting frame without openings. For the case 5, 10 and 15 story buildings the displacement percentage growth 26.16 %, 56.24% and 50.33 % in comparison with the case without openings.

Table 5.2. Increase percentage of story drift for different cases of opening, compared by without opening case.

Opening Case	**5-Story**	**10-Story**	**15-Story**
Alternately	1.43 %	3.25 %	2.43 %
Horizontal	6.27 %	4.91 %	23.22 %
Vertical	9.57 %	5.2 %	28.59 %
Zigzag	18.61 %	10.09 %	34.74 %
Moment Resisting F	38.38 %	62.58 %	54.97 %

As shown in Table (5.2), the minimum variation in the drift is for the case alternately openings, which in this case the percentage of drift is1.43 % for 5 story building, and maximum drift percentage is for the case moment resisting frame that is 62.58 % for 10 story building rated by without opening.

Table 5.3. Increase percentage of story displacement and story drift for different percentage size of opening for 10 story building, compared by without openings.

Opening Rate	**Displacement**	**Drift**
11 %	18.61 %	4.90 %
15 %	20.13 %	5.20 %
18.75 %	37.53 %	10.20 %
50 %	40.92 %	29.22 %
71 %	41.91 %	30.18 %
100 %	56.24 %	62.58 %

In the present study a 10-storey building having shear walls with different size of openings are analyzed, in which volume of shear wall reduced is incorporated by increasing the dimensions of opening using Time History methods. It was observed that displacement and drift are dependent on the size of opening. The displacement of the buildings increases from 18.61% to 56.24% and drift increases about 4.90% to 62.58% due to the provisions of different size of openings in shear walls. With the increase in openings in shear wall lateral displacement increases to greater extent. But reducing the opening in shear wall by 50% then the displacement is save up to 22.31%. The story drift for the case 100 % opening in shear wall is very large than the without opening shear wall, A very good control over drift, can be achieved by without opening provided in shear wall.

Summary of results:

1-The effect of existing shear walls in comparison to the case only with moment-resisting frames is very considerable. Shear walls are effective in improving the seismic behavior of structures.

2- Creating both regular and zigzag openings in shear walls increases displacements and drifts.

3- The minimum drift happened in the building without openings.

4- The maximum displacement increased along the height of structure as the story level of the building was higher.

5- The buildings drifts in an ascending fashion are: the shear walls with alternately openings, horizontal openings, vertical openings, zigzag openings, and moment-resisting frames.

6- The least drift and the maximum base shear happen in the lower stories.

7- In the 5-story buildings the contribution of the zigzag openings in the buildings displacement in comparison to the vertical and horizontal openings is greater in the X direction.

8- In the 10-story building the contribution of the zigzag openings in comparison with the vertical, horizontal, alternately openings is greater in the X direction. Additionally, the buildings without openings in comparison to the buildings with zigzag, vertical, and horizontal openings have less displacement. The shear walls without openings have the minimum displacement as well.

9- The minimum displacement in the 15-story buildings happen in the case which the shear walls does not have openings. The other cases with the least displacement in ascending are: the building with alternately openings, horizontal openings, vertical openings, zigzag openings, and finally the moment-resisting frame without openings.

10- As the height increases, the displacements increase in a way that in the 15-story building in comparison to the 5 and 10-story buildings the structural behavior—in spite of having shear walls—is very similar to the case without shear walls.

11- The difference between the horizontal displacements in the 15-story building is more than others. The sensible phase difference creates some sort of a damping, or—to be more correct—an energy absorption phenomenon in the structures. In this regard, it can be concluded that this phase difference can improve the energy absorption capacity of the structures and make them more ductile.

12- The amount of the base shear in the lowest level was the most, and by increasing the height from the ground decreases due to the accumulative mass of the stories. Increasing the vertical load on the walls in the event of an earthquake makes the walls foundations to yield later, improving the nonlinear performance of the walls.

13- The 5, 10, and 15-story buildings with shear wall without openings have created the maximum base shear.

14- It was observed that displacement and drift are dependent on the size of opening (percentage of openings), with the increase in openings in shear wall lateral displacement and drift increases to greater extent.

