EVALUATION OF DUCTILITY OF REINFORCED CONCRETE STRUCTURES WITH SHEAR WALLS HAVING DIFFERENT OPENING SIZES

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
AMER MOHAMMAD SHEHADAH JUM'AH

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

NICOSIA, 2019

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Approval of Director of Graduate School of Applied Sciences

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

Name, Last name: AMER JUMAH
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Date:

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ABSTRACT

Ductility is related to the concepts of strength, stiffness and structural ductility, known as the ability to predict the maximum capacity of the structure. Ductility is one of the most important properties that determine the structure capability to resist earthquake, so in this study the non-linear static analysis (pushover) were used for analyzing and designing 72 3D models and they are analyzed and compared the results to know the impact of the different sizes of the opening on the RC structure's ductility. Different parameters were also evaluated in this study. Besides examining the impacts of other parameters like the different story height, span length, compressive strength ($F'c$) and yield strength (Fy) as well as discussing them in order to find conclusions for this research. The ETABS software is applied to design and analysis the models of the RC structures located at moderate and high-risk seismic zones.

After extracting the results and discussing them, it was concluded that an increase in the value of ductility happens when the opening percentage in the buildings increases, but this increase in the ductility value increases by a greater percentage in openings such as doors than openings such as windows. Increasing the opening percentage in buildings also results in a decrease in building strength.

Keywords: Ductility; pushover curves; Non-linear static analysis; seismic analysis; ETABS software

ÖZET

Uysallık, mukavemet, katılık ve yapısal kırılganlıkların kavramları ile ilişkilidir. Yapının en yüksek kapasitesini tahmin eden, bilinen bir özelliktir. Uysallık deprem direncine karşı yapının kabiliyetini kararlaştıran en önemli özelliklerden biridir. Dolayısıyla bu çalışmada, 72 3D modellerini analiz ve dizayn edebilmek için doğrusal olmayan statik analiz kullanıldı ve demirli betonların farklı boyutların etkilerinini öğrenmek için analiz edildi ve bulunan sonuçlar kıyaslandı. Bu çalışmada ayrıca farklı parametreler de değerlendirildi. Diğer taraftan bu araştırmanın sonuçlarını bulmak için başka parametreler etkilerinin değerlendirilmesini, örneğin farklı kat yüksekliklerini, karış uzunluk, basınç ve akma mukavemetlerini, ele alır. Orta ve yüksek sismik bölgeler demirli beton yapıların modellerini analiz ve dizayn etmek için ETABS yazılımı uygulanır.

Sonuçların çıkarılması ve tartışılmasından sonra uysallık değerlerinde açılma yüzdesinin artmasıyla bir artış olduğu tespit edildi. Fakat uysallık değerlerindeki bu artış açılan kapı ve pencere gibi daha büyük bir açılma yüzdesi tarafından artırılır. Binalardaki açılma yüzdesi artışı, binanın mukavemetinde bir düşüşe neden olur.

Anahtar Kelimeler: Uysallık; basit eğriler; doğrusal olmayan statik analiz; sismik analiz; ETABS yazılımı

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LIST OF ABBREVIATIONS

ACI: American Concrete Institute

ASCE: American Society of Civil Engineers

UBC: Uniform Building Code

AIK: Korean Building Code

IBC: Indian building Congress

FEMA: Federal Emergency Management Agency

ATC: Applied Technology Council

SW: Shear Wall System

MRF: Moment Resisting Frame

MRFSW: Moment Resisting Frame with Shear wall

CHAPTER 1
INTRODUCTION

1.1 General

The earthquake represented one of the biggest dangers that threaten nature and human life. Earthquake is a phenomenon that releases a huge amount of energy through the earth in a short time; the seismic-resistant designed building must have enough strength, stiffness, ductile behavior at the time of the earthquake.

The damage doesn't depend only on the magnitude of the earthquake but also on the type of structural system, the number of the floor and the construction technique when the walls are not correctly connected to the floor and that makes the building more susceptible to the earthquake damage, the damage is mainly concentrated on the upper levels of the tall building, because the movement is bigger there, and in the building with lighter wall and roofs materials the damage during the earthquake is lesser than in the buildings with heavier materials.

The structural systems are classified as follow:

1. Structural frame system

   The structural systems consisting of frame slabs, beams and columns are the basic elements of the structural system; these frames can carry loads of gravity with enough rigidity.
2. Structural wall system

   All vertical elements of this type consist of concrete walls called shear walls.
3. Frame-shear wall system(dual system)

   This system consists of concrete reinforced frames that react with shear walls of reinforced concrete.

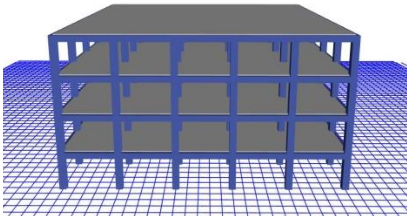


Figure 1.1: frame system

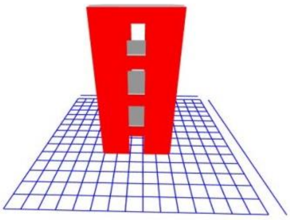


Figure 1.2: Shear wall system

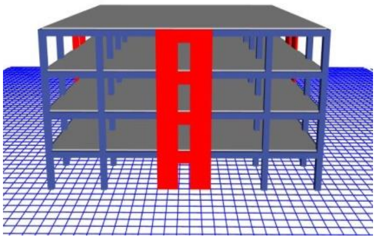


Figure 1.3: Dual system

The main purpose of all the structure system that is used in building is to support the gravity load and the most common loads that are resulted from the gravity are the dead load, the live load and snow load beside this it also subjected the lateral load caused by explosions, wind, and earthquake, so we must work on developing a structural system that will satisfy the design standards with being as efficiently and thrifty as possible. Some of the most important factors that must be looked at in seismic-resistant building are **ductility**, strength, and stiffness.

One of the emerging fields in designing seismic structure is the performance-based design. The seismic design slowly transforms from a stage where a linear elastic analysis for the structure enough for its elastic and ductile design, to a stage where the nonlinear analysis in a special method. The bases of the linear analysis approach lie on the response reduction factor(R) that for example (R=7) that means only 1/7 of the seismic force is taken, and it's also designed by ductile capacity. In reinforced concrete (RC) structure there are detailed beams and columns to ensure that the frame can take the whole impact without collapsing.

The nonlinear static pushover analysis can predict the failure mechanism and also detect the mechanism and the location of any in advance, the need for a sample methods to predict the nonlinear attitude of a structure under the seismic load and it saw the light in what that also pushover known as gradually clarify how do the failure in the structure happens and, determine the final failure pattern, and it's simple to conduct a nonlinear analysis to estimate the capacity of the structure to exceed the elastic limit, in this method the weak spots in the structure can be predicted by what is called hinges.

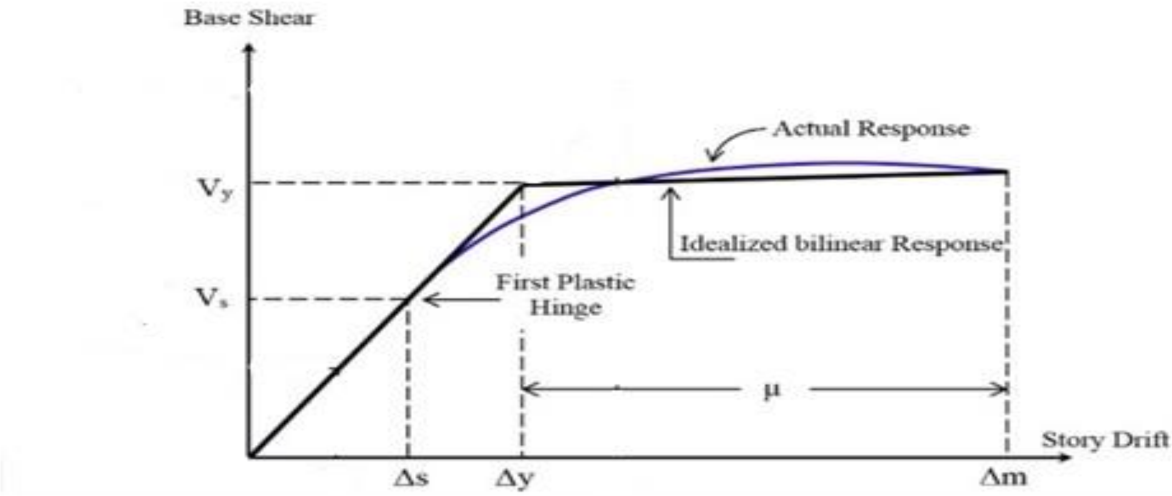


Figure 1.4: The capacity (pushover) curve with bilinear

Nonlinear static pushover analysis that considers the inelastic behavior of the building as a simple and practical tool to calculate seismic demands that imposed on the design earthquake on the structure.

Nonlinear static pushover analysis provides enough information about the strength and deformation capacity of the building and finding the yield displacement as well as the maximum displacement and that's to find the **ductility** of the structure by dividing the maximum displacement by the yield displacement.

The shear wall represented an effective structurally to support the building system because the main function of the shear wall is to increase the stiffness to resist the lateral load, to serve different architectural purposes like doors and windows. We need to make the opening in the shear wall in a different location, the size and the location of the opening might change from the architectural and functional point of view, the shear wall opening affect its attitude like changing the load shifting mechanism and changing its strength, stiffness and **ductility level**.

1.2 Problem statement

The effect of opening in shear walls on ductility with the difference in the size and type (doors, windows) of the opening isn't very clear so the **ductility** of the building will be assessed by the different types and sizes of opening and its effect will be discussed.

1.3 Objectives and scope of the thesis

The current work includes seismic evaluation for RC shear wall with different size of openings to find the **ductility** of the models with different heights (low-rise building, mid-rise building) and the different seismic zone is considered. The same section's dimensions and the same reinforcement percentage for beams and columns will be determined for similar models, to focus on the effect of different sizes of opening on **ductility** values.

The main objective of the study is to evaluate **ductility** for RC building with the change of different factors; the most important one is the difference in the size of the opening in the shear wall. The research project aims to seismic evaluation and finding of ductility of the models by using the static non-linear methods and knowing the level of effects of the different types and dimensions of the shear wall openings.

1.4 Hypothesis

- To implement the seismic analysis of (MRF) and (SW) with different sizes of openings for low-rise buildings (4-story), mid-rise building (8-story), and extracting the pushover by using the software (ETABS) at the moderate seismic zone.
- To find the **ductility** of the pushover curve for all models.
- To compare the obtained results of different sizes of openings in shear walls.
- To repetition the same previous steps but with the different seismic zone (high-risk seismic zone).

1.5 Significance of the study

Ductility is one of the most important factors in the seismic-resistant building and it affects the building's behavior during the earthquake, so this thesis provides an evaluation of the ductility in buildings with different opening sizes in shear walls and it affects the building's behavior during the earthquake.

1.6 outline of a thesis

The study presented in this thesis was separated into five chapters: Chapter 2 presents the literature reviews of topics about this study; chapter 3 presents a methodology of my study; chapter 4 present discussions and results of all models in this study; Chapter 5 Contains conclusions and recommendations for this thesis.

CHAPTER 2
LITERATURE REVIEW

2.1 Earthquake-resisting buildings

Eams and Earls (2000) when we think about destructive earthquake that happens over the centuries we always mention the amount of the casualties, as well as the losses in structures and the main reason for most of these losses, is not considering the seismic force sufficiently but now, Council (2010) specialists can design structures able to withstand these destructive seismic forces with a small amount of damage, but with remarkable extra cost that comes with it.

Fardis et al. (2005) so for the structure, the energy that represents the earthquake is required to be accommodated. The deformation happens in structure or another element in the seismic area is the reason for the damage in structure or other elements that follows an earthquake, so the Euro code 8(EN 1998-1, 2004)."It states that compliance standards should be expressed to limit the damage limit (i.e. performance level) in terms of deformation limits. For composite or chassis-mounted equipment, damage-related limits can be expressed in terms of response acceleration at the locations of the equipment supports".

King (1998) the main goal for designing buildings that are resistant to seismic forces is to keep it from collapsing when an earthquake happens by reducing casualties and injuries for people in the earthquake area. Because devastating earthquakes are rare, and so economics expect the damage to buildings but collapse should be prevented.

Omer and Amine (2013) the seismic-resistant designs are provided mainly for the inertial effects associated with the deformities resulted from the structure shaking because of the earthquake. And this inertial effect gives a reason for most of the total damage happening. But in very few cases where there is minimal inertial effect resulting in considerable damage.

Paulay (1996) the deformation capacity of a structural system and the advantages of its worldwide effect that is ductility is broadly approved. But the problem is that ductility is rarely traced or quantified even when it's very useful and can be used to save people's lives. Providing reserve deformation capacity is the main purpose with no considerable decline in the resistance to the lateral forces. In areas of the high risk of earthquake, deformation capacity is the most valuable property where the economic restraints limit how much seismic resistance that can be afforded.

2.2 Reinforced Concrete frame building

Fanella et al. (2011) in any structure, the structure members must stand the entire load on the structure including the inhabitant's live load, the building's dead load, and the wind or earthquake lateral load. But, in some buildings, the structure must be designed for unusual loads like vehicular impact or explosions. Typically, the reinforced concrete structure is composed of different RC members and the soil or the rock around the structure foundation is the main support for the loads that are applied on the structural members that transfer it to the foundation then to the soil or rocks around it.

Indian building Congress (2007) in high buildings, the importance of lateral forces increases with the increase of the building's height. In such buildings, the traditional load-bearing walls won't be viable because these masonry walls need to be very thick in the lower stores. And building such thick masonry walls won't only cost more, but it will decrease the size of the rooms and increase the mass so it will attract more seismic forces. So in these situations, the load-bearing walls won't be as suitable as frames as shear walls system. So, in the high-risk seismic zone, it's better to use a framed construction even in a short building (one story or two stores).

Xu and Niu (2003) to resist seismic forces the moment resisting reinforced concrete frames are more commonly used as a major element or with sheer walls.

Indian building Congress (2007) recently earthquakes (seismic loads) and wind loads exposed serious flaws in the buildings constructed in the recent past, because of the less attention to seismic and wind forces in many low and medium-rise framed buildings. But now, the need to design seismic loads in accordance with the prevailing codes of practice is more realized.

2.3 Reinforced Concrete Shear Wall

Rana et al. (2004) a nonlinear static analysis was done in San Francisco to an RC building with 19 floors and RC frames with shear walls (dual system) were used. With a total area of 430,000 ft^2, and the building was designed by UBC97. The analysis was done in the life safety performance level to check the requirement and guidelines when the building is exposed to seismic design.

Lee et al. (2007) his study contained a comparison between three analytical models with 17-story of RC walls and having different bottom floor's irregularity when undergoing the same seismic load. The first analytical model is composed of a frame structural system, the second model composed of a dual system with shear walls in exterior frames. After the test was done, the results showed that the fundamental time periods for other models except for the mention models were found to be accepted in UBC97 and AIK2000. The damage energy absorption regardless of whether the shear wall existed or where it's located was similar. Shear deformation following overturning causes the absorption of a huge amount of energy. The stiff system of the upper story provided the collapsing behavior of the lower story. Hence, the structure weight forms about 23% of resistance against.

Esmaili et al. (2008) the structural features of an RC 56- story building in a high seismic area were studied. In this study shear wall and an irregular opening, the system was provided for gravity loads and lateral loads. These conditions resulted in concerns towards the coupling beams and many more aspects. The seismic criteria were broken down into multiple nonlinear analyses which were used to judge the behavior of the structure with prevailing retrofitting provisions as per FEMA 356. The study assessed the load-bearing system with features that were considered and accessible. Later on in the study, the ductility levels of the shear wall were described in this study.

Fahjan et al. (2010) after an in-depth study of multiple different modeling approaches the linear and nonlinear shear wall behavior for structure analysis. The complete structural behavior of the system correlates to using different models and different modeling approaches that were collected and equated.

Gonzales and Almansa (2012) did research aiming to provide knowledge seismic rules and regulations for a design for thin-wall structure buildings. Beginning goals were to track seismic behavior for structures and to portray the preliminary assessment towards design and to spread the study towards a great extent for further research. The investigation focuses on buildings that were located in Peru which were contrasted against the circumstances in other countries. The weaknesses of multiple buildings were examined using nonlinear static and dynamic analysis for characteristics that were obtained from testing data. The outcome portrayed was that the building has a low seismic capacity. Seismic performance may be enhanced by minor corrections in the configuration of the structure. Cheap and effective design solutions were dispensed.

Martinelli et al. (2013) studied the proficiency between two characteristics of fiber-beam-column finite elements which were used to simulate the dynamic performance of a shear wall exhausting the shake Table test.

Todut et al. (2014) the outcome of the program studied the seismic performance for RC wall panels with and without openings. The features and configuration of the specimen were sampled from a very widely used Romanian project since 1981 and were scaled 1:1:2 owed to constraints which were dictated by laboratory facilities. This kind of precast wall panels was mostly implemented in residential buildings which has multiple flats that were built from 1981 to 1989. The capability of these tested panels disclosed a shear failure that was impacted by the type of opening and there was also a noticeable absence of reinforcement in some areas. Numerical analysis was carried out to create a model foreseeing conduct in precast concrete RC shear walls of various sizes.

2.4 Beam-columns joints in RC frame buildings

Meher (2008) the column together with the slab that lies deep in the beam that gets enclosed into a column that all forms the RC joint.

Jain and Uma (2006) in the structure, beam-column joints in an RC moment-resisting frame are an important area for transferring loads between connecting elements (I.e. Beams and columns) efficiently. In normal design practice, the gravity load design check is not certain since it's considered not important. During some earthquakes a shear in joint during a collapse it results in the RC frames failure. And there is a disagreement in different parts of the design as shown in related research results on beam-column joints from various countries. So, many programs were directed towards this issue on the design disagreement to solve the problem by many researchers from different countries.

Uma (2015) the beam-column joints are divided into the interior, exterior and corner joints with respect to geometric configuration, and it's shown in Figure 2.1.

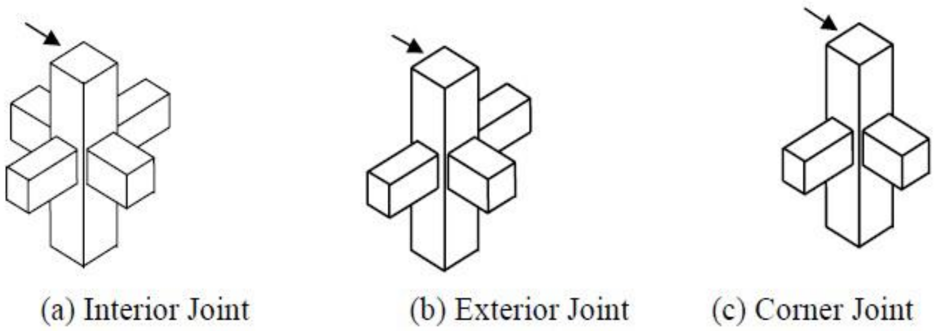


Figure 2.1: Types of Joints in an MRF Uma (2015)

Uma (2015) the intersection zone between beams and columns is the functional requirements of a joint in the RC moment-resisting frame structure; it's to allow attached members to reach ultimate capacity. The demand for this fixed size item is very intense and complicated due to the action of the 3D frame structures. And finally, what considers one direction of loading at a time and arrive at the design parameters for the joint are the codes.

Pak and Chemung (1991) the beams-columns typically undergo great shear force resulted from the lateral loads of earthquakes in moment-resisting frames. And this is illustrated in Figure 7 for typical planar frame joints. For the fast strength degradation that they suffer for the limited energy dissipation properties, it got the reinforced concrete beam-column joints to undergo inelastic deformations. So for the earthquakes resistance designed moment-resisting frame structures when any inelastic deformation happen it required to be in any other area than the beam-column joints.

Megget and Brooke (2004) in New Zealand they suggested some years ago a few criteria for beam-column joints which are defined as follows:

1- The joint strength should be more than the weakest member connected to it, to stop the necessity to repair less accessible regions and to the necessity to dissipate energy by strength and stiffness degradation mechanism when undergoing cyclic loading in the inelastic range.
2- The column capacity shouldn’t be threatened by potential joint's strength degradation.
3- The joints must respond within its elastic range in a moderate earthquake because the deformation must not affect the structure stiffness that leads to the inter-story shift.
4- The joint must be reinforced to evade any needless problems in construction and also to guarantee sufficient performance.

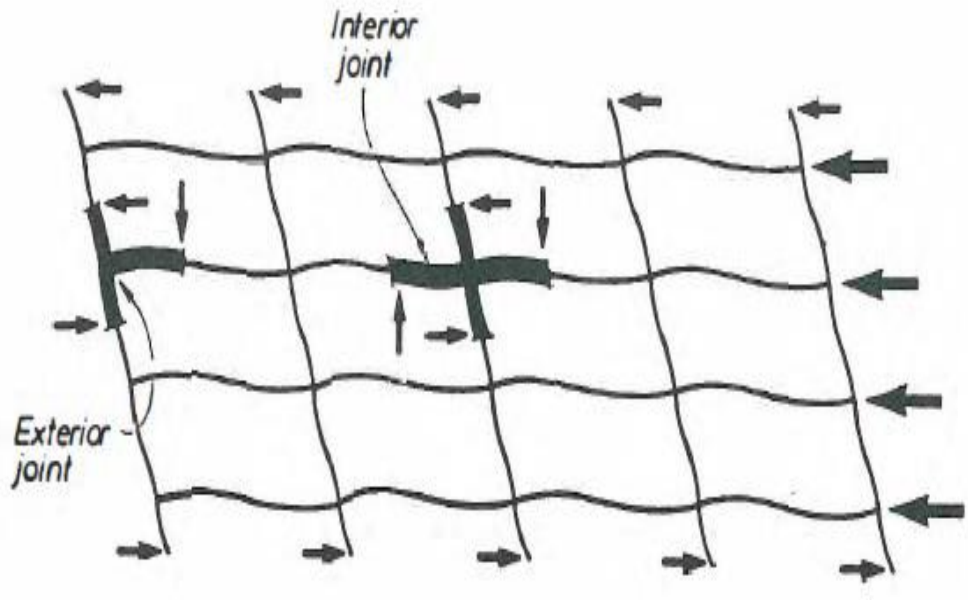


Figure 2.2: Joint between Beam and Column of a Ductile MRF Subjected to Lateral Loads. Pak and Cheung (1991)

2.5 Effects of the openings in the shear walls

Adrian Beckon and Peter Roško (2011) proposes a simplified way of analyzing large shear wall-frame structures with regular openings, this method consumes an essential structure in a collection of platforms comparable to platforms whose solidity properties are assessed from limited component tests, This ideal structure with imperforated cantilever wall having equivalent firmness properties, this ideal structure with imperforated cantilever wall having equivalent firmness properties, then analyzed by hand by engineering theory of bending for design deflections and stresses. It was discovered that this method is only suitable for wall framed structures with a height-to-width ratio of more than 2 plus more than 2 vertical opening bands. This method would be less accurate if the ratios b / B and h / H is less than 0.25 each, which in this case would make a plane frame analysis more appropriate.

J. Kobaynshi, T. Korenag, A. Shibata, K. Akino, T. Tiara (1995) 26 wall samples were examined in reactor structures to test the effect of the small opening on the stiffness and strength of its sheer walls. The openings' shape, number, arrangement and the reinforcing technique around the openings all these parameters were tested. Reversed cyclic loads were applied to the samples, and to understand these parameters effects based on the test results a comparison of their strength and restoring force properties with each other were done, and two methods for predicting the shear strength of walls with several small openings are examined. The first method is to calculate the strength directly along expected failure lines, the second method agree to estimate the design strength reduction factors, taking into account the effect of openings. The two methods are useful for estimating the strength of such shear walls. And such walls stiffness can be assessed using a combined multi-spring model, but a simplified reinforcing method can be used for the reinforcing methods around openings, and by checking the contribution of the reinforcement to the wall strength the method effectiveness can be discussed. Therefore, the authors stated that the strength decrease as a result of small openings in the shear wall can't be assessed by the loss ratio in the horizontal cross-section. Scattered small openings affect strength if they were positioned close to each other, the test results do approve the predicted strength obtained by assuming the failure lines in walls, as long as the failure lines are formed as expected. The likelihood of estimating the stiffness of walls with openings is established by a simple multi-spring model.

Clark (1997) to test ultimate load capacity and stiffness four different wall configurations including multiple openings and with one control wall with no openings were examined. The lengths for all the walls were 40 feet that contains a tie-down anchorage at the extreme ends of the wall. Two replications of the five wall designs were fabricated.

1. Monotonic displacement pattern
2. Sequential phased displacement pattern.

For a given wall configuration, a better understanding of the effect of monotonic and cyclic loading on ultimate load capacity and stiffness and the association between the two loading types were tested. For designing a competent shear wall, it must identify the effect of openings on shear wall performance.

Qamaruddin.M (1998) invented a new way of determining the in-plane stiffness of shear wall with openings, assuming that the spandrels are elastic, And under lateral load can interpret and rotate. The new method provides very different in-plain stiffness of shear wall with openings results which are very different than the results provided from the other well-known methods. The linear elastic finite element method that determines the in-plane stiffness of the wall which goes well with results obtained by the new method, using the new method design charts, the in-plane stiffness of the shear wall with openings was estimated.

Kim and Lee (2003) proposed a new efficient analysis method to analyze shear walls with openings by the use of super elements that were introduced by fictitious beams, using the matrix condensation technique. Multiple different models were analyzed to determine the accuracy and efficiency of the proposed method.

Balkaya and Erol (2004) during the 3D action, the flexibility of the diaphragm and the transverse walls and slab walls interaction performance were investigated as well as the effect of 3D and 2D modeling on the capacity assessment. The importance of different openings' size and position along the wall having multiple reinforcement ratios were clarified in this study. The increasing global lateral resistance, which is significantly influenced by the tension-compression coupling effect that is caused by the interaction between wall-to-wall and wall-to-slab. This study results showed that the stress flow and crack designs around the openings of the 3D models were extremely different than those for the 2D models.

Hyun Kim, Dongguan Lee, Chee Kyeong Kim (2005) For the analysis of structures with the shear wall with openings a refined finite element model must be done but for high-rise buildings, it would take a huge amount of computing time and memory if the whole structure were subdivided into a finer mesh. So a new method was proposed in this study that can efficiently analyze the high-rise structures with shear walls with openings no matter the size, numbers or the position of the openings along the wall. This method uses substructures, super elements, and fictitious beams. To prove the accuracy of this method, static analysis, and dynamic analysis were done to example models with several kinds of openings.

2.6 Ductility of Reinforced Concrete Frame Buildings

Department of Public Works (2002) the ductility represents the structure ability to undergo inelastic deformation without collapsing by having enough strength to support the structure's loads even if the building was damaged.

Iskhakov (2003) during a strong earthquake, the structure should have inelastic behavior (economical resistance) we can use average plastic energy, dissipated during the design ground motion by the structure for performance evaluation and to gather information. There are two important key points for RC structure failure mode control, including suppression of brittle failure mode in which it delivers an appropriate amount of ductility. Detailed members should be provided after estimating ductility to have the proper section ductility.

Mantawy (2015) the plastic hinges are the main energy absorption source to provide a ductile response during an earthquake loading cycle, which is used by the present design practice. In addition, careful details should be given for expecting the plastic hinges possible locations. Structures should resist minor to moderate earthquakes without damage or at most without serious damage or collapsing, and that all according to the seismic design provisions in modern building codes.

Sextos and Skoulidou (2012) the response range that is decreased appropriately by the behavior factor (q in Europe) or force reduction factor (R in the U.S) which will cause the spectral accelerations. The stable energy absorption is possible by specific geometric and minimum reinforcement requirements with the related detailing rules are depending on the lower level of strength structural design. Some essential requirements can be accomplished to improve the global ductility in the capacity design (I.e. avoiding collapse, limiting damage and a minimum level of serviceability).

Vaseva (2003) carrying out an equivalent elastic in the place of inelastic analysis is required by the use of the q factor which considered a quite simple tool for designers as it signifies an international characteristic of structural behavior.

$$\mu_{\Delta} = \frac{\Delta_u}{\Delta_y}$$

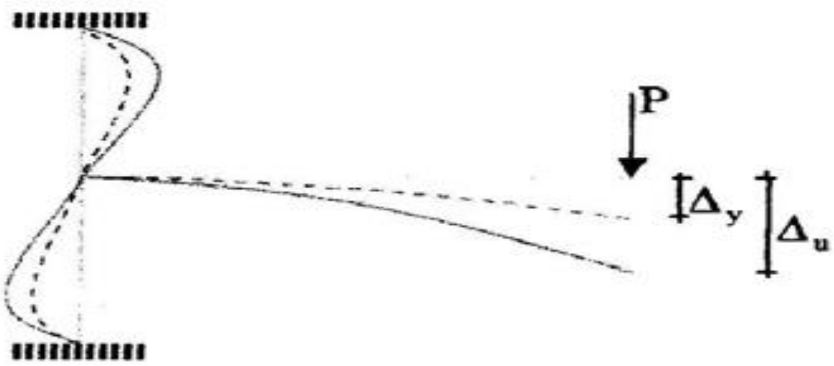


Figure 2.3: Ductility displacement of a beam

2.7 Non-linear static pushover analysis

Jianguo et al. (2006) got a rectangular steel tube filled with concrete to examine its behavior. 10 floors moment-resisting frame consist of CFRT columns with steel beams were analyzed using pushover analysis. It turned out that the pushover analysis was sensitive to lateral load patterns, so it was suggested that two load patterns must be used which is expected to bound the inertia force distributions. Pushover analysis was discovered to use in estimating the characteristics of a structure as follow:

1- Capacity of the structure as characterized by the base shear versus the top displacement graph,
2- Ultimate rotation and ductility of the critical components,
3- Distribution of plastic hinges at the ultimate load; and
4- Distribution of damage in the structure as expressed in local damage indices at the ultimate load.

During an earthquake, plastic hinges form usually at the beams and columns end in a frame structure. Plastic hinges commonly caused by uniaxial bending moments for the beam elements, but for the column elements, the plastic hinges are caused commonly by axial loads and biaxial bending moments.

Chugh (2004) after explaining the effectiveness of non-linear analysis for seismic design of structures suggesting the following:

- Linear performance is limited to a small response area
- When the stresses are excessive, material nonlinearity exposes.
- At large displacements, geometric nonlinearity reveals.

A residual response will still be left in a large response area if the loading is removed. As soon as the yielding occurs, the linear elastic analysis of a structure will not be valid and the statically uncertain structures enter an inelastic stage. Designing a structure based on the elastic spectrum would be too expensive, where the code (IS 1893) allowing the use of the reduction factor R to decrease the seismic loads. By using the non-linear analysis this decrease will be possible without structural collapse providing enough ductility and to get the correct response, which is called limited analysis.

Sadjadi et al (2006) proposed a nonlinear static analysis, also known as a pushover analysis, that involving pushing of the structure in the same direction with a specific lateral force or displacement distribution until a specified drift is achieved or a numerical instability has happened. To study the assemblage behavior one effective way is the pushover analysis, putting emphasis on the order of cracking and yielding of the members as the base shear value rises. The acquired information can later be used to estimate the structure performance as well as knowing the inelastic deformation locations and getting a general idea of the general capacity of the structure. The pushover analysis finds the possible sites to be exposed to large inelastic deformation, which helps to evaluate the structure's performance and the component detailing design. The pushover test for irregular structures will not be accurate because the pushover inter-story drift distributions are mainly the first mode and the dynamic inter-story drift distributions contain considerable second mode influences.

Bansal (2011) preferred Pushover analysis as the method for studying seismic performance of structures by the main restoration guidelines and codes because it is generally easy this pushover analysis method where is the computer model after being exposed to lateral load that its intensity progressively rise and the sequence of cracks, plastic hinge formation, yielding and structure component failure will all be recorded.

Mehmet et al. (2006) explained that the structural engineers have been using the static non-linear analysis method due to how easy it is. The pushover analysis is done for several nonlinear hinge characters accessible in specific programs based on the guidelines of the FEMA-356 and ATC-40 he also mentioned that Plastic hinge length has substantial effects on the displacement capacity of the structures. Because of the default-hinge characteristics, so the arrangement and the axial load degree of the column cannot be considered correct.

Shuraim et al. (2007) utilized the nonlinear static analysis as to how ATC-40 introduced it to estimate the existing design of a fresh reinforced concrete frame when it was exposed to a moderate seismic load then assessed by the static non-linear tactics. The design was evaluated in this method by redesigning the model under designated seismic mixture as to show which component needs more reinforcement. Most of the columns when undergoing seismic forces needed substantial added reinforcement to signify their weakness. The pushover procedure shows that the frame is capable of tolerating the assumed seismic force with some substantial yielding at all beams and one column.

Kadid and Boumrkik (2008) proposed the use of static non-linear analysis as a possible way to judge damage liability of a building designed according to Algerian code. Pushover analysis was a Sequence of accumulative static analysis accomplished to improve a capacity curve for the structure. Based on that capacity curve, an estimate of the displacement on the obtained building that is produced by the design earthquake. The damage that the structure underwent at this target displacement represents the Damage that the structure experience when underwent a design level earthquake. When subjecting an RC structure to seismic loads its behavior could be greatly inelastic, plastic yielding effects would dominate the total inelastic performance of reinforced concrete structures and as consequence, the ability of the analytical models to stop these effects would affect the pushover analysis accuracy.

CHAPTER 3
METHODOLOGY

3.1 Introduction

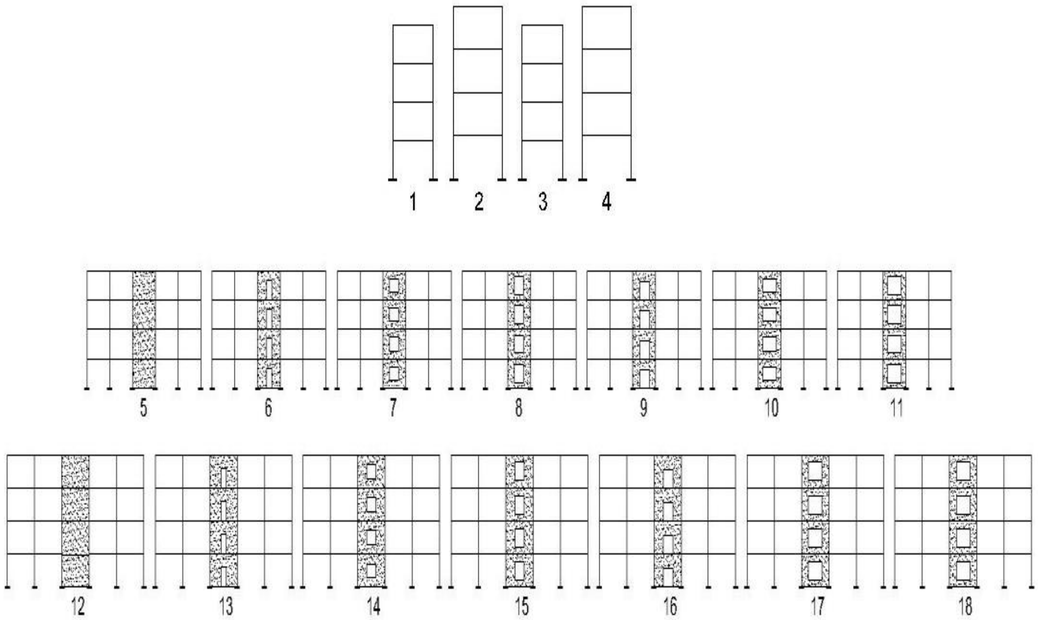
In the research, RC moment-resisting frame (MRF) system and dual system (MRFSW) with opening were studied and an analysis was done to determine yield displacement, maximum displacement and ductility for different openings models in different seismic zone, and 72 models were designed to identify the effect of the sizes of the different openings, stories height, compressive strength, yield strength and span length using ACI 318-08, ASCE 7-10, UBC97 codes in this study.

3.2 Building configuration

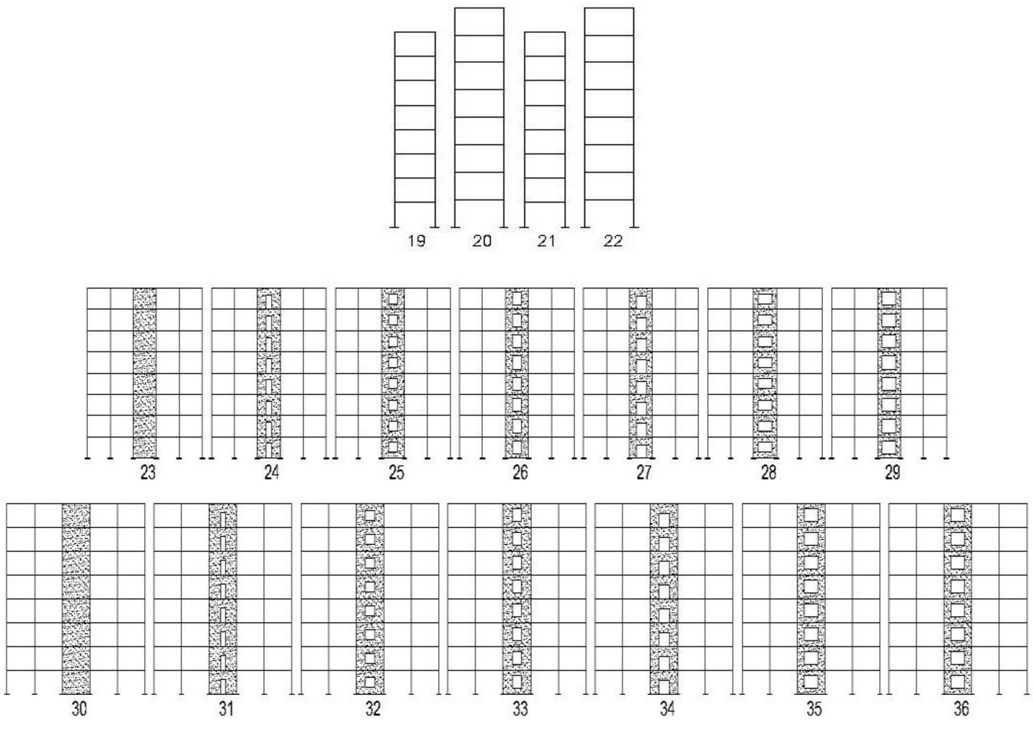
Three types of structural systems are chosen in this study: moment resisting frame system (MRF), shear walls system (SW) and the dual system (MRFSW) for the four-story buildings and the eight-story buildings. With different numbers of spans for each type one or five spans with 5m or 6m, and 3.2m or 3.6m for the story height at the high-risk seismic zone and the moderate seismic zone which is shown in Figure 3.1a and 3.1b.

3.2.1 Material properties

Two different yield strength (3000, 4200 Kgf/cm^2) and compressive strengths (250, 300 Kgf/cm^2) are used. In the following table, 3.1 more details are shown about the studied building in this section.



(a)



(b)

Figure 3.1: The various structure models adopted for building height: (a) low-rise (4-story) (b) mid-rise (8-story) building.

Table 3.1: Details of the buildings studied: low- rise building (4-story) and mid-rise building (8-story) at a moderate and high-risk seismic zone

NUMBER OF MODELS		STORY HEIGHT (m)	NUMBER OF SPAN	SPAN LENGTH (m)	F'c (Kgf/cm^2)	FY (Kgf/cm^2)	THICKNESS OF THE SHEAR WALL (m)	OPENING SIZE (width x height) (m)
LOW-RISE BUILDING	MID-RISE BUILDING							
1	**19**	3.2	1	5	250	3000	-	-
2	**20**	3.6	1	6	250	3000	-	-
3	**21**	3.2	1	5	300	4200	-	-
4	**22**	3.6	1	6	300	4200	-	-
5	**23**	3.2	5	5	250	3000	0.250	-
6	**24**	3.2	5	5	250	3000	0.250	2.2X1.1
7	**25**	3.2	5	5	250	3000	0.250	1.5X1.1
8	**26**	3.2	5	5	250	3000	0.250	2.0X2.0
9	**27**	3.2	5	5	250	3000	0.250	2.2X2.0
10	**28**	3.2	5	5	250	3000	0.250	1.5X3.0
11	**29**	3.2	5	5	250	3000	0.250	2.0X3.0
12	**30**	3.6	5	6	300	4200	0.300	-
13	**31**	3.6	5	6	300	4200	0.300	2.2X1.1
14	**33**	3.6	5	6	300	4200	0.300	1.5X1.1
15	**34**	3.6	5	6	300	4200	0.300	2.0X2.0
16	**34**	3.6	5	6	300	4200	0.300	2.2X2.0
17	**35**	3.6	5	6	300	4200	0.300	1.5X3.0
18	**36**	3.6	5	6	300	4200	0.300	2.0X3.0

3.2.2 Reinforcement details of the models

The structures are designed according to ACI318-14, the beams and columns are designed according to the approach to capacity design. The Tables 3.2 to 3.5 shows the details of beams and columns reinforcement for low-rise buildings (4-story) and mid-rise buildings (8-story) at a moderate seismic zone and the Tables 3.6 to 3.9 shows the details of beams and columns reinforcement at a high-risk seismic zone in this chapter.

