EVALUATION OF STIFFNESS OF REINFORCED CONCRETE SHEAR WALLS WITH DIFFERENT SIZES OF OPENING AGAINST LATERAL LOADING

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

By
KOZHIN JANGI OMER AL-KOIY

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

NICOSIA, 2018

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Approval of Director of Graduate School of Applied Sciences

Prof. Dr. Nadire Çavuş

We certify that this thesis is satisfactory for the award of the degree of Master of Science in Civil Engineering

Examining Committee in Charge:

Prof. Dr. Kabir Sadeghi	Supervisor, Department of Civil Engineering, NEU
Assoc. Prof. Dr. Rifat RESATOGLU	Department of Civil Engineering, NEU
Assit. Prof. Dr. Çiğdem ÇAĞNAN	Department of Architecture, NEU

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: Kozhin Jangi

Signature:

Date:

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To my family ...

ABSTRACT

One of the greatest natural problems that can lead to loss life and at the same time destroy properties is an earthquake. It is essential to ensure that the structures have the required stiffness and strength to withhold vertical loads and displace lateral forces. The most effective way of dealing with this problem is by using a shear wall system. There are several factors that influence the stiffness of shear walls. Most of the engineers need to provide openings inside shear walls for different purpose. So the effect of these openings on the stiffness of the structure should be investigated. This study is carried out on a 2D reinforced concrete frame and shear walls with different sizes of opening are analyzed to determine the elastic stiffness factor, natural time period and maximum base shear. First, software computer program ETABS-2016 is used to analyze and design 832 models performing static linear analysis, and then pushover analysis is performed in order to obtain the results of elastic stiffness factor, natural time period and maximum base shear for each model. These results are utilized to determine the effect of different parameters on the elastic stiffness factor, natural time period and maximum base shear of the structure. This study verified that adding of shear wall greatly reduces lateral displacements, increase the elastic stiffness factor and reduce the natural time period of 2D reinforced concrete frame structure. The elastic stiffness factor and maximum base shear are gradually decreased with increase in percentage of openings. On the other hand, the natural time period is increased with increase in percentage of openings.

Keywords: Elastic stiffness factor; lateral resisting system; maximum base shear; opening; pushover analysis; shear walls; natural time period;

ÖZET

Hayat kaybına yol açabilecek ve aynı zamanda mülkleri yok edebilecek en büyük doğal sorunlardan biri de depremdir. Yapıların, düşey yükleri veya anal kuvvetleri karşılamak için yeterli rjitliğe ve dayanıma sahip olması sağlamak gerekli ve önemlidir. Bu sorunla baş etmenin en etkili yolu bir perde duvar sistemi kullanmaktır. Perde duvarlarının rijitliğini etkileyen çeşitli faktörler vardır. Birçok mühendis perdelerde farklı amaçlar için duvar içerisinde boşluklar bırakırlar. Bundan dolayı bu açıklıkların yapının rijitliği üzerinde olan etkisi araştırılmalıdır. Bu çalışma, iki boyutlu bir betonarme çerçeve üzerinde gerçekleştirlmiş ve rijitlik faktörünü, doğal periyodunu ve maksimum taban kesme kuvvet değerini belirlemek için farklı boyutlarda ve açıklıklara sahip perde duvarları incelenmiştir. Öncelikle, ETABS-2016 yazılım programı yardımı ile 832 modelin doğrusal statik analizi ve tasarımı yapılmıştır. Daha sonra her bir modelin rijitlik farktörü, doğal periyodu ve maksimum taban kesme kuvveti sonuçlarını için static item analiz yöntemi kullanılmıştır. Bu sonuçlar, farklı parametrelerin başlangıç rijitliği faktörü, zaman periyodu ve yapının maksimum taban kesme dayanımı üzerindeki etkisini belirlemek için kullanılmıştır. Bu çalışmada perde duvarının eklenmesinin yanal yer değiştirmeleri büyük ölçüde azalttığını, rijitliği artırdığını ve iki boyutlu betonarme çerçevelerin doğal periyodunun azalttığını doğrulamıştır. Perdedeki boşluk oranın yükselmesi ile rijitlik faktörünün ve maksimum taban kesme değeri kademeli olarak azaltmaktadır. Öte yandan, boşlukların yüzdesindeki artışla doğal periyod artmaktadır.

Anahtar Kelimeler: Elastik rijitlik faktörü; yanal dirençli sistem; maksimum taban kesme; boşluk; itme analizi, perde duvarları; doğal periyot;

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LIST OF ABBREVIATIONS

ACI: American Concrete Institute

ASCE: American Society of Civil Engineers

LRS: Lateral Resisting System

NSP: Nonlinear Static Procedure

SCSW: Special Reinforced Concrete Shear Wall

SDC: Seismic Design Category

SMRF: Special Moment Resisting Frame

CHAPTER 1
INTRODUCTION

1.1 Overview

One of the greatest natural problems that can lead to loss or life and at the same time destroy properties is an earthquake. This usually occurs when buildings have failed to withstand gravity loads. As such, structural systems are used to sustain gravity loads. The widely known forms of loads that are formed as a result of gravity are live load, snow load and dead load. Lateral loads are also prone to vibrations, sway movements and high stress ACI Committee (2005). Thus, it is of paramount importance to ensure that the structures have the necessary stiffness and strength to withhold vertical loads and displace lateral forces.

In as much as there as so many different educated individuals such as scientist and engineers, there are also various types of lateral resisting systems (LRS). These are used to reinforce concrete building structures and can be found to exist in the following categories: Stafford et al. (1991).

1. Shear Wall–Frame Systems which are composed of reinforced concrete shear walls working together with the reinforced concrete frames.
2. Structural Wall Systems: Commonly called shear walls. In this type of structures, all the vertical members are created of structural walls.
3. Structural frame systems which are made up of columns, beams and floor slabs and used to sustain gravity while at the same time offering the required stiffness.

Taranath (2010) established that the interaction between columns and slabs may result is a frame action that is not capable of giving the desired stiffness especially in buildings that are more than 10 storeys tall. As a result, the framing tall building structures is considered not to be a good way of addressing structural load and stability problems. The most effective way of dealing with this problem is by using a shear wall system which helps to boost the stability of tall buildings. Hence, shear walls are said to be in strong position to withhold a lot of horizontal and lateral shear forces. But the ability of the shear walls to act against overturning moments and withstand storey torsion, shear forces and lateral storey is determined by the structure's geometric configuration, orientation and location.

There are several factors that influence the stiffness of shear walls and some of these factors may initially prove not to be essential but later pose a significant effect on the stiffness of a building structure. Hence, it is essential to ensure that engineers are fully aware of these factors and how they can affect the stiffness of a building structure. It must be emphasized that ignoring these factors will possibly cause bad consequences in the future. Hence, it is not always good to ignore these factors. If such factors are to be ignored, then it must be done within reasonable limits. This will help to enhance design efficiency and save time.

Meanwhile, engineers must consider cases were shear walls must have openings and this must be done in relation to what the engineer wants to achieve. But there are cases where it is impossible not to have shear walls with no openings. Such openings are useful for plumbing, electrical and mechanical, electrical reasons as well as architectural uses that include having doors and windows. However, buildings with staircases and elevators are required to have an opening so as to allow access into all the areas of the building but the magnitude of the openings will vary from one building structure to the other. On the other hand, different opening sizes have got different effects on the stiffness of a building structure. For instance, an opening which is as big as the size of a door will have a totally different effect on stiffness compared to opening of smaller such as a window.

The challenge that is encountered when dealing with openings is that engineers can sometimes neglect how an opening will affect the shear wall's structural responsiveness. Either way, it is always important to have an idea of how having openings affects the performance of the shear walls together with its ability to deal with seismic effects.

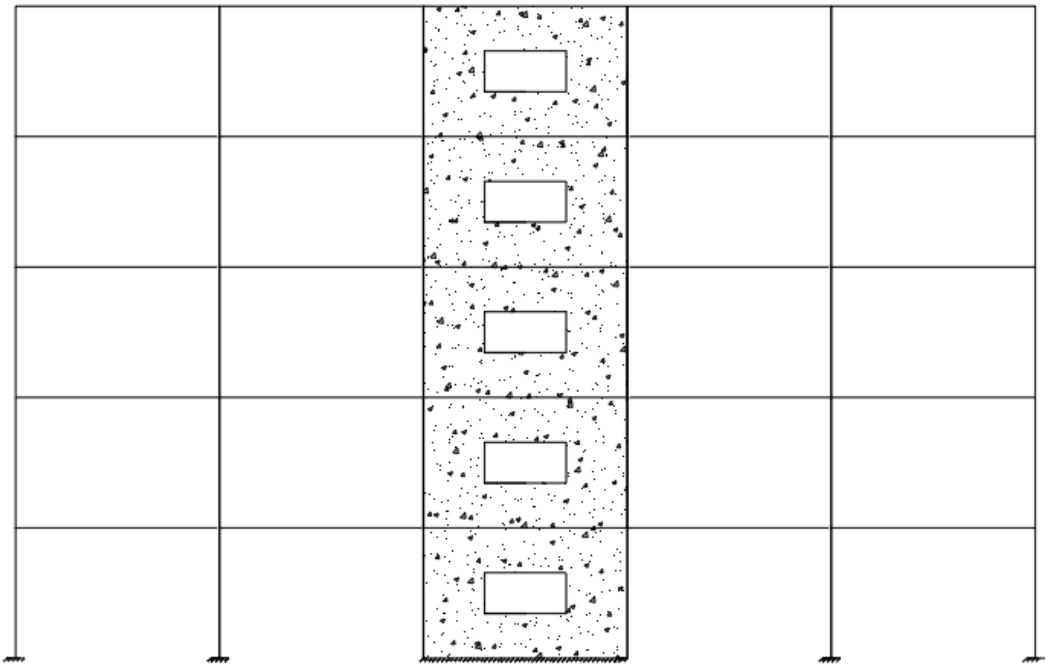
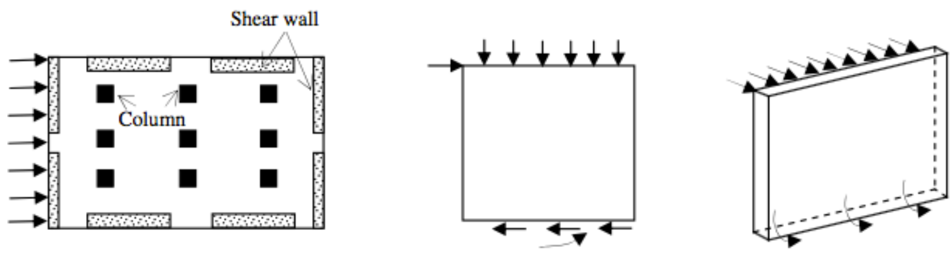


Figure 1.1: Shear wall with openings

1.2 Shear Wall

In engineering, the dual system (shear wall-frame system) is usually suitable for use in high-rise buildings but nowadays, buildings that have got reinforced concrete shear walls tend to effectively withstand seismic effects as compared to buildings reinforced with concrete frames. This is because they have got a high capacity to resist deformation and this prevents the building from collapsing. Shear walls have got a high capacity to increase the stiffness of a structure in withholding horizontal forces and hence, they are considered as an effective way of improving the stiffness of a structure.

Shear wall must be built starting from the foundation of the building and their thickness must be between lengths of 150mm - 400mm. Their importance lies in the ability to withhold lateral and gravity loads and this includes the ability to withstand horizontal and lateral forces caused by earthquakes. As such, they can be said to be capable of handling overturning and shear moments. This is mainly because one of the shear walls can rise up while the other one is pushed down as a result of on application of a load and ability to move it was causes shear walls to be in a position to avoid overturning moments caused by an earthquake. Shear walls are either found to be in the form of pillars that surrounds lifts and stairs, at the sides of a building. They are also widely used in the construction of residential and commercial buildings that are even 30 storey more than those recommended by tubular structures. Figure 1.2 shows the different positions where shears walls can be located. All the shear walls have an ability to withstand gravity loads.



(a) Shear walls in both plane (b) in-plane shear capacity (c) out-of-plane flexural capacity

Figure 1.2: Building plan configuration of shear wall

Both the shears can withhold lateral loads caused by earthquakes either “out of plane” Figure 1.2(c) or “in-plane” which can be determined by subjected the wall to a load as depicted in Figure 1.2(b). Figure 1.1(c) shows on of the ways that can be used to determine the flexural capacity of the walls. The structural response of the walls will vary according to the way they withstand and transfer seismic forces caused by an earthquake. This is relatively influenced by how strong and ductile the wall is as well as its capacity to reduce the imposed energy.

Having inelastic walls means that the wall will not be in a position to handle deformation and this can cause the either crack or break and some of the imposed damages might be difficult to repair. Previous experiences have shown that shear walls tend to perform way better in any normal circumstance even during intensive ground motion. This is attributed to their ductile behavior and stiff responsiveness when subjected to huge loads. Studies by Atimtay and Kanit (2006); Klinger et al. (2012) and Rahimian (2011) established that shears wall have got built in characteristics that make them different.

As a result, they recommended that designers must follow the following guidelines when designing structures that can withstand the effects of an earthquake resistant:

- The building structure has the required stiffness which will make it able to withstand seismic effects and prevent damages to both structural and non-structural items.
- The building is strong enough and relatively elastic to effectively handle seismic effects so as to prevent structural damages.
- Be in a position to enhance the structural ductility of the building so as to reduce the amount of energy that is negatively imposed on the building. This helps to prevent permanent damages if not extreme damages, then damages to property.

In order to have the above functions and serve the required architectural purposes, openings can be made on the shear walls. Bu the size of the openings will vary according to the size of the structure. This study desires to look at this issue by examining the responsive of shear walls with openings and offer possible ways of improving the responsiveness of shear walls.

1.3 Classification of Shear Walls

There are a series of analytical examinations and experimental studies that look at ways of classifying shear walls. There is a common agreement amongst these studies that shear walls can be grouped into different classes based on their (i) geometry, (ii) aspect ratio and (iii) structural materials.

1.3.1 Based on structural materials

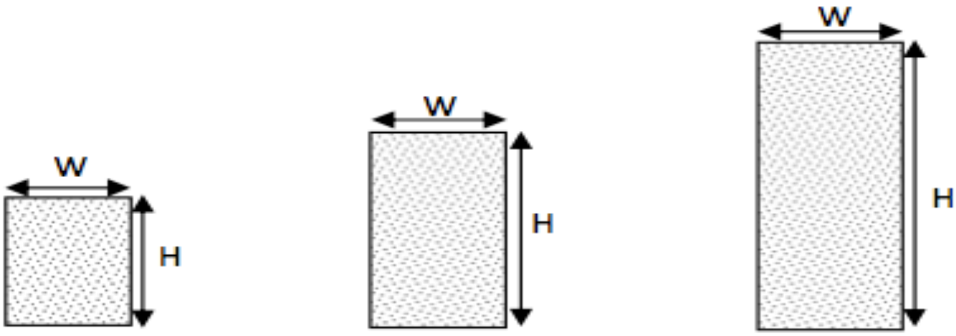
Shear walls can be categorized into different elements or groups according to their structural materials and the notable types includes of shear walls that exists are:

1. Steel plate shear wall.
2. RC hollow concrete block masonry
3. Midply shear wall
4. Plywood shear wall
5. RC shear wall.

Steel shear walls are mainly used when constructing industrial structures and this is mainly because their associated future costs are lower than their initial costs. One of the major benefits of using shear walls is that they have a high strength-weight ratio. It must be noted that different shear walls offer different important benefits depending on the location of the building structure. For instance, in cold regions, lightweight structures such as timber shear walls are usually more preferable. However, they cannot be used in high-rise structures because they are not strong enough to support or hold building structures. On the other hand, it is not advisable to use masonry shear walls in building structures that have more than four storeys. This is based on the argument that tall buildings are unstable. Meanwhile, there is a high usage of RC shear walls in commercial and residential places and this is one of the main reasons why a significant number of researches focus on this area.

1.3.2 Based on aspect ratio

Aspect ratio refers to the proportion of the shear wall's height (H) to its width (W) and plays an important part in structural engineering because it determines how a shear wall will behave over the course of time. Figure 1.3 provides a classification of the available different types of shear walls. Generally, when shear walls have an aspect ratio that is below 1, they are often regarded as being short. Meanwhile, short walls always serve an important purpose in people's lives and their importance dates back early to the period 1920 where they were mainly being used as a protection tool. However, they were totally being referred to, using a different name.



Short shear wall (H/w≤1)   Squat Shear wall (1<H/W≤3)   Slender Shear Wall (H/W>3)

Figure 1.3: Classification of shear wall on the basis of aspect ratio

Normally when the aspect ratio is within the range of 1-3, considerations can be made that the shear walls are Squat. Also, shear walls can be considered to be squat if the aspect ratio is in between the range of one to three. Paulay and Priestley (1992) are of the view that having short and squat shear walls is totally undesirable because they are easily affected by the problem of brittle failure. When slender shear walls have got a high margin ratio above 3, the condition is called flexure mode. It is for this reason that shear deformation was not looked at in this study.

1.3.3 Geometry of shear wall

When looking at the concept of geometry shear wall, attention must be given that there are a lot of reinforced concrete shear walls. This was considered to be true by Murthy (2004) who went on to list the notable concrete shear walls as being composed of core, column supported, framed, coupled, flanged, rectangular and bar bell shaped shear walls. But the most common and widely used shear walls are flanged, bell shaped and rectangular shears walls.

1.4 Elastic Stiffness Factor

Natural stiffness measures the ability of a building structure or object to maintain its natural shape rather than deforming when a load is applied to it. That is, the extent to which a building structure deforms when subjected to a load. This is important because it provides an indication of the building's responsiveness capacity. The basic idea is that lateral stiffness determines the weight of the load the structure will hold. As such, less stiff structures are not capable of sustaining a huge force as compared to stiffer structures. Moreover, the resistance to deformation caused by applied loads. The amount of lateral load resisted by individual members in buildings is controlled by their lateral stiffness – stiffer elements attract more force than flexible ones. Since elastic lateral stiffness plays an important role in overall response of buildings. It is important to have uniform distribution of stiffness in a building to ensure uniform distribution of lateral deformation and lateral forces over the plan and elevation of a building Li et al. (2010).

1.5 Lateral Displacements

One of the essential decisive element is lateral displacement which used for building design. In the situation that the maximum displacement should be limited due to serviceability issue or adjacent buildings, however the biggest difficulties could be the way in reduce displacement to allowable amounts. Hook's law refers to the implemented force to displacement utilizing the concept of stiffness, and this law also applies using the equation below

$$F = K \times d \tag{1.1}$$

Where

F = Applied forces

K = Stiffness that created the association between F & d

d = Displacement

Furthermore, displacement is extremely affected by stiffness therefore; it is a significant to recognized how changes in stiffness can impact the behavior of structure in terms of maximum lateral displacements ASCE 7-10.

1.6 Natural Period

This is defined as the amount of time required to complete an oscillation measured in seconds (s). All buildings are characterized by their own respective natural periods (T) and this means that their periods vary from one building structure to another. T is determined by stiffness (k) and mass (m) and is computed as follows;

$$T = 2\pi\sqrt{\frac{m}{k}} \tag{1.2}$$

Using expression (1.2), it can be noted that natural period is high in buildings that are less stiff and have got a high mass value as compared to stiff and light buildings. The natural frequency (fn) is an inverse of the building's natural period and is measured in Hertz. Natural period is useful because it can be used to determine the responsiveness of a building after being shacked at its natural frequency. In most cases, shacking a building is at its natural frequency causes the building to have a very low resistance capacity. During such an exercise, the building will pass through a long oscillation when agitated at the natural frequency as compared to other frequencies. One to twenty storey buildings reinforced with steel and concrete have natural periods of 0.05 to 2.00 seconds. It is usually desirable to use T as opposed to fn in building when dealing with structural resistance matters in engineering ASCE 7-10.

1.7 Objective and Scope

This study research is aimed at distinguishing and evaluating the elastic stiffness factor, natural time period and maximum base shear of reinforced concrete shear walls with different sizes of opening acting against a lateral load. On a different circumstance, to conduct a non-linear static analysis (pushover analysis) to assess the impact of various parameters on the elastic stiffness factor, natural time period and maximum base shear of the reinforced concrete shear walls with different types of opening acting against a lateral load.

1.8 Significance of the Study

The study helps in determining which size of an opening in shear walls influences the stiffness of the reinforced concrete moment resisting frame shear walls. As a result, the opening sizes which do not effectively decrease the stiffness of shear walls can be overlooked. Also, the downfall of the shear walls as a result of exposure to lateral loads can be mitigated.

1.9 Thesis Structure

This study consists of the following chapters:

Chapter One: Deals with the introductory insights of the study, research objectives, significance of the research and structure of the thesis.

Chapter Two: Consists of previous studies about the shear walls and the influence of the size of opening on the shear walls.

Chapter Three: Looks at the applied methods, samples, procedures and statistical studies conducted.

Chapter Four: Focuses on data analysis, research findings and discussion.

Chapter Five: The last chapter of this thesis consists of conclusions and recommendations based on the findings.

CHAPTER 2
LITERATURE REVIEW

This chapter provides a review of existing studies and experiments on shear walls, structural response of shear walls with openings and pushover analysis.

2.1 Experimental and Analytical Studies on Shear

Lee et al. (2007) concentrated on examining how reinforced concrete walls of three 17-storey building models respond when subjected to the same seismic effects caused by an earthquake. The building models had different structures at the bottom and one of the models had exterior frames with infill shear walls, the second model had its middle frame supported by an infill shear wall while the last one was fitted with moment resisting frames of equal sizes. The reported findings denoted that the occurrence of overturning and shear deformation caused all the models to absorb lot of energy. The computed figures also showed that shear walls and moment resisting frame models had different and unusual natural time periods in UBC 97. However, the issue of having an infill shear wall and the changing of the location of their locations did not cause changes in the way the models absorbed total energy. Shear deformation was discovered to be having a low energy absorption capacity as compared to overturning and that the weight of the model had an estimated resistance contribution of more than 23%.

Gonzales and Almansa (2012) did a study that was aimed at providing details and specification about how walls should be designed to handle seismic forces. Nonlinear dynamic and nonlinear static analysis were used to assess the vulnerability of the structures and conclusions were made from the reported findings. It was highlighted that the basic step is to first understand how the structures behave in response to seismic effects. It was further established that studying the behavior of structures will result in the development of news studies aimed at preventing the catastrophic effects of seismic activities. The findings showed that the structures had a low ability to handle seismic activities and improvements were needed to boost their performance. Suggestions were made that this must be done in an effective and inexpensive manner.

Chandurkar (2013) used 4 models to identify ways that can be used to find the best position to place shear walls in structures with several storeys in seismic zone 2, 3, 4 and 5 using ETABS. The study was narrowed to the examination of changes in total cost of developing the ground floor, story drift and lateral displacement of the structure. These aspects were discovered to fall when shear walls are added to the structures. It is from these observations that it was considered that shear walls are cheaper and effective in dealing with seismic effects. The notable observation that was made is that placing the shear wall at the right position will greatly enhance the strength of the structure by dampening displacements effects and thereby lowering future costs.

Varsha (2014) calculated seismic parameters in line with IS 1893 Part II using STAAD Pro and data collected from an area classified as seismic zone II. The analysis focused on 6-storey buildings using 4 different types of structures that included an X-type shear wall, shear walls at the edge of the structures, a structure without a shear walland an L-type shear wall. The findings demonstrated that positioning the shear wall at the edge of the structure improves the load resistance performance of the structure. Such an ability is believed to be as a result of a high deflection ability.

Kameswari et al. (2011) examined the effectiveness of changing the types and position of shear walls within a building storey. This was done (i) by using lift core walls (ii) by arranging the wall diagonally, in an alternate way and zig zag manner, (iii) by using conventional shear walls within a building storey. Of all the structures that were used, it was noted that zig zag shear walls help to boost the stiffness and strength of the structure because of their high capacity to handle inter storey and lateral drifts as compared to other shear walls. Hence, they consider that zig zag shear walls be used in high seismic zones to avert the effects of an earthquake.

A research carried out by Gattesco, et al. (2017), the aim of this study was to compare an opening window with the code provision with particle boards. The results showed that only few differences were found between them, in terms of ductility, the capability and dissipative capability.

Venkatesh and Bai (2011) based their study on the examination of the ability of 10-storey buildings to handle beam and column forces, support reaction and joint displacement of internal and external shear walls. Rectangular column walls were noted to perform poorly when exposed to a lateral as compared to square shear walls. The study suggested that the thickness of the wall does not have a significant influence on the ability of the wall to handle shear forces. On the other hand, internal shear walls showed a high capability to handle shear forces and were recommended as the best way of reinforcing a structure in a high earthquake prone zone.

Sardar et.al (2013) using ETABS to assess changes in displacement, storey shear and storey drift in response to changes in the position of the shear walls using dynamic and static analysis approaches. The study was confined to structures located in zone 5 and a 25 storey building was used as a base for modelling the parameters. The findings were recorded and contrasted with each other. Deductions were made that positioning shear walls in the Y and X direction that is parallel to the walls improves the stability of the structure. That is, the displacement of the structure becomes low as a wall is placed either in a Y or X direction as a result of an increase in the stiffness of the structure.

Firoozabad et al. (2012) used SAP 2000 information on stop-storey building specifications to determine their performance. The study was at attempt to prove if in reality top-storey buildings actually suffer from storey drift and their findings confirmed this to be true. It was suggested that this problem can be solved by changing the position of the shear wall. another observation that was made was that having more shear walls has no meaningful effect on the responsiveness of the building.

2.2 Structural Response of Shear Wall with Openings

There are a lot of analytical and experimental studies over the past ten years to examine changes in the performance of shear walls with openings when subjected to different types of loads. This chapter looks at some of the notable analytical and experimental studies that stirred further research on shear wall with openings.

Kabeyasawa et al. (2007) carried an empirical examination of the influence of openings and boundary elements on the responsiveness of 6 shear walls of 80 mm×2000 mm×2200 mm (thickness×width×height). The openings were established to be having a high ductility as opposed to walls that do not have openings. However, the stiffness of the walls declined with a successive increase in the number of openings put on the walls. Hence, openings can be said to lower the strength of a wall by reducing its stiffness.

Fragomeni et al. (2012) did a study similar to the one done by Kabeyasawa et al. (2007) but this time using 7 RC shear walls that had had openings in 1 and 2-way activities. However, a 0.031% ratio was used for ratio of both the horizontal and vertical reinforcement and the size of the openings was relatively smaller and averaged 1200 mm × 1200 mm. the results were also similar to each other and outlined that surrounding conditions of the support systems together with the design of the openings had a huge influence on the crack patterns and failure load. 1-way panels performed better that 2-way panels which had a high proportional failure rate of 200-400%. Also, an increase in the number of openings was established as lowering failure loads. This shows the importance of addressing the impact of openings on dealing with structural failure. Fragomeni et al. (2012) supports this idea and established that a lot of studies have not been paying much attention on the impact of openings. Suggestions were given that the effects of openings be analysed in line with international practices.

Lee (2008) did tests that were aimed at assessing the impact of doors and windows on the deformability and strength shears walls. The study was done in line with the AS3600-2009 which required that a reinforcement ratio of 0.31% be kept between horizontal and vertical walls. The findings established that the presence of openings can weaken the strength of a structure and that there is need to put reinforce the edge of the openings with small bar strips. This suggest that it isa also important to ensure that the size of the openings remains up to par with the prevailing codes and standards.

Neuenhofer (2006) took a different approach and focused on separating the effects of shear walls with and with no openings. The results showed that both shear walls served the same purpose but what made their effectiveness different is the position of the openings. In this way, observations were made that placing the opening at the middle of the wall weakens the strength of the shear wall but does not affect the shear wall's moment capacity. On the other hand, different flexural and shear strengths were observed when the openings were placed at the edge of the walls. This led to an agreement that openings must be placed at the centered of shear walls.

Masood et al. (2012) conducted a finite element based analytical study using ANSYS (Version 5.4) to determine the response of shear wall with base opening and concluded that base opening beyond 60% resulted in tremendous decrease in strength and stiffness degradation. Even though base opening has always been a risky option considering its structural importance, because of the need to provide parking access, it has become an automatic functional requirement in the recent years.

Yarnal et al. (2015) used shear walls various openings to assess their effectiveness in handling seismic forces in zone III. The structures were analyzed based on their stiffness to handle shear and drift forces using ETABS. The conclusions derived showed that the storey drift of building provided with openings in shear wall is more than shear wall with no openings. Natural time period is directly proportional to the openings in shear wall i.e. as area of openings increases in shear wall, natural time period also increases. Base shear is relatively less for shear walls with openings than shear walls without openings.

Gong, Chen and Su (2014) gave establishment of simplified mechanical model and numerical simulation researches on shear wall with opening were reviewed, the research findings on shear wall with opening at home and abroad were summarized, and the seismic behaviors were induced and analyzed. The researchers found that shear capacity and lateral stiffness of the shear wall are reduced because of the openings, the ductility and energy-dissipation capacity can be improved. And the seismic behaviors of the shear wall will be influenced by the frame constraint, the size and the location of opening.

Chowdhury (2012) focused on 6- story buildings and attempted to determine the responsive changes in structural stiffness attributed to changes in opening sizes using ETABS. The study was carried out in areas that are highly affected by earthquakes. The results showed that all the structures were equally prone to seismic forces but their ability to withstand the effects was highly determined by the position of the openings. This entails that a proper positioning of openings results in an increase in structural stiffness.

Deore (2015) used a 12-storey building to model the effects of an earthquake using load handling systems with and with no openings in Zone 5. The results showed that an increase in the height of the building is associated with an increase in displacement capacity. However, reducing the size of the openings was noted as causing a decrease in the walls' displacement potential by more than 40%.

Nagar et al. (2017) studied the effects of changing the position of reinforcing system on the loading resistance capacity of a structure using ETABS in seismic Zone 3. The computation of the findings was done in respect of frequency, natural time period and displacement. It was noted that both modal period, displacement effects and storey drift reduced the effectiveness of the shear walls by more than 30%, 18% and 25% respectively. This implied that the frequency, natural time period and displacement of the structure must be examined carefully and considered when selecting the best structural stability enhancement systems.

Swetha and Akhil (2017) carried out a study on a seven story frame- shear wall building, using linear elastic analysis, with the help of finite element software ETABS, using time history method. The objective is to study natural time period, displacement, base shear, storey drift and storey acceleration of shear wall with openings arranged in vertical, horizontal and zigzag manner and by varying percentage of opening in zigzag manner. They founded that the occurrence of storey shear, storey displacement, storey drift and storey acceleration in structure with shear wall having openings arranged in zigzag manner is approximately 4% lesser as compared to vertical and horizontal arrangement of openings. Finally, the zigzag arrangement of openings in shear walls is suggested to be applied in practice, since it provides comparatively 4% better performance than other arrangement of opening.

On the basis of literature review carried above, it can be concluded that limited experimental and analytical work has been performed to investigate the influence of openings, its sizes and shapes on ductile response of shear wall under severe loading conditions until collapse. In order to develop the design guidelines, there is a necessity to analyze in detail the shear walls with openings.

Gupta et al (2018) carried out a study on a fifteen storey frame structure shear wall building, with the help of ETABS software in using time history method. The scope of this work was to study seismic responses of the fifteen storeys RC shear wall building with or without openings. Its check the parameters results of storey drift, displacement, base shear of the structure openings in shear wall buildings. The magnitude of strength reduction depends on the size of openings. They conclude that Lateral load resisting capacity of shear wall frame increases significantly on decreasing the size of opening in shear wall. when openings are large enough, the load capacity becomes less. And for openings up to 14%, the load carrying capacity and ultimate displacement response were not found to be severely affected by openings. However, for openings beyond 14%, the load carrying capacity of shear wall gets affected due to the presence of opening

Pooja and SV Itti (2014) studied the effects of base openings in reinforced concrete shear walls. They analyzed a 5-storeyed shear wall using ANSYS software with wide opening at the lower storey only, and concluded that shear walls with symmetric wide openings at the base story performs better than eccentric openings when they are subjected to lateral loads. Hence eccentricity in the base opening must be avoided as far as possible.

2.3 Studies on Pushover Analysis

Raju et al (2015) undertook an NLA of frames to determine how shear walls can be effectively positioned in multi-storey buildings. Pushover curves were produced using ETABS as a result of the application of earthquake loads on four different models of an eight-storey building with shear walls that are located at different seismic zones. The approaches ranged from nonlinear dynamic and static to linear examinations. The findings strongly argued that the base shear and displacement of the load must be taken into consideration when examining the effective positioning of shear walls. As a result, they suggested that the location of the shear walls is of great importance when deciding on how to position in any structure. The occurrence of an earthquake was considered to impose huge force on structures up to a level where the entire can collapse if not then fracture. Such cases are considered as difficult to model and may require the use of examination methods involving the use of geometric and material nonlinearities.

Esmaili et al. (2008) did a study that examined the seismic capabilities in tall buildings with storeys that are as high as 56-storeys. Efforts were also to determine how reinforcements and other lateral and resistant mechanisms can be used for retrofitting purposes in line with FEMA 356 standards. The study involved the use of shear walls and various openings of different sizes. The results showed that having different structures of various shapes and sizes can weaken the strength of the structure. The stiffness of the structures was considered to decline following the use of various load resistant mechanisms of varying sizes and shapes. This causes the structures to displace loads at different pace and magnitude. In other words, the structures became more sensitive to seismic effects following the combined use of various load resistant mechanisms of varying sizes and shapes. Proposed solutions steel bracings were recommended for use in every structure that is located in an area that is prone to seismic effects. But the use of shear walls as bracing mechanism does not result in compatibility of the reinforcement systems and can even result in high future costs.

Shah et al (2011) established that the use of some seismic determination methods is followed by a repetition of steps. This was discovered to be true especially in the case with NLSA. Recommendations were given that in most cases estimation software be used to determine the seismic effects. The recommendations pointed towards the use of ETABS which was deemed to be effective and simple.

Balaji et al. (2012) conducted an analysis involving the determination of the structural requirements needed to sustain seismic effects using pushover analysis. The behavior of the structures was noted to be following a nonlinear pattern and this made it difficult for the researchers to assess the exact seismic performance of the structure. The pushover analysis was conducted using two different approaches one involving displacing the entire structure to seismic effects and the other as a control structure. Observations were made from the time the structure was displaced up until its failed. The reported results showed that a lot of force is produced during the displacement of a structure which causes the structure to fail. Hence, it was considered that there is need to reinforce the structures to withstand displacement effects caused by earthquakes.

Fahjan et al. (2009) did a study that looks at the importance of modelling and the use of shear walls to handle seismic effects. The point of recognition of their study is that both linear and nonlinear analysis approaches rely on proper modelling techniques. Their argument was that the modelling approaches used for shear walls are numerous and involve the use of various frames. The study recommends that nonlinear responses be modeled using structures with different layers. But the presence of plastic hinges on the structures influences the distribution of lateral forces and this is some cases modelled as a sperate issue. Hence, they considered that the effects of plastic hinges be incorporated into the modelling process. In addition, the study considered that events in which involves the use of plastic hinges and nonlinear behavioural activities must be put together and seismic effects modelled together.

Shah et al (2011) established that the use of some seismic determination methods is followed by a repetition of steps. This was discovered to be true especially in the case with NLSA. Recommendations were given that in most cases estimation software be used to determine the seismic effects. The recommendations pointed towards the use of ETABS which was deemed to be effective and simple.

Abhilash et al. (2009) also agreed with ideas given by Fahjan et al. (2009) and highlighted that the use of pushover analysis is subjective in some cases. They established that aspects such as the size of the load, position of the openings and shear walls have an influence on the entire pushover analysis. As a result, any misspecification may affect the ability of the analysis to give accurate results about the behavioural changes of the structures. This can also end up affecting measures devised to improve the structural performance of the entire system. They recommended that guidelines such as SAP2000 and ETABS software be used during the modelling process so as to obtain effective results.

CHAPTER 3
METHODOLOGY

3.1 Introduction

In this study, 2D reinforced concrete frame and shear walls with different sizes of opening are analyzed to determine the elastic stiffness factor, natural time period and maximum base shear. A quantitative approach is chosen to determine the elastic stiffness factor, natural time period and maximum base shear of reinforced concrete shear walls with different sizes of opening against lateral loading. First, software computer program ETABS-2016 is used to analyze and design 832 models performing static linear analysis, and then pushover analysis is performed in order to obtain the results of elastic stiffness factor, natural time period and maximum base shear for each model. these results are utilized to determine the effect of different sizes of openings, span length, number of spans, number of stories, story height, compressive strength of concrete, yield strength of steel and thickness of shear wall on the elastic stiffness factor, natural time period and maximum base shear of the structure. Codes that are used in obtaining some of the information are ACI 318-08 and seismic information is obtained from ASCE 7-10.

