ABSTRACT

Earthquakes are one of the most disturbing natural hazards which cause enormous life and property losses. However, earthquake engineering has highlighted itself as an interdisciplinary subject over the past few decades. Different professions as seismology, structural and geotechnical engineering, architecture, urban planning, information technology and some of the social sciences, have began to address different characteristic effects on the earthquake resistance of buildings.

The purpose of this study is to investigate lack of safety in the event of earthquake occurrence due to interior modification in the buildings during their life cycle.

This study investigates the potential problems arising due to improper interior changes, applied on existing structures, and also tries to reveals the importance of careful considerations, before any modification from architectural point of view.

This study reviews some background information regarding the issue of earthquake as well as a Turkish seismic design code of practice developed together with an explanation of the so – called "irregular building".

Also two case studies were performed to show the importance of interdisciplinary work of interior architects with civil engineers when performing any change on the building.

Keywords: Earthquake Codes**,** Irregular Building, Interior Modification, Earthquake Architecture

ÖZ

Depremler muazzam can ve mal kaybına yol açabilen sarsıcı doğal felaketlerdendir. Ne var ki, geçtiğimiz birkaç onyılda deprem mühendisliği, disiplinlerarası bir dal olarak kendini göstermeye başladı. Sismoloji, yapı ve jeoteknik mühendisliği, mimarlık, şehircilik, bilgi teknolojileri ve bazı sosyal bilim dalları da yapıların depreme dayanıklılığı ile ilgili farklı konulara dikkat çekmektedirler.

Bu çalışmanın amacı, yapıların yaşam süresi boyunca maruz kaldıkları iç-mekan müdahalelerinin bir deprem sırasında yol açabileceği güvenlik sorunlarını araştırmaktır.

Bu çalışma, mevcut yapılarda usule uygun yapılmayan iç-mekan müdahalelerinin ortaya çıkarabileceği potansiyel sorunları irdeler ve herhangi bir mimari değişiklikten önce detaylı araştırmalar yapılmasının önemine dikkat çeker.

Bu araştırma, depreme dair temel bilgiler ile birlikte Türk deprem yönetmeliği ve düzensiz yapıları konu alan araştırmaları da inceler.

Bunlara ek olarak, bir binaya yapısal müdahale sırasında iç-mimarlar ile inşaat mühendislerinin birlikte çalışmasının önemini göstermek amacıyla iki vaka incelemesi gerçekleştirilmiştir.

Anahtar Kelimeler: Deprem Yönetmelikleri, Düzensiz Yapılar, İç Mekan Müdahaleleri, Deprem Mimarlığı

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Chapter 1

INTRODUCTION

One of the most devastating natural disasters in the world is an earthquake. Earthquakes are reason for huge number of life and property losses. “On average, 10,000 people die each year due to earthquakes, while annual economic losses are in the order of billions of dollars, which constitute a large percentage of the gross national product of countries affected” (A.S.Elnashai & L.D.Sarna, 2008).

Throughout history, Turkey is one of the countries which suffered more due to its position on the Alp-Himalayas Fault which is one of the most active earthquake areas on the world. However the earthquakes that occur especially on the North Anatolian fault are very dangerous because they are very close, about 5-30 km from the surface of the earth (Ministry of Public Works and Settlement of Republic of Turkey, 2011, cited in Soyluk and Harmankaya 2012). “In the last 58 years, 58,202 people were killed, 122,096 were injured due to earthquake in Turkey. Moreover nearly 411,465 buildings had collapsed or heavily damaged”; In brief, approximately 1,003 people die and 7,094 buildings collapse per year in Turkey (Turkish Republic Disaster and Emergency Management Presidency, Earthquake Department, 2012, cited in Soyluk and Harmankaya 2012).

Cyprus also has the risk of earthquakes as it is located on the Alp-Himalayan earthquake belt but fortunately this island has not suffered any serious earthquakes in the last 70 years (Hürol & Wilkinson, 2005).

1.1 Research Problem

Earthquake engineering was highlighted as an interdisciplinary subject over the past few decades. Different professions such as seismology, structural and geotechnical engineering, architecture, urban planning, information technology and some of the social sciences, begin to address different characteristic effects on the earthquake resistance of buildings. However, many "building codes" suggested "earthquake problem can only be solved by applying a structural engineering solution" (Y. Hürol & N. Wilkinson, 2005).

Having said this, in such countries, architects and interior architects do not focus enough on this issue during their education, which may eventually bring up with serious problems. Experiences from past earthquakes in Turkey show most of the damages at buildings were directly or indirectly related to architectural design (Arnold, 1996).

Hence, Arnold (2001) used the phrase of "earthquake architecture" to underline the importance of the architectural expression on some aspect of earthquake action or resistance.

Reports of earthquake show that many reinforced concrete (RC) buildings collapsed due to irregularity problems (Paz, 1994; ITU, 1999). From 1998, some adjustments have been made in the Turkish Earthquake Code titled "Irregular Buildings", since, extensive damages during earthquakes are consequently due to irregularity of buildings (TEC, 1998). Reasons for these problems are generally wrong Architectural and/or structural design, poor construction and wrong interior modifications.

So the problem might be defined as how to make a link between structure, architecture and interior architecture disciplines, under the notion of irregular buildings.

1.2 Aims and Objectives

This study aims to investigate earthquake resistance capability of existing buildings, subjected to interior changes, and reveal importance of such changes in either increasing or decreasing the earthquake associated risks. As Habraken has mentioned if the structure of a building is not designed to undergo changes, any later modifications might be dangerous (Habraken 1998).

To achieve that, different types of irregularities in buildings such as: Irregularities in plan, elevation and reconfiguration of structural elements will be studied.

1.3 Outline of the Study

This dissertation is structured in a way to categorize all collected data into six entire chapters, consistent with the defined aims, objectives and major steps, described in the methodology part. Along these lines, the basic structure of each chapter is as follows:

Chapter 1: The introduction.

Chapter 2: Reviews some background information regarding the issue of earthquake, its definition, nature and its associated risks; with specific attention to address the issue in Turkey and North-Cyprus.

Chapter 3: Tries to provide some background information on Turkish seismic design code for practice development together with an explanation of the so – called "irregular building".

Chapter 4: Investigates earthquake resistance of RC frame buildings subjected to some later modifications. Also attempt will be focused on the evaluation of different types of buildings such as “Open Buildings” which are designed for adaptive usage as well as ordinary fixed plan ones that are not suitable for changes.

Chapter 5: Evaluates earthquake resistance of two buildings in the city of Famagusta in North Cyprus after modifications.

Chapter 6: The conclusion. The final chapter comprises of a summary of the previous assessments and the discussion of the results of the case studies. It also makes some recommendations for the further studies.

1.4 Field Study and Research Methodology

The field study focuses on the two chosen buildings in the city of Famagusta in North Cyprus. The Kutup hotel apart, evaluated in this study is an apartment re-functioned as a hotel apart and the Arkın Palm Beach hotel, which was renovated several times. These buildings are evaluated according to the findings of this study based on earthquake resistance of buildings after modifications.

A qualitative method was used in the present study by conducting interviews with the owners of the buildings, architects and civil engineers as well as observations and analyzing previous and present situations of the buildings.

The two above-mentioned cases were selected from the buildings in the Famagusta city. Aarkın Palm Beach hotel was selected since it was the only successful building from the perspective of renovation and collaboration of its architecture, interior architecture and civil engineer. The second case study had to have the interior modifications in all the stories of the building, therefore Kutup hotel was selected since it met all these conditions and the architectural plans were provided by the owner of the building.

1.5 Limitations of the Research

Earthquake resistante design is a broad and a major subject to be studied in building sciences. As EQE, (2000) mentioned, several factors are effective on resistance of a building in the event of an earthquake. These factors include soil structure interaction, footing design, lateral load resisting system and overall configuration of structural elements.

This study, however, focuses on the effects of the interior changes on earthquake resistance of buildings with reinforced concrete frame systems.

Chapter 2

EARTHQUAKE

2.1 Introduction

Earthquake is one of the most devastating hazards that cause great loss of life and property. "During the twentieth century over 1,200 destructive earthquakes occurred worldwide and caused damage estimated at more than $10 billion" (Coburn and Spence, 2002). Research has also shown that as from 1900 to 1999 death rates due to earthquakes have tremendously increased approximately to 1.8 million, on a consequential average of 10,000 yearly deaths (Bolt, 1999).

This chapter reviewed and presented some background information regarding earthquake, its definition, nature and risks associated with.

2.2 Definition of Earthquake

According to Elnashai and Sarno (2008), earthquakes occur when there is a ground vibration initiated by rapid discharge of energy in the Earth; and might result due to "underground movement or motions, also term as tectonic", or "volcanic eruptions", "landslides", "rockbursts", or explosion caused by "humans activities, as well as the collapse of underground cavities caused by explosive mechanisms, such as land mines" (Chen and Lui 2006).

Along with the several theories the "plate tectonic theory" is one of particular interest amongst structural and civil engineers, because earthquakes related to tectonic motions are the largest and most important one. For a better understanding of this theory acquiring some knowledge related to nature of the earth makes us more familiar in the foundation of the general topic.

Figure 2.1 shows: the earth is composed of different parts with different proportions. These are in the order from inner part to outer part: solid inner core with thickness of (radius ~ 1290km), liquid outer core with thickness of (radius ~ 2200km), mantle, extending from a depth of about 30km below with thickness of (radius ~ 2900km) and the crust or lithosphere with thickness of (radius ~ 5 to 40 km) and, the outer rock layer of the earth with thickness of 25-65 km (Murty, 2004).

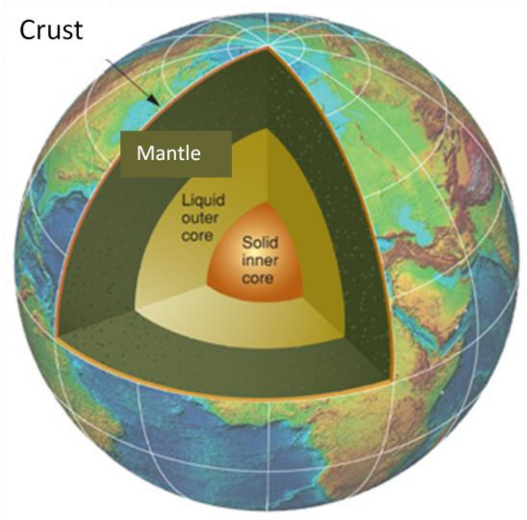


Figure 2.1. Earth Section (www.nersc.gov)

In the global sense, “tectonic earthquakes result from motion between a number of large plates comprising the earth’s crust or lithosphere” (Chen and Lui 2006). These plates are known as “tectonic plate”.

In accordance to the continental drift theory, tectonic plates are divided into 15 plates in the crust; which comprises of the “continental” and “oceanic plates” as shown diagrammatically in Figure 2.2. On the other hand, “seismic belts” are the plate boundaries, where earthquakes are often or regularly take place (Kanai, 1983).

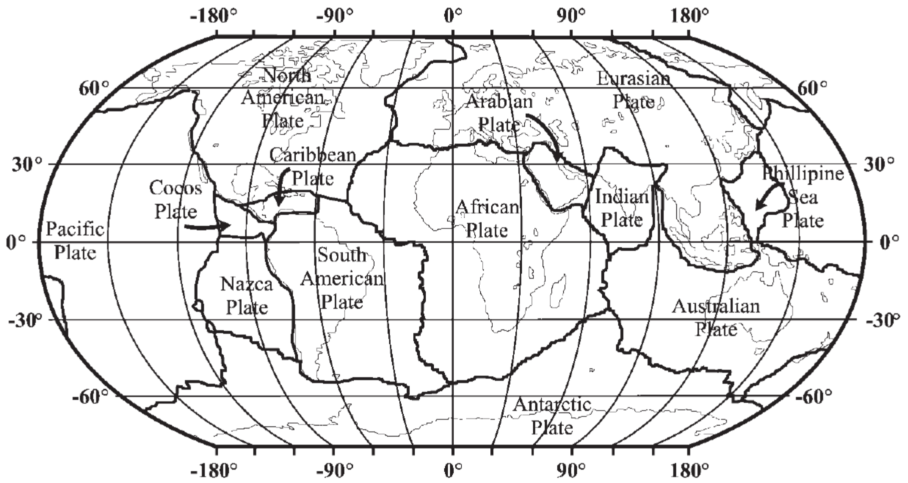


Figure 2.2. Tectonic Plates (Elnashai and Sarno 2008)

Elnashai and Sarno, (2008) stated the “tectonic plates” move differentially to each other on the asthenosphere which is the “upper layer of the mantle just below the lithosphere”. “Lithosphere” is a softer and warmer layer of mantle. Tectonic plate’s movements occurs due to convection currents in the mantle; and is deduced to have an approximate velocity movement of 1 to 10 cm/year” (Elnashai and Sarno 2008).

Nevertheless, movement related to “lithosphere asthenosphere complex” is reasoned to provide large tectonic forces at the seismic belts. These forces activate chemical and physical changes and change the geology of the neighboring plates. However, “only the lithosphere has strength and the brittle behavior to fracture, thus causing an earthquake” (Elnashai and Sarno 2008).

Elnashsi and Sarno (2008) grouped the main types of seismic belts into three zones as “Divergent or rift zones”, “Convergent or subduction zones” and “Transform zones or transcurrent horizontal slip”.

I. The “Divergent or rift zones”: is separation of plates with either effusion of magma or divergence of lithosphere.

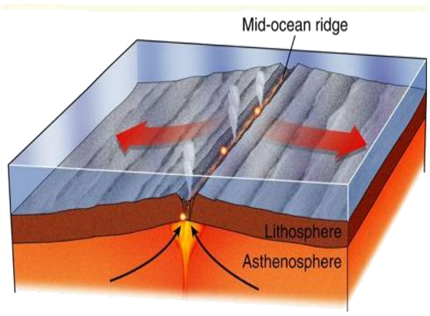


Figure 2.3. Divergent Zones (earthquakesandplates.wordpress.com)

II. “Convergent or subduction zones”; in this case “neighboring plates converge and crash”. Convergent zones can be enumerated into two types:

1. “Oceanic convergent”-Takes place when there is a crashing of two plates comprising of “oceanic lithosphere”.

2. “Continental lithosphere convergent boundaries”-This emanates when both grinding plates comprises of continental lithosphere. As well, the two main instances of Circum-Pacific and Eurasian belts, correspondingly are called oceanic and continental lithosphere convergent boundaries (Elnashai and Sarno 2008).

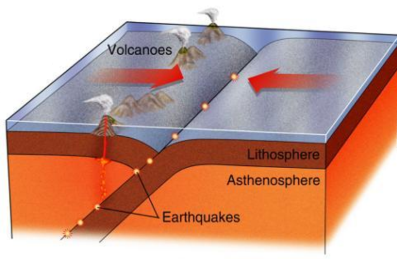


Figure 2.4. Convergent Zone (earthquakesandplates.wordpress.com)

III. “Transform zones or trans-current horizontal slip” –in this kind of zones, binary (two) plates glide past each other without generating any new lithosphere or taking away the old lithosphere , as illustrated in Figure 2.5.

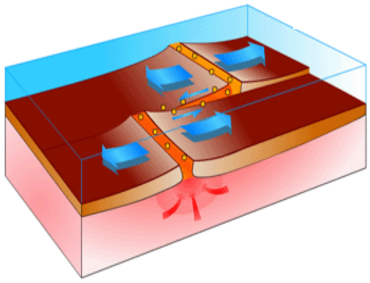


Figure 2.5. Transform Zone (earthquakesandplates.wordpress.com)

2.3 Faulting

Faults are causes of releasing elastic strain energy in boundaries between nearby tectonic plates, thus may be hundreds of kilometers long. In addition, there are thousands of shorter faults which are branching or parallel with main fault zone. Generally, longer faults are the cause of larger earthquakes (Chen and Lui 2006).

Housner (1973) asserted that assorted fault mechanisms are present, and are in correlation to how tectonic plates move in respect to each other. On the other hand, Chen and Lui (2006) categorized the main types of fault mechanisms as demonstrated in Table 2.1.

Table 2.1. Major Kinds of Fault Mechanisms (Chen and Lui 2006)

Fault type	Description
Transform or Strike-slip fault	• relative fault motion occurs in the horizontal plane, parallel to the strike of the fault.
Dip-slip fault	• motion at right angles to the strike, up-or down –slip.
Normal fault	• dip-slip motion, two side in tension, move away from each other.
Reverse fault	• dip-slip, two sides in compression, and move toward each other.
Thrust fault	• low angel reverse faulting.

Furthermore, Figure 2.6 illustrates several faults, which comprises the combinations of “strike-slip and dip-slip” movement; and can also be designated as “oblique slip”.

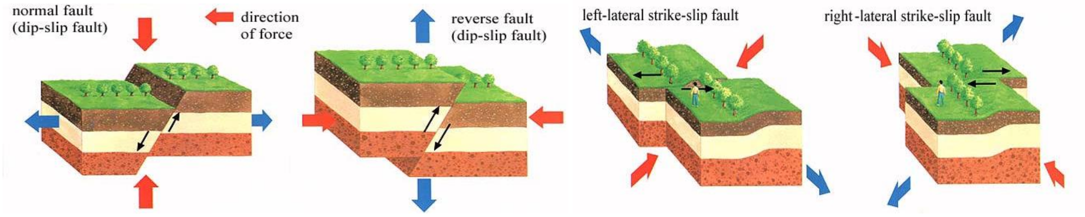


Figure 2.6. Fault Mechanisms (www.earthquakeusgs.org)

2.4 Focus or Hypocenter/ Epicenter

Elnashai and Sarno (2008) state that, the focus or hypocenter of an earthquake is “the point beneath the surface where the rupture is supposed to have initiated”(Elnashai and Sarno, 2008). Furthermore, “epicenter is when there is a projection of the focus on the surface; whereas decrease of the focus to a point is called point- source estimate as shows in Figure 2.7”(Mallet, 1862).

Then again, estimate is used to delineate the “hypocentral” parametric quantities. However, virtually all earthquakes have focal depths, which ranges from of 5 to 15 km; on the other hand, intermediate events have foci which ranges from 20 to 50 km, while deep earthquakes take place at 300-700km underground. In addition to that, “Crustal earthquakes are usually found to have depths of nearly 30 km or lesser”, (Elnashai and Sarno 2008). Earthquakes, which cause damage to buildings, are less than 50 km which are vital for structural engineers, (Elnashai and Sarno 2008).

Figure 2.7, demonstrated that the source is not a single point, which implies that distance from the source is of significance. Therefore, careful precaution is taken when using relationships based on source-site measurements, particularly for near-field and magnanimous events (Elnashai and Sarno 2008).

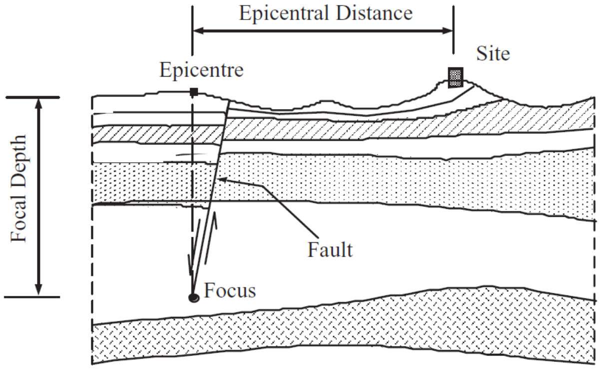


Figure 2.7. Definition of Source Parameters (Elnashai and Sarno 2008)

2.5 Seismic Waves

Elnashai & Sarno (2008) asserted that "fault ruptures", induce brittle fractures of the Earth's crust, which dispel approximately 10 percent of the total plate tectonic energy in seismal waves form. Furthermore, earthquake shaking can be classified into two substantial elastic seismic wave types; "body waves" and "surface waves". However, the shaking is felt as a compounding of these waves, particularly at a shorter length from the source or near-field (Elnashai and Sarno 2008).

2.5.1 Body Waves

The waves that move or travel through the Earth's inner layers are characterized as body waves. "Body Waves" incorporates longitudinal or primary waves, occasionally termed as "P-waves" and transverse or secondary waves which are somewhat referred to as S-waves.

Elnashai & Sarno (2008), describe "P waves" as "seismic waves" that potentially have comparatively slight damage and on the other hand, delineate "S-waves propagation, as waves that mutually cause significant damage, as well as the main inducer of vertical (SV) and horizontal (SH) side-to-side motion"; as schematically shown in Figure 2.8 (Elnashai & Sarno, 2008).

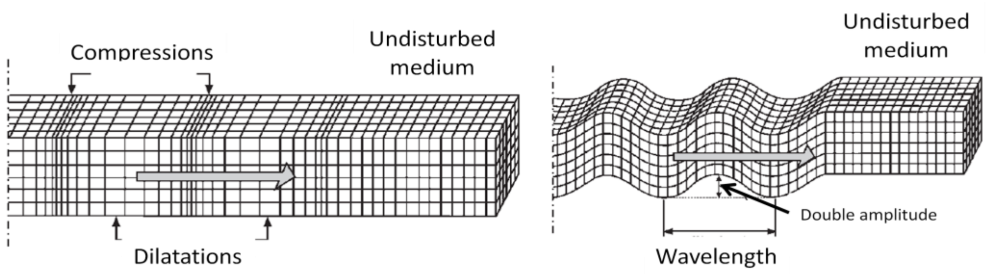


Figure 2.8. Schematically Showing the Travel Path of a Body Waves; Starting from Left to Right, P-wave and S-wave Respectively (Bolt, 1999)

2.5.2 Surface Waves

Waves that spread all over the exterior layers of the Earth's crust are referred to as surface waves. Kanai, (1983) elucidates, surface waves as waves that are produced due to constructive interference of body waves moving in parallel with the earth surface, together with several underlying boundaries (Kanai, 1983).

Kanai, (1983) furthermore, described surface waves as consisting of two basic fundamental waves types; "Love (L or LQ waves) and Rayleigh (R or LR waves) waves, which are tempt generally large displacements and are commonly referred to as principal motion"(Kanai, 1983).

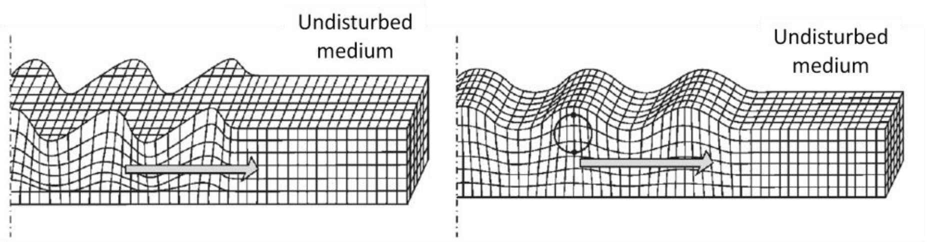


Figure 2.9. Depicts Travel Route of Surface Waves; Starting From Left to Right, Love and Rayleigh Respectively (Bolt, 1999)

Moreover, Elnashai & Sarno, (2008), described surface waves, to probably impact serious damage to structural systems during earthquakes, as a result of their long or prolonged duration, see illustration in Figure 2.10.

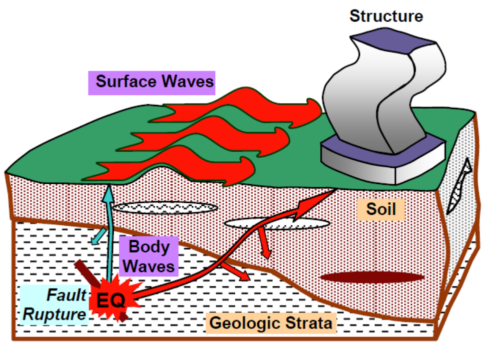


Figure 2.10. Shows Arrival of Seismic Waves at a Site (Murty, 2004)

2.6 Measuring Earthquakes

Earthquake size can be conveyed in distinct ways. However, from a general standpoint, earthquake measurements are categorized into two main folds, the “qualitative or non-instrumental” and “quantitative or instrumental measurements”; and can be further explained in more details as enumerated below:

I. “Qualitative or non-instrumental”: These measurements are very substantial for pre-instrumental events, which indicates its necessity for the collection of historical earthquake catalogues for determinations of perilous investigation or analysis. In addition to that, Ambraseys and Finkel, (1986), states that the evaluation of historical records are not always visible and may lead to inconsistent or inappropriate results referable to inevitable biases (Ambraseys and Finkel, 1986).

II. “Quantitative or instrumental measurements”: This are earthquakes that have been recorded or entered instrumentally, which implies that “qualitative scales are complementary to the instrumental records”(Elnashai and Sarno, 2008). Additionally, research have also shown that another technique for evaluating Earthquakes is the “Descriptive methodology” which is substantively based for earthquake- induced damage, coupled with its spatial distribution. These methods can be further broken down to two categories; “intensity”, and “magnitude”. These methods are deliberated and detailed as follows;

2.6.1 Intensity

On the one hand, the terms intensity method can simply be described as the non-instrumental detectability measure of damage to structure, earth surface upshots, as well as human responses to earthquake shaking; and has been traditionally utilized for determining earthquake size, particularly, in pre-instrumental events.

On the other hand, this method is widely known as descriptive method, and also as a subjective “damage appraisal metric, due to its qualitative nature, which is correlated to population density, as well as its acquaintance with earthquake and constructions types”(Elnashai and Sarno 2008).

Among other classifications, various scientific publication have intensively looked into the most common intensity scales (Reiter, 1990; Kramer, 1996; Lee et al., 2003; Elnashai and Sarno, 2008), and is tabularised accordingly in Table 2.2:

Table 2.2. Classfication of Intensity Scales

Mercalli-Concani-Seiberg (MCS):

- 12-level scale used in southern Europe.

Modified Mercalli (MM):

- 12-level scale proposed in 1931 by Wood and Neumann, who adapted the MCS scale to the California data set. It is used in America and several other countries.

Medvedev-Sponheuer-Karnik (MSK):

- 12-level scale developed in Central and Eastern Europe and use in several other countries.

European Macroseismic Scale (EMS):

- 12-level scale adopted since 1998 in Europe. It is a development of the MM scale.

Japanese Meteorological Agency (JMA):

- 7-level scale used in Japan. It has been revised over the years and has recently been corrected to maximum horizontal acceleration of the ground.

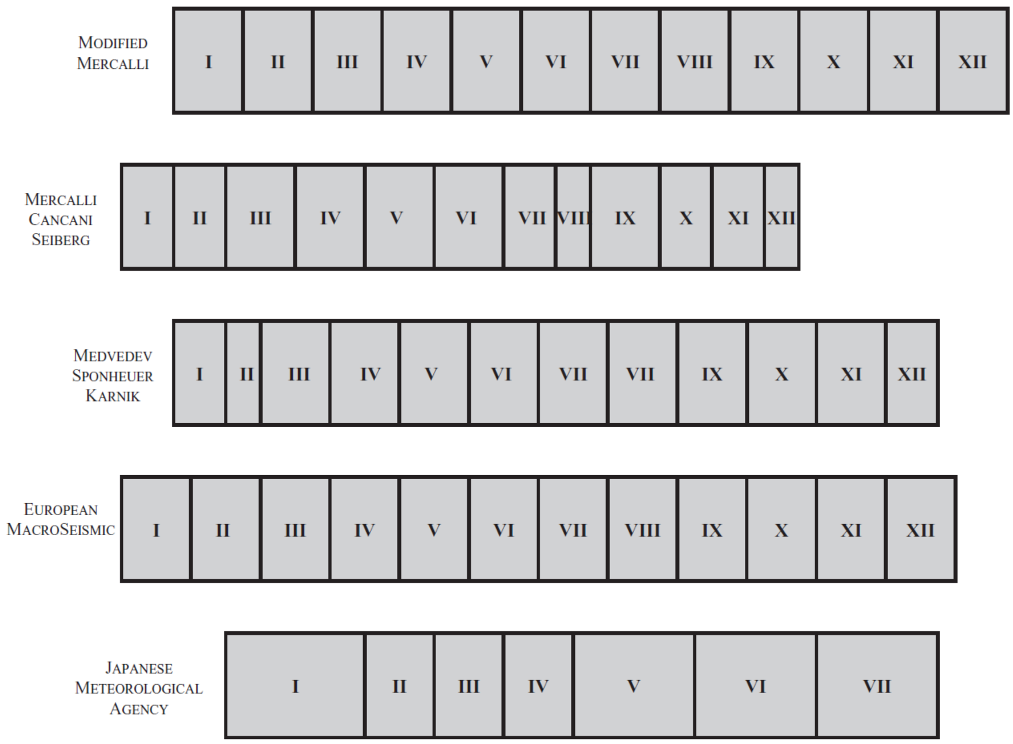


Figure 2.11. Comparison Between Seismic Intensity Scales (Elnashai and Sarno 2008)

Some intensity scales are developed in pre-instrumental times and the most common today is (MMI) which is "Modified Mercalli intensity". MMI, is a "subjective scale definition the level of shaking at a specific site on a scale of I to XII" Chen and Lui (2006).