Table 3.2: The Details of beams reinforcement for the low-rise buildings (4-story) at moderate seismic zone

MODEL NO.	SECTION SIZE (mm)	LONGITUDINAL REINFORCEMENT		SHEAR REINFORCEMENT
		TOP	BOTTOM	
1	350X400	6 Ø22	4 Ø20	Ø10 @125 mm
2	350X400	6 Ø22	4 Ø18	Ø10 @100 mm
3	350X400	6 Ø20	4 Ø18	Ø10 @125 mm
4	350X400	6 Ø20	4 Ø18	Ø10 @100 mm
5	350X400	8 Ø20	4 Ø20	Ø12 @75 mm
6	350X400	8 Ø20	4 Ø20	Ø12 @75 mm
7	350X400	8 Ø20	4 Ø20	Ø12 @75 mm
8	350X400	8 Ø20	4 Ø20	Ø12 @75 mm
9	350X400	8 Ø20	4 Ø20	Ø12 @75 mm
10	350X400	6 Ø20	4 Ø20	Ø12 @75 mm
11	350X400	6 Ø20	4 Ø20	Ø12 @75 mm
12	400X450	8 Ø20	4 Ø20	Ø12 @100 mm
13	400X450	8 Ø20	4 Ø20	Ø12 @100 mm
14	400X450	8 Ø20	4 Ø20	Ø12 @100 mm
15	400X450	8 Ø20	4 Ø20	Ø12 @100 mm
16	400X450	8 Ø20	4 Ø20	Ø12 @100 mm
17	400X450	6 Ø20	4 Ø20	Ø12 @100 mm
18	400X450	6 Ø20	4 Ø20	Ø12 @100 mm

Table 3.3: The Details of beams reinforcement for the mid-rise buildings (8-story) at moderate seismic zone

MODEL NO.	SECTION SIZE (mm)	LONGITUDINAL REINFORCEMENT		SHEAR REINFORCEMENT
		TOP	BOTTOM	
19	450X450	6 Ø22	4 Ø18	Ø10 @150 mm
20	450X450	6 Ø25	6 Ø18	Ø10 @150 mm
21	450X450	6 Ø18	4 Ø16	Ø10 @150 mm
22	450X450	7 Ø20	4 Ø18	Ø10 @150 mm
23	400X450	6 Ø22	5 Ø18	Ø10 @150 mm
24	400X450	6 Ø22	5 Ø18	Ø10 @150 mm
25	400X450	6 Ø22	4 Ø18	Ø10 @150 mm
26	400X450	6 Ø22	4 Ø18	Ø10 @150 mm
27	400X450	6 Ø22	4 Ø18	Ø10 @150 mm
28	400X450	5 Ø22	5 Ø18	Ø10 @150 mm
29	400X450	6 Ø22	4 Ø18	Ø10 @150 mm
30	450X500	6 Ø22	4 Ø18	Ø10 @150 mm
31	450X500	6 Ø22	4 Ø18	Ø10 @150 mm
32	450X500	6 Ø22	4 Ø18	Ø10 @150 mm
33	450X500	6 Ø22	4 Ø18	Ø10 @150 mm
34	450X500	6 Ø22	4 Ø18	Ø10 @150 mm
35	450X500	6 Ø22	4 Ø18	Ø10 @150 mm
36	450X500	6 Ø22	4 Ø18	Ø10 @150 mm

Table 3.4: The Details of columns reinforcement for the low-rise buildings (4-story) at moderate seismic zone

MODEL NO.	SECTION SIZE	LONGITUDINAL REINFORCEMENT	SHEAR REINFORCEMENT
1	400X400	10 Ø20	Ø10 @150 mm
2	400X400	10 Ø20	Ø10 @150 mm
3	400X400	10 Ø20	Ø10 @150 mm
4	400X400	10 Ø20	Ø10 @150 mm
5	400X400	8 Ø20	Ø10 @200 mm
6	400X400	8 Ø20	Ø10 @200 mm
7	400X400	8 Ø20	Ø10 @200 mm
8	400X400	8 Ø20	Ø10 @200 mm
9	400X400	8 Ø20	Ø10 @200 mm
10	400X400	8 Ø20	Ø10 @200 mm
11	400X400	8 Ø20	Ø10 @200 mm
12	450X450	8 Ø20	Ø10 @200 mm
13	450X450	8 Ø20	Ø10 @200 mm
14	450X450	8 Ø20	Ø10 @200 mm
15	450X450	8 Ø20	Ø10 @200 mm
16	450X450	8 Ø20	Ø10 @200 mm
17	450X450	8 Ø20	Ø10 @200 mm
18	450X450	8 Ø20	Ø10 @200 mm

Table 3.5: The Details of columns reinforcement for the mid-rise buildings (8-story) at moderate seismic zone

MODEL NO.	SECTION SIZE	LONGITUDINAL REINFORCEMENT	SHEAR REINFORCEMENT
19	450X450	12 Ø22	Ø10 @150 mm
20	450X450	12 Ø22	Ø10 @150 mm
21	450X450	12 Ø22	Ø10 @150 mm
22	450X450	12 Ø22	Ø10 @150 mm
23	450X450	12 Ø20	Ø10 @200 mm
24	450X450	12 Ø20	Ø10 @200 mm
25	450X450	12 Ø20	Ø10 @200 mm
26	450X450	12 Ø20	Ø10 @200 mm
27	450X450	12 Ø20	Ø10 @200 mm
28	450X450	12 Ø20	Ø10 @200 mm
29	450X450	12 Ø20	Ø10 @200 mm
30	500X500	12 Ø20	Ø10 @200 mm
31	500X500	12 Ø20	Ø10 @200 mm
32	500X500	12 Ø20	Ø10 @200 mm
33	500X500	12 Ø20	Ø10 @200 mm
34	500X500	12 Ø20	Ø10 @200 mm
35	500X500	12 Ø20	Ø10 @200 mm
36	500X500	12 Ø20	Ø10 @200 mm

Table 3.6: The Details of beams reinforcement for the low-rise buildings (4-story) at high-risk seismic zone

MODEL NO.	SECTION SIZE (mm)	LONGITUDINAL REINFORCEMENT		SHEAR REINFORCEMENT
		TOP	BOTTOM	
1	450X500	6 Ø22	4 Ø20	Ø10 @150 mm
2	450X500	7 Ø25	4 Ø22	Ø10 @150 mm
3	450X500	6 Ø20	4 Ø16	Ø10 @150 mm
4	450X500	6 Ø22	4 Ø20	Ø10 @150 mm
5	400X450	6 Ø22	4 Ø18	Ø10 @150 mm
6	400X450	6 Ø22	4 Ø18	Ø10 @150 mm
7	400X450	6 Ø22	4 Ø18	Ø10 @150 mm
8	400X450	6 Ø22	4 Ø18	Ø10 @150 mm
9	400X450	6 Ø22	4 Ø18	Ø10 @150 mm
10	400X450	6 Ø22	4 Ø18	Ø10 @150 mm
11	400X450	6 Ø22	4 Ø18	Ø10 @150 mm
12	450X500	6 Ø22	4 Ø18	Ø10 @150 mm
13	450X500	6 Ø22	4 Ø18	Ø10 @150 mm
14	450X500	6 Ø22	4 Ø18	Ø10 @150 mm
15	450X500	6 Ø22	4 Ø18	Ø10 @150 mm
16	450X500	6 Ø22	4 Ø18	Ø10 @150 mm
17	450X500	6 Ø22	4 Ø18	Ø10 @150 mm
18	450X500	6 Ø22	4 Ø18	Ø10 @150 mm

Table 3.7: The Details of beams reinforcement for the mid-rise buildings (8-story) at high-risk seismic zone

MODEL NO.	SECTION SIZE (mm)	LONGITUDINAL REINFORCEMENT		SHEAR REINFORCEMENT
		TOP	BOTTOM	
19	500X550	6 Ø22	4 Ø20	Ø10 @150 mm
20	500X550	6 Ø25	5 Ø20	Ø10 @150 mm
21	500X550	4 Ø18	4 Ø18	Ø10 @150 mm
22	500X550	6 Ø22	4 Ø18	Ø10 @150 mm
23	450X500	6 Ø20	4 Ø18	Ø10 @150 mm
24	450X500	6 Ø20	4 Ø18	Ø10 @150 mm
25	450X500	6 Ø20	4 Ø18	Ø10 @150 mm
26	450X500	6 Ø20	4 Ø18	Ø10 @150 mm
27	450X500	6 Ø20	4 Ø18	Ø10 @150 mm
28	450X500	6 Ø20	4 Ø18	Ø10 @150 mm
29	450X500	6 Ø20	4 Ø18	Ø10 @150 mm
30	500X550	5 Ø20	4 Ø16	Ø10 @150 mm
31	500X550	6 Ø20	4 Ø16	Ø10 @150 mm
32	500X550	6 Ø20	4 Ø18	Ø10 @150 mm
33	500X550	6 Ø20	4 Ø18	Ø10 @150 mm
34	500X550	6 Ø20	4 Ø18	Ø10 @150 mm
35	500X550	6 Ø20	4 Ø18	Ø10 @150 mm
36	500X550	6 Ø20	4 Ø18	Ø10 @150 mm

Table 3.8: The Details of columns reinforcement for the low-rise buildings (4-story) at high-risk seismic zone

MODEL NO.	SECTION SIZE	LONGITUDINAL REINFORCEMENT	SHEAR REINFORCEMENT
1	500X500	12 Ø22	Ø12 @150 mm
2	500X500	12 Ø22	Ø12 @150 mm
3	500X500	12 Ø22	Ø12 @150 mm
4	500X500	12 Ø22	Ø12 @150 mm
5	450X450	8 Ø22	Ø12 @200 mm
6	450X450	8 Ø22	Ø12 @200 mm
7	450X450	8 Ø22	Ø12 @200 mm
8	450X450	8 Ø22	Ø12 @200 mm
9	450X450	8 Ø22	Ø12 @200 mm
10	450X450	8 Ø22	Ø12 @200 mm
11	450X450	8 Ø22	Ø12 @200 mm
12	500X500	8 Ø22	Ø12 @200mm
13	500X500	8 Ø22	Ø12 @200mm
14	500X500	8 Ø22	Ø12 @200mm
15	500X500	8 Ø22	Ø12 @200mm
16	500X500	8 Ø22	Ø12 @200mm
17	500X500	8 Ø22	Ø12 @200mm
18	500X500	8 Ø22	Ø12 @200mm

Table 3.9: The Details of columns reinforcement for the mid-rise buildings (8-story) at high-risk seismic zone

MODEL NO.	SECTION SIZE	LONGITUDINAL REINFORCEMENT	SHEAR REINFORCEMENT
19	550X550	12 Ø22	Ø12 @150 mm
20	550X550	12 Ø22	Ø12 @150 mm
21	550X550	12 Ø22	Ø12 @150 mm
22	550X550	12 Ø22	Ø12 @150 mm
23	500X500	12 Ø22	Ø12 @200 mm
24	500X500	12 Ø22	Ø12 @200 mm
25	500X500	12 Ø22	Ø12 @200 mm
26	500X500	12 Ø22	Ø12 @200 mm
27	500X500	12 Ø22	Ø12 @200 mm
28	500X500	12 Ø22	Ø12 @200 mm
29	500X500	12 Ø22	Ø12 @200 mm
30	550X550	8 Ø22	Ø12 @200 mm
31	550X550	8 Ø22	Ø12 @200 mm
32	550X550	8 Ø22	Ø12 @200 mm
33	550X550	8 Ø22	Ø12 @200 mm
34	550X550	8 Ø22	Ø12 @200 mm
35	550X550	8 Ø22	Ø12 @200 mm
36	550X550	8 Ø22	Ø12 @200 mm

3.3 Model Description

This study contains a moment-resisting frames system (MRF), shear walls system (SW), moment-resisting frames with shearwalls system (Dual system). The support type for all the models was assumed fixed and in the following, the variable parameters in this study are mentioned:

1. Number of stories

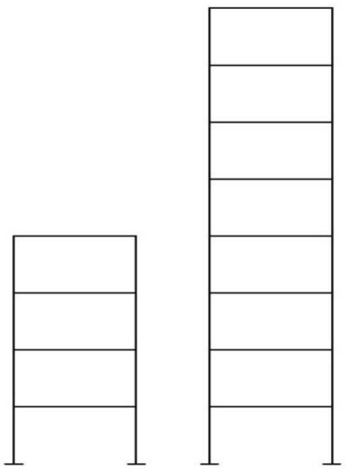


Figure 3.2: Number of stories

2. Number of spans

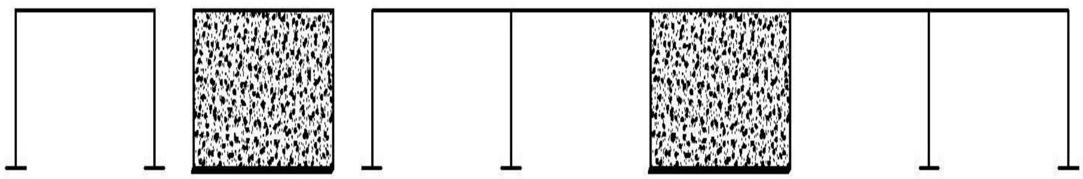


Figure 3.3: Number of spans: one span or five spans

3. Different sizes and type of openings

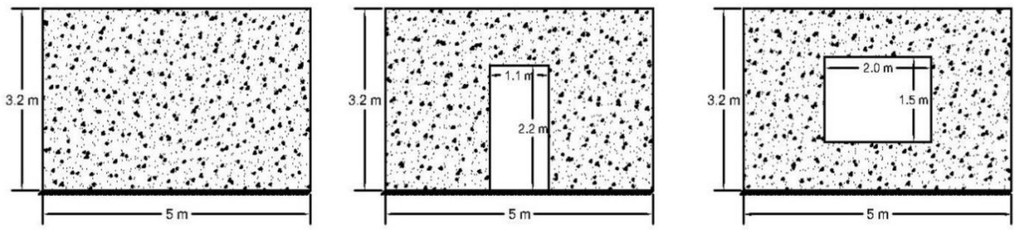


Figure 3.4: Different size and type of openings

Table 3.10: Openings type and size

Sample No.	Opening sizes (m)	
	Width	height
1 (Door)	1.10	2.20
2 (Window)	2.00	1.50
3 (Window)	2.00	2.00
4 (Door)	2.00	2.20
5 (Window)	3.00	1.50
6 (Window)	3.00	2.00

4. Length of the span

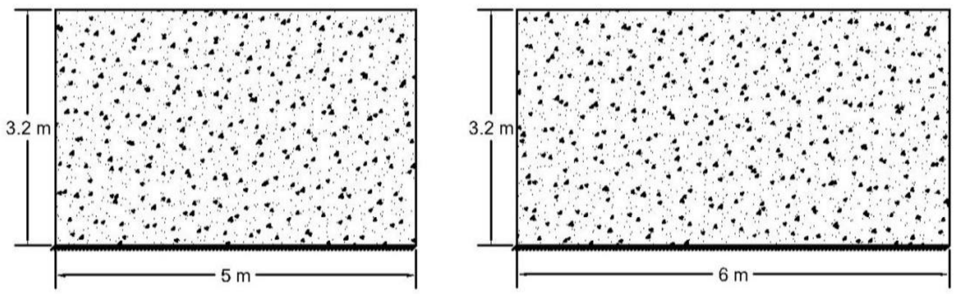


Figure 3.5: Different length of the span

5. The height of all the floors used is 3.2and 3.6m.

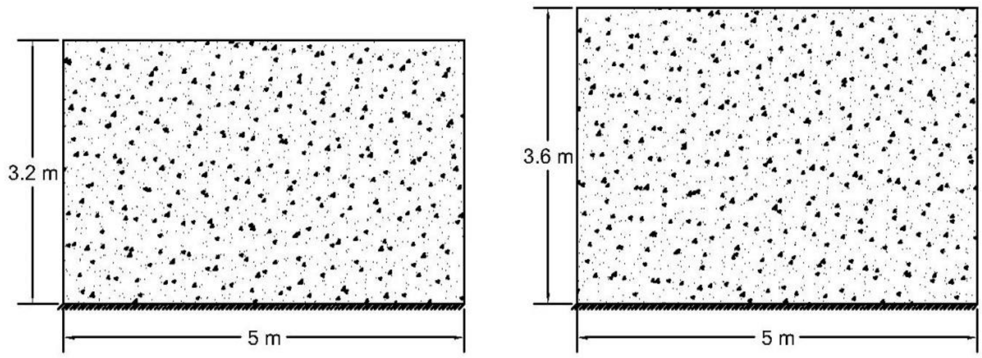


Figure 3.6: Different height of the span

6. Two different yield strength (3000, 4200 Kgf/cm^2) and compressive strengths (250, 300 Kgf/cm^2) are used.

7. The thickness of the shear walls used is 0.25m and 0.30m.

3.4 Loads

The buildings are designed to resist gravity and seismic loads, a different group of loads has been tested according to (ACI318-14) and the design was made based on the worst cases in the different loads group, and the formulas below demonstrates the load combinations cases used in the analysis and designing of the studied models in this chapter:

i. 1.4 DL …………………………………………………….…………….. (Eq1).

ii. 1.2 DL + 1.6 LL ……………………………….…….…….………...… (Eq2).

iii. 0.9 DL + 1 E ………………….………………………....……..............…. (Eq3).

iv. 1.2 DL + 1 LL + 1 E ………………………………………....………. (Eq4).

The deal load is composed of the self-weight (that is calculated automatically using ETABS program), the brick weight was taken 5 KN/m (assumed) over the beams, and for the slabs of a 150 mm thickness a dead load is taken 8 KN/m^2 and live load 3.5 KN/m^2 for all the models in this chapter.

3.5 seismic parameters

The following seismic parameters are used according to UBC97 to calculate the seismic loads and the design for all the models:

- **Seismic zone:** A) Moderate zone (2B).

  B) High risk zone (3).
- **Soil type:** medium soil (soil type S_D).
- **Importance factor:** 1 (residential building).
- **Response reduction factor (R):**
  - Moment resisting frames system (MRF): (5.5).
  - Shear walls system (SW): (5.5).
  - Dual system (MRFSW): (6.5).
- **Damping ratio:** 0.05.

3.6 Modeling of the different types of structural systems

This section contains the modeling of the different types of structural systems followed in this study with different number of floors and the systems are moment resisting system (MRF), frame system with the shear wall (Dual system) and frame system with the shear wall (Dual system) with an opening which was designed by Etabs-2016 software.

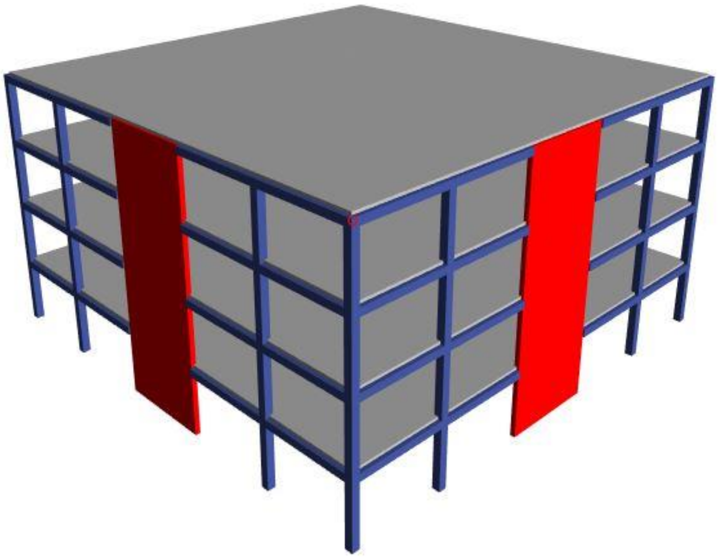
A. Moment Resisting Frames (MRF)

(a) The low-rise building (4-story)

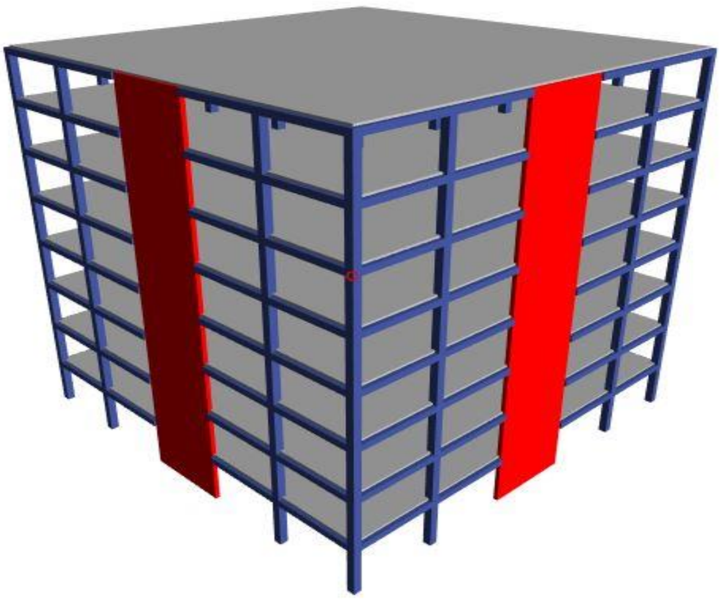
(b) The mid-rise building (8-story)

Figure 3.7: Three-dimensional views for a moment-resisting frame (MRF): (a) low-rise building (b) mid-rise building

B. Frame system with the shear wall (Dual system)



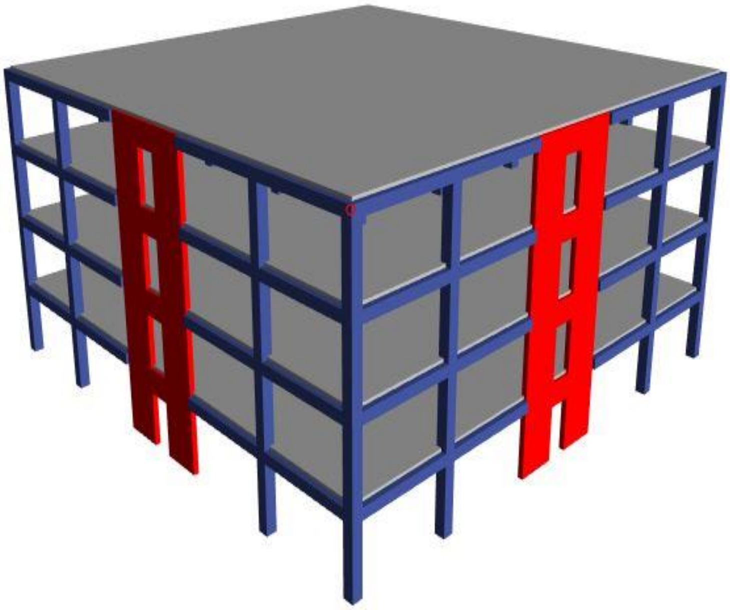
(a) The low-rise building (4-story)



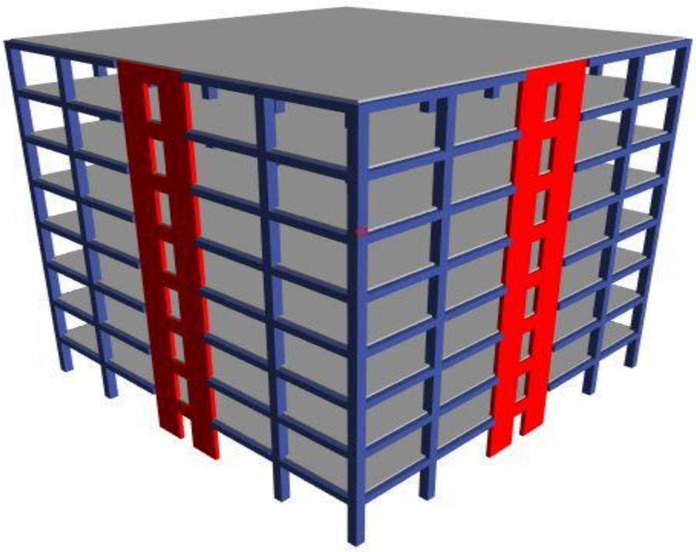
(b) The mid-rise building (8-story)

Figure 3.8: Three-dimensional views for Dual system (MRFSW): (a) low-rise building (b) mid-rise building

C. Frame system with the shear wall (Dual system) with opening



(a) The low-rise building (4-story)



(b) The mid-rise building (8-story)

Figure 3.9: Three-dimensional views for Dual system (MRFSW) with openings: (a) low-rise building (b) mid-rise building

3.7 Some samples of sear walls designs with different opening's sizes

The difference in opening type and size affects the shear walls reinforcing design, and the Figure from 3.10 to 3.15 shows the effect of the openings different types and sizes on the reinforcing area in shear walls.

- **Model 1:** shear wall without opening

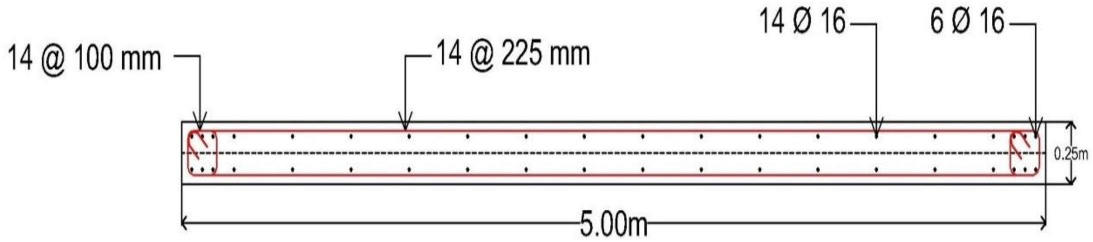


Figure 3.10: Steel reinforcement of shear wall without opening

- **Model 2:** Shear wall with opening 1.1mx2.2m (Door)

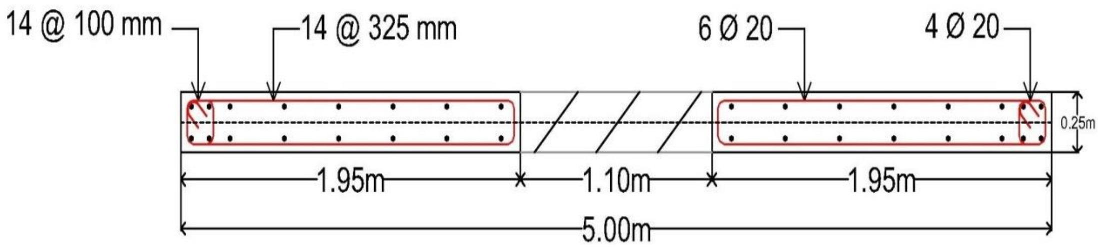


Figure 3.11: Steel reinforcement of shear wall with opening 1.1mx2.2m (Door)

- **Model 3:** Shear wall with opening 1.5mx2.0m (Window)

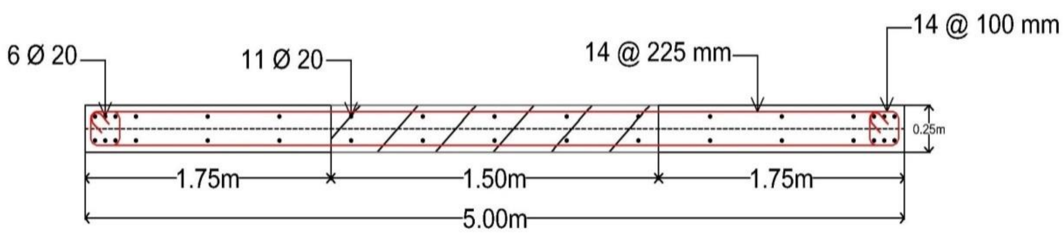


Figure 3.12: Steel reinforcement of shear wall with opening 1.5mx2.0m (Window)

- **Model 4:** Shear wall with opening 2.0mx2.0m (Window)

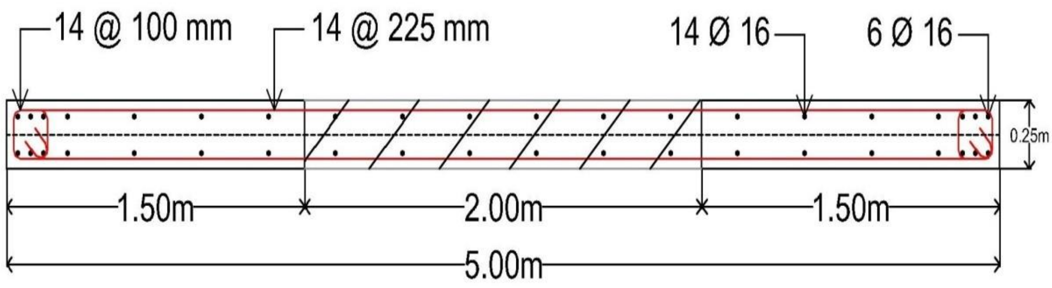


Figure 3.13: Steel reinforcement of shear wall with opening 2.0mx2.0m (Window)

- **Model 5:** Shear wall with opening 3.0mx1.5m (Window)

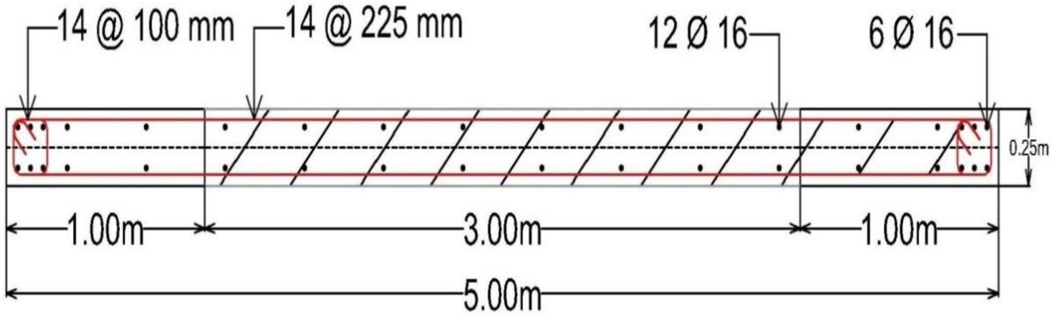


Figure 3.14: Steel reinforcement of shear wall with opening 3.0mx1.5m (Window)

- **Model 6:** Shear wall with opening 3.0mx2.0m (window)

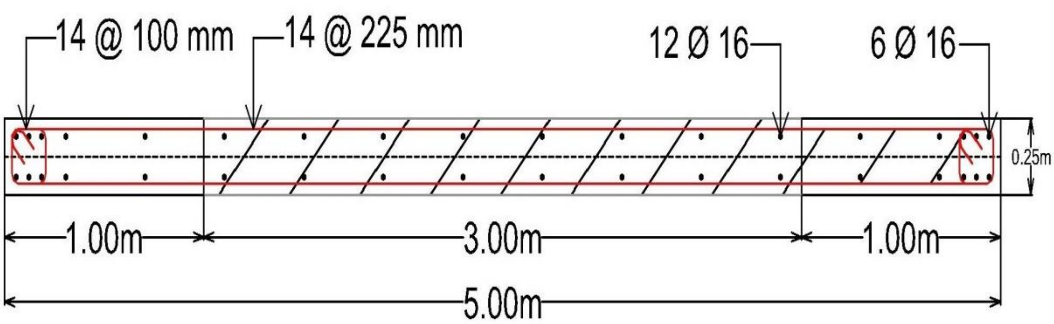


Figure 3.15: Steel reinforcement of shear wall with opening 3.0mx2.0m (Window)

3.8 Seismic analysis methods

Since earthquake forces are random in nature and unpredictable, the static and dynamic analysis of structures has become the primary concern of civil engineers. The primary parameters of seismic analysis of structure are load-carrying capacity, ductility, stiffness, damping, and mass. The type of seismic analysis to be used to evaluate the structure depends on:

1. External action.
2. The behavior of structure or structural materials.
3. The type of structural model select

The different analysis procedures are:

1. Linear Static Analysis
2. Nonlinear Static Analysis
3. Linear Dynamic Analysis
4. Nonlinear Dynamic Analysis

The static non-linear analysis was selected because it's less complicated than a dynamic analysis which is better and more accurate, and static analysis is accepted if these conditions are available:

I. The height of the building should be less than (75m).
II. The building should be regular.
III. There is no big difference in the form of horizontal projection in the building between the repeated floors.
IV. Continuity in structural systems on the entire height of the building.
V. There is no difference in structural systems and building materials.

Non-linear static analysis Also known as Pushover Analysis Used to evaluate the strength and drift capacity of the present structure and the seismic demand for this structure experiencing a selected earthquake. It can also be used to verify the adequacy of a new structural design. It is an assessment in which a mathematical model includes the nonlinear characteristics of the load-deformation characteristics of individual components and elements subject to increased lateral loads representing the inertia forces in an earthquake until the ' target displacement ' is exceeded. The response features that can be acquired from the pushover assessment are:

- ❖ Estimates of the structure’s force and displacement capacity.
- ❖ Element failure sequences and the consequent impact on general structural stability
- ❖ Identification of critical areas where inelastic deformations are anticipated to be large and identifying building resistance irregularities.

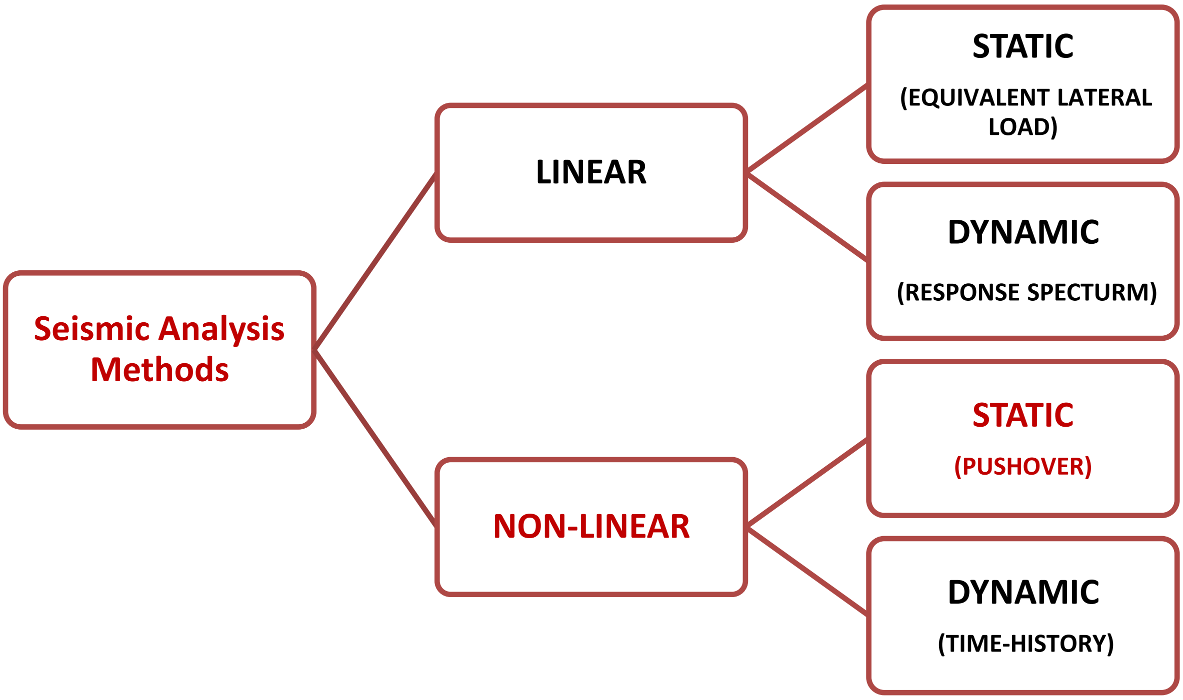


Figure 3.16: seismic analysis methods

3.9 Bilinear curve of capacity (pushover) curve

A pushover curve is a plot of lateral load resistance of a building as a function of a distinctive lateral displacement, typically a base shear versus the top displacement curve (or the same standardized values, respectively, for building weight and height), extracted from nonlinear static (pushover) analysis. The proper way to ' bilinear ' a pushover curve is still a rather contentious problem, in the sense that, based on the particular analysis aim, distinct methods are more suitable.

It should be remembered here that it is suggested in the manuals FEMA356 (2000) and ATC-40 (1996) to bilinearise the capacity curve in relation to the earlier estimated target displacement, This means that during each iteration the bilinear curve changes, which is not a very useful operation.

The approach is based on the FEMA356 guidelines, assuming equal areas under the original and bilinear curve, but there are several differences, mainly with respect to the definition of the ' maximum ' point and the slope of the post-yield branch. Bilinear pushover curves are built for each type of model building and represent distinct levels of seismic design and building performance. Each such curve is characterized by two points: capacity ‘yield ‘and capacity ‘maximum’.

The yield capacity represents the strength level beyond which the building's reaction is highly nonlinear and is greater than the design strength owing to minimum code demands, the real material strength is greater than the design value (mean concrete and steel strength values were used in nonlinear analyzes).

The maximum capacity is reached after a total mechanism has been established the global structural system and a 20 percent decrease in strength have happened due to the failure of some members in the sense that they exceeded their deformation capacity. Therefore, the strength corresponding to the maximum capability usually does not coincide with the real maximum strength recorded during the analysis. Moreover, the yield capacity is not the building's strength when a member's first yield happens.

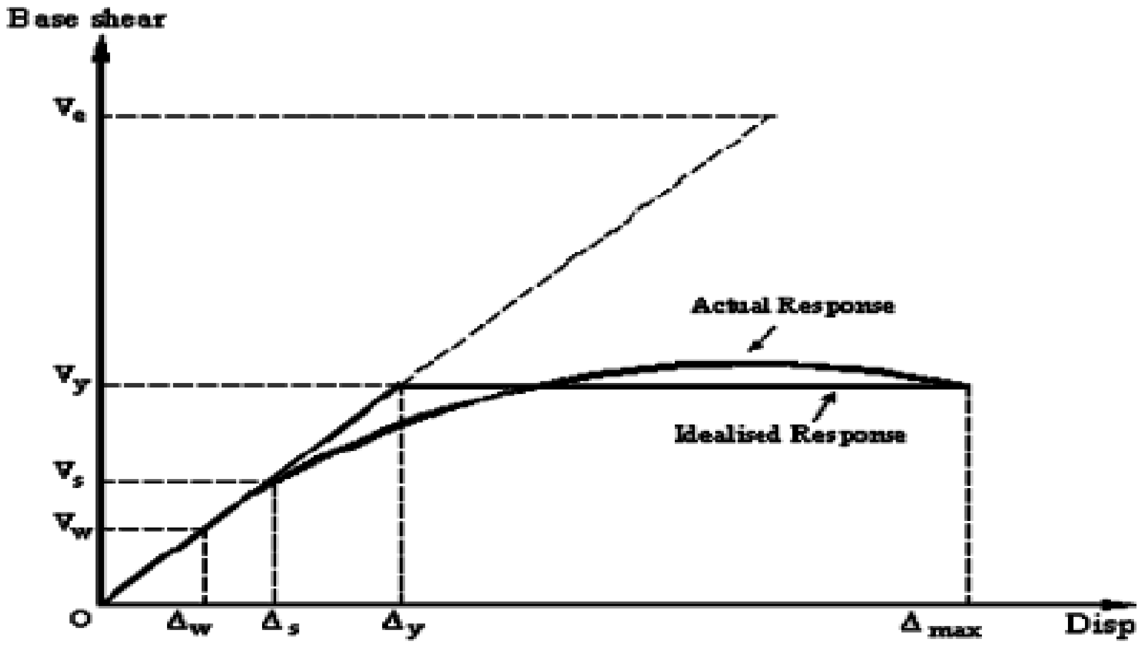


Figure 3.17: The bilinear curve of capacity (pushover) curve

3.9.1 Sample of the bilinear curve of capacity curve

As shown in Figure 3.18 bilinear curve with the capacity curve, Figure shows that the value of the area below the capacity curve should equal the area above the capacity curve and AutoCAD.V15 program was used to calculate areas.

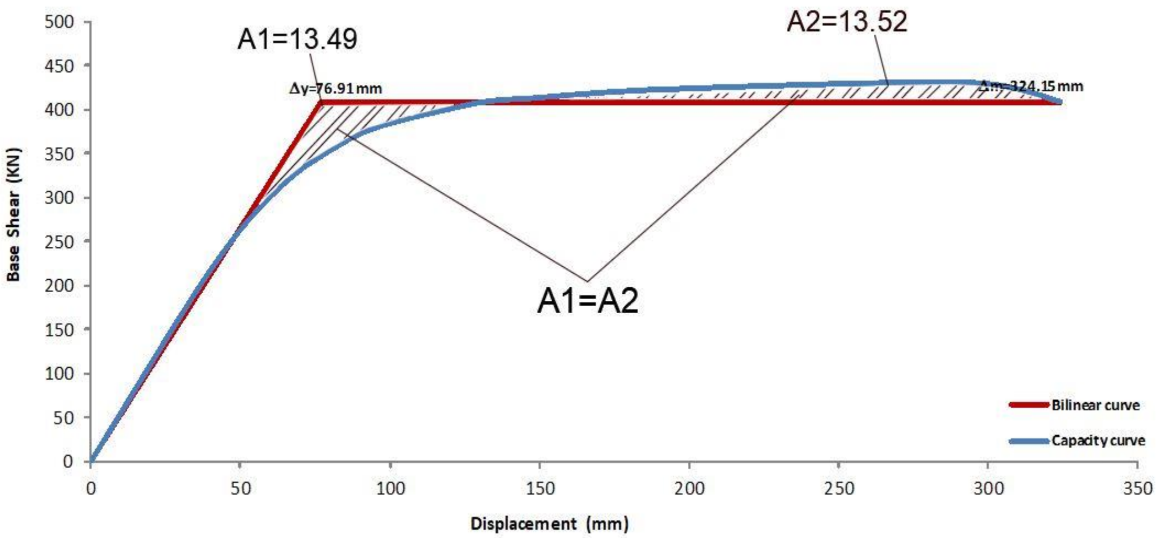


Figure 3.18: Calculate the area above capacity curve and area below the capacity of the bilinear curve

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Introduction

If the structure loses elasticity, the deformation will increase significantly under seismic load. Furthermore, resistance of any structure to any lateral load without collapse is known as **ductility,** which can be defined as the building's maximum displacement, divided by the displacement at the start of the deformation (Δu/Δy) and this parameter can be obtained from the capacity (pushover) curves with a bilinear curve. You must know that when the first plastic hinge in the structure is formed, the yielding displacement value is measured, and the capacity (pushover) curves for the different 3D models are extracted using (ETABS) software. The findings in this chapter include maximum displacement, yield displacement, maximum shear, yield shear, The impact of change in some parameters will be studied and the most significant parameter is a difference in opening ratios and size will be studied other parameters include span length, floor height, compressive strength, yield strength.

4.2 Results

The two Tables below provide an abstract for the maximum and yield displacement and an estimates of the ductility of the different percentage of the openings that have been obtained by the pushover analysis in Appendix A at moderate seismic zone and appendix B at high seismic zone, the obtained results is presented in Table 4.6 for the 4-story models and in Table 4.7 for the 8-story models at moderate seismic zone and Table 4.8 and Table 4.9 at high risk seismic zone. The results are taken from one axis in this study because all the models are matching on the x and y-axes.

Table 4.1: Summary of nonlinear static analysis results for low-rise models (4-story) at moderate seismic zone

Structure system type	MODEL NO.	Δ_y (mm)	Δ_m (mm)	V_m (KN)	OPENING SIZE (width x height) (m)	OPENING AREA (%)	DUCTILITY FACTOR (μ)
Moment resisting Frame system (MRF)	1	89.31	249.46	298.12	-	-	**2.79**
	2	124.14	264.49	283.55	-	-	**2.13**
	3	93.52	237.55	349.01	-	-	**2.54**
	4	134.86	253.75	342.37	-	-	**1.88**
Dual system (MRFSW)	5	50.91	168.67	9659.21	-	-	**3.34**
	6	44.24	177.06	9676.28	1.10x2.20	15.13	**4.01**
	7	47.45	186.49	7503.48	2.00x1.50	18.75	**3.93**
	8	51.06	196.58	7109.23	2.00x2.00	25.00	**3.80**
	9	49.10	198.89	7184.37	2.00x2.20	27.50	**4.12**
	10	53.66	208.07	6079.90	3.00x1.50	28.13	**3.87**
	11	56.68	223.82	5824.97	4.00x1.50	37.50	**3.73**
	12	42.87	172.60	13011.75	-	-	**4.02**
	13	40.62	174.16	12756.54	1.10x2.20	11.20	**4.28**
	14	46.85	178.94	11701.66	2.00x1.50	13.89	**3.82**
	15	52.76	189.98	11315.71	2.00x2.00	18.52	**3.60**
	16	44.09	194.44	10240.35	2.00x2.20	20.37	**4.41**
	17	45.95	196.65	9668.50	3.00x1.50	20.83	**4.28**
	18	50.20	208.36	9281.90	3.00x2.00	27.78	**4.15**

Table 4.2: Summary of nonlinear static analysis results for mid-rise models (8-story) at moderate seismic zone

Structure system type	MODEL NO.	Δ_y (mm)	Δ_m (mm)	V_m (KN)	OPENING SIZE (width x height) (m)	OPENING AREA (%)	DUCTILITY FACTOR (μ)
Moment resisting Frame system (MRF)	19	74.78	351.52	292.97	-	-	**4.70**
	20	161.67	376.00	288.75	-	-	**2.33**
	21	79.43	339.27	320.58	-	-	**4.27**
	22	168.07	356.60	318.86	-	-	**2.12**
Dual system (MRFSW)	23	91.25	411.53	4668.49	-	-	**4.51**
	24	87.82	416.27	4504.20	1.10x2.20	15.13	**4.74**
	25	99.08	426.79	4566.09	2.00x1.50	18.75	**4.58**
	26	98.26	444.88	4530.35	2.00x2.00	25.00	**4.49**
	27	95.12	451.83	4443.91	2.00x2.20	27.50	**4.75**
	28	104.00	454.48	4237.42	3.00x1.50	28.13	**4.37**
	29	109.09	468.16	4050.51	4.00x1.50	37.50	**4.26**
	30	103.69	451.06	7356.61	-	-	**4.22**
	31	104.14	461.36	7210.03	1.10x2.20	11.20	**4.43**
	32	112.05	481.82	7168.41	2.00x1.50	13.89	**4.30**
	33	116.63	486.59	7117.28	2.00x2.00	18.52	**4.17**
	34	108.40	491.07	7120.44	2.00x2.20	20.37	**4.53**
	35	111.49	498.40	7011.89	3.00x1.50	20.83	**4.47**
	36	116.71	511.20	6952.72	3.00x2.00	27.78	**4.38**

Table 4.3: Summary of nonlinear static analysis results for low-rise models (4-story) at high-risk seismic zone

Structure system type	MODEL NO.	Δ_y (mm)	Δ_m (mm)	V_m (KN)	OPENING SIZE (width x height) (m)	OPENING AREA (%)	DUCTILITY FACTOR (μ)
Moment resisting frame system (MRF)	**1**	55.56	177.89	479.31	-	-	**3.20**
	2	85.08	230.98	494.55	-	-	**2.71**
	3	57.68	170.72	556.33	-	-	**2.96**
	4	89.70	218.84	582.92	-	-	**2.44**
Dual system (MRFSW)	**5**	52.23	153.34	12655.35	-	-	**2.94**
	6	51.43	165.49	10258.10	1.10x2.20	15.13	**3.22**
	7	55.56	166.99	9963.33	2.00x1.50	18.75	**3.00**
	8	56.64	178.90	9736.41	2.00x2.00	25.00	**3.16**
	9	45.77	181.27	9212.76	2.00x2.20	27.50	**3.96**
	10	47.83	184.70	8002.64	3.00x1.50	28.13	**3.86**
	11	54.23	197.69	7895.27	4.00x1.50	37.50	**3.64**
	12	55.81	158.19	17829.29	-	-	**2.83**
	13	53.98	159.68	17749.90	1.10x2.20	11.20	**2.95**
	14	57.98	167.34	16112.60	2.00x1.50	13.89	**2.89**
	15	59.28	171.92	15726.21	2.00x2.00	18.52	**2.92**
	16	54.43	174.95	15357.41	2.00x2.20	20.37	**3.21**
	17	52.36	179.17	14187.02	3.00x1.50	20.83	**3.42**
	18	57.94	188.45	13261.72	3.00x2.00	27.78	**3.25**

Table 4.4: summary of nonlinear static analysis results for mid-rise models (8-story) at high-risk seismic zone

Structure system type	MODEL NO.	Δ_y (mm)	Δ_u (mm)	V_y (KN)	OPENING SIZE (width x height) (m)	OPENING AREA (%)	DUCTILITY FACTOR (μ)
Moment resisting frame system (MRF)	**19**	76.91	324.15	408.81	-	-	**4.22**
	20	123.20	416.75	457.61	-	-	**3.38**
	21	77.01	320.95	441.89	-	-	**4.16**
	22	120.84	401.42	501.84	-	-	**3.32**
Dual system (MRFSW)	**23**	80.97	340.12	6384.46	-	-	**4.20**
	24	77.93	349.54	6415.71	1.10x2.20	15.13	**4.48**
	25	82.66	356.96	6108.63	2.00x1.50	18.75	**4.31**
	26	85.23	376.70	6067.96	2.00x2.00	25.00	**4.41**
	27	83.59	379.33	5519.94	2.00x2.20	27.50	**4.53**
	28	88.14	383.83	5370.85	3.00x1.50	28.13	**4.35**
	29	93.21	398.96	5192.82	4.00x1.50	37.50	**4.28**
	30	109.25	380.58	9546.05	-	-	**3.48**
	31	107.32	389.04	9286.36	1.10x2.20	11.20	**3.62**
	32	112.29	396.88	9040.63	2.00x1.50	13.89	**3.53**
	33	116.40	401.58	8997.12	2.00x2.00	18.52	**3.42**
	34	109.16	404.42	8860.78	2.00x2.20	20.37	**3.70**
	35	106.79	411.65	8669.65	3.00x1.50	20.83	**3.85**
	36	111.43	426.99	8458.53	3.00x2.00	27.78	**3.77**

4.3 Discussion of the results

In this section, the discussion of the results and it's performed in two parts; a) in the first part, the discussion of the impact of some parameters on the **ductility** value at moderate and high-risk seismic zones, b) the second part, the discussion of the effect of the difference in the size and the type of the openings on **ductility** values with a change of some parameters at moderate and high risk seismic zones and focusing on the discussion of the sizes of the different opening and it effect on the building's **ductility** of the different models for 4- story and 8- story models.

