# EVALUATION OF RESPONSE MODIFICATION FACTOR OF THE REINFORCED CONCRETE STRUCTURES WITH SHEAR WALLS HAVING DIFFERENT SIZES OF OPENINGS AGAINST THE LATERAL LOADING

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

> By ODAY MA'MOUN KALBOUNEH

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

ODAY EVALU MA' MOUN CONCRETE ST KALBOUNEH

**CONCRETE STRUCTURE WITH SHEAR WALLS HAVING DIFFERENT SIZES OF OPENINGS** EVALUATION OF RESPONSE MODIFICATION FACTOR OF THE REINFORCED AGAINST THE LATERAL LOADING NEU 2020

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## ABSTRACT

Lateral loading caused by factors such as by earthquakes and wind load. It is an important concept to consider and understand due to the consequences it may lead to if it is ignored, such as cracks in the structural joint and the elements that caused structure failure. This study evaluates the response modification factor (RMF) of reinforced concrete structures with shear walls, conducting different sizes of openings resisting against the lateral load by using the pushover analysis method with applying ETABS v 18.0.1 software. Twenty-eight 2D reinforced concrete frames with shear walls were examined and designed to perform a nonlinear static pushover analysis. These models checked two different story heights and two different span lengths with different size of openings. The method resulted in a curve that portrays relationship among base shear and displacement of the structure. The study found a connection amid structures having shear walls with opening and the RMF system. Using the pushover analysis method by determine the R $\mu$ , RS and R $\xi$  to determine the RMF. It is an appropriate method to use when evaluating reinforced concrete structure with shear walls having different sizes of opening against lateral loading. The existing results proof that the openings in the 2D reinforced concrete frames with shear walls effected the RMF.

*Keywords:* Response modification factor; pushover analysis; overstrength factor; ductility factor; moment resisting frame

# ÖZET

Deprem, rüzgar yükü ve su basıncı gibi etkenlerden kaynaklanan yanal yükleme. Yapısal ek ve yıkımlardaki çatlaklar göz ardı edilmesi halinde sonuçlar açısından dikkate alınması ve idrak edlmesi gereken önemli bir kavramdır. Bu çalışma, ETABS v 18.0.1 bilgisayar yazılımıyla statik itme analizi yöntemi kullanılarak, yanal yüke karşı direnç gösteren farklı ölçülerdeki açılmalara iletken olan betonarme perde duvarların tepkime modifikasyon faktörü (RMF)'nü değerlendirmektedir. Doğrusal olmayan statik itme analizi yapılması amacıyla yirmisekz 2D betonarme perde duvar çerçevesi incelenmiş ve tasarlanmıştır. Bu modeller, farklı boşluk boylarında iki farklı kat yüksekliği ve iki farklı mesafe boyunu içermektedir. Bu yöntem yapının yer değiştirmesi ve temel kesme arasındaki ilişkiyi betimleyen bir eğriyle sonuçlanmıştır. Bu çalışma perde duvarlardaki boşluklarla RMF arasında bir bağlantı bulmuştur. Düklitile azaltma faktörü, aşırı dayanım faktörü ve sönümleme faktörü uygulanarak statik itme analizi yöntemi kullanımıyla RMF elde edilmesi, yanal yüke karşı farklı boyutlarda boşluklar olan betonarme perde duvar yapılarını değerlendirmekte kullanılan uygun bir yöntemdir. İşbu çalışma 2D betonarme perde duvar çerçevelerdeki boşlukların RMF'yi etkilediğine ilişkin kanıt sunmaktadır.

*Anahtar Kelimeler:* Tepkime modifikasyon faktörü; statik itme analizi; aşırı dayanım faktörü, düktilite faktörü; moment dirençli çerçeve

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# ABBREVIATIONS AND SYMBOLS

CPA:	Conventional pushover analysis	
Dy:	Yield displacement	
<b>H</b> <sub>1</sub> :	Hypothesis use in this study	
Ie:	Importance factor	
kN:	kilonewton	
MDOF:	Multiple degrees of freedom	
m:	Meter	
mm:	Millimeter	
MPA:	Model pushover analysis	
MRF:	Moment resisting frame	
MRFSWs:	Moment resisting frame with shear walls	
PGAm:	Maximum displacement	
PGAy:	Yield displacement	
PMPA:	Practical model pushover analysis	
<b>R:</b>	Force factor	
RC:	Reinforced concrete	
RMF:	Response modification factor	
Rs:	Over strength factor	
<b>R</b> μ:	Ductility factor	
Rξ:	Damping factor	

- **SDOF:** Single degree of freedom
  - **V:** Force reduction factor
  - Vd: Design base shear
  - **Ve:** Elastic base shear
  - **Vi:** Base shear at first plastic hinge
  - Vs: Yield base shear
  - Vu: Maximum inelastic force
  - **Vy:** Yield force of a structure
  - Vve: Maximum elastic force
  - **2D:** Two dimensional
  - **3D:** Three dimensional

#### **CHAPTER 1**

#### **INTRODUCTION**

#### **1.1. Introduction**

Human safety is a known priority in the world, thus civil engineering has an important duty in developing structure types that can resist any type of lateral load such as an earthquake, wind load, water pressure etc. Hence, many factors should be studied to reach a structure type that can resist the lateral force without collapsing and sustain human life. As a result, some lateral displacements can cause collapsing of structural joints that can lead to catastrophes. When building a structure, civil engineers look for factors such as, response modification factor (RMF), ductility reduction factor ( $R\mu$ ), overstrength factor (Rs) and damping factor (R $\xi$ ). Taking all these factors into consideration can prevent structural damage and failures. Openings existing in shear walls has effects on the stiffness and the ductility. On the other hand, openings cause effect on the factors mentioned previously. Consequently, this study will investigate the opening effects on shear walls, through an investigation in the response to modification factor, RMF. When designing a building it is key to consider its location. There are high seismic and low seismic zones. When buildings are constructed in high seismic zones, they are more inclined to earthquakes with varying magnitudes, and thus must be evaluated and designed carefully. This study preforms seismic analysis on reinforced concrete buildings using the dual system. The dual system is the joining of two lateral resisting forces, it is known for resisting lateral loads successfully.

When constructing a building it is important to consider the seismic demands to ensure safety and prevent structure collapsing during dangerous weather conditions. A study has shown a modal pushover analysis that is able to approximation the seismic demands of a building during earthquake forces. Therefore, it was determined that using the modal pushover analysis is a suitable and precise procedure to design and evaluate structures. Globalization increases challenges in the construction sector, construction projects become larger and advance widely (Darwish, 2012). Design recommendations require more specifications to get more safety of buildings (Simplokoukou, et al., 2014). One of nature's risky hazards which threaten human lives are earthquakes, this issue is very important to consider in the design phase (Godschalk, 2003).

Reinforced concrete structures with shear walls performance a significant role in enhancing the behavior of structures resisting earthquakes. In addition to substantial earthquake resistance, the speed and ease is further used in the multi-unit construction of suburban buildings (Standard B, 2005). Openings in structural shear walls enhance the negative effect on the behavior of the shear wall. Therefore, openings in the shear walls should be considered when looking at the seismic design for safety (Balkaya and Kalkan, 2003) and (Varela, et al., 2004).

RMF for each structural system depends on the location of the building (soil properties) and building properties (energy absorption capacity, strength, degrees of freedom, the shape of a building, structural irregularities) (Sadeghi, et al., 2017). Moreover, the response modification factor is a relation between the strength and ductility of the structure. Thus, the negative effects of openings in the shear walls, causes an effect on the strength, the ductility and on RMF of the structure.

#### **1.2. Problem Statement**

The design phase is an important step in construction. Therefore, it is recommended to create a special design for shear walls with openings to enhance more strength and flexibility for the structure to be able to resist seismic effects. Ignoring the negative effects of the seismic behaviour of shear walls with openings, causes a hazard for human life.

#### **1.3.** Objectives

This study will highlight the RMF of reinforced concrete with shear walls conducting different sizes of openings resisting against the lateral load. This is in terms of base shear, story shear in addition story drift in two dimensional reinforced concrete frames

with or without opening in the shear wall. In this study, nonlinear static analysis will be completed on all models.

## 1.4. Significant of Study

The importance of this study is to investigate the effect of the sizes of openings in shear walls on the RMF of the reinforced concrete moment-resisting frame with shear walls (MRFSWs).

## 1.5. Hypothesis

H<sub>1</sub>: There is a relationship between openings in shear walls and the RMF.

### 1.6. Analysis Method

There are four methods to be able to analyse the seismic effect on the structures exposed to lateral load, in addition to earthquake load. The selected method to design and analyse the 2D frame is highlighted as shown in Figure 1.1



Figure 1.1: Seismic analysis methods

### 1.7. Moment Resisting Frame

This type of frame is built by beams on the horizontal axis and columns on the vertical axis as shown in Figure 1.2. This causes shear and axial load resistant's, however, it's

not useful for earthquake loading. In addition, this type has brittle resistance to prevent the fragile shear failure and also decreases the lateral vibrations in the structural frame.



Figure 1.2: Moment resisting frame (MRF)

This study uses a system with supported shear walls as shown in Figure 1.8. This system uses frame behavior for resisting the earthquake loads, lateral displacement, vibration, shear force, and prevents brittle shear failure.



Figure 1.3: MRF with shear wall

## **1.8.** Chapters Included in This Study

There are five chapters included in the study. The first chapter includes an introduction and a general description about the factors that will be investigated in this study, the reason why the study was used, the main role of the study, the importance of study, hypothesis and the analysis method.

Studies applied for investigating the RMF is included in the second chapter. Previous studies are cleaved into four parts, the first section investigates the topic in general, the second section discusses shear wall properties and the effect of openings in the shear wall, the third section includes the RMF and the other factors used to evaluate RMF and the last section discusses the deals with a pushover analysis path.

The third chapter includes the methodology, which explains the formulations and figurers that were created to estimate the RMF and design the structural elements.

The fourth chapter is compromised of the results, by which they are investigated and compared to between different RMF values.

The fifth chapter includes the conclusions and the recommendations for the results in this study.

#### **CHAPTER 2**

#### LITERATURE REVIEW

#### 2.1. General

The preferred structural system uses the resistant of the gravity load and the lateral load that is reinforced in the concrete structure with the shear wall. Recently, the best design method to use for seismic loading is force base shear design. With modern seismic codes, the response of the structures could be evaluated by an investigation in displacement ability, including the non-linear static analysis method. This analysis method depends on evaluating the displacement ability by determining the DOF of the structure to set it for a single SDOF. On the other hand, there are codes that are not recommended with an equivalent system to the single degree of freedom system. The full-time history of flexible powerful reaction to a solitary accelerator might be assessed by methods for the well-ordered joining of the conditions of movement (Bosco, et al., 2009).

#### 2.2. Shear Wall

The common structural system used to resist lateral forces applied on structures such as earthquake's load and wind load is the shear wall. Structural engineers have an interest within the accurateness of arithmetic models for shear walls as a result for dynamic loading. The main limiters for designing base shear walls structures are the ultimate stiffness of shear wall structures. The lateral forces to the shear walls are distributed in line with their relative stiffness for that the relative stiffness of shear walls is an essential issue. The center of rigidity of shear walls should be close center of mass of structure to prevent the structure facing torsion (MACLEOD, 1967).

The popular system used for resisting lateral force is reinforced shear wall systems and the frame systems. They are efficient systems that increase the behavior of structures in resistance to the lateral force due to earthquakes besides the resistance of the torsional effects. Coupled shear walls could be a continuous wall with vertical rows of a gap created by windows and doors, coupled by connecting beams. Sense additional shear walls are interconnected by a system of beams or slabs. The whole stiffness of the system exceeds the summation of the individual wall stiffness as a result of the connecting block or beam restraints, the individual cantilever action by forcing the system to figure as a composite unit. Such associate degree interacting shear wall system is used economically to resist lateral forces in structures up to concerning (Taranath, 1998).

