ASSESSING ARCHITECT'S ROLE IN SEISMIC EVALUATION AND RISK MITIGATION

A Dissertation for the Degree of Master in Disaster Management

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CANDIDATE’S DECLARATION

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct and with full citations and referencing all materials.

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ABSTRACT

Dhaka City having a faster urbanization has an increasing threat of hazard as the risk is more complex and complicated than the rural area due to its increased population in a concentrated area and competitive economic activities. Due to the complexity of the urban dynamics earthquake vulnerability assessment to plan measures for effective mitigation is mandatory. The morphology of Dhaka City has emerged from the South of the city towards the northern part.Hence, three selected wards are chosen according to the morphological growth of the Dhaka City towards the northen region.

Dhaka city is highly susceptible to earthquake and lack of awareness of built forms without maintaining any codes and guidelines with the help of poor insitituional efficiency is degrading the current situation. In this study three procedures are implemented to assess the vulnerability of three selected wards of Dhaka City Coporation.the first procedure involves the vulnerability assessment report of the selected wards. The wards are segregated into cluster level and with the help of Rapid Visual Screening and Turkish Method a methodology is adopted and assessed and with the help of flowcharts, the results are illustrated.

Secondly a questionnaire survey is developed to understand and question the awareness and consciousness, interest and awareness of the architects practicing architecture in Bangladesh.

Finally the implications of the results have guided the applications of architecture-based issues in seismic design for the use of architects.Three individual buildings from the three selected wards are taken to evaluate the the attributes and elements that actually influence the earthquake vulnerability of the building.

Overall it is seen that even though the building in Chawkbazar is the most vulnerable, the other two buildings of Dhanmondi and Banani even though designed by architects and structural engineers is comparatively less vulnerable but has huge gaps in designing according to the seismic issues.Further research is recommended to assess the building vulnerability by monitoring the building codes while designing and constructing a building by the architects and structural engineers.

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ROXANA NAUREEN HUQ

Abbreviations

AHP	Analytical Hierarchy Process
BBS	Bangladesh Bureau of Statistics
BFSCD	Bangladesh Fire Service and Civil Defence
BNBC	Bangladesh National Building Code
BNUS	Bangladesh Network Office for Urban Safety
CBDRM	Community-Based Disaster Risk Management
CBO	Community-Based Organization
CDMP	Comprehensive Disaster Management Programme
DCC	Dhaka City Corporation
DNCC	Dhaka North City Corporation
DRR	Disaster Risk Reduction
DSCC	Dhaka South City Corporation
FAR	Floor Area Ratio
FGD	Focus Group Discussion
GIS	Geographic Information System
IAB	Institute of Architects of Bangladesh
IFI	Impact Factor Index
PAR	Pressure and Release
PAR	Participatory Action Research
PGV	Peak Ground Velocity
PRA	Participatory Rural Appraisal
PRI	Physical Risk Index
RAJUK	Rajdhani Unnayan Kartipakya
RVS	Rapid Visual Screening
SL	Sustainable Livelihoods
SoVI	Social Vulnerability Index
UDRI	Urban Disaster Risk Index
URM	Unreinforced Masonry Building

Acronyms

$(\Delta i)_{max}$:	Maximum storey drift
$(\Delta i)_{min}$:	Minimum storey drift
$(\Delta i)_{ort}$:	Average storey drift
Δ:	Storey drift
A:	Gross floor area
Ab:	Total area of openings
Ae :	Effective shear area
ax, ay :	Projection dimensions
cm :	Centimeter
d :	Separation distance
df :	Degrees of freedom
E :	Eccentricity
F :	Earthquake force
H :	Height
H1 :	Alternative hypothesis
Ho :	Null hypothesis
km :	Kilometer
L :	Length
Lx, Ly :	Plan dimensions
m :	Meter
M, M1 :	Magnitude of an earthquake in Richter Scale
mm :	Millimeter
MMI :	Modified Mercalli Intensity Scale
UBC :	Uniform Building Code
VAR :	Variable number
W :	Width
ηbi :	Torsional Irregularity Factor
ηci :	Strength Irregularity Factor
ηki :	Stiffness Irregularity Factor

1. Introduction

1.1 Background

Bangladesh is known to be the fifth natural disaster prone country globally that is mostly affected by natural disasters such as tropical cyclones, storm surges, floods, river erosion landslides etc. Such natural events impact on socially and politically and on the social composition of the population affected. Bangladesh is a small country in south Asia. Its geography makes it unlike any other place on Earth. To the north of Bangladesh are the Himalayas, the world's largest mountain range. Three great rivers — the Brahmaputra, Ganges and Meghna — flow from the Himalayas and other nearby mountain ranges and merge in Bangladesh.

Bangladesh isn't shaped by just rivers and flooding. It's also shaped by what's happening beneath the surface, where tectonic plates are shifting. Bangladesh is one of the most tectonically active regions in the world. It sits where three tectonic plates meet: the Indian Plate, the Eurasian Plate, and the Burmese Plate. The Indian Plate is moving northeast, slowly colliding with the Eurasian Plate. This collision formed the Himalayan Mountains — and they are still rising. There are many active faults along this boundary, such as the enormous Dauki fault that borders northern Bangladesh. Movement along this fault formed the large Shillong Plateau. To the east, the Burmese Plate pushes west against the Indian Plate. As the the India plate subducts beneath the Burmese Plate, rocks fold and buckle to form the hills and valleys of the Burma Arc. Of course, active faults can also generate huge earthquakes. The devastating 2004 earthquake and tsunami in Sumatra occurred along the boundary between the Indian and Burmese plates. Scientists think that a major earthquake closer to Bangladesh is only a matter of time.

Bangladesh has been classified into three seismic zones in the zoning map according to earthquake hazard i.e. Zone-I, Zone-II and Zone-III where Dhaka falls in Zone-II (BNBC, 1993). Dhaka is highly vulnerable to tremor under Madhupur Fault as expressed by local experts, as the phenomenal urbanization, density of population and high-rise structures are growing fast here (SAARC, 2010).

According to a report published by United Nations IDNDR-RADIUS Initiatives, Dhaka and Tehran are the cities with the highest relative earthquake disaster risk (Rahman, 2004). Although no moderate to large earthquake has struck Dhaka city in historical past, it experiences minor tremors almost all the year round which indicates the region to be seismically active (Khan, 2004).

In 1762, a major earthquake submerged 150 square kilometers of land. Five hundred people in Dhaka, then a small town, were killed. Between 1850 and 1950, seven earthquakes with magnitude from 7.0 to 8.7 on the Richter scale struck the region. More recently, since 1997, Bangladesh has experienced several earthquakes of magnitude higher than 5 (GoB, n.d.a).

The National Building Code of Bangladesh (DMM, 2012) specifies three seismic zones, identified through a series of seismic-tectonic studies. These zones identify the level of earthquake risk faced by particular areas; Zone III being the most at risk, and Zone I the least at risk. Seismic zoning in Bangladesh indicates that Dhaka is under Zone II, and as such is at a real risk of an earthquake of significant magnitude.

The 1897 Great Indian Earthquake which originated at an epicentral distance of only 230 km from Dhaka caused extensive damage of brick masonry structures in Dhaka (Oldham, 1899). Dhaka metropolis together with its surroundings is situated in the seismic zone 2 which is moderate risk prone area (BNBC, 1993). The metropolis Dhaka is an integral part in the southern tip of Madhupur Tract encircled by some very active tectonic units' viz. the Sylhet Trough on the North, the Jamalpur Graben on the west, The Dhaka Depression on the south and northeast-southwest trending Meghna Fault Zone in the east (Ansary et al, 2004).

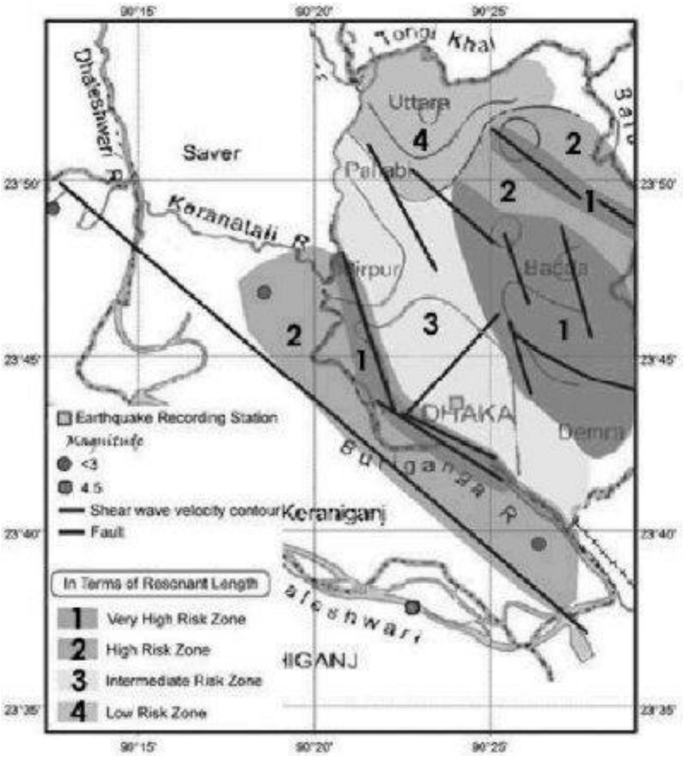

Figure 1.1: Seismic Vulnerability Map of Dhaka Megacity (Source: http://www.slideshare.net/ahmedsumon5602728/earthqukake-in-dhaka-city)

The tectonic evaluation of Dhaka city can be explained as the north moving Indian plate with the Eurasian plate. Dhaka is moving 30.6 mm/year in the direction northeast (Figure 1.1). Moreover, in and around Dhaka the rate of strain accumulation is relatively high (Ali and Choudhury, 2001). The shallow subsurface of Dhaka is characterized by number of faults of variable dimensions. Three major faults of Dhaka city as observed in satellite images and aerial photographs by the Geological Survey of Bangladesh and its field surveys are along Bagunbari Khal, trending east-west in the southern part of the city, along an abandoned channel, in the Uttara area, across Zia International Airport, trending north-south in the northern part of the city and along the Turag River, in Mirpur near Dhaka Zoo, trending north-south in the western part of the city (Ali and Choudhury, 2001).

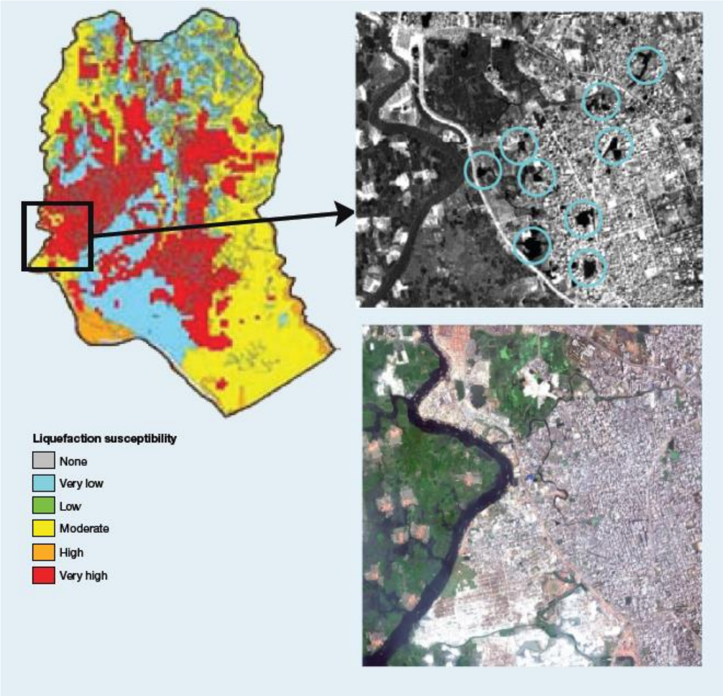

Figure 1.2:Liquefaction susceptibility of Dhaka City (Source: http://www.preventionweb.net/english/hyogo/gar/2011/en/what/images/figure2.1.png)

In fact, globally, Dhaka is one of the most vulnerable cities to earthquake according to the Earthquake Disaster Risk Index of Stanford University (World Bank, 2013). In the urban context, major earthquake risk is associated with the high vulnerability of buildings to collapse due to inadequate construction materials and processes. The urban DRR framework report has found that, in some areas, construction according to official building codes was followed for less than 10 per cent of buildings (Shaw, 2013). Representatives of the Comprehensive Disaster Management Programme (CDMP) have specified that 78,000 out 326,000 buildings in Dhaka are vulnerable to collapse. This vulnerability was demonstrated by the Rana Plaza building collapse in April 2013. Even those not living in large structures are at risk from falling objects, leaking gas lines and fires resulting from earthquakes.

In addition to these direct impacts, earthquakes can cause liquefaction of soils, rendering built-up areas further vulnerable to structural collapse. Liquefaction is a process wherein sand and silt become more compact and force ground water upwards. The resulting fluidity at the upper level fails to support structures, causing buildings to sink and collapse (USGS, 2013). Dhaka's largely shallow water table and soft sediment terrain make it highly susceptible to this phenomenon (Stone, 2011; Ansary and Rashid, 2000). The historical trend of seismicity and some recent tremors occurred in Bangladesh and adjoining areas indicate that the country is also at high risk of earthquake.

1.2 Status of Earthquakes in Bangladesh

Bangladesh is surrounded by the regions of high seismicity which include the Himalayan Arc and shillong plateau in the north, the Burmese Arc, Arakan Yoma anticlinorium in the east and complex Naga-Disang-Jaflong thrust zones in the northeast. It is also the site of the Dauki Fault system along with numerous subsurface active faults and a flexure zone called Hinge Zone. These weak regions are believed to provide the necessary zones for movements within the basin area.

In the generalized tectonic map of Bangladesh the distribution of epicenters is found to be linear along the Dauki Fault system and random in other regions of Bangladesh. The investigation of the map demonstrates that the epicenters are lying in the weak zones comprising surface or subsurface faults. Most of the events are of moderate rank (magnitude 4-6) and lie at a shallow depth, which suggests that the recent movements occurred in thesediments overlying the basement rocks. In the northeastern region (surma basin), major events are controlled by the Dauki Fault system. The events located in and around the madhupur tract also indicate shallow displacement in the faults separating the block from the alluvium.

The first seismic zoning map of the subcontinent was compiled by the Geological Survey of India in 1935. The Bangladesh Meteorological Department adopted a seismic zoning map in 1972. In 1977, the Government of Bangladesh constituted a Committee of Experts to examine the seismic problem and make appropriate recommendations. The Committee proposed a zoning map of Bangladesh in the same year.

In the zoning map, Bangladesh has been divided into three generalized seismic zones: zone-I, zone-II and zone-III. Zone-I comprising the northern and eastern regions of Bangladesh with the presence of the Dauki Fault system of eastern Sylhet and the deep seated Sylhet Fault, and proximity to the highly disturbed southeastern Assam region with the Jaflong thrust, Naga thrust and Disang thrust, is a zone of high seismic risk with a basic seismic co-efficient of 0.08. Northern Bangladesh comprising greater Rangpur and Dinajpur districts is also a region of high seismicity because of the presence of the Jamuna Fault and the proximity to the active east-west running fault and the Main Boundary Fault to the north in India. The Chittagong-Tripura Folded Belt experiences frequent earthquakes, as just to its east is the Burmese Arc where a large number of shallow depth earthquakes originate. Zone-II comprising the central part of Bangladesh represents the regions of recent uplifted Pleistocene blocks of the Barind and Madhupur Tracts, and the western extension of the folded belt. The Zone-III comprising the southwestern part of Bangladesh is seismically quiet, with an estimated basic seismic co-efficient of 0.04 (Ali & Chowdhury, 2009).

1.3 Aims and Objectives

The prime objective of this research portrays the exploration of the existing state of interest, awareness and consciousness of architects towards a holistic attitude on earthquake hazard and architecture-based issues related to earthquake resistant building design.

The analysis of vulnerability situation of Dhaka City due to earthquake is the prime concern of this research. The recommendations of this dissertation contribute to develop the risk reduction plan of Dhaka City.

The research will aim towards on the following important issues-

- To study earthquake vulnerability of three selected ward of Dhaka City.
- How architects experience and perceive seismic design: roles, responsibilities, awareness, and knowledge of architecture based seismic design issues.
- To formulate risk reduction strategies based on discussions and recommendations on the existing condition of the occupancy and building structure.

1.4 Scope of the study

The research offers a wide scope of knowledge on earthquake hazard vulnerability in Dhaka city. It has a combination of both structural and socio-economic issues that lead to the selected locality to the potential earthquake hazards. The study focuses on a selected number of ward of both North and South Dhaka City Corporation.

It has compiled methods of assessing vulnerability of earthquake and fire and then incorporated social vulnerability with physical vulnerability. Though the study focuses on a small portion of Dhaka City, the methodology can be used for whole Dhaka City to analyze the overall vulnerability condition. Thus the research provides a great scope for disaster management in Dhaka City by identifying hotspot or the highest impact areas in order to focus respective disaster planning and decision making.

1.5 Organization of the study area

The research is based on the architectural scope and awareness of architects in seismic design into 5 chapters.

Chapter One: It introduces the main objectives with possible outcomes and background information of earthquake hazards, its types, scope of the study for further research and also limitations in conducting the research.

Chapter Two: This chapter encompasses the literature review of earthquakes and role and responsiveness of architects towards earthquake hazard mitigation in a densely populated city like Dhaka City. It also reveals the factors behind physical and social vulnerability that can cause greater risk to earthquake hazards. It also defines the design practice aids with professional interaction between architects and structural designers in strengthening seismic design. This chapter not only exposes the possible interaction but also assess professional license for authentication. It also acknowledges post-earthquake roles of architects.

Chapter Three: This chapter leads to the methodology and selection of the study area in order to meet the requirements of the possible fulfillment of the objectives mentioned.

Chapter Four: This chapter comprises the architecture based issues in seismic design. It also contains the characteristics of the study area covering physical, socio-economic and demographic features from field survey and WARD map of Dhaka City Corporation. It also discusses the building and structural configuration issues that determines the vulnerability attributes during any earthquake. The chapter also provides detail information of the structural and non-structural characteristics associated with earthquake.

Chapter Five and Six: Prior to the discussion on the major findings of this research and their implications for earthquake hazard mitigation both the chapters deduce and reccomend some risk reduction strategies and conclusions.

1.6 Limitations of the Study

Limitations of the research process and resulting data should be highlighted and considered throughout the report. In terms of the research process, further representation of local residents and institutions was hindered due to time constraints which limited opportunity for additional data collection. This study considers the earthquake and fire hazard vulnerability of the existing buildings along with social vulnerability of local people but cannot incorporate loss estimation of these hazards. As the inhabitants of the study area frequently face fire, but has never experienced earthquake, it was difficult for them to perceive earthquake vulnerability. Some buildings were not accessible for the surveyors. During the survey period, the study suffered much from lack of assistance from the residing people. It was very hard to conduct physical survey as the study area is a busy region dominated by mixed land use.

2. Literature Review

2.1 Earthquake

In nearly every ancient culture, earthquakes have been described as divine judgement because of their apparent randomness, lack of any visible cause, and frightening destructiveness. In many beliefs, they were thought to be the instruments of displeasure of the mythological Gods for the sinners (Coburn and Spence, 1992). Until the science of seismology became formalized, mythological earthquake legends existed within many cultures; even today, they are still in existence (Lagorio, 1990). Coburn and Spence (1992) state that it was begun to be understood what earthquakes are and what causes them, only in the twentieth century.

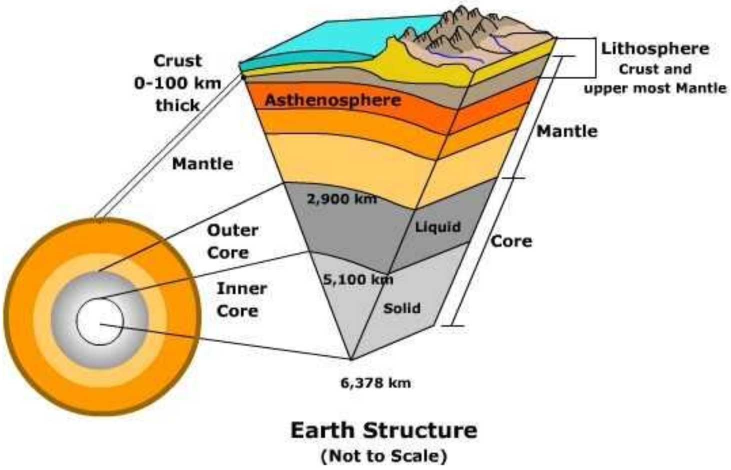

Figure 2.1: The structure of the earth (Celep and Kumbasar, 1992)

The occurrence of earthquake is related to the structure of earth (Figure 2.1). The earth is composed of three main parts with different properties. These are, respectively from outer part to inner part: the crust, the mantle, and the core. The core, with a radius of 3500 km, is liquid in property. The mantle is 2900 km in thick and it has plastic (semi-molten) in property. The crust measures about 5 km in thickness under oceanic portions and 30-60 km in thickness under continental portions (Bayülke, 1989; Celep and Kumbasar, 1992).

Among the various theories, which have been proposed on the causes of earthquakes, the plate tectonics theory is considered as the most reliable one. According to the plate tectonics theory, the earth's crust, which is known as lithosphere, is fragmented into segment (plates) of landmasses and oceans (Wakabayashi, 1986).

These several large and small hard plates are in continuous movement relative to each other with slow velocities on the semi-molten mantle. This movement is thought to be driven by the convection currents in the mantle. These plates pull apart from each other, override one another, and slide past each along their borders, which are called faults (Krinitzsky, Gould and Edinger, 1993). The motions of the plates cause stresses and deformations. Geographical formations become apparent by the movements, which take several hundred thousand years to come into being.

However, sometimes, the adjacent plates cannot move because of the friction between them. They are locked into place (Lagorio, 1990). Strain energy is stored on the faults, until it exceeds the friction capacity of the plates. When accumulation of energy becomes huge enough to make the plates continue to move, rupture takes place with a sudden release of energy. Ambrose and Vergun (1985) state that “vibrations, called seismic waves, emit from the location of the energy release and travel throughout the earth’s mass. On the surface of the earth these waves cause a vibratory motion”. That vibration is what we feel as the earthquake.

2.2 Definition of some basic terms

2.2.1 The Focus/Center/Hypocenter of the Earthquake

The point where the seismic motion originates is called the focus, the center, or the hypocenter of the earthquake (Wakabayashi, 1986).Hypocenters are found at a considerable depth below the surface. Vibrating waves move away from the hypocenter in various directions. The waves can travel to all places on the Earth and make the planet rapidly vibrate because of their immense power. While the hypocenter is the origin of earthquakes, scientists typically plot the epicenter on a map to identify the location of the quake. This method of mapping an earthquake’s location is the reason large quakes are usually named after the city or geographic location closest to the epicenter.

Shallow-focus earthquakes occur from 0 to 40 miles deep. They result from the movement of crustal plates against each other, and they are measured using the Richter scale. Deep-focus earthquakes occur more than 180 miles below the surface of the Earth. They are common in island arcs and deep ocean trenches where plates slip over each other in sub-duction zones. Deep-focus earthquakes are measured using the moment magnitude scale. Shallow-focus earthquakes occur more frequently and are more destructive than deep-focus earthquakes.

2.2.2 The Epifocus/ Epicenter of the Earthquake

The epicenter of an earthquake is the point on the surface of the Earth directly above the point in the crust where a seismic rupture occurs. This origin point (Figure 2.2) within the crust is called the hypocenter or focus. Though the epicenter is central to the area of effect of an earthquake, it is not necessarily where the strongest shaking is experienced. Historically, the epicenter was believed to be so, but modern seismic measuring equipment has shown in several instances that shaking is more severe in areas several miles away. From this, a debate has emerged over whether earthquakes should be named after the location of their epicenters or the communities they primarily affect.

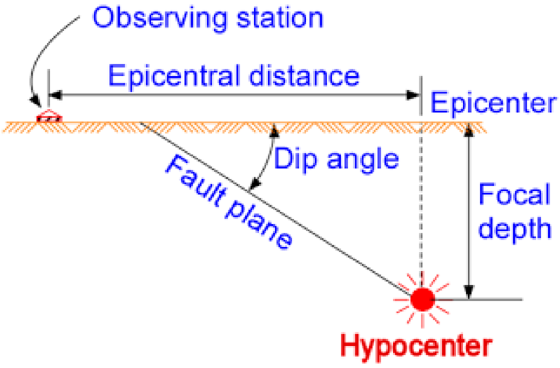

Figure 2.2: The hypocenter of the earthquake

2.2.3 The Focal Region

Seismic waves propagate from the focus through a limited region of the surrounding earth body. That is called the focal region. The size of the focal region is proportional to the strength of the earthquake (Wakabayashi, 1986).

The focal mechanism of an earthquake describes the deformation in the source region that generates the seismic waves. In the case of a fault-related event it refers to the orientation of the fault plane that slipped and the slip vector and is also known as a fault-plane solution. Focal mechanisms are derived from a solution of the moment tensor for the earthquake, which itself is estimated by an analysis of observed seismic waveforms.

The focal mechanism can be derived from observing the pattern of "first motions", that is, whether the first arriving P waves break up or down. This method was used before waveforms were recorded and analyzed digitally and this method is still used for earthquakes too small for easy moment tensor solution. Focal mechanisms are now mainly derived using semi-automatic analysis of the recorded waveforms.

2.2.4 Types of Earthquake

Earthquakes are usually classified on the following bases:

(a) Cause of origin;

(b) Depth of focus; and

(c) Intensity and magnitude of earthquake.

a) Cause of Origin: On the basis of the causes of earthquake, they are classified as: - (i) Tectonic and (ii) Non-tectonic earthquakes. The non-tectonic earthquakes are mainly of three types due to surface causes, volcanic causes and collapse of cavity roofs. The non-tectonic earthquakes due Volcanic to surface causes Earthquakes or Denudation earthquakes

b) Depth of focus: As we know, the instrument designed to detect seismic waves is called seismometer and the seismograph is a seismometer to record the earth vibration. This record of earth vibration is known as seismogram. It has now become possible to estimate the depth of focus of an earthquake by analyzing seismograms.

On the basis of the depth of focus, earthquakes are classified as:

i) Surface-earthquakes

ii) Shallow-focus earthquakes or normal earthquakes.

iii) Intermediate-focus earthquakes, and

iv) Deep-focus earthquakes.

i) Surface-earthquakes: Surface-earthquakes are those in which the depth of the focus is less than 10,000 metres.

ii) Surface-earthquakes: The earthquakes with the hypocenter at a depth of 10 to 50kms are known as shallow-focus earthquakes.

iii) Intermediate-focus earthquakes: When the earthquake is originated at a depth of 50 to 300Kms, it is called intermediate- earthquake.

iv) Deep-focus earthquakes: The deep-focus earthquakes or the plutonic earthquakes are those with hypocenters located at depths more than 300kms. Majority of the deep focus earthquakes originate between 500 and 700kms.

Shallow-focus earthquakes constitute about 85 percent of all the earthquakes and the intermediate and deep-focus earthquakes account for 12 and 3 percent respectively of all the earthquakes. Thus it is seen that the intermediate and deep-focus earthquakes together account for only 15 percent of the earthquakes.

c) Intensity and Magnitude of Earthquakes:

As we know, the tremors caused by earthquake may be so feeble and imperceptible that they can only be registered by highly sensitive instruments and may be so vigorous to cause large scale devastation. The strength of an earthquake can be measured either by its intensity or by its magnitude.

Intensity of an earthquake is a measure of the degree of damage and destruction it can cause. These effects can be observed without the help of any instrument. It is also a fact that intensity of an earthquake diminishes outwards from the epicenter.

Therefore places in which the earthquake has manifested itself with equal intensity are contoured with - a line known as 'isoseismal'. Areas with one and the same intensity of earthquake restricted by isoseismal lines are known as isoseismal areas. There is a number of disadvantages in using intensity as a measure of the strength of a particular earthquake, some of the important disadvantages are as follows:

i) The strength of an earthquake decreases with distance from its epicentre. Thus different degree of damage occurs at different distances for the same earthquake.

ii) The degree of damage depends much on the geological characteristics of a particular area as well as the type of construction, population-density etc.

2.2.5 According to the Focal Depth of the Earthquakes

In seismology, the depth of focus or focal depth refers to the depth at which an earthquake occurs. Earthquakes occurring at a depth of less than 70 km (43 mi) are classified as shallow-focus earthquakes, while those with a focal depth between 70 km (43 mi) and 300 km (190 mi) are commonly termed mid-focus or intermediate-depth earthquakes. In subduction zones, where older and colder oceanic crust descends beneath another tectonic plate, deep-focus earthquakes may occur at much greater depths in the mantle, ranging from 300 km (190 mi) up to 700 km (430 mi).

The cause of deep-focus earthquakes is still not entirely understood since sub ducted lithosphere at that pressure and temperature regime should not exhibit brittle behavior. A possible mechanism for the generation of deep-focus earthquakes is faulting caused by olivine undergoing a phase transition into a spinel structure, with which they are believed to be associated. Earthquakes at this depth of focus typically occur at oceanic-continental convergent boundaries, along Wadati-Benioff zones.

Earthquakes can occur anywhere between the Earth's surface and about 700 kilometers below the surface. For scientific purposes, this earthquake depth range of 0 - 700 km is divided into three zones: shallow, intermediate, and deep.

Shallow earthquakes are between 0 and 70 km deep; intermediate earthquakes, 70 - 300 km deep; and deep earthquakes, 300 - 700 km deep. In general, the term "deep-focus earthquakes" is applied to earthquakes deeper than 70 km. All earthquakes deeper than 70 km are localized within great slabs of shallow lithosphere that are sinking into the Earth's mantle.

The most obvious indication on a seismogram that a large earthquake has a deep focus is the small amplitude, or height, of the recorded surface waves and the uncomplicated character of the P and S waves. Although the surface-wave pattern does generally indicate that an earthquake is either shallow or may have some depth, the most accurate method of determining the focal depth of an earthquake is to read a depth phase recorded on the seismogram. The depth phase is the characteristic phase pP-a P wave reflected from the surface of the Earth at a point relatively near the hypocenter. At distant seismograph stations, the pP follows the P wave by a time interval that changes slowly with distance but rapidly with depth. This time interval, pP-P (pP minus P), is used to compute depth-of-focus tables. Using the time difference of pP-P as read from the seismogram and the distance between the epicenter and the seismograph station, the depth of the earthquake can be determined from published travel-time curves or depth tables.

Another seismic wave used to determine focal depth is the sP phase - an S wave reflected as a P wave from the Earth's surface at a point near the epicenter. This wave is recorded after the pP by about one-half of the pP-P time interval. The depth of an earthquake can be determined from the sP phase in the same manner as the pP phase by using the appropriate travel-time curves or depth tables for sP.

If the pP and sP waves can be identified on the seismogram, an accurate focal depth can be determined.

The earthquakes can be classified into three groups depending on their focal depths

(Lindeburg and Baradar, 2001).

- Shallow earthquakes: The focal depth is less than 60 km.
- Intermediate earthquakes: The focal depth ranges from 60 to 300 km.
- Deep earthquakes: The focal depth is up to 700 km.
- Deep earthquakes: The focal depth is up to 700 km.

2.2.6 According to the Distance from the Recording Device

According to the distances from the recording devices, earthquakes can be classified into four groups (Özmen, 2002).

- Local Earthquake: The distance is less than 100 km.
- Proximity Earthquake: The distance is between 100-1000 km.
- Regional Earthquake: The distance is between 1000-5000 km.
- Distant Earthquake: The distance is more than 5000 km.

2.2.7 According to the Magnitude of the Earthquake

Six groups of earthquakes can be classified according to their magnitudes measured by Richter scale (Özmen, 2002).

- Very Strong Earthquake: M>8.0
- Strong Earthquake: 7.0<M<8.0
- Medium Earthquake: 5.0<M<7.0
- Small Earthquake: 3.0<M<5.0
- Micro Earthquake: 1.0<M<3.0
- Ultra- Micro Earthquake: M<1.0

Wakabayashi (1986) states that, earthquakes of larger magnitude occur less frequently than those of smaller magnitude.

2.2.8 According to the Origin

According to the origin, the earthquakes can be classified into four groups-

Tectonic Earthquake: The earth's crust consists of loose broken fragments of lands known as the tectonic plates. These tectonic plates have the ability to slowly and gradually move. Now, these plates can away from each other, towards each other, can collide or can slide past each other. When the two tectonic plates slide over each other a huge tremor takes place, and that's how a tectonic earthquake occurs.

Tectonic earthquakes are the most common type of earthquake. It may be of small or of extremely high magnitude. Most of the mass destruction caused by an earthquake over the history is due to the tectonic earthquakes. The tremors caused by tectonic earthquakes are mostly severe and if they are of high magnitude, they can completely destroy a whole city within seconds.

Volcanic Earthquake: Volcanic earthquakes are comparatively less common than the tectonic earthquakes and usually occur either before or after a volcanic eruption. There are two types of volcanic earthquakes: Volcano tectonic earthquakes and long period volcanic earthquakes. The volcanic tectonic earthquakes occur usually after a volcanic activity has taken place. The magma that erupts during an earthquake leaves a space, to fill the space left by the magma the rocks move towards the space to fill it in, causing severe earthquakes

Most of the times after the release of lava, the lava falls on its vent blocking it, and not letting the pressure release. The retained pressure does not stay for long; it releases with a huge explosion. The explosion causes a severe earthquake, mostly of extremely high magnitude. The long period volcanic earthquakes occur post a volcanic eruption. Few days before the great explosion, the change in heat of magma below the earth's surface creates seismic waves, causing an earthquake.

Collapse Earthquakes: Collapse earth quakes are comparatively small earthquakes and they take place around underground mines. These earthquakes are also referred to as the mine bursts. The collapse earthquakes are caused by the pressure induced within the rocks. It results in the collapse of the roof of the mine which causes further tremors. Collapse earthquakes are common in small towns near these underground mines.

Explosion Earthquakes: The explosion earthquakes are caused due to the nuclear explosions. These man induced earthquakes are one of the biggest side effects of the modern nuclear war. In the 1930s during the American nuclear tests many small villages and towns suffered through such tremors, many of them were completely destroyed due to this heinous act.

2.3 Seismic Waves

Seismic waves are waves of energy that travel through the Earth's layers, and are a result of earthquakes, volcanic eruptions, magma movement, large landslides and large man-made explosions that give out low-frequency acoustic energy. Many other natural and anthropogenic sources create low-amplitude waves commonly referred to as ambient vibrations. Seismic waves are studied by geophysicists called seismologists. Seismic wave fields are recorded by a seismometer, hydrophone (in water), or accelerometer.

The propagation velocity of the waves depends on density and elasticity of the medium. Velocity tends to increase with depth and ranges from approximately 2 to 8 km/s in the Earth's crust, up to 13 km/s in the deep mantle.

Earthquakes create distinct types of waves with different velocities; when reaching seismic observatories, their different travel times help scientists to locate the source of the hypocenter. In geophysics the refraction or reflection of seismic waves is used for research into the structure of the Earth's interior, and man-made vibrations are often generated to investigate shallow, subsurface structures.

Seismic waves are the waves of energy caused by the sudden breaking of rock within the earth or an explosion. They are the energy that travels through the earth and is recorded on seismographs.

2.3.1 Types of Seismic Waves

There are several different kinds of seismic waves, and they all move in different ways. The two main types of waves are body waves and surface waves. Body waves can travel through the earth's inner layers, but surface waves can only move along the surface of the planet like ripples on water. Earthquakes radiate seismic energy as both body and surface waves.

BODY WAVES

Traveling through the interior of the earth, body waves arrive before the surface waves emitted by an earthquake. These waves are of a higher frequency than surface waves.

P WAVES

The first kind of body wave is the P wave or primary wave. This is the fastest kind of seismic wave, and, consequently, the first to 'arrive' at a seismic station. The P wave can move through solid rock and fluids, like water or the liquid layers of the earth. It pushes and pulls the rock it moves through just like sound waves. P waves are also known as compressional waves, because of the pushing and pulling they do. Subjected to a P wave, particles move in the same direction that the the wave is moving in, which is the direction that the energy is traveling in, and is sometimes called the 'direction of wave propagation'.

