



BEHAVIOUR OF SHORT REINFORCED CONCRETE COLUMN AGAINST THE EARTHQUAKE

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*MSc (CE5516) Structural Engineering Individual Dissertation 2016-2017 submitted to the TPO of
Department of Mechanical, Aerospace and Civil Engineering*

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Submission date: 09 August 2017

Word Count: 21,417

ABSTRACT:

THIS STUDY EXAMINES THE EFFECTS OF STRUCTURAL FORM AND SHORT REINFORCED CONCRETE COLUMN (MEZZANINE FLOOR AND SHEAR WALL) ON THE BEHAVIOUR OF RC STRUCTURES EXPOSED TO 2011 VAN EARTHQUAKE.

ALL TESTS ARE MODELLED AND ASSESSED IN FINITE ELEMENT ANALYSIS (FEA) SOFTWARE CALLED SAP2000. REGULAR, WIDE AND SLENDER MOMENT RESISTANCE FRAME (MRF) (THE FORMS OF BUILDINGS) ARE INVESTIGATED. HOPE THE OUTCOMES AND ANALYSIS OF THIS STUDY WILL BE UTILIZED BY DESIGNERS AND ACADEMICS AS A STUDY OF ASSISTANCE ALONG WITH BS EN 1998-1:2004 AND OTHER REGULATIONS CONCERNING SIGNIFICANTLY THE EFFECTS OF INCORRECT STRUCTURAL APPLICATIONS OVER A RC BUILDING EXPOSED TO GROUND MOTION.

ACKNOWLEDGEMENTS:

I would like to sincerely thank Dr. Zhaohui Huang who is my supervisor for his great support and contribution on my study during my dissertation. I also appreciate members of my family and friends who did not leave me alone throughout this study.

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CHAPTER 1: INTRODUCTION

1.1 Introduction:

Since the industrial revolution, construction of new buildings has been increased. This growing up has significantly climbed especially last three decades. Now security of these buildings against natural disaster especially earthquake is the matter in question than ever. Nowadays, there is a tendency to construct RC structure in developing and undeveloped countries due to their cost.

Reinforced concrete (RC) is a composite material in which concrete's relatively low tensile strength and ductility are counteracted by the inclusion of reinforcement having higher tensile strength or ductility.

The RC buildings properly designed and constructed according to regulations to have a resistance against earthquake but after an extreme earthquake, buildings would collapse or have severe damages. A substantial number of structural damages to RC building can be defined due to a poor behaviour of the lateral load- resisting system, which is called construction error. Thus, to understand this error, column will be a quite appropriate example for lateral load- resisting system. To scrutinize the damage of column after an earthquake, three reinforced-concrete plane frame system will be designed.

1.2. Purpose and Objectives

Even though in reality no building is enough strong to absorb earthquake, the aim of this study is to:

Analyze and examine the behavior of normal and short reinforced concrete column against Van earthquake in Turkey (**7.8M_w**)

Compare the moment, shear and axial force of short reinforced concrete column with the same column without short column formation

In general, this study will be utilized to provide guidance to academic investigations that will be used in addition to the rules and regulations in Eurocode8. Moreover, the results of this

study will assist us to provide set data for short reinforced concrete column, which will illustrate the negative effects of a short column to RC building against Van earthquake. This study will finally help us to minimize the loss of life and the devastating social, economic and environmental effects due to 2011 Van earthquake, Turkey

1.3. Scope:

Objectives of this study have been specified; apart from achieving these objectives, there are a few tasks (below) that need to be carried out.

1. Collecting the whole relevant data (such as ground accelerations, displacements and velocities) from 2011 Van earthquake, Turkey (**ML 5.6**)
2. Then creating a nonlinear time history analysis utilizing the data collected. Also, the set data can be utilized to model and simulate how a structure would behave and respond to similar situations in real life.
3. By using the time history analysis on FEA software like SAP2000, the following tests on simple two-dimensional and four-story frames with 2 spans will be run.
 - I. The first test will be three different structural forms (slender, wide and regular frame).
 - II. The second one will be a RC frame having short column formation on columns of ground floor.
 - III. The last run will be normal reinforced concrete frame without any structural error (mezzanine floor or shear wall).

The results of these tests will be utilized in order to analyze how the structural forms and short column formation affected the performance of building under 2011 Van earthquake, Turkey and these will be utilized to interpret the behavior of the building (if it was built in

Van in Turkey, what would happen the column and beam specified). The following overview of each chapter will be in more details:

- Chapter 1 is an introduction to the objectives, scope and aims of this study
- Chapter 2 is the literature review containing the principles of earthquake resistant design, the loading applied to RC building during 2011 Van Earthquake, an analysis of the contemporary seismic resistance design and the fundamental concepts of earthquake engineering
- Chapter 3 will be a general knowledge of the Eurocode8 for seismic resistant design of short column formations
- Chapter 4 will justify and explain the reasons for choosing the software (SAP2000), analyses and the methods carried out in this dissertation
- Chapter 5 will discuss, illustrate and analyse the results of the tests.
- Chapter 6 will discuss the results in detail and show specified tables, graphical results obtained from SAP2000
- Chapter 7 will be an executive summary and discussion of the results about the behaviour of short reinforced concrete column against 2011 Van earthquake as well as few further research, recommendations and work

CHAPTER 2: LITERATURE REVIEW

This chapter consists of behavior of one type of structure error (short-column formation) under 2011 Van earthquake and gives the solution for that incorrect structural application. There will also be an introduction to:

- The fundamental concepts and background for seismic engineering and different earthquakes
- Types of structural loads once a building is subjected to ground motion
- Response of a structure when it subjected to 2011 Van Earthquake
- The types of short column formation
- Design of a building for earthquake resistance

2.1 Background to the Physical Phenomenon of Earthquakes

2.1.1 Seismic Loading

Seismic loading refers to different vibrations or earthquakes such as wind and tsunami. Also, it is one of the main concepts of seismic engineering. This engineering discipline aims that the effects of earthquakes must be mitigated by utilising different methods such as seismic isolation systems. In addition, this engineering discipline consists of different experts such as architects, seismologists, civil engineers and geotechnical engineers. Earthquakes may directly cause landslides, faulting of a surface, ground failure and cracking. Also, it might indirectly lead to fire, floods and tsunamis (Yilmaz et al., 2011)

2.1.2 Estimation of Seismic Loads

When an earthquake occurs, a building is exposed to ground motion. This is because the building is subjected to inertia forces acting in opposite direction to the acceleration of earthquake. These inertia forces called seismic loads are usually dealt with by assuming forces external to the construction. When ground motions vary with time and inertia forces differ with direction and time, in terms of space and time, seismic forces are not constant. In

designing buildings, the top story shear force is the most influential one. Thus, seismic loads are the static loads to give the top story shear force for each floor (equivalent static seismic loads).

2.1.3 Idealization of building and location of input ground motion

The movement of a building against ground motion is quite complex. However, idealized adequate mathematical model of the building is utilized to assess the seismic load. Each floor of the building is often modelled as a lumped mass.

As can be seen from Figure 2.1a, the building located on a firm ground can be modelled as a fixed base model.

Sway-Rocking model (SR model) utilize to demonstrate not stiff structure ground (as shown in figure 2.1b).

For taking account of motions of the ground and pile foundations, Figure 2.1c could be utilized to model a structure.

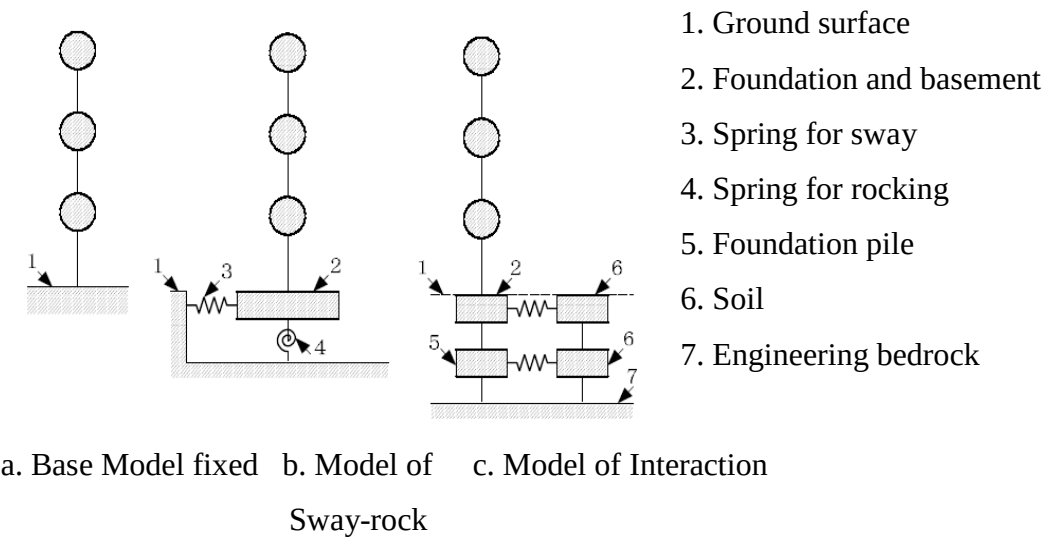


Figure 2. 1: Type of Models for Building (Alwaeli et al., 2016)

2.2 Types of Earthquakes and Characteristics

2.2.1 Earthquake and Plate Tectonics

A sudden change of the location of soil in the earth is called earthquake (or the shaking of the ground) Stress released within the soil might be accumulation of hundreds of years. In the 1960's, Geologists claimed that Earth's rigid outer layer does not consist of just one piece. It has 12 large pieces called plates. The term "tectonics" is named by Geologists for deformation of the Earth's. Divergent/ spreading, convergent/sliding, collision/crush or transform/slip-sliding are the types of plate boundaries known (Okamura and Fujita, 2007).

2.2.2 Characteristics of Earthquake

2.2.2.1 Focus and Epicenter

When a plate collides with another plate in the earth, crack occurs in the crust. Even small friction along the fault may cause creep. This type of movement does not usually lead to injury or death.

When it comes to the location of movement, if the movement occurs along a fault and the earth's surface, they are called the earthquake's ***hypocenter (or focus)*** and ***epicenter*** respectively (as depicted in figure2.2)

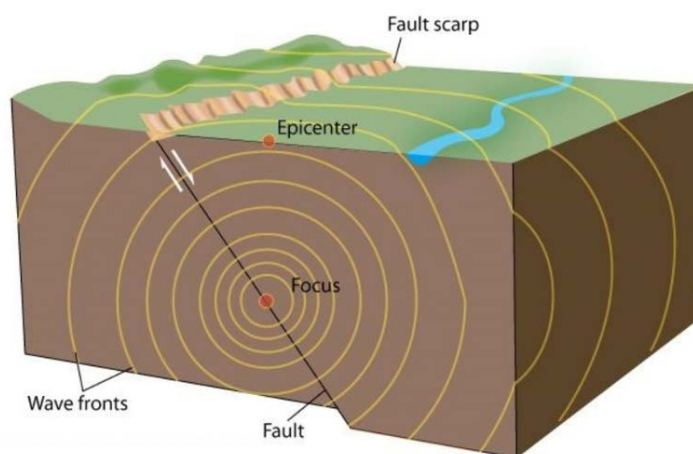


Figure 2. 2: The location of earthquake movement (Alwaeli et al., 2016)

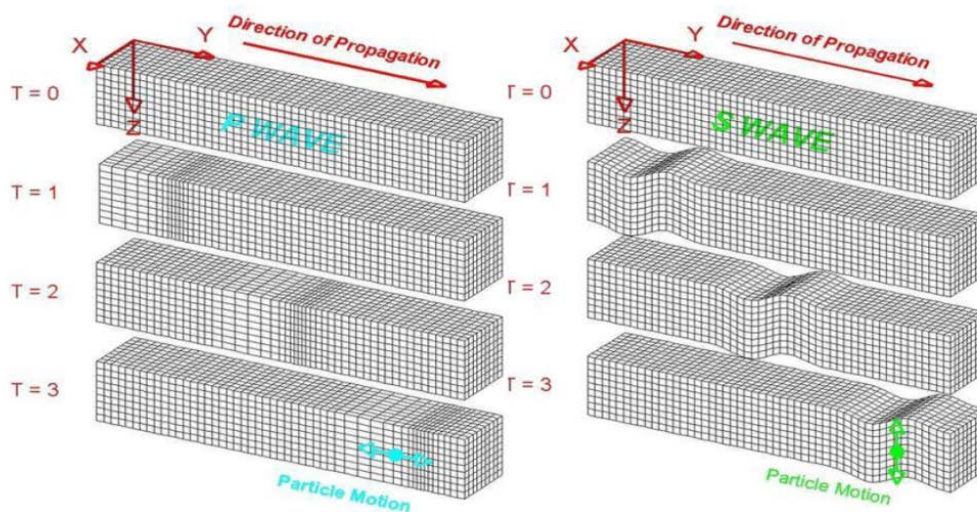
2.2.2.2 Seismic Wave

Two types of deformation: **static** and **dynamic resulted from** ruptured earthquake fault. Because of the event, Static one has a permanent displacement of ground. However, dynamic motion creates sound wave when the fault ruptures. There are different types of seismic waves moving in different ways. Those called **Body waves** and **surface waves** are the main types of waves. Body waves can be defined as travelling through inner layers of earth but surface waves can be understood from its name, it can just move along the surface of planet.

➤ Body waves: Primary (P) wave and Secondary (S) wave

- The *primary wave* or P wave or is the first one which is fastest seismic wave. It can move through fluids and solid rock (as depicted in figure 2.2a). It can be calculated by the formulation ($V_s = \sqrt{(k + 4\mu/3)/\rho}$)
- *S wave, shear wave or secondary*, which can be understood from its name, is the second wave which is approximately 60-70% slower than the primary wave. In addition, in an earthquake, it can be felt (as shown in figure 2.2b). It can be calculated by the formulation ($V_s = \sqrt{\mu/\rho}$)

(Alwaeli et al., 2016)



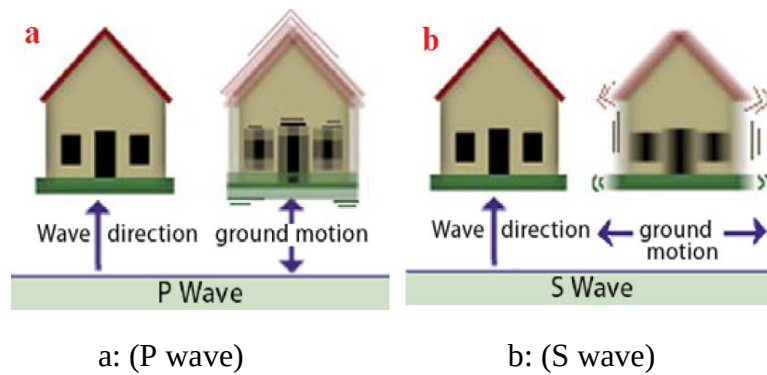


Figure 2. 3: Seismic waves (Alwaeli et al., 2016)

➤ **Surface waves: Love (L) wave and Rayleigh (R) wave**

- **Love** or **L wave** which is named after a British mathematician the first types of surface wave and fastest one as well as moving the ground from side-to-side (as illustrated in Figure 2.3a).
- **Rayleigh wave is the second** wave named after Lord Rayleigh. It rolls along the ground and moves the ground down and up. Moreover, an earthquake shaking felt is because of the Rayleigh wave (as depicted in figure 2.3b).

In general, the wave speeds can be summarized as $V_P > V_S > V_P, V_L$

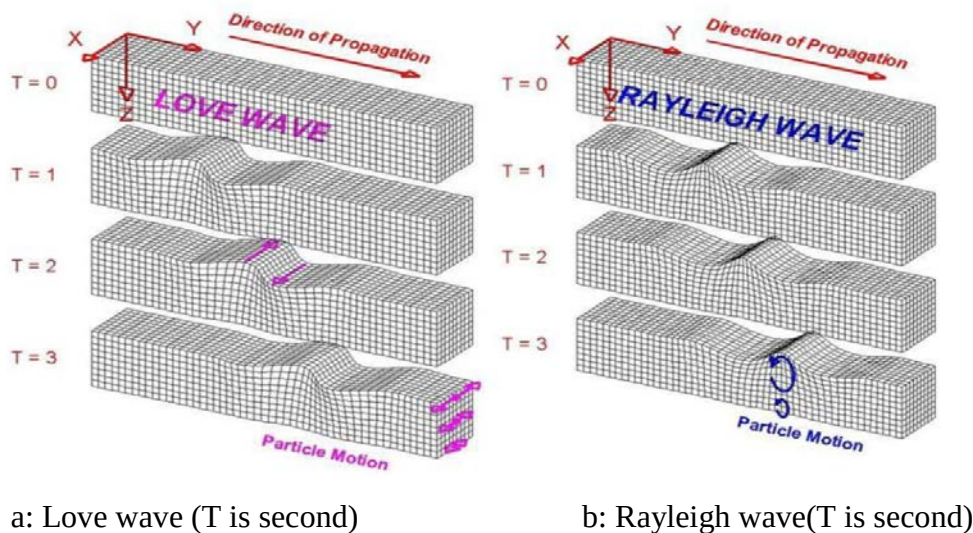


Figure 2. 4: Seismic waves (Alwaeli et al., 2016)

2.2.2.3 Locating Earthquakes

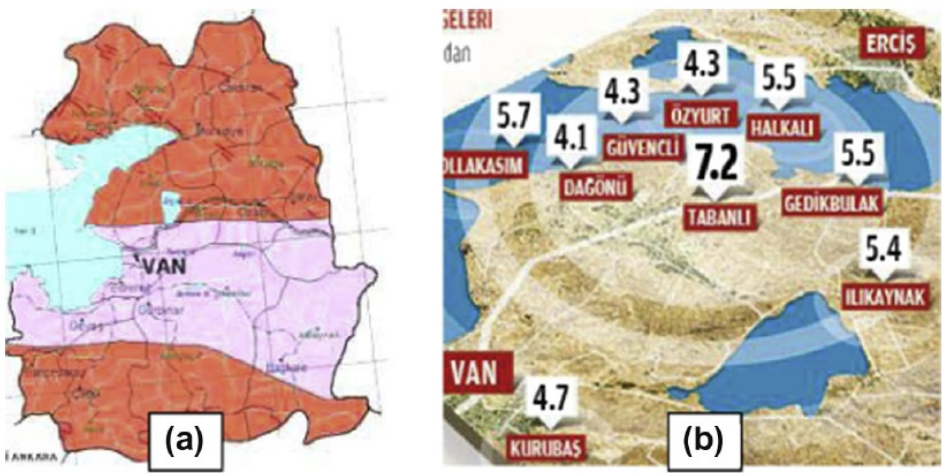
At least three seismographs which are at different locations are needed to determine an earthquake location.

In this study, 2011 Van earthquake, Turkey will be used so that some information is given below;

Turkey is a country which is the second most seismically active region in the world and lying on the Anatolian Peninsula on the Alpide–Himalayan earthquake belt (Korkmaz, 2015).



Figure 2. 5: General tectonic setting of Turkey (Murat, 2015)



(a) Seismic zones of Van

(b) effect area of earthquakes

Figure 2. 6: The seismic zone and effect area of Van Earthquake (Dogan, 2011)

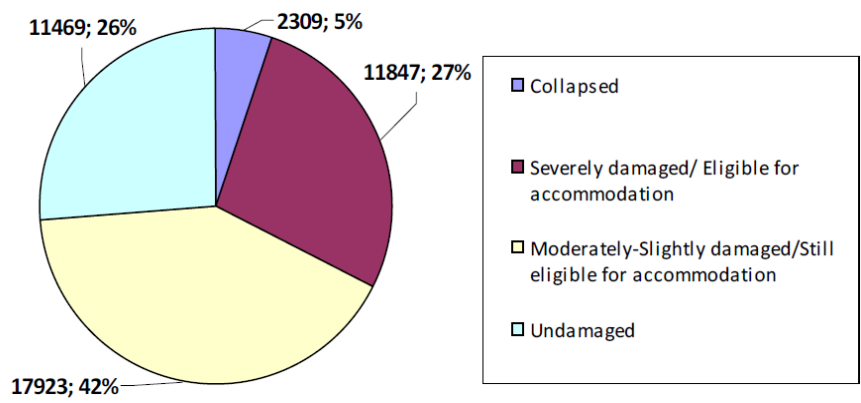


Figure 2. 7: Statistic of building damage in Van, Turkey (Zengin and Cakti, 2013)

The statistic illustrates that 17,923, 230, 11,847 structures have been slightly damaged, collapsed and severally damaged respectively (Zengin and Cakti, 2013).

2.3 Intensity and Magnitude of Earthquake

Both are significant to design a building having enough earthquake resistance

2.3.1 Earthquake Magnitude

Magnitude is a *quantitative* measure of the actual size of the earthquake. In other words, it is indicated by a number. Either the amplitude or the duration of specific types of recorded seismic waves is measured to calculate the magnitude. A base- 10 logarithmic scale known as Richter Magnitude (M_L) scale is used to measure it.

$$M_L = \log_{10}^A + (\text{Distance correction Factor})$$

(Equation 2. 1: Richter Magnitude M_L)

Table 2. 1: Earthquake Magnitude Scale (Alwaeli et al., 2016)

Class	Magnitude	Earthquake effects	Estimated number each year
Minor	2.5 or less	Usually not felt	900,000
Light	2.5 to 5.4	Often felt	30,000
Moderate	5.5 to 6.0	Slight damage	500
Strong	6.1 to 6.9	May lead to lots of damage	100

Major	7.0 to 7.9	Serious damage	20
Great	8.0 or over	Great earthquake	One every 5 to 10 years

2.3.2. Earthquake Intensity

Intensity of earthquake is a *qualitative* measure, and is assigned as *Roman Capital Numerals* between XII at the high and I at the low. The Modified Mercalli Scale (MMS) is used to measure its class categorized as 12 increments (as depicted in Table 2.2) (Alwaeli et al., 2016).

Table 2. 2: Intensity Scale of Earthquake (Alwaeli et al., 2016)

Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

2.3.3. Dynamic effects due to earthquake

As mentioned above, breaks or dislocations in the earth’s crust produce earthquakes. The ground motion due to earthquake, however, is quite complex motion in both vertical and horizontal direction. In the response of structure, horizontal motion is more significant than the other direction because the forces coming from vertical direction is assumed to be absorbed by the weight of the structure.

When it comes to intensity of an earthquake, there are various methods of classification to be used. A shock which is considered as minor earthquake has 0.1 times the gravitational acceleration (0.1g) while strong motion differs between 0.1g and 1.0g (Boswell and D'Mello, 1993).

In this study, 2011 Van earthquake, Turkey will be applied the building. Therefore, some information which is about Van earthquake is given below;

1. The earthquake occurred in eastern Turkey on November 19, 2011
2. The most effective ground motion was **0.53g**
3. The magnitude was **5.6 (M_L)**

(Mertol, Baran and Gunes 2014)

2.3.4 Earthquake Design

A building must critically have an earthquake resistant design but in practice, the exact earthquake design is almost impossible to be predicted and also critical response will differ due to limit states (serviceability or ultimate)

The structure designed according to serviceability limit state should remain essentially elastic along earthquake excitation period. In the past, peak site acceleration has been utilized to determine an earthquake design. An average response spectrum is, however, generally accepted to be used (Boswell and D'Mello, 1993).

2.3.5. Response spectrum for acceleration

A response spectrum helps engineers to obtain the most descriptive representation of the influence of a given earthquake on a building.