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APPENDIX

APPENDIX 1. EXTENDED TURKISH SUMMARY (GENİŞLETİLMİŞ TÜRKÇE ÖZET)

BOŞLUKLU PERDELİ YAPI SİSTEMLERİNDE PERDE BOŞLUK ORANLARININ VE BOŞLUK KONUMLARININ YAPI DAVRANIŞINA ETKİSİNİN ARAŞTIRILMASI

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Yanal yüklere karşı olumlu performansları nedeniyle, (deprem yüküne karşı moment dirençli sistemlerinden biri olan) beton perde duvarları, orta ve yüksek katlı binalarda yaygın olarak kullanılmaktadır. Pek çok durumda yapılar, mimari ihtiyaçları karşılamak için farklı boyutlarda boşluklar gerektirmektedir. Duvarlardaki boşlukların boyutu, konumu ve sayıları perde duvarlarının direnci ve sismik davranışını etkileyen en önemli faktörlerdir. Bu çalışmada, depreme maruz boşluklu, boşluksuz perdeli ve perdesiz yapılarda oluşan yer değiştirme, yanal kayma ve gerilmeler ETABS yazılımı ile değerlendirilmiştir. Ayrıca boyut ve konumun perde duvarlarının davranışına etkisi incelenmiştir. Bu bağlamda, 5, 10 ve 15 katlı 3 bina grubu perde duvarlarında farklı yüzde ve geometrili boşluklar ile modellenmiş ve zaman tanım alanında analiz edilmiştir. Sonuçlar, alternatif bir yanal yük-dirençli sistem olarak moment dirençli çerçevelerin sonuçlarıyla karşılaştırıldı. Binalar, deprem ivmesinin zaman tanım alanı yüklenmesiyle yüklenmiştir. Sonuçlar, 10 katlı binanın boşluk yüzdesi arttıkça, yer değiştirme ve yanal kaymanın da arttığını ortaya koymuştur. Minimum kayma ve yer değiştirme miktarı boşluksuz bina için elde edilmiştir. Ayrıca, moment-dirençli çerçeve durumunda minimum ve maksimum taban kesmesi kuvveti sırası ile15 katlı binada ve boşlukları olmayan binada meydana geldi. Genel olarak, boşluklar bulunan binalarda deprem kapasitesi azalmıştır.

Anahtar kelimeler: Boşluk, Deprem ivmesi , Kayma, Perde duvar, Zaman tanım alanı analizi.

GİRİŞ

Depremdeki yapıların davranışları rasgele olduğundan, yanal yük-direnç sistemi, hasarı -bina sakinlerinin güvenliğini garanti eden- kabul edilebilir sınırlar içinde tutmak zorundadır. Bu nedenle yapı, –çökmeden- büyük kuvvetlere ve deformasyonlara direnmek için yeterince esnek olmalıdır.

Yapısal tasarım, üç temel gerekliliği sağlamalıdır: ilk olarak, yapıların erken çökmesini önlemek için gerekli olan ve herhangi bir yapının temel ihtiyacı olan dayanım; ikincisi, yapılar küçük depremler durumunda yer değiştirmelerin etkisini kontrol ederek yapısal olmayan elemanların hasar görmesini önlemek için yeterli bir rijitlik gerektirir; son olarak, yapılar depremler tarafından salınan enerjiyi emerek ve yeterli esneklik sağlayarak güçlü depremler sırasında güvenli olmalıdır. Bunun için, moment-dirençli çerçeveler, beton perde duvarları ve çift çerçeve duvar sistemleri kullanılabilir.

Perde duvarları kullanmak, deprem yüküne direnmek için kullanılan farklı yöntemlerden biridir. Beton yapılarda yanal rijitlik yaratmada o kadar önemli bir rol oynarlar ki, çoğu bölgede deprem yükleri olan yanal yüklere karşı yapının neredeyse tüm mukavemeti perde duvarlar tarafından sağlanır. Bu nedenle bu yapı elemanlarının davranışlarını incelemek, mühendislik için büyük önem taşımaktadır (Naveed, 2002).