4.3.1 Discussion of the results at moderate seismic zone

4.3.1.1 The effect of some parameters on ductility

This section presents a study on the impact of some parameters on the ductility value, parameters are span length, floor height, compressive strength, and steel yield strength. This section consists of two parts, the first part discusses the impact of span length and story height in **ductility**, and the second part discusses the impact of the difference in compressive strength and yield strength on **ductility** at a moderate seismic zone.

4.3.1.1.1 The effect of span length and story height on ductility and the capacity curves

The difference in the span length and the story height are parameters that their effect will be studied at the moderate seismic zone, and therefor knowing to wither the increase in story height and span length will lead to decrease or increase the **ductility**. Table 4.5 shows the **ductility** values with different span length for models (4-story) and models (8-story), and Figure 4.1 and Figure 4.2 show the difference in the capacity (pushover) curve with different span length. The Table 4.5, when increasing the span length for models (4-story) and models (8-story), the (5m) span length has more **ductility** compared with the (6m) width spans and when the span length is increased the maximum displacement (Δ_m) and yield displacement (Δ_y) values will also increase, but the further increase in yield displacement will lead to a decrease in the **ductility** as it's shown in Figure 4.1 for models

(4-story) and Figure 4.2 for models (8-story). As it's shown Table 4.6, when story height is increased in models (4-story) and models (8-story) from 3.2m to 3.6m, that will lead to a decrease dramatically in **ductility** values and as it's shown in Figure 4.3 for models (4-story) and Figure 4.4 for models (8-story) that when increasing the story height, the yield displacement (Δ_y) values will increase also the maximum displacement (Δ_m) values will increase, that's how the **ductility** value decreases.

Table 4.5: Results of ductility values of models with different span length at a moderate seismic zone

Number of stories	**Span length**	
	5 m	**6 m**
4-story	2.79	2.13
8-story	4.70	2.33

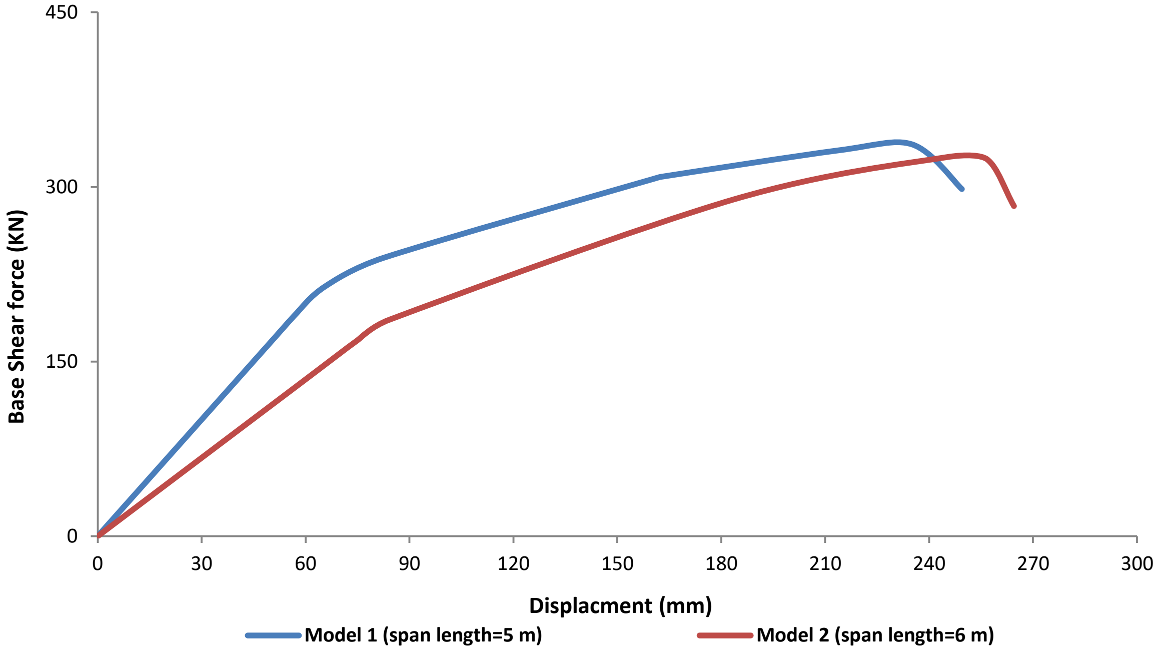


Figure 4.1: The effect of the span length change in a capacity curve of the 4-story model at a moderate seismic zone

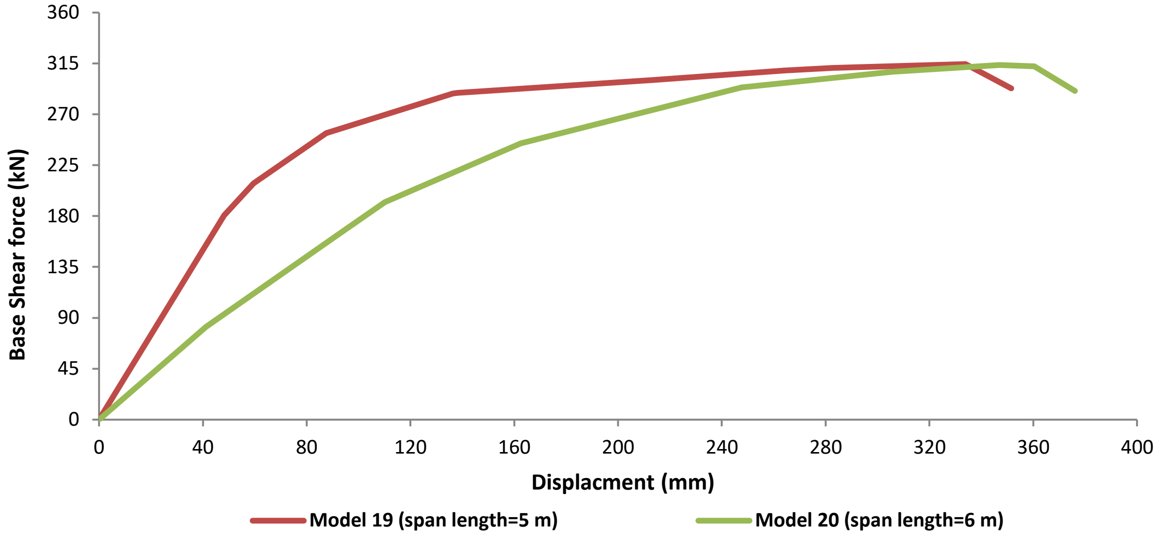


Figure 4.2: The effect of the span length change on the capacity (pushover) curve of the 8-story models at moderate seismic zone

Table 4.6: Results of ductility values of models with different story height at a moderate seismic zone

Number of stories	Story height	
	3.2 m	**3.6 m**
4-story	2.54	1.88
8-story	4.27	2.12

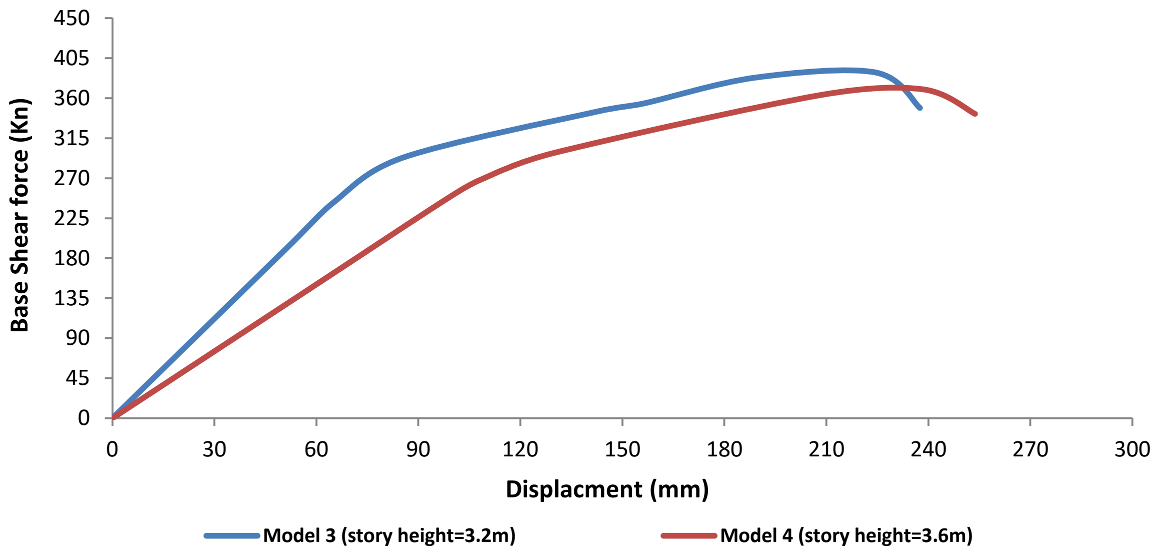


Figure 4.3: The effect of the story height change on the capacity (pushover) curve of the 4-story models at a moderate seismic zone

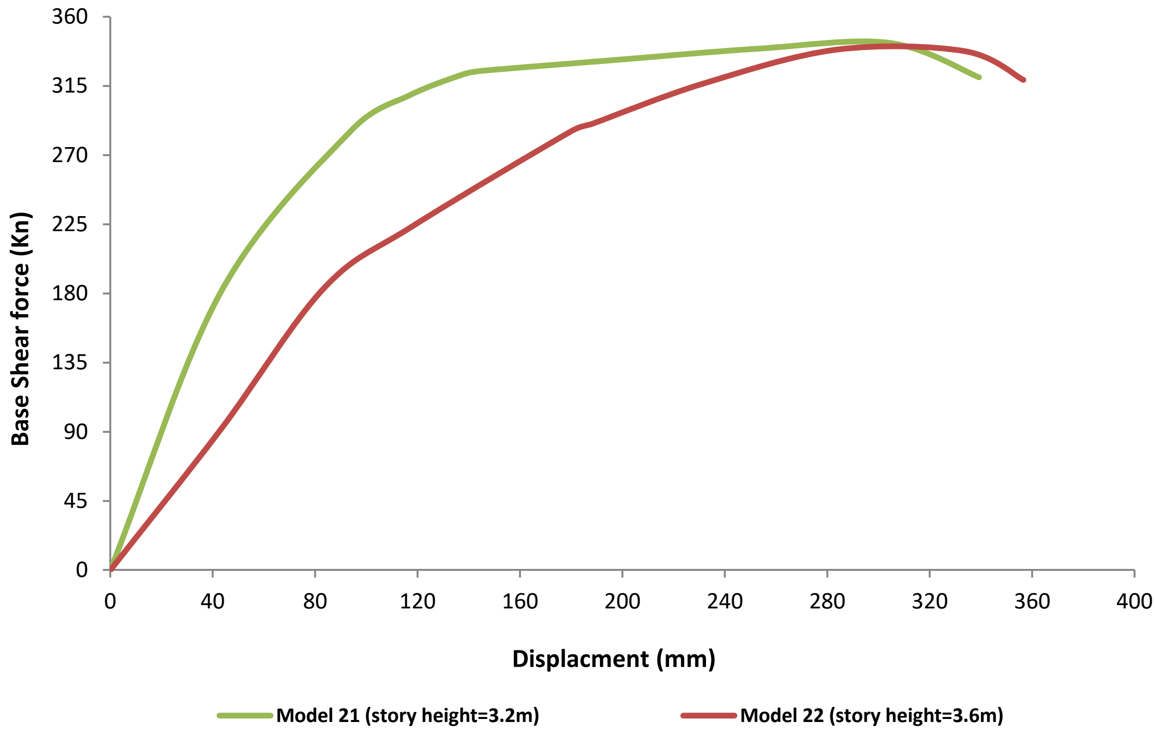


Figure 4.4: The effect of the story height change on the capacity curve of the eight-story models at a moderate seismic zone

4.3.1.1.2 The effect of the (F'_c) and (F_y) on ductility and the capacity curves

The difference in (F'_c) and (F_y) is considered one of the most important parameters that affect the building's behavior and **ductility** and so it will be known to either the change in compressive and yield strength affect the **ductility** positively or negatively at a moderate seismic zone. table 4.7 and figure 4.5 illustrate the **ductility** with a difference in compressive and model yield strength (4-story) and in Table 4.18 and Figure 4.6 they show the **ductility** values for the models (8-story).

As it appears in Table 4.7 and Figure 4.5 for models (4-story) and Table 4.8 and Figure 4.6 for models (8-story), when changing the compressive strength from (250 Kgf/cm^2) to (300 Kgf/cm^2) and yield strength from (3000 Kgf/cm^2) to (4200 Kgf/cm^2) a decrease in **ductility** values happen and that decrease the maximum displacement (Δ_m) and increase yield displacement (Δ_y), but the rise in (Δ_y) and the reduction in (Δ_m) resulted in a reduction in the value of ductility.

Table 4.7: Results of ductility values of models with different compressive strength and yield strength for the low-rise model (4-story) at moderate seismic zone

Span length	compressive strength \ Yield strength	
	3000 Kgf/cm^2 \ 250 Kgf/cm^2	4200 Kgf/cm^2 \ 300 Kgf/cm^2
5 m	2.79	2.54
6 m	2.13	1.88

Table 4.8: Results of ductility values of models with different compressive strength and yield strength for the mid-rise model (8-story) at moderate seismic zone

Span length	Compressive strength \ Yield strength	
	3000 Kgf/cm^2 \ 250 Kgf/cm^2	4200 Kgf/cm^2 \ 300 Kgf/cm^2
5 m	4.70	4.27
6 m	2.29	2.12

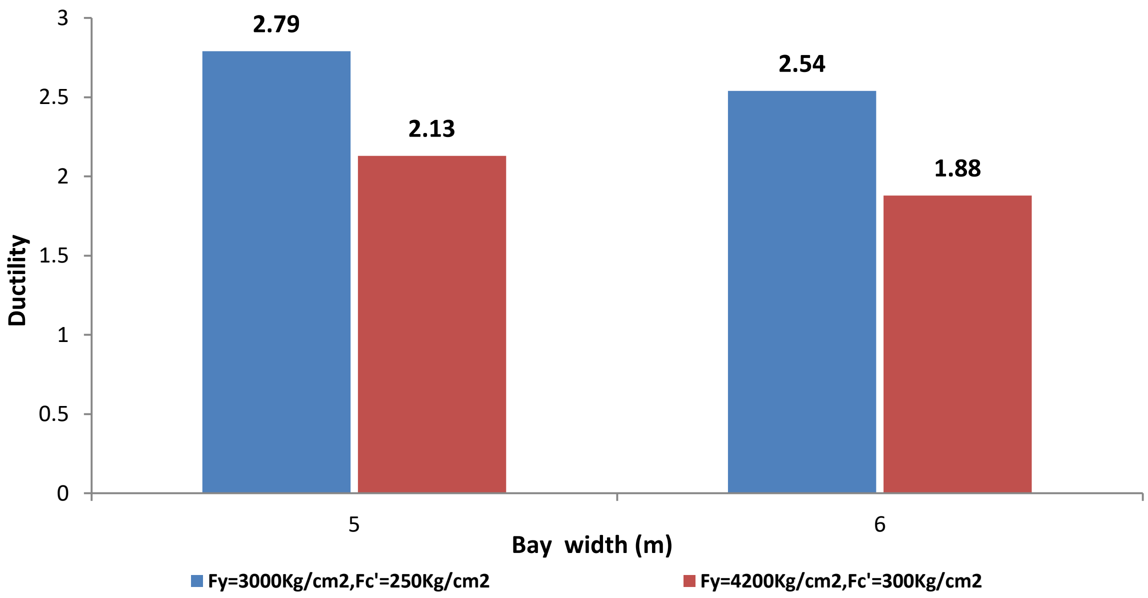


Figure 4.5: a comparison between the ductility values for the 4-story models with different compressive and yield strength at moderate seismic zone

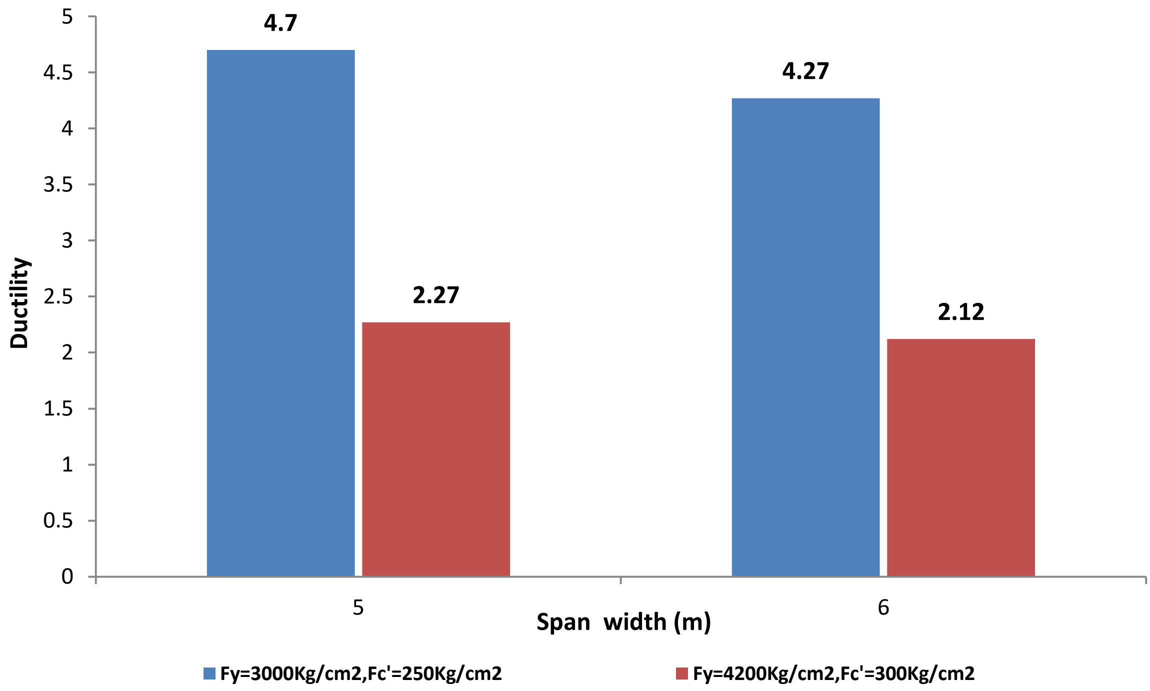


Figure 4.6: a comparison between the ductility values for the 8-story models with different compressive and yield strength at moderate seismic zone

4.3.1.2 The impact of different size and type of openings on ductility and capacity curves

This section provides a study about the effect of the difference in the size and the type of the openings on **ductility** values with a change of some parameters and they are the story height, span length, yield strength and compressive strength at a moderate seismic zone.

4.3.1.2.1 The impact on the ductility of different sizes and type of openings with (F'_C=250 Kgf/cm^2) and (F_y=3000 Kgf/cm^2)

The difference in openings sizes and its effect on **ductility** values is considered the main parameter in this study, and the effect of change in its type and size on **ductility** will be known in a moderate seismic zone. In this section, the models will be studied with (F'_C= 250 Kgf/cm^2) and (F_y= 3000 Kgf/cm^2), and Table 4.9 and Figure 4.7 shows the **ductility** values for model (4-story) and models (8-story), and Figure 4.8 shows a comparison of models capacity (pushover) curves (4-story), and Figure 4.9 shows a comparison between capacity (pushover) curves for models (8-story), as it shows in

Table 4.9 and Figure 4.7 that when increasing the size and the percentage of the openings, the **ductility** value increase for 4-story and 8-story buildings the reason for the increase in **ductility** value is the decrease in yield displacement (Δ_y) value and the increase in maximum displacement (Δ_u) whenever the percentage of the opening in the shear wall increases and noticing a decrease in yield shear (V_y), and therefore a decrease in the strength of the building as is shown in Figure 4.8 and 4.9.

Parameters in this section: story height = 3.2m, span length = 5m, shear wall thickness = 0.25m, F_y = 3000 Kgf/cm^2, F'_C= 250 Kgf/cm^2

Table 4.9: Results of ductility values of models without and with openings with different number of stories with (F'_C=250 Kgf/cm^2) and (F_y=3000 Kgf/cm^2) at moderate seismic zone

Model No.	Number of stories	
	Low-rise (4-story)	**Mid-rise (8-story)**
Model 1 (without opening)	3.34	4.51
Model 2 (1.1mx2.2m)	4.01	4.74
Model 3 (2.0mx1.5m)	3.93	4.58
Model 4 (2.0mx2.0m)	3.80	4.49
Model 5 (2.0mx2.2m)	4.12	4.75
Model 6 (3.0mx1.5m)	3.87	4.37
Model 7 (3.0mx2.0m)	3.73	4.26

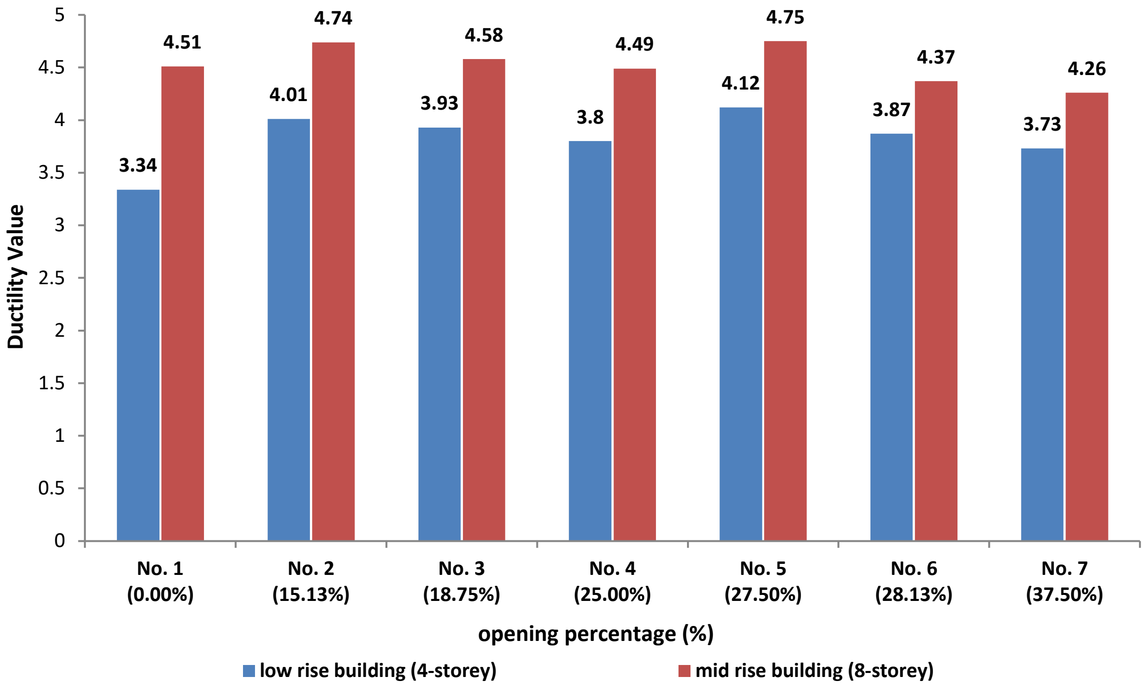


Figure 4.7: a comparison between the ductility values with the different opening sizes and it's a percentage for the 4- story and 8-story models with ($\boldsymbol{F_y}$=3000 Kgf/cm^2, $\boldsymbol{F'_c}$=250 Kgf/cm^2) at moderate seismic zone

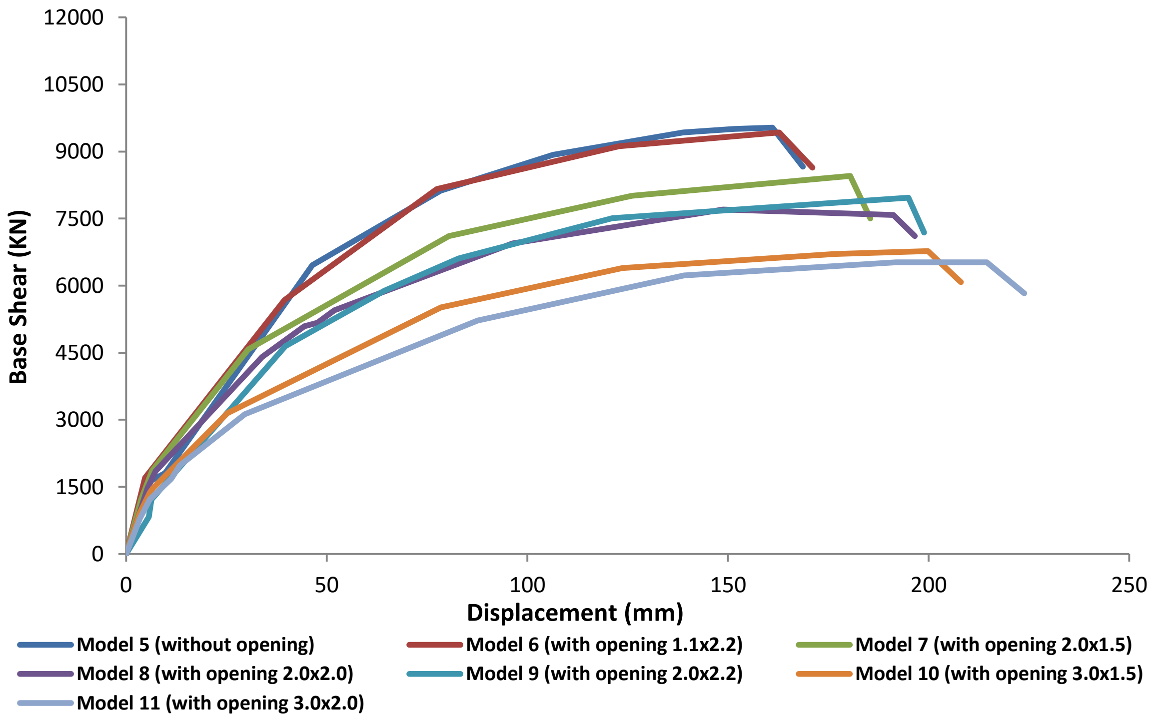


Figure 4.8: The effect of the change in the opening size and it's a percentage on the capacity (pushover) curve of the 4-story models ($\boldsymbol{F_y}$=3000 Kgf/cm^2, $\boldsymbol{F'_c}$=250 Kgf/cm^2) at moderate seismic zone

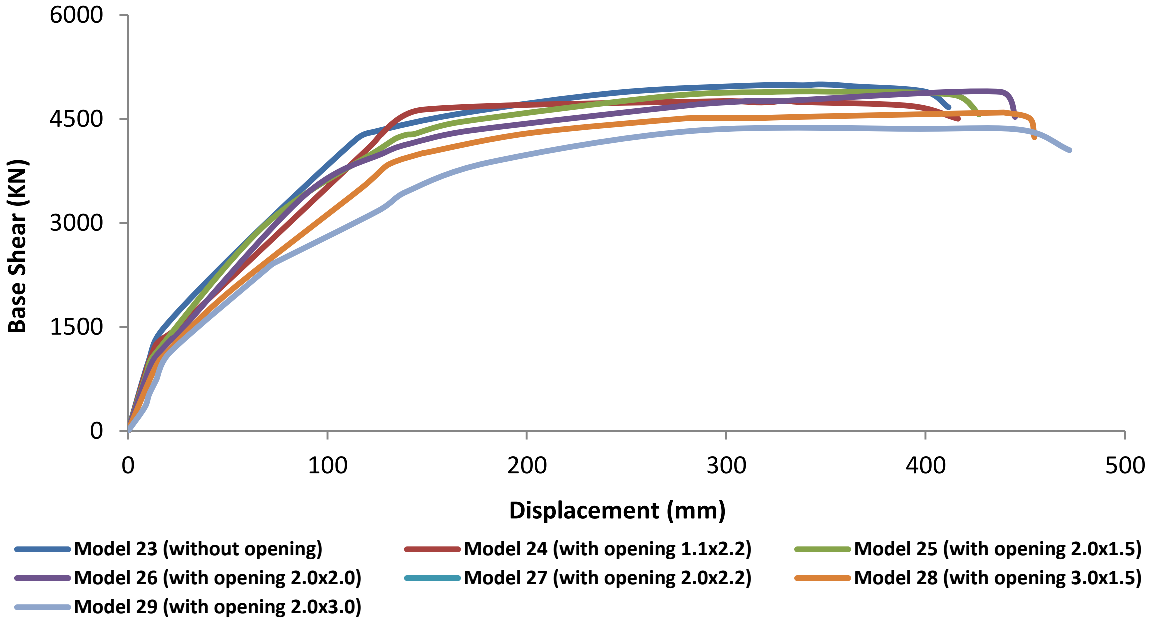


Figure 4.9: The effect of the change in the opening size and it's a percentage on the capacity (pushover) curve of the 8-story models with ($\boldsymbol{F_y}$=3000 Kgf/cm^2, $\boldsymbol{F'_c}$=250 Kgf/cm^2) at moderate seismic zone

4.3.1.2.2 The impact on the ductility of different sizes and type of openings with (F'_c= 300 Kgf/cm^2) and (F_y=4200 Kgf/cm^2)

As it been mentioned in the previous section, the difference in openings size and its effect on **ductility** is considered the main parameter in this study. So in this section, the discussion will be for the size of the same openings with different percentage after changing a few parameters at a moderate seismic zone. In this section, the models are studied with (F'_c= 300 Kgf/cm^2) and (F_y= 4200 Kgf/cm^2) in Table 4.10 and Figure 4.10 the **ductility** values for 4-story and 8-story models. Figure 4.11 shows a comparison between the capacity (pushover) curves for models (4-story), and Figure 4.12 shows a comparison between capacity (pushover) curves for models (8-story). As it shows, the **ductility** values dramatically increase whenever the opening's size and percentage increase in shear walls. This rise in **ductility** values results from a rise in maximum displacement (Δ_m) and a reduction in yield displacement (Δ_y) for openings such as doors and increase in yield displacement but less than the maximum displacement (Δ_m) for openings such as windows, and it's noticed that a decrease in maximum shear (V_m) and yield shear (V_y) happen, all the effect the building's strength as a whole is shown in Figure 4.11 and 4.12.

Parameters in this section: story height = 3.6m, span length = 6m, shear wall thickness = 0.30 m, F_y = 4200 Kgf/cm^2, F'_C = 300 Kgf/cm^2

Table 4.10: Results of ductility values of models without and with openings with different number of stories with (F'_C=300 Kgf/cm^2) and (F_y=4200 Kgf/cm^2) at moderate seismic zone

Model No.	**Number of stories**	
	Low-rise (4-story)	**Mid-rise (8-story)**
Model 1 (without opening)	4.02	4.22
Model 2 (1.1mx2.2m)	4.28	4.43
Model 3 (2.0mx1.5m)	3.82	4.30
Model 4 (2.0mx2.0m)	3.60	4.17
Model 5 (2.0mx2.2m)	4.41	4.53
Model 6 (3.0mx1.5m)	4.28	4.59
Model 7 (3.0mx2.0m)	4.15	4.38

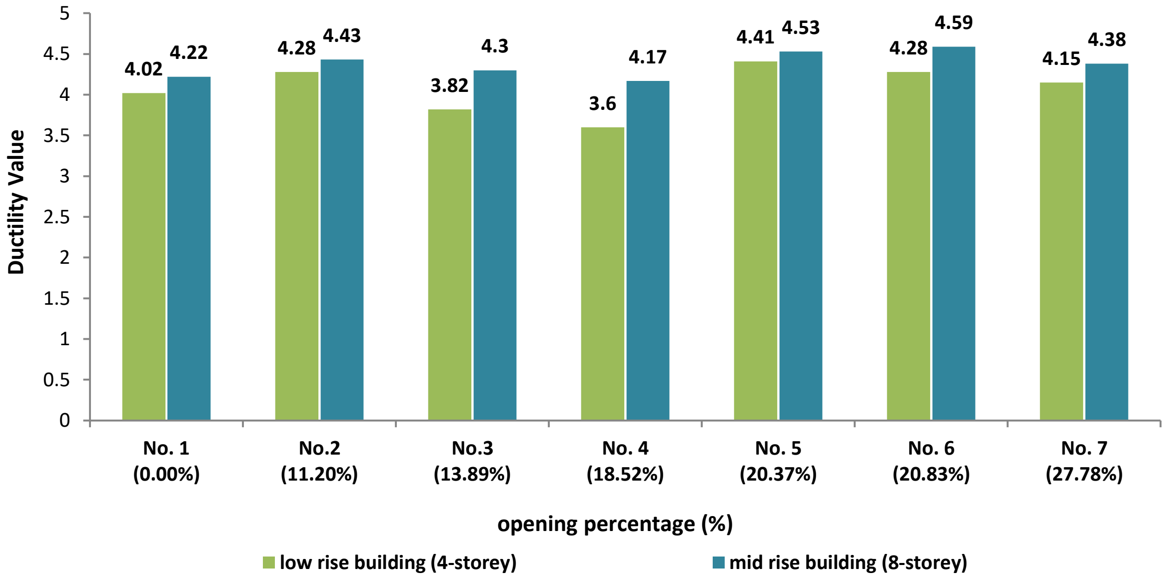


Figure 4.10: a comparison between the ductility values with the different opening sizes and it's a percentage for the 4-story and 8-story models with (F_y=4200 Kgf/cm^2, F'_C=300 Kgf/cm^2) at moderate seismic zone

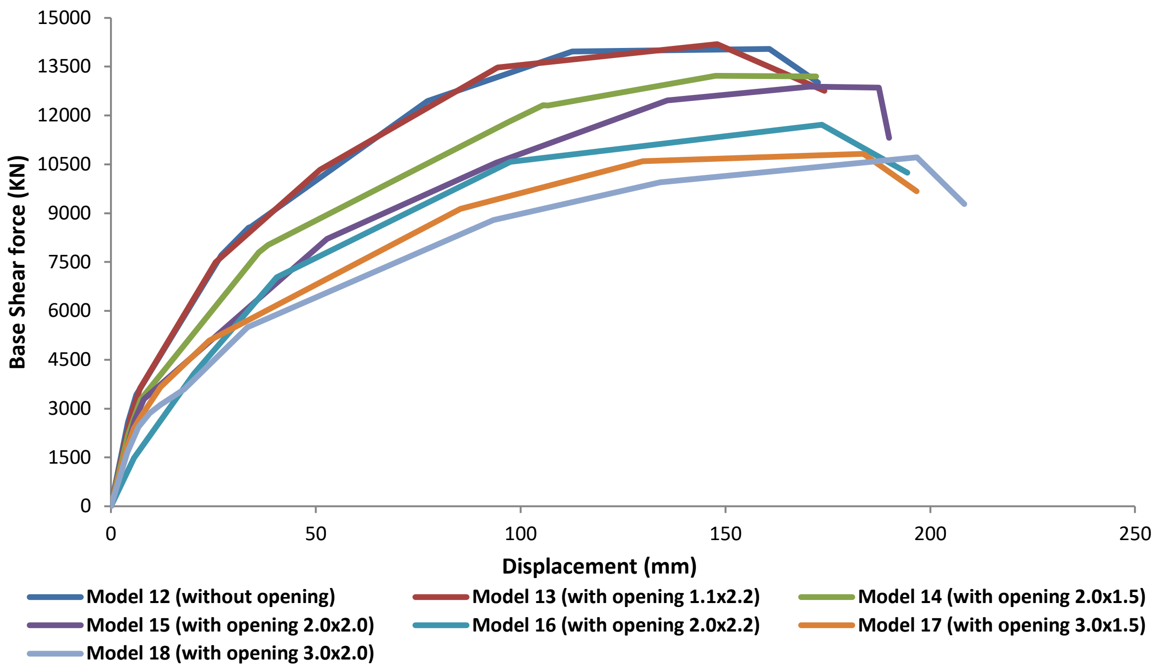


Figure 4.11: The effect of the change in the opening size and it's a percentage on the capacity (pushover) curve of the 4-story models with ($\boldsymbol{F_y}$=4200 Kgf/cm^2, $\boldsymbol{F'_C}$=300 Kgf/cm^2) at moderate seismic zone

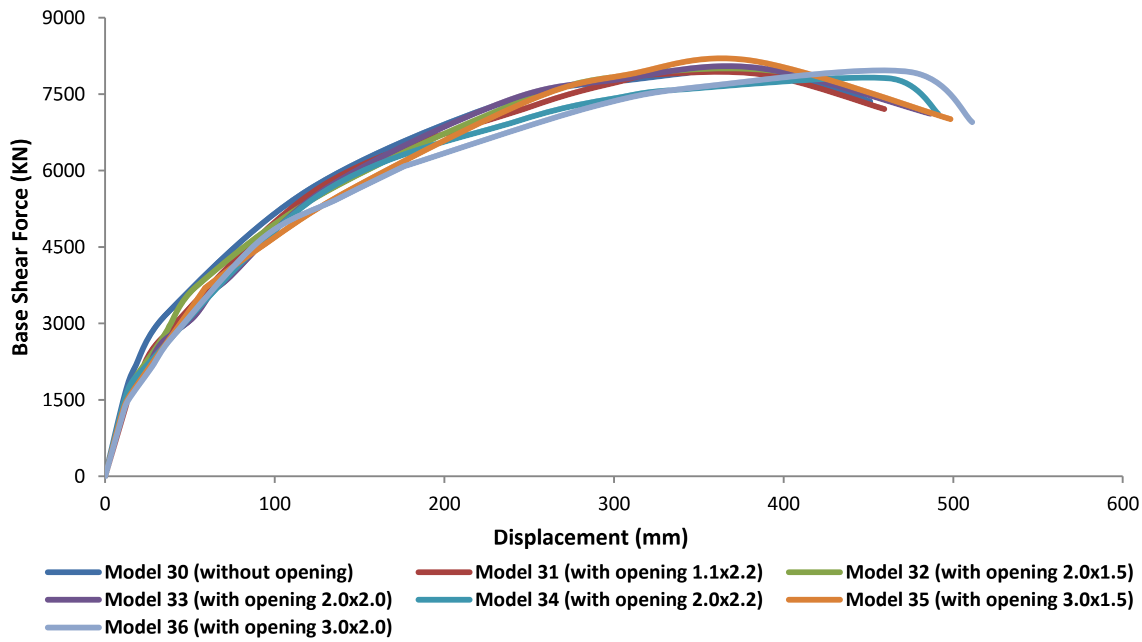


Figure 4.12: The effect of the change in the opening size and it's a percentage on the capacity (pushover) curve of the 8-story models with ($\boldsymbol{F_y}$=4200 Kgf/cm^2, $\boldsymbol{F'_C}$=300 Kgf/cm^2) at moderate seismic zone

4.3.2 Discussion of the results at high-risk seismic zone

4.3.2.1 The effect of some parameters on ductility

This section provides a study about the effect of some parameters on the **ductility** value; parameters are span length, floor height, compressive strength, and yield strength. This section consists of two parts, the first part will discuss the effect of the span length and the story height in the **ductility** and the second part will discuss the effect of the difference of the compressive strength and yield strength on the ductility at a high-risk seismic zone.

4.3.2.1.1 The effect of span length and story height on ductility and the capacity (pushover) curves

As mentioned in the previous section, the width and height of the span are the important parameters that play an important part in the ductility of the structures. So in this section will study their effect on the **ductility** at high-risk seismic zones. Table 4.11 shows the effect of the span length from 5m to 6m for 4-story and 8-story models at a high-risk seismic zone and the Figure 4.13 shows the difference in capacity (pushover) curves with different span length for models (4-story) and Figure 4.14 for models (8-story). As it shows in Table 4.11 that when increasing span length a decrease in **ductility** values happens in the 4-story models and 8-story models, and it appears that the decrease rate for 8-story is higher than the decrease rate in 4-story models. And it has been noticed that yield displacement ($\varDelta_y$) and maximum displacement ($\varDelta_m$) values increase that's because the **ductility** decrease for the models (4-story) and models (8-story) as it shows in Figure 4.13 for 4-story models and Figure 4.14 for 8-story models.

Table 4.12 shows **ductility** values for models (4-story) and models (8-story) with the difference in story height from 3.2m to 3.6m at a high-risk seismic zone, and Figure 5.4 shows the difference in the capacity (pushover) curves with difference story height for models (4-story) and Figure 4.16 for models (8-story). As it shows in Table 4.12 for models (4-story) and models (8-story) that when story height increased, the **ductility** values decrease but the decrease rate in models (8-story) is higher than the decrease rate in models (4-story) and it's also been noticed that yield displacement ($\varDelta_y$) values increase when the story height increase and also maximum displacement ($\varDelta_m$) values increase so that's the reason for the decrease in **ductility** value in the models as it shows in Figure 4.15 for models (4-story) and Figures 4.16 for models (8-story).