Table 2.3. shows educated observers assign the intensity level based on the field observation of destruction in according with the description of damage listed in the Modified Mercalli Scale (Wood and Neumann 1931).

Table 2.3. Modified Mercalli Intensity Scale (Wood and Neumann 1931)

I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of building. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing track. Duration estimated.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows and doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rock noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instance of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction slight to moderate in wall-built ordinary structure; considerable in poorly built or badly designed structure. Some chimneys broken. Noticed by persons driving motor cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly build structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Change in wall water. Persons driving motor cars disturbed
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed over banks.
XI	Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

2.6.2 Magnitude

As earlier mentioned in the previous paragraphs, “Magnitude” well describes the quantitative method, which are applied when measuring earthquake size and defect dimensions. In this method, the uttermost amplitudes of body or surface seismic waves are paramountly considered and established on an instrumental, quantitative, as well as objective scale, (Table 2.4 demonstrates and classified some the most common Magnitude scales). In addition to the augment, research has shown that japan was the first to deliberate or delimitate magnitude scales, by Wadati and subsequently by Richter in California within 1930s (Elnashai and Sarno, 2008).

Table 2.4. Classified Some of the Most Common Magnitude Scales (Elnashai and Sarno 2008)

Local (or Richter) magnitude ($\boldsymbol{M}_{\mathrm{L}}$):

- Measures the maximum seismic wave amplitude A (in microns) recorded on standard Wood-Anderson seismographs located at a distance of 100 km from the earthquake epicentere.

Body wave magnitude ($\boldsymbol{m}_{\mathrm{b}}$):

- Measures the amplitude of P-waves with a period of about 1.0 second, i.e. less than 10-km wavelengths.

Surface wave magnitude ($\boldsymbol{M}_{\mathrm{S}}$):

- Is a measure of the amplitudes of LR-waves with a period of 20 seconds, i.e. wavelength of about 60 km, which are common for very distant earthquakes, e.g. where the epicentre is located at more than 2,000 km.

Moment magnitude ($\boldsymbol{M}_{\mathrm{w}}$):

- Accounts for the mechanism of shear that takes place at earthquake sources. It is not related to any wavelength. As a result, $\boldsymbol{M}_{\mathrm{w}}$ can be used to measure the whole spectrum of ground motions.

$\boldsymbol{M}_L$ is “Richter magnitude” which exhibits several limitations is the scale type which is appropriate only to small and shallow earthquakes in California and for epicentral distances less than 600 km. It is, therefore, a regional (or local) scale, while $\boldsymbol{m}_b$, $\boldsymbol{M}_S$, and $\boldsymbol{M}_W$ are worldwide scales. The main properties of the above magnitude scales are summarized in Table 2.5.

Elnashai and Sarno, (2008) averred that "the lowest values of magnitude that can be estimated by sensitive seismographs is – 2 approximately. On the one side, as a general rule of thumb, earthquakes with magnitude that ranges within "4.5 and 5.5" are described as local, while on the other hand, huge seismic events mostly have a magnitude that ranges within "6.0 to 7.0". "In contrast, earthquakes with magnitude greater than 7.0 are identified as great earthquakes"(Elnashai and Sarno, 2008).

Table 2.5. Properties of Major Magnitude Scales (Elnashai and Sarno 2008).

Scale type	**Author**	**Earthquake Size**	**Earthquake depth**	**Epicentre distance (km)**	**Reference Parameter**	**Applicability**
M L	Richter (1935)	Small	Shallow	< 600	Wave amplitude	Regional (California)
m b	Gutenberg and Richter (1956)	Small - to - medium	Deep	> 1,000	Wave amplitude (P- waves)	Worldwide
M S	Richter and Gutenberg (1936)	Large	Shallow	> 2,000	Wave amplitude	(LR- waves) Worldwide
M w	Kanamori (1977)	All	All	All	Seismic moment	Worldwide

Earthquakes of distinctive size or energy release might have similar magnitude, such as referring to the 1906 San Francisco (California) Earthquakes and 1960 Chile earthquakes examples. Both events where recorded to have an $\boldsymbol{M}_s$ = 8.3. However, the fault or defect rupture area in Chile was anticipated to be 35 times greater than that observed in California. This implies that, the magnitude of Earthquake can be utilized to measure the level of energy released during defect ruptures (Elnashai ans Sarno 2008).

The graphical expression in Figure 2.12 describes the correlation between "surface wave magnitude" (***M_s)*** and earthquakes energy released, with other associated earthquakes outcomes per annum.

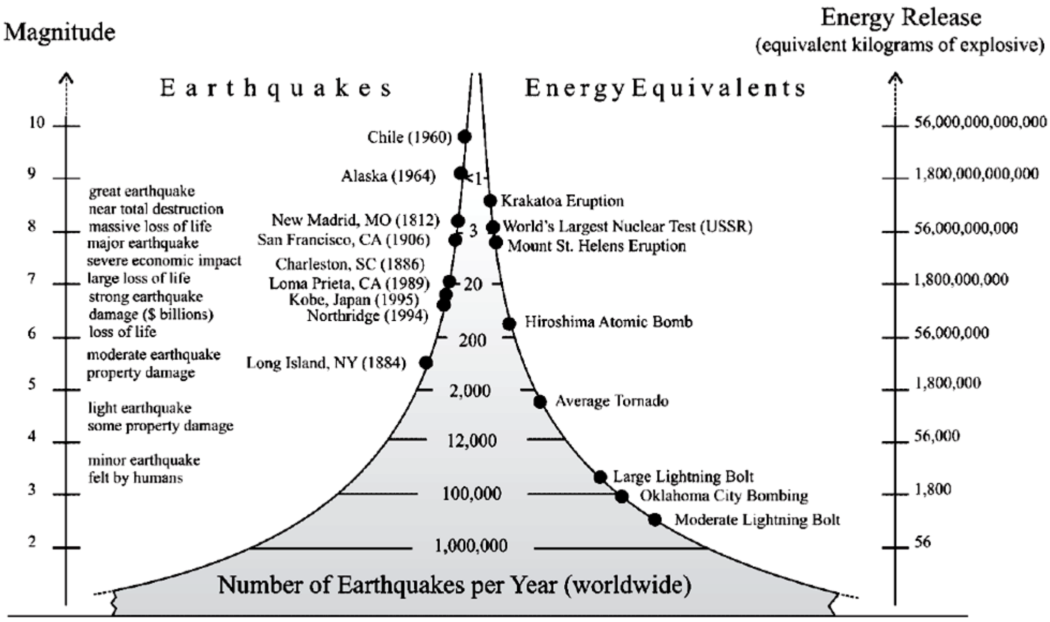


Figure 2.12. Graphically Represents Magnitude and Energy Release Relationship (Bolt.1999)

2.6.3 Intensity – Magnitude Relationships

This relationship are needed in case of using historical earthquakes which no instrumental records exist; as revealed in Table 2.6.

Table 2.6. Relationships Between Iintensity and Magnitude (Tuna, 2000)

Intensity	IV	V	VI	VII	VIII	IX	X	XI	XII
Magnitude	4	4.5	5.1	5.6	6.2	6.6	7.3	7.8	8.4

2.7 Seismicity of the World

By focusing on Figure 2.13 it is obvious, 95 % of earthquakes around the world arise on two main earthquake belts which are "Pacific earthquake belt" and "Alp-Himalayan earthquake" belt. It should be noted here, 80 % of all the earthquakes, occur on the coasts of the Pacific Ocean. (Erman, 2002).

Critical earthquakes frequently happen in China, Japan, the west side of the America, the west coast of Canada, Alaska, countries on the west coast of the South America continent, New Zealand, Indonesia and Philippines (Bayülke, 1989).

In addition, 15 % of all the earthquakes occur in Alp-Himalayan earthquake belt and contains all Mediterranean countries such as Iran, Caucasus, Turkey and Cyprus (Celep and Kumbasar, 2004).

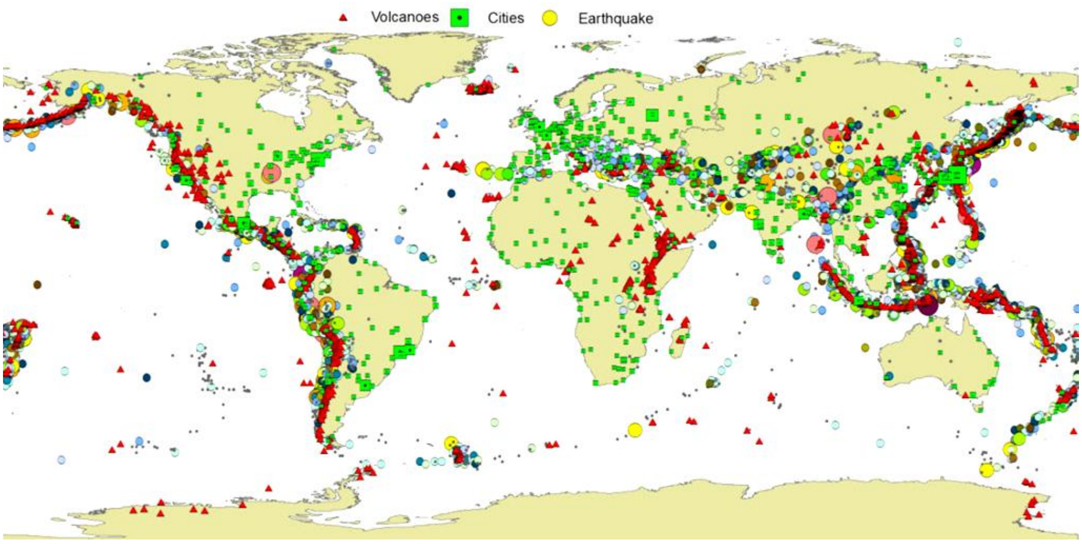


Figure 2.13. The Geographical Distribution of Earthquake

(www. historyofgeology.fieldofscience.com)

2.8 Seismicity of Turkey

Turkey is identified in the world as one of the countries exposed to the risk of earthquakes. It was placed as number three in the world when 58,202 people were reported dead and 122,096 wounded, within the last 58 years as a result of earthquakes outbreaks (Harmankaya and Soyluk 2012).

Recent research publication have shown that, almost 411,465 buildings in Turkey suffers nervous collapse or great extent damaged, which have left approximately 1,003 people dead and 7,094 buildings ruin annually (Harmankaya and Soyluk 2012).

According to Gülkan, Koçyiğit, Yücemen, Doyuran and Başöz, (1993) Turkey is divided into 17 earthquake faults or defects, and are constricted by the displacement or drift of Africa, Eurasia, and Arabian plates, as well as the main dynamic fault zones; the North Anatolian Fault Zone (NAFZ) and East Anatolian Fault Zone (EAFZ), as depicted in a diagrammatic manner in Figure 2.14.

It is also vital to note that, virtually one of the dynamic and leading strike-slip faults discovered in the world is the North Anatolian Fault (NAF). It is ascertained to have a distance of 1500 km, and can result to annihilating earthquakes which slips at an expected value range of 20–25 mm/year. It is also reported that, within the century now, over 25 earthquakes above 900 km of its length have been ensued on the fault ruptured (Barka and Nalband 1998).

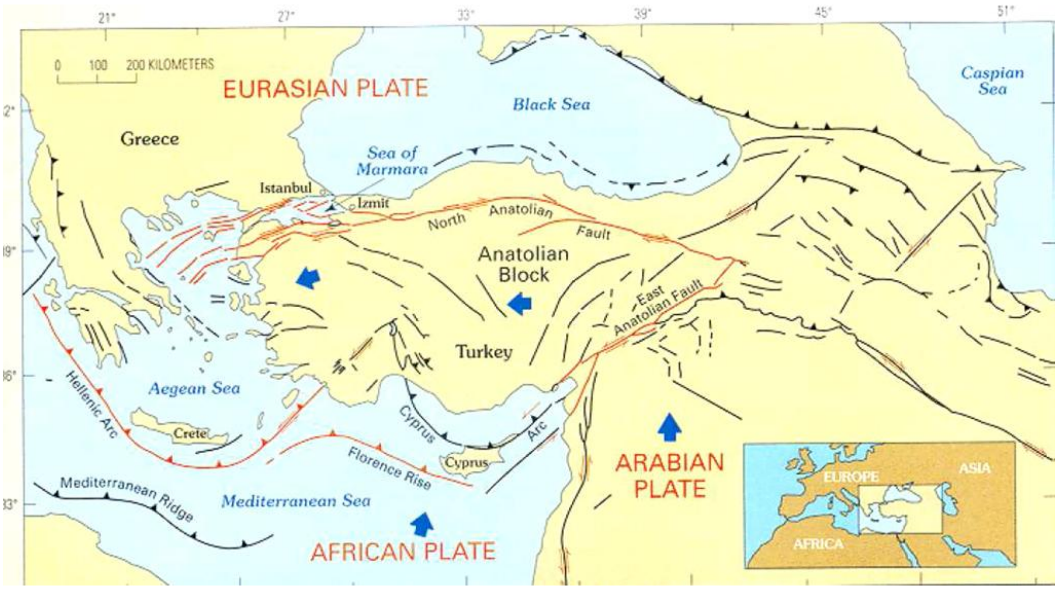


Figure 2.14. Tectonic Structure of Turkey (Seymen and Akin 1999)

In terms of the earthquake risk capacity, Turkey is separated into five earthquake zones as shown in Figure 2.15. The most risky zones on which vast and destructive earthquakes are expected to occur are the 1st and 2nd ones. Moderate earthquakes are normally expected to occur on 3rd and 4th zones which are likely to be affected from the great earthquakes of 1st and 2nd zones (Bayülke, 1989).

5th zone is the zone with no risk of Earthquake whatsoever. No earthquake is expected to occur here or only smaller earthquakes happen, but it is not even affected by the earthquakes of other five zones (Bayülke, 1989).

Erman at 2002 mentioned, Ankara and Konya from middle Anatolia are on the 4th earthquake zone and Karaman and the south part of Aksaray are on the 5th earthquake zone. In this case Turkey may know as the 2nd degree earthquake zone in the world with no earthquake greater than 8.0 magnitudes (Erman, 2002).

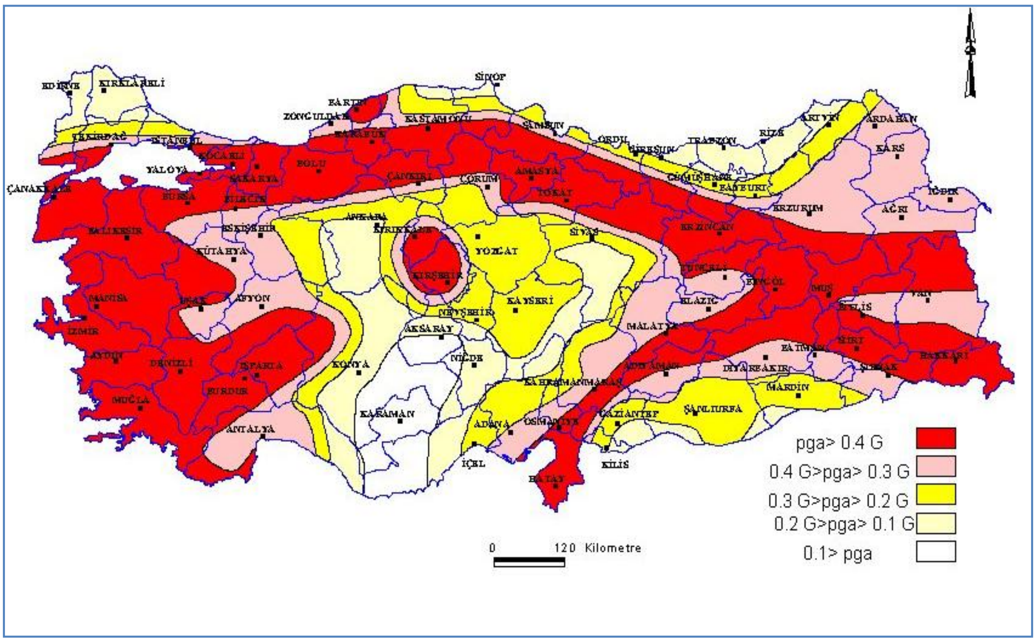


Figure 2.15. Earthquake Zones in Turkey (www.afetler.net)

2.9 Seismicity of Cyprus

Cyprus Island is situated along the boundary between “Eurasian, African and Arabian Plate”. However, history shows that Cyprus Island have suffered from several severe earthquakes across in the past. According to Cagnan and Tanircan, (2010), African Plate moves comparatively northeastward of Eurasian Plate, and in like manner, Arabian Plate moves toward no different direction, however, at a faster rate in contrast to the African Plate. Then again, “Anatolian Sub-plate” is constrained to move in the westward direction, due to the collision of Eurasian Plate with the African and Arabian plates, as depicted in Figure 2.14. However, the North and the East Anatolian Fault (EAF) have a dynamic expansion to the both north and south of Cyprus, which implies that, Cyprus as a whole moves with the Anatolian Sub-plate in a directional westward (Cagnan and Tanircan 2010), (Figure 2.16).

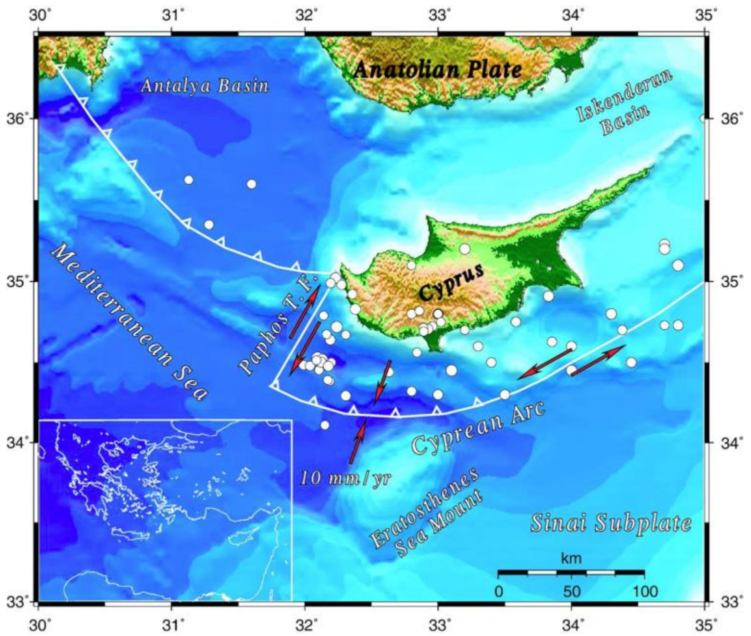


Figure 2.16. Map of the Future Plate Boundary in the Eastern Mediterranean Region (Papaioannou 2001)

Therefore, research by scholars have shown that, the occurrence of severe or major earthquakes are more often found in the southern part of the Cyprus island, which has been reported to induce damage in some part, such as Paphos, Limassol, and Famagusta, as shown in the map for Earthquake Zones in Cyprus in Figure 2.17. For example, the following earthquakes magnitudes has be studied and recorded for references purposes over the years (Galanopoulos and Delibasis 1965; Ambraseys 1992; Kalogeras et al. 1999), which consist of, 342 (M_w 7.4), 1222 (M_w 6.8), 1577 (Mw 6.7), 1785 (M_w 7.1), 1940 (Mw 6.7), and 1996 (M_w 6.7)" correspondently (Cagnan and Tanircan 2010).

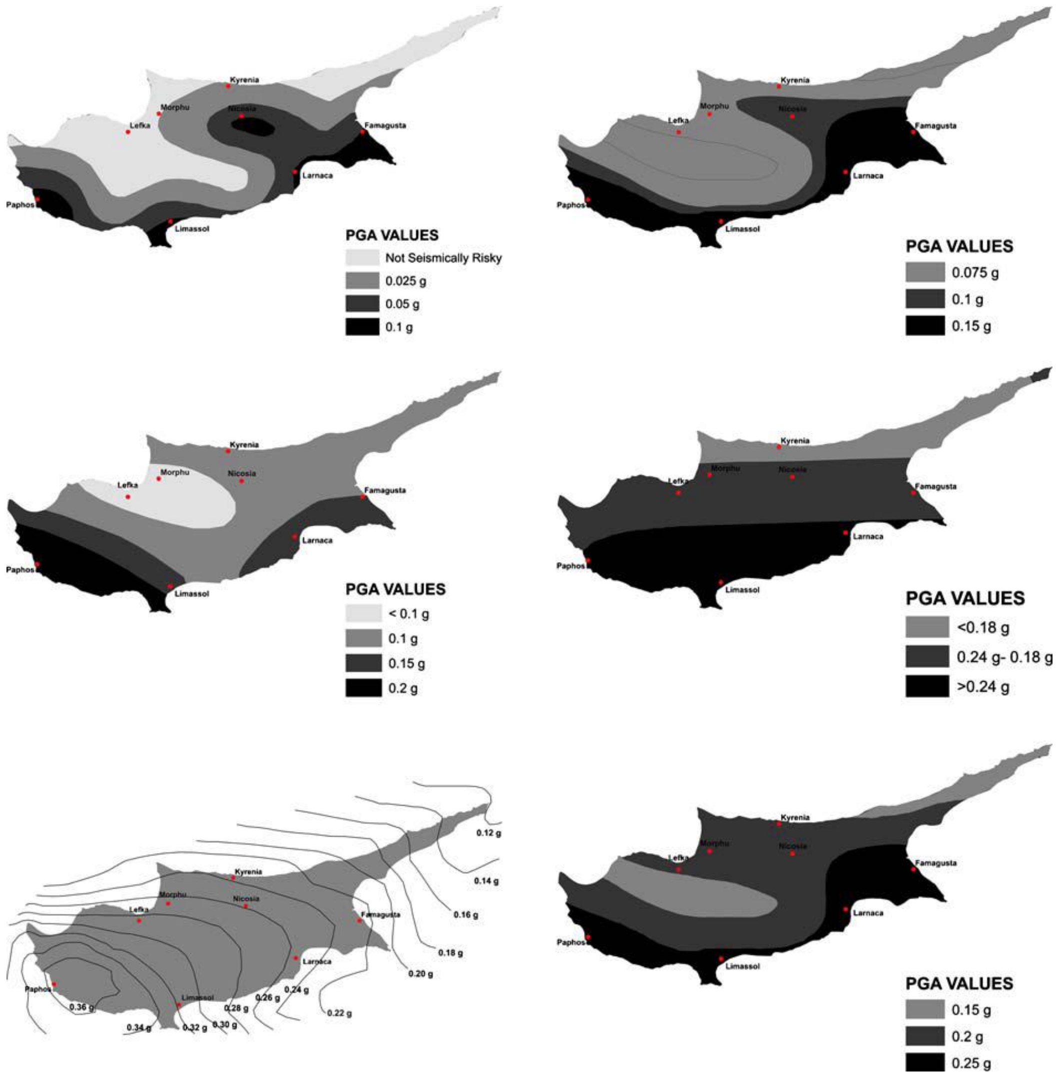


Figure 2.17. Previously Proposed Seismic Hazard Maps for Cyprus (Erguney and Yurdatapan 1973, unpublished manuscript; Cyprus Civil Engineers and Architects Association 1992; Erdik et al. 1997; Can 1997; Algermissen and Rogers 2004; CEN 2007)

Shallow earthquakes in Cyprus, principally occurs along the “Cyprus Arc” and the “Dead Sea fault zone”, while the intermediate depth earthquakes occurs underneath the island central part (Figure 2.18).

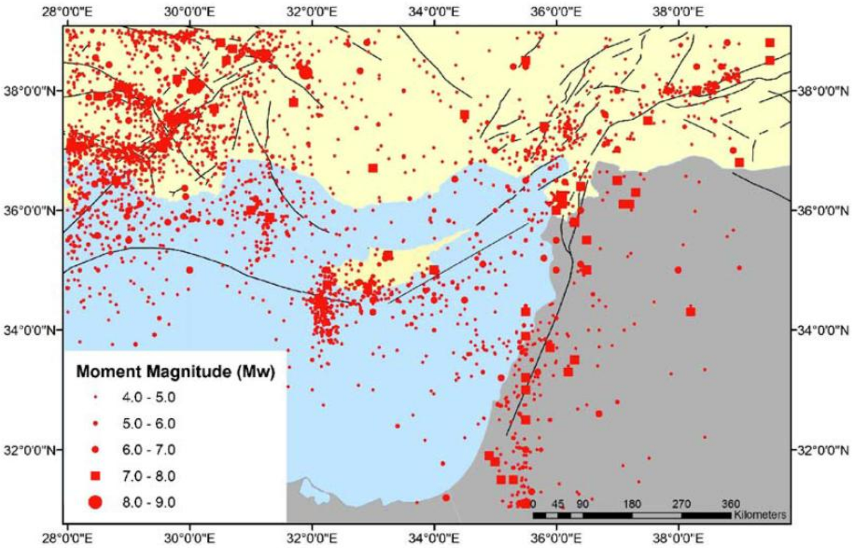


Figure 2.18. Shows the Dispersion of Earthquake Epicenters in the Region, Predicted from 2150 B.C. Through 2006 (with kind permission of the Geological Survey Department of Cyprus, 1995).

In addition the above arguments, Cagnan and Tanircan, (2010) added that “the western and central parts of the Cyprus Arc are mostly the regions affected seismically, and the earthquakes emanating or occurring from these regions or areas are usually experienced all through the island”. On the one side, eastern part is fairly still up to the Famagusta triple junction where it has links with East Anatolian Fault. “On the other side, the seismic activity of Cyprean Arc (Figure 2.16), all together, is somewhat lesser than the adjacent Hellenic Arc; Dead Sea, and East Anatolian Fault zones” (Cagnan and Tanircan, 2010).

2.10 Effect of Earthquakes

In general, an earthquake is placed as one of the most harmful tragedies by huge shocking numbers in respect to loss of human life and livelihood; and its negative outcomes is contingent on numerous factors.

On the one side, these factors are associated with the size of Earthquakes and are articulated by either the intensity or magnitude; focal depth and epicentral distance; topographical conditions and local geology which are considered as the greatest significant earthquake features.

On the other hand, the reasons for losses and degree of damage is largely contingent to the type of constructions and population density present in that region. Elnashai & Sarna, (2008) also mentioned that “Earthquakes impact a substantial toll on all aspects in the societal systems, and might impose more than a few direct or indirect effects” (Elnashai & Sarna, 2008) as shown in Figure 2.19.