Three orthogonal components of ground acceleration are recorded by the accelerograph at a certain location. Moreover, duration, content of earthquake and frequency, the peak ground acceleration can be obtained from an accelerograms which can be integrated to obtain ground displacement and the time variations of the ground velocity

To find ground motion

$$m(\ddot{u} + \ddot{u}_g) + c\dot{u} + ku = 0 \Rightarrow m\ddot{u} + c\dot{u} + ku = -m\ddot{u}_g$$

Where $m, c, k, U_g(t)$ and $u(t)$ are global mass, damping, stiffness matrix, the ground motion and the motion of the mass relative to ground respectively

In this study, the 2011 Van, Turkey earthquake will be used. Thus, ground motion values which are the most unfavourable one is given below;

Measured PGA value: 513cm/sec²

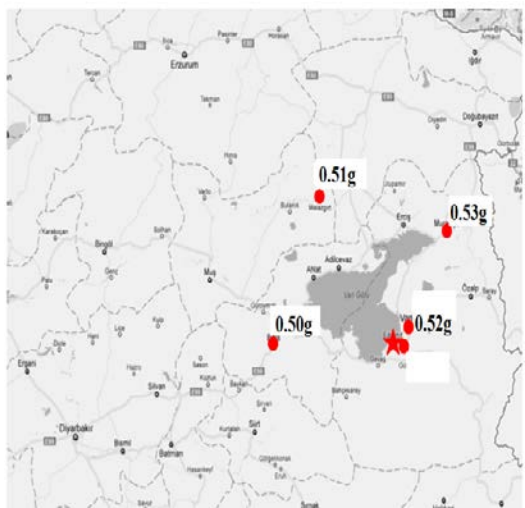


Figure 2. 8: Measured PGA values Earthquake (Mertol et al., 2014)

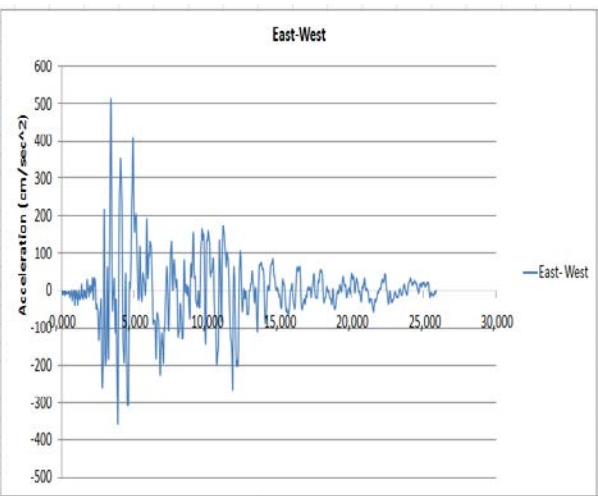


Figure 2. 9: Ground motions of 2011 Van east- west direction (Mertol et al., 2014)

2.4 Response of a structure once it subjected to Ground Motion:

Response of a building to ground excitation differs as it depends on different factors at the construction site such as the characteristics of the structure itself, soil and ground type.

2.4.1 The effect of soil on the performance of building against ground motion

There have been numerous examples of damage to buildings due to cyclic softening or the effects of liquefaction of soil in important earthquake events. It is well known fact that the

extent of the damage to buildings, resulting from earthquakes is related to local soil conditions. For example, if there is a ground subsidence on the building, large scale structural displacement will occur. As a result of that, the relationship between local soil conditions and the structural damage will be apparently seen ground motion and deformations resulting from an earthquake are vital stage of performance-based design, particularly for soft soil. Earthquakes occurred in the world demonstrates that the buildings having especially soft soil are unable to withstand large deformation (Khoshnoudian et al., 2017).

2.4.2 Periods and resonance case in ground motion

Each Building has a natural period (T_N) indicating the amount of time (in second) to vibrate back and forth. The ground also has a specific resonant frequency varying according to the type of soil for example softer sediments have less frequencies than hard bedrock if the frequency of ground excitation matches the natural resonance of a building, the largest oscillations causing the biggest damage will occur on the building When it comes to some definitions,

- **Frequency** is defined as the number of wave per second (for a point)
- The amount of time to finish one wave cycle is named as **Period**
- **Resonance** *can be defined as* the tendency of a building to oscillate with the largest displacement

One of fundamental properties of high- rise building is natural vibration depending on rigidity and the mass of the building (Xilin et al., 2014). The period helps engineers to define whether the structure satisfies the requirements of codes and is the reflection of characteristics of the building such as shear- gravity ratio, story drift limit and stability

Engineers can assess rigidity of high-rise buildings and the suitability for mass by using the reference range of natural period of the building (Xilin et al, 2014). Real structures have several vibration modes and are considered by software as multi-degree-of freedom systems. The mode having the longest period is called natural period or the fundamental period.

The fundamental period (T , in second) of building is roughly calculated as blow

$T_1=0.1* H$ where H is building height (as depicted in Figure 2.7) (linear relation)

According to EUROCODE8, however, to get exact period of structure, it must be calculated as below;

$$T_1=C_t*H^{3/4}$$

Where **H** is the height of the building (in metres) from the top of the foundations

And **C_t** can be taken as 0.075 for the frame. To make it understandable, the following figure is given:

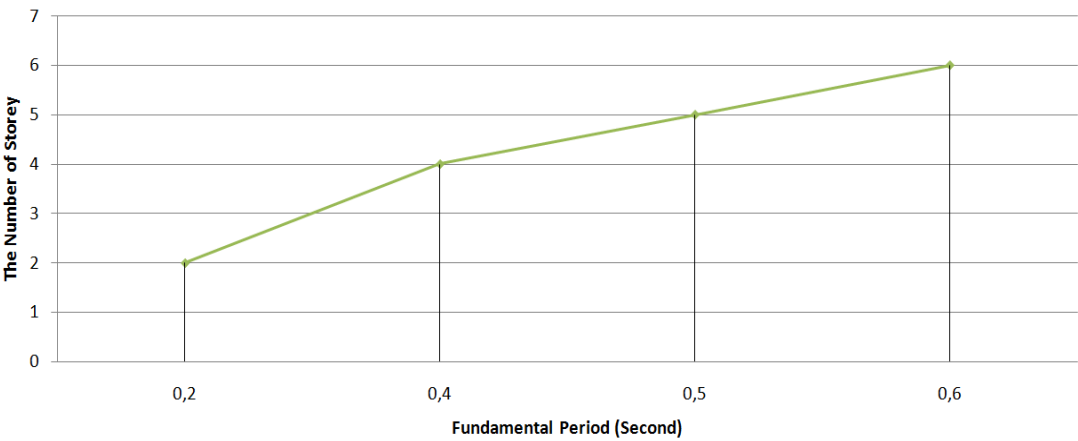


Figure 2. 10: Rough Calculation of Period of Structure

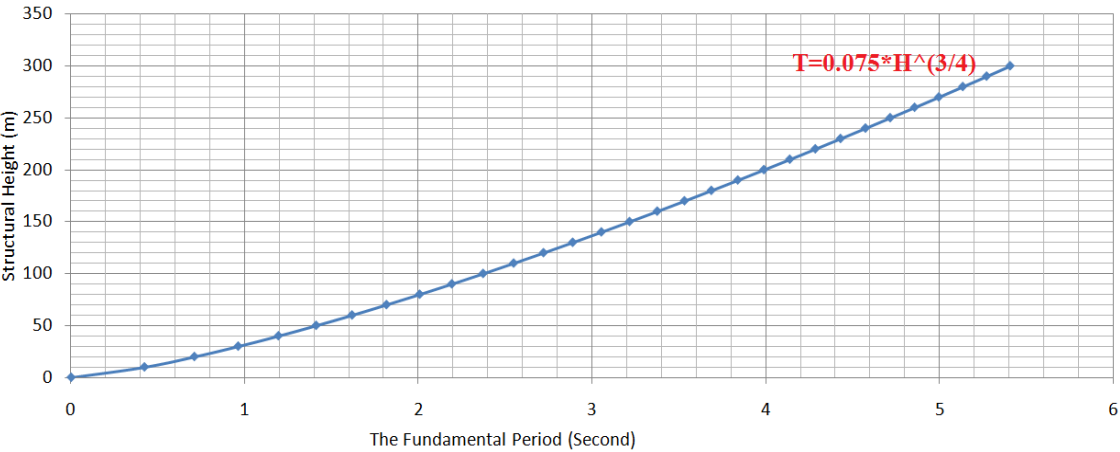


Figure 2. 11: Relationship between Structural Height and Fundamental Period

2.5 Earthquake Resistance of RC Structure

One of the most challenging duties of civil engineering is to design a building having seismic resistance because earthquake may cause unpredictable forces in the structure. Therefore, structure engineers should consider additional forces in the building. Moreover, the regulations (such as Eurocode8) should be used to make sure of having enough earthquake resistance. However, making the buildings earthquake proof is almost impossible and not logical design because the cost of construction is also important

Hatzigeorgiou (et al., 2010) stated that the complexity of experimental and theoretical research must be reduced to be able to express them in a simple structural model.

On average, for a building, there is the concept of “acceptable risk, “which means a balance between the cost of seismic resistance design and the extent of structural damage (Boswell and D'Mello, 1993).

Some techniques can be applied buildings to have earthquake resistance;

- Base isolation methods
- Energy dissipation Device (seismic damper)
- Less structural height
- Reducing the mass of the building
- Utilising more stiffer materials

(Hatzigeorgiou et al., 2010)

2.5.1. Demand estimation

In a critical region of the structure, predictions of displacement and force demand are based on two criterions “First one is the simplicity of the systems and the second one is inelastic analyses of complex structural configurations. Dynamic inelastic analyses of models are utilized to obtain the variation of demand with ground-motion and major structural parameters consisting of the structure force, principal member yield levels and fundamental period. Moreover, the pseudo-dynamic method of testing, shaking tables can be used to obtain helpful information on demand” (Gharehbaghi and Khatibinia, 2015) (as shown in Figure 2.9).

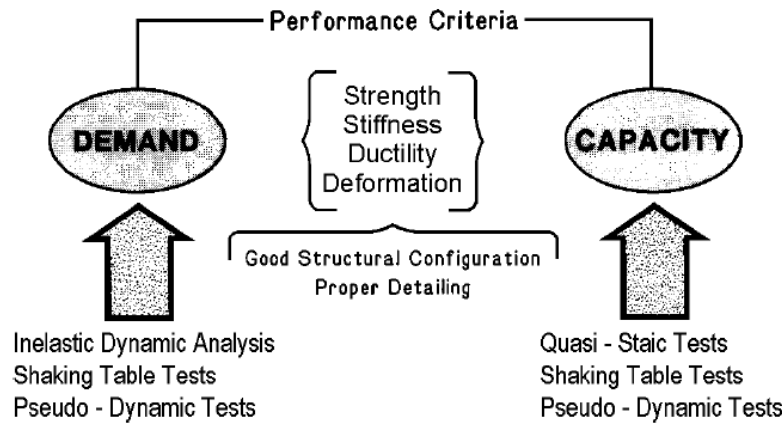


Figure 2. 12: Components of earthquake-resistant building design (Gharehbaghi and Khatibinia, 2015)

Apart from all these lateral resistive systems, some additional consideration are discussed in following paragraph

2.5.2. Influence of dead load

“Dead load is general drawback for building as the lateral force is directly proportional to dead load. Developing the construction details and choosing materials for the building must be done carefully in order to avoid creating unnecessary dead load, especially at upper levels. This, however, should not be forgotten that dead load is necessary for foundation and useful for overturn resistance” (Tefamariam, Stierner and Qin, 2012).

2.5.2.1. Construction material

Choosing the right construction material is always a dilemma for engineers. The decision that has been made will affect the results in terms of general quality, schedule and the cost of structure. Today, steel and concrete are two dominant construction materials both can be used as well to make a good combination in construction. However, in this study concrete structure is decided because the dominant construction type is concrete in Van which is a city in Turkey. The advantages and disadvantages and the other reasons of choosing concrete will be discussed in following paragraph.

2.5.2.1.1 Advantages and drawbacks of concrete

Concrete has a lot of advantages which make it the main construction material. On the other hand, of course as other materials it has many drawbacks as well.

2.5.4.1.1.1 Advantages

The fundamental reason of choosing concrete is because it is dealing with complex geometry and cheap. It also has higher fire resistance compared with steel structure.

2.5.4.1.1.2 Disadvantages

On the other hand, it has low toughness, less ductile, little tensile and specific strength (Nilson, Darwin and Dolan 2010).

2.5.3. Advantage of simple form and symmetry

Building that is symmetrical and simple form will reduce complex equations. Once a complex structural design is deemed to be necessary, then the cost of construction must be acknowledged (Tesfamariam et al., 2012)

2.5.4. Importance of Load Path of RC Structure

Load path of structure or the integrity of movement of load is vital case because unsuitable movement of load causes additional forces in the building. The movement of load should be as figure 2.10 (Jiang and Li, 2010).

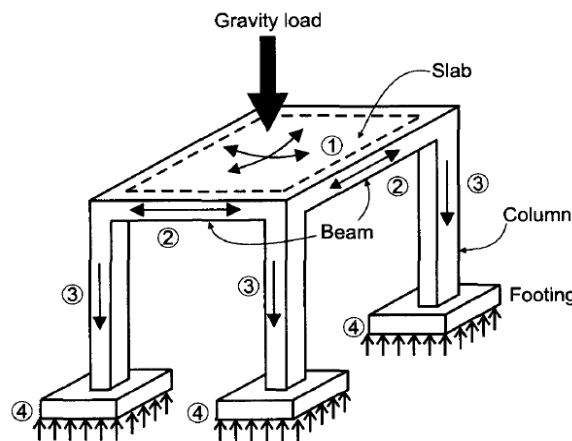


Figure 2. 13: Load Path of RC Structure (Jiang et al., 2010)

2.5.5. Importance of Connection between Beam and Column

Due to dynamic and shaking effects, the connections between columns and beams must be adequate rigid. The connection failure is the fundamental reasons of many collapses during earthquake (Tesfamariam et al., 2012).

2.5.6. Resistant Elements in Building

During ground motion, building is exposed to loads which are more than two directions so that vertical load resisting systems which are structural diaphragms, moment resisting frame, shear walls and column should be chosen carefully.

2.5.6.1 RC Moment Resisting Frames

Moment resisting frame consisting of vertical columns, joint connections and horizontal girder elements carries lateral loads in the structure. The fundamental reason of designing a MRF is the ability of inelastic behaviour in the structure. There are types of RC Moment Frames which can be categorized as Ordinary Moment Frame (OMF), Special Moment Frame (SMF) and Intermediate Moment Frame (IMF) (Fragiadakis and Papadrakakis, 2008).

2.5.6.1.1 Intermediate Moment Frame (IMF)

As mentioned before, selection MRF depends on structural height and different parameters given in regulations.

2.5.6.1.2 Ordinary Moment Frame (OMF)

This type of Moment Frame is used for low earthquake possibility such as the UK, Nederland. Therefore, many earthquake parameters will be ignored such as high ductility so on.

2.5.6.1.3 Special Moment Frame (SMF)

However, this Moment Frame is used for high ductility which means having more energy absorption than the other two types of frames

2.5.6.1.4 Structural stiffness, strength and ductility

Ductility(c), lateral strength (b) and Lateral stiffness (a) are characteristic of structures. To Begin with lateral stiffness, this is known as the initial stiffness of the structure. The second property is lateral strength which means the maximum resistance of the structure. The last one is ductility which is quite important for a building. This property is known as the ratio of ultimate to safety deformation (Mazars and Millard et al., 2009) (as depicted in figure2.11).

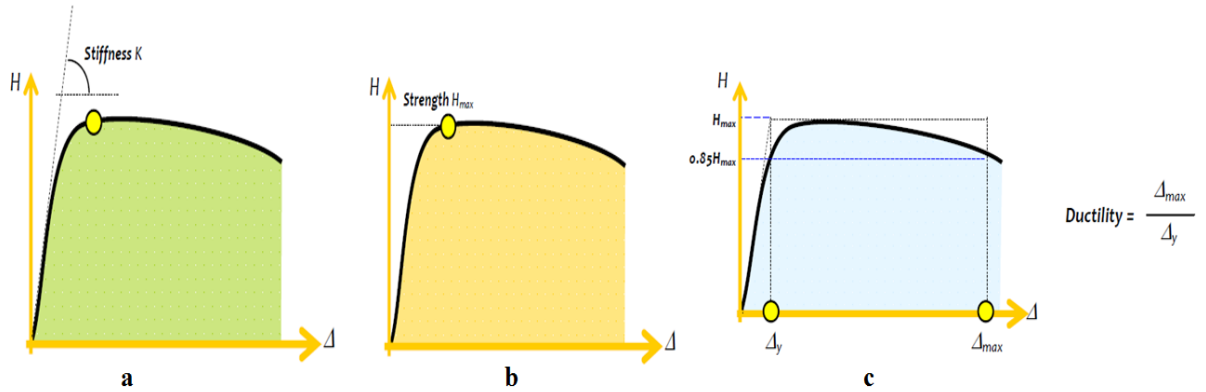


Figure 2. 14: Structural properties (a) lateral stiffness, (b) lateral strength, and (c) ductility (Mazars, et al 2009)

2.5.6.2 Shear wall (structural wall)

Shear wall reduces global displacement of buildings and withstands lateral force resulting from ground motion. Moreover, it reduces bending moment and shear forces of columns and beams. Providing shear wall which is along the height of structure will help the building to perform better during earthquake. To show how the continuity of shear wall affects the performance of the building, the following figure (2.12) is given (Nilson et al., 2010). As a reminder, in this study, a shear wall will be used to demonstrate short column formation

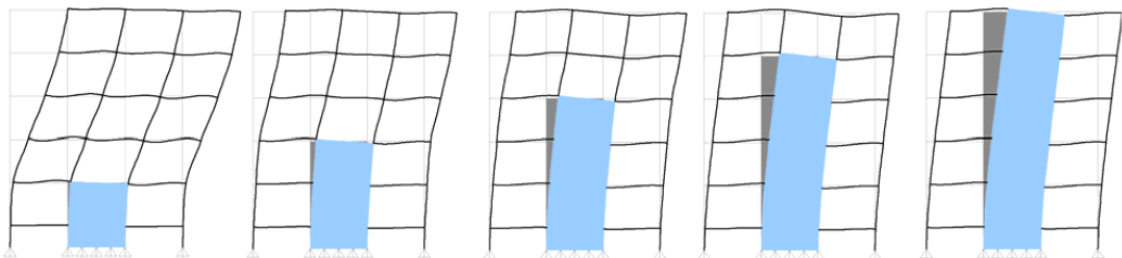


Figure 2. 15: Discontinuing Shear Wall in Upper Storeys (Mazars et al., 2009)

2.5.6.3 Structural diaphragms

Acting as a single unit under the action of seismic forces are vital important to obtain better performance from building. In this sense, diaphragms provide lateral stability to the structure to transfer the loads to the foundation of the building (such as frames and structural wall). Diaphragm can be sometimes seen as a vertical form such as concrete ramp or gable roof. Earthquake and wind actions which are the most common lateral loads are resisted by diaphragms of the structure. A concrete slab in RC construction is an example of diaphragm.

Also, there are two types of diaphragms in the building. First is rigid and second one is flexible (Nilson et al., 2010). The following diagram (2.13) illustrates rigid diaphragm which is necessary for better seismic performance.

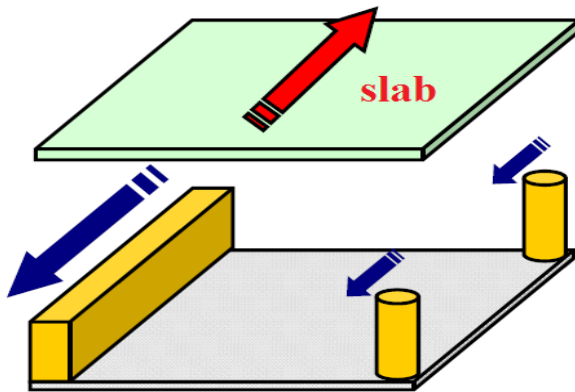


Figure 2. 16: Rigid diaphragm in the building (Mazars et al., 2009)

2.5.6.4 Column

The aim of designing reinforced concrete column which is composed of concrete and steel is to carry compressive loads. For design purposes, the columns are categorized into two types of columns which are short columns and slender columns.

2.5.6.4.1 Slender column

When an excessive axial load is applied to a stock column, crushing failure is more likely to happen. Similarly, if a critical combination of axial load and moment is applied to a stock column, most probably failure of the material will happen

2.5.6.4.2 Short column formation

If a column subjected ground motion in a reinforced concrete frame structure is restricted from any direction movement, short column effect is inevitable. In other words, a short column is much stiffer than a tall column, and it is also exposed to larger seismic forces. It is well known that resistance to deformation depends on the stiffness of a column. Large stiffness attracts large force in order not to deform a lot. As shown below in figure 2.14, the shear forces can be easily calculated by the moment (top +bottom) to height of column ratio if there is any application causing short-column formation (such as mezzanine floor, shear wall so on) in the structure, it will reduce height of column causing more shear force in the

column and change lateral stiffness of the structure causing more moment in the column. **To support this mathematical explanation**, a study which has been done by Dogan (2011) stated that the length of short column (h_s) is direct proportion to shear force and moment of column. When this ratio increases, both values go up. However, the rate of moment will be bigger than the rate of shear force. Moreover, in some case, when length of short column (h_s) increases, moment reduces but shear force still increases. Both cases are given in figure 2.15.

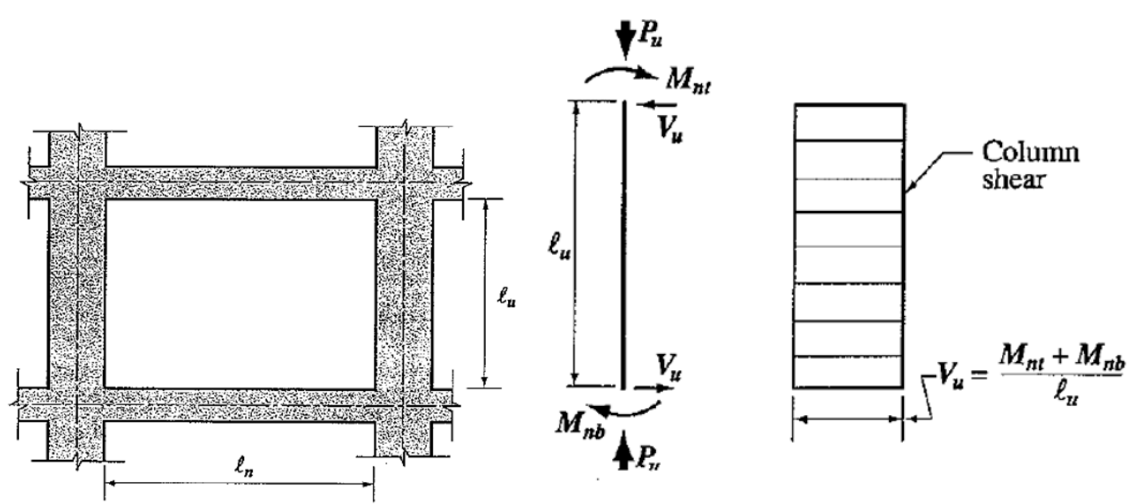


Figure 2. 17: The Definition of Short Column (Boswell and D'Mello, 1993)

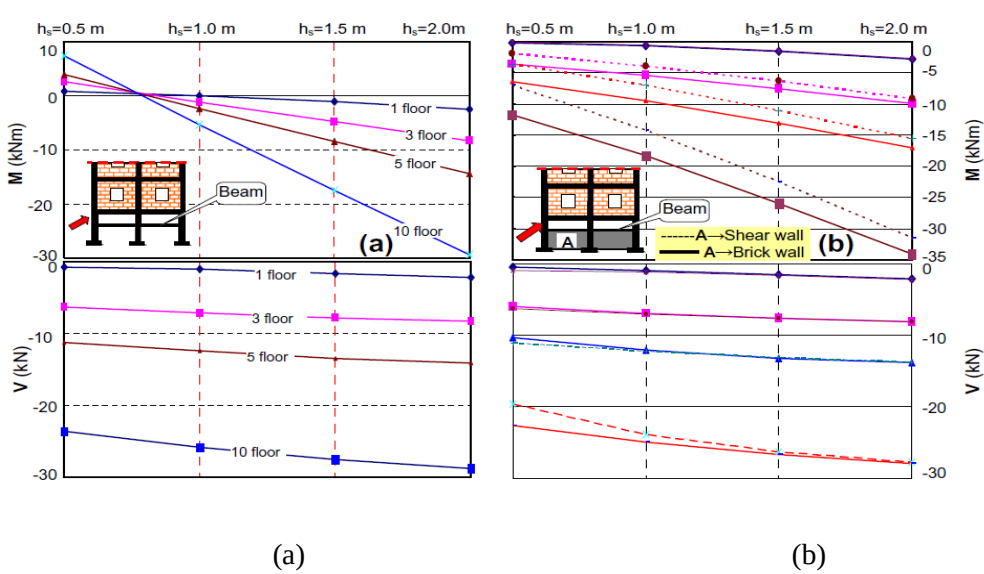


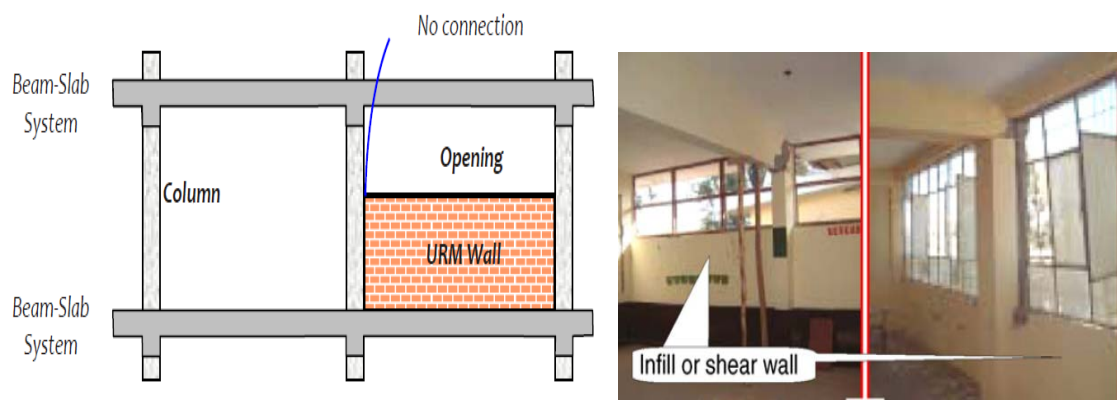
Figure 2. 18: Shear Force and Moment Distribution, (a) mezzanine floor application and (b) shear and brick wall application (Dogan, 2011)

If there is not adequate transverse reinforcement in the short column, during an earthquake, significant damage is inevitable. This type of damage occurs in the column as X-shaped crack due to shear failure. The following paragraph will discuss the type of short-column applications which can be seen in the real life.