Table 4.11: Results of ductility values of models with different span length at high-risk seismic zone

Number of stories	Span length	
	5 m	**6 m**
4-story	3.20	2.71
8-story	4.22	3.38

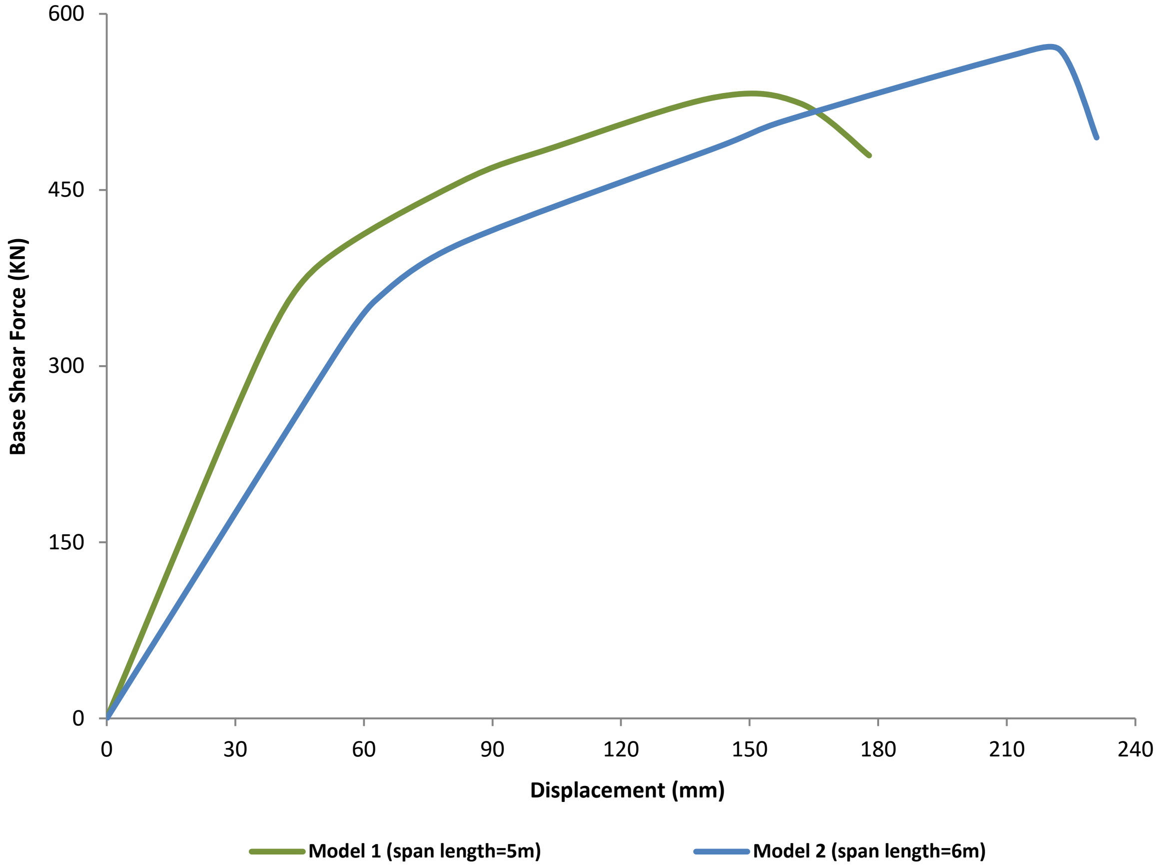


Figure 4.13: The effect of the span length change on the capacity (pushover) curve of the 4-story models at high-risk seismic zone

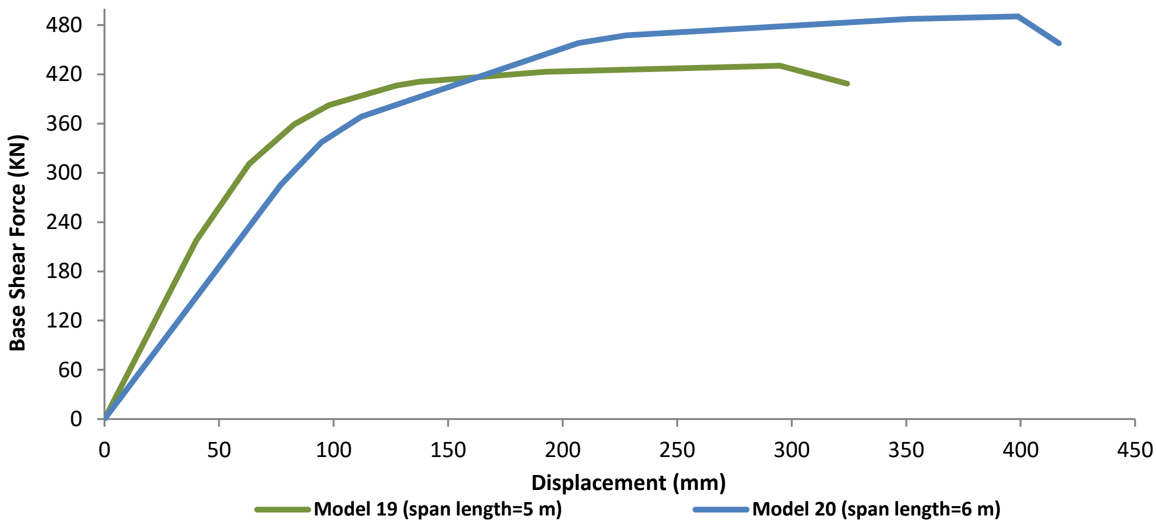


Figure 4.14: The effect of the span length change on the capacity (pushover) curve of the 8- story models at high-risk seismic zone

Table 4.12: Results of ductility values of models with a different story height at high-risk seismic zone

Number of stories	Story height	
	3.2 m	3.6 m
4-story	2.96	2.44
8-story	4.16	3.32

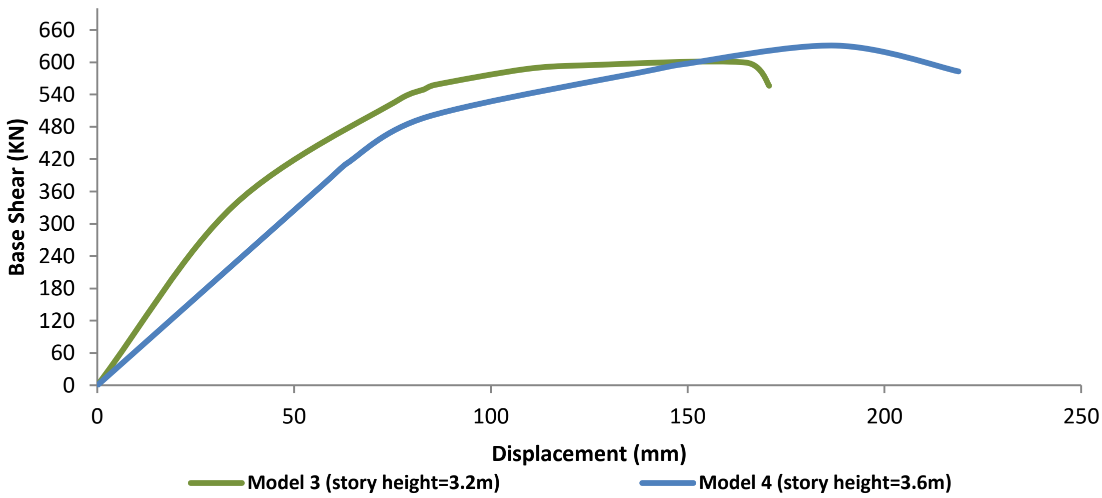


Figure 4.15: The effect of the story height change on the capacity (pushover) curve of the 4-story models at high-risk seismic zone

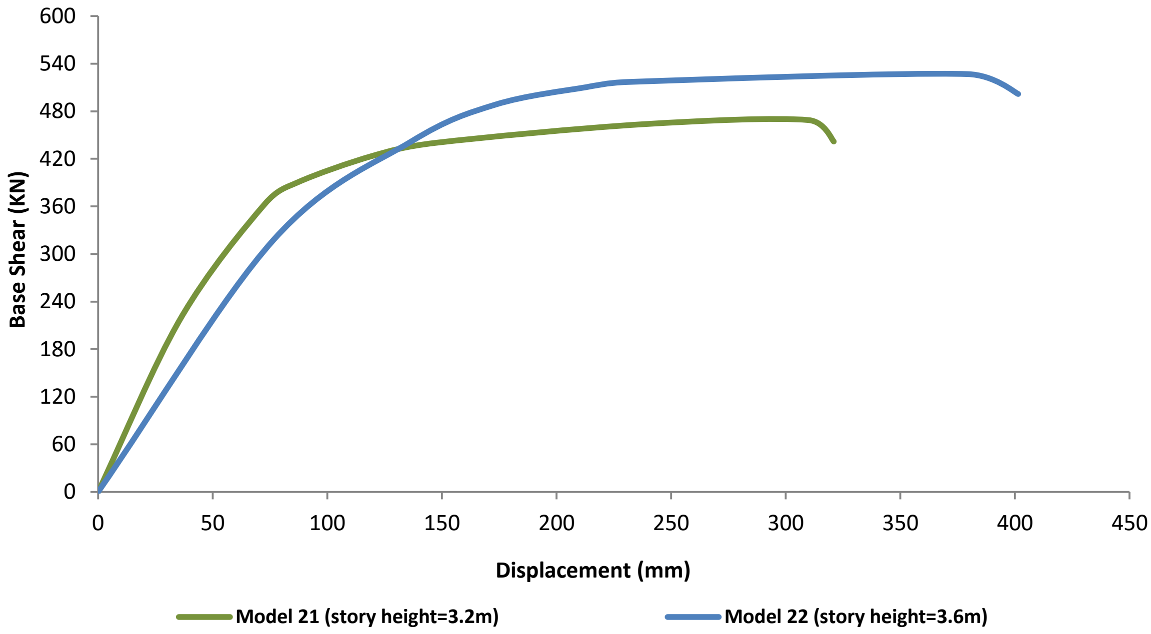


Figure 4.16: The effect of the story height change on the capacity (pushover) curve of the 8-story models at high-risk seismic zone

4.3.2.1.2 The effect of the compressive strength and yield strength on ductility and the capacity curves

As it been mentioned before that the difference in compressive strength and yield strength are parameters that its effect on the models (4-story) and models (8-story) will be studied. As this change in compressive strength and in yield strength is affecting positively or negatively on **ductility** at a high-risk seismic zone. Table 4.13 and Figure 4.17 illustrates difference ductility values in (F'_c) and (F_y) for models (4-story) and Table 4.14 and Figure 4.18 shows the **ductility** values for models (8-story), and as it shows in Table 4.13 and Figure 4.17 for models (4-story) and Table 4.14 and Figure 4.18 for models (8-story), when changing compressive strength from (250 Kgf/cm^2) to (300 Kgf/cm^2) and yield strength from (3000 Kgf/cm^2) to (4200 Kgf/cm^2), a decrease in **ductility** values happens, and this decrease happens when yield displacement (Δ_y) values increase and maximum displacement (Δ_m) values decrease but the yield shear (Vy) increase.

Table 4.13: Results of ductility values of models with different compressive strength and yield strength for the low-rise model (4-story) at high-risk seismic zone

Span length	Compressive strength \ Yield strength	
	3000 Kgf/cm^2 \ 250 Kgf/cm^2	4200 Kgf/cm^2 \ 300 Kgf/cm^2
5 m	3.20	2.96
6 m	2.71	2.44

Table 4.14: Results of ductility values of models with different compressive strength and yield strength for the mid-rise model (8-story) at high-risk seismic zone

Span length	Compressive strength \ Yield strength	
	3000 Kgf/cm^2 \ 250 Kgf/cm^2	4200 Kgf/cm^2 \ 300 Kgf/cm^2
5 m	4.22	4.16
6 m	3.38	3.32

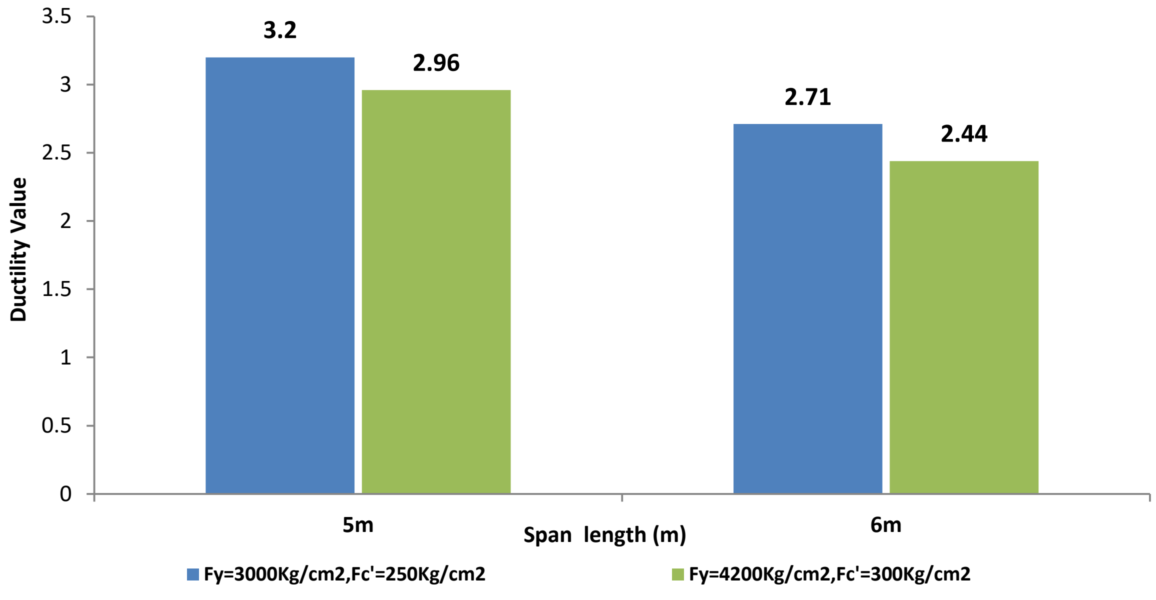


Figure 4.17: a comparison between the ductility values for the 4-story models with different compressive and yield strength at high-risk seismic zone

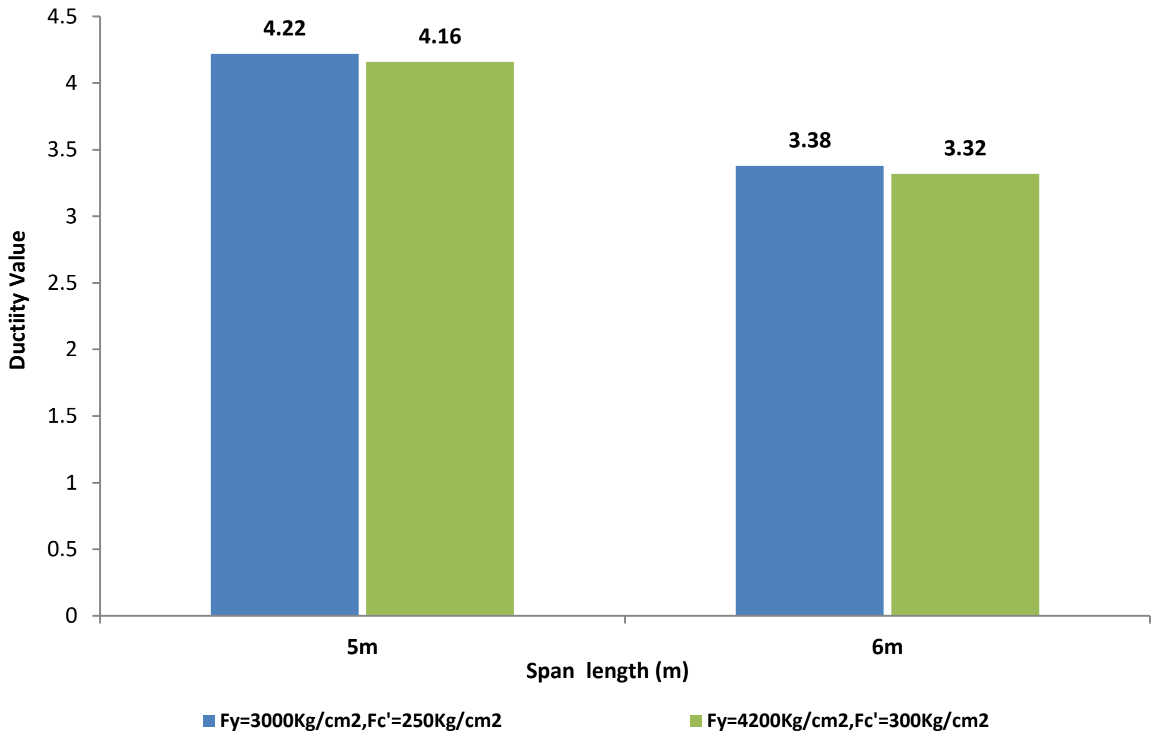


Figure 4.18: a comparison between the ductility values for the 8-story models with different compressive and yield strength at high-risk seismic zone

4.3.2.2 The effect of different size and type of openings on ductility factor and capacity (pushover) curves

This section offers a study on the impact of the difference in size and type of openings on ductility values with a change in certain parameters, including the window height, span length, yield strength, and compressive strength at the high-risk seismic zone.

4.3.2.2.1 The impact on the ductility of different sizes and type of openings with (F'_C=250 Kgf/cm^2) and (F_y=3000 Kgf/cm^2)

As it been mentioned in the previous chapter that the significant parameter in this study is the change in openings size and type that affect **ductility,** and as this change in openings has a negative or positive effect on models (4-story) and models (8-story) in this section the effect of the openings with compressive strength (F'_C=250 Kgf/cm^2) and yield strength (F_y=3000 Kgf/cm^2) will be discussed at a high-risk seismic zone. The Table 4.15 and Figure 4.19 shows the **ductility** values for models (4-story) and models (8-story) at a high-risk seismic zone, and the Figure 4.20 shows a comparison between capacity (pushover) curves for models (4-story) and the Figure 4.21 for models (8-story). As it shows in Table 4.15 and Figures 4.19 that **Ductility** values in models (4-story) and models (8-story) increase the size of the openings in the shear wall and the **ductility** increase rate openings such as doors are higher than openings such as windows. The reason for the **ductility** increase is due to a decrease in yield displacement (Δ_y) value and an increase in maximum displacement (Δ_m) and it has been noticed that changing the opening size affects the building strength after a decrease in yield shear (V_y) and maximum shear (V_m) at a high-risk seismic zone.

Parameters in this section: story height = 3.2m, span length = 5m, shear wall thickness = 0.25 m, F_y= 3000 Kgf/cm^2, F'_C = 250 Kgf/cm^2

Table 4.15: Results of ductility values of models without and with openings with different number of stories with (F'_C=250 Kgf/cm^2) and (F_y=3000 Kgf/cm^2) at high risk seismic zone

Model No.	Number of stories	
	Low-rise (4-story)	**Mid-rise (8-story)**
Model 1 (without opening)	2.94	4.20
Model 2 (1.1mx2.2m)	3.22	4.48
Model 3 (2.0mx1.5m)	3.00	4.31
Model 4 (2.0mx2.0m)	3.16	4.41
Model 5 (2.0mx2.2m)	3.96	4.53
Model 6 (3.0mx1.5m)	3.85	4.35
Model 7 (3.0mx2.0m)	3.64	4.28

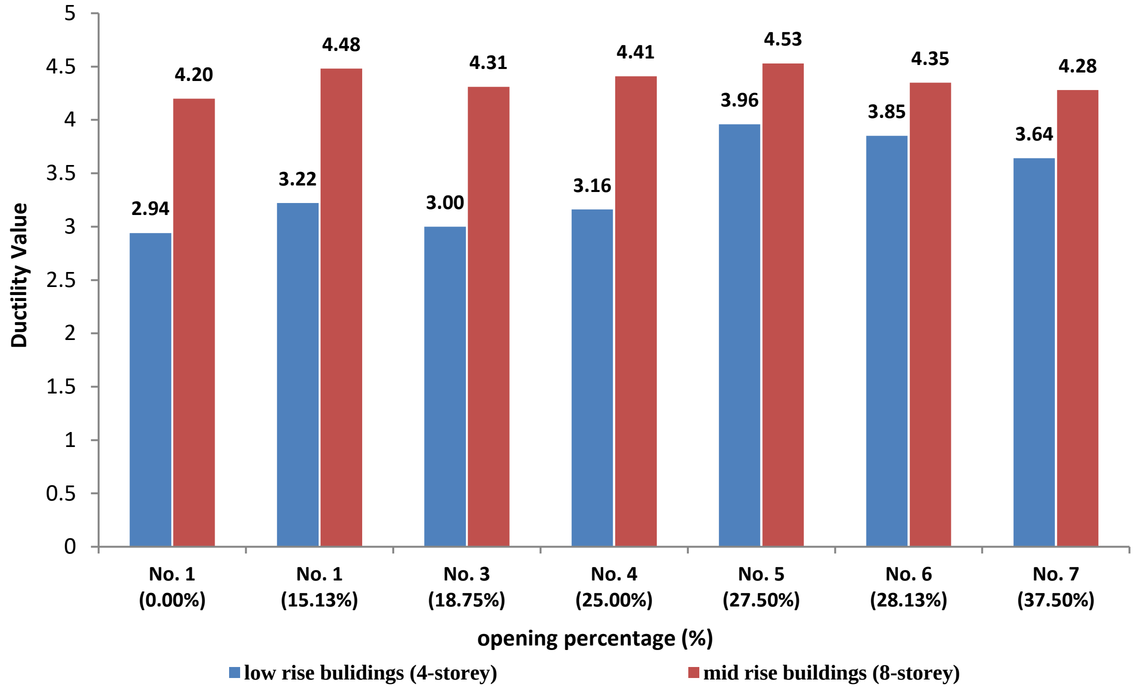


Figure 4.19: a comparison between the ductility values with the different opening sizes and it's a percentage for the 4-story and 8-story models with ($\boldsymbol{F_y}$=3000 Kg/cm^2, $\boldsymbol{F'_C}$=250 Kgf/cm^2) at high risk seismic zone

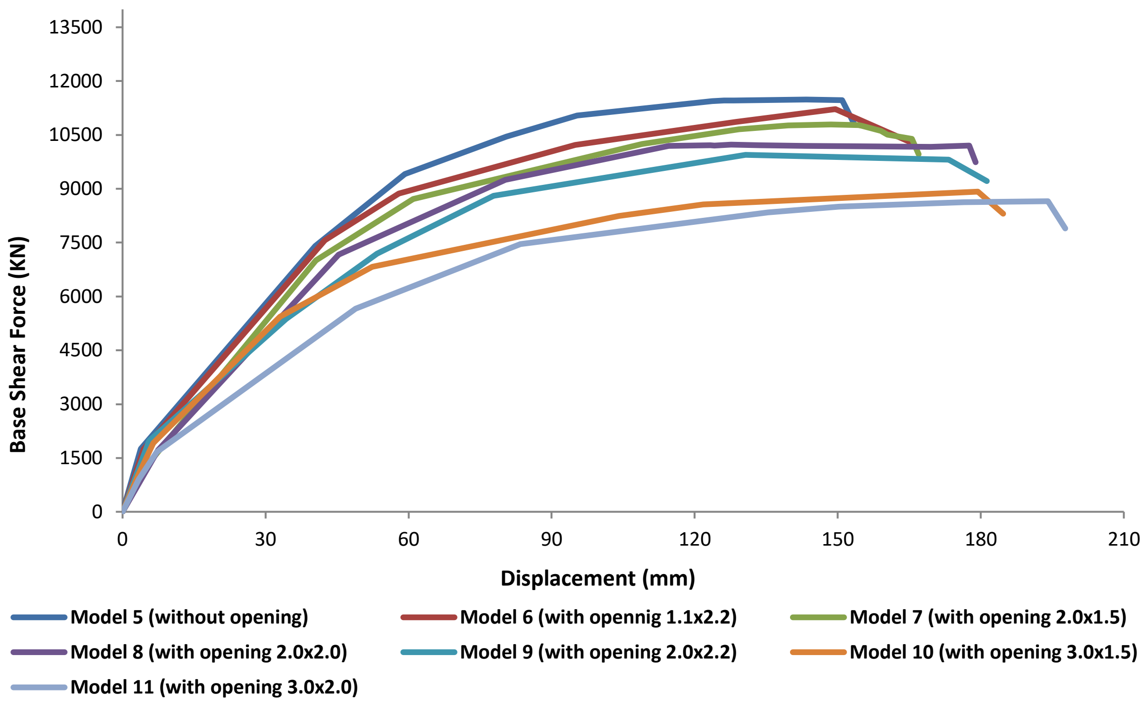


Figure 4.20: The effect of the change in the opening size and it's a percentage on the capacity (pushover) curve of the 4-story models ($\boldsymbol{F_y}$=3000 Kgf/cm^2, $\boldsymbol{F'_C}$=250 Kgf/cm^2) at high risk seismic zone

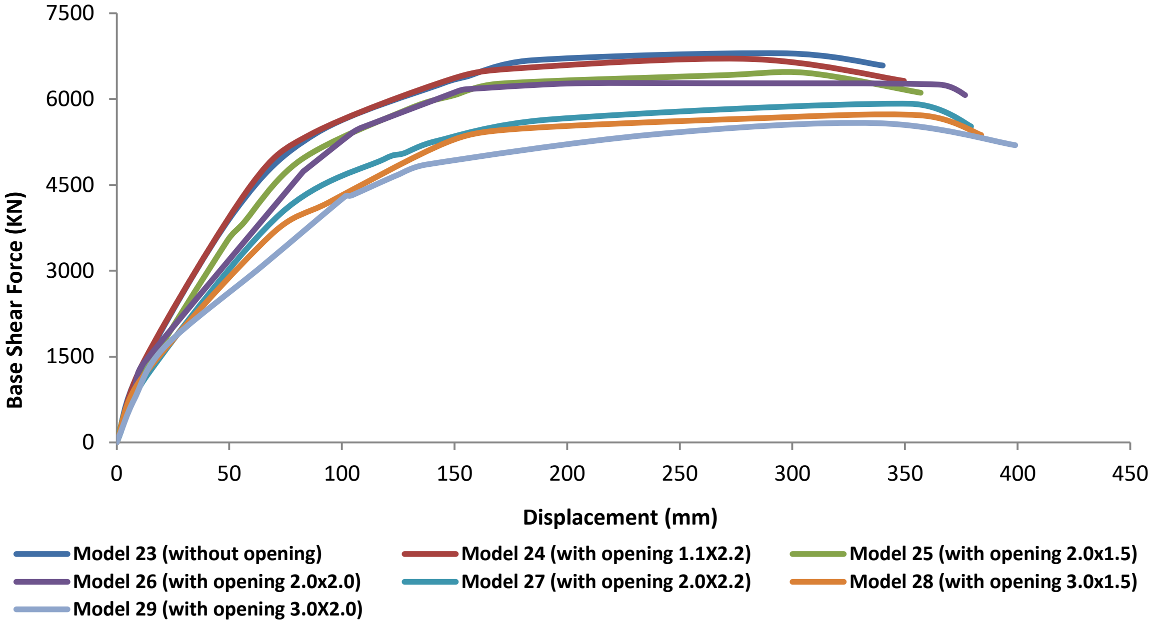


Figure 4.21: The effect of the change in the opening size and it's a percentage on the capacity (pushover) curve of the 8-story models with ($\boldsymbol{F_y}$=3000 Kgf/cm^2, $\boldsymbol{F'_C}$=250 Kgf/cm^2) at high risk seismic zone

4.3.2.2.2 The impact on the ductility of different sizes and type of openings with (F'_C= 300 Kgf/cm^2) and (F_y=4200 Kgf/cm^2)

As it been mentioned in the previous chapter that the most significant parameter in this study is the difference opening size and its effect on **ductility**, and so it's effect will be discussed at the high-risk seismic zone after changing few parameters from the previous section with (F'_C=300 Kgf/cm^2) and (F_y=4200 Kgf/cm^2). Table 4.16 and Figure 4.22 illustrates the **ductility** value for the models (4-story) and models (8-story) and the Figure 4.23 a comparison between the capacity (pushover) curves fore models (4-story), and the Figure 5.24 shows a comparison between capacity curve (pushover) curves for models (8-story). As it shows in Table 4.16 and Figure 4.22 for 4-story and Figure 4.23 for 4-story an increase in **ductility** value and the increase in **ductility** is a result of the increase in yield displacement (Δ_y) value for openings such as windows and the decrease in yield displacement (Δ_y) value for openings such as doors and an increase in maximum displacement (Δ_m) value. As it has been shown that as much as the change in opening size increase in rate, the building strength decrease as a result of a decrease in yield shear (V_y) values at a high-risk seismic zone.

Parameters in this section: story height = 3.6m, span length = 6m, shear wall thickness = 0.30 m, F_y= 4200 Kgf/cm^2, F'_C = 300 Kgf/cm^2

Table 4.16: Results of ductility values of models without and with openings with different number of stories with (F'_C=300 Kgf/cm^2) and (F_y=4200 Kgf/cm^2) in high risk seismic zone

Model No.	Number of stories	
	Low-rise (4-story)	**Mid-rise (8-story)**
Model 1 (without opening)	2.83	3.48
Model 2 (1.1mx2.2m)	2.95	3.62
Model 3 (2.0mx1.5m)	2.89	3.53
Model 4 (2.0mx2.0m)	2.92	3.42
Model 5 (2.0mx2.2m)	3.21	3.70
Model 6 (3.0mx1.5m)	3.42	3.85
Model 7 (3.0mx2.0m)	3.25	3.77

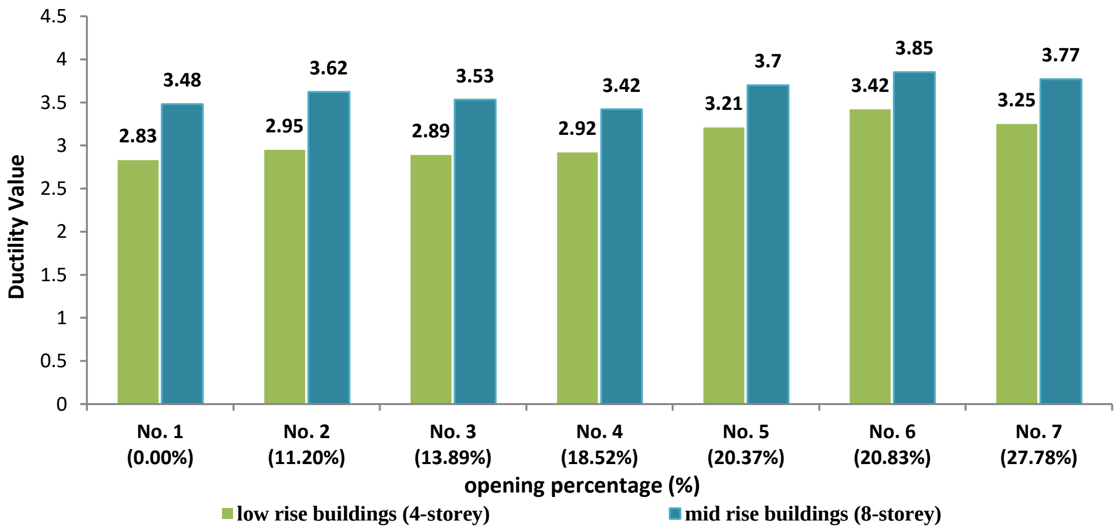


Figure 4.22: comparison between the ductility values with the different opening sizes and it's a percentage for the 4- story and 8-story models with (F_y=4200 Kgf/cm^2, F'_C=300 Kgf/cm^2) at high risk seismic zone

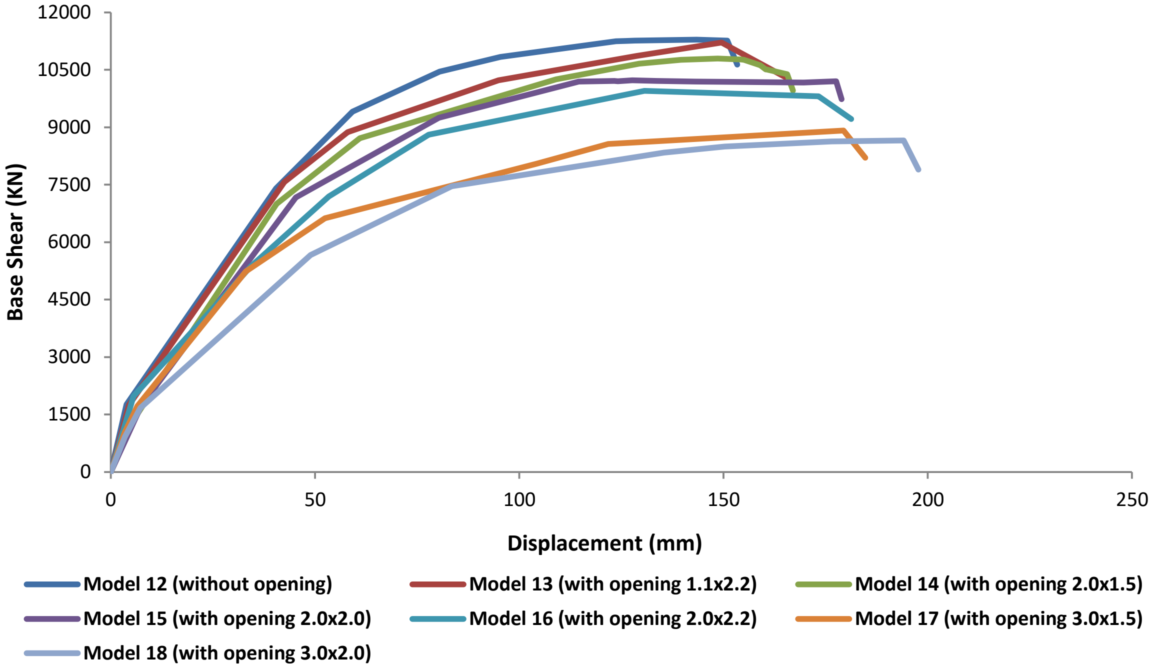


Figure 4.23: The effect of the change in the opening size and it's a percentage on the capacity (pushover) curve of the 4-story models with (F_y=4200 Kgf/cm^2, F'_c=300 Kgf/cm^2) at high risk seismic zone

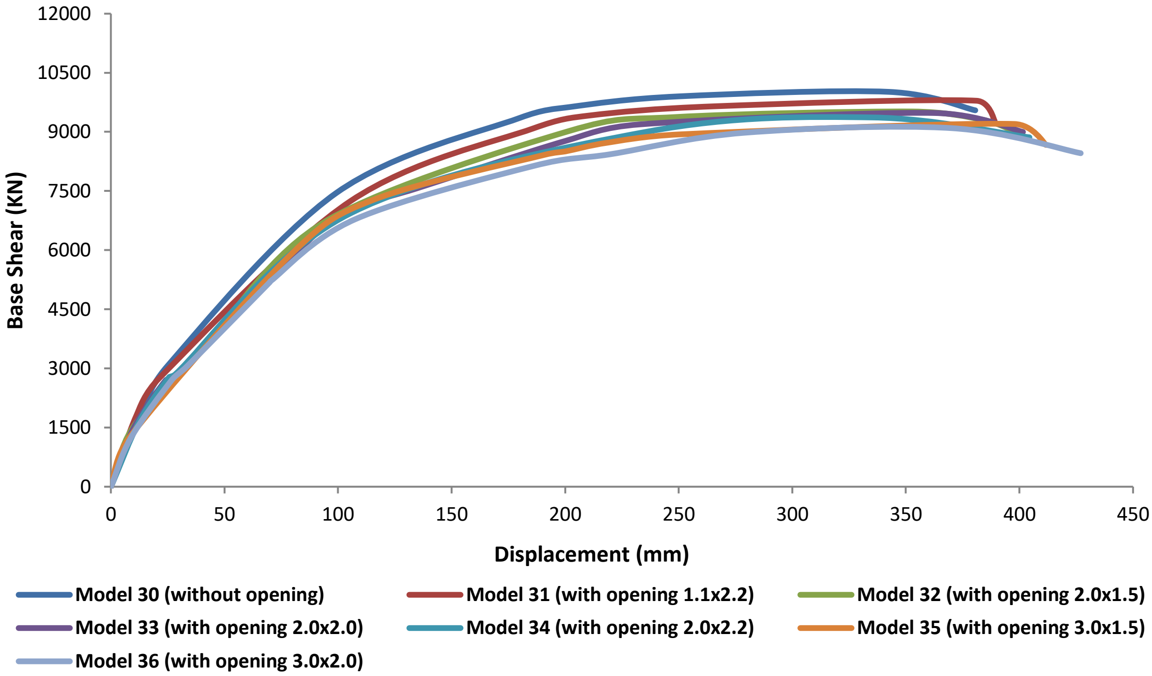


Figure 4.24: The effect of the change in the opening size and it's a percentage on the capacity (pushover) curve of the 8-story models with (F_y=4200 Kgf/cm^2, F'_c=300 Kgf/cm^2) at high risk seismic zone

Table 4.17: The average ductility values for the low-rise (4-story) and mid-rise (8-story) building models at moderate and high-risk seismic zones

No. of story	Moderate seismic zone				High risk seismic zone			
	MRF	**MRFSW**	**MRFSW WITH OPENING (Door)**	**MRFSW WITH OPENING (Window)**	**MRF**	**MRFSW**	**MRFSW WITH OPENING (Door)**	**MRFSW WITH OPENING (Window)**
Low-rise building (4-story)	2.34	3.68	4.20	3.89	2.83	2.89	3.34	3.26
Mid-rise building (8-story)	3.36	4.36	4.61	4.39	3.77	3.84	4.08	3.99

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 conclusions

In this research, the 3D moment resisting frame system (MRF) and the dual system (MRFS) have been studied, and shear wall system (SW) has been excluded from this study for not achieving the desired results and its inaccuracy. The models are designed with different opening sizes in a shear wall to determine the **ductility**, maximum displacement, yield displacement, maximum shear, and yield shear. 72 models have been analyzed and designed, but after excluding the shear wall system results they became 72 models by ETABS **V16** program and after that the pushover curves were extracted to determine the required parameters the models were studied in two different seismic zones, high-risk seismic zone, and moderate seismic zone, the main parameter in this study was the effect openings in shear wall on **ductility** values, other parameters including the story height, span length, and $F'_C$and Based on the findings the conclusion of the research was:

- The span length difference from 5m to 6m decreases **ductility** values for mid-rise buildings (8-story) more than low-rise buildings (4-story) at a moderate and high-risk seismic zone.

- An increase in span length from 5m to 6m causes an increase in yield displacement (Δ_y) and maximum displacement (Δ_m) values at a moderate and high-risk seismic zone.

- An increase in story height from 3.2m to 3.6m causes a decrease in **ductility** values, but the decrease rate in **ductility** values in mid-rise buildings (4-story) is higher than low-rise buildings (8-story) at a moderate and high-risk seismic zone.

- When changing the story height from 3.2m to 3.6m an increase in yield displacement (Δ_y) and maximum displacement (Δ_m) values happen for at a moderate and high-risk seismic zone.
- When increasing the compressive strength (F'_c) and yield strength (F_y), the **ductility** value will decease at a moderate and high-risk seismic zone.

- When changing (F'_c) and (F_y) the yield displacement (Δ_y) values increase and maximum displacement (Δ_m) values decrease at the moderate and high-risk seismic zone.

- When increasing the span length from 5m to 6m because of a decrease in the building strength, maximum shear (V_m) and yield shear (V_y) values will decrease at a moderate and high-risk seismic zone.

- When increasing the story height from 3.2m to 3.6m that cause a decrease in the building's strength and maximum shear (V_u) and yield shear (V_y) values will decrease.

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- When increasing compressive strength (F'_c) from 250 Kgf/cm^2 to 300 Kgf/cm^2 and yield strength (F_y) from 3000 Kgf/cm^2 to 4200 Kgf/cm^2, yield shear (V_y) and maximum shear (V_m) values will decrease at the moderate and high-risk seismic zone.

- In the shear wall system, **ductility** values are very high and won't be accurate enough so it was excluded from this study.

- The ductility of the building increases the higher the size of the openings in the shear wall, but this rise in ductility happens at a greater rate for openings such as doors than openings such as windows.

- The **ductility** increase rate in the low-rise building (4-story) is higher than in mid-rise buildings (8-story).

- The increase rate in **ductility** values in buildings is affected by compressive strength ($F_{C'}$) and yield strength (F_y), so that the decrease rate for the buildings with F_y=4200 Kgf/cm^2 and F'_C=300 Kgf/cm^2 be less than the increase in buildings with F_y=3000 Kgf/cm^2 and F'_C=250 Kgf/cm^2.

- The increase rate in **ductility** value in buildings is affected by the seismic force, so the increase in **ductility** values for models that are located at a moderate seismic zone has a higher effect than the increase in **ductility** values for models at a high-risk seismic zone.

- The vertical type openings (door) are better than horizontal type openings (window) in terms of its effect on **ductility**.

- When an increase in size and rate of the openings, maximum displacement (Δ_m) value will increase.

- The building's strength decrease when decreasing the yield shear (V_y) and maximum shear (V_m) wherever the sizes of the openings and rate increase in the shear wall.

5.2 Recommendations

I. In this study all the models were symmetric, so in the future, it's possible making the models non-symmetric and studying them in two directions.

II. The four-story and eight-story buildings were used to study the different openings on ductility, the impact of the openings on the high-rise building can be studied in future studies.

III. Shear walls system were excluded from this study so the shear walls can be studied and focused on.

IV. The openings were distributing equally on a story in this study, so distributing the openings randomly along the building can also be studied.