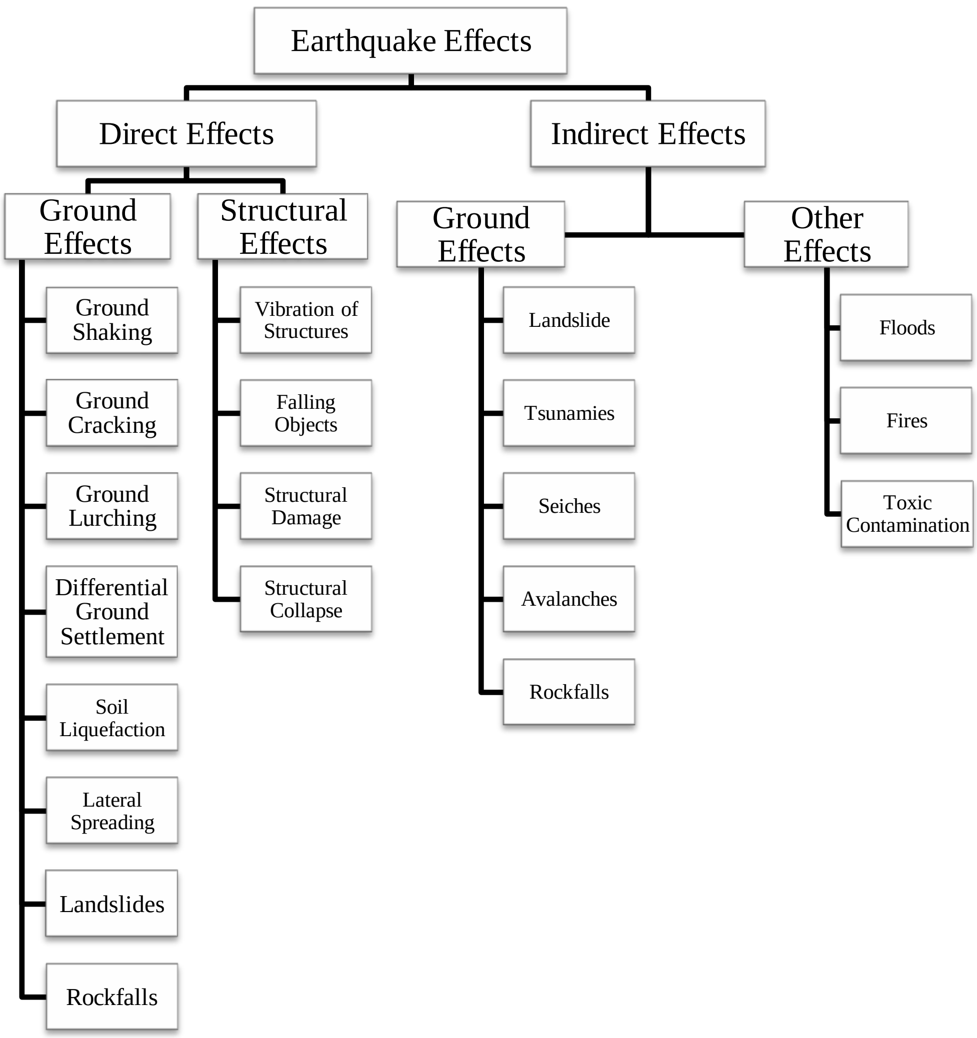


Figure 2.19. Direct and Indirect Earthquake Effects (Elnashai & Sarna, 2008)

Chapter 3

COMMON SEISMIC DESIGN PROBLEMS DUE TO ARCHITECTURAL DESIGN

3.1 Introduction

As mentioned previously in chapter two, the structural irregularity of a building is attributed as one of the main causes for heavy damages when earthquake occurs. Many buildings have been damaged or collapsed during past earthquakes, directly or indirectly due to irregularities in architectural design (Soyluk and Harmankaya 2012). Hence, the title of "irregular building" in (TEC) Turkish Earthquake Code has come into center of consideration since 1998. Based on this title, architects are advised to avoid these kinds of irregular configuration in their designs (Soyluk and Harmankaya 2012).

Since the same building codes, (seismic resistance design) are being used in Turkey and Turkish Republic of Northern Cyprus during the structural design and construction of buildings; probably those buildings will be faced with similar serious problems through all major earthquakes (Hürol and Wilkinson, 2005).

This chapter will try to provide some background information on Turkish seismic design code of practice development together with explanation of so – called "irregular building".

3.2 Development of the Turkish Earthquake Code

The seismic design codes of practice, present the minimum requirements to be provided in architectural, structural design and also construction of various structures with different functionalities such that the public safety is assured. These documents are usually published by officials in each country (Harmankaya and Soyluk, 2012).

The M 7.9 Erzincan earthquake in 1939 was a devastating earthquake in Turkey in 20th century. Soon after "The Turkish Ministry of Public Works and Settlement" formed a committee towards developing "regulations for the seismic design of buildings in Turkey" (Sezen et al. 2000).

Having said this, the earthquake code of Turkey for derivation of equivalent lateral forces induced by strong ground shaking has gone through various revisions since 1939. A major change was applied in 1968 when restrictions for ensuring ductile behavior of structural components, including regulations for placement of transverse stirrups, were adopted. These concepts were first introduced in U.S. (Uniform Building Code) and many countries including Turkey adopted the concepts from there (Sezen et al. 2000).

Development of seismic codes are usually a result of both development in background science and gaining experience in the form of observing the behavior of structures designed according to an active seismic code after a major earthquake.

57 earthquakes have occurred in Turkey during the 20th century and some of the most devastating ones were followed by changes in the Codes of practice (Sezen et al. 2000). Table 3.1 shows key events in the evolution of seismic code in Turkey.

Table 3.1. Lists key Events in the Evolution of Seismic Codes in Turkey (Sezen et al. 2000; Harmankaya and Soyluk, 2012)

Date	Location	Magnitude	Fatalities	Code development
1939	Erzincan	7.9	32,700	
1940				First seismic code published
1942				Earthquake map prepared; map promulgated in 1945
1943	Tosya	7.2	4000	
1944	Gerede	7.5	3959	Seismic code revised
1953	Yenice	7.2	265	Seismic code revised
1957	Fethiye&Abant	7.1	119	
1958				Ministry of Reconstruction and Resettlement established
1961				Seismic code revised
1963				Earthquake zone map revised
1964	Manyas	7.0	23	
1966	Varto	7.1	2396	
1967	Adapazari	7.1	89	
1968				Seismic code revised
1970	Gediz	7.2	1089	
1975				Seismic code revised; ductile detailing required
1976	Muradiye	7.5	3840	
1983	Erzincan	6.9	1155	
1997&1998				Seismic code revised; ductile detailing required
1999	Izmit	7.6	17.127	
1999	Düzce	7.2	894	
2007				Seismic code revised
2011	Van	7.2	604	

Reinforced concrete building’s poor performance before 1975 was believed to be the reason of heavily damaged structures and huge number of casualties. Because of this issue, serious revisions introducing ductile behavior of structural elements has been added to the seismic building code (Iner, Ozmen and Bilgin, 2008).

Later, it was discovered that the brittle behavior is not the only cause of insufficient performance but another issue is “irregular building”. These issues were clearly defined in 1998 version of Turkish seismic code in the section titled “Analysis Requirements for Earthquake Resistant Buildings” (Harmankaya and Soyluk, 2012). Its further describes various deficiencies under the overall name of irregularities and prohibits construction of such buildings due to their “unfavorable seismic performance”

While the code defines some procedures to be considered in the case of irregularities, the designer is strongly advised to avoid such designs (Harmankaya and Soyluk, 2012).

3.3 Structural Irregularities

There are many kinds of structural irregularities which are initiated during the architectural design stage. Tezcan and Cenk, (2001) states that the irregularities of buildings might include the following; plan of buildings not appropriately designed and vertical direction, disjointedness in mass and rigidity distribution, not paying attention to conformation of structural elements on serial axis, not considering distinct height between floors, implementation of short pillars and pounding effects” (Tezcan and Cenk, 2001).

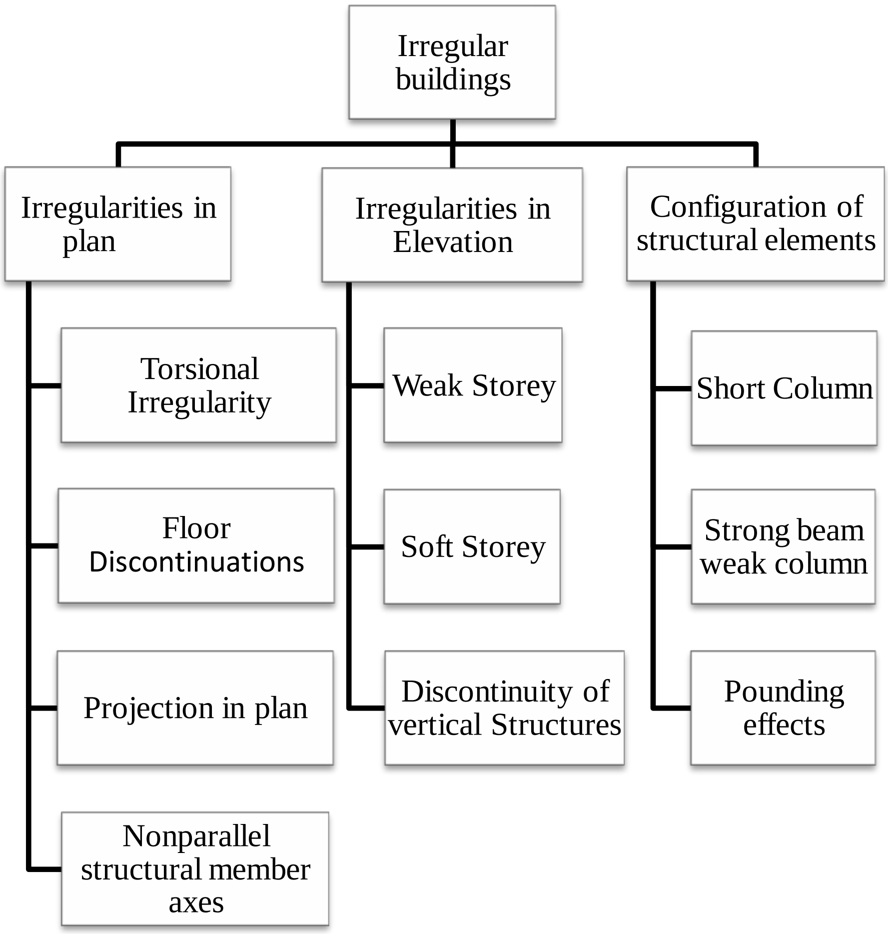


Figure 3.1. Structural Irregularities According to 2007 Turkish Earthquake Code.

3.3.1 Irregularities in Plan

"Irregularities in plan" is primarily categorised into four major types of structural irregularity, which includes the;

- Torsional irregularity
- Floor discontinuities or disjointedness in floor levels
- Projections in plan
- Nonparallel or serial structural member axes

3.3.1.1 Torsional Irregularity

Regarding building structures that resist earthquake; “a seismic force acts on the center of gravity of the building, and the building deforms in horizontal direction and also rotates about the center of rigidity” (Kato, 2011). Thus, extreme deformation occurs in part of the building, consequential in damage to structural members, if the point which the gravity acts (center of gravity) and the center rigidity are excessively far away from one another. As a result, load-bearing capacity of the building reduces, and the load of the seismic force is intense on the other parts, which may lead to fail of the building (Kato, 2011).

“The center of gravity is the center of planar shape of a building and is the center of gravity. The center of rigidity is the center of forces that counteract a horizontal force. The center of rigidity can be determined from horizontal rigidities of earthquake-resistant elements such as shear walls and their coordinates”. Furthermore, a difference between the center of rigidity and the center of gravity of a building is cleared by an eccentricity and an eccentric distance. “The eccentricity that can be calculated from the eccentric distance, is defined as the ratio or proportion of the distance between the center of gravity and the center of rigidity to torsional resistance” (Kato, 2011).

Figure 3.2 shows the main concept of eccentricity in plan when centers of gravity and rigidity do not coincide. Large eccentricities will induce large in plane torsions which need to be accounted for. Having said this, most seismic codes require a minimum (usually 5 per cent) eccentricity to be considered even in the case of regular structures to account for imperfections due to construction tolerances (Özmen and Ünay, 2007).

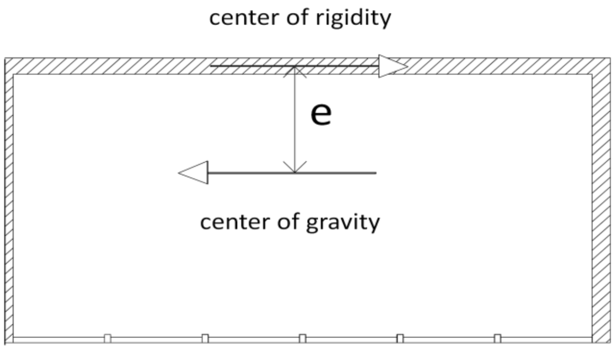


Figure 3.2. Working Mechanism of Gravity and Rigidity Center (Ambrose & Vergun, 1985)

While changing the center of mass is rather difficult, rigidity center can be altered by displacing the columns, shear walls, together with the dimensions of beams and columns (Özmen and Ünay, 2007). An example of effect of addition of shear wall on decreasing the torsion is schematically presented in Figure 3.3.

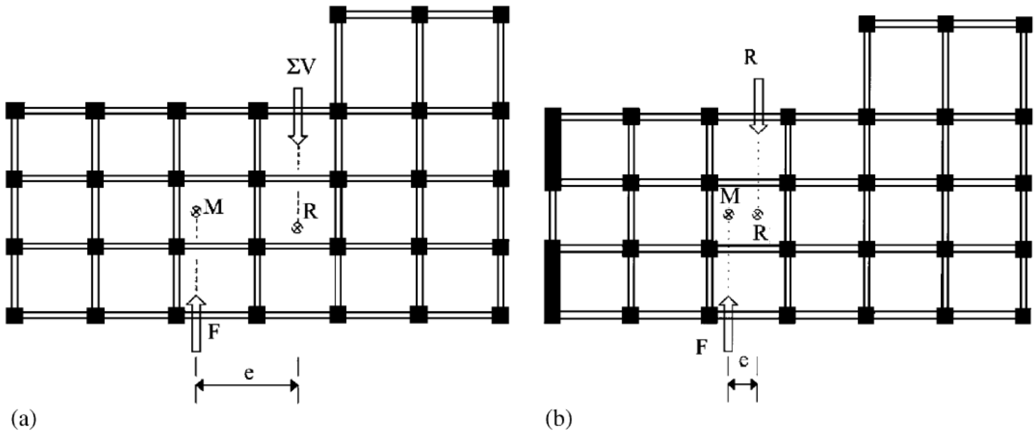


Figure 3.3. Modifying the Center of Rigidity (Özmen and İ. Ünay, 2007)

It should be clarified by now that a building should include both appropriate forms (vertically and horizontally) and contain well-arranged structural elements. In other words, it is better from a seismic performance point of view that a structure be simple and symmetric, as designated by Ambrose and Vergun, (1985). It’s of paramount concern to comprehend the general behavior of simple building structures that are prone to earthquake conditions or activities.

Despite of simplicity in plan, irregularity in rigidity distribution may be the source of in plane torsions at storey levels. An example is the case when asymmetric shear wall system is used in a building. In such situations when one side is kept firm the other side is free to move which may lead to torsion (Karaesmen, 2002).

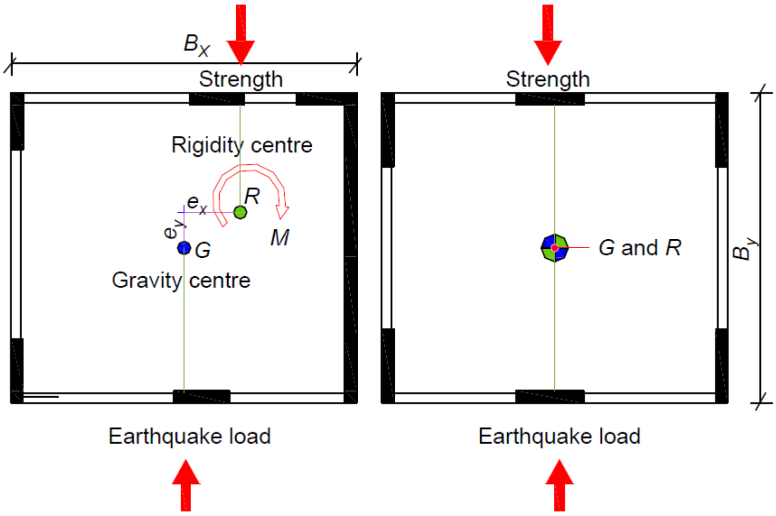


Figure 3.4. Torsional Effect on Symmetric Building due to Irregular Configuration of Shear Walls (İnan and Korkmaz 2011)

In agreement to Arnold, (2001), as well as Dimova and Alashki, (2003), another source for torsion is unequal distribution of stiffness along the perimeter of building which causes uneven resistance and in turn torsional moments. Beachfront apartments, for instance, are buildings that were designed with open facades, with orientation facing the beach side, which serves as a good illustration for unequal spreading of the strength and rigidity, leading to torsional moments. Other instances of such structures or buildings, are “bank halls, shops, including department stores as well” (İnan and Korkmaz 2011).

Figure 3.5. A Building Damaged due to Torsion Eccentricity (Özmen and İ.Ünay, 2007)

In addition to above, location of stair cases may greatly influence the seismic characteristic of the building due to their contribution to stiffness. However, (Su 2010) mentioned that, stairs are composed be primary structure element such as beams; slab and columns which contribute to increase the stiffness of the buildings. Hence the stair cases elements are sometimes characterized by their high seismic demand (Shyamanada Singh, 2012)

3.3.1.2 Floor Discontinuities

"Floor discontinuity" can simply be defined as presence of openings in the slab. Slabs play an essential role in any structure that is transmitting lateral forces to the earth through beams and columns. Any distraction in floor continuity can be viewed like an obstacle along the path of the force hence preventing reliable load transfer (Celep and Kumbasar, 2004).

The Turkish earthquake code enumerates floor disjointedness or discontinuity as below and is also diagrammatically clarified in figure 3.6;

1. “Openings overall areas, consisting stairs cases as well as elevator shafts should not surpass one-third of a given gross floor area of any storey building”.

2. “Local floor openings conveying seismic loads to the perpendicular structural supports is problematic or almost impossible”.

3. “Sudden decreases applied in the in-plane stiffness and floors strength” (İnan and Korkmaz 2011)

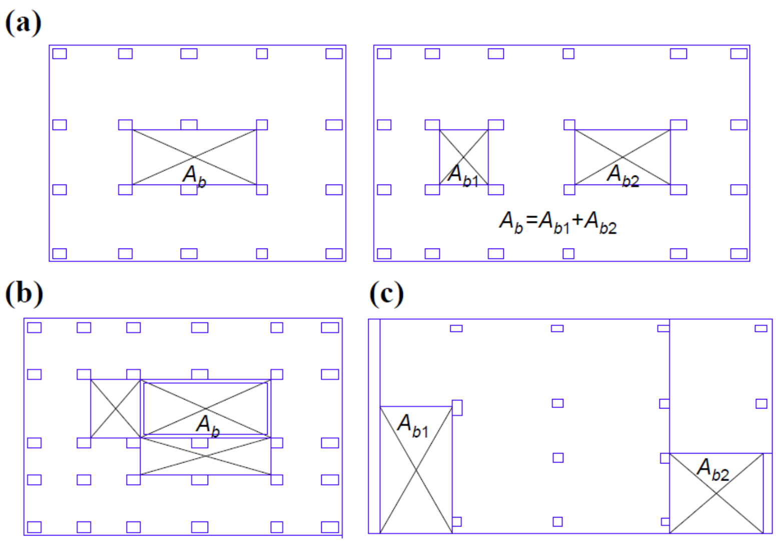


Figure 3.6. Floor Discontinuity Conditions (İnan and Korkmaz 2011)

Reliable load transfer should be guaranteed by means of division of discontinued floors to regular and simple geometric shapes. However, rigid diaphragm (or slab, is an element which one of its dimensions is very large compared to the other two) behavior should be assured by careful considerations (Ambrose and Vergun, 1985).

İnan and Korkmaz, (2011) also deliberated that the intermediate correlation of floor opening locations in plan and its fundamental interaction with supporting or load bearing walls or system, is carefully considered in the performance of buildings in terms of earthquake, as schematically shown in figure 3.7. It was equally noted that, buildings structures which are made up of central floor opening and L-shaped shear walls at their angles or comers" are mostly preferred, compared to "that with floor openings on one end or corners" in terms of earthquake outcomes or occurrence (İnan and Korkmaz 2011).

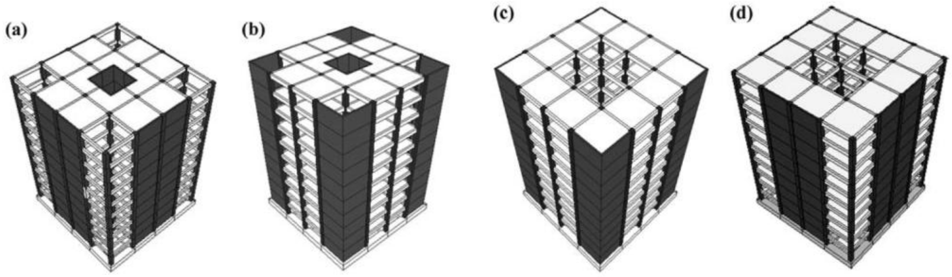


Figure 3.7. Shows the Intermediate Interaction of Floor Discontinuity and Structural System (İnan and Korkmaz 2011)

3.3.1.3 Projections in Plan

In view of architectural concern and functionality demands, it is observed that nearly all entire reinforced concrete buildings (RCB) comprises overhangs in their plan, particularly residential buildings. The ratio of projections or overhangs in the entire plan, should be significantly considered in terms of seismic performance of the RC buildings. Mostly, large projections will provide additional stresses on the structure which in turn results in torsional eccentricities. However, the most "climacteric shear forces and moments take place in the projection point of intersection and the primary body" (Özmen and Ünay, 2007).

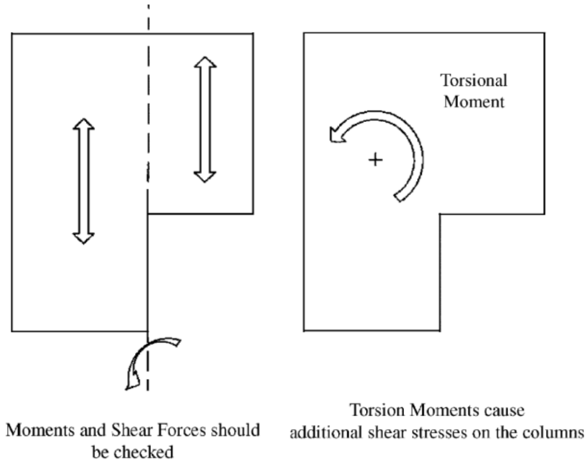


Figure 3.8. Disadvantages of Projections in Plan (Özmen and Ünay 2007)

Arnold, (2001) also identifies best forms as circle and square due to their simple and symmetric shape. He also noted that, two major problems are associated with complex, shapes such as “torsion” and “rigidity or stiffness variations”.

On the other hand, Atımtay, (2000), as well as Charleson, (2008) asserted that asymmetric complex plans “for instance “L”, “H”, “T”, “U”, “Y”, and “þ”, have trivial energy absorbing ability attributable to the torsional effects and stress absorption at notch points”

This is also true for structures containing different blocks which come together. Each wing in such buildings will move separately inducing stress concentrations at connection points. Figure 3.9 shows how different blocks of a building are separated for insuring independent behavior (İnan and Korkmaz 2011).

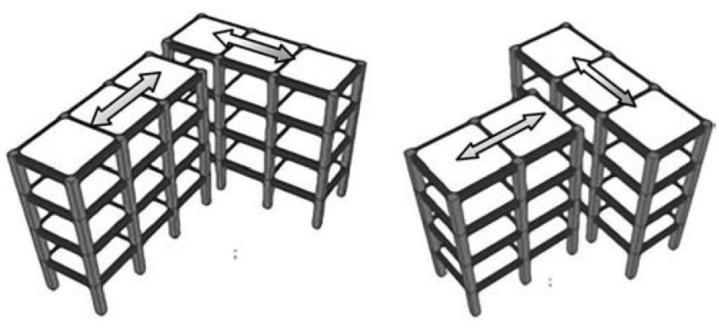


Figure 3.9. Seismic Joints (İnan and Korkmaz 2011)

The earthquake code of Turkey for the overhangs in plan irregularity is vividly described as when the “overhangs outside the re-entrant angles or corners in both of the two major directions in plan surpass the overall plan sizes of the building by greater than twenty percent in the considered individual dimensions, as schematically outlined in Figure 3.10.’’.

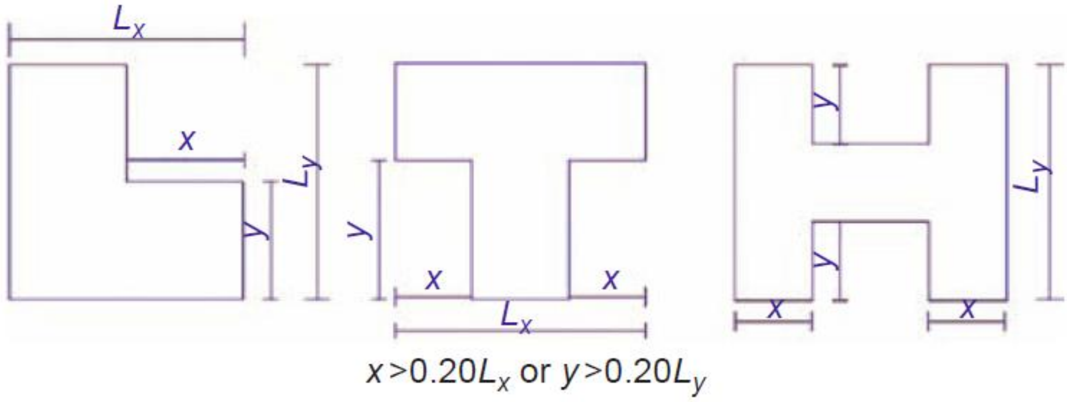


Figure 3.10. Projections in Plan (İnan and Korkmaz 2011)

Özmen and Ünay (2007) declare that in terms of necessary projections, the structure ought to be disjointed into a number of sections with structural expansion joints, as show is Figure 3.11. On the other hand, Figure 3.12 shows a building that was ruined after Marmara earthquake, and is attributed to irregularities in plan.

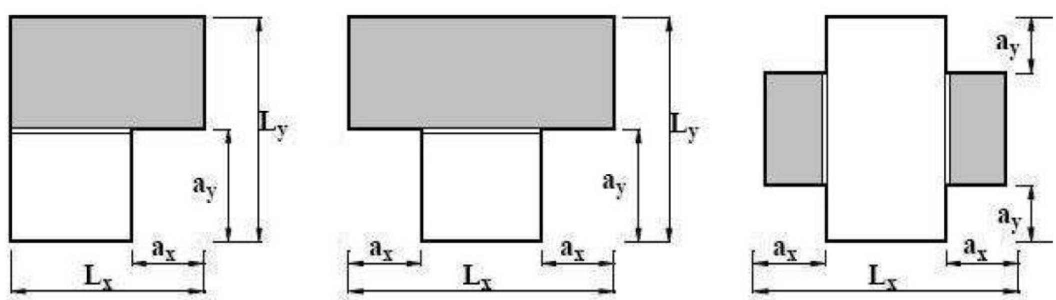


Figure 3.11. Structural Expansion Joints (Divided in to Several Sections as a Prevention Method) (Tezcan, 1998)

Figure 3.12. Illustration of a Building that was Ruined after Marmara Earthquake, Attributed to Irregularities in Plan (Balyemez and Berköz, 2005)

3.3.1.4 Non-parallel Axis in Plan

On the other hand, the earthquake code of Turkish refers to Non-parallel axis in plan irregularity as below;

Non-parallel axis in plan is when the principal axes of the vertical structural members in plan are not in everywhere equidistant and not intersecting to the deliberated orthogonal “earthquake” directions (see Figure 3.13).

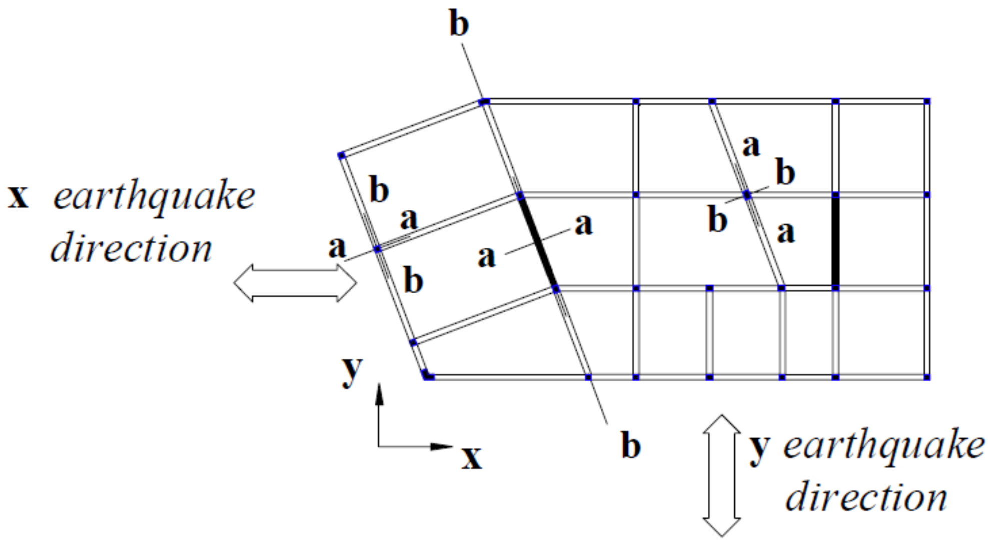


Figure 3.13. Non-Parallel Axes (TEC, 2007)

Architects as a rule begin to design a building to comply with the “parcel form”, doing so, is to gain level best advantage of the parcel land. On the other hand, as a result of the intersection in street or organization of the space demands, designers are sometimes forced to construct structures with “nonparallel” or serial axis to solve the issue at hand. However, this irregularity is not secure from “lateral earthquake” load standpoint (İnan and Korkmaz, 2011).