The types of obstructions are given below;

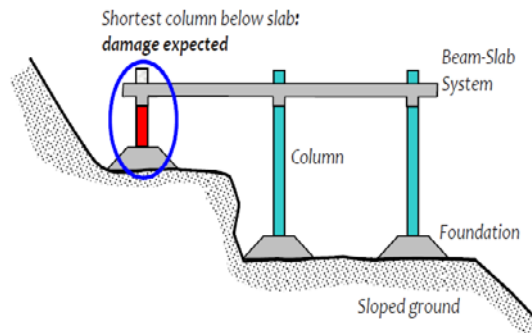
- 1) Designing infill wall with opening between two RC columns (as depicted in figure 2.14a)
- 2) Shorter columns at basement floor due to sloping ground (as illustrated in figure 2.14b)
- 3) a staircase beam or K-braces meeting the columns at an intermediate height (as can be seen from figure 2.14c)
- 4) a mezzanine slab (meeting the columns at an intermediate height) (figure 2.14d) and
- 5) a plinth beam (shorter column than that of the column above) (figure 2.14e)

(Mazars et al., 2009)

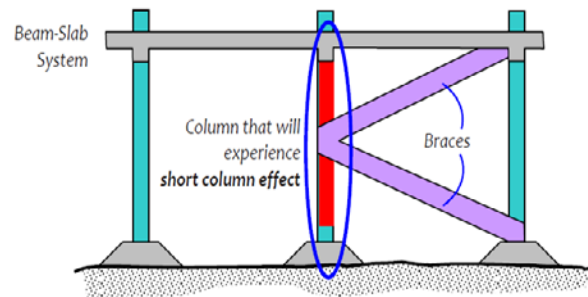


(Dogan, 2011)

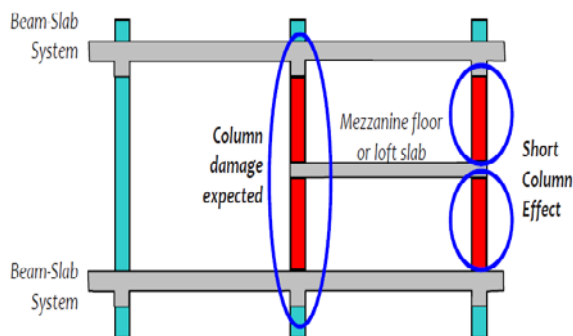
(a)



(b)



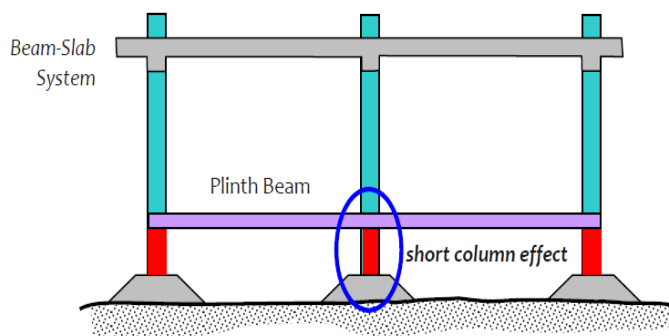
(c)



(d)



(Dogan, 2011)



(e)

Figure 2. 19: Types of short column formations in RC columns in buildings due to incorrect design or application, (a) Designing infill wall with opening between two RC columns, (b) Shorter columns at basement floor due to sloping ground, (c) a mezzanine slab, (d) a staircase beam or K-braces meeting the columns at an intermediate height, (e) a plinth beam (Mazars et al., 2009)

In this study, first (a) and third (c) type of short column formations will be discussed in another chapter

2.5.7 Sustainable future earthquake resistance systems

The meaning of “*sustainability*” shortly is to remain in ecological balance. Nowadays, it is so important than ever because there are countless examples where human being have damaged their own environment and they put in danger their own survival chances. However, despite of those, there is a tendency to design buildings which are environmentally friendly as well as having seismic resistance. The following paragraphs are discussed new technological solutions which are being developed to meet both these needs.

2.5.7.1 (FRP) Fiber- Reinforced Plastic Wrap

Designing a building having earthquake resistance makes sense once you are constructing a new building. However, how about old buildings? What should be done for them? Of course, this question is answered by engineers. A new technological material called FRP (Fiber-Reinforced Wrap) has been developed to retrofit both historical structures and conventional old buildings. These wraps are produced by mixing carbon fibers with binding polymers such as polyester, nylon, epoxy, vinyl or ester. This material is also quite lightweight, much easier to implement and incredibly strong. It is, however, a bit expensive to apply a building where it is located at countryside (Bank, 2012).

2.5.7.2 Cardboard as an environmental structure material

Earthquake resistant design is always the main question all over the world what about using cardboard at building? That sounds interesting but what civil engineers want to utilise at construction is easily obtainable, environmentally friendly and locally available material. Of course, few experimental studies are done to meet these needs, for example, a Japanese architect came up with a new idea which is extremely flexible and light material for the primary framing elements. This idea was applied several buildings incorporating cardboard tubes coated with polyurethane. The results were quite satisfying. In 2013, after a strong earthquake in Christchurch, New Zealand, 98 giant cardboard tubes reinforced with wooden beams are utilized to construct the church performing much better than concrete during ground motion. However, this was not only feasible and cheap solution to construct a structure. Here some different examples of environmentally friendly solution for construction, in Peru, reinforcing wall with plastic mesh is an example of traditional adobe

structures which is much stronger. In India, bamboo which is another example of using local material at construction is successfully utilized to strengthen concrete (Allaoui, Aboura and Benzeggagh, 2009)

2.5.7.3 Green concrete as environmental construction material

The amount of CO₂ emission emitted by concrete factories has caused many to focus on alternative concrete which does not emit carbon dioxide gas. Few studies are being done to reduce CO₂ emissions. One of these is green concrete made from concrete wastes, sawdust, foundry sand, Slag, power plant wastes, recycled concrete, waste glass, incinerator residue, red mud, burnt clay, combustor ash, mining and quarrying wastes. It is also cheap to manufacture due to no charges for high durability, lower energy consumption, using waste and the disposal water. Therefore, protecting environment from waste disposal and fewer natural resources consumption will be hopefully possible in the foreseeable future (Georgopoulos and Minson, 2014).

2.5.8. Structural Analysis

Four types of analysis methods based on EN1998 (Eurocode8) can be utilized in order to see how the building would behave during ground motion. This section will give more details about the types of structural analysis methods. However, it is quite significant to keep in mind that every structural method cannot be utilized for any structure. Type of method utilized in the design depends on the structural characteristics. Before going details about types of structural analysis methods, some definitions that will be needed in the following paragraph are given below;

- Linear analyses (first order analysis) can be defined the elastic-linear hypothesis for the materials of the building
- Non-linear analyses are defined as considering mechanical non-linearity

2.5.8.1 Lateral force method (First order linear-elastic method)

Lateral force method would be utilised on buildings whose behaviour is not considerably changed by contribution of other modes of the building

If the two following conditions are provided in the design, then first order linear-elastic method can be used.

1. If the fundamental periods of vibration (T_1) are smaller than the two values given below;

$$T_1 \leq \begin{cases} 4T_c \\ 2,0s \end{cases}$$

(Equation 2. 2: Fundamental period of vibration)

Where T_c is the spectrum period at the upper limit of the constant acceleration region

2. A building should satisfy the conditions listed in 4.2.3.3 for regularity in elevation

(BS EN 1998-1:2004, 2004)

2.5.8.2 Modal response spectrum analysis (second order linear- elastic)

If the conditions given in lateral force method do not satisfy the requirements to choose the aimed structural analysis method. Then modal response spectrum method considering the response of whole modes contributing to the global response should be chosen as a solution. Of course, to check whether this method is the suitable one, according to Eurocode8, following two conditions should be checked.

1. “The sum of the effective modal masses for the modes considered amounts to at least 90% of the total mass of the structure”
2. “All modes with effective modal masses greater than 5% of the total mass are considered.”

(BS EN 1998-1:2004, 2004)

2.5.8.3 “Pushover” analysis (First order plastic-nonlinear)

This is first order plastic non-linear static analysis method carried out increasing horizontal loads in monotone and gravity loads. Application of “Pushover” analysis method is possible for both new and existing designed buildings to check and verify the performance of structure in ground motion. The elastic response spectrum (see 3.2.2.2) can be used to determine the target displacement. The equation (4.3.3.4.2.3) is used to determine the capacity curve representing the relation between control node displacement and base shear force.

$$F_i^* = m_i \times \Phi_i$$

(Equation 2. 3: Normalized lateral force)

F_i^* , Φ_i and m_i represent normalized lateral forces, normalized displacements and the mass in the storey respectively.

The assumption ($\Phi_n=1$) is done to find relative displacement in the building.

(BS EN 1998-1:2004, 2004)

2.5.8.4 Time history analysis (second order plastic – non-linear dynamic)

If an equivalent linear model (10.9.2(5)) is not enough to satisfy the needs, time-history analysis should be used to assess the seismic response. In other words, if the rules stated in Eurocode8 are satisfied, second order plastic- non-linear dynamic method can be used.

(BS EN 1998-1:2004, 2004)

CHAPTER 3: EUROCODE 8 DESIGN OF BUILDING FOR SEISMIC RESISTANCE

3.1. Introduction

3.1.1 Overview on Eurocodes

The Eurocodes are a type of regulation, which has been used by European countries. As other codes, Eurocodes have some specific designing restrictions. This regulation which is composed of 9 subsections is utilized by structural engineers for designing.

3.1.2 Introduction to Eurocode8

An overview on BS EN 1998 (Eurocode8) based on seismic resistant design will be discussed in the following paragraph. This code associated with limit state design philosophy is composed of 6 subsections to design earthquake resistant building. In addition to better meeting the societal needs (security, comfort and sustainability, safety), the dialogue between engineers and actors of the construction industry is simplified by Eurocode8.

3.2 The main rules for designing RC buildings according to Eurocode

3.2.1 Fundamental objective of the Eurocode8

During ground motion, giving priority to civil protection, minimizing the damage to a building and designing ductile construction depending on the type of building (such as hospitals or school buildings) are the main aims of BS EN 1998 (BS EN 1998-1:2004, 2004). In addition, in a case of structural issue, the minimum values obtained from Eurocode8 can be applied to the design.

3.2.2 The main requirements for seismic design in Eurocode8

Some requirements (Eurocode8, section 2.1 of BS EN 1998) given in the following paragraph are met to construct and design a building subjected to a ground motion. The requirements considered carefully will assist designers and engineers to construct adequate structural necessities.

3.2.2.1 No- Collapse Requirement

According to section 3 of Eurocode8, No-collapse requirement defines that the building had better withstand the seismic loads without global or local collapse. According to the code, a

building exposed to ground motion should keep a residual load bearing capacity and its structural integrity even an extreme earthquake. In other words, (Arya, 1994) stated that if a structure does not exceed its ULS (ultimate limit state), the building will be safe against sudden collapse in an earthquake. The fundamental reason for this requirement based on without global and local collapse is to save people lives against seismic events (BS EN 1998-1:2004, 2004).

3.2.2.2 Damage limitation requirement

According to Eurocode8, the meaning of damage limitation is that the building had better be constructed and designed to resist larger earthquake than the design one without any damage. However, the cost of the building would be quite high. Therefore, the regulation (BS EN 1998) allows slight seismic damage on the building in order to reduce the cost of the structure (BS EN 1998-1:2004, 2004).

3.2.3 Basic principles of conceptual design

In the early process of the design of a structure, the seismic zone of the building should be considered to take some precaution against seismic damage in the structure. Thus, to meet the main requirements (which are discussed in section 5.2.2 of this report) for the seismic design of the building, eurocode8 (section 4.2.1) identifies the six (6) guiding principles given below;

1. **Structural simplicity:** The existence of direct paths and clear for the transmission of the earthquake forces is a significant design philosophy for structural behaviour in earthquake. Structural simplicity is needed to be considered throughout the detailing, analysing, dimensioning and modelling. If the design of a structure is so complex, the prediction of its seismic behaviour is not reliable.
2. **Symmetry, redundancy and uniformity:** “Symmetry, redundancy and uniformity in the plan are categorized by a distribution of the structural elements which allows direct transmission and short of the inertia forces” (BS EN 1998-1:2004, 2004). Along the height of the building, the uniformity of loads is also crucial. There is a close relationship between the distribution of resistance and the distribution of masses. Distribution of load applied to a building depends on the stiffness of elements.

3. **Bi-directional resistance and stiffness:** “Horizontal seismic motion is a bi-directional phenomenon” (BS EN 1998-1:2004, 2004). Therefore, the structure exposed to horizontal seismic motion should have bi-directional resistance. In addition to designing of similar stiffness and resistance in both fundamental directions, arranging an orthogonal in the plan of building is also necessary to obtain better seismic resistance.
4. **Torsional resistance and stiffness:** Apart from lateral resistance and stiffness in a building, adequate stiffness and torsional resistance are also needed to prevent any additional forces.
5. **Diaphragmatic behaviour at storey level:** In buildings, getting better seismic resistance on the structure, several subjects are needed to be met. One of these is horizontal diaphragms transmitting and collecting the forces to the vertical member of the building.
6. **Adequate foundation:** the uniformity in the load distribution is important for foundation.

3.3 Specific Materials

The type of material utilized in the designing of a seismic resistant structure is so significant to obtain better seismic performance from the building. When it comes to reinforced concrete, it is a composite material but concrete has relatively low ductility and tensile strength. Therefore, the inclusion of reinforcement having ductility or higher tensile strength is necessary step to improve the behaviour of the final building under working loads (BS EN 1998-1:2004, 2004).

3.4 Capacity design of RC building (failure of the most critical parts)

Member strength of the building should be adequate to resist forces resulting from seismic loads. “Strength design.” is known as a design concept. At ultimate strength condition, both concrete and reinforcing steel must behave inelastic without any collapse. Engineers should verify that both the structure and the structural elements have adequate ductility. The expected exploitation of ductility depending on the behaviour factor and the selected system should be also known to estimate failure modes of the building. To avoid brittle failure mode in the structure, specific material related requirements, as defined in sections 5 of Eurocode8, should be satisfied. When it comes to the frame, as stated previously, RC frame is designed to resist lateral loads through moments, shears and axial forces in their rigid joints, columns

and girders. The combination of reinforcing steel and concrete resisting tensile and compression forces respectively, work together to obtain better building performance in an earthquake (as depicted in figure 3.1). The form of plastic hinges in beams or girders provides damping and absorbs earthquake energy in the dynamic response of the building. On the other hand, the reasons for the failure of ductility in the building will be given in the following paragraphs.

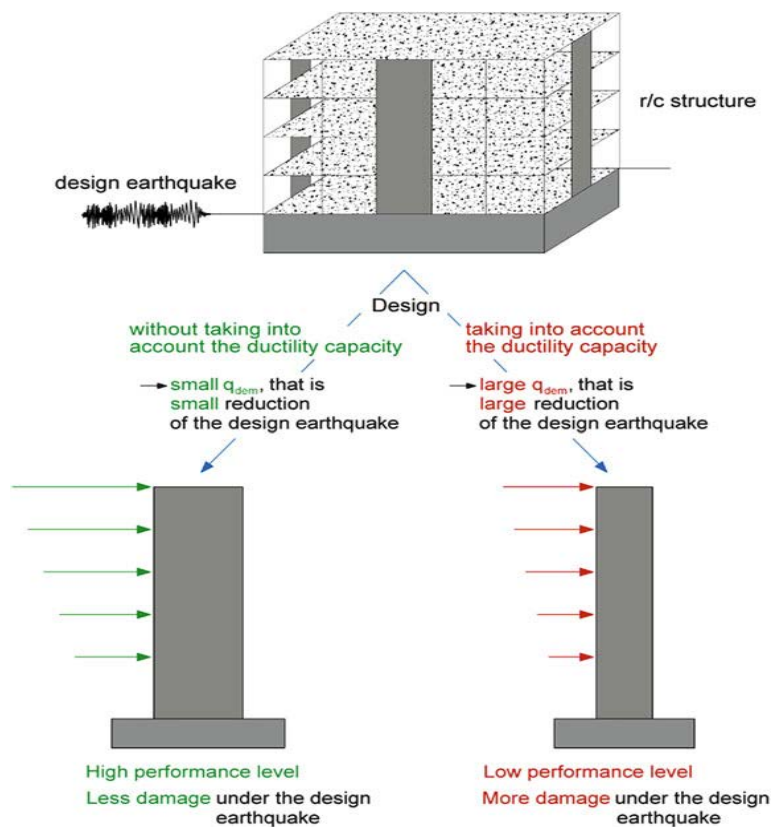


Figure 3. 1: The effect ductility over the performance of building (Mazars et al., 2010)

According to section 4.4.2.3(8) of Eurocode8, ductility can be provided if all of the following conditions are met:

1. “plastic mechanisms obtained by pushover analysis are satisfactory “(section 4.4.2.3(8))

2. “global, inter storey and local ductility and deformation demands from pushover analyses (with different lateral load patterns) do not exceed the corresponding capacities” (section 4.4.2.3(8))
3. “brittle elements remain in the elastic region” (section 4.4.2.3(8))

3.5 Issues (failure of ductility) in seismic design of reinforced concrete buildings

The focus of this paragraph is the type of RC common failures during a seismic event. The first type of failures is shear failures which can occur in two major forms (Mazars et al., 2010):

1. a soft-story failure and
2. confinement failure

3.5.1 soft- story

If the moments and large shear forces cannot be resisted by lateral load resistance of the building, the structure is more likely to collapse over the other story (because of parking arrangements or retail shopping) (Anastasopoulos, 2013) (as depicted in figure 3.2). According to section 4.4.2.3 (3) of Eurocode8, “in multi-storey buildings formation of a soft storey plastic mechanism shall be prevented, as such a mechanism might entail excessive local ductility demands in the columns of the soft storey” (BS EN 1998-1:2004, 2004).

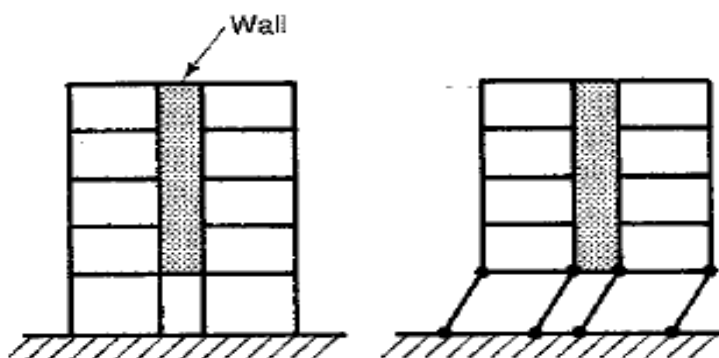


Figure 3.2: Soft-Story Mechanism (Anastasopoulos., 2013)

3.5.2 Confinement failure

3.5.2.1 Short column

Without going detail (because it is discussed in detail in section 2.5.8.2.3.1.2 of this dissertation), additional information will be given. Figure 3.3 shows a half- brick wall is constructed between two RC columns. During a ground motion, “the column was intended to contribute to the inelastic behaviour of the lateral load resisting system (LLRS) by deforming with the rest of the frame” (MacGregor et al 2005). However, the wall restricted the movement of the column. An unexpected structural behaviour occurred caused a shear failure (as depicted in figure 3.3) in the column if components of the structural frame have had adequate transverse reinforcement, this problem would not have occurred (Anastasopoulos, 2013).

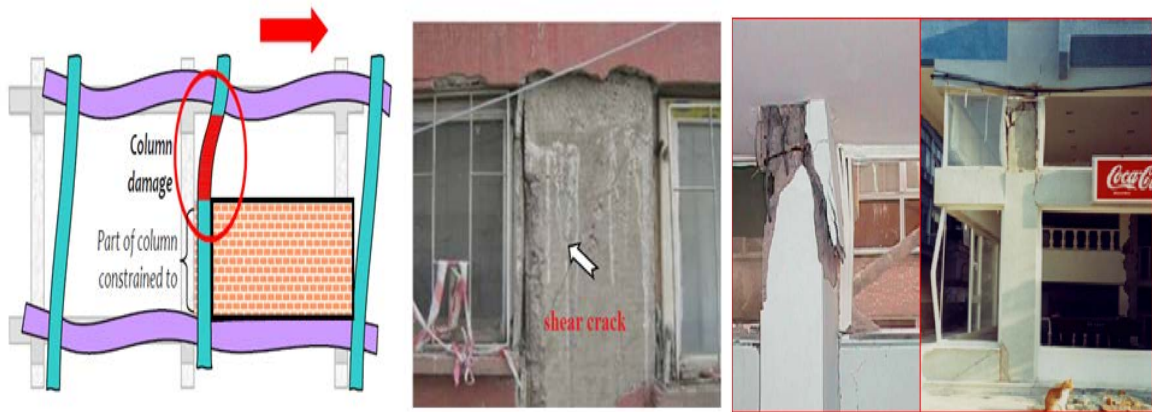


Figure 3.3: An Example of Short-Column Formation (Mazars, 2010)

To solve this issue, section 3.17.1 of Eurocode2 says that a column should be checked whether it is short column or not by using the equation below,

$$\frac{l_{ex}}{h} \text{ and } \frac{l_{ey}}{b} < 15 \text{ for a braced column}$$

(Equation 3. 1: Checking for braced column)

$$\frac{l_{ex}}{h} \text{ and } \frac{l_{ey}}{b} < 10 \text{ for an unbraced column}$$

(Equation 3. 2: Checking for unbraced column)

Where l_{ex} and l_{ey} are the effective lengths obtained from $l_e = \beta \cdot l_o$ (β is obtained from Table 3.1).

Table 3. 1: Values of β for unbraced and braced columns

End condition at top	Values of β for braced columns			Values of β for unbraced columns		
	End condition at bottom			End condition at bottom		
	1	2	3	1	2	3
1	0.75	0.80	0.90	1.2	1.3	1.6
2	0.80	0.85	0.95	1.3	1.5	1.8
3	0.90	0.95	1.00	1.6	1.8	–
4	–	–	–	2.2	–	–

3.5.2.2 Compression failure

Another confinement example is figure 3.4 (a) illustrating a column buckled under seismic compressive loads because of insufficient transverse reinforcement. In addition to holding the longitudinal reinforcement bars in position, Transverse reinforcements designed also prevent their buckling in compression. The figure 3.4 (b) illustrates how confinement affects the load carried. The confined RC column resists more stress than unconfined one.