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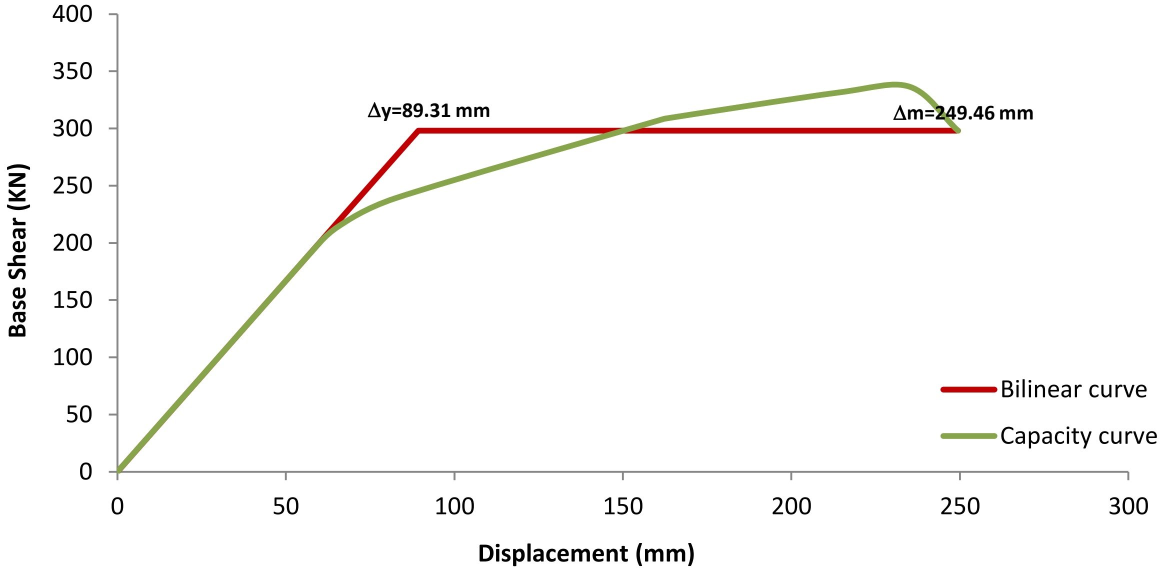
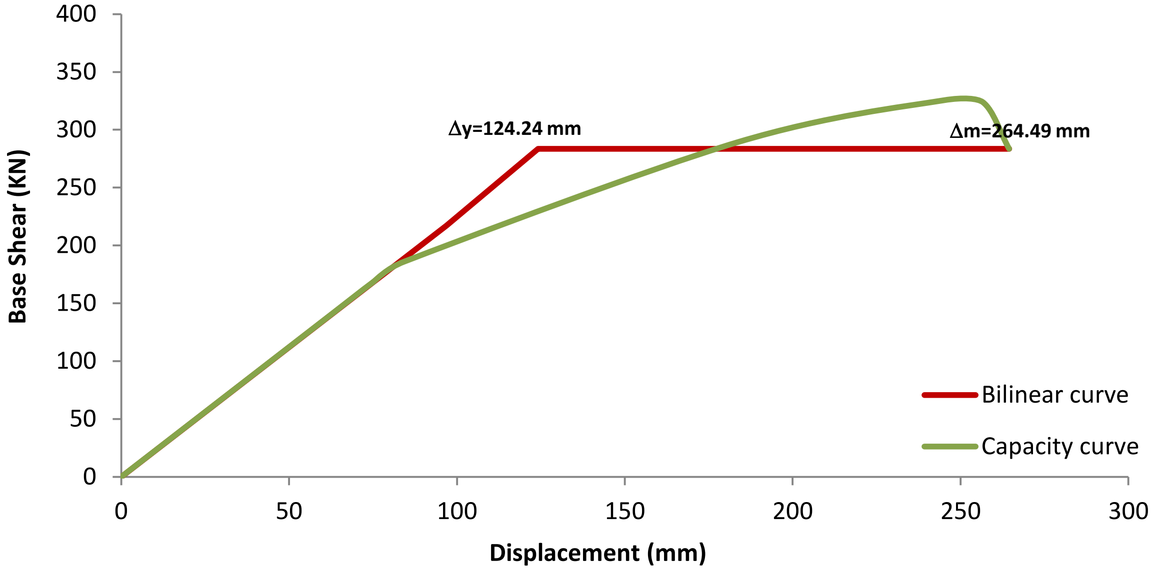
APPENDICES

Appendix A

Capacity (Pushover) curves for all models at moderate seismic zone

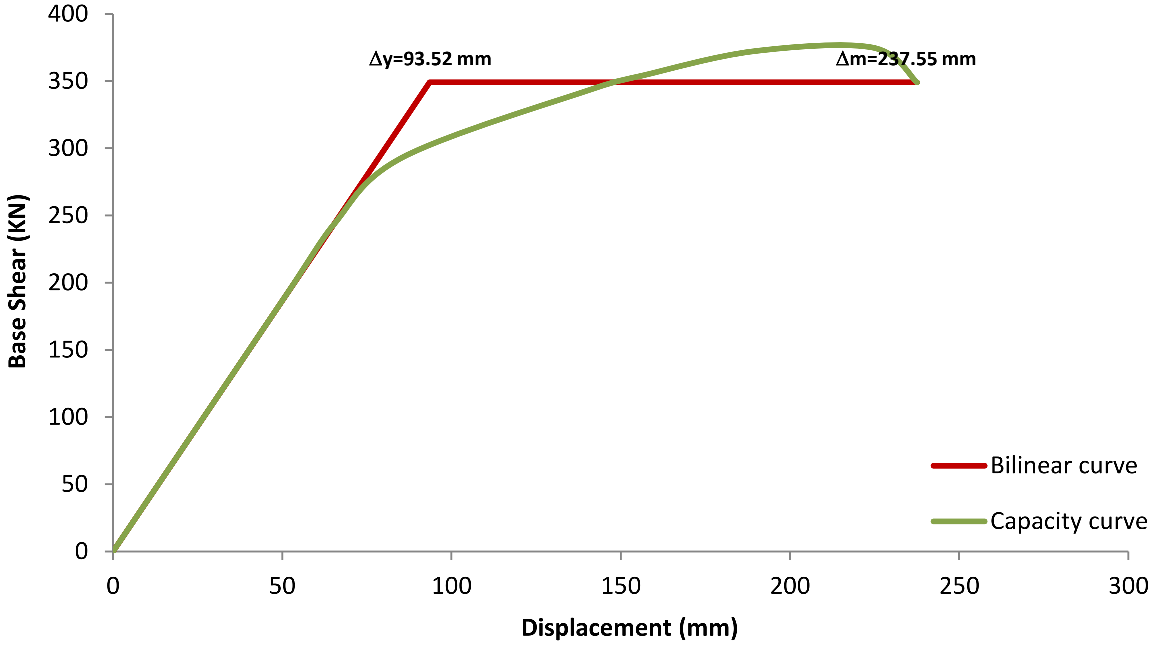


a) Model 1 (the span length= 5m)

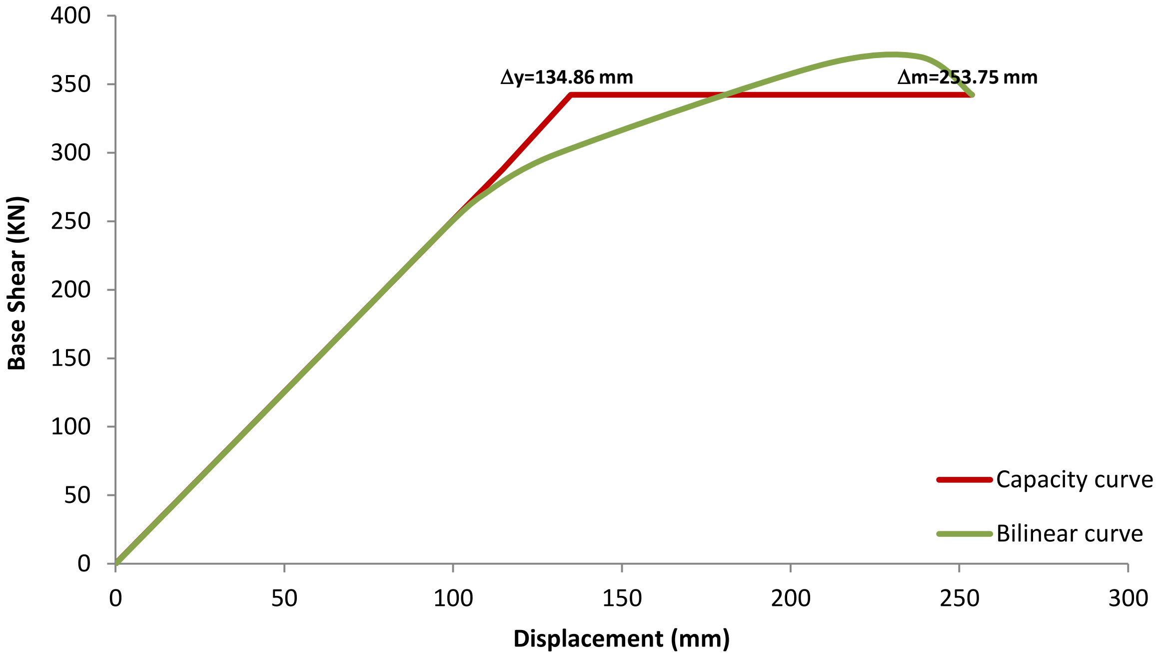


b) Model 2 (the span length= 6m)

Figure A.1: Capacity (pushover) curve with a bilinear curve of the analytical models-4 story (frame system) with ($\boldsymbol{f'c}$=250 Kgf/cm^2, $\boldsymbol{fy}$=3000 Kgf/cm^2)

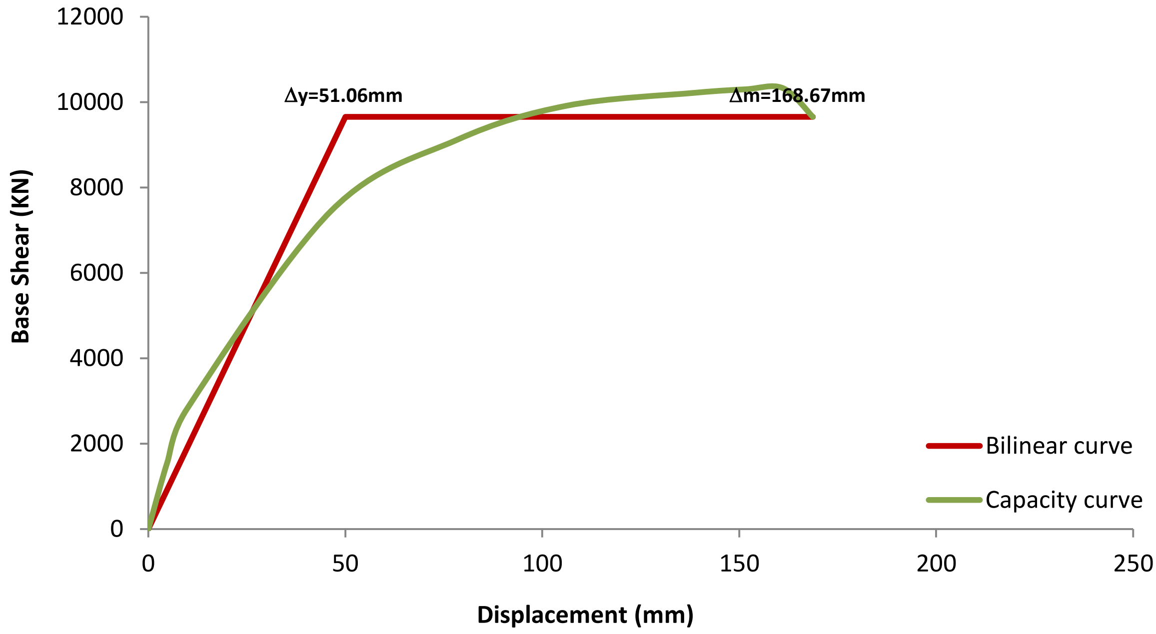


a) Model 3 (the span length= 5m)

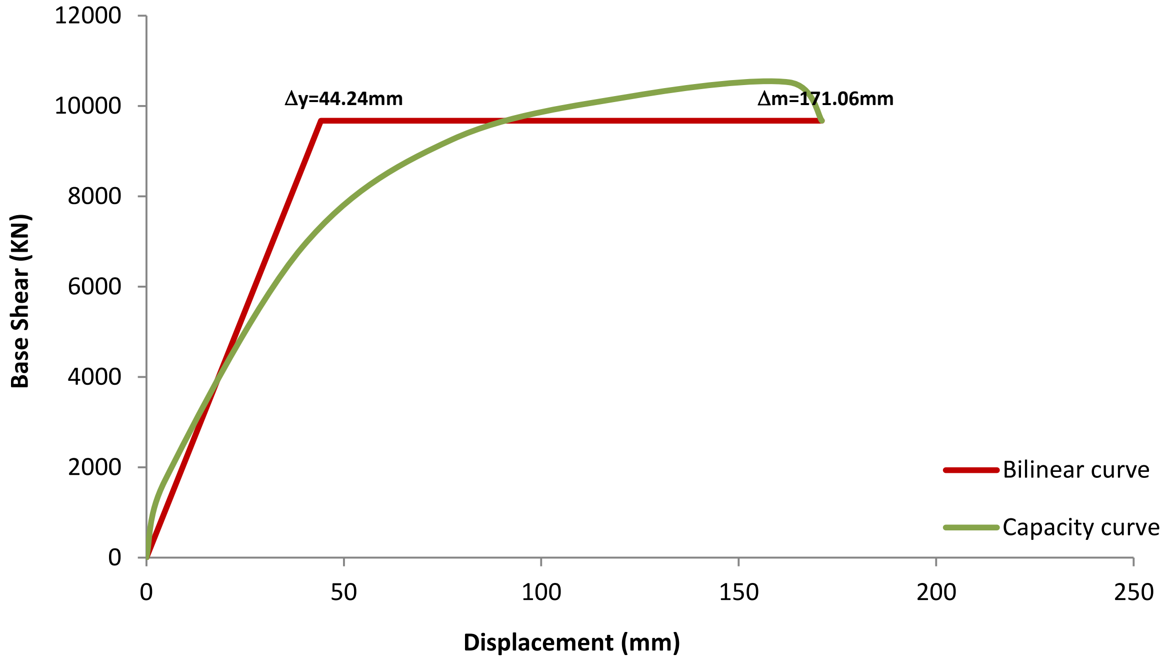


b) Model 4 (the span length= 6m)

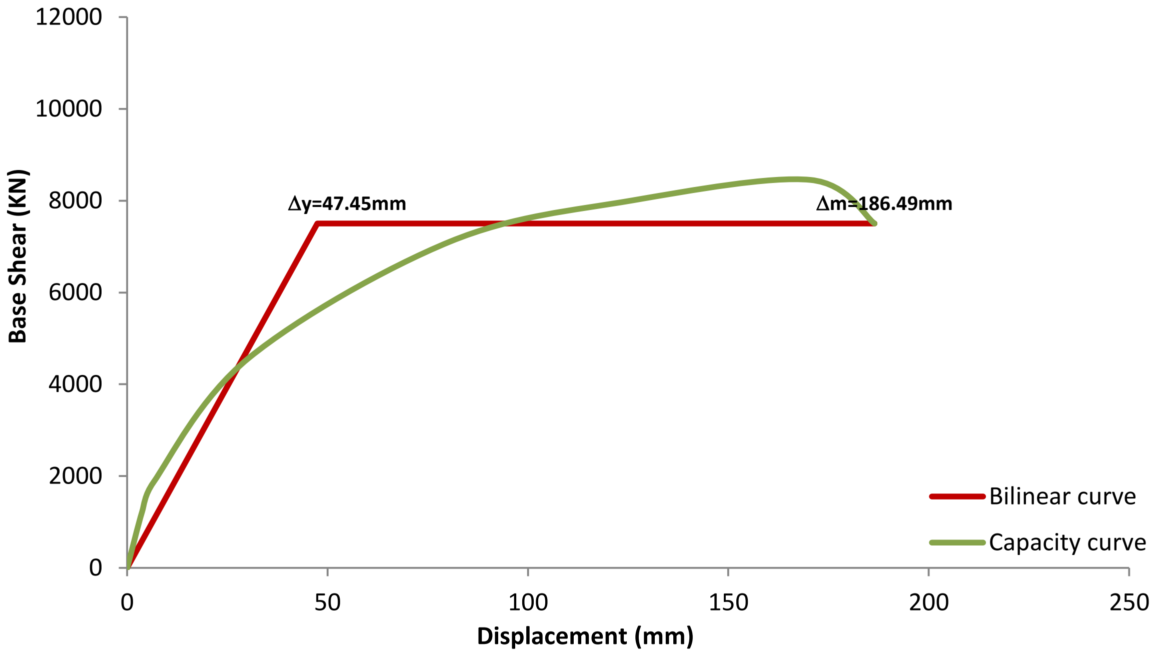
Figure A.2: Capacity (pushover) curve with a bilinear curve of the analytical models-4 story (frame system) with ($f'c$=300 Kgf/cm^2, fy=4200 Kgf/cm^2)



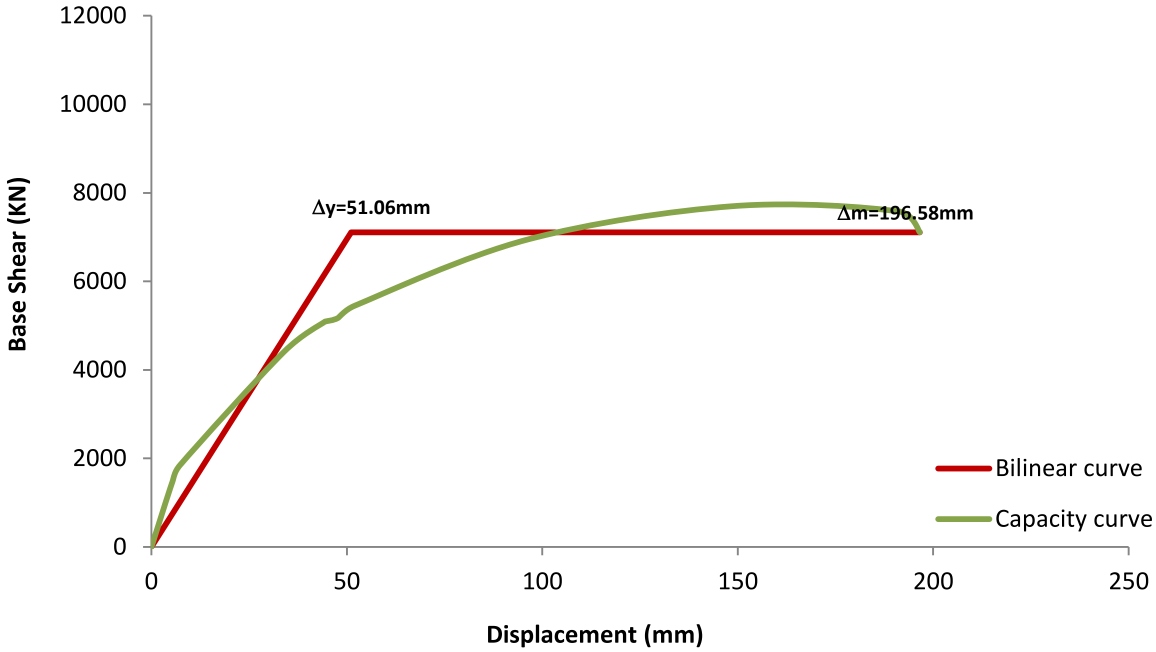
a) Model 5 (without opening)



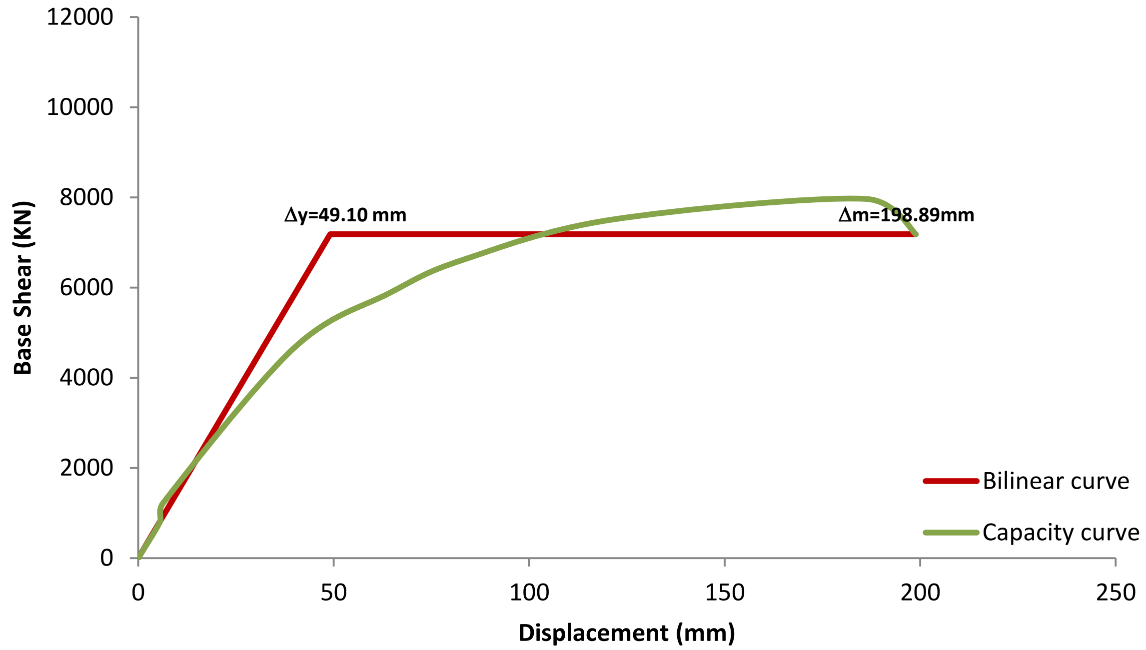
b) Model 6 (with opening 1.1mx2.2m)



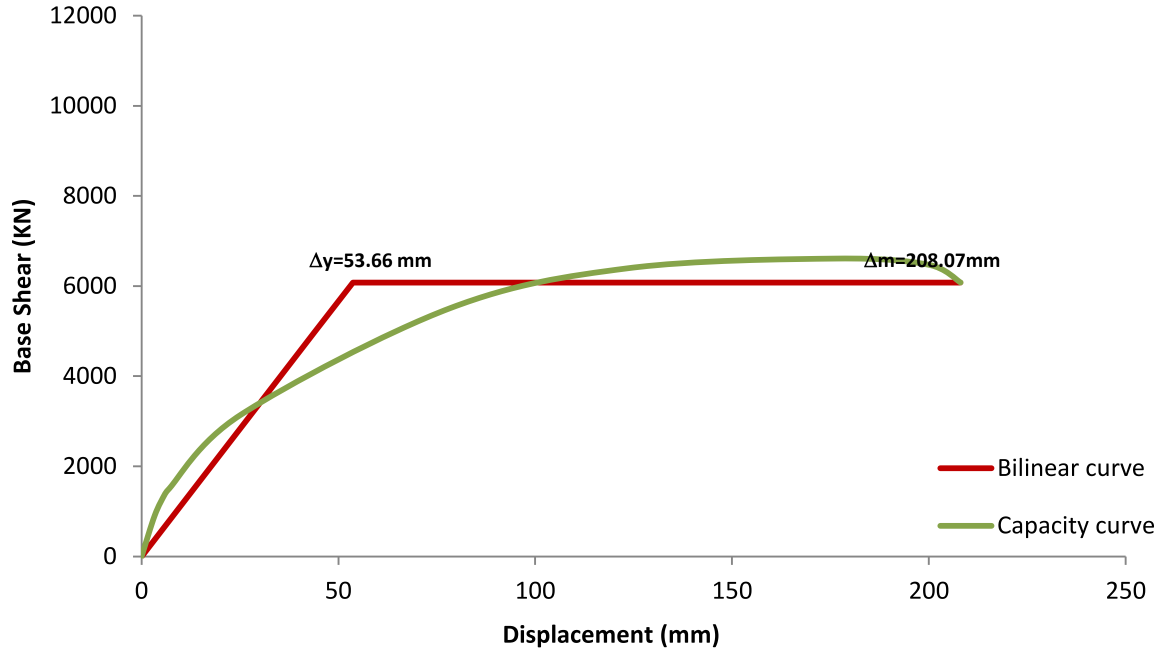
c) Model 7 (with opening 2.0mx1.5m)



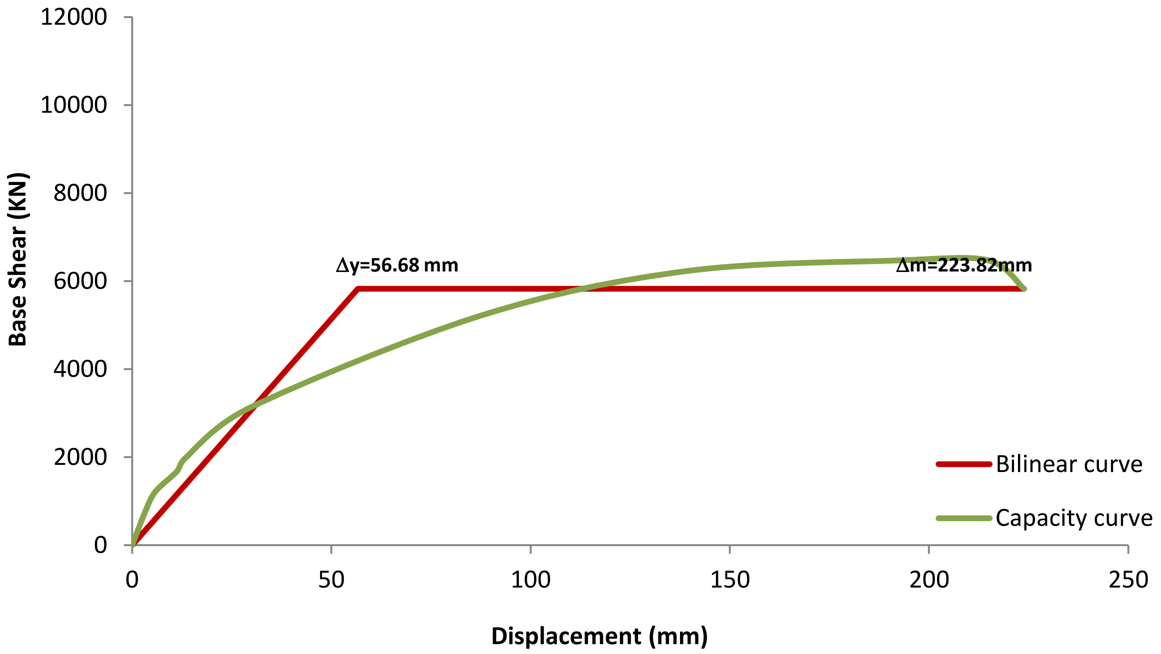
d) Model 8 (with opening 2.0mx2.0m)



e) Model 9 (with opening 2.0mx2.2m)

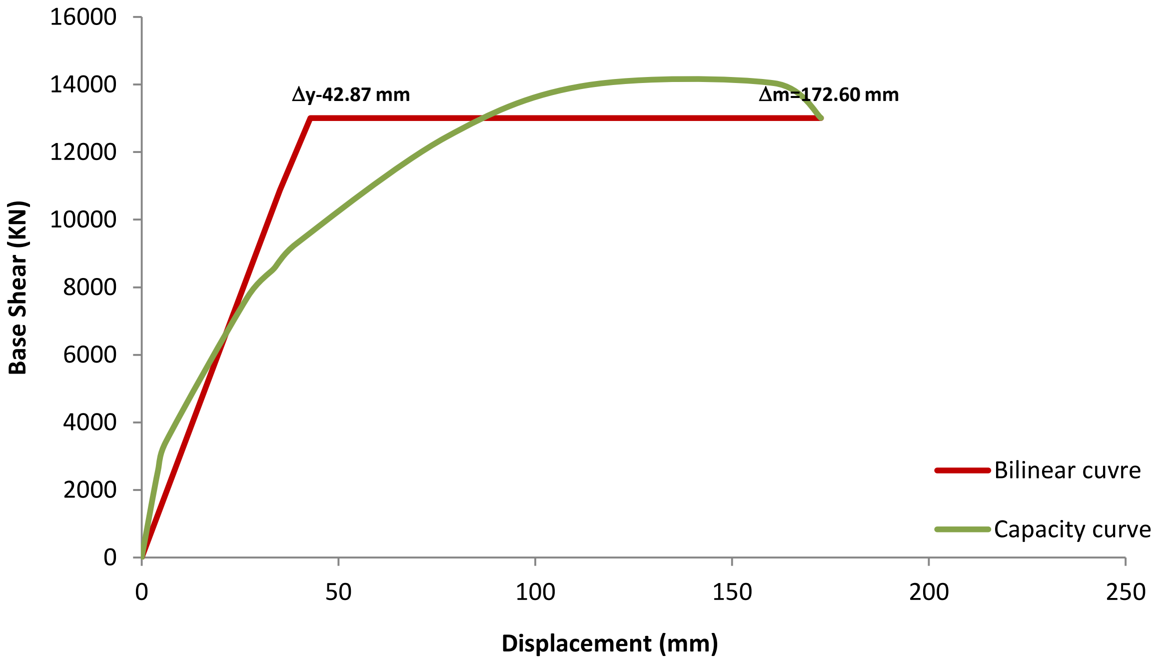


f) Model 10 (with opening 3.0mx1.5m)

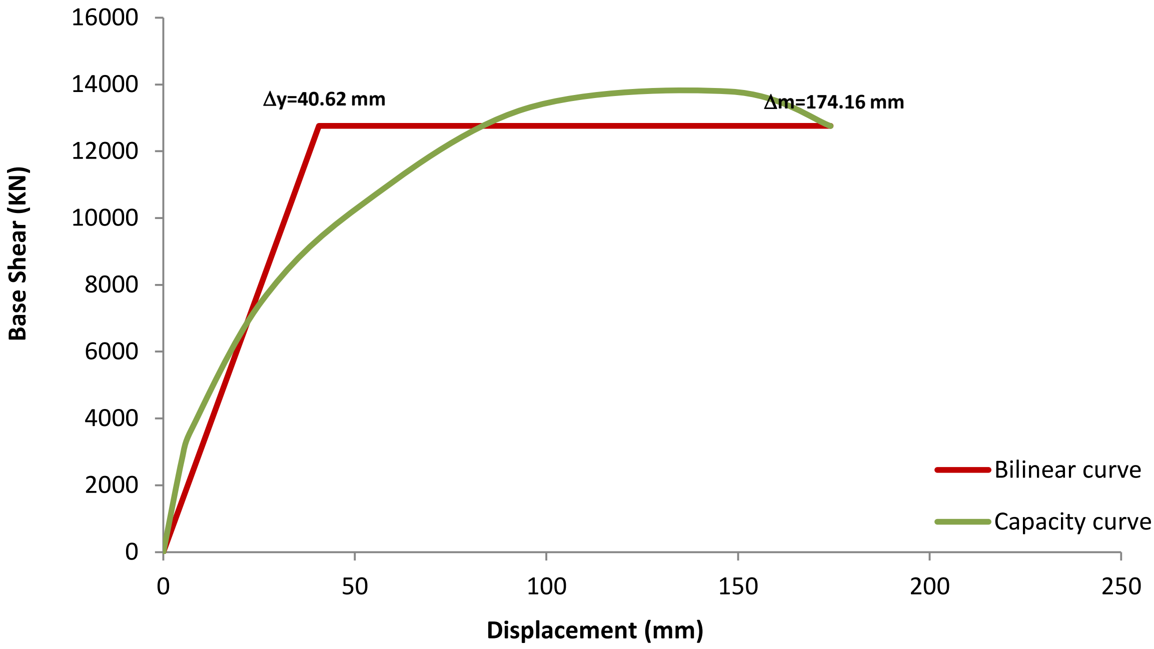


g) Model 11 (with opening 3.0mx2.0m)

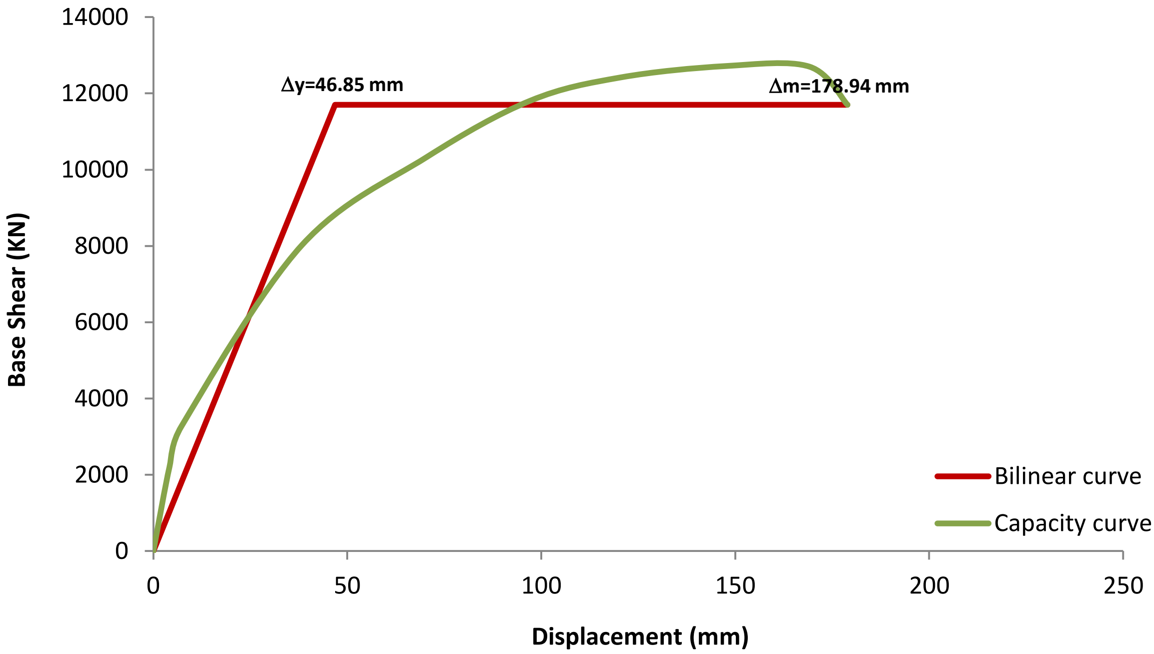
Figure A.3: Capacity (pushover) curve with a bilinear curve of the analytical models-4 story (Dual system) with ($f'c$=250 Kgf/cm^2, fy=3000 Kgf/cm^2)



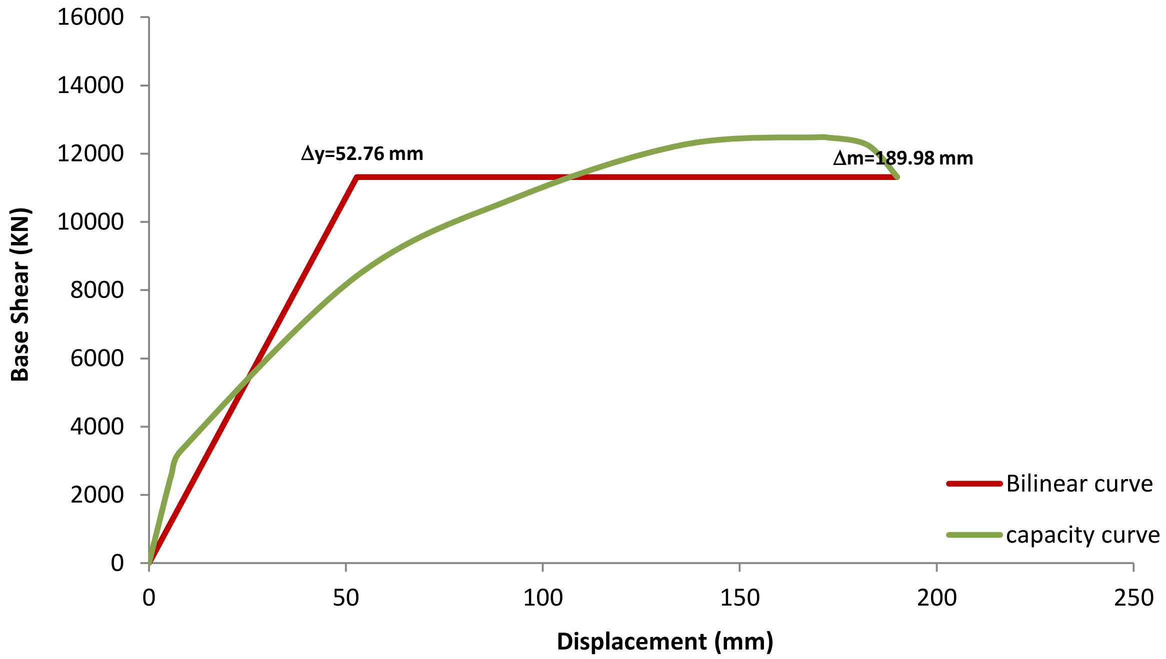
a) Model 12 (without opening)



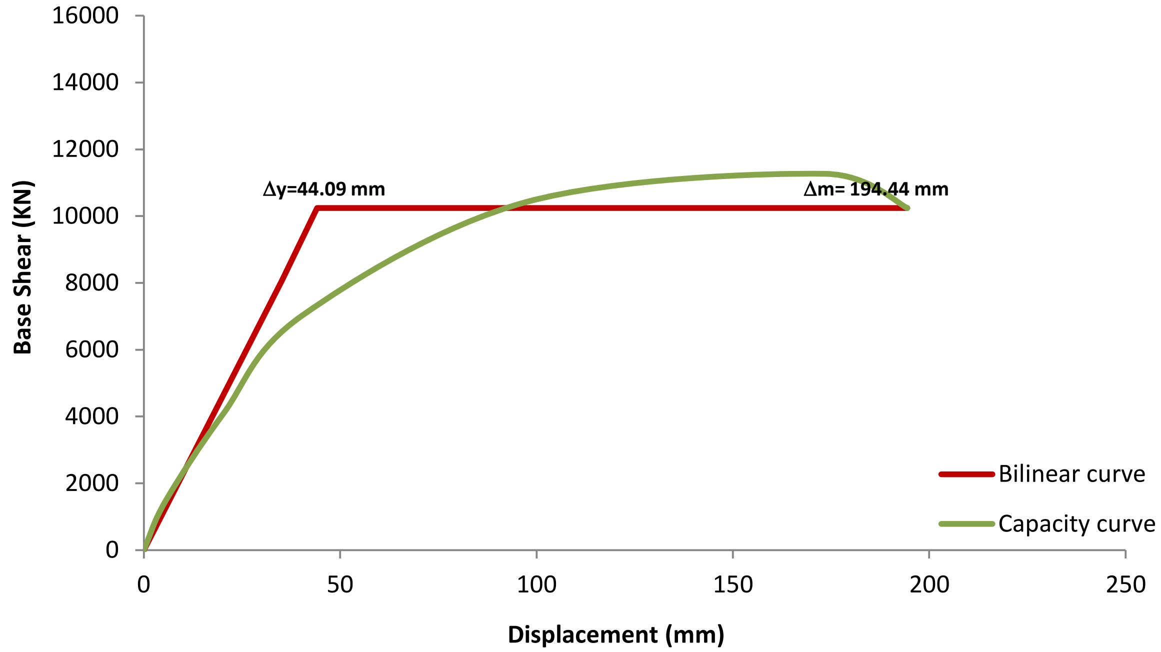
b) Model 13 (with opening 1.1mx2.2m)



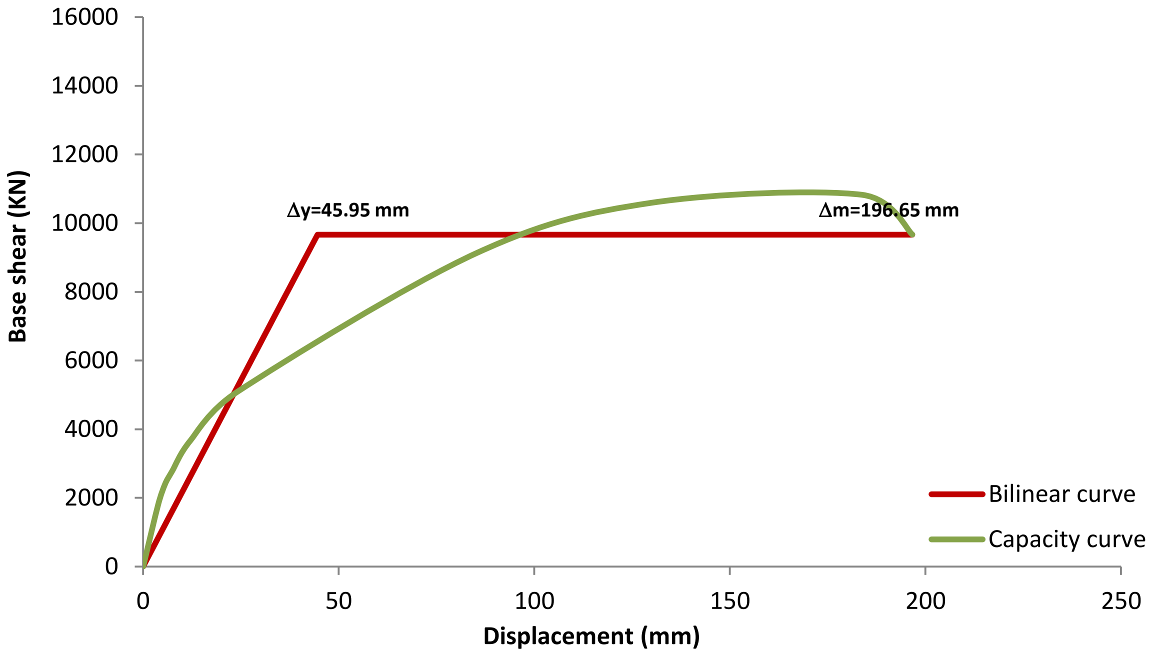
c) Model 14 (with opening 2.0mx1.5m)



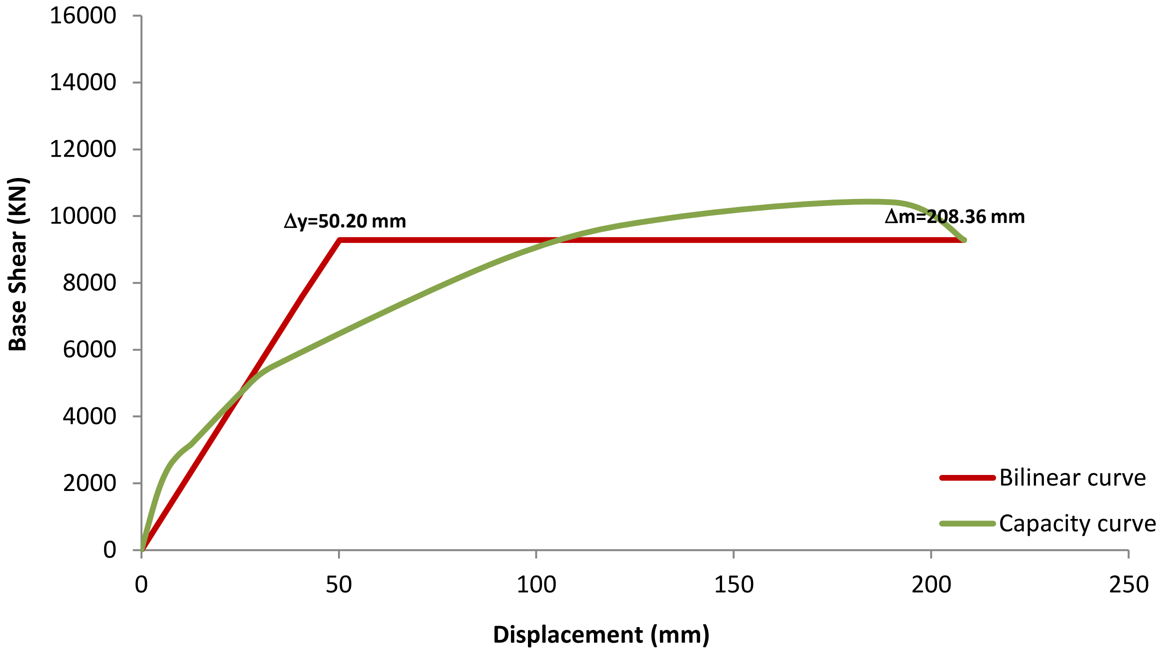
d) Mode 15 (with opening 2.0mx2.0m)



e) Model 16 (with opening 2.0mx2.2m)

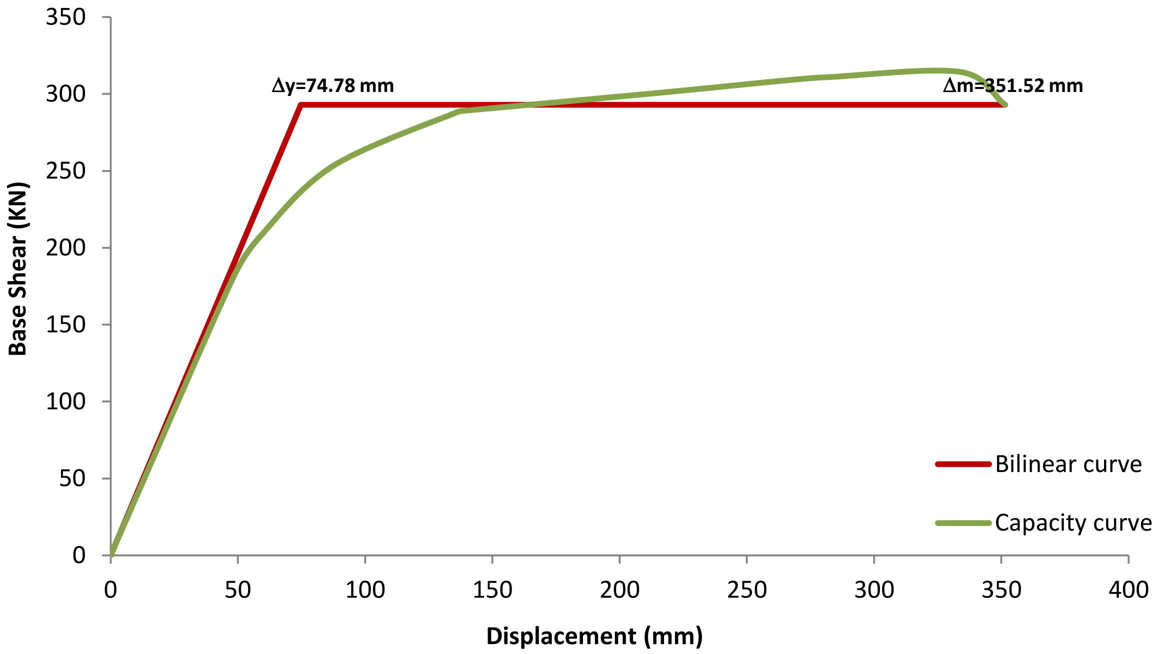


f) Model 17 (with opening 3.0mx1.5m)