3.2 Model Description

In this study, special moment resisting frame (SMRF), special reinforced concrete shear wall (SCSW) and special reinforced concrete shear walls in dual systems are used with different sizes of opening. The foundation of all models are assumed to be fixed. These are parameters that have been changed for the above structural systems:

1. **Number of spans (N):** One bay and five bay

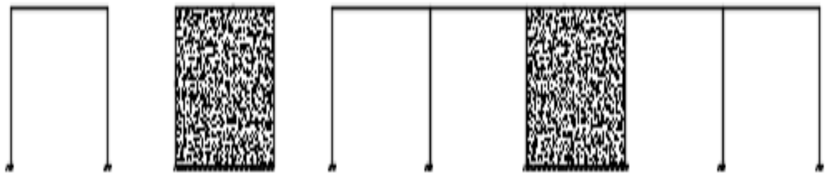


Figure 3. 1: Configuration of shear wall with different number of spans

2. **Five different sizes of openings:**

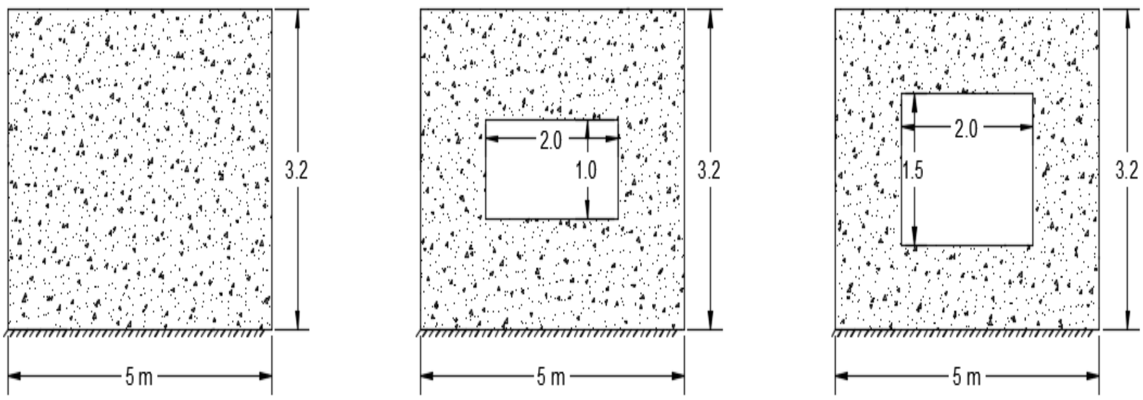


Figure 3. 2: Shear wall with different sizes of opening

Table 3. 1: Opening sizes

Sample No.	Opening sizes (m)	
	H	**V**
1	2	1
2	2	1.5
3	2	2
4	3	1
5	3	1.5

A. **Span lengths (L):** 5 and 6 m.

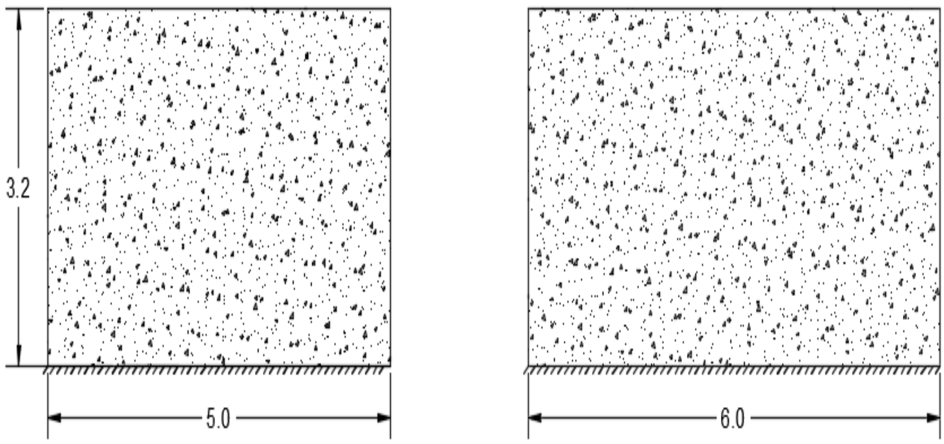


Figure 3. 3: Representing different span lengths with 3.2m height

A. **Story height (H):** 3.2 and 3.6 m.

B. **Two different yield strengths of steel f_y:** 300, 415 MPa

C. **Two compressive strengths f_c':** 25, 30 MPa

D. **Thickness of shear walls (t):** 0.25 and 0.3 m.

E. **Number of stories:** 1 (Low-rise) and 5 (Mid-rise)

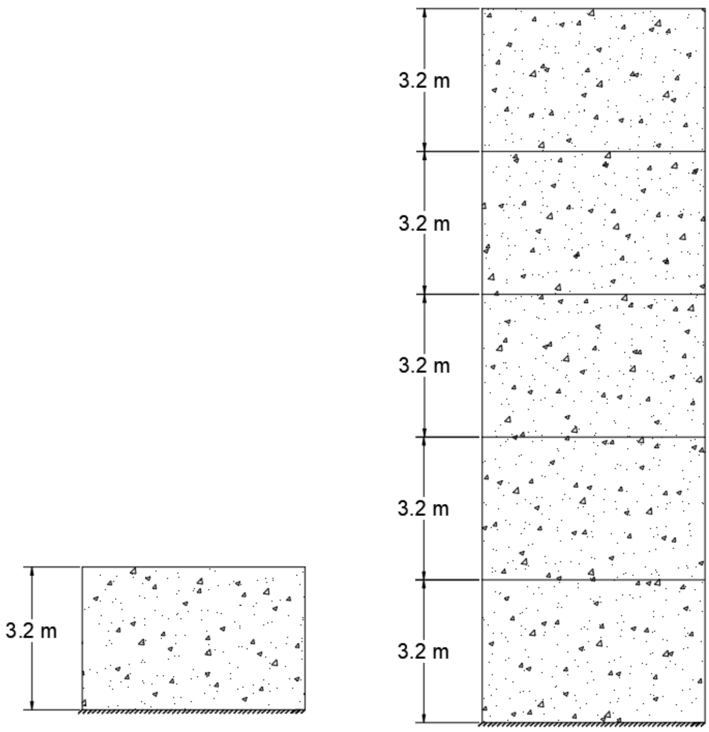


Figure 3. 4: Number of stories

3.3 Material and Section Properties

This research is mainly about shear walls and parameters affecting a shear wall-frame building, concrete structures will be studied. As a result, the only materials used in all of the models are concrete and reinforcement steel. As be seen in the Table 3.2, the all materials properties summary that have been applied effectively in this study. The size and dimension of sections used for low-rise and med-rise models are described in Table 3.3:

Table 3. 2: Material properties

Materials	Properties
f_c' for shear walls	250 and 300 N/mm^2
Modulus of elasticity of concrete	23500 and 25742.96 N/mm^2
f_y of reinforcement steel	300 and 415 N/mm^2
Unit weight of concrete	24 kN/m^3

Table 3. 3: Section properties

Element	Dimensions
Rectangular Beam	500×300
Square column	500×500

3.4 Loads

The main loads that have been implemented properly and effectively in this study can be found as follow:

3.4.1 Gravity Loads

One of the main load that has been used in this study was live and dead loads which are fall under the gravity load's categories. Concerning live loads that are summarized in the table 3.4 and the dead load is the result of the structure self-weight calculation (which is automatically calculated by ETABS program) and Live loads are taken from relevant tables of ASCE/SEI 7-10.

Table 3. 4: Gravity loads

Load case	Value
Super dead load	20 kN/m
Live load	25 kN/m

3.4.2 Lateral Loads

The researcher employed a pattern of improving and raising lateral load, as a part of pushover analysis. Various lateral load designs consequence in various curves. In the case of the curve has shown as underestimated or overestimated then the seismic capability as a result the estimation of displacements result might not be realistic. For this reason, choosing load pattern is considered as an essential and significant aspect in pushover examination.

3.5 Seismic Analyzing Methods

The decision about which method to use in analyzing building structures is no less important than choosing an appropriate modelling technique. As stated above both nonlinear and linear analysis are considered as essential method. As for the multistory buildings we usually apply linear elastic analysis because of the simplicity. We can apply dynamic or static method in order to perform linear elastic examination effectively. Concerning static analysis, engineers are able to apply loads acting as constant and the building structure as stationary but without time dependent. The influences of all types of loads are clarified and idealized in this method. The majority of earthquake codes, are suggested and advised to use the equivalent later force method, the static method generally utilized in the elastic analysis of multistory buildings which might face the earthquake. Analysis approaches are generally categorized as nonlinear dynamic analysis, nonlinear static, linear dynamic and linear static. And first two methods are suitable when the loads of the structure are small. Generally, the structural loading might fail due to earthquake load; moreover, the material stress might be over yield stresses. Therefore, the geometrical nonlinearity and material nonlinearity will be combined into the analysis to obtain greater findings.

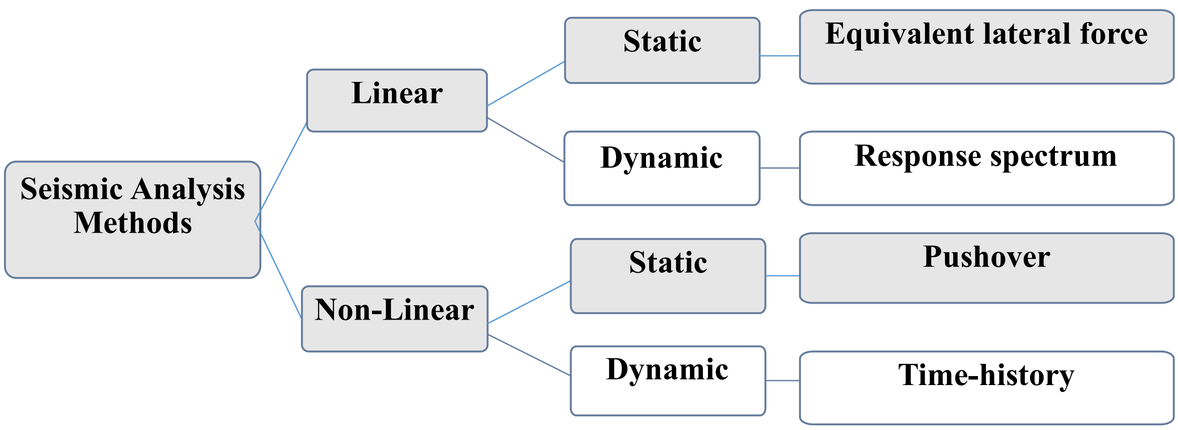


Figure 3. 5: Seismic analysis methods

In order to design and examine all models, first applied the equivalent lateral force method for analyzing and designing all models then applied Pushover method for finding elastic stiffness factor, natural time period and maximum base shear of all samples, by performing ETABS 2016. These two methods (the equivalent lateral force method and Pushover method) are summarized in the following sections.

3.5.1 Equivalent lateral force method

Most of design engineers prefer to apply the equivalent lateral approach due to it is considered as simple method. However, this method is according to the several assumptions Celep et al. (2000) as follow:

- In order to represent the dynamic response of the structure, the linear lateral approach could be utilized significantly for this purpose.
- The influence of yielding on the building structure is estimated utilizing elastic spectral acceleration decreased through changing the elements.

There are some processes and procedures should be applied in order to examine the building that is utilizing the equivalent lateral load method, these procedures are as follow:

- Identifying of the application's point of design seismic loads.
- Identifying of the entire equivalent seismic load.
- Identifying of the initial natural vibration period.
- Identifying of design seismic loads acting.
- Investigation of the structural scheme.

3.6 Procedure or Selecting Structural System and System Parameters According to ASCE 7-10

a. **Identifying building occupancy category (I-IV):** In this research frames are measured in order to be designed for the purpose of residential building meanwhile risk category I is utilized according to Table 1.5-2 ASCE 7-10.

b. **Identifying basic ground motion parameters (SS, S1):** In this research S_1 and Ss values are chosen from Erbil city in Kurdistan region of Iraq as shown below:

$$S1= 0.13\ g$$

$$Ss= 0.52\ g$$

Where

S1: Mapped MCE_R spectral response acceleration parameter at a period of 1 second.

Ss: Mapped MCE_R spectral response acceleration parameter for short periods.

g: Is acceleration due to gravity and is used as unit of acceleration for Ss and S_1.

c. **Identifying site classification (A-F):** when we are facing unknown location, ASCE 7-10 is permitted engineers to be used site class D. Since in this thesis site class D is used.

d. **Identifying site coefficient adjustment factors (Fa, Fv):** These coefficients are usually resulting from the site class according to spectral response acceleration parameters according ASCE Tables11.4-1 and 11.4-2, respectively. These coefficients are founding from Table 3.5 and 3.6.

$$F_v = 2.28$$

$$F_a = 1.375$$

Table 3. 5: Site coefficient Fa

Site Class	Mapped MCE_R spectral response acceleration parameter at short periods				
	$S_S \leq 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1	1	1	1	1
C	1.2	1.2	1.1	1	1
D	1.6	1.4	1.2	1.1	1
E	2.5	1.7	1.2	0.9	0.9
F	See section 11.4.7 of ASCE				

Table 3. 6: Site coefficient Fv

Site Class	Mapped MCE_R spectral response acceleration parameter at 1-s period				
	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \geq 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1	1	1	1	1
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See section 11.4.7 of ASCE				

e. **Computation of SMs and S_{M1}**

Based on ASCE 7-10 equations 11.4-1 and 11.4-2, S_{Ms} and S_{M1} are equals to the site coefficient, F_a and F_v, multiplied by short periods S_S for short periods and S1 a period of 1 second. And S_{Ms} and S_{M1} are founding from equation (3.1) and (3.2).

$$S_{MS} = F_a \times S_S \tag{3.1}$$

$$S_{MS} = 1.375 \times 0.52\ g = 0.715\ g$$

$$S_{M1} = F_v \times S_1 \tag{3.2}$$

$$S_{M1} = 2.28 \times 0.13\ g = 0.2964\ g$$

f. Computation of S_{DS} and S_{D1}

Based on the Equation 11.4-3 of the ASCE 7-10, in the case for the short period the design spectral response acceleration coefficient, S_{DS} is equal to two-thirds of S_{MS}. S_{DS} is founding from equation (3.3).

$$S_{DS} = 2/3\ S_{MS} \tag{3.3}$$

$$S_{DS} = 2/3 \times 0.715 = 0.476$$

As well as, based on the Equation 11.4-4 of the of the ASCE 7-10, in the case for the 1-second period, S_{D1} is equal to two-thirds of S_{M1}. S_{D1} is founding from equation (3.4).

$$S_{D1} = 2/3\ S_{M1} \tag{3.4}$$

$$S_{D1} = 2/3 \times 0.2964 = 0.197$$

g. Selection of seismic design category, SDC

According Table 11.6-1 and 11.6-2 in ASCE7-10. choose the appropriate seismic design category. The seismic design category is founding from Table 3.7 and 3.8 is equal to C

Table 3.7: Seismic design category based on short period response acceleration parameter

	Risk Category	
Values of S_{DS}	**I or II or III**	**IV**
$S_{DS} < 0.167$	A	A
$0.167 \leq S_{DS} < 0.33$	B	C
$0.33 \leq S_{DS} < 0.50$	C	D
$0.5 \leq S_{DS}$	D	D

Table 3.8: Seismic design category based on 1-S period response acceleration parameter

Values of S_{D1}	Risk Category	
	I or II or III	IV
$S_{DS} < 0.067$	A	A
$0.067 \leq S_{DS} < 0.133$	B	C
$0.133 \leq S_{DS} < 0.2$	C	D
$0.2 \leq S_{DS}$	D	D

h. **Identifying the importance factor:** In the case of the frames are considered to be designed for residential building, the $I_e = 1$ according to Table 1.5-2 ASCE 7-10.

i. **Select structural system and system parameters:** Once the SDC is already has been found, according to Table 12.2-1 ASCE7-10 special moment resisting frame (SMRF), Special reinforced concrete shear wall (SCSW) and special reinforced concrete shear walls in dual systems are selected. And each design coefficients and factors for seismic force resisting systems are showed in Table 3.9 according Table of 12.2-1 and 12.8-1 ASCE7-10.

Table 3.9: Seismic required information

Seismic force resisting system	Site class	Response modification factor	Over strength factor	Deflection implication factor
SMRF	D	8	3	5.5
SCSW	D	5	2.5	5
Dual system	D	7	2.5	5.5

3.6 Modeling of Some Designed Samples

This section presents the modeling of some designed samples of special moment resisting frame and shear walls frame systems with and without opening which were determined using ETABS-2016.

a. **Special moment resisting frame**

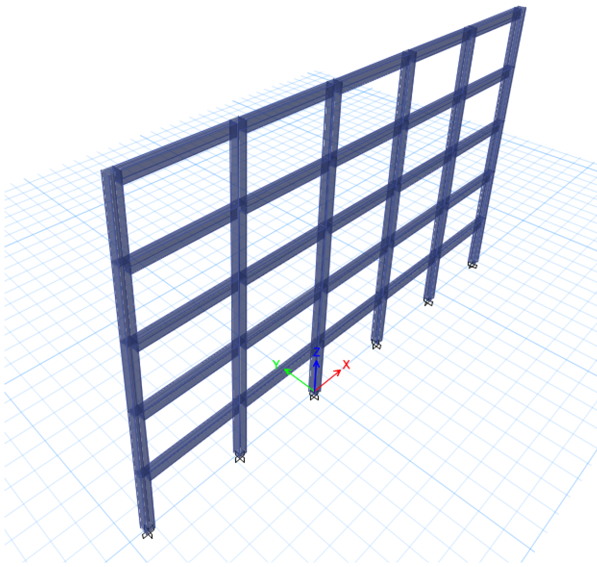


Figure 3.6: Mid-rise Special moment resisting frame

b. **Shear Wall–Frame Systems (Dual system)**

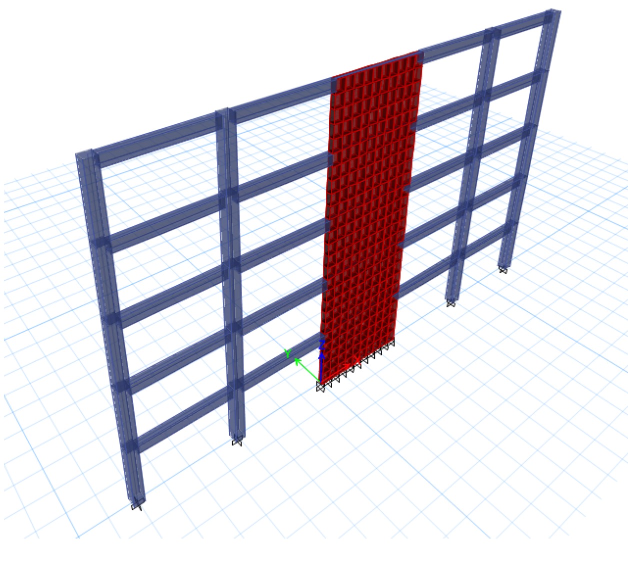


Figure 3. 7: Mid-rise Shear Wall–Frame Systems (Dual system)

c. Shear Wall–Frame Systems (Dual system) with opening

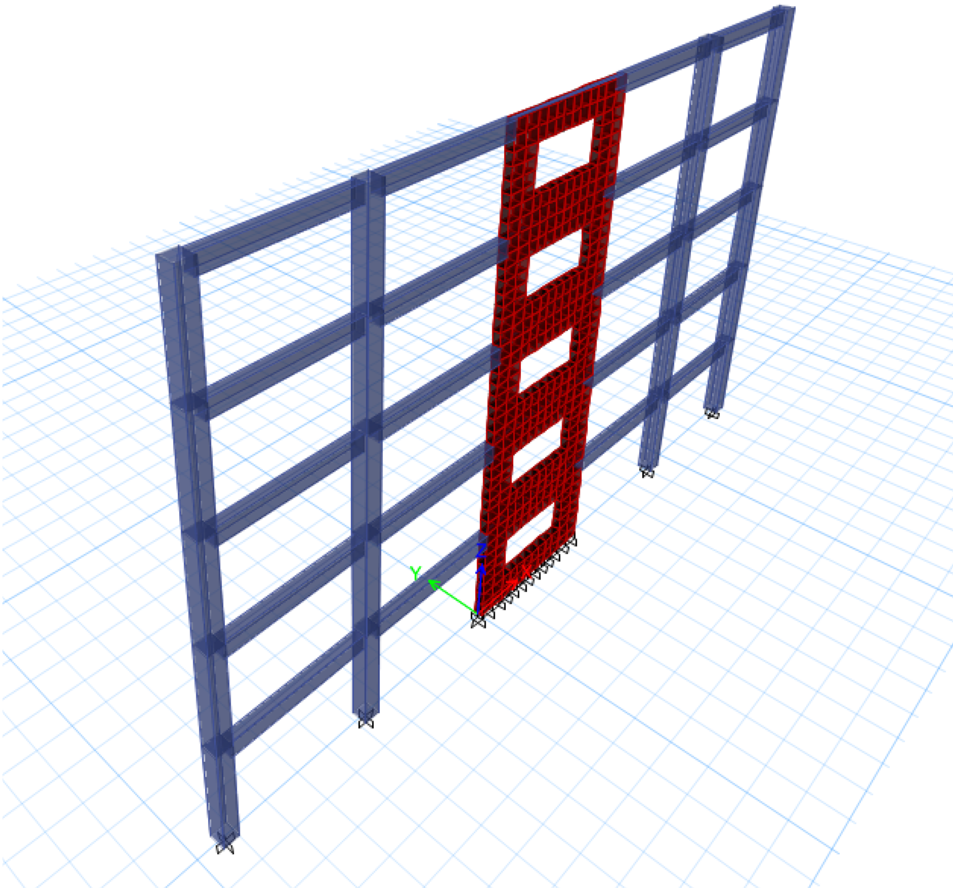


Figure 3.8: Mid-rise Shear Wall–Frame Systems (Dual system) with opening

3.8 Some Samples of Designed Section Considering Different Parameter

a. **Number of spans (N):** The fixed parameters are S = L, L= 5m, H = 3.2 m, $f_c' = 25$ MPa, f_y= 300 MPa, t = 250 mm

Changes in number of spans is one of the factors which affect the steel reinforcement of frames. Figure 3.9 illustrate the influence of number of spans on the area of steel reinforcement of frames and shear without opening.

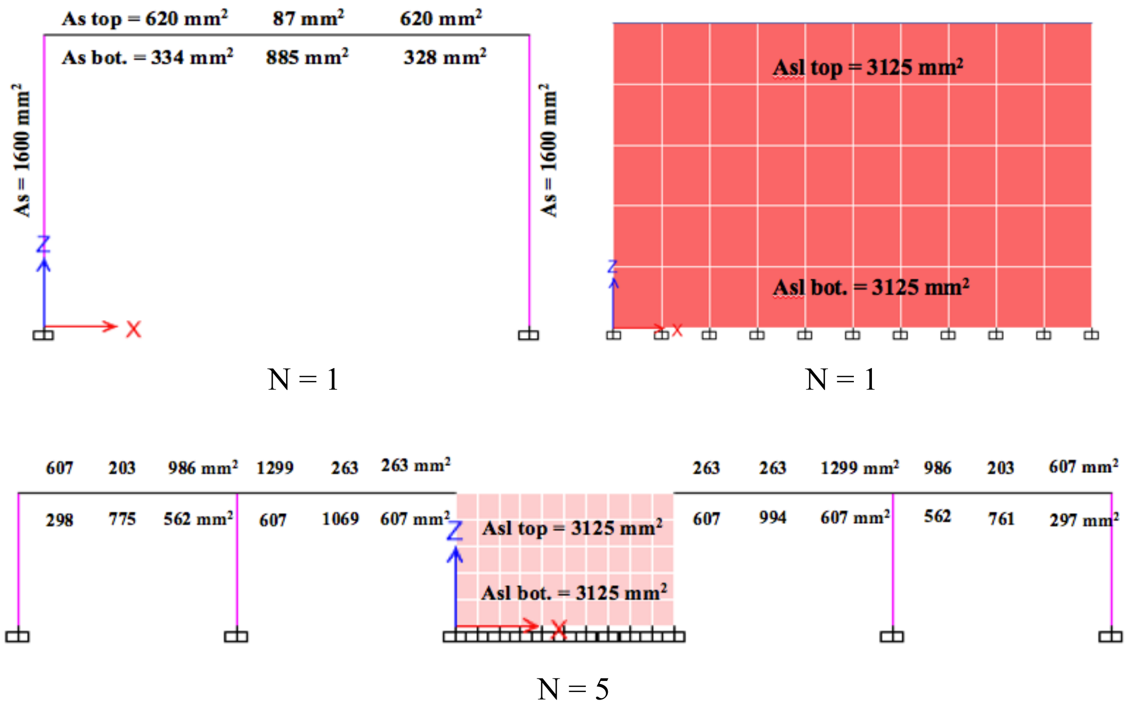


Figure 3.9: The effect of number of spans on the steel reinforcement of frames and shear walls

b. Span lengths (L): The fixed parameters are S = L, N=1, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

Variety in span length is one of the factors which influence the steel reinforcement of frames and shear walls. Figure 3.10 and 3.11 shows the area of steel reinforcement of SMRF and shear walls without opening with different span length.

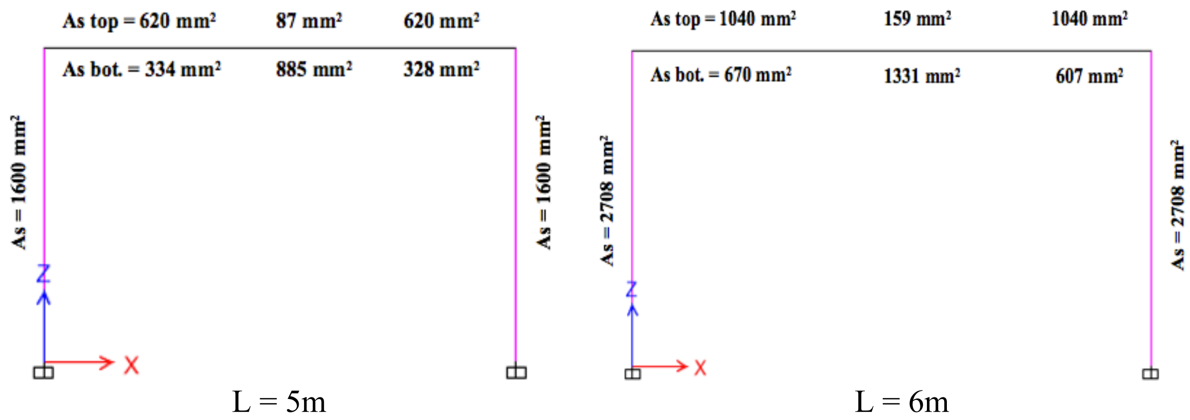


Figure 3.10: The effect of span lengths on the steel reinforcement of frames

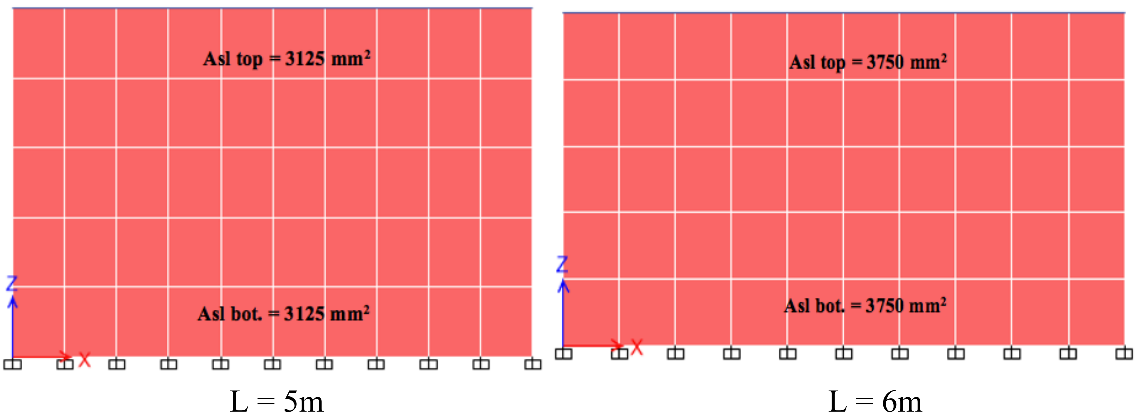


Figure 3.11: The effect of span lengths on the steel reinforcement of shear walls

c. **Story height (H):** The fixed parameters are S = L, N=1, L=5m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

Another factor which affects the steel reinforcement of frames is changing in story height. Figure 3.12 and 3.13 shows the area of steel reinforcement of SMRF and shear walls without opening with different story height.

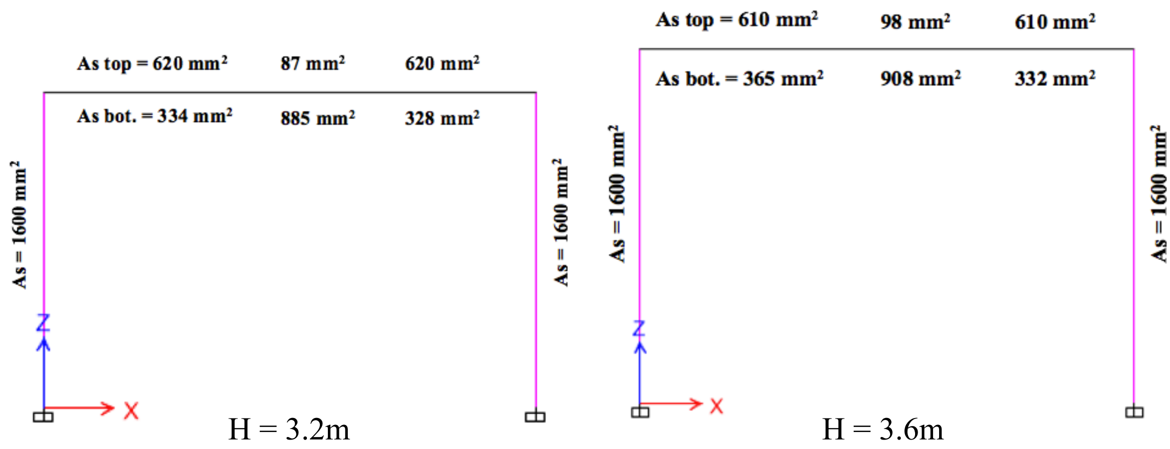


Figure 3. 12: The effect of story height on the steel reinforcement of frames

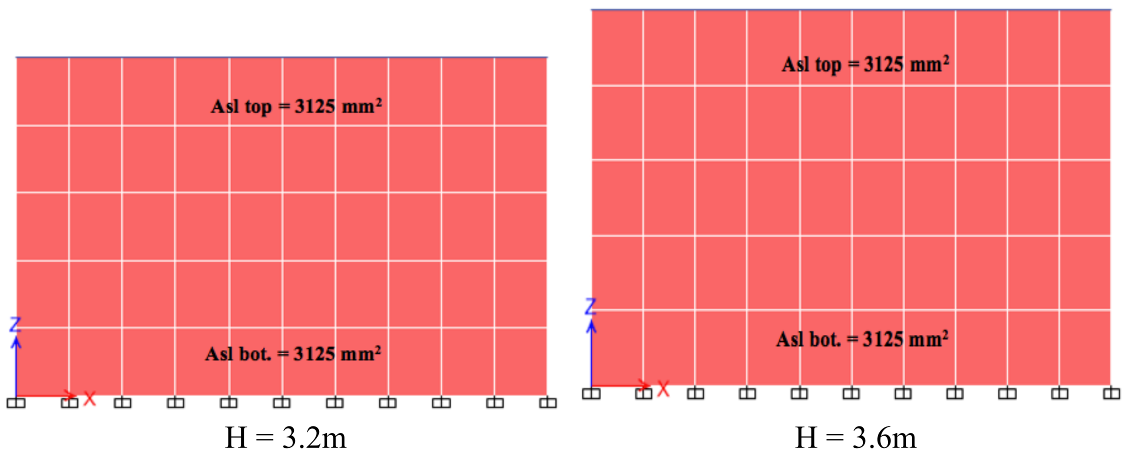
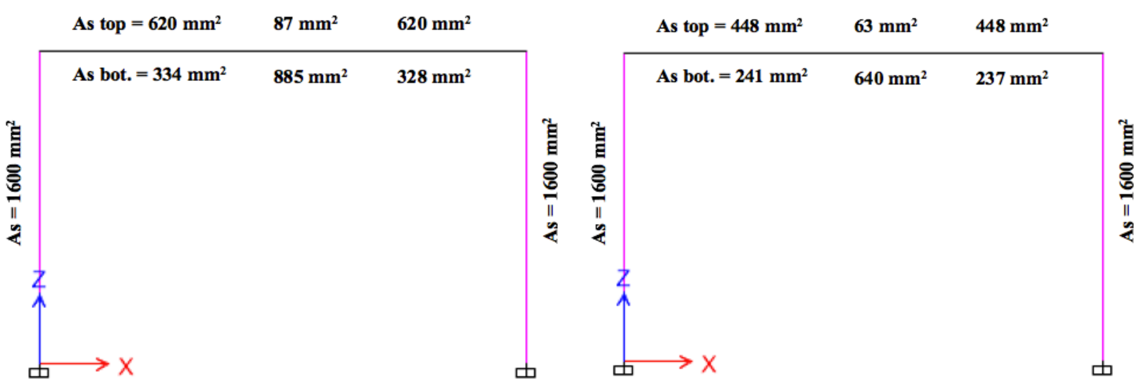


Figure 3. 13: The effect of story height on the steel reinforcement of shear walls

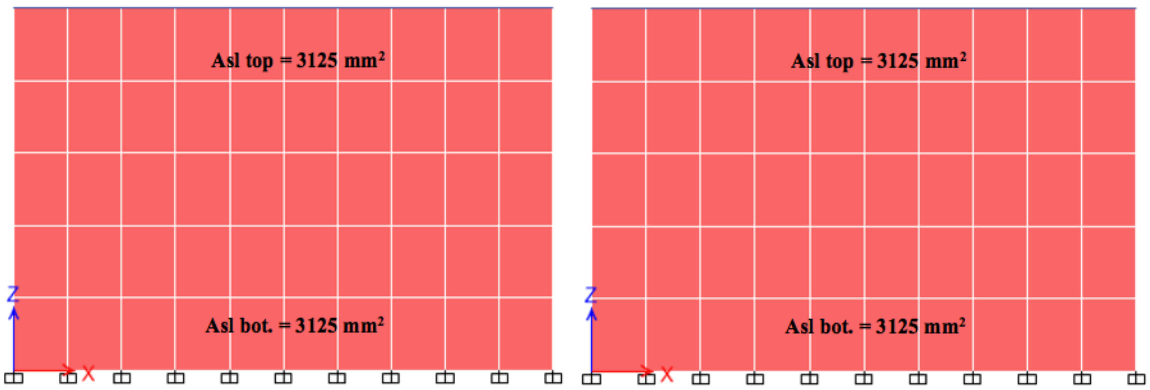
d. **Yield strengths of steel (f_y):** The fixed parameters are S = L, N = 1,H = 3.2, L = 5m, f_c' = 25 MPa, t = 250 mm

The yield strength of steel is one of the factors which influence the steel reinforcement of frames. Figure 3.14 and 3.15 shows the area of steel reinforcement of SMRF and shear walls without opening with different yield strength of steel.



f_y= 300 MPa f_y= 415 MPa

Figure 3. 14: The effect of Yield strength of steel on the steel reinforcement of frames

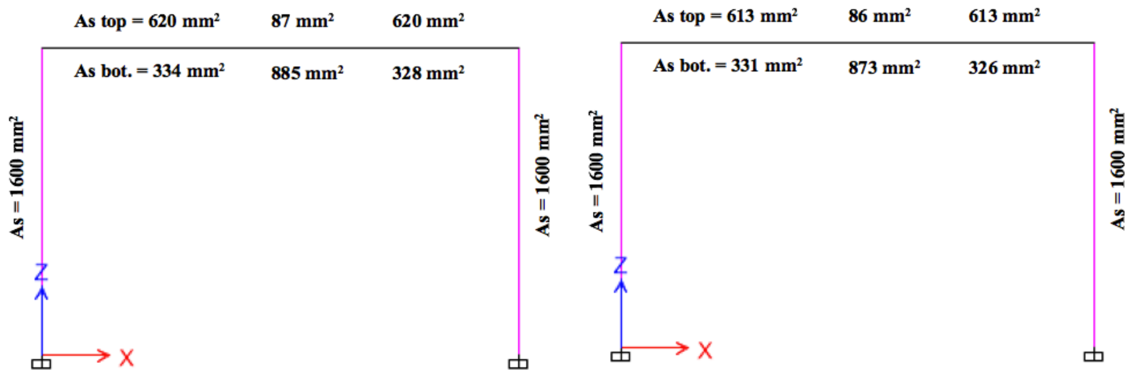


f_y= 300 MPa f_y= 415 MPa

Figure 3. 15: The effect of yield strength of steel on the steel reinforcement of shear walls

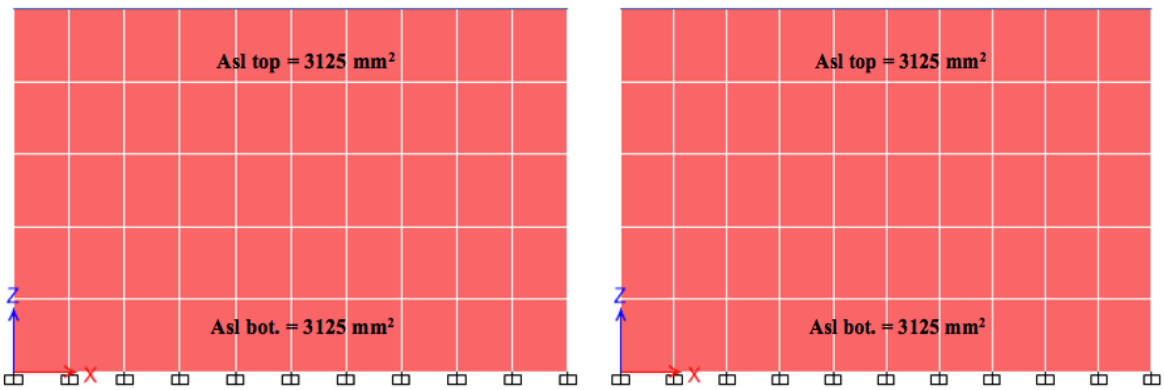
e. Compressive strengths (f'_c): The fixed parameters are S = L, N=1, H = 3.2, L=5m, MPa, f_y= 300 MPa, t = 250 mm

variation in compressive strength of concrete is one of the factors which affect the steel reinforcement of frames. Figure 3.16 and 3.17 shows the area of steel reinforcement of SMRF and shear walls without opening with different compressive strength of concrete.



f'_c = 25 MPa f'_c = 30 MPa

Figure 3. 16: The effect of compressive strength of concrete on the steel reinforcement of frames



f'_c = 25 MPa f'_c = 30 MPa

Figure 3. 17: The effect of compressive strength of concrete on the steel reinforcement of shear walls

f. **Thickness of shear walls (t):** The fixed parameters are S = L, N=1, H = 3.2, L=5m, f_c' = 25 MPa, f_y= 300 MPa

Any increment in the shear wall thickness it leads to an increase in the steel reinforcement of shear walls. Figure 3.18 shows the effect of thickness of shear walls on the steel reinforcement of shear walls.