Araştırma Hedefleri

Bu çalışmanın temel amaçlarından biri, beton perde duvarlarındaki boşlukların konumlarının ve boyutlarının, beton binalarda duvarların davranışları üzerindeki etkisini değerlendirmek ve alternatif bir yanal yük-direnç sistemi olarak moment-dirençli çerçevelerle perde duvarları karşılaştırmaktır.

Diğer hedefler aşağıdaki gibi özetlenebilir:

1- Boşlukların yüzdesinin perde duvarların ve binaların performansına etkisi.

2- Boşluk konumlarının perde duvar ve binaların performansına etkisi.

3- Kısa, orta ve yüksek katlı binalarda boşlukların etkisi arasında bir karşılaştırma yapmak.

4- Perde duvarlarının boşluklu veya boşluksuz sismik performanslarını değerlendirmek ve sonuçların alternatif bir yanal yük-dirençli sistemi olarak moment-dirençli çerçevelerle karşılaştırması.

KAYNAK BİLDİRİŞLERİ

Balkaya ve Kalkan, (2004), boşlukların perde duvarlarının davranışları üzerindeki etkisinin değerlendirilmesine yönelik bir çalışmada, bağlantı kirişinde diyagonal formda çubukların kullanılmasını sağlamıştır. 2-B ve 3-B durumlarında zaman tanım alanı analizleri kullanarak boşlukların etrafındaki taşıma kapasitesini ve gerilme dağılımını belirledikten sonra sonuçları, dirençli moment diyagramı ve yük-yerdeğiştirme diyagramı olarak boşluk uzunluğu ve genişliği cinsinden açıkladılar (Bakaya, Kalkan, 2004).

MATERYAL

Yerçekimi yüklerine karşı kararlılığa ilaveten, binalar yanal kuvvetlere karşı da kararlılıklarını korumalıdır. Yüksek rijitliğe sahip perde duvarları, yanal yüklere ve ortaya çıkan momentlere direnebilir. Bir çok binada mimari ihtiyaçlar, perde duvarlarında, uygulanan yüklere karşı duvarların rijitliğini azaltan boşluklar oluşturulmasını gerektirmektedir. Bu çalışmada, boşlukların boyut ve konumlarının perde duvarına etkisi değerlendirilmiştir. Sonuçlar, boşluk alanında artışla birlikte kayma ve deformasyonların eksponansiyel olarak değiştiğini göstermektedir. Gerilimlerin yanı sıra konsantrasyonların da değerlendirilmesi yapılmıştır.

YÖNTEM

Bu çalışmada, ETABS 2015 yazılımı ile farazi bir yapısal geometri formunun çizilmesi, modellenmesi ve analizi gerçekleştirilmiştir. Bu yöntemde, belli bir açıklığa sahip binaların sismik davranışları üzerinde boşlukların etkisi değerlendirilmiştir. Bu amaçla aşağıdaki durumlar ayrı ayrı göz önüne alınmıştır:

1- Boşlukları olmayan beton perde duvar olması durumu,

2- Tüm katlarda düzenli boşluklu perde duvar olması durumu,

3- Dönüşümlü katlardaki perdelerde boşlukların olması durumu, 4- Boşluk konumunun etkisi (perde boşluklarının katlarda zikzak şeklinde oluşturulması durumu).

5- Boşluk şeklinin etkisi (bu durumda, perde duvarlarının iki farklı boyutu dikkate alınmıştır).

6- Perde duvarların olmaması durumu (moment-dirençli çerçeve sistemler)

7- Aynı kat adedine sahip perdeli-çerçeveli binada farklı oranda boşluk oranlarına sahip olması durumu

8- Perde duvarlarının tipine göre taban kesme (iç kuvvet) dağılımının etkilerinin değerlendirilmesi.