In tall buildings, especially in the construction of service apartments and commercial buildings, the use of the shear walls is a very important issue. Moreover, the shear walls system had proven that it enhances the building's behavior in seismic resistance. (Marsono and Subedi, 2000).

#### 2.3. Response Modification Factor (RMF)

RMF is used in almost all structure codes. RMF is most important lateral force in the structure compared to the forces designed to resist it. Therefore, it is recommended to use RMF in the design face. RMF enhance the ductility and increases the overstrength factor, on the other hand, it helps structures by decreasing the excess lateral forces and increasing the ductility of the structures to become more flexible, in other words, RMF allows the elements of the structure to crack without collapsing (Salem and Nasr, 2014).

RMF is a concern in the seismic system for modern structures in the USA. Recently, these values of the R depend on engineering senses, not on the basis. Ductility of seismic framing method could be one-ninth of the RMF. Virtually, the forces that correspond with the elastic reaction of the seismic structure design such as lateral force could be smaller (Whittaker, et al., 1999).

Structure flexible investigation under earthquakes can generate base shear power and stress, which are detectably greater than the structure's reaction. Structure can retain steady from many seismic forces and is resistant when it enters the inelastic scope of distortion. Overstrength in structures is identified by the greatest sidelong quality of a structure. Consequently, seismic codes decrease the configuration ration loads, exploiting the over strength and pliability of the structure. Truth be told, the reaction

alteration factor incorporates inelastic execution of structure and demonstrates over quality and flexibility in the inelastic stage (Asgarian and Shokrgozar, 2009).

Contingent upon the seriousness planning of seismic forces, the structures may experience nonlinear conduct. The nonlinear dynamic methods investigation, in spite of the fact that yields exact outcomes, is tedious and intricate. Scientists are keen on quick growing and proficient strategies to mimic nonlinear conduct of structures under earthquake loads. Conventional pushover analysis (CPA), notwithstanding its qualities, has a few disadvantages. For instance, the state of horizontal burden designs is consistent and remains the equivalent during structural investigations. This shape is typically founded on the principal versatile method of the structure. As it were, the higher mode impacts or the job of increasingly successful modes are not represented. Model pushover analysis (MPA) was presented which represents higher mode impacts. A typical downside in both CPA and MPA is the absence of representing the change in the worldwide difficulty grounds during structural analysis (Izadinia, et al., 2012).

The shear forces and stresses that are created from an elastic analysis of buildings could be greater than the real lateral forces. The analysis method of structural over strength is defined as the maximum lateral force that is applied to the structure. For that reason, design codes reduce design forces, assuming that the structure has its own overstrength and flexibility. In reality, the main reason for using RMF is because it enhances the strength and ductility of the structure (Asgarian and Shokrgoza, 2009).

Structural elastic analysis under earthquakes can create base shear forces and stress, which are noticeably larger than real structure response. Overstrength in structures is related to the fact that the maximum lateral strength of a structure generally exceeds its design strength. Seismic codes reduce design loads, taking advantage of the fact that structures possess overstrength and ductility. The RMF includes an inelastic performance of structure and indicates over strength and ductility in an inelastic stage. Vy shows the yield force of a structure and the yield displacement is  $\delta y$ . The maximum base shear in a perfectly elastic behavior is Ve. The ratio of maximum base shear considering elastic behavior Ve to maximum base shear inelastic perfect behavior V is called force reduction factor. The overstrength factor is defined as the ratio of maximum

base shear in actual behavior Ve to the first significant yield strength in structure Vs (Mahmoudi and Abdi, 2012).

#### 2.3.1. Ductility reduction factor (Rµ)

Ductility factors ( $R\mu$ ) are used to assess the percent ductility. The relationship between maximum elastic force (Vue) and maximum inelastic force (Vu) can establish the  $R\mu$  factors for the structure under inelastic behaviour. There are studies about RMF that were established from ductility (Abdi, et al., 2018).

The definition of ductility factor is the maximum bend divided by the equivalent bend that is present during yielding. By taking this into consideration, this can design a multistory building into one degree of freedom system, in addition, the availability to investigate the international drift ductility, can develop a relationship between the flexibility and the displacement (Miranda and Bertero, 1994).

The ductility reduction factor is defined as the percentage among the maximum base shear in an elastic region and the maximum base shear in an inelastic region. The definition of displacement ductility is the difference between two stories divided by the story height. In a genuine multiple degrees of freedom (MDOF) building, higher mode impacts cause a base shear request, Vb MDOF, bigger than that of its equal SDOF framework, Vb SDOF, with a versatile period relating to the MDOF framework's principal period. The proportion of the two base shears is the shear amplification factor (Zerbin, et al., 2019).

#### 2.3.2. Overstrength factor (Rs)

Fashionable computer-aided tools enable engineers to model and style structures that closely match those who are literally designed. Major simplification and assumption area units are incorporated within the method. These assumptions apply area units that are in favor of a conservative design to maintain a safety aspect. The presence of overstrength in structures is also examined in an exceedingly native and world manner (Balkaya and Kalkan, 2003).

Due to the ability of the structural elements, handle forces are greater than the design forces. The design lateral forces will be smaller than the maximum lateral strength of the structure. Material properties usually exceed the normal properties. The relationship between the maximum forces and the design forces has a value depending on the seismic conditions of the building. However, these values will vary depending on the seismic zone for the building (Hwang, et al., 1998).

Overstrength factor is used as a protection for some types of structural elements for reinforced concrete frames against seismic load. While externally identical to the overstrength factor for building structures – and it is, to be sure, executed in precisely the same way – the theoretical application for force factor is very extraordinary. Rather than giving a power rectification factor to inexact nonlinear conduct utilizing straight investigation, it is utilized to correct unfortunate conduct in port by expanding expected parallel power dimensions of nonstructural parts. This thus expands the powers exchanged to the support (Johnson and Dowell, 2017).

#### 2.3.3. Damping factor (Rξ)

Damping characterizes energy dissipation in a building frame. Such characterization is achieved no matter whether or not the energy is dissipated through hysteretic behavior or through viscous damping. Damping is an impression that's either purposely created or essential to a system. In structural engineering, the explanation for this energy dissipation is expounded to material internal friction, friction at joints, radiation damping at the supports, or hysteretic system behavior. Model damping ratios measure utilized models to estimate unknown nonlinear energy dissipation among a structure (LovaRaju and Balaji, 2015).

#### 2.4. Pushover Analysis

Performing pushover analysis to structures that are highly likely exposed to earthquakes, will enhance proper estimations for inelastic deformation, in addition to inflexibility, it will investigate the design's weakness points in the flexible design side for structural elements such as beams and columns (Krawinkler and Seneviratna, 1998). The pushover analysis enhances an appropriate investigation for the elastic factor, in addition to inelastic analysis for structures against earthquakes, sufficient demonstration of the structures creates a professional distribution for the lateral load and present the results in clearer way, leading to achieve the best result. Pushover analysis is the most proper analysis method for low and rise frame structure (Mwafy and Elnashai, 2001). Pushover analysis is also known as a nonlinear static analysis, this analysis method uses a nonlinear approach to investigate the structure's seismic behavior. It is also the most widely used analysis method because of the simple procedure it provides to inelastic analysis. In addition, it doesn't present the excessive modes that appear in tall structures, it is exclusive for low and mid structures as described in the FEMA-273~1997. In the pushover static methodology, a nonlinear model of the working being referred to is dislodged to an objective uprooting under the activity of monotonically expanding horizontal burdens (El-Tawil and Kuenzli, 2002).

Pushover analysis is a nonlinear behavior done by using perpendicular loads and gently increasing lateral loads, which are equivalent to the seismic load. The pushover analysis is done by taking the base shear from the top floor against the displacement of the structure. This can provide information about the failure load and the ductility of the structure (Khan, et al., 2015).

Pushover analysis uses 3D structures that are exclusive to the horizontal movement of the earth, regardless of the irregularity of the structure (the horizontal and vertical symmetric). Previous studies presented developments in this method called the practical modal pushover analysis (PMPA) procedure. The accuracy of this method is similar as much as the linear dynamic analysis response spectrum (Reyes and Chopra, 2011).

#### **CHAPTER 3**

#### METHODOLOGY

#### 3.1. Methodology of Estimating the RMF Using Pushover Curve

Pushover analysis is used to evaluate the RMF by using software ETABS v 18.0.1. It considers the occurrence of powerful earthquakes, as most structures have nonlinear behavior in seismic resistance. Both the linear and nonlinear responses are controllable. By way of explanation, we can enhance the structural nonlinear behavior by applying some measurement in the design phase of hinge composition that enhances the horizontal Plateau of pushover curve. This means the structure gets more ductility and flexibility to make the initial hinge remain safe during the composition of the next hinge and not collapse.

Pushover analysis is administered by exposure of structure to a lateral force. The lateral load is distributed on the stories as specified in the ASCE 7-10. Pushover analysis was done by applying a step by step-controlled displacement method until the structure reaches the maximum lateral displacement.

The relationship between the horizontal base shear and the displacement is shown in figure 3.1 (Pushover curve). The overall response of a structure is described in the shape of base shear-horizontal displacement curve. This figure represents the actual and bilinear idealized response of the response curve. The vertical and horizontal axes show the base shear and the relative lateral displacement. The RMF is equal to the ratio of elastic base shear (V<sub>e</sub>) to the design base shear (V<sub>design</sub>), where V<sub>e</sub> represents the linear-elastic response (NEHRP, 2001). Therefore, according to AISC-LRFD regulations

$$R = \frac{V_e}{V_{design}} \tag{3.1}$$

Numerous studies have recommended a formula to calculate the R-Factor (Uang, 1991), (Whittaker et la., 1999), (Kappos, 1999), and (Borzi and Elnashai, 2000). The suitable definitions for the R-Factor it depends on dividing it into three different factors:  $R\mu$ ,  $R_{\xi}$ , and Rs:

$$\mathbf{R} = \mathbf{R}\boldsymbol{\mu} \, \mathbf{R} \mathbf{s} \, \mathbf{R}_{\boldsymbol{\xi}} \tag{3.2}$$



Figure 3.1: Pushover curve, relationship between the base shear and the displacement

The idioms used in the figure are Ve: elastic base shear, Vs: yield base shear, V1: base shear at first plastic hinge and Vd: design base shear.

Pushover is relationship between force factor (R), overstrength factor (Rs) and ductility reduction factor (R $\mu$ ).

Ductility reduction factor is a factor which reduce the element force demand to the level of idealized yield strength of the structures. According to Mwafy and Elnashi study, published in 2002, the ductility reduction factor can be estimated depending on the structural response for earthquake using the following formula:

$$R\mu = \frac{PGAm (\delta max)}{PGAy (\delta y)}$$
(3.3)

Where PGAm ( $\delta_{max}$ ) is the maximum displacement on the roof and PGAy ( $\delta_y$ ) is the yield displacement.

The overstrength factor Rs play an important role in collapse prevent of buildings. It can be estimated according to Taieb and Sofiane's study, published in 2014, by the following formula:

$$Rs = \frac{Vy}{V1}$$
(3.4)

The damping factor ( $R\xi$ ) represents the effect of the additional damping to the structure. It is used for buildings that have supplemental energy dissipation devices, otherwise, it's not applicable to use and its equal to 1.0 (Taieb and Sofiane, 2014).

#### **3.2. Design Phase Procedure**

After building up the models and preliminary design finish and estimating the RMF for each frame, the final design phase procedure is observed as follows.