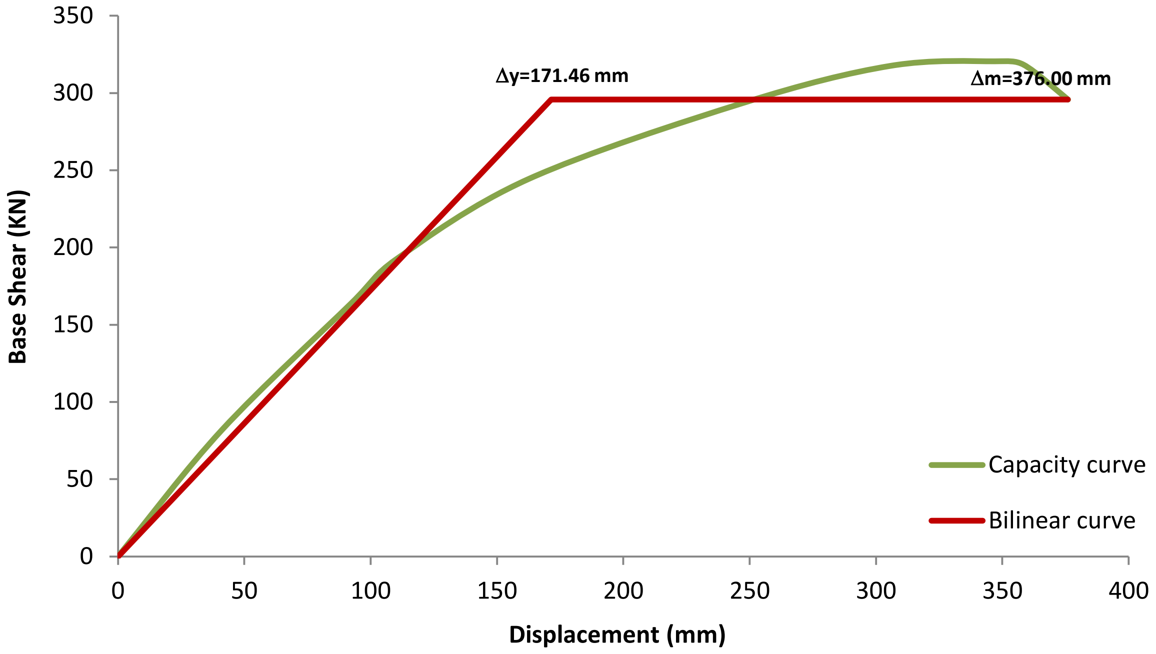


g) Model 18 (with opening 3.0mx2.0m)

Figure A.4: Capacity (pushover) curve with a bilinear curve of the analytical models-4 story (Dual system) with ($\boldsymbol{f'c}$=300 Kgf/cm^2, $\boldsymbol{fy}$=4200 Kgf/cm^2)

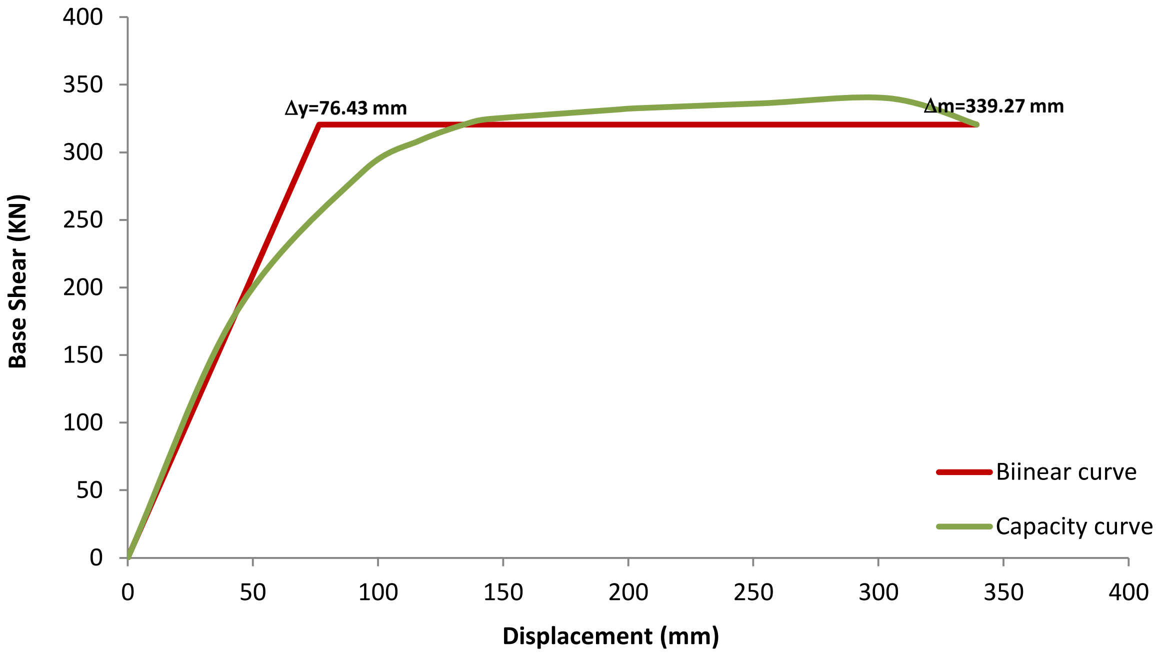


a) Model 19 (the span length= 5m)

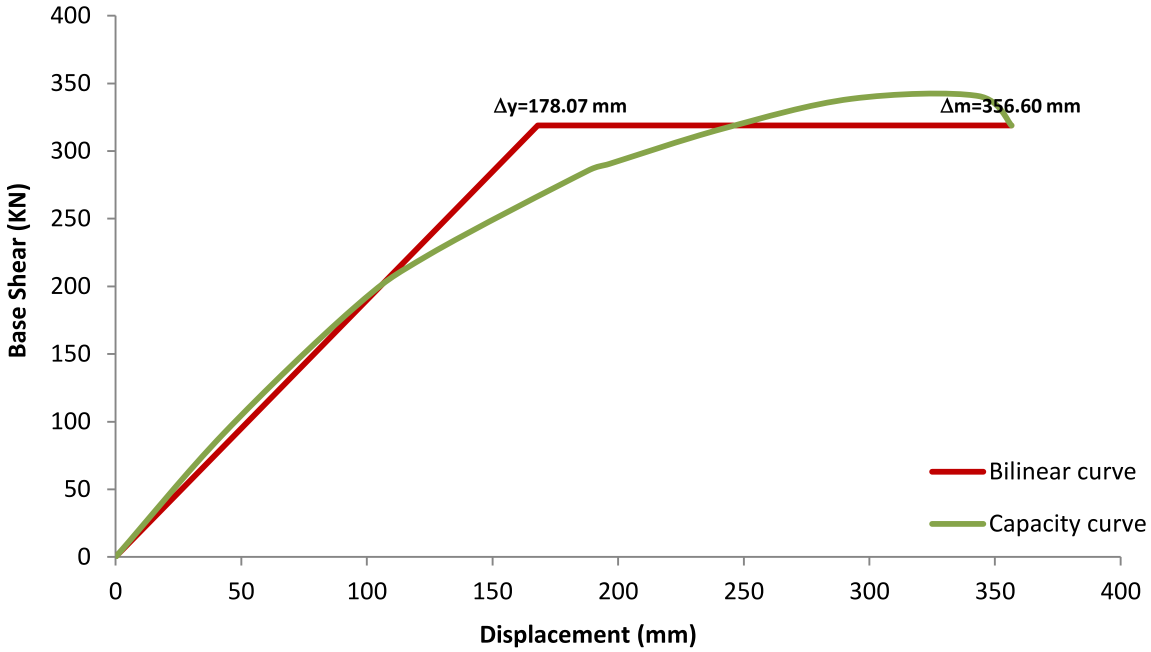


b) Model 20 (the span length= 6m)

Figure A.5: Capacity (pushover) curve with a bilinear curve of the analytical models-8 story (frame system) with ($\boldsymbol{f'c}$=250 Kgf/cm^2, $\boldsymbol{fy}$=3000 Kgf/cm^2)

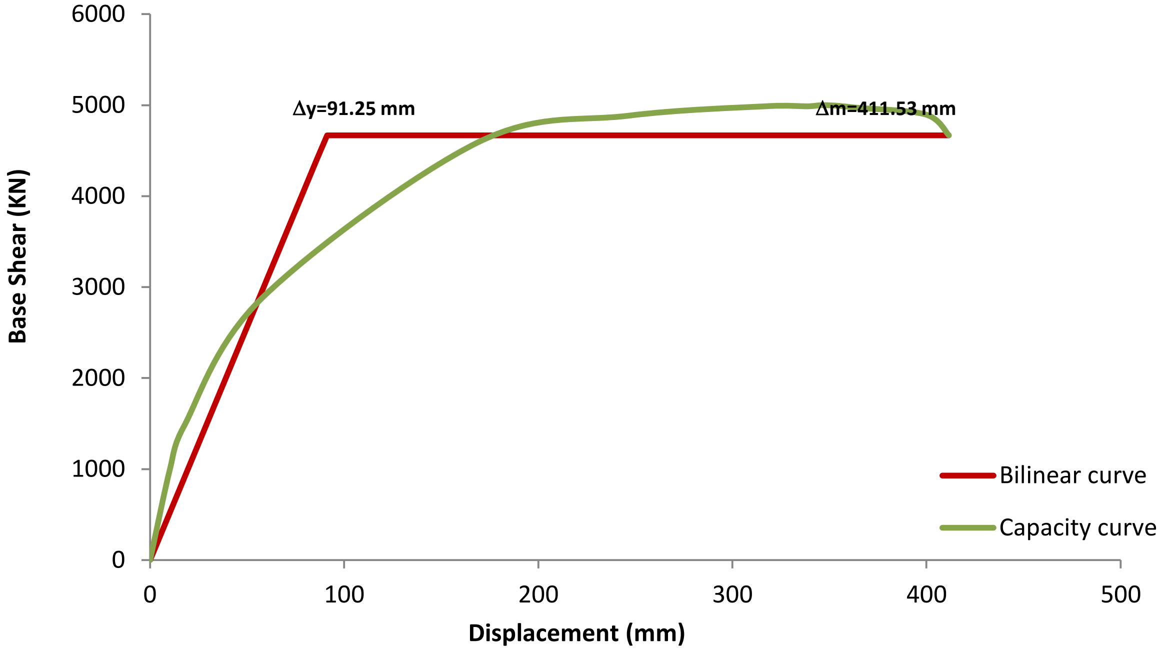


a) Model 21 (the span length= 5m)

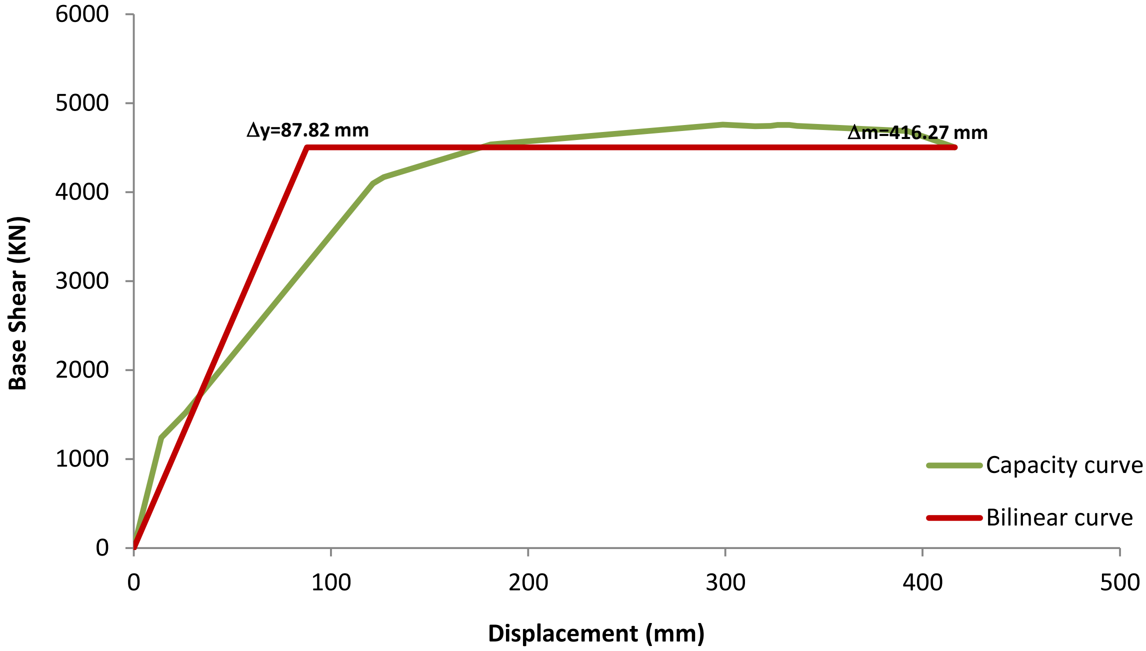


b) Model 22 (the span length= 6m)

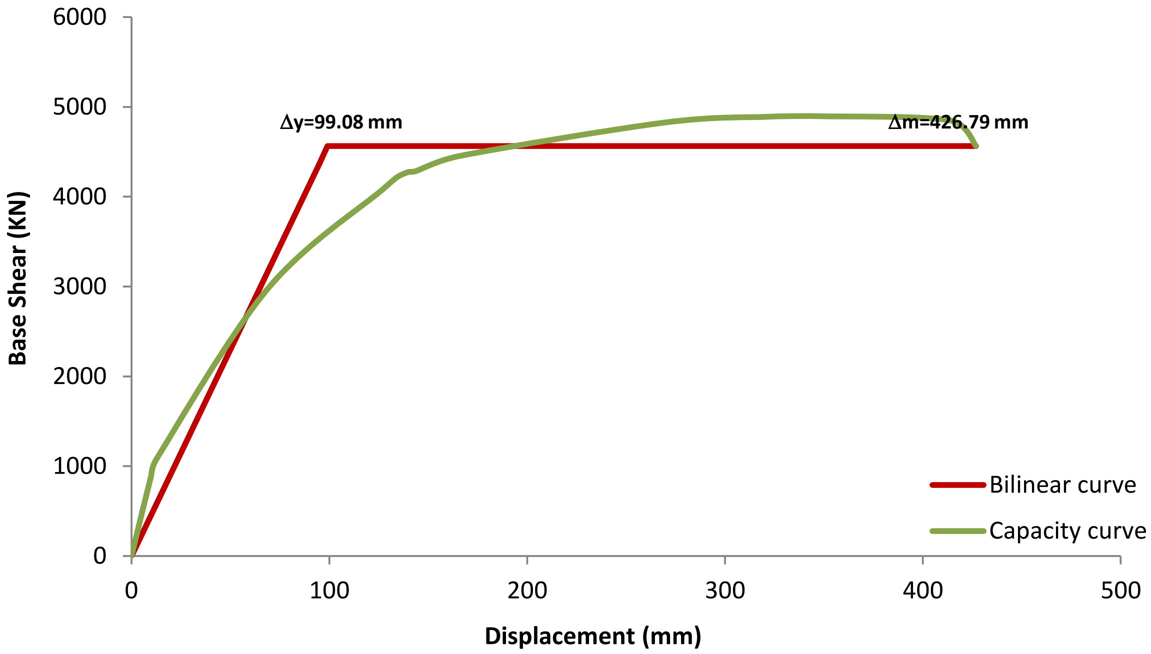
Figure A.6: Capacity (pushover) curve with a bilinear curve of the analytical models-8 story (frame system) with ($\boldsymbol{f'c}$=300 Kgf/cm^2, $\boldsymbol{fy}$=4200 Kgf/cm^2)



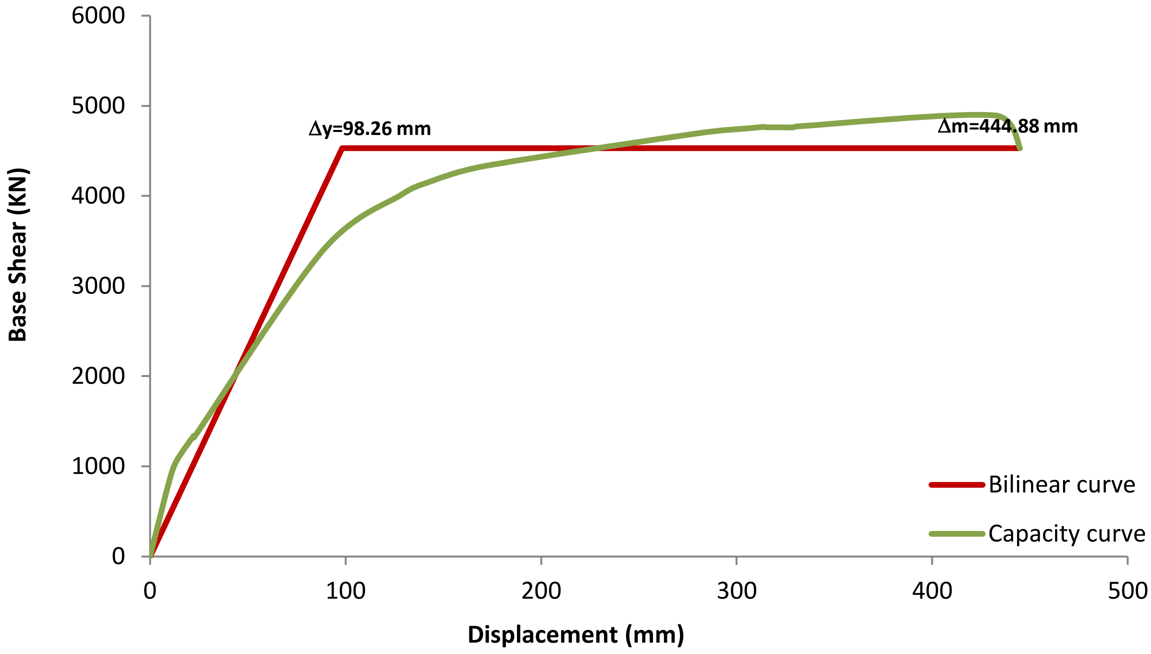
a) Model 23 (without opening)



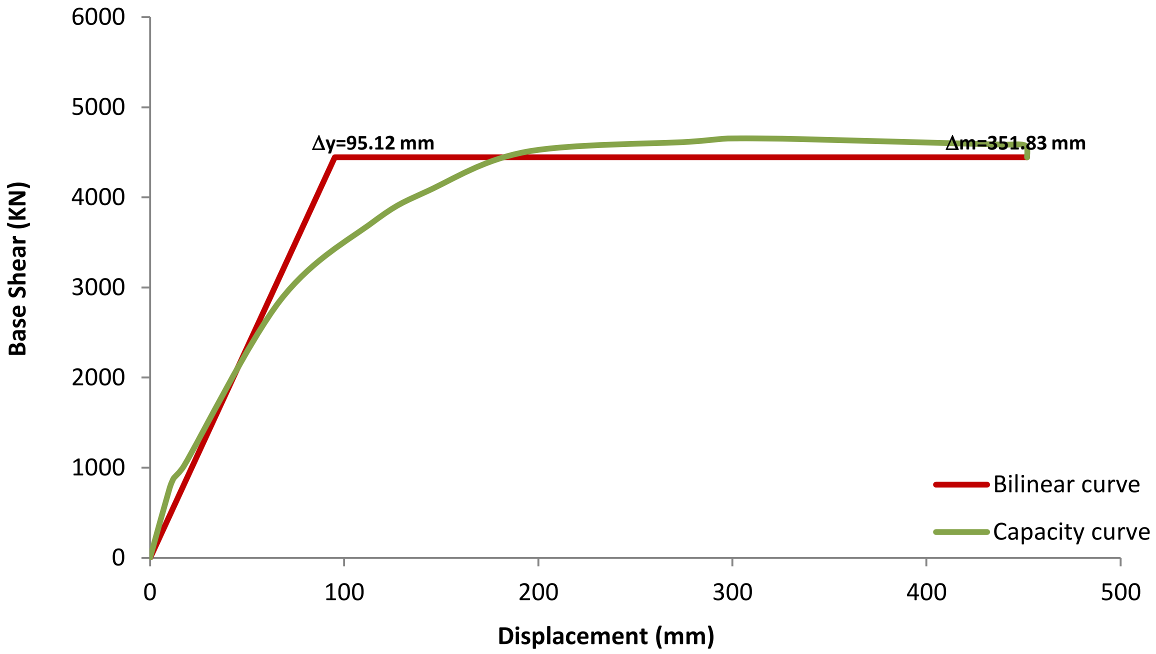
b) Model 24 (with opening 1.1mx2.2m)



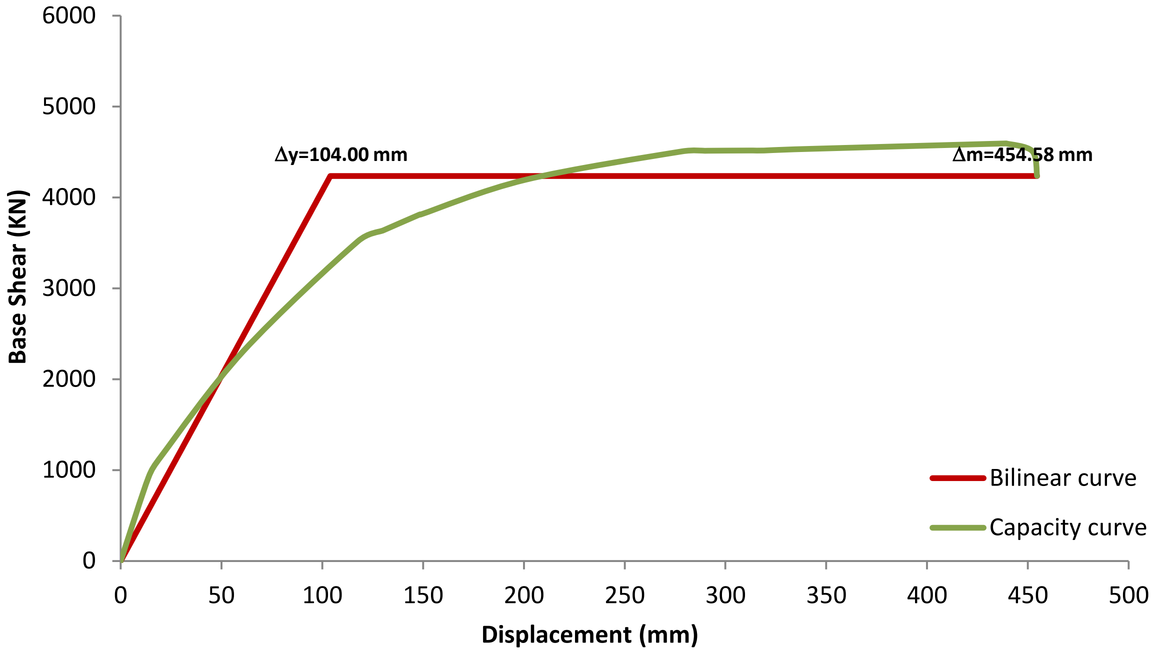
c) Model 25 (with opening 1.5mx2.0m)



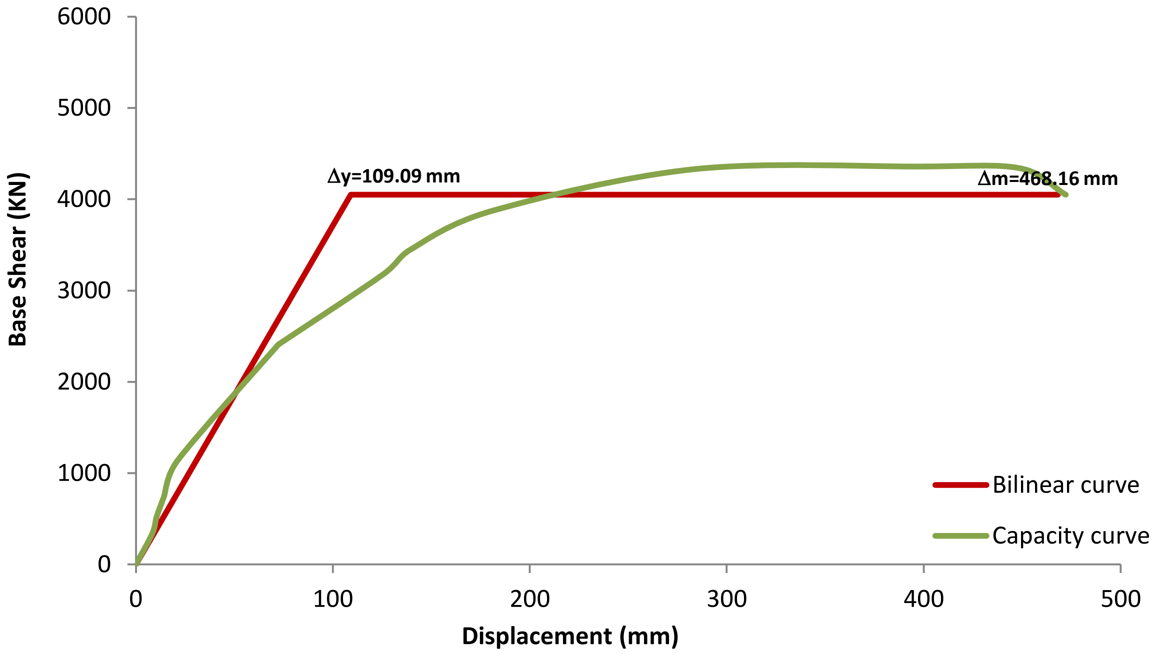
d) Model 26 (with opening 2.0mx2.0m)



e) Model 27 (with opening 2.0mx2.2m)

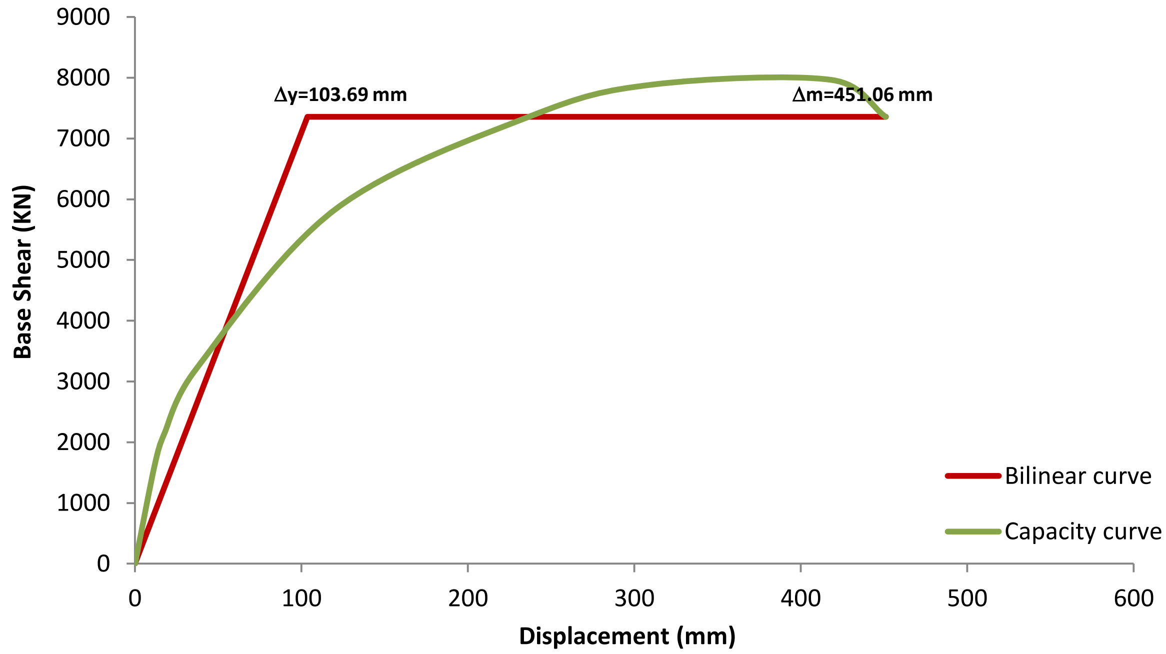


f) Model 28 (with opening 1.5mx3.0m)

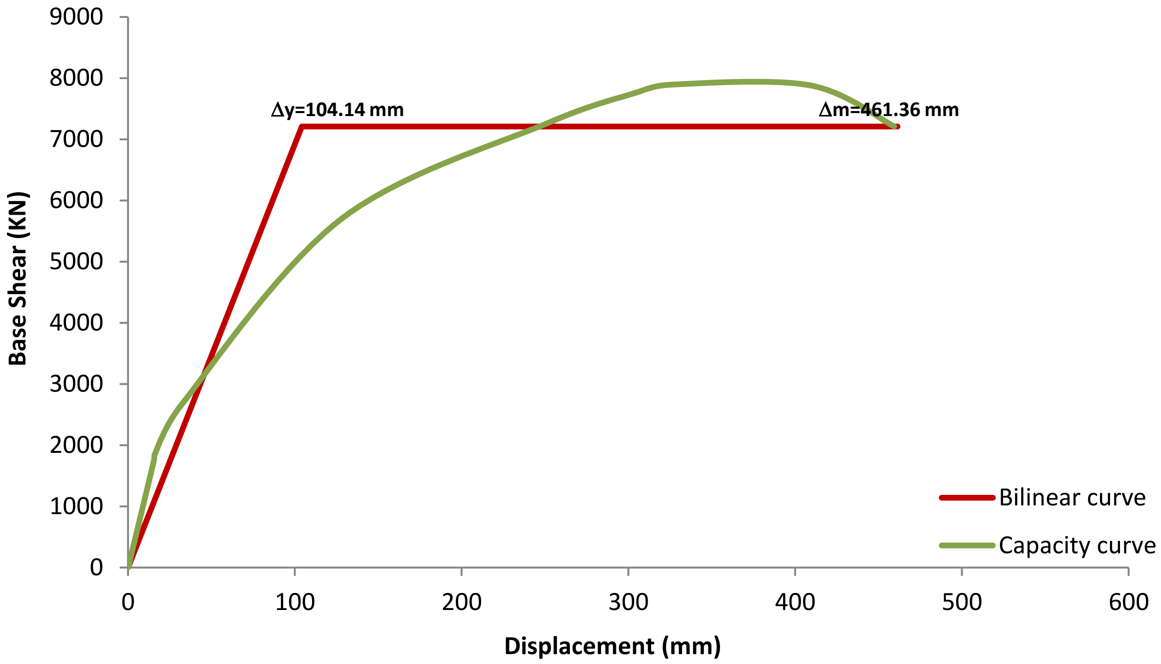


g) Model 29 (with opening 2.0mx3.0m)

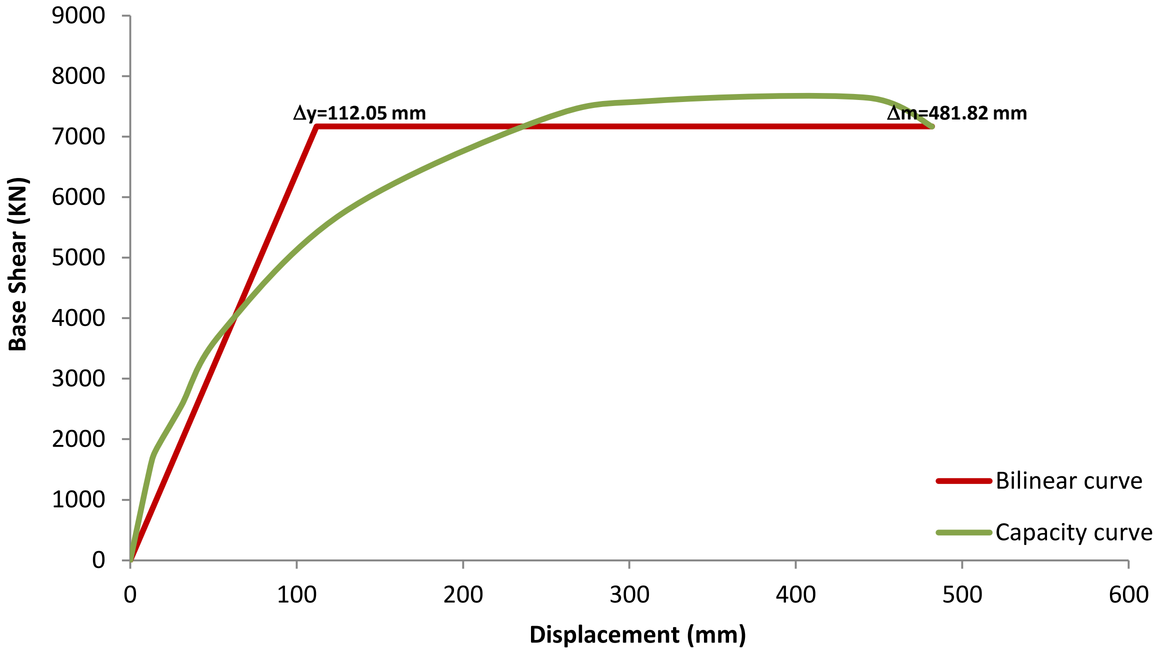
Figure A.7: Capacity (pushover) curve with a bilinear curve of the analytical models-8 story (Dual system) with ($f'c$=250 Kgf/cm^2, fy=3000 Kgf/cm^2)



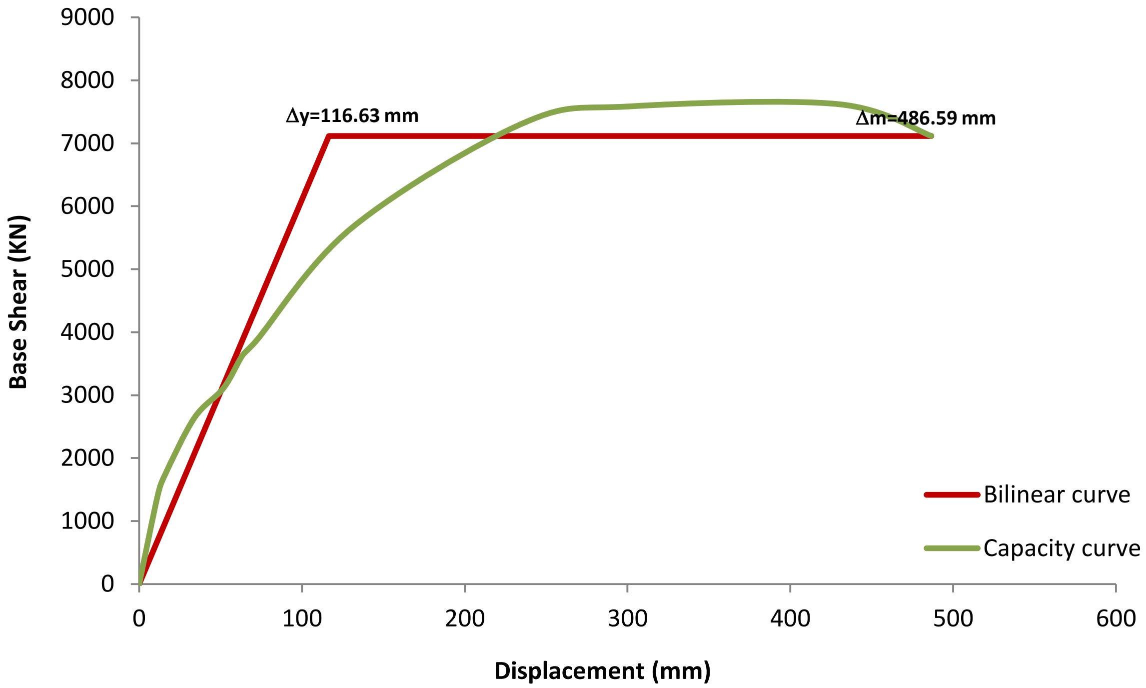
a) Model 30 (without opening)



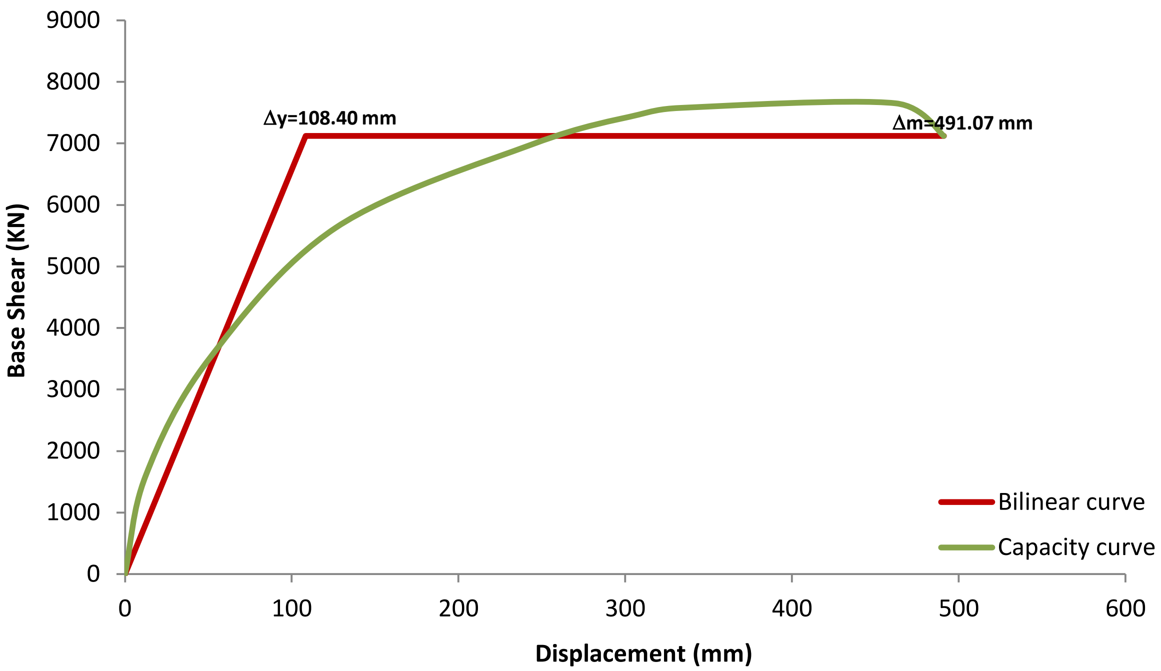
b) Model 31 (with opening 1.1mx2.2m)



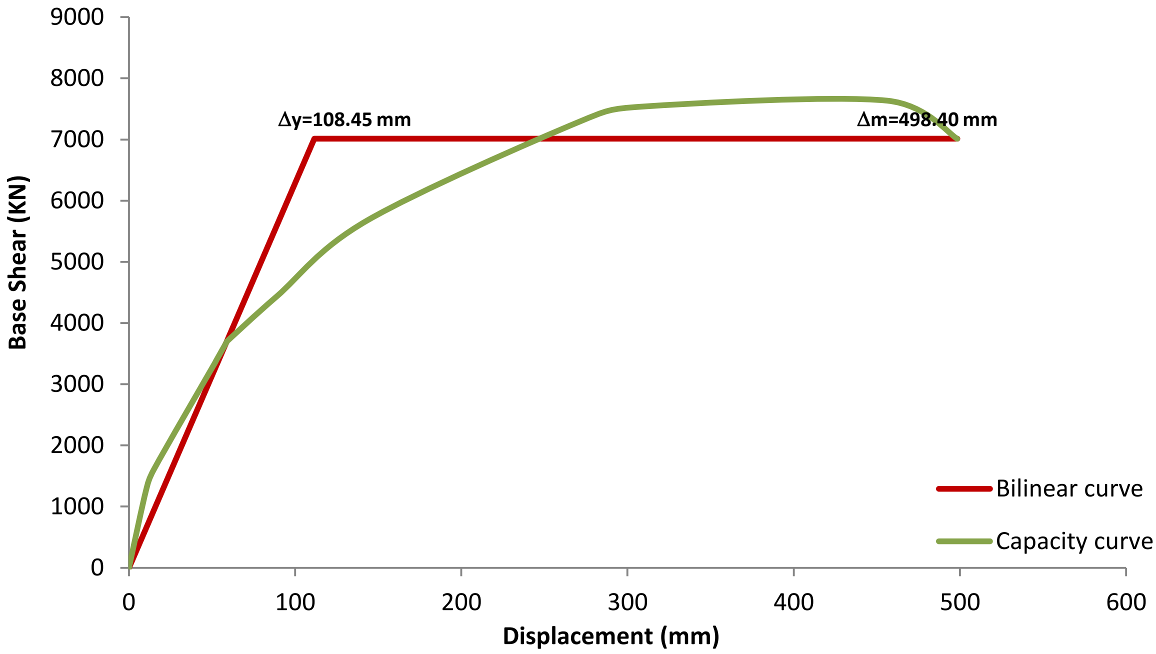
c) Model 32 (with opening 1.5mx2.0m)



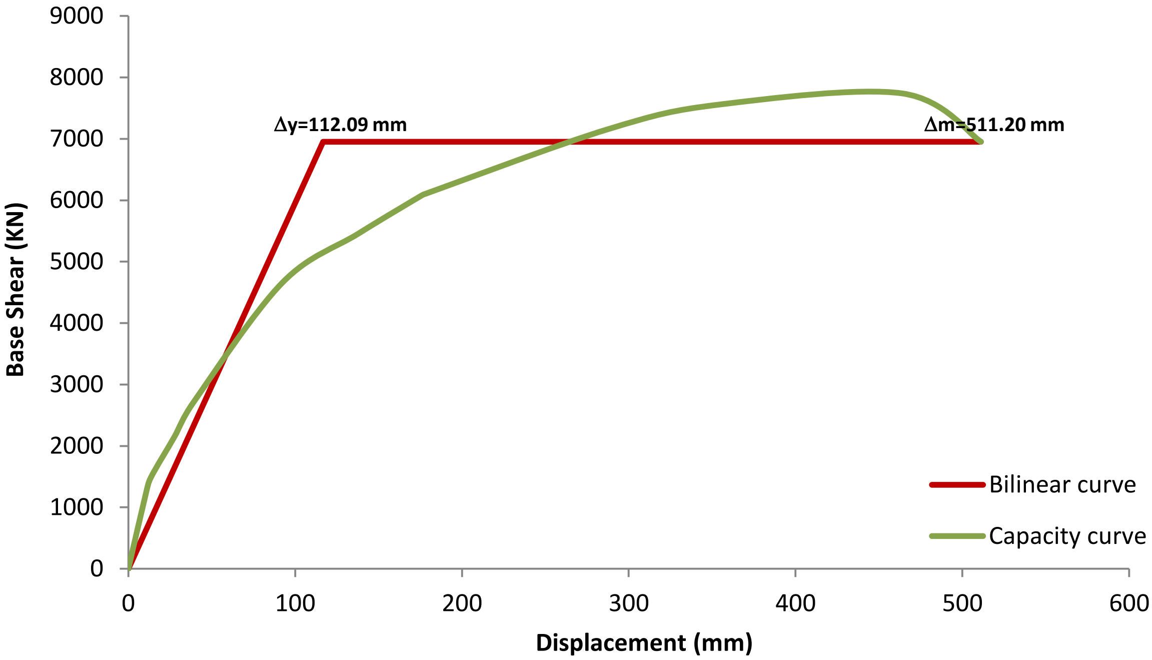
d) Model 33 (with opening 2.0mx2.0m)



e) Model 34 (with opening 2.0mx2.2m)



f) Model 35 (with opening 1.5mx3.0m)

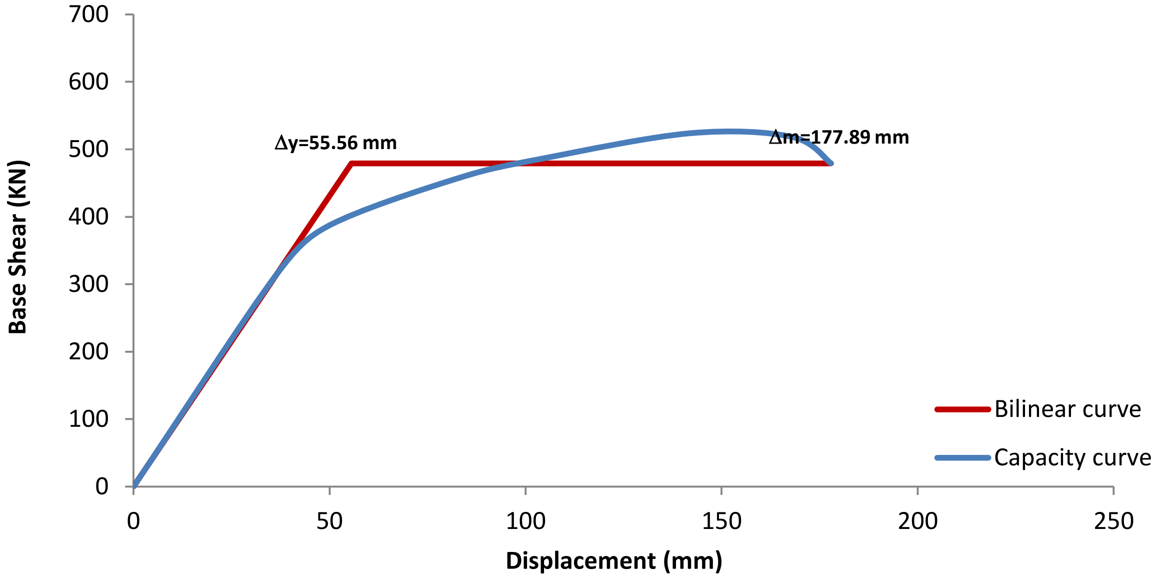


g) Model 36 (with opening 2.0mx3.0m)