S WAVES

The second type of body wave is the S wave or secondary wave, which is the second wave you feel in an earthquake. An S wave is slower than a P wave and can only move through solid rock, not through any liquid medium. It is this property of S waves that led seismologists to conclude that the Earth's outer core is a liquid. S waves move rock particles up and down, or side-to-side--perpendicular to the direction that the wave is traveling in (the direction of wave propagation).

The first kind of surface wave is called a Love wave, named after A.E.H. Love, a British mathematician who worked out the mathematical model for this kind of wave in 1911. It's the fastest surface wave and moves the ground from side-to-side. Confined to the surface of the crust, Love waves produce entirely horizontal motion.

RAYLEIGH WAVES

The other kind of surface wave is the Rayleigh wave, named for John William Strutt, Lord Rayleigh, who mathematically predicted the existence of this kind of wave in 1885. A Rayleigh wave rolls along the ground just like a wave rolls across a lake or an ocean. Because it rolls, it moves the ground up and down, and side-to-side in the same direction that the wave is moving. Most of the shaking felt from an earthquake is due to the Rayleigh wave, which can be much larger than the other waves.There exist two types of seismic waves: the body wave and the surface wave. The body waves, P wave (primary, longitudinal or compressive) and S wave (secondary, transverse or shear), radiate from the hypocenter through the interior of the earth.

The P wave, which reaches the surface first, propagates in the same direction as its own vibration. The S wave, which travels more slowly than the P wave, propagates in a direction perpendicular to its vibration causing the majority of damage to structures (Wakabayashi, 1986). Wakabayashi (1986) states that the waves transmitted along the earth’s surface are called the surface waves. They are detected more often in shallow earthquakes and they arrive after P and S waves. The two kinds of surface waves are L wave (love) and R wave (Rayleigh). The L wave vibrates in a plane parallel to the earth’s surface and perpendicular to the direction of wave propagation. The R wave vibrates in a plane perpendicular to the earth’s surface and exhibits an elliptic movement.

As the earth’s structure is not homogeneous and the various layers having different characteristics are near the earth’s surface, various kinds of waves are produced by reflections and refractions through the various layers of earth.

2.4 Magnitude

In order to give a complete picture of an earthquake, it is necessary to use two measures: the magnitude and the intensity. When they are used together, they give the answers of these questions: Where the seismic event takes place, how large it is and what its impacts are on the built environment (Lagorio, 1990).

Wakabayashi (1986) describes magnitude as a quantitative measure of the size of an earthquake, which is closely related to the amount of energy released from the hypocenter. A number of magnitude scales are in use. The most extensively used magnitude scale is the Richter Magnitude Scale developed by Professor Charles Richter in 1935 (Lagorio, 1990) and denoted as M or Ml (Dowrick, 1987).

Richter magnitude is expressed in whole numbers and decimals. As the Richter scale is a logarithmic scale, the significance goes up rapidly. Lagorio (1990) states that, “every upward step of one magnitude unit represents the multiplication of the recorded amplitude by a factor of 10”.

For example, a Richter magnitude of 4 records 10 times the amplitude of a ‘Richter 5’, and a ‘Richter 6’ records 100 times much energy than that of the ‘Richter 4’. Although the Richter Magnitude Scale is an open-ended scale with no upper limit, the largest known earthquakes have approached to a Richter 9.0 (Lagorio, 1990).

It is important to notice that earthquakes of similar Richter magnitudes may differ greatly from each other in the physical effects produced on the built environment. Because the destructive effects of earthquakes with similar magnitudes depend on the geological characteristics, through which seismic waves travel, and the depth of the earthquake (Lagorio, 1990). A shallow-focused earthquake will be more destructive than a deep-focused one even the magnitudes of them are similar (Bayülke, 1989).

The magnitudes of earthquakes can be grouped into four categories.

These are: Magnitudes less than 4.5: Magnitude 4.5 represents an energy release of about 10 tons TNT being exploded underground. Although earthquakes with magnitudes 4.5 or less may be quite widely felt by people, they have little potential to cause damage. For earthquakes of magnitude 3.0 or 2.0 become difficult for seismographs to detect unless they occur close to the earth’s surface (Coburn and Spence, 1992). Magnitudes less than 4.5 to 5.5 - local earthquakes: Magnitude 5.5 represents an energy release of about 1000 tons TNT being exploded underground. Earthquakes with magnitudes up to about 5.5 can occur almost anywhere in the world as being the level of energy release that is possible in normal non-tectonic geological processes. For earthquakes of magnitude 5.0 to 5.5 may cause damage if they are shallow earthquakes (Coburn and Spence, 1992).

Magnitudes 6.0 to 7.0 - large magnitude earthquakes: Magnitude 6.0 represents an energy release of about 6000 tons TNT being exploded underground. A magnitude of 6.3 is generally taken as being about equivalent to an atomic bomb being exploded underground. If large magnitude earthquakes occur close to earth’s surface, they may cause severe damage of buildings. However, some of these are associated with tectonic processes at depth and may be relatively harmless to people on the earth’s surface (Coburn and Spence, 1992).

Magnitudes 7.0 to 8.9 - great earthquakes: Magnitude 8.0 represents an energy release more than of about 400 atomic bomb being exploded underground, almost as much as a hydrogen bomb. The largest earthquake yet recorded has the magnitude of 8.9. They have great destructive potential to the very large areas with strong intensities (Coburn and Spence, 1992).

The magnitude is a number that characterizes the relative size of an earthquake. Magnitude is based on measurement of the maximum motion recorded by a seismograph. Several scales have been defined, but the most commonly used are (1) local magnitude (ML), commonly referred to as "Richter magnitude", (2) surface-wave magnitude (Ms), (3) body-wave magnitude (Mb), and (4) moment magnitude (Mw). Scales 1-3 have limited range and applicability and do not satisfactorily measure the size of the largest earthquakes. The moment magnitude (Mw) scale, based on the concept of seismic moment, is uniformly applicable to all sizes of earthquakes but is more difficult to compute than the other types. All magnitude scales should yield approximately the same value for any given earthquake.

The intensity and death toll depend on several factors (earthquake depth, epicenter location, and population density, to name a few) and can vary widely. Minor earthquakes occur every day and hour. Beyond 9.5, while extremely strong earthquakes are theoretically possible, the energies involved rapidly make such earthquakes on Earth effectively impossible without an extremely destructive source of external energy.

2.5 Intensity

The intensity is a number (written as a Roman numeral) describing the severity of an earthquake in terms of its effects on the earth's surface and on humans and their structures. Several scales exist, but the ones most commonly used in the United States are the Modified Mercalli scale and the Rossi-Forel scale. There is much intensity for an earthquake, depending on where you are, unlike the magnitude, which is one number for each earthquake. Dowrick (1987) describes intensity as “a qualitative or quantitative measure of the severity of seismic ground motion at a specific site” (p.5). Intensity is based on damage and other observed effects on people, buildings, and other features (Lindeburg and Baradar, 2001).

An intensity scale is the scale of ground-motion intensity as determined by human feelings and by the effects of ground motion on structures and on living things (Wakabayashi, 1986). Lindeburg and Baradar (2001) state that an intensity scale consists of a series of responses, such as people awakening, furniture replacement, and chimneys being damaged. Although a number of intensity scales have been developed, the most widely used is the Modified Mercalli Intensity Scale (MMI), developed in 1931 by the American seismologists Harry Wood and Frank Neumann (Lindeburg and Baradar, 2001). The Modified Mercalli Intensity Scale consists of 12 increasing levels of intensity expressed as roman numerals, ranging from MM-I to MM-XII. While the lower numbers of the intensity scale (Table 2.1) are based on the manner in which the earthquake is felt by people, the higher numbers are based on observed structural damage (Lindeburg and Baradar, 2001).

Table 2.1: The Relationship between the Intensity and the Magnitude of an Earthquake (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

As the intensity is not the expression of the direct record of seismographs, the trained observers assign the intensity level according to the field observations of destruction in accordance with the descriptions of damage listed (Table 2.2) in the Modified Mercalli Scale (Lagorio, 1990).

Table 2.2: The Scale and Intensity of Earthquake

Intensity	Observed effects of arthquake
I	Not felt except by very few under especially

(Not noticeable)	favorable conditions.
II (Scarcely noticeable- Very slight)	Felt only by a few persons at rest, especially by those on the upper floors of buildings. Delicately suspended objects may swing.
III (Weak)	Felt quite noticeably by persons indoors, especially in the upper floors of buildings. Many people do not recognize it as an earthquake. Standing vehicles may rock slightly. Vibrations similar to the passing a truck. Duration estimated.
IV (Largely observed)	During a day, felt indoors by many, outdoors by a few. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing vehicles may rock noticeably.
V (Strong)	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI (Slight damage)	Felt by all, many frightened. Some heavy furniture moved. A few instances of all fallen plaster. Damage slight.
VII (Damage to buildings)	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built structures. Some chimneys broken.
VIII (Destruction of buildings)	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings, with partial collapse. Damage great in poorly built structures. Fallen chimneys, factory stacks, columns, monument, and walls. Heavy furniture overturned.
IX (General damage to buildings)	Damage considerable in specially designed structures; well- designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X (General destruction to buildings	Some well-built wooden structures destroyed; most masonry and frame structures with foundations destructed. Rails bent.
XI	Few, if any, masonry structures remain

(Catastrophe)	standing. Bridges destroyed. Rails bent greatly.
XII (Landscape changes)	Damage total. Lines of sight and level are distorted. Objects thrown into air.

2.6 Seismicity of Dhaka

Recent earthquakes with low to moderate magnitude very close to Dhaka are certainly indications of its earthquake source and vulnerability. In addition, micro-seismicity data also supports the existence of at least four earthquake source points in and around Dhaka (Ansary et al., 1999, 2001; Ansary, 2005; Hussain et al., 2010 ;) Islam et al., 2010a, 2010b; Islam and Ahmad, 2010).

The earthquake disaster risk index has placed Dhaka among the 20 most vulnerable cities in the world (Khan, 2004). Several earthquakes of large magnitude (Richter magnitude 7.0 or higher) with epicenters within Bangladesh and in India close to Indo- Bangladesh have occurred (Ali and Choudhury, 1992). There are lists of the major earthquakes that have affected besides and in between Bangladesh (Islam et al., 2011a). Furthermore the country is divided into three zones determined from the earthquake magnitude for various return periods and the acceleration attenuation relationship (Ali and Choudhury, 1994) namely zones 1, 2, 3 being most to least severe gradually.

The recently measured plate motions at six different sites of Bangladesh including Dhaka (the research being jointly conducted by Lamont-Doherty earth observatory, Columbia University, USA and the department of Geology, Dhaka University) clearly demonstrate that Dhaka is moving 30.6 mm/year in the direction northeast. In addition, the rate of strain accumulation is relatively high in and around Dhaka. It may precipitate in an earthquake of magnitude 6.8 in the event of the release of accumulated strain (Khan and Hussain, 2005). However Dhaka, the capital of Bangladesh is one of the most populous towns in the world. The infrastructure and life safety here against seismic hazard is now a burning concern.

The time history analysis procedure cannot be applied by using composite envelope motions, as can be done for the response spectrum procedure. Rather, multiple time histories that together provide a response that envelop the expected motion must be used. Seismology is unlikely ever to be able to predict with precision what motions will occur at a particular site and so multiple time histories are likely to be a feature of this procedure in the foreseeable future. There is a broad aspect of earthquake motions but each project will require individual selection of appropriate records. However, for site specific earthquake data is of widely needed to deal the dynamics of structures. So development of earthquake time history for the region Dhaka vicinity, Bangladesh to carry out seismic analysis is of utmost important concern. The study covers the extent to propose earthquake time history of Dhaka, Bangladesh region to consider it apposite for practical dynamic design.

2.7 History of Earthquakes in Bangladesh

Accurate historical information on earthquakes is very important in evaluating the seismicity of Bangladesh in close coincidences with the geotectonic elements (Table 2.3). Information on earthquakes in and around Bangladesh is available for the last 250 years. The earthquake record suggests that since 1900 more than 100 moderate to large earthquakes occurred in Bangladesh, out of which more than 65 events occurred after 1960. This brings to light an increased frequency of earthquakes in the last 30 years. This increase in earthquake activity is an indication of fresh tectonic activity or propagation of fractures from the adjacent seismic zones. Before the coming of the Europeans, there was no definite record of earthquakes. Following is a chronology of important earthquakes from 1548.

Table 2.3: History of Earthquakes in Bangladesh

Chronology (1548 – 2003)

1548	The first recorded earthquake was a terrible one. Sylhet and Chittagong were violently shaken; the earth opened in many places and threw up water and mud of a Sulphurous smell.
1642	More severe damage occurred in Sylhet district. Buildings were cracked but there was no loss of life.
1663	Severe earthquake in ASSAM, which continued for half an hour. Sylhet district was not free from its shock.
1762	The great earthquake of April 2, which raised the coast of Foul island by 2.74m and the northwest coast of Chedua island by 6.71m above sea level and also caused a permanent submergence of 155.40 sq km near Chittagong. The earthquake proved very violent in Dhaka and along the eastern bank of the MEGHNA as far as Chittagong. In Dhaka 500 persons lost their lives, the RIVERs and *JHEEL*s were agitated and raised high above their usual levels and when they receded their banks were strewn with dead fish. A large river dried up, a tract of land sank and 200 people with all their CATTLE were lost. Two volcanoes were said to have opened in the Sitakunda hills.
1775	Severe earthquake in Dhaka around April 10, but no loss of life.
1812	Severe earthquake in many places of Bangladesh around May 11. The earthquake proved violent in Sylhet
1865	Terrible shock was felt, during the second earthquake occurred in the winter of 1865, although no serious damage occurred.
1869	Known as Cachar Earthquake. Severely felt in Sylhet but no loss of life. The steeple of the church was shattered, the walls of the courthouse and the circuit bungalow cracked and in the eastern part of the district the banks of many rivers caved in.
1885	Known as the Bengal Earthquake. Occurred on 14 July with 7.0 magnitude and the epicenter was at Manikganj. This event was generally associated with the deep-seated Jamuna Fault.
1889	Occurred on 10 January with 7.5 magnitudes and the epicenter at Jaintia Hills. It affected Sylhet town and surrounding areas.
1897	Known as the Great India Earthquake with a magnitude of 8.7 and epicenter at Shillong Plateau. The great earthquake occurred on 12 June at 5.15 pm, caused serious damage to masonry buildings in Sylhet town where the death toll rose to 545. This was due to the collapse of the masonry buildings. The tremor was felt throughout Bengal, from the south Lushai Hills on the east to Shahbad on the west. In Mymensingh, many public buildings of the district town, including the Justice House, were wrecked and very few of the two-storied brick-built houses belonging toZAMINDARs survived. Heavy damage was done to the bridges on the Dhaka-Mymensingh railway and traffic was suspended for about a fortnight. The river communication of the district was seriously affected (BRAHMAPUTRA). Loss of life was not great, but loss of property was estimated at five million Rupees. Rajshahi suffered severe shocks, especially on the eastern side, and 15 persons died. In Dhaka damage to property was heavy. In Tippera masonry buildings and old temples suffered a lot and the total damage

	was estimated at Rs 9,000.
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1918	Known as the Srimangal Earthquake. Occurred on 18 July with a magnitude of 7.6 and epicenter at Srimangal, Maulvi Bazar. Intense damage occurred in Srimangal, but in Dhaka only minor effects were observed.
1930	Known as the Dhubri Earthquake. Occurred on 3 July with a magnitude of 7.1 and the epicenter at Dhubri, Assam. The earthquake caused major damage in the eastern parts of Rangpur district.
1934	Known as the Bihar-Nepal Earthquake. Occurred on 15 January with a magnitude of 8.3 and the epicenter at Darbhanga of Bihar, India. The earthquake caused great damage in Bihar, Nepal and Uttar Pradesh but did not affect any part of Bangladesh.
	Another earthquake occurred on 3 July with a magnitude of 7.1 and the epicenter at Dhubri of Assam, India. The earthquake caused considerable damages in greater Rangpur district of Bangladesh.
1950	Known as the Assam Earthquake. Occurred on 15 August with a magnitude of 8.4 with the epicenter in Assam, India. The tremor was felt throughout Bangladesh but no damage was reported.
1997	Occurred on 22 November in Chittagong with a magnitude of 6.0. It caused minor damage around Chittagong town.
1999	Occurred on 22 July at Maheshkhali Island with the epicenter in the same place, a magnitude of 5.2. Severely felt around Maheshkhali island and the adjoining sea. Houses cracked and in some cases collapsed.
2003	Occurred on 27 July at Kolabunia union of Barkal upazila, Rangamati district with magnitude 5.1. The time was at 05:17:26.8 hours.

The present generation of people in Bangladesh hasn't witnessed any major earthquake. As a result the population has been generally complacent about the risk of earthquakes. During the last seven or eight years, the occurrence and damage caused by some earthquakes (magnitude between 4 and 6) inside the country or near the country's border, has raised the awareness among the general people and the government as well. The damage has been mainly restricted to rural areas or towns near the epicenter, but there have been some instances of damage in urban areas 50 to 100 km away.

Dhaka, located in the central region of Bangladesh, could be affected by any of the four earthquake source zones, presented earlier. Another point of major concern is that there are active faults near the city also. This was realized during the 19 December 2001 magnitude 4+ Dhaka earthquake that caused panic among many city residents. The epicenter was very close to Dhaka city. Frightened people in several high rise buildings rushed down the stairs, as they felt considerable shaking in the upper floors. The location of a probable earthquake source so near Dhaka with the probable earthquake magnitude needs to be further investigated.

The 1993 Bangladesh National Building Code provides guidelines for earthquake resistant design. The code provides a seismic zoning map which divides Bangladesh into three seismic zones: The north-northeast potion which includes Sylhet, Mymensingh, Bogra, Rangpur falls in the zone "liable to severe damage" (0.25g motion). The middle and southeast portion which includes Dinajpur, Sirajganj, Naogaon, Dhaka, Feni, and Chittagong fall in the zone “liable to moderate damage" (0.15g motion). The rest of the country in the south-west falls in the zone “liable to slight damage" (0.75g motion).

2.8 Vulnerability Assessment

According to Varnes & IAEG Commission on Landslides and other Mass-Movements (1984), “vulnerability is the degree of loss to a given element or set of elements at risk resulting from the occurrence of a hazard of an elements at risk resulting from the occurrence of a hazard of a given magnitude in a given area”.According to United Nations Development Programme (UNDP, 1994), “vulnerability depends upon the degree of loss to a given vulnerability depends upon the degree of loss to a given element at risk at a certain severity level. Generally, it is an element at risk at a certain severity level. Generally, it is expressed as the percentage of loss (between 0: no damage to 1: total damage) the percentage of loss (between 0: no damage to 1: total damage) for the given hazards” (cited in Sterlacchini, 2011).

Vulnerability can be categorized in three forms such as:

High Vulnerability: If an event occurred it would have severe impacts over large geographic areas or more densely populated areas and have a serious financial impact on county residents and businesses.

Moderate Vulnerability: If an event occurred it would have confined impacts on the safety of residents and would have a financial impact on county residents and businesses.

Low Vulnerability: If an event occurred it would have a very minimal impact on the safety of residents and a minimal financial impact on county residents and businesses (NOAA, 1999).

Vulnerability assessment is a crucial step in risk assessment, translating hazard levels into risk levels. It requires the analysis of hazard consequences on the different components or dimensions of a system, community, etc.

It is a function of the type, magnitude and frequency of hazard and it depends on system’s exposure, sensitivity and its adaptive capacity. In short term, when a disaster strikes, the primary concern are the potential losses due to casualties (deaths, missing persons and potential losses due to casualties (deaths, missing persons and injured people) physical consequences on services, buildings and infrastructure and direct economic losses. In the long term, indirect economic losses, and social disruption and, in the long term, indirect economic losses, social disruption and environmental degradation may become of greater importance (Sterlacchini, 2011).

Vulnerability assessment is a comprehensive process involving hazard identification and analysis and determining the resultant vulnerabilities of critical infrastructure, society, economic resources and environment (NOAA, 1999).

Vulnerability assessment means the evaluation of the impact of natural hazards on the human-built environment, business, social structure and services, and the natural environment, considering the preparedness of a community and its ability to respond to and recover from a disaster event.

Typically, natural hazard initiatives emphasize the identification of physical attributes of potential events, such as frequency or spatial extent. They consider variations in the physical events but they must also consider differences in infrastructures and building stock, land-use policy, economic conditions, political climates, stakeholders‟ perceptions and pre-existing preparedness strategy (Schellnhuber, 2001).

Various vulnerability assessment methods have been proposed, differing by resources, scale and technique. Vulnerability assessment may focus on resources or issues like critical facilities, on social characteristics (Morrow, 1999), or on the integration of bio-physical and social systems (Cutter et al., 2000). Spatial scales of proposed vulnerability assessments vary from cities (FDCA, 1997) to nations. Vulnerability assessment may be technical expert-based (Urban Regional Research, 1988), community based (Cutter et al., 2000).

Regardless of methodology, vulnerability assessments are conducted so that communities can develop targeted strategies to reduce their exposure and potential for loss. The vulnerability assessment looks at such points as population concentrations, age-specific populations, and development pressures, types of housing, presence of agriculture, sprawl, and other issues that may make a place more vulnerable to specific hazards. The vulnerability assessment relies heavily on the community profile of this Hazard Mitigation Plan, as it compares areas where hazards overlap with people and key public facilities. In order to make efficient use of mitigation resources, it is not only enough to know if, when, or even where a hazard event will strike but also where the vulnerabilities are so one can make the most of the pre-disaster planning efforts (NOAA, 1999).

2.9 Vulnerability Assessment of Earthquakes

An Earthquake is a sudden and violent motion of the earth caused by volcanic eruption, plate tectonics or manmade explosions which lasts for a short time and within a very limited region. Most earthquake last for less than a minute. The larger earthquakes are followed by a series of aftershocks which also may be dangerous. But large majority of earthquakes especially big earthquakes are invariably caused by plate tectonics. Earthquakes can be caused by volcanic eruption or by plate tectonics; blasting, quarrying and mining; and underground nuclear explosions.

Tectonics earthquakes are believed to occur according to the elastic rebound theory, which was developed by Reid (1910) subsequent to the Francisco earthquake of 1906. In this theory- “An earthquake represents a sudden release of strain energy, which was built up over a period of time.

In response to tectonic forces one block of rock mass moves past.” Another, the rock is elastic and can, up to a point, accumulate strain where adjacent areas of rocks are subjected to forces pushing or pulling them. When the stress exceeds the strength of the rock, the rock breaks along a pre-existing or new fracture plane called a FAULT. As a whole, Earthquake can be defined -- An earthquake is a shaking or vibration of the ground.

An earthquake occurs when rocks being deformed suddenly break along a fault. The two blocks of rocks on both sides of the fault, slip suddenly, setting off ground vibrations. This slippage occurs most commonly at plate boundaries, regions of the Earthquake crust or upper mantle where most of the ongoing deformations take place.

Earthquake hazard can be defined as any physical phenomena associated with an earth produce adverse effects on human activities. Depending upon the size and location an earthquake can cause the physical phenomena of ground shaking, surface fault rupture and ground failure from liquefaction and in some coastal areas, tsunamis. Earthquake may cause a number of secondary hazards such as ground failure, surface fault rupture, regional tectonic deformations, tsunami run-up; earthquake induced flooding, fire and explosions.

The hazard cannot be modified but mitigated to reduce loss. To mitigate risk the potential losses (direct & indirect) should be minimized and the community should be prepared. Urban earthquake risk today derives from the combination of local seismicity the likelihood of a large-magnitude earthquake combined with high dense built environment, informal settlement in urban areas, large numbers of poorly built or highly vulnerable dwellings, poor infrastructure, contiguous building character and lack of preparedness, etc.

Urban vulnerability and risk to natural hazards such as earthquakes is a function of human behavior. It describes the degree to which socioeconomic pattern and physical infrastructures in urban areas are either susceptible or resilient to the impact of natural hazards. Over the past two decades, vulnerability has come to represent an essential concept in hazards research and in the development of mitigation strategies at the local, national, and international levels (White and Haas, 1975).

2.10 Impact of Earthquake

Within minutes of shaking, the earthquake reveals the vulnerabilities of buildings, households, communities and of a country. The consequences expose flaws in governance, planning and setting of physical structure, design, construction and use of the built environment in country with seismic hazard. It reveals the capacity of the community to be prepared for an earthquake hazard based on the influence of prevailing culture and way of life.

The scale of physical damage and social disruption inflicted upon a community or a nation by an earthquake event is the measure of how vulnerable the community or the nation is. There are different categorizes of earthquake impact - physical impact, social impact, economic impact and cultural impact.

Physical Impact

The most significant physical impact of any earthquake is the tremendous loss of built environment, lots of deaths and injuries, loss of physical assets, failure to function of lifeline facilities or destroy of the part of infrastructure, etc. Every physical loss can be mitigated by reducing physical or material vulnerability in any urban areas.

The developing country renders disaster risk reduction as a higher priority action. Then, addressing the policies on earthquake resistance, metropolitan Earthquake prevention Plan should be built. Finally the plan should be implemented, with high priority. Physical impact depends on physical vulnerability which can be measured by weakness of built environment designing and existence of unsafe building, lack of policies to reduce earthquake vulnerability, violation of rules in designing building, poor infrastructure layout and lack of awareness.

Social Impact

The most significant societal impact of the Kobe earthquake, Japan, 1995 was the tremendous loss of human life, the earthquake with duration of approximately 10-12 seconds caused over 5,000 deaths. There were in excess of 26,000 injuries. Although the total number of rescues is unknown, news reports which appeared during the first three days after the earthquake indicated that over 1,000 people were missing, most of whom were presumed to be buried under collapsed structures.

For over 300,000 survivors in the heavily impacted cities of Kobe, Ashiya and Nishinomiya who were displaced from their homes, there were the hardships of finding shelter, securing food and water, locating friends and family members and acquiring warm clothing for the cold, damp winter weather. Indeed, two weeks after the earthquake, reports of influenza and pneumonia are becoming common. Food, water for drinking and sanitation, blankets and warm clothing were in short supply (Goltz, nd).

Economic Impact

The economic cost of disasters can be classified into direct costs relate to the capital costs of assets destroyed or damaged by the disasters and indirect costs refer to the damage to the flow of goods and services. Lower outputs from damaged factories, loss of sales or rise in the prices of raw materials due to damaged infrastructure, loss of income, loss due to reduce tax collection, and expenses for relief, recovery, and rehabilitation are the indirect costs of disasters.

Secondary effects pertain to short and long-term impacts of a disaster on overall economic performance of a country. Lost development efforts, the necessity to restructure the development expenditure to cater to reconstruction and the resulting imbalances in government budget and the perspective plans are the indirect effects. Increased indebtedness is one of the serious consequences of an earthquake disaster. Official estimates released one week after the Kobe earthquake place the economic toll at up to 10 trillion yen (roughly $100 billion) in repair costs alone (Chang, 2000).

Cultural Impact

Cultural monuments, temples, churches are social properties of immense importance. They represent social achievements in social values and norms. The possible damage or destruction by earthquakes brings physical loss but more importantly a loss of cultural assets, which serve as a source of income through tourism. Loss of religious centers and schools inhibit psychological recovery following an earthquake and hence need to be rebuilt on a priority basis. A mosque, temple or a church provides solace and support within families and communities. They are the centers for bringing back community's cohesiveness and for engendering a promise for a more positive future.

2.11 Tools of Earthquake Vulnerability Assessment

Vulnerability Analysis of building stocks in a region is a very difficult and time-consuming process. Step by step identification of buildings at most seismic risk can make the whole procedure comparatively simpler. First step in this process can be quickly screening of buildings to determine if evaluation is required. Then detail analysis is performed to confirm status of the building. Assessment of the buildings is usually performed in three levels including preliminary inspection, simplified vulnerability assessment and detail analysis. In preliminary inspection, the buildings are visually inspected to get a gross impression about the structure. Simplified vulnerability assessment procedure requiring limited engineering analysis based on information from visual observations and structural drawings or on site measurements. The method is widely known as Rapid Visual Screening (RVS) method. Two widely used RVS methods are FEMA Rapid Visual Screening and Turkish Simple Survey Procedure (Level I and II). Detail vulnerability assessment procedure requires detailed structural analysis of the building. This procedure is recommended for all important and lifeline structures.

FEMA Rapid Visual Screening

The Federal Emergency Management Agency (FEMA) of the United States of America has developed pre-earthquake screening method of potential seismic hazard assessment of buildings based on rapid visual screening method, widely known as RVS method, originated in 1988, with the publication of the FEMA 154 Report, a Handbook. It is generally used for rapid evaluation of seismic vulnerability profiles of existing building stocks. RVS provides a procedure to identify record and rank buildings that are potentially seismically hazardous (FEMA, 2002).

It is a "sidewalk survey" approach that enabled users to classify surveyed buildings into two categories: those acceptable as to risk to life safety or those that may be seismically hazardous and should be evaluated in more detail by a design professional experienced in seismic design. The Data Collection Form of RVS includes space for documenting building identification information, including its use and size, a photograph of the building, sketches, and documentation of pertinent data related to seismic performance, including the development of a numeric seismic hazard score.

Basic Structural Hazard Scores based on Lateral Force Resisting System for various building types are provided on the form, and the screener circles the appropriate one. The screener modifies the Basic Structural Hazard Score by identifying and circling Score Modifiers related to observed performance attributes, by adding (or subtracting) them a final Structural Score, „S" is obtained. The score below which a structure is assumed to require further investigation is termed as “cut-off” score. The value of “cut off” score and choice of RVS form depends on the seismic zonation of the area. It is suggested that buildings having an S score less than the “cut-off” score should be investigated by an experienced seismic design professional experienced in seismic design. If the obtained “final score” is greater than the “cut-off” score the building should perform well in a seismic event.

Turkish Simple Survey Procedure

The Turkish Simple Survey procedure is a two level risk assessment procedure which has been proposed on the basis of statistical correlations obtained by employing a database of 477 damaged buildings surveyed after the 1999 Düzee earthquake (Sucuoglu and Yazgan, 2003). The first level incorporates recording of building parameters from the street side and in the second level, these are extended by structural parameters measured by entering into the ground storey.

The basic scoring for both the levels are based on the height of the building (number of stories) and local Soil Conditions where three intensity zones are specified in terms of associated PGV (Peak Ground Velocity) ranges. Once the vulnerability parameters of a building are obtained from two-level surveys and its location is determined, the seismic performance and vulnerability scores are calculated. The final seismic Performance Score is obtained by using following equation. A “cut-off” performance score of 50 has been suggested for both survey levels.

PS = (Initial Score) - Σ (Vulnerability Parameter) X (Vulnerability Score)

The first level is a street survey procedure and involves the observation of the parameters, the number of stories above ground, presence of a soft story, presence of heavy overhang, apparent building quality, and presence of a short column. In the second level the parameters of first level are confirmed or modified through closer observations. Then a sketch of the framing plan at the ground story is made and the dimensions of columns, concrete and masonry walls are measured.

The added parameters in this stage are pounding between adjacent buildings, topography effect, plan irregularity, redundancy, and strength index. The consistency in distribution of lateral loads to frame members is judged by redundancy and the strength index figures out the influence of size of the vertical members of the building, material strength, frame geometry etc. on the lateral strength of the building. The results of the Level - II procedure can be used to determine the potential status of the selected buildings, and to further short-list the buildings requiring detailed vulnerability assessment.

2.12 Factors of Earthquake Vulnerability

Earthquake vulnerability of building depends on some factors such as shape of buildings, redundancy, strength index, short column and pounding effect etc. The factors are described as follow:

Plan Irregularity and Vertical Irregularity

Irregularity in building plan (Figure 2.3) is a deviation from a rectangular plan, having orthogonal axis systems in two directions. Such deviation from plan irregularity leads to irregularities in stiffness and strength distributions which in turn increase the risk of damage localization under strong ground excitations. In earthquake resistant design, regularity in plan is encouraged.

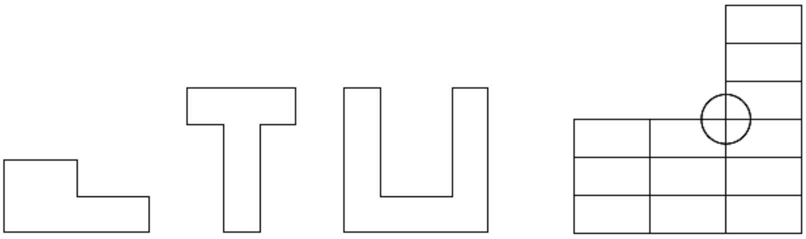


Figure 2.3: Plan Irregular and Regular Form

Redundancy

When the number of continuous frames or number of bays in a building system is insufficient, lateral loads may not be distributed evenly to frame members. Especially those frames exhibiting inelastic response during earthquakes suffer from lack of sufficient redundancy, which leads to localized heavy damages. A normalized redundancy ration (NRS) is calculated. The equation for NRS is a function of tributary area for a typical column, the area of ground floor and the number of continuous frames in x and y directions, respectively.

Strength index

The lateral strength of a building is strongly related to the size of its vertical members among other factors including material strengths, detailing and frame geometry. Since measuring the sizes of vertical members at the ground story of an existing building is possible, a strength ratio (SR) is determined using the collected data related to shape (square or rectangular) of the column and the cross section area of each column, shear wall and masonry in-filled wall, respectively (Ozcebe et al., 2003).

Short Column and Pounding Effect

A short column (Figure 2.4) is that in which both compression and bending is significant, generally having a slenderness ratio between 30 and 120-150. During an earthquake short column suffered more damage as compared to tall columns in the same storey because short column is stiffer as compared to the tall column, and it attracts larger earthquake force. In existing buildings with short columns, different retrofit solutions can be employed to avoid damage in future earthquakes.

Figure 2.4: Short Column

Pounding of adjacent buildings (Figure 2.5) could have worse damage as adjacent buildings with different dynamic characteristics which vibrate out of phase and there is insufficient separation distance or energy dissipation system to accommodate the relative motions of adjacent buildings. The non-structural damage involves pounding or movement across separation joints between adjacent structures.

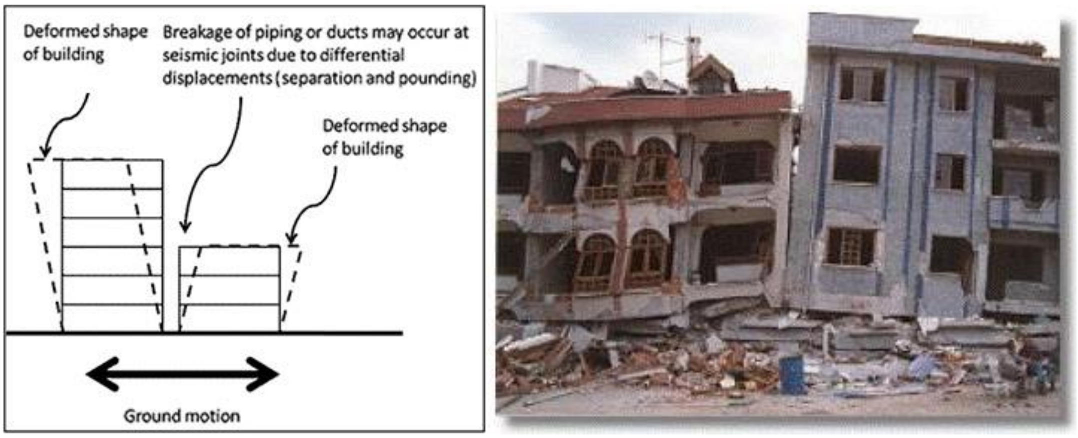


Figure 2.5: Seismic Pounding between Adjacent Buildings

Soft Storey

Recently many buildings are constructed with a special feature that the ground storey is left open for the purpose of parking i.e., columns in the ground storey do not have any partition walls (of either masonry or RC) between them. Such buildings are often called open ground storey buildings or soft storey building (Figure 2.6). An open ground storey building, having only columns in the ground storey and both partition walls and columns in the upper storey. Open ground storey buildings have shown poor performance during earthquakes across the world; a significant number of buildings have collapsed. The presence of walls in upper storey makes them much stiffer than the open ground storey. Thus, the upper storey move almost together as a single block and most of the horizontal displacement of the building occurs in the soft ground storey itself (Figure 2.7).