- Estimate dead load and live load on the building.
- Estimate the equivalent lateral load.
- Define the load combination should use.

#### **3.3. Loads and Load Combinations Used**

Loads can be classified into two main categories.

**4** Gravity loads (Dead, Superimposed dead and Live loads).

Lateral loads (Earthquake load).

## 3.3.1. Gravity loads

## Dead load

The dead load includes loads that are relatively constant over time, including the selfweight of the structural elements.

Superimposed dead load (SID):

The superimposed dead load includes the weight of non-structural elements shown in figure 3.2, and detailed as follows:

Use SID = 5.5 kN/  $m^2$ 



Figure 3.2: Floor Layers

➤ Live load:

The live load is a momentary, of short duration or a moving load which is produced during maintenance by workers, equipment, and materials, and during the life of the structure by people, furniture or any other movable object.

According to IBC-2012 (Table 1607.1), given in appendix 2 (page. 82), the values of live load used are  $3.5 \text{ kN/m}^2$ 

## 3.3.2. Lateral loads

It consists of seismic load that might cause to act upon a structural system in any horizontal direction or vertical direction. It was defined using two approaches:

 Linear static approach: using Equivalent Static Method as per ASCE 7-10. There were two load patterns were defined, to compute for x direction movement (EX1, EX2) using to design the structural elements beams, column and shear walls.

According to IBC 2012 (Table 1604.5), given in appendix 2 (page. 83), the building is assigned to a risk category III.

According to ASCE 7-10 (Table 1.5-2), given in appendix 2 (page.83) and depending on risk category, the importance factor.

 $I_e = 1.25$ .

According to IBC 2012 (section 1613.3.5(1) or 1613.3.5(2)) and based on the risk category and the design spectral response acceleration parameters,  $S_{DS}$  and  $S_{D1}$ , the building is assigned to a seismic design category D.

According to ASCE 7-10 (Table 12.2-1), given in appendix 2 (pages. 77-81) and depending on the seismic design category the seismic force-resisting system is building frame system with special reinforced concrete shear walls.

2. Nonlinear static pushover analysis method. There was one load pattern was defined, to compute for x-direction movement (push-X) using to obtain the RMF values for the models.

## **3.4. Load Combinations**

According to IBC-2012 (Section 1605), required strength U shall be at least equal to the effects of factored loads as shown in table 3.1.

Load Combination	Equation No.
U = 1.4(D+F)	16-1
U = 1.2(D+F) + 1.6(L+H) + 0.5(Lr  or  S  or  R)	16-2
$U = 1.2(D+F) + 1.6(Lr \text{ or } S \text{ or } R) + 1.6H+(f_1L \text{ or } 0.5W)$	16-3
$U = 1.2(D+F) + 1.0W + f_1L + 1.6H + 0.5(Lr \text{ or } S \text{ or } R)$	16-4
$U = 1.2(D+F) + 1.0E + f_1L + 1.6H + f_2S$	16-5
U = 0.9D + 1.0W + 1.6H	16-6
U = 0.9(D+F) + 1.0E + 1.6H	16-7

**Table 3.1:** Load Combination used. (equation number is referred to the code)

Where:

- $\triangleright$  D = Dead load.
- > E = Combined effect of horizontal and vertical earthquake-induced forces as defined in Section 12.4.2 of ASCE 7.
- $\succ$  F = Load due to fluids with well-defined pressures and maximum heights.
- > H = Load due to lateral earth pressures, groundwater pressure or pressure of bulk materials.
- > L = Roof live load greater than 0.96 kN/m<sup>2</sup> and floor live load.
- $\blacktriangleright$  Lr = Roof live load of 0.96 kN/m<sup>2</sup> or less.
- $\triangleright$  R = Rain load.
- $\succ$  S = Snow load.
- $\blacktriangleright$  W = Load due to wind pressure.

#### **3.5.** Computer Modeling

In this study, 2D reinforced concrete frames are considered with different size of openings, two heights 3.2m and 3.6m, different size of openings, and two span length 5m, 6m and modeled in ETABS.

#### **3.5.1.** The body of the study

## a. Length of spans and height of the story.

There are two lengths of the spans that will include in this study as shown in figures 3.3 - 3.6. These figures explain the distribution of the shear walls in the frames and the span lengths and the story heights.



Figure 3.3: Shear wall with 5m. Span length and 3.2m. Height of story



Figure 3.4: Shear wall with 5m. Span length and 3.6m. Height of story

The figures above explain the distribution of shear walls in frame with 5m of span length and story heights 3.2 and 3.6 m.



Figure 3.5: Shear wall with 6m. Span length and 3.2m. Height of story



Figure 3.6: Shear wall with 6 m. Span length and 3.6 m. Height of story

The figures above explain the distribution of shear walls in frame with 6m of span length and story heights 3.2 and 3.6 m.

# b. Size of openings.

In this study, there are six different sizes of openings shown in table 3.2. The figure 3.7 will explain the distribution of opening size.

	Sample	Opening sizes (m)	
	No.	н	V
-	1	0	0
	2	2	1
	3	2	1.5
	4	2	2
	5	3	1
	6	3	1.5
_	7	3	2

 Table 3.2: Size of opening



Figure 3.7: Cross-section from 2D frame shown opening in a shear wall

#### c. The dimension of structural elements.

As mentioned earlier, building frame system with reinforced concrete shear walls is used for resisting both gravity and seismic loads.

This system uses a complete two-dimensional space frame to support gravity loads (vertical loads) where the load will be transmitted from beams, walls to the columns going down to reach the footings, and the shear walls take the lateral forces but may support some limited gravity loads.

The cross sections use for beams is 0.45 m \* 0.45 m, for the columns is 0.5 m \* 0.5 m and the thickness of the shear wall is 0.25 m as shown in figure 3.8.



Figure 3.8: Elements cross section used in models this cross section not on scale

#### d. Material uses in this study.

In this study, the material used to perform the structural elements are concrete and steel where Concrete is a composite material composed of cement, fine aggregate, coarse aggregate, and sometimes concrete include chemical admixture.

Although ASTM A 706 (A 706M), with a minimum yield strength  $F_y$  of 60,000 psi (420 mpa), is including requirements that enhance it to be more controllable for tensile properties. The materials will be elaborated used is shown in table 3.3
# Table 3.3: Materials properties

Structural Element	Concrete Type	fc' (mpa)	E <sub>c</sub> (mpa)	ft' (mpa)	fr (mpa)
Reinforced concrete elements	B300	25	$2.48*10^4$	1.75	3.28
Reinforcing steel	Yield strength (Fy)	Ultimate strength (f <sub>u</sub> )	Steel grade	Modulus of elasticity (Es)	
	420 mpa	615 mpa	60	200 GPa	

Where:

- ➤ f<sub>c</sub>': Cylindrical concrete compressive strength.
- Ec: Concrete modulus of elasticity (Linearity)which is calculated according to ACI 318-14 (Equation 19.2.2.1.b)
- f<sub>t</sub>': Concrete direct tensile capacity which is calculated according to ACI 209R-92 (Equation 2.4)
- f<sub>r</sub>: Concrete flexural capacity "Modulus of rupture" according to ACI 209R-92 (Equation 2.3)
- >  $V_c = 25 \text{ kN/m}^3$  (unit weight of reinforced concrete).
- >  $V_{c'} = 23 \text{ kN/m}^3$  (unit weight of plain concrete).
- $\triangleright$  v = 0.2 (Poisson's ratio).
- >  $\lambda = 1$  for normal weight concrete (shear strength reduction factor).

# **3.6.** Pushover Analysis Steps

The pushover analysis method is done by control displacement on the structure joints. It follows specific procedures as exemplified below to estimate the response modification factor and the effects of openings on this factor.

- 1. Create a 2D frame and define the appropriate sections for structural elements.
- 2. Define the load pattern for all load types, define pushover load as push -x loud as acceleration load in load case.
- 3. Assumed hinges for beams and columns and define shear wall as the layered type to make ETABs analysis walls as nonlinear analysis.
- 4. Define mass source by including 25% of live load, 100% dead load and 100% superimposed dead load.

#### **CHAPTER 4**

#### STUDY RESULTS AND DISCUSSION

This chapter includes the analysis result for 2D reinforcement concrete frames with shear walls after analysis these models. Results will be discussed and be compared in graphs and tables for different geometry properties for the frames, the height of the story, the span length and the size of the opening. This obtains the RMF for 2D frames with different properties. In order to observe the effect of openings on shear walls with different sizes, the effect of story height on RMF, the effect of span length and obtain the RMF for each frame. Number of models for this study is equal to 28 models.

Below shows the reader the labels used to describe the 28 specific model names.

# **RC-SL-SH-SO**

Where:

RC: Reinforced Concrete

SL: Span Length

SH: Story Height

SO: Size of Opening

#### 4.1. Calculation

These are some sample calculations for a couple of models that show the results of pushover curve and the calculations done to determine the RMF, RS, and R $\mu$ . As shown in the figures and tables below. Figures 4.1, 4.3, 4.5 and 4.7 represent the pushover curve for 2D reinforcement concrete structures, while figures 4.2, 4.4, 4.6 and 4.8 represent that plastic hinges assigned to the structures. Table 4.1 includes max displacement, Dy, Vy, V1, Rs, R $\mu$  and RMF from the pushover curve.

1. For a 2D frame with no openings, RC-5m-3.2m-0×0, the pushover curve results, the plastic hinges are shown in figure 4.1 and 4.2 and the RMF values in table 4.1



Figure 4.1: Push-Over curve for a 2D frame with opening, RC-5m-



**Figure 4.2:** Deformed shape and plastic hinges for a 2D frame with opening, RC-5m-3.2m-0×0

2. For a 2D frame with no openings, RC-5m-3.2m-2×2, the pushover curve result, the plastic hinges are shown in figure 4.3 and 4.4 and the RMF values in table 4.1.



Figure 4.3: Push-Over curve for a 2D frame with opening, RC-5m-3.2m-2×2



**Figure 4.4:** Deformed shape and plastic hinges for a 2D frame with opening, RC-5m-3.2m-2×2

3. For a 2D frame with no openings, RC-6m-3.2m-2×1.5, the pushover curve result, the plastic hinges are shown in figure 4.5 and 4.6 and the RMF values in table 4.1.



Figure 4.5: Push-Over curve for a 2D frame with opening, RC-6m-



**Figure 4.6:** Deformed shape and plastic hinges for a 2D frame with opening, RC-6m-3.2m-2×1.5

4. For a 2D frame with no openings, RC-6m-3.6m-3×2, the pushover curve result, the plastic hinges are shown in figure 4.7 and 4.8 and the RMF values in table 4.1.



**Figure 4.7:** Push-Over curve for a 2D frame with opening, RC-6m-3.6m-3×2



**Figure 4.8:** Deformed shape and plastic hinges for a 2D frame with opening, RC-6m-3.6m-3×2

MODEL CODE	MAX.DIS	Dy	Vy	<b>V1</b>	Rμ	Rs	RMF		
RC-5m-3.2m-0×0	38.5	9.44	1184.4	713.2	4.08	1.67	6.78		
RC-5m-3.2m-2×2	12.63	4.485	593.8	553.35	2.81	1.1	3.1		
RC-6m-3.6m-2×1.5	22.718	7.84	1072.2	729	2.9	1.61	4.66		
RC-6m-3.6m-3×2	27.717	12.83	1019.8	496.56	2.16	2.05	4.44		

**Table 4.1:** Sample calculations for RMF

#### \*The rest of the results can be found in appendix 1.

#### 4.2. Response Modification Factor for Different Models

In this study, the differences in RMF values is estimated by applying the pushover analysis method. This method applied for 2D frames with shear wall, 25 mpa compressive strength for concrete and 420 mpa tension strength of steel reinforcement. This study is created for the different size of the opening, span length, story height.