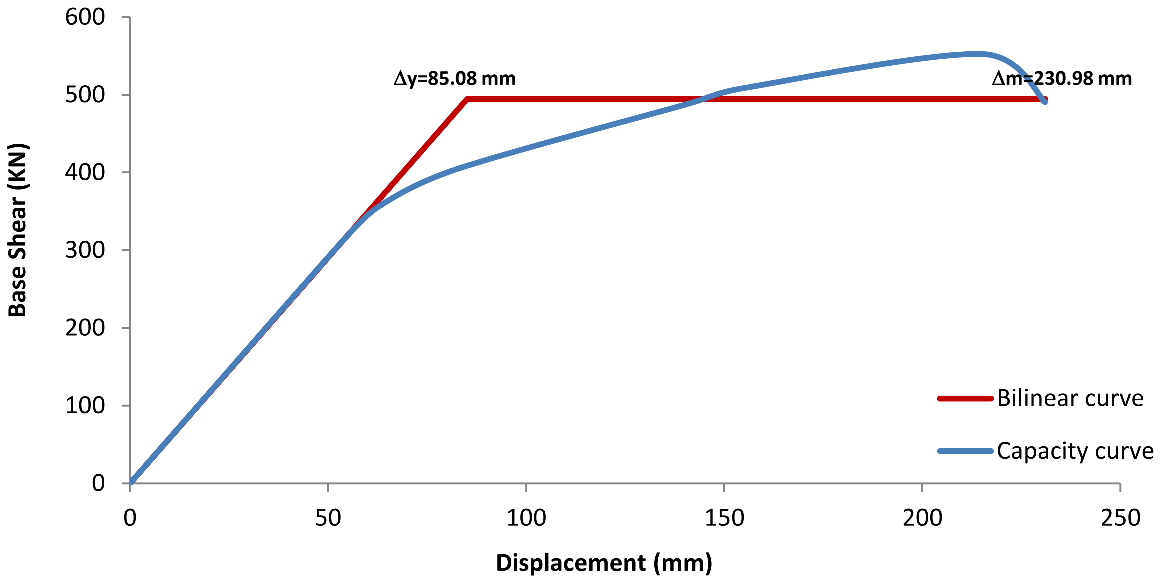
Figure A.8: Capacity (pushover) curve with a bilinear curve of the analytical models-8 story (Dual system) with ($\boldsymbol{f'c}$=300 Kgf/cm^2, $\boldsymbol{fy}$=4200 Kgf/cm^2)

Appendix B

Capacity (Pushover) curves for all models at high-risk seismic zone

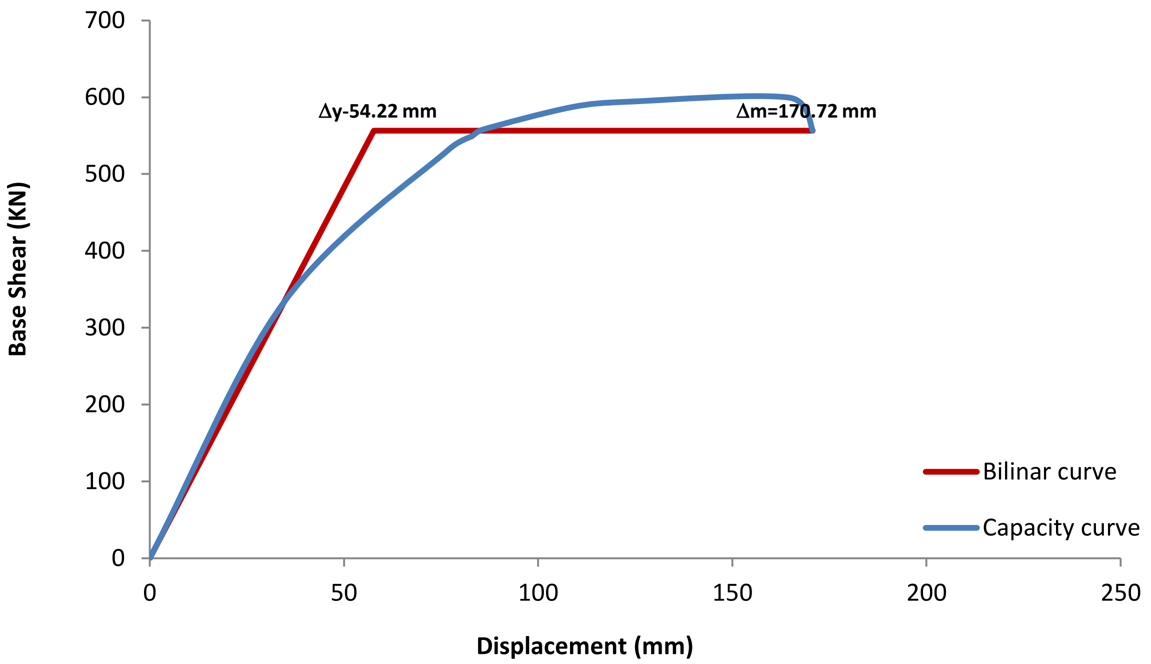


a) Model 1 (the span length= 5m)

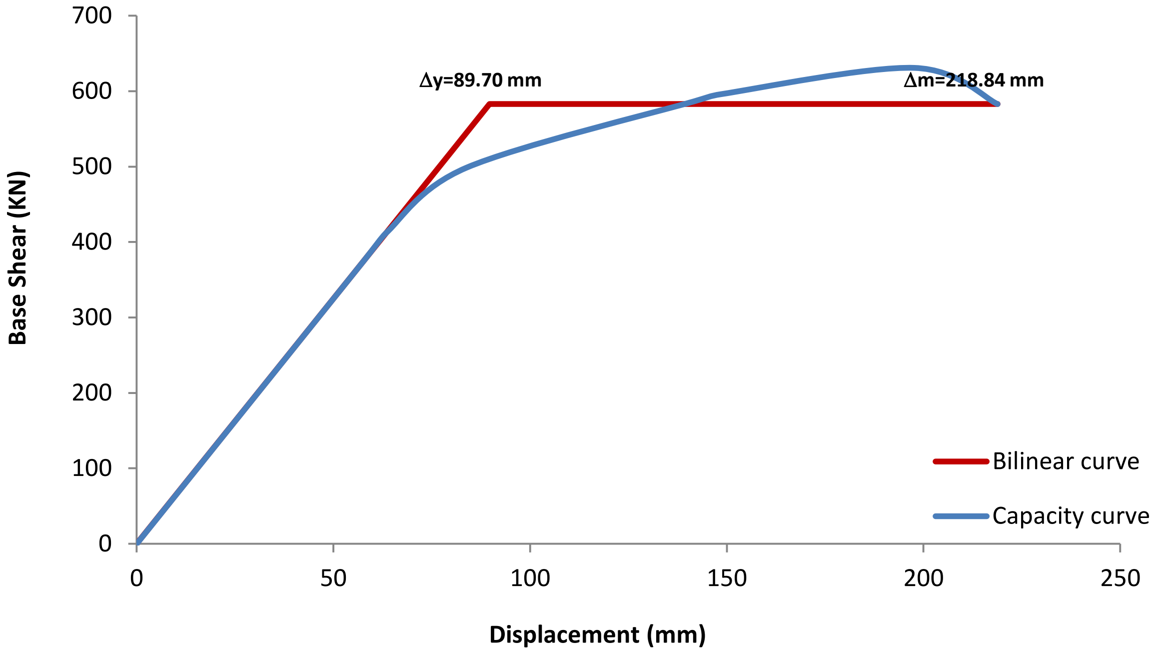


b) Model 2 (the span length= 6m)

Figure B.1: Capacity (pushover) curve with a bilinear curve of the analytical models-4 story (frame system) with ($\boldsymbol{f'c}$=250 Kgf/cm^2, $\boldsymbol{fy}$=3000 Kgf/cm^2)

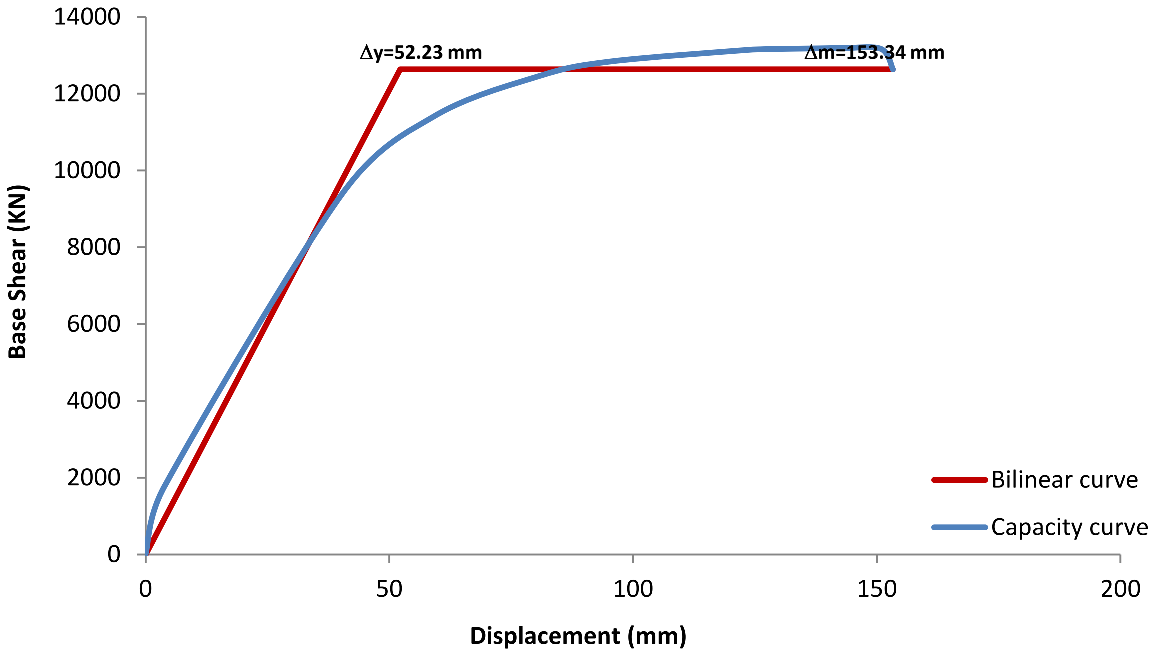


a) Model 3 (the span length= 5m)

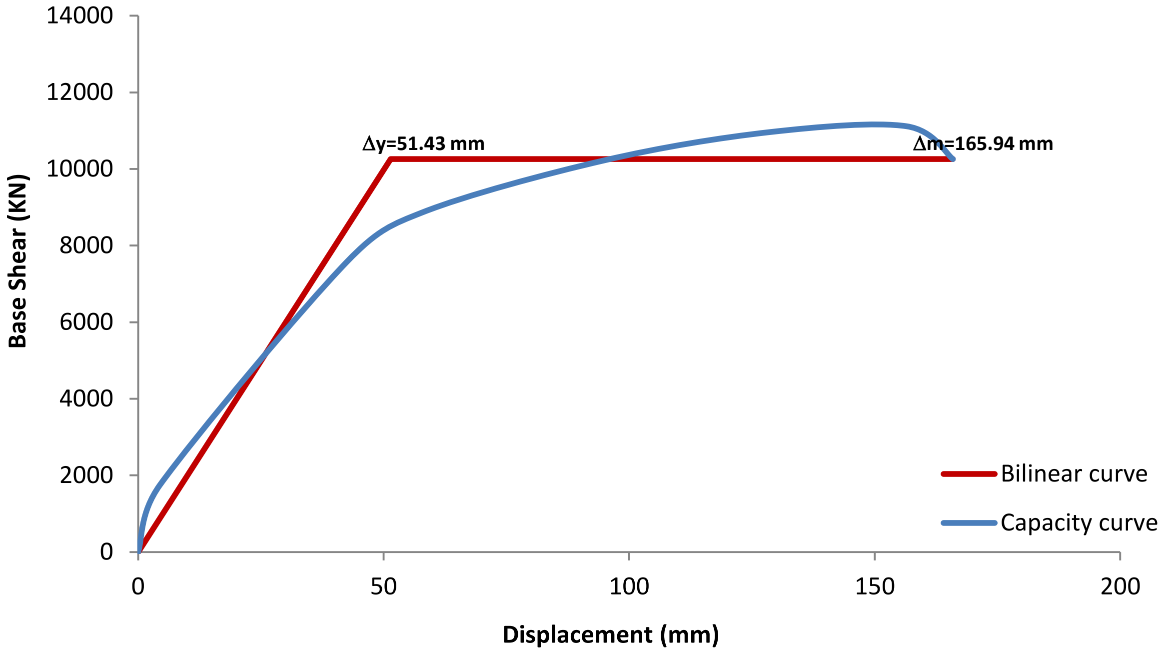


b) Model 4 (the span length= 6m)

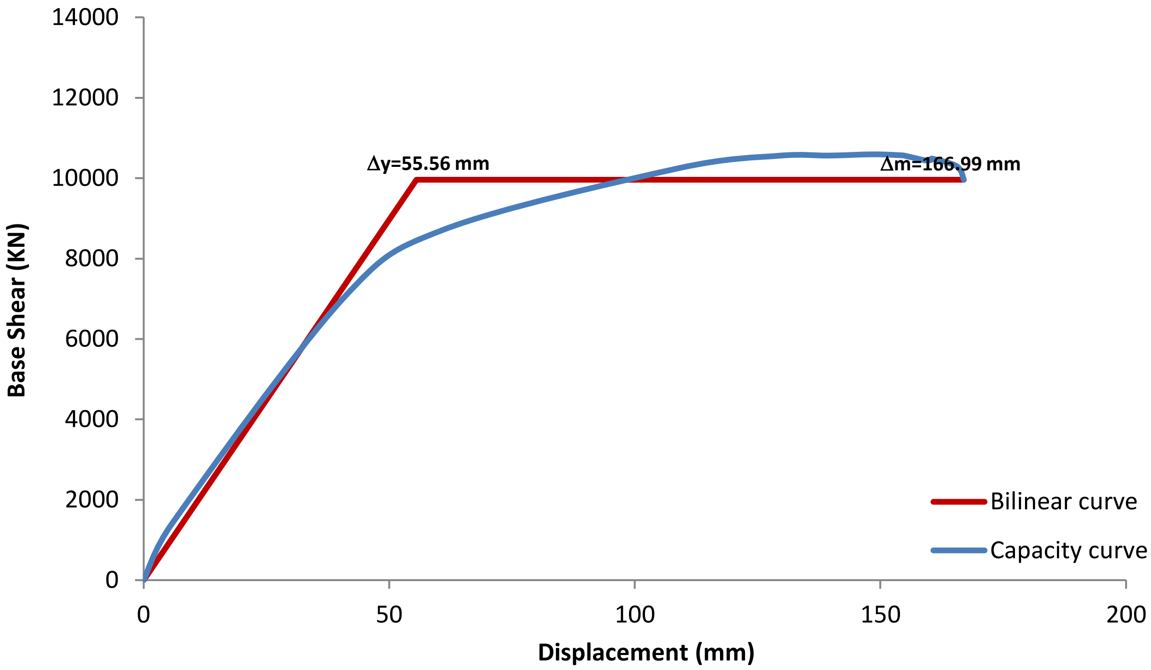
Figure B.2: Capacity (pushover) curve with a bilinear curve of the analytical models-4 story (frame system) with ($\boldsymbol{f'c}$=300 Kgf/cm^2, $\boldsymbol{fy}$=4200 Kgf/cm^2)



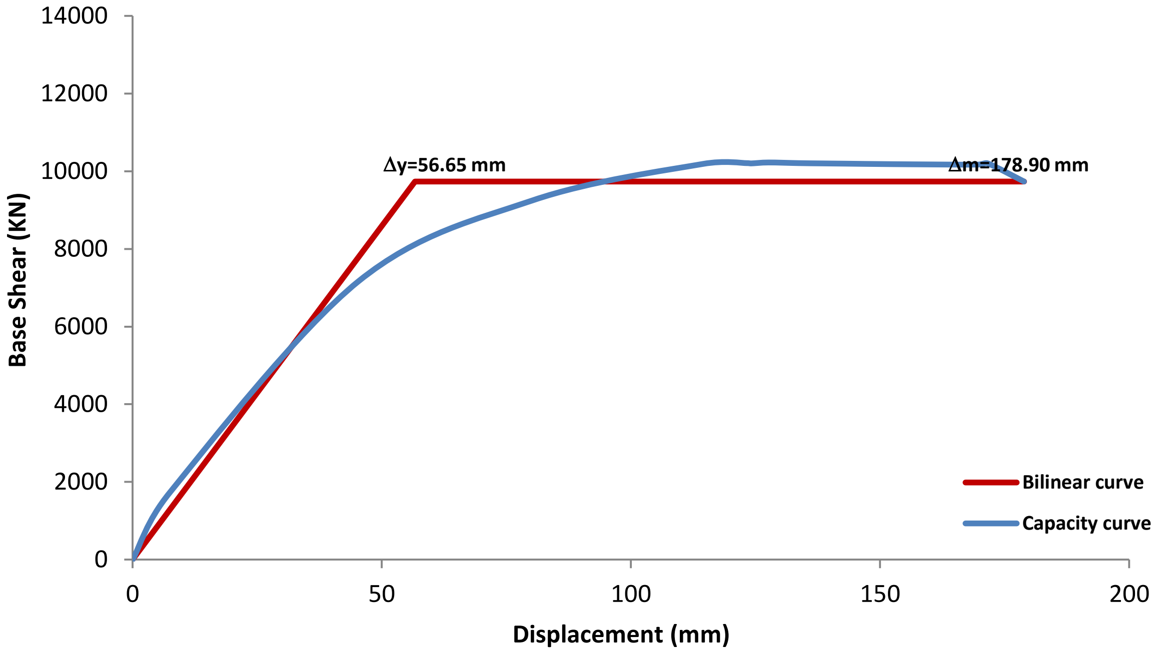
a) Model 5 (without opening)



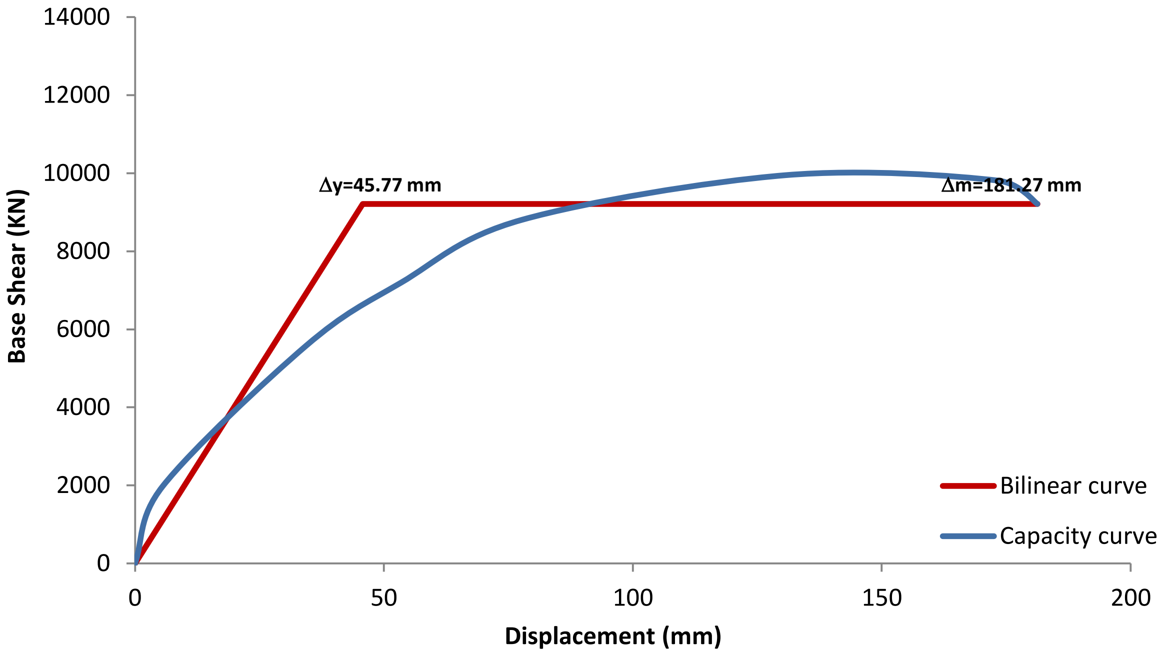
b) Model 6 (with opening 1.1mx2.2m)



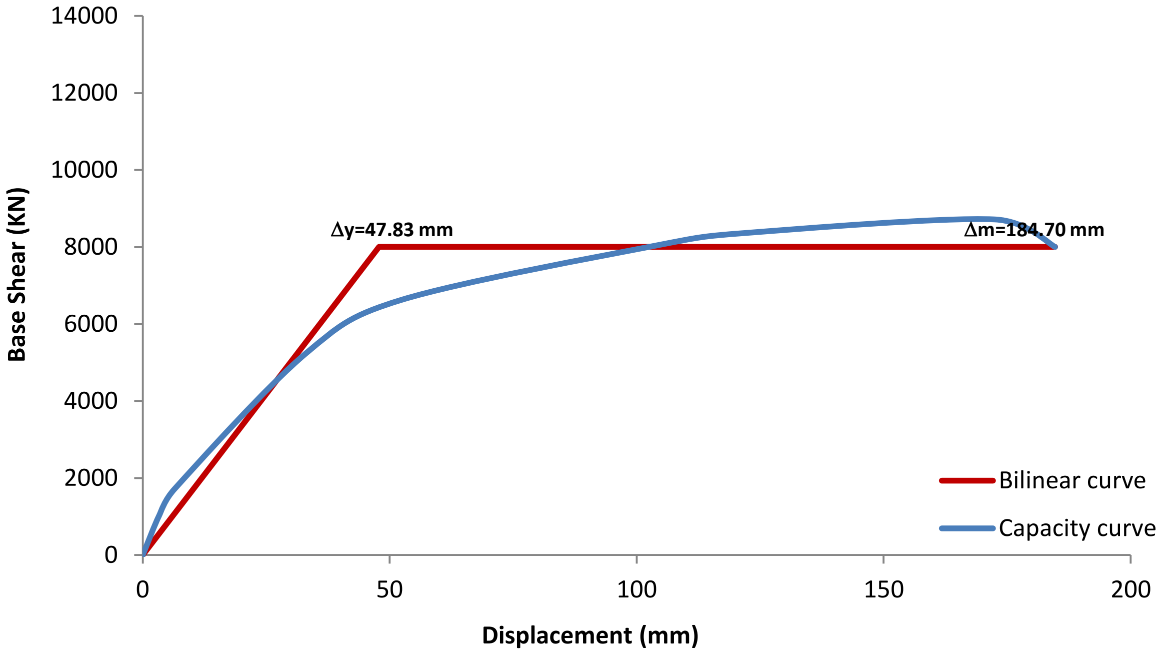
c) Model 7 (with opening 2.0mx1.5m)



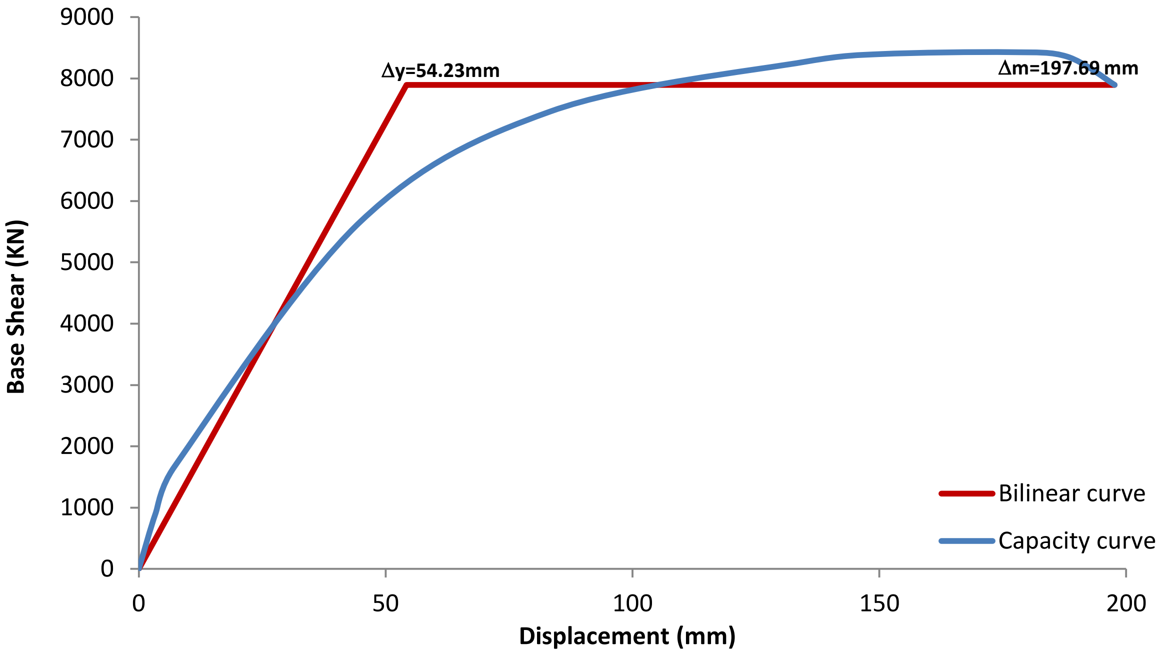
d) Model 8 (with opening 2.0mx2.0m)



e) Model 9 (with opening 2.0mx2.2m)

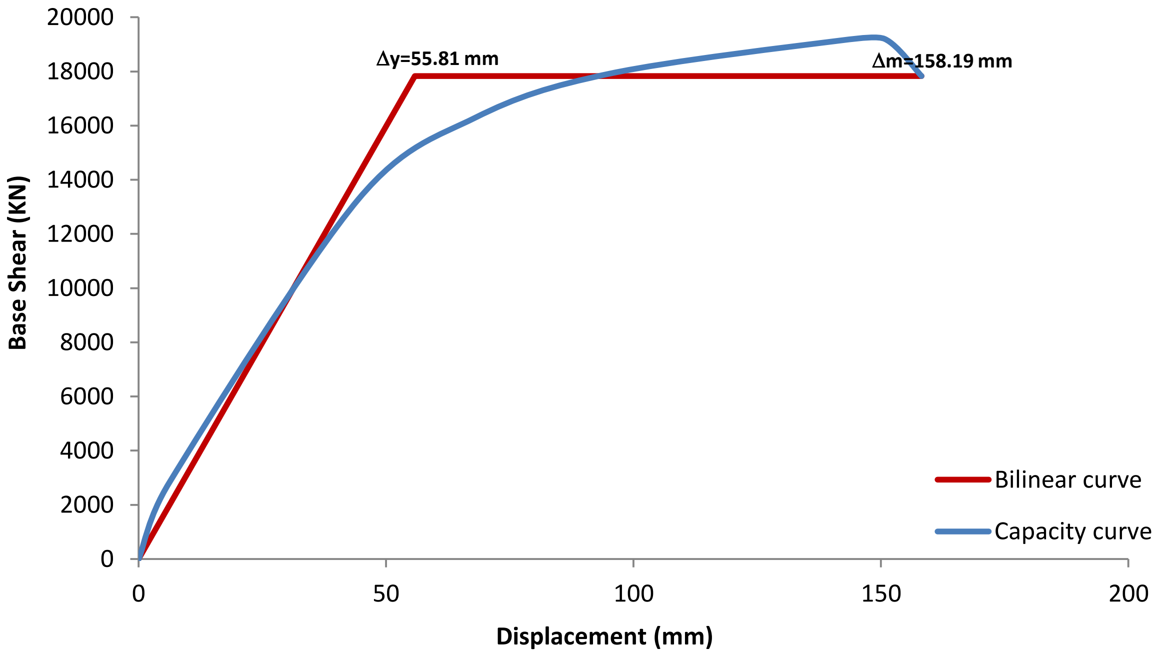


f) Model 10 (with opening 3.0mx1.5m)

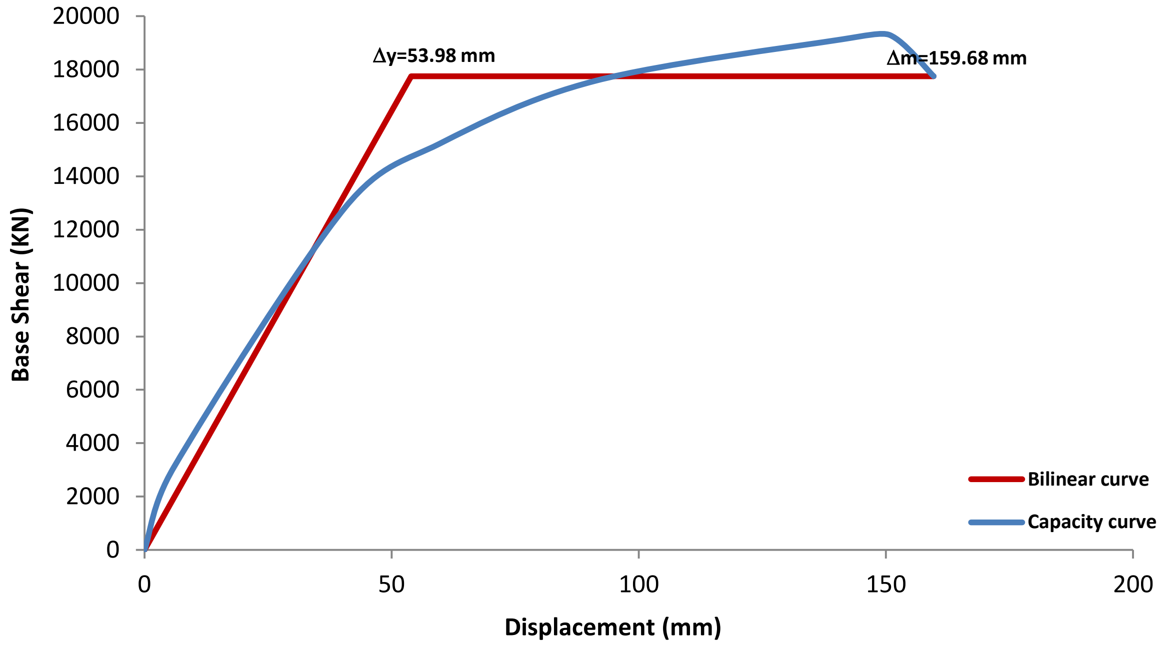


g) Model 11 (with opening 3.0mx2.0m)

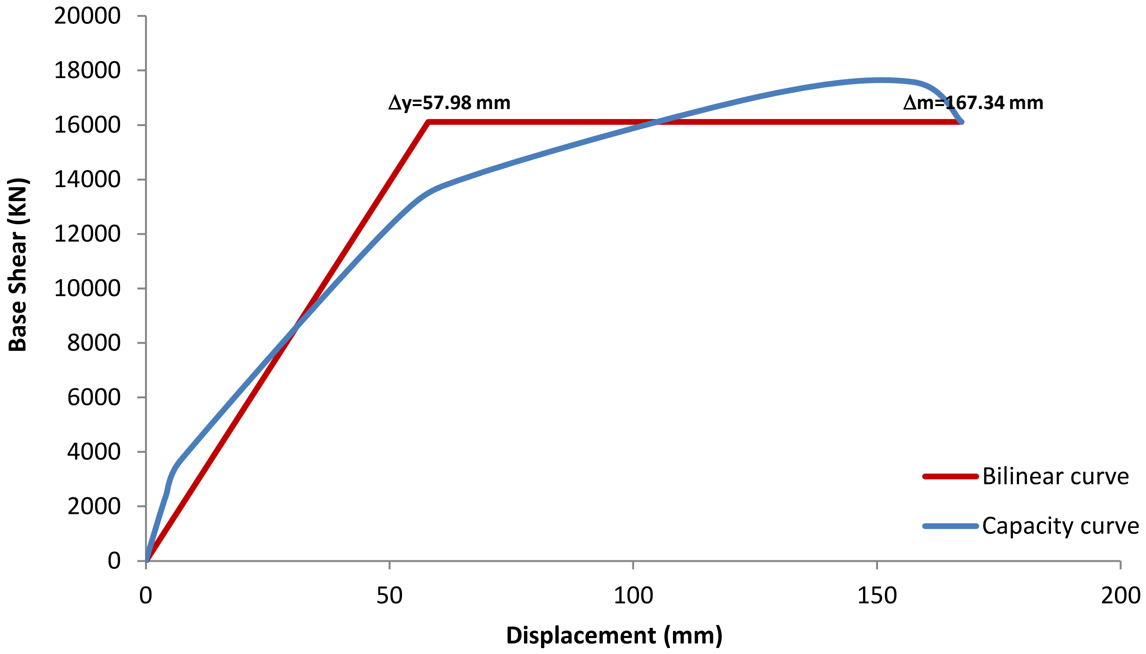
Figure B.3: Capacity (pushover) curve with a bilinear curve of the analytical models 4-story (Dual system) with ($f'c$=250 Kgf/cm^2, fy=3000 Kgf/cm^2)



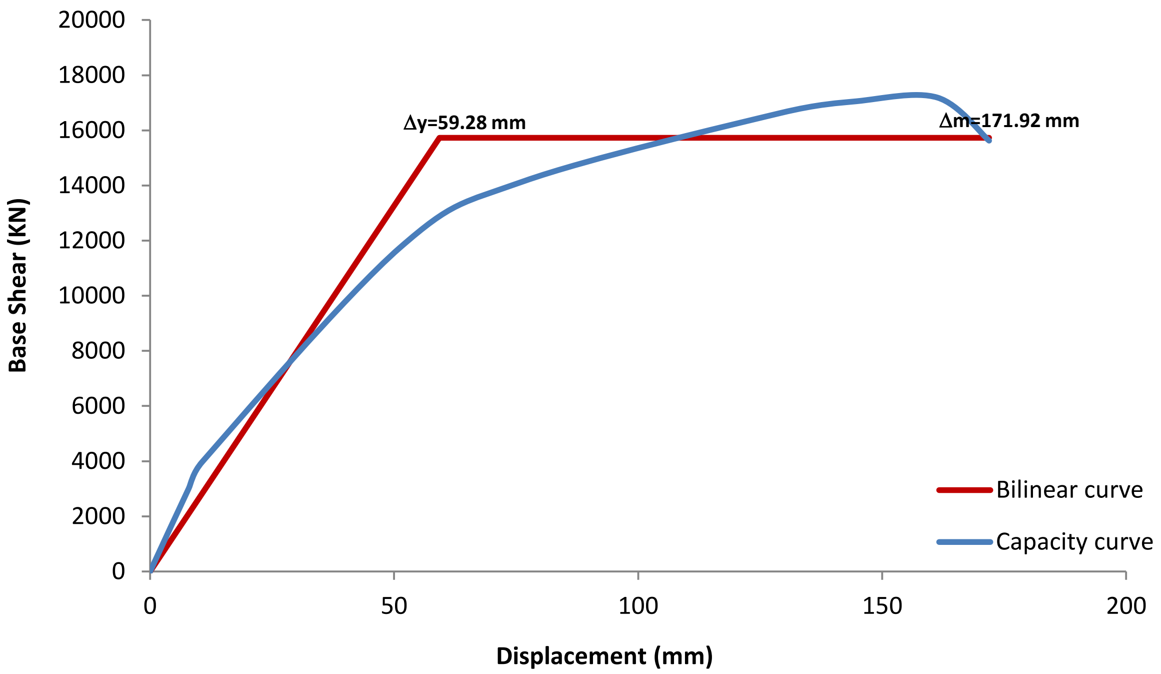
a) Model 12 (without opening)



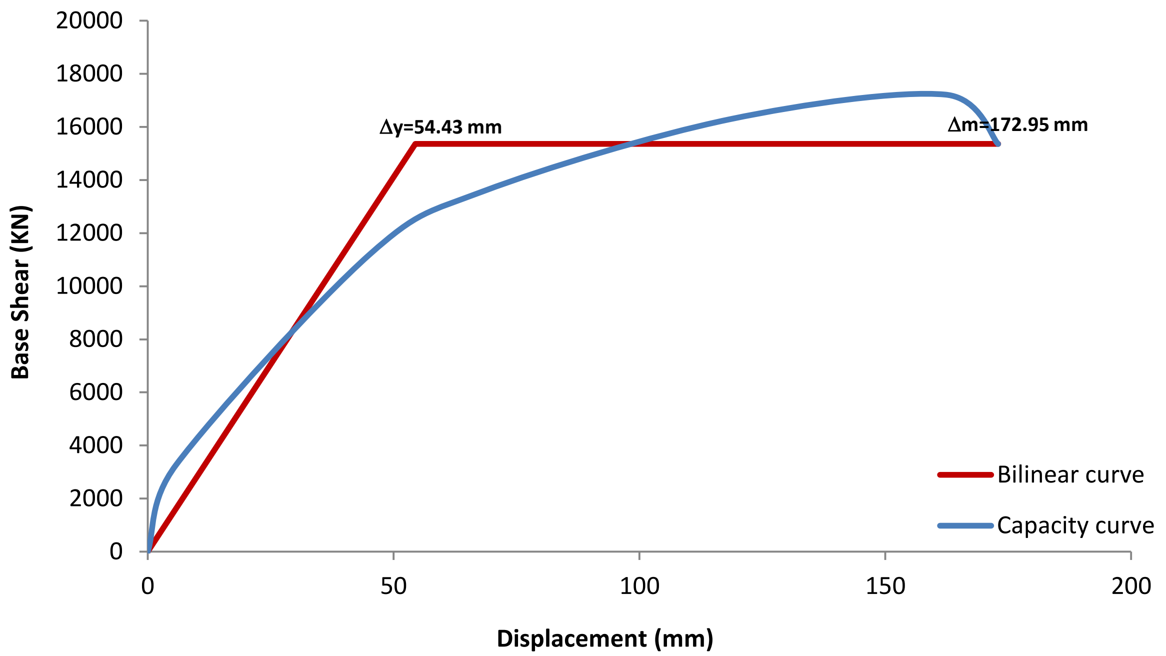
b) Model 13 (with opening 1.1mx2.2m)



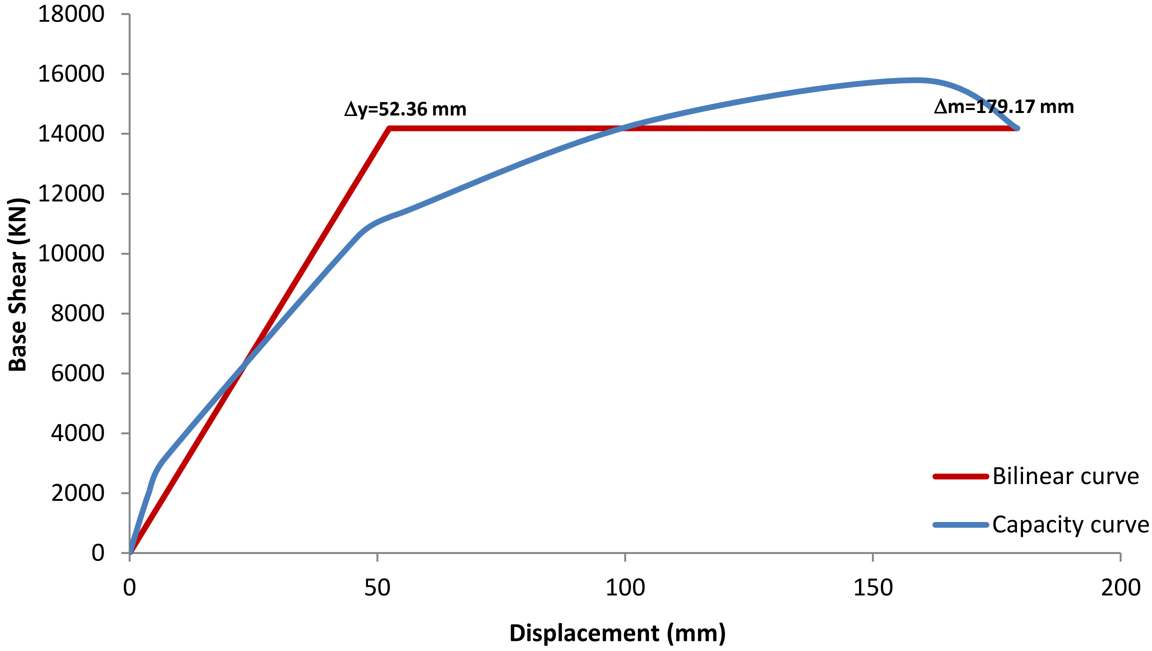
c) Model 14 (with opening 2.0mx1.5m)



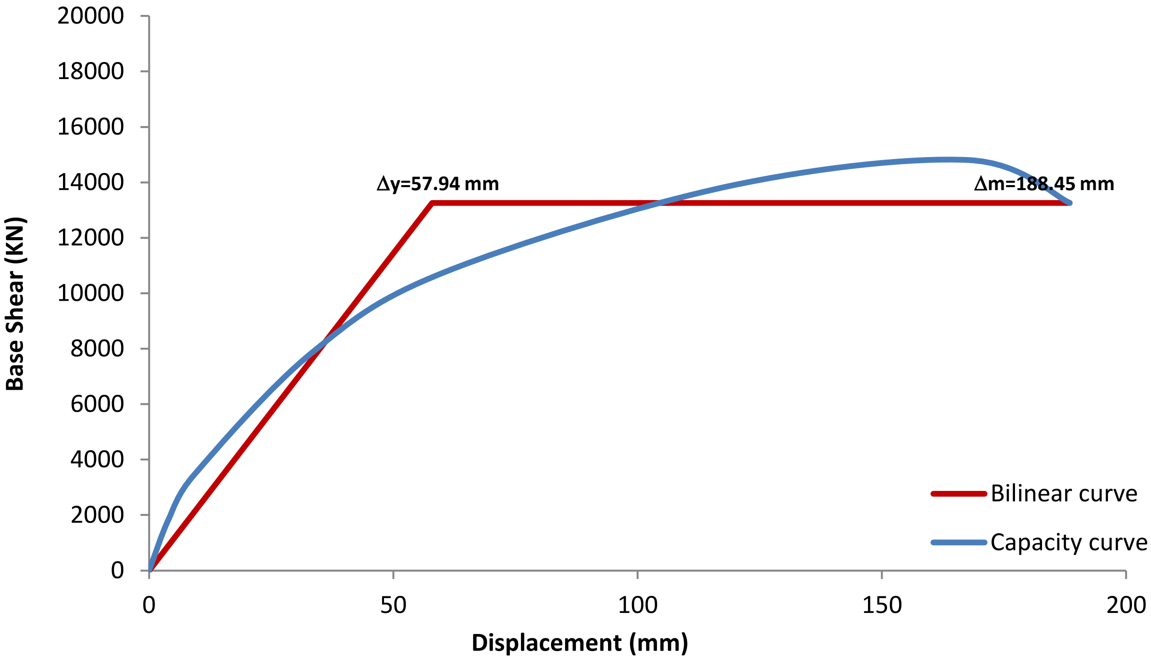
d) Mode 15 (with opening 2.0mx2.0m)



e) Model 16 (with opening 2.0mx2.2m)

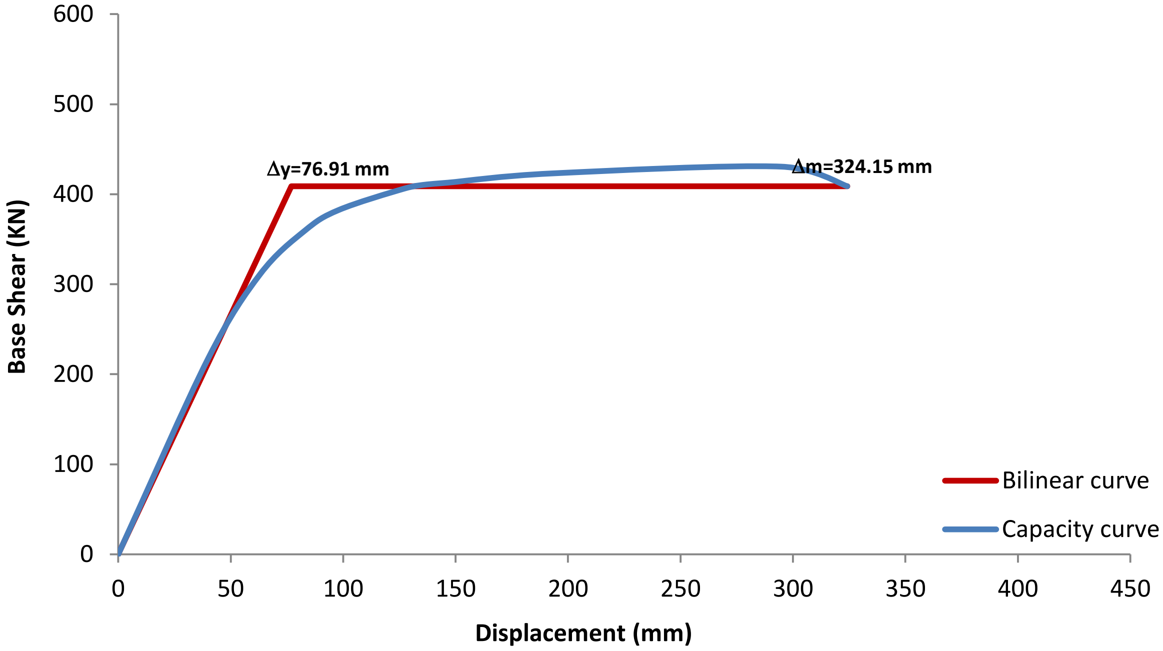


f) Model 17 (with opening 3.0mx1.5m)