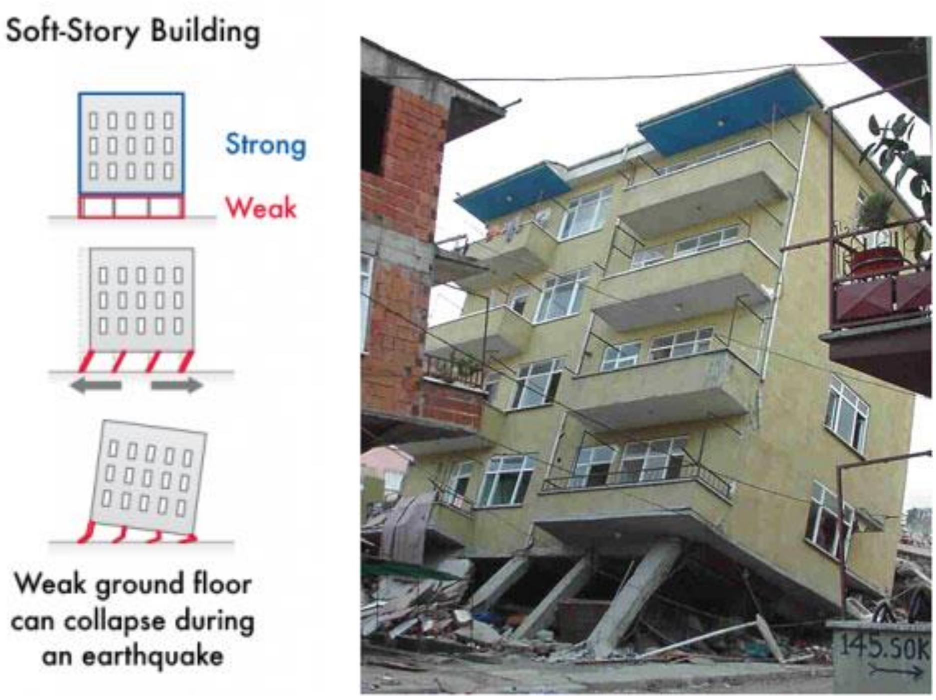


Figure 2.6 Soft Storey

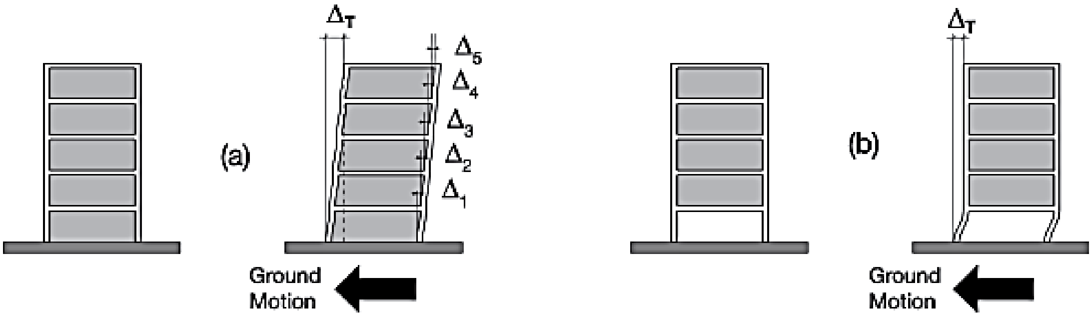


Figure 2.7: Distribution of total displacement generated by an earthquake in (a): a regular building; and (b) a building with soft storey irregularity.

Heavy Overhang

Heavy balconies and overhanging floors in multistory reinforced concrete buildings shift the mass center upwards; accordingly increase seismic lateral forces and overturning moments during earthquakes (Figure 2.8). Buildings having balconies with large overhanging cantilever spans enclosed with heavy concrete parapets sustained heavier damages during the recent earthquakes in Turkey compared to regular buildings in elevation. Since this building feature can easily be observed during a walk-down survey, it is included in the parameter set.

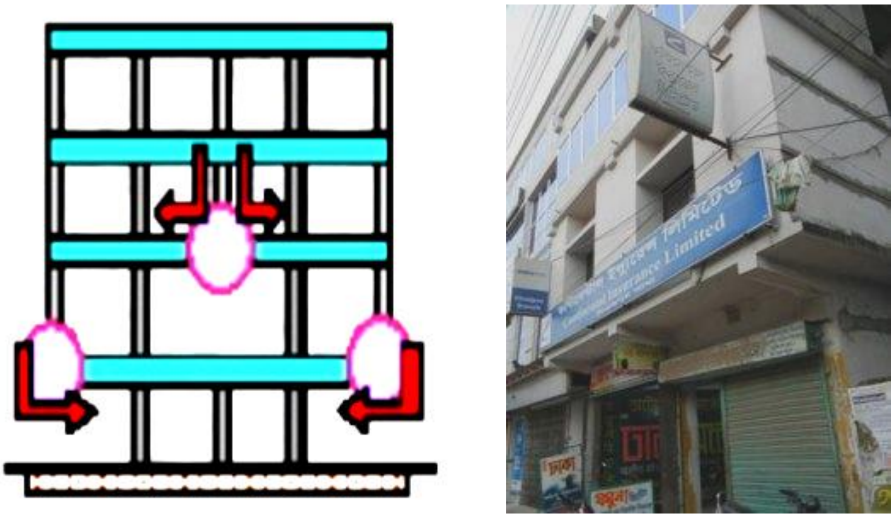
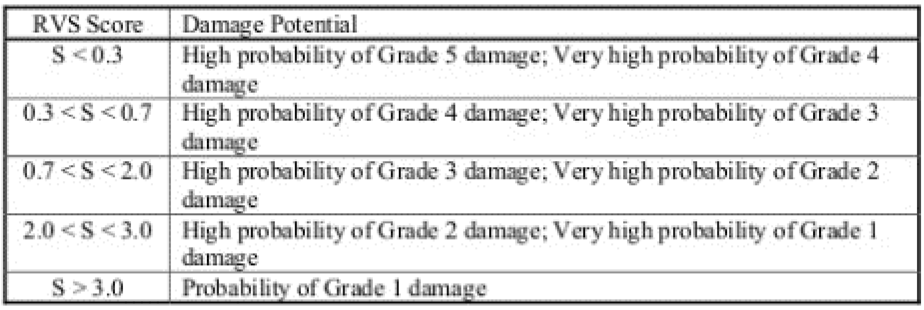


Figure 2.8: Heavy Overhang

Building Performance Score

Once the vulnerability parameter of the building are obtained from two-level building surveys in Turkish method and its location are determined, the seismic performance scores for survey levels 1 and 2 are calculated using tables. In these tables, an initial score is given first with respect to the number of stories and the intensity zone. Then, the initial score is reduced for every vulnerability parameter that is observed or calculated(Figure 2.9). A general equation for calculating the seismic performance score (PS) can be formulated as follows:

P S = (Initial Score) - Σ (Vulnerability Parameter) x (Vulnerability Score).



RVS Score	Damage Potential
S < 0.3	High probability of Grade 5 damage; Very high probability of Grade 4 damage
0.3 < S < 0.7	High probability of Grade 4 damage; Very high probability of Grade 3 damage
0.7 < S < 2.0	High probability of Grade 3 damage; Very high probability of Grade 2 damage
2.0 < S < 3.0	High probability of Grade 2 damage; Very high probability of Grade 1 damage
S > 3.0	Probability of Grade 1 damage

Figure 2.9: Rapid Visual Screening Score

2.13 Architecture Based Issues in Seismic Design

The architectural design decisions that influence the seismic performance of the buildings can be classified into three groups:

Building configuration issues (as a whole),

Structural system configuration issues (in plan and in vertical),

Non-structural architectural components' configuration issues (with their architectural detailing).

Although the classification is changeable, it is serviceable in order to understand their influences on seismic performance and the interactions among groups. Dowrick (1987) states that the configuration of the construction is the geometrical arrangement of all of the elements: architecture, structure, equipment, and contents. Consideration of configuration must include concerns both for the form of the building as a whole and the form of the structural and non-structural system of the building. They are all determined by the architects during the architectural design process.

2.13.1 Building Configuration Issues

According to Arnold (1989), there exist three major determinants of building configuration. These are:

Building function and planning,

Urban design and planning requirements,

Need for a distinctive or attractive image.

The final configuration is the balance of these varying requirements within an architectural concept and a budget. Arnold (1989) points out that "for a given ground motion, the major determinant of the total inertial force in the building is the building mass". The form and the size of the building with the choice of materials establish the mass. As configuration mostly determines how seismic forces are distributed throughout the building, it is an important consideration from seismic point of view. It also influences the relative magnitude of seismic forces. A variety of configuration can be designed for any architectural program, each of which affects the distribution of seismic forces differently. For a better seismic performance, 'regular' configuration, which means the optimum or ideal configuration in dealing with lateral forces (such as earthquake forces), should be designed. ‘Regular’ configuration should be present both in plan and in vertical. However, sometimes functional requirements and architectural creativity dictate less ideal seismic configurations. Actually, the variety prevents the built environment to become a boring place (Arnold, 1989). On the other hand, the term ‘regularity’ does not mean symmetric and repetitive solutions, which are limited by a strict set of principles. It is rather searching for solutions appropriate for seismic behaviour of buildings that are in harmony with technological innovations (Mezzi, Parducci and Verducci, 2004).

2.13.2 Form / Geometry

According to Mezzi, Parducci and Verducci (2004), the shape has been recognized as a fundamental parameter in controlling buildings’ response to earthquake forces. As Ambrose and Vergun (1985) state, “the form of a building has great deal to do with the determination of the effects of seismic activity on the building”. For a good seismic performance, regular configuration is obtained by simplicity and symmetry of the building form.

2.13.3 Simplicity

Earthquakes repeatedly demonstrate that the simplest structures have the greatest chance to survive after severe earthquakes. According to Dowrick (1987), there are three main reasons for this:

- The ability to understand the overall behavior of a simple structure is greater than it is for a complex one. Therefore, unpredictable stress concentration that may cause local collapses and modifications of the dynamic behavior are avoided (MezziParducci and Verducci, 2004).

- The ability to understand simple structural details is considerably greater than it is for complicated ones.

- Simple structures are likely to be more buildable than complex ones (Figure 2.10).

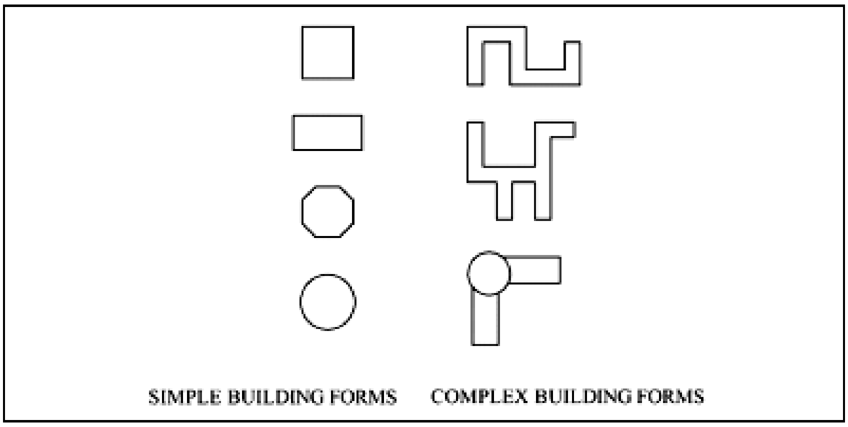


Figure 2.10: Simple and complex Building Forms

The most appropriate form of a building is a square or a circle from seismic point of view. A regular building form, which is simple and symmetric, proves the same rigidity in all directions. Accordingly, seismic forces acting to the buildings do not vary. In this respect, circle is the most ideal building form. However, generally it is not appropriate for analyses, construction, and functional requirements. A rectangular form approaching to a square, which is not so long in plan, is also an appropriate building form in terms of simplicity and symmetry (Bayülke, 2001).

The shape of the building can become a negative factor as an irregularity in itself. This is mainly because of its effect on the structural system. Irregularities in the structural system are determinant in reducing the seismic performance of buildings. When a complex form is to be designed, the structural cost must be acknowledged. Moreover, appropriate three-dimensional earthquake analyses should be done in the design process (Ambrose and Vergun, 1985; Dowrick, 1987; Mezzi, Parducci and Verducci, 2004).

2.13.4 Symmetry

As Arnold (1989) states, “the term symmetry denotes a geometrical property of building plan configuration”. It is desirable to have symmetry both in the form of the building as a whole (architectural symmetry) in three directions and in the disposition of the structural elements of the lateral resistive system (structural symmetry). Otherwise, torsional effects are produced leading to destruction of building (Figure 2.11).

The critical concern is the coincidence of the center of building mass (generally considered as the geometrical center of the building) with the center of rigidity (considered as the center of vertical elements of the structural system). When a building is not architecturally symmetrical, the structural system must be adjusted so that the center of rigidity becomes close to the center of the mass (Ambrose and Vergun, 1985).

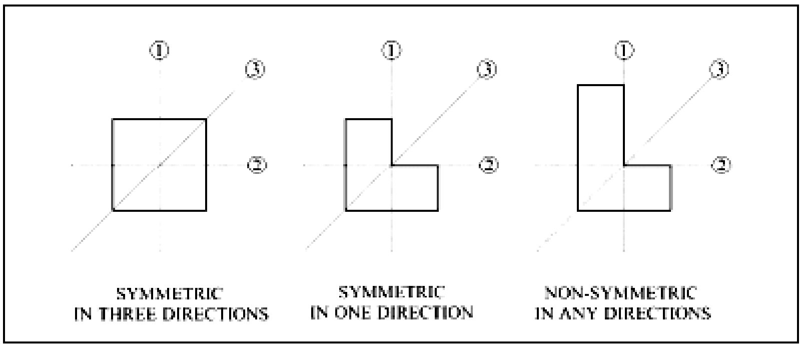


Figure 2.11: Architectural Symmetry

A building with re-entrant corner is not necessarily asymmetrical, but it is irregular. Thus, symmetry is not sufficient on its own and it is beneficial only when it is combined with simplicity. When good seismic performance is to be achieved with maximum economy of design and construction, symmetrical and simple forms should be preferred. However, architectural requirements often make the symmetrical design impossible. In these circumstances, it may be necessary to take precautions (Arnold, 1989).

Sometimes, although a building, whose form is a square or a rectangle, is simple and symmetrical in overall plan, torsional forces may be created due to the irregularities inside the building. The irregularities may result from the rigidity differences of diaphragms, improper shear wall design or unsymmetrical location of service cores (Bayülke, 2001).

2.13.5 Scale, Size and Proportion

The length, the height, and the proportions of these two have influences on seismic performance of the building.

2.13.6 Length

Limiting the size of a building in plan and making it compact are important considerations for seismic performance of a building. When a plan becomes extremely large, even if it is symmetrical and simple, it may have problems in responding to the ground movements as one unit (Arnold, 1989). Because, a building with elongated plan is likely to have different ground movements applied along its length. Moreover, a building with a long and an extended form in plan experiences greater variation in soil conditions. This variation may be due to differences in geological conditions (Dowrick, 1987).

When a long building is needed for planning reasons, the solutions are:

- to subdivide the building (Figure 2.12) into separate short lengths and compact forms with movement gaps between them (the use of seismic separation joints) (Coburn and Spence,1992),
- to add lateral force resisting elements (shear walls and columns) in order to reduce the span of the diaphragm, although this may introduce problems in the use of the building (Arnold, 1989),
- to choose the appropriate types of the foundation (Dowrick, 1987).

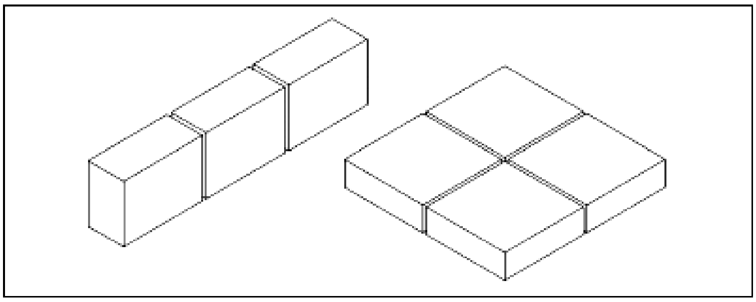


Figure 2.12: Subdivision of the Building into Compact Forms

2.13.7 Height

Although there had been some limitations on building dimensions in earthquake prone zones for the past years, with the introduction of new materials with greater strength, it has been recognized that height is not a negative factor for the seismic response. In fact, a greater height can increase the natural period of the building and shift it in the range where the response is lower (Mezzi, Parducci and Verducci, 2004).

In Figure 2.13, three different building profiles illustrate different potential responses to earthquake loads with regard to the natural period of vibration and the lateral deflection. In general, as the rigidity increases, the natural period of vibration of a building becomes shorter (Architectural Institute of Japan, 1970). The short and rigid building tends to absorb larger earthquake loads because of its quick response (short natural period of vibration). On the other hand, the tall, slender, and flexible building responds slowly to earthquake loads having long natural period of vibration. It dissipates the seismic energy in its motion. However, much deflection may create deformation problems (Ambrose and Vergun, 1985).

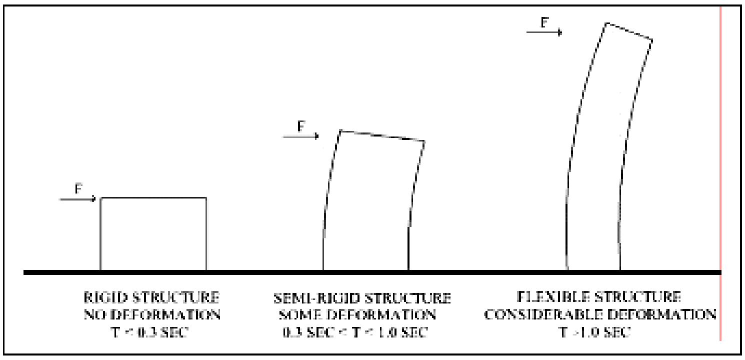


Figure 2.13: Seismic Response of Buildings with Different Heights

As urban land becomes more expensive, there is a trend towards designing very tall buildings, which may have a large slenderness (height / depth) ratio. It is not illogical to build tall buildings on earthquake zones. Because tall buildings generally have complete earthquake analyses and construction processes. Moreover, they tend towards symmetry and simplicity. According to Arnold (1989), the seismic problems are most apparent in the medium height buildings, where considerable choice of plan forms and the multi masses of buildings exist. Yakut, Gülkan, Bakır and Yılmaz (2005) state that half of the buildings, which damaged (light, moderate and severe) and collapsed in the August 17, 1999 Kocaeli Earthquake, were five stories in height. The next largest group is for six-storey buildings comprising 32 % of the total. On the other hand, as the height of the building increases, two important seismic problems come to existence. These are resonance and overturning effect (Figure 2.14).

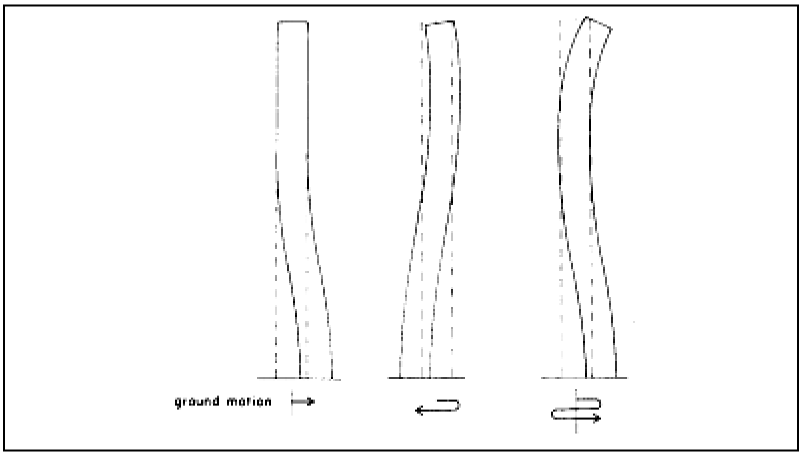


Figure 2.14: Resonance in tall buildings (Ambrose and Vergun 1985)

When the natural period of vibration of a building coincides with the natural period of ground, a synchronized resonance between the two occurs. If the building exceeds its elastic range by absorbing the earthquake forces, it may come to the fracture point resulting in failure or total collapse. So, the effect of the building period must be considered in relation to the period of ground movements. In the design of tall buildings, the architect must realize the importance of the relationship (Lagorio, 1990).

It is important to compare the natural periods of vibration of building and ground and to prove the tall building not to suffer from resonance. If they are close to each other, precautions should be taken against earthquake loads by adjusting building configuration and structural configuration. Thus, the natural periods of vibration of the building and the ground become differentiated from each other (Zacek, 1999).

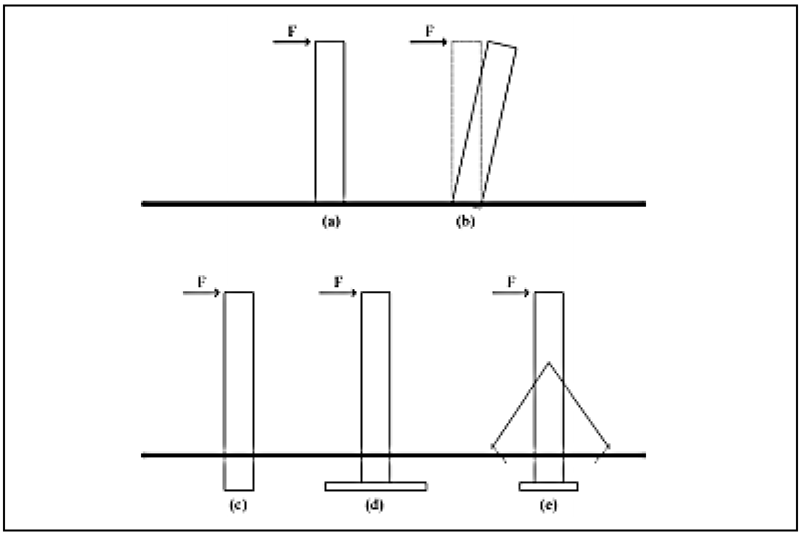


Figure 2.15: Overturning

As the overturning effect (Figure 2.15) is related to the vertical form of the building, tall and slender buildings are highly vulnerable to overturning. Overturning results in the building to tip over with or without its foundation. There exist techniques in order to resist overturning. According to Ambrose and Vergun (1985), these are:

- to modify the existence supports,
- to spread the base in order to increase the moment arm for stabilizing moment,
- to add a separate and an external bracing system.

2.13.8 Proportion

Arnold (1989) states that in seismic design, the proportions of a building may be more important that it’s absolute size (Figure 2.16). For tall buildings, the ‘slenderness ratio’ (height / depth) of a building is a more considerable issue than just ‘height’ (Coburn and Spence, 1992). A building with a large slenderness ratio exhibits large lateral displacement under lateral forces. Very slender buildings should be avoided in strong earthquakes zones. Because, the axial-column force due to overturning moment in a slender building tends to become very large. Moreover, their foundation stability may be difficult to achieve because of the forces acting on the foundation (Dowrick, 1987; Wakabayashi, 1986).

Dowrick (1987) states that the slenderness ratio of a building should not exceed about 3 or 4, otherwise it leads to uneconomical structures and requires dynamic analyses for proper seismic response. On the other hand, Zacek (1999) states that it is recommended not to design a building whose ratio of the sides to one another is greater than 3.

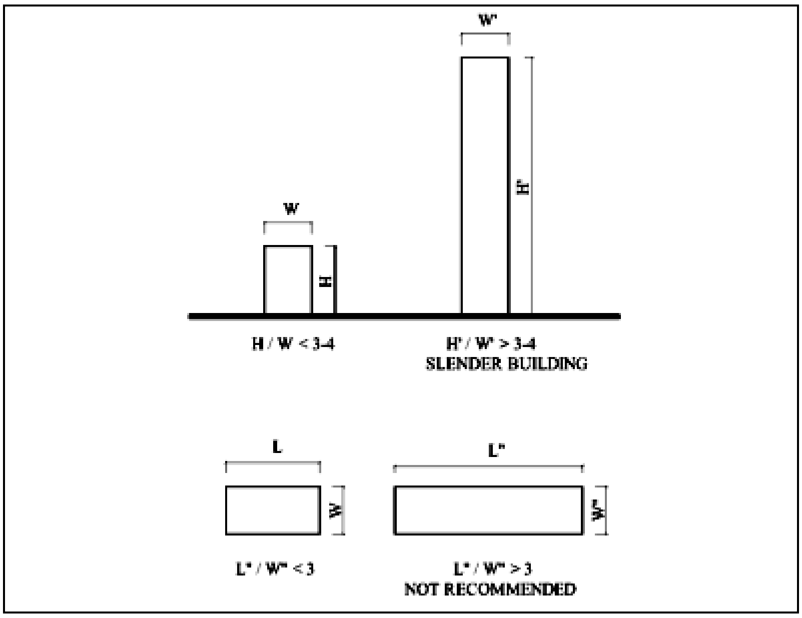


Figure 2.16: Proportions

2.13.9 Building with Re-entrant Corners and Multi-massed Buidlings

The shape of H, L, T, U, Y, +, or a combination of these forms are the typical examples of building configuration which have projections or wings in plan constituting re-entrant corners (Figure 2.17). They are commonly designed for high-density housing and hotel projects as they enable large plan areas in compact forms, which have different vistas and lighting opportunities from different angles (Arnold, 1989).

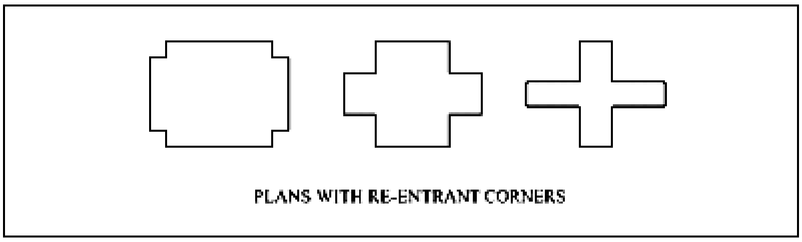


Figure 2.17: Re-entrant corners in plan

The 1998 Turkish Earthquake Code states the ratio of the projections to the entire plan, as they are important in terms of seismic behaviour of the building. A3 – Projections in Plan:

The cases where projections beyond the re-entrant 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%.

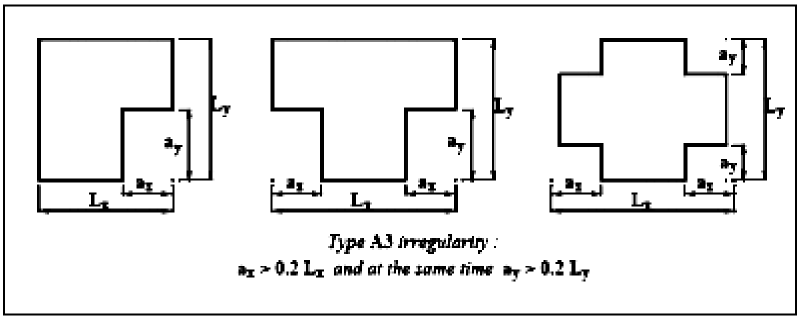


Figure 2.18: Projections in Plan (Turkish Earthquake Code, 1998)

Wakabayashi (1986) states that, the buildings having projections (or wings) have often been severely damaged in earthquakes.There are two related problems created by these forms. The first problem is local stress concentration at the ‘notch’ of the reentrant corner where the wings meet. This is due to the variations of rigidity and different movements of the different parts of the building. The second problem is torsion. This is because the center of mass and the center of rigidity in this form cannot geometrically coincide for all possible earthquake directions. The result is rotation, which tends to distort the form and results in torsional forces that are very difficult to analyse and predict (Arnold, 1989).

The seismic performance of an L-shaped building shown in Figure 2.18 is an example. Each wing of the L-shaped building experiences different deformation depending on the incoming direction of the earthquake forces. Under the influence of the earthquake force, wing ‘A’, which is parallel to the direction of earthquake force, is stiffer than wing ‘B’ because of its more rigid axis. On the other hand, wing ‘B’, which is perpendicular to the direction of earthquake forces is more flexible than wing ‘A’ and its seismic performance is weaker in that direction. As a result, undesirable torsional forces are introduced in this type of plan configuration under the influence of earthquake motions, causing rotation of wing ‘B’ relative to the center of rigidity of the L-shaped building (Figure 2.19). Unless the two wings are designed with the capacity to resist and dissipate the torsional effects adequately, the building system may severely damage, particularly at the notch (Lagorio, 1990). However, according to Faella, irregularity of an L-shaped plan becomes only ‘apparent’ if provisions such as designing rigid diaphragms are adopted in order to avoid the dangerous local effects and if the distribution of the lateral force resisting elements fit to the geometry. Consequently, very slight torsional effects come into existence that can be accounted for at design stage (Mezzi, Parducci and Verducci, 2004).

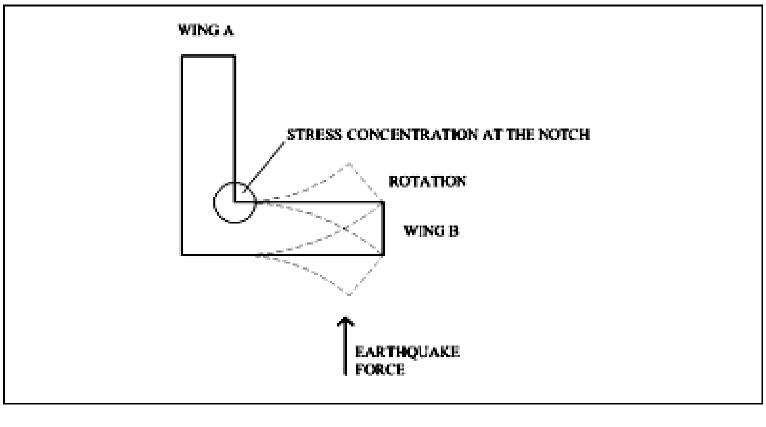


Figure 2.19: L-shaped Building Behavior under Earthquake Force

According to Arnold (1989), the stress concentration at the notch and the torsional effects are interrelated. The magnitude of the forces and the serious of the problem depend on:

- the mass of the building,
- the structural system,
- the length of the wings and their ratios,
- the height of the wing and their slenderness ratios.

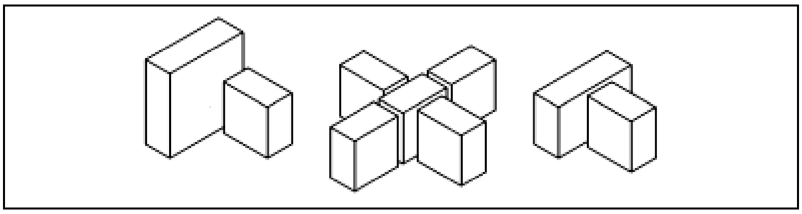


Figure 2.20: Separation of Buildings into Portions

In general, there exist two alternative solutions in order to overcome the problem.

These are:

- to separate the building structurally into simple forms (Figure 2.20) ,
- to tie the building together strongly at lines of stress concentration and to locate resisting elements to reduce torsion (Arnold, 1989).

In order to permit independent movements of substructures, actual dimension of separation between adjacent structures (with the use of seismic separation joints) must be provided to ensure that no hammering occur (Ambrose and Vergun, 1985; Paulay and Priestley, 1992). According to Arnold (1989), as the free ends of the wings tend to distort most under torsion, it is desirable to place structural elements at these locations (Figure 2.21).

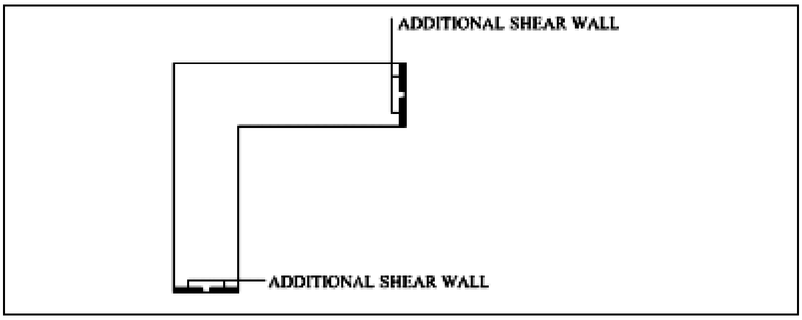


Figure 2.21: Additional Shear Wall to Free End of Wings

The use of splayed re-entrant corners rather than right angle one (Arnold, 1989) or softening the right angle re-entrant corner (Zacek, 1999) lessens the stress concentration at the notch (Figure 2.22). According to Zacek (1999), another solution to reduce the stress concentration at the notch is to increase the section of the vertical structural element, which is placed at the notch.

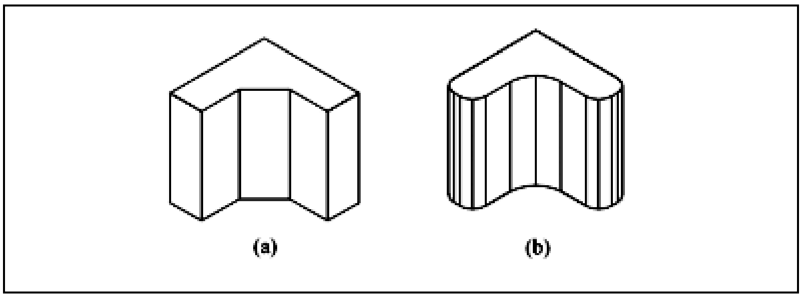


Figure 2.22: Softening the Right-angle Re-entrant Corner

The architectural separation of the masses is sometimes emphasized with a linkage element. Sometimes, two buildings are joined with elements such as staircases or transition parts. These elements may damage during earthquakes. In order to avoid the problem, separating the connection part from the main buildings with seismic joints and considering it as a self-standing structure is the most appropriate solution (Zacek, 1999). Besides this, it may be designed strong enough in order to behave as a continuous structure during earthquake movement or it may be separated from one side and attached to the other side in order to behave as a part of the attached side (Ambrose and Vergun, 1985).

Individual joined masses are sometimes so different in size or stiffness. In this case, the smaller part is simply attached to the larger one, treated as attachments without developing their own bracing. It is called tag along structure (Figure 2.23). The tag along technique is often used for elements having lightweight compared with main structures such as staircases, chimneys, entries, connecting corridors, and other elements that are part of a building, but are generally outside the main mass (Ambrose and Vergun, 1985).

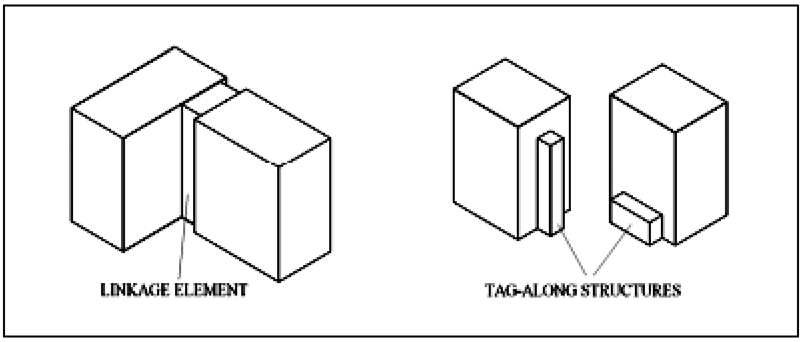


Figure 2.23: Buildings with Linkage Element and Tag-along Structures

2.13.10 Buildings with Vertical Setbacks

A setback is an abrupt change of strength and stiffness in elevation, which are likely to invite poor structural responses. A setback may be introduced for several reasons. Arnold (1989) states that the seriousness of the setback effect depends on the relative proportions and absolute size of the separate parts of the building. As the absolute size of setback increases, the amount of the deformation increases. For example, as the slenderness ratio of a tower increases, the risk of overturning of the tower on to the base portion becomes apparent. As the tower and the base do not have the same natural period of vibration, their responses to earthquake forces are different in phase (Figure 2.24). So, opposite displacements may occur, which result in stress concentrations at and near the level of discontinuity. They are difficult to predict without sophisticated computerized analytical methods. Moreover, even if known, the building could not be adequately detailed at the critical spots (Zacek, 1999).