#### 4.2.1. The results of RMF for different sizes of openings

The RMF for each model resulted in different geometry properties and different sizes of openings. These differences affect the seismic behavior for each model effecting the RMF value. This behavior is included in three parameters, ductility reduction factor, overstrength reduction factor, dumping factor. These factors are indicated in points located on pushover curve, the max displacement, Dy, Vy, V1, Rs, Rµ and various variables of RMF are estimated as shown in tables 4.2, 4.3, 4.4 and 4.5. There is a direct relationship between the RMF and the opening size as shown in tables and figures below, the fact is when the opening size increases irrespective of the difference in span length and story height the RMF value decrease.

MODEL NUM.	MODEL CODE	MAX.DIS	Dy	Vy	<b>V1</b>	Rμ	Rs	RMF
1	RC-5m-3.2m-0×0	38.5	9.44	1184.40	713.2	4.08	1.67	6.78
2	RC-5m-3.2m-2×1	15.93	9.10	928.23	335.48	1.76	2.77	4.85
3	RC-5m-3.2m-2×1.5	25.29	9.37	931.86	630.64	2.7	1.48	3.99
4	RC-5m-3.2m-2×2	30.04	12.48	978.08	795.09	2.41	1.24	2.97
5	RC-5m-3.2m-3×1	28.19	10.25	928.63	565.12	2.75	1.65	4.52
6	RC-5m-3.2m-3×1.5	30.766	10.28	797.00	455.365	3	1.76	5.24
7	RC-5m-3.2m-3×2	18.52	6.51	412.63	241.15	2.85	1.72	4.87

 Table 4.2: Response modification factor values for RC-5m-3.2m

 Table 4.3: Response modification factor values for RC-5m-3.6m

MODEL NUM.	MODEL	MAX.DIS	Dy	Vy	<b>V</b> 1	Rμ	Rs	RMF
8	RC-5m-3.6m-0×0	39.869	11.58	1066.311	601.1	3.45	1.78	6.11
9	RC-5m-3.6m-2×1	31.83	10.90	905.70	562.21	2.93	1.62	4.71
10	RC-5m-3.6m-2×1.5	32.08	10.49	817.43	550.73	3.06	1.49	4.54
11	RC-5m-3.6m-2×2	32.475	11.69	834.24	526.5	2.78	1.59	4.41
12	RC-5m-3.6m-3×1	30.5	11.4	798.2	354.4	2.67	2.26	6.01
13	RC-5m-3.6m-3×1.5	30.705	12.3	792.0506	384.49	2.5	2.07	5.15
14	RC-5m-3.6m-3×2	36.73	12.73	645.74	449.12	2.89	1.44	4.15

 Table 4.4: Response modification factor values for RC-6m-3.2m

MODEL NUM.	MODEL	MAX.DIS	Dy	Vy	<b>V</b> 1	Rμ	Rs	RMF
15	RC-6m-3.2m-0×0	26.31	8.10	1505.33	836.50	3.25	1.8	5.85
16	RC-6m-3.2m-2×1	19.70	9.189	1079.8	477.93	2.15	2.26	4.85
17	RC-6m-3.2m-2×1.5	22.72	7.84	1172.23	729.01	2.90	1.61	4.66
18	RC-6m-3.2m-2×2	18.57	7.246	1086.8	637.23	2.57	1.71	4.37
19	RC-6m-3.2m-3×1	26.623	8.246	1152.2	681.24	3.23	1.7	5.47
20	RC-6m-3.2m-3×1.5	26.63	9.859	1141.5	608.45	2.71	1.88	5.07
21	RC-6m-3.2m-3×2	30.94	12.84	1085.95	863.09	2.41	1.26	3.04

MODEL NUM.	MODEL	MAX.DIS	Dy	Vy	<b>V1</b>	Rμ	Rs	RMF
22	RC-6m-3.6m-0×0	35.083	10.431	1402.9	701.01	3.37	2.01	6.74
23	RC-6m-3.6m-2×1	14.296	5.759	824.91	354.99	2.49	2.33	5.77
24	RC-6m-3.6m-2×1.5	25.518	9.267	1090.2	643.41	2.76	1.7	4.67
25	RC-6m-3.6m-2×2	25.943	9.949	1051.9	606.85	2.61	1.74	4.52
26	RC-6m-3.6m-3×1	27.765	8.829	1040.6	598.46	3.15	1.74	5.47
27	RC-6m-3.6m-3×1.5	27.727	9.947	976.45	561.41	2.79	1.74	4.85
28	RC-6m-3.6m-3×2	27.717	12.829	1019.8	496.56	2.17	2.06	4.44

 Table 4.5: Response modification factor values for RC-6m-3.6m

The model with shear wall should have least displacement followed by the model with openings at the shear wall as shown in the tables above.

Figures 4.9, 4.10, 4.11 and 4.12 graph the RMF values of 28 models presented from tables 4.2, 4.3, 4.4 and 4.5, consecutively. The X-axis represents the Model code, Y-axis represent RMF. This figure gives the reader an overall view of the RMF values of the 28 models.

As can be seen from figures 4.9, 4.10, 4.11 and 4.12 there are different RMF values although the areas of openings are equal. For example, models RC-5m x  $3.2m-2 \times 1.5$  and RC-5m x  $3.2m-3 \times 1$  both structures have the same areas of openings resulted in two different RMF values. The difference between of RMF values is due to the different arrangement (shape) of the openings in the shear walls, on the other hand, the first model has 2 m in the horizontal direction and 1.5 m in the vertical direction, while the second model has 3 m in the horizontal direction and 1 m in the vertical direction.



Figure 4.9: Different values of RMF for RC.5m.3.2m with different size of openings



Figure 4.10: Different values of RMF for RC.5m.3.6m with different size of openings



Figure 4.11: Different values of RMF for RC.6m.3.2m with different size of

openings



Figure 4.12: Different values of RMF for RC.6m.3.6m with different size of openings

# 4.2.2. Values of RMF for different span lengths and story heights

Differences between models with different geometry properties (span length, story height, opening size) as shown in tables previously presented above. It seems that increasing of opening size led to decreasing the value of RMF. Table 4.6 show the values of RMF for different model numbers without opening. All RMF values in table 4.6 are approximated to 6.

**Table 4.6:** Response modification factor values for different span lengths and story



heights

Figure 4.13: Different values of RMF for deferent span length and story height

#### 4.3. The RMF Values According to ASCE 7-10 Recommendation

Applying the factors submitted in ASCE 7-10 Table 12.2-1 given in appendix 2 (pages. 77-81), the RMF values are estimated, these factors depend on the structural conditions. In this study, the recommended RMF value ranges between (3-6).

#### 4.3.1. The effect of openings on RMF

According to the results taken from the analysis in tables 4.2 and 4.5, values for RMF are affected when openings existed in shear walls. The presence of openings in shear walls affected the ductility for the shear wall as shown in figures 4.14, 4.15, 4.16 and 4.17. Curves are shifting down due to the decrease occurring to the shear capacity and the maximum displacement for the structures.



Figure 4.14: Pushover curves for RC-5m-3.2m with different size of openings



Figure 4.15: Pushover curves for RC-5m-3.6m with different size of openings



Figure 4.16: Pushover curves for RC-6m-3.2m with different size of openings.



Figure 4.17: Pushover curves for RC-6m-3.6m with different size of openings

#### 4.3.2. Recommended design for shear walls with openings

According to ACI 318-14 (section 18.10.6.3), structural shear walls that aren't designed according to ACI 318-14 (section 18.10.6.2) should have different boundary elements at the edge and surround the openings due to the most compressive strength exceeding the design load compensation and the earthquake effect on the structure.

As stated above, the code recommended to reinforce the shear walls that included openings, especially the edges and the boundaries with more reinforcement with the analysis design recommended.

#### 4.4. The Effect of Opening sizes on Rµ and Rs

The ductility and flexibility of shear walls are affected in the presence of openings. Figures below analyze the openings existing in the shear walls that cause a reduction in the R $\mu$  and the Rs that affects the RMF value. Figures 4.18, 4.19, 4.20 and 4.21 analyze the openings existing in the shear walls that cause a reduction in the R $\mu$  and the Rs that affects the RMF value.



Figure 4.18: The result of  $R\mu$  and Rs for RC-5m-3.2m



Figure 4.19: The result of  $R\mu \& Rs$  for RC-5m-3.6m





Figure 4.21: The result of Rµ & Rs for RC-6m-3.6m

# **CHAPTER 5**

# **CONCLUSION AND RECOMMENDATIONS**

#### 5.1. Conclusion

- The RMF is evaluated by using the pushover analysis method on 28 2D structural frames for different span lengths, story heights and sizes of openings.
- The frames are analyzed in pushover by applying gravity loads and lateral loads. The analysis results are related with the code references, the effect of openings in shear walls on RMF and the effect of the existence of the openings in shear walls on ductility.
- Results of RMF in this study presented a difference in span lengths and story heights for the shear walls with or without openings achieved according to ASCE 7-10 Table 12.2-1, given in appendix 2 (pages. 77-81) recommendation.
- An increase in the story height by 11% causes decrease in the RMF value by 10%.
- There is a relationship between the opening sizes and the area of the shear walls. The ratio between opening sizes to the area of the shear walls effect the RMF, in which the ratio was less than 85%, decreasing the value for RMF more than the recommended code.
- The decrease is compensated with the ductility in shear walls with openings by redesigning the boundary elements in shear walls, according to ACI 1-14 (section 18.10.6.3 and 18.10.6.2).
- Openings effect the maximum base shear and the maximum displacement that causes a decrease in the RMF values, due to the reduction in the Rs and Rµ.

• As the opening size becomes bigger for the shear wall area, the shear wall performance changes to beam and column in resisting the shear, moment and lateral forces.

# 5.2. Recommendations

In this research, just 2D structural frames are investigated, which means the lateral forces are applied in one dimension, to get the effects of openings in all directions. The 3D structures are more rather compatible than the 2D structures. Moreover, in this study the similarity was achieved, so not all the structures have similar conditions, reasoned to torsional problems in the structures.

For this study, the 2D frames are not considered in the torsion problem, knowing that the torsion causes a total change in design for the structures. The openings existing should take into consideration in the design.