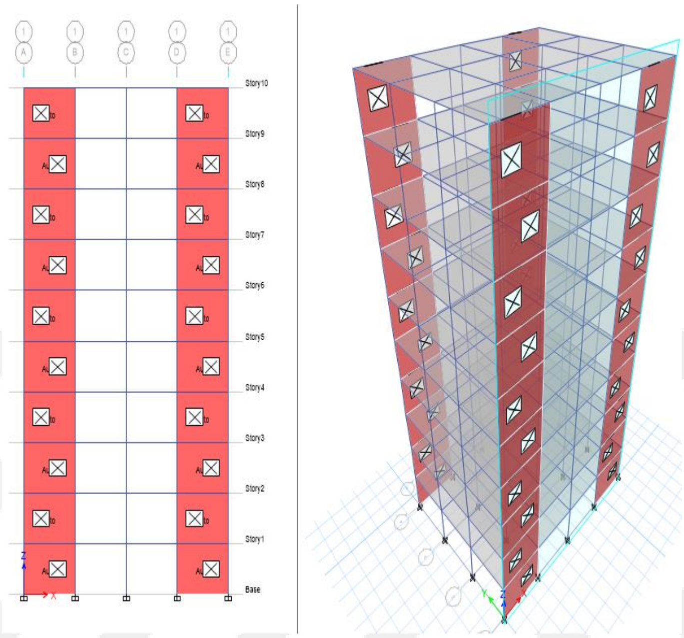
Analiz Yöntemleri

Bu çalışmada, binaların davranışlarını değerlendirmek için doğrusal olmayan zaman tanım alanı analizi kullanılmıştır. Bu yöntemde, deprem ivmesi zaman tanım alanında binalara yüklenerek yapılar analiz edilir ve tepkiler zamana bağlı olarak belirlenir. Zaman tanım alanı analizinde, deprem sırasında bina esnekliği nedeniyle yüksek modların yanısıra eylemsizlik yükleme modelindeki değişikliklerin etkisi otomatik olarak değerlendirilmektedir. Bu yöntemde, yapıya belirli bir ivme (kaydı) ile uygulanan maksimum toplam yer değiştirme belirlenir ve bu parametrenin ampirik-teorik denklemlere dayalı olarak tahmin edilmesine gerek yoktur. Bu nedenle, ivme (kaydının) ölçeklendirilmesi ve uygulanan yöntem, analiz sonuçları üzerinde doğrudan bir etkiye sahiptir.