Therefore, according to Zacek (1999), it is desirable that each floor has the same shape in plan.

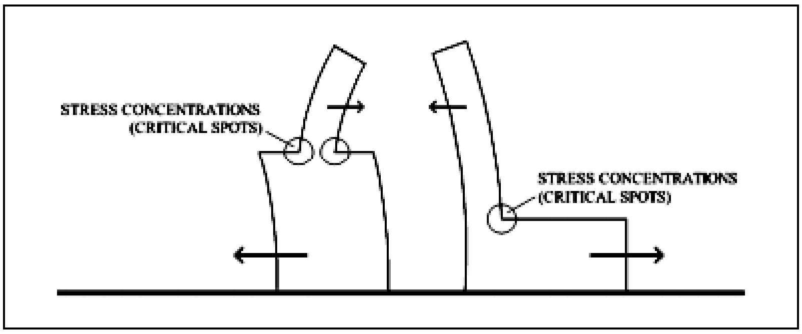


Figure 2.24: Stress Concentrations due to Setbacks

Arnold (1989) states that, solutions for the setback problem are similar to those for the re-entrant corner (its horizontal counterpart in plan). According to Zacek (1999), the solutions for reducing the negative effects of the setbacks are:

- to separate the portions in vertical (so that portions of the building (base and the tower) are free to react independently) (Figure 2.25),
- to remove the re-entrant corners by gradually reducing building form,
- to reinforce the re-entrant corners on vertical

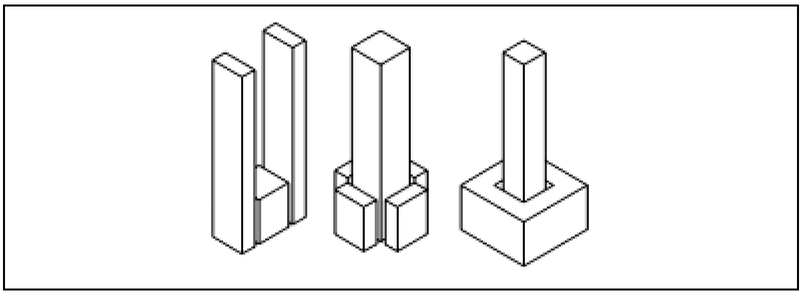


Figure 2.25: Separating the Portions of the Buildings

2.13.11 Other Issues-Pounding (Battering or Hammering)

Two structures standing side by side may respond to seismic forces differently due to their different natural periods of vibration. Bumping to each other called ‘pounding’ (battering or hammering) between structures is a common occurrence, which may lead to failure.

Adequate separation with sufficient space between individual buildings is to be maintained to avoid the problem. The minimum separation distance depends on the height of the building and the flexibility of the building. The distance between adjoining buildings should exceed the sum of lateral displacements of each storey with an extra allowance (Coburn and Spence, 1992)

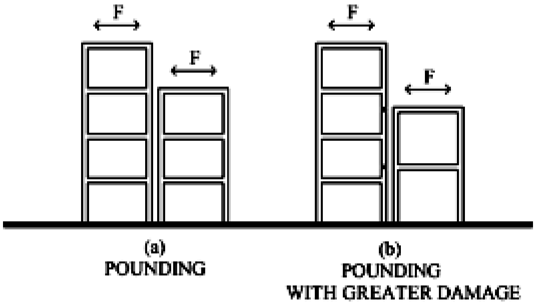


Figure 2.26: Pounding

If the structures are of similar height and their floor levels match, damage may be only in ‘apparent’ (Figure 2.26). However, if the floors are at different levels, the floor of one structure may hit and damage the column of the adjacent structure causing structural damage and possibly collapse (Krinitzsky, Gould and Edinger, 1993). However, when the blocks with different heights are separated from each other with adequate seismic joints, they do not damage each other, although they experience different motions due to seismic forces and their varying stiffness and rigidities. According to the 1998 Turkish Earthquake Code, up to 6 m height, the separation width should be at least 30 mm. As the height of the building increases, 10 mm is to be added every 3 m height.

2.13.12 Weight of the Building

The earthquake force is directly proportional to mass (weight) of the building. Therefore, dead load constituting the building weight is a disadvantage in earthquakes. Ambrose and Vergun (1985) states that care should be exercised in developing the construction details and in choosing materials for the building in order to avoid creating unnecessary dead load, especially at upper levels in the building. Light materials for infill walls, floor and wall claddings should be preferred (Gönençen, 2000). A structure must be designed in order to resist earthquake forces, which is equal to 40 % of its total weight (Erman, 2002). On the other hand, dead load is useful for overturning resistance and it is necessary for the foundations that must anchor the building.

2.13.13 Structural System Configuration Issues

2.13.14 Structural System (Lateral Resistive System) Configuration in Plan

Attention should be paid to the arrangement of the lateral resistive elements. Regular configuration of structural system in plan mostly cannot be obtained due to the form of the site and the architectural planning requirements. Irregular arrangements of the elements make the seismic analyses difficult and the structure subject to torsional forces. Moreover, the coincidence of centers of mass and rigidity becomes hard to achieve (Bayülke, 2001).

2.13.15 Column, Shear Wall and Beam Configuration in Plan

The vertical elements of lateral resistive system configuration (columns and shear walls) should have these necessities in plan:

- The vertical structural elements should be arranged regularly on an axis system. Irregular and random arrangement should be avoided in order not to produce irregular and uncertain stresses due to seismic and other forces (Dowrick, 1987).

- It is necessary to locate equal number of elements on both axes (Tuna, 2000).

- The axes should have equal or close to equal intervals in order to achieve economy. If possible, the columns should be placed with regular spans (Zacek, 1999).

- In order to make seismic resistance and rigidity of the structure identical to each other for both directions, it is necessary to place columns on two directions (Bayülke, 2001)

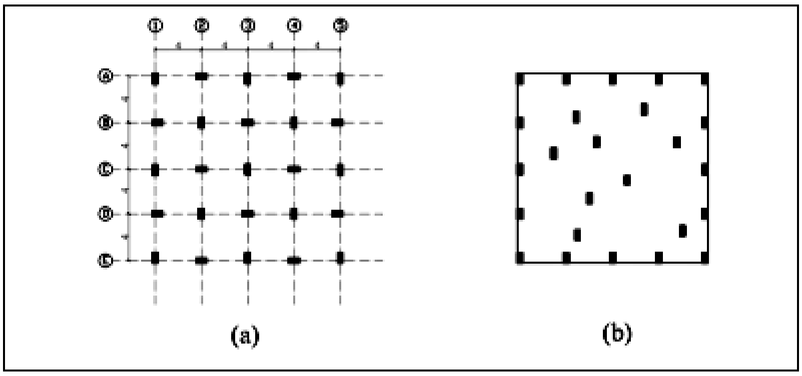


Figure 2.27: Regular and Irregular Vertical Structural System Configuration in Plan

- The vertical structural elements must be stacked on top of each other (Figure 2.27). The lack of vertical structural elements at the lower stories should be avoided (Architectural Institute of Japan, 1970). If long and short sides of the columns for all stories do not coincide, eccentricity and torsion may be developed among stories (Bayülke, 2001).

- It is necessary to place the vertical structural elements perpendicular to the sides of the plan. As the most important damages occur on the columns and shear walls at the corners, it is needed to design L-shaped columns and shear walls on the corners (Tuna, 2000) (Figure 2.28).

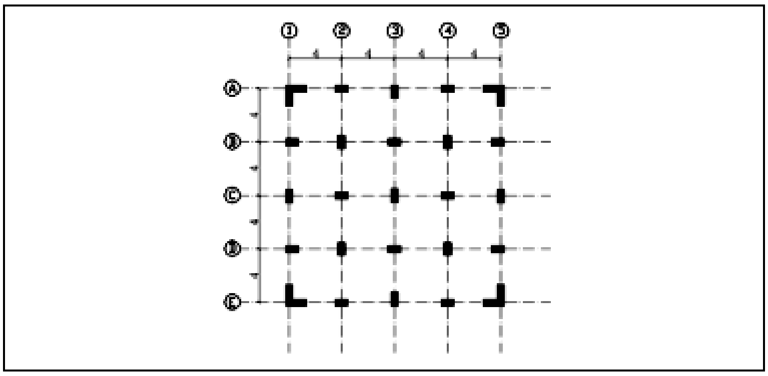


Figure 2.28: L-shaped Columns and Shear Walls on the Corners

- The vertical structural elements should be tied with beams on two directions to form a rectangular frame (Architectural Institute of Japan, 1970). If not, the distribution of seismic forces due to rigidities becomes difficult to achieve, so some of the elements are exposed to seismic forces more than the other ones (Bayülke, 2001).

- It is necessary to make the sections of the columns and beams nearly same (Figure 2.29). As the seismic loads are distributed to the structural members proportional to their rigidities, the sections of elements should not change suddenly (Dowrick, 1987; Zacek, 1999).

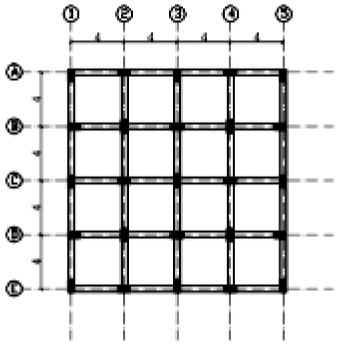


Figure 2.29: Rectangular Frame with Columns and Beams

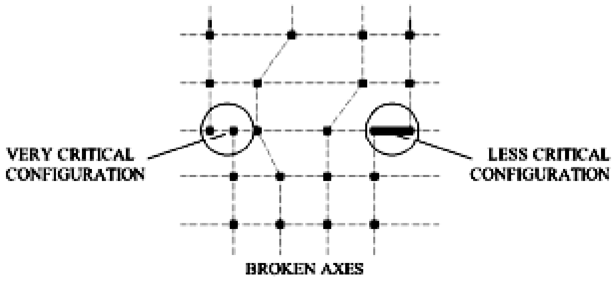


Figure 2.30: Frames with Broken Axes

- As beams with broken axes are less resistant to lateral forces (figure 2.30), frame configurations with broken axes should be avoided due to excessive torsions that may occur (Özmen, 2002).

- Being an engineering attribution, which plays an important role in seismic performance, design of the connections between elements is highly important for the integrity of the whole lateral resistive system. It is necessary to detail the connections for an integrated, an interconnected, and a monolithic structure (Arnold, 1989).

- The centers of mass and rigidity should be coincided with the placement of vertical structural elements, if they do not, the eccentricity should not exceed 5% of the building dimension (Tuna, 2000) (Figure 2.31). There exist additional necessities about shear walls. Shear walls are generally placed as the periphery of the staircases and lifts' shafts. However, if they are not symmetrically arranged in the building plan, torsional effects due to the eccentricity between the center of mass and center of rigidity become apparent (Bayülke, 2001).

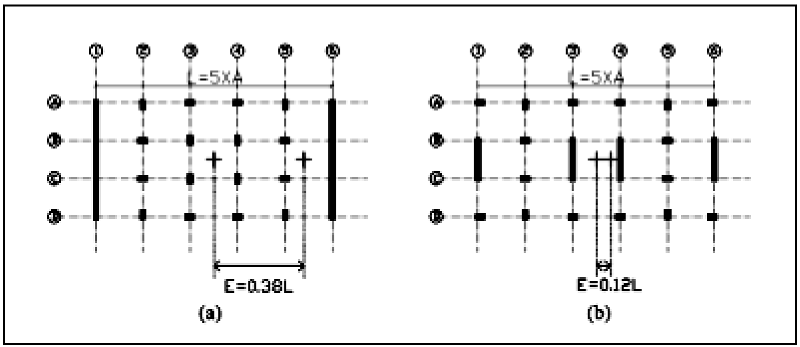


Figure 2.31: Eccentricity due to Shear Walls Arrangement

It is more appropriate to distribute shear walls within the building in a symmetric manner. According to Uniform Building Code (UBC), which has been used in United States of America, minimum four shear walls are to be placed on both axes. This is why, if one of the shear walls at one side of the building has been damaged during earthquake, the center of rigidity does not change much. Hence, large torsional effects due to eccentricity are not produced. If two shear walls instead of four are arranged and one of them has been damaged, large displacement of center of rigidity and torsional effects may occur (Bayülke, 2001).

According to Bayülke (2001), two important principles for the arrangement of shear wall on building plan are:

- existences of many numbers of shear walls on plan (Figure 2.32),
- distribution of the shear walls within the building.

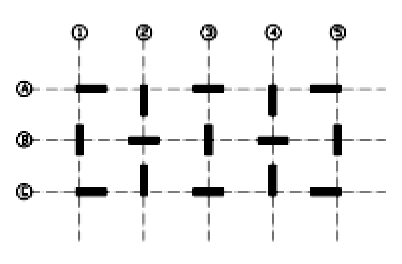


Figure 2.32: Distribution of the Shear Walls within the Building

Beams should have these necessities:

- It is necessary to arrange beams at every storey, so that columns and beams form a rectangular frame (Architectural Institute of Japan, 1970).
- If two beams are placed in a misleading manner (Figure 2.33), the section of the common column should be designed large enough. As an engineering attribution, the reinforcing of the column should be rearranged and accordingly increased. This is the effect of architectural design to the structural system design (Bayülke, 2001).

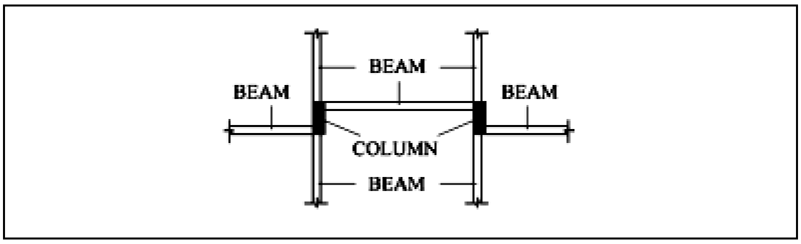


Figure 2.33: Beams with in a Misleading Manner

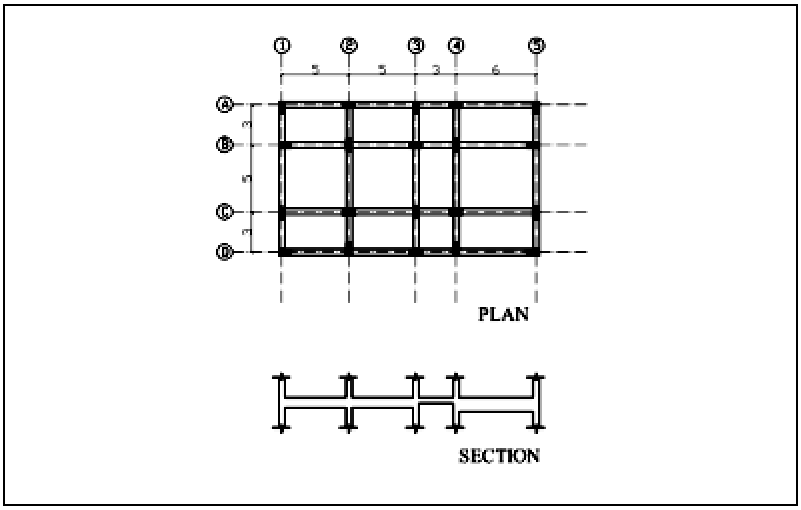


Figure 2.34: The Depth of the Beams due to Spans

- The depth of the beams should be adjusted according to the span of the columns. If the columns are arranged with equal spans, the depths of the beams are necessary to be equal in order to avoid stress concentrations. If the spans are not equal, the more shallow beams should tie the short span columns in order not to cause the short span columns to become more rigid (Figure 2.34) (Bayülke, 2001).

However, in order to estimate the stresses due to the lateral loads properly, to design formwork economically and to detail the reinforcement conveniently, it is necessary to design equal spans and uniform beam sections (Özmen, 2002).

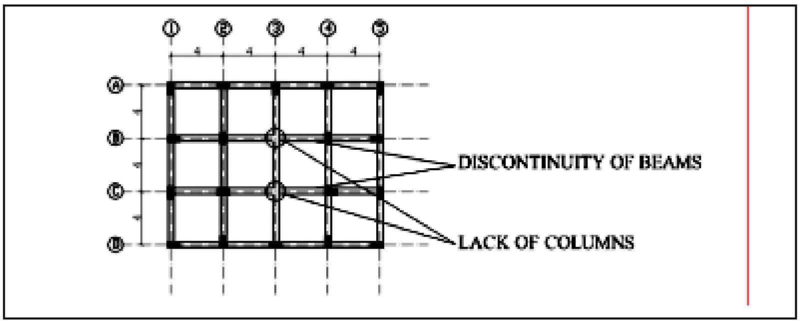


Figure 2.34: Irregularities about Beams

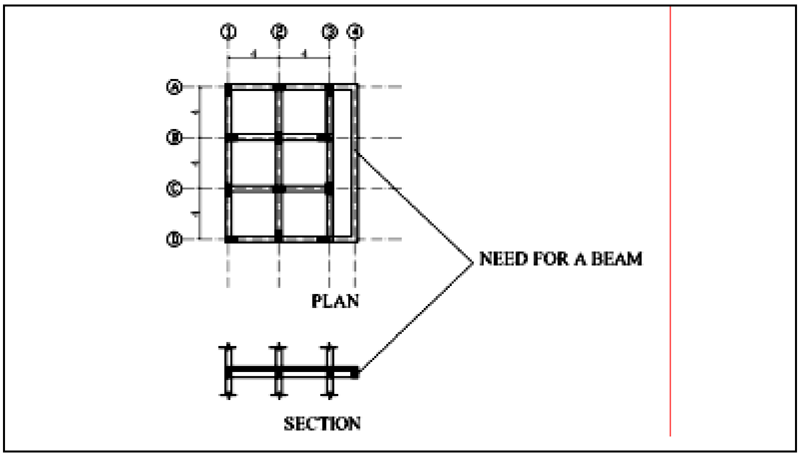


Figure 2.35: Beam for Cantilever

- It is necessary to avoid beam-to-beam connections. The lack of column at the coincidence of the beams is undesirable (Figure 2.34) (Tuna, 2000).

- It is necessary to avoid non-continuous beams along the axis (Figure 2.34) (Dowrick, 1987).

- Beams should be placed at the edges of the cantilevers (Figure 2.35) (Tuna, 2000).

2.13.16 Torsional Rigidity

The center of building mass is generally considered as the geometrical center of the building and the center of rigidity is considered as the center of vertical elements of the structural system. The center of rigidity of a building should coincide with the center of mass (Figure 2.36).

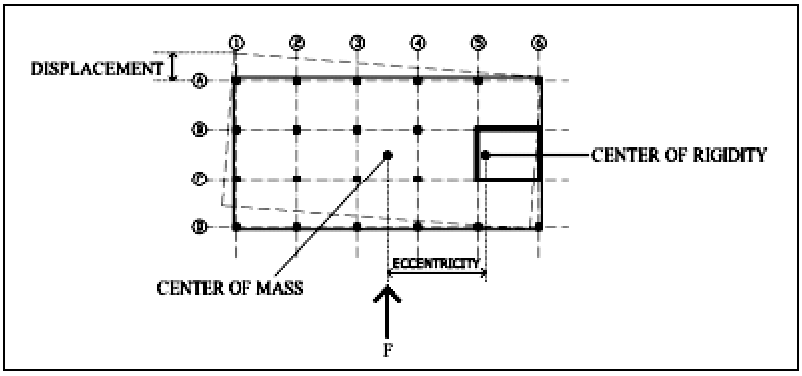
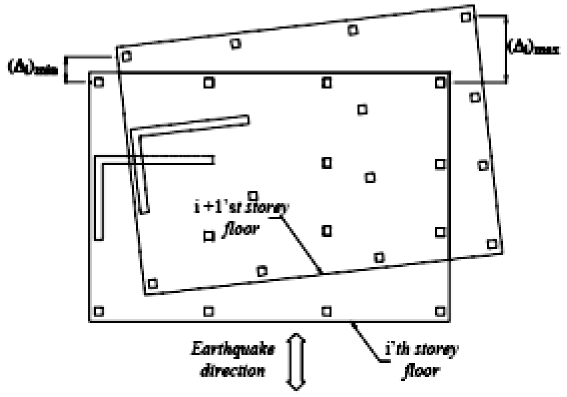


Figure 2.36: Torsional Response

When the center of a building mass does not coincide with the center of rigidity, torsion and stress concentrations occur in the building when it is subjected to seismic loads. Eccentricity between the centers makes the building rotate due to seismic forces. In order to avoid torsional deformation, it is desirable to have symmetry both in the building configuration and structure. The vertical structural elements of the lateral resistive system should be arranged in order to approach the centers of mass and rigidity to each other and in order to produce high resistance to torsional effects on the building (Ambrose and Vergun, 1985; Wakabayashi, 1986).



In the case where floors behave as rigid diaphragms in their own planes:

$$(\Delta_i)_{ort} = 1/2\ [(\Delta_i)_{max} + (\Delta_i)_{min}]$$

Torsional irregularity factor :

$$\eta_{bi} = (\Delta_i)_{max} / (\Delta_i)_{ort}$$

Torsional irregularity : $\eta_{bi} > 1.2$

Figure 2.37: Torsional Irregularity (Turkish Earthquake Code, 1998)

A1 – Torsional Irregularity:

The case where Torsional Irregularity Factor, which is defined for any of the two orthogonal earthquake directions as the ratio of the maximum storey drift at any storey to the average storey drift at the same storey in the same direction, is greater than 1.2 (Figure 2.37).

[$\Delta i = (\Delta i)\ max / (\Delta i)\ ort > 1.2$]

2.13.17 Diaphragm Configuration

Diaphragms, which transfer forces between vertical structural elements, are needed to connect them and to make them resist to the seismic forces as one body. Architectural Institute of Japan (1970) states that they behave like columns when the lateral forces are considered as the horizontal forces.

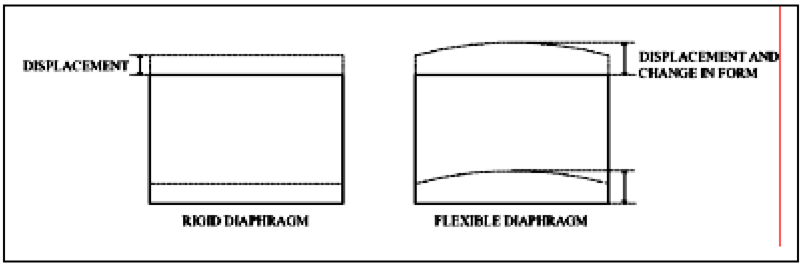


Figure 2.38: Behaviour of the Diaphragm under Earthquake Loading

A diaphragm may act either in a rigid or a flexible manner. Rigid diaphragm moves as a rigid body without deformations due to lateral forces, whereas the form of the flexible diaphragm tends to change with the displacement (Figure 2.38) (Bayülke, 2001).

According to Zacek (1999), the rigidity of the diaphragms depends on:

- form and size (Long and narrow diaphragms are more flexible. Damages due to stress concentrations are seen at the re-entrant corners of the diaphragms.) (Figure 2.39),
- material,
- connections of the structural elements,
- penetration (opening)

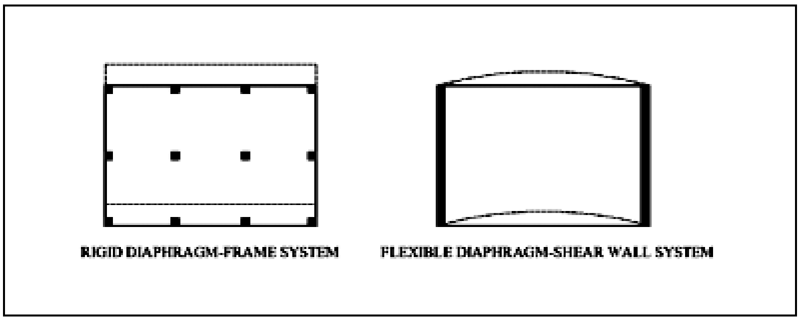


Figure 2.39: Behavior of the Diaphragm According to the Structural System

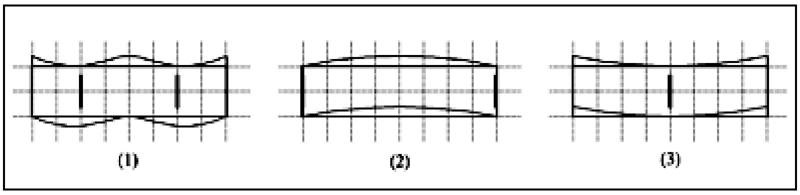


Figure 2.40: Behavior of the Diaphragm According to the Locations of Shear Walls

Sometimes, diaphragm, which ties the columns, may behave as a rigid plane whereas diaphragm with same property, which ties the shear walls, may behave as a flexible one.

The rigidity of diaphragms may also change according to the locations of shear walls (Bayülke, 2001) (Figure 2.40).

Architectural requirements such as necessities for vertical traffic within a multistory building, visual integration of stories, and other purposes result in a variety of diaphragm penetrations such as staircases, elevators, atriums, duct shafts, skylights, and so on. The size, location, and even shape of the penetrations are critical to the effectiveness of the diaphragm. Diaphragm penetration and their geometrical irregularities weaken the load carrying capacity and the lateral rigidity leading to torsion and stress concentration. For instance, the logical planning location for an elevator in an L-shaped building is at the notch of the building, which is also the area of seismic stress concentration (Arnold, 1989).

2.13.18 Axis System

It is necessary to place the vertical structural elements parallel to the major orthogonal axes of the structural system. If the columns are arranged and beams are tied with an angle different from 90, building exercises poor seismic performance with its nonparallel axes system. In this condition, there exists a high probability of torsional forces under earthquake motion, because the centers of mass and resistance cannot coincide for all directions of earthquake motion. In this case, the building should be separated into simple and regular forms with seismic joints in order to reduce the effects of torsion.

The 1998 Turkish Earthquake Code describes the situation as an irregularity called A4 – Nonparallel Axes of Structural Elements and as follows:

A4 – Non-parallel Axes of Structural Elements:

The cases where the principal axes of vertical structural elements in plan are not parallel to the orthogonal earthquake directions considered.

A characteristic form of ‘nonparallel axes’ condition is the triangular or wedge shaped building that results from street intersections at an acute angle. The narrower portions of the building tend to be more flexible than the wider ones, which increase the tendency to torsion (Figure 2.41) (Arnold, 1989).

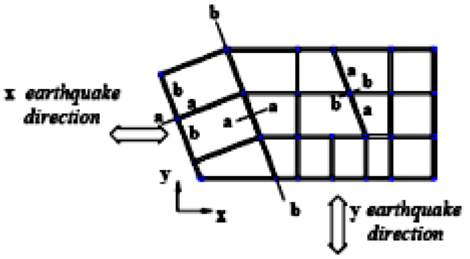


Figure 2.41: Non-parallel Axes of Structural Elements (Turkish Earthquake Code, 1998)

Dimension and Density of Structural Elements

The resistance of the structural system depends on the sections of the members. As the section of a reinforced concrete structure member increases, its earthquake resistance increases (Erman, 2002). Dowrick (1987) states that reinforced concrete columns and beams should have nearly the same or similar width. This promotes good detailing and helps the transfer of moments and shears through the connection of the members. Very wide or shallow beams may fail near the connections of normal-sized columns.

The total area of the vertical structural elements divided by the gross floor area is defined as structural plan density. There is an enormous reduction of structural plan density of modern buildings when it is compared to historical ones. The size and density of structural elements in the buildings of early centuries are strikingly greater than in today’s building. For instance, the structural plan density of a typical 10-20 story steel frame building is 1 %, frame-shear wall design is 2 %,whereas the structural plan density of a historical building (for example: Taj Mahal) is 50 % (Arnold, 1989) (Figure 2.42).

Earthquake forces are generally greatest at the ground level. The bottom story is required to carry its own lateral load in addition to the shear forces of all the stories above. The most efficient seismic configuration is the need of greatest intensity of vertical structural elements at the ground floor, whereas programmatic and aesthetic criteria often demand the removal of them as much as possible (Arnold, 1989).

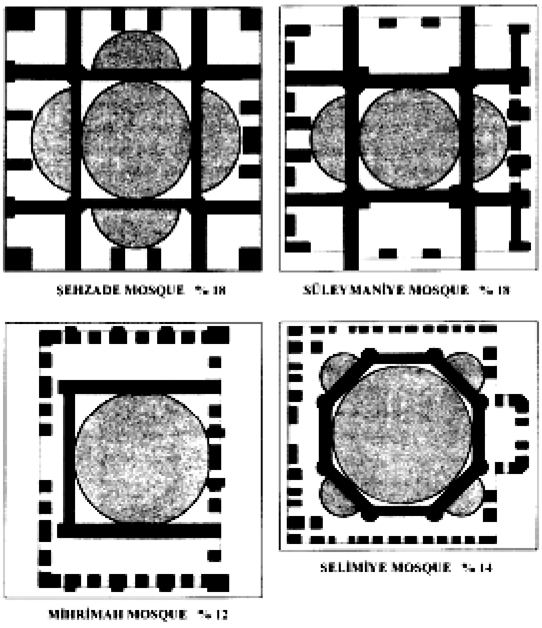


Figure 2.42: The Structural Plan Density of Historical Buildings (Unay, 2002)

2.13.19 Structural System (Lateral Resistive System) Configuration in Vertical

Uniformity in the distribution of masses, rigidities, and strength is also desirable in the vertical direction of the building. The structural elements of lateral resistive system configuration (columns and shear walls) should have these necessities in vertical in order to make structures more easily analyzed and avoid undesirable stress concentrations and torsions:

- All vertical elements of lateral resistive system should be continuous throughout the building height, from roof to foundation. Non-existence of elements on the ground floor or the interruption of them somewhere in the building storey is too detrimental in terms of lateral forces (Bayülke, 2001).

- It is necessary to make all the column heights equal for a story (Zacek, 1999).

- It is necessary to make the rigidity of the stories similar. At the upper stories, the decrease in rigidity can be acceptable which makes the vibration of the building decrease (Zacek, 1999).

- Homogeny in buildings must be present. As all the structural system have their own dynamic responses to the earthquake forces due to their weight, rigidity, and geometry, using different structural systems together may cause failures (Zacek, 1999).

Buildings with shear wall systems generally performed well during the 7.4 magnitude of Kocaeli Earthquake on August 17, 1999. Storey collapses were not observed in buildings containing shear walls, but it should be noted that shear walls were not widely used in the epicentral region. On the other hand, buildings with reinforced concrete frame systems behaved poorly during the earthquake. According to official estimates, more than 20,000 buildings with frame systems collapsed and many suffered from moderate to severe damage (Sezen, Whittaker, Elwood, and Mosalam, 2003).

There exist additional necessities about the shear walls. The inclined bases of the shear walls lead to decrease in rigidity of the ground floor (Figure 2.43). Moreover, the deformations of the bases become too complicated (Bayülke, 2001).

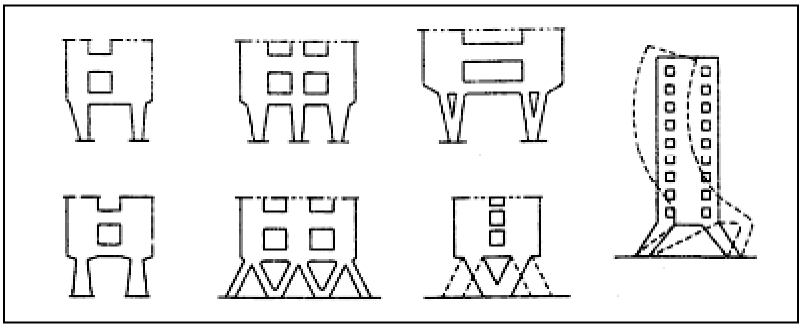


Figure 2.43: The Inclined Base of the Shear Walls and its Behavior due to Earthquake forces (Bayulke, 2001)

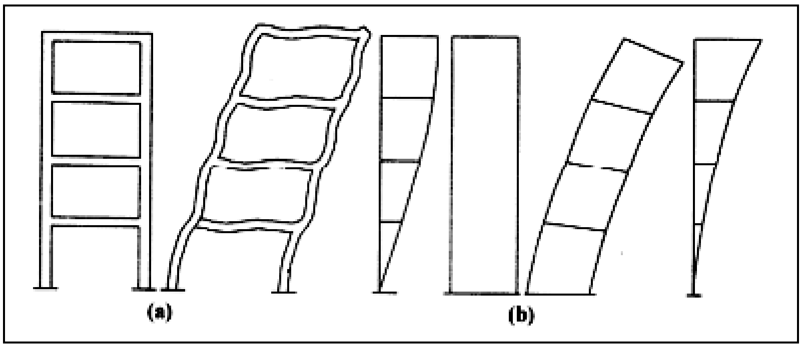


Figure 2.44: The Deformations of Frame System (a) Shear Wall System (b) (Bayulke, 2001)

The deformations, due to lateral forces, of the shear wall system and frame system of a building are different from each other. The lateral deflections of the shear walls increase as the building grows up, whereas the lateral deflections of the frames and successive deflections among stories decrease as the building grows up (Figure 2.44). Shear walls limit the lateral deflection of the frames at lower stories, whereas frame systems limit the lateral deflection of the shear walls at upper stories (Bayülke, 2001). On the other hand, in 1999 Kocaeli Earthquake, although the shear wall in a dual wall-frame building was likely sufficiently stiff to protect the frame, failure of the first storey columns was observed (Sezen, Whittaker, Elwood, and Mosalam, 2003)

2.13.20 Soft Storey

Any abrupt change in lateral stiffness results in deformation and stress in a building, which is subjected to earthquake loads (Ambrose and Vergun, 1985). A building with soft story is defined as a building with a stiff and a rigid superstructure placed on top of an open and a flexible floor (Lagorio, 1990) (Figure 2.45). The condition is most critical when it occurs at the ground floor, because the loads are generally greatest at the ground floor level (Arnold, 1989).

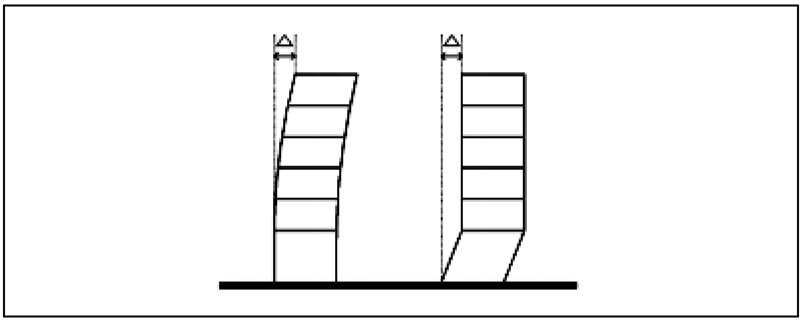


Figure 2.45: The Soft Storey Formation

If all stories are approximately equal in strength and stiffness, the entire building deflection under earthquake forces is distributed approximately equally to each story. If the ground floor is significantly less strong or more flexible, a large portion of the total building deflection tends to concentrate there, with consequent concentration of stresses at the upper floor connections (Arnold, 1989). Unless the connection between the open ground floor and the stiffer upper floors has been adequately designed to absorb the stress concentrations and to allow for the transition of forces to the vertical structural elements at the lower floor, failure may occur (Lagorio, 1990).

These are the major causes of the soft-story formation (Figure 2.46). The soft storey formation is observed:

• when the ground story of a building is significantly taller than upper floors. This results in less stiffness and more deflection in the ground story.

• when there exists an abrupt change of stiffness at the upper story, although the story heights remain approximately equal. This is caused primarily by material choice, for example, the use of heavy precast concrete elements above an open ground story. Tuna (2000) 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 story formation.

• when the vertical structural elements do not continue down to the foundations and interrupt at any floor level, when there exists discontinuous load paths. Thus, it also creates change of stiffness (Arnold, 1989).