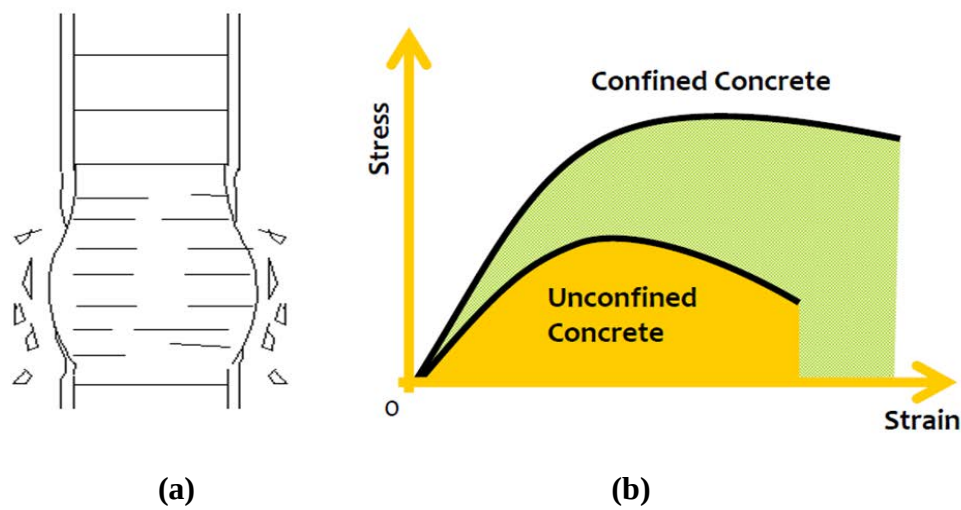


Figure 3.4: Compression Failure (Mazars, 2010) (a) and Unconfined and Confined Concrete (b) (Boswell and D’Mello, 1993)

Section 9.5.3 of Eurocode2 states that compression failure can be prevented by applying minimum transverse reinforcements (as depicted in figure 3.5)

$$✓ s_{cl,tmax} = \min \{ 12 f_{min}; 0.6b ; 240mm \}$$

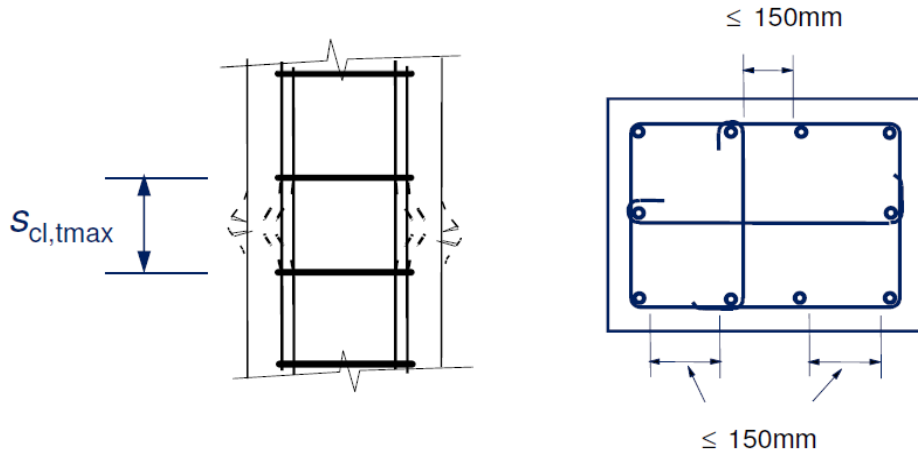


Figure 3.5: Minimum values of transverse reinforcements of column (Eurocode2)

CHAPTER 4: METHODOLOGY

4.1 Introduction

This chapter intends to justify and explain the reasons for choosing the methods, the software, tests and analyses carried out in this report as well as the behaviour of RC building subjected to Van earthquake, Turkey. All analysis, modelling and assessments will be done in FEA software known as SAP2000 which will be explained in following paragraph. As mentioned before, the main aim of this report is to make some research data available to be used by engineers and academics as assistance along with the other regulations and BS EN 1998 concerning the design of earthquake resistant reinforced concrete building. Apart from getting help from a few articles associated with 2011 Van earthquake, Turkey and short-column formation studied before. Three different 4-storey RC buildings with two spans designed in SAP2000. Two of these models have short-column formation (by using shear wall and mezzanine floor) and the other model is a normal 4-storey RC building without having short column issue. Of course, both designs subjected 2011 Van earthquake, Turkey to examine their performance against a specified earthquake.

4.2 Finite Element Modelling

4.2.1 SAP2000

Using engineers experience and the own knowledge was the key point of traditional building designs. However, especially last five decades, with the new invention of computer technology, engineers can now model different types of buildings in the software (such as sap2000), even in various seismic conditions. The results obtained from the software, such as SAP2000, can be used when it comes to solving structural problems. Thus, the possibilities of making mistakes can be reduced by all these results obtained from programs.

In this dissertation, the specified computer program (SAP2000) was utilised as the responses or failure of structures, even in complex structural models, as said before, the software used in this dissertation is SAP2000 based on Finite Element Analysis (FEA) design. This program is introduced more than 30 years ago and has been used by mechanical engineers, structural engineers and aerospace engineers. It can be named as the art engineering program making the analyses and models simpler, even many complex three-dimensional structures. This program is still being updated with useful tools.

4.2.2 Time History Function

The use of a time history function portraying the various loads over time is crucial part of creating a model. To find out how the building would behave under those earthquake loads. Firstly, a set of 2011 Van earthquake data from the accelerograph is needed. Secondly, these data are applied to the building and finally, the behaviour of building against specified earthquake can be obtained from the software results.

In this dissertation, as said before, the 2011 Van, earthquake, Turkey will be utilised for analysis this is because it led to for devastation of economy of Turkey, social life of people of the region and many deaths located in east of Turkey. The data of the earthquake is taken from Turkish Meteorology Agency (TMA). Mertol et al (2014) stated that “The main shock of the earthquake was felt within an approximately 200 km radius of the epicentre.”

The Van earthquake that happened on the 23th of October 2011 in the east of Turkey measured at **5.6 on the Richter** scale and led to more than \$50 million in property damage. 604 were killed and more than 1000 were injured (Korkmaz, 2015).

The effects of earthquake made many changes to the Turkish earthquake regulation (TS500) such as concentrating on having more stable and stronger beam column connections, transverse reinforcement and concrete classes. Moreover, few new restrictions are added the TS500 (Turkish standard). They can be defined as “short column”, “weak column strong beam” and “soft-story” (Mertol et al., 2014).

As mentioned before (in the section 2.3.5 of this dissertation), the ground motion data of 2011 Van earthquake, Turkey is obtained from TMA (Turkish Meteorology Agency) and then modified to be ready for use in the SAP2000 software. The following four steps are used to assign the specified ground motion into SAP200 based on FEA method.

1. ‘.txt’ file taken from Turkish Meteorology Agency (TMA) is extracted by choosing function type in the software.
2. The figure 4.1 illustrates the time history function assigned in the specified program
3. The next step was to assign the load case data consisting of linear analyse type, modal solution type and (due to the unit of acceleration extracted) scale factor (as depicted in figure 4.1).
4. And the final step was two logical assumptions associated with time step and step size

Function Name VAN EARTHQUAKE

Function File
File Name: Browse...
c:\users\kral\Desktop\dissertation\yeni klasor\van earthquake\van earthquake.txt

Header Lines to Skip: 1
Prefix Characters per Line to Skip: 0
Number of Points per Line: 1
Convert to User Defined View File

Values are:
☐ Time and Function Values
☒ Values at Equal Intervals of 7.800E-03

Format Type
☒ Free Format
☐ Fixed Format
 Characters per Item:

Modal Load Case
Use Modes from Case: MODAL

Loads Applied

Load Type	Load Name	Function	Scale Factor
Accel	U1	VAN EARTH	1.
Accel	U1	VAN EARTHQA	1.

Show Advanced Load Parameters

Time Step Data
 Number of Output Time Steps: 10714
 Output Time Step Size: 7.800E-03

Other Parameters
 Modal Damping: Constant at 0.05 Modify/Show...

Mass Source
Previous (MSSSRC1)

Function Graph: [14.5867 , -40.8732]

OK Cancel Display Graph

Figure 4. 1: Load case data and time history function in SAP2000

4.3 The properties of Model

To obtain reliable results from the software, a trustworthy structural analysis must be carried out under correct model properties and controlled design. One of these properties will be the class of concrete in RC frame, its structural elements (such as column and beam) and the building geometry. All these are discussed in following paragraphs.

4.3.1 The properties of RC structure

The class of concrete illustrates how strength (N/mm²) it is and associated with compressive strength depending on the especially quality of the curing, time and the water-cement ratio. Also, the compressive strength of concrete can reach 14,000 psi. However, the tensile strength of concrete is 10 to 15% of the compressive. The specified program (SAP2000) allows for the selection the class of concrete utilized in the model. The class of concrete utilized is selected during the design phase by civil engineers and depends on the purpose of the building and geometry, as well as the conditions of the location of construction built such as the rate of seismic activity. For this dissertation, the class of concrete utilized will be C25 (25MPa) (normal weight) (Nilson, 2010).

4.3.2 The Geometry of Design

To obtain reliable results from the software, the trustworthy analysis must be carried out under correct model properties and controlled design. The frames designed should have member sizes and the same spans because different dimensions would affect the performance of buildings against seismic loading.

4.3.3 The Elements of Building

The frame chosen is both vertical (6.5m) and horizontal (3m) symmetric. Also, beam and column are designed not to be very strong (for the more real purpose).

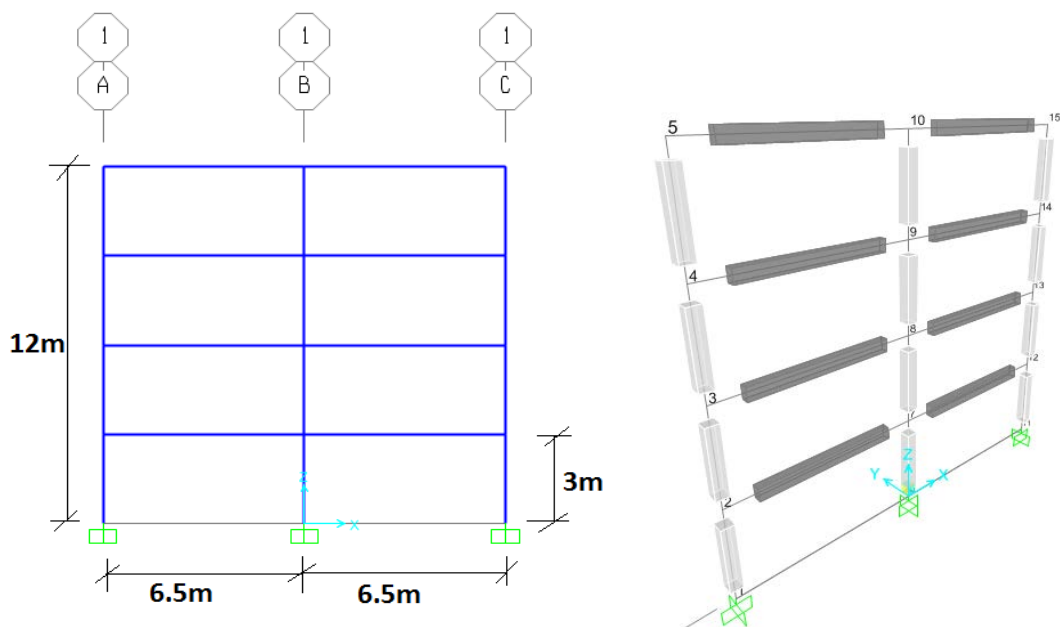


Figure 4. 2: Dimensions of Structure utilized in SAP2000

Table 4. 1: Structural Properties

	The members		
Designation of section	Column(mm)	Beam(mm)	Shear wall(mm)
Width of section	400	250	250
Depth of section	400	400	6500
Concrete class	C25(N/mm ²)	C25(N/mm ²)	C25(N/mm ²)
Yield stress of reinforcement	420(N/mm ²)	420(N/mm ²)	420(N/mm ²)

Concrete cover	40	60	-
Longitudinal bar size	12H20	-	H20
confinement bar size	H8/150 spacing	-	-

4.4 The Effect of Various Structural Dimensions on the Behaviour of Building under Seismic Loading Condition (from tests 1 to 3)

As it is mentioned in the introduction of this report, the first study will examine the effect of various building dimensions and misapplications (such as shear wall and mezzanine floor) in the building on the behaviour of the building under the specified earthquake loads. Both tests will be discussed in the following paragraphs. The first study will be the behaviour of three various frames recorded under 2011 Van Earthquake. As it is well known that the biggest values will be at the top of the building in terms of displacement and acceleration. Therefore, both parameters will be recorded at the top of the structure. Moreover, changes in shear, axial forces and bending moment will be shown to demonstrate how the various dimensions affected the behaviour of the building under the specified earthquake.

The second study will be the effects of short-column formation in the building. In this test, the critical place will be at confined region (where short- column formation occurs) in the building. Therefore, the ground floor including changes in axial force, shear force, displacement and moment diagrams will be shown. However, span dimensions and materials will remain the same to keep fair the test in the structure.

4.4.1 Wide frame (low rise frame)

The low-rise frame is the opposite meaning of high rise (slender) frame. It is the shortest one specified in this dissertation. The low-rise frame will have a width of 8 bays and a height of 2 spans, whose height to width ratio is less than 1(< one). Moreover, the results taken in SAP2000 for this frame should consist of forces and major effects under the specified earthquake. The tests which will be carried out for high rise frame and low rise should provide enough information to estimate the other possible results for regular (medium) frame which will be achieved in the following paragraphs. It is well known that low rise frames have better earthquake performance and are more stable due to less high and large plan causing buckling moment.

4.4.2 Regular (medium) Frame

As said before, these differences are all about the dimension of the frames. In this sense, this frame is neither widest frame nor the tallest one. This is just the logical balance between high rise building and low-rise frame. This is 'regular' (medium) frame having 2 spans and 4 bays tall whose height to width ratio is about one.

4.4.3 Slender Frame (high rise)

As can be understood from its name, high rise frame is the least wide frame and the tallest one in the specified frames in this dissertation. This frame has a 2 spans width and height of 8 bays whose height to width ratio is bigger than one (>1). Moreover, its behaviour and stability in seismic loading conditions is quite bad due to not enough lateral resistance and the high of building.

4.5 The effect of two incorrect applications during construction over seismic resistance of building (tests from 4 to 9)

The tests will be examining the effects (over seismic resistance) of incorrect applications (short column formations) during construction of a building. One of these will be reinforced concrete column abutted on either side by a partial shear wall (as mentioned in section 2.5.8.2.3.1.2 of this dissertation) and a mezzanine floor (as illustrated in previous sections) will be the second incorrect application in construction.

In this dissertation, the regular frame which is 4 bays tall and 2 spans wide will be used to demonstrate the tests. Each incorrect application will be run in SAP2000. A shear wall is used to resist lateral loads. However, during the construction of a shear wall, a band window which is incorrect application is opened. The other structural mistake applied is mezzanine floor used for meeting room purpose. The effects of structural incorrect applications over the performance of a building in specified seismic loading (2011 Van Earthquake, Turkey) will be utilized and compared against each other to demonstrate how each incorrect application causes catastrophic consequences. Also, it is significant that the shear forces are experienced over critical members (connection joints, column) as well as the displacement and acceleration of each frame. The same methods for frames, which will be mentioned in following paragraphs, will be followed in this dissertation. The incorrect structural applications which will be tested are discussed below.

4.5.1 Application of Shear Wall

Shear wall is one of the lateral resistance members in a building but during the construction of a shear wall, a band window which is incorrect structural application is opened. This mistake ends up with catastrophe during ground motion.

4.5.2 Application of Mezzanine Floor

It originally comes from the French language. The mezzanine floor opens double-height ceiling floor and would be also used for stair case in buildings. This uncounted beam application causes additional shear forces in the column (as it is mentioned in section 2.5.8.2.3.1.2 of this dissertation) and the transverse reinforcement of column cannot finally carry these extra forces and the column fails.

4.6 Seismic and dead loading conditions

Imposed load (40kN/m) and dead load (20kN/m) are taken into count, especially in a modal analysis (free vibration). The following equation based on Eurocode2 is used to calculate ultimate design load (UDL)

$$W=1.35Gk+1.5Qk$$

(Equation 4. 1: Equation for calculation of UDL)

$$(1.35 \times 20) + (1.5 \times 40) = 87 \text{ kN/m}$$

However, despite the reality of imposed and dead loads in a design, in this dissertation, this reality will be ignored in order to make the analysis understandable. In other words, the design will be run without the contribution of imposed and dead load.

4.7 Beam-Column Connection

Beam-column connection must have enough ductility to capture progressive collapse during ground motion. They are designed as a member of RC frame experiencing, axial loads, shear forces and bending moments.

4.8 Damping

Designing strong lightweight materials, increased properties of material and knowledge of structural loading have helped engineers to obtain better earthquake performance from a building. However, despite all these developments, there are lots of cases of systems failing

or not meeting performance targets due to excessive vibration, resonance or fatigue of components. When it comes to a building, two fundamental factors control the frequency of vibration and the amplitude:

- The magnitude of ground excitation and
- The response of the structure to that ground motion

The first one is out of this section. Designing a building having better earthquake resistance should be the first priority. Therefore, this section will focus on the response of the structure subjected an earthquake. The response of a building depends on the location of the exciting motion, the method of application and the dynamic characteristics of the construction (such as inherent damping level and natural frequencies). Moreover, too much resonance of ground motion would lead to significant damage to non-structural elements.

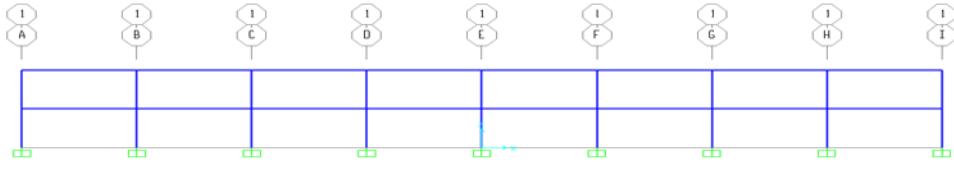
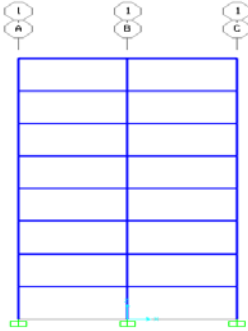
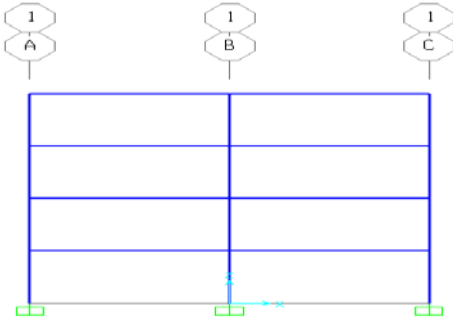
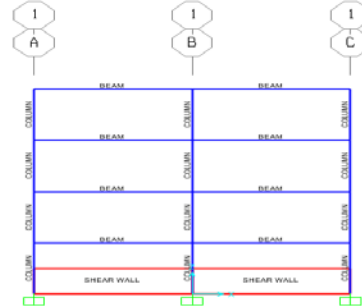
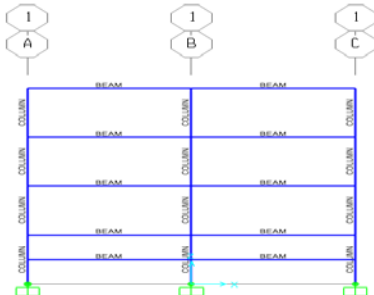
The flexibility of structure presented in a response spectrum is quite important in the design of a building. In other words, it affects the seismic resistance of a building. In this sense, Peak ground acceleration (PGA) in a response spectrum depends on the type of soil (from A to E) and damping differing from 2, 5% to 10%. As a reminder, in this dissertation, 5% damping will be used.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Introduction

As it is mentioned in previous chapter, 5 tests will be run. Three of them relating to forms of structures (Low rise, Medium and High rise) and other two tests are the type of short column formations done (Mezzanine floor, shear wall and normal moment resisting RC frame). This chapter will be the results of the discussion and tests run. The following figures illustrate type of frames utilized in this dissertation.

Table 5. 1 Showing Types of Frame, Structural Applications and the Number of Tests

Test1-Wide (low rise) moment resisting frame with no short column formation (structural issue)	
	
Test2: Slender (high rise) moment resisting frame	Test3: Regular(Medium) moment resisting frame without any short-column formation(structural issue)
	
Test4: Medium(Regular)Frame with one of short-column formation (Shear Wall)	Test5: Medium(Regular) with one of short-column formation (Mezzanine Floor)
	

As it is mentioned in the previous chapter the same class of concrete (C25) will be utilized in all structural elements and all frames will also have the same properties. These similarities will keep the tests reliable and comparable. Also, if a design error occurs, the results could still be utilized because similarities create estimations on the behaviour of frames. In the design, an earthquake was considered so that the direct effects of the ground motion could be assessed (due to dead and impose load ignored). In the pre- testing, the modal case was utilized to ensure whether the buildings could resist against life-like loads. This chapter will consist of a few discussions and comparisons between the results of the tests.

5.2 Response Spectrum

The following figure 5.2 called acceleration response spectrum illustrates the response of the building to Van earthquake 2011. The peak ground acceleration (PGA) for a specified point can also be found in that spectrum. Moreover, A PGA can be utilised with previous earthquake response spectra to estimate other possible peak ground acceleration of the location. When it comes to the regulation, Eurocode8 states that "PGA corresponds to the reference return period (T_{NCR}) of the seismic action for the no-collapse requirement" (EN 1998-1-2004). As it is said before acceleration of the system is affected by initial forces applied to the building. Therefore, the spectrum (acceleration of joint 6) provided in figure 5.1 is chosen from a fixed connection between the ground at the middle side and the building. It is well known that the response spectrum given in figure 5.1 is just related to specified ground motion. In other words, the peak value of the figure below is the maximum acceleration applied the building (this maximum acceleration is utilized for all tests in this dissertation). However, the peak ground acceleration (PGA) provided for each frame will vary to each other due to the type of short column formation applied to the structure, mass and the stiffness of building.

As it is mentioned previous chapter of this dissertation (in section 4.8) the damping used is 5 % (0.05).

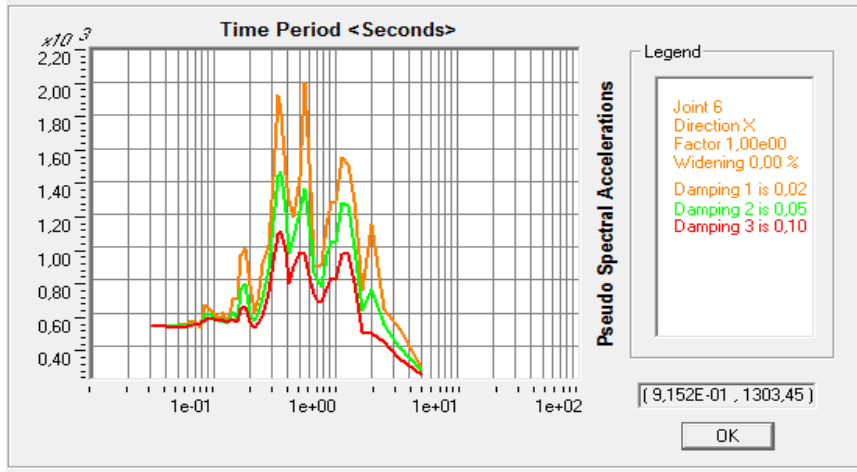


Figure 5. 1: Acceleration (cm/sec²) Response Spectrum for 2011 Van Earthquake

The natural period of the building gives information about the peak response of structure to ground motion. Therefore, the fundamental period of vibration (T_1) based on Rayleigh method will be calculated according to Eurocode8 (as shown below or in section 2.4.2 of this dissertation). For designing a structure having enough resistance against seismic loading conditions, the maximum force that the structure will be exposed should be known. If the frequency of ground motion reaches the natural resonance frequency of a building, the greatest damage and the largest oscillation will be inescapable. This is because various damages occur at two buildings located next to each other.

As it is mentioned above the main period of vibration (4 bays tall and 2 spans wide) can be calculated by using following equation (for moment resisting frame);

$$T_n = C_t \times H^{3/4} = 0.075 \times 12^{3/4} = 0.48 \text{ seconds (2dp)} = 0.96 \text{ Hz}$$

(Equation 5. 1: Fundamental period of vibration)

Where C_t is estimated to be 0.075 and H (the height of building) is 12 m (3 x 4).

As can be seen from the response spectrum given above three different peak ground accelerations (PGA) are provided to compare the results depending on damping value (10%, 5% and 2%). The maximum value of PGA for 10% is 109g whereas at 2% damping it is 204g. This illustrates an inverse proportion between PGA and damping. In this dissertation, 5% (147g) damping which is the common one is assigned to SAP2000.

5.2.1 Ground Acceleration

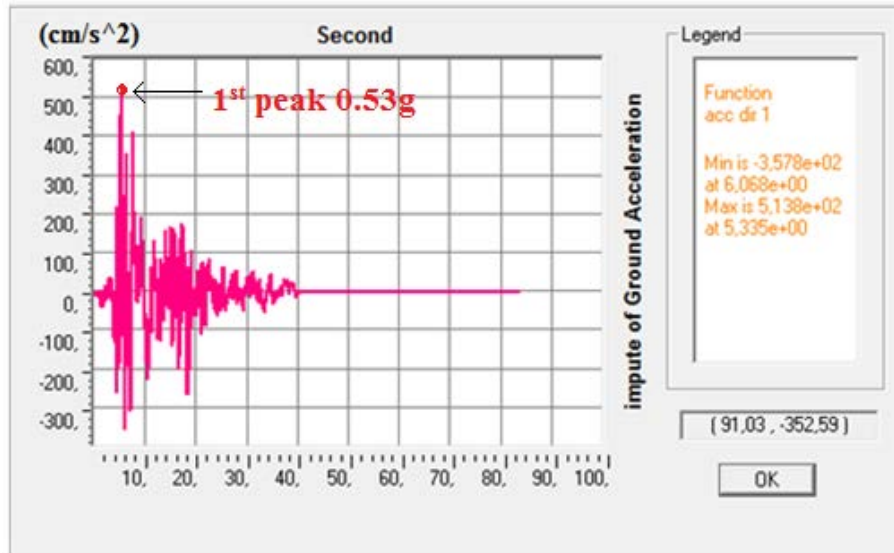


Figure 5. 2: Impute of Ground Acceleration for 2011 Van Earthquake (cm/sec²)

The figure given above illustrates impute of ground acceleration (cm/sec²) for 2011 Van Earthquake. The Peak Ground Acceleration (**PGA**) which is East- West direction is **513.8 cm/s² (0.53g)** (as it is discussed in detail in section 6.3.5 of this dissertation). **1st peak 0.53g**

5.3 How Dimensional Variation affects the behaviour of RC structure under Ground Motion

Limitations are quite a normal word for civil engineering because the engineer designs the building under restrictive conditions which are what purpose it is being constructed for, the building availability and the budget of construction. In this section of this dissertation will examine and answer the question (how Dimensional Variation (the form of structure) affects the behaviour of RC structure under Seismic Loading Conditions). Specified structural conditions (as it is introduced in section 5.1 of this dissertation) and the material properties will be kept the same to obtain reliable results from these analyses.