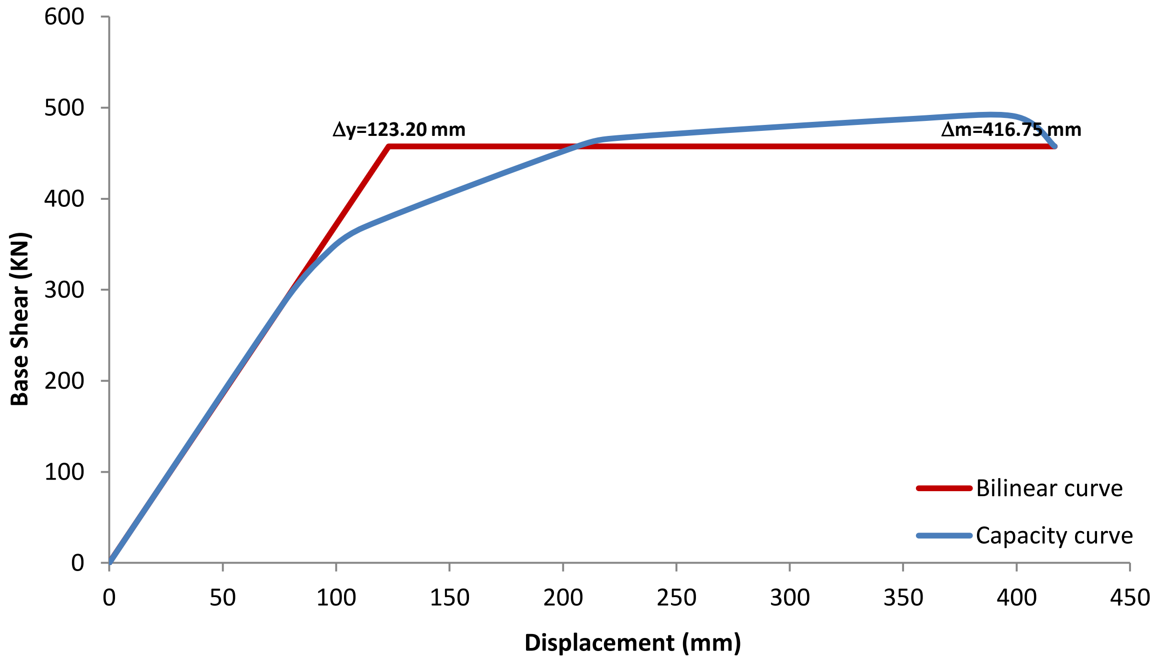


g) Model 18 (with opening 3.0mx2.0m)

Figure B.4: Capacity (pushover) curve with a bilinear curve of the analytical models 4-story (Dual system) with ($\boldsymbol{f'c}$=300 Kgf/cm^2, $\boldsymbol{fy}$=4200 Kgf/cm^2)

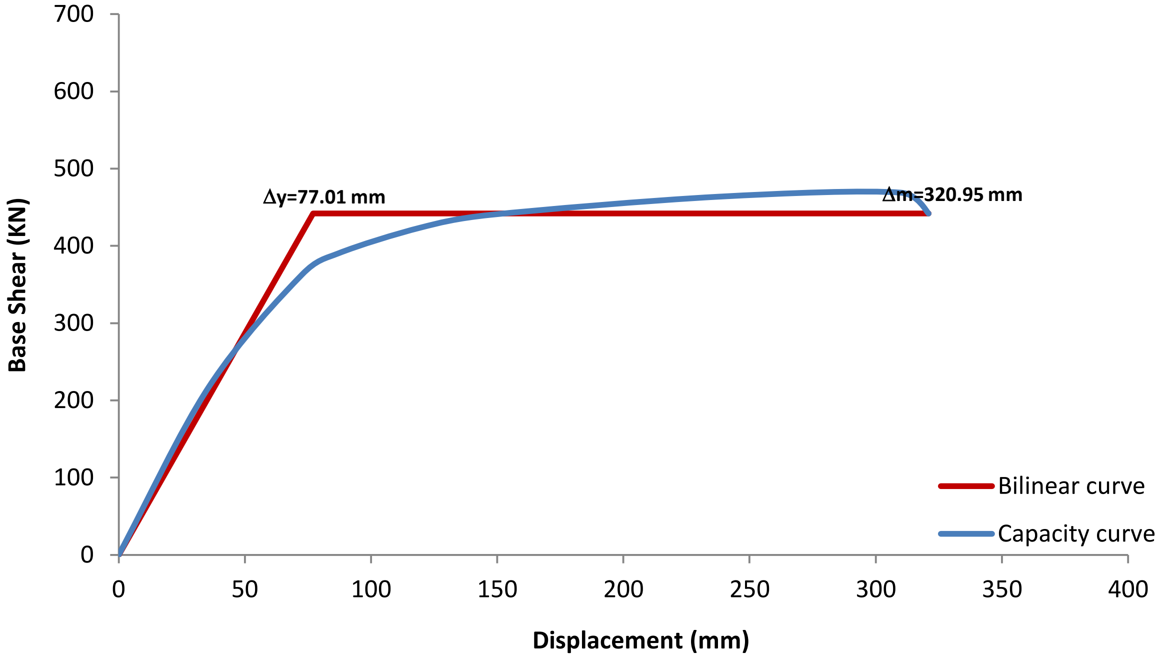


a) Model 19 (the span length= 5m)

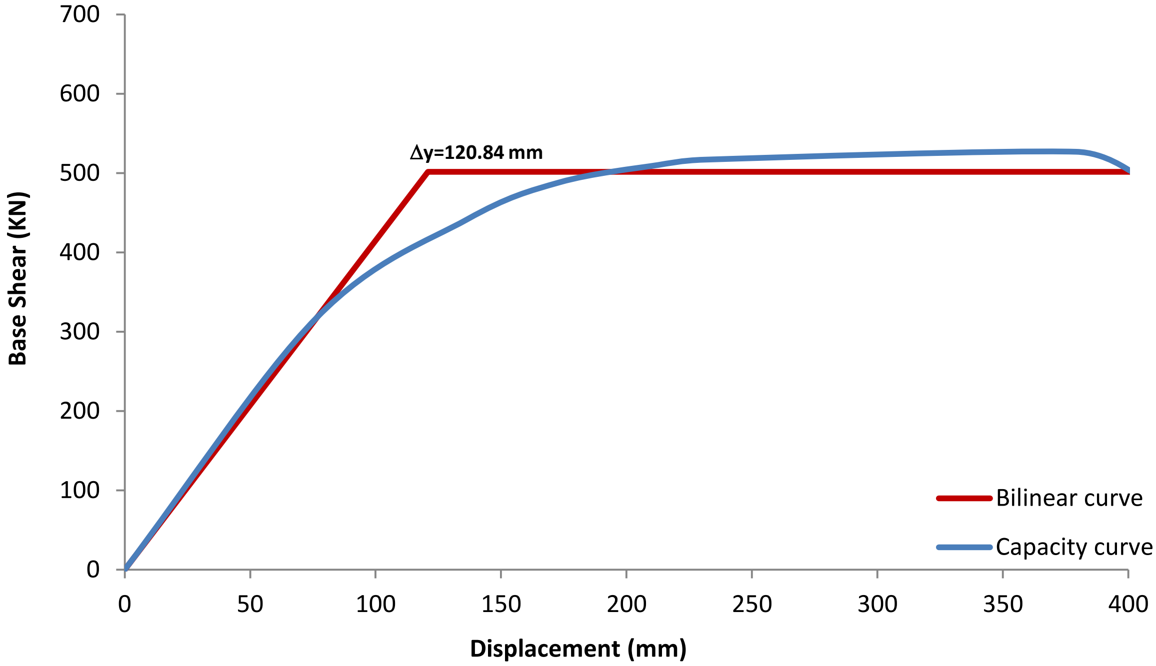


b) Model 20 (the span length= 6m)

Figure B.5: Capacity (pushover) curve with a bilinear curve of the analytical models 8-story (frame system) with ($\boldsymbol{f'c}$=250 Kgf/cm^2, $\boldsymbol{fy}$=3000 Kgf/cm^2)

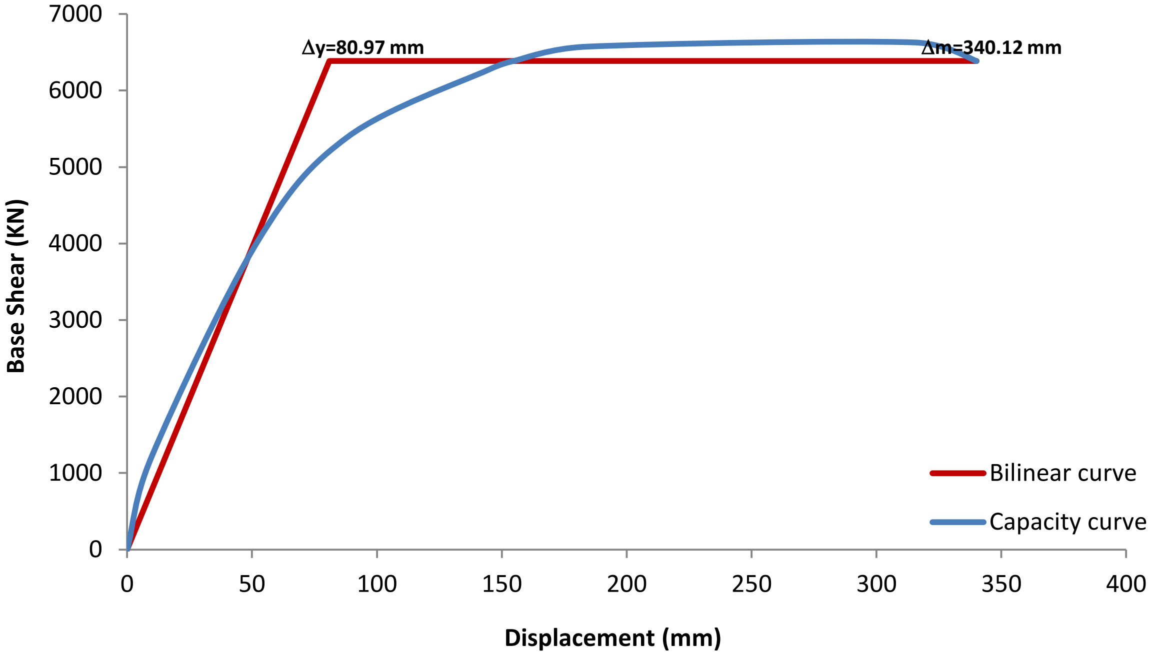


a) Model 21 (the span length= 5m)

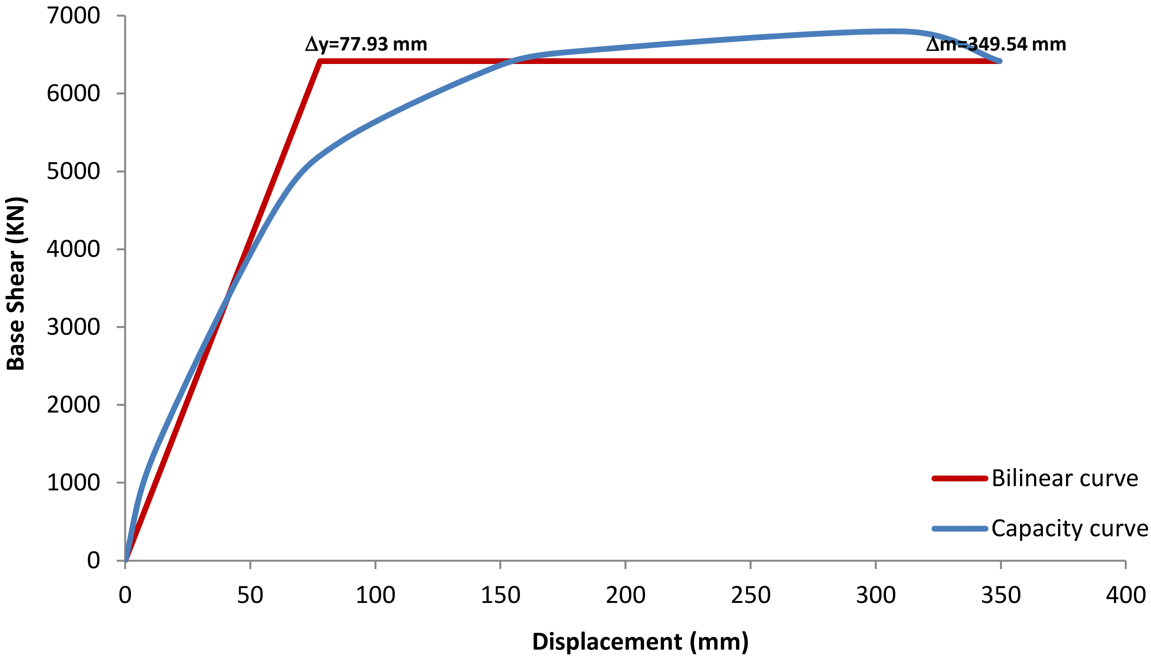


b) Model 22 (the span length= 6m)

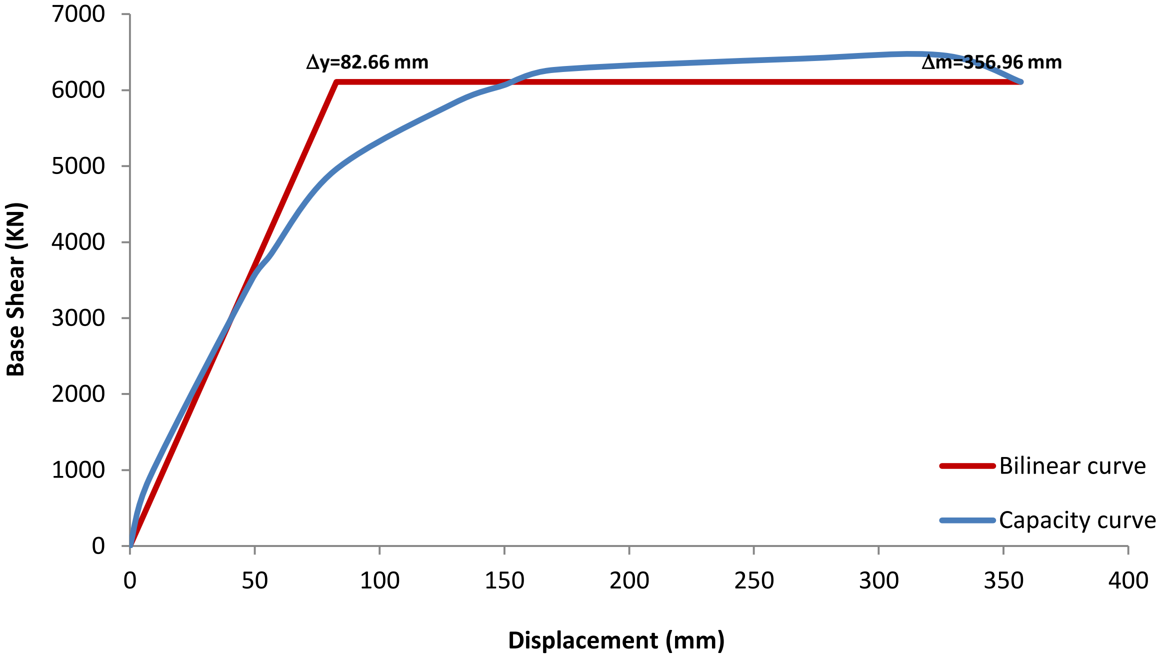
Figure B.6: Capacity (pushover) curve with a bilinear curve of the analytical models 8-story (frame system) with ($\boldsymbol{f'c}$ =300 Kgf/cm^2, $\boldsymbol{fy}$=4200 Kgf/cm^2)



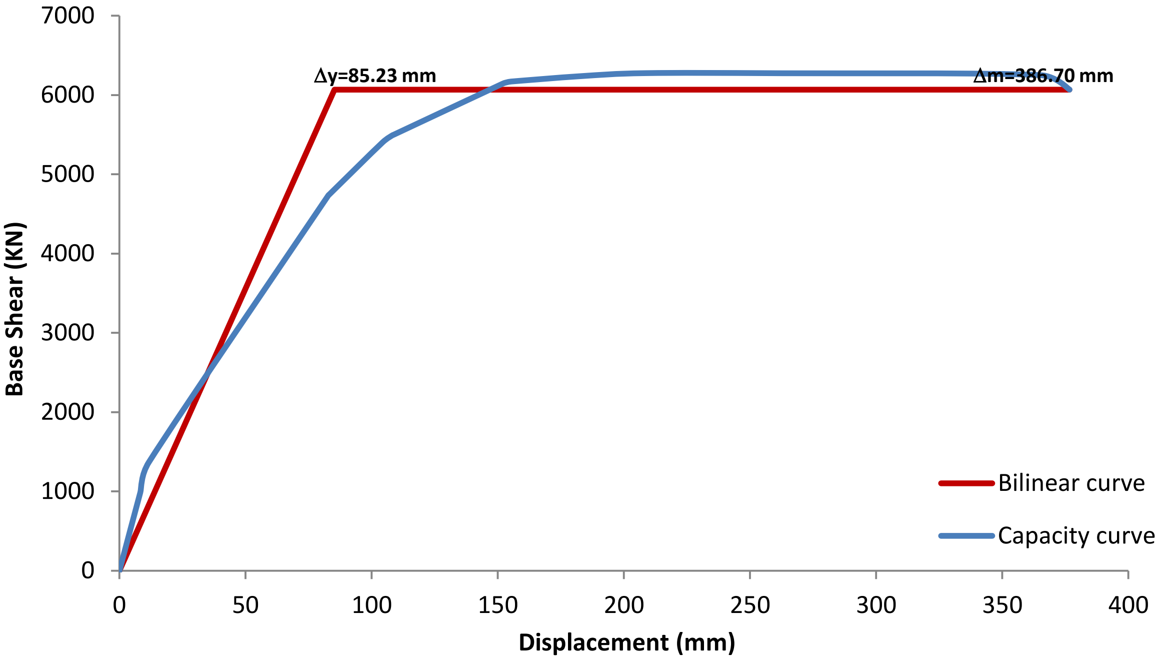
a) Model 23 (without opening)



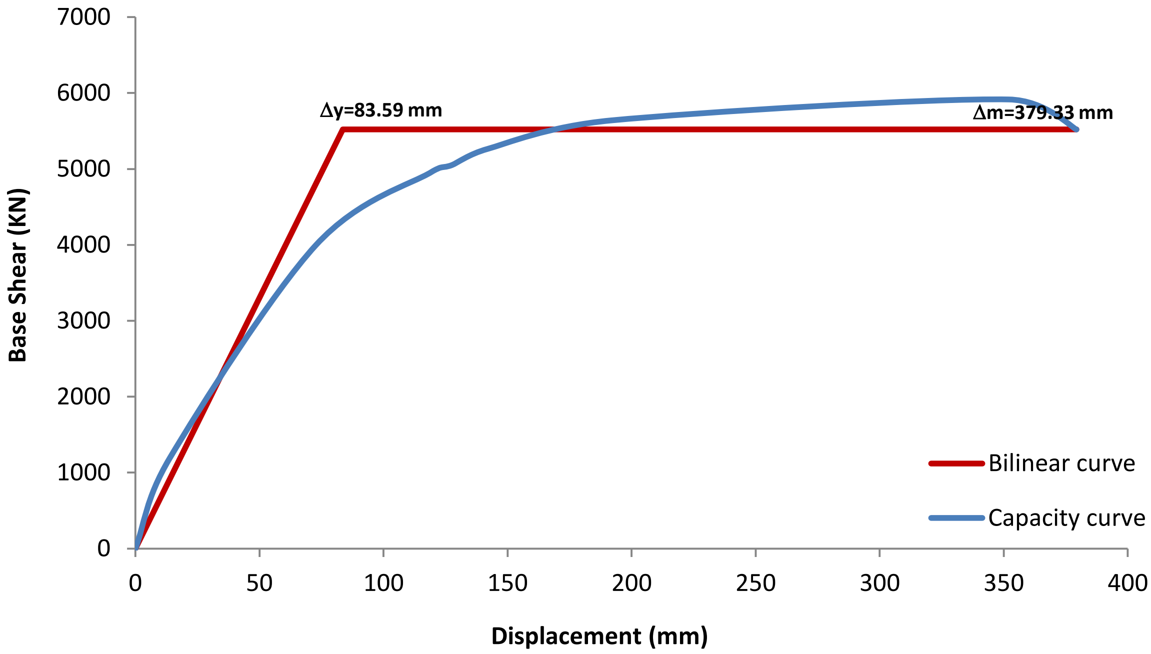
b) Model 24 (with opening 1.1mx2.2m)



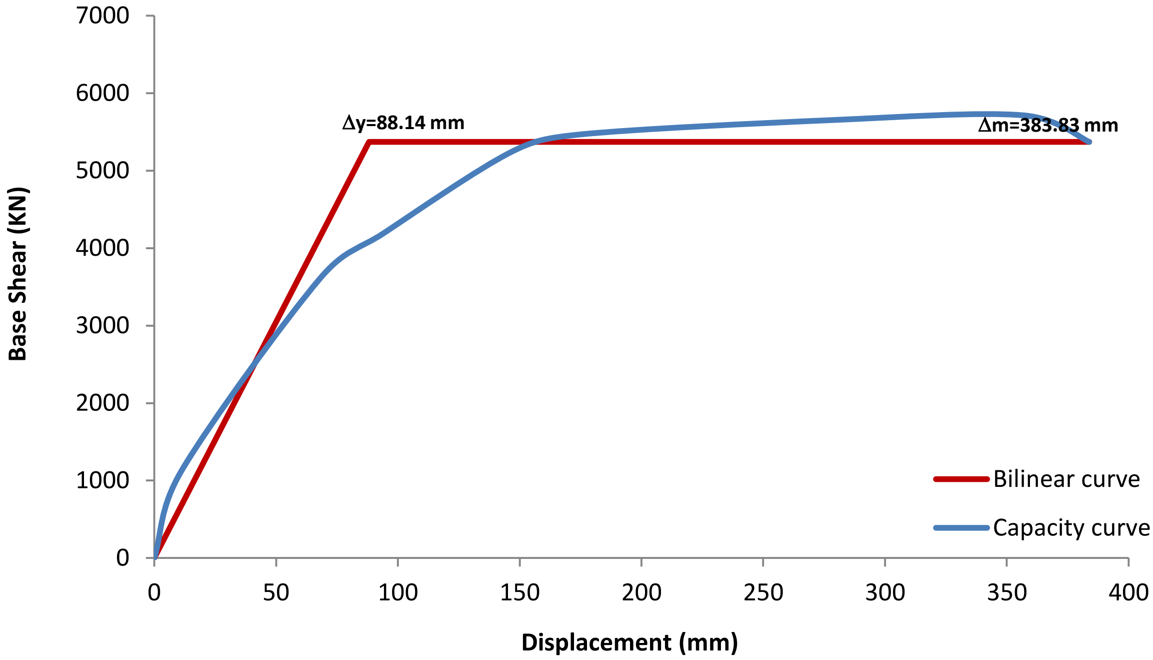
c) Model 25 (with opening 1.5mx2.0m)



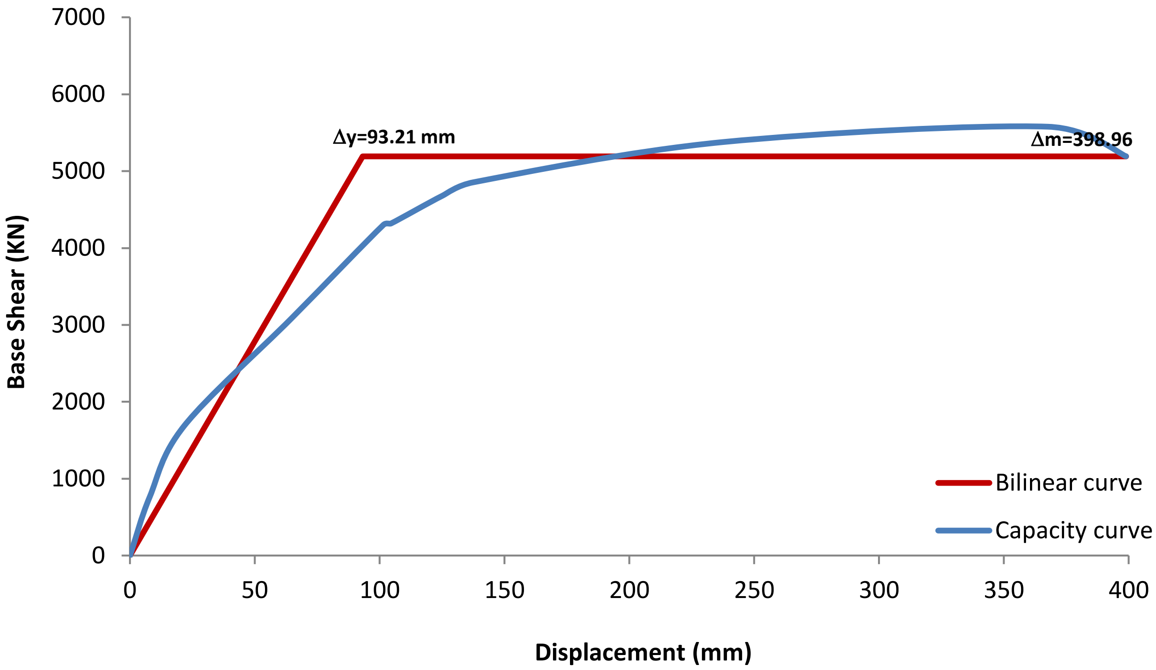
d) Model 26 (with opening 2.0mx2.0m)



e) Model 27 (with opening 2.0mx2.2m)

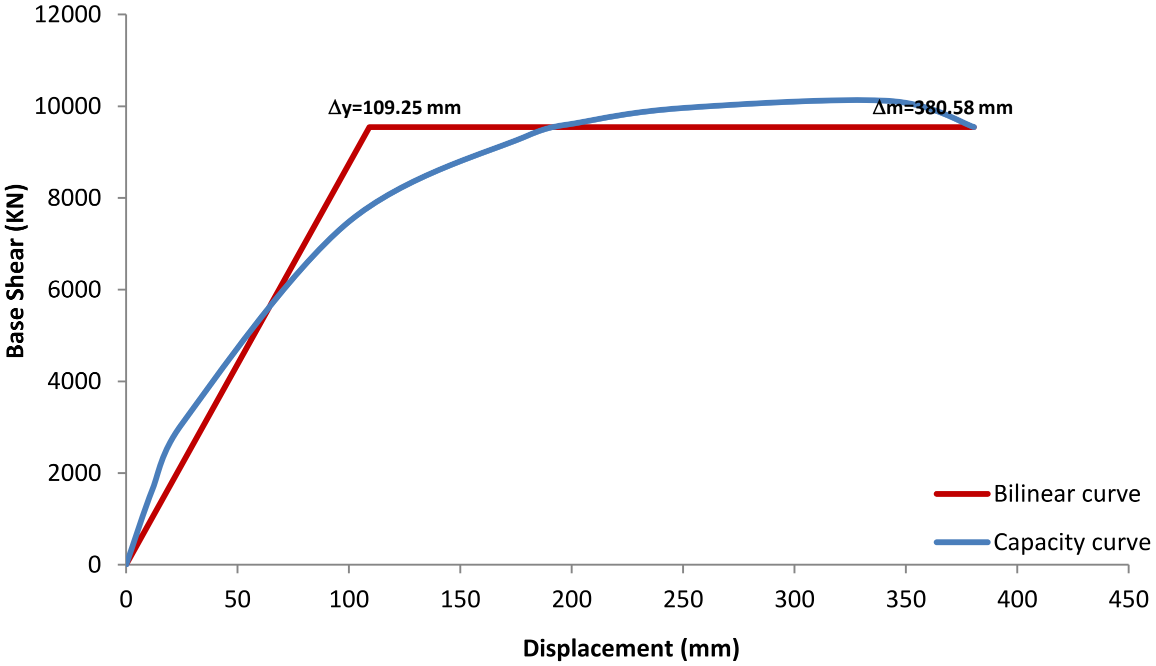


f) Model 28 (with opening 1.5mx3.0m)

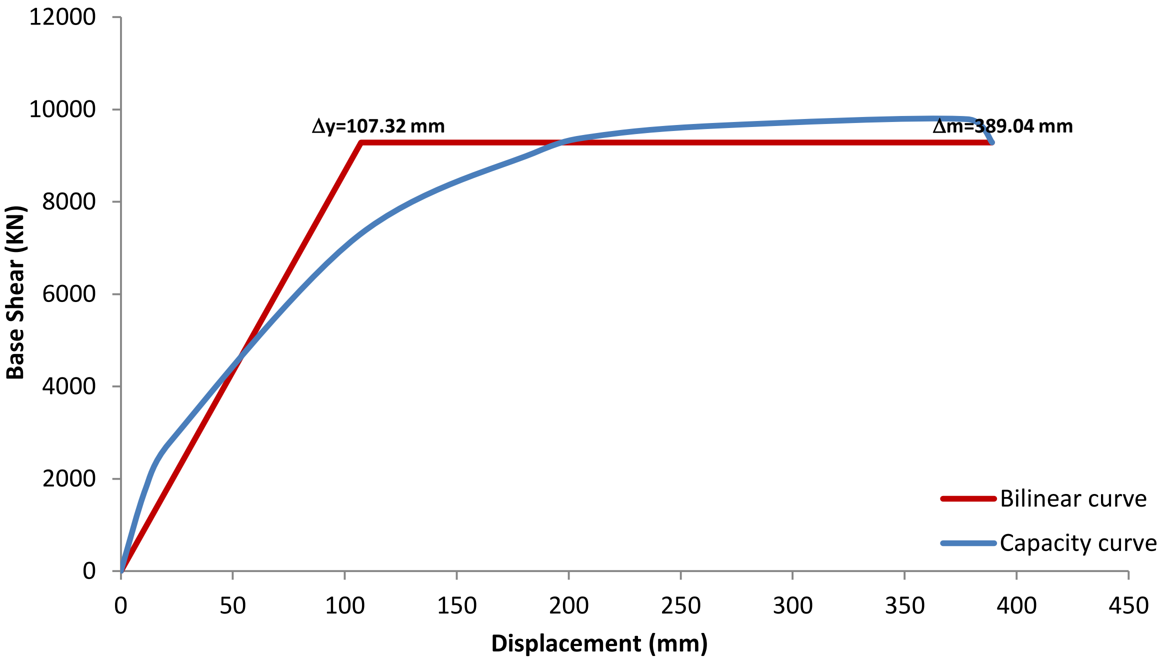


g) Model 29 (with opening 2.0mx3.0m)

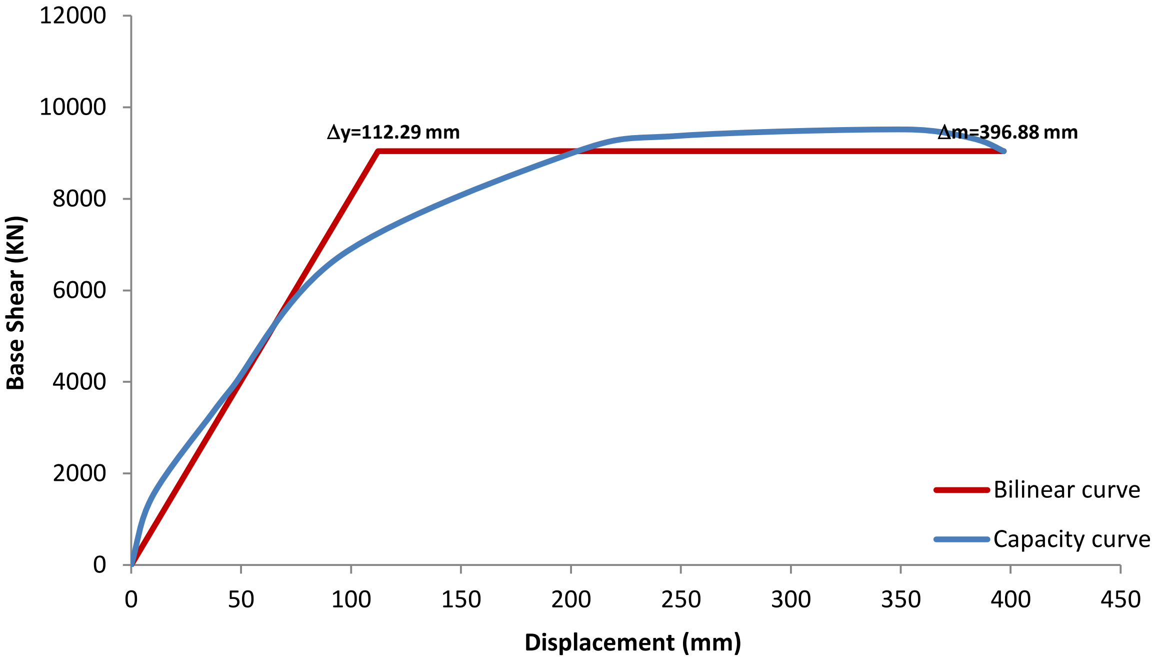
Figure B.7: Capacity (pushover) curve with a bilinear curve of the analytical models 8-story (Dual system) with ($\boldsymbol{f'c}$=250 Kgf/cm^2, $\boldsymbol{fy}$=3000 Kgf/cm^2)



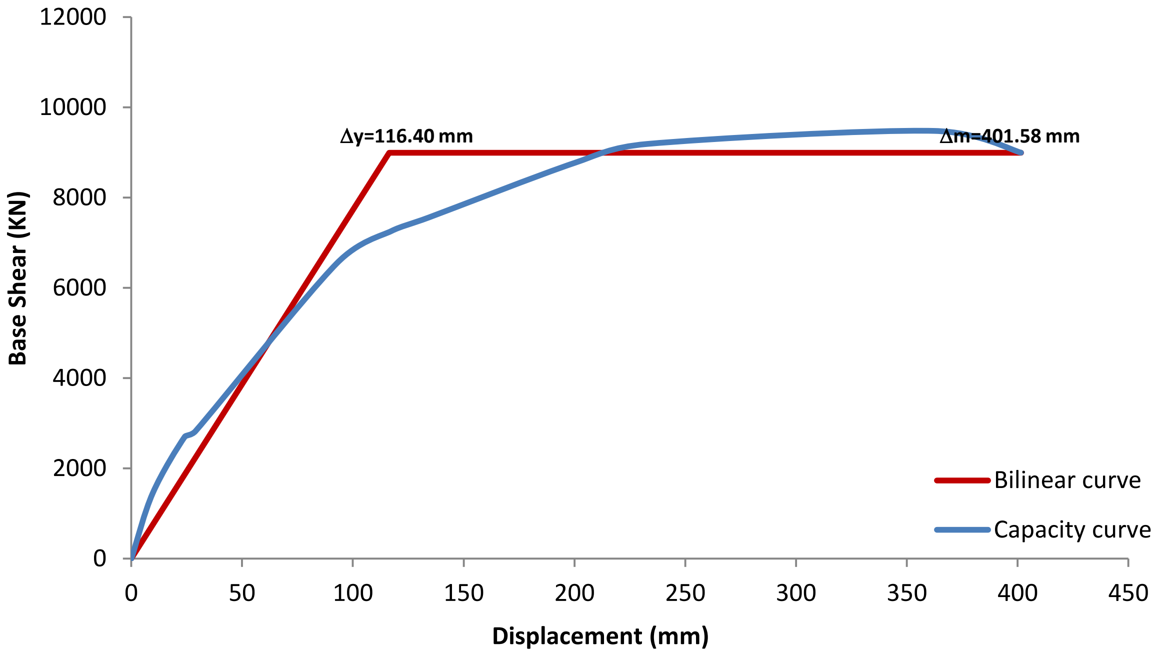
a) Model 30 (without opening)



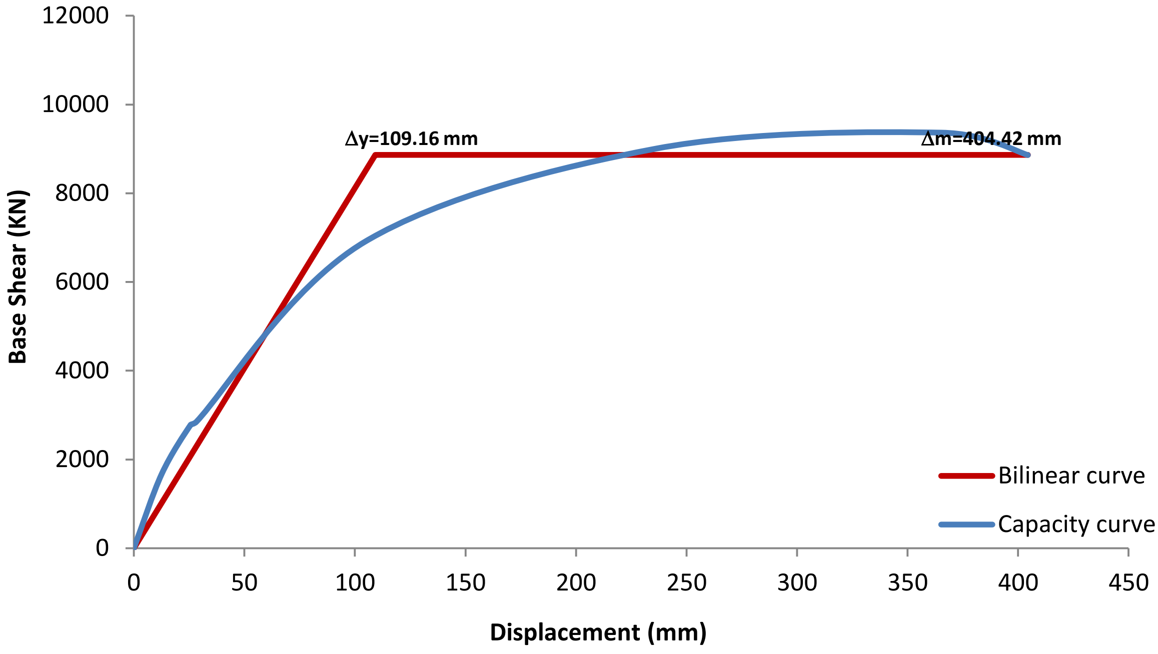
b) Model 31 (with opening 1.1mx2.2m)



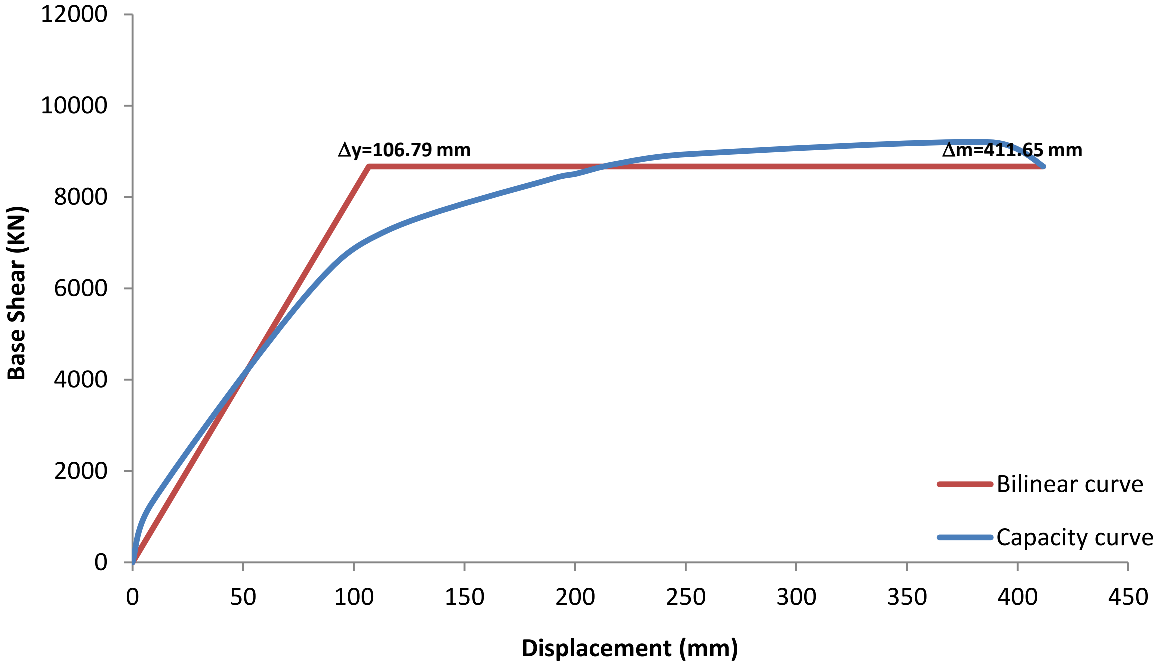
c) Model 32 (with opening 1.5mx2.0m)



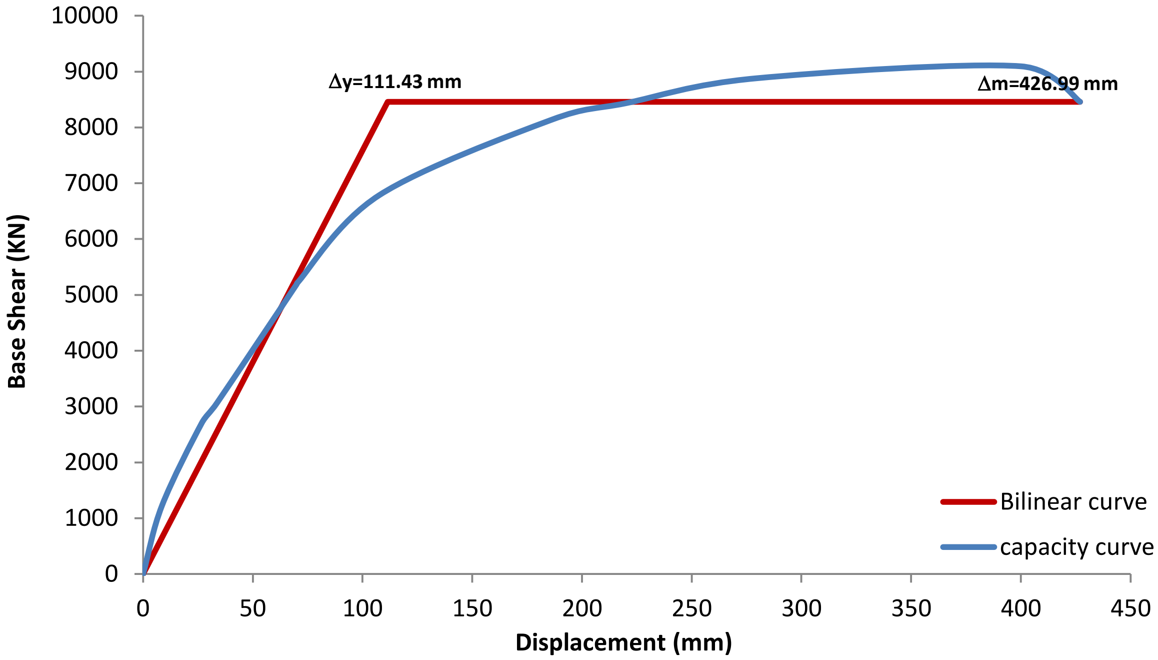
d) Model 33 (with opening 2.0mx2.0m)



e) Model 34 (with opening 2.0mx2.2m)



f) Model 35 (with opening 1.5mx3.0m)



g) Model 36 (with opening 2.0mx3.0m)

Figure B.8: Capacity (pushover) curve with a bilinear curve of the analytical models 8-story (Dual system) with ($\boldsymbol{f'c}$=300 Kgf/cm^2, $\boldsymbol{fy}$=4200 Kgf/cm^2)