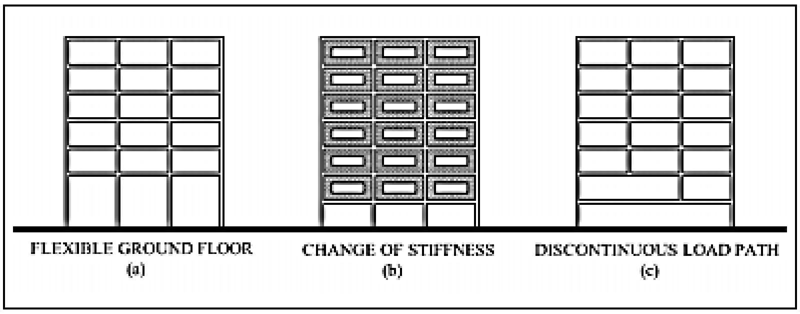


Figure 2.46: The Causes of Soft Storey Formation

Many of the collapses are attributed to the formation of soft first stories that formed due to the differences in frame system and infill wall geometry between the first and upper stories. Many of the buildings constructed with hollow clay tile infill walls create stiffness discontinuities in these buildings by concentrating the drift demands in the first storey. Generally, these walls are almost unreinforced and they adjoin the frame members without being tied to them (Sezen, Whittaker, Elwood, and Mosalam, 2003).

To reduce the reduction of the soft storey effect remedies are given below (Figure 2.47):

- to brace some of the openings,
- to keep the building plan periphery open, while providing a rigidly braced interior,
- to increase the number or the stiffness of the ground floor column,
- to use tapered or arched forms for the ground floor,
- to develop a rigid ground story as an upward extension of heavy foundation structure,
- to equalize the rigidity of the stories by separating the non-structural elements from the structural ones or using light and less rigid non-structural elements for infill walls and exterior claddings (Zacek, 1999).

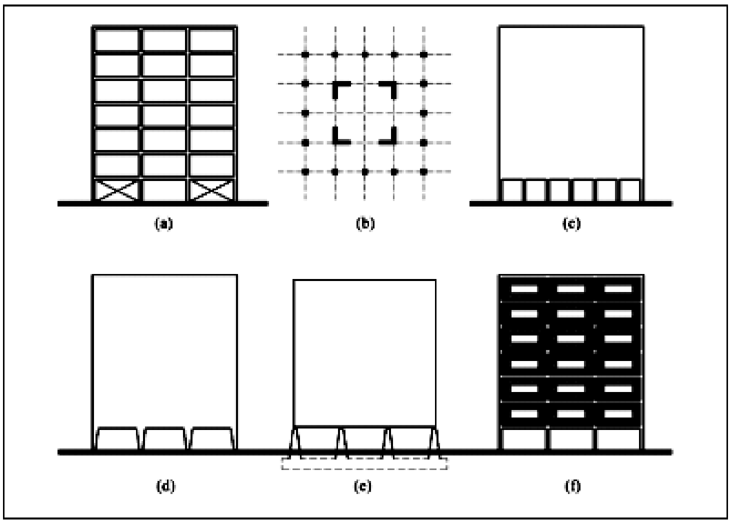


Figure 2.47: The Remedies of Soft Storey Formation

As the aim of seismic design is to form a system, which is able to dissipate earthquake energy and the effects of the lateral deformation on the response of the entire building, the soft story is actually a method for major energy absorption, which could be a positive factor in some situations. However, the major stress concentrations and deformations must be carefully provided for and true dynamic analyses are certainly indicated (Ambrose and Vergun, 1985; Mezzi, Parducci and Verducci, 2004).

2.13.21 Weak Story

Any abrupt change in lateral strength results in deformation and stress in a building is subjected to earthquake loads. Weak story is described as a discontinuity in capacity. It is essential to understand the distinction between a soft story and a weak story, although it is possible for a single story to be both. The soft story is based on stiffness or simply the relative resistance to lateral deformation or relative displacement (drift) of a story. The weak story is based on strength in terms of force resistance (static) or energy capacity (dynamics) (Ambrose and Vergun, 1985).

The required ratio of strength is stated in the 1998 Turkish Earthquake Code as follows:

B1 – Interstorey Strength Irregularity (Weak Storey):

In reinforced concrete buildings, the case where in each of the orthogonal earthquake directions, Strength Irregularity Factor which is defined as the ratio of the effective shear area of any storey to the effective shear area of the storey immediately above, is less than 0.80.

[$\eta_{ci} = (\sum A_e)_i / (\sum A_e)_{i+1} < 0.80$]

Definition of effective shear area in any storey:

$\sum A_e = \sum A_w + \sum A_g + 0.15 \sum A_k$

Discontinuity of Structural Elements

Forces applied to buildings must travel from their points of origin through the whole system and into the ground, in the design for lateral loads. The force paths must be complete. Where there are interruptions in the normal flow of the forces, problems occur. In a multi-story building, columns and shear walls must be stacked on top of each other. If a column is removed in a lower story, a major problem is created, requiring the use of a heavy transfer girder or other device to deal with the discontinuity (Ambrose and Vergun, 1985).The 1998 Turkish Earthquake Code describes the irregularity as follows:

B3 - Discontinuity of Vertical Structural Elements:

The cases where vertical structural elements (columns or structural walls) are removed at some stories and supported by beams or gusseted columns underneath, or the structural walls of upper stories are supported by columns or beams underneath.

2.14 Related Research in Bangladesh

The city of Cox's Bazar is located in the south eastern part of the country which falls in the High Risk Zone for tropical cyclones. However, the earthquake and the resulting tsunami have recently appeared as additional threats to this region. Recent series of disasters in Bangladesh and neighboring countries have posed an added concern on the importance of emergency alerts. Early Warning System is considered to be one of the most effective measures for Disaster Preparedness

For the research purpose Cox’s Bazar, the main tourist spot and long sea beach of Bangladesh, has been considered as a study area.It is located at (22º-35´-0´´ N, 92º-01´-0´´E), bounded by the Chittagong district to the north, the Bandarban district to the east and the Bay of Bengal to the west. This area falls under seismic zone II as per BNBC1993 and have experienced earthquake magnitude between 6 and 7 as per historical data. As a result, Cox’s Bazar and its nearby area is high risk zone to earthquake.

This study mainly targets to attract the interest on the present situation of Cox’s Bazar for future earthquake by seismic vulnerability assessment based on rapid visual screening. It is seen that concrete moment resisting frame (most popular in residential category) is under threat for forthcoming earthquake by several vulnerability factors. If one of the soft storey buildings under liquefaction fails it will affect the others very easily because all the building structures very close to each other. Moreover, it will be catastrophic disaster if the earthquake occurs at night. It also demonstrated that most of the buildings which looks good and build within 10 years have increasing the vulnerability factors day by day.

Another study was carried out to identify most vulnerable structures in Dhanmondi residential area, Lalmatia and the greater Mohammadpur by using RVS-FEMA and Turkish method (Sadat et al, 2010).

In another research, about 1383 buildings (77%) in Ward 68 in Dhaka City were analyzed using Rapid Visual Screening (RVS) to assess vulnerability of the existing buildings. In this study, 1.5 has been considered as a “cut-off” score according to the experts‟ opinion, considering the existing site condition. About 53% buildings have been found as vulnerable to earthquake and needed detailed analysis (Jahan, 2011).

2.15 Practices in Different Countries

Vietnam is recognized as one of the most disaster prone countries in the Asia Pacific Region. Over the last 30 years, disasters have been a major contributor to fatalities, injury and economic losses totaling about 1.0 – 1.5% GDP. Current challenges of disaster risks and impacts are likely to be further exacerbated by global climate change. According to Sven and David (2013), Vietnam ranked 6th globally in terms of climate risk. Vietnam is also one of the 30 “extreme risk” countries according to the Climate Change Vulnerability Index over the next three decades. In recognition of the importance of the natural disasters and climate change, the Government of Viet Nam (GoV) has developed and issued a number of programs to address these challenges including the National Target Program to Respond to Climate Change (NTPRCC), National Strategy for Natural Disaster Prevention, Response and Mitigation to 2020 (NSNDPRM), and Community-based Risk Disaster Management (CBDRM).

It is commonplace that traditional approaches to community development, poverty reduction and disaster management focus on practices of government and non-governmental organizations providing direct goods, services, infrastructure to the poor and target communities. While that type of support is necessary, it is not enough to build the success, effectiveness and sustainability of development work, not to mention empowerment of targeted populations. Therefore, communities and development practitioners always strive to seek new approaches for sustainable development. The approach promoted under Community-based Disaster Risk Management (CBDRM) is to build people’s capacity of coping with disaster risks and reducing their vulnerability thereby developing safer and more resilient communities. These approaches have been recognized and widely practiced by various community groups, national and international organizations and government departments for over two decades in South East Asia countries. In Vietnam, CBDRM was first introduced by some international NGOs in 2000 and has soon become popular for many disaster risk reduction projects and programs implemented by NGOs and government organizations. Especially, in the context of climate change worsening the complicated nature and severity of disasters, it is very critical for communities and development organizations to adopt innovative approaches like CBDRM. To increase the success of disaster risk reduction programs and promote CBDRM practices in Vietnam, a consortium of 14 international NGOs and national organizations have participated in the Joint Advocacy Network Initiative (JANI). This project has been supported by European Commission's Humanitarian Aid Office

(ECHO) since 2007. One of the major recommendations of the previous phase of JANI was that CBDRM practitioners in Vietnam should come up with a consolidated CBDRM framework that systemizes diverse CBDRM guidelines and methodologies in Vietnam. Therefore this documentation has been developed, through a consultative process, reviewing and consolidating of existing CBDRM materials and methodologies in Vietnam. The document will serve the purpose of a theoretical and practical base reference for CBDRM practitioners at national and provincial level in implementing disaster risk management. The idea behind preparing this documentation is to facilitate CBDRM practitioners, including government and non-government agencies, to effectively implement natural disaster management programs in Vietnam.

3. Methodology

3.1 Research Process

The recent trend of R.C.C frame building structure has become increasingly common in urban Dhaka City. Many such buildings constructed in recent times have a special feature- the ground storey is left open for the use of parking, driver's waiting room and electro-mechanical rooms. The columns in the ground floor as a result do not have any partition walls between them and termed as 'Soft Storey' buildings.

Open ground storey buildings have consistently shown poor performance during the past earthquakes worldwide. The buildings collapsed during the major earthquake causing more death tolls. A significant number of buildings with concept of Soft Storey building have been built in recent times. The objective of this study is to compile a database of R.C.C (with or without Soft Storey and Unreinforced Masonry Building (U.R.M) within the three wards of Dhaka City selected and make a vulnerability analysis of the building structures within the selected zones as well as determine the architect's consciousness in seismic design.

The objective has been carried out in three steps. The first one is to assess the seismic vulnerability of R.C.C and U.R.M structures of the selected area by R.V.S (Rapid Visual Screening) method and Turkish Method via cluster sampling. Such methods were first implemented in BUET and Dhaka University Campus (Rajon, 2006 and Wahid, 2005).Secondly, a study based on data of an empirical research about the architectural consciousness in seismic design. Lastly for step three, three building from each ward is selected evaluate architecture based issue in seismic design. All the process comprise literature review from various sources (documents, Internet, journals, articles and books) on subjects related to earthquake.

In order to design simple structures like low rise buildings, engineers idealize earthquake ground acceleration as horizontal forces applied at the elevated floor and roof levels. These horizontal forces are then transmitted to the foundations by specially designed walls called Shear Walls. The seismic forces are transmitted by the floors and roof to the Shear Walls in the earth's surface. Floor and roof framing specially designed to carry seismic loads to the walls are known as diaphragms to structural engineers. The diaphragm and Shear walls work in conjunction to transmit the seismic load to the foundation. The particular type of system carries lateral loads in the same way a box resist collapses.

For the past more than a decade Bangladesh had been rising in the Real Estate sector starting from Dhaka South City Corporation to Dhaka North City Corporation. Apartments with Soft Storey concept are mostly seen. Thus the main goal of the study relates to the apartments with Soft Storey and the provision of earthquake resistance and how the structures react as designed by architects and structural engineers.

The primary task was to select the three wards for the study of the buildings. The three wards include ward 28 of DSCC, Chawkbazar, Ward 49 of DSCC, Dhamondi and Ward 19 of DNCC, Banani.

3.2 Selection of the Study Area

Dhaka with the passage of time, testifies different faces of history. Now-a-days Dhaka is the most densely populated and rapidly growing city in the third world countries. As the growth of population in Dhaka is taking place at an exceptionally high rate, it has become one of the most populous Mega Cities in the world. In the process of urbanization, the physical characteristics of Dhaka City are gradually changing as open spaces and water bodies are converted into built up areas.

The growth and development of Dhaka can be categorized into six periods, e.g. the pre-Mughal period (1205-1610), the Mughal period (1620-1757), the East India Company period (1758-1858), the British colonial period (1858-1947), the Pakistan period (1947-1971) and the Bangladesh period (from 1971).

The study selection relates to the construction trend of Dhaka City after the Colonial period. The reason behind choosing the selected area involves the new trend of building apartments with a weaker ground storey and the buildings do not resemble any specific occupancy as city started to grow inorganically towards the Northern part.

The residential buildings are turned into semi-commercial area in the recent past in an unplanned way. As a result the vulnerability of the building becomes more risky. After vulnerability assessment of the selected zones, three buildings are later selected from each of the wards to understand the architecture based issues in seismic design by the architects. This study would help to assess the implications of an earthquake on this selected area of the wards.

The three Case Study that has been organized accordingly for the vulnerability assessment are mentioned below with illustrations-

3.3 Sampling

Step I

The total number of buildings of **Ward 28** is 3,057, **Ward 15** is 2,729 and **Ward 19** is 7,323 according the cluster count referred from CDMP Report, 2010.Physical survey of building is conducted through cluster sampling for earthquake vulnerability assessment. The survey contributes physical attributes of a building such as construction type, land use, number of storey, occupancy type, and structural type.

Cluster sampling is a used to select the sample. The main reason to cluster sample is to increase the efficiency of survey administration by reducing costs (particularly travel costs). When cluster sampling, the selected building is first split into geographic areas (‘clusters’). Some of these clusters are then randomly selected to form a sampling frame from which a sample is chosen.

To evaluate the sample size the following method is used to determine what probability should be assigned to each cluster.

We have: a population of size N,
we select a sample of size n,
we split the population into j clusters,
we select *a* clusters and

we select *b* individuals within each cluster for our sample,

To ensure building in the population has an equal chance of being included in the sample we need:

Probability an individual building is in the sample = $\frac{n}{N}$

We can say that:

$$n = a \times b$$

If we say that Nj is the total number of buildings in cluster j then:

$$\frac{n}{N} = \frac{(a \times b)}{N}$$

$$= \frac{(a \times b \times N_j)}{(N \times N_j)}$$

$$= \left(\frac{(a \times N_j)}{N}\right) \times \left(\frac{b}{N_j}\right)$$

The first part $\left(\frac{(a \times N_j)}{N}\right)$ gives the probability that should be assigned to cluster *j*.

The second part $\left(b/N_j \right)$ is the resulting probability an individual within cluster *j* has of being included in the sample if cluster *j* is included in the sample.

With the above equation we can find out how many buildings in each ward and the probability we should assign to each ward when selecting clusters. It also shows probability a single building within each cluster of every ward is selected in the sample if a ward is selected and how the overall probability of selection is more or less equal for all group clusters.

For example, total building population, N =13,109

a =5 (select 100 buildings in 5 group clusters of the wards)

Nj= 678 (DCL 1902=678 population of Ward 19)

$\left(\frac{(a \times N_j)}{N}\right)$ =5X678/13,109

= 28.5%

b=100

$\left(b/N_j \right)$ =100/678

=14.7%

Hence, overall probability of a building included in the sample survey is 28.5X14.7/100=3.79%.

Calculating other group clusters provide percentage close to 3.

Step II

The study is based on the data of an empirical research about the architectural consciousness in seismic design. The study conducted on basis of qualitative (based on comments) and quantitative (based on percentages) analyze. The main concern is to point out the importance of seismic design within architectural community from the perspective of architects, who are experienced in designing.

Setting of the study and sample group

The sample group mainly contains the architects who are working in the architectural design offices in Dhaka. The names of the architectural design offices were detected by checking the registration list of architectural offices enlisted in IAB, Dhaka. Although all the selected offices were phoned in order to be informed about the survey, only 20 of them were got in touch..

Procedure

Acquaintance architects working in the offices participated in the research study. The first stage was related to architects' education, working experience in architectural office, and designing experience on seismic zones. Second stage of the questionnaires included questions on the importance of roles and responsibilities of the architects, attitudes of the architects towards seismic design, and their familiarity of architecture-based seismic design issues. The final stage was related to sufficiency of the Bangladesh Earthquake Code, necessity of mutual coordination with structural engineer, and the ways for integration of seismic design into architectural design problem.

Step III

Three buildings chosen from three selected wards are evaluated for architecture based issues. The issues that influence the seismic performance of the buildings are the building configuration, structural configuration issues (plan and vertical) and non-structural architectural components.

Procedure

The study comprised of the buildings location, surrounding environment, form/geometry, scale, building's configuration, vertical setbacks, structural configuration in plan and section by the help of the ACAD architectural layout.

3.4 Data Collection

3.4.1 Primary Data Collection

Primary data from field survey is collected by the researcher and it took 3 months to conduct all the survey steps. The method focuses mainly on earthquake vulnerability assessment and architectural based issues in a building for seismic design. The step uses FEMA-RVS, Turkish Method Sampling and Questionnaire Survey (vide Appendix A).

FEMA-RVS (Federal Emergency Management Agency)-

Rapid visual screening (RVS) of buildings for potential seismic hazards, originated in 1988 with the publication of the FEMA 154 Report, Rapid Visual Screening of Buildings for Potential Seismic Hazards a Handbook. RVS provides a procedure to identify record and rank buildings that are potentially seismically hazardous (FEMA 154, 2002). This screening methodology is encapsulated in a one-page form, which combines a description of a building, its layout and occupancy, and a rapid structural evaluation related to its seismic hazard.

Although RVS is applicable to tall buildings, its principal purpose is to identify (1) older buildings designed and constructed before the adoption of adequate seismic design and detailing requirements (2) buildings on soft or poor soils, or (3) buildings having performance characteristics that negatively influence their seismic response. Once identified as potentially hazardous, such buildings should be further evaluated by a design professional experienced in seismic design to determine if, in fact, they are seismically hazardous The rapid visual screening method is designed to be implemented without performing any structural calculations. The procedure utilizes a scoring system that requires the evaluator to (1) identify the primary structural lateral load-resisting system, and (2) identify building attributes that modify the seismic performance expected for this lateral load-resisting system. The inspection, data collection and decision-making process typically occurs at the building site, and is expected to take around 30 minutes for each building. The screening is based on numerical seismic hazard and vulnerability score.

Basic Structural hazard scores for various building types are provided on the RVS form. The screener modifies the basic structural hazard score by identifying and circling score modifiers which are then added (or subtracted) to the basic structural hazard score to arrive at a final structural score, S. The basic structural hazard score, score modifiers, the final structural score S, all relate to the probability of building collapse. The result of the screening procedure is a final score that may range above 10 or below 0, with a high score indicating good expected seismic performance and a low score indicating a potentially hazardous structure. While the score is related to the estimated probability of major damage, it is not intended to be a final engineering judgment of the building, but merely to identify buildings that may be hazardous and require detailed seismic evaluation. If the score is 2 or less, a detailed evaluation is recommended. On the basis of detailed evaluation, engineering analysis and other detailed procedures, a final determination of seismic adequacy and need foe rehabilitations can be made. Figure 3.4 shows a sample R.V.S scoring form.

Turkish Method-

In recent times, after the 1999 earthquake in the cities of Kocaeli and Duzce, Government of Turkey and Japan International Cooperation Agency (JICA) came forward for implementing a regional seismic assessment and rehabilitation program. Researchers from various universities were involved in this program supported by the Government of Turkey and JICA. A simple Two-level Seismic Assessment Procedure for a building stock was proposed (Sucuoglu and Yazgan; 2003). In this most vulnerable buildings that may undergo severe damage in a future earthquake are identified. A survey of 477 damaged buildings (1-7 storey) affected by Duzce earthquake (November 1999) was carried out. This was then complied to form a database of damaged buildings to be used for future research work. This database was employed for developing the performance score (PS) equation to determine the vulnerability of a reinforced concrete building. Figure 3.4 shows a sample Turkish Form.

Level-1 Survey

The trained observers collect data through walk-down visits. The parameters that are selected in Level-1 survey for representing building vulnerability are the following:

a. The number of stories above ground

b. Presence of a Soft Storey (Yes or No)

c. Presence of heavy overhangs, such as balconies with concrete parapets (Yes or No)

d. Apparent building quality (Good, Moderate or Poor)

e. Pounding between adjacent buildings (Yes or No)

f. Local soil conditions (Stiff or Soft)

g. Topographic effects (Yes or No)

All of the above parameters are found to have a negative feature on the building system under earthquake excitations on a variable scale.

Building Performance Score

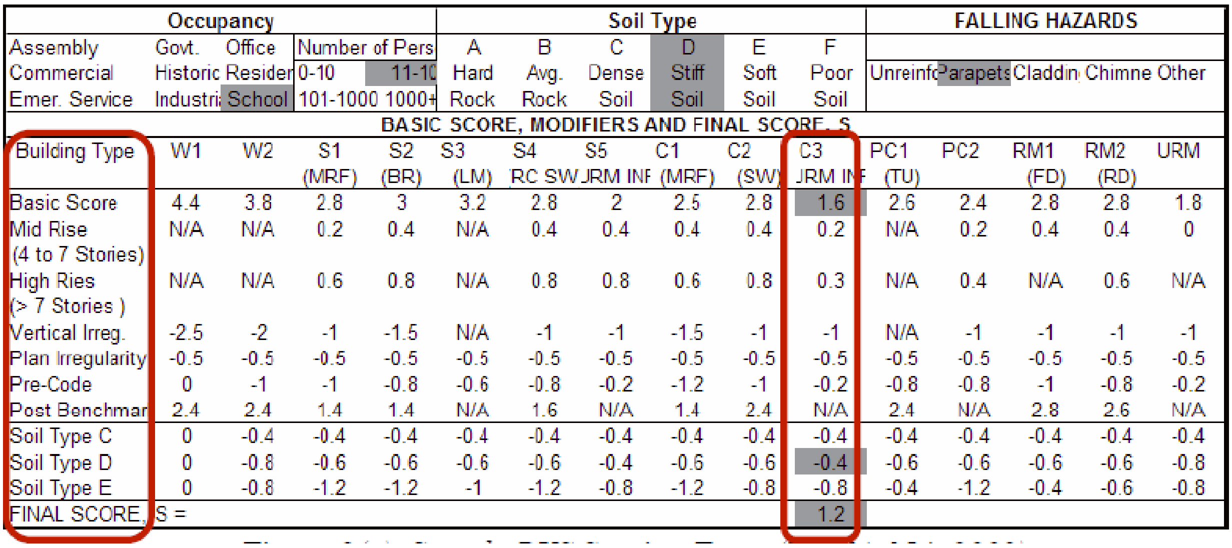
Once the vulnerability parameters of a building are obtained from two-level surveys and its location is determined, the seismic performance scores for survey levels 1 and 2 are calculated by using Tables 2 and 3, respectively. In these Tables, an initial score is given first with respect to the number of stories and intensity zone. Then the initial score is reduced for every vulnerability parameter that is observed or calculated. A general equation for calculating performance score (PS) can be formulated as follows:

PS = (Initial Score – Σ (Vulnerability parameter) X (Vulnerability Score)

PS<50 → Vulnerable Structure

Level 2 Survey

Level 2 Survey is done for the buildings of a stock when those are found to be failing into the moderate and high risk levels using level 1 risk assessment (Figure 3.1). The trained observer teams enter into the basements and ground stories of these buildings for collecting more data for Level 2 risk assessment. Their first task is to confirm or modify the previous grading on soft stories, short columns and building quality, through closer observations. The second and more elaborate task is to prepare a sketch of the ground floor plan and measure the dimensions of columns, concrete and masonry walls. This data is then employed for calculating the following parameters.



Occupancy			Number of Pers		Soil Type						FALLING HAZARDS
Assembly	Govt.	Office	Number of Pers		A	B	C	D	E	F	
Commercial	Historic	Resider	0-10	11-10	Hard	Avg.	Dense	Stiff	Soft	Poor	Unreinfo Parapets Claddin Chimne Other
Emer. Service	Industri	School	101-1000	1000+	Rock	Rock	Soil	Soil	Soil	Soil	

BASIC SCORE, MODIFIERS AND FINAL SCORE, S

Building Type	W1	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 RC SW	S5 JRM INF	C1 (MRF)	C2 (SW)	C3 JRM INF	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM
Basic Score	4.4	3.8	2.8	3	3.2	2.8	2	2.5	2.8	1.6	2.6	2.4	2.8	2.8	1.8
Mid Rise (4 to 7 Stories)	N/A	N/A	0.2	0.4	N/A	0.4	0.4	0.4	0.4	0.2	N/A	0.2	0.4	0.4	0
High Ries (> 7 Stories)	N/A	N/A	0.6	0.8	N/A	0.8	0.8	0.6	0.8	0.3	N/A	0.4	N/A	0.6	N/A
Vertical Irreg.	-2.5	-2	-1	-1.5	N/A	-1	-1	-1.5	-1	-1	N/A	-1	-1	-1	-1
Plan Irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Pre-Code	0	-1	-1	-0.8	-0.6	-0.8	-0.2	-1.2	-1	-0.2	-0.8	-0.8	-1	-0.8	-0.2
Post Benchmar	2.4	2.4	1.4	1.4	N/A	1.6	N/A	1.4	2.4	N/A	2.4	N/A	2.8	2.6	N/A
Soil Type C	0	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Soil Type D	0	-0.8	-0.6	-0.6	-0.6	-0.6	-0.4	-0.6	-0.6	-0.4	-0.6	-0.6	-0.6	-0.6	-0.8
Soil Type E	0	-0.8	-1.2	-1.2	-1	-1.2	-0.8	-1.2	-0.8	-0.8	-0.4	-1.2	-0.4	-0.6	-0.8
FINAL SCORE, S =										1.2					

Figure 3.1 Tables and General Equation of Turkish Procedure, Collected (Sucuoglo & Yazgan, 2003)

3.4.2 Secondary Data Collection

Secondary data has been collected by reading books, journals, newspapers.

3.5 Data Analysis

The survey was mainly focused on earthquake issues such as identifying building type, plot size and shape, clear distances from surrounding structures, road width and basic information of the building: type of foundation, slab type, year of construction, no. of storey, no. of inhabitants etc.

The detail analysis (or the level-2 analysis) covered the determination of plinth area (length x width), column size and direction, lift core size, cantilever length of the building etc. Digital photographs of each building from at least two directions were taken. Based on the survey results, several meaningful statistical relationships between building attributes have been derived and used for simulating the missing building attributes from the available ones.

From the collected database and vulnerability maps, the major findings regarding to the seismic vulnerability of building can be summarized as the followings:

- The vulnerability factor which is the most common in Dhaka city is soft story (52%).

- Among occupancy classes in city corporation area, residential class is the major proportion. Their proportions are 81.3% in Dhaka.

- Among structural type of non-engineered buildings from the survey results, BF (brick in cement mortar masonry with flexible roof) is the most common type. For engineered buildings, C3 (concrete frame with masonry infill walls) is the most common class.

- From the survey results, age of buildings has been related to structural types. For example, it was found that most buildings with concrete slab-column frames (C4) are constructed less than 10 years. On the other hand, most masonry buildings with concrete floors (BC) ages more than 10 years. Also, light reinforced concrete buildings (LC) are found to be older than reinforced concrete buildings (RC).

• As expected, all residential types have an average number of occupants per floor area in the daytime less than the nighttime; nevertheless, the other occupancy classes as commercial, industrial, government and education have the number of occupants in the daytime more than the nighttime.

• By defining road blockade potential as the building density (number of building per area) dividing by the total length in each ward. In Dhaka, this value is found to be the highest in southern part of Dhaka which is the old city. In addition, the road blockade potential in Dhaka is the highest compared to the other city corporation areas.

3.6 Risk Reduction Strategy

Hazard mitigation is defined as any action taken to permanently eliminate or reduce the long-term risk to life and property from natural and technological hazards. The wide variety of actions that fall under this definition can usefully be categorized as risk avoidance measures—primarily of a nonstructural nature—risk spreading measures, and structural vulnerability reduction measures.

The use of one type of mitigation measure does not exclude any other type of measure. Structural and non-structural measures can be selected to complement each other, and can be effectively integrated in a multi-sectoral or area-wide disaster mitigation plan.

Risk Avoidance Measures (Non-structural measures) Discourage location of settlements, infrastructure and economic activities in known hazardous areas through:

- Land-use regulations, ordinances
- Financial incentives or penalties
- Disclosure of risk information
- Public infrastructure policy
- Natural resource management policy

Risk Spreading Measures

- Property damage and revenue loss insurance
- Crop diversification
- Redundancy in lifeline systems

Vulnerability Reduction Measures (Structural measures) Physical measures designed to enhance natural hazard impacts:

- Retrofitting of existing structures
- Use of appropriate building standards
- Reducing hazard proneness of site (dams, retaining walls, windbreaks)

3.7 Preparation of Final Report

The methodology to understand the factors to assess earthquake vulnerability and suggest risk reduction strategy with the help of the analysis is designed in the following flowchart to have a better overview of the study area (Figure 3.2).

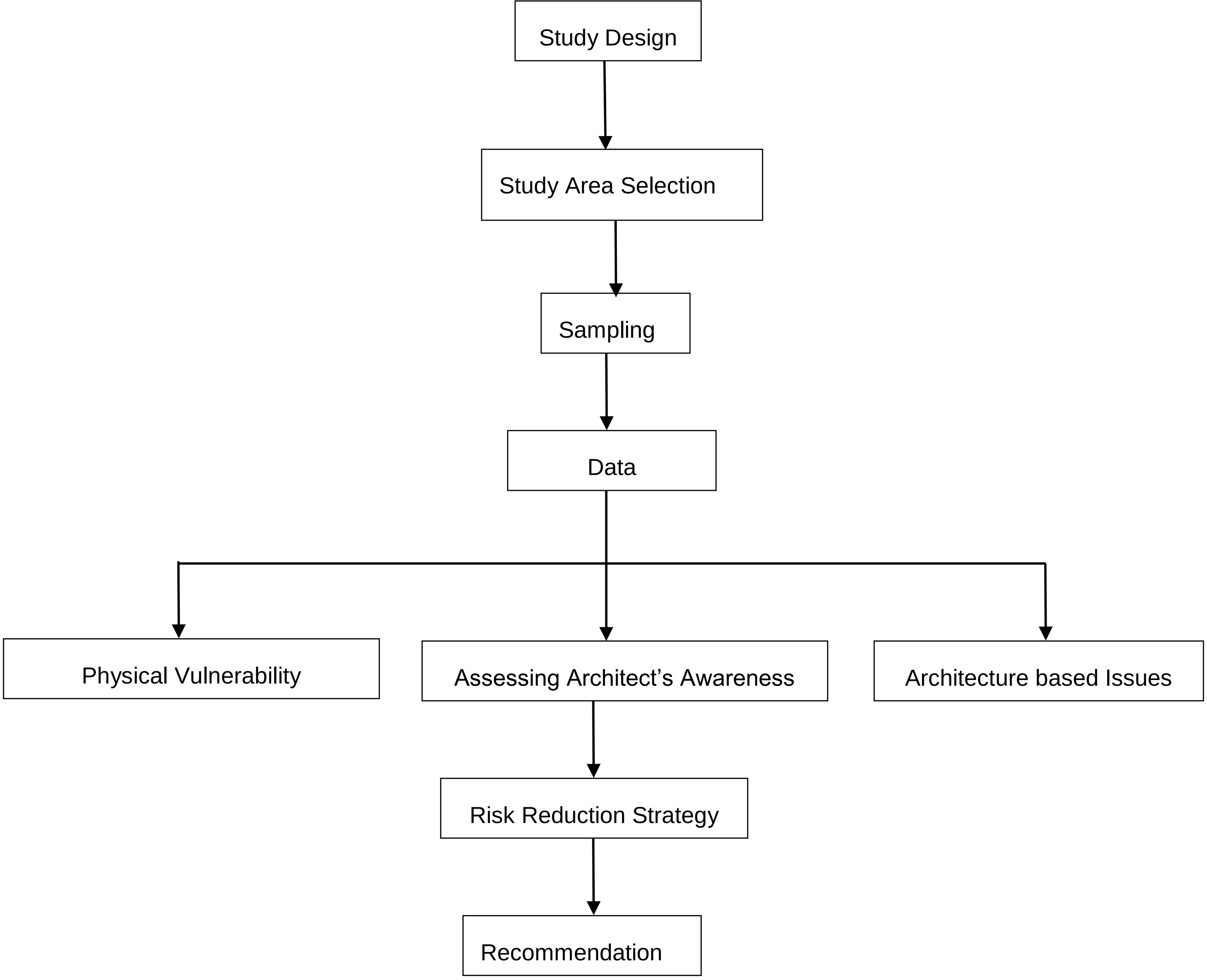


Figure 3.2 Flow chart showing Methodology

4. Study Area Profile

4.1 Introduction

Case Study One

Ward 28 of DCSS, Chawkbazar (Figure 4.1), which was known as Ward 64 of former DCC is selected for the vulnerability assessment of earthquake in this research. The ward is the third most densely populated ward (BBS, 2011) in Dhaka City with 127,425 people per square kilometer. This chapter reveals the characteristics of the study area such as the physical characteristics, topography, socio-economic characteristics, road network and such other related issues.

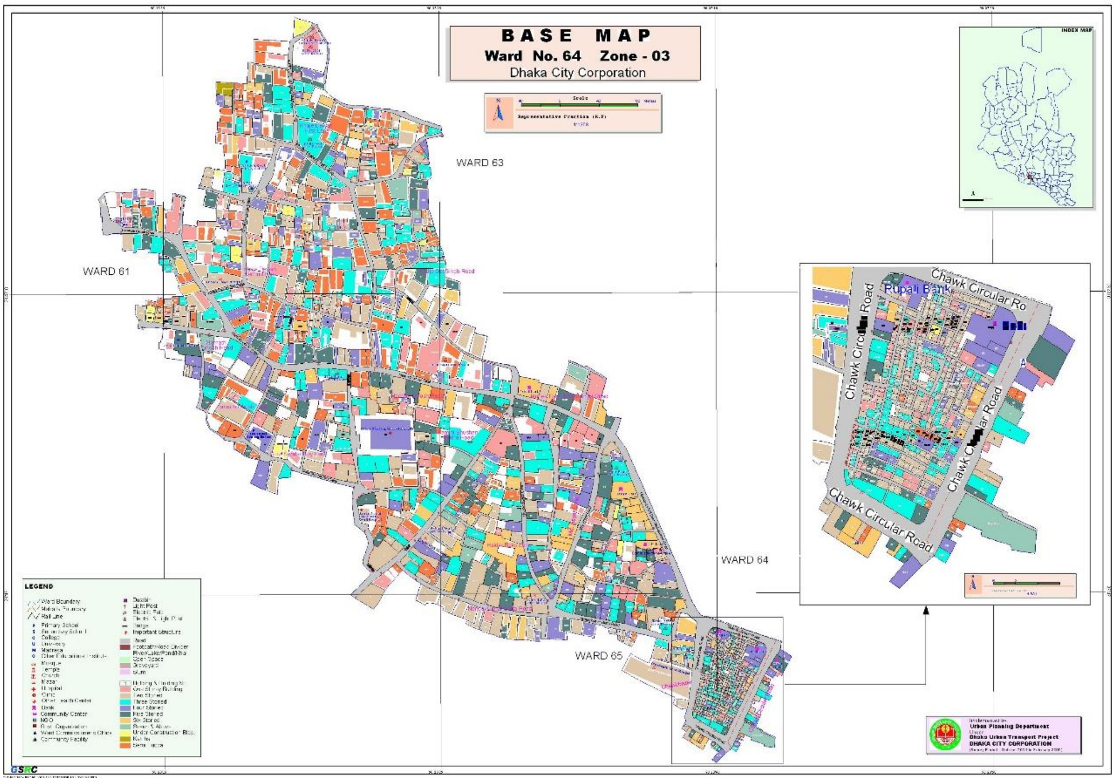


Figure 4.1: Base Map of Ward 28 (Source: Report, CDMP 2010)

Case Study Two

Ward 15-Ward 49 of DSCC previously is now Ward 15 and is known as Dhanmondi Residential Area (Figure 4.2) is located in south west part of Dhaka City Corporation (DCC) area. It is located in Dhanmondi Thana at 23.7389° N 90.3847° E. Dhanmondi R/A covers most of the part of DCC ward 49 in Zone 5. Although it was developed on paddy field back in 1950s, its locational importance has increased with expansion of Dhaka city. It is now located within 1.5 kilometers of Karwan Bazar, the second CBD in Dhaka city. So it can be said that the location of Dhanmondi is near the central part of Dhaka city.