In addition, Özmen and Ünay (2007), argued that beam connections with non-parallel axis can consequentially leads to torsional moments, as shown in Figure 3.14. Nonetheless, architects or engineers should abstain from implementing over-rigid and inadequate or short beam, since excessive torsional irregularity may occur (Özmen and Ünay 2007).

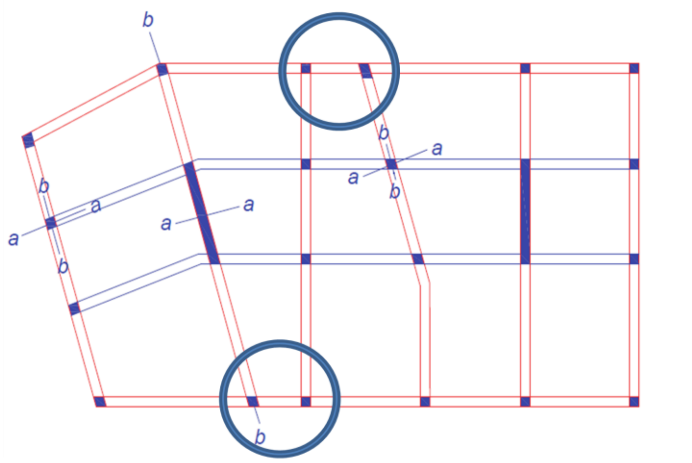


Figure 3.14. Over-Rigid and Short Beam (İnan and Korkmaz 2011)

3.3.2 Irregularities in Elevation

Irregularities in elevation involves three major structural irregularity which includes; “weak” and “soft storey”, as well as “discontinuity of structural components”.

3.3.2.1 Weak Storey

Kira, Dogan and Ozbasaran (2011) describes that weak-storey as "simply formed by the neighbor floors which have redundant columns, concrete walls and brick-wall areas".

Weak-storey irregularity usually takes place at the first storey of the building as a result of accumulated maximum loads. It can also be ascribe to minor strength or main tractability between floors. Furthermore, when the entire stories of the buildings are equilaterally inclined in terms of stiffness or strength, earthquake forces can be evenly dispersed homogeneous among stories (İnan and Korkmaz, 2011).

Weak-storey irregularities in Turkey, became one of the most common type of damage comes upon the phase of earthquake. Mostly, architects in Turkey functions the base floors as; shopping stores, car parking or other commercial purposes. Hence, base floor needs to visually face to City Street from one or both sides especially to the main city streets. In cases which sides facades, facing to the main street use of glass partitioning walls for presentation purposes are communal (Kirac, Dogan and Ozbasaran, 2011).

Above mentioned types of plan, lead to the configuration labeled as ‘‘weak stories" which are more in danger in case of earthquake than others due to the fact that they are less stiff, less resistant, or both (Kirac, Dogan and Ozbasaran, 2011).

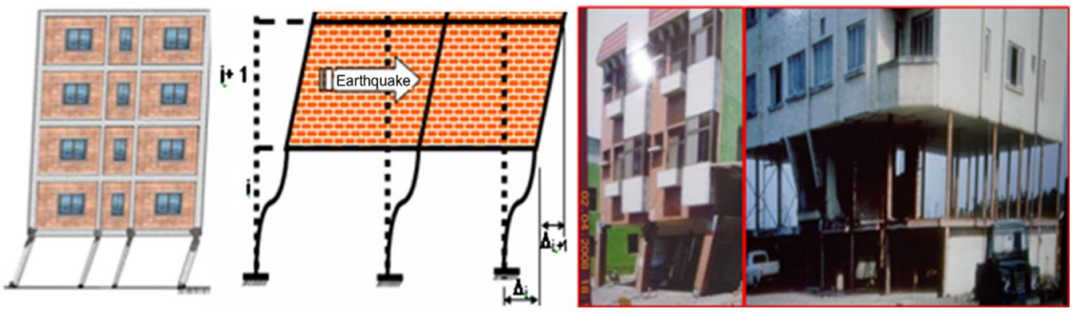


Figure 3.15. Behavior of Soft-Storey During Earthquake (Kirac, Dogan and Ozbasaran 2011)

Weak-storey irregularity is not just presented at base floor but also in some cases exist in the middle floors as well. In this case, these floors can be damaged instead of base floor (Figure 3.16). Therefore, symmetry of the structural elements is necessary in both vertical and horizontal directions to have symmetrical regularity in structure to minimize damages in phase of earthquake as much as possible (Kirac, Dogan and Ozbasaran 2011).

Figure 3.16. Failure of Middle Floors under Earthquake Loads (Doğan 1986)

According to examinations and analysis done by experts, the walls linking two columns act as beneficial elements in earthquake resistance. Having said this, correct use of partitions and infill walls increase the rigidity of the building and provide significant rigidities and lateral load carrying capacities, when they are subjected to low lateral loads (Kirac, Dogan and Ozbasaran 2011).

Bayülke, 2001 mentioned analysis shows that, during an earthquake to prevent the excessive displacements of the structure, use of infill walls, installed in a frame which act as shear walls could be a good solution. Hence, partitions and infill walls have considerable rigidities and "lateral load" carrying capacities, when they are subjected to low lateral loads. Reinforced concrete frame with partitions and infill walls has a shorter natural period of vibration than the one without partitions and infill walls (Bayülke, 2001).

General analysis of the Turkey earthquakes shows that most of buildings are collapsed or partially damaged due to weak storey irregularity. As an example of this we can mention 1999 Izmit earthquake by 725 damaged buildings out of 1215 as a reason of weak-storey (Kirac, Dogan and Ozbasaran 2011).

There are parameters which have effects on the weak-storey irregularity formation in structures; these parameters are listed as follows:

1. Height of the weak-storey.
2. Existence of mezzanine floor.
3. Rigidity and distribution of columns in weak-storey.
4. Overhang and cantilever projection existence in weak-storey.
5. Infill wall material properties.
6. Soil class and properties.
7. Floor number.
8. Seismic conditions.

3.3.2.2 Soft Storey

Another problematic issue in phase of earthquake is existence of soft storey in building (see Table 3.3). Building with a “stiff and a rigid superstructure placed on top of and an open and a flexible floor” is defined as building with soft storey (Lagorio, 1990).

It is quite possible that soft storey occur at an upper level. However in buildings with soft storey, critical condition occurs when the soft storey is located at the ground floor, because generally greatest shear is at the ground floor level (Ambrose and Vergum, 1999) In case of earthquake, any unexpected loads which provide changes in lateral stiffness will result in deformation and stress in a building, (Ambrose and Vergum, 1990).

Arnold (2001) mentioned several constraints that can give forth to soft storey irregularity as follows**;**

Table 3.2. Various Characteristics that can Contribute to Soft Storey Irregularity (Arnold, 2001)

When the ground storey of a building is significantly taller than upper floors. This results in less stiffness and more deflection in the ground storey (Figure 3.17a).
When there exists an abrupt change of stiffness at the upper floor, although the floor heights remain approximately equal. This is caused primarily by material choice, for example, the use of heavy precast concrete elements above an open ground floor. Figure 3.17b states that greater dimensions of columns and beams at the upper floors, when compared to the lower ones, and infill walls at the upper floor, which are not taken into consideration during earthquake analyses, also increase the rigidity of the upper floors and result in soft storey formation.
When the vertical structural elements do not continue down to the foundations and interrupt at any floor level, when there exist discontinuous load paths **(**Figure 3.17c**)**. Thus, it also creates change of stiffness

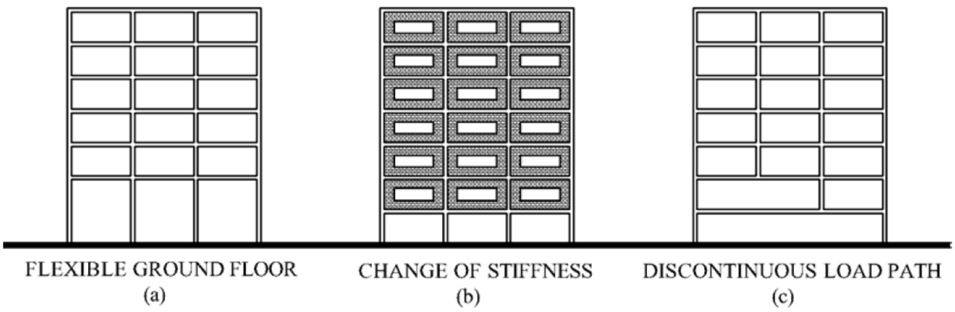


Figure3.17. The Case of Soft Storey Formation

Therefore, it’s due to distinction in rigidity or stiffness between floors or stories, however, more displacement exhibited at the ground floors compared to the others floors. Here it is important to note that in buildings with open ground floor, for examples, “shops”, “meeting rooms”, as well as “banking halls” and etc. moreover, for such buildings, excessive floor drift emerges in the ground floor, while the upper floors is displace similar to a diaphragm (Figure 3.18).

Tezcan, 1998 also noted that “high stress concentration surfaces on the connection line in the middle of the ground and first floor, which results to flaws such as distortion as well as collapse in building structures” (Tezcan, 1998).

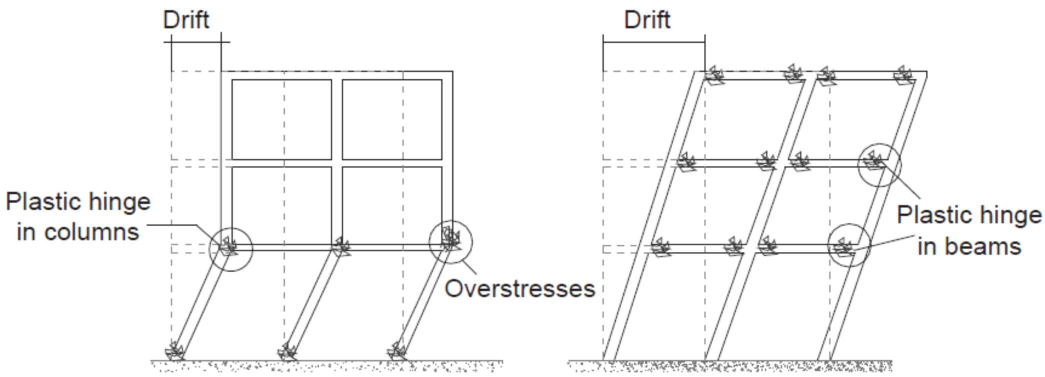


Figure 3.18. Storey Displacement and Hinges (İnan and Korkmaz 2011)

Figure 3.19. Collapse due to Soft or Weak Storey (Tolleson, 2010)

Table 3.3. Shows certain likely remedies for lessening soft and weak storey effects, if relatively open ground floor is necessary (Ambrose and Vergun, 1985).

Table 3.3. Some Feasible Way Out to Decrease “soft” and “weak” Storey Characteristic (Ambrose and Vergun, 1985)

1. Bracing some of the open bays (Figure 3.20a). If designed adequately for the forces, the braced frame (truss) should have a classification of stiffness closer to a rigid shear wall, which is the usual upper structure in these situations. However, the soft or weak storey effect can also occur in rigid frames, where the “soft” storey is simply significantly less stiff.
2. Keeping the building plan periphery open, while providing a rigidly braced interior (Figure 3.20b).
3. Increasing the number and/or stiffness of the ground-floor columns for an all rigid frame structure (Figure 3.20c).
4. Using tapered or arched forms for the ground-floor columns to increase their stiffness (Figure 3.20d).
5. Developing a rigid first storey as upward extension of a heavy foundation structure (Figure 3.20e).
6. It is also possible to put elastic materials between structural elements and the walls (Figure 3.20f) (Paz, 1994).

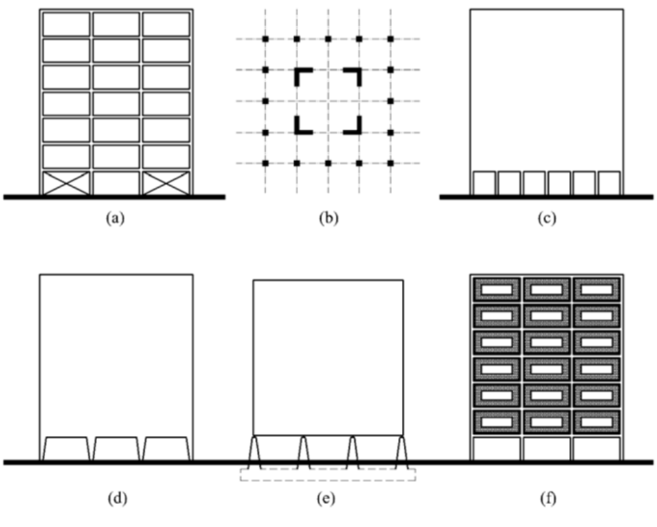


Figure 3.20. Solution for Weak Storey (Ambrose and Vergun, 1985)

It is necessary to understand the difference between a soft storey and a weak storey; however, it is possible for a single storey to be both (Ambrose and Vergum, 1999).

Criteria of International Building Code (2003) about this issue are:

Stiffness irregularity-Soft Storey: "A soft storey is one in which the lateral stiffness is less than 70% of that in the storey above or less than 80% of the average stiffness of the three stories above" (associated with displacement).

Discontinuity in capacity-Weak storey: "A weak storey is one in which the storey strength is less than 80%of that in the storey above. The storey strength is the total strength of all seismic-resisting elements sharing the storey shear for the direction under consideration" (associated with strength).

3.3.2.3 Discontinuity of Structural Elements

In the design for lateral loads, the function of structures is to bring into play a pathway for traveling forces enforced to the structures from their point of reference or source through the entire members and into the ground. As a result of that, the vector paths must be complete without any disruptions in the actual rate of flow in order to evade problem (Özmen and Ũnay 2007).

Özmen and Ũnay, (2007) mentioned that in a whole building height (top to bottom), "shear-walls", "partition walls", including columns may discontinue before the highest floor. However, Ambrose and Vergun, (1985) refer to occurrence of problem caused by discontinuity of structure especially in multi-storey buildings, and also cited that columns and shear walls ought to be arranged in stack on top one another.

Ambrose and Vergun (1985) therefore, added that, in the lower storey of a building, when a column is detached, it implies that the application of weighty transfer girder, couples with other device are necessary to handle the discontinuity. However, can be problematic when not treated appropriately, as demonstrated in (Figure 3.21) (Ambrose and Vergun, 1985).

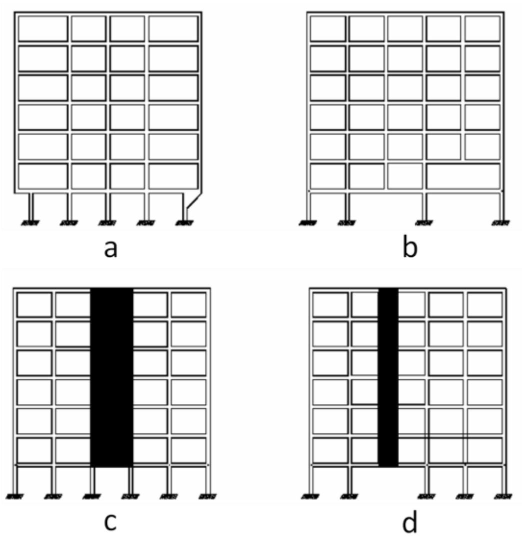


Figure 3.21. Discontinuity of Vertical Structural Element (TEC, 2007)

According to TEC, this irregularity is present where perpendicular structural elements are situated inappropriately, and are elucidated as follows;

- “Gusseted pillars (columns) and projected columns leaning against horizontal beam are forbidden (Figure 3.21a) (TEC 1998).
- In circumstances where a column leans against a beam reinforced with columns at both ends, in this situation the entire interior forces comprising perpendicular and seismic loads from the direction of earthquake should be enhanced by 50 % at all sections of the entire beams, in addition to the columns which are conterminous to the beam (Figure 3.21b) (TEC 1998).
- On no circumstances should the shear walls be appropriated to hinge on the columns (Figure 3.21c) (TEC 1998).

- On no account should the shear walls be permissible to lean on the beams" (Figure 3.21d) (TEC 2007).

Until 1998, according to earthquake code, these types of irregularity were not forbidden, but from 2007 earthquake code were modified. These modifications clarified that structural components which include columns and shear-walls must not be interrupted from end to end of the entire building height (Soyluk and Harmankaya, 2012).

Furthermore, if the structural elements are not continually functioning according to above mentioned rules then the structural components of the buildings might weaken the storey or emanate to torsional effects.

3.3.3 Configuration of Structural Elements

Configuration of structural elements is another remarkable issue which consists of three diverse categories of structural abnormality. These configurations are considered as follows:

(a) Short column (column lacking in length), (b) weak column-strong beam, and (c) pounding effects (Gönençen 2000).

3.3.3.1 Short Column

"Short columns may be developed due to structural arrangements or due to openings provided in infill walls between columns (Figure 3.22.**).** In cases where short columns cannot be avoided, shear force for transverse reinforcement shall be calculated" (TEC, 2007).

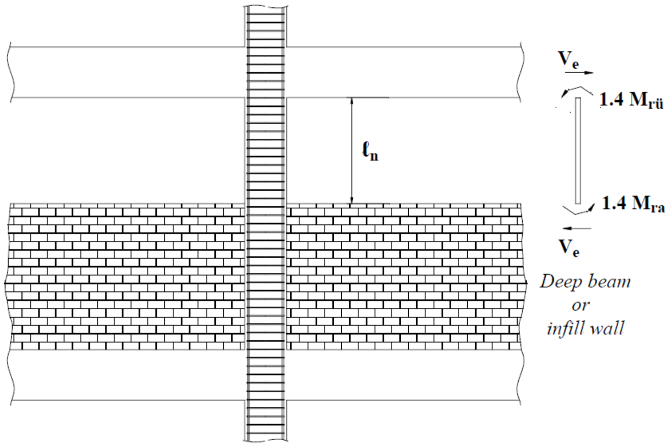


Figure 3.22. Definition of Short Column (TEC, 2007)

According to Murthy, 2007, a building can be exposed to shear cracks (X-shaped) at both ends of a column, if there is an extreme increase of seismic energy on a building (Murthy, 2007). As an example, there will be two times more shear on that column, if the height of an element reduced to half as shown in Figure 3.23.

Inan and Korkmaz, (2011) classified some of the significant situations instigating short columns as;

a. Conterminous columns to the openings of stair landings,

b. Mechanical floors,

c. Mezzanine floors,

d. Graded foundations,

e. Hillside sides, and

f. Ribbon window or partial opening, are attributed to the major characteristic that leads to implementation of short columns in building structures.

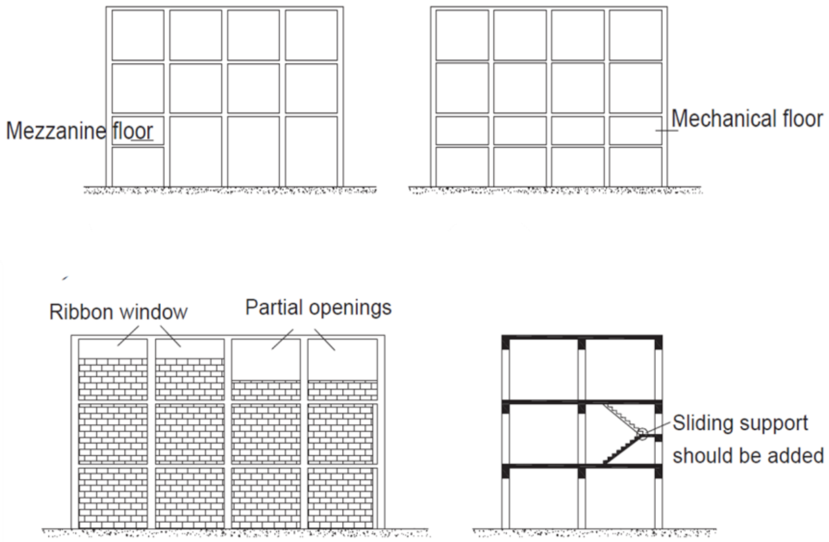


Figure 3.23. Formation of Short Columns (İnan and Korkmaz, 2011)

Generally, architects must be conscious about the circumstances that leads short column irregularity in buildings. Hence, mutual understanding between the structural engineers and architects is necessary to avoid this kind of problem in the architectural design process (Gonencen, 2000).

Mostly, the structural analytic aspect are calculated by engineers without considering the infill walls. Nonetheless, partition infill walls play a significant role on the seismic performance of the structure. Moreover, this might affect the building negatively, as well as reducing the ductility of the structure and resulting to shear stresses and torsion on structural components or effect positively by acting as shear-walls.

Özmen and Ünay, 2007, also state that, short columns irregularity is one of the most frequent problems initiated through low partition walls, which are not inaccessible from the RC structure consisting of earthquake joints (Özmen and Ünay, 2007).

3.3.3.2 Strong Beam Weak Column

Weakness in columns temper with the entire stability of a structure. Notwithstanding, in a common structure, it is anticipated that beams should initiate deforming ahead of columns, however, beam distortion partly affects the building. Accepting these facts, more emphasis should be given to flexibility of the beams, which is of paramount importance than the columns. Hence, from a structural view point, placing a plastic hinging at both ends of the columns, induce storey displacement or in other words, may lead to overall failure or collapse of the building (Bayülke, 2001).

Murthy, (2007) again mentioned that, to prevent plastic hinging in columns, we should have weakest links in the beams instead of columns. This is achieved when sizing of the structural element are properly proportioned and appropriate quantity of steel in total structure is selected or suggested appropriately utilised (Murthy, 2007). Some researchers consider total capacity of columns in a joint to be greater than total capacity of beams by at least 20 percent. However, in TEC (2007) this is required if the structure in going to be designed as "highly ductile".

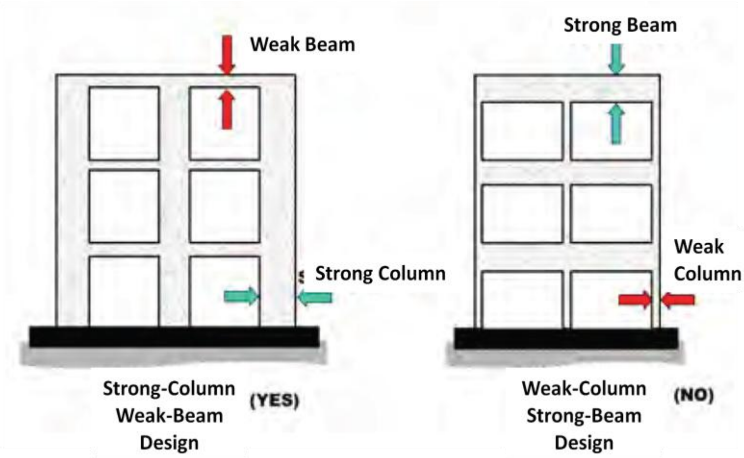


Figure 3.24. Strong Beam Weak Column (The Beams must be Designed to Act as the Weak Links in a RC Frame Building; this can be Achieved by Designing Columns to be Stronger than Beams) (Murty, Charleson and Sanyal, 2006)

The most important fact is that the researches done related to structure in terms of earthquake is saving human life. As a result of that, emphasis on reinforced concrete structure is to avoid an entire or partial collapse. Özmen and Ünay, (2007) pointed out that one of the major or important considerations is the ability for a structure to withstand the highest energy by ductile deformations in column–beam connections, while the other is preservation of the lateral stability of the structure (Özmen and Ünay, 2007).

Usually, "ductile deformations" take place at the upper and lowest points of the columns, in this situation it can be established that the moment capacity of the beams of the building are more than the columns. In such circumstances the columns can simply lose their lateral strength, due to excessive displacements (Özmen and Ünay, 2007).

Demolition of the whole building is a sad tragedy in phase of earthquake and this tragedy happens when the highest earthquake energy takes place or happened at the ground floor, then the columns in this level will first collapse. Hence, "ductile deformations" may be initiated at the ends of the beams if the moment capacity of the columns higher.

Özmen and Ünay (2007) argued that the beams are capable of absorbing lots of energy by ductile deformations without any substantial damage in the load conveying capability.

One duty of architects is to keep in mind the codes use in design for strong column and weak beam, as well as implement it in accordance to stated Codes (see Figure 3.25) (Özmen and Ünay, 2007).

Figure 3.25. Illustration of the Destruction Triggered by Weak Column-Strong Beam Structure (Gulkan et al. 2002)

3.3.3.3 Pounding Effects

If two buildings are located in a very close distance into each other, subsequently they may collide during strong shaking; this effect is known as pounding. The pounding or hammering effect is more apparent in taller buildings. When buildings heights do not match with each other, then the roof of the shorter building may pound at the mid-height of the columns in the taller building; this can be very dangerous, and lead to storey collapse (Murty, Charleson and Sanyal, 2006).

Pounding generally occurs because of inadequate seismic gap or attributed to gap absence between two adjacent structures (Doğan, 2007). İnan and Koray, 2011 also added that, “soft ground floors” and “irregular plan geometry”, are also two parameters which can induce building to excessive deformations (İnan and Koray, 2011).

Figure 3.26 demonstrates the distinctions for pounding situations in different floor levels.

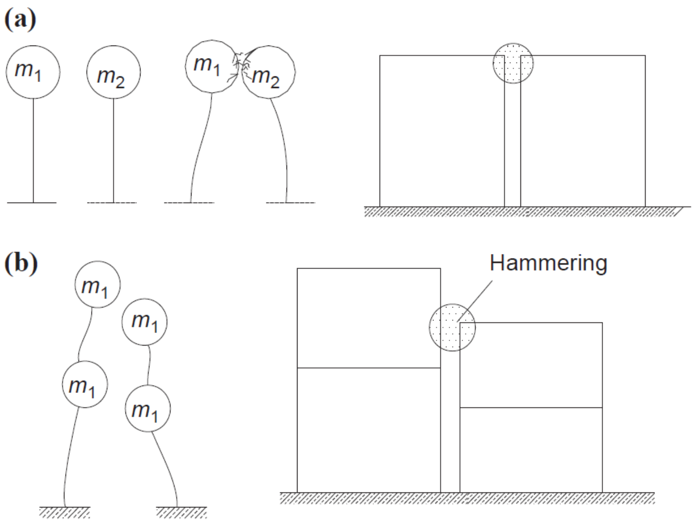


Figure 3.26. Dynamic Pounding Effects

Notes: (a) from the portrayed -same storey level; (b) at the bottom described -different storey level

According to documents presented by TEC, (2007) "the lapses induce stress concentration, as well as initiating the blocks to collide with one another which consequently changes the vibrations of the blocks".

Investigation on dynamic behavior of buildings proves that, the building mass is piled up or accumulated at the floor level. On the other hand, a "mass accumulation" can be determined for respective storey of the building, however, with the assurance that "individual storey has rigidity and damping coefficient" (TEC, 2007).

Other substantial issue here is positioning of floors at the same level between two buildings, if not the act of hammering occurs and damages will increase. In Turkey, the act of hammering is count as one of the most important effects during the phase of earthquake as neighboring structures implementation are enormously frequent ascribed to nonexistence of building lots. Figure 3.27 shows the effect of hammering on buildings after the Bingöl Earthquake.

Figure 3.27. Hammering Effect for Adjacent Building (Doğangün, 2004)

Based on rules driven by TEC, (2007) the “seismic gaps” must be minimum of 30 mm, adequate to 6 m in height and as from there for every 3 m height addition, minimum 10 mm seismic gaps should be added (TEC, 2007).