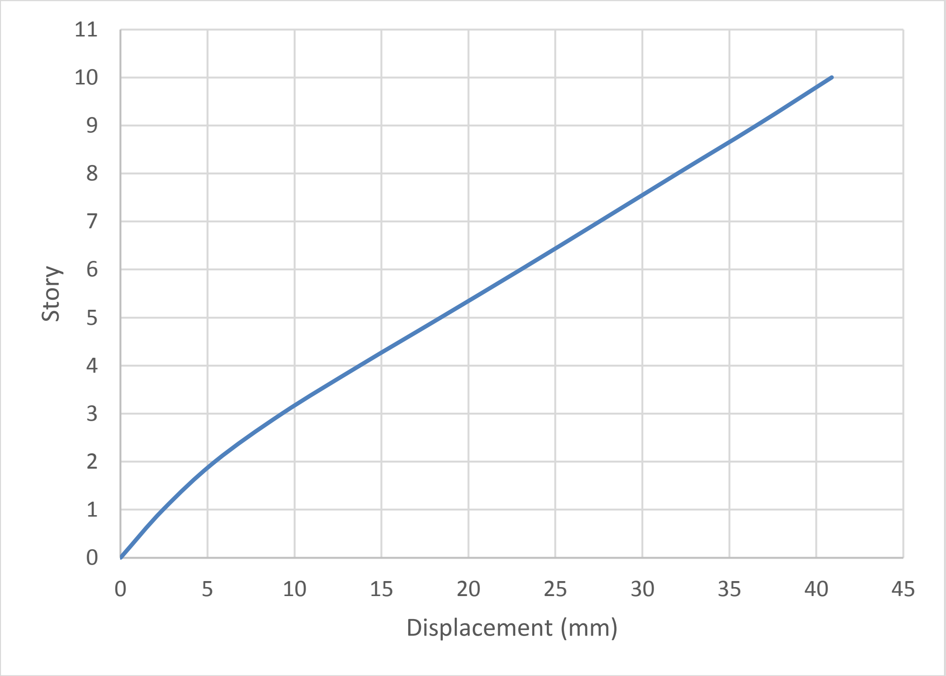
Analiz Sonuçları

Durum 3 Zikzak deseninde boşluklu perde duvarı

Model 8; zikzak boşluklu 10 katlı bina

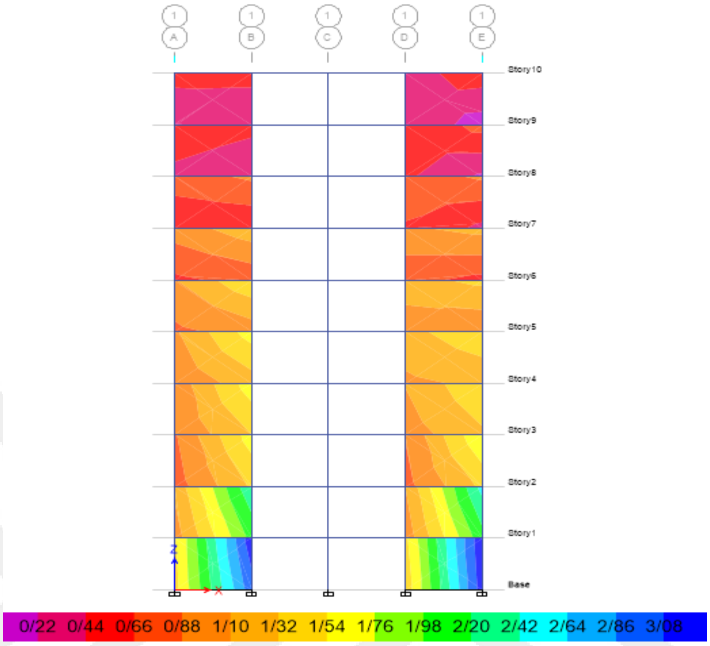


Şekil 1. Beton perde duvarlı ve zikzak boşlukları olan 10 katlı bina.



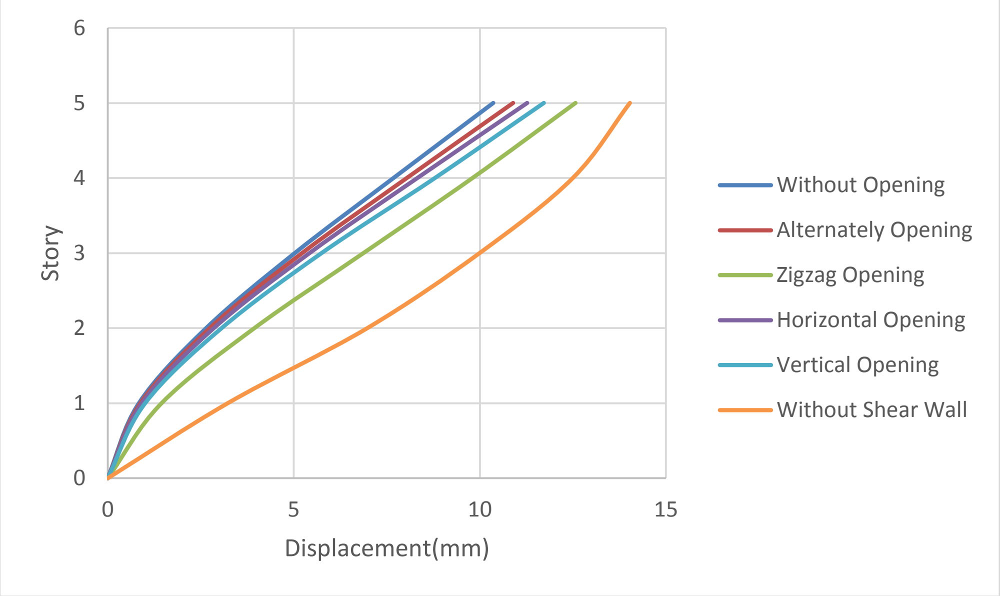
Şekil 2. 10 katlı bina için X yönünde yer değiştirme diyagramı.

Onuncu kat yerdeğiştirmesi 40.88 mm'dir ve bu diğer katların yerdeğiştirmelerinden daha fazladır. Bu eğrinin eğimine bakıldığında, yer değiştirmenin üst katlarda daha fazla olduğu görülmektedir (Şekil 2).