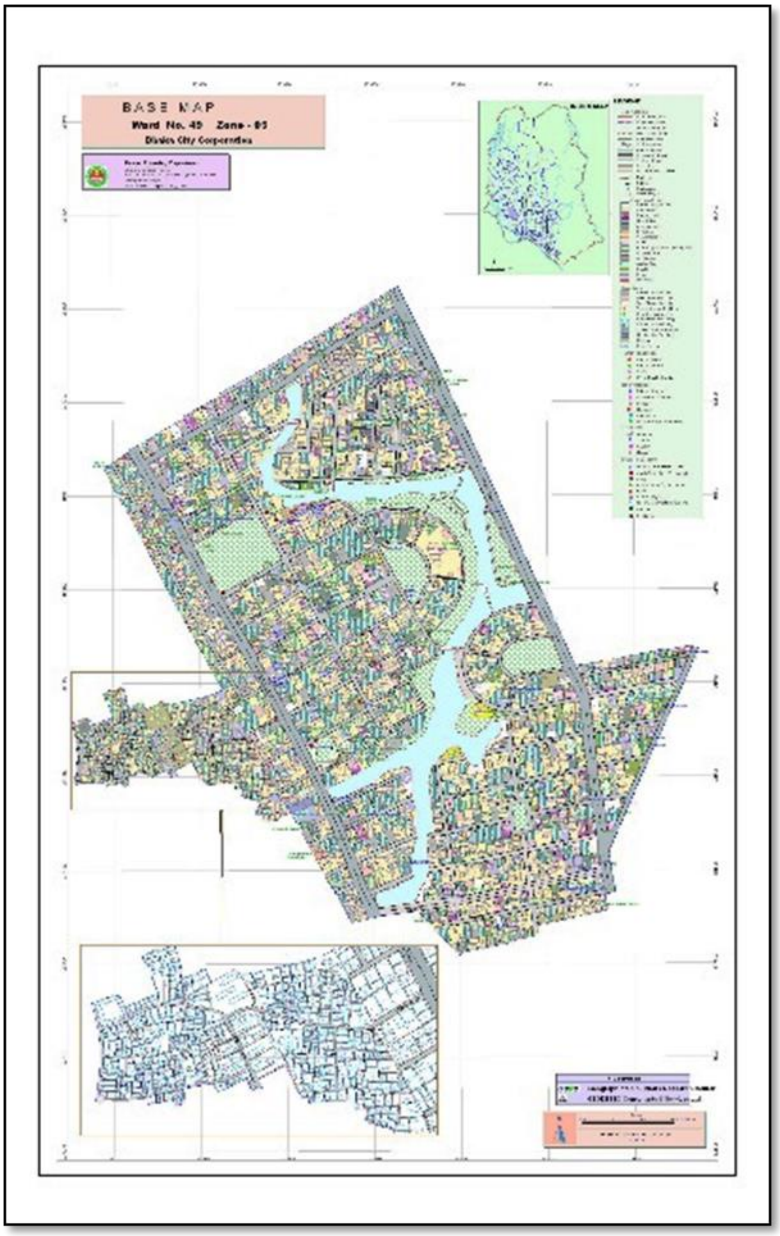


Figure 4.2: Base Map of Ward 49 which is now 15 (Source: Report, CDMP 2010)

Case Study Three

Ward 19-Banani was developed as a High Class Residential Area and was planned in the style of a regular system of roads to provide residential accommodation for high income groups after independence. The area is about 10 kilometers far from Motijheel, Central Business District (CBD) of the Dhaka Metropolitan City. The area lies in 23 0 47 | to 23 0 48 | N, Latitude and 90 \ 0 24 | to 90 0 24 | 29 | | E, Longitude (Nancy, 2004) by the side of Banani Lake. It has grid iron \ pattern road network and the major thoroughfare (Dhaka-Mymensingh Road) is about 100 feet width while the secondary roads are of 45 feet and access roads of 25 feet width (Nancy, 2004). The Mymensingh Road provides linkage to the northern part of the country. Kamal Ataturk Avenue passing through Banani Residental Area joining with Gulshan plays important roles for providing smooth access facilities of the locality and also real estate sector development. Figure 4.3 shows the Location of Study Area and the jurisdiction of Banani Residential Area.

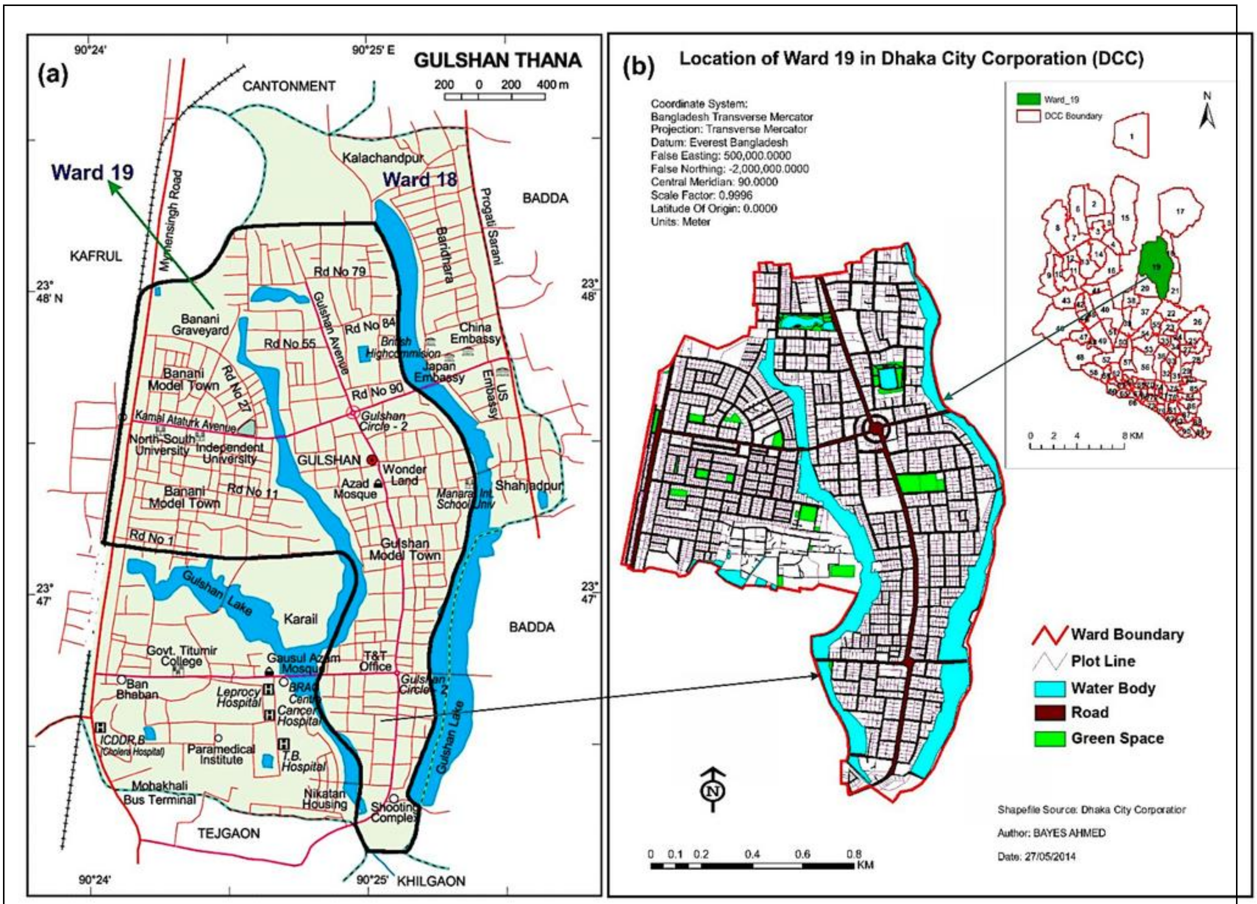


Figure 4.3: Base Map of Ward 19 (Source: Report, CDMP 2010)

4.2 Detailed Description of the Study Area

The three tables below lists the area, population, population density and the Thana of the designated study area.

Table 4.1 Area and Population of ward 28, 15 and 19 (Source: Report CDMP, 2010)

Ward 28-Chawkbazar

Area	0.478 square kilometer (RAJUK, 2006)
Population	58, 233 populations (BBS, 2011)
Population Density	127,425 persons/sq km (BBS, 2011)
Dhaka Metropolitan Thana	Chawkbazar

Source: RAJUK (2006); Report CDMP

Ward 15-Dhanmondi

Area	4.34 square kilometer (RAJUK, 2006)
Population	201,529 populations (BBS, 2011)

Population Density	20,691 persons/sq km (BBS, 2011)
Dhaka Metropolitan Thana	Dhanmondi

Source: RAJUK (2006); Report CDMP

Ward 19-Gulshan, Banani

Area	8.85 square kilometer (RAJUK, 2006)
Population	145,969 populations (BBS, 2011)
Population Density	16,494 persons/sq km (BBS, 2011)
Dhaka Metropolitan Thana	Gulshan, Banani

Source: RAJUK (2006); Report CDMP

4.3 SWOT Analysis

CHAWKBAZAR (WARD 28)

Strengths

- Chawkbazar is one of the important economic poles of Puran Dhaka.It should remain safe for having a sustainable economy and a sustainable city.
- Construction of Chawkbazar dates back to Colonial Period and has many valuable historical buildings.
- Chawkbazar is not only a dynamic commercial center of Puran Dhaka but also a social and cultural hub for its inhabitants for a very long time.

Weaknesses

- Severe destruction of the structural parts of the buildings
- Lack of suitable urban infrastructures.
- Lack of monitoring and suitable control systems.
- Lack of appropriate risk management and alert risk systems.
- Non-resistant structures which cannot resist during earthquake.
- The narrow road width networks intertwined in Puran Dhaka.
- Lack of open spaces which are to be considered a safe place for evacuation of people in the time of any disaster.
- 6-9 family or more live together under one shelter in a very small area of land.

Opportunities

- Open spaces with no land use can act as pockets of rescue during any emergency evacuation.
- Using open spaces can also act as multi-function spaces for parking and remedial centers.
- People living there can take self-initiative in preserving their history and culture.
- High capacity for tourism development.

Threats

- Continuance of deterioration process in the historical parts surrounding the places
- High cost of restoration and insurance, especially at commercial parts of the area
- Lack of management quality is discouraging people from community participation

- Willingness of people to demolish the old and build new commercial centers, instead of restoration in the traditional style
- Public desire for enlarging access routes which may damage the whole structure of the area.

DHANMONDI (WARD 15)

Strengths

- Dhanmondi is one of the high-class planned residential areas of Dhaka City. This area was developed in the early fifties by Public Works Department to provide residential accommodation for high-income groups of population.
- The total area is cocooned and landscaped with the beautiful Dhanmondi Lake and natural vegetation.

Weaknesses

- Dhanmondi is gradually transforming into a district of mixed use with more transition of land uses to commercial activities in the last one-two decades.
- Lack of proper regulatory framework development has boomed in a haphazard way reaching the inner portions of the area and ultimately leading to chaos, traffic congestion and environmental pollution.
- Building occupancy has no single identity.
- New buildings lack of building code according to its occupancy type.
- Lack of suitable urban infrastructures.
- Lack of monitoring and suitable control systems.
- Lack of appropriate risk management and alert risk systems.

Opportunities

- Open spaces with no land use can act as pockets of rescue during any emergency evacuation.
- Using open spaces can also act as multi-function spaces for parking and remedial centers.
- People living there can take self-initiative in preserving their history and culture.

Threats

- New development will slowly eradicate the natural landscape as well as pockets of open spaces will diminish.
- Wide roads are becoming narrower due to new building developments.
- Buildings are built tall and slender that has a high risk of earthquake.
- Buildings set back are minimal and can be a threat during earthquake.
- Lack of management quality is discouraging people from community participation
-

BANANI (WARD 19)

Strengths

- Banani in the mid-seventies developed as one of the major planned residential model town in Dhaka city. Most of the houses are structurally and aesthetically pleasing and beautiful reflecting the internal and external taste and the culture of the dwellers.
- Banani is tiny pockets of open spaces used mostly for play fields by kids.

Weaknesses

- Banani is gradually developing with substantial commercial and institutional functions. This rapid urban development made the place more crowded.
- Building occupancy has no single identity.
- Utility is creating a shortage due to rapid development of residence apartments and commercial buildings.
- Lack of monitoring and suitable control systems.
- Lack of appropriate risk management and alert risk systems.
- Population is density is increasing more though the land size remains the same.

Opportunities

- Open spaces with no land use can act as pockets of rescue during any emergency evacuation.
- Using open spaces can also act as multi-function spaces for parking and remedial centers.
- People living there can take self-initiative in preserving their history and culture.

Threats

- New development will slowly eradicate the natural landscape as well as pockets of open spaces will diminish.
- Wide roads are becoming narrower due to new building developments.
- Buildings are built tall and slender that has a high risk of earthquake.
- Buildings set back are minimal and can be a threat during earthquake.
- Lack of management quality is discouraging people from community participation

4.4 Physical Characteristics of the Study Area

The location, topographic characteristics, existing land use pattern and building pattern are discussed under the physical characteristics of the study area.

Location

Ward No. 28- Chawkbazar is located on the northern bank of river Buriganga at Old Dhaka. The ward is under the jurisdiction of Chawkbazar Thana of Dhaka South City Corporation (DSCC). Lalbagh Fort is situated just at north boundary of the Ward. The nearest bench mark points of the area are located at north east corner of the boundary wall of Lalbagh Fort and beside a drain and High Voltage Electric Tower at Islambagh.

Ward No. 15- Dhanmondi Residential Area (DRA) is one of the high-class residential areas in Dhaka city. The area (*Ward* 49) was planned and developed in the early fifties to provide residential accommodation for high and higher middle income groups of population in Dhaka city. The area was designed with large plots, wide roads and good environment, within five kilometers from the Central Business District (CBD) of Dhaka City. After liberation in 1971, the characteristics of the residential area were being changed and the area was gradually being invaded by non-residential uses like commercial and professional offices, private hospitals and clinics, community centers, educational institutions (private schools, colleges and universities) etc. The most connected roads are Mirpur Road and Satmasjid Road, kept constant in all phases except 1952. And later the connector road, which passes through the Roads 7A-15A, becomes the highest connected roads.

Ward No. 19-RAJUK started its residential development program through Gulshan and Banani in 1961 based on site and service approach. On the other hand, Banani was developed as a high-class residential area after the independence in 1971. In Banani till 1987, the total number of plots of various sizes allotted for residential use stands at 1239 (Jahan, 2002). In 2006, the total number of plots allocated for residential use stands at 1418 and the total population 1, 10,764 (estimated) in 1.41 sq. km. of the Banani Residential Area (Geo-Consult, 2006). In the whole ward 19 (Banani and Gulshan) with an area of 4.62 sq. km., the population was 50,859 (estimated in 1998) in 1998 (Geo-Consult, 2006). Due to acute shortage of land regarding residential accommodation to cope with the tremendous population growth in the study area, especially after 1990, the real estate sector started playing important role to meet this housing need for high class residents by providing apartment provision at a great number (Nancy, 2004). A number of diversified uses have been developed so far both along the major thoroughfare (Dhaka-Mymensingh Road) and the secondary road (Kamal Ataturk Avenue) as well as access roads of the study area. In the study area, in addition to residential land use, some important commercial land uses have been developed such as school, colleges, private universities, shops, banks, clinics and other public services.

Topographic Characteristics

Ward No. 28- The elevation of the study area lies between 2.55 to 10.1 meters above the mean sea level. Most of the areas lie at the elevation of 5.58 to 7.08 meters above the mean sea level. The elevation data of the study area is collected from Rajdhani Unnayan Kartripakkha (RAJUK). The study area is located just beside Buriganga River. Beside this, there is only a water body at the west.

Ward No. 15- The elevation of the study area lies between 19.39 meters above the mean sea level.The elevation data of the study area is collected from Rajdhani Unnayan Kartripakkha (RAJUK). The study area is located near Dhanmondi Road 27 that plays the main arterial road of Dhanmondi Residential Area.

Ward No. 19- The elevation of Gulshan/Banani is 4.00 meters above the mean sea level.. The elevation data of the study area is collected from Rajdhani Unnayan Kartripakkha (RAJUK). The study area is located in Banani Model Town.

4.4.1 Land Use Pattern

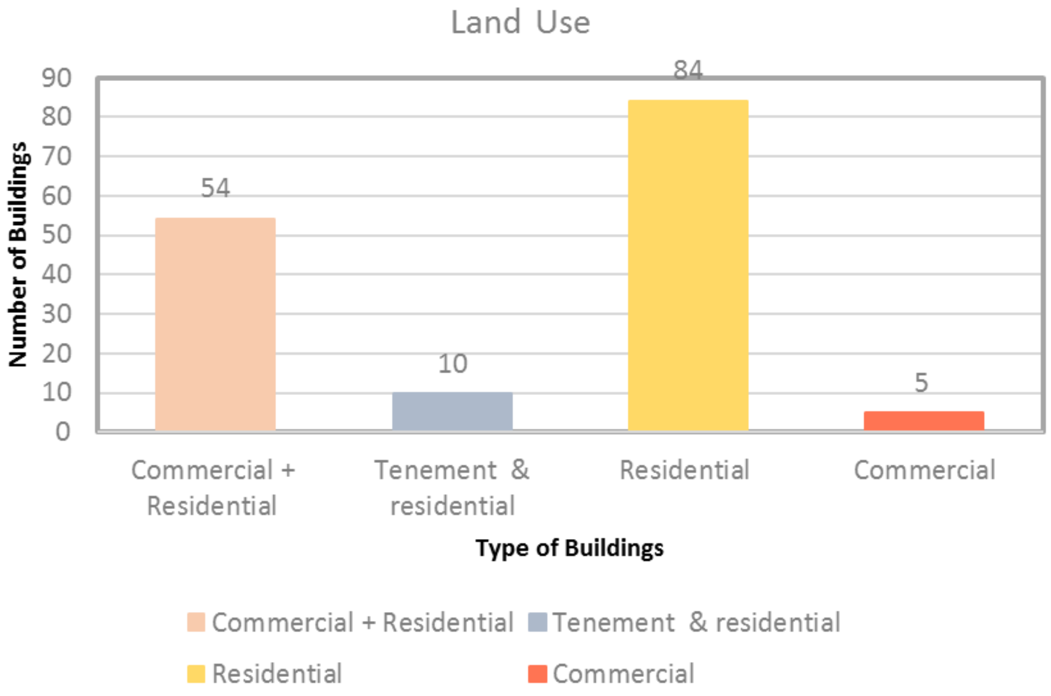


Figure 4.4 Land Use of Ward 28 (Source: Report, CDMP 2010)

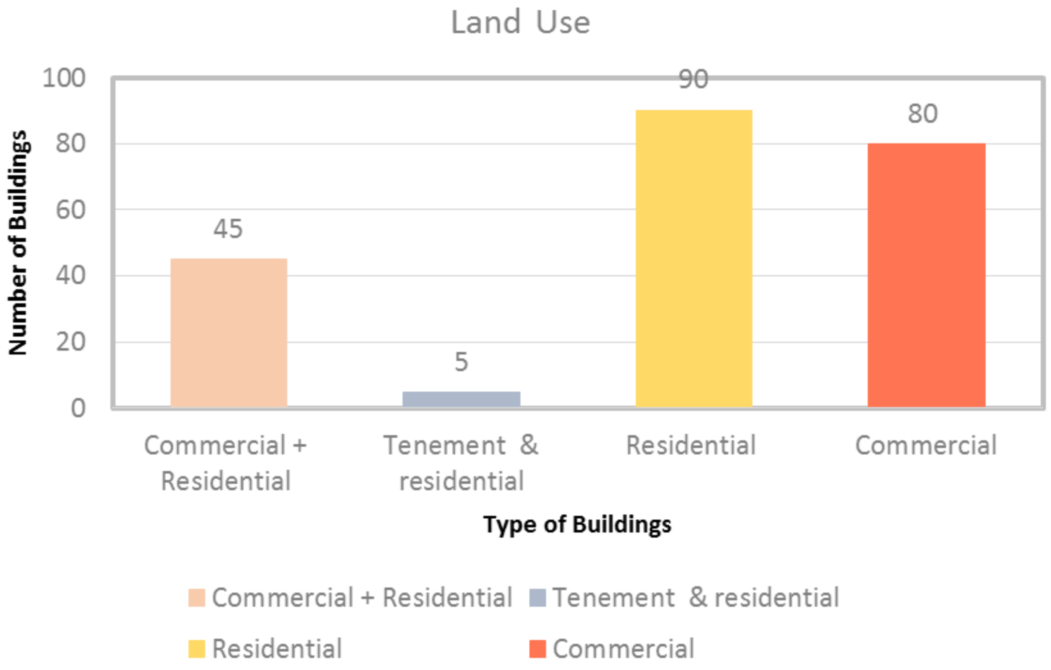


Figure 4.5 Land Use of Ward 15 (Source: Report, CDMP 2010)

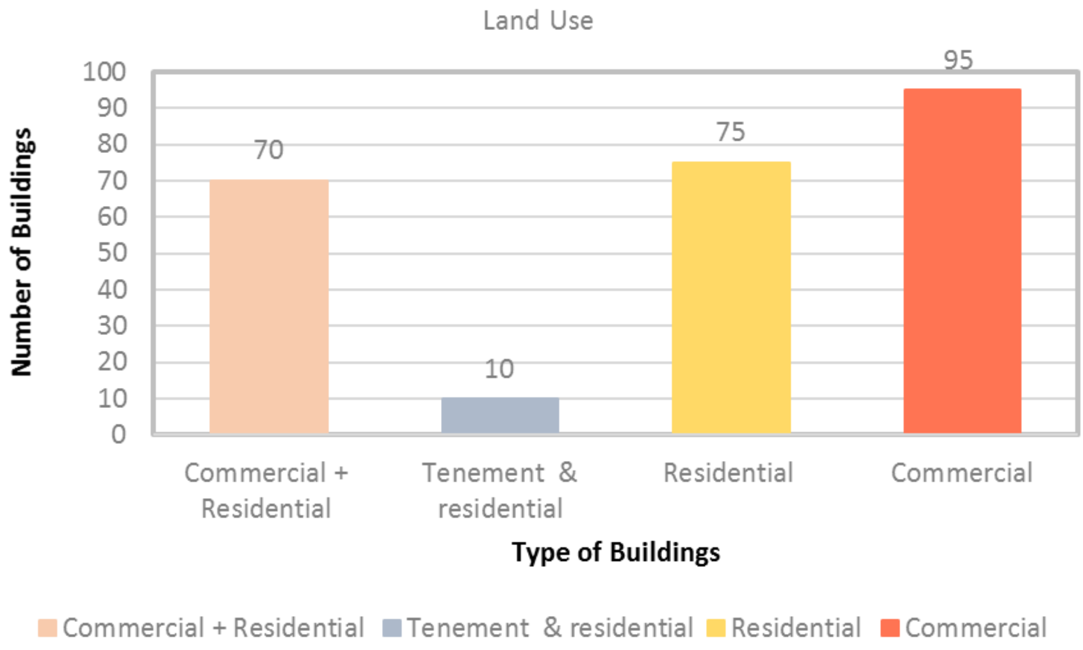


Figure 4.6 Land Use of Ward 19 (Source: Report, CDMP 2010)

4.4.2 Building Use Pattern

From data collceted (2013), it has been found that different kind of land uses in the selected study area exists as residential, commercial, manufacturing and processing, educational, community services, service activity, recreational uses and mixed uses. A common scenario in the study area is that the ground floors of most of the buildings are used for non-residential purpose where the upper floors are purely residential. More than 50.9% buildings are found to be used as mixed use activity such as shops and industry at ground floor and residence at upper floor. But according to RAJUK (2006), about 59.63% buildings are residential where mixed use is 16%. So it has been seen that economic activity of the study area has been increased very rapidly in the recent few years.

Table 4.2 Essential Facilities of Ward 28, 15, 19 (Source: Report, CDMP 2010)

Ward	Residential	Commercial	Industrial	Essential Facilities			Other	Total
				Medical Care	Emergency Response	School		
28	2,479	502	24	3	1	12	36	3,057
15	1,995	514	48	45	3	82	42	2,729
19	6,009	1,108	44	44	5	77	36	7,323

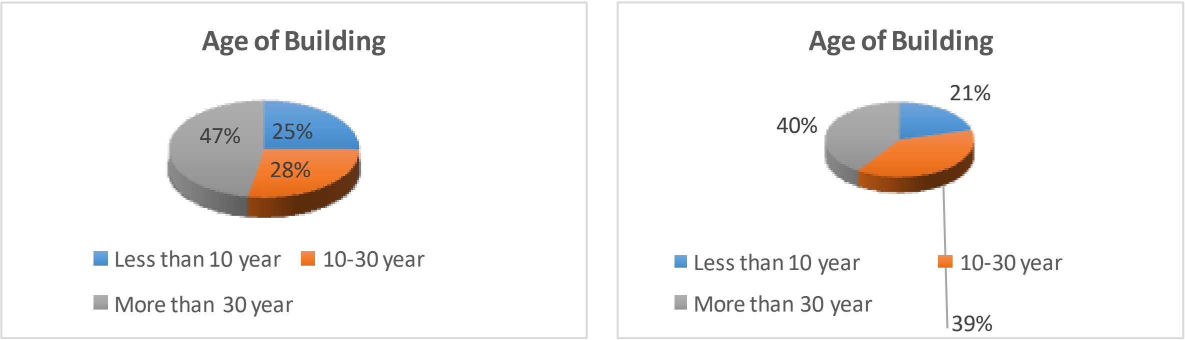
4.4.3 Number of Buildings of Dhaka in Cluster Level

Table 4.3 Table showing cluster, area, building number and density.

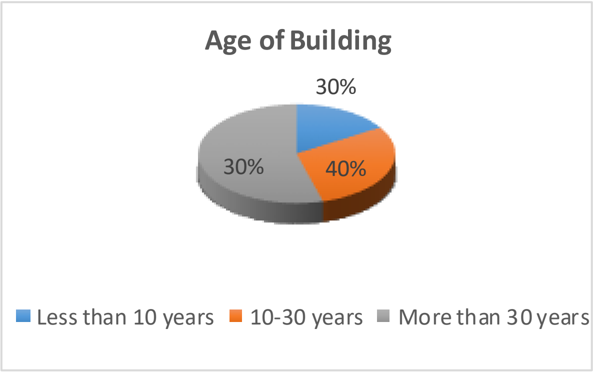
Ward	Cluster	Area (Km2)	Building Number (No.)	Building Density (No./Km2)
19	DCL1901	0.467	2,808	6,013
	DCL1902	0.466	678	1,455
	DCL1903	0.531	592	1,115
	DCL1904	0.333	253	760
	DCL1905	0.375	339	904
	DCL1906	0.297	149	502
	DCL1907	0.347	277	798
	DCL1908	0.368	600	1,630
	DCL1909	0.379	314	828
	DCL1910	0.491	381	776
	DCL1911	0.398	293	736
	DCL1912	0.244	164	672
	DCL1913	0.343	300	875
	DCL1914	0.240	175	729
Total		5.279	7,323	1,387
28	DCL2901	0.141	563	3,993
	DCL2902	0.153	639	4,176
	DCL2903	0.140	953	6,807
	DCL2904	0.076	375	4,934
	DCL2905	0.078	527	6,756
Total		0.588	3,057	5,199
15	DCL4901	0.467	482	1,032
	DCL4902	0.370	335	905
	DCL4903	0.268	249	929
	DCL4904	0.354	869	2,455
	DCL4905	0.392	427	1,089
	DCL4906	0.400	367	918
Total		2,251	2,729	1,212

4.4.4 Age of Building

As the study area is one of the parts of Dhaka city, there are some buildings aged above 50 years. In contrast, newly constructed buildings which were constructed up to 10 years before dominate with about 49% share of all surveyed buildings. It has revealed that most of the old structures have been demolished and reconstructed recently as the population is growing very fast. 47% buildings are constructed 11 to 20 years before and 25% buildings are constructed 21 to 30 years before in ward 28. For Ward 15, 40% buildings are constructed 11 to 20 years before and 39% buildings are constructed 21 to 30 years before. For Ward 19, 30% buildings are constructed 11 to 20 years before and 40% buildings are constructed 21 to 30 years before.



Ward 28 Ward 15



Ward 19

Figure 4.7 Age of Building (Source: Report, CDMP 2010)

4.4.5 Type of Building

According to study area, it mainly comprises of pucca structures which is about 73.1% of all surveyed buildings. But according to RAJUK (2006), most of the structures (52%) are semipucca which are masonry buildings.

Structural Type

Structural type or model building type is the key factor in assessing overall building performance, loss of function, and casualties. There are mainly 5 structural types in Bangladesh; reinforced concrete building (RC), lightly reinforced concrete building (LC), brick in cement mortar with concrete floor (BC), brick in cement mortar with flexible roof (BF) and thin shed (TSL).

Table 4.4 List of Building Structures

Ward	**Structure (No. of buildings)**					**Total**
	Concrete		**Masonry**		**TSL+BAL+Other**	
	RC	**LC**	**BC**	**BF**		
28	1,493	280	532	296	466	3,058
15	1,843	175	513	141	59	2,731
19	2,921	327	1,096	319	2,562	7,315

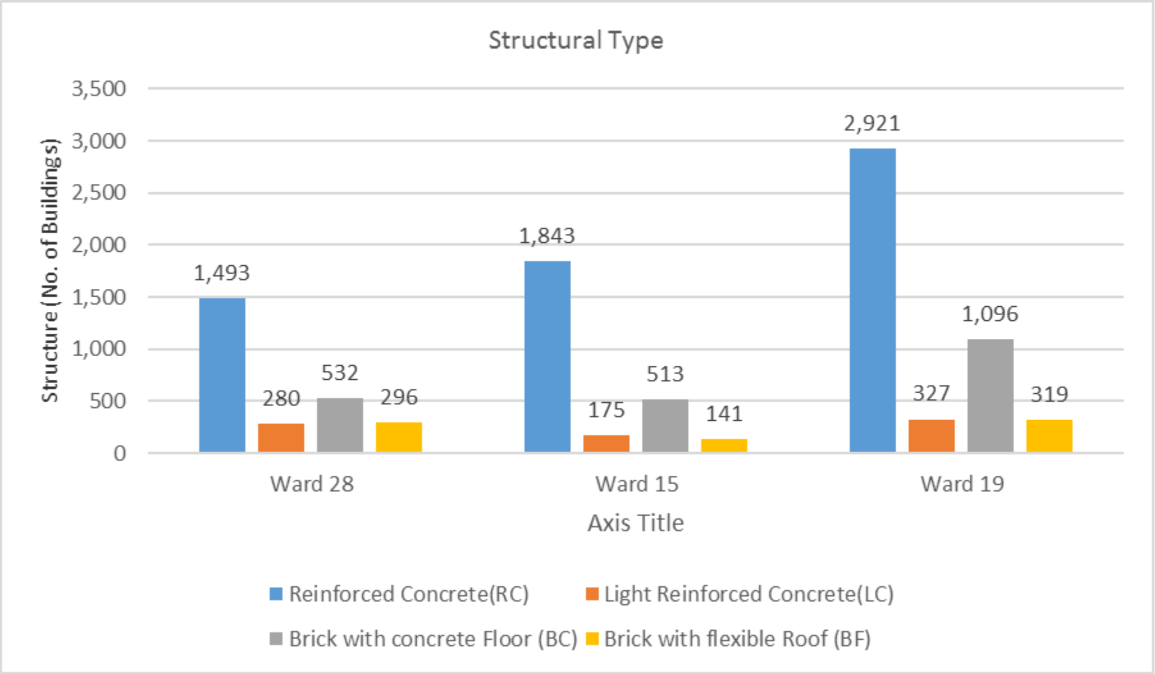


Figure 4.8 Structural Type (Source: Report, CDMP 2010)

4.4.6 Height of Building

Building height is one of the key factor in assessing overall building performance, loss of function, and casualties.

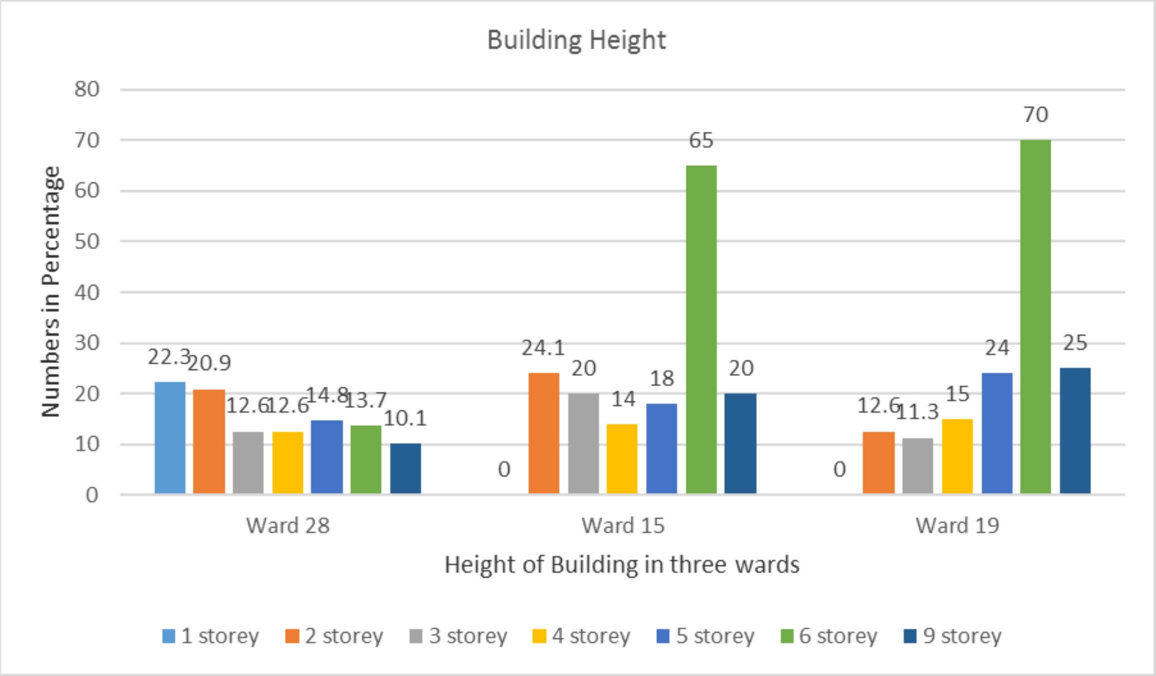


Figure 4.9: Building Height (Source: Report, CDMP 2010)

4.4.7 Number of Occupants of Dhaka in Cluster Level

Number of building occupants is an important parameter for earthquake loss estimation of a number of casualties, a number of refugees and etc. Due to difference in number of building occupants during day and night, it is also important to know the number of building occupants in the different period of time. Idealistically, we would prefer to use the exact number of occupants in each occupancy class however such a data is not exist in Bangladesh and it is impossible for the scope in this project to conduct such a survey for every building in the city corporation area.