The following conditions show the sizes of gaps for the seismic joints in between building blocks or apartments, as well as older structures and recently built constructions “ought not to be below the square root of the sum of squares of average floors or storey/level displacements times the coefficient” (TEC, 2007).

3.4 Irregularity Due to Wrong Frame Elements Location

Although irregularity due to wrong frame elements location is not directly addressed in seismic codes, they have significant effect on lateral resistance of structure during ground shaking. These are problems both in plan and elevation in other words they might be taught of 3D irregularities.

3.4.1 Element Design Faults about Beams

One of the essential issues here is an architect must avoid designing discontinuous beams or breaking the continuity of beams in floor plans. Hence, in the buildings with this kind of configuration lateral forces will be distributed to the beams or shear walls through the adjacent floor slab (Özmen and Ünay, 2007).

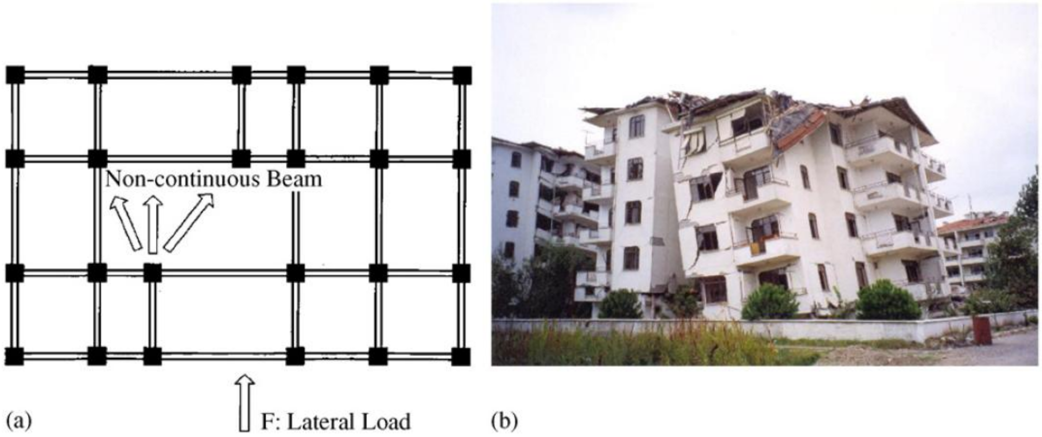


Figure 3.28. Discontinuous Beam (Özmen and Ünay, 2007)

Sometimes due to spatial considerations in floor plan of building, vertical load-bearing members of the structure (columns) are absent at the “beam-to-beam” point of connections. In this kind of configuration, large point load, creating critical moments on the connection points of beams which may lead to “huge deflections” and “beam collapse or cracks”.

If such a connection is close to the support, there is that tendency that extreme acute torsion moments will occur on the beams connection, as shown in Figure 3.29. Additionally, to produce system strong enough to overwhelm or withstand earthquakes, extremely large and wasteful component cross-sections will be desirable (TSE, 2000).

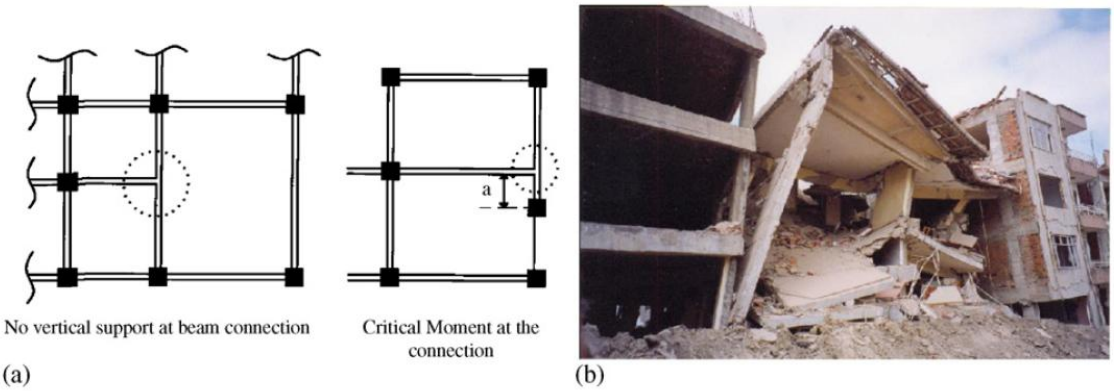


Figure 3.29. Beam Intersecting Without Vertical Supports (Özmen and Ünay, 2007)

Like non-parallel axis, beams with broken-axis will create significant “torsion moments” on structural system. It implies that, the lateral rigidity of the structure will altered across the entire plan; hence inducing irregular displacements. To build a system that can survive earthquakes on the structure with broken-axis, extraordinary and uneconomical component cross-sections is necessary or essential in this case.

In addition, most engineers converts three-dimensional building into two-dimensional frames to attain an effectual analytical result. However, in frame systems with broken-axis, treating the system with two-dimensional analysis are impossible. Consequently, in such a condition the loads cannot be rationally ascertained, as shown in Figure 3.30 (Özmen and Ünay, 2007).

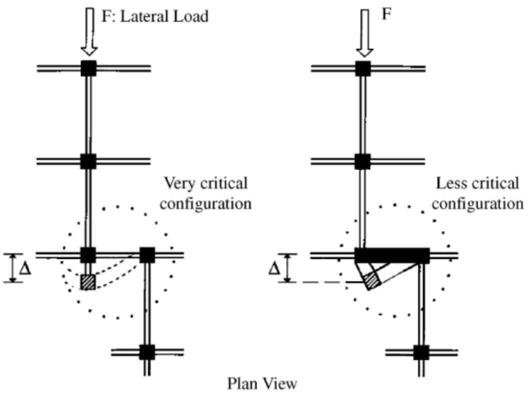


Figure 3.30. Beam and Frames with Broken Axis (Özmen and Ünay, 2007)

3.4.2 Element Design Faults about Slabs

Rigidity in plan is one of the important factors of calculating the shear stresses performing on the columns. Özmen and Ünay (2007), also point out taht "over-overextended one-way slabs can absolutely cause huge deflections under "lateral loads, as illustrated in Figure 3.31 below".

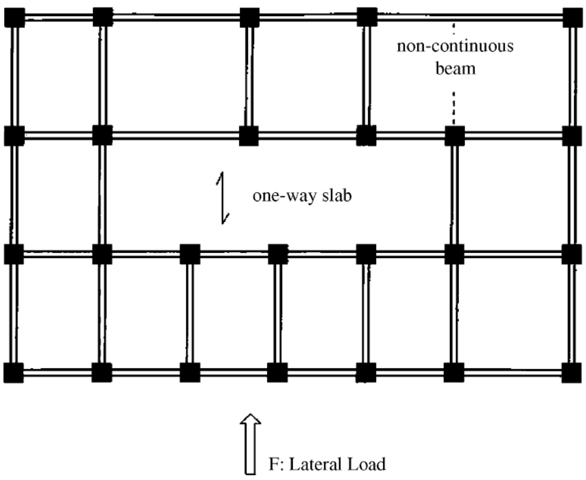


Figure 3.31. Over-Stretched One-Way Slabs (Özmen and Ünay, 2007)

3.4.3 Element Design Faults about Columns

Represented cases in Figure 3.32; clarify irregular and regular column configuration. Figure 3.32a shows irregular configuration of column with broken-axis. It will be really challenging to construct uninterrupted frames in this particular type of irregular plan.

On the one hand, Figure 3.32b shows, that the columns have been regular located in accordance to an axial system and dispersed consistently or adequately for all earthquake direction effect. On the other hand, buildings with regular axis system has extraordinary or maximum lateral rigidity, although, the displacements are insufficient.

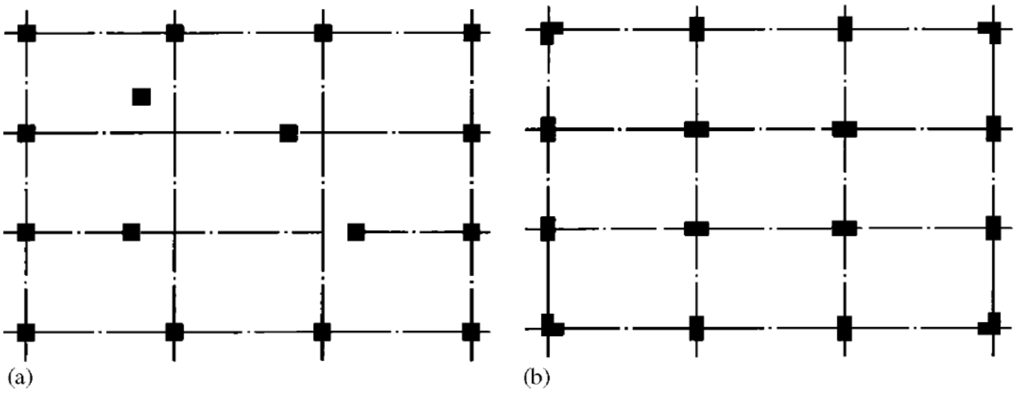


Figure 3.32. Illustration of Irregular and Regular Configuration of columns (starting from right to left) (Özmen and Ünay, 2007)

3.5 Heavy Overhang

Due to public improvement laws, developers have the possibility to increase the plan dimensions at upper floors then the ground floor. This kind of plan extension provides serious problem during earthquake events (Doğangün, 2004).

Therefore, under earthquake motion, these kinds of projection particularly the proximate type will result to “critical displacements”, as well as “partial collapse” subjected to a vertical component of the earthquake (TEC, 2007).

Özmen and Ünay, (2007) related to this issue points out to support cantilever projections; beams should be continued under the cantilever slab. Figure 3.33 shows for increasing overall rigidity of cantilever parts, side beams should be designe around the border of the projection.

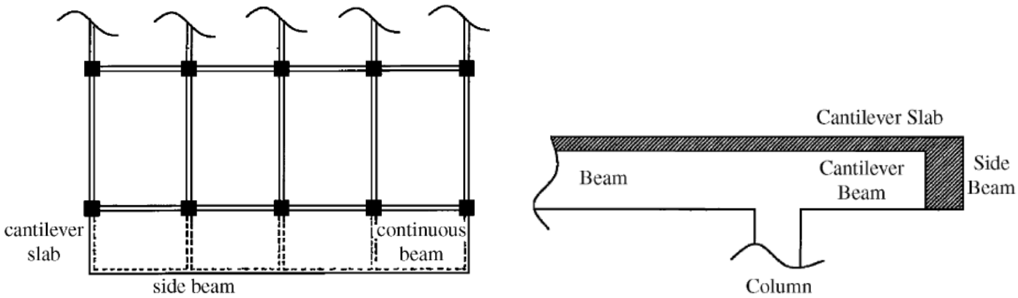


Figure 3.33. Cantilever Slab (Özmen and Ünay, 2007)

Figure 3.34. Heavy Cantilevers and Balconies (Doğangün, 2004)

Chapter 4

EFFECTS OF INTERIOR CHANGES ON EARTHQUAKE RESISTANCE OF BUILDINGS WITH REINFORCED CONCRETE FRAMES

4.1 Introduction

There is a crystal-clear concern that in today's lifestyle, changes in buildings will be made to meet at least an acceptable percentage of the needs of clients. Consequently, nobody can foresee the future, but it is possible to investigate what kind of changes may be made in the future, to have a better perspective on what building elements will be replaced.

As Habraken, (1976) has mentioned "The styles of ten years ago are not today's styles". Having said this, our lifestyles today will not exactly be the same in the future, and our knowledge about future generations is limited to presume the future. However, there are some reasons as high price of lands, high expenses to move from one place to another, sense of belonging to our own place and neighborhood and other related issues which lead people to prefer changes in their building. In addition to above, there is no definitive answer for what reason and when buildings are going to be changed or modernized. On the other hand, usually people try to change their house according to their needs.

Having said this, by spending time and just walking through our city, it is obvious that the functions of some buildings have been changed, buildings converted into stores, shops, garages, galleries and etc. These changes are not just applied on very old buildings, but also done in 10 or 20 years old neighborhoods.

Especially, in reinforced concrete frame buildings later modifications are more common. For example, in India, Algeria, Northern Cyprus and Turkey, usual modifications contain enclosing of balconies to expand room sizes, or removing interior walls to enlarge the existing space; and also in some cases removing a part of the walls to create openings (Murty, Charleson, and Sanyal, 2006).

Changes in buildings by users is a predicted future. These changes sometimes provide irregularity problems on RC buildings and this could be extremely risky in the event of an earthquake. Investigations on reports of earthquakes show that many RC buildings have been collapsed due to irregularity problems (Paz, 1994 and ITU, 1999). Irregularity problem is generally reason of wrong design, wrong construction and also inappropriate interior changes. Irregularity due to interior changes mostly has been formed by subtraction from the existing building structure or additions to the structure of an existing building (Hürol, 2013).

In a building capable of accepting future modifications, the structure is mostly seen as a separate level (Open buildings approach, see section 4.4). Then the other parts of the building are designed to accommodate the new changes without having a negative effect on earthquake resistance of buildings (Habraken, 1998; Leupen, 2005).

If the building is not designed for change and if future changes are not carefully designed, the structure will be influenced by new interior design concepts and new additive elements. Then, it can cause serious earthquake resistance problems (Habraken, 1998; Leupen, 2005).

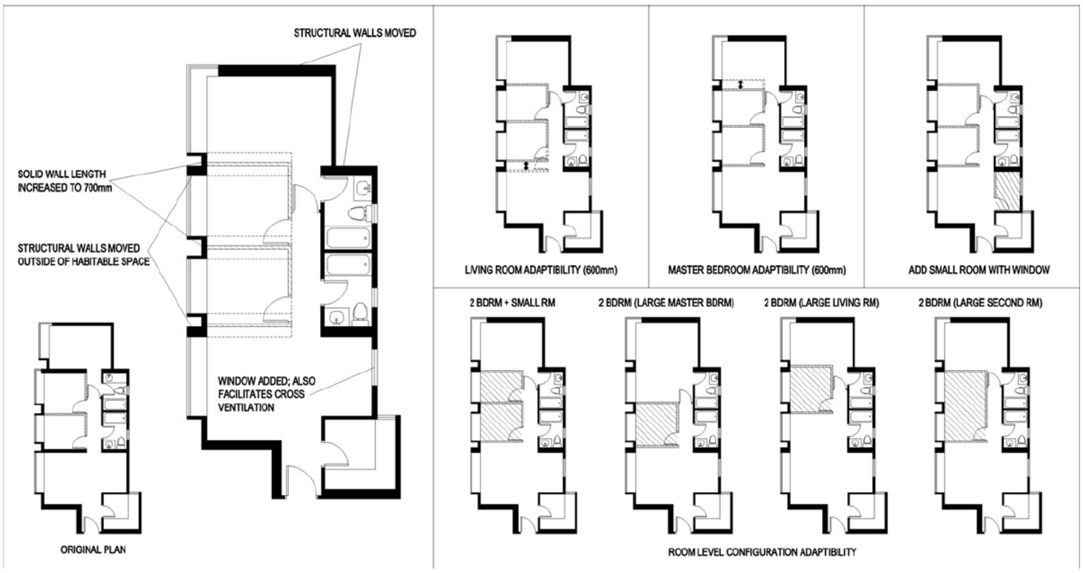


Figure 4.1. An Example of Possible Interior Modifications if the Structure Remains Untouched (Wong, 2010)

4.2 Problems Due to the Subtractions Made From the Existing Building Structure

Structure of buildings is generally recognized as different pieces of structure added to each other. These pieces are similar to each other or they are completely different. To form a 3D frame there is a possibility to have many bays of frames added to each other. (Lin and Stotesbury, 1981).

Hürol, (2013) cited; “structural design in interior design, which creates extension systems, cannot only be explained by adding structures to each other”. In view of the fact that an existing building is the object of interior design, then for interior designers it becomes possible or necessary to subtract pieces of the existing building structure.

Interior designers firstly imagine the subtractions and then start to design the necessary additions. However, if subtraction is applied on the existing building structure without considering the essential rules in changing the original design or is undertaken without involvement of qualified professionals, then the risk of earthquake damage will increase (Hürol, 2013).

Hence, subtracting from the existing building consists of subtraction of different structural elements such as:

I. Columns and beams
II. Slabs
III. Stairs
IV. Rigid infill walls
V. Light- weight infill walls

4.2.1 Columns and Beams Subtraction

For the reason that beams and columns in RC frame buildings are primary structural elements, subtracting them from existing building will disturb the continuity of the load transferring path in the structure of the building; even if the building is not in an earthquake region (Shyamanada Singh et al. 2012).

Subtracting columns will be the reason of discontinuity of vertical structural elements. Since 2007, in the "Turkish Earthquake Code or rules" the discontinuity of perpendicular structural components or members has been known as a type of building irregularity. The TEC describes this type of irregularity as; ''The circumstances where perpendicular structural elements (columns or structural walls) are detached at some floor levels and reinforced by beams or gusseted columns at the bottom or the structural walls of the upper floor levels are reinforced by columns or beams at the bottom (TEC, 2007)".

Hürol, (2013) quoted "the beams, which transfer their load to that column, do not have sufficient depth and reinforcement to carry their new load without that column. If vertical elements of a structure are removed, then they have to be replaced".

On the other hand, the beams are the connections between the frames and also they are the connection between the frames and the slabs. Hence, subtraction of a beam will disturb the formation of the frames. This provides "irregularity in plan".

Thus, in respect to the subject of "earthquake resistance" it is a very important requirement that availability of continuous frames from one side to the other side of the buildings should be achieved. Satisfying this requirement necessitates continuity of axes.

4.2.2 Slab Subtraction

Another critical issue under the title subtracting from RC structure is removing a slab, which will provide floor discontinuities irregularities. Inan and Korkmaz (2011), pointed out about the significance of the position of the floor disjointedness which its rate and its collaboration with structural components, influence on the earthquake performance of constructions (İnan and Korkmaz, 2011).

Hürol, (2013) also state, subtraction of slab in some parts or removing a slab as a whole in some cases is possible but "in any case, before deciding to make changes in slabs, it is necessary to get advice from a structural engineer" even if it is a small hole in the slab to pass pipes.

Slabs in the structure act as diaphragms connecting vertical elements and the removal of slabs will stop the structure from behaving as a unit which has effect on the earthquake resistance of that building (Dowrick, 1990). Furthermore, reinforced concrete slabs have reinforcement in them. If the majority of the reinforcement in one direction is cut, this will provide radical change to the original composition of the slab (Hürol, 2013). Removing slabs effects earthquake resistance of buildings negatively, therefore, it is not recommended in earthquake regions.

In case of removing a slab, the structural engineers have to evaluate the structure according to the new findings and examine the model to avoid different types of irregularity such as floor discontinuities and etc., if applicable.

4.2.3 Stair Subtraction

Stairs are one of the most artistic elements of design especially for interior designers. Generally, interior designers are removing the old existing staircase and the more artistic ones are added (Mornement, 2007). Generally the new stairs are usually designed by light-weight structures. Hürol, (2013) states that, if removing the stairs does not weaken the remaining parts of the existing structure, then it is possible to take it away, or replace it with a new one.

Hence, the most important problem in replacing the old stairs with the new one is the role of the old stairs within the original structure. However staircase, is categorized as a secondary structural system and it greatly affects the lateral stiffness of the frame and dynamic performance of the building by its contribution to increase the stiffness of the building (Shyamanada Singh et al. 2012).

Moreover, it should be noted that removing the stairs can also cause some changes in the structural behavior and may weaken the structure (Shyamanada Singh et al. 2012). Because of this, removing stairs is a critical issue , therefore, it is necessary to get advice from a structural engineer.

4.2.4 Rigid Infill Walls Subtraction

Rigid infill walls are not only the architectural elements for division of interior spaces; these elements are also a part of structural system. These elements are generally removed or added during interior modifications without any respect to the general structure of the building. Frequently, amongst the architects and interior designers there are some beliefs that the removal of the rigid infill walls does not affect the structure.

However, removal of rigid infill walls possibly will cause problems such as; vertical irregularity, soft or weak storey and twisting instability problems (Kirac, Dogan and Ozbasaran 2011).

Inel, Ozmen and Bilgin, (2008) mentioned that "Soft storey due to the absence of infill walls at the ground storey is found to be more detrimental than soft storey due to greater heights of the ground storey".

Generally, when the ground floor is re-functioned into a bar, restaurant, shop or other public functions, architects or interior designers remove the infill walls to have a more open floor plan and also provide clear vision from inside to the public street. Hence, removing infill walls in floors plan without considering the issue of continuity in structure in vertical position will provide serious problems.

On the other hand, adding infill walls in the right place of a building may solve the problem of soft or weak storey and increase the earthquake resistance of building. Based on reports of the 1999 Izmit earthquake, 725 buildings out of 1215 buildings are damaged due to weak-storey problem (Kirac, Mizam and Ozbasaran, 2011).

WBased on the above discussion, removing rigid infill walls is possible if this action does not lead to problems as soft or weak storey or twisting instability. Therefore, removing rigid infill walls must be done after careful assessment of building and getting advice from structural engineers.

4.2.5 Light- Weight Infill Walls Subtraction

Hürol, (2013) mentioned that "the only totally free action that the interior designers can perform is the removal of the light-weight infill walls". Light-weight infill walls are timber or gypsum based partitions.

Removal of any other heavy material subtraction as infill brick-wall or other type of infill walls must be done based on the advice of a structural engineer.

4.3 Problems Due to Addition Made to the Existing Building Structure

Hürol, (2013) mentioned that, the addition of new structures to the existing structure of the building is common among interior designers. Additions as linear elements, surfaces or masses are permitted and can be added outside the structure, within the structure, or originate from the inside and extend outside.

Structural elements such as columns, beams, slabs, stairs and infill walls, can be added to the existing structure, but as they are described as extension systems, they are added to the existing structure and they are dependent on it (Mornement, 2007).

These additional parts of structures must be connected only to the joints of the existing building structure (Hürol, 2013). In the event of an earthquake, the connectivity of additions to the existing structure avoid separate behavior of the old and new structures. Also, their connectivity to the joints of the existing structure avoids any disturbing load transfer between them. However, additional parts may also change the dynamic properties of the structure, thus the structure may behave different than originally designed. This may be dangerous and need careful consideration.

In order to undertake "extension systems" safety during the events of an earthquake, the connection of new beam and column joints to the existing building is one of the most important issues. Also, light-weight structure and partition walls are necessary to be in a proper connection to the existing structure in order to consider the safety of users.

Ching, (1996) stated that: "the additional structure should have an order so that a second system, which is connected to the existing building system, can be formed". The formation of frames within a structure is stated in many earthquake terms. "Planar frames which usually exist in two perpendicular directions should start from one side of the building and end at the other end of it in order to have a consistent frame system". (Ministry of Public Works and Settlement Government of the Republic of Turkey, 2007). Thus, the additional structure should also be in line with this structure. ITU, (1999) mentioned that: most of the buildings which collapsed in Kocaeli earthquake, have non-continuous frames.

However, the structural rules of construction of a new building cannot be the same as structural rules when a change in an existing structure occurs. In this case, rules of addition are different from the rules of an initial design. In other words, structural hypothesis defined initially by the designer applies a restriction on any potential changes. This of course, changes from building to building, and from designer to designer and a clear cut answer is not possible.

Habraken, (1998) and Leupen, (2005) state that: "Extensions of existing structures should be light-weight structures". Addition of stone walls irregularly on existing structures is not a good suggestion as "the additions should not change the centre of rigidity of the existing structure so as not to create a twisting instability problem" (Jeong and Elnashai, 2007).

Adding rigid infill walls to the existing structure must be done in a way not to create any vertical irregularity problems or torsional irregularity. On the other hand, in some cases adding right infill walls can solve existing soft or weak floor problems.

As a consequence, in interior architecture, the definition of structures is different from the architecture. Hence, in interior design, use of light weight structures such as geodesic domes, bicycle-wheel structures, membranes, suspension structures, steel frames and slabs are more common, because they are light-weight structures.

Last but not least, Habraken, (1998) pointed that “All load-bearing additions to the existing building structure require a new structural engineering project as well as a new interior design project”. Both effects of subtractions from the existing structure and any additions to it should be considered in this structural engineering project. Changes in building also require professional projects. Therefore, “this is the requirement of the basic code of rules and professional ethics, according to which there should not be any difference between a building and the professional project, which was designed for it” (Habraken, 1998).

4.4 Open Building

‘‘Open Building is a multidisciplinary approach applied in building design that supports building adaptability according to different requirements (Kendall & Teicher, 2000).

Open building, is generally put into practice for reappearance of a changeable and user-responsive infill (fit-out) level. The “infill” may possibly exist to be determined or distorted for each household or resident without disturbing the support or base building. Hence, might be possible to state; the infill is more durable than furniture or finishes, but not as much durable as the base building (Kendall and Teicher. 2000).

Having said this, “Open Building” is a design methodology which permits later modification in building especially in an earthquake region by dividing building into two independent levels labeled as “support” and “infill”. These levels are described as follows:

- Kendall and Teicher, (2000) describe building “support” as the part of the building which contains the main frame of the building and external elements as well as structural and architectural aspects of a building, planned and constructed to meet the natural, traditional and legal conditions of the construction location.
- The internal parts which are put up to effectively use the space enclosed by the shell are titled as the “infill” or fit-out (Kendall, 2004). The partition walls are in general taking action to form rooms for different purposes and sizes to represent a vital portion of the infill elements. Internal components of different types in the building in support of the specific lifestyle and living standards of the dwellers of each unit, are part of the infill. (Kendall and Teicher, 2000).

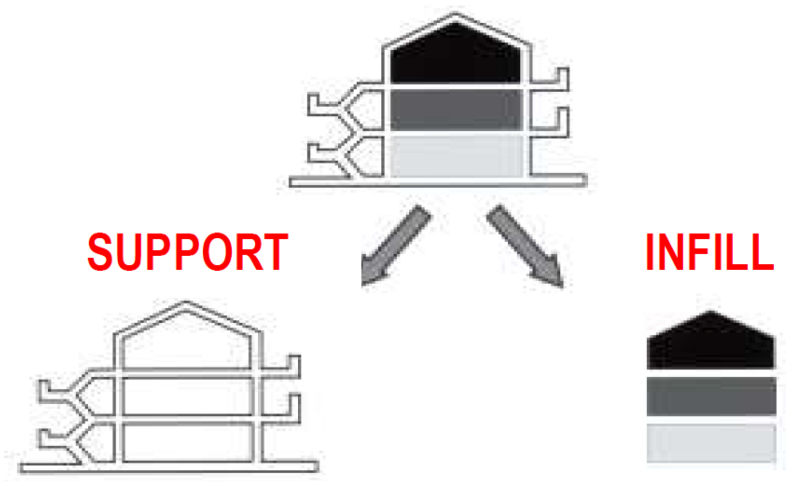


Figure 4.2. “Support” Level-“Infill” Level (Kamo, 2000)

The basic principles of Open Building have been described by Habraken (2002) as follows:

Table 4.1.The Basic Principles of Open Building (Habraken, 2002)

The idea of distinct levels of intervention in the built environment, such as those represented by 'support' and 'infill', or by urban design and architecture.
The idea that users / inhabitants may make design decisions as well.
The idea that, more generally, designing is a process with multiple participants also including different kinds of professionals.
The idea that the interface between technical systems allows the replacement of one system with another performing the same function. (As with different fit-out systems applied in a same base building.)
The idea that the built environment is in constant transformation and change must be recognized and understood.
The idea that the built environment is the product of an ongoing, never ending, design process in which environment transforms part by part.

During modifications on an open building any changes in supports which count as primary structural system, needs consulting with structural engineers. However, changes in light partition walls which are the detachable units can be freely applied. In open building using both rigid and light-weight infill walls are possible (Habraken, 1998; Leupen, 2005).

In “open building” the building supports are calculated and designed in a way that it became unnecessary to make any modification in the supports at later stage. Besides, applying changes in the infill becomes possible if needed. For this purpose zone and margins are formed. In Figure 4.3 the drawn lines (the dotted lines represent the margin and continuing lines represent the zones) form a system to provide “zones” and “margins”.