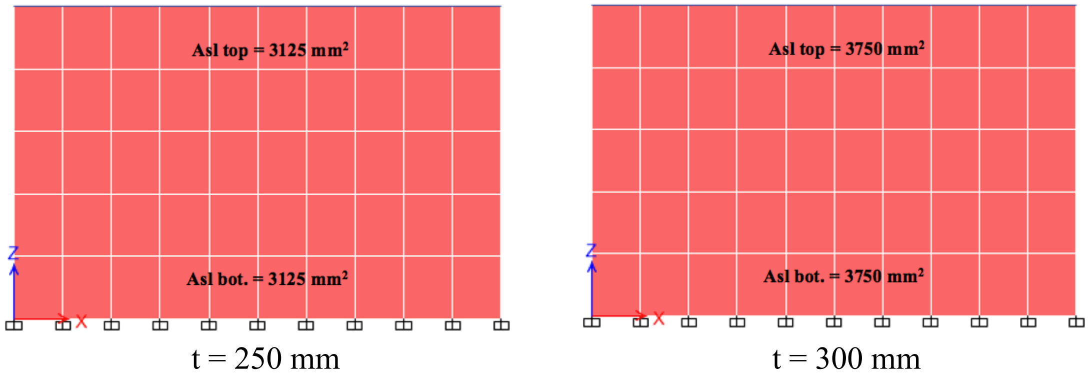


Figure 3. 18: The effect of thickness of shear walls on the steel reinforcement of shear walls

g. **Shear wall with opening:** The fixed parameters are S = L, N=1, H = 3.2, L=5m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm. Figure 3.19 demonstrates the influence of opening on the steel reinforcement of shear walls.

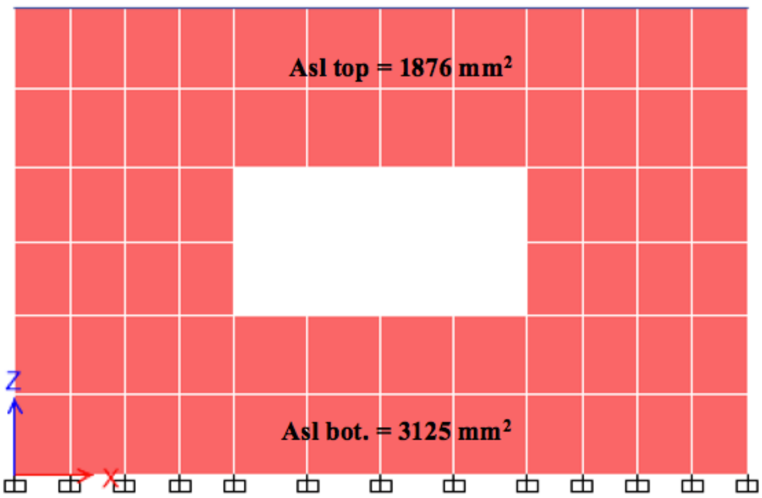
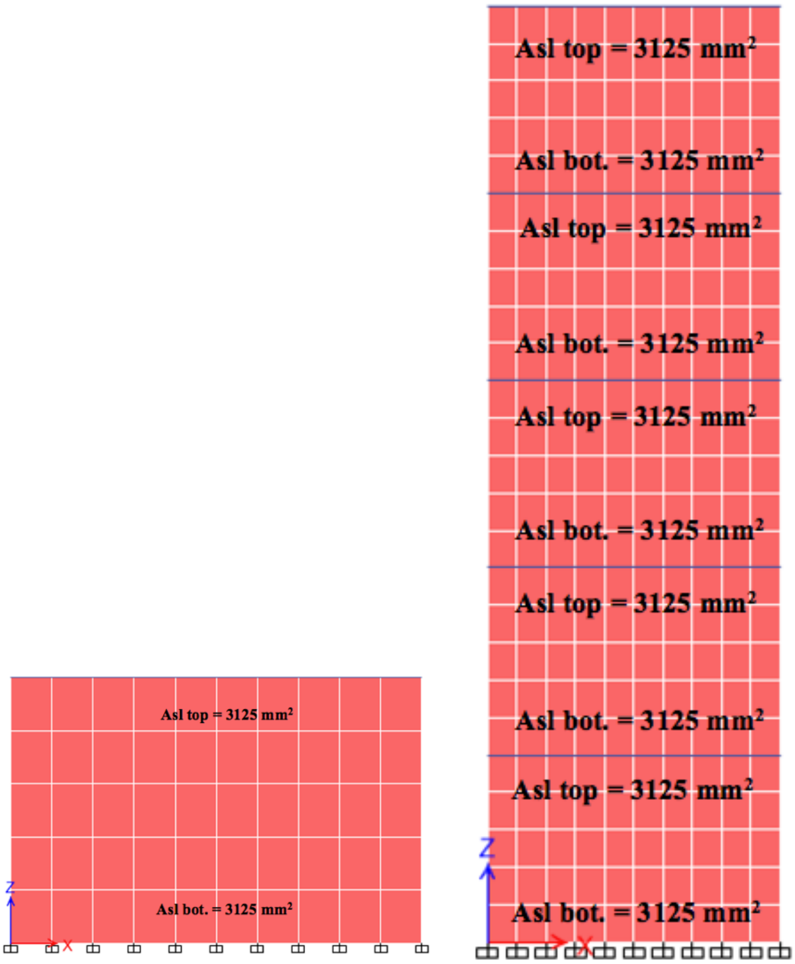


Figure 3. 19: The effect of opening on the steel reinforcement of shear walls

h. **Number of stories (S):** The fixed parameters are N=1, H = 3.2, L=5m, $f_c' = 25$ MPa, f_y= 300 MPa, t = 250 mm. Figure 3.20 determines the effect of number of stories on the steel reinforcement of shear walls.



S = 1 (Low-rise) S = 5 (Mid-rise)

Figure 3. 20: The effect of number of stories on the steel reinforcement of shear walls

3.9 Pushover Analysis

When the buildings are facing earthquake, then we will find an inelastic building behavior, in this circumstance it is important to employ an inelastic nonlinear analysis at the time the behavior comes with seismic evaluation for reinforced concrete buildings. The pushover analysis is also known as nonlinear static procedure (NSP), which is the common inelastic method because of the accurateness and simplicity. Upcoming sections demonstrate the pushover analysis, furthermore illustrating the method's disadvantages and advantages, also procedures for implementing pushover analysis.

3.9.1 Description of pushover analysis

This method comprises a sequence of elastic analysis, overlaid to about a force-displacements curve of the complete structure. Trilinear or bilinear are some dimensional model of load-deformation diagrams of all lateral force resisting factor is initially designed and gravity loads are implemented firstly. A predefined lateral load pattern is then applied that is distributed over the height of the building. At the time member's yield, then the lateral forces will improve and increase. The structural model is adapted and changed in order enable to apply for decreased stiffness and when more members' yield then the lateral force will improve and increase accordingly. According to Oguz. (2005) when the control displacements get to the higher level of deformation then the process will be ended, which means that process will keep continue till reach that point and the structure becomes unstable. The Non-linear Static analysis (Pushover analysis) is recommended by Applied Technical Council and Federal Emergency Management Agency, based on ATC-40, FEMA-273 and FEMA-356. Sometimes displacements controlled or force controlled can be known as pushover analysis. Usually, pushover analysis is implemented as displacement-controlled, in the displacement- controlled procedure the magnitude of applied load is not known. The magnitude of load is increased or decreased until the control displacement reaches a specified value. But force- controlled procedure should be used when the load is known (such as gravity loading).

3.9.2 Purpose of pushover analysis

According to Ismail, A. (2014), the pushover analysis aims to assess the estimated structure's performance through approximating the demand of deformation and strength through inelastic analysis, also comparison of this demand with obtainable capacities at the performance levels.

Furthermore, as per Mouzzoun et al. (2013), illustrated pushover analysis's characteristics as follow:

1. In order to evaluate the structural performance of retrofitted or existing buildings.
2. Identifying forces for the member's' demands, for instance moment demands on beam-column connections and axial force demands on columns.
3. At the ultimate load shows the allocation of plastic hinges. And ductility and maximum rotation of critical members.
4. Shows the allocation of damage in the building.
5. It is used as a substitute to the design based on linear analysis.
6. The structure's capability as provided by the base shear versus roof- displacement graph.
7. Estimations of inter-story drifts and its distribution along the height.

3.9.3 Advantages of pushover analysis

Khan and Vyawahare, (2013), demonstrated and found the following pushover analysis's advantages:

1. Dose not need selection and scaling of ground motion.
2. It allows us to examine the consecutive formation of plastic hinges in the separate structural elements constituting the entire structure.
3. It permits us to assess whole performance characteristics and structural behaviors.

3.10 Implementation of Pushover Analysis with ETABs-2016

One of the common programs of nonlinear and linear analysis of structures is ETABS-2016. This software offers an influential aspect for performing pushover analysis based on different types of codes and procedures. Therefore, this software utilized in the application of pushover analysis which will be explained and demonstrated in the upcoming sections.

3.10.1 Performance point

The performance point is the place that capability of spectrum crosses the suitable demand spectrum. Usually, it is taken into consideration to design point of forces in order to achieve the required performance of the structure. Building performance is the combined performance of both structural and non-structural components of the building, Figure 3.21 shows the performance levels and damage functions. In order to describe of the building performance applying the pushover analysis, many various level of performance will be applied as we can see in the following section:

- **Operational level (OL):**

In this performance level building are expected no permanent damages and structure sustains the main stiffness and strength. The main cracking is viewed in partition ceilings and walls also in the structural elements.

- **Immediate occupancy (IO):**

In this performance level building are expected no drift and structure retains original strength and stiffness. Fire protection is operable, elevators can be restarted and minor cracking in partition walls is observed.

- **Life Safety (LS):**

In this level some stiffness and residual strength is left available in the structure. The building is beyond economical repair and few drift might be found along with few damages to the building and walls.

- **Collapse prevention (CP):**

Usually buildings have some stiffness and residual strength when it's meeting this performance level. At this level the building remains in collapse level.

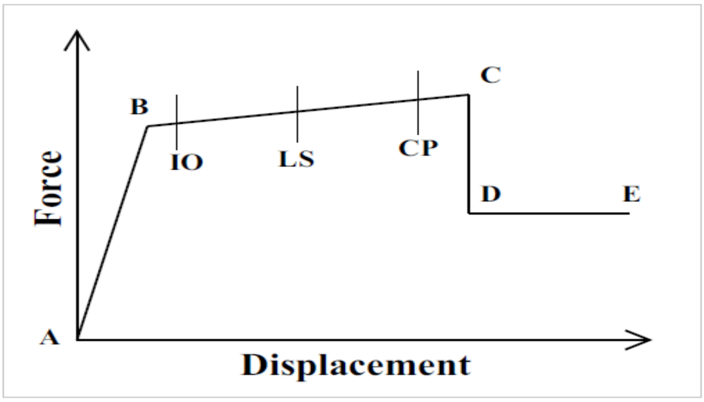


Figure 3. 21: Performance levels and damage functions (Shelke. et. al 2017)

3.10.2 Plastic hinge

The plastic hinge is the location of structural member's inelastic action. When the buildings are facing the earthquake the maximum moments occur near the ends of the beams and columns, in this case the plastic hinge is mostly will be design there and it is highly needed for ductility to be implemented.

It is significant that wall materials and frame be created, for instance reinforcement could be determined for walls and concrete frames, before starting the running of a nonlinear analysis using hinges. ETABs has three types of hinges as follow:

- Program Generated Hinge Properties.
- User-Defined Hinge Properties.
- Auto Hinge Properties.

In this study implemented an auto hinge property to analyze the current study.

3.10.3 Pushover analysis procedure in ETABS-2016

The following steps are the procedure of pushover analysis used in this study to find elastic stiffness factor, natural time period and maximum base shear of all the samples by using ETABS-2016:

1. Create a two dimensional model of the structure. Shear walls are modeled as shell elements and Beams and column are modeled as line objects.
2. Define dead load and live load then assign these loads to the structure.
3. Define a load case of seismic loads, it is defined for X direction.
4. Using auto load combinations then design the structure by linear analysis.
5. Once the building's design is completed then unlock the model.
6. Identify a nonlinear static load case for gravity loads containing of portion of live load and dead load.
7. Define the pushover load case (nonlinear static load case).

This case could endure from state at end of the nonlinear gravity load case. The load used to this load case is the pre-defined seismic load case. This load case requires to be used as displacements- controlled case. This load case includes the seismic loads that will push the building to the target displacement.

8. Define hinge properties and then assign it to model elements.
9. Run the analysis.
10. Review the pushover analysis results.

Once the procedure of pushover analysis is completed, a curve is drawn which is called pushover curve Figure 3.22 shows pushover curve, pushover curve is used to find the Elastic stiffness factor, natural time period and maximum base shear of the models as follows.

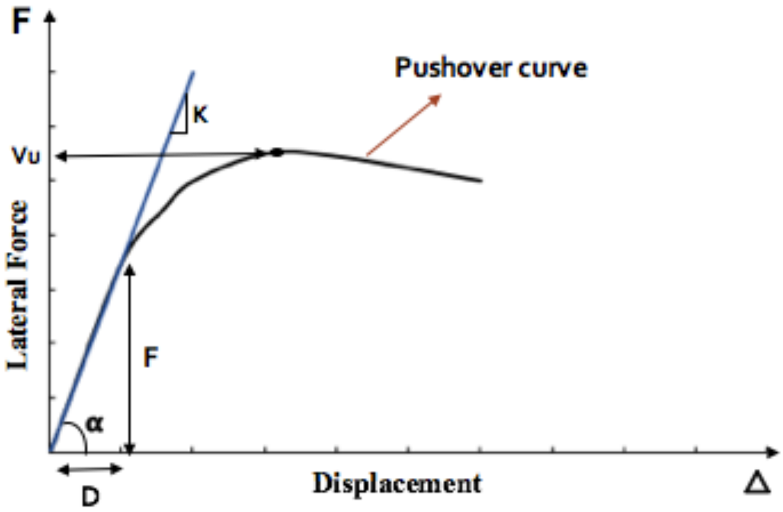


Figure 3. 22: Pushover Curve

(Vu) = Maximum base shear

Tanα = $\frac{F}{D}$

Tanα = stiffness (K)

So

$$K = \frac{F}{D} \quad kN/m \tag{3.5}$$

Where:
F = First significance yield strength (first hinge formation)
D = Displacement at first plastic hinge formation
Ki = Elastic stiffness factor
All the results are found using above methods

$$T = 2\pi\sqrt{\frac{m}{k}} \tag{3.6}$$

Where:
m = Gravity loads composed of dead loads and a specified portion of 25% live loads
k = Elastic stiffness factor
T = Natural time period.

CHAPTER 4
RESULTS AND DISCUSSION

This chapter consist of results and discussion of 2D reinforced concrete frame and shear walls with and without opening that are analyzed based on parametric study in the previous chapter. The results include elastic stiffness factor, natural time period and maximum base shear, these results are utilized to probe the effect of seven factors on the responsiveness of the special moment resisting frame and shear wall without and with opening. The factors considered in this thesis are (different sizes of openings, span length, number of spans, compressive strength of concrete, number of stories, story height, yield strength of steel and thickness of shear wall). This chapter is made up of six sections; section one shows the effect of the results on the elastic stiffness factor by these seven factors, second part demonstrates the effect of the results of these factors on the natural time period, third section shows the effect of the results these seven factor on the maximum base shear, fourth section shows the summary of factor affecting on the elastic stiffness factor, natural time period and maximum base shear of the SMRF and shear wall without and with opening, fifth section demonstrates the effect of the results of horizontal and vertical opening in shear wall and last section shows the result of pushover curve of special moment resisting frame and shear wall without and with opening. And the symbols used in the graphs and tables are clarified below.

SMRF: Special moment resisting frame

SW: shear wall

O: Opening

S: Number of stories

N: Number of spans

H: story height

L: Span length

f_c': Compressive strength of concrete

f_y: Yield strength of steel

t: Thickness of shear wall

4.1 Factors Affecting on the Elastic stiffness factor

This section presents the effect of the results of different sizes of openings, span length, number of spans, compressive strength of concrete, number of stories, story height, yield strength of steel and thickness of shear wall on the elastic stiffness factor.

4.1.1 The effect of different opening sizes of shear walls on the elastic stiffness factor of the reinforced concrete frames

Opening is one of the factors which affects the stiffness of shear walls because it reduces the total area of a wall. Due to opening, the moment of inertia is not the same throughout the whole height of the shear wall. Figure 4.1 shows the average elastic stiffness factor of special moment resisting frame and shear wall without and with opening, from the graphs it can be seen that after inserting the shear walls without and with openings into the system the elastic stiffness factor of the frames is increased compared to special moment resisting frame. As noted in Figure 4.1, it was found when the area of the openings increases the elastic stiffness factor is decreased in comparison to the shear wall without openings. Figure 4.2 shows the elastic stiffness factor of shear wall without openings is approximately 61 times larger than the special moment resisting frame.

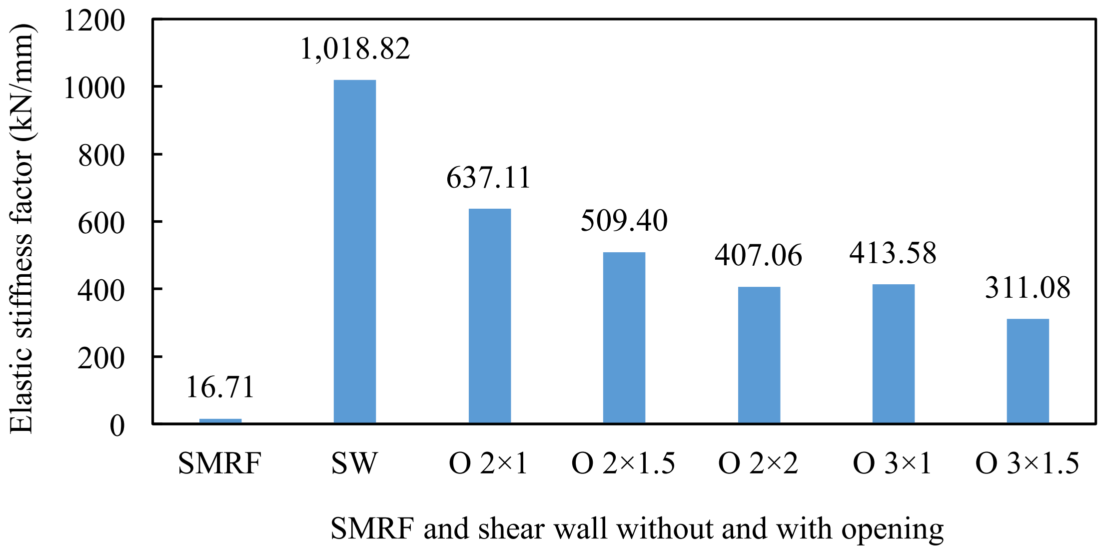


Figure 4. 1: Average elastic stiffness factor of SMRF and Shear wall with and without opening

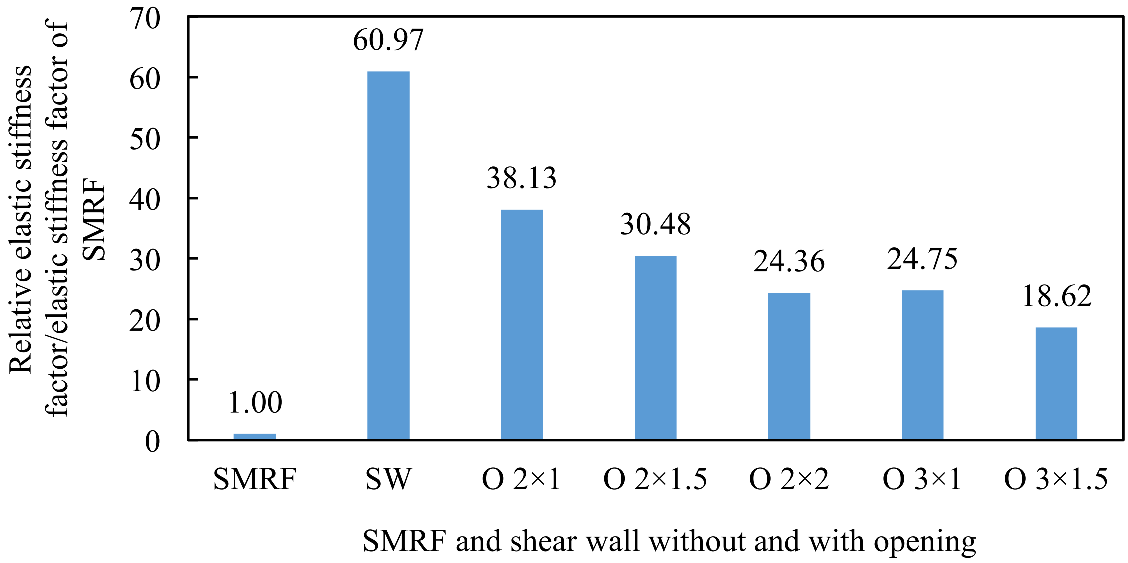


Figure 4. 2: Comparison of elastic stiffness factors of shear walls with and without opening with respect to SMRF

4.1.2 The effect of span length on the elastic stiffness factor of SMRF and shear walls with different sizes of opening

Variety in span length is one of the factors which influence the stiffness and seismic performance of shear walls. Changes in the span length could have an important impact on the weight of the shear walls. Consequently, any change in the length of the span leads to a decrease or increase in the stiffness of the shear walls. Figure 4.3 and Table 4.1 shows the elastic stiffness factor of SMRF and shear wall without and with opening with different span length. As it can be seen in the Figure 4.3 and Table 4.1, it is observed that after increasing span length for all type of the models from 5 m to 6 m the elastic stiffness factor for shear walls without and with opening also increased. But, the elastic stiffness factor of SMRF decreased by increasing the span length. From the table it is seen that SMRF has the lowest elastic stiffness factor, and shear wall without opening has highest elastic stiffness factor.

Assuming fixed parameters for Figure 4.3 and Table 4.1 are S = L, N = 1, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

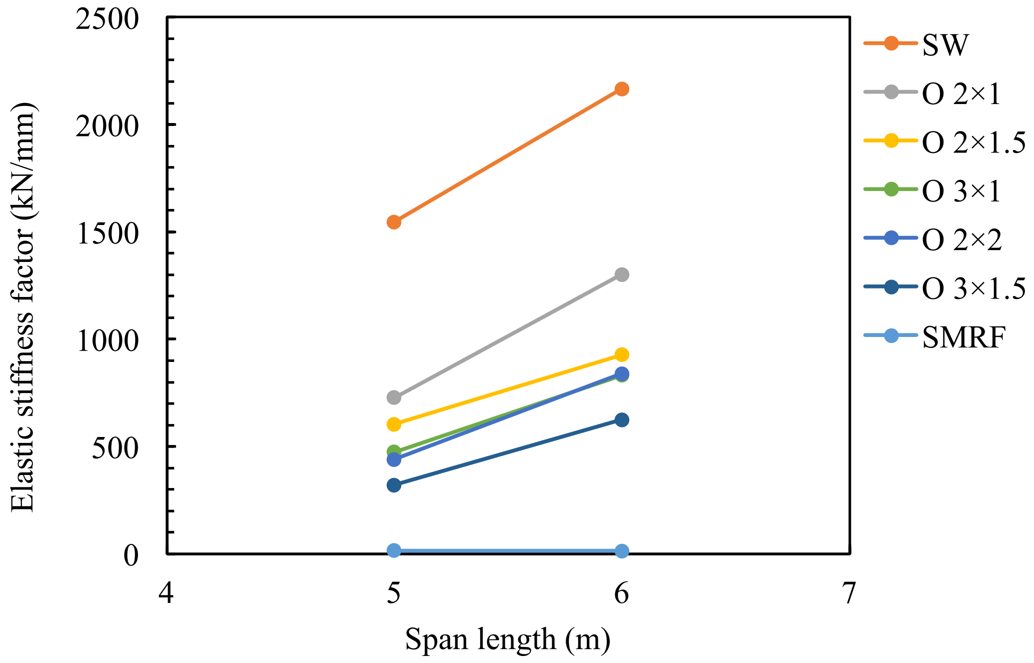


Figure 4. 3: The elastic stiffness factor of SMRF and shear wall without and with opening with different span length

Table 4. 1: Results of elastic stiffness factor of SMRF and shear wall without and with opening with different span length

	Span length	
Framing types	**5 m**	**6 m**
SMRF	15.1751	14.0995
SW	1545.6218	2167.1228
O 2×1	728.0079	1301.4986
O 2×1.5	604.0553	928.0468
O 2×2	440.5275	840.0776
O 3×1	474.1380	831.8626
O 3×1.5	320.4809	624.9517

4.1.3 The effect of number of spans on the elastic stiffness factor of SMRF and shear walls with different sizes of opening

Changes in number of spans is one of the factors which affect the stiffness and seismic performance of shear walls. Any alteration in the number of the span leads to a reduction or an increase in the lateral stiffness of the shear walls. Figure 4.4 and Table 4.2 illustrates the elastic stiffness factor of SMRF frame and shear wall without and with opening with different number of spans. The results reveal that after inserting the shear wall to the system the stiffness of the frames ascended, but when the number of spans increasing from (1) to (5) the stiffness of the shear wall without opening is reduced. For the shear walls with opening and SMRF the elastic stiffness factor ascended with increasing the number of spans.

Assuming fixed parameters for Figure 4.4 and Table 4.2 are S = L, L = 5, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

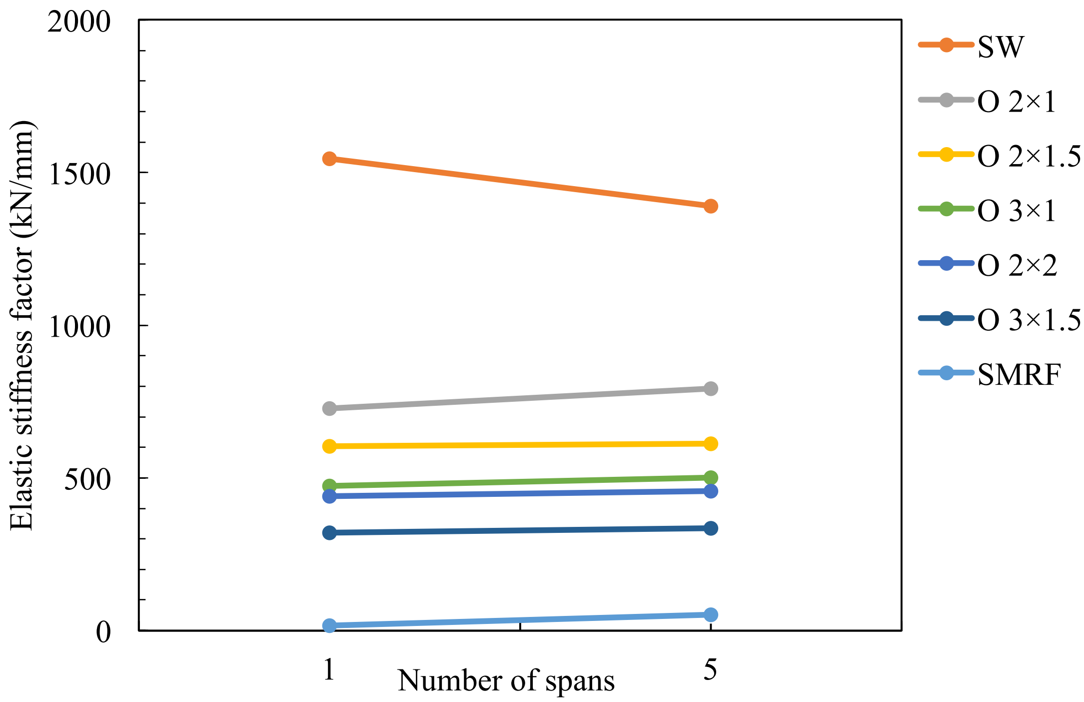


Figure 4. 4: The elastic stiffness factor of SMRF and shear wall without and with opening with different number of spans

Table 4. 2: Results of elastic stiffness factor of SMRF and shear wall without and with opening with different number of spans

	Number of span	
Framing types	**1**	**5**
SMRF	15.1751	50.7595
SW	1545.6218	1389.510
O 2×1	728.0079	793.134
O 2×1.5	604.0553	611.610
O 2×2	440.5275	455.893
O 3×1	474.1380	500.388
O 3×1.5	320.4809	334.9363

4.1.4 The effect of number of stories on the elastic stiffness factor of SMRF and shear walls with different sizes of opening

Variety in number of stories is one of the factor which impact the stiffness of the building. Changes in the number of stories could have unfavorable effect on the stiffness of the SMRF and shear walls. Therefore, any increasing in the number of stories leads to increases the deflection of the structure and decreases lateral stiffness. Figure 4.5 and Table 4.3 illustrates the elastic stiffness factor of SMRF and shear wall without and with opening with different number of stories. As it can be seen in the Figure 4.5 and Table 4.3, the results show that after increasing number of stories for SMRF and shear walls with and without opening from low-rise to mid-rise the elastic stiffness factor is decreased.

Assuming fixed parameters for Figure 4.5 and Table 4.3 are N=1, L = 5, H = 3.2 m, $f_c' =$ 25 MPa, f_y= 300 MPa, t = 250 mm

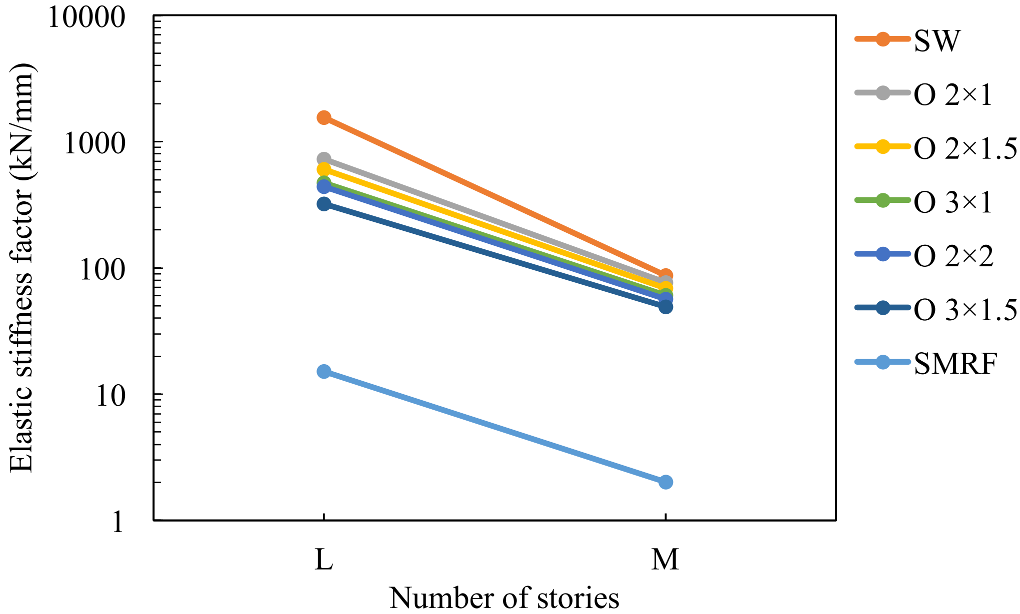


Figure 4. 5: The elastic stiffness factor of SMRF and shear wall without and with opening with different number of stories

Table 4. 3: Results of elastic stiffness factor of SMRF and shear wall without and with opening with different number of stories

	Number of stories	
Framing types	**Low-rise**	**Mid-rise**
SMRF	15.1751	2.011
SW	1545.6218	86.868
O 2×1	728.0079	76.190
O 2×1.5	604.0553	68.671
O 2×2	440.5275	56.563
O 3×1	474.138	60.618
O 3×1.5	320.4809	48.9126

4.1.5 The effect of story height on the elastic stiffness factor of SMRF and shear walls with different sizes of opening

Another factor which affects the stiffness and seismic performance of shear wall is changing in story height. Changes in the story height could have a negative effect on the stiffness of the SMRF and shear walls. So that, any increasing in the story height it leads to increases the deflection of the structure and reduces elastic stiffness factor. The elastic stiffness factor of SMRF and shear wall with and without opening with different story height are shown in Figure 4.6 and Table 4.4. The results demonstrate that after increasing the story height for SMRF and shear walls without and with opening from 3.2 m to 3.6 m the elastic stiffness factor gradually decreasing.

Assuming fixed parameters for Figure 4.6 and Table 4.4 are S=L, N=5, L = 5, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

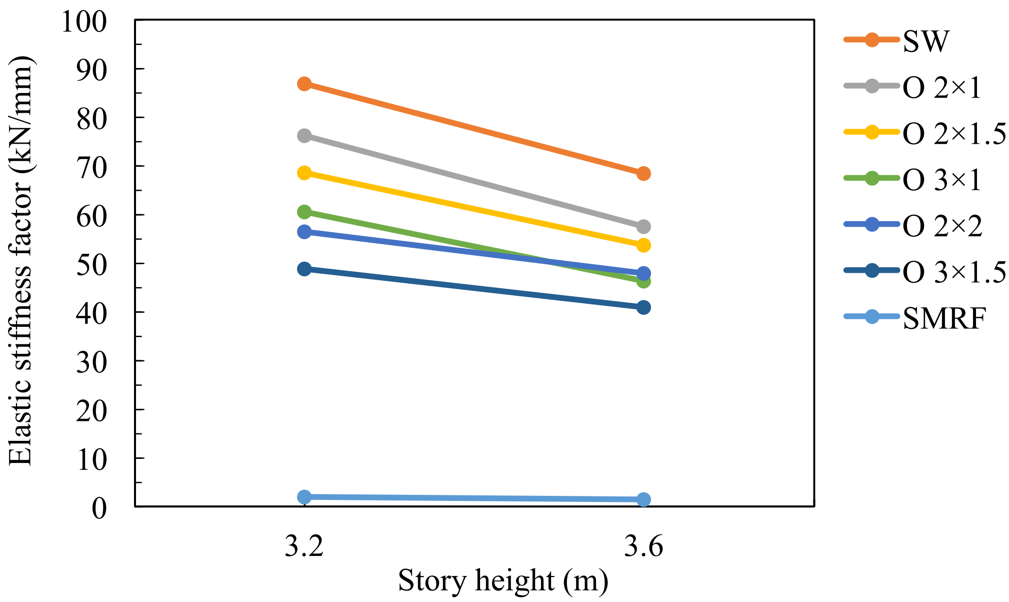


Figure 4. 6: The elastic stiffness factor of SMRF and Shear wall without and with opening with different story height

Table 4. 4: Results of elastic stiffness factor of SMRF and Shear wall without and with opening with different story height

	Story height	
Framing types	**3.2m**	**3.6m**
SMRF	2.011	1.523
SW	86.868	68.442
O 2×1	76.19	57.536
O 2×1.5	68.671	53.726
O 2×2	56.563	47.892
O 3×1	60.618	46.398
O 3×1.5	48.912614	40.988237

4.1.6 Effect of different compressive strength of concrete on the elastic stiffness factor of SMRF and shear walls with different sizes of opening

Change in compressive strength of concrete is one of the factors which affect the stiffness and seismic performance of shear wall. Consequently, any change in the compressive strength of concrete decreases or increases the elastic stiffness factor of the shear walls. Figure 4.7 shows the elastic stiffness factor of SMRF and shear wall without and with opening with different compressive strength of concrete, and Table 4.5 shows the results of elastic stiffness factor of SMRF and shear wall without and with opening with different compressive strength of concrete. According to the Figure 4.7 and Table 4.5, the elastic stiffness factor of SMRF and shear walls with and without opening ascended by increasing the compressive strength of concrete from 25 MPa to 30 MPa. So, as the compressive strength of concrete increases, rigidity and stiffness of the structure is likely to increase.