Table 4.5 Occupancy List in Cluster Level

Ward	Cluster	Area	Population (No.)		Population Density (No./km2)	
			Daytime	Nighttime	Daytime	Nighttime
28	DCL2801	0.141	10,179	13,179	72,189	97,441
	DCL2802	0153	19,718	15,204	128,875	99,373
	DCL2803	0.14	20,181	26,437	144,150	188,835
	DCL2804	0.076	9,144	13,304	120,313	175,052
	DCL2805	0.078	9,449	12,878	121,136	165,104
Total		0.588	68,670	81,562	116,786	138,711
15	DCL1501	0.467	24,479	13,204	52,418	28,274
	DCL1502	0.37	12,479	9,749	33,777	26,349
	DCL1503	0.268	11,463	6,637	42,773	24,767

	DCL1504	0.354	23,224	19,304	65,605	54,531
	DCL1505	0.392	17,679	12,488	45,100	31,858
	DCL1506	0.4	14,048	11,731	35,119	29,326
Total		2.251	103,391	73,114	45,931	32,480
19	DCL1901	0.467	17,975	29,847	38,491	63911
	DCL1902	0.466	19,391	15,761	41,612	38,823
	DCL1903	0.531	18,331	14,745	34,521	27,768
	DCL1904	0.333	5,412	6,593	16,251	19,798
	DCL1905	0.375	9,152	8,488	24,405	22,634
	DCL1906	0.297	4,339	3,095	14,610	10,423
	DCL1907	0.347	10,2330	6,589	29,480	18,990
	DCL1908	0.368	26,554	12,777	72,159	34,719
	DCL1909	0.379	9,018	6,862	23,795	18,107
	DCL1910	0.491	13,898	9,550	28,306	19,451
	DCL1911	0.398	10,231	7,518	25,706	18,890
	DCL1912	0.244	7,163	3,721	29,355	15,249
	DCL1913	0.343	8,856	9,124	25,818	26,602
	DCL1914	0.24	6,269	4,365	26,120	18,188
Total		5.279	166,819	139,036	31,601	26,338

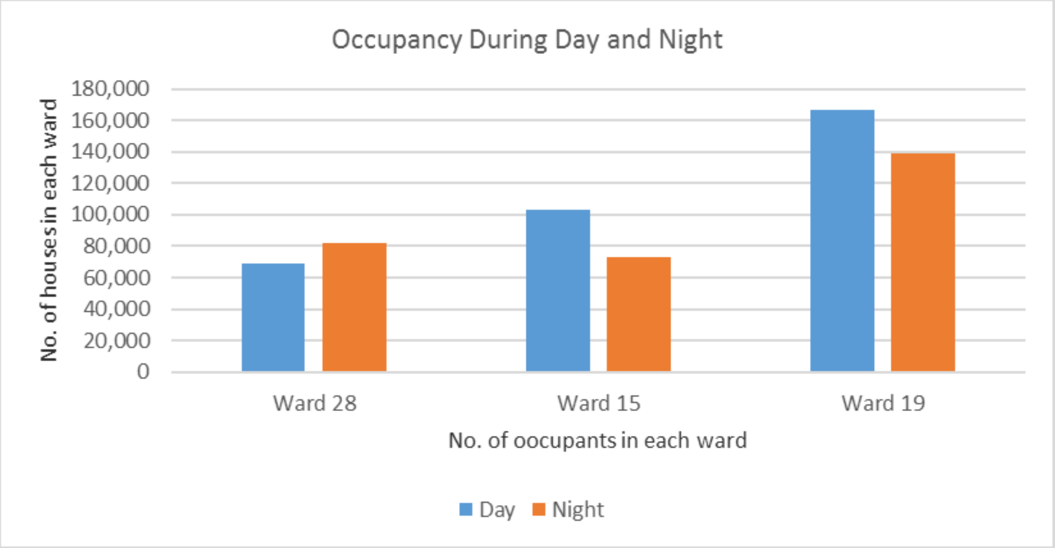


Figure 4.10: Occupancy during Day and Night (Source: Report, CDMP 2010)

4.4.8 Structural Type and Vulnerability Factors of Dhaka in Cluster Level

For concrete buildings, 5 significant vulnerability factors are observed including (1) soft story, (2) heavy overhang, (3) short column, (4) pounding possibility between adjacent buildings, and (5) topographic effects (buildings constructed on slope ground). Relationships between structural type and the presence of the above vulnerability factors are shown below.

Table 4.6 Structural Type and Vulnerability Factors Table

Ward	Cluster	Soft Story	Heavy Overhang	Short Column	Pounding	Topographic	Concrete Building (No.)
28	DCL2801	143	112	95	85	1	316
	DCL2802	161	126	106	95	1	577
	DCL2803	292	228	193	174	2	249
	DCL2804	130	101	84	74	1	270
	DCL2805	137	107	91	81	1	445
Total		710	556	471	422	4	1,025
15	DCL1501	159	118	97	80	1	190
	DCL1502	107	80	66	55	1	143
	DCL1503	81	60	50	41	0	557
	DCL1504	312	235	193	161	2	266
	DCL1505	150	112	92	77	1	219
	DCL1506	123	93	76	63	1	538
Total		931	699	573	477	5	1,913
19	DCL1901	67	51	43	37	0	377
	DCL1902	207	157	130	110	1	372
	DCL1903	204	155	128	108	1	175
	DCL1904	97	73	60	51	1	214
	DCL1905	118	89	73	62	1	84
	DCL1906	46	35	29	24	0	158
	DCL1907	87	66	54	46	0	289
	DCL1908	158	120	99	84	1	178
	DCL1909	98	74	61	52	1	227
	DCL1910	125	95	78	66	1	182
	DCL1911	101	76	63	53	1	101
	DCL1912	56	42	35	29	0	102
	DCL1913	56	42	35	30	0	197
	DCL1914	110	83	68	57	1	624
Total		1,529	1,158	955	808	8	3,280

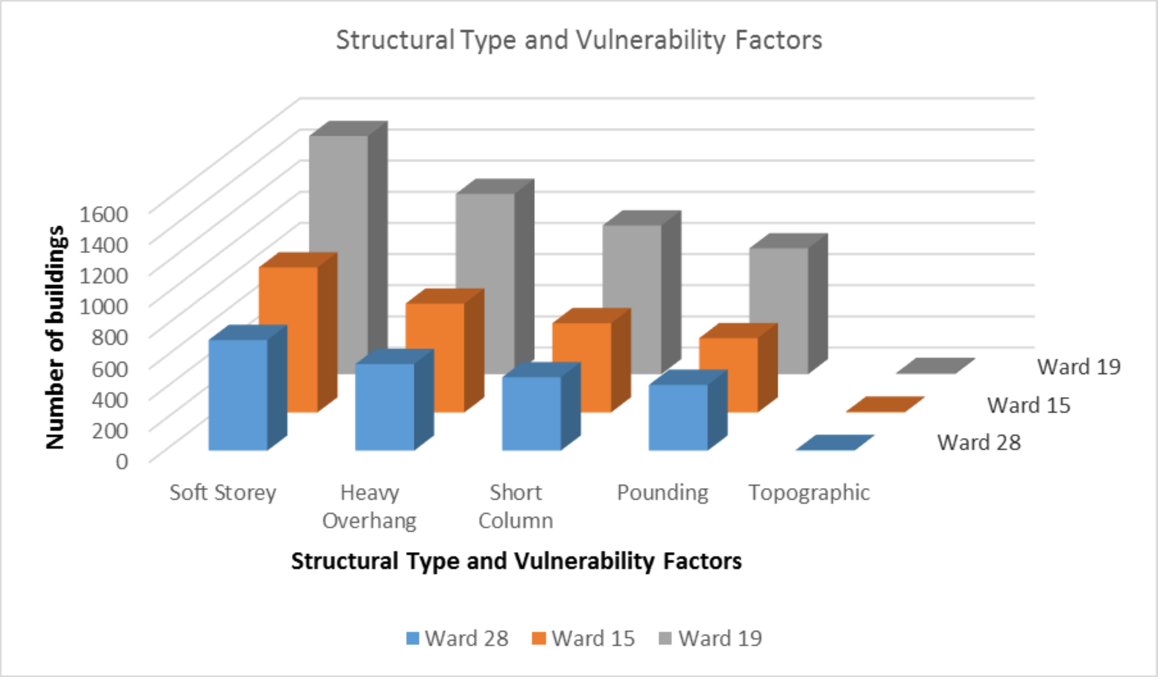


Figure 4.11:Relationship between Structural Type and Vulnerability Factors (Source: Report, CDMP 2010)

The above bar graph displays the relationship between structural type and vulnerability factors (CDMP, 2010) of the selected three wards in cluster form.

The graph shows that the number of soft storey, heavy overhang, short column and pounding effects increasing in an ascending manner with the growth of Dhaka City towards the northern part of the city. It can be deduced that the increasing trend of the factors are rising from Ward 28 to Ward 19 that with the morphological growth of the Dhaka City from the South to the North doesn’t have any effect on the improvement of the vulnerability factors.

A questionnaire survey has been conducted amongst the architects to understand the awareness and consciousness in seismic design of a building.

Step II

GRADUATION SCHOOL		
	Frequency	Percentage
Honors	30	60%
Diploma	N/A	N/A
EXISTENCE OF POST GRADUATION		
	Frequency	Percentage
Yes	46	92%
No	4	8%
DESIGNING EXPERIENCE OF SEISMIC ZONE		
	Frequency	Percentage
Yes	10	20%

No	35	70%
WORKING EXPERIENCE IN ARCHITECTURAL OFFICE		
Years Of Experience	Frequency	Percentage
1-5	30	60%
6-10	5	10%
11-15	3	6%
16-20	2	4%
21-25	2	4%
26-30	8	16%
31+		
IMPORTANCE OF ARCHITECTURAL ISSUES IN SEISMIC DESIGN OF A BUILDING		
	Frequency	Percentage
Agree	15	30%
Disagree	35	70%
ARCHITECTS WORKING WITH STRUCTURAL ENGINEERS FROM THE INITIAL STAGE OF A DESIGN		
	Frequency	Percentage
Agree	8	16%
Disagree	42	84%

Table 4.7 Table showing the awareness and qualifications of the architects

The main objective is about the awareness. It was hypothesized that “architects, who are aware of the importance of the architectural design and its related issues on seismic performance of the building, are conscious about their roles and responsibilities in earthquake resistant building design” but they are very small in number. 16% of architects stated that architects have much roles and responsibilities in seismic design, where 70% of them stated that they do too much designing and it is not possible to outreach all aspects of building configurations.

The significant relationship displays that architects, who consider architecture-based seismic design issues as design criteria with the more ordinary ones, tend to be more aware about the importance of the architectural design and their roles and responsibilities in seismic design.

According to the results of the questionnaire:

- 38.4 % of the architects found ‘building’s form and geometry’ important, where 46.5 % of the architects found the architecture-based s issue very important,
- 14 % of the architects found ‘building’s structural system and its configuration’ important, where 83.7 % of the architects found the issue very important,
- 25 % of the architects found ‘detailing of the non-structural architectural components’ important, where 25 % of the architects found the issue very important,

The frequency analyses reveal that the respondents are aware of the issues. According to the sample group, much more consideration should be paid to building's structural system and its configuration than building's form and geometry and the least consideration to the detailing of the non-structural architectural components in terms of seismic performance of buildings.

It was also analyzed along experience and education characteristics of the respondents. Although majority of them reported that they are experienced in designing buildings on seismic zones, it is interesting that no statistically significant relationship was found between designing experience on seismic zones and the awareness of roles and responsibilities in seismic design, as expected. In the same way, no statistically significant relationship was observed between working experience in architectural offices and the awareness of roles and responsibilities in seismic design. However, the experienced architects are expected to become more aware about their roles and responsibilities.

The analyses of frequency distributions explore that majority of the respondents consider 'earthquake' as an engineering expertise related to the structural engineers.

The result was also checked and confirmed by a control question comparing the roles and responsibilities of architects and structural engineers. 96.4 % of the architects stated that structural engineers have much and too much roles and responsibilities, where 74.1 % of them stated that architects have much and too much roles and responsibilities. Hence, priority of the roles and responsibilities seems to belong structural engineers as expected.

In order to search the reasons of regarding 'earthquake' as the province of engineering profession, the study was explored in terms of structural engineers' ability in seismic design. The number of architects in the sample group, who agree that structural engineers are able to transform every building into earthquake resistant ones with the static calculations and alternative solutions no matter how they are designed by architects, are almost equivalent to the ones who disagree. Hence a mutual consideration between the architects and the structural engineers is important in terms of seismic performance of the buildings.

Step III

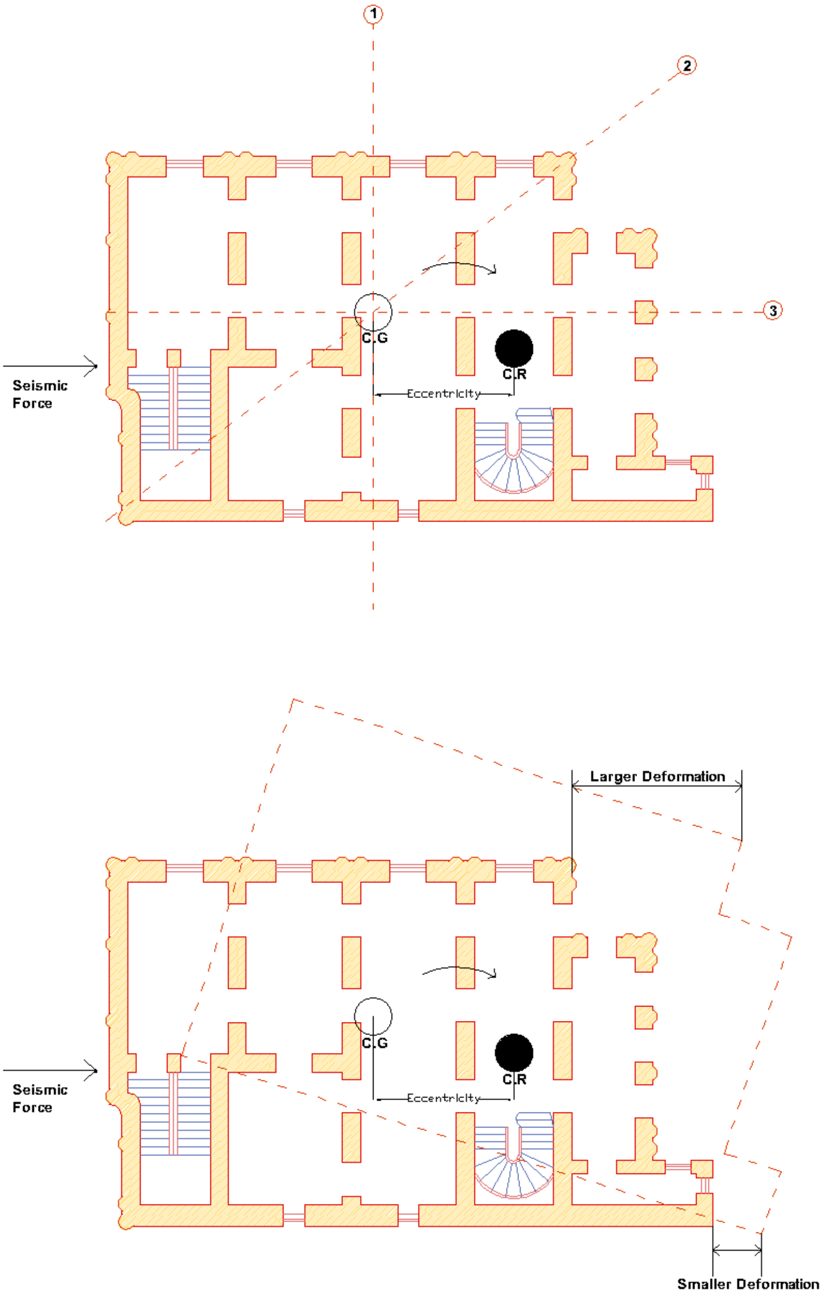
It should be noted that not only irregular shaped buildings have poor seismic performance but apparently regularly shaped building can be unbalanced too. Hence, this segment of study analysis will point out the issues that augment the poor seismic performance of existing buildings. Three buildings are chosen for study from the three wards- 28, 15, 19 respectively.

The building beside the Shahi mosque of Chawk Bazar is more than 60 years old and has not been renovated. The owner's great grandfather built the house and he has tried to maintain the building as it was before. The building plan is a symmetrical plan though the center of gravity and rigidity do not coincide.

This makes the building unbalanced as it produces torsion due to eccentricity and column and shear wall layout is not uniform.

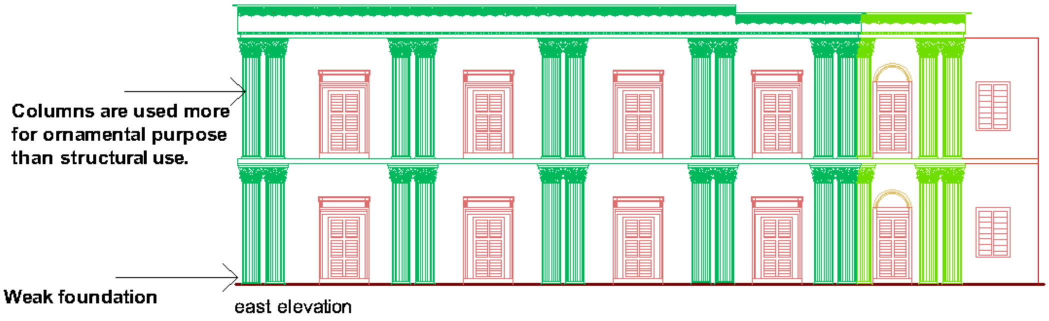
Horizontal stiffness of the structural frame is very weak as the beam and column is made of bricks and is not uniform. Hence cross bracing and retrofitting the beam may prevent the building to collapse during any magnitude of earthquake.

Figure 4.12 WARD 28- 2 Storied Residence beside Shahi Mosque (Plan)

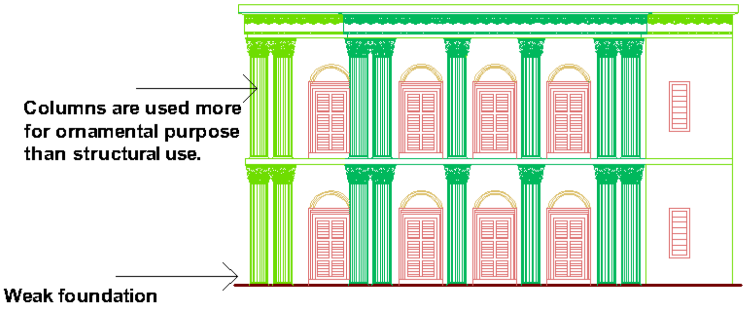


- Form and geometry follows simplicity but has an irregularity in the structural system and reducing the seismic performance of the building.
- Unbalanced Planar Rigidity-unbalanced layout of shear walls with high rigidity.Local collapse can occur due to torsional behaviour.
- Symmetric in one direction

Figure 4.13 WARD 28- 2 Storied Residence beside Shahi Mosque (Elevation)

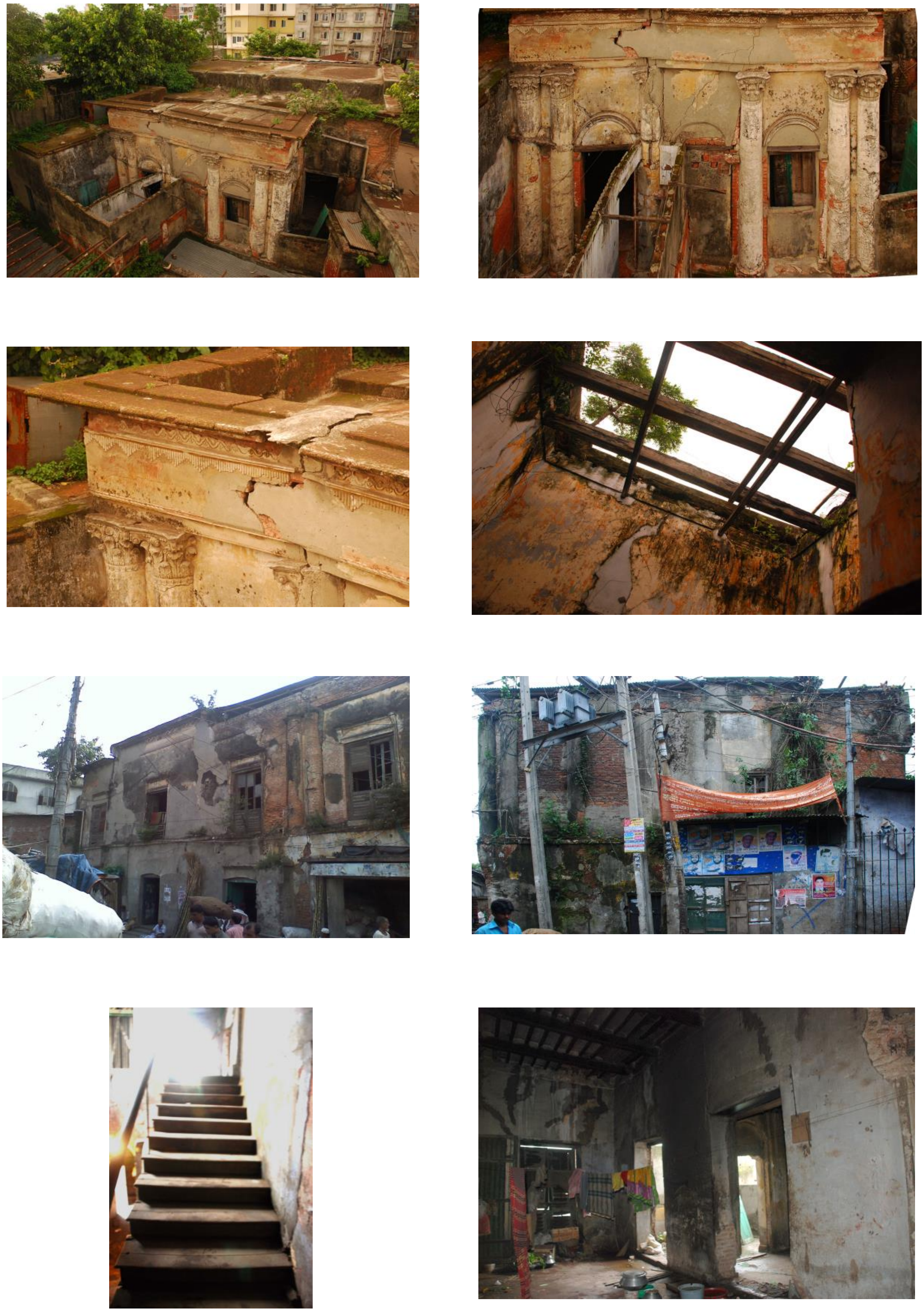


east elevation



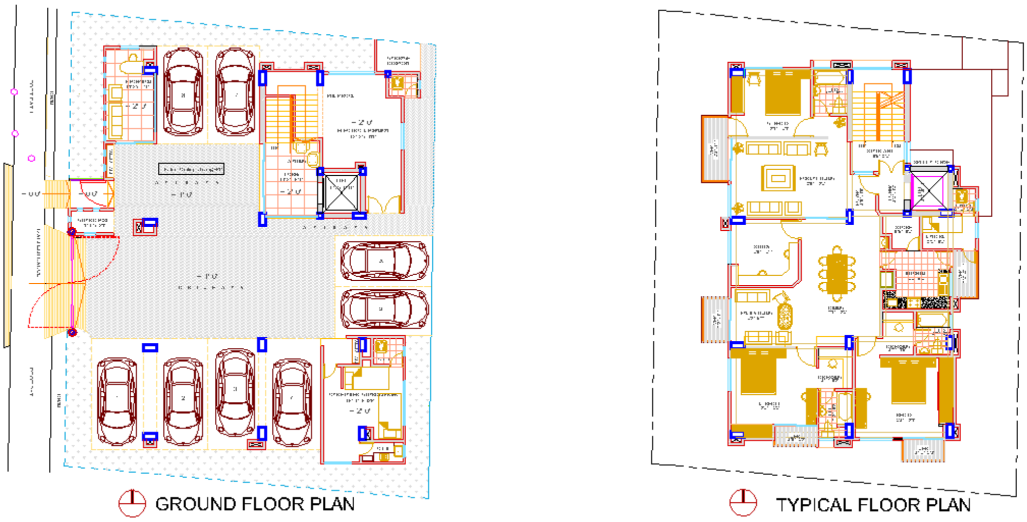
south elevation

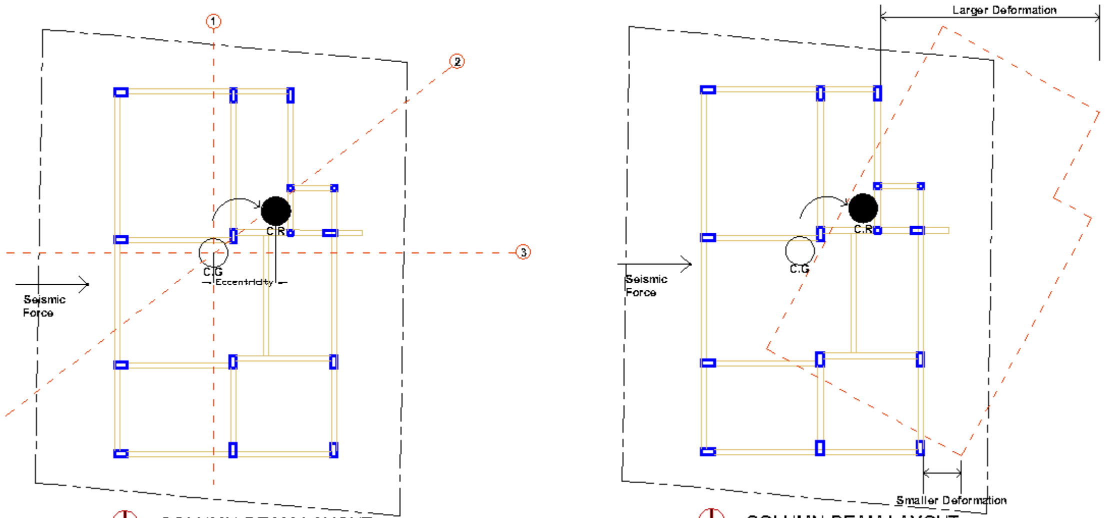
- Rigid frame structure though the columns and beams are not structurally sound.
- Story heights are uniform



Picture 3.3: Pictures of Chawkbazaar building

Figure 4.14 **WARD 15- 9 Storied Residence Apartment in Dhanmondi Road 15(Plan)**


GROUND FLOOR PLAN TYPICAL FLOOR PLAN



COLUMN-BEAM LAYOUT COLUMN-BEAM LAYOUT

- **Form and geometry follows simplicity but has an irregularity in the structural system and reducing the seismic performance of the building.**
- **Unbalanced Planar Rigidity-unbalanced layout of shear walls with high rigidity.Local collapse can occur due to torsional behaviour.**
- **Symmetric in one direction**

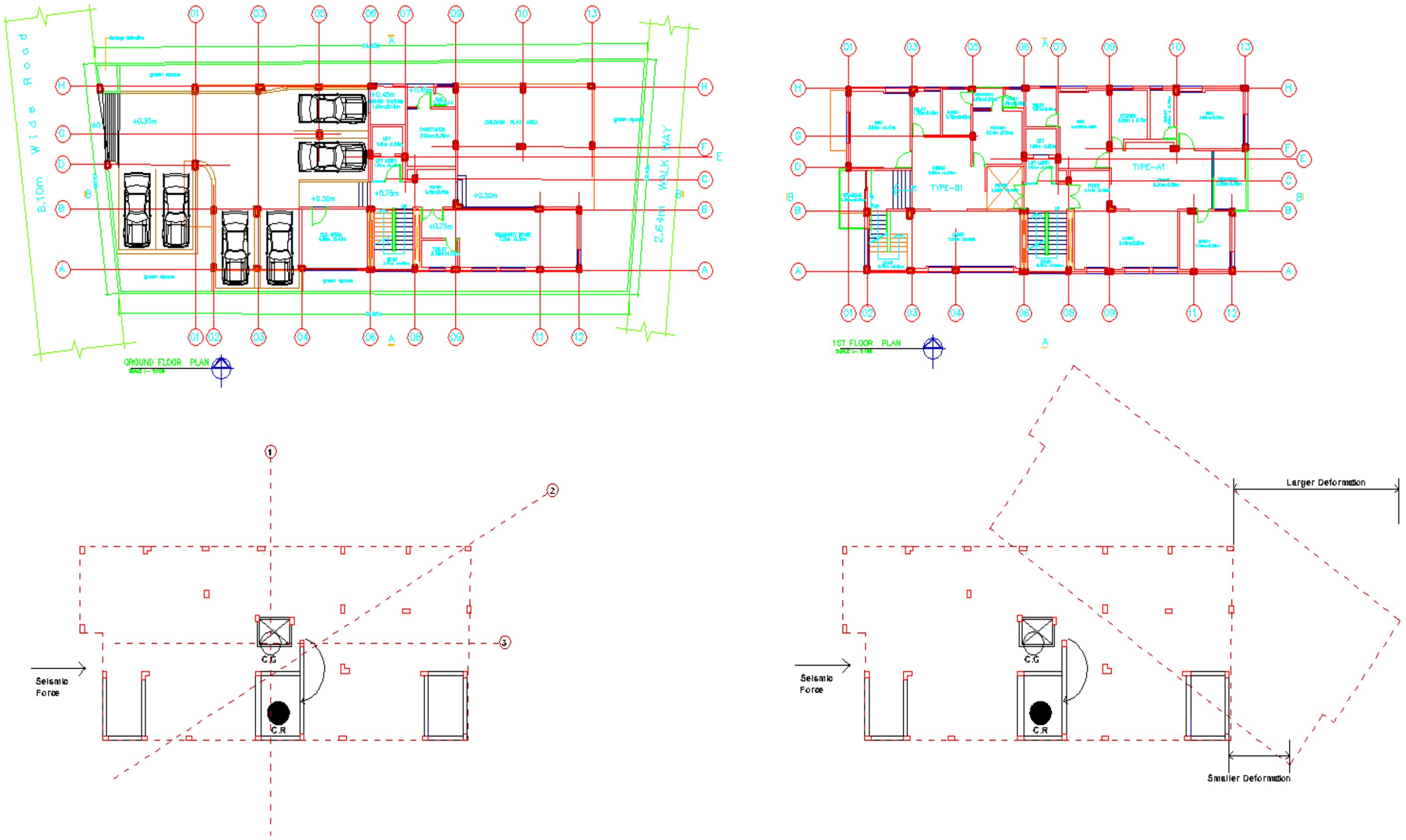
Figure 4.15 WARD 15- 9 Storied Residence Apartment in Dhanmondi Road 15(Section & Elevation)

Section

SOUTH ELEVATION

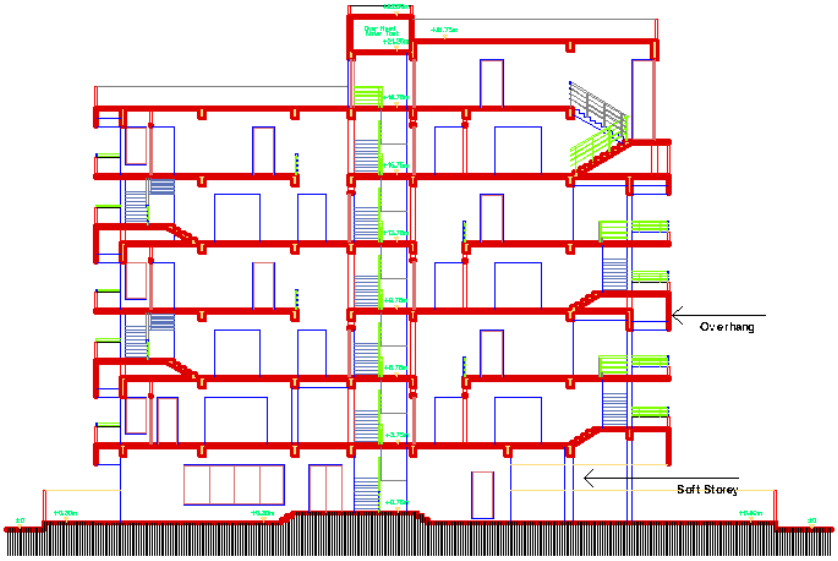
- Rigid frame structure.
- Story heights are uniform.
- Overhang is present.
- Soft storey is seen in the ground floor making the building vulnerable.

Figure 4.16 WARD 19- 6 Storied Residence Apartment in Banani Road 28 (Plan)

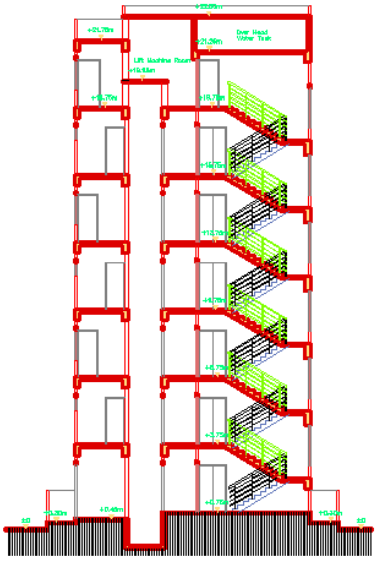


- Form and geometry follows simplicity but has an irregularity in the structural system and reducing the seismic performance of the building.
- Unbalanced Planar Rigidity-unbalanced layout of columns with high rigidity.Local collapse can occur due to torsional behaviour.
- Symmetric in one direction

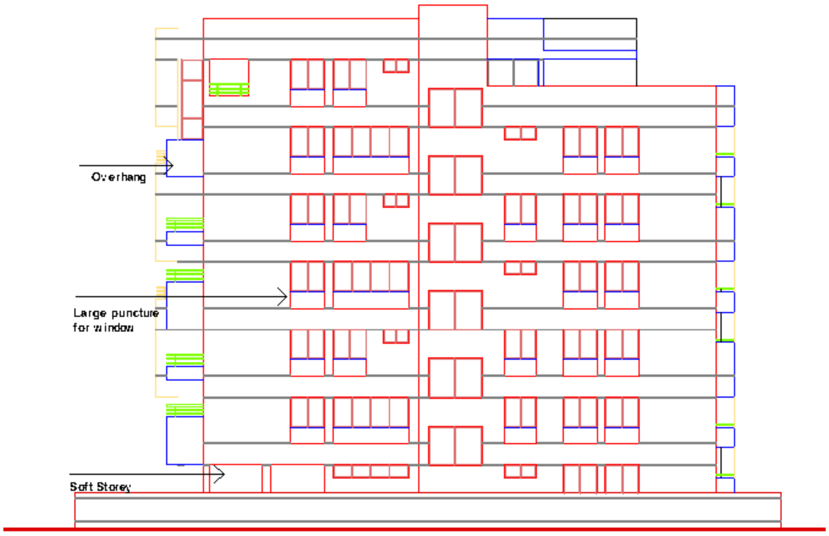
Figure 4.17 **WARD 19- 6 Storied Residence Apartment in Banani Road 28**



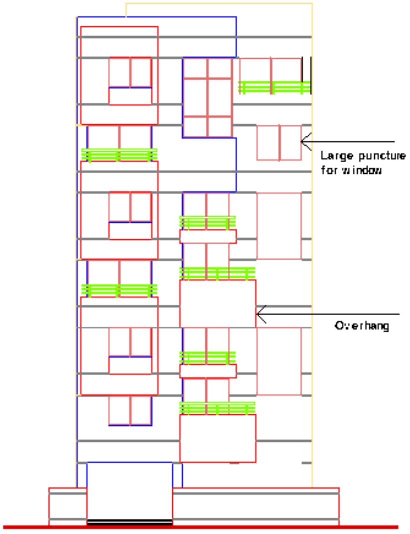
SECTION : B–B
SCALE : 1:100



SECTION : A–A
SCALE : 1:100



SOUTH ELEVATION
SCALE : 1:100



WEST ELEVATION
SCALE : 1:100

- Rigid frame structure.
- Story heights are uniform.
- Heavy overhang is present.
- Soft storey is seen in the ground floor making the building vulnerable.

(Sections & Elevations)

Building Location	Soft Storey	Heavy Overhang	Plan Irregularities	Vertical Irregularities	Pounding Possibilities	Absence of Basement	Short Column	No Frame Action	Soft Soil Condition
Chawk Bazaar	X	X	√	X	√	√	X	X	X
Dhanmondi	√	√	√	√	√	√	X	X	√
Banani	√	√	√	√	√	√	X	X	√

Table 4.8 Table showing the vulnerability factors of the buildings

From the study it can be deduced that buidlings in Chawkbazar is in the most vulnerable state than the buildings located in Dhanmondi and Banani. Architects and Engineers have considered the vulebrability factors while designing the buioldings though heavy overhangs predominates in Dhanmondi and Banani buidlings.