These lines are drawn in the methodical progress of variations in arrangement that satisfy one specific set of criteria. Zones and margins moreover are able to be used as assistant in the design of supports within which units can be built that conform to such criteria (Habraken, 1976).

The zones and margins are supported in the standard formulation to plan units within a designed, or yet to be designed, support. Hence, the "Zone and margins are known as fixed bands within which spaces can be placed according to certain conventions" (Habraken, 1976). The "support" design depends on a set of standards that are integrated into a definite zone/margin system.

Figure 4.3. Habraken's Basic Support and Three Layout Options of Infill Arrangements (Wong, 2010)

The most important advantage of open buildings in earthquake prone regions is that structural designers usually consider a variety of possible changes in the building and hence design accordingly. In other words, during structural design, a uniformly distributed dead load is applied to the structure to be representative of movable partitions. It should be noted that in such cases usually construction of heavy infill walls as partitioning elements is prohibited.

Many buildings around the world, especially the none-residential ones are constructed according to "Open Building" ideology and strategies. For instance, offices with “open plan” layout are more capable of supporting different interior modifications and also provide a variety of work space distribution.

In many countries located in earthquake regions like Japan, the residential open building concept is widely familiar and they try to use it.

As a successful sample of open building in Japan, “the next 21”, might be a good example. “Next 21” was completed in 1994 in Osaka city planned for Osaka Gas Company. This building demonstrates an understandable division between “base-building” and “fit- out” following the SAR (Foundation for Architects Research) definition. In “Next 21”, the buildings fit-out are different for each unit and the base-building serves as a collective facility. In order to fit out individual units the “Utida team” applied available sub-systems by clear rules for separation of base building and fit-out to enable the new distribution of design responsibilities. (Habraken, 2008)

Figure 4.4. NEXT21 Project (Habraken, 2008)

Buildings such as open building or the ones as a piece of time-based-architecture with light-weight infill walls are generally designed for accepting later modifications. In such building’s interior changes may be done without affecting on the structural system (Hürol, 2013).

Therefore, “Open Building” distinguishes changeable interior fit-out from more durable structure and skin, by offering opportunity to the dwellers to apply later modification on their buildings without any negative effect on earthquake resistance of building.

Distinguishing between “base building” and “fit-out” assigns a specific scope to the interior architect or dwellers. It establishes a new cluster of products and defines new kinds of production activity (Kendall and Teicher. 2000). However, Open Building distinguishes changeable interior fit-out from more durable structure and skin, give opportunity to the dwellers to apply modification on their buildings without any negative effecting on earthquake resistance of building. Case of that this concept is highly recommended for residential buildings in the earthquake region.

Hürol, (2013) mentioned, in this case only by subtracting or adding some light-weight infill walls it is possible to complete the interior design. “If the building is not designed for change and if it is necessary to go beyond removing and adding some light-weight infill walls, then the interior design of that building should be carried out parallel to a structural engineering project designed for it”.

Chapter 5

FIELD STUDY

5.1 Introduction

Over the past two decades Turkey has been experiencing several earthquakes which resulted in major loss of life and property. Same as Turkey, Cyprus which is located on the Alp-Himalayan earthquake belt (see chapter 2) also has the risk of earthquakes. However, it has been 70 years that this island has not faced any serious earthquakes (Hürol & Wilkinson, 2005).

Based on seismic hazard map of Cyprus, the earthquake risks are reduced towards the eastern and northern part of the island. Figure 2.17 shows that Famagusta is the only city in Northern Cyprus that is located in a hazardous zone.

Therefore, as the location, structural systems, materials and building codes of Northern Cyprus and Turkey during the design and building construction are same. The field study focuses on two chosen buildings in the city of Famagusta. These buildings are evaluated according to the findings of this study, based on earthquake resistance of the buildings after modifications.

A qualitative method was used in the present study by conducting interviews with the owners of the buildings, architects and civil engineers as well as systematic observation and analyzing previous and present situations of both buildings. The two buildings which are evaluated in this study are an apartment transformed to a hotel apartment and the hotel which was renovated several times. The evaluations are based on structural irregularity problems according to the 2007 Turkish Building Code which are formulated in Table 5.1.

Table 5.1 .Irregularity of a Building

5.2 Field Study No: I-Kutup Hotel Apartment (Famagusta)

The information given about the history of the building is based on the interviews with the owner of the building, Mr Ersun Kutup.

5.2.1 Historical Background

The building type is a residential apartment located at the city of Famagusta in North Cyprus.

The first architectural drawings and engineering details of this building had been done for a 7 floor apartment during 1970-1972. After division of Cyprus island into two parts, in 1974, the owner sold this land with all drawings and detailing. However, at that time the building had only one floor.

New owner added the first floor of the building in 1975. However, he did some modifications to the building to open some free space for the factory machines. During 1975-1979 this building was being used as a zipper factory.

In 1980, he added three more floors to the factory and started to use it as a residential apartment. At that time the factory was not operational and ground floor remained empty. In 1985 the owner bought another piece of land adjacent to the present building and built a hotel apartment on that and during construction of the new building, some other modifications were done on the existing building, and in 1993 both buildings started to function as a hotel apartment.

In 2000, according to new regulations hotel, apartments had to have fire exits. From that time on emergency exits were added to the buildings and both buildings were connected to each other by a covered fire exit.

After that time, many small modifications were done to the buildings and the existing situation of the building is now far from its initial architectural concept and engineering detailing (Figure 5.1). In 2010, the last modification, which totally changed the elevation of the building, was done. The ground floor of the building was divided into different parts. A restaurant and a store were added to it.

Interior (1995)

Interior (1995)

Interior (2013)

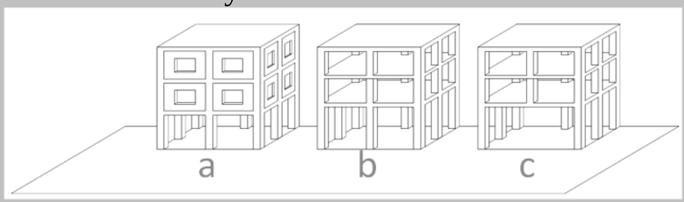
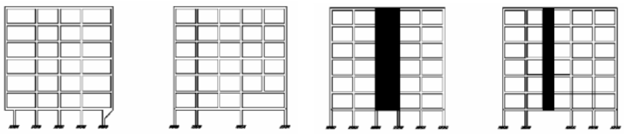
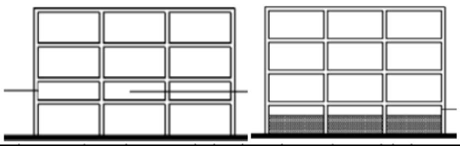
Interior (2013)

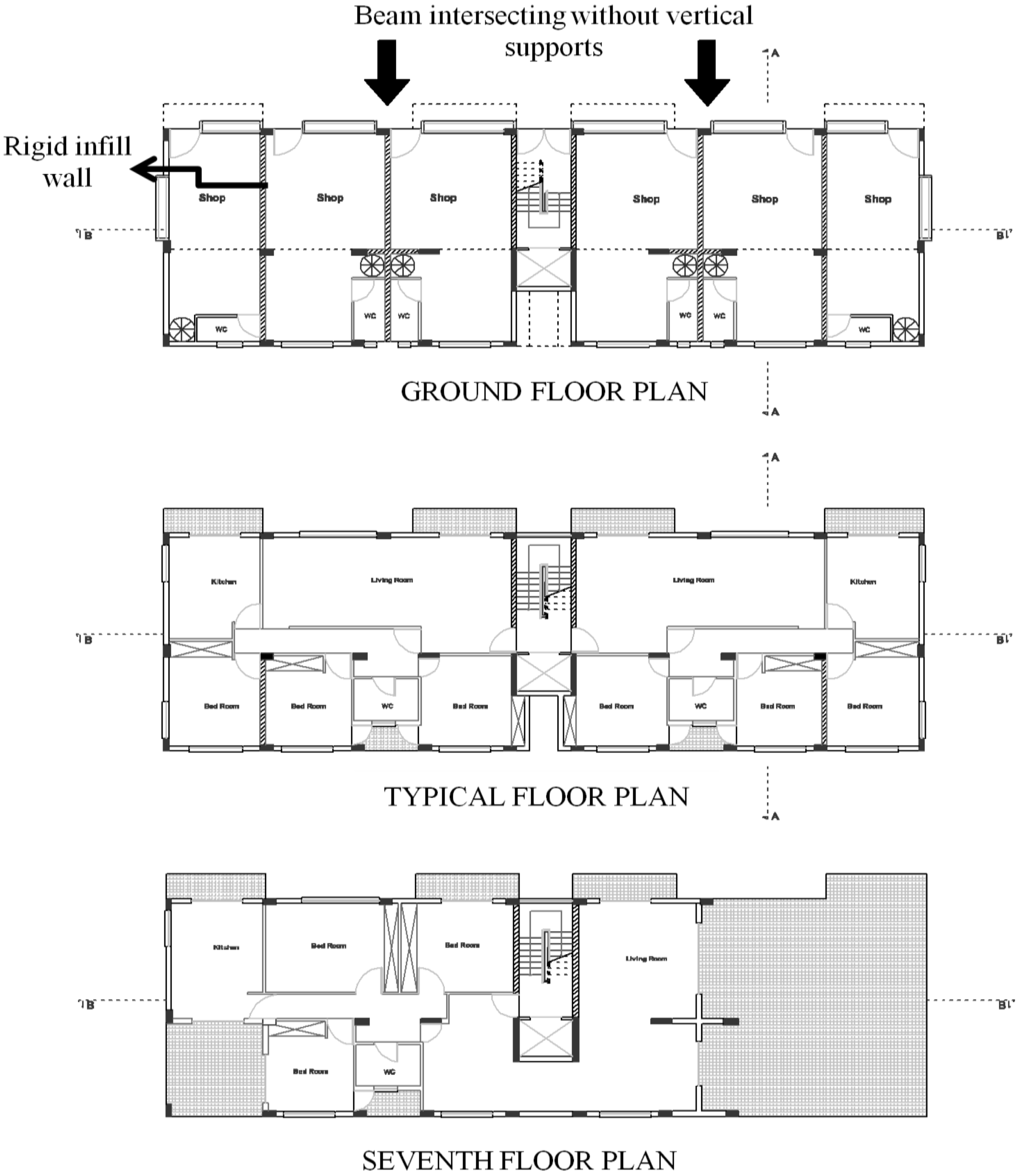
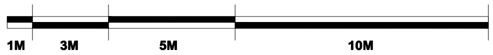
Figure 5.1. Interior of the Building in 1995 and 2013

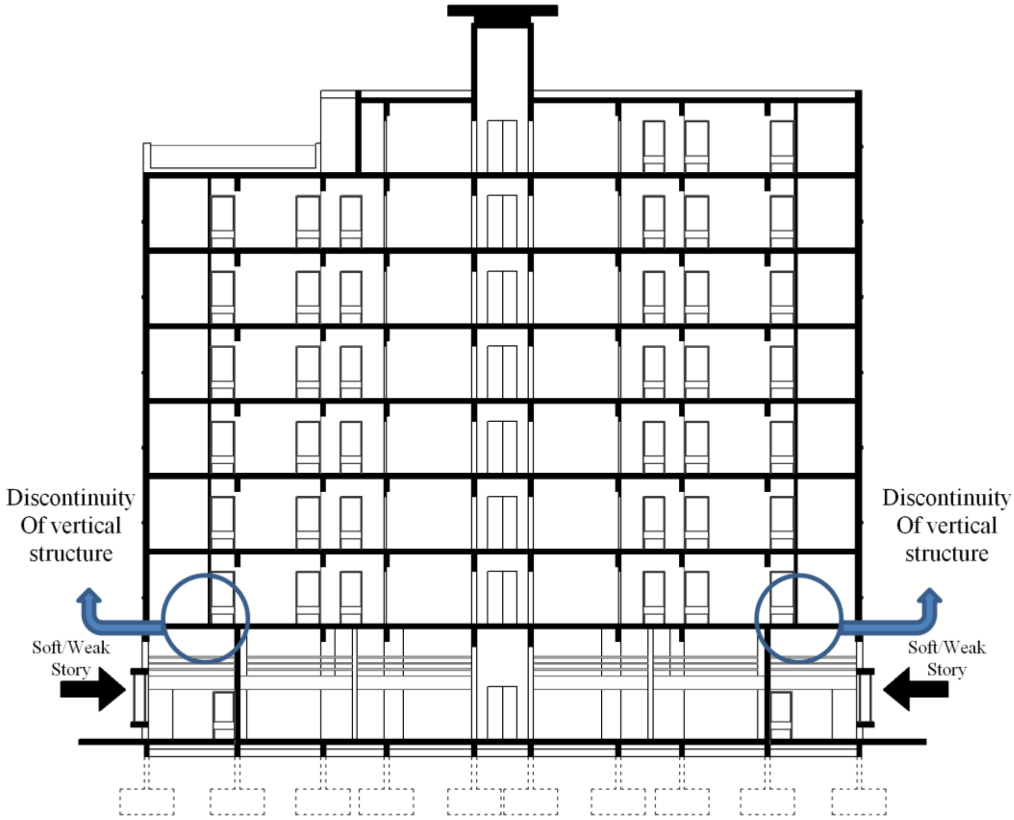
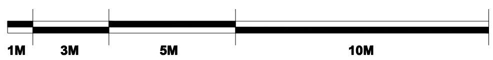
Table 5.2. Present General Information about Kutup Hotel Apartment Building

Table 5.2 General information: Original Architectural Drawings	
Project date:	1970
Building code date:	1968
Earthquake zone:	1
Structure type:	RC
Total building height:	17m
Total number of storeys:	5
Modification floor:	All floors
Function of building before modification:	Residential apartment
Function of building after modification:	Apart Hotel

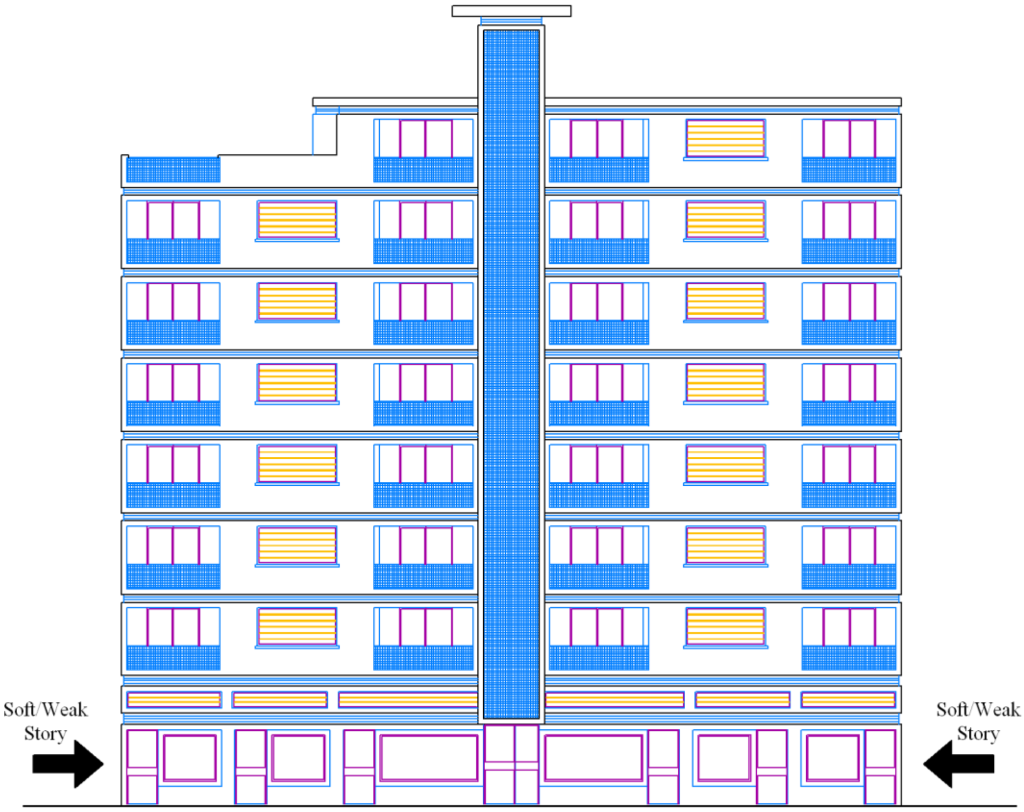
The Table below examines the original situation of the mentioned building according to Table 5.1, which shows structural irregularities.

Table 5.3 Original Building Problems	**Global (System) Failures**	**Local (member) Failures**
1) Torsional Irregularity:		
2) Floor Discontinuations:		
3) Projection in plan:		
4) Nonparallel axes:		
5) Soft or Weak Storey: 	b	
6) Discontinuity of Vertical Structural Element: 	*	
7) Strong Beam-Weak Column Formation:		
8) Short Column Effect: 	*	
9) Pounding effects		
10) Wrong frame elements location I. Discontinuous beam. II. Beam intersecting without vertical supports. III. Beam and frames with broken axis. IV. Irregular configuration of columns.	II&IV	
11) Heavy overhangs		

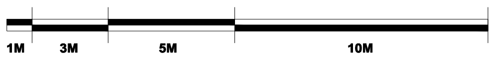
<table>
<tr><td>Original drawing of the building</td><td>Date :1970</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>Type of problem:
Beam intersecting without vertical supports.
Irregular configuration of columns.</td><td>
</td></tr>
</table>

Date:1970	Original drawing of the building
 SECTION B-B	
Type of problem: Discontinuity of vertical structure element. Soft/weak floor	

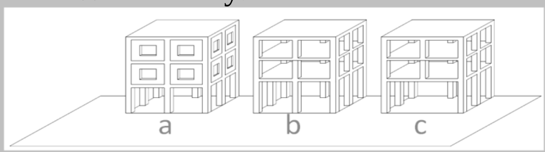
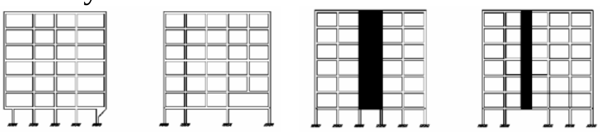
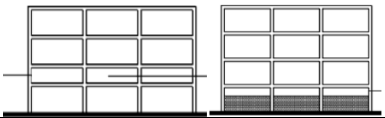
Date:1970	Original drawing of the building



EAST ELEVATION

Type of problem: Soft/weak floor	

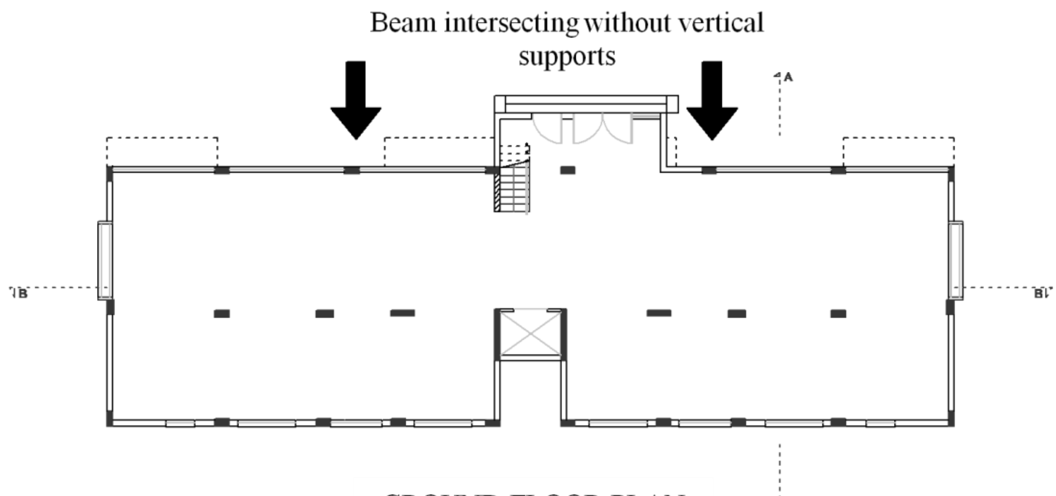
In 1975 the building had only two floors which were used as a zipper factory in first modification in 1980, three floors had been added to existing ones. Table 5.4 shows Irregularity problems of building after the first modification in 1980.

Table 5.4 Irregularity Problems after First Modification in 1980.	Global (System) Failures	Local (member) Failures
1) Torsional Irregularity:	*[1]	
2) Floor Discontinuations:		
3) Projection in plan:		
4) Nonparallel axes:		
5) Soft or Weak Storey: 	b	
6) Discontinuity of Vertical Structural Element: 	*	
7) Strong Beam-Weak Column Formation:		
8) Short Column Effect: 	*	
9) Pounding effects		
10) Wrong frame elements location I. Discontinuous beam. II. Beam intersecting without vertical supports. III. Beam and frames with broken axis. IV. Irregular configuration of columns.	II&IV	
11) Heavy overhangs		

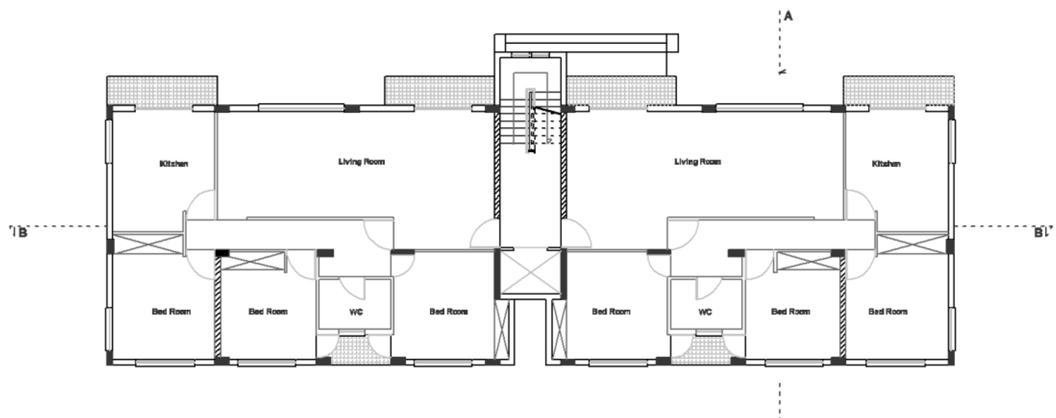
[1] Removing rigid infill walls has been changed the center of rigidity of the building which may create torsional irregularity.

Table 5.5 Subtractions Made from the Existing Building		Global(System) Failures	Local(member) Failures
Columns			
Beam			
Slab	Mezzanine floors	Soft floor	
Staircases	Staircase shifted		
Rigid infill walls	*	Soft floor Torsional	
Light-weight infill walls and partitions	*		
Windows and doors	*		

<table>
<tr><td>Date:1980</td><td>First Modification</td></tr>
<tr><td colspan="2">

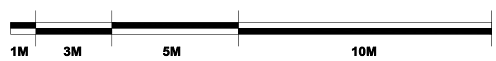


GROUND FLOOR PLAN



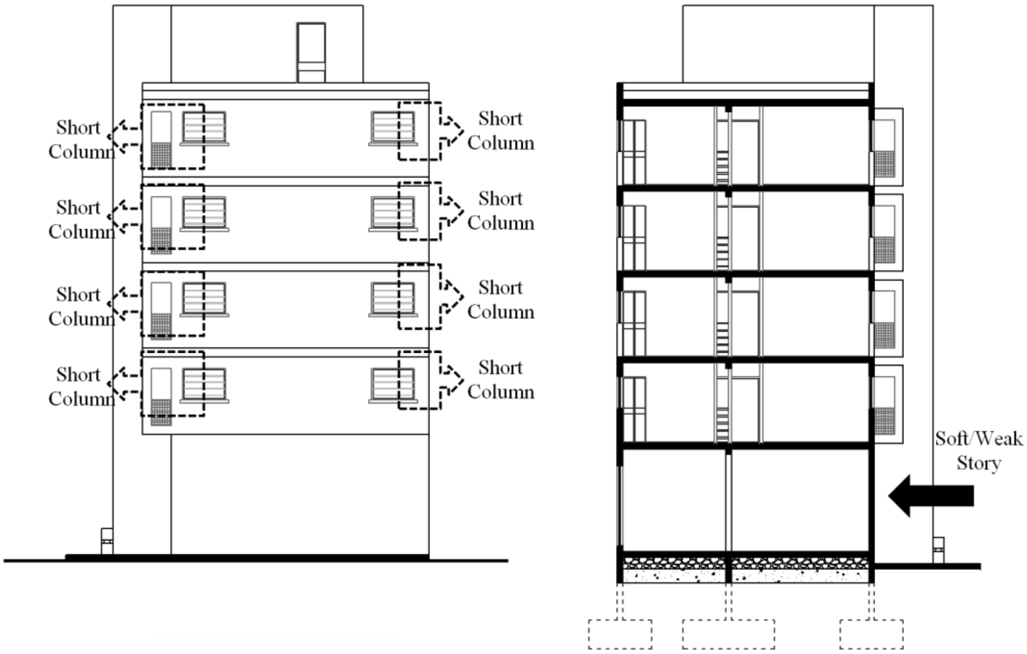
TYPICAL FLOOR PLAN

</td></tr>
<tr><td>Type of problem:
Beam intersecting without vertical supports.
Irregular configuration of columns.</td><td>

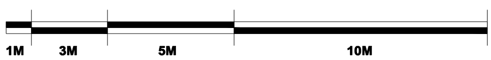


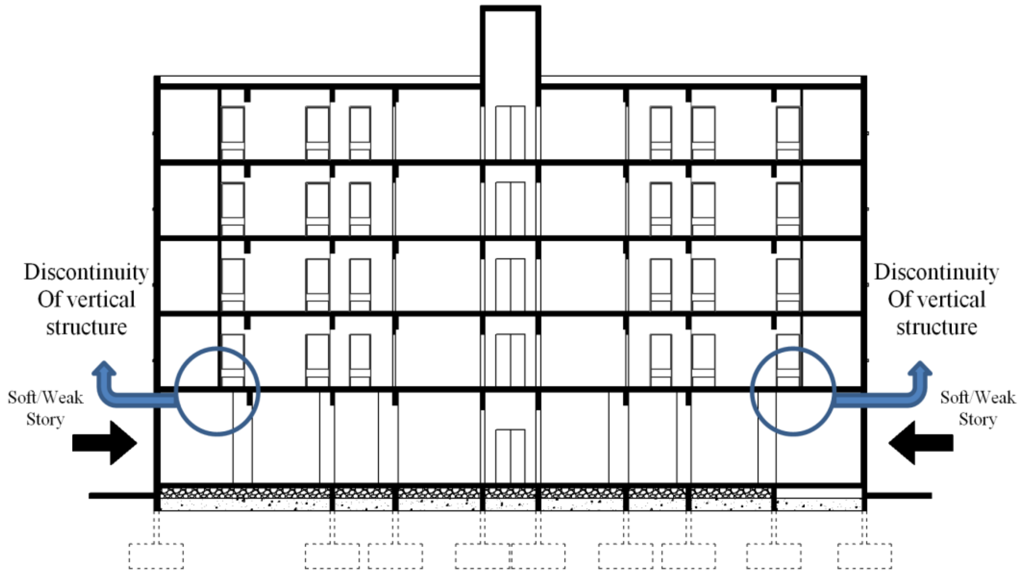
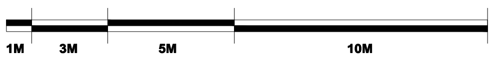
</td></tr>
</table>

Date:1980	First Modification



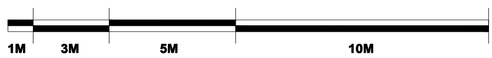
NORTH ELEVATION SECTION A-A

Type of problem: Short column Soft/weak Storey	

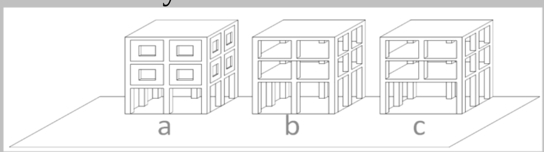
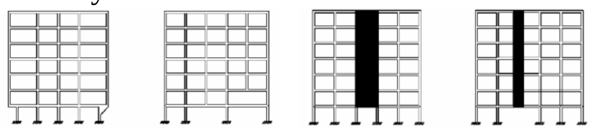
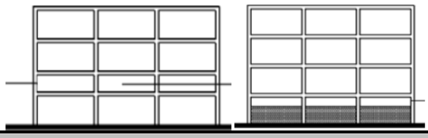
Date:1980	First Modification
 SECTION B-B	
Type of problem: Discontinuity of vertical structure element. Soft/weak floor	

Date:1980	First Modification

EAST ELEVATION

Type of problem: Soft/weak floor	

In 1985 the building was re-functioned as hotel apartment. Table 5.6 shows Irregularity problems of building after being re-functioned.