Assuming fixed parameters for Figure 4.7 and Table 4.5 are S = L, N = 1, H = 3.2 m, L = 5, f_y= 300 MPa, t = 250 mm

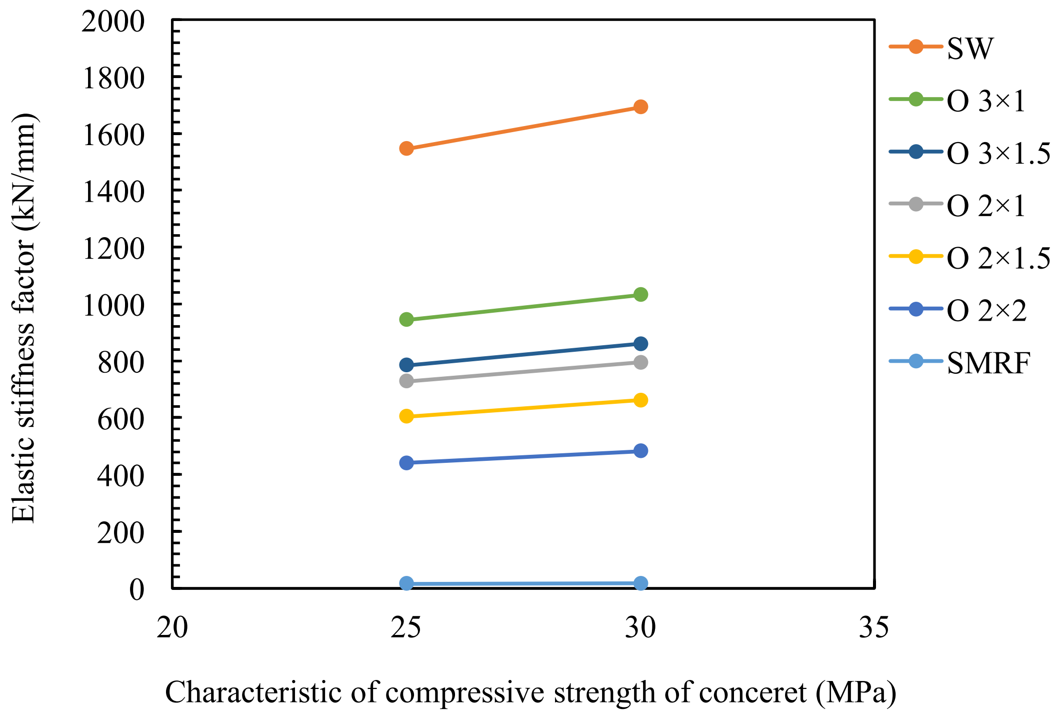


Figure 4. 7: The elastic stiffness factor of SMRF and Shear wall without and with opening with different compressive strength of concrete

Table 4. 5: Results of elastic stiffness factor of SMRF and Shear wall without and with opening with different compressive strength of concrete

	Compressive strength of concrete	
Framing types	**25 MPa**	**30 MPa**
SMRF	15.1751	16.6308
SW	1545.6218	1692.2091
O 2×1	728.0079	794.4539
O 2×1.5	604.0553	661.584
O 2×2	440.5275	482.2733
O 3×1	943.6026	1031.4132
O 3×1.5	784.3720	859.8389

4.1.7 Effect of change yield strength of steel on the elastic stiffness factor of SMRF and shear walls with different sizes of opening

The yield strength of steel is one of the factors which does not have any notable effects on the elastic stiffness factor of SMRF and shear wall. So, any change in the yield strength of steel either leads to small changes or remained the same in the lateral stiffness of the SMRF and shear walls without and with opening. Figure 4.8 and Table 4.6, indicates the elastic stiffness factor of SMRF and shear wall without and with opening with different yield strength of steel. The results demonstrate that the elastic stiffness factor of SMRF and shear walls without and with opening are approximately remained the same by increasing the yield strength of steel from 300 MPa to 415 MPa.

Assuming fixed parameters of Figure 4.8 and Table 4.6 are S = L, N = 1, H = 3.2 m, $f_c' =$ 250 MPa, L = 5, t = 250 mm

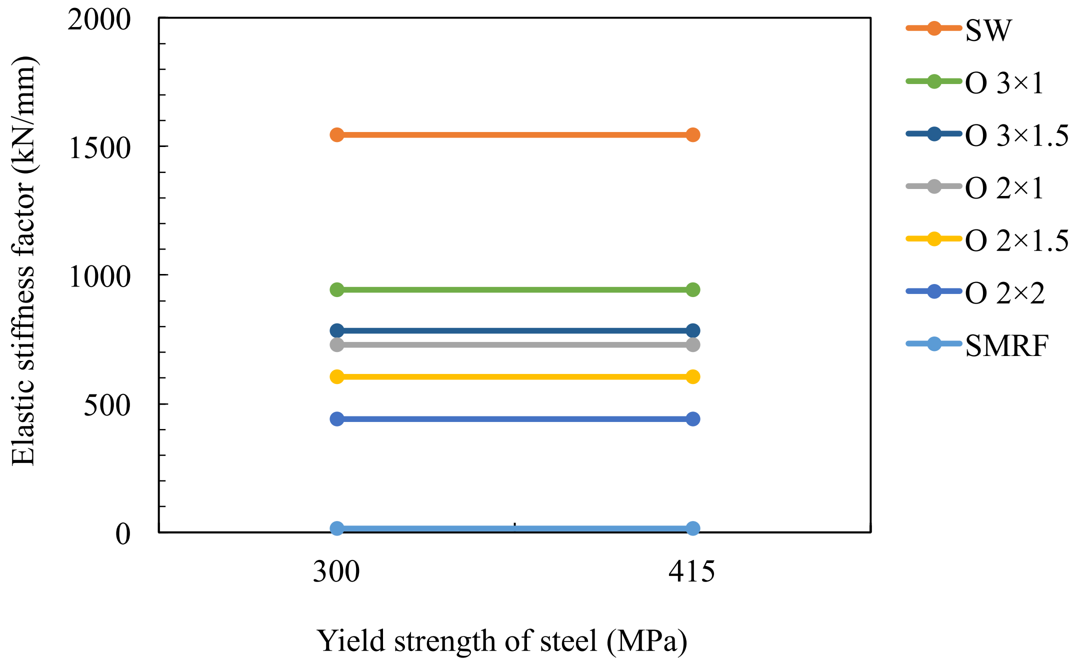


Figure 4. 8: The elastic stiffness factor of SMRF and Shear wall without and with opening with different yield strength of steel

Table 4. 6: Results of elastic stiffness factor of SMRF and Shear wall without and with opening with different yield strength of steel

	Yield strength of steel	
Framing types	**300 MPa**	**415 MPa**
SMRF	15.1751	15.1863
SW	1545.6218	1545.622
O 2×1	728.0079	728.008
O 2×1.5	604.0553	604.055
O 2×2	440.5275	440.528
O 3×1	943.6026	943.603
O 3×1.5	784.3720	784.3720

4.1.8 Effect of different shear wall thickness on the elastic stiffness factor of the shear walls with different sizes of opening

Changes in shear wall thickness are one of the factors which affect the stiffness and seismic performance of shear wall. So, any increasing in the shear wall thickness increases the lateral stiffness of shear wall without and with opening. Figure 4.9 and Table 4.7 illustrates the elastic stiffness factor of SMRF and shear wall without and with opening with different thicknesses. According to the Figure 4.9 and Table 4.7, the elastic stiffness factor of shear walls without and with opening increased by increasing thickness of shear wall from 250 mm to 300 mm.

Assuming fixed parameters for Figure 4.9 and Table 4.7 are S = L, N = 1, H = 3.2 m, f_c' = 250 MPa, f_y= 300 MPa, L = 5

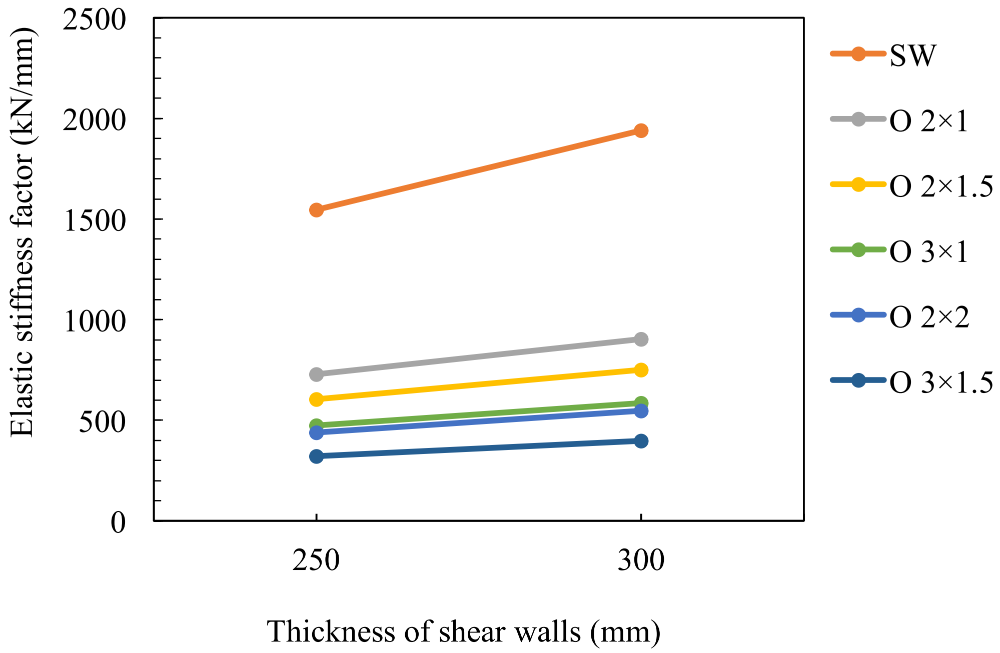


Figure 4. 9: The elastic stiffness factor of shear walls with and without opening with different thickness

Table 4. 7: Results of elastic stiffness factor of shear walls with and without opening with different thickness

Framing types	Thickness of shear wall	
	250 mm	**300 mm**
SW	1545.622	1941.849
O 2×1	728.008	904.060
O 2×1.5	604.055	751.803
O 2×2	440.528	546.547
O 3×1	474.138	585.809
O 3×1.5	320.481	397.609

4.2 Factors Affecting on the Natural time period

This section shows the effect of the results of different sizes of openings, span length, compressive strength of concrete, number of spans, number of stories, story height, yield strength of steel and thickness of shear wall on the natural time period.

4.2.1 The effect of different opening sizes of shear walls on the natural time period of the reinforced concrete frames

Natural time period is related with the stiffness, and opening can affect the total stiffness since opening is one of the factors which affect the natural time period of shear wall because it reduces the total area of a wall. Due to opening, the moment of inertia is not the same throughout the whole height of the shear wall. Figure 4.10 demonstrates the average natural time period of SMRF and Shear wall without and with opening, from the graphs it seen that after inserting the shear walls without and with openings to the system the natural time period of the frames is reduced compared to SMRF. Using Figure 4.10, it is found when the area of the openings increases the natural time period is increased in comparison to the shear wall without openings. According to figure 4.11, the natural time period of shear wall without openings is approximately 0.18 times smaller than the natural time period of SMRF.

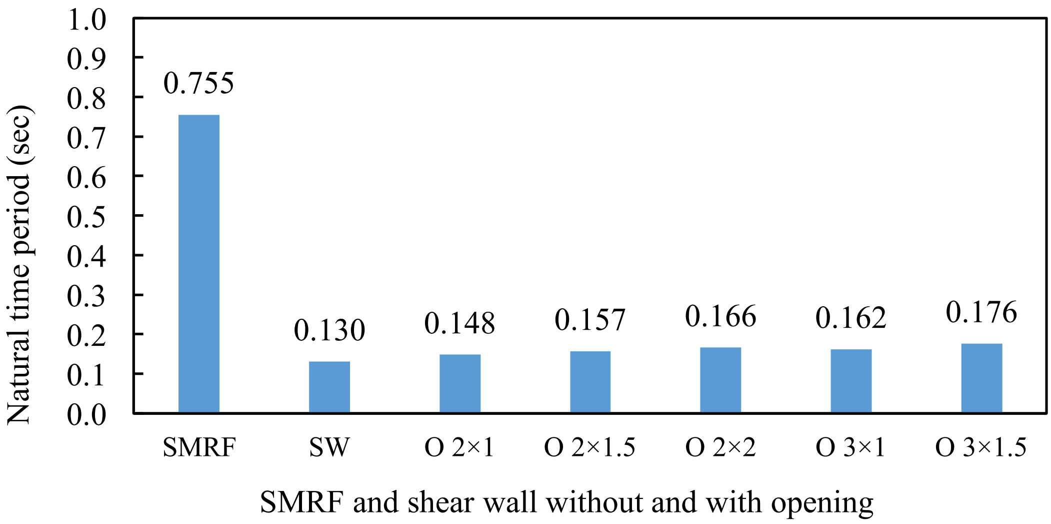


Figure 4. 10: Average natural time period of SMRF and shear wall without and with opening

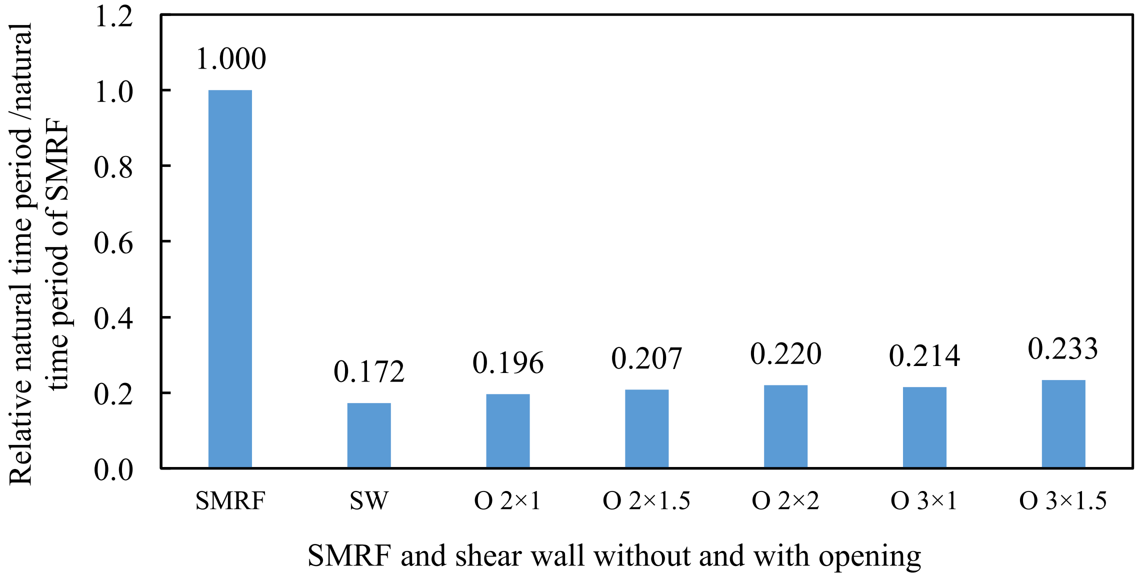


Figure 4. 11: Comparison of natural time period of shear wall without and with opening with respect to SMRF

4.2.2 The effect of span length on the natural time period of the SMRF and shear walls with different sizes of opening

Variety in span length is one of the factors which affect the natural time period of SMRF and shear wall. Changes in the length of the span could have a significant effect on the weight of shear walls. Consequently, any change in the length of the span decreases or increases the natural time period of the SMRF and shear walls. Figure 4.12 and Table 4.8 shows the natural time period of SMRF and shear wall without and with opening with different span length. As it can be seen in the Figure 4.12 and Table 4.8, the results show that After increasing span length from 5m to 6m the natural time period of SMRF is increased, but for the shear wall without and with opening after increasing the span length the natural time period decreased since the stiffness of shear wall is greater than the stiffness of SMRF.

Assuming fixed parameters for Figure 4.12 and table 4.8 are S = L, N = 1, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

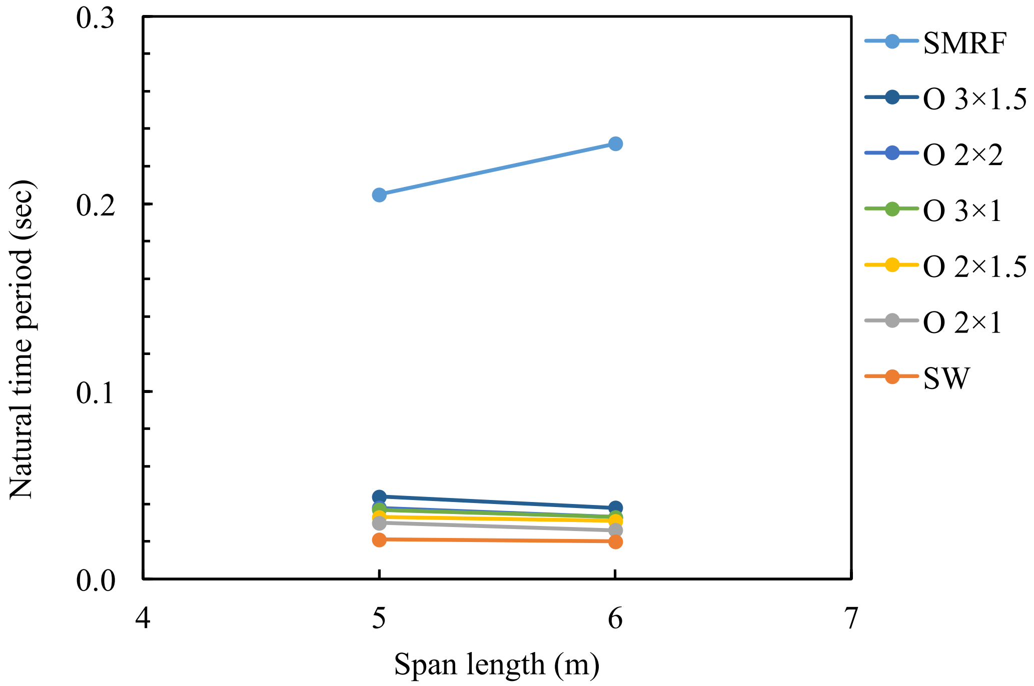


Figure 4. 12: The natural time period of SMRF and Shear wall without and with opening with different span length

Table 4. 8: Results of natural time period of SMRF and Shear wall without and with opening with different span length

	Span length	
Framing types	**5 m**	**6 m**
SMRF	0.205	0.232
SW	0.021	0.02
O 2×1	0.03	0.026
O 2×1.5	0.033	0.031
O 2×2	0.038	0.033
O 3×1	0.037	0.033
O 3×1.5	0.044	0.038

4.2.3 The effect of number of spans on the natural time period of the SMRF and shear walls with different sizes of opening

Changes in number of spans are another factor which affects the stiffness and seismic performance of shear wall. Any change in the number of the span leads to decreases or increases the natural time period of the shear walls. Figure 4.13 and Table 4.9 are shows the natural time period of SMRF and Shear wall without and with opening with different number of spans. The results show that after inserting the shear wall to the system the natural time period of the frames is decreased, but when the number of spans increases from 1 to 5, the natural time period of the SMRF and shear wall without and with opening also increased.

Assuming fixed parameters for Figure 4.13 and Table 4.9 are S = L, L = 5, H = 3.2 m, $f_c' =$ 25 MPa, f_y= 300 MPa, t = 250 mm

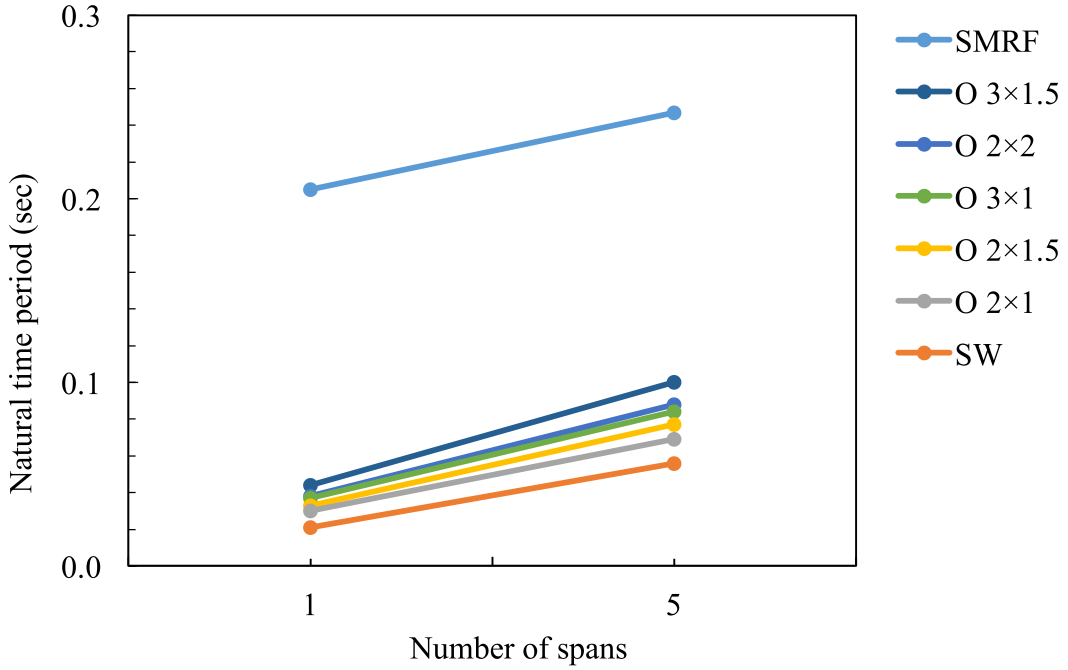


Figure 4. 13: The natural time period of SMRF and Shear wall without and with opening with different number of spans

Table 4. 9: Results of natural time period of SMRF and Shear wall without and with opening with different number of spans

	Number of spans	
Framing types	**1**	**5**
SMRF	0.205	0.247
SW	0.021	0.056
O 2×1	0.03	0.069
O 2×1.5	0.033	0.077
O 2×2	0.038	0.088
O 3×1	0.037	0.084
O 3×1.5	0.044	0.1

4.2.4 The effect of number of stories on the natural time period of the SMRF and shear walls with different sizes of opening

Varity in number of stories is one of the factors which affect the natural time period of the shear wall. Changes in the number of stories could have an effect on the elastic stiffness factor of SMRF and shear walls and natural time period are related with the stiffness. Therefore, any increase in the number of stories leads to an increase in the deflection of the structure, decreases lateral stiffness and increasing the natural time period. Figure 4.14 and Table 4.10 are showing the natural time period of SMRF and shear wall without and with opening with different number of stories. As it can be seen in the Figure 4.14 and Table 4.10, the results display that after increasing number of stories for SMRF and shear walls without and with opening from low-rise to mid-rise the natural time period is increased.

Assuming fixed parameters for Figure 4.14 and Table 4.10 are N=1, L = 5, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa , t = 250 mm

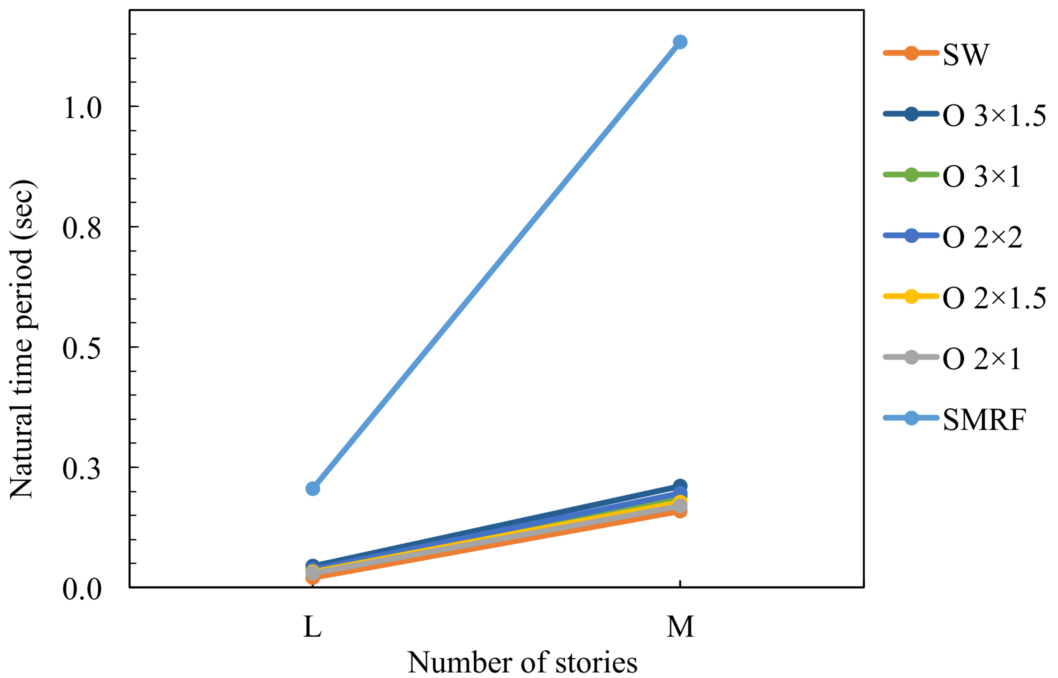


Figure 4. 14: The natural time period of SMRF and Shear wall without and with opening with different number of stories

Table 4. 10: The natural time period of SMRF and Shear wall without and with opening with different number of stories

	Number of stories	
Framing types	**Low-rise**	**Mid-rise**
SMRF	0.205	1.134
SW	0.021	0.159
O 2×1	0.03	0.169
O 2×1.5	0.033	0.178
O 2×2	0.038	0.196
O 3×1	0.037	0.19
O 3×1.5	0.044	0.211

4.2.5 The effect of story height changes on the natural time period of the SMRF and shear walls with different sizes of opening

Changes in story height are one of the parameters which affect the natural time period of shear wall. Changes in the story height could have an effect on the stiffness of the SMRF and shear walls. Therefore, any increasing in the story height leads to increases the deflection of the structure, decreases lateral stiffness and increasing the natural time period. Figure 4.15 and Table 4.11 shows the natural time period of SMRF and shear wall without and with opening with different story height. From the Figure 4.15 and Table 4.11, demonstrates the results display that after increasing the story height for SMRF and shear walls without and with opening from 3.2m to 3.6m the natural time period is increased.

Assuming fixed parameters for Figure 4.15 and Table 4.11 are S=L, N=5, L = 5, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

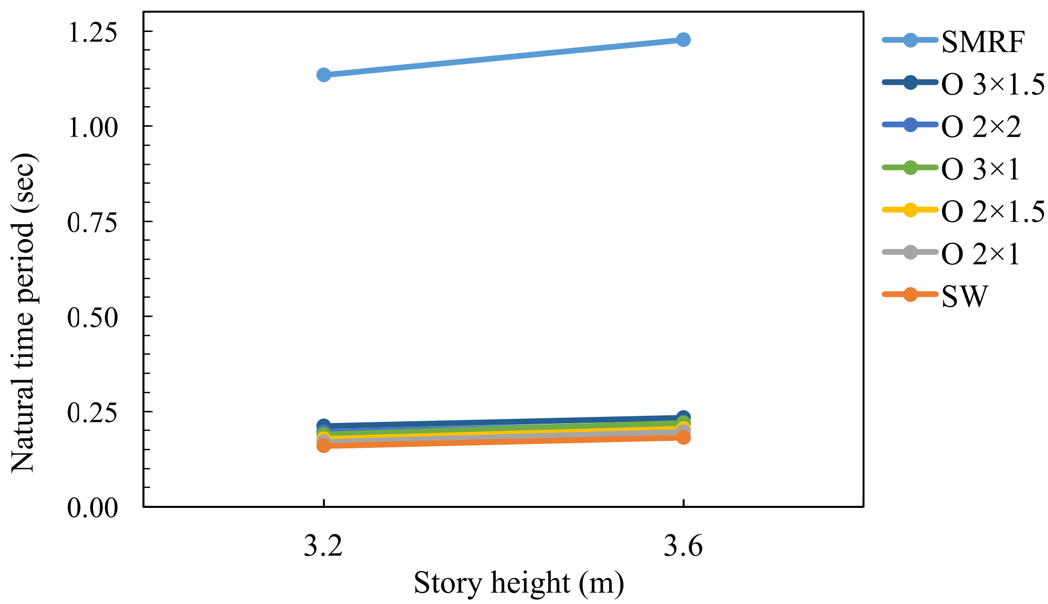


Figure 4. 15: The natural time period of SMRF and shear wall without and with opening with different story height

Table 4. 11: Results of natural time period of SMRF and shear wall without and with opening with different story height

	Story height	
Framing types	**3.2 m**	**3.6 m**
SMRF	1.134	1.226
SW	0.159	0.181
O 2×1	0.169	0.197
O 2×1.5	0.178	0.204
O 2×2	0.196	0.216
O 3×1	0.19	0.22
O 3×1.5	0.211	0.233

4.2.6 Effect of changing compressive strength of concrete on the natural time period of the SMRF and shear walls with different sizes of opening

Changes in compressive strength of concrete are one of the factors which affect the natural time period of shear wall. Consequently, any change in the compressive strength of concrete leads to decreases or increases the natural time period of shear walls. Figure 4.16 and Table 4.12 shows the natural time period of SMRF and Shear wall without and with opening with different compressive strength of concrete. According to the Figure 4.16 and Table 4.12, the results demonstrate that the natural time period of SMRF and shear walls without and with opening are reduced by increasing the compressive strength of concrete from 25 MPa to 30 MPa.

Assuming fixed parameters for Figure 4.16 and Table 4.12 are S = L, N = 1, H = 3.2 m, L = 5, f_y= 300 MPa, t = 250 mm

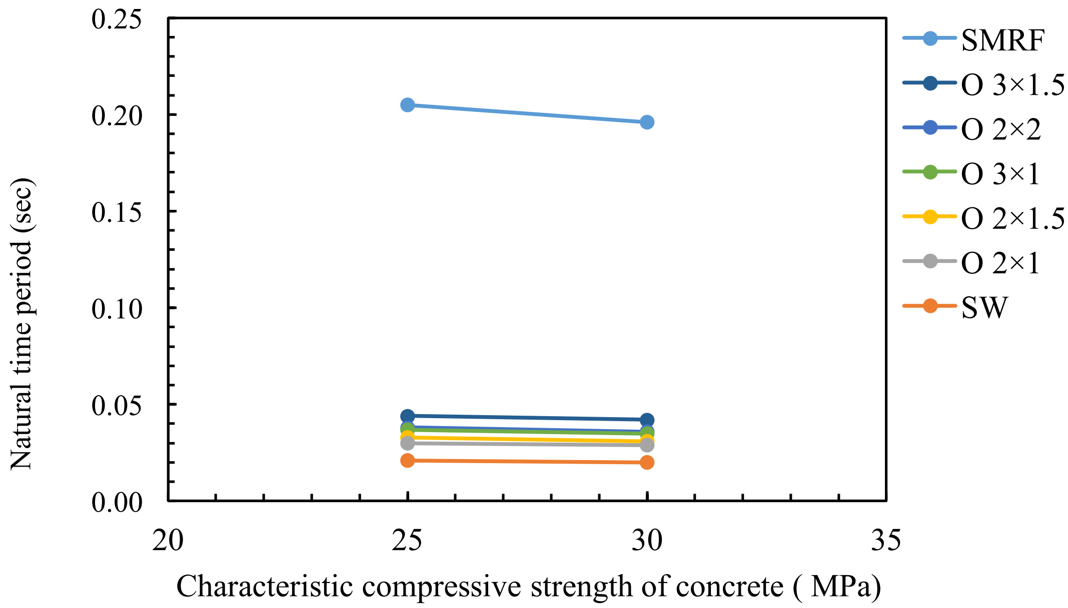


Figure 4. 16: The natural time period of SMRF and Shear wall without and with opening with different compressive strength of concrete

Table 4. 12: Results of natural time period of SMRF and Shear wall without and with opening with different compressive strength of concrete

	Compressive strength of concrete	
Framing types	**25 MPa**	**30 MPa**
SMRF	0.205	0.196
SW	0.021	0.02
O 2×1	0.03	0.029
O 2×1.5	0.033	0.031
O 2×2	0.038	0.036
O 3×1	0.037	0.035
O 3×1.5	0.044	0.042

4.2.7 Effect of change yield strength of steel on the natural time period of the SMRF and shear walls with different sizes of opening

Yield strength of steel is one of the factors which effect on the natural time period of shear wall. So, any change in the yield strength of steel either leads to a small changing or remained the same in the natural time period of the SMRF frame and shear walls with and without opening. Figure 4.17 and Table 4.13 shows the natural time period of SMRF and Shear wall without and with opening, with different yield strength of steel.

From the Figure 4.17 and Table 4.13, the results demonstrate that the natural time period of SMRF and shear walls without and with opening remained the same by increasing the yield strength of steel from 300 MPa to 415 MPa.

Assuming fixed parameters for Figure 4.17 and Table 4.13 are S = L, N = 1, H = 3.2 m, f_c' = 25 MPa, t = 250 mm, L = 5

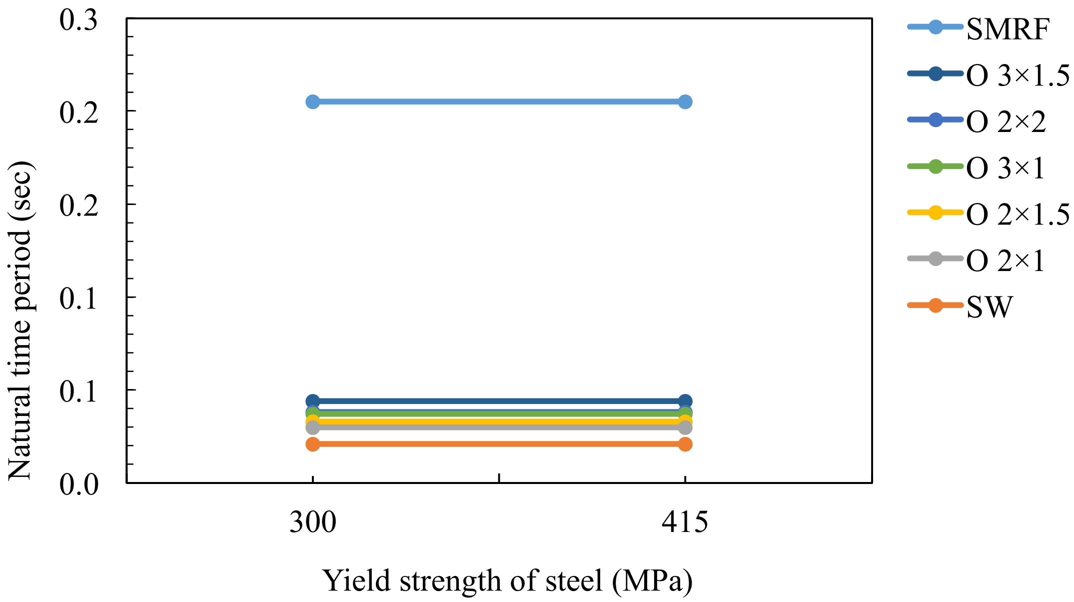


Figure 4. 17: The natural time period of SMRF and Shear wall without and with opening with different yield strength of steel

Table 4. 13: Results of natural time period of SMRF and Shear wall without and with opening with different yield strength of steel

	Yield strength of concrete	
Framing types	**300 MPa**	**415 MPa**
SMRF	0.205	0.205
SW	0.021	0.021
O 2×1	0.03	0.03
O 2×1.5	0.033	0.033
O 2×2	0.038	0.038
O 3×1	0.037	0.037
O 3×1.5	0.044	0.044

4.2.8 Effect of different Thickness of shear wall on the natural time period of the shear walls with different sizes of opening

Changes in shear wall thickness are one of the factors which affect the natural time period and seismic performance of shear wall. Consequently, any increment in the shear wall thickness it leads to a decrease in the natural time period of the shear wall without and with opening. Figure 4.18 and Table 4.14 shows the natural time period of shear wall without and with opening with different thicknesses.

From Figure 4.18 and Table 4.14, the results display that the natural time period of shear walls without and with opening are gradually reduced by increasing the thickness of shear wall from 250 mm to 300 mm.