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APPENDICES

# **APPENDIX 1**

# TABLE OF THE RESULTS FOR DIFFERENT GEOMETRY PROPERTIES

A1.1: Results of pushover for RC-5m-3.2m frames with different size of opening

Displacement mm	Base Shear kl	N Displacement mm	Base Shear kN
0.0	0.0	22.1	1481.9
5.7	713.2	22.5	1485.8
8.6	987.1	22.8	1490.5
12.5	1193.2	23.6	1489.3
12.6	1199.6	28.7	1585.4
12.6	1201.4	37.8	1685.9
12.6	1201.1	37.8	1685.7
13.1	1205.9	38.1	1686.7
16.1	1345.5	38.1	1686.8
16.1	1345.2	38.2	1689.3
17.0	1374.4	38.2	1690.4
18.1	1394.9	38.3	1690.0
18.3	1388.5	38.5	1691.3
22.1	1482.0	38.5	1691.8
Vy kN	Dy mm	Rs Rm	R
1184.40	9.44	1.66 4.08	6.77

 Table A1.1.1: Results of pushover for RC-5m-3.2m without opening



Figure A1.1.1: Pushover curve for RC-5m-3.2m without opening

Displacement mn	n Base She kN	ar Di	splacement mm	Base Shear kN
0.00	0.00		14.91	1116.10
3.05	335.48		14.92	1115.99
8.91	870.63		15.02	1117.86
10.74	965.26		15.03	1117.72
10.75	966.47		15.89	1109.92
10.85	968.15		15.89	1109.92
11.26	965.18		15.90	1110.18
11.47	969.25		15.91	1110.16
13.56	1077.60		15.93	1110.02
Vy kN	Dy mm	Rs	Rm	R
928.23	9.10	2.77	1.75	4.84

 Table A1.1.2: Results of pushover for RC-5m-3.2m-2×1 frame



**Figure A1.1.2:** Pushover curve for RC-5m-3.2m with opening 2×1

Displacement mr	n Base Shear kN	Displacement mm	Base Shear kN
0.00	0.00	17.82	1127.25
6.34	630.64	22.12	1219.32
12.19	999.63	24.69	1245.60
12.25	1001.66	24.72	1245.75
12.83	1009.48	24.72	1244.91
15.42	1096.35	24.72	1245.07
16.57	1116.82	24.91	1251.36
16.59	1116.76	24.91	1251.41
17.20	1110.59	24.99	1248.97
17.27	1109.05	25.29	1254.00
Vy kN	Dy mm	Rs Rm	R
931.86	9.37	1.48 2.70	3.99

 Table A1.1.3: Results of pushover for RC-5m-3.2m-2×1.5 frame



**Figure A1.1.3:** Pushover curve for RC-5m-3.2m with opening 2×1.5

Displacemen	t mm F	Base Shear kN	Displacement mm	Base Shear kN
0.00		0.00	28.89	1396.67
10.15		795.09	28.92	1382.05
15.04		1022.20	30.01	1394.38
17.48		1073.50	30.04	1392.31
23.47		1278.76	30.04	1392.51
24.33		1291.69	30.04	1392.52
28.87		1396.72		
Vy kN	Dy mm	Rs	Rm	R
978.08	12.48	1.23	2.41	2.96

**Table A1.1.4:** Results of pushover for RC-5m-3.2m-2×2 frame



**Figure A1.1.4:** Pushover curve for RC-5m-3.2m with opening 2×2

Displacement n	nm Base	e Shear kN	Displacement mm	Base Shear kN
0.00	(	0.00	18.82	1050.50
6.24	56	55.12	21.79	1093.15
9.29	76	58.52	21.80	1091.72
9.92	79	96.35	21.92	1086.63
10.55	81	0.57	22.36	1094.42
13.01	90	)4.61	25.55	1125.61
13.69	92	22.78	26.06	1123.07
14.74	93	37.51	27.17	1132.68
14.84	93	35.02	28.19	1123.59
Vy kN	Dy mm	Rs	Rm	R
928.63	10.25	1.64	2.75	4.52

**Table A1.1.5:** Results of pushover for RC-5m-3.2m-3×1 frame



**Figure A1.1.5:** Pushover curve for RC-5m-3.2m with opening 3×1

Displ	lacement mm	Base Shear kN		
	0		0	
	5.774		455.3653	
	12.668		814.5728	
	20.979		1002.614	
	24.586		1055.728	
	27.482		1071.439	
	29.155		1095.738	
	29.488		1098.237	
	30.527		1108.481	
	30.766		1109.573	
Vy kN	Dy mm	Rs	Rm	R
797.00	10.28	1.75	2.99	5.24

 Table A1.1.6: Results of pushover for RC-5m-3.2m-3×1.5 frame



**Figure A1.1.6:** Pushover curve for RC-5m-3.2m with opening 3×1.5

Displacement mm		Base Shear kN	Displacement mm	Base Shear kN
0.00		0.00	10.22	453.66
3.81		241.15	10.30	451.82
7.25		421.95	10.30	451.83
7.59		431.74	10.30	451.83
7.60		431.74	10.55	455.60
8.68		448.37	12.46	495.68
8.83		447.45	16.84	558.73
8.90		446.13	18.49	567.88
9.88		450.69	18.52	567.85
Vy kN	Dy mm	Rs	Rm	R
412.63	6.51	1.71	2.84	4.87

 Table A1.1.7: Results of pushover for RC-5m-3.2m-3×2 frame

This Table values represent the base shear and displacement for the 2D frame with shear wall with openings  $3\times 2$ .



Figure A1.1.7: Pushover curve for RC-5m-

3.2m with opening  $3 \times 2$ 

# A1.2: Results of pushover for RC-5m-3.6m frames with different size of opening

<b>Table A1.2.1:</b> Results of pushover for RC-5m-3.6m. without openings framework the second sec
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Displacement r	nm Ba	ase Shear kN	Displacement mm	Base Shear kN
0		0	26.496	1330.412
6.53	(	501.1044	27.128	1333.496
8.161	-	734.1021	27.169	1332.883
15.309	:	1103.065	27.761	1331.582
16.03	:	1123.452	28.14	1333.545
16.46	:	1128.614	34.65	1420.618
16.803	:	1128.311	35.91	1429.306
20.337	:	1235.282	37.844	1451.217
20.454	:	1232.435	38.172	1453.324
20.851	:	1239.862	39.625	1469.574
21.093	:	1239.641	39.625	1469.574
21.578		1240.96	39.706	1469.907
21.638	:	1238.741	39.788	1469.677
25.926		1323.646	39.869	1468.39
Vy kN	Dy mm	Rs	Rm	R
1066.31	11.58	1.77	3.44	6.11



Figure A1.2.1: Pushover curve for RC-5m-3.6m without openings

Displacement mm		Base Shear kN	Displacement mm	Base Shear kN
0.00	)	0.00	22.92	1112.88
6.76	5	562.21	22.95	1113.36
11.2	7	850.81	23.02	1081.88
14.1	2	950.55	23.14	1074.56
14.2	3	950.24	23.53	1080.42
14.7	14.72		23.80	1076.59
17.4	1	1029.43	27.70	1164.80
17.8	0	1035.82	30.38	1198.54
18.2	8	1036.88	31.54	1209.23
18.7	18.79		31.54	1209.16
20.0	20.01		31.54	1209.16
22.77		1113.36	31.83	1199.77
22.7	7	1113.42		
Vy kN	Dy mm	Rs	Rm	R
905.70	10.90	1.61	2.92	4.70

 Table A1.2.2: Results of pushover for RC-5m-3.6m-2×1 frame



Figure A1.2.2: Pushover curve for RC-5m-3.6m with openings 2×1

Displacement	mm Bas	e Shear kN	Displacement mm	Base Shear kN
0.00		0.00	24.74	1108.08
7.07	5	50.73	25.41	1111.10
13.71	8	91.44	26.15	1119.78
16.34	9	71.56	26.16	1120.03
17.11	9	82.01	26.33	1121.49
17.39	9	83.66	26.38	1121.31
18.49		93.91	32.08	1109.58
19.24	10	)05.69		
Vy kN	Dy mm	Rs	Rm	R
817.43	10.49	1.48	3.06	4.54

 Table A1.2.3: Results of pushover for RC-5m-3.6m-2×1.5 frame


Figure A1.2.3: Pushover curve for RC-5m-3.6m with openings 2×1.5

Displacement	mm Bas	e Shear kN	Displacement mm	Base Shear kN
0		0	26.784	1084.359
7.377	I	526.4977	28.185	1099.532
14.232	8	363.3194	28.295	1098.653
14.886	8	372.1448	28.995	1098.748
17.502	9	947.3638	29.17	1098.081
20.519	9	982.4188	31.645	1127.607
20.625	9	980.6253	32.475	1133.126
20.732		979.463		
Vy kN	Dy mm	Rs	Rm	R
834.24	11.69	1.58	2.78	4.40

 Table A1.2.4: Results of pushover for RC-5m-3.6m-2×2 frame



**Figure A1.2.4:** Pushover curve for RC-5m-3.6m with openings 2×2

Displacement	Displacement mm Base k		Displacement mm	Base Shear kN
0		0	24.102	995.7301
4.948		354.3653	24.68	992.4485
9.412	(	644.5805	30.116	1037.297
13.831	8	804.4682	30.116	1037.36
15.387	8	841.1053	30.116	1037.362
16.973	8	859.5013	30.453	1039.5
22.217	9	974.9905		
Vy kN	Dy mm	Rs	Rm	R
798.18	11.42	2.25	2.67	6.01

 Table A1.2.5: Results of pushover for RC-5m-3.6m-3×1 frame



**Figure A1.2.5:** Pushover curve for RC-5m-3.6m with openings 3×1

Displacement	mm	Base Shear kN	Displacement mm	Base Shear kN
0		0	29.32	1027.087
5.627		384.4889	30.159	1035.565
13.378		779.1413	30.255	1035.456
15.355		827.7397	30.493	1037.205
15.743		829.3653	30.674	1035.852
24.978		985.5004	30.68	1035.904
28.493		1024.125	30.691	1035.966
28.906		1025.038	30.694	1035.991
29.113		1026.754	30.705	1036.051
Vy kN	Dy mm	Rs	Rm	R
792.05	12.30	2.06	2.50	5.14

 Table A1.2.6: Results of pushover for RC-5m-3.6m-3×1.5 frame



Figure A1.2.6: Pushover curve for RC-5m-3.6m with openings

3×1.5

Displacement mm	Base Shear kN	D	Displacement mm	Base Shear kN
0	0		26.377	859.5703
8.852	449.1182		27.131	862.9037
16.372	682.3599		27.445	863.5309
16.708	688.8826		32.234	927.6859
16.866	690.2445		36.568	962.4986
26.369	859.8848		36.726	962.8734
26.375	859.5445			
Vy kN	Dy mm	Rs	Rm	R
645.74	12.73	1.44	2.89	4.15

 Table A1.2.7: Results of pushover for RC-5m-3.6m-3×2 frame



**Figure A1.2.7:** Pushover curve for RC-5m-3.6m with openings 3×2

## A1.3: Results of pushover for RC-6m-3.2m frames with different size of opening

Displacement	t mm	Base Shear kN	Displacement mm	Base Shear kN
0		0	19.821	1962.373
4.395		836.4995	19.859	1957.435
7.783		1290.576	19.936	1950.882
11.003		1560.124	25.986	2150.005
11.508		1571.62	25.987	2149.893
14.387		1756.129	26.124	2152.53
15.086		1779.196	26.158	2152.523
15.776		1788.998	26.294	2152.891
18.752		1934.877	26.294	2152.898
18.905		1938.028	26.294	2152.898
19.514		1958.528	26.308	2112.127
Vy kN	Dy mm	Rs	Rm	R
1505.33	8.10	1.80	3.25	5.84

**Table A1.3.1:** Results of pushover for RC-6m-3.2m. without openings frame



Figure A1.3.1: Pushover curve for RC-6m-3.2m without openings

Displacement n	ım Base Shear kN		Displacement mm	Base Shear kN
0		0	18.455	744.5005
3.962		477.9299	18.463	743.4573
6.422		746.4108	18.471	743.8799
8.194		821.0399	18.475	743.3582
10.666		947.3383	18.477	743.4483
14.035		1032.956	18.478	743.3829
14.465		1039.124	18.479	743.3175
14.529		1037.67	18.48	743.2521
14.982		1033.835	19.45	663.8672
16.042		959.0463	19.702	643.0839
18.175		732.7597		
Vy kN	Dy mm	Rs	Rm	R
1079.76	9.19	2.26	2.14	4.84

**Table A1.3.2:** Results of pushover for RC-6m-3.2m. with opening  $2 \times 1$  frame



**Figure A1.3.2:** Pushover curve for RC-6m-3.2m with opening 2×1

Displacement	mm	Base Shear kN	Displacement mm	Base Shear kN
0		0	20.923	1669.103
4.877		729.0075	22.223	1696.799
11.115		1348.805	22.224	1696.943
11.346		1357.694	22.548	1709.535
11.782		1358.627	22.564	1709.711
11.882		1355.255	22.696	1709.677
13.848		1458.398	22.696	1709.716
15.352		1500.79	22.713	1710.453
15.434		1501.716	22.717	1710.555
15.735		1496.252	22.718	1710.549
16.839		1506.464	22.718	1710.55
Vy kN	Dy mm	Rs	Rm	R
1172.23	7.84	1.61	2.90	4.66