Table 5.6 Irregularity Problems after Second Modification in 1985.	**Global (System) Failures**	**Local (member) Failures**
1) Torsional Irregularity:	* [1]	
2) Floor Discontinuations:		
3) Projection in plan:		
4) Nonparallel axes:		
5) Soft or Weak Storey: 	b	
6) Discontinuity of Vertical Structural Element: 	*	
7) Strong Beam-Weak Column Formation:		
8) Short Column Effect: 	*	
9) Pounding effects		
10) Wrong frame elements location I. Discontinuous beam. II. Beam intersecting without vertical supports. III. Beam and frames with broken axis. IV. Irregular configuration of columns.	II&IV	
11) Heavy overhangs	*	

[1] Removing rigid infill walls has changed the center of rigidity of the building which may crate torsional irregularity.

Table 5.7 Subtractions Made from the Existing Building		**Global(System) Failures**	**Local(member) Failures**
Columns			
Beam			
Slab			
Staircases			
Rigid infill walls	*	Soft floor Torsional	
Light-weight infill walls and partitions	*		
Windows and doors	*		

Table 5.8 Addition Made to the Existing Building		**Global(System) Failures**	**Local(member) Failures**
Structure type of addition part			
Is Addition structure connected to the joints of the building?			
Rigid infill walls			
Light-weight infill walls	*		
Part Projection from Roof			
Windows and doors	*		
Overhang			*

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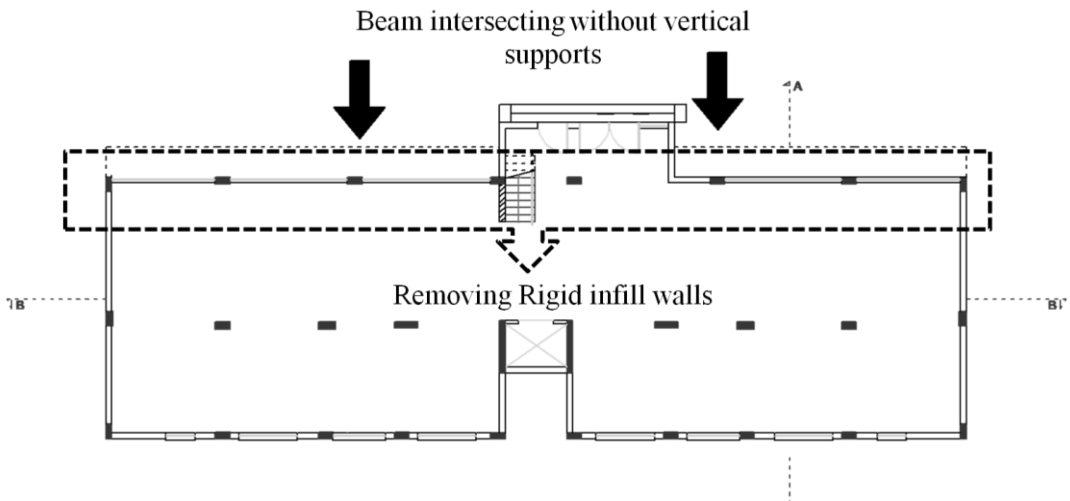
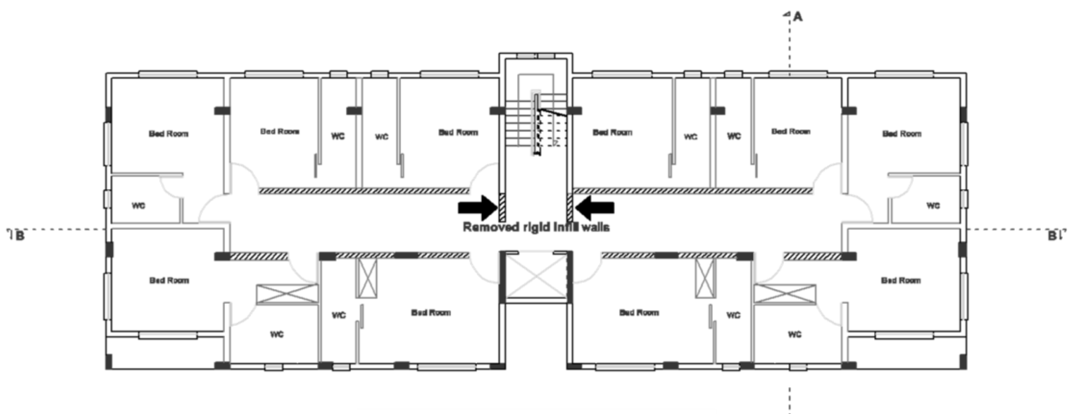


GROUND FLOOR PLAN


TYPICAL FLOOR PLAN
</td></tr>
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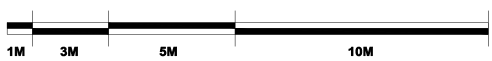
Irregular configuration of columns.</td><td>

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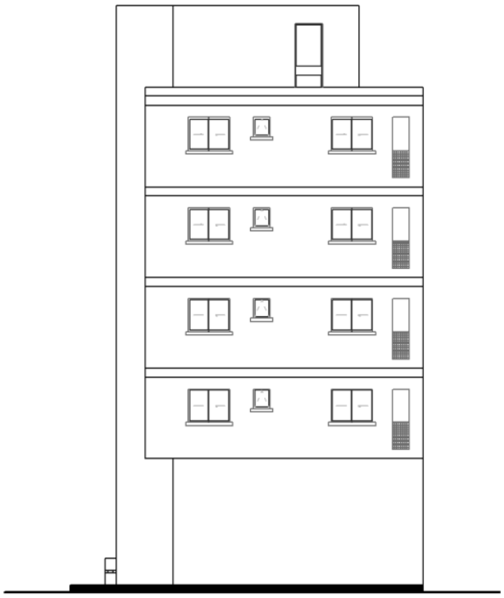
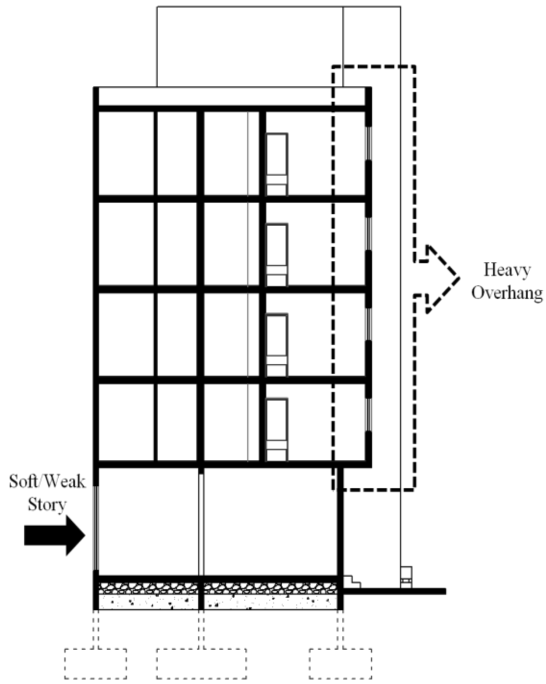
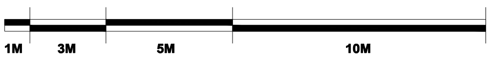
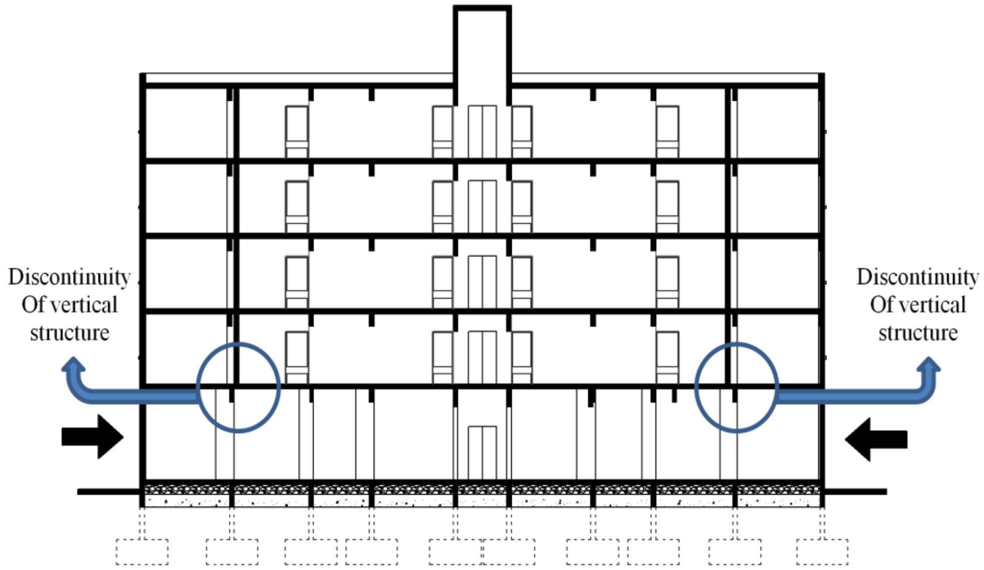
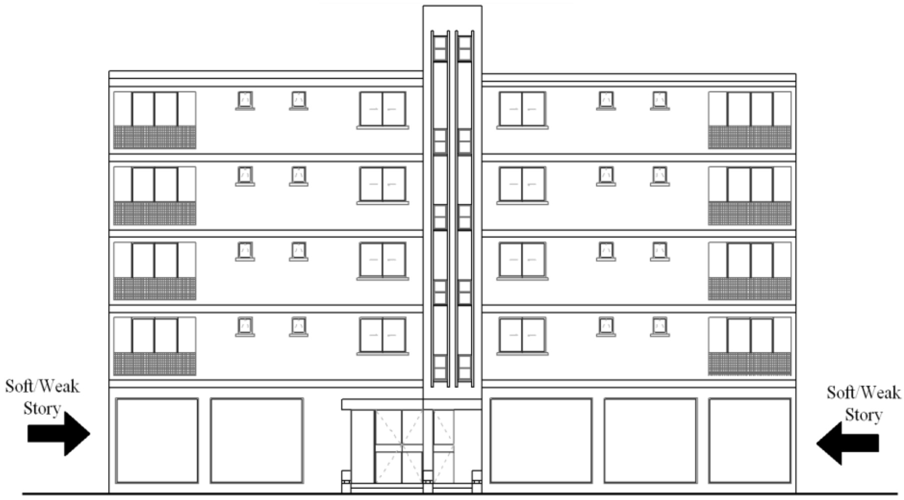
 NORTH ELEVATION	 SECTION A-A
Type of problem: Heavy Overhang Soft/weak Storey	

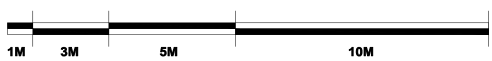
Date:1985	Second Modification



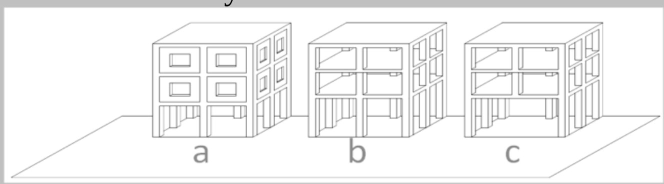
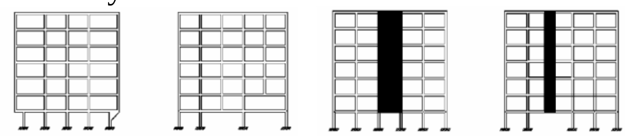
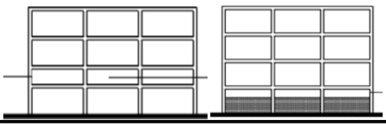
SECTION B-B



EAST ELEVATION

Type of problem: Discontinuity of vertical structure Soft/weak Storey	

In 2000 two hotel apartments were joined together with an emergency exit. Table 5.6 shows Irregularity problems of building last modified on 2000.

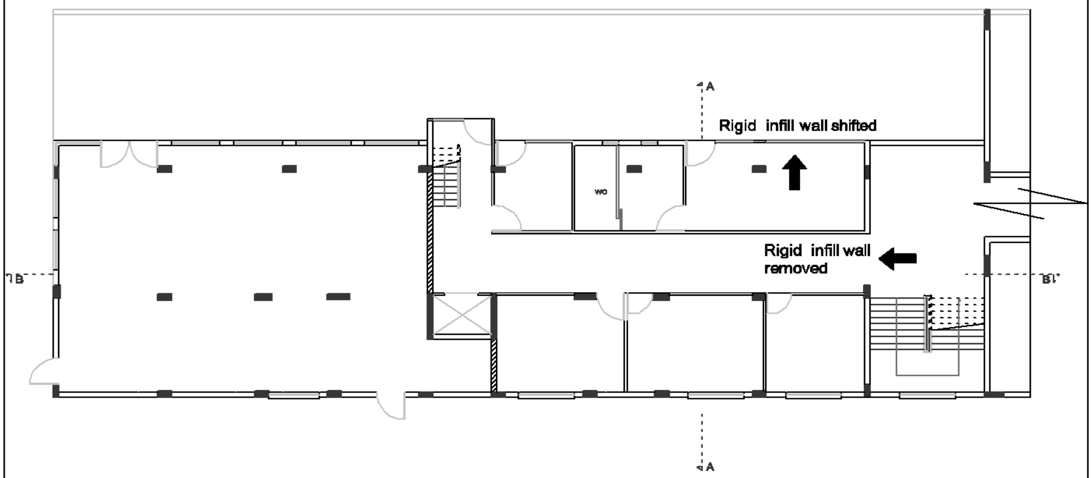
Table 5.9 Irregularity Problems after Third Modification in 2000.	**Global (System) Failures**	**Local (member) Failures**
1) Torsional Irregularity:	*[1]	
2) Floor Discontinuations:		
3) Projection in plan:		
4) Nonparallel axes:		
5) Soft or Weak Storey: 	b	
6) Discontinuity of Vertical Structural Element: 	*	
7) Strong Beam-Weak Column Formation:		
8) Short Column Effect: 	*	
9) Pounding effects		
10) Wrong frame elements location I. Discontinuous beam. II. Beam intersecting without vertical supports. III. Beam and frames with broken axis. IV. Irregular configuration of columns.	II&IV	
11) Heavy overhangs		

[1] Adding or removing rigid infill walls has been changed the center of rigidity of the building which may crate torsional irregularity.

Table 5.10 Subtractions Made from the Existing Building		**Global(System) Failures**	**Local(member) Failures**
Columns			
Beam			
Slab			
Staircases			
Rigid infill walls	*	Soft floor Tursional	
Light-weight infill walls and partitions	*		
Windows and doors	*		

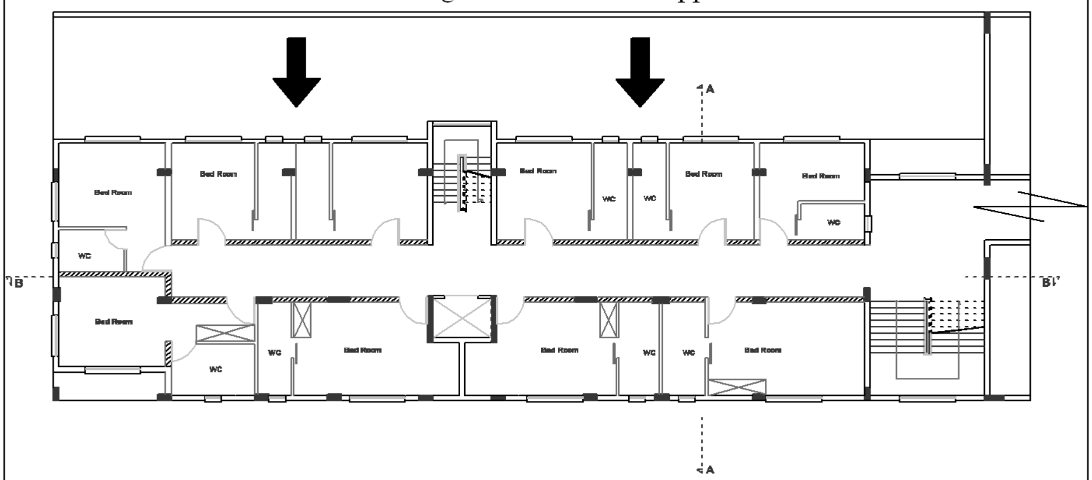
Table 5.11 Addition Made to the Existing Building		**Global(System) Failures**	**Local(member) Failures**
Structure type of addition part	RC		
Is Addition structure connected to the joints of the building?	No		Emergency staircase
Rigid infill walls	*	*	
Light-weight infill walls	*		
Part Projection from Roof			
Windows and doors	*		
Overhang			

Date:2000	Third Modification

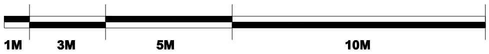


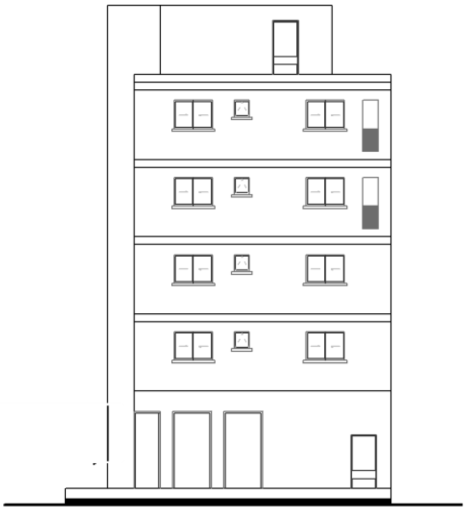
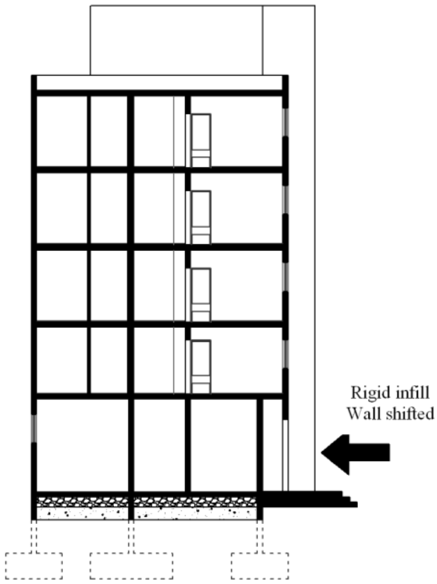
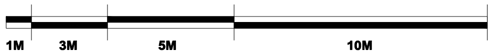
GROUND FLOOR PLAN

Beam intersecting without vertical supports

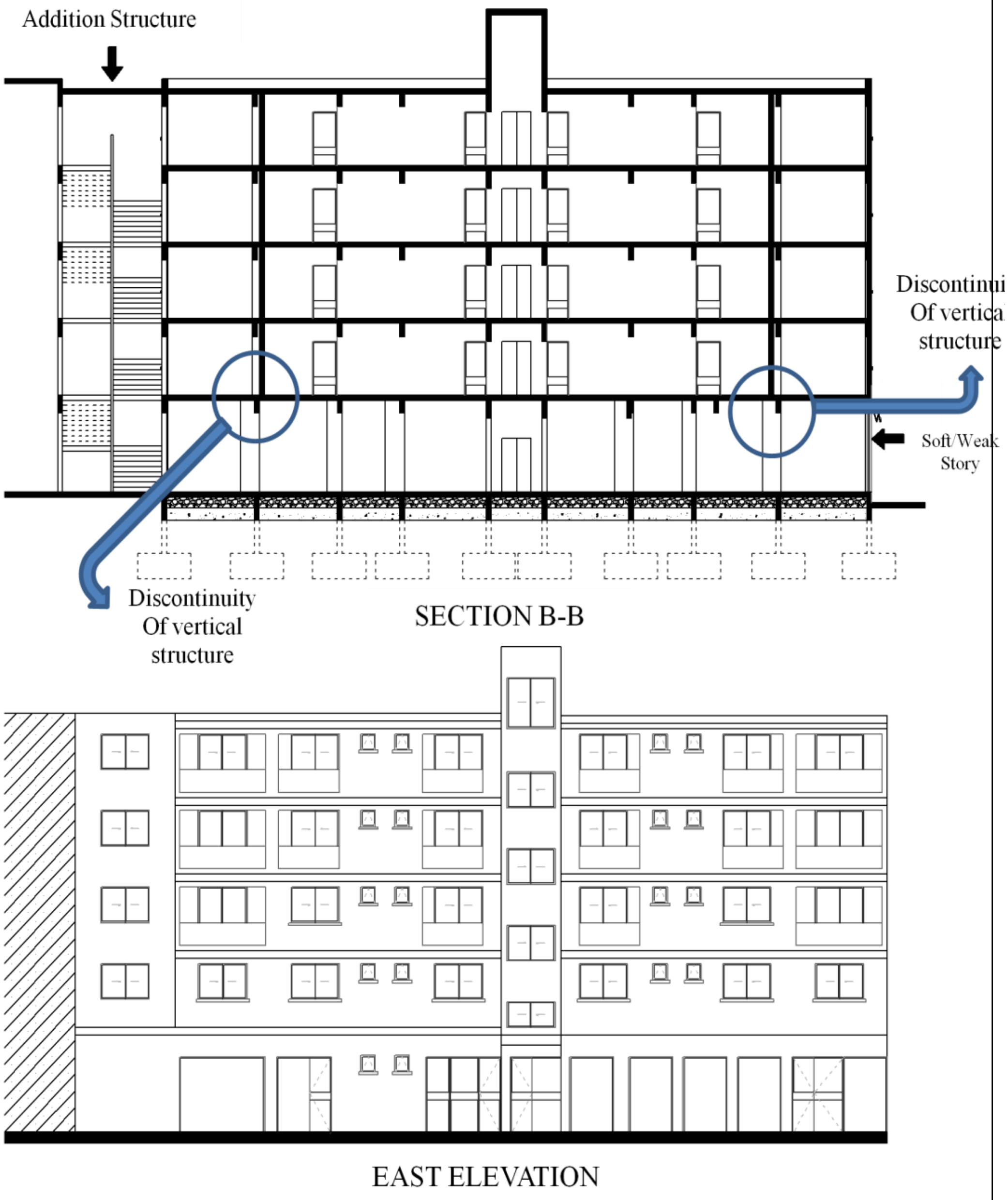


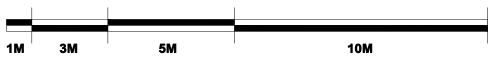
TYPICAL FLOOR PLAN

Type of problem: Beam intersecting without vertical supports. Irregular configuration of columns.	

Date:2000	Third Modification
 NORTH ELEVATION	 SECTION A-A
Type of problem: Rigid infill wall shifted	

Date:2000	Third Modification



Type of problem: Discontinuity of vertical structure Soft/weak Storey	

Tables 5.12 and 5.13 Showing subtractions and additions made to the existing building at each step of modification.

Table 5.12 Subtractions Made from the Existing Building.	First modification	Second modification	Third Modification	Global (System) Failures	Local (member) Failures
Columns					
Beam					
Slab	Mezzanine floors			*	
Staircases					
Rigid infill walls	*	*	*	*	
Light-weight infill walls and partitions	*	*	*		
Windows and doors	*	*	*		*

Table 5.13 Additions Made to the Existing Building	First modification	Second modification	Third Modification	Global (System) Failures	Local (member) Failures
Structure type of addition part					
Is Addition structure connected to the joints of the building?					
Rigid infill walls			*	*	
Light-weight infill walls		*	*	*	
Part Projection from Roof					
Windows and doors		*	*		
Overhang		*			*

5.3 Field Study No: II- Arkın Palm Beach Hotel (Famagusta)

The information given about the history of the building is based on the interviews with the architect of the building Mr. Burak Tursoy.

5.3.1 Historical Background

Exact construction time of the building is not known. This is due to loss of documents as a result of division of Cyprus in 1974. However, its construction is estimated to be in the late 1940s and early 1950s. As mentioned above engineering details of the building had been lost and present architectural plans are built as measure drawings, with no information about engineering aspects e.g. properties of materials used, size and location of reinforcements etc.

The structure had originally been built as a hotel and has gone through various changes during its life span before and after 1974. Major changes before 1974 are:

1) addition of two wings to the central building.

2) First and second floors to be used as hotel rooms.

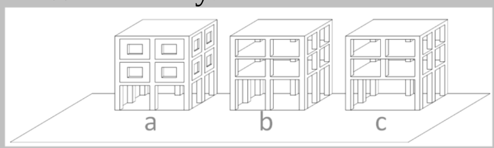
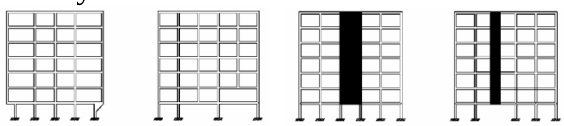
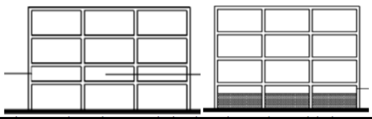
From 1974 to 2011 no major change was done. In 2011 the hotel was subjected to major architectural and structural modification. A professional team consisting of civil and mechanical engineers, together with chemists, architects and interior architects were hired to work on the project. Right wing has just gone through architectural modification with minimum or no structural strengthening or change on the existing building. A new part has been added to the existing building at this wing which works separately.

Major changes, however, were performed on the left wing of the building . A systematic soil stabilization and column strengthening were done using new materials and new techniques. Again a new part was added to be used for technical service with a completely separate structure.

Table 5.14 present general information about Arkın Palm Beach hotel apartment building

Table 5.14 General Information: Original Architectural Drawings	
Project date:	Late 1940s or early 1950s
Building code date:	
Earthquake zone:	1
Structure type:	Mostly RC
Total building height:	19m
Total number of storeys:	5
Modification floor:	All floors
Function of building before modification:	Hotel
Function of building after modification:	Hotel

The Table below examines the original situation of the mentioned building according to Table 5.1. Table 5.15 shown structural irregularities according to the 2007 Turkish Earthquake Code .