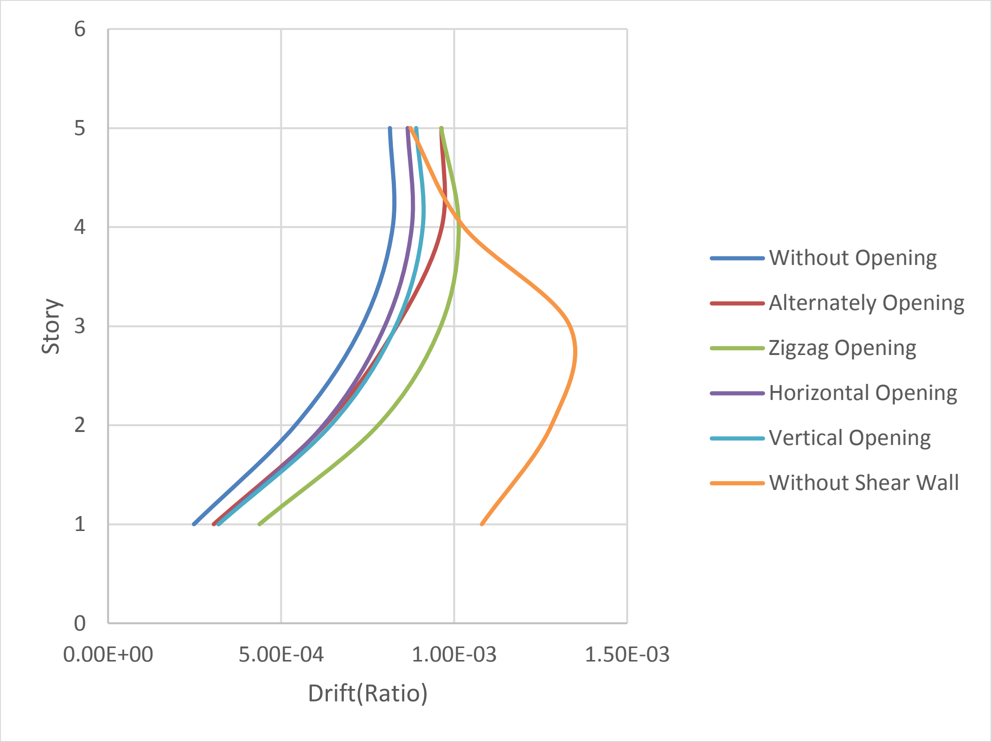
Şekil 3. On katlı bina için perde duvarlarında (σ_x) gerilme konturları.

Bulgular ve Sonuç



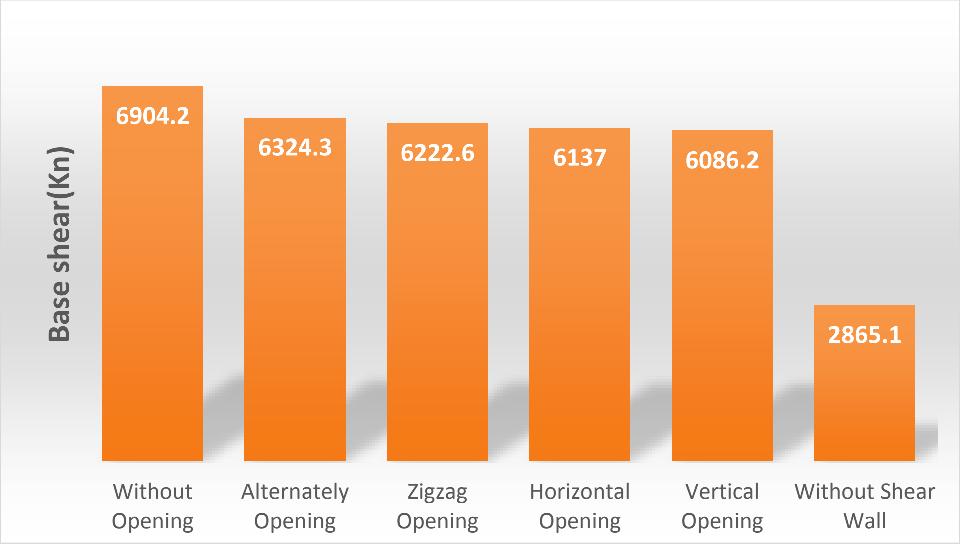
Şekil 4. Beş katlı bina için X yönündeki yer değiştirme kıyaslama diyagramı.