**Table A1.3.3:** Results of pushover for RC-6m-3.2m. with opening 2×1.5 frame



**Figure A1.3.3:** Pushover curve for RC-6m-3.2m with opening 2×1.5

Displacement mm		ase Shear kN	Displacement mm	Base Shear kN
0		0	13.865	1420.536
4.249	(	537.2333	13.915	1419.843
9.101		1171.51	13.915	1419.695
9.501		1191.38	13.927	1417.271
12.423	:	1409.555	17.706	1575.099
13.175	:	1425.273	17.941	1578.245
13.231	1425.315		17.943	1578.691
13.245	:	1424.603	18.51	1602.142
13.358	:	1422.671	18.511	1602.175
13.414		1419.157	18.567	1604.266
Vy kN	Dy mm	Rs	Rm	R
1086.75	7.25	1.71	2.56	4.37

**Table A1.3.4:** Results of pushover for RC-6m-3.2m. with opening 2×2 frame



**Figure A1.3.4:** Pushover curve for RC-6m-3.2m with opening  $2 \times 2$ 

<b>Table A1.3.5:</b> Results of pushover for RC-6m-3.2m. with opening $3 \times 1$ framework for RC-6m-3.2m.	me
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Displacement	mm	Base Shear kN	Displacement mm	Base Shear kN	
0		0	16.77	1394.511	
4.875		681.2368	16.94	1397.439	
8.75		1096.198	20.085	1504.355	
10.483		1203.284	21.619	1536.757	
10.788		1211.226	21.62	1536.831	
11.37		1244.183	21.634	1521.042	
11.734		1206.746	22.18	1533.637	
14.239		1337.64	23.71	1581.674	
14.507		1335.16	23.842	1578.752	
15.041		1332.051	24.105	1580.739	
15.292		1331.788	26.622	1623.895	
15.543		1336.918	26.623	1623.91	
Vy kN	Dy mm	Rs	Rm	R	
1152.23	8.25	1.69	3.23	5.46	



**Figure A1.3.5:** Pushover curve for RC-6m-3.2m with opening 3×1

Displacement	mm B	ase Shear kN	Displacement mm	Base Shear kN
0		0	16.002	1291.258
5.086		608.4516	16.482	1291.507
11.049		1126.583	17.767	1314.117
11.154		1132.337	21.195	1436.762
11.629		1148.925	23.484	1486.315
12.013		1152.243	23.653	1476.421
12.216		1157.944	23.88	1478.057
12.318		1157.563	26.63	1536.845
Vy kN	Dy mm	Rs	Rm	R
1141.48	9.86	1.88	2.70	5.07

**Table A1.3.6:** Results of pushover for RC-6m-3.2m. with opening 3×1.5 frame



Figure A1.3.6: Pushover curve for RC-6m-3.2m with opening 3×1.5

Displacement n	ım Ba	se Shear kN	Displacement mm	Base Shear kN
0		0	17.689	1177.591
10.207	8	63.0932	17.77	1173.996
13.718	1	065.952	17.77	1174.147
16.054	1	147.838	23.361	1336.776
16.273	1	152.644	23.443	1338.233
16.71	1	154.433	24.309	1337.8
17.147	1	158.549	28.275	1416.963
17.486	1	170.694	28.795	1420.298
17.528	1	169.316	30.943	1451.645
17.528	1	169.389		
Vy kN	Dy mm	Rs	Rm	R
1085.95	12.84	1.26	2.41	3.03

**Table A1.3.7:** Results of pushover for RC-6m-3.2m. with opening 3×2 frame



**Figure A1.3.7:** Pushover curve for RC-6m-3.2m with opening 3×2

# A1.4: Results of pushover for RC-6m-3.6m frames with different size of opening

Table A1.4.1: Results	s of pushover	for RC-6m-3.6m.	without of	openings frame

Displacement	mm	Base Shear kN	Displacement mm	Base Shear kN		
0		0	22.267	1737.828		
5.017		701.0084	22.623	1736.052		
8.864		1124.853	22.628	1734.724		
13.29		1410.066	22.717	1729.07		
13.62		1416.439	22.806	1720.515		
13.956		1420.29	27.743	1862.081		
16.968		1571.585	28.055	1841.069		
17.127		1574.258	33.194	1953.22		
17.762		1589.913	34.847	1974.085		
18.08		1586.155	35.083	1967.218		
18.119		1584.204				
Vy kN	Dy mm	Rs	Rm	R		
1402.85	10.43	2.00	3.36	6.73		



Figure 1.4.1: Pushover curve for RC-6m-3.6m without opening

Displacement m	um Ba	ise Shear kN	Displacement mm	Base Shear kN
0.00		0.00	11.78	1015.61
2.42		354.99	11.91	1011.52
4.83		678.76	11.96	1008.95
8.35		948.93	12.37	1012.58
9.09		967.26	12.68	1020.94
9.66		974.30	12.93	1023.78
9.92		986.31	13.19	1029.33
10.03		971.11	14.13	1064.13
10.08		935.97	14.13	1064.28
10.09		932.78	14.22	1070.29
10.20		936.70	14.25	1070.15
11.66		1012.30	14.30	1070.13
Vy kN	Dy mm	Rs	Rm	R
824.91	5.76	2.32	2.48	5.77

**Table A1.4.2:** Results of pushover for RC-6m-3.6m. with opening  $2 \times 1$ 



**Figure 1.4.2:** Pushover curve for RC-6m.3-6m with opening 2×1

Displacement 1	mm Ba	se Shear kN	Displacement mm	Base Shear kN
0.00		0.00	23.06	1495.10
5.47		643.41	23.21	1493.80
11.93	1	160.56	23.36	1499.97
12.00	1	155.09	24.07	1513.71
12.01	1	154.38	24.42	1511.44
14.85	1	298.64	24.77	1515.82
15.29	1	1303.47	24.82	1514.70
15.34	1	301.24	24.99	1518.03
15.78	1	1319.50	25.16	1509.45
17.56	1	361.48	25.33	1511.03
18.20	1	1371.16	25.50	1516.87
18.23	1	371.14	25.51	1517.01
18.55	1	1372.46	25.52	1517.12
18.71	1	374.78	25.52	1517.12
18.92	1	356.42		
Vy kN	Dy mm	Rs	Rm	R
1090.21	9.27	1.69	2.75	4.67

**Table A1.4.3:** Results of pushover for RC-6m-3.6m. with opening  $2 \times 1.5$ 



Figure 1.4.3: Pushover curve for RC-6m-3.6m with opening 2×1.5

Displacement m	m Ba	ase Shear kN	Displacement mm	Base Shear kN
0.00		0.00	18.02	1305.88
5.67		606.85	18.97	1318.63
13.51		1183.41	18.99	1317.47
13.64		1184.03	19.10	1316.15
13.78		1184.19	19.16	1314.33
13.99		1193.80	25.32	1492.72
14.18		1197.08	25.34	1487.85
16.14		1277.69	25.94	1498.24
17.33		1305.33	25.94	1498.00
Vy kN	Dy mm	Rs	Rm	R
1051.86	9.95	1.73	2.61	4.52

**Table A1.4.4:** Results of pushover for RC-6m-3.6m. with opening  $2 \times 2$ 



Figure 1.4.4: Pushover curve for RC-6m-3.6m with opening 2×2

Displacement n	nm Bas	e Shear kN	Displacement mm	Base Shear kN
0.00		0.00	19.51	1336.13
5.01	5	98.46	20.33	1356.74
11.22	1	114.64	20.49	1359.51
11.31	1	118.62	20.57	1361.70
11.63	1	123.27	20.58	1362.09
11.65	1	123.28	21.09	1375.48
11.76	1	123.40	21.17	1358.11
12.28	1	115.03	26.16	1467.96
12.33	1	113.20	27.44	1486.41
14.19	1	197.98	27.59	1487.66
14.35	1	201.16	27.62	1488.13
14.65	1	213.08	27.66	1487.74
15.09	1	219.71	27.76	1487.05
15.09	1	218.98	27.77	1487.08
15.48	1	185.43		
Vy kN	Dy mm	Rs	Rm	R
1040.63	8.83	1.74	3.14	5.47

**Table A1.4.5:** Results of pushover for RC-6m-3.6m. with opening 3×1



**Figure 1.4.5:** Pushover curve for RC-6m-3.6m with opening 3×1

Displacement n	nm Ba	ase Shear kN	Displacement mm	Base Shear kN
0.00		0.00	26.84	1383.06
5.65		561.41	27.23	1376.25
12.05		1008.85	27.23	1376.35
13.03		1049.63	27.42	1382.42
13.76		1067.88	27.51	1382.46
14.86		1111.16	27.56	1381.93
15.48		1124.78	27.58	1381.99
16.38		1152.17	27.69	1380.66
16.39		1152.09	27.70	1378.79
18.73		1186.90	27.72	1376.59
24.34		1341.60	27.72	1376.60
24.45		1341.97	27.72	1376.62
24.79		1349.64	27.72	1376.63
25.15		1348.36	27.73	1376.43
Vy kN	Dy mm	Rs	Rm	R
976.45	9.95	1.74	2.79	4.85

**Table A1.4.6:** Results of pushover for RC-6m-3.6m. with opening 3×1.5



Figure A1.4.6: Pushover curve for RC-6m-3.6m with opening 3×1.5

Displacement mi	n Base k	Shear N	Displacement mm	Base Shear kN
0.00	0.	.00	24.35	1242.77
5.85	490	6.56	25.08	1254.67
13.84	98	5.87	25.47	1257.57
15.18	103	6.49	26.72	1283.95
15.76	105	0.06	26.72	1283.98
16.74	105	7.12	26.72	1283.98
17.12	106	4.63	27.40	1294.34
17.16	106	4.31	27.72	1290.51
17.25	106	4.35		
Vy kN I	Dy mm	Rs	Rm	R
1019.84	12.83	2.05	2.16	4.44