Table 5.15 Building Problems Before Modification.	**Global (System) Failures**	**Local (member) Failures**
1) Torsional Irregularity:		
2) Floor Discontinuations:	*	
3) Projection in plan:		
4) Nonparallel axes:	*	
5) Soft or Weak Storey: 	a&c	
6) Discontinuity of Vertical Structural Element: 	*	
7) Strong Beam-Weak Column Formation:		
8) Short Column Effect: 	*	
9) Pounding effects		
10) Wrong frame elements location I. Discontinuous beam. II. Beam intersecting without vertical supports. III. Beam and frames with broken axis. IV. Irregular configuration of columns.	II,III&IV	
11) Heavy overhangs	*	

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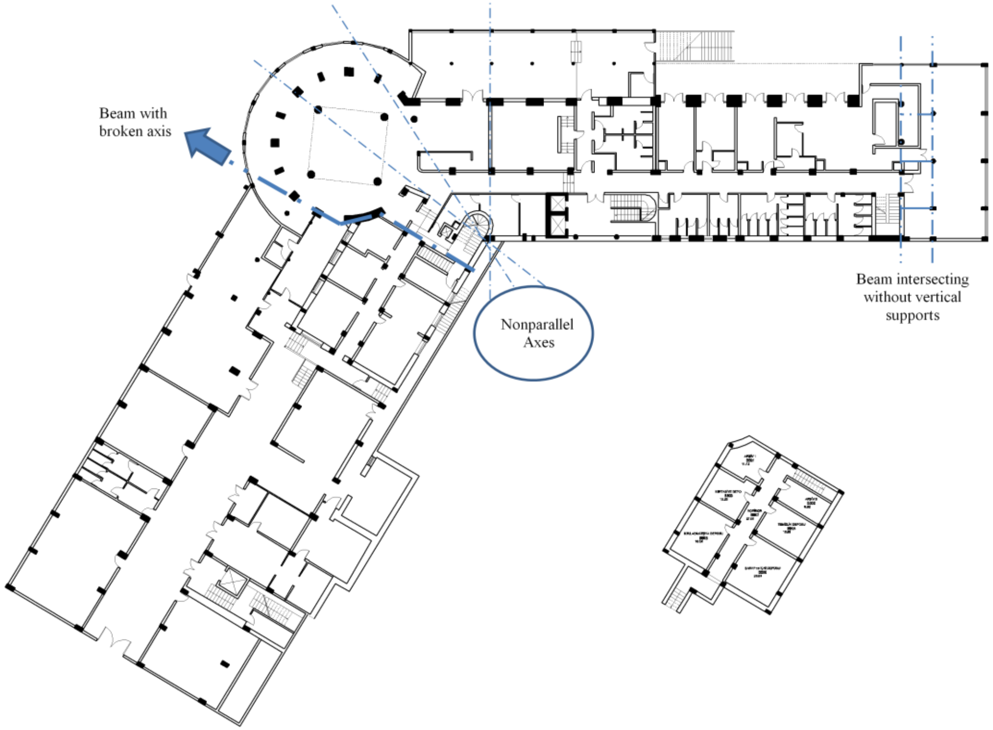
<tr><td colspan="2">
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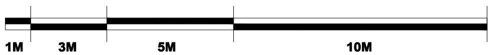
Beam and frames with broken axis.
Irregular configuration of columns.</td><td>
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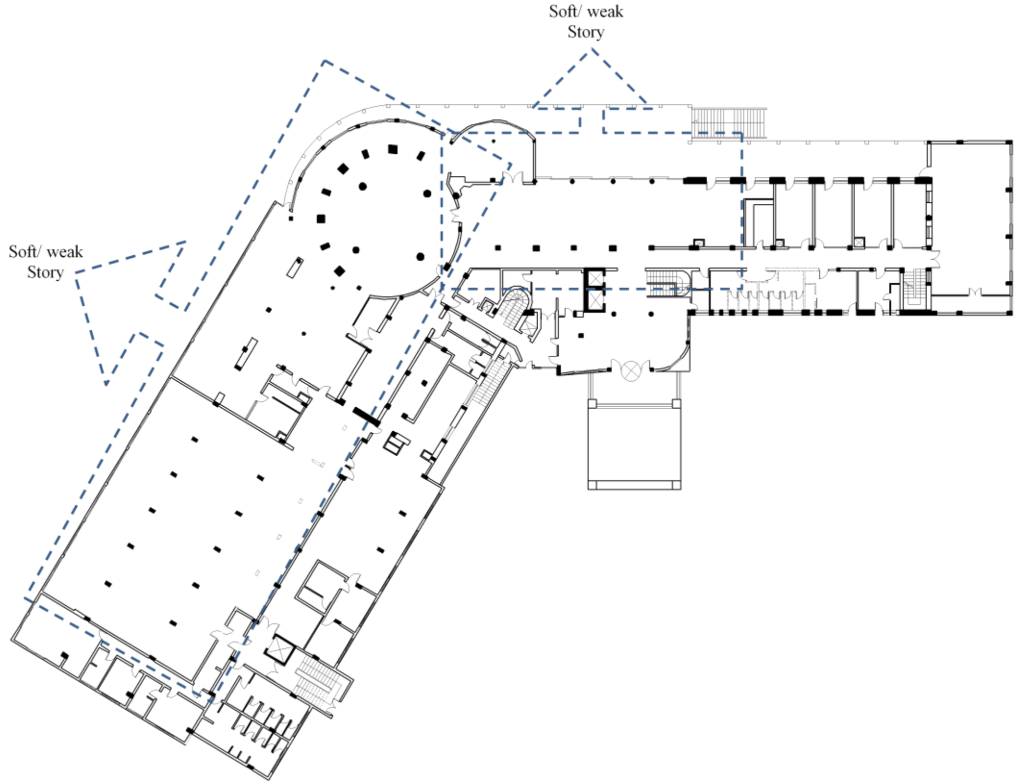
<tr><td colspan="2">
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<tr><td>Type of problems:
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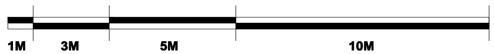
Beam and frames with broken axis.
Irregular configuration of columns.
Soft/Weak story .</td><td>
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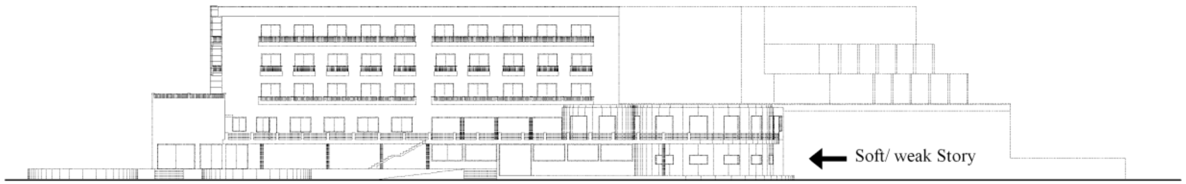
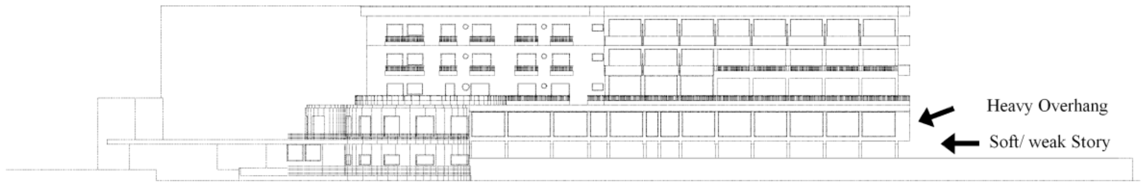


EAST ELEVATION-RIGHT WING


WEST ELEVATION- LEFT WING


SOUTH ELEVATION- LEFT WING
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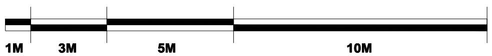
<tr><td>Type of problems:
Soft/Weak Story
Heavy Overhang
Short Column</td><td>
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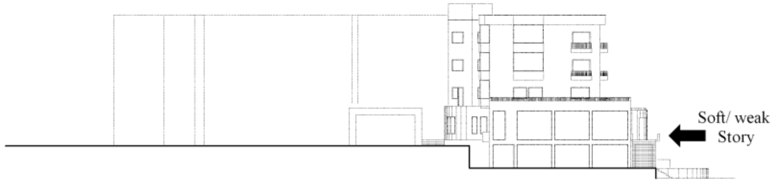
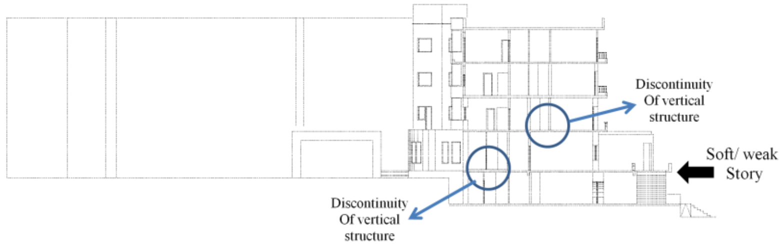
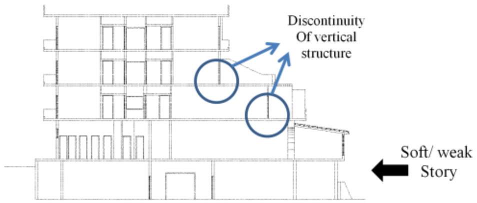
Survey drawing , 1974	Elevations

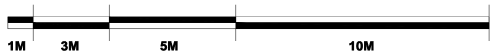


SOUTH ELEVATION- RIGHT WING





Type of problems:
Discontinuity of vertical Structure
Soft/Waek Story



In 2011 the hotel has been renovated. Table 5.16 shows Irregularity problems of building after renovation.

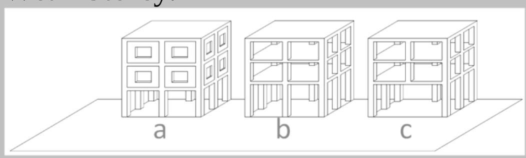
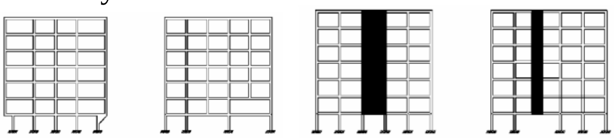
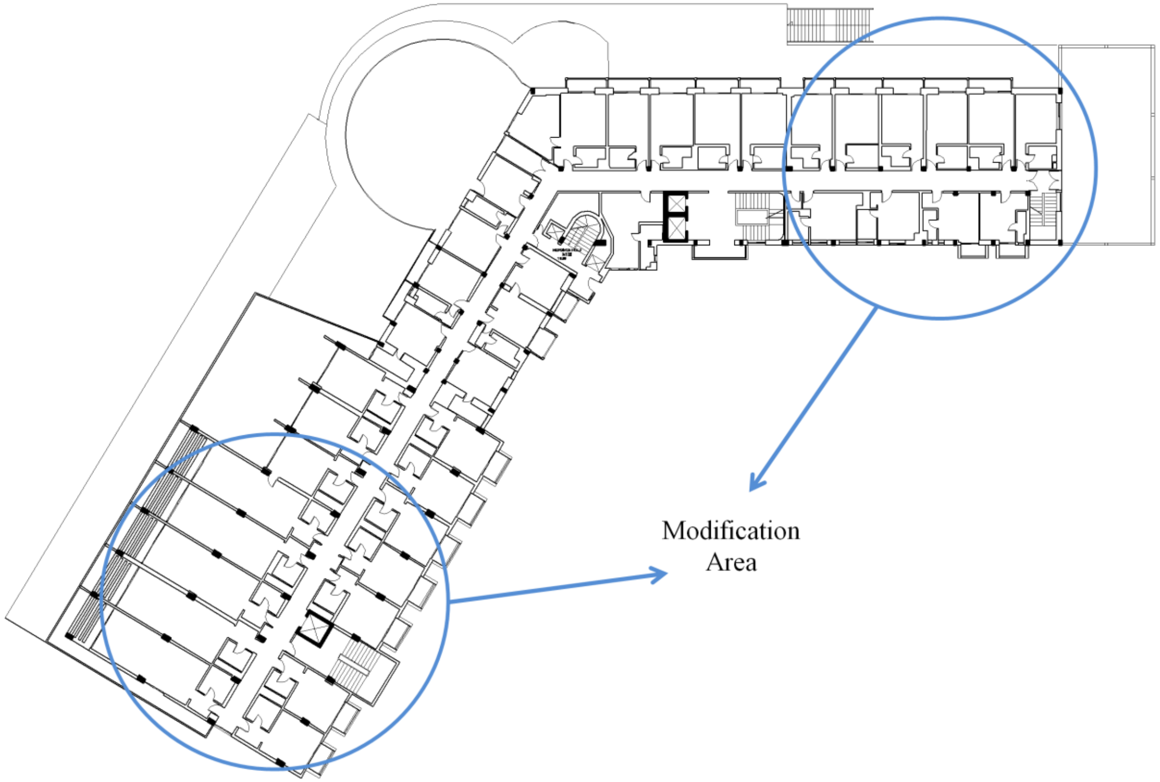
Table 5.16 Irregularity Problems after Modification in 2011.	**Global (System) Failures**	**Local (member) Failures**
1) Torsional Irregularity:		
2) Floor Discontinuations:	*	
3) Projection in plan:		
4) Nonparallel axes:	*	
5) Soft or Weak Storey: 	a	
6) Discontinuity of Vertical Structural Element: 	*	
7) Strong Beam-Weak Column Formation:		
8) Short Column Effect: 		
9) Pounding effects		
10) Wrong frame elements location I. Discontinuous beam. II. Beam intersecting without vertical supports. III. Beam and frames with broken axis. IV. Irregular configuration of columns.	II,III&IV	
11) Heavy overhangs		

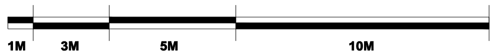
Table 5.17 Subtractions Made from the Existing Building.		**Global (System) Failures**	**Local (member) Failures**
Columns			
Beam			
Slab	*	Floor discontinuity	
Staircases			
Rigid infill walls	*		
Light-weight infill walls and partitions	*		
Windows and doors	*		

Table 5.18 Addition Made to the Existing Building .		**Global(System) Failures**	**Local(member) Failures**
Structure type of addition part	RC		
Addition structure connected to the joints of the building.	NO		
Rigid infill walls			
Light-weight infill walls	*		
Part Projection from Roof			
Windows and doors			
Overhang			

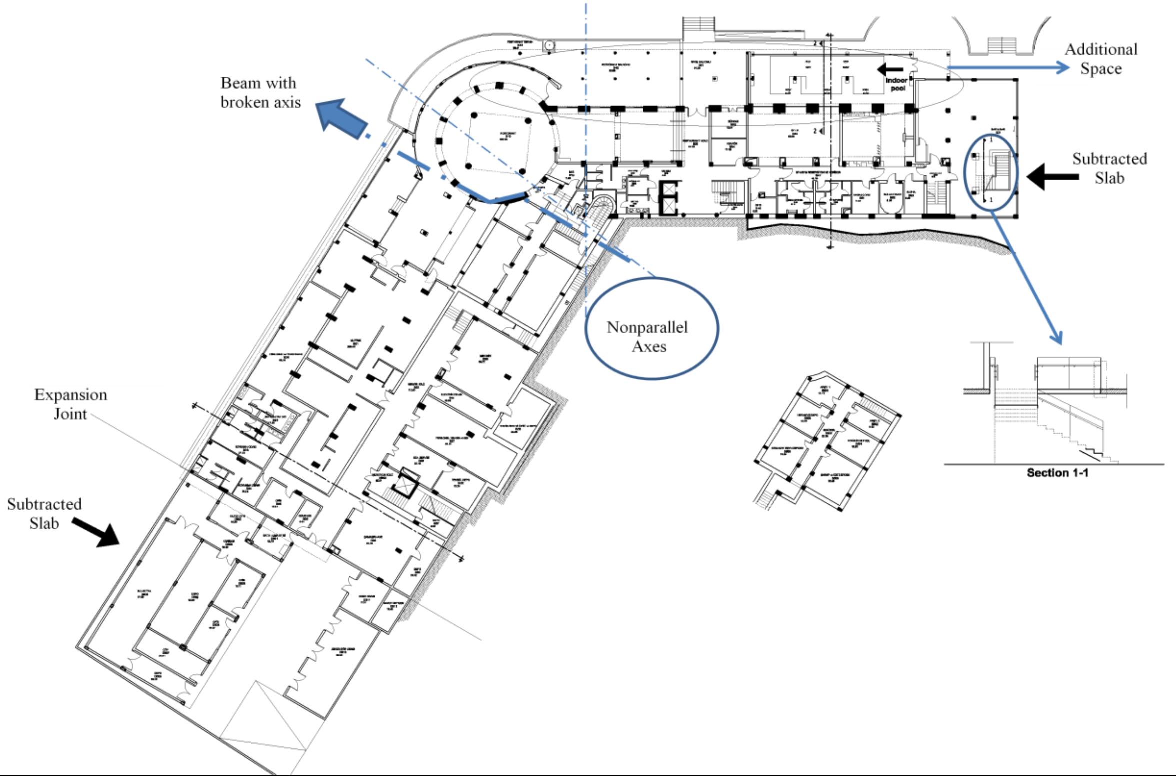
In the interview with a member of engineering team responsible for strengthening of the Palm Beach hotel he mention that some irregularities inherent in the structure cannot be modified. “However, we tried to control overall seismic performance of the structure” he said. He also mentioned that some modern civil engineering methods, were used for assessing the performance of the building by considering nonlinear properties of the elements. Details of those methods are beyond the scope of present research. He also mentioned that all architectural and interior architectural modification was performed under civil engineers supervision.

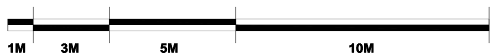
Modification Date 2009-2011	Typical floor plan



Type of problems: There is not any specific problem in this floor .	

Modification Date 2009-2011	Basement Plan



Type of problems: Beam intersecting without vertical supports. Beam and frames with broken axis. Irregular configuration of columns. Floor Discontinuation	

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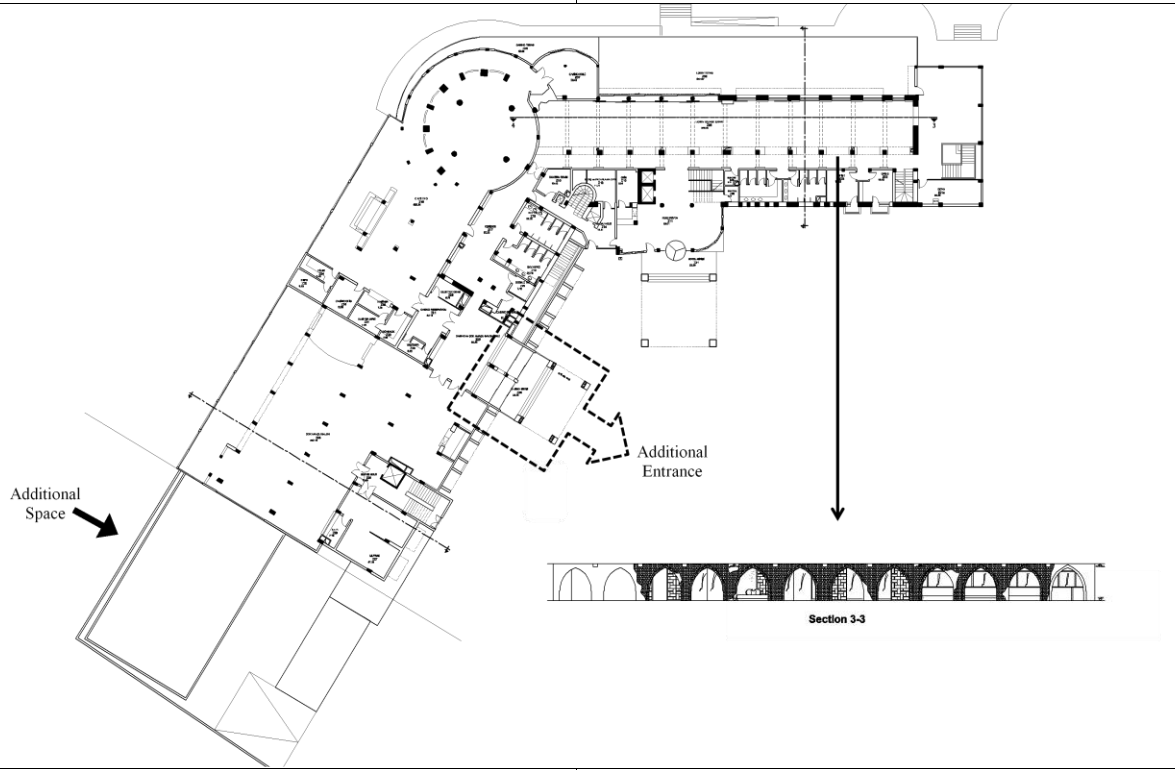
<tr><td colspan="2">
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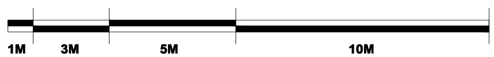
Beam and frames with broken axis.
Irregular configuration of columns.
Soft/Weak story problem had been solved by adding rigid infill walls</td><td>
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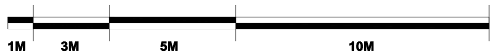
<table>
<tr><td>Modification Date 2009-2011</td><td>Elevations</td></tr>
<tr><td colspan="2">


EAST ELEVATION-RIGHT WING

WEST ELEVATION- LEFT WING

SOUTH ELEVATION- LEFT WING
</td></tr>
<tr><td>Type of problems:
There is not any specific problems on this floor .
Heavy overhang and the short column problem has been solved</td><td>


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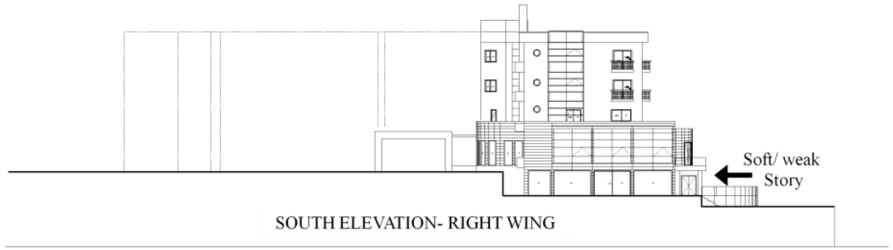
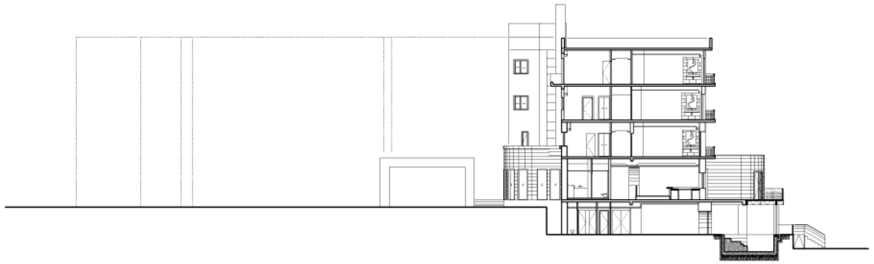
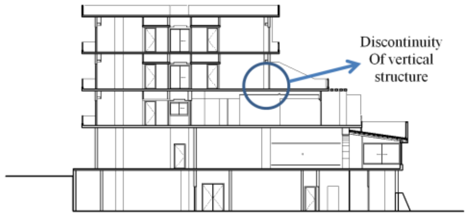
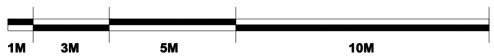
<tr><td colspan="2">



</td></tr>
<tr><td>Type of problems:
Discontinuity of vertical Structure
Soft/Waek Story</td><td>
</td></tr>
</table>

Chapter 6

CONCLUSION

To wrap up the previous discussion through the chapters, it is necessary to mention, “building codes” that different countries proposed based on damages which happen during an earthquake can only be resolved by applying a “structural engineering solution”.

However, based on experiences from previous earthquakes there is a definite connection between collapses or damages that to buildings and architecturally inclined design. In addition, to convey a degree of architectural expression of some aspect of earthquake action or resistance, a phrase was created by Christopher Arnold (Arnold 1996) as “an earthquake architecture”.

Hence, architects who work at seismic regions are expected to give serious consideration to “earthquakes” within design principles next to the more ordinary facts such as customer demands, function, aesthetics etc. This issue has to be taken into consideration even through, the engineers check the final design and solve some of the problems during the detailing stage.

Nevertheless, most of interior modification either by architect/interior architect or any other occupant of the building which is done without consulting with engineers may provide some serious problem and damages in the building in the event of an earthquake.

As a fact, from the vision of an interior architect the main object of design is the existing buildings. Hence, many issues related to the structure and construction of existing buildings before modifications has to be taken into serious consideration. Consulting with expert engineers is strongly necessary and recommended before any modification or application on an existing building.

The present study tried to reveal the importance and potential of interior changes on the overall lateral performance of structures as well as architectural consequences. Several structural deficiencies are also discussed and their relation to "interior change – seismic performance" is investigated. In addition to the above, two case studies are conducted on the issue.

The most noteworthy or essential part to be considered by architects in terms earthquake is the code for dealing with "irregular building", therefore, the focus of this study is on the most important problem regarding interior changes is the possibility of creating "irregular building" or applying modification without considering irregularity of existing building. This may become a serious issue in the case of old buildings – which are more likely to undergo changes and, which are more vulnerable against earthquakes – and careless change application.

On the other hand, it is quite possible to correct – at least partially – the performance of a building by executing some architectural modifications, such as the resulting performance of the building being better than the original structure.

In case No. II (palm beach hotel) we can see wonderful co-work between architect and engineers who are solving some of the important problems like soft floor and short columns by designing static structural elements as well as injecting chemical material into structure to increase the strength of the structural members.

In addition, other significant issues which need to be taken into consideration for later interior modification on the project are using light material and structure which together effects on earthquake resistance of buildings. Based on this issue, open building became an important concept especially in countries like Japan with higher risk of earthquakes.

Hence, interior modification especially done on residential buildings without consulting experts, the role of an architect in further modifications is extremely important.

Architects in earthquake region have to consider important issues such as flexibility and adaptability during the design process of a building to offer some possibilities for future modification by occupants without creating any problems related to earthquake resistance of buildings. As pointed out in case No. I any modification without considering that the building is located in hazard zone may put the building in critical situation.

6.1Future Study

In terms of the significance of seismic design issues in architectural education, further studies may search for the task of 'architecture education in earthquake region' as being one of the ways of introducing seismic design issues into architectural design courses.

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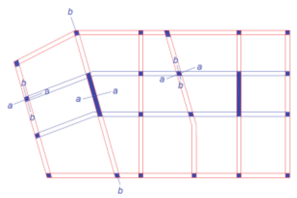
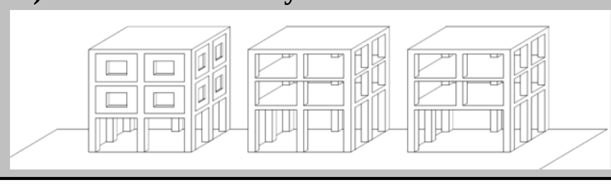
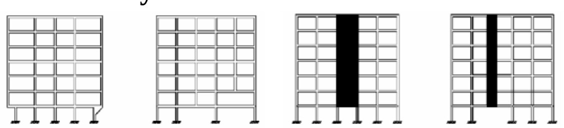
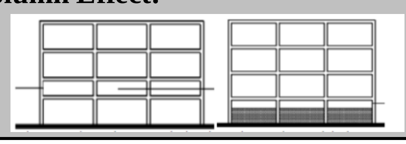
Table 5.1.Irregularity of a building

A1) Torsional Irregularity:	“When the Centers of a building mass does not coincide with the center of rigidity, torsion and stress concentrations occur in the building” (Soyluk and Harmankaya, 2012).
A2)Floor Discontinuations:	Floor discontinuity can simply be defined as presence of openings in the slab (TEC, 2007)**.**
A3)Projection in plan:	‘‘Projection in plan are where projections beyond the reentrant corners in both of the two principal directions in plan exceed the total plan dimensions of the building in the respective directions by more than 20% (TEC, 2007)”
A4)Nonparallel structural member axes: 	“Non-parallel axis in plan, are the cases where the major axes of vertical structural elements in plan are not parallel to the considered orthogonal earthquake directions”(TEC, 2007).
B1&B2) Weak or Soft Story: 	1) **Discontinuity in capacity-Weak Storey:** “A weak story is one in which the story strength is less than 80% of that in the story above. The story strength is the total strength of all seismic-resisting elements sharing the story shear for the direction under consideration” (Criteria of International Building Code, 2003). 2) **Stiffness irregularity-Soft Storey: “**A soft story is one in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average stiffness of the three stories above” (Criteria of International Building Code, 2003).
B3) Discontinuity of Vertical Structural Element: 	“Where vertical structural elements are positioned unsuitably” (TEC, 2007). This irregularity is clarified as follows: I. “Gusseted columns or the columns which rests on cantilever beams are prohibited. II. In the case where a column rests on a beam supported with columns at both ends. III. In no case the shear walls should be allowed to rest under the columns. IV. In no case the shear walls should be allowed to rest on beams” (TEC, 2007).
C1) Short Column Effect: 	Some columns in RC frames may be considerably shorter in height than other columns in the same story, this issue known as short column problem. *Short columns* occur in buildings constructed on a slope or in buildings with mezzanine floors or loft slabs that are added in between two regular floors (Murty. 2006)
C2) Strong Beam-Weak Column Formation:	“In structural systems comprised of frames only or of a combination of frames and wall, the sum of ultimate moment resistances of columns framing into a beam-column joint should be at least 20% more than the sum of ultimate moment resistances of beam framing into the same joint” (Doğangün, 2004).
C3)Pounding effects:	**“**Pounding is a damage type in two buildings or different parts of the same building under earthquake loads. It commonly occure due to the insufficient seismic gap or no gap between two adjacent buildings”(Doğan, 2007).
Wrong frame elements location:	I. Discontinuous beam. II. Beam intersecting without vertical supports. III. Beam and frames with broken axis. IV. Irregular configuration of columns.
Heavy over hangs:	Increase the plan dimensions at upper floors in comparison to the ground floor (TEC, 2007).