Şekil 4'de görüldüğü üzere, mevcut perde duvarlarının sadece moment-dirençli çerçeveli duruma kıyasla olan etkisi dikkate değerdir. Perde duvarları yapıların sismik davranışını iyileştirmede etkilidir. Dikey ve zikzak boşluklar, X doğrultusunda binaların yer değiştirmesinde, dikey ve yatay boşluklara göre daha büyük bir katkıya sahiptir. Ayrıca, zigzag, dikey ve yatay boşluklara sahip binalara göre boşluklı binalar daha az yer değiştirmektedir.



Şekil 5. Beş katlı bina için X yönündeki kayma dagisimi diyagramı.

Artan kayma sırasına göre en küçük kaymaya sahip olan diğer durumlar: % 50 boşluklara sahip bina, yatay boşluklara sahip bina, dikey boşluklara sahip bina, zikzak boşluklara sahip bina ve nihayetinde boşluk olmayan moment-dirençli çerçeveli bina (Şekil 5).



Şekil 6. Kesme duvarlarının tipine göre 15 katlı binaların kesme tabanı.

Boşlukların (zikzak, yatay veya tek sayi boşlukların) veya boşlukların ile perde duvarların (moment dirençli çerçeveler) olmaması durumunlarının, her birinin (Şekil 6), gösterildiği üzere taban kaymasının dağılımı üzerinde kendi etkileri vardır. Boşluklu olmayan olan 10, 5 ve 15 katlı binalar, maksimum taban kaymasını oluşturmuştur. Diğer durumlar arasında, tek sayi boşlukların bulunduğu durum, boşlukları olmayan olgulardan sonra, maksimum taban kesimine sahiptir. Binalarda minimum taban kesme, perde duvarli olmayan durumlarda meydana gelmiştir. Sonuç olarak, boşluklar binaların taban kesme kuvvetini arttırır.

Sonuçların özeti:

1- Minimum kayma, boşluklar olmayan binada gerçekleşti.

2- Artan sıralamayla binalardaki kaymalar şu şelikdedir: % 50 boşluklı perde duvarlar, yatay boşluklar, dikey boşluklar, zikzak boşluklar ve moment-dirençli çerçeveler.

3- 15 katlı binalardaki minimum yer değiştirme, perde duvarlarının boşluklarının olmadığı durumda gerçekleşir. Artan sıralama ile en az yer değiştiren diğer durumlar şunlardır: tek sayi boşluklı, yatay boşluklı, düşey boşluklı, zikzak boşluklı ve son olarak boşlukları olmayan moment-dirençli çerçeve.

4- 5 katlı binalarda, zigzag boşluklarının binaların yer değiştirmesindeki yatay ve dikey boşluklara oranla katkısı X yönünde daha büyüktür.

5- 10 katlı binada, yatay boşlukların dikey boşluklara göre katkısı X yönünde daha büyüktür. Ayrıca, zikzak, dikey ve yatay boşluklara sahip binalara kıyasla boşlukları olmayan binaların daha az yer değiştirmesi vardır. Boşlukları olmayan perde duvarları da minimum yer değiştirmeye sahiptir.

CURRICULUM VITAE

Zahra Rashid TAHA was born in - Erbil / Iraq, finished her secondary and high school education from Private Mathematic School Iran in 2007. The same year had accepted in Civil Engineering Department of Engineering College at Salahaddin University – Erbil. In 2012 she had graduated from Civil Engineering Department. In February 2016, she started her postgraduate study in the Civil Engineering Department, Institute of Natural and Applied Sciences at Van Yüzüncü Yıl University – VAN.

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THE INSTITUTE OF NATURAL AND APPLIED SCIENCES

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