**Table A1.4.7:** Results of pushover for RC-6m-3.6m. with opening 3×2



**Figure 1.4.7:** Pushover curve for RC-6m-3.6m with opening 3×2

## **APPENDIX 2**

### **REINFORCED COCRETE STRUCTURAL DESIGN CODES**

## Table A2.1: Design Coefficients and Factors for Seismic Force-Resisting Systems

	ASCE 7 Section	~			Structural System Limitations Including Structural Height, h <sub>e</sub> (ft) Limits <sup>e</sup>					
		Detailing	Modification	Orvertenesth	Deflection	Sei	ismic	Desigr	ı Catej	ory
	Seismic Force-Resisting System	Are Specified	R <sup>e</sup>	Factor, Ω <sub>0</sub> <sup>#</sup>	Factor, C <sup>b</sup>	В	С	$\mathbb{D}^d$	E	$\mathbf{F}^{t}$
A.	BEARING WALL SYSTEMS									
L	Special reinforced concrete shear walls <sup>2, #</sup>	14.2	5	2%i	5	NL	NL	160	160	100
2.	Ordinary reinforced concrete shear walls <sup>2</sup>	14.2	4	2%i	4	NL	NL.	NP	NP	NP
3.	Detailed plain concrete shear walls <sup>d</sup>	14.2	2	2%	2	NL	NP	NP	NP	NP
4.	Ordinary plain concrete shear walls <sup>1</sup>	14.2	1½	2%	132	NL	NP	NP	NP	NP
5.	Intermediate precast shear walls 2	14.2	4	2½	4	NL	NL	$40^k$	$40^{t}$	40 <sup>k</sup>
6.	Ordinary precast shear walls <sup>4</sup>	14.2	3	21/2	3	NL	NP	NP	NP	NP
7.	Special reinforced masonry shear walls	14.4	5	2%	31/2	NL	NL	160	160	100
8.	Intermediate reinforced masonry shear walls	14.4	31/2	21/2	24	NL	NL	NP	NP	NP
9.	Ordinary reinforced masonry shear walls	14.4	2	21/2	154	NL	160	NP	NP	NP
10.	Detailed plain masonry shear walls	14.4	2	21/2	134	NL	NP	NP	NP	NP
11.	Ordinary plain masonry shear walls	14.4	11/2	2%	114	NL	NP	NP	NP	NP
12.	Prestressed masonry shear walls	14.4	195	2%	134	NL	NP	NP	NP	NP
13.	Ordinary reinforced AAC masonry shear walls	14,4	2	21/2	2	NL	35	NP	NP	NP
14.	Ordinary plain AAC masonry shear walls	14.4	192	21/2	13/2	NL.	NP	NP	NP	NP
15.	Light-frame (wood) walls sheathed with wood structural panels rated for shear resistance or steel sheets	14.1 and 14.5	612	8	4	NL	NL	65	65	65
16.	Light-frame (cold-formed steel) walls sheathed with wood structural panels rated for shear resistance or steel sheets	14.1	6)2	3	4	NL	NL	65	65	65
17.	Light-frame walls with shear panels of all other materials	14.1 and 14.5	2	2%z	2	NL	NL.	35	NP	NP
18.	Light-frame (cold-formed steel) wall systems using flat strap bracing	14.1	4	2	3%	NL	NL	65	65	65
В.	BUILDING FRAME SYSTEMS									
t.	Steel eccentrically braced frames	14.1	8	2	4	NL.	NL.	160	160	100
2	Steel special concentrically braced frames	14.1	6	2	5	NL	NL	160	160	100
3.	Steel ordinary concentrically braced frames	14.1	314	2	3%	NL	NL.	35	35	NP

Continued

CHAPTER 12	SEISMIC DESIGN REQUIREMENTS FOR BUILDING STRUCTURES
	Table 12.2-1 (Continued)

	ASCE 7 Section	ASCE 7 Section Where Response Detailing Modification Requirements Coefficient	Overstrength		Structural System Limitations Including Structural Height, h <sub>n</sub> (ft) Limits <sup>e</sup> Seismic Design Category					
	Detailing Requirements			Deflection Amplification						
Seismic Force-Resisting Syster	n Are Specified	Re	Factor, $\Omega_0^{t}$	Factor, Cd	В	С	$\mathbb{D}^{t}$	$\mathbf{E}^{t}$	F	
<ol> <li>Special reinforced concrete shear walls<sup>in</sup></li> </ol>	r 14.2	6	2%	5	NL	NL	160	160	100	
5. Ordinary reinforced concrete shea	r walls <sup>7</sup> 14.2	5	2%	4%	NL	NL	NP	NP	NP	
6. Detailed plain concrete shear wa	lls <sup>r</sup> 14.2 and 14.2.2.8	2	21/2	2	NL	NP	NP	NP	NP	
7. Ordinary plain concrete shear wa	alls <sup>i</sup> 14.2	152	2%	1%	NL	NP	NP	NP	NP	
8. Intermediate precast shear walls <sup>1</sup>	14.2	5	21/2	41/2	NL	NL	40 <sup>x</sup>	$40^{i}$	404	
9. Ordinary precast shear walls'	14.2	4	255	4	NL	NP	NP	NP	NP	
<ol> <li>Steel and concrete composite eccentrically braced frames</li> </ol>	14.3	8	2 1/2	4	NL	NL	160	160	100	
<ol> <li>Steel and concrete composite spo concentrically braced frames</li> </ol>	ecial 14.3	5	2	41/2	NL	NL	160	160	100	
<ol> <li>Steel and concrete composite or braced frames</li> </ol>	linary 14.3	3	2	3	NL	NL	NP	NP	NP	
<ol> <li>Steel and concrete composite pla shear walls</li> </ol>	ite 14.3	61/2	2%	5½	NL	NL	160	160	100	
shear walls										
<ol> <li>Steel and concrete composite ord shear walls</li> </ol>	finary 14.3	5	2%	4½	NL	NL	NP	NP	NP	
16. Special reinforced masonry shear	r walls 14.4	51/2	255	4	NL	NL	160	160	100	
17. Intermediate reinforced masonry walls	shear 14.4	4	2%	4	NL	NL	NP	NP	NP	
<ol> <li>Ordinary reinforced masonry she walls</li> </ol>	ar 14.4	2	2%	2	NL	160	NP	NP	NP	
19. Detailed plain masonry shear wa	ils 14.4	2	2%	2	NL	NP	NP	NP	NP	
20. Ordinary plain masonry shear wa	alls 14.4	11/2	255	11/4	NL	NP	NP	NP	NP	
21. Prestressed masonry shear walls	14.4	11/2	252	134	NL	NP	NP	NP	$\mathbb{N}\mathbb{P}$	
<ol> <li>Light-frame (wood) walls sheath with wood structural panels rated shear resistance</li> </ol>	ed 14.5 I for	7	255	452	NL	NL.	65	65	65	
<ol> <li>Light-frame (cold-formed steel) v sheathed with wood structural pa rated for shear resistance or steel</li> </ol>	walls 14.1 nels sheets	7	2%	4½	NL	NL.	65	65	65	
<ol> <li>Light-frame walls with shear par all other materials</li> </ol>	nels of 14.1and 14.5	2%	2%	2%	NL	NL	35	NP	NP	
25. Steel buckling-restrained braced frames	14.1	8	2%	5	NL	NL	160	160	100	
26. Steel special plate shear walls	14.1	7	2	6	NL	NL	160	160	100	

		ASCE 7 Section	E7 ion		ASCE 7 Section				Structural System Limitations Including Structural Height, h <sub>n</sub> (ft) Limits <sup>e</sup>				
		Where Detailing Requirements	Response Modification Coefficient	Overstrength	Deflection Amplification	Seismic Design Catego							
	Seismic Force-Resisting System	Are Specified	Rª	Factor, Qit	Factor, Ca	В	С	$\mathbb{D}^{t}$	$\mathbf{E}^d$	F			
c.	MOMENT-RESISTING FRAME SYSTEMS												
1.	Steel special moment frames	14.1 and 12.2.5.5	8	3	5%	NL	NL	NL	NL	NL			
2.	Steel special truss moment frames	14.1	7	3	5%	NL	NL	160	100	NP			
3.	Steel intermediate moment frames	12.2.5.7 and 14.1	4%	3	4	NL	NL	35*	NP <sup>4</sup>	NP			
4.	Steel ordinary moment frames	12.2.5.6 and 14.1	3%	3	3	NL	NL	NP	NP <sup>i</sup>	NP			
5.	Special reinforced concrete moment frames <sup>#</sup>	12.2.5.5 and 14.2	8	3	5%	NL	NL	NL	NL	NL			
6.	Intermediate reinforced concrete moment frames	14.2	5	3	41/2	NL	NL	NP	NP	NP			
7.	Ordinary reinforced concrete moment frames	14.2	3	3	21/2	NL	NP	NP	NP	NP			
8.	Steel and concrete composite special moment frames	12.2.5.5 and 14.3	8	3	5%2	NL	NL	NL	NL	NL			
9.	Steel and concrete composite intermediate moment frames	14.3	5	3	41/2	NL	NL	NP	NP	NP			
10.	Steel and concrete composite partially restrained moment frames	14.3	6	3	5%2	160	160	100	NP	NP			
11.	Steel and concrete composite ordinary moment frames	14.3	3	3	2%	NL	NP	NP	NP	NF			
12.	Cold-formed steel-special bolted moment frame?	14.1	3½	3*	3%1	35	35	35	35	35			
D.	DUAL SYSTEMS WITH SPECIAL MOMENT FRAMES CAPABLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES	12.2.5.1											
I.	Steel eccentrically braced frames	14.1	8	252	4	NL	NL	NL	NL	NL			
2.	Steel special concentrically braced frames	14.1	7	2%	5%	NL	NL	NL	NL	NL			
3.	Special reinforced concrete shear walls <sup>1</sup>	14.2	7	2%	51/2	NL	NL	NL	NL	NL			
4.	Ordinary reinforced concrete shear walls <sup>4</sup>	14.2	6	2%	5	NL	NL	NP	NP	NP			
5.	Steel and concrete composite eccentrically braced frames	14.3	8	2%	4	NL	NL	NL	NL	NL			
6.	Steel and concrete composite special concentrically braced frames	14,3	6	25/2	5	NL	NL	NL	NL	NL			

Table 12.2-1 (Continued)

CHAPTER 12 SEISMIC DESIGN REQUIREMENTS FOR BUILDING STRUC	TURES
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	ASCE 7 Section		Response Iodification Coefficient, Overstrength R* Factor, Ωe <sup>g</sup>	Deflection Amplification Factor, C <sub>4</sub> <sup>b</sup>	Structural System Limitations Including Structural Height, h <sub>a</sub> (ft) Limits <sup>c</sup> Seismic Design Category				
	Detailing	Response Modification Coefficient, R <sup>a</sup>							
Seismic Force-Resisting System	Requirements Are Specified				В	С	$D^d$	Eř	F
<ol><li>Steel and concrete composite plate shear walls</li></ol>	14.3	71/2	2%	6	NL	NL	NL	NL	NL
8. Steel and concrete composite special shear walls	14.3	7	2%	6	NL	NL	NL	NL	NL
9. Steel and concrete composite ordinary shear walls	14.3	6	292	5	NL	NL	NP	NP	NP
10. Special reinforced masonry shear walls	14.4	5%	3	5	NL	NL	NL	NL	NL
<ol> <li>Intermediate reinforced masonry shear walls</li> </ol>	14.4	4	3	3½	NL	NL	NP	NP	NP
<ol> <li>Steel buckling-restrained braced frames</li> </ol>	14.1	8	2%	5	NL	NL	NL	NL	NL
13. Steel special plate shear walls	14.1	8	2%	6½	NL	NL.	NL	NL	NL
E. DUAL SYSTEMS WITH INTERMEDIATE MOMENT FRAMES CAPABLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES	12.2.5.1								
<ol> <li>Steel special concentrically braced frames<sup>f</sup></li> </ol>	14.1	6	255	5	NL	NL	35	NP	NP
2. Special reinforced concrete shear walls	4 14.2	6½	2%	5	NL	NL	160	100	100
<ol> <li>Ordinary reinforced masonry shear walls</li> </ol>	14.4	3	3	2%	NL	160	NP	NP	NP
<ol> <li>Intermediate reinforced masonry shear walls</li> </ol>	14.4	3%	3	3	NL	NL	NP	NP	NP
<ol><li>Steel and concrete composite special concentrically braced frames</li></ol>	14.3	5%	2%	41/2	NL	NL	160	100	NP
<ol> <li>Steel and concrete composite ordinary braced frames</li> </ol>	14.3	3½	25/2	3	NL	NL	NP	NP	NP
<ol><li>Steel and concrete composite ordinary shear walls</li></ol>	14.3	5	3	41/2	NL	NL	NP	NP	NP
<ol> <li>Ordinary reinforced concrete shear walls<sup>d</sup></li> </ol>	14.2	5%	2%	4%	NL	NL	NP	NP	NP
F. SHEAR WALL-FRAME INTERACTIVE SYSTEM WITH ORDINARY REINFORCED CONCRETE MOMENT FRAMES AND ORDINARY REINFORCED CONCRETE SHEAR WALLS!	12.2.5.8 and 14.2	4½	242	4	NL	NP	NP	NP	NP