5.3.1 Test1: Wide (low rise) moment resisting frame without any short-column formation

As said previous chapter, the low-rise moment resisting frame having 8 bays wide (52m) and 2 bays tall (6m) were run to obtain specified results (as it is mentioned in section 4.4 of

this dissertation). It is well known that the stability of low rise frame is higher than high rise frame because the low-rise frame will not experience extreme seismic loads. However, despite above fact, the length of a frame would cause additional forces because the load also depends on the number of waves taken within 1 second. Irregular amounts of forces, displacements and accelerations imposed on the building are inevitable for this type of frame due to the length of the wave. The diagrams given for the low-rise frame below illustrate shear force diagram envelopes (SFD) and bending moment diagram (BMD) aiming to depict the maximum positive and negative forces imposed on the building subjected to 2011 Van earthquake.

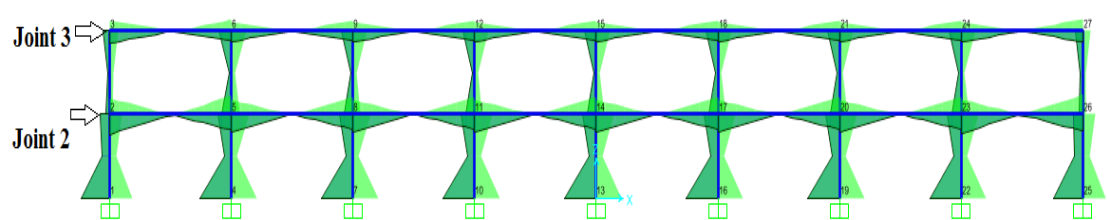


Figure 5. 3 Bending Moment Diagram (BMD) envelope for wide frame (low rise)

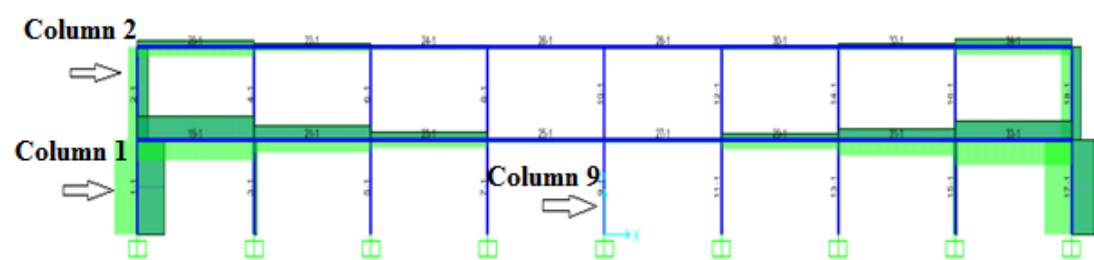


Figure 5. 4: Axial Force Diagram (AFD) envelope for wide frame (low rise)

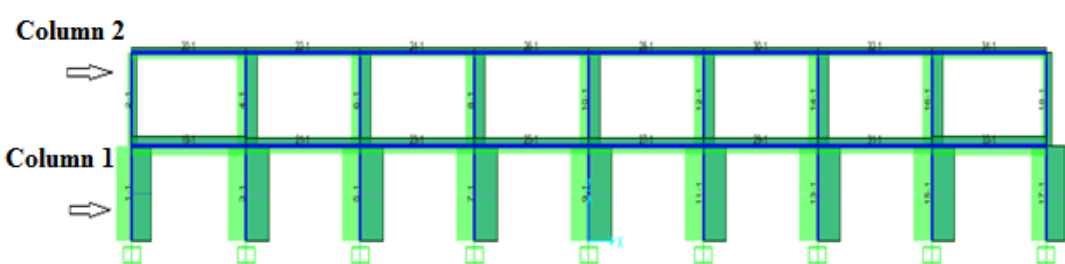


Figure 5. 5: Shear Force Diagram (SFD) envelope for wide frame (low rise)

As can be seen from figure 5.4, the moment of the frame subjected to specified earthquake decreases linearly from the bottom (joint2) to top (joint3). This linear moment diagram was expected to be seen because the seismic loads create a single force on the frame. The evidence of it is figure 5.6.

Also, the value of shear force at the bottom (Column 1) is bigger than the top value (Column 2). When it comes to axial forces (as depicted in figure 5.5), It decreases through the corner of the frame (Column 1) to the middle of the frame (Column 9). By using the equation 5.1 in section 5.2, the fundamental period of vibration based on Eurocode8 is calculated to be 0.326 sec. Compared with regular frame building which was 0.48 sec. Logically it can be said that there is a relationship between the number of stories and the fundamental period of structure (as said before, each storey is approximately equal 0.1 sec).To obtain the accurate fundamental period of the frame, it must be analysed (e.g. for the low rise frame, the fundamental period is 0.16 sec according to SAP2000).

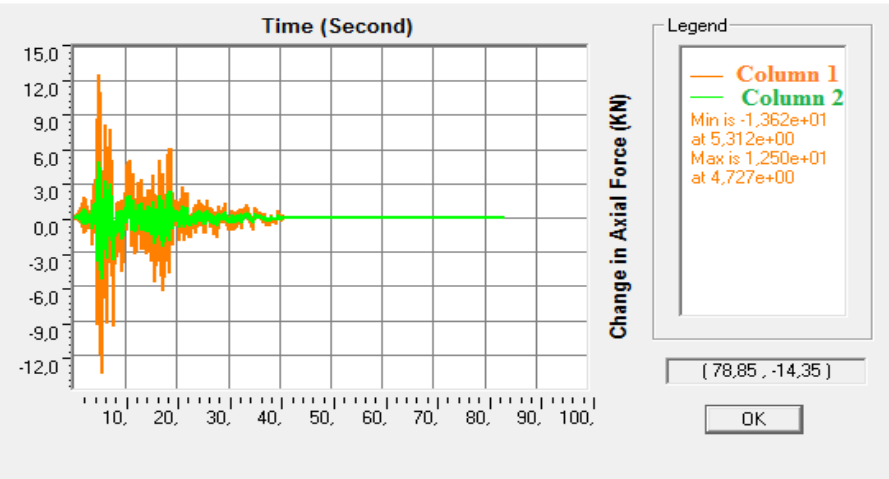


Figure 5. 6: Changing in Axial Force (KN) over time for the Wide Frame

Figure 5.6 above given illustrates the change in axial force of the columns (Column1 and Column 2) (as depicted in figure 5.5). The axial force carried by Column 1 is more than two times Column 2 because Column 1 which is at the bottom carries both ground and first floor loads separated.

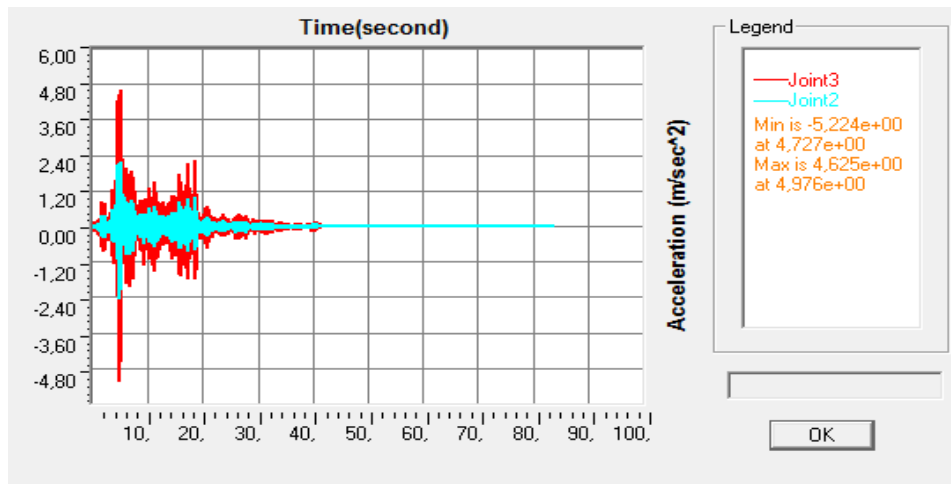


Figure 5. 7: Changing in Acceleration (m/sn²) over time for the Wide Frame

The figure 5.7 e above illustrates the acceleration of joint 2 and 3 (Which is depicted in figure5.3). Both have different Acceleration value. It is obvious that joint2 (which is located at bottom left of the building) has less acceleration than joint 3(at top left of the structure) due to sway angle in the frame

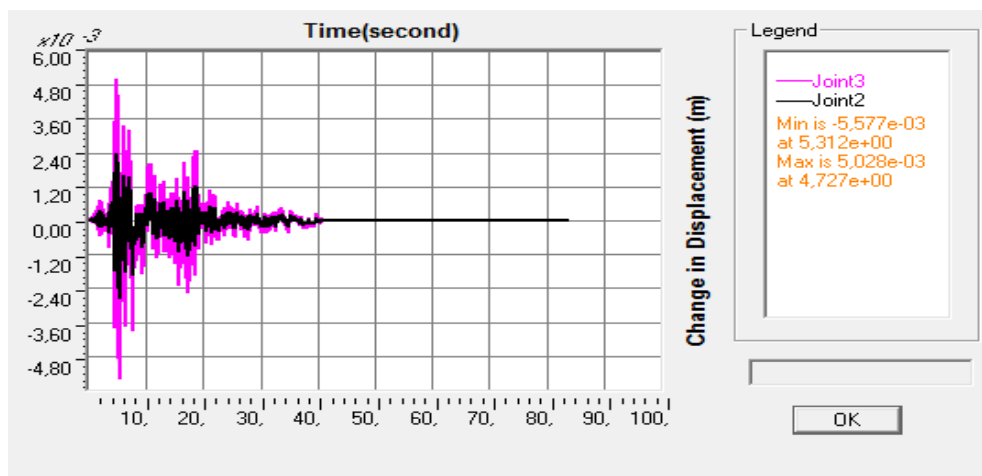


Figure 5. 8: Changing in Displacement (m) over time for the Wide Frame

As can be seen from figure 5.8, the lateral displacement of joint3 (maximum 5.6×10^{-3} m) is greater than the other joint (joint2) (2.7×10^{-3} m) (Which is depicted in figure5.3) because the lateral displacement depends on the high of a building (Eurocode8). The diagrams of displacement and acceleration which is given above illustrate that sudden and irregular changes occur in the wide frame because it is all about the number of waves within 1 second. In other words, the response of building to ground motion is quite short to travel through the building.

5.3.2 Test 2: Tall (High Rise) Moment Resisting Frame without any Short-Column Formation

Test 2 called high rise moment resisting frame was run in SAP2000 and some results given below were obtained from it. This frame has 2 spans (7m) and 8 bays (24m). As it is mentioned in section 4.4.3, during seismic activity, the stability of high rise frame is lower than the wide frame. Also, it has bigger shear forces and moments compared with low rise MRF.

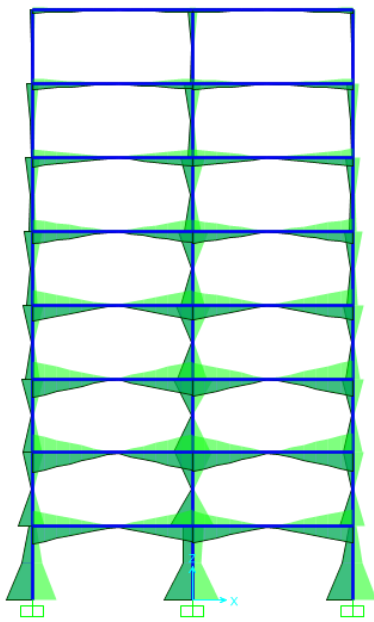


**Figure 5. 9 Envelope Bending
Moment Diagram (BMD)**

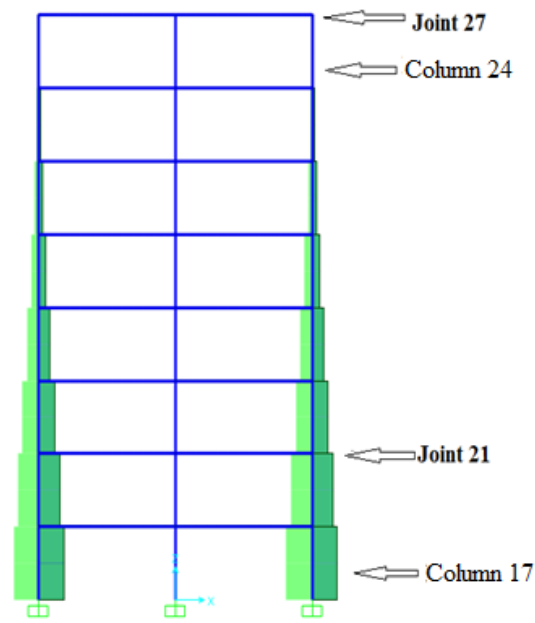


**Figure 5. 10 Axial Force Diagram (AFD)
Envelope for Slender Frame**

By utilizing the equation 5.1, the fundamental period based on Eurocode 8 is calculated to be 0.92 sec. Compared with the period of the regular frame building which was 0.48 sec. Logically it can be said that there is a relationship between the number of stories and the fundamental period of structure (as said before, each story is approximately equal 0.1 sec). To obtain the accurate fundamental period of the frame, it must be analyzed (e.g. for the slender frame, the fundamental period is 0.76 sec according to SAP2000). Logically it can be said that the effect of ground acceleration on high rise MRF will be less than its counterparts.

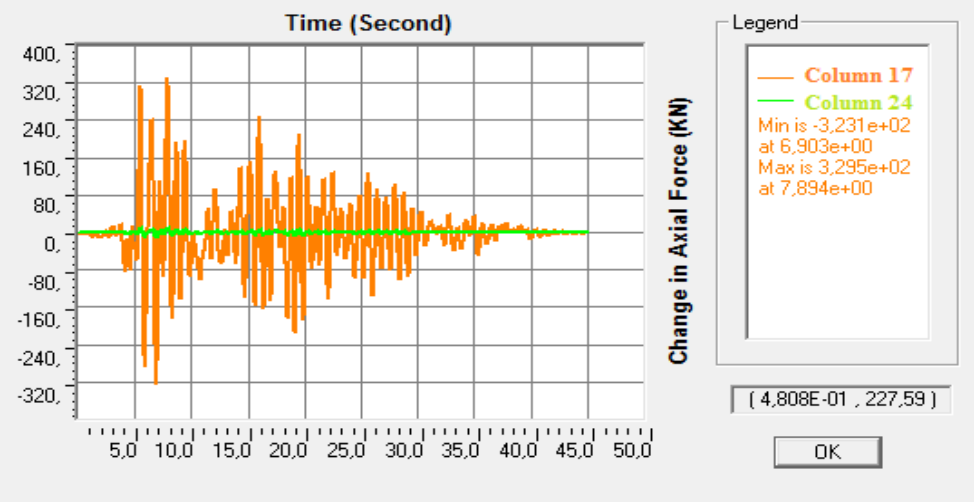


Figure 5. 11: Changing in Axial Force (KN) over time for the Slender Frame

Figure 5.11 above given illustrates the change in axial force of the frames (Column17 and Column 24) (as depicted in figure 5.10). The axial force carried by Column 17 is almost thirty times as much as Column 24 because Column 17 which is at the bottom carries all other 7 story axial loads. It is important to know that the distribution of loads does not change. Always the loads are transferred through the top of the column to the bottom of the column.

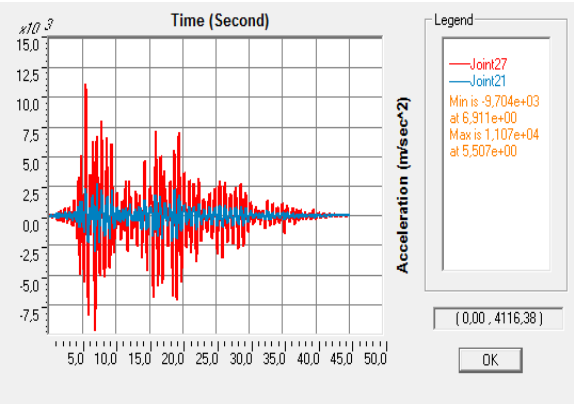


Figure5.12: Changing in Acceleration (m/sec²)

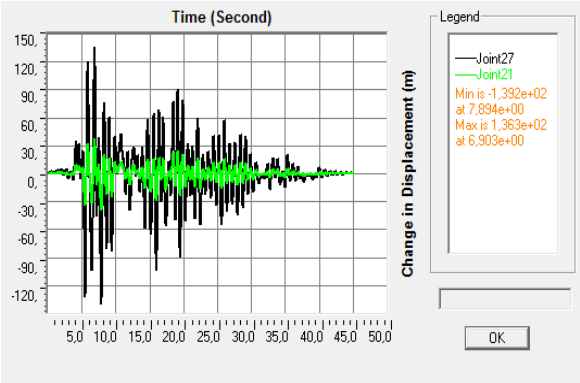


Figure 5.13: Changing in Displacement (m) over time for the Slender Frame

To illustrate Changes in Acceleration and displacement over time for joint 27, the two figures (5.12 and 5.13) given above are obtained from SAP2000. Also, both diagrams can be used to compare slender and high-rise frame in terms of regularity of frames. As can be seen from both figures, slender frame is more predictable than low rise frame and has regular changes in accelerations and displacements because it is all about the response of building to ground motion. In other words, during seismic activity, the period of slender MRF is higher than low rise MRF.

5.4 The effect of short-column formation (incorrect structural application) on behavior under ground motion

This section of this dissertation will examine and answer the question (how short- column formation affects the behavior of RC structure under Seismic Loading Conditions).

5.4.1 Regular MRF (Moment Resisting Frame) without any short-column formation (incorrect structural application)

The rigidity of Regular moment resisting frame is higher than the other two frames (low rise frame and slender frame). Also, the beam and column connection designed in the specified software is rigid which means no rotation and moment transfer at the beam- column joint.

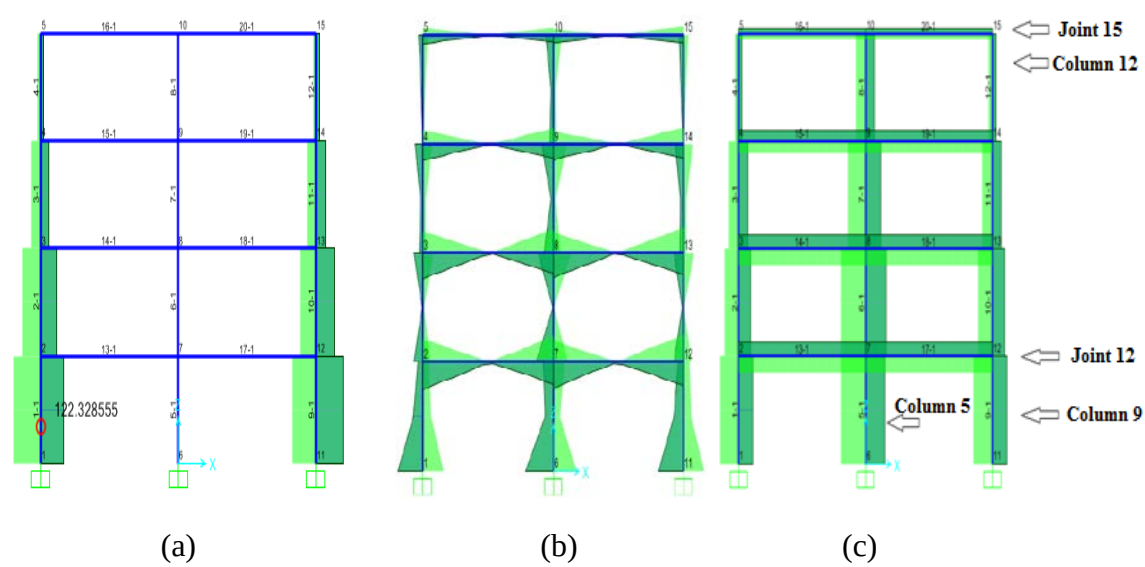


Figure 5. 14 Axial Force Diagram envelope (AFD) (a), Bending Moment Diagram envelope (BMD) (b), Shear Force Diagram envelope (SFD) (c)

By using the equation 5.1 in section 5.2, the fundamental period of vibration based on Eurocode 8 is calculated to be 0.48 sec. As said previous section, logically it can be said that there is a relationship between the number of stories and the fundamental period of the structure. To obtain accurate fundamental period of frame, it must be analyzed in FEA software.

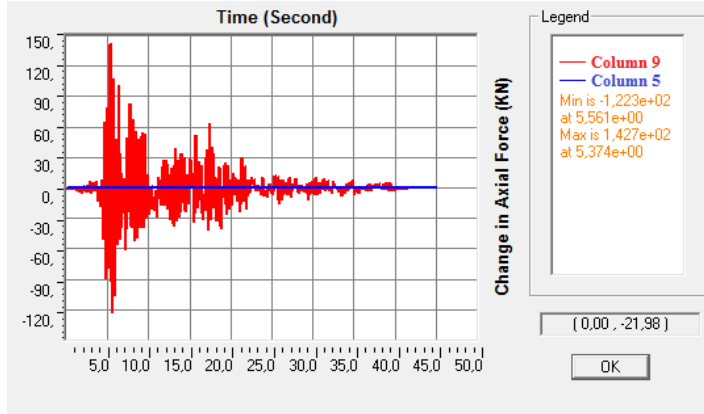
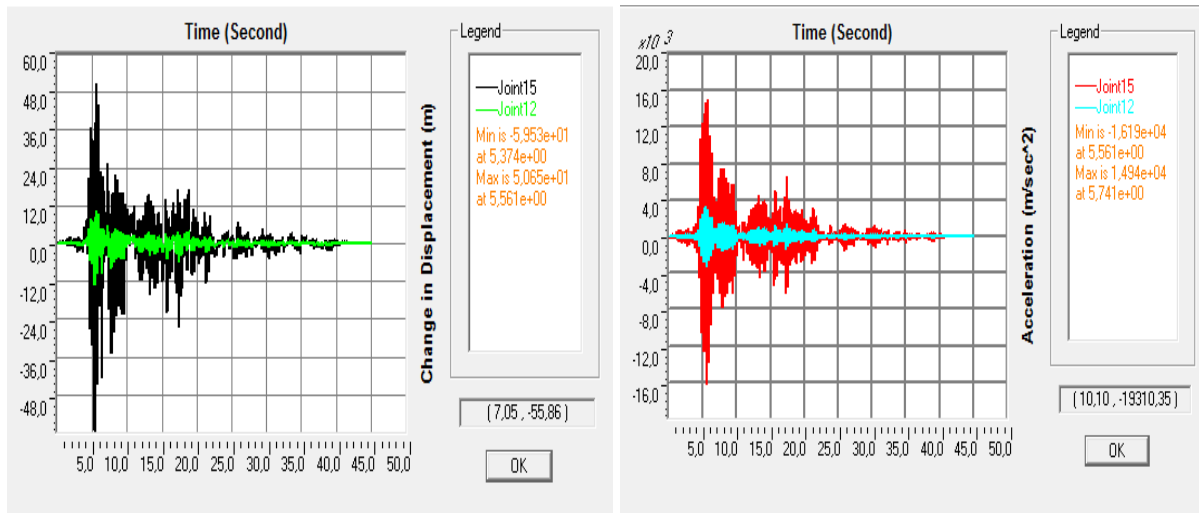


Figure 5. 15: Changing in Axial Force (KN) over time for the Regular Frame without any short-column formation

The graph given above illustrates Column 9 which is right at the bottom and Column 5 which is the middle column of the ground floor. The largest change for Column 9 is at around 5 seconds while in Column 5, the force is equal zero which means no axial force during the seismic activity.



(a)

(b)

Figure 5. 16: Changing in Displacement (m) (a) and in Acceleration (m/sec^2) (b) over time for Regular MRF without any short-column formation

The PGA of the building is around 16.2m/sec^2 at joint 15 at 5.4 seconds. Knowledge based on this study and previous tests illustrates that large accelerations and displacements are inevitable for moment resistant frame. However, there is a design fact which is Ultimate Limit State (ULS) if the building exceeds that value, a plastic deformation will occur and finally the structure will collapse. This type of damage is not wanted to be seen. Therefore, the regulations depending on countries restrict the design of structure against seismic loading conditions (e.g. Moment Resisting Frame (MRF) is designed with more ductile steel). However, a sustainable design cannot always provide by considering MRF as can be seen from the figures (5.16(a) and (b)) given above due to simultaneous maximum acceleration and displacement (at 4.5 seconds).