Assuming fixed parameters for Figure 4.18 and Table 4.14 are S = L, N = 1, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, L = 5

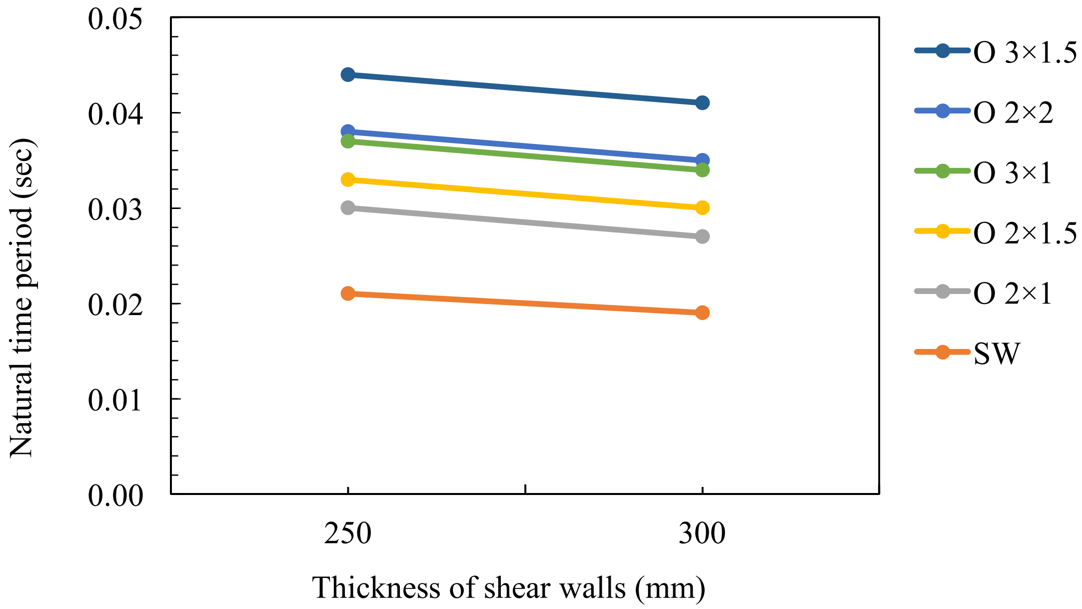


Figure 4. 18: The natural time period of shear walls without and with opening with different thickness

Table 4. 14: Results of natural time period of shear walls without and with opening with different thickness

	Thickness of Shear walls	
Framing types	**250 mm**	**300 mm**
SW	0.021	0.019
O 2×1	0.03	0.027
O 2×1.5	0.033	0.03
O 2×2	0.038	0.035
O 3×1	0.037	0.034
O 3×1.5	0.044	0.041

4.3 Factors Affecting on the Maximum Base Shear

This section shows the effect of the results of different sizes of openings, span length, number of spans, compressive strength of concrete, number of stories, story height, yield strength of steel and thickness of shear wall on the maximum base shear.

4.3.1 The effect of different opening sizes of shear walls on the maximum base shear of the reinforced concrete frames

Generally, maximum base shear is the lateral force that is stirred by seismic ground motion at the structure's foundation. Maximum base shear is related with the stiffness, and opening can affect the total stiffness of the shear wall. Since openings decrease the stiffness of the building at each level and natural time period is increased, less shear is applied to the structure.

Figure 4.19, shows the average maximum base shear of SMRF and shear wall without and with opening, from the graphs it was seen that after inserting the shear walls without and with openings to the system the maximum base shear increased as compared to SMRF. From the Figures 4.19 it was found when the area of the openings increases the maximum base shear decreased in comparison to the shear wall without openings. From Figure 4.20 the maximum base shear of shear wall without openings is approximately 7.2 times greater than the SMRF.

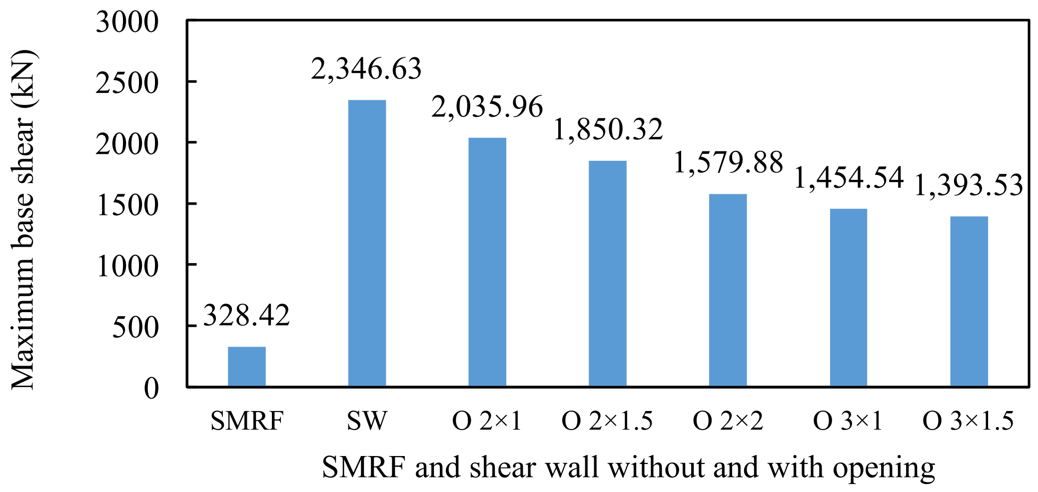


Figure 4. 19: Average maximum base shear of SMRF and Shear wall without and with opening

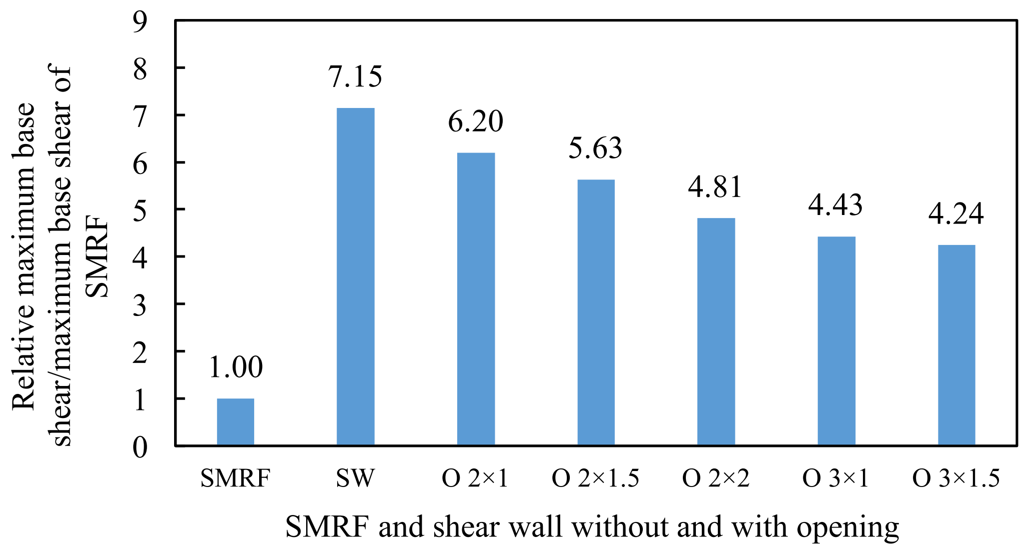


Figure 4. 20: Comparison of maximum base shear of shear wall with and without opening with respect to SMRF

4.3.2 The effect of span length on the maximum base shear of the SMRF and shear walls with different sizes of opening

Changes in span length are one of the parameter which impact the maximum base shear of shear wall. Changes in the length of the span could have huge implications on the weight of shear walls. Consequently, any change in the length of the span leads to decreases or increases the maximum base shear of the shear walls. Figure 4.21and Table 4.15 shows the maximum base shear of SMRF and shear wall without and with opening with different span length.

From the Figure 4.21 and Table 4.15, the results show that After increasing span length for all type of the models from 5 m to 6 m the maximum base shear is increased too. Therefore, as the span length in a shear wall increases, rigidity and stiffness of the wall will increase.

Assuming fixed parameters for Figure 4.21 and Table 4.15 are S = L, N = 1, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

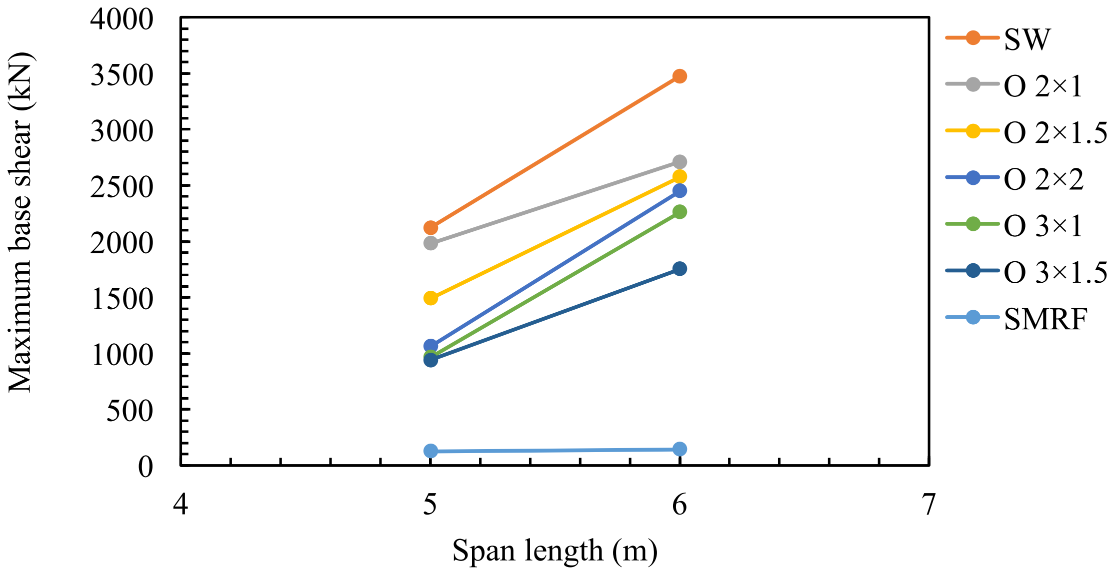


Figure 4. 21: The maximum base shear of SMRF and Shear wall without and with opening with different span length

Table 4. 15: Results of maximum base shear of SMRF and Shear wall without and with opening with different span length

	Span length	
Framing types	**5 m**	**6 m**
SMRF	123.725	142.9731
SW	2120.9987	3474.3082
O 2×1	1980.8779	2710.2138
O 2×1.5	1488.9987	2575.8109
O 2×2	1060.9071	2449.7421
O 3×1	963.7073	2260.3326
O 3×1.5	938.8844	1753.5472

4.3.3 The effect of number of spans on the maximum base shear of the SMRF and shear walls with different sizes of opening

Changes in number of spans are one of the factors which affect the maximum base shear of shear wall. Any change in the number of the span, it led to a decrease or increase in the lateral stiffness of the shear walls. Figure 4.22 and Table 4.16 shows the maximum base shear of SMRF and Shear wall without and with opening with different number of span. The results show that after inserting the shear wall to the system the maximum base shear of the frames increased, and when the number of spans increases from 1 to 5 the maximum base shear of the SMRF and shear wall without and with opening increased too. The result of maximum base shear of opening 2 ×1 and shear wall without opening are near to each other.

Assuming fixed parameters for Figure 4.22 and Table 4.16 are S = L, L = 5, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

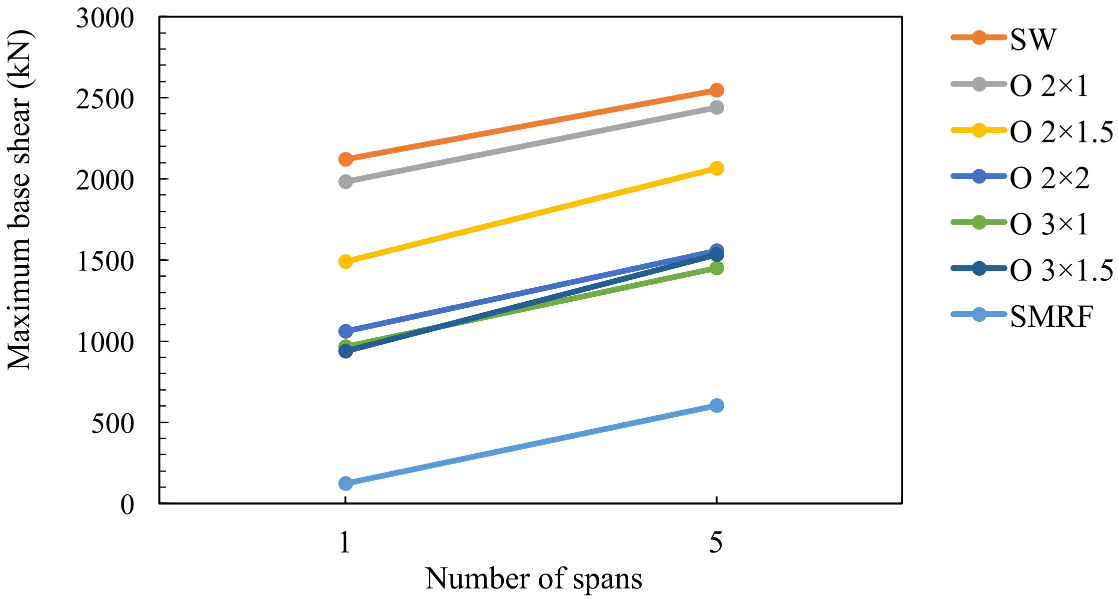


Figure 4. 22: The maximum base shear of SMRF and Shear wall without and with opening with different number of spans

Table 4. 16: Results of maximum base shear of SMRF and Shear wall without and with opening with different number of spans

	Number of spans	
Framing types	**1**	**5**
SMRF	123.725	600.733
SW	2120.999	2547.009
O 2×1	1980.878	2440.331
O 2×1.5	1488.999	2065.482
O 2×2	1060.907	1557.372
O 3×1	963.707	1451.676
O 3×1.5	938.8844	1534.3009

4.3.4 The effect of number of stories on the maximum base shear of the SMRF and shear walls with different sizes of opening

Changes in number of stories are one of the factors which affect the maximum base shear of shear wall. Changes in the number of stories could have an implication on the structure's stiffness while maximum base shear is related with the stiffness of the frame. Therefore, any increment in the number of stories increases the deflection of the structure, decreases lateral stiffness and maximum base shear. Figure 4.23 and Table 4.17 presents the maximum base shear of SMRF and Shear wall without and with opening with different number of stories.

From the Figure 4.23and Table 4.17 the results show that after increasing number of stories for SMRF and shear walls with and without opening from low-rise to mid-rise the maximum base shear decreases.

Assuming fixed parameters for Figure 4.23 and Table 4.17are N=1, L = 5, H = 3.2 m, $f_c' =$ 25 MPa, f_y= 300 MPa, t = 250 mm

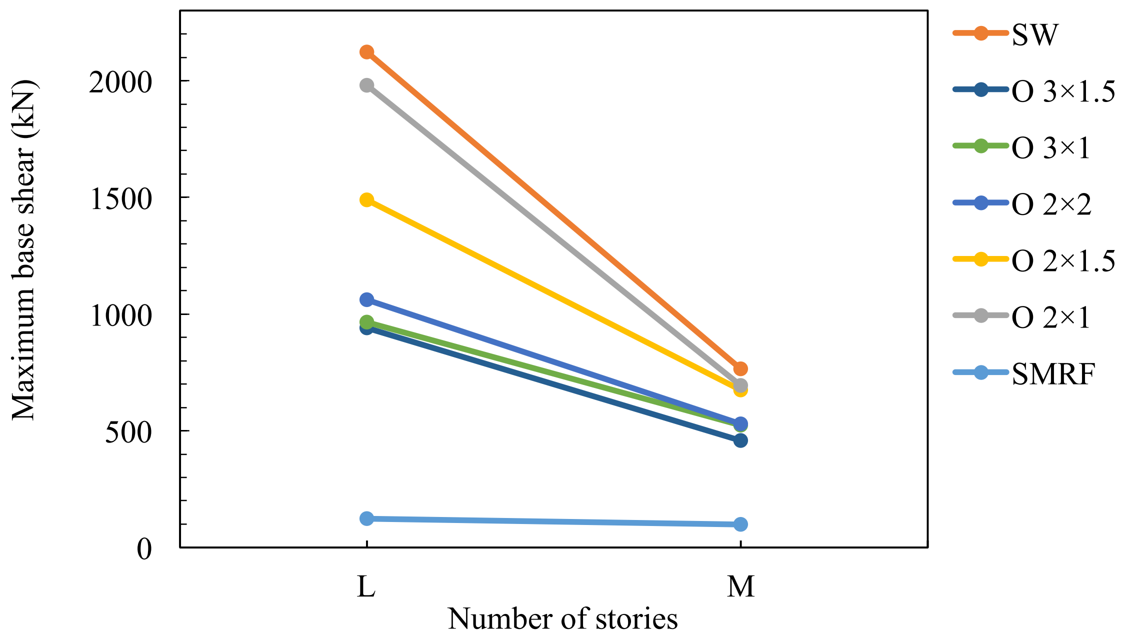


Figure 4.23: The maximum base shear of SMRF and Shear wall without and with opening with different number of stories

Table 4. 17: Results of maximum base shear of SMRF and Shear wall without and with opening with different number of stories

	Number of stories	
Framing types	**Low-rise**	**Mid-rise**
SMRF	123.725	98.888
SW	2120.999	765.99
O 2×1	1980.878	694.814
O 2×1.5	1488.999	673.996
O 2×2	1060.907	528.041
O 3×1	963.707	523.613
O 3×1.5	938.8844	458.7474

4.3.5 The effect of story height on the maximum base shear of the SMRF and shear walls with different sizes of opening

Another parameter which affects the maximum base shear and seismic performance of shear wall is changing in story height. Changes in the story height could have an effect on the maximum base shear of the SMRF and shear walls. The maximum base shear of SMRF and Shear wall without and with opening, with different story height are shown in Figure 4.24 and Table 4.18. The results show that after increasing number of stories for SMRF and shear walls without and with opening from 3.2 m to 3.6 m the maximum base shear gradually decreases.

Assuming fixed parameters for Figure 4.24 and Table 4.18 are S=L, N=5, L = 5, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

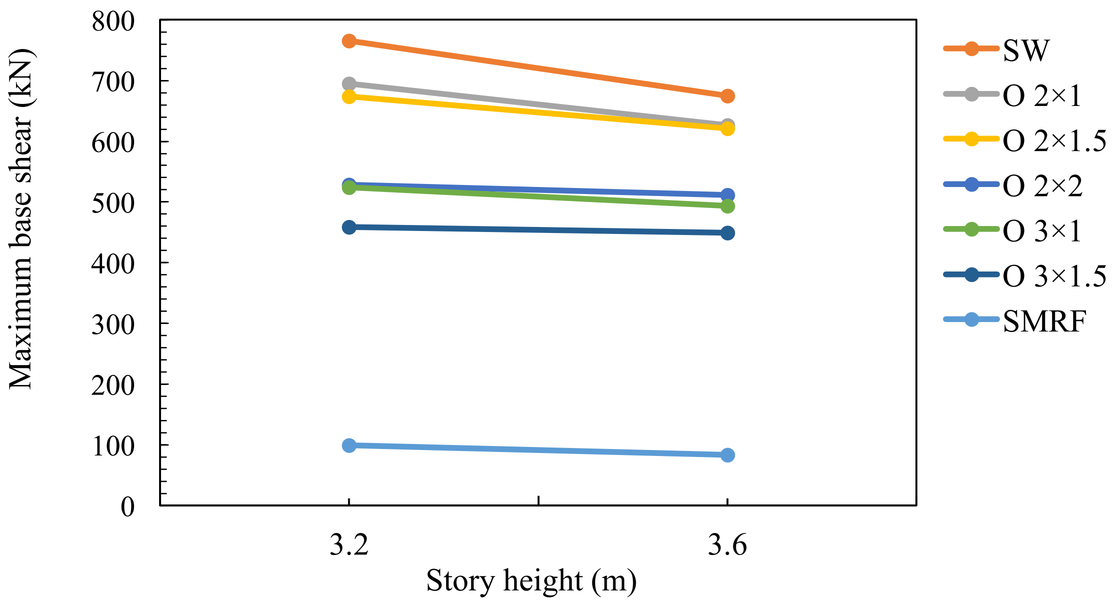


Figure 4. 24: The maximum base shear of SMRF and Shear wall without and with opening with different story height

Table 4. 18: Results of maximum base shear of SMRF and Shear wall without and with opening with different story height

	Story height	
Framing types	**3.2 m**	**3.6 m**
SMRF	98.888	83.949
SW	765.99	674.421
O 2×1	694.814	626.769
O 2×1.5	673.996	620.906
O 2×2	528.041	511.405
O 3×1	523.613	493.258
O 3×1.5	458.7474	449.3289

4.3.6 Effect of different compressive strength of concrete on the maximum base shear of the SMRF and shear walls with different sizes of opening

Changes in compressive strength of concrete are one of the factors which affect the maximum base shear of shear wall. Figure 4.25 and Table 4.19 show the maximum base shear of SMRF and shear wall without and with opening with various compressive strength of concrete.

From the Figure 4.25 and Table 4.19, the results demonstrate that by increasing the compressive strength of concrete from 25 MPa to 30 MPa. The maximum base shear of SMRF and shear walls without and with opening are ascended. So, as the compressive strength of concrete increases, maximum base shear of the wall is about to increase.

Assuming fixed parameters for Figure 4.25 and Table 4.19 are S = L, N = 1, H = 3.2 m, L = 5, f_y= 300 MPa, t = 250 mm

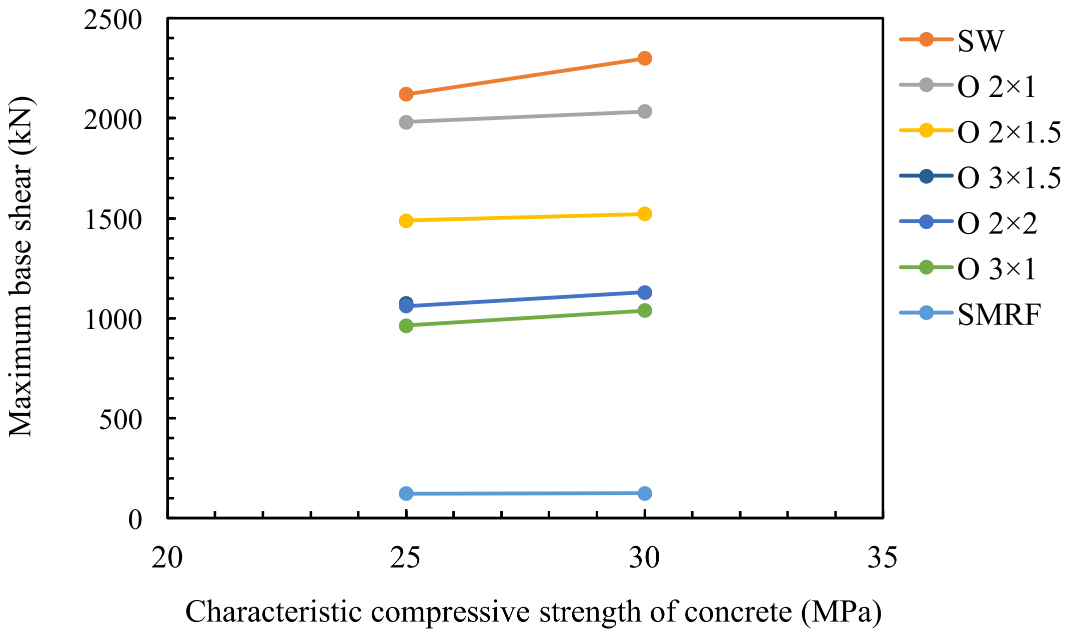


Figure 4. 25: The maximum base shear of SMRF and Shear wall with and without opening with different compressive strength of concrete

Table 4. 19: Results of maximum base shear of SMRF and Shear wall with and without opening with different compressive strength of concrete

Framing types	Compressive strength of concrete	
	25 MPa	**30 MPa**
SMRF	123.725	125.2541
SW	2120.0097	2300
O 2×1	1980.8779	2033.6053
O 2×1.5	1488.9987	1522.2554
O 2×2	1060.9071	1129.9228
O 3×1	953.7073	1038.2108
O 3×1.5	938.8844	1073.8499

4.3.7 Effect of change yield strength of steel on the maximum base shear of the SMRF and shear walls with different sizes of opening

Yield strength of steel is one of the factors which have influence on the maximum base shear of shear wall. So, any change in the yield strength of steel, it leads to a small change in the maximum base shear of the SMRF and shear walls without and with opening. Figure 4.26 and Table 4.20 indicates the maximum base shear of SMRF and shear wall without and with opening, with different yield strength of steel.

Figure 4.26 and Table 4.20, demonstrates that by increasing the yield strength of steel from 300 MPa to 415 MPa. The maximum base shear of SMRF and shear walls without and with opening are increased.

Assuming fixed parameters for Figure 4.26 and Table 4.20 are S = L, N = 1, H = 3.2 m, f_c' = 25 MPa, t = 250 mm, L = 5

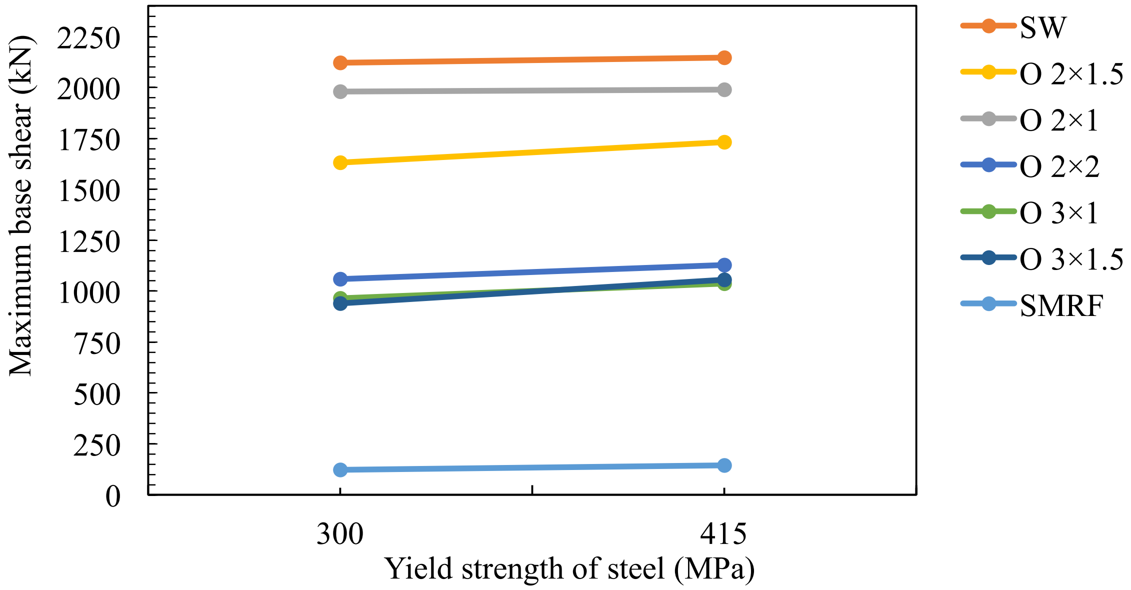


Figure 4. 26: The maximum base shear of SMRF and Shear wall without and with opening with different yield strength of steel

Table 4. 20: Results of maximum base shear of SMRF and Shear wall without and with opening with different yield strength of steel

	Yield strength of concrete	
Framing types	**300 MPa**	**415 MPa**
SMRF	123.725	143.5957
SW	2120.999	2145.875
O 2×1	1980.878	1989.559
O 2×1.5	1631.5	1731.5
O 2×2	1060.907	1127.236
O 3×1	963.707	1038.211
O 3×1.5	938.8844	1055.5303

4.3.8 Effect of change shear wall thickness on the maximum base shear of the shear walls with different sizes of opening

Changes in shear wall thickness are one of the factors which affect the maximum base shear and seismic performance of shear wall. Consequently, any increment in the shear wall thickness leads to an increase in the maximum base shear of shear wall without and with opening. Figure 4.27 and Table 4.21 shows the maximum base shear of Shear wall without and with opening with different thicknesses.

Assuming fixed parameters for Figure 4.27 and Table 4.21 are S = L, N = 1, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, L = 5

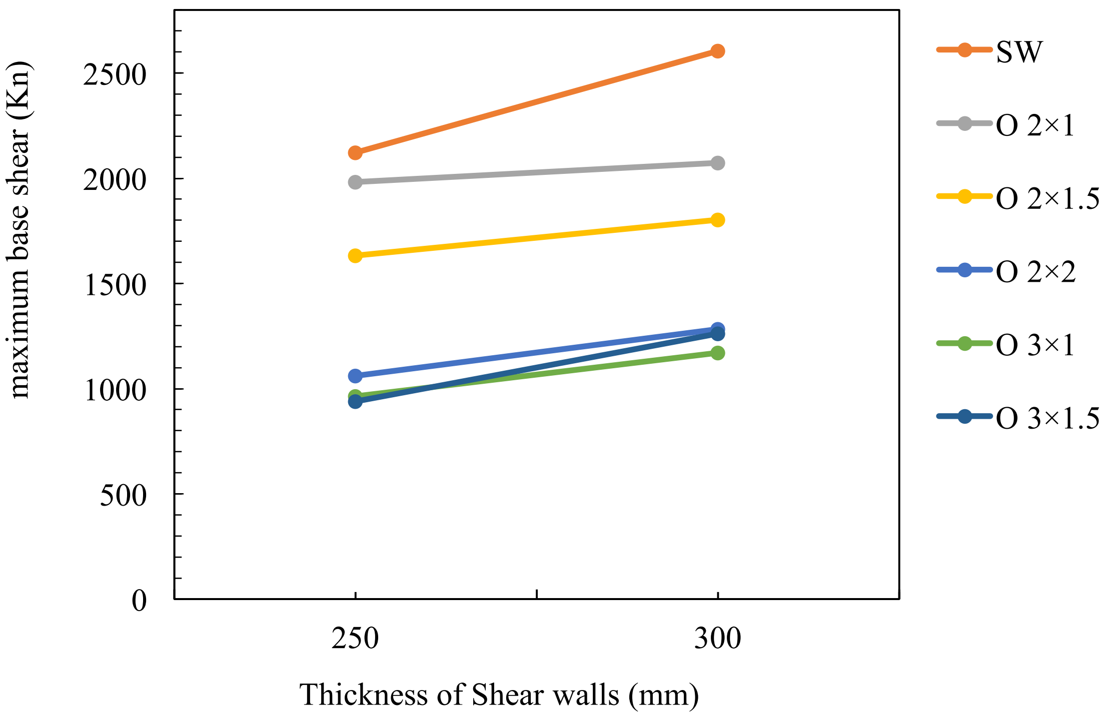


Figure 4.27: The maximum base shear of Shear walls with and without opening with different thickness

Table 4.21: Results of maximum base shear of Shear walls with and without opening with different thickness

	Thickness of Shear walls	
Framing types	**250 mm**	**300 mm**
SW	2120.999	2604.717
O 2×1	1980.878	2074.165
O 2×1.5	1631.5	1802.533
O 2×2	1060.907	1282.308
O 3×1	963.707	1170.814
O 3×1.5	938.8844	1261.7358

As it can be seen in the Figure 4.27 and Table 4.21, The results display that the maximum base shear of shear walls without and with opening increased by increasing thickness of shear wall from 250 mm to 300 mm. Therefore, thickness of shear wall is one of the factors which contribute in rising the stiffness and rigidity of the shear walls.

4.4 Summary of Factor Affecting on The Elastic stiffness factor, Natural time period and Maximum Base Shear

This section is dedicated to show the effect of parameters including span length, number of spans, compressive strength of concrete, number of stories, story height, yield strength of steel and thickness of shear wall on the elastic stiffness factor, natural time period and maximum base shear of SMRF and shear walls without and with opening and all the results are shown in Table 4.22 through 4.24.

Table 4. 22: Summary of the effect of increasing six factors on the elastic stiffness factor, time period and maximum base shear of the SMRF

	SMRF		
Factors	**Elastic stiffness factor**	**Natural time period**	**Maximum base shear**
Increasing span length	Decreased	Increased	Increased
Increasing number of spans	Increased	Increased	Increased
Increasing number of stories	Decreased	Increased	Decreased
Increasing story height	Decreased	Increased	Decreased
Increasing compressive strength of concrete	Increased	Decreased	Increased
Increasing Yield strength of steel	Same	Same	Increased

Table 4.23: Summary of the effect of increasing seven factors on the elastic stiffness factor, natural time period and maximum base shear of the shear wall without opening

	SW		
Factors	**Elastic stiffness factor**	**Natural time period**	**Maximum base shear**
Increasing span length	Increased	Decreased	Increased
Increasing number of spans	Decreased	Increased	Increased
Increasing number of stories	Decreased	Increased	Decreased
Increasing story height	Decreased	Increased	Decreased
Increasing compressive strength of concrete	Increased	Decreased	Increased
Increasing yield strength of steel	Same	Same	Increased
Increasing thickness of shear walls	Increased	Decreased	Increased

Table 4. 24: Summary of the effect of increasing seven factors on the elastic stiffness factor, natural time period and maximum base shear of the shear wall with opening

	SW with opening		
Factors	**Elastic stiffness factor**	**Natural time period**	**Maximum base shear**
Increasing span length	Increased	Decreased	Increased
Increasing number of spans	Increased	Increased	Increased
Increasing number of stories	Decreased	Increased	Decreased
Increasing story height	Decreased	Increased	Decreased
Increasing compressive strength of concrete	Increased	Decreased	Increased
Increasing yield strength of steel	Same	Same	Increased
Increasing thickness of shear walls	Increased	Decreased	Increased

4.5 Effect of Horizontal and Vertical Opening in Shear Wall with Same Area on the Elastic stiffness factor, Natural time period and Maximum Base Shear of Shear Wall

Dimension of opening is one of the factors which affect the stiffness, natural time period and maximum base shear of shear wall because it reduces the total area of a wall. Due to opening, the moment of inertia is not the same throughout the whole height of the shear wall. on the other hand, the effect of horizontal and vertical opening with same area is different on the stiffness, natural time period and maximum base shear of shear wall. Figure 4.28 shows the elastic stiffness factor of shear wall with open 2 ×1.5 and 3 ×1, from the graph it seen that both of the opening has same area but the elastic stiffness factor of open 3 ×1 is smaller than the elastic stiffness factor of open 2 ×1.5. As it can be seen in Figure 4.29 the natural time period of shear walls with open 2 ×1.5 and 3 ×1, from the graph it seen that both of the opening has same area but the natural time period of open 2 ×1.5 is smaller than the natural time period of open 3 ×1 since the shear wall with open 2 ×1.5 is stiffer than shear wall with open 3 ×1. Figure 4.30 shows the maximum shear strength of shear wall with open 2 ×1.5 and 3 ×1. From the figure, it can be concluded that the maximum base shear of open 3×1 smaller than the maximum base shear of open 2×1.5. At the end from Figure 4.28, 4.29 and 4.30, however it can be concluded that putting the opening in the vertical dimension is much better than horizontal opining in shear wall.