### MINIMUM DESIGN LOADS

		ASCE 7 Section	Response Modification Coefficient, R <sup>e</sup>	Overstrength Factor, $\Omega_c^{t}$	Deflection Amplification Factor, Ca	Structural System Limitations Including Structural Height, h <sub>a</sub> (ft) Limits <sup>c</sup>				
Seismic Force-Resisting System	Detailing Requirements	Seismic Design Category								
	Are Specified	В				С	$\mathbb{D}^{i}$	$\mathbb{E}^{d}$	F	
G.	CANTILEVERED COLUMN SYSTEMS DETAILED TO CONFORM TO THE REQUIREMENTS FOR:	12.2.5.2								
1.	Steel special cantilever column systems	14.1	2½	1%	252	35	35	35	35	35
2.	Steel ordinary cantilever column systems	14.1	114	1%	14	35	35	NP	NP	NP
3.	Special reinforced concrete moment frames*	12.2.5.5 and 14.2	2%	1%	2½	35	35	35	35	35
4.	Intermediate reinforced concrete moment frames	14.2	1½	1%	1½	35	35	NP	NP	NP
5.	Ordinary reinforced concrete moment frames	14.2	1	1%	1	35	NP	NP	NP	NP
6.	Timber frames	14.5	1½	13/2	11/2	35	35	35	NP	NP
H.	STEEL SYSTEMS NOT SPECIFICALLY DETAILED FOR	14.1	3	3	3	NL	NL	NP	NP	NP

EXCLUDING CANTILEVER

Response modification coefficient, R, for use throughout the standard. Note R reduces forces to a strength level, not an allowable stress level. <sup>a</sup>Deflection amplification factor,  $C_{ab}$  for use in Sections 12.8.6, 12.8.7, and 12.9.2. <sup>a</sup>NL = Not Limited and NP = Not Permitted. For metric units use 30.5 m for 100 ft and use 48.8 m for 160 ft.

\*See Section 12.2.5.4 for a description of seismic force-resisting systems limited to buildings with a structural height, h<sub>w</sub> of 240 ft (73.2 m) or less. \*See Section 12.2.5.4 for seismic force-resisting systems limited to buildings with a structural height, h<sub>w</sub> of 160 ft (48.8 m) or less. \*Ordinary moment frame is permitted to be used in lieu of intermediate moment frame for Seismic Design Categories B or C.

"Where the tabulated value of the overstrength factor,  $\Omega_{h}$  is greater than or equal to 2%,  $\Omega_{e}$  is permitted to be reduced by subtracting the value of 1/2

for structures with flexible diaphragms.

\*See Section 12.2.5.7 for limitations in structures assigned to Seismic Design Categories D, E, or F. /See Section 12.2.5.6 for limitations in structures assigned to Seismic Design Categories D, E, or F. /Steel ordinary concentrically braced frames are permitted in single-story buildings up to a structural height, h<sub>n</sub> of 60 ft (18.3 m) where the dead load of the roof does not exceed 20 psf (0.96 kN/m<sup>2</sup>) and in penthouse structures.

An increase in structural height, he to 45 ft (13.7 m) is permitted for single story storage warehouse facilities.

<sup>1</sup>In Section 2.2 of ACI 318. A shear wall is defined as a structural wall. <sup>2</sup>In Section 2.2 of ACI 318. The definition of "special structural wall. <sup>2</sup>In Section 2.2 of ACI 318. The definition of "special moment frame" includes precast and cast-in-place construction. <sup>3</sup>In Section 2.2 of ACI 318. The definition of "special moment frame" includes precast and cast-in-place construction. <sup>3</sup>Alternately, the seismic load effect with overstrength, E<sub>mb</sub> is permitted to be based on the expected strength determined in accordance with AISI S110. <sup>4</sup>Cold-formed steel – special bolted moment frames shall be limited to one-story in height in accordance with AISI S110.

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COLUMN SYSTEMS

OCCUPANCY OR USE	UNIFORM (psf)	CONCENTRA	OCCUPANCY OR USE	UNIFORM (psf)	CONCENTRATED (lbs.)
1. Apartments (see residential)			23. Penal institutions	40	
2. Access floor systems	<u>,</u>	-	Corridors	100	1.00
Office use	50	2,000	24 Restational areas	9 6	
Computer use	100	2,000	Bowling alleys, poolrooms and	90124	
<ol><li>Armories and drill rooms</li></ol>	150 <sup>m</sup>	=	similar uses	75 <sup>m</sup>	
<ol> <li>Assembly areas         Fixed seats (fastened to floor)         Follow spot, projections and             control rooms      </li> <li>Lobbies</li> </ol>	60 <sup>m</sup> 50 100 <sup>m</sup>		Gymnasiums Reviewing stands, grandstands and bleachers Stadiums and arenas with fixed seats (fastened to floor)	100 <sup>m</sup> 100 <sup>m</sup> 100 <sup>c,m</sup>	<del></del>
Movable seats Stage floors Platforms (assembly) Other assembly areas	Movable seats     100 m       Stage floors     150 m       Platforms (assembly)     100 m       Other assembly areas     100 m			10 20 30	
5. Balconies and decks <sup>h</sup>	Same as occupancy — served		All other areas Hotels and multifamily dwellings Private rooms and corridors serving	40	
6. Catwalks	40	300	them Public rooms" and corridors serving	40	
7. Cornices	60		them	100	
8. Corridors First floor Other floors	100 Same as occupancy served except as indicated	-	26. Roofs All roof surfaces subject to main- tenance workers Awnings and canopies: Fabric construction supported by a skeleton structure All other construction Ordinary flat, eitched, and curved	5 nonreducible 20 20	300
9. Dining rooms and restaurants	100**	-	roofs (that are not occupiable)	075755	
10. Dwellings (see residential)	-		where primary roof members are exposed to a work floor, at single		
<ol> <li>Elevator machine room grating (on area of 2 inches by 2 inches)</li> </ol>	-23	300	panel point of lower chord of roof trusses or any point along primary structural members supporting roofs:		
<ol> <li>Finish light floor plate construction (on area of 1 inch by 1 inch)</li> </ol>	-	200	Over manufacturing, storage ware- houses, and repair garages All other primary trof members		2,000
13. Fire escapes On single-family dwellings only	The escapes 100 Cocupiable roofs: On single-family dwellings only 40 - Roof gardens		Occupiable roofs: Roof gardens	100	
<ol> <li>Garages (passenger vehicles only) Trucks and buses</li> </ol>	40 m Sea S	Note a	All other similar areas	Note 1	Note 1
15 Handrails quards and grab bars	See S	action 1607.8	Classrooms	40	1,000
16. Helipads	See S	ection 1607.6	Corridors above first floor First-floor corridors	80	1,000
17. Hospitals Corridors above first floor	80	1.000	<ol> <li>Scuttles, skylight ribs and accessible ceilings</li> </ol>	-	200
Operating rooms, laboratories Patient rooms	60 40	1,000 1,000	<ol> <li>Sidewalks, vehicular drive ways and yards, subject to trucking</li> </ol>	250 <sup>d,m</sup>	8,000"
18. Hotels (see residential)	-		OCCUPANCY OR USE	UNIFORM (psf)	CONCENTRATED (lbs.)
19. Libraries Corridors above first floor Reading rooms	Ibraries         30. Stairs and exits           Corridors above first floor         80         1,000         One- and two-family dwellings           Reading rooms         60         1,000         All other		40 100	300 <sup>4</sup> 300 <sup>7</sup>	
20. Manufacturing Heavy Light	Stack rooms         1.00 <sup>-1</sup> 1.000         51. Storage warenouses (shall be designed for heavier loads if required for anticipated storage)           Manufacturing         250 <sup>n</sup> 3,000         Heavy         Heavy         Light         125 <sup>n</sup> 2,000         Light         Light <td>250" 125"</td> <td>I</td>		250" 125"	I	
21. Marquees	75		32. Stores Retail		
22. Office buildings Corridors above first floor File and computer rooms shall	igs ove first floor 80 2,000 computer rooms shall		First floor Upper floors Wholesale, all floors	100 75 125 <sup>m</sup>	1,000 1,000 1,000
be designed for heavier loads			33. Vehicle barriers	See Se	ction 1607.8.3
Lobbies and first-floor corridors Offices	100 50	2,000 2,000	(other than exitways) 35. Yards and terraces, pedestrians	60 100 <sup>m</sup>	

## **Table A2.2:** Live load values according to IBC-2012 (Table 1607.1)

## Table A2.3: risk category according to IBC 2012 (Table 1604.5), TABLE 1604.5 RISK CATEGORY OF BUILDINGS AND OTHER STRUCTURES

RISK CATEGORY	NATURE OF OCCUPANCY								
T	Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to Agricultural facilities. • Certain temporary facilities. • Minor storage facilities.								
Ш	Buildings and other structures except those listed in Risk Categories I, III and IV								
	<ul> <li>Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to:</li> <li>Buildings and other structures whose primary occupancy is public assembly with an occupant load greater than 300.</li> <li>Buildings and other structures containing elementary school, secondary school or day care facilities with an occupa load greater than 250.</li> <li>Buildings and other structures containing adult education facilities, such as colleges and universities, with an occupant load greater than 500.</li> <li>Group 1-2 occupancies with an occupant load of 50 or more resident care recipients but not having surgery or emergency treatment facilities.</li> <li>Group 1-3 occupancies.</li> <li>Any other occupancy with an occupant load greater than 5,000<sup>4</sup>.</li> <li>Power-generating stations, water treatment facilities for potable water, waste water treatment facilities and other public utility facilities not included in Risk Category IV.</li> <li>Buildings and other structures not included in Risk Category IV containing quantities of toxic or explosive materials that:</li> <li>Exceed maximum allowable quantities per control area as given in Table 307.1(1) or 307.1(2) or per outdoor control area in accordance with the <i>International Fire Code</i>; and Are sufficient to pose a threat to the public if released <sup>8</sup>.</li> </ul>								
IV	<ul> <li>Buildings and other structures designated as essential facilities, including but not limited to:</li> <li>Group I-2 occupancies having surgery or emergency treatment facilities.</li> <li>Fire, rescue, ambulance and police stations and emergency vehicle garages.</li> <li>Designated earthquake, hurricane or other emergency shelters.</li> <li>Designated emergency preparedness, communications and operations centers and other facilities required for emergency response.</li> <li>Power-generating stations and other public utility facilities required as emergency backup facilities for Risk Category IV structures.</li> <li>Buildings and other structures containing quantities of highly toxic materials that:</li> <li>Exceed maximum allowable quantities per control area as given in Table 307.1(2) or per outdoor control area ir accordance with the <i>International Fire Code</i>; and Are sufficient to pose a threat to the public if released <sup>b</sup>.</li> <li>Aviation control towers, air traffic control centers and emergency aircraft hangars.</li> <li>Buildings and other structures having critical national defense functions.</li> <li>Water storage facilities and pump structures required to maintain water pressure for fire suppression.</li> </ul>								

## Table A2.4: Importance factor according to ASCE 7-10 (Table 1.5-2)

Table 1.5-2	Importance	Factors by	Risk	Category	of Buildings	and Oth	er Structures	for Snow, I	ce, and
				Earthqu	ake Loads4				

Risk Category from Table 1.5-1	Snow Importance Factor, I <sub>z</sub>	Ice Importance Factor—Thickness, <i>I</i> <sub>i</sub>	Ice Importance Factor—Wind, Iw	Seismic Importance Factor, I <sub>e</sub>
1	0.80	0.80	1.00	1.00
11	1.00	1.00	1.00	1.00
ш	1.10	1.25	1.00	1.25
IV	1.20	1.25	1.00	1.50