5.4.2. Incorrect Structural Applications

5.4.2.1 Mezzanine Floor (The First Test)

As it is mentioned in chapter 4 of this dissertation, mezzanine floor opening double-height ceiling floor is a necessary component of a building. However, if the designer does not consider its effects on the behavior of a structure during seismic activity, the consequence will be catastrophic because it creates additional shear forces which are higher than maximum shear force capacity in the column. This is just one of incorrect structural applications causing short-column formation in the building. Its effects will be discussed in this section below

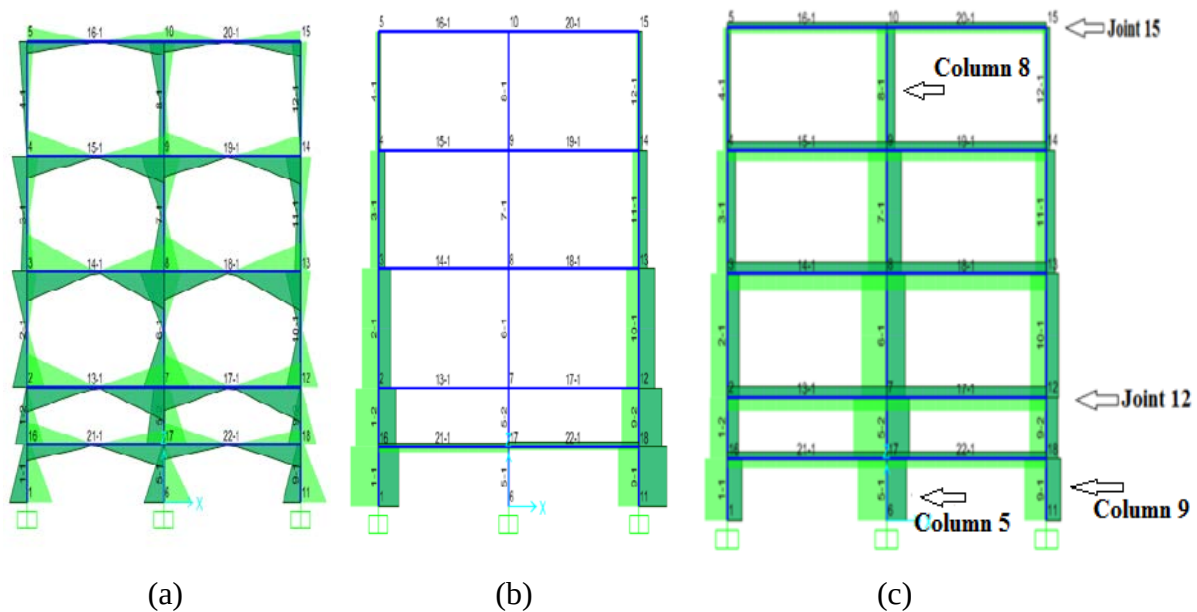


Figure 5. 17: Bending Moment Diagram envelope (BMD) (a), Axial Force Diagram envelope (AFD) (b), Shear Force Diagram envelope (SFD) (c)

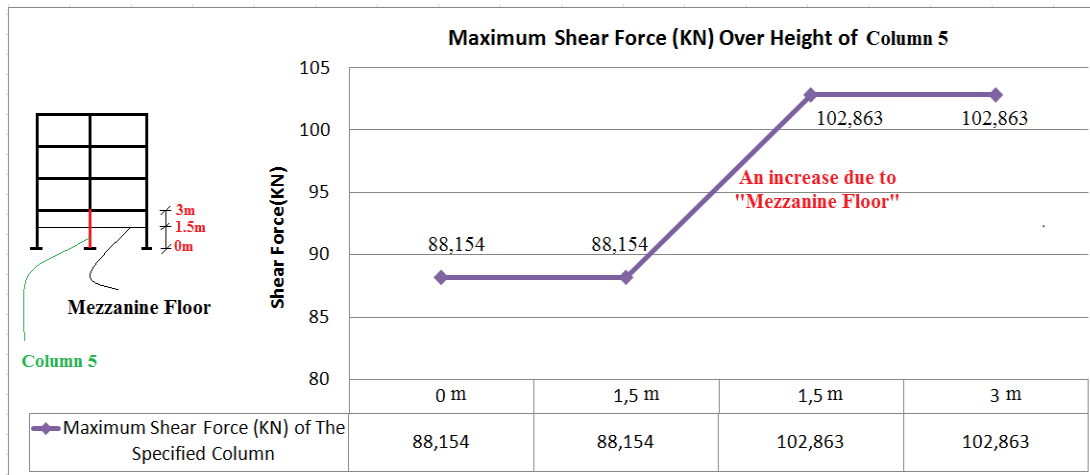
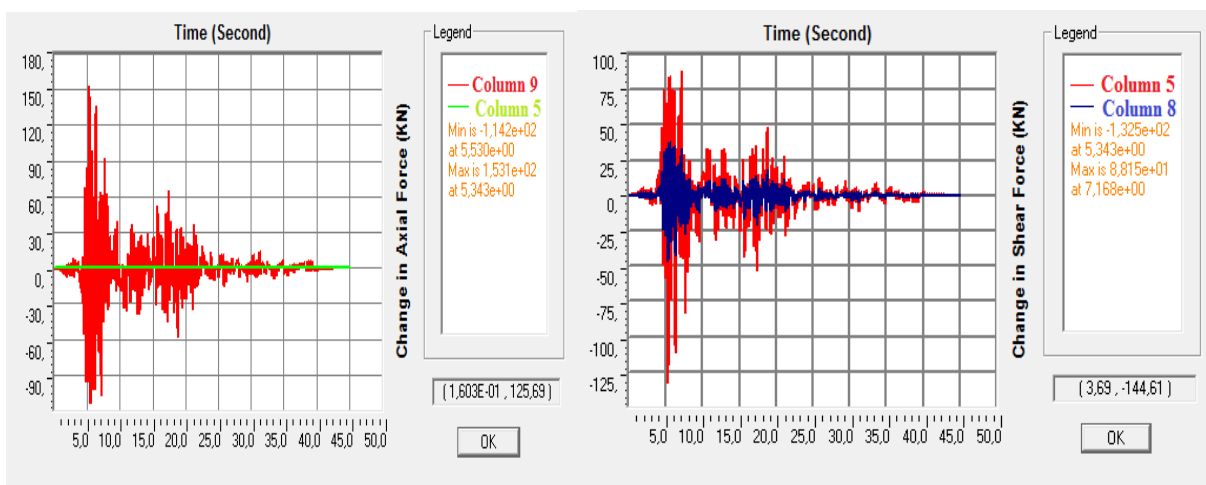


Figure 5. 18: Showing the Maximum Shear Force over the height of Column 5 (Test 4)

The first test was a mezzanine floor usually locating on the ground floor of the structure (According to Dogan (2011)). It was aimed to illustrate short-column formation in the building. The envelope diagrams given above demonstrates the negative and positive shear, axial forces and bending moments imposed on the building during ground motion. It is obvious that bending moments, axial forces and shear forces are taken by beams and columns in the building. The failure mode in shear particularly depends on the lateral reinforcements of the column. Shear failure can occur during seismic activity if transverse reinforcements are not enough. Figure 5.18 shows that the critical height of the column is 1.5m because, in that height, the shear force of column 5 increased about 15% (from 88.154 KN to 102.863 KN) which means additional shear force for column 5. As it is discussed in section 2.5.8.2.3.1.2 of this dissertation, the height of column significantly changes shear force of column (Dogan, 2011).



(a)

(b)

Figure 5. 19 Changing in Axial Force (KN) (a) and Shear Force (KN) (b) over time for the Regular Frame with one type of short-column formations (Mezzanine Floor)

The changes for Column 5 and 9 are different. In the middle column (5) of the ground floor, the axial force is zero but Column 9 has the largest value in the structure. The reason of not having axial force in the middle of the frame is symmetry. It is well known that the loadings increase cumulatively towards ground floor. Due to the mezzanine floor used in this dissertation, the maximum positive shear force of Column 5 is 102.863 KN while the shear force of regular column (without any short-column formation) in the same column is 98.6 KN. This means the shear force of column 5 increased approximately 5% (from 98.6 KN to 102.863 KN) due to mezzanine floor application. Therefore, the effects of the incorrect structural application called mezzanine floor must be considered during the project. As it is mentioned before, this application increases the shear and locally axial forces in the structure. That is why the additional forces must be prevented by taking some precautions (such as reducing the space of transverse reinforcements).

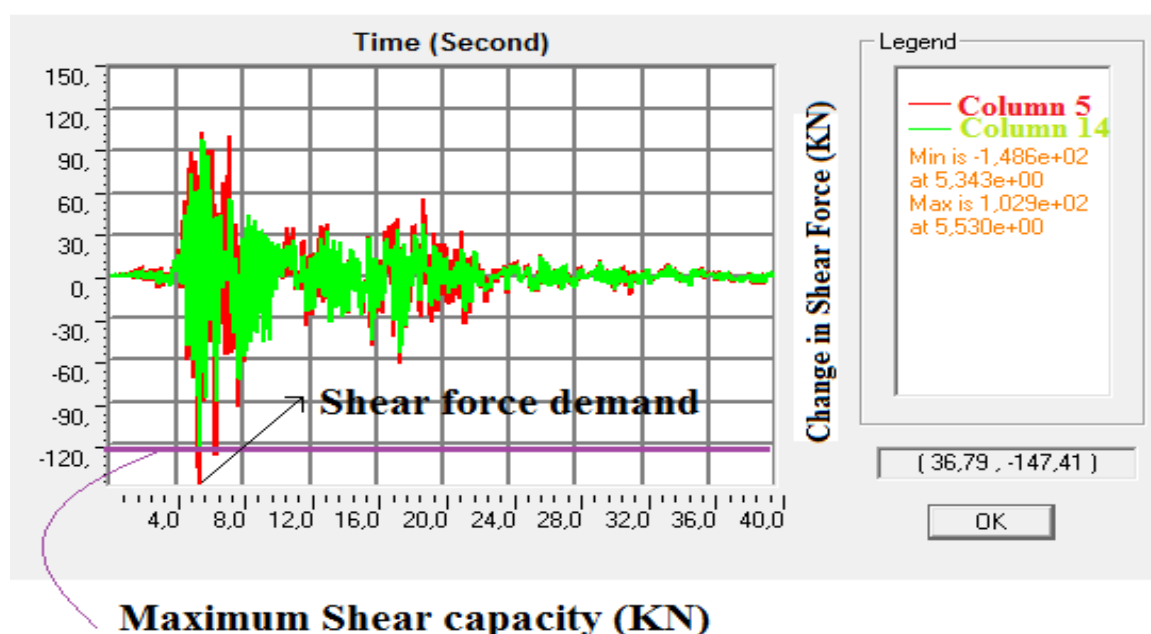


Figure 5. 20: Shear force demand (KN) and shear capacity of Column 5

The figure (5.20) which is given above shows how mezzanine application increased the shear force of the Column (5). As can be seen from the figure, the negative shear force of Column 5 which is demanded (in mezzanine floor application) is about 149 KN. While the maximum shear capacity of Column 14 (Normal column application taken from test 3) is approximately

124 KN. This means that shear force which is demanded from Column 5 is higher than its shear capacity (Column 14). Consequently, this additional shear forces would cause the collapse of the column during ground motion.

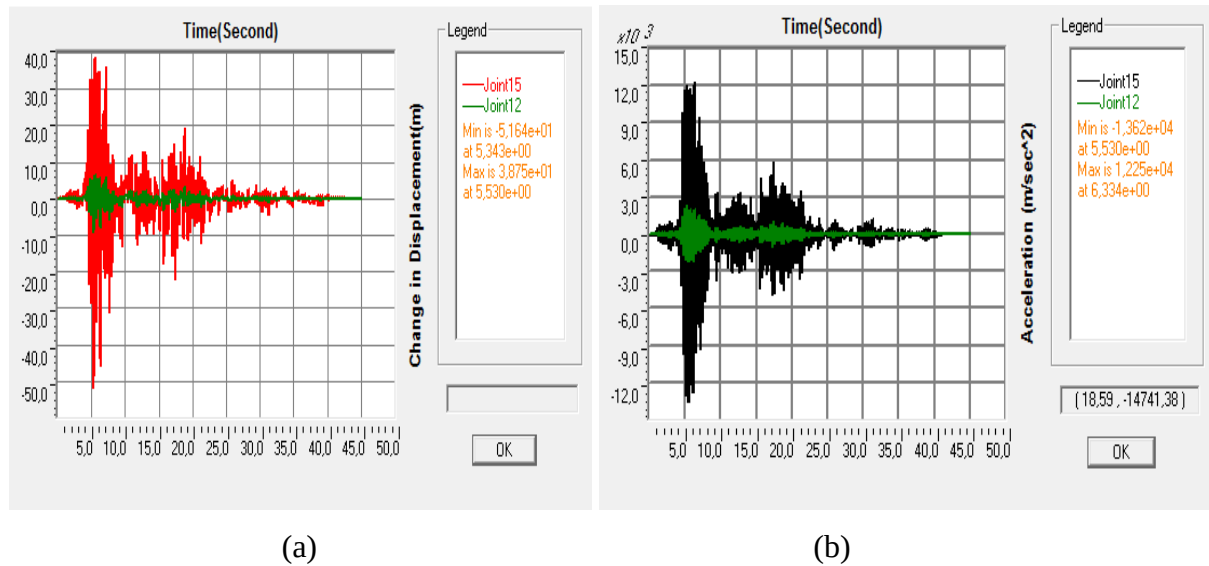


Figure 5. 21: Changing in Displacement (m) (a) and in Acceleration (m/sec²) (b) over time for Regular MRF with one type of short-column formation (Mezzanine Floor)

Figure 5.21 given above demonstrates an obvious correlation between acceleration and displacement in the joints of the frame. During the seismic activity, the acceleration of the floor depends on the distance from the ground. Without losing in proportion to each other, the acceleration and displacement at joint 12 (which is at the bottom right side of the building) are smaller than at joint 15. This resulted from a sway angle on the frame, which is necessary for the building.

5.4.2.2 Application of Shear Wall (The Second Test)

Shear wall is the second type of short-column formation run against 2011 Van earthquake. This incorrect structural application is located on the ground floor (0m to 1.5m). As it is mentioned in the literature review, a shear wall is used to have lateral load resistance in RC structure and is widely designed in the corner or center of a building to resist in-plane loads applied along its height. However, as stated in previous chapters, the aim of this shear wall (small) is to demonstrate the consequences of incorrect structural application (short-column formation). Band window opened is a good example to understand how short-column formation is created in the RC building (the effects of shear wall studied by Dogan (2011) on the behavior of the building is another good example of this study). Normally this structural system increases the

stiffness of a building and reduces acceleration and displacement of a construction (which will be discussed in chapter 6).

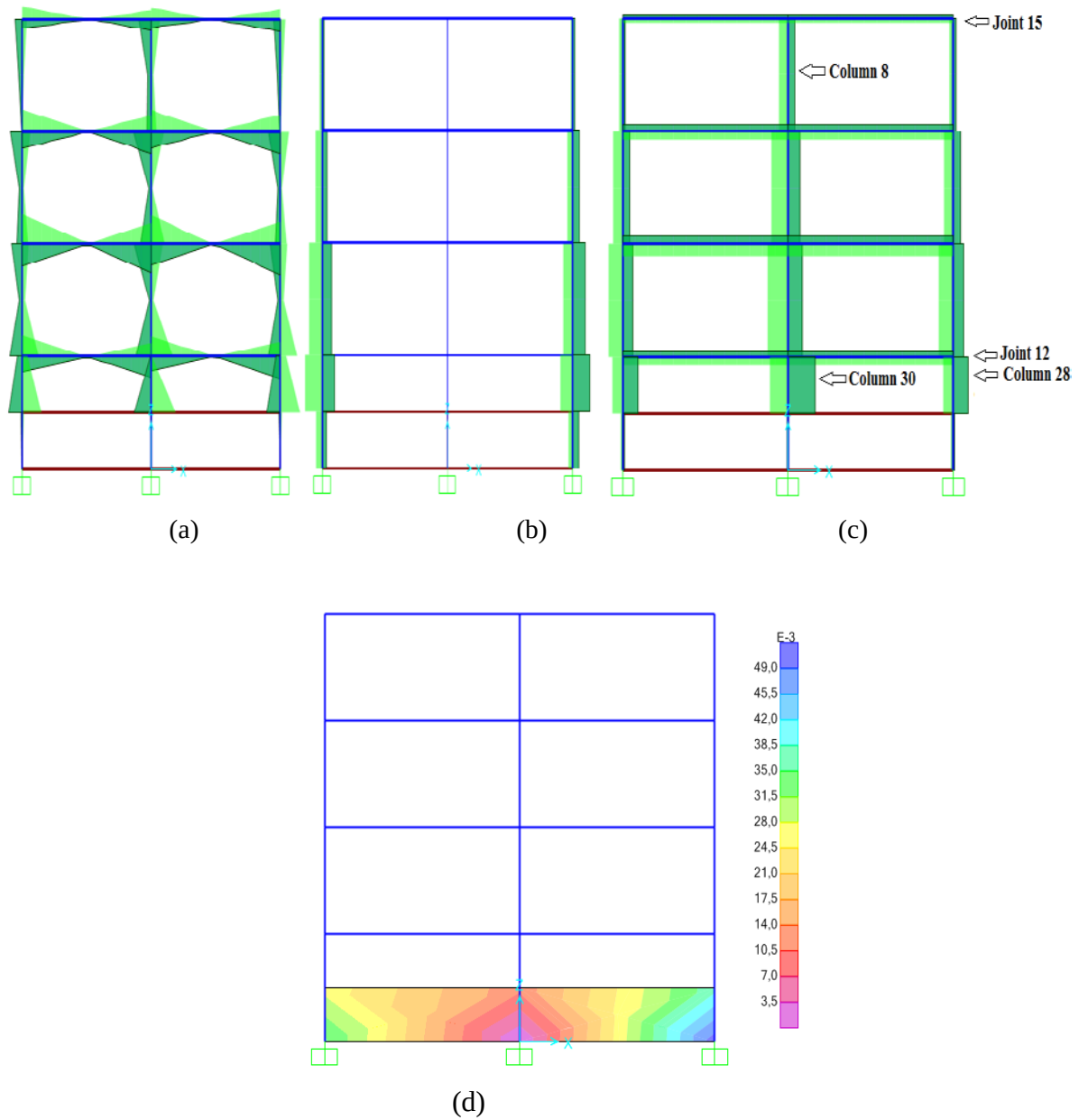


Figure 5. 22: Bending Moment Diagram envelope (BMD) (a), Axial Force Diagram envelope (AFD) (b), Shear Force Diagram envelope (SFD) (c) and The Internal Force of Shell Element (KN)(F22) (d)

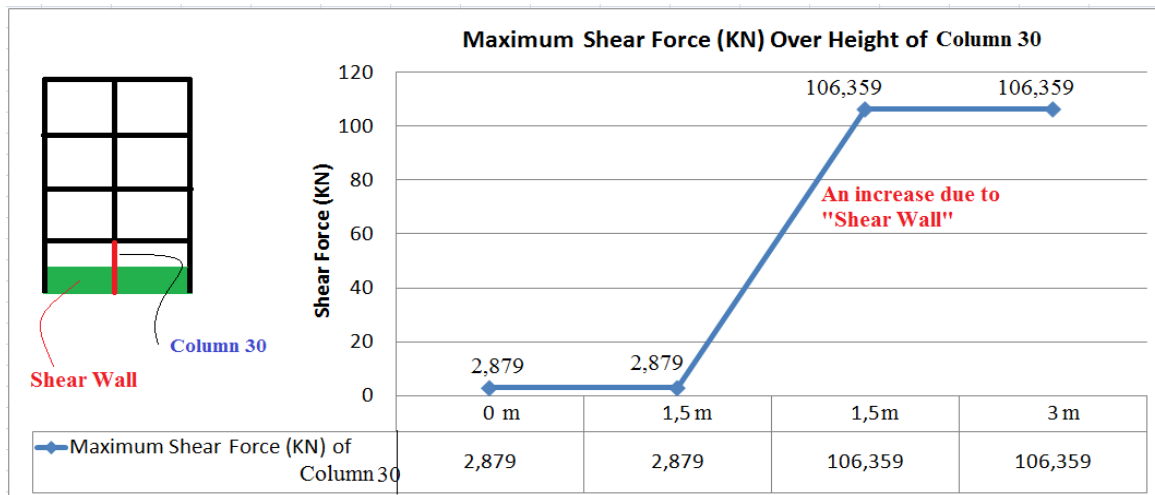
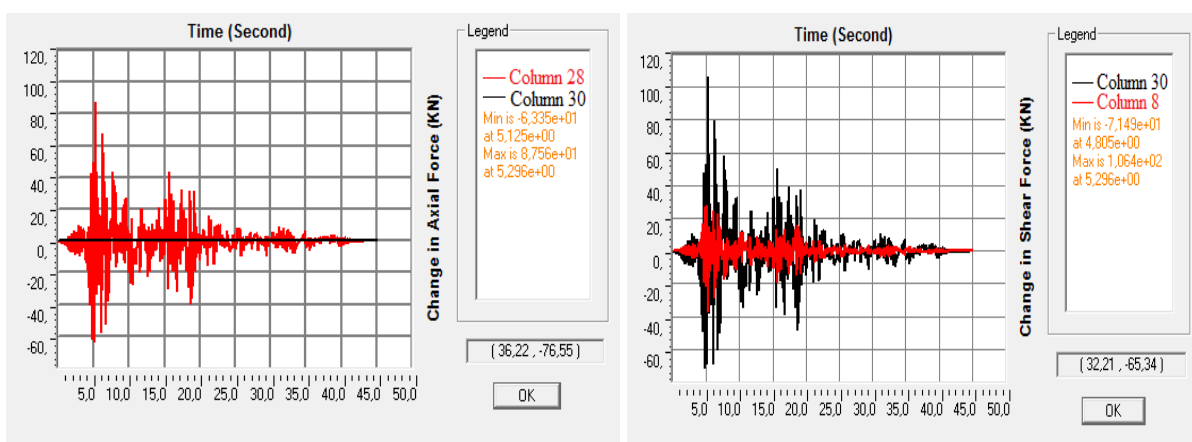


Figure 5. 23 Showing the Maximum Shear Force over the height of Column 30 (Test 5)

The figure given above illustrates that the building demonstrates the similar distribution of axial, shear force and bending moment as the first test. After analysing the Axial Force Diagram (AFD) above, the shear wall reduced the axial force and the bending moment of Column 28 (it is significant to keep in mind that dead and impose loads of all members are ignored in this dissertation to demonstrate the effects of seismic loading condition). This can be interpreted that the axial loads and bending moments were transferred to the shear wall because Figure 5.22d shows shear wall carries shear force (F22) causing stress in the wall. When it comes to analysing SFD, the shear force of Column 30 showed a significant increase (from 2.879 KN to 106.359 KN) because shear wall leads to additional shear force (as it is mentioned in detail in section 2.5.8.2.3.1.2 of this study). In order to prevent any shear failure, space of transverse reinforcements should be reduced (this will be discussed in chapter 6 in detail).



(a)

(b)

Figure 5. 24: Changing in Axial Force (KN) (a) and Shear Force (KN) (b) over time for the Regular Frame with one type of short-column formation (Shear Wall)

Graph (a) given above illustrates that the axial load of Column 30(the middle column of the ground floor) is zero while Column 28 (the bottom right of the structure) has the biggest axial force in the structure. However, the shear force of Column 30 given in the graph (b) is bigger than the shear loads of all other frames. The reason of seeing this kind of result is the shear wall. It causes additional shear forces in the frame (as stated in the previous paragraph).