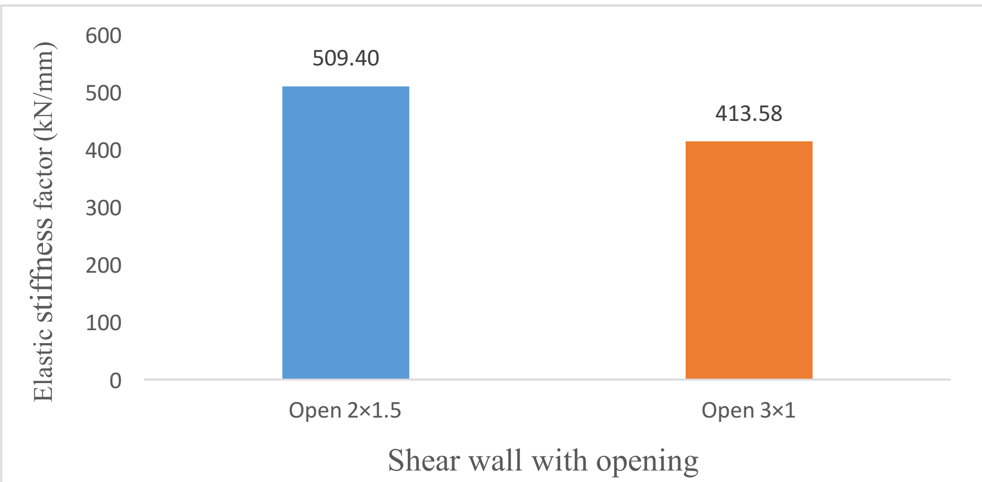


Figure 4. 28: Elastic stiffness factor of Shear wall with opening

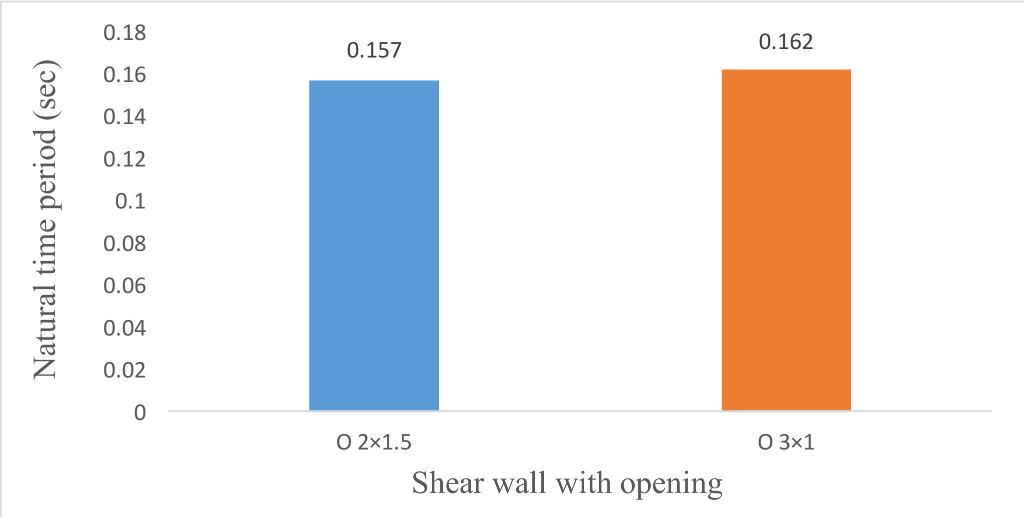


Figure 4. 29: Tine period of Shear wall with opening

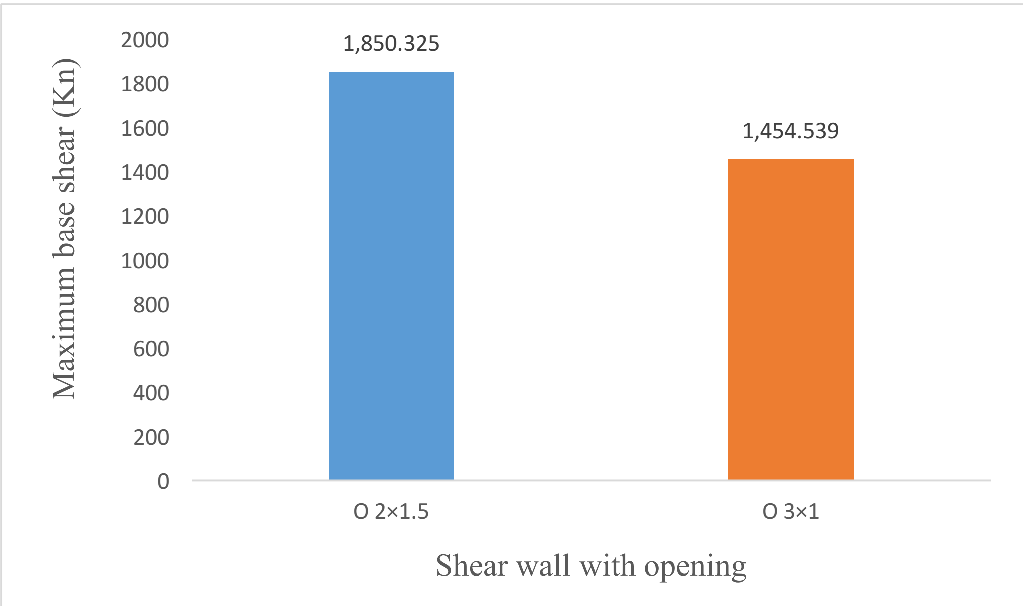


Figure 4. 30: Maximum base shear of Shear wall with opening

4.6 The effect of SMRF and shear walls with and without opening on the pushover curve

After applying pushover analysis, a curve called pushover curve was drawn. Figure 4.31 shows the pushover curve for SMRF and shear walls without and with opening, from the graphs it seen that after inserting the shear walls without and with openings to the system the capacity and performance of the frames are increased compared to SMRF. It was found that when the area of the openings increases in the shear wall the capacity and performance is decreased in comparison to the shear wall without openings. From the Figure 4.31 can be concluded that the capacity of shear wall is much more than the capacity of SMRF. Therefore, shear wall can resist more base shear than SMRF. From Figure 4.31 and 4.32 after increasing the number of stories from 1 to 5, the capacity and performance of the frames and shear walls without and with opening are decreased. It can be concluded that any increasing in the number of stories leads to decreases the capacity of the structure. From Figure 4.31 and 4.33 after increasing the number of span from 1 to 5 spans, the capacity and performance of the frames and shear walls with and without opening are increased in comparison to 1 span.

Assuming fixed parameters of S = L, L=5m, N = 1, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

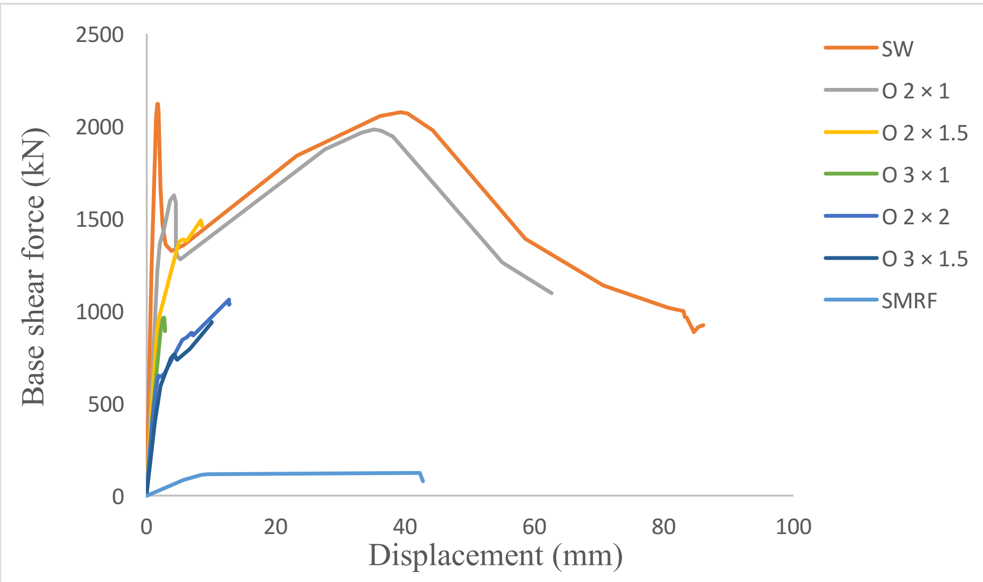


Figure 4. 31: Pushover curve for SMRF and shear walls with and without opening

Assuming fixed parameters of S = M, L=5m, N = 1, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

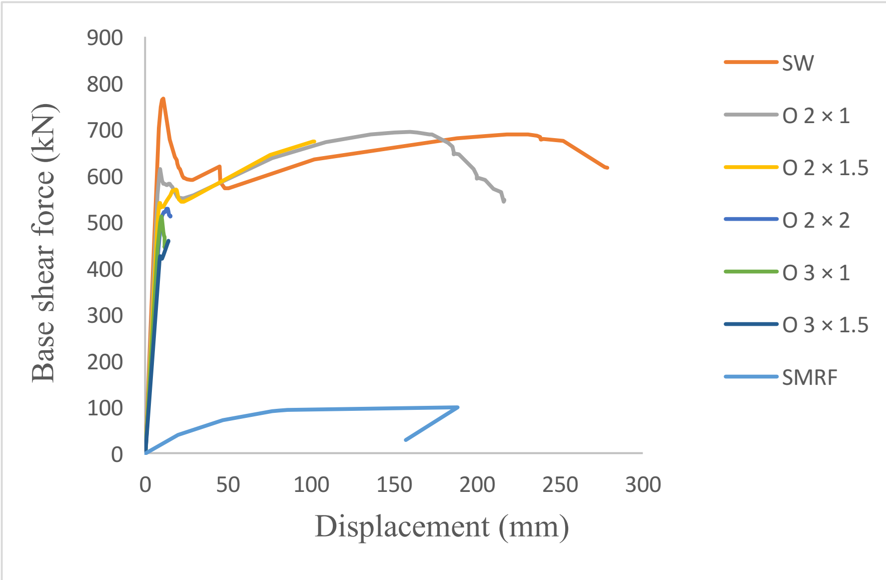


Figure 4. 32: Pushover curve for SMRF and shear walls with and without opening

Assuming fixed parameters of S = L, L=5m, N = 5, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

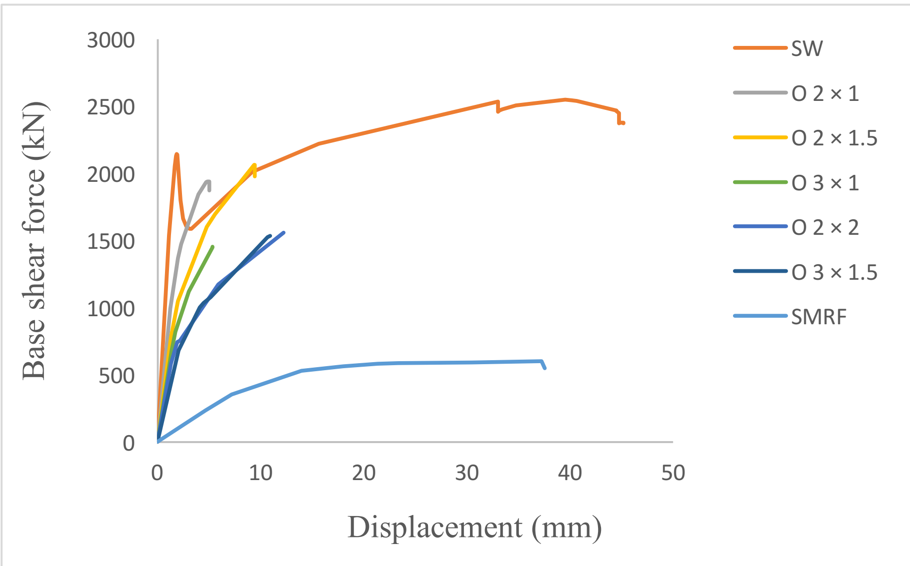


Figure 4. 33: Pushover curve for SMRF and shear walls with and without opening

4.6.1 Factors affecting on the pushover curve of SMRF and shear walls without and with opening

Figure 4.34 to 4.39 are dedicated to show the effect of different parameters including span length, number of spans, compressive strength of concrete, number of stories, story height and yield strength of steel on the pushover curve of SMRF and shear walls without and with opening.

Assuming fixed parameters of S = L, N = 1, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

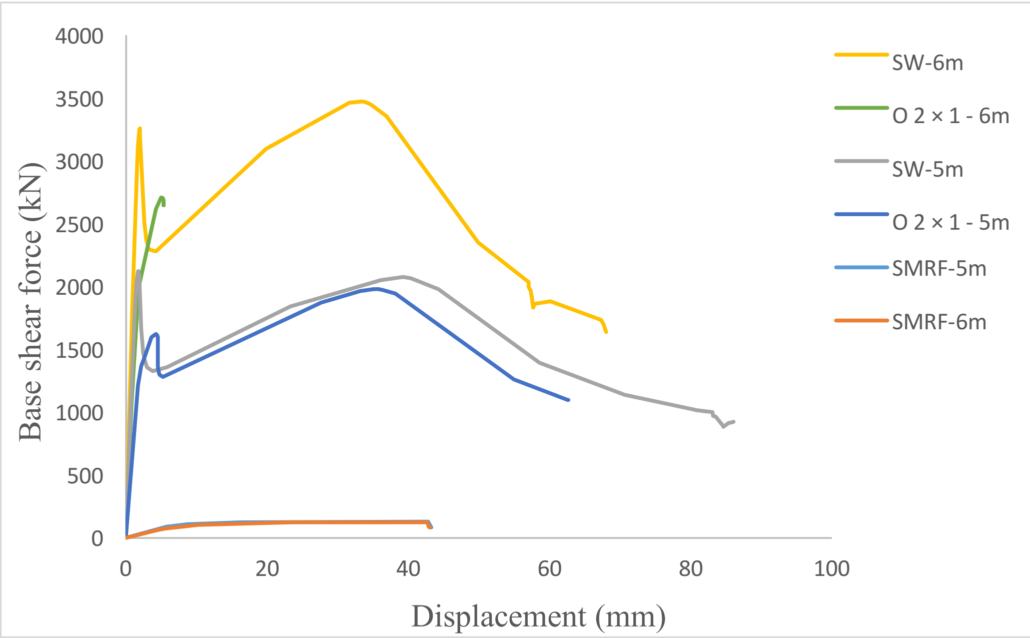


Figure 4. 34: Pushover curve for SMRF and shear walls without and with opening with different span length

As it can be seen in the Figure 4.34 shows pushover curve for SMRF and shear walls without and with opening with different span length, from the graphs it seen that the capacity and performance of the shear walls without and with opening are increased by increasing the span length. On the other hand, it is found that as the span length increases, the capacity and performance of the SMRF is decreased.

Figure 4.35 shows pushover curve for SMRF and shear walls without and with opening with different number of span, from the graphs it seen that the capacity and performance of the shear walls without opening is decreased by increasing the number of span. On the other hand, it is found that as the span length increases, the capacity and performance of the SMRF and shear walls with opening are increased.

Assuming fixed parameters of S = L, L = 5 m, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

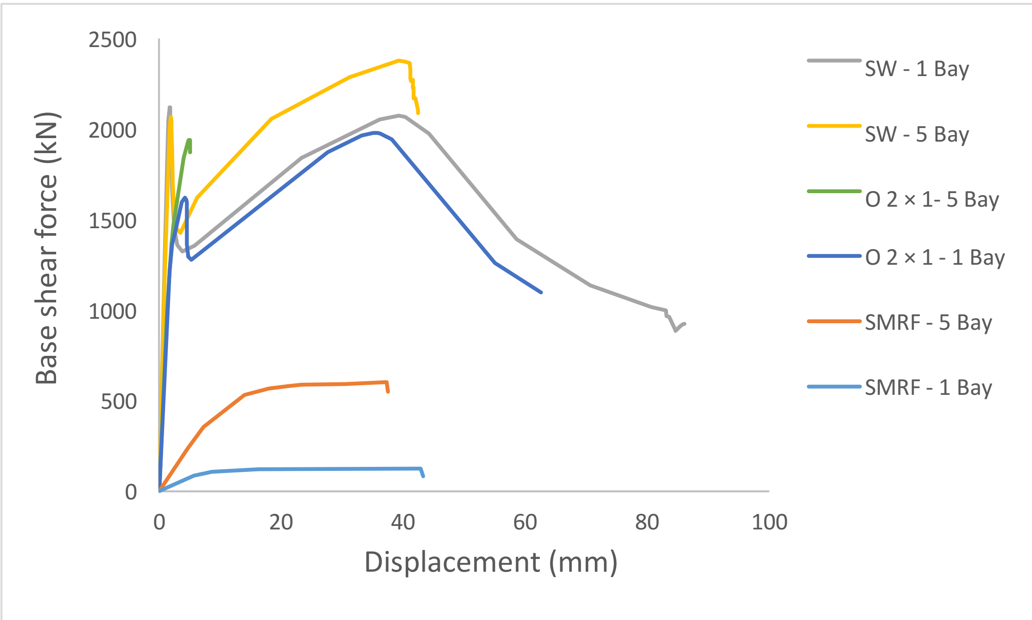


Figure 4. 35: Pushover curve for SMRF and shear walls with and without opening with different number of spans

As it can be seen in the Figure 4.36 shows pushover curve for SMRF and shear walls without and with opening with different number stories, from the graphs it seen that the capacity and performance of the SMRF and shear walls without and with opening are decreased by increasing the number of stories.

Assuming fixed parameters of N = 1, L = 5 m, H = 3.2 m, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

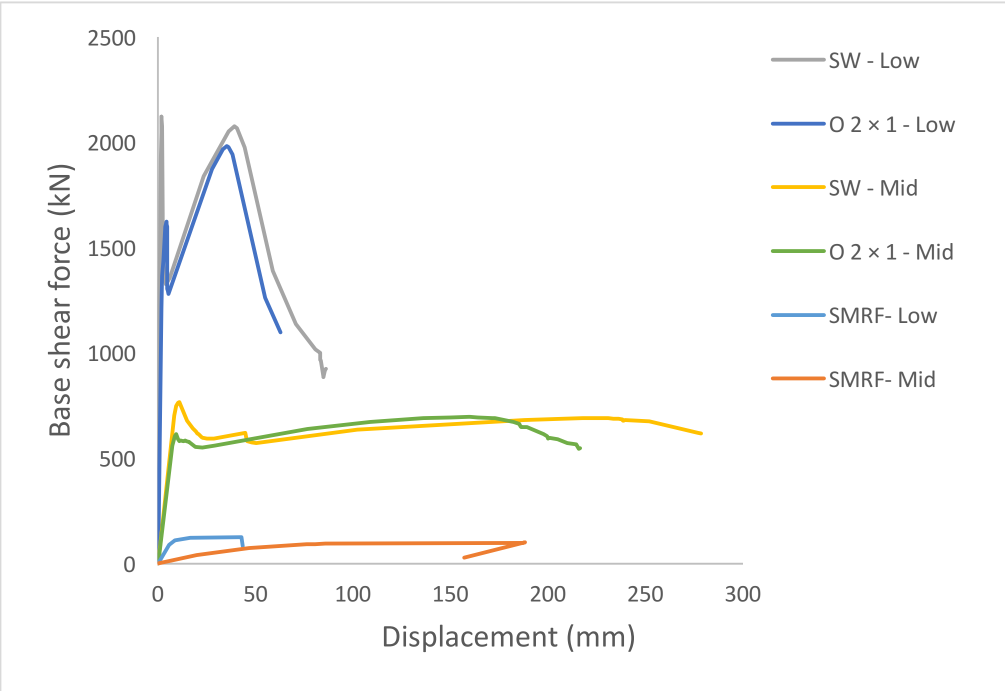


Figure 4. 36: Pushover curve for SMRF and shear walls with and without opening with different number stories

Figure 4.37 shows pushover curve for SMRF and shear walls without and with opening with different story height, from the graphs it seen that the capacity and performance of the SMRF and shear walls without and with opening are decreased by increasing the story height from 3.2m to 3.6m.

Assuming fixed parameters of N = 1, L = 5 m, S = L, f_c' = 25 MPa, f_y= 300 MPa, t = 250 mm

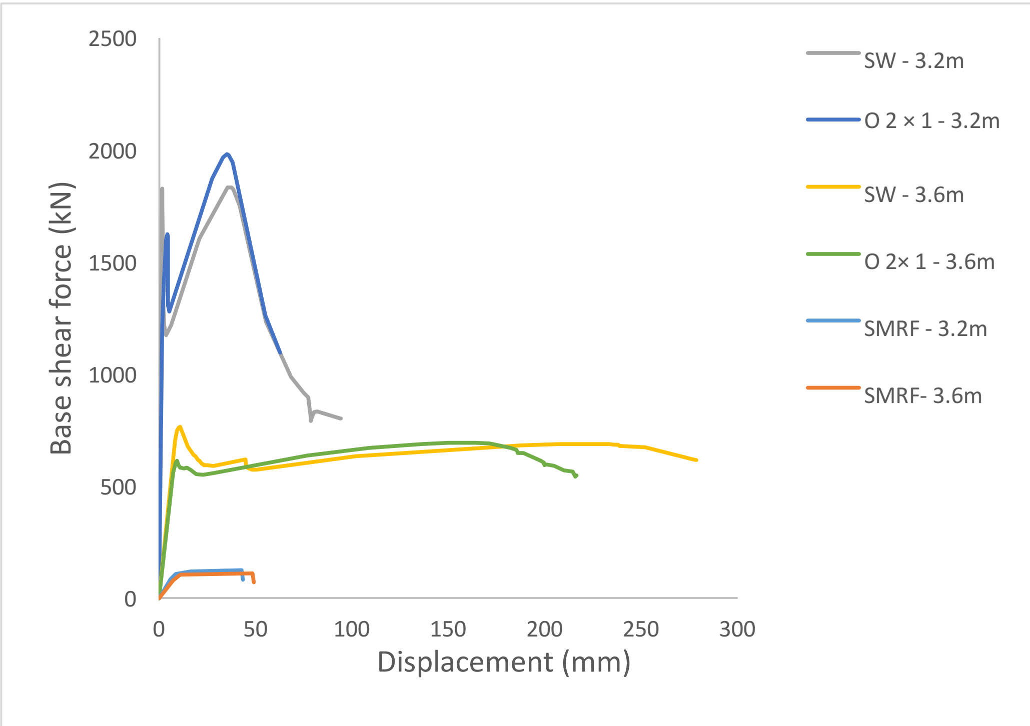


Figure 4. 37: Pushover curve for SMRF and shear walls with and without opening with different story height

As it can be seen in the Figure 4.38 shows pushover curve for SMRF and shear walls without and with opening with different compressive strength of concrete, from the graphs it seen that the capacity and performance of the SMRF and shear walls without and with opening are increased by increasing the compressive strength of concrete from 25 MPa to 30 MPa.

Assuming fixed parameters of N = 1, L = 5 m, S = L, H = 3.2m, f_y= 300 MPa, t = 250 mm

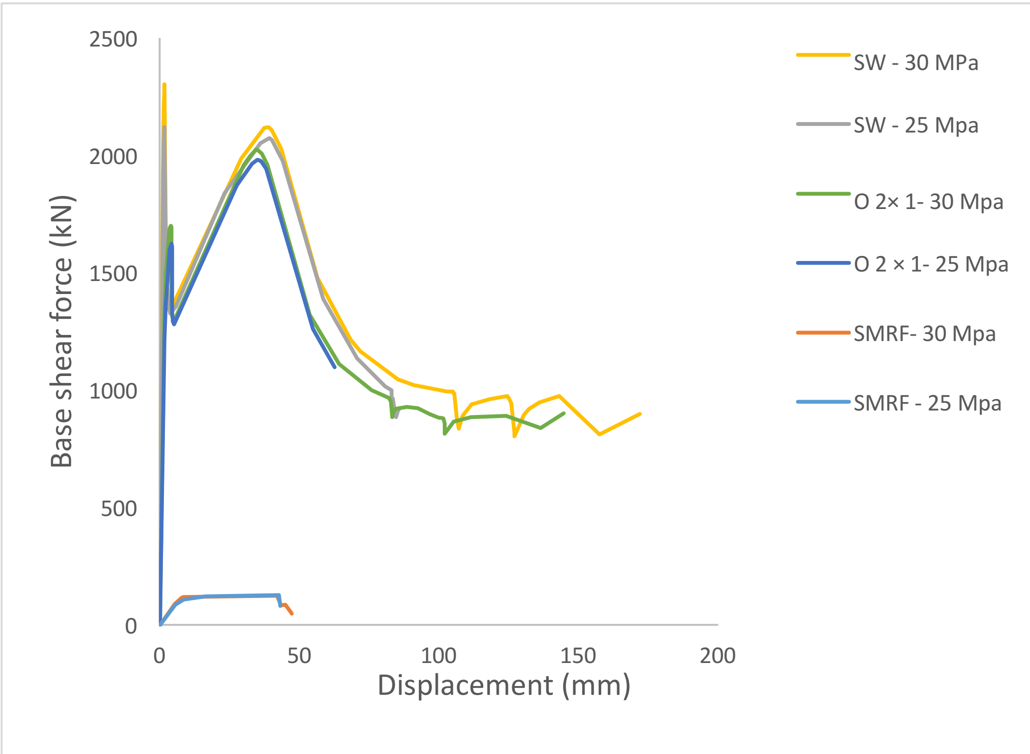


Figure 4. 38: Pushover curve for SMRF and shear walls with and without opening with different compressive strength of concrete

Figure 4.39 shows pushover curve for SMRF and shear walls without and with opening with different yield strength of steel, from the graphs it seen that the capacity and performance of the SMRF and shear walls without and with opening are increased by increasing the yield strength of steel from 300 MPa to 415 MPa.

Assuming fixed parameters of N = 1, L = 5 m, S = L, H = 3.2m, $f_c' = 25$ MPa, t = 250 mm

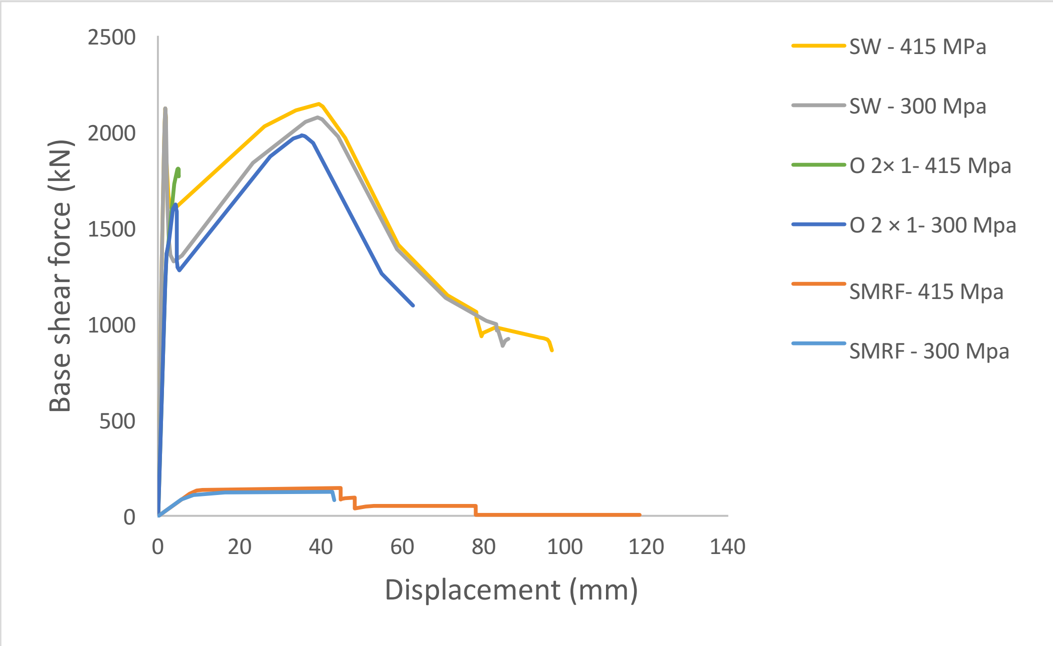


Figure 4. 39: Pushover curve for SMRF and shear walls with and without opening with different yield strength of steel

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this thesis, 2D reinforced concrete frame and shear walls with different sizes of opening were analyzed to determine the elastic stiffness factor, natural time period and maximum base shear. First, software computer program ETABS-2016 was used to analyze and design 832 models performing static linear analysis, and then pushover analysis was performed in order to obtain the results of elastic stiffness factor, natural time period and maximum base shear for each model. The results were utilized to determine the effect of different sizes of openings, span length, compressive strength of concrete, number of spans, number of stories, story height, yield strength of steel and thickness of shear wall on the elastic stiffness factor, natural time period and maximum base shear of the SMRF and shear wall with and without opening. Based on the findings, the study came to conclude the followings;

- Adding shear wall into the structure lead to increase the elastic stiffness factor of 2D reinforced concrete frame and decreases lateral displacements in structures due to application of earthquake forces. On the other hand, provision of opening in the shear wall results decreasing the elastic stiffness factor of shear wall. Meanwhile, with the increase of openings area in shear wall lateral displacement of the structure increases.
- Changing the span length for shear wall with and without opening from 5m to 6m increases the elastic stiffness factor. But the elastic stiffness factor of SMRF decreases by increasing span length.
- Altering the number of spans from 1 to 5, increases the elastic stiffness factor of SMRF and shear wall with opening increases, but the elastic stiffness factor of shear walls without opening is decreased.
- Increasing the number of stories for SMRF and shear wall with and without opening from low-rise to mid-rise cause a decrease in the elastic stiffness factor.
- Increasing the story height for SMRF and shear walls with and without opening from 3.2 m to 3.6 m gradually decreases the elastic stiffness factor.

- Elastic stiffness factors of SMRF and shear walls without and with opening are ascended by increasing compressive strength of concrete from 25 MPa to 30 MPa.
- Elastic stiffness factor of SMRF and shear wall without and with opening are remained same by increasing yield strength of steel from 300 MPa to 415 MPa.
- Increasing the thickness of shear wall from 250 mm to 300 mm causes the elastic stiffness factor of shear walls to increase.
- Adding shear wall into the structure decreases the natural time period of 2D reinforced concrete frame. On the other hand, the provision of opening in the shear wall results in an increase in the natural time period of shear wall. Since, the increase of openings area in shear wall lateral displacement of the structure increases, elastic stiffness factor of shear walls decreases and natural time period increases.
- Enhancing the span length from 5m to 6m increases the natural time period of SMRF, but for the shear wall with and without opening after increasing the span length, the natural time period decreased since the stiffness of shear wall was greater than the stiffness of SMRF.
- Changing the number of spans from 1 to 5, increases the natural time period of SMRF and shear wall without and with opening.
- Having a high number of stories for SMRF and shear wall with and without opening from low-rise to mid-rise cause an increase in the natural time period.
- Altering the story height for SMRF and shear walls with and without opening from 3.2 m to 3.6 m gradually increases the natural time period.
- Varying the compressive strength of concrete from 25 MPa to 30 MPa reduces the natural time period of SMRF and shear walls without and with opening. So, as the compressive strength of concrete increases, natural time period of the wall is likely to decrease.
- The natural time period of shear walls with and without opening decreases by increasing thickness of shear wall from 250 mm to 300 mm.
- The provision of shear wall in to the structure results increases the maximum base shear of 2D reinforced concrete frame. On the other hand, the provision of an opening in the shear wall decreases the maximum base shear of shear wall. Since, with the

increase of openings area in shear wall lateral displacement of the structure increases, elastic stiffness factor and maximum base shear decreases.

- Changing in span length for SMRF and shear wall with and without opening from 5m to 6m the maximum base shear is increased. So that, as the span length in a shear wall increased maximum base shear of the wall is likely to increase.
- Varying the number of spans from 1 to 5, increases the maximum base shear of SMRF and shear wall with and without opening.
- Increasing number of stories for SMRF and shear wall with and without opening from low-rise to mid-rise cause a decrease in the maximum base shear.
- Enhancing the story height of the SMRF and shear walls with and without opening from 3.2 m to 3.6 m gradually decreases the maximum base shear.
- Changing the compressive strength of concrete from 25 MPa to 30 MPa increases the maximum base shears of SMRF and shear walls with and without opening.
- An increase in the yield strength of steel from 300 MPa to 415 MP causes an increase in the maximum base shear.
- The maximum bases shear of shear walls with and without opening can be increased by increasing the thickness of shear wall from 250 mm to 300 mm. Consequently, thickness of shear wall is one of the factors which assist to increase the maximum base shear of the shear walls.
- Provision of vertical opening is much better than horizontal opining in shear wall. it can be concluding that shear walls with vertical opening can resist more lateral load than shear walls with horizontal opening, since shear wall with vertical opening is much stiffer than the shear walls with horizontal opening.
- From the pushover curve it can be concluded that after inserting the shear walls with and without openings into the system, increases the capacity and performance of the frames as compared to SMRFs. When the area of the openings increases in the shear wall the capacity and performance is decreased in comparison to the shear wall without openings.
- The capacity and performance of the shear walls without and with opening can be increased by increasing the span length. On the other hand, the capacity and performance of the SMRF will decrease.

- The capacity and performance of the shear walls without opening are reduce by increasing the number of spans. But it was found that as the span length increases, the capacity and performance of the SMRF and shear walls with opening also increase.
- The capacity of the SMRF and shear walls without and with opening will decrease by increasing the number of stories and story height.
- The capacity and performance of the SMRF and shear walls without and with opening are increased by increasing the compressive strength of concrete and yield strength of steel.

5.2 Recommendations

1. Only one type of shear wall has been studied in this thesis, so different types of shear walls should be investigated in the future works.
2. 2D frames are evaluated through this study, since the models in reality are built in 3D.
3. In this study, placed the shear walls directly to the lateral loads, in the further studies the can be placed in different orientations against lateral load to know the effect of the orientation of shear wall.