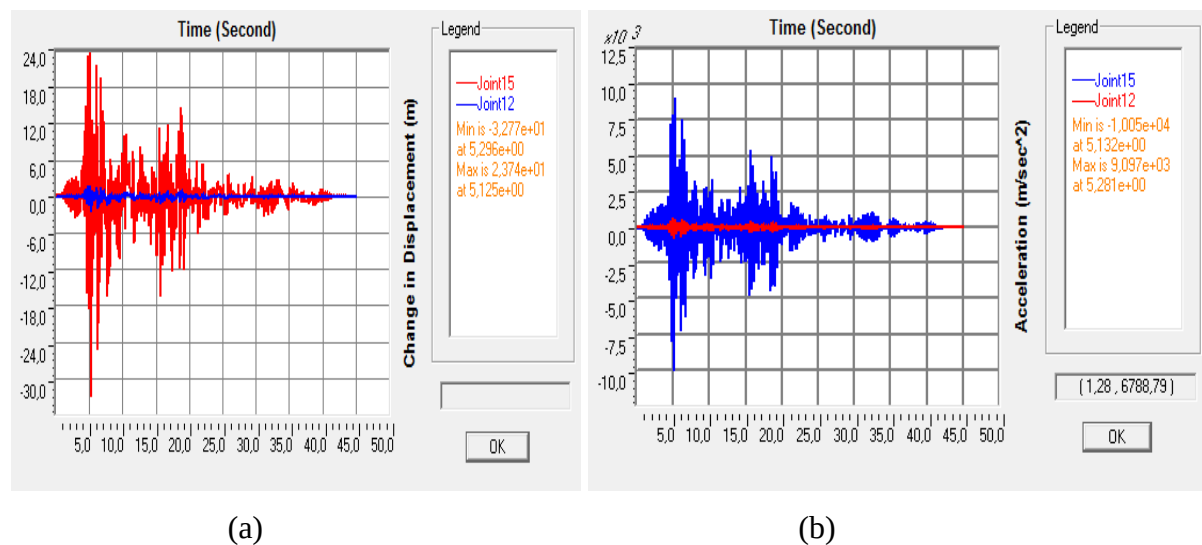


Figure 5. 25: Changing in Displacement (m) (a) and in Acceleration (m/sec²) (b) over time for Regular MRF with one type of short-column formation (Shear Wall)

Figure 5.25 demonstrates an obvious correlation between displacement and acceleration in the joints of the frame. During the seismic activity, the acceleration of the floor depends on the distance from the ground. Without losing in proportion to each other, the displacement and acceleration at joint 12(which is at the bottom right side of the building) are smaller than at joint 15. This resulted from a sway angle on the frame, which is necessary for the building. After taking PGA, both displacement and acceleration fluctuate until losing their whole energy.

CHAPTER 6: FURTHER ANALYSIS AND DISCUSSION OF RESULTS

The previous chapter (5) was aimed to investigate the effect of incorrect structural application and structural form of behavior of RC structures exposed to 2011 Van earthquake, but the aim of this chapter will be detailed analyses and discussions of the tests run in SAP2000. Also, by doing this chapter, the objectives of this study will be fulfilled. **As it is mentioned before, self-weights and impose loads of structural members are ignored (just seismic loading is considered) to evaluate the direct effect of seismic loading condition as well as making the design more understandable for everybody.** In order to ensure whether or not the structure could withstand the life- like loads, static loading was utilized in the pre-test of this study.

6.1 How Dimensional Variation affects the behaviour of RC structure under Seismic Loading Conditions

In order to find the answer (How Dimensional Variation affects the behaviour of RC structure under Seismic Loading Conditions), three different Moment Resisting Frames (MRF) have been tested without any short-column formation. These frames are given below:

1. Low Rise (Wide) Moment Resisting Frame (having 8 spans and 2 bays high)
2. High Rise(Slender) Moment Resisting Frame (having 2 spans and 8 bays high)
3. Regular (Medium) Moment Resisting Frame (having 2 spans and 4 bays high)

In the previous chapter, a few tests relating to above three types of structural form have been run. These results (for each at two different locations) were demonstrated in the envelope diagrams (Shear, Axial force and Bending Moment) as well as graphs of axial force, acceleration and displacement. These results will be discussed further to find out the weaknesses and strengths for each structural form against the specified ground motion (2011 Van earthquake).

The maximum displacement of each floor is quite a good way to compare it with other displacements. Therefore, the table (6.1) and figure 6.1 given below illustrate the displacements of each joint over the Van earthquake duration.

Table 6. 1: Displacements of Three Different Structural Forms on Each Floor Level (from Test1 to test 3)

	Maximum Displacement (mm) on Each Floor Level without any short-column formation								
Floor Level	0	1	2	3	4	5	6	7	8
High rise(slender)	0.00	14.12	38.82	64.33	87.65	107.40	122.75	133.25	139.24
Medium (Regular)	0.00	12.94	33.21	49.71	59.54	-	-	-	-
Low rise(Wide)	0.00	2.70	5.58	-	-	-	-	-	-

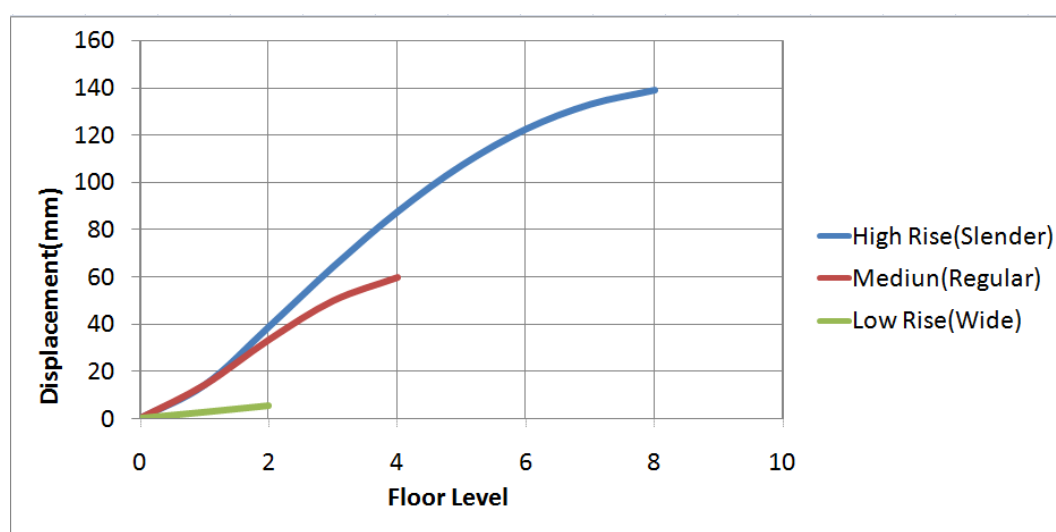


Figure 6. 1: Displacements of three different structural forms on each floor level (from Test1 to test 3)

The Figure (6.1) given above summarizes some information (the maximum displacements, analyzing the sway angles of frames) given the previous paragraph. The figures help the reader of this dissertation to see how big difference there are between each displacement of structural form even on the same story, for the high-rise frame on the 4th floor is 87,65mm which is around 70% of the same level for the Medium Frame. This results from the fundamental period and stiffness of the building. The following explanation relates to these reasons:

$$\text{Fundamental Period of Vibration (Tn)} = C_t \cdot (H)^{3/4}$$

Equation 6. 1: From section 2.4.2

H and **C_t** are defined the height of the building and 0.075 for RC MRF respectively.

$$\text{Stiffness (k)} = AE/L \text{ (As stated in section 6.5.8.2)}$$

Equation 6. 2: Calculation of stiffness

Where **L**= the height of the building and **AE**= Area x the young module of the column or shear wall

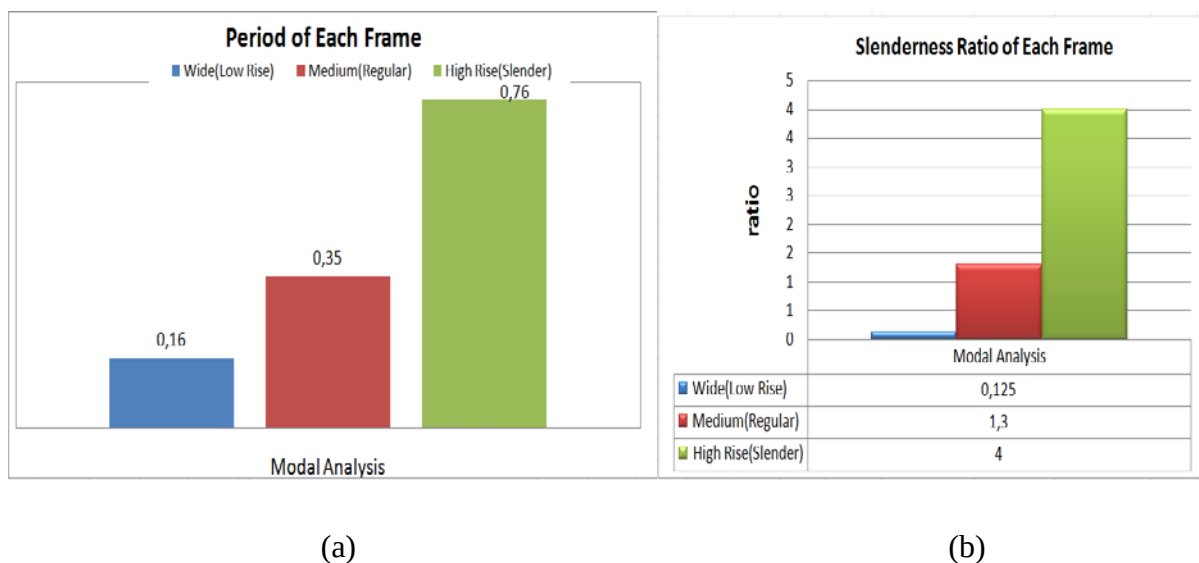


Figure 6. 2: The period of three different structural forms from SAP2000 (from test1 to test 3) (Modal Analysis of Each Frame) (a) and Slenderness Ratio of Each Frame (b)

The figure (6.2 (a)) given above illustrates the period of each structural forms. As can be seen from the figure, it can be interpreted that the period of taller frames is higher than the short frame. Also, the taller frame is not as stiff as the short frame because the period is inversely proportional to stiffness. The displacements over the time graphs given above sections (for low and high-rise frames) can be used to see which period affects the behavior of the building. As stated before, the periods of vibration of three frames vary between 0.2 sec and 0.9 sec due to different height of structures, for example, the vibration period of low rise and high-rise frame is 0.29seconds equal to 3.48Hz and 0.81 seconds equal to1.23Hz respectively (by using the equation 5.1 obtained from Eurocode8) Once the building is exposed to unequal ground

oscillations. Changes in displacement and acceleration given above sections display how each frame behaved over the time.

Also, there is an important fact that should not be forgotten. This is resonance case which can be defined that the ground has a specific resonant frequency which varies the type of soil, for example, softer sediments have fewer frequencies than hard bedrock if the frequency of ground excitation matches the natural resonance of a structure, the largest oscillations causing the greatest displacement will occur on the building. By using this sense of displacement, protecting the building from ground motion must be provided. Therefore, reduction in the height of the building aimed to have a low period can be applied or in the same sense, the stiffness of the building can be increased to have a low period. In addition to both solutions, there are additional two ways which would be expensive.

The first way of reducing the amplification through resonance is the estimation of ground motion and the period of ground motion that would have in the future during seismic activity. Finding the location of the earthquake that would happen (how far away the building is from the earthquake epicenter) and the location of the building that will be designed. The second one is a seismic isolation system mitigating the effects of ground motion by reducing the period of building. This type of protection is generally used in active earthquake regions such as Japan, USA or Italy. As stated before, it is a little expensive. It is well known that the motion of seismic waves happens through the surface. This natural ground motion and the circulation of seismic waves cause an irregular amount of displacements, accelerations and loads which are imposed on the building as well as big amount of thermal stress in Wide (Low Rise) Frame.

The analyses done by programs have always been controversial circumstance due to inaccurate results. As stated before, in this dissertation the program called SAP2000 based on FEA is utilized to analyze the frames designed. However, even this program is not enough accurate for the results because the analyses consist of highly complex processes even the loads (earthquake) applied to the building may not be as simple as it looks like. In other words, a seismic wave normally travels through the building but it sometimes affects one-point end first and the other end of the building later. This could be interpreted that the building is exposed to the higher load than it can resist during the earthquake. It is important to know that the complexity of earthquake cannot be solved by using SAP2000 because just one location in the building is used to record the seismic data. Because of these facts, for further work, instead of using just one location for data in the building, a method allowing many accelerographs to be placed in the building should be found in order to record the forces applied to each of these points. As stated

before, structural symmetry (the location of the mass center and resistance are the same) is crucial to prevent large tensional forces in the building. According to Eurocode8, the frame designed should be as symmetric as possible. However, it is not always feasible due to ground constraints. As stated in section 3.2.3 of this dissertation, symmetry is also one of the characteristics of earthquake resistance of a building. It is important to know that in this dissertation, the designs carried out in SAP2000 were a 2D frame. It means that the word of symmetry is pointless in this dissertation but it is quite important for a structure.

Another crucial factor in the design of a building is the ratio between the height (bays) and the width (spans). The three frames tested in this dissertation were aimed to illustrate the effects of different ratios during specified ground motion (2011 Van Earthquake). The ratio of the low-rise frame, the medium frame and the slender frame (high) were below 1, about 1 and above 1 respectively (as depicted in figure 6.2 (b)). The displacement graphs given above sections and the knowledge about different slenderness ratios for each of these frames help the reader of this dissertation to make a clear comparison between the ratio and displacement of a frame. It can be said that slenderness ratio and the displacement of a frame are directly proportional to each other.

6.2 The effect of short-column formations (incorrect structural application) on behaviour of a building under ground motion

The first study of this dissertation was to investigate the effects of the 3 different slenderness ratios. This is presented in previous sections. However, as stated before, the second one was incorrect structural applications called short-column formation. This section will discuss the results obtained from SAP 2000. The two most common types of short-column formation were tested in this study. First one was the mezzanine floor and the second one was the shear wall.

A Moment Resisting Frame (no rotation and no moment transfer between beam and column) without any short-column formation was also tested to compare the results. The each short-column formation was not perfectly assigned to SAP2000 to make it a more real application (due to the meaning of “incorrect”) for example the meshing of shear wall is limited (just one mesh is used in the whole shear wall). The second application was the mezzanine floor. Therefore, the main column was not divided into two different small columns in order to see how this incorrect structural application affected the values (shear force, bending moment or axial forces).

As it is mentioned before, each type of short-column formation affected differently the behaviour of the structure imposed on 2011 Van earthquake. The results of their responses consist of maximum axial, shear forces and bending moment for the columns and the maximum displacement for the specified joints.

6.2.1 Displacement

Inter story drift occurred in the building and the amount of displacement can be enough to measure the stiffness of the building. After analysing the specified joint in every frame, it can be said that the joint which is the furthest from the ground of the building had the maximum displacement. This explanation is depicted in the following table (6.2). It is well known that the structural behaviour against a ground motion depends on the type of short-column formation designed, the stiffness of the building and the average vibration frequency. This is the answer to why the maximum displacement did not happen at the same time, even the same ground motion (2011 Van Earthquake) imposed on the building.

Table 6. 2: Showing lateral displacement of structural application and the time required for maximum displacement at each floor level (Test 3, 5 and 5)

		Storey level					Time
	applications	0	1	2	3	4	When the maximum displacement occurred (second)
Displacement (mm)	MRF without any short-column formation	0.00	12.94	33.21	49.71	59.54	5.37
	Applying shear wall	0.00	2.43	14.34	25.69	32.77	5.29
	Applying mezzanine floor	0.00	9.00	26.94	42.35	51.64	5.34

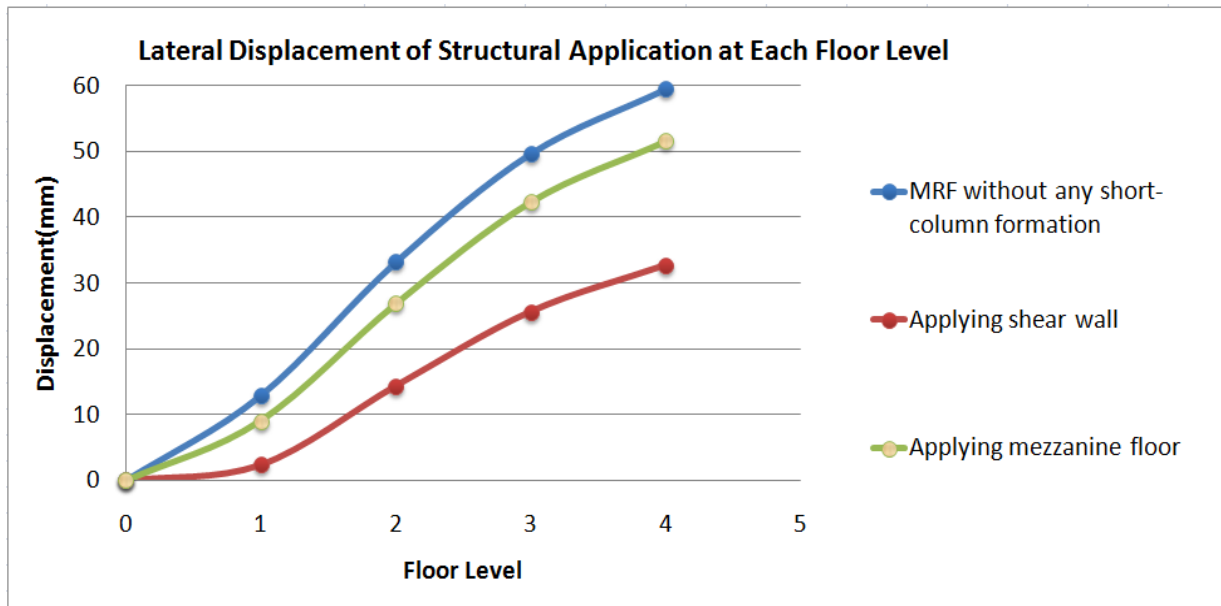


Figure 6. 3: Showing lateral displacement (mm) of structural application and the time required for maximum displacement at each floor level (Test 3, 4 and 5)

After analyzing the graph given above, one can say that the maximum displacement occurred in the fourth story of the building having no short-column formation (the blue one in the above figure) was 59.54mm which was about 1.4 times larger than the average maximum displacement (42.21mm-4th floor) occurred in both incorrect structural applications. The ground motion energy in the Moment Resisting Frame (MRF) is normally absorbed by plastic hinges in the frame.

As stated before, in order to prevent sudden collapse, ductile structures had better be designed. Large sways are also a quite high possibility during an earthquake. Therefore, it should be considered in the design. Otherwise, these large sways will cause large deformations causing inter storey drift in MRF and second order effect (ignored in this dissertation).

Another case causing a large displacement (apart from an earthquake) in the building is the wind and imposed loads. Both loads lead to additional forces in the structure. Therefore, a smart choice must be done for the frame, especially once serviceability limit states (SLS) are main issues. As can be seen from the figure (6.3) given above illustrates that frame with one of the short-column formations has less displacement than the frame which does not have any short-column formation in the building because the beam or the shear wall assigned increased lateral stability of the structure. However, the main aim of this dissertation is not to show how these incorrect structural applications increased the lateral resistance of the building. Therefore, the

time spent on this case will be a little. As stated before, the fundamental aim of this work piece is to examine the negative effects of short-column formation on behaviour of the structure during 2011 Van earthquake.

6.2.2 Axial Force in the Column with and without Short-Column Formation (Test3, 4 and 5)

Once a ground motion (such as earthquake) imposes to a building, it will create internal forces in the structural members. In order to withstand these loads created, the structure must have lateral and axial resistances (such as column and shear wall) and should be able to transfer these loads to the foundation. During seismic activity column, shear wall and beam will take bending moments, shear and axial forces varying over time period of earthquake depending on the frequency of motion. Big recorded ground motion means large PGA (Peak Ground Acceleration) causing more forces on the structural members. The following table and figure illustrate maximum axial forces of the specified column (as depicted in figure 6.4) in the structure.

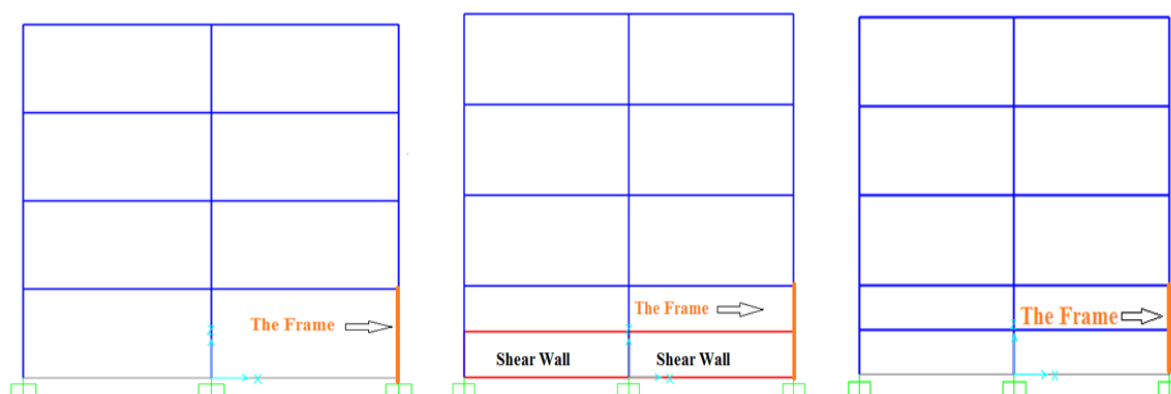


Figure 6. 4: Showing the Specified Column for Comparison of Maximum Axial Forces (Test3, 4 and 5)

Table 6. 3: Maximum Axial Force (KN) in the specified Column with and without Short-Column Formation (Test3, 4 and 5)

applications	Maximum Axial Forces(KN) on the ground floor (The Column on the Right Corner)	When the maximum axial force occurred(second)
MRF without any short- column formation	142.7	5.35
Applying shear wall	87.55	5.30
Applying mezzanine floor	153.14	5.34

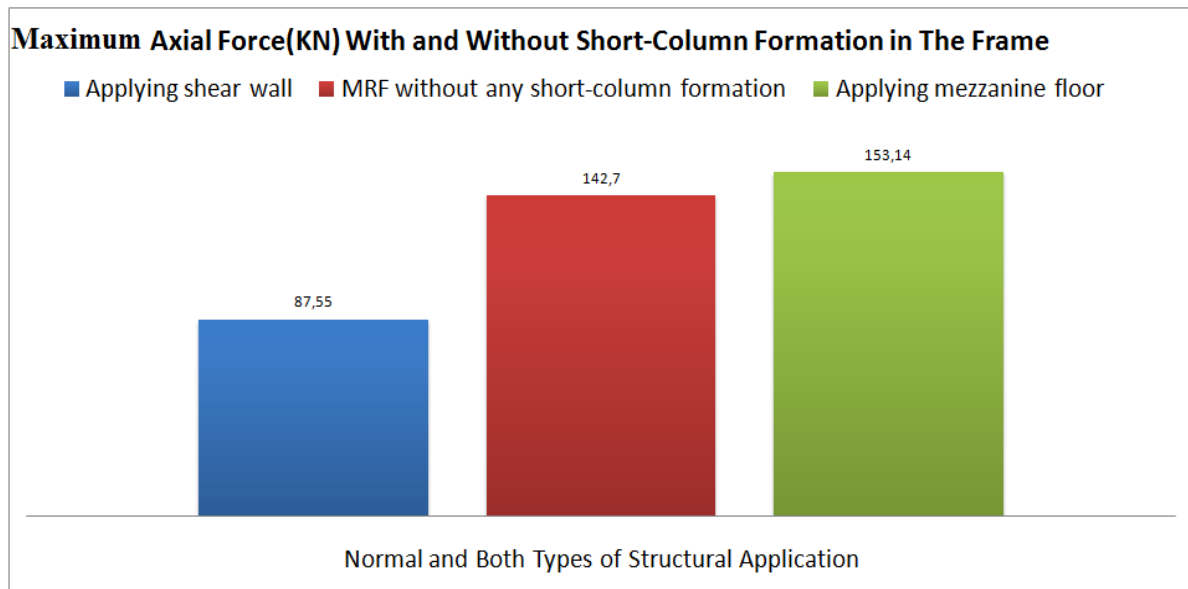


Figure 6. 5: Maximum Axial Force (KN) in the specified Column with and without Short-Column Formation (Test3, 4 and 5)

As can be seen from the figure (6.5) given above, the difference between ‘the mezzanine floor application’ and ‘normal column application’ (without any short-column formation) is approximately 7%. While this difference is about 63% between ‘shear wall application’ and ‘normal column application’. This difference is more likely to increase once additional dead and imposed loads are added to the column.

The figure given above illustrated that ‘the mezzanine floor application’ had the maximum axial force (153.14KN) while ‘Shear Wall Application’ had the least axial force (87.55KN) in three different structural designs. These results also showed that ‘Mezzanine Floor Application’ caused the more axial force on the Specified column (in figure 6.4) compared with ‘application

of shear wall' on the same location. It can be said by looking at the figures (6.4 and 6.5) that the reason of less axial force on the column (due to 'Shear Wall Application') is the shear wall because the axial forces were transferred into stress in the shear wall (as depicted in figure 6.4). In other words, the height of the column is reduced to half and this half column reduced axial forces of the column. Structurally, high amount of axial load will require large cross sections and this large cross section will cause more axial loads and high-stress level on the column and would lead to compression failure on the structure.

6.2.3 Shear Force in the Column with and without Short-Column Formation (Test3, 4 and 5)

Once a ground motion (such as an earthquake) imposes to a building, it will create internal forces in the structural members. In order to withstand these loads created, the structure must have lateral and axial resistances (such as column and shear wall) and should be able to transfer these loads to the foundation. During seismic activity column, shear wall and beam will take bending moments, shear and axial forces varying over the time period of earthquake depending on the frequency of motion. Big recorded ground motion means large PGA (Peak Ground Acceleration) causing more forces on the structural members. The following table and figure illustrate maximum shear forces of the specified column (as depicted in figure 6.6) in the structure.

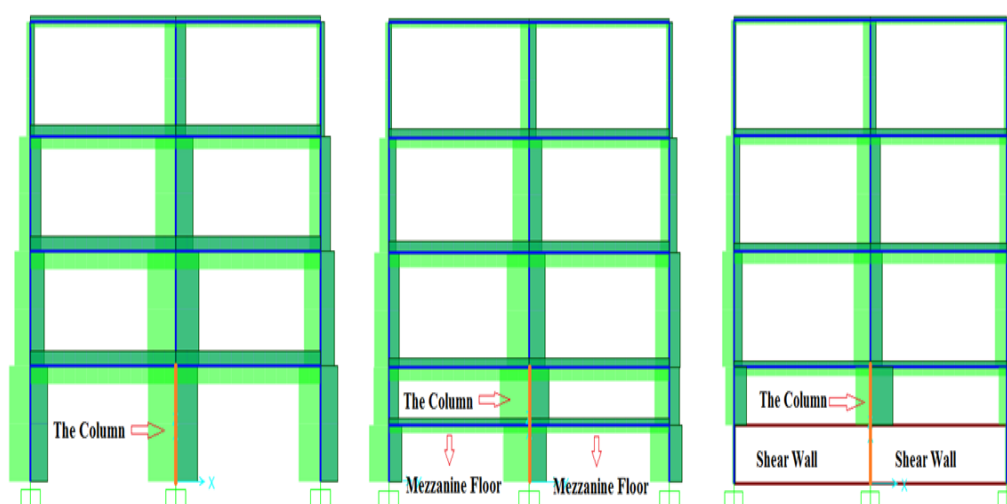


Figure 6. 6: Showing the Specified Column for Maximum Shear Forces (Test3, 4 and 5)

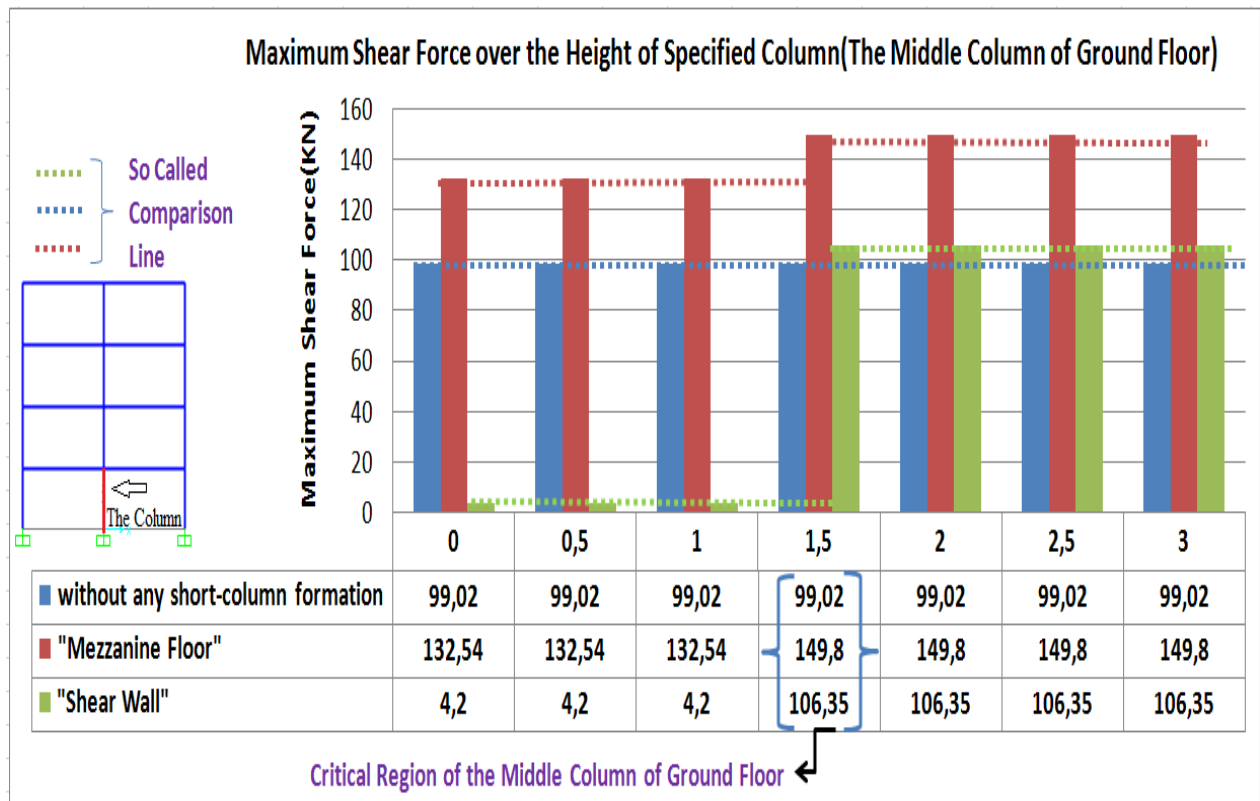


Figure 6. 7: Maximum Shear Force (KN) over the Height of the Middle Column of Ground Floor with and without Short-Column Formation (Test3, 4 and 5)

Each blue chart shows the maximum shear force on middle column of the ground floor (without any short-column formation) while the other two charts (grey and green) illustrate each type of incorrect structural application. As can be seen from the figure given above, three lines, check mark (✓) and cross mark (X) were drawn in order to make the figure understandable.

The check marks (✓) demonstrate that incorrect structural application reduced the shear force on the middle column of ground floor while the last four charts (1.5, 2.0, 2.5 and 3m) show that there is an increase in shear force of middle column of ground floor due to “The Mezzanine Floor” and Shear Wall “.

In addition to all those explanations in the figure which is given above, the critical region where the height of the column of the ground floor is 1.5m was emphasized the location of maximum shear force exposed by 2011 Van Earthquake.

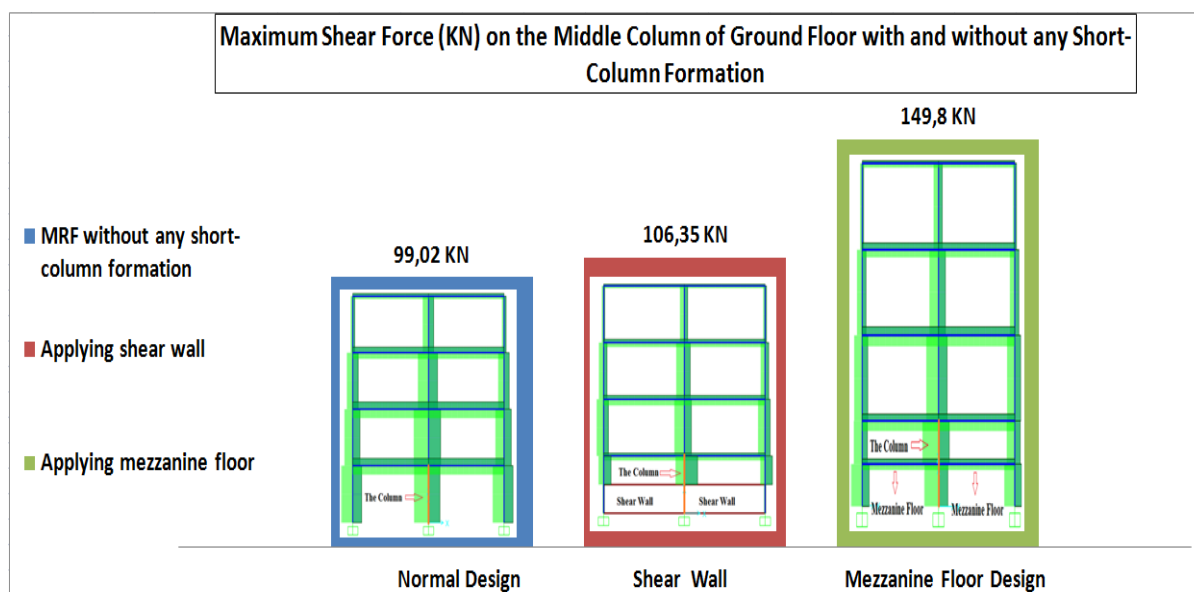


Figure 6. 8: Maximum Shear Force (KN) on the Middle Column of Ground Floor with and without Short-Column Formation (Test3, 4 and 5)

This is the second important comparison of the middle column of the ground floor. This figure was given addition to Figure 6.7. As can be seen from the figure (6.8) given above, **the difference between ‘Mezzanine Floor Application’ and ‘normal column application’ (without any short-column formation) is approximately 5% While this difference is about 7.5% between ‘shear wall application’ and ‘normal column application’.** This difference is more likely to increase once additional dead and imposed loads are added to the column.

The figure given above illustrated that ‘Mezzanine Floor Application’ had the maximum shear force (149.8KN). While ‘Shear Wall Application’ had 106.35KN shear force in three different structural designs. These results also showed that **‘Shear Wall Application’ caused more shear force on the Specified column (in figure 6.7) compared with ‘Mezzanine Floor Application’ on the same location. The reason of having higher shear force on the specified column (on ‘Shear Wall Application’) is shear wall compared with both the other two because the shear wall reduced the lateral movement of the column.** In other words, it can be said that the height of the column is reduced to half and this half column increased shear forces of the column (as discussed in detail in section 2.5.8.2.3.1.2 of this dissertation). Structurally, high amount of shear force will reduce lateral resistance of the column against the ground motion. Logically, additional transverse reinforcement will be a solution in order to prevent any catastrophic consequences.

For further work, the whole columns (from top to bottom) of ground floor should be considered as a critical region (as shown in figure3.6) in order to reduce the risk of shear failure in case of any incorrect structural application (as discussed before) (the number of lateral reinforcements will be higher than the number of rebars required). As a solution of this problem, considering critical region of column is also claimed by Dogan (2011).

6.2.4 Moment in the Column with and without Short-Column Formation (Test3, 4 and 5)

Once a ground motion (such as an earthquake) imposes to a building, it will create internal forces in the structural members. In order to withstand these loads created, the structure must have lateral and axial resistances (such as column and shear wall) and should be able to transfer these loads to the foundation. During seismic activity column, shear wall and beam will take bending moments, shear and axial forces varying over the time period of earthquake depending on the frequency of motion. Big recorded ground motion means large PGA (Peak Ground Acceleration) causing more forces on the structural members. The following figure6.9 illustrates maximum moment over the height of the specified column (the middle column of the ground floor) in the structure. Also, each **blue chart** shows the maximum moment of the middle column of the ground floor (without any short-column formation) while the other two charts(**red and green**) illustrate each type of incorrect structural application. As can be seen from the figure given above, a **line**, **check mark (✓)** and **cross mark(X)** were drawn in order to make the figure understandable.

The check marks (✓) demonstrated that incorrect structural application reduced the moment carried by the middle column of ground floor while the last two charts(2.5 and 3m) show that there is an increase in moment of the middle column of the ground floor due to “The Mezzanine Floor “. Also, these moment reduced by the short-column application is supporting the idea claimed by Dogan (2011) (which is discussed in Chapter 2 of this study).

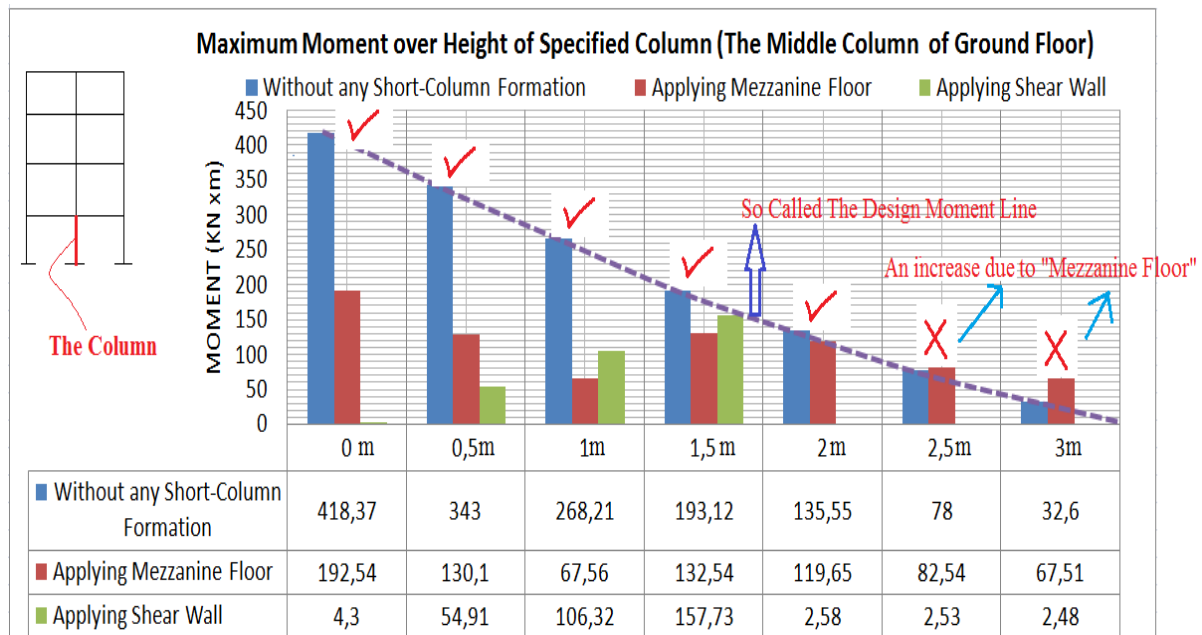


Figure 6. 9: Showing Maximum Moment (KN x m) over Height of Specified Column (The Middle Column of Ground Floor)

6.3 Sample Calculation for shear stiffness of column against lateral loads

It is well known that the rigidity of beams is accepted as infinite in a structure. This is because it is to make the analysis easier. The following figure will give the rigidity of beam and column (Dogan, 2011).

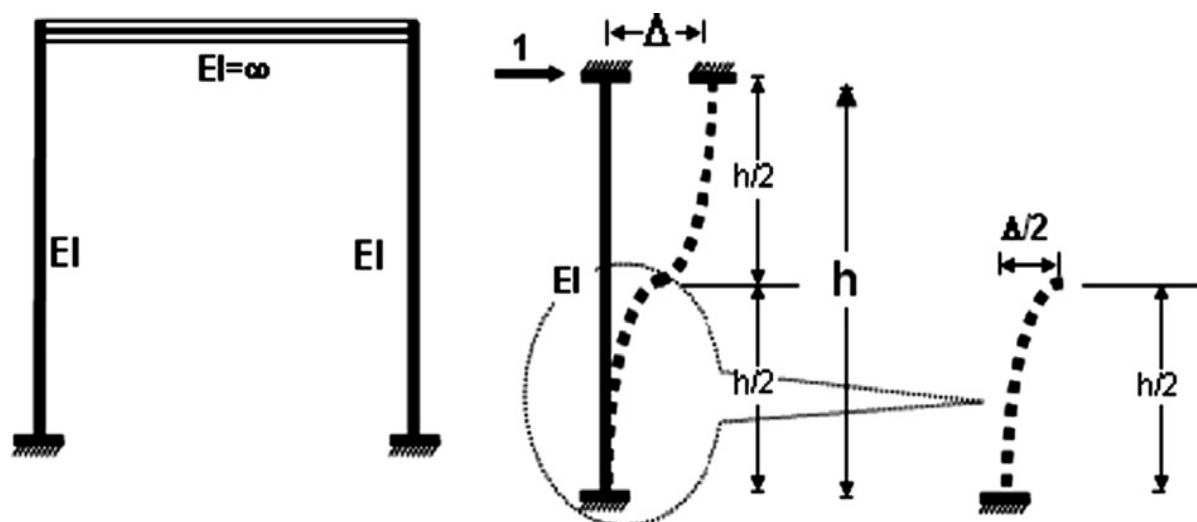


Figure 6. 10: Shear stiffness of a column (Dogan, 2011)

Shear force of column:

$$\frac{\Delta}{2} = \frac{1}{3EI} \left[\frac{h}{2} \right]^3 \Rightarrow \Delta = \frac{h^3}{12EI} \quad V = \frac{1}{\Delta} = \frac{12EI}{h^3} \quad \text{For Regular Column}$$

(Equation 6. 3: Shear Force of Regular Column)

$$\frac{\Delta^*}{2} = \frac{1}{3EI} \left[\frac{h}{3} \right]^3 \Rightarrow \Delta = \frac{h^3}{96EI} \quad V = \frac{1}{\Delta} = \frac{96EI}{h^3} \quad \text{For Short Column}$$

(Equation 6. 4: Shear Force of Short Column)

As can be from the equations, when the length of column (h) decreases, the shear force (V) increases. In other words, once the length of column halves, the shear force of the column increased by 8 times. As discussed before, this mathematical explanation shows how short column increases the shear force of a column. The following study done by Dogan (2011) obviously illustrates changing in shear force depending on the length of short column. The study which has been done in this dissertation is just aimed to illustrate when the length of short column is half of the whole column (h/2).

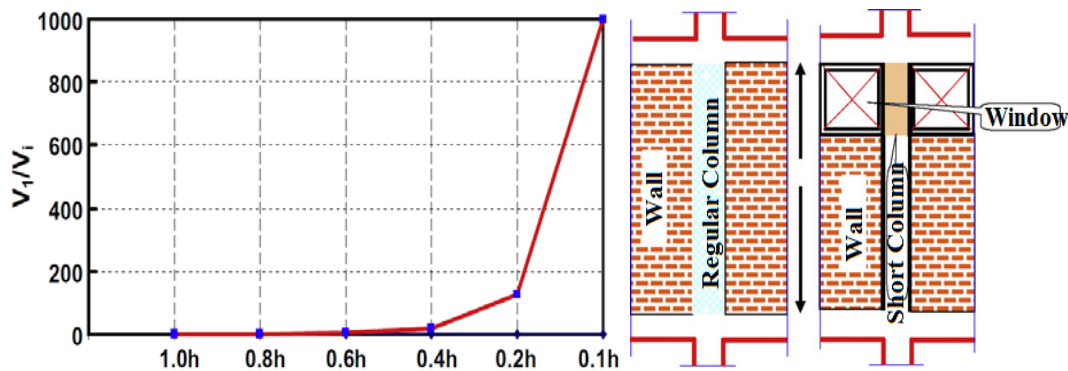


Figure 6. 11: Shear force ratio (Dogan, 2011)

The figure (6.11) illustrates the ratio of the length of the column to window gap. When this ratio is 0.1h, the proportion of shear force of regular column to shear force of short column is about 1000 ($1/(0.1)^3$). This figure is aimed to show how the specified ratio increased shear force on the column as well as illustrating how a gap between column and wall changes the shear force of the column.

CHAPTER 7: CONCLUSIONS AND FURTHER WORK

The fundamental aim of this study was to examine and compare the effects of the most common incorrect structural applications (Mezzanine Floor and Shear Wall) exposed to 2011 Van Earthquake as well as evaluating the effect of three different structural form on its behavior. However, both a huge number of different design choices and the vast number of earthquake resistance systems (such as seismic isolation systems) in buildings available, engineers always face the issues associated with the seismic design of the building and incorrect structural applications. Thus, this study (dissertation) was dedicated to demonstrating the effects of the most common incorrect structural applications (Mezzanine Floor and Shear Wall) (**Test4 and 5**) and comparing them with the normal design not causing any short-column formation in the building (**Test3**). Although many studies are being done to demonstrate and analyze their effects on the structural behavior, FEA software called SAP2000 was successfully used in these investigations.

It is sincerely hoped that the tests and results from this dissertation will be utilized by designers and academics as a study of assistance along with BS EN 1998-1:2004 and other regulations concerning significantly the effects of incorrect structural applications over an RC building exposed to ground motion.

7.1 Effects of Different Structural Forms

It is well known that the global stiffness and the period of the building can change the lateral displacement and acceleration of each floor level. To support that general knowledge, section 5.3, the figures (6.2 (a) (b) and 6.1) and the table 6.1 of this dissertation consists of quite useful information. As it is mentioned in chapter 6, slenderness ratio (calculated by height to width of the building) can deeply change the stability of the building. This theoretical knowledge was proved by comparison of the results of SAP2000 for Medium (Regular), Low rise and RC high rise building, for example, the low-rise frame has the high global stiffness (stability), approximately 7 times lower period of vibration, lower lateral displacement and sway than the high rise frame. Large lateral displacement and lower stiffness are not beneficial for the building and can lead to the structure to fail. The test results of the medium frame (regular) illustrate that it has about two times lower period of vibration, lateral displacement and sway than high rise frame, once subject to 2011 Van earthquake. Changing slenderness ratio (closer to one) of the building can be a solution of failure in the slender frame. However, some factors (such as the purpose of the building, budget of the structure and the area of land available) would restrict its

application. Thus, the other solutions which are high technology are required to solve that failure such as using seismic isolation system, changing the amount of damping and the mass of the building.

7.2 The effect of short-column formation

The graphs which are given in section 5.4.2 of this dissertation (by the buildings' acceleration, lateral displacement of the top story, shear and axial forces of the ground floor) illustrated that the incorrect structural applications (mezzanine floor and shear wall) used to change the behavior of the building once expose to 2011 Van Earthquake.

As can be seen from the results of tests, Moment Resisting Frame (MRF) without any short-column formation has higher displacement (about 30%) than the average of the other two incorrect structural applications because both “Mezzanine Floor” and “Shear Wall” increased the global lateral stiffness of the structure. This study was aimed to examine the effects of each incorrect structural application over the behavior of the building. **As stated before, the governing factor in the comparison of this dissertation is shear, axial forces and moment of the ground floor column. As a reminder, those comparisons were done to support previous studies associated with the reasons of demolition on the building having short-column formation** (as discussed in section 2.5.8.2.3.1.2).

When it comes to comparison of both incorrect structural applications (test4 and 5) and the same size building not having any short-column formation(test3), “Shear Wall” application caused more shear force (106.36KN) than “Mezzanine Floor” application (102.86KN) on the middle column of ground floor while the normal building had just 99.02KN in the same column. As a result of tests carried out in this dissertation, one can say that each type of sort-column formation badly affects the seismic performance of the building. Therefore, designers should avoid all type of incorrect structural applications (as shown in 2.5.8.2.3.1.2).

7.3 Further Work

Especially in last 2 decades, negative effects of earthquake increased significantly due to different structural design (unusual designs) and incorrect structural applications. Therefore, many studies have been done in order to find out the answers (such as when does failure occur? what can be done to mitigate devastating effects of an earthquake? or how the performance of the structure against earthquake can be improved?). The regulations which are being utilized by many countries are based on all these studies done. New earthquake resistant systems,

designs and accurate solutions have been searched by engineers since the occurrence of the earthquake. Some of the futuristic ideas will be discussed in this section.

One of them could be software which can give more accurate result than SAP2000 and Abaqus. It is well known that one of the disadvantages of SAP2000 is that modelling the response of the quite high structure is not possible for example pretty wide structure or bridges, exposed to ground motion with finite speed. Because during a seismic wave, pretty wide frame (low rise) will undergo an irregular amount of displacements, acceleration and imposed forces through the building due to affecting one end first and the other end of the building later. Consequently, the building would experience much higher loadings than it can resist. These loads causing a massive amount of calculations cannot be modelled in the program called SAP2000 because SAP2000 records the data for ground motion at only one location in the building. However, utilizing accelerograms on the long and wide buildings or new advanced software carried out by a research community could be a solution for this analyzing issue.

In this dissertation, few tests were run in SAP2000. Therefore, **the extension of this report could be one of the most useful studies for further work. Testing wide range of different forms of the building having short-column formation and different types of structural protections against short-column formations could be good improvements, for example, the whole columns (from top to bottom) of ground floor could be considered as a critical region (as shown in figure3.6) in order to reduce the risk of shear failure in case of any incorrect structural application (as discussed before, the number of transverse reinforcements will be higher than the number required).Dogan (2011) stated that the effects of short-column formation can be minimized by placing elastic materials, reducing stirrup spacing, limiting and controlling shear stress between walls and column. Moreover, Seismic isolation system or structural foam between wall and column could also be used as a protection against shear failure. After these different tests run in FEA program, the results could be compared with the report of this dissertation (chapter 6 and 7).**

In addition to these further works given above, the testing wide range of different widths of the band windows between the columns could be another nice further work to compare them with the results of this dissertation. Finally, the data taken from those further works could be put together in order to identify different solutions for short-column formation.

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