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APPENDICES

Appendix 1

Results of elastic stiffness factor, natural time period and maximum base shear of SMRF

LP1,5,3.2,300,25

Where:
L = Low-rise
P1= Number of span equal 1
5 = Length of span
3.2 = High of span
300 = Yield strength of steel
25 = Compressive strength of concrete

Frame Type	Ki (kN/mm)	Natural time period (Sec)	Fu Max (kN)
LP1,5,3.2,300,25	15.175128	0.205	123.725
LP1,5,3.2,300,30	16.630846	0.196	125.2541
LP1,5,3.2,415,25	15.186334	0.205	143.5957
LP1,5,3.2,415,30	16.64331	0.196	146.6911
LP1,5,3.6,300,25	11.19344	0.24	110.5171
LP1,5,3.6,300,30	12.267838	0.23	111.7463
LP1,5,3.6,415,25	11.199152	0.24	128.2348
LP1,5,3.6,415,30	12.273881	0.23	131.2172
LP1,6,3.2,300,25	14.09953	0.232	142.9731
LP1,6,3.2,300,30	15.455246	0.221	155.8829
LP1,6,3.2,415,25	14.121708	0.232	174.2388
LP1,6,3.2,415,30	15.479744	0.221	176.9361
LP1,6,3.6,300,25	10.404371	0.271	104.3182
LP1,6,3.6,300,30	11.40521	0.259	139.7767
LP1,6,3.6,415,25	10.415636	0.271	155.56597
LP1,6,3.6,415,30	11.417713	0.259	158.089
MP1,5,3.2,300,25	2.01086	1.134	98.8884
MP1,5,3.2,300,30	2.208857	1.007	101.4849

MP1,5,3.2,415,25	2.01147	1.055	117.2839
MP1,5,3.2,415,30	2.209498	1.007	121.658
MP1,5,3.6,300,25	1.523387	1.226	83.9491
MP1,5,3.6,300,30	1.674299	1.169	87.8257
MP1,5,3.6,415,25	1.523701	1.226	99.4716
MP1,5,3.6,415,30	1.674635	1.169	105.5578
MP1,6,3.2,300,25	1.765191	1.217	107.0708
MP1,6,3.2,300,30	1.940812	1.16	111.7415
MP1,6,3.2,415,25	1.768036	1.217	125.3048
MP1,6,3.2,415,30	1.943885	1.16	132.4138
MP1,6,3.6,300,25	1.338967	1.411	92.925
MP1,6,3.6,300,30	1.473216	1.345	96.7433
MP1,6,3.6,415,25	1.340545	1.441	108.4676
MP1,6,3.6,415,30	1.474923	1.345	114.8774
LP5,5,3.2,300,25	50.759544	0.247	600.733
LP5,5,3.2,300,30	55.6701	0.236	503.6991
LP5,5,3.2,415,25	50.817145	0.247	614.9268
LP5,5,3.2,415,30	55.698651	0.236	625.7505
LP5,5,3.6,300,25	37.162114	0.29	432.4314
LP5,5,3.6,300,30	40.735469	0.277	441.96
LP5,5,3.6,415,25	37.175039	0.29	540.5439
LP5,5,3.6,415,30	40.749883	0.277	558.8218
LP5,6,3.2,300,25	46.976746	0.278	611.5083
LP5,6,3.2,300,30	51.542931	0.266	624.8642
LP5,6,3.2,415,25	47.733173	0.278	774.5909
LP5,6,3.2,415,30	52.325806	0.266	799.604
LP5,6,3.6,300,25	34.530487	0.326	541.1961
LP5,6,3.6,300,30	37.885424	0.311	553.5096
LP5,6,3.6,415,25	34.965805	0.326	685.8482
LP5,6,3.6,415,30	38.334628	0.311	707.8161
MP5,5,3.2,300,25	8.31981	1.148	438.386

MP5,5,3.2,300,30	9.14324	1.095	452.4234
MP5,5,3.2,415,25	8.323075	1.148	541.3074
MP5,5,3.2,415,30	9.146795	1.095	591.1239
MP5,5,3.6,300,25	6.244289	1.335	388.0785
MP5,5,3.6,300,30	6.866808	1.273	392.932
MP5,5,3.6,415,25	6.246145	1.335	4.97.6693
MP5,5,3.6,415,30	6.868829	1.273	516.0234
MP5,6,3.2,300,25	7.327723	1.325	417.0397
MP5,6,3.2,300,30	8.062334	1.263	459.8364
MP5,6,3.2,415,25	7.349474	1.325	577.0685
MP5,6,3.2,415,30	8.085482	1.263	576.9827
MP5,6,3.6,300,25	5.509235	1.539	365.7422
MP5,6,3.6,300,30	6.066623	1.467	403.0844
MP5,6,3.6,415,25	5.522272	1.539	500.6828
MP5,6,3.6,415,30	6.080495	1.467	517.7427

Appendix 2

Results of elastic stiffness factor, natural time period and maximum base shear of Shear wall without opening

Frame Type	Opening	Ki (kN/mm)	Natural time period (Sec)	Fu Max (kN)
SWLP1,5,3.2,300,25,0.25	/	1545.621823	0.021	2120.9987
SWLP1,5,3.2,300,30,0.25	/	1692.209106	0.02	2300
SWLP1,5,3.2,415,25,0.25	/	1545.621823	0.021	2145.8574
SWLP1,5,3.2,415,30,0.25	/	1692.209106	0.02	2302.9017
SWLP1,5,3.2,300,25,0.3	/	1941.848686	0.019	2604.7167
SWLP1,5,3.2,300,30,0.3	/	2126.004865	0.018	2825.9779
SWLP1,5,3.2,415,25,0.3	/	1941.848686	0.019	2627.0343
SWLP1,5,3.2,415,30,0.3	/	2126.004865	0.018	2825.9779
SWLP1,5,3.6,300,25,0.25	/	1395.696479	0.022	2195.5405
SWLP1,5,3.6,300,30,0.25	/	1527.876889	0.021	2383.3799
SWLP1,5,3.6,415,25,0.25	/	1395.696479	0.022	2195.545
SWLP1,5,3.6,415,30,0.25	/	1527.876889	0.021	2354.8786
SWLP1,5,3.6,300,25,0.3	/	1752.878095	0.02	2699.5743
SWLP1,5,3.6,300,30,0.3	/	1918.881167	0.019	2931.7362
SWLP1,5,3.6,415,25,0.3	/	1752.878095	0.02	2699.5743
SWLP1,5,3.6,415,30,0.3	/	1918.881167	0.019	2931.7362
SWLP1,6,3.2,300,25,0.25	/	2167.122815	0.02	3474.3082
SWLP1,6,3.2,300,30,0.25	/	2372.743011	0.02	3544.5301
SWLP1,6,3.2,420,25,0.25	/	2167.122815	0.02	3589.6586
SWLP1,6,3.2,420,30,0.25	/	2372.743011	0.02	3659.7475
SWLP1,6,3.2,300,25,0.3	/	2760.501777	0.019	4262.4283
SWLP1,6,3.2,300,30,0.3	/	3022.396315	0.018	4350.3708
SWLP1,6,3.2,415,25,0.3	/	2760.501777	0.019	4412.0267
SWLP1,6,3.2,415,30,0.3	/	3022.396315	0.018	4494.5077
SWLP1,6,3.6,300,25,0.25	/	2010.265433	0.022	3469.4023

SWLP1,6,3.6,300,30,0.25	/	2200.749293	0.021	3757.6833
SWLP1,6,3.6,415,25,0.25	/	2010.265433	0.022	3469.4023
SWLP1,6,3.6,415,30,0.25	/	2200.749293	0.021	3757.6833
SWLP1,6,3.6,300,25,0.3	/	2554.075528	0.02	4270.3428
SWLP1,6,3.6,300,30,0.3	/	2796.067852	0.019	4626.5039
SWLP1,6,3.6,415,25,0.3	/	2554.075528	0.02	4270.3428
SWLP1,6,3.6,415,30,0.3	/	2796.067852	0.019	4626.5039
SWMP1,5,3.2,300,25,0.25	/	86.868286	0.159	765.9902
SWMP1,5,3.2,300,30,0.25	/	103.909336	0.144	740.348
SWMP1,5,3.2,415,25,0.25	/	86.868286	0.159	765.9902
SWMP1,5,3.2,415,30,0.25	/	103.909336	0.144	761.8027
SWMP1,5,3.2,300,25,0.3	/	115.21365	0.142	836.8075
SWMP1,5,3.2,300,30,0.3	/	126.008857	0.136	881.9628
SWMP1,5,3.2,415,25,0.3	/	115.21365	0.142	866.3856
SWMP1,5,3.2,415,30,0.3	/	126.008857	0.136	897.1404
SWMP1,5,3.6,300,25,0.25	/	68.441654	0.181	674.4213
SWMP1,5,3.6,300,30,0.25	/	74.854048	0.173	723.1743
SWMP1,5,3.6,420,25,0.25	/	68.441654	0.181	674.4213
SWMP1,5,3.6,420,30,0.25	/	74.854048	0.173	723.1743
SWMP1,5,3.6,300,25,0.3	/	83.010824	0.171	524.4654
SWMP1,5,3.6,300,30,0.3	/	90.787302	0.164	858.385
SWMP1,5,3.6,415,25,0.3	/	83.010824	0.171	799.6488
SWMP1,5,3.6,415,30,0.3	/	90.787302	0.164	858.385
SWMP1,6,3.2,300,25,0.25	/	153.317017	0.154	1182.5518
SWMP1,6,3.2,300,30,0.25	/	179.858418	0.143	1228.0705
SWMP1,6,3.2,415,25,0.25	/	153.317017	0.154	1233.3969
SWMP1,6,3.2,415,30,0.25	/	179.858418	0.142	1272.3962
SWMP1,6,3.2,300,25,0.3	/	199.453907	0.142	1391.7608
SWMP1,6,3.2,300,30,0.3	/	218.156796	0.136	1452.1354
SWMP1,6,3.2,415,25,0.3	/	199.453907	0.142	1452.5018
SWMP1,6,3.2,415,30,0.3	/	218.156796	0.136	1499.6515

SWMP1,6,3.6,300,25,0.25	/	112.011236	0.186	1084.8549
SWMP1,6,3.6,300,30,0.25	/	121.841261	0.178	1148.4525
SWMP1,6,3.6,415,25,0.25	/	112.011236	0.186	1135.4697
SWMP1,6,3.6,415,30,0.25	/	121.841261	0.178	1168.2686
SWMP1,6,3.6,300,25,0.3	/	135.029198	0.179	1280.7827
SWMP1,6,3.6,300,30,0.3	/	158.311094	0.164	1364.9681
SWMP1,6,3.6,415,25,0.3	/	135.029198	0.179	1338.712
SWMP1,6,3.6,415,30,0.3	/	158.311094	0.164	1379.3254
SWLP5,5,3.2,300,25,0.25	/	1389.509529	0.056	2547.0089
SWLP5,5,3.2,300,30,0.25	/	1529.708069	0.053	2596.2959
SWLP5,5,3.2,415,25,0.25	/	1403.483363	0.055	2850.7066
SWLP5,5,3.2,415,30,0.25	/	1542.728573	0.053	2906.7123
SWLP5,5,3.2,300,25,0.3	/	1668.913125	0.052	2915.1174
SWLP5,5,3.2,300,30,0.3	/	1837.487054	0.05	2970.7165
SWLP5,5,3.2,415,25,0.3	/	1687.722454	0.052	3223.1529
SWLP5,5,3.2,415,30,0.3	/	1854.650594	0.049	3285.0707
SWLP5,5,3.6,300,25,0.25	/	1219.45616	0.059	2272.6853
SWLP5,5,3.6,300,30,0.25	/	1345.153383	0.056	2347.4582
SWLP5,5,3.6,415,25,0.25	/	1234.245401	0.059	2570.3752
SWLP5,5,3.6,415,30,0.25	/	1358.354741	0.056	2613.2101
SWLP5,5,3.6,300,25,0.3	/	1466.908898	0.055	2596.1609
SWLP5,5,3.6,300,30,0.3	/	1618.420518	0.052	2786.3549
SWLP5,5,3.6,415,25,0.3	/	1486.333792	0.055	2921.5438
SWLP5,5,3.6,415,30,0.3	/	1635.585329	0.052	2968.7613
SWLP5,6,3.2,300,25,0.25	/	1624.584934	0.062	3813.3675
SWLP5,6,3.2,300,30,0.25	/	1791.680907	0.059	3904.1578
SWLP5,6,3.2,415,25,0.25	/	1715.075632	0.062	4140.034
SWLP5,6,3.2,415,30,0.25	/	1877.527185	0.059	4251.8135
SWLP5,6,3.2,300,25,0.3	/	1992.215846	0.058	4400.6279
SWLP5,6,3.2,300,30,0.3	/	2194.62149	0.056	4487.5084
SWLP5,6,3.2,415,25,0.3	/	1824.063418	0.058	4628.2142

SWLP5,6,3.2,415,30,0.3	/	2282.676941	0.055	4885.3302
SWLP5,6,3.6,300,25,0.25	/	1624.113065	0.064	3447.4647
SWLP5,6,3.6,300,30,0.25	/	1777.65238	0.061	3522.7696
SWLP5,6,3.6,415,25,0.25	/	1573.599783	0.064	3765.2511
SWLP5,6,3.6,415,30,0.25	/	1728.536975	0.061	3869.24
SWLP5,6,3.6,300,25,0.3	/	1976.168564	0.06	3977.5936
SWLP5,6,3.6,300,30,0.3	/	2110.596718	0.058	4073.7338
SWLP5,6,3.6,415,25,0.3	/	1976.168564	0.06	4181.6411
SWLP5,6,3.6,415,30,0.3	/	2110.596718	0.058	4453.0132
SWMP5,5,3.2,300,25,0.25	/	108.560969	0.293	1356.5778
SWMP5,5,3.2,300,30,0.25	/	118.806223	0.28	1393.8896
SWMP5,5,3.2,415,25,0.25	/	108.60127	0.293	1569.7967
SWMP5,5,3.2,415,30,0.25	/	118.838673	0.28	1610.9746
SWMP5,5,3.2,300,25,0.3	/	127.610878	0.272	1473.8711
SWMP5,5,3.2,300,30,0.3	/	139.594432	0.26	1517.6723
SWMP5,5,3.2,415,25,0.3	/	117.298728	0.285	1666.4838
SWMP5,5,3.2,415,30,0.3	/	139.58028	0.26	1739.0457
SWMP5,5,3.6,300,25,0.25	/	78.896513	0.345	1214.8427
SWMP5,5,3.6,300,30,0.25	/	86.712886	0.329	1242.7308
SWMP5,5,3.6,415,25,0.25	/	78.183473	0.347	1414.6357
SWMP5,5,3.6,415,30,0.25	/	86.212111	0.33	1450.2727
SWMP5,5,3.6,300,25,0.3	/	92.782338	0.321	1317.4795
SWMP5,5,3.6,300,30,0.3	/	101.712086	0.306	1344.9903
SWMP5,5,3.6,415,25,0.3	/	91.851057	0.323	1526.9515
SWMP5,5,3.6,415,30,0.3	/	101.115752	0.307	1562.6812
SWMP5,6,3.2,300,25,0.25	/	166.473773	0.26	1732.7665
SWMP5,6,3.2,300,30,0.25	/	182.107106	0.249	1791.809
SWMP5,6,3.2,415,25,0.25	/	166.699498	0.26	1920.2325
SWMP5,6,3.2,415,30,0.25	/	169.037002	0.258	2006.6053
SWMP5,6,3.2,300,25,0.3	/	198.517361	0.241	1908.7949
SWMP5,6,3.2,300,30,0.3	/	217.014047	0.23	1970.4452

SWMP5,6,3.2,415,25,0.3	/	198.040539	0.241	2079.9125
SWMP5,6,3.2,415,30,0.3	/	216.59961	0.23	2196.1317
SWMP5,6,3.6,300,25,0.25	/	123.129987	0.305	1560.6895
SWMP5,6,3.6,300,30,0.25	/	134.538484	0.291	1610.2334
SWMP5,6,3.6,415,25,0.25	/	119.200458	0.308	1712.3982
SWMP5,6,3.6,415,30,0.25	/	131.534723	0.293	1808.914
SWMP5,6,3.6,300,25,0.3	/	147.429162	0.283	1717.1139
SWMP5,6,3.6,300,30,0.3	/	160.865594	0.27	1769.2549
SWMP5,6,3.6,415,25,0.3	/	142.436906	0.284	1881.0323
SWMP5,6,3.6,415,30,0.3	/	156.61979	0.271	1979.0387

Appendix 3

Results of elastic stiffness factor, natural time period and maximum base shear of Shear wall with opening 2×1

Frame Type	Opening	Ki (kN/mm)	Natural time period (Sec)	Fu Max (kN)
SWLP1,5,3.2,300,25,0.25	2×1	728.007992	0.03	1980.8779
SWLP1,5,3.2,300,30,0.25	2×1	794.453955	0.029	2033.6053
SWLP1,5,3.2,415,25,0.25	2×1	728.007992	0.03	1989.5594
SWLP1,5,3.2,415,30,0.25	2×1	794.453955	0.029	2096.181
SWLP1,5,3.2,300,25,0.3	2×1	904.060286	0.027	2074.1652
SWLP1,5,3.2,300,30,0.3	2×1	987.416375	0.026	2168.0405
SWLP1,5,3.2,415,25,0.3	2×1	904.060286	0.027	2202.6599
SWLP1,5,3.2,415,30,0.3	2×1	987.416375	0.026	2560.8321
SWLP1,5,3.6,300,25,0.25	2×1	740.562365	0.03	1801.6842
SWLP1,5,3.6,300,30,0.25	2×1	808.72411	0.029	1839.9773
SWLP1,5,3.6,415,25,0.25	2×1	740.562365	0.03	1864.4208
SWLP1,5,3.6,415,30,0.25	2×1	808.72411	0.029	1904.3522
SWLP1,5,3.6,300,25,0.3	2×1	919.540398	0.028	2203.8267
SWLP1,5,3.6,300,30,0.3	2×1	1122.090498	0.025	2250.4118
SWLP1,5,3.6,415,25,0.3	2×1	919.540398	0.028	2280.3172
SWLP1,5,3.6,415,30,0.3	2×1	1122.090498	0.025	2392.9046
SWLP1,6,3.2,300,25,0.25	2×1	1301.498601	0.026	2710.2138
SWLP1,6,3.2,300,30,0.25	2×1	1425.635851	0.025	2808.4954
SWLP1,6,3.2,420,25,0.25	2×1	1301.498601	0.026	3392.504
SWLP1,6,3.2,420,30,0.25	2×1	1425.635851	0.025	3166.6442
SWLP1,6,3.2,300,25,0.3	2×1	1644.061514	0.024	3303.0339
SWLP1,6,3.2,300,30,0.3	2×1	1800.667594	0.023	3424.198
SWLP1,6,3.2,415,25,0.3	2×1	1644.061514	0.024	3687.1125
SWLP1,6,3.2,415,30,0.3	2×1	1800.667594	0.023	3744.5834
SWLP1,6,3.6,300,25,0.25	2×1	1287.078179	0.027	3024.098

SWLP1,6,3.6,300,30,0.25	2×1	1409.940874	0.026	3092.2387
SWLP1,6,3.6,415,25,0.25	2×1	1287.078179	0.027	2796.688
SWLP1,6,3.6,415,30,0.25	2×1	1409.940874	0.026	2899.2299
SWLP1,6,3.6,300,25,0.3	2×1	1622.654862	0.025	3709.7239
SWLP1,6,3.6,300,30,0.3	2×1	1777.419789	0.024	3205.7601
SWLP1,6,3.6,415,25,0.3	2×1	1622.654862	0.025	3836.8063
SWLP1,6,3.6,415,30,0.3	2×1	1777.419789	0.024	3920.5686
SWMP1,5,3.2,300,25,0.25	2×1	76.189576	0.169	694.8141
SWMP1,5,3.2,300,30,0.25	2×1	82.855439	0.162	723.4407
SWMP1,5,3.2,415,25,0.25	2×1	76.189576	0.169	718.9156
SWMP1,5,3.2,415,30,0.25	2×1	82.855439	0.162	742.4588
SWMP1,5,3.2,300,25,0.3	2×1	91.548212	0.159	818.2282
SWMP1,5,3.2,300,30,0.3	2×1	99.409629	0.153	851.9285
SWMP1,5,3.2,415,25,0.3	2×1	91.548212	0.159	844.742
SWMP1,5,3.2,415,30,0.3	2×1	99.409629	0.153	873.5738
SWMP1,5,3.6,300,25,0.25	2×1	57.535697	0.197	626.6586
SWMP1,5,3.6,300,30,0.25	2×1	62.609393	0.189	651.7163
SWMP1,5,3.6,420,25,0.25	2×1	57.535697	0.197	649.4336
SWMP1,5,3.6,420,30,0.25	2×1	62.609393	0.189	669.993
SWMP1,5,3.6,300,25,0.3	2×1	69.112164	0.187	738.4627
SWMP1,5,3.6,300,30,0.3	2×1	75.022529	0.179	769.2719
SWMP1,5,3.6,415,25,0.3	2×1	69.112164	0.187	763.5689
SWMP1,5,3.6,415,30,0.3	2×1	75.022529	0.179	788.8204
SWMP1,6,3.2,300,25,0.25	2×1	138.27629	0..16	1148.5453
SWMP1,6,3.2,300,30,0.25	2×1	146.08749	0.157	1191.5996
SWMP1,6,3.2,415,25,0.25	2×1	138.27629	0..16	1196.2359
SWMP1,6,3.2,415,30,0.25	2×1	151.316653	0.153	1231.3974
SWMP1,6,3.2,300,25,0.3	2×1	161.710481	0.156	1353.4619
SWMP1,6,3.2,300,30,0.3	2×1	183.596488	0.146	1407.5685
SWMP1,6,3.2,415,25,0.3	2×1	167.786251	0.153	1409.1685
SWMP1,6,3.2,415,30,0.3	2×1	183.596488	0.146	1451.0252

SWMP1,6,3.6,300,25,0.25	2×1	102.523267	0.192	1050.2042
SWMP1,6,3.6,300,30,0.25	2×1	111.813175	0.184	1088.6818
SWMP1,6,3.6,415,25,0.25	2×1	102.523267	0.192	1095.0472
SWMP1,6,3.6,415,30,0.25	2×1	111.813175	0.184	1128.109
SWMP1,6,3.6,300,25,0.3	2×1	127.756371	0.18	1239.218
SWMP1,6,3.6,300,30,0.3	2×1	139.779986	0.172	1285.6354
SWMP1,6,3.6,415,25,0.3	2×1	127.756371	0.18	1291.0432
SWMP1,6,3.6,415,30,0.3	2×1	139.779986	0.172	1330.5031
SWLP5,5,3.2,300,25,0.25	2×1	793.133965	0.069	2440.3309
SWLP5,5,3.2,300,30,0.25	2×1	874.991321	0.066	2574.5804
SWLP5,5,3.2,415,25,0.25	2×1	800.622479	0.069	2794.9846
SWLP5,5,3.2,415,30,0.25	2×1	881.935497	0.066	2860.2529
SWLP5,5,3.2,300,25,0.3	2×1	943.217064	0.065	2876.0051
SWLP5,5,3.2,300,30,0.3	2×1	1040.873906	0.62	2312.9858
SWLP5,5,3.2,415,25,0.3	2×1	954.391986	0.064	3163.5021
SWLP5,5,3.2,415,30,0.3	2×1	1051.121727	0.061	2628.5179
SWLP5,5,3.6,300,25,0.25	2×1	750.618714	0.072	2239.943
SWLP5,5,3.6,300,30,0.25	2×1	832.203656	0.068	2283.3641
SWLP5,5,3.6,415,25,0.25	2×1	773.081196	0.071	2512.6093
SWLP5,5,3.6,415,30,0.25	2×1	853.39955	0.068	2569.523
SWLP5,5,3.6,300,25,0.3	2×1	910.596688	0.066	2554.9731
SWLP5,5,3.6,300,30,0.3	2×1	1008.182406	0.063	2603.9564
SWLP5,5,3.6,415,25,0.3	2×1	932.231683	0.066	2843.6848
SWLP5,5,3.6,415,30,0.3	2×1	1026.832564	0.063	2900.9154
SWLP5,6,3.2,300,25,0.25	2×1	1283.294846	0.072	2852.4478
SWLP5,6,3.2,300,30,0.25	2×1	1378.889589	0.069	2930.4693
SWLP5,6,3.2,415,25,0.25	2×1	1121.306645	0.072	3285.4837
SWLP5,6,3.2,415,30,0.25	2×1	1229.742846	0.069	3386.8448
SWLP5,6,3.2,300,25,0.3	2×1	1389.253231	0.067	3373.3069
SWLP5,6,3.2,300,30,0.3	2×1	1520.542818	0.064	3461.1724
SWLP5,6,3.2,415,25,0.3	2×1	1345.111336	0.067	3836.1205

SWLP5,6,3.2,415,30,0.3	2×1	1476.799269	0.064	3783.437
SWLP5,6,3.6,300,25,0.25	2×1	1317.850944	0.074	2500.9179
SWLP5,6,3.6,300,30,0.25	2×1	1393.1948	0.071	3336.1632
SWLP5,6,3.6,415,25,0.25	2×1	1054.243416	0.075	2863.3136
SWLP5,6,3.6,415,30,0.25	2×1	1160.92025	0.071	2955.2694
SWLP5,6,3.6,300,25,0.3	2×1	1468.290379	0.069	3769.2932
SWLP5,6,3.6,300,30,0.3	2×1	1581.214583	0.066	3034.258
SWLP5,6,3.6,415,25,0.3	2×1	1266.847922	0.07	3339.9889
SWLP5,6,3.6,415,30,0.3	2×1	1396.560513	0.066	3448.1966
SWMP5,5,3.2,300,25,0.25	2×1	91.660313	0.323	1259.2714
SWMP5,5,3.2,300,30,0.25	2×1	101.065766	0.308	1314.302
SWMP5,5,3.2,415,25,0.25	2×1	92.112379	0.323	1327.4623
SWMP5,5,3.2,415,30,0.25	2×1	101.230069	0.308	1422.4862
SWMP5,5,3.2,300,25,0.3	2×1	108.293725	0.3	1378.3948
SWMP5,5,3.2,300,30,0.3	2×1	118.837369	0.286	1464.0353
SWMP5,5,3.2,415,25,0.3	2×1	108.406922	0.299	1465.1073
SWMP5,5,3.2,415,30,0.3	2×1	118.901053	0.286	1574.4127
SWMP5,5,3.6,300,25,0.25	2×1	70.604456	0.369	1194.0901
SWMP5,5,3.6,300,30,0.25	2×1	73.973263	0.361	1204.6927
SWMP5,5,3.6,415,25,0.25	2×1	70.604456	0.369	1340.141
SWMP5,5,3.6,415,30,0.25	2×1	74.305358	0.36	1408.6119
SWMP5,5,3.6,300,25,0.3	2×1	79.225341	0.352	1274.3772
SWMP5,5,3.6,300,30,0.3	2×1	87.904649	0.333	1328.0239
SWMP5,5,3.6,415,25,0.3	2×1	78.82189	0.353	1439.9315
SWMP5,5,3.6,415,30,0.3	2×1	87.549347	0.334	1466.8638
SWMP5,6,3.2,300,25,0.25	2×1	139.580135	0.287	1530.5586
SWMP5,6,3.2,300,30,0.25	2×1	153.515662	0.274	1667.4109
SWMP5,6,3.2,415,25,0.25	2×1	141.176912	0.286	1613.1537
SWMP5,6,3.2,415,30,0.25	2×1	154.87001	0.273	1742.9397
SWMP5,6,3.2,300,25,0.3	2×1	166.746682	0.265	1874.3788
SWMP5,6,3.2,300,30,0.3	2×1	183.130202	0.253	1942.9251

SWMP5,6,3.2,415,25,0.3	2×1	168.004472	0.264	1833.3617
SWMP5,6,3.2,415,30,0.3	2×1	169.878123	0.263	1434.8144
SWMP5,6,3.6,300,25,0.25	2×1	109.222462	0.326	1382.9897
SWMP5,6,3.6,300,30,0.25	2×1	119.387012	0.312	1488.0281
SWMP5,6,3.6,415,25,0.25	2×1	105.378348	0.331	1440.3041
SWMP5,6,3.6,415,30,0.25	2×1	116.508591	0.314	1562.0361
SWMP5,6,3.6,300,25,0.3	2×1	130.2483	0.302	1582.449
SWMP5,6,3.6,300,30,0.3	2×1	142.205026	0.289	1716.4607
SWMP5,6,3.6,415,25,0.3	2×1	126.115203	0.305	1636.6428
SWMP5,6,3.6,415,30,0.3	2×1	138.943175	0.29	1785.9683

Appendix 4

Results of elastic stiffness factor, natural time period and maximum base shear of Shear wall with opening 2×1.5

Frame Type	Opening	Ki (kN/mm)	Natural time period (Sec)	Fu Max (kN)
SWLP1,5,3.2,300,25,0.25	2×1.5	604.055327	0.033	1631.4996
SWLP1,5,3.2,300,30,0.25	2×1.5	661.58401	0.031	1671.0167
SWLP1,5,3.2,415,25,0.25	2×1.5	604.055327	0.033	1731.4996
SWLP1,5,3.2,415,30,0.25	2×1.5	661.58401	0.031	1771.0167
SWLP1,5,3.2,300,25,0.3	2×1.5	751.802527	0.03	1802.5333
SWLP1,5,3.2,300,30,0.3	2×1.5	823.327794	0.029	1855.0949
SWLP1,5,3.2,415,25,0.3	2×1.5	751.802527	0.03	2114.8165
SWLP1,5,3.2,415,30,0.3	2×1.5	823.327794	0.029	2139.103
SWLP1,5,3.6,300,25,0.25	2×1.5	541.549641	0.035	1649.2658
SWLP1,5,3.6,300,30,0.25	2×1.5	591.163863	0.034	1486.8153
SWLP1,5,3.6,415,25,0.25	2×1.5	541.549641	0.035	1689.0026
SWLP1,5,3.6,415,30,0.25	2×1.5	591.163863	0.034	1634.8992
SWLP1,5,3.6,300,25,0.3	2×1.5	672.402559	0.032	1728.55
SWLP1,5,3.6,300,30,0.3	2×1.5	734.104693	0.031	1810.3537
SWLP1,5,3.6,415,25,0.3	2×1.5	672.402559	0.032	2080.8055
SWLP1,5,3.6,415,30,0.3	2×1.5	734.104693	0.031	1991.1482
SWLP1,6,3.2,300,25,0.25	2×1.5	928.046824	0.031	2575.8109
SWLP1,6,3.2,300,30,0.25	2×1.5	1013.756347	0.03	2667.3089
SWLP1,6,3.2,420,25,0.25	2×1.5	928.046824	0.031	2765.9101
SWLP1,6,3.2,420,30,0.25	2×1.5	1013.756347	0.03	3064.4105
SWLP1,6,3.2,300,25,0.3	2×1.5	1165.254463	0.029	3206.3818
SWLP1,6,3.2,300,30,0.3	2×1.5	1446.653436	0.026	3297.1079
SWLP1,6,3.2,415,25,0.3	2×1.5	1165.254463	0.029	3386.0394
SWLP1,6,3.2,415,30,0.3	2×1.5	1446.653436	0.026	3750.1646
SWLP1,6,3.6,300,25,0.25	2×1.5	1016.067687	0.031	2369.5506

SWLP1,6,3.6,300,30,0.25	2×1.5	1112.735636	0.29	2450.2927
SWLP1,6,3.6,415,25,0.25	2×1.5	1016.067687	0.031	2718.0572
SWLP1,6,3.6,415,30,0.25	2×1.5	1112.735636	0.29	2780.5225
SWLP1,6,3.6,300,25,0.3	2×1.5	1278.757225	0.028	2882.3201
SWLP1,6,3.6,300,30,0.3	2×1.5	1400.373491	0.027	2990.5148
SWLP1,6,3.6,415,25,0.3	2×1.5	1278.757225	0.028	3321.1533
SWLP1,6,3.6,415,30,0.3	2×1.5	1400.373491	0.027	3399.2794
SWMP1,5,3.2,300,25,0.25	2×1.5	68.670748	0.178	673.9957
SWMP1,5,3.2,300,30,0.25	2×1.5	74.647464	0.17	715.6957
SWMP1,5,3.2,415,25,0.25	2×1.5	68.670748	0.178	668.1125
SWMP1,5,3.2,415,30,0.25	2×1.5	74.647464	0.17	712.9219
SWMP1,5,3.2,300,25,0.3	2×1.5	82.456064	0.167	790.8657
SWMP1,5,3.2,300,30,0.3	2×1.5	89.404476	0.161	841.4626
SWMP1,5,3.2,415,25,0.3	2×1.5	82.456064	0.167	789.6312
SWMP1,5,3.2,415,30,0.3	2×1.5	89.404476	0.161	833.6691
SWMP1,5,3.6,300,25,0.25	2×1.5	53.72604	0.204	620.9056
SWMP1,5,3.6,300,30,0.25	2×1.5	58.497248	0.195	645.9732
SWMP1,5,3.6,420,25,0.25	2×1.5	53.72604	0.204	641.4187
SWMP1,5,3.6,420,30,0.25	2×1.5	58.497248	0.195	663.5784
SWMP1,5,3.6,300,25,0.3	2×1.5	64.579246	0.192	731.3171
SWMP1,5,3.6,300,30,0.3	2×1.5	70.143628	0.185	761.6431
SWMP1,5,3.6,415,25,0.3	2×1.5	64.579246	0.192	752.9082
SWMP1,5,3.6,415,30,0.3	2×1.5	70.143628	0.185	780.9364
SWMP1,6,3.2,300,25,0.25	2×1.5	123.408521	0.169	1130.2044
SWMP1,6,3.2,300,30,0.25	2×1.5	135.06107	0.161	1174.3604
SWMP1,6,3.2,415,25,0.25	2×1.5	123.408521	0.169	1176.4192
SWMP1,6,3.2,415,30,0.25	2×1.5	135.06107	0.161	1213.271
SWMP1,6,3.2,300,25,0.3	2×1.5	149.751078	0.161	1332.1141
SWMP1,6,3.2,300,30,0.3	2×1.5	157.826963	0.157	1181.5542
SWMP1,6,3.2,415,25,0.3	2×1.5	149.751078	0.161	1385.0822
SWMP1,6,3.2,415,30,0.3	2×1.5	157.826963	0.157	1269.9957

SWMP1,6,3.6,300,25,0.25	2×1.5	95.442069	0.197	1036.0152
SWMP1,6,3.6,300,30,0.25	2×1.5	104.126219	0.189	1074.6555
SWMP1,6,3.6,415,25,0.25	2×1.5	95.442069	0.197	1079.8712
SWMP1,6,3.6,415,30,0.25	2×1.5	104.126219	0.189	1112.2975
SWMP1,6,3.6,300,25,0.3	2×1.5	115.200456	0.189	1222.0811
SWMP1,6,3.6,300,30,0.3	2×1.5	129.985827	0.178	1269.5723
SWMP1,6,3.6,415,25,0.3	2×1.5	115.200456	0.189	1272.8339
SWMP1,6,3.6,415,30,0.3	2×1.5	129.985827	0.178	1311.9878
SWLP5,5,3.2,300,25,0.25	2×1.5	611.610253	0.077	2065.4819
SWLP5,5,3.2,300,30,0.25	2×1.5	674.954923	0.074	2114.926
SWLP5,5,3.2,415,25,0.25	2×1.5	612.122738	0.077	2357.255
SWLP5,5,3.2,415,30,0.25	2×1.5	675.473499	0.074	2512.0775
SWLP5,5,3.2,300,25,0.3	2×1.5	713.881202	0.073	2044.6262
SWLP5,5,3.2,300,30,0.3	2×1.5	800.496696	0.069	2691.3782
SWLP5,5,3.2,415,25,0.3	2×1.5	728.054354	0.072	2387.6736
SWLP5,5,3.2,415,30,0.3	2×1.5	803.341114	0.069	2825.0026
SWLP5,5,3.6,300,25,0.25	2×1.5	583.595685	0.08	1712.0514
SWLP5,5,3.6,300,30,0.25	2×1.5	645.273925	0.076	1773.1942
SWLP5,5,3.6,415,25,0.25	2×1.5	589.151823	0.08	1964.4384
SWLP5,5,3.6,415,30,0.25	2×1.5	650.399662	0.076	2034.4988
SWLP5,5,3.6,300,25,0.3	2×1.5	693.328266	0.074	1952.3489
SWLP5,5,3.6,300,30,0.3	2×1.5	767.093469	0.071	2022.5951
SWLP5,5,3.6,415,25,0.3	2×1.5	702.121489	0.074	2255.6592
SWLP5,5,3.6,415,30,0.3	2×1.5	775.061651	0.07	2325.9454
SWLP5,6,3.2,300,25,0.25	2×1.5	1021.003717	0.077	3077.6929
SWLP5,6,3.2,300,30,0.25	2×1.5	1117.658898	0.074	3127.8292
SWLP5,6,3.2,415,25,0.25	2×1.5	896.031769	0.078	3498.2349
SWLP5,6,3.2,415,30,0.25	2×1.5	1030.496234	0.074	3634.9061
SWLP5,6,3.2,300,25,0.3	2×1.5	1140.318254	0.072	3489.9089
SWLP5,6,3.2,300,30,0.3	2×1.5	1290.276009	0.069	3579.6991
SWLP5,6,3.2,415,25,0.3	2×1.5	1087.588243	0.073	3807.8561

SWLP5,6,3.2,415,30,0.3	2×1.5	1111.070159	0.071	3948.6698
SWLP5,6,3.6,300,25,0.25	2×1.5	1230.597756	0.08	2551.9865
SWLP5,6,3.6,300,30,0.25	2×1.5	1284.062742	0.077	2616.3709
SWLP5,6,3.6,415,25,0.25	2×1.5	880.810855	0.08	2955.0541
SWLP5,6,3.6,415,30,0.25	2×1.5	953.628155	0.077	3,025
SWLP5,6,3.6,300,25,0.3	2×1.5	1442.327604	0.075	2937.4083
SWLP5,6,3.6,300,30,0.3	2×1.5	1507.949832	0.071	3020.3392
SWLP5,6,3.6,415,25,0.3	2×1.5	1040.077679	0.075	3407.7115
SWLP5,6,3.6,415,30,0.3	2×1.5	1143.562069	0.072	3497.5311
SWMP5,5,3.2,300,25,0.25	2×1.5	81.212207	0.346	1258.4673
SWMP5,5,3.2,300,30,0.25	2×1.5	89.731632	0.329	1306.7782
SWMP5,5,3.2,415,25,0.25	2×1.5	81.993528	0.344	979.7295
SWMP5,5,3.2,415,30,0.25	2×1.5	90.364628	0.328	1398.9693
SWMP5,5,3.2,300,25,0.3	2×1.5	97.26737	0.319	1163.5679
SWMP5,5,3.2,300,30,0.3	2×1.5	104.762782	0.307	1260.6612
SWMP5,5,3.2,415,25,0.3	2×1.5	96.190283	0.32	1010.3844
SWMP5,5,3.2,415,30,0.3	2×1.5	105.991684	0.305	1331.2864
SWMP5,5,3.6,300,25,0.25	2×1.5	65.266804	0.386	1180.4843
SWMP5,5,3.6,300,30,0.25	2×1.5	71.80824	0.368	1105.481
SWMP5,5,3.6,415,25,0.25	2×1.5	58.221511	0.411	989.7701
SWMP5,5,3.6,415,30,0.25	2×1.5	65.24879	0.388	1028.8318
SWMP5,5,3.6,300,25,0.3	2×1.5	76.813599	0.358	1270.7233
SWMP5,5,3.6,300,30,0.3	2×1.5	84.274115	0.342	1233.5056
SWMP5,5,3.6,415,25,0.3	2×1.5	69.459641	0.379	955.9984
SWMP5,5,3.6,415,30,0.3	2×1.5	77.686036	0.358	1016.5646
SWMP5,6,3.2,300,25,0.25	2×1.5	125.717322	0.304	1410.6649
SWMP5,6,3.2,300,30,0.25	2×1.5	137.959171	0.29	1483.2354
SWMP5,6,3.2,415,25,0.25	2×1.5	126.469448	0.303	1487.1216
SWMP5,6,3.2,415,30,0.25	2×1.5	135.574471	0.293	1603.2622
SWMP5,6,3.2,300,25,0.3	2×1.5	148.81543	0.282	1601.1385
SWMP5,6,3.2,300,30,0.3	2×1.5	163.595722	0.268	1694.2796

SWMP5,6,3.2,415,25,0.3	2×1.5	150.238712	0.281	1695.7347
SWMP5,6,3.2,415,30,0.3	2×1.5	164.441856	0.268	1802.1587
SWMP5,6,3.6,300,25,0.25	2×1.5	99.550018	0.342	1432.4469
SWMP5,6,3.6,300,30,0.25	2×1.5	109.944676	0.325	1350.6754
SWMP5,6,3.6,415,25,0.25	2×1.5	100.445437	0.34	1342.0346
SWMP5,6,3.6,415,30,0.25	2×1.5	110.277176	0.325	1424.528
SWMP5,6,3.6,300,25,0.3	2×1.5	118.866761	0.315	1502.07
SWMP5,6,3.6,300,30,0.3	2×1.5	130.40298	0.301	1553.2366
SWMP5,6,3.6,415,25,0.3	2×1.5	109.857636	0.329	1200.134
SWMP5,6,3.6,415,30,0.3	2×1.5	122.285642	0.312	1272.7242

Appendix 5

Results of elastic stiffness factor, natural time period and maximum base shear of Shear wall with opening 2×2

Frame Type	Opening	Ki (kN/mm)	Natural time period (Sec)	Fu Max (kN)
SWLP1,5,3.2,300,25,0.25	2×2	440.527519	0.038	1060.9071
SWLP1,5,3.2,300,30,0.25	2×2	482.273393	0.036	1129.9228
SWLP1,5,3.2,415,25,0.25	2×2	440.527519	0.038	1127.236
SWLP1,5,3.2,415,30,0.25	2×2	482.273393	0.036	1207.3957
SWLP1,5,3.2,300,25,0.3	2×2	546.5465	0.035	1282.308
SWLP1,5,3.2,300,30,0.3	2×2	598.219651	0.033	1373.1683
SWLP1,5,3.2,415,25,0.3	2×2	546.5465	0.035	1378.0829
SWLP1,5,3.2,415,30,0.3	2×2	598.219651	0.033	1468.3013
SWLP1,5,3.6,300,25,0.25	2×2	441.457624	0.039	1040.1614
SWLP1,5,3.6,300,30,0.25	2×2	483.38984	0.037	1106.1772
SWLP1,5,3.6,415,25,0.25	2×2	441.457624	0.039	1107.5882
SWLP1,5,3.6,415,30,0.25	2×2	483.38984	0.037	1169.2241
SWLP1,5,3.6,300,25,0.3	2×2	548.738464	0.035	1261.2056
SWLP1,5,3.6,300,30,0.3	2×2	600.803006	0.034	1414.4311
SWLP1,5,3.6,415,25,0.3	2×2	548.738464	0.035	1344.8961
SWLP1,5,3.6,415,30,0.3	2×2	600.803006	0.034	1205.2504
SWLP1,6,3.2,300,25,0.25	2×2	840.077685	0.033	2449.7421
SWLP1,6,3.2,300,30,0.25	2×2	919.639848	0.031	2608.8359
SWLP1,6,3.2,420,25,0.25	2×2	840.077685	0.033	2596.1001
SWLP1,6,3.2,420,30,0.25	2×2	919.639848	0.031	2754.7649
SWLP1,6,3.2,300,25,0.3	2×2	1055.430448	0.03	2982.0039
SWLP1,6,3.2,300,30,0.3	2×2	1155.313785	0.029	3214.8217
SWLP1,6,3.2,415,25,0.3	2×2	1055.430448	0.03	3178.7367
SWLP1,6,3.2,415,30,0.3	2×2	1155.313785	0.029	3371.2095
SWLP1,6,3.6,300,25,0.25	2×2	804.07018	0.035	2257.5301

SWLP1,6,3.6,300,30,0.25	2×2	880.314553	0.033	2396.8399
SWLP1,6,3.6,415,25,0.25	2×2	804.07018	0.035	2407.6257
SWLP1,6,3.6,415,30,0.25	2×2	880.314553	0.033	2553.5873
SWLP1,6,3.6,300,25,0.3	2×2	1009.539967	0.032	2753.1451
SWLP1,6,3.6,300,30,0.3	2×2	1105.171265	0.031	2924.4196
SWLP1,6,3.6,415,25,0.3	2×2	1009.539967	0.032	2940.9194
SWLP1,6,3.6,415,30,0.3	2×2	1105.171265	0.031	3117.7337
SWMP1,5,3.2,300,25,0.25	2×2	56.562516	0.196	528.0407
SWMP1,5,3.2,300,30,0.25	2×2	61.677539	0.187	555.2101
SWMP1,5,3.2,415,25,0.25	2×2	56.562516	0.196	544.298
SWMP1,5,3.2,415,30,0.25	2×2	61.677539	0.187	567.6885
SWMP1,5,3.2,300,25,0.3	2×2	68.051925	0.184	613.354
SWMP1,5,3.2,300,30,0.3	2×2	74.175016	0.176	658.1414
SWMP1,5,3.2,415,25,0.3	2×2	68.051925	0.184	631.1935
SWMP1,5,3.2,415,30,0.3	2×2	74.172824	0.176	658.9785
SWMP1,5,3.6,300,25,0.25	2×2	47.891683	0.216	561.4048
SWMP1,5,3.6,300,30,0.25	2×2	54.561607	0.201	597.934
SWMP1,5,3.6,420,25,0.25	2×2	47.891683	0.216	558.8197
SWMP1,5,3.6,420,30,0.25	2×2	54.561607	0.201	593.6065
SWMP1,5,3.6,300,25,0.3	2×2	60.457355	0.197	659.6552
SWMP1,5,3.6,300,30,0.3	2×2	62.402471	0.196	702.7887
SWMP1,5,3.6,415,25,0.3	2×2	60.457355	0.197	650.3448
SWMP1,5,3.6,415,30,0.3	2×2	62.402471	0.196	673.1201
SWMP1,6,3.2,300,25,0.25	2×2	96.923952	0.19	1015.7996
SWMP1,6,3.2,300,30,0.25	2×2	105.873358	0.182	905.6842
SWMP1,6,3.2,415,25,0.25	2×2	96.923952	0.19	1076.8932
SWMP1,6,3.2,415,30,0.25	2×2	105.873358	0.182	914.5618
SWMP1,6,3.2,300,25,0.3	2×2	117.111173	0.181	1012.2534
SWMP1,6,3.2,300,30,0.3	2×2	127.805018	0.174	1056.1304
SWMP1,6,3.2,415,25,0.3	2×2	117.111173	0.181	1250.4543
SWMP1,6,3.2,415,30,0.3	2×2	127.805018	0.174	1075.1849

SWMP1,6,3.6,300,25,0.25	2×2	86.622671	0.206	1021.2061
SWMP1,6,3.6,300,30,0.25	2×2	92.518369	0.2	914.7401
SWMP1,6,3.6,415,25,0.25	2×2	86.622671	0.206	1034.7811
SWMP1,6,3.6,415,30,0.25	2×2	92.518369	0.2	933.8785
SWMP1,6,3.6,300,25,0.3	2×2	102.315519	0.2	1204.6639
SWMP1,6,3.6,300,30,0.3	2×2	111.76381	0.191	1077.8575
SWMP1,6,3.6,415,25,0.3	2×2	102.315519	0.2	1150.5123
SWMP1,6,3.6,415,30,0.3	2×2	111.76381	0.191	1293.3491
SWLP5,5,3.2,300,25,0.25	2×2	455.893174	0.088	1557.372
SWLP5,5,3.2,300,30,0.25	2×2	504.401961	0.083	1641.9001
SWLP5,5,3.2,415,25,0.25	2×2	452.249154	0.088	2037.1965
SWLP5,5,3.2,415,30,0.25	2×2	501.23639	0.083	1855.7574
SWLP5,5,3.2,300,25,0.3	2×2	538.406591	0.082	1751.3511
SWLP5,5,3.2,300,30,0.3	2×2	596.012199	0.078	1853.9222
SWLP5,5,3.2,415,25,0.3	2×2	535.791453	0.082	1964.7233
SWLP5,5,3.2,415,30,0.3	2×2	593.987163	0.078	2071.9235
SWLP5,5,3.6,300,25,0.25	2×2	440.191883	0.09	1371.5705
SWLP5,5,3.6,300,30,0.25	2×2	487.11815	0.086	1487.7314
SWLP5,5,3.6,415,25,0.25	2×2	439.069713	0.09	1452.3303
SWLP5,5,3.6,415,30,0.25	2×2	486.266239	0.086	1638.8329
SWLP5,5,3.6,300,25,0.3	2×2	520.747291	0.084	1561.0944
SWLP5,5,3.6,300,30,0.3	2×2	576.858826	0.08	1685.1433
SWLP5,5,3.6,415,25,0.3	2×2	522.017334	0.084	1652.495
SWLP5,5,3.6,415,30,0.3	2×2	578.03433	0.08	1766.6323
SWLP5,6,3.2,300,25,0.25	2×2	843.274026	0.084	2830.8683
SWLP5,6,3.2,300,30,0.25	2×2	906.255459	0.08	3013.009
SWLP5,6,3.2,415,25,0.25	2×2	748.627004	0.084	3082.6962
SWLP5,6,3.2,415,30,0.25	2×2	819.001452	0.08	3266.7706
SWLP5,6,3.2,300,25,0.3	2×2	1029.996786	0.078	3253.5892
SWLP5,6,3.2,300,30,0.3	2×2	1035.354687	0.075	3469.636
SWLP5,6,3.2,415,25,0.3	2×2	817.4894	0.081	3248.7202

SWLP5,6,3.2,415,30,0.3	2×2	897.399884	0.077	2594.8602
SWLP5,6,3.6,300,25,0.25	2×2	931.760303	0.087	2547.7835
SWLP5,6,3.6,300,30,0.25	2×2	978.799973	0.084	2697.1376
SWLP5,6,3.6,415,25,0.25	2×2	711.310563	0.087	2793.4049
SWLP5,6,3.6,415,30,0.25	2×2	778.734966	0.083	2952.3734
SWLP5,6,3.6,300,25,0.3	2×2	1106.921546	0.081	2935.0134
SWLP5,6,3.6,300,30,0.3	2×2	1166.087878	0.078	3109.2872
SWLP5,6,3.6,415,25,0.3	2×2	850.872734	0.081	3206.288
SWLP5,6,3.6,415,30,0.3	2×2	932.758051	0.078	3394.2669
SWMP5,5,3.2,300,25,0.25	2×2	66.721815	0.384	886.4455
SWMP5,5,3.2,300,30,0.25	2×2	73.516238	0.366	934.8274
SWMP5,5,3.2,415,25,0.25	2×2	66.76515	0.384	887.9975
SWMP5,5,3.2,415,30,0.25	2×2	73.553445	0.366	966.3591
SWMP5,5,3.2,300,25,0.3	2×2	79.637558	0.354	992.3333
SWMP5,5,3.2,300,30,0.3	2×2	86.107943	0.34	1043.9452
SWMP5,5,3.2,415,25,0.3	2×2	78.36961	0.357	996.6894
SWMP5,5,3.2,415,30,0.3	2×2	86.342678	0.34	1061.5414
SWMP5,5,3.6,300,25,0.25	2×2	57.583957	0.414	863.1772
SWMP5,5,3.6,300,30,0.25	2×2	63.49112	0.394	945.0462
SWMP5,5,3.6,415,25,0.25	2×2	57.893208	0.413	968.3287
SWMP5,5,3.6,415,30,0.25	2×2	63.716124	0.393	993.2008
SWMP5,5,3.6,300,25,0.3	2×2	67.318521	0.386	984.1041
SWMP5,5,3.6,300,30,0.3	2×2	74.264632	0.367	1049.0766
SWMP5,5,3.6,415,25,0.3	2×2	67.929274	0.384	1004.5127
SWMP5,5,3.6,415,30,0.3	2×2	74.738591	0.366	1016.3403
SWMP5,6,3.2,300,25,0.25	2×2	100.128252	0.341	948.9888
SWMP5,6,3.2,300,30,0.25	2×2	109.93224	0.325	1234.8278
SWMP5,6,3.2,415,25,0.25	2×2	95.452727	0.351	971.6281
SWMP5,6,3.2,415,30,0.25	2×2	105.678001	0.333	1337.8054
SWMP5,6,3.2,300,25,0.3	2×2	120.51305	0.314	1331.4833
SWMP5,6,3.2,300,30,0.3	2×2	131.649455	0.3	1392.4813

SWMP5,6,3.2,415,25,0.3	2×2	110.376735	0.329	1437.735
SWMP5,6,3.2,415,30,0.3	2×2	131.546391	0.3	1499.38
SWMP5,6,3.6,300,25,0.25	2×2	89.450147	0.363	1121.8702
SWMP5,6,3.6,300,30,0.25	2×2	97.751171	0.347	1191.1255
SWMP5,6,3.6,415,25,0.25	2×2	81.486094	0.381	1066.6493
SWMP5,6,3.6,415,30,0.25	2×2	90.697164	0.361	1091.6214
SWMP5,6,3.6,300,25,0.3	2×2	105.745327	0.336	1272.1394
SWMP5,6,3.6,300,30,0.3	2×2	115.664664	0.321	1367.8211
SWMP5,6,3.6,415,25,0.3	2×2	105.36828	0.336	1313.8044
SWMP5,6,3.6,415,30,0.3	2×2	115.464632	0.321	1428.7281

Appendix 6

Results of elastic stiffness factor, natural time period and maximum base shear of Shear wall with opening 3×1

Frame Type	Opening	Ki (kN/mm)	Natural time period (Sec)	Fu Max (kN)
SWLP1,5,3.2,300,25,0.25	3×1	474.138009	0.037	963.7073
SWLP1,5,3.2,300,30,0.25	3×1	520.148955	0.035	1038.2108
SWLP1,5,3.2,415,25,0.25	3×1	474.138009	0.037	1033.5117
SWLP1,5,3.2,415,30,0.25	3×1	520.148955	0.035	1049.2108
SWLP1,5,3.2,300,25,0.3	3×1	585.809141	0.034	1170.8144
SWLP1,5,3.2,300,30,0.3	3×1	642.439278	0.032	1261.3865
SWLP1,5,3.2,415,25,0.3	3×1	585.809141	0.034	1170.8144
SWLP1,5,3.2,415,30,0.3	3×1	642.439278	0.032	1261.3865
SWLP1,5,3.6,300,25,0.25	3×1	492.182188	0.037	1039.9672
SWLP1,5,3.6,300,30,0.25	3×1	539.91747	0.035	915.0615
SWLP1,5,3.6,415,25,0.25	3×1	492.182188	0.037	1148.3288
SWLP1,5,3.6,415,30,0.25	3×1	539.91747	0.035	1076.3425
SWLP1,5,3.6,300,25,0.3	3×1	614.2628	0.033	1253.5436
SWLP1,5,3.6,300,30,0.3	3×1	673.585643	0.032	1253.1176
SWLP1,5,3.6,415,25,0.3	3×1	614.2628	0.033	1324.4898
SWLP1,5,3.6,415,30,0.3	3×1	673.585643	0.032	1399.4043
SWLP1,6,3.2,300,25,0.25	3×1	831.862686	0.033	2260.3326
SWLP1,6,3.2,300,30,0.25	3×1	912.198753	0.031	2357.9787
SWLP1,6,3.2,420,25,0.25	3×1	831.862686	0.033	2425.1637
SWLP1,6,3.2,420,30,0.25	3×1	912.198753	0.031	2514.5667
SWLP1,6,3.2,300,25,0.3	3×1	943.602632	0.032	2181.0838
SWLP1,6,3.2,300,30,0.3	3×1	1031.413202	0.031	2659.2171
SWLP1,6,3.2,415,25,0.3	3×1	943.602632	0.032	3070.4594
SWLP1,6,3.2,415,30,0.3	3×1	1031.413202	0.031	3106.6999
SWLP1,6,3.6,300,25,0.25	3×1	832.367969	0.034	2137.0114

SWLP1,6,3.6,300,30,0.25	3×1	912.963436	0.032	2027.6482
SWLP1,6,3.6,415,25,0.25	3×1	832.367969	0.034	2327.322
SWLP1,6,3.6,415,30,0.25	3×1	912.963436	0.032	2292.4046
SWLP1,6,3.6,300,25,0.3	3×1	1048.695805	0.031	2329.1978
SWLP1,6,3.6,300,30,0.3	3×1	1149.97197	0.03	2202.3677
SWLP1,6,3.6,415,25,0.3	3×1	1048.695805	0.031	2824.9505
SWLP1,6,3.6,415,30,0.3	3×1	1149.97197	0.03	2453.9189
SWMP1,5,3.2,300,25,0.25	3×1	60.617504	0.19	523.6133
SWMP1,5,3.2,300,30,0.25	3×1	66.301219	0.181	543.1257
SWMP1,5,3.2,415,25,0.25	3×1	60.617504	0.19	511.8098
SWMP1,5,3.2,415,30,0.25	3×1	66.301219	0.181	541.6625
SWMP1,5,3.2,300,25,0.3	3×1	72.555034	0.179	592.0849
SWMP1,5,3.2,300,30,0.3	3×1	78.985004	0.172	648.6046
SWMP1,5,3.2,415,25,0.3	3×1	72.555034	0.179	592.0849
SWMP1,5,3.2,415,30,0.3	3×1	78.985004	0.172	627.319
SWMP1,5,3.6,300,25,0.25	3×1	46.397982	0.22	493.2582
SWMP1,5,3.6,300,30,0.25	3×1	49.53267	0.213	484.2516
SWMP1,5,3.6,420,25,0.25	3×1	46.397982	0.22	491.9295
SWMP1,5,3.6,420,30,0.25	3×1	49.53267	0.213	482.2516
SWMP1,5,3.6,300,25,0.3	3×1	58.856429	0.201	536.2207
SWMP1,5,3.6,300,30,0.3	3×1	64.463294	0.192	568.3113
SWMP1,5,3.6,415,25,0.3	3×1	58.856429	0.201	537.7357
SWMP1,5,3.6,415,30,0.3	3×1	64.463294	0.192	568.3113
SWMP1,6,3.2,300,25,0.25	3×1	111.432847	0.179	917.1477
SWMP1,6,3.2,300,30,0.25	3×1	122.066187	0.171	1115.4134
SWMP1,6,3.2,415,25,0.25	3×1	111.432847	0.179	917.1477
SWMP1,6,3.2,415,30,0.25	3×1	122.066187	0.171	1015.6128
SWMP1,6,3.2,300,25,0.3	3×1	134.216369	0.171	1230.8266
SWMP1,6,3.2,300,30,0.3	3×1	146.968641	0.164	1298.4549
SWMP1,6,3.2,415,25,0.3	3×1	134.216369	0.171	1132.761
SWMP1,6,3.2,415,30,0.3	3×1	146.968641	0.164	1181.2479

SWMP1,6,3.6,300,25,0.25	3×1	88.475377	0.206	907.5385
SWMP1,6,3.6,300,30,0.25	3×1	96.9362	0.197	963.7133
SWMP1,6,3.6,415,25,0.25	3×1	88.475377	0.206	907.5385
SWMP1,6,3.6,415,30,0.25	3×1	96.9362	0.197	957.61
SWMP1,6,3.6,300,25,0.3	3×1	107.146	0.197	1190.6995
SWMP1,6,3.6,300,30,0.3	3×1	117.397594	0.188	1249.6003
SWMP1,6,3.6,415,25,0.3	3×1	107.146	0.197	1100.4549
SWMP1,6,3.6,415,30,0.3	3×1	117.397594	0.188	1253.7825
SWLP5,5,3.2,300,25,0.25	3×1	500.387951	0.084	1451.6757
SWLP5,5,3.2,300,30,0.25	3×1	550.963103	0.08	1541.0173
SWLP5,5,3.2,415,25,0.25	3×1	503.182493	0.084	1525.845
SWLP5,5,3.2,415,30,0.25	3×1	553.861452	0.08	1617.2489
SWLP5,5,3.2,300,25,0.3	3×1	592.054501	0.078	1627.3625
SWLP5,5,3.2,300,30,0.3	3×1	652.59747	0.075	1737.8448
SWLP5,5,3.2,415,25,0.3	3×1	604.067351	0.078	1712.1997
SWLP5,5,3.2,415,30,0.3	3×1	656.335817	0.074	1822.5823
SWLP5,5,3.6,300,25,0.25	3×1	476.716238	0.087	1096.3606
SWLP5,5,3.6,300,30,0.25	3×1	527.812041	0.083	1505.6362
SWLP5,5,3.6,415,25,0.25	3×1	476.716238	0.087	1768.6019
SWLP5,5,3.6,415,30,0.25	3×1	543.720759	0.082	1417.4496
SWLP5,5,3.6,300,25,0.3	3×1	584.697361	0.08	1456.7595
SWLP5,5,3.6,300,30,0.3	3×1	647.135935	0.076	1547.5831
SWLP5,5,3.6,415,25,0.3	3×1	584.697361	0.08	1502.0597
SWLP5,5,3.6,415,30,0.3	3×1	654.923507	0.075	1930.2402
SWLP5,6,3.2,300,25,0.25	3×1	745.753888	0.084	2492.2136
SWLP5,6,3.2,300,30,0.25	3×1	817.161168	0.08	2638.8957
SWLP5,6,3.2,415,25,0.25	3×1	725.722956	0.085	2674.0982
SWLP5,6,3.2,415,30,0.25	3×1	800.031844	0.081	2838.8957
SWLP5,6,3.2,300,25,0.3	3×1	900.520511	0.078	2887.2262
SWLP5,6,3.2,300,30,0.3	3×1	986.148166	0.075	2396.1068
SWLP5,6,3.2,415,25,0.3	3×1	895.4039	0.078	3675.7295

SWLP5,6,3.2,415,30,0.3	3×1	983.731874	0.075	3263.6383
SWLP5,6,3.6,300,25,0.25	3×1	726.887107	0.086	2453.9782
SWLP5,6,3.6,300,30,0.25	3×1	797.037705	0.082	2427.3638
SWLP5,6,3.6,415,25,0.25	3×1	699.481935	0.087	2421.2687
SWLP5,6,3.6,415,30,0.25	3×1	770.152154	0.083	2976.1104
SWLP5,6,3.6,300,25,0.3	3×1	882.363015	0.08	2714.6375
SWLP5,6,3.6,300,30,0.3	3×1	967.262861	0.076	2784.1048
SWLP5,6,3.6,415,25,0.3	3×1	848.025059	0.081	2776.381
SWLP5,6,3.6,415,30,0.3	3×1	978.933189	0.076	2962.1889
SWMP5,5,3.2,300,25,0.25	3×1	71.125864	0.371	832.1411
SWMP5,5,3.2,300,30,0.25	3×1	78.837312	0.352	773.7539
SWMP5,5,3.2,415,25,0.25	3×1	71.610233	0.37	841.6704
SWMP5,5,3.2,415,30,0.25	3×1	79.15546	0.352	858.6784
SWMP5,5,3.2,300,25,0.3	3×1	83.562967	0.345	885.6743
SWMP5,5,3.2,300,30,0.3	3×1	93.48132	0.326	901.9438
SWMP5,5,3.2,415,25,0.3	3×1	85.054646	0.342	889.2638
SWMP5,5,3.2,415,30,0.3	3×1	93.485317	0.326	915.1053
SWMP5,5,3.6,300,25,0.25	3×1	56.564069	0.416	750.2919
SWMP5,5,3.6,300,30,0.25	3×1	62.666785	0.395	786.6323
SWMP5,5,3.6,415,25,0.25	3×1	56.564069	0.416	773.3506
SWMP5,5,3.6,415,30,0.25	3×1	62.601743	0.396	791.6767
SWMP5,5,3.6,300,25,0.3	3×1	66.910267	0.386	817.4594
SWMP5,5,3.6,300,30,0.3	3×1	70.952007	0.375	813.8269
SWMP5,5,3.6,415,25,0.3	3×1	66.910267	0.386	817.7368
SWMP5,5,3.6,415,30,0.3	3×1	73.628586	0.367	840.6519
SWMP5,6,3.2,300,25,0.25	3×1	110.798678	0.325	1043.8054
SWMP5,6,3.2,300,30,0.25	3×1	123.167851	0.308	1087.3081
SWMP5,6,3.2,415,25,0.25	3×1	114.676333	0.319	1120.9692
SWMP5,6,3.2,415,30,0.25	3×1	118.192292	0.315	1159.4723
SWMP5,6,3.2,300,25,0.3	3×1	136.82272	0.294	1237.9348
SWMP5,6,3.2,300,30,0.3	3×1	150.179168	0.281	1494.4975

SWMP5,6,3.2,415,25,0.3	3×1	133.26898	0.299	1224.6869
SWMP5,6,3.2,415,30,0.3	3×1	147.916751	0.283	1279.8054
SWMP5,6,3.6,300,25,0.25	3×1	91.725954	0.357	1201.2887
SWMP5,6,3.6,300,30,0.25	3×1	100.922764	0.34	1267.3869
SWMP5,6,3.6,415,25,0.25	3×1	90.840178	0.358	1064.5452
SWMP5,6,3.6,415,30,0.25	3×1	100.411974	0.341	1118.8757
SWMP5,6,3.6,300,25,0.3	3×1	108.909261	0.33	1342.8787
SWMP5,6,3.6,300,30,0.3	3×1	119.735286	0.315	1436.1379
SWMP5,6,3.6,415,25,0.3	3×1	107.722532	0.332	1120.3305
SWMP5,6,3.6,415,30,0.3	3×1	119.064027	0.315	1436.1379

Appendix 7

Results of elastic stiffness factor, natural time period and maximum base shear of Shear wall with opening 3×1.5

Frame Type	Opening	Ki (kN/mm)	Natural time period (Sec)	Fu Max (kN)
SWLP1,5,3.2,300,25,0.25	3×1.5	320.480932	0.044	938.8844
SWLP1,5,3.2,300,30,0.25	3×1.5	351.265051	0.042	1073.8499
SWLP1,5,3.2,415,25,0.25	3×1.5	320.480932	0.044	1055.5303
SWLP1,5,3.2,415,30,0.25	3×1.5	351.265051	0.042	1068.3456
SWLP1,5,3.2,300,25,0.3	3×1.5	397.608836	0.041	1261.7358
SWLP1,5,3.2,300,30,0.3	3×1.5	435.625652	0.039	1172.1481
SWLP1,5,3.2,415,25,0.3	3×1.5	397.608836	0.041	1263.1067
SWLP1,5,3.2,415,30,0.3	3×1.5	435.625652	0.039	1329.5276
SWLP1,5,3.6,300,25,0.25	3×1.5	348.696889	0.043	938.6554
SWLP1,5,3.6,300,30,0.25	3×1.5	382.229847	0.041	993.3735
SWLP1,5,3.6,415,25,0.25	3×1.5	348.696889	0.043	1040.1408
SWLP1,5,3.6,415,30,0.25	3×1.5	382.229847	0.041	1091.1979
SWLP1,5,3.6,300,25,0.3	3×1.5	432.98533	0.04	1147.4798
SWLP1,5,3.6,300,30,0.3	3×1.5	474.543953	0.038	1206.4798
SWLP1,5,3.6,415,25,0.3	3×1.5	432.98533	0.04	1255.9322
SWLP1,5,3.6,415,30,0.3	3×1.5	474.543953	0.038	1313.5551
SWLP1,6,3.2,300,25,0.25	3×1.5	624.951722	0.038	1753.5472
SWLP1,6,3.2,300,30,0.25	3×1.5	685.223289	0.036	2232.6548
SWLP1,6,3.2,420,25,0.25	3×1.5	624.951722	0.038	1441.1185
SWLP1,6,3.2,420,30,0.25	3×1.5	685.223289	0.036	2230.5506
SWLP1,6,3.2,300,25,0.3	3×1.5	784.372076	0.035	2489.1915
SWLP1,6,3.2,300,30,0.3	3×1.5	859.838936	0.033	2672.9929
SWLP1,6,3.2,415,25,0.3	3×1.5	784.372076	0.035	2515.6858
SWLP1,6,3.2,415,30,0.3	3×1.5	859.838936	0.033	2784.7523

SWLP1,6,3.6,300,25,0.25	3×1.5	575.370606	0.041	2037.1171
SWLP1,6,3.6,300,30,0.25	3×1.5	627.896308	0.039	2169.2799
SWLP1,6,3.6,415,25,0.25	3×1.5	575.370606	0.041	2081.9528
SWLP1,6,3.6,415,30,0.25	3×1.5	627.896308	0.039	2247.2776
SWLP1,6,3.6,300,25,0.3	3×1.5	718.390383	0.038	2476.5506
SWLP1,6,3.6,300,30,0.3	3×1.5	783.779604	0.036	2640.8318
SWLP1,6,3.6,415,25,0.3	3×1.5	718.390383	0.038	2575.7441
SWLP1,6,3.6,415,30,0.3	3×1.5	783.779604	0.036	2772.1843
SWMP1,5,3.2,300,25,0.25	3×1.5	48.912614	0.211	458.7474
SWMP1,5,3.2,300,30,0.25	3×1.5	57.304059	0.193	473.9437
SWMP1,5,3.2,415,25,0.25	3×1.5	48.912614	0.211	480.0633
SWMP1,5,3.2,415,30,0.25	3×1.5	57.304059	0.193	502.9175
SWMP1,5,3.2,300,25,0.3	3×1.5	63.425702	0.189	517.7999
SWMP1,5,3.2,300,30,0.3	3×1.5	69.471679	0.181	566.8927
SWMP1,5,3.2,415,25,0.3	3×1.5	63.425702	0.189	551.2343
SWMP1,5,3.2,415,30,0.3	3×1.5	69.471679	0.181	574.582
SWMP1,5,3.6,300,25,0.25	3×1.5	40.988237	0.233	449.3289
SWMP1,5,3.6,300,30,0.25	3×1.5	44.629401	0.223	466.0793
SWMP1,5,3.6,420,25,0.25	3×1.5	40.988237	0.233	458.9442
SWMP1,5,3.6,420,30,0.25	3×1.5	44.626649	0.223	476.9728
SWMP1,5,3.6,300,25,0.3	3×1.5	52.174263	0.212	519.7932
SWMP1,5,3.6,300,30,0.3	3×1.5	57.124273	0.203	532.5438
SWMP1,5,3.6,415,25,0.3	3×1.5	52.174263	0.212	515.7563
SWMP1,5,3.6,415,30,0.3	3×1.5	57.124273	0.203	539.7017
SWMP1,6,3.2,300,25,0.25	3×1.5	92.485165	0.194	914.4278
SWMP1,6,3.2,300,30,0.25	3×1.5	101.325102	0.186	940.3276
SWMP1,6,3.2,415,25,0.25	3×1.5	92.485165	0.194	962.0196
SWMP1,6,3.2,415,30,0.25	3×1.5	101.325102	0.186	1014.5871
SWMP1,6,3.2,300,25,0.3	3×1.5	111.96644	0.185	1109.4043
SWMP1,6,3.2,300,30,0.3	3×1.5	122.513829	0.177	1164.5298
SWMP1,6,3.2,415,25,0.3	3×1.5	111.96644	0.185	1125.5832

SWMP1,6,3.2,415,30,0.3	3×1.5	122.513829	0.177	1176.9316
SWMP1,6,3.6,300,25,0.25	3×1.5	78.350074	0.216	938.4086
SWMP1,6,3.6,300,30,0.25	3×1.5	85.945483	0.207	990.0629
SWMP1,6,3.6,415,25,0.25	3×1.5	78.350074	0.216	933.5539
SWMP1,6,3.6,415,30,0.25	3×1.5	85.945483	0.207	975.6506
SWMP1,6,3.6,300,25,0.3	3×1.5	94.893488	0.207	1098.8843
SWMP1,6,3.6,300,30,0.3	3×1.5	103.965753	0.198	1163.4753
SWMP1,6,3.6,415,25,0.3	3×1.5	94.893488	0.207	1090.8887
SWMP1,6,3.6,415,30,0.3	3×1.5	103.965753	0.198	1141.052
SWLP5,5,3.2,300,25,0.25	3×1.5	334.936371	0.1	1534.3009
SWLP5,5,3.2,300,30,0.25	3×1.5	375.174563	0.095	1591.811
SWLP5,5,3.2,415,25,0.25	3×1.5	369.013881	0.096	1603.2307
SWLP5,5,3.2,415,30,0.25	3×1.5	388.175159	0.093	1788.7587
SWLP5,5,3.2,300,25,0.3	3×1.5	391.371684	0.094	1705.7378
SWLP5,5,3.2,300,30,0.3	3×1.5	438.946648	0.089	1779.176
SWLP5,5,3.2,415,25,0.3	3×1.5	435.96563	0.089	1788.9108
SWLP5,5,3.2,415,30,0.3	3×1.5	455.149871	0.087	1782.7874
SWLP5,5,3.6,300,25,0.25	3×1.5	374.248736	0.097	1380.9848
SWLP5,5,3.6,300,30,0.25	3×1.5	410.99945	0.092	1441.4157
SWLP5,5,3.6,415,25,0.25	3×1.5	344.980318	0.1	1488.5438
SWLP5,5,3.6,415,30,0.25	3×1.5	383.289839	0.095	1579.3188
SWLP5,5,3.6,300,25,0.3	3×1.5	437.246933	0.09	1550.4046
SWLP5,5,3.6,300,30,0.3	3×1.5	482.221929	0.086	1617.8769
SWLP5,5,3.6,415,25,0.3	3×1.5	412.17769	0.093	1670.9713
SWLP5,5,3.6,415,30,0.3	3×1.5	460.326511	0.088	1770.3301
SWLP5,6,3.2,300,25,0.25	3×1.5	654.646142	0.092	2355.2854
SWLP5,6,3.2,300,30,0.25	3×1.5	716.321214	0.088	2538.2621
SWLP5,6,3.2,415,25,0.25	3×1.5	534.366168	0.097	2478.0423
SWLP5,6,3.2,415,30,0.25	3×1.5	601.462176	0.092	2643.4574
SWLP5,6,3.2,300,25,0.3	3×1.5	761.734775	0.085	2686.8804
SWLP5,6,3.2,300,30,0.3	3×1.5	833.79839	0.082	2925.9659

SWLP5,6,3.2,415,25,0.3	3×1.5	620.043201	0.091	1829.5238
SWLP5,6,3.2,415,30,0.3	3×1.5	711.570239	0.086	3032.4928
SWLP5,6,3.6,300,25,0.25	3×1.5	609.033276	0.094	216.0433
SWLP5,6,3.6,300,30,0.25	3×1.5	666.780001	0.09	2382.951
SWLP5,6,3.6,415,25,0.25	3×1.5	517.247123	0.1	2269.0571
SWLP5,6,3.6,415,30,0.25	3×1.5	580.571184	0.094	2449.6158
SWLP5,6,3.6,300,25,0.3	3×1.5	718.884482	0.088	2556.0978
SWLP5,6,3.6,300,30,0.3	3×1.5	789.063686	0.084	2759.4916
SWLP5,6,3.6,415,25,0.3	3×1.5	613.715706	0.093	2653.1583
SWLP5,6,3.6,415,30,0.3	3×1.5	690.454343	0.088	2834.7316
SWMP5,5,3.2,300,25,0.25	3×1.5	61.271612	0.404	944.961
SWMP5,5,3.2,300,30,0.25	3×1.5	65.111538	0.393	922.0126
SWMP5,5,3.2,415,25,0.25	3×1.5	61.667062	0.403	990.6896
SWMP5,5,3.2,415,30,0.25	3×1.5	66.496099	0.388	1027.5484
SWMP5,5,3.2,300,25,0.3	3×1.5	68.316559	0.386	893.5113
SWMP5,5,3.2,300,30,0.3	3×1.5	79.222795	0.357	918.5187
SWMP5,5,3.2,415,25,0.3	3×1.5	72.687156	0.373	1013.278
SWMP5,5,3.2,415,30,0.3	3×1.5	77.239978	0.363	1049.2539
SWMP5,5,3.6,300,25,0.25	3×1.5	49.164542	0.452	779.8714
SWMP5,5,3.6,300,30,0.25	3×1.5	55.358458	0.425	911.1626
SWMP5,5,3.6,415,25,0.25	3×1.5	50.548124	0.444	931.4117
SWMP5,5,3.6,415,30,0.25	3×1.5	55.727974	0.424	822.2181
SWMP5,5,3.6,300,25,0.3	3×1.5	57.280034	0.421	811.3555
SWMP5,5,3.6,300,30,0.3	3×1.5	64.049257	0.398	826.1226
SWMP5,5,3.6,415,25,0.3	3×1.5	58.720007	0.415	847.0744
SWMP5,5,3.6,415,30,0.3	3×1.5	65.712439	0.392	858.794
SWMP5,6,3.2,300,25,0.25	3×1.5	96.876834	0.351	1166.465
SWMP5,6,3.2,300,30,0.25	3×1.5	106.645784	0.335	1174.8862
SWMP5,6,3.2,415,25,0.25	3×1.5	96.823363	0.351	1285.792
SWMP5,6,3.2,415,30,0.25	3×1.5	105.506718	0.336	1304.6048
SWMP5,6,3.2,300,25,0.3	3×1.5	114.511332	0.325	1219.6015

SWMP5,6,3.2,300,30,0.3	3×1.5	126.122305	0.31	1241.5463
SWMP5,6,3.2,415,25,0.3	3×1.5	115.260744	0.324	1334.0719
SWMP5,6,3.2,415,30,0.3	3×1.5	124.321943	0.312	1359.2505
SWMP5,6,3.6,300,25,0.25	3×1.5	82.005777	0.381	1244.4465
SWMP5,6,3.6,300,30,0.25	3×1.5	90.385599	0.363	1016.1386
SWMP5,6,3.6,415,25,0.25	3×1.5	81.282163	0.383	1077.1388
SWMP5,6,3.6,415,30,0.25	3×1.5	89.925472	0.364	1094.1109
SWMP5,6,3.6,300,25,0.3	3×1.5	97.619658	0.352	1079.7944
SWMP5,6,3.6,300,30,0.3	3×1.5	107.26673	0.336	1124.4392
SWMP5,6,3.6,415,25,0.3	3×1.5	96.791184	0.353	1152.0799
SWMP5,6,3.6,415,30,0.3	3×1.5	106.739408	0.336	1167.8074