5. Risk Reduction Strategy and Architect's Responsiveness in Seismic Design

5.1 Introduction

Recent devastating earthquakes in the Indian Ocean, Pakistan, China, Haiti, New Zealand, Japan, and Nepal serve as painful reminders of the urgent need to disseminate both scientific and technical information to earthquake safety practitioners working in the world's most seismically vulnerable communities. Yet before this information can be successfully passed on, it is essential to establish an understanding of the development and implementation of disaster risk reduction (DRR) and seismic risk reduction (SRR) practices that are currently in place worldwide. Developing a knowledge base of these practices, which may be structural or nonstructural in nature, may help identify the possibility of reproducing, modifying, and integrating model risk reduction practices in different cities and communities around the world. In order to continue to evaluate the feasibility and success of different practices, it is necessary to first uncover what current DRR and SRR programs and initiatives look like for earthquake-prone cities on a global scale. The purpose of this chapter is to identify the extent to which these practices are relevant, accessible, and relied upon in lower-income nations. Specifically, this chapter examines catalysts for incorporating DRR and SRR strategies into community planning and building efforts in earthquake-prone communities. It also identifies which of these strategies are considered most useful across the different contexts.

5.1.1 Risk Reduction Strategies

Discussions of strategies for reducing risk in the event of an earthquake are often dominated by structural engineering measures. While structural mitigation efforts are indeed invaluable in terms of SRR, they by no means are the only way in which these initiatives take shape in a community. Respondents in this study expressed a wide variety of efforts aimed at enhancing SRR practices, including, but not limited to, structural mitigation efforts.

Table 5.1 illustrates the wide variety of SRR strategies that can be implemented. The mitigation and preparedness efforts outlined above are designed to assist with risk assessment, to encourage physical protection, or to increase response and recovery capacity through pre-event planning.

The types of programs described are aimed at assisting and/or engaging one or more levels of social organization, ranging from:

- The micro-level, which includes individuals and households
- The meso-level, which comprises schools, hospitals, businesses, local government, community- and faith-based organizations, neighborhoods, and communities
- The macro-level, which covers regional, national, and international policymaking bodies.

Mitigation	Preparedness
Structural mitigation (building retrofit programs; structural strengthening program; unreinforced masonry removal)	Map Your Block, neighborhood resource mapping programs
Nonstructural mitigation (fastening contents in buildings)	Neighborhood Empowerment Network
Enhanced building design	Staff preparedness training
Identification of collapse hazards	CPR training; emergency medical care training; psychological first aid training
Identification of high-priority buildings for retrofitting	Public risk education; disaster awareness trainings
Structural assessment program	School-based hazard education
Lifeline protection	School-based emergency drills
Earthquake and Megacities Initiative	Public emergency drills
Environmental conservation programs	Distribution of emergency kits and emergency supplies
Slope stability efforts	Neighborhood capacity, skill, resource mapping
Hazard risk mapping	Disaster preparedness teams
Investment planning for mitigation actions	Community organizing for disaster preparedness
Disaster mitigation awareness programs (promoting an understanding of the importance of mitigation)	Safe School Initiatives (school disaster management and evacuation plans)
Population relocation programs (moving persons and businesses out of vulnerable structures and areas)	Emergency training exercises
Micro-zonation maps	Business continuity planning; tabletop exercises and disaster simulations
Planning regulations or policies that incentivize mitigating actions	Disaster volunteer recruitment and training programs
Improved building codes	Parent–child reunification programs

Table 5.1 Table showing the illustrates the wide variety of SRR strategies that can be implemented.

We also learned that these risk reduction practices that develop at a macro-, meso-, or micro-level may work their way down—from an international or national program to a local level—or up, from a local program to a national or international best practice. In addition, the diversity in approaches may indicate that some strategies might require access to many resources (i.e., structural mitigation), while others may be put into place with little to no need for specialized resources (i.e., inventorying building contents). In fact, the practitioners whom we interviewed often had limited budgets, but still managed to serve many residents, groups, and organizations in their local communities. One of the primary ways in which respondents were able to achieve successful programmatic outcomes was through partnering with and/or learning from trusted organizations and individuals, both within their cities and from outside regions. Understanding the wide array of individuals, groups, and institutions involved, as well as the variety of groups targeted in preparedness programming, can lead to a clearer sense of the collaborative abilities and responsibilities related to DRR and SRR actions and programs. Effective collaboration (both externally and internally) with representatives from the government, business, health care, education, and grassroots sectors could mean that SRR practices will be able to reach a significantly larger portion of people within a given community.

5.1.2 Major causes of Vulnerability

The study area of the selected ward faces some vulnerability of the earthquake primarily for the ignorance of the architect’s awareness and consciousness while designing a building. A building is designed not for the importance of seismic issues but for the aesthetic purposes. The sprawling and straggling expansion of buildings in an unplanned manner has made the places more vulnerable to earthquake.

Besides the architect’s unconsciousness the lack of awareness of the poor people living in very poor and vulnerable conditions makes it more vulnerable. Most of the houses they live have no structural safety as most of the cases seen the buildings are not used for mixed use activities. These people live on the upper floor whereas ground floor is used for commercial purposes.

Another issue that leads to greater vulnerability is the high population density. Due to high value on land prices most of the buildings built nowadays are seen to be expanded vertically. Most of the time it is seen that the buildings do not follow proper setbacks and building codes, as a result it becomes vulnerable to earthquake.

Poor access to road and utilities is also another issue that influences the vulnerability to earthquake. There is hardly any open space in the study area where people can congregate during any outbreak of a major disaster.

5.1.3 Structural Measures

Road

- As a short term measure, access roads should be widened by covering open drainage. Road-side storage of construction material and industrial goods should be removed in short term.
- The main road network which is about 30 feet wide should be free from road-side tea stall (tong) and other obstacles in short term.
- As intermediate term measure, tin-made houses at side of road should be demolished to widen road.
- As a long term measure, new road network should be constructed which is practically impossible for the study area at present. The inhabitants have proposed that in future if a big earthquake or fire occurs, most of the buildings will be destroyed, then it may be possible to reconstruct the area with new planned road network.

Structure

- The study area is more vulnerable to fire hazard than earthquake. As a short term measure, industrial refuses should be removed regularly and combustible material should be kept away from heat sources which are important factors of fire hazard.
- In long term, buildings with residential uses should be segregated from industrial use. The south-west part of the study area consists of a number of tin-made houses which is the living place of workers of local industries. This place may be demolished and reconstructed as new industrial zone. A major road of Dhaka City is going just beside this area. So go down and industry can be relocated here so that the inner side of the area cannot be affected by loading and unloading goods.

5.1.4 Non-structural Measures

Evacuation Plan

- Evacuation plan at local level should be developed and spread to the local people so that they get clear idea about the location of evacuation shelters and the safest route to reach those shelters during disaster.
- Evacuation centers should be chosen on the basis of structural safety of building and road accessibility. Three existing open spaces in the study area must be kept free from encroachment.
- Road network around possible evacuation centers and open spaces should be kept free from any kind of obstructions.

Awareness Raising and Training

- The inhabitants of the study area should have adequate knowledge on what to do before, during and after an earthquake or a fire attack. To raise awareness among local people, there should be training program on earthquake and fire hazard safety in the study area and participation of at least one member from each household should be ensured. After training, he or she will disseminate knowledge to the other members of the family.
- There should be regular community group discussion and meeting on earthquake and fire hazard awareness at school, social clubs and panchayet’s office with the local people. Social clubs may organize team of volunteer using the local youth.
- Bangladesh Fire Service and Civil Defence, and some NGOs have already started earthquake and fire hazard awareness training programs all over the country but have not been started yet in the study area. Some International NGOs like Islamic Relief Worldwide, Plan International and Action Aid Bangladesh has initiated school safety programs which have not reached yet at the study area. These organizations should be requested to start the programs as soon as possible in Ward 29 by showing them the present vulnerability condition. It should be ensured that these programs are working effectively and raising awareness among local people about vulnerability to hazard and their life safety.

- Educational institutions such as school and madrasha are respected by community and considered to be in a position to provide leadership in promoting disaster risk management in the study area. These institutions may help the local people in raising awareness by organizing and providing community trainings and planning, bridging hazard phenomenon knowledge gaps etc.
- Religious organizations play an important role in community disaster risk reduction as these have major impact on different groups of people. In old Dhaka, governing body of mosque is widely respected by local people. Imam of the mosque can give valuable suggestion after Jumma khutba (speech) about hazard mitigation.

5.2 Implementation of Risk Reduction Strategies

- Implement local level earthquake safe model projects (seismic safe construction/retrofitting) using national building code and earthquake safe construction guideline.
- Strengthen the capacity of the governments to better prepare for post disaster recover through advocating policies, guideline, etc in National Disaster Management plan.
- Regional knowledge exercise and networking
- Lessons and experience sharing through training, workshops, seminars on regional Building Code practice, Earthquake safe construction.

5.3 Capacity Building and Risk Reduction Measures

Development of Seismic Engineering Design Skills

- Introduction of earthquake engineering in the civil engineering and architecture curricula across the state so that all future graduating civil engineers and architects will be equipped with adequate background in earthquake engineering and a teacher training program to effect these changes
- Continuing education programs for the practicing engineer in earthquake engineering
- Upgradation of skills in government engineers

5.4 Regulatory Framework, Implementation Procedures and Monitoring Mechanisms

There is a clear need to put in place a system wherein the municipal authorities are in a position to enforce seismic code provisions in all new constructions. Two issues are involved here: to gain confidence of the concerned municipal engineers so that they feel secure in handling this new responsibility and capacity building of the municipal engineers for review of structural drawings.

5.4.1 Review of Development Control Regulations

In view of the magnitude and scale of deficiencies in the development control rules, it is divided in to two parts- One part should pertain to issues dependent on local conditions such as procedure regulations and application formats for structural design regulations; fire safety regulations; hazardous waste disposal/ pollution regulations). Issues such as planning regulations, local building regulations and standards, maintenance and upgradation regulations.

5.4.2 Certification of Engineers

Structural Engineers need to be registered with the Municipal Corporation in order to practice. This registration is based on experience and engineering degree and does not check competency. Additional tests need to be conducted to ensure proficiency in the field.

5.4.3 Code Compliance

Not all structures built for earthquake resistance in urban areas are being designed or built in compliance with seismic codes. This is primarily because a robust mechanism to ensure compliance to building codes is not yet in place and the misconceived perception of risk that an earthquake does not strike at the same place twice in one lifetime. Unless a code compliance monitoring mechanism is put in place, many of other capacity building measures will be futile.

5.4.4 Accountability

There is presently no protocol defining responsibility and accountability of various stakeholders such as the structural designer, contractor, construction engineer/supervisor, builder/developer, municipal engineer or government in the event of failure of a structure. As a result, there is no motivation for any of the players to strictly and scrupulously perform their roles and responsibilities. Even in the unlikely event of the identification of the errant party, there are no punitive measures laid down and the offender tends to go scot-free. Their situation needs to be addressed on priority.

5.4.5 Seismic Safety Commission

A Commission in line with the California Seismic Safety Commission may be established which besides drafting a seismic safety policy would be responsible for commissioning and monitoring research and development in earthquake related fields. Further, it would make recommendations regarding projects, programs, legislation and policies required for seismic vulnerability and risk reduction.

5.4.6 Essential Services

Essential facilities such as schools and hospitals which cater to the needs of a special section of society and which are desired to be functional after a seismic event require special specifications for design and performance. The city council may consider putting in place performance criteria for all hospital and health care facilities which are to be conformed to by a realistic deadline. They city may set a target date to ensure required seismic resistance of all school buildings. It may also need to establish a policy of retrofit versus reconstruction especially for the old school buildings.

5.4.7 Insurance

In Dhaka city scenario there is no requirement of seismic code compliance to procure a housing insurance. A possible incentive for ensuring seismic safety is lost as the premium for insuring a house against an earthquake remains the same irrespective of whether the structure has been designed for earthquakes or not.

5.5 Measures for Earthquake Risk Reduction

For better understanding of all the possibilities of earthquake risk reduction, it is important to classify them in terms of the role that each one of them could play. Therefore, in the pre-earthquake phase, preparedness, mitigation and prevention are concepts to work on. Post-disaster, immediate rescue and relief measures including temporary sheltering soon after an earthquake until about 3months later and reconstruction and re-habilitation measures for a period of about six months to three years need to follow.

To encapsulate, the most effective measures of risk reduction are pre-disaster mitigation, preparedness and preventive measures to reduce vulnerability and expeditions, effective rescue and relief actions immediately after the occurrence of the earthquake. Depending upon the calamity and its consequences, strategies can also be divided into long term (five to fifteen years), medium term (one to five years) and short term (to be taken up immediately in high risk areas). Since it has been realized that earthquakes don’t kill people but faulty constructed buildings do, the task of reducing vulnerability of structures and buildings will be the key to earthquake risk reduction. Also, pre-disaster preparedness through a post-earthquake response plan, including training of the concerned personnel in various roles, is considered essential for immediate and effective response after an earthquake occurrence.

5.5.1 Long-term measures

Reframing building codes, guidelines, manuals and byelaws and their strict implementation. Tougher legislation for highly seismic areas.

Incorporating earthquake resistant features in all buildings at high-risk areas. Making all public utilities like water supply system.

5.6 Summary

For a building to be structurally safe and sound it is ideal for an architect to work in association with the structural designer during commencement of any building design. Dhaka city is overpopulated and it is mandatory to follow the National Building Code, Bidhimala and Earthquake safe construction as most of the buildings are built vertically upwards. The architectural issues if properly addressed designed according to seismic designed then the building vulnerability will reduce.

6. Findings, Recommendations and Conclusion

6.1 Findings

This final chapter concludes the study by providing some recommendations on the basis of some major findings of the vulnerability assessment of earthquake to develop risk reduction strategies by the architect's community.

6.1.1 Present Scenario

The buildings that are surveyed comprises both old and new buildings with very little setback. The selected ward does not have any standard individual occupancy use. Almost all the wards have mixed use buildings with unpredictable amount of occupancy use both day and night. According to the structural aspect most of the new buildings are seen to have large overhangs, soft storey and building eccentricity is greater even though designed by the architects. Three such buildings from individual ward are seen to have similar symptoms. The center of gravity and rigidity varies greatly.

6.1.2 Views of Architects Regarding Risk Reduction Strategies

The present state of attitudes (interest, awareness and consciousness) of architectural community towards earthquake and architecture-based issues related to seismic design is searched.Primary issue explored the architect's experience and perception towards seismic design. As the second issue the possible ways to enhance the incorporation of earthquake as a design parameter with the other and more ordinary ones are explored.the results of the case study from the architectural viewpoint requires urgent need of incorporation of specifications as a formal earthquake code for the use of architects while deisgning a building.

6.2 Recommendations

6.2.1 The Architect's Role in Building Design

Primarily when a building is designed for construction architects play an intricate role during the entire implementation. The architects are usually the only leading professional with a total overview of every aspects of design and construction phase.

The architect initiates the design process by serving the clients, introduces structural engineer and associated engineers (plumbing, electrical and mechanical professionals) along with contractors who executes the architect's vision and client's desire. In short, the architect coordinates the entire project from the beginning till the end. As a result architects play a crucial role and influence greatly on seismic design of building structures.

Such qualities remain dormant most of the times. It is evident that during the initial phases of a building design the option to influence the project's quality and cost remains substantial but descends steadily afterwards. The initial decision on structural concept can foster an effective seismic resistance of that building to a large extent.

The second consideration evokes the economics pressure due to design and construction process of a project. A site susceptible to earthquake requires careful observation and scrutiny by experienced practitioners associated with broader knowledge on seismic design.

Economic constraints on design and construction practices may result in structures that comply with codes but are nevertheless susceptible to significant damage. They may cause many severe casualties when an earthquake occurs. Even if no lives are lost, poorly performing buildings and their contents can suffer major damage, which can be devastating to occupants, e.g., tenants or businesses forced to vacate or suspend operations.

In the prevailing circumstances, the fees public and private owners appear willing to pay for architectural engineering work are often insufficient to provide the levels of professional service needed for adequate attention to seismic resistance. Consequently, at the outset the buyer or owner should understand the relationship between design and construction costs, and the levels of quality control and building reliability being purchased with the fees budgeted.

While improving building performance is likely to mean some increase in construction and design costs, these added expenses may not be significantly more than those of a structure built to minimal seismic standards. Furthermore, typical kinds of earthquake damage are controllable for very little added expense. In short, owners' decisions to go for the lowest fee in design contract negotiations may save little at the beginning, while proving very costly later in the event of a damaging earthquake.

The recommendations may clarify important design practice issues and provide guidance in dealing with major issues of earthquake hazard. Implementation of the recommendations may also strengthen the role of architects in the design and construction process. Moreover the recommendations for improvements in practice can reduce exposure to damage claims and liability suits due to building failures.

6.2.2 The Architect's Role in Community Leadership

A simplistic view of the role is that architects create architecture, and their responsibilities encompass all that is involved in doing so. This would include articulating the architectural vision, conceptualizing and experimenting with alternative architectural approaches, creating models and component and interface specification documents, and validating the architecture against requirements and assumptions. However, any experienced architect knows that the role involves not just these technical activities, but others that are more political and strategic in nature on the one hand, and more like those of a consultant, on the other. These activities drive the competencies that the architect needs to be successful.

"Good leadership consists of showing average people how to do the work of superior people." John D. Rockefeller

Architects are frequently involved in the seismic strengthening of existing buildings— many of which are older structures, some with architectural merit, historic character, or long- term associations with community life. Where possible, these values should be preserved, and architects can help by mediating between the needs of structural retrofit technology and the goals of historic and architectural preservation. Thus they are in a position to promote improved seismic safety, while also seeking to maintain intrinsic values that might be lost.

Approaches to seismic hazard abatement depend on a community's physical environment, and its social, economic and political circumstances. Influential factors include the prevalence of hazardous buildings, the availability of alternative affordable housing, the demography and composition of the community, economic pressures for redevelopment, and the ability to obtain economic and fiscal resources to help pay for mitigation of earthquake hazards.

Architects can help formulate appropriate mitigation strategies for their communities. First, they can work as advocates for sensible and prudent seismic safety programs.

Second, they can help address the needs of displaced residents for affordable housing or alternative commercial space.

Third, they can promote mitigation plans that respect and preserve the historic fabric of the community through architecturally sensitive retrofit designs.

Fourth, they can join in multidisciplinary research efforts to advance new technologies and directions in earthquake hazard mitigation activities.

6.2.3 Design Practice Aids

Each construction job involves unique circumstances, but use of common methods, procedures, and documentation by design-team members can facilitate better awareness of mutual responsibilities and promote improved seismic design. Several of these aids are discussed below, including checklists, guides and other sample documents. Their appropriate use by design teams could help clarify task assignments, reduce uncertainties, promote teamwork, and improve seismic design.

Use of such aids could also help design teams explain to owners and others the level of building performance in earthquakes that a proposed project budget is likely to buy, and what it is not likely to assure. Used in contract negotiations, such aids may facilitate a better match between owners' expectations and realistic anticipated building performance. Accordingly professional organizations representing architects, engineers and owners are urged to collaborate in developing and publicizing the value of and availability of practice and documentation aids such as those suggested herein.

6.2.4 Strengthening Seismic Design Practice

The uniqueness of every construction project requires the exercise of professional judgment and a multitude of design and construction decisions. In the interest of strengthening seismic design practice, architects should consider certain concepts and procedures, adapting them to their own individual approach Options for Improving Architectural Seismic Design Practice-

Participate in continuing education programs, with special attention to seismic design and performance.

Participate in post-earthquake site visits to examine damage and study patterns of structural behavior.

Participate in the development of seismic codes and guidelines, work on code committees, and promote the use of design guidelines.

Work with structural engineers who are experienced in seismic design.

Develop seismic goals and expectations for each project, jointly with the owner and other members of the design team.

Ensure that conceptual and schematic designs are developed with joint architect/engineer participation.

Develop a scope-of-work definition (a division of tasks between architect, engineer and builder) for incorporation in each architect/engineer contract.

Develop formal architect/engineer interaction techniques to deal with basic seismic issues, such as a professional interaction guide for all critical aspects of design (site characteristics, configuration, structural system and performance, and nonstructural components).

Develop seismic performance guidelines and evaluation reports.

Seek appropriate compensation for seismic design (based on defined scope-of-work and services.)

Educate owners on seismic design issues.

Educate builders on seismic design issues. Encourage owners to discuss seismic design issues with builders.

Provide independent expert design review for major projects.

6.2.5 Seismic Goals and Expectations

Preparation of a statement on seismic goals and expectations can help design team members and owners agree on goals that are reasonably in line with resources available. Before construction begins, agreement by the design team and the owner, including the construction manager, if involved, on a project's goals and expectations can help achieve the desired level of performance and limit later surprises due to unexpected earthquake damage. This objective will be promoted by making a seismic goals and expectations statement part of a project's building program documents.

The architect should organize the discussion of appropriate goals and statements, and ensure that they are fully understood by the owner and design team. The architectural and structural engineering professions should consider collaborating on a manual on the preparation of such statements.

The Institute of Architects of Bangladesh, IAB and The Institute of Engineers, Bangladesh, IEB and Rajdhani Unnayn Katripakkha, RAJUK and Public Works Department, PWD, should encourage the preparation and use of seismic goals and expectations statements on all projects where such use is considered appropriate in Dhaka City. The contents of such statements can then be agreed on by the principal parties—design team, contractor, and owner—and made part of each project's building program documents.

6.2.6 Seismic Performance Guidelines and Evaluation Report

Agreement on a project's seismic goals and expectations makes possible the preparation of specific seismic performance guidelines—as well as a seismic performance evaluation—for each building type, configuration, and structural system under active consideration. Performance guidelines and evaluation reports prepared in the early stages of each design project can be used in design-team discussions with the owner and contractor, to facilitate a meeting of minds on major issues of seismic design. Each seismic performance evaluation can present the design-team's professional opinion regarding key questions about the structure and the site, such as the following:

- Does the structure's configuration have important implications for its seismic performance?
- What are the probable linear and nonlinear behaviors of the structure and its principal components during ground motion?

- In an earthquake are the building and its main components likely to prove brittle and experience degrading behavior, or is ductile performance and stable behavior a reasonable expectation?
- Is the building likely to exhibit unbalanced nonlinear behavior, and if so what are the implications for its earthquake performance?
- What is the structure’s potential for dissipating earthquake energy without suffering undue damage?
- What is the degree of drift and deformation compatibility?
- If the structure is damaged, how difficult and costly are repairs likely to be?
- Is the building's serviceability and continued function an important consideration?
- Is the site on or adjacent to an active earthquake fault?
- Would the site geology be likely to increase ground shaking intensity in an earthquake?
- Is the site stable?
- Is the site subject to liquefaction?
- Are the up-slope and down-slope environments near the site stable?
- Are building separations adequate to prevent battering (pounding) during an earthquake?
- Are adjacent buildings collapse hazards?
- Are hazardous materials stored or used in the vicinity of the site?
- Will site access and egress be secure against earthquake-caused obstruction?
- Are transportation, communication and utility lifeline systems vulnerable to disruption or failure?

Table 6.1: Seismic Evaluation Report

Seismic Goals and Expectations				
A. Earthquake Performance of Structural Systems				
Earthquake effects	Damage			
	No Life Threatening Collapse	Repairable Damage: Evacuation	Repairable Damage: No Evacuation	No Significant Damage
Low-Moderate				
Mod-Large				
Large				
B. Earthquake Performance of Non-structural Systems				

Earthquake effects	Damage			
	No Life Threatening Collapse	Repairable Damage: Evacuation	Repairable Damage: No Evacuation	No Significant Damage
Low-Moderate				
Mod-Large				
Large				

C. Function Continuance: Structural/Nonstructural

Earthquake effects	Time to Reoccupy			
	6 months +	To 3 months	To 2 weeks	Immediate (hours)
Low-Moderate				
Mod-Large				
Large				

Notes: 1) Effects of Nearby Earthquakes:

Low-Moderate: Up to Richter M 6.5 Moderate-Large: Richter M 6.5-7.5 Large: Richter M 7.5 +

2) Classification of earthquake effects and extent of anticipated damage may be modified by site conditions—such as poor soils, ground failure potential, or vulnerable adjacent structures—which may result in stronger shaking and greater damage.

6.2.7 Scope of Work Guideline and Agreements

Costs and economic pressures tend to restrict the time made available for design. Working within limited budgets, architects and engineers, while following customary practice, may nevertheless leave some design tasks to engineers employed by contractors or vendors (e.g., precast cladding panels, windows, stairs, and elevators). At times, unless carefully monitored, this can reduce building quality and performance to levels that may be less than desirable with respect to seismic safety.

To enhance performance, all the principal parties—designers, owners, contractors, and sub-contractors—should clearly understand the scope of design work involved in construction projects, and the assignment of responsibilities and tasks. Agreement should be reached on the budgeting of adequate fees to pay for the necessary services. Scope-of-work agreements seek to allocate and assign tasks properly, and to budget adequate fees to do what is needed.

Lack of agreement early in a project’s life may increase the likelihood of omitting tasks, budgeting insufficient funds for necessary design services, or making other compromises that can adversely affect building quality and seismic performance.

In negotiating such agreements, architects and engineers are encouraged to educate owners on the benefits of retaining design teams to observe construction and review implementation of design, in the interest of achieving good structural results through effective quality control.

Reducing the likelihood of future claims is another valuable benefit.

Scope-of-work agreements can be based on guidelines such as those in Table 3. Use of such guidelines in negotiating agreements may assist design professionals in their efforts to convince owners that providing for modest additional amounts of professional time during design and construction may yield large dividends in the long run. Scope-of-work agreements could also be valuable tools for architects to use in defining and clarifying their roles in design and construction.

The architectural and structural engineering professions should be encouraged to develop and publicize the availability of reference guidelines such as those suggested in Table 4. RAJUK, IAB, IEB, PWD should be encouraged to promote use of such guidelines by practicing professionals wherever appropriate, adapted to the unique circumstances of individual projects.

Owners should be encouraged to retain architects and engineers to monitor the construction processes in all projects. In negotiations with owners and builders, design teams should be encouraged to seek the allocation of sufficient funds to pay for appropriate services to improve the seismic performance of the structures they design, including site review or on-site observation during construction. Where it is appropriate, scope-of-work agreements should be incorporated into building contracts.

Table 6.2: Design Scope-of-Work Guidelines

Design Scope-of-Work Guidelines						
	Activity					
	Design	Corrdinate	Check	Shop DWGS	Sign/Stamp	Field Review
Foundation	SE	A	G	SE	SE	A,SE
Superstructure						
Steel Frame	SE	A	SE	SE	SE	A,SE
Concrete Frame	SE	A	SE	SE		A,SE
P/T Floors	V	SE	SE	SE	V,SE	
Open Web Joists	V	SE	SE	SE	V,SE	
Cladding						
Precast	V	A,SE	SE	SE	V	A,SE
Metal	V	A	SE	A	V	A
Glass	V	A	A	A	-	A

Design Scope-of-Work Guidelines						
Stairs	A,SE	A	SE	SE	V,SE	A,SE
Elevator	V	A	SE	A,SE	V	A,SE
Ceilings	A	A	SE	A		A
Equipment	V	A	SE	A	V,SE	A,SE
MEP Systems	MEP	A	SE	MEP	MEP	MEP

Note: This table represents a hypothetical project and should not be taken as a suggestion for assigning specific responsibilities, which must be uniquely established for each project.

Key: A = Architect
SE = Structural Engineer
MEP =Mechanical, electrical, plumbing services
V = Vendor or manufacturer of prefabricated components G = Geotechnical Engineer

6.2.8 Peer Review of Architectural Firms

In addition to encouraging use of consistent documentation and procedures, some professions use organizational peer reviews or performance audits to evaluate the methods and procedures of individual practitioners and firms. Project-specific peer reviews may also consider the design and other features of individual projects. In a typical design profession organizational peer review, several experienced architects or engineers spend several days studying a participant firm’s stated policies and procedures, and comparing them to what is actually being done. Because they are effective in improving standards of practice, such organizational peer reviews ought to be used more widely by the design professions.

Some insurance companies already recognize the value of peer review in architecture, offering significant premium reductions as incentives for submitting to a peer- review process, or taking special exams or other actions intended to improve performance. An organizational peer review examines policy holder practices in general management, professional development, project management, human resources management, financial management and business development. They also reimburse its structural engineering policyholders for technical peer reviews that evaluate individual projects, from conceptual design through design calculations, contracts, shop drawing review, and field observation.

The architectural and engineering professions should seek wider use of such incentives by the insurance industry, based on peer reviews and other methods of strengthening standards of practice. Every design firm, whether a one-person firm or a 100-person firm, has something to gain from an objective review of how their business is managed. Peer review offers the valuable opportunity to gain insight into how business practices and management techniques are working and how they could be improved. Peer review audits should include examination of seismic design practice, professional interaction between architects and engineers, and use of the guides and procedures suggested in this report.

6.2.9 Testing and Licensing Architects

The exam should specially be formulated to include seismic concerns that architects designing in earthquake regions should know about. The exam specifications should be rewritten to ensure inclusion of questions demonstrating that those admitted to the profession qualify for a minimum standard of seismic practice.

IAB should continue to take all reasonable steps needed to ensure that all who successfully complete the architectural licensing process authorizing practice in Dhaka City possess high levels of seismic awareness and competence. It is imperative that all candidates who acquire licenses for practice in Dhaka City be properly tested for knowledge of the principles of good seismic design.

6.2.10 The Potentials of Architectural Education

Dhaka is susceptible to earthquake hazard, so architectural education in this state should be given special attention to good seismic design. It is in the public interest that all architecture students who graduate with a professional degree and enter the profession should be familiar with the principles of earthquake-resistant design.

6.2.11 Enhance and Strengthen Architectural Academic Program

Architecture and engineering are considered distinct professions globally and follow separate educational careers. For best results, however, practicing architects and engineers need to work in close collaboration. Through joint programs, schools of architecture and engineering can promote early development of architectural students' understanding of architect-engineer team relationships and responsibilities.

Further, the seismic-design awareness of graduating architecture students' needs to be strengthened. Interdisciplinary programs can educate architecture students in the fundamentals of good seismic design, the seismic consequences of various design decisions, and methods of analyzing structures for seismic resistance. All schools of architecture that prepare students for practice should offer and require adequate instruction in the basic principles of seismic design, where possible in collaboration with schools of engineering.

6.2.12 Enhance Faculty Consciousness to Seismic Design

Architectural school faculty members are not, however, typically well versed in seismic design principles. Moreover the many competing demands on curriculum and teaching time have limited the attention given to the crucial responsibilities of architects for the earthquake resistance of structures they design. Concerted efforts are needed to ensure that architecture school faculty becomes more fully acquainted with the importance of seismic design and the proper role of architects in ensuring the seismic resistance of structures built in earthquake regions.

To this end, symposia and seminars should be developed to familiarize architectural school faculty members with seismic design, emphasize its importance to the architectural profession, and facilitate the introduction of seismic considerations into design studio work. In future recruitment of faculty members for teaching roles in building technology, structures, and construction, candidates' qualifications should include a realistic grasp of seismic design and its importance in architectural practice.

6.2.13 Post-Earthquake Roles of Architects

There are several significant roles architects could play after damaging earthquakes. These roles generally are beyond the training and experience most architects now have, but with appropriate advance preparation they could participate actively. Thus architects could help evaluate the safety of damaged structures, and assist recovery and reconstruction efforts. By involving themselves in these roles, architects can also improve their professional knowledge of seismic safety and building vulnerability.

6.2.14 Rapid Screening and Evaluation of Damaged Buildings

Moderate or large earthquakes in urban areas may place heavy demands on the design and construction professions. Damaged buildings must be identified and screened to guide decisions on the safety of continued occupancy and the need to post some structures as unsafe. The demand for rapid screening and the urgent need for shelter may require help from a broad segment of the design and construction professions.

Previous earthquake experience, good advance training, or both, are essential for proficiency in post-earthquake screening and evaluation.

Architects can also acquire the skills needed for effective post-earthquake screening and evaluation. With adequate training, they can make significant contributions to earthquake-disaster response. Participation in training and post-earthquake site visits are excellent ways to increase architects' seismic knowledge, which will also assist them in their regular practice.

Architects and engineers and construction professionals should be encouraged to continue development of appropriate training programs on the rapid screening and evaluation of damaged buildings. The ultimate goal should be a substantial cadre of architects willing, able and qualified to join earthquake-damage assessment teams in responding to future earthquake disasters.

6.2.15 Local Cooperation on Recovery and Reconstruction

Following a significant earthquake, damage assessment and environmental impact analysis by teams of architects, planners, engineers, and geotechnical experts can facilitate recovery and reconstruction planning. As team members, architects can help assess a community's architectural and historical resources, and advice on alternative strategies for recovery and reconstruction.

Such disaster response teams do not need to draft precise solutions or plans, but can suggest design themes and generic solutions illustrating concepts for future reconstruction. These in turn can stimulate community action in formulating local reconstruction plans. Perhaps the most important result of such endeavors is the positive psychological impact of looking beyond the immediate destruction toward the future of a rebuilt city.

IAB and IEB should promote measures to strengthen local architects' ability to respond quickly and effectively in helping provide emergency planning and technical assistance. To this end, state and local chapters of the AIA should join with the National AIA Urban Design and Planning Committee, Regional Urban Design Assistance Teams, in developing architects' capacity for early response to major disasters, including earthquakes.

6.2.16 Lessons Learnt from Past Earthquakes

Site visits immediately after damaging earthquakes are probably the best way to enhance architects' awareness of the effects of seismic forces on various kinds of structures and designs. Site visits and post-earthquake investigations can teach design professionals a great deal about the kinds of structures that are vulnerable to failure, as well as those that perform well in earthquakes. Concerted efforts are needed to get more architects to make site visits immediately after damaging earthquakes, and to attend subsequent debriefings. IAB and IEB should work actively to further such efforts, and should recommend membership meetings and chapter media to inform members on the value of post-earthquake site investigations and debriefings. After major earthquakes, the professional organizations and the licensing boards should plan for and sponsor special debriefing workshops for design professionals. A joint venture between professionals and development sector should sponsor and promote the preparation of a book on earthquake damage for use by owners, architects, engineers and other construction professionals. It should contain photographs, graphics and text illustrating and explaining the causes of typical failures, and recommending ways to avoid them

6.3 Conclusion

Exploring architect's consciousness and vulnerability assessment can be a tool of decision making in order to reduce or mitigate earthquake as a hazard. In this study, vulnerability assessment of earthquake in three selected wards of Dhaka City has been explored along with questionnaire survey among architects to assess the vulnerability of the selected zones. It is seen with layers of vulnerability issues that Ward 28-Chawkbazar is more susceptible to earthquake vulnerability than Ward 15-Dhanmondi and Ward 19-Banani as the buildings do not follow any proper codes and guidelines to seismic design issues. Assessing all the attributes come to an understanding that it is mandatory to incorporate seismic deisgn issues in academic years.

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

Earthquake architecture is an approach to architectural design that draws upon earthquake engineering design issues as a significant source of inspiration (Charleson, Taylor and Preston, 2001). Arnold (1996) describes 'earthquake architecture' as the architectural expression of some aspect of earthquake action or resistance in order to contribute architectural enrichment of buildings. These expressive possibilities range from metaphorical and symbolic uses of seismic issues to the exposure of seismic technology. Earthquake architecture helps bridging the gap between structure courses and architectural design studios and facilitates the integration of the two disciplines. By the way, the seismic design issues may be incorporated to the design and the structure courses.

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APPENDIX

ARCHITECT'S RECORD DATA QUESTIONNAIRE

ON SEISMIC DESIGN

Dear Architect, with the given state of recent earthquakes in Bangladesh, it is quite important for architects to be aware to prevent damages that may result to huge loss of lives and properties. This questionnaire in general will allow architects to explore and evaluate the general interest and awareness of earthquake as a hazard and consider their viewpoint and opinion on the phenomena and how to incorporate the seismic design issue into architectural practice.

Name: ____

Name of Firm: ____

Address: ____

Telephone: _______________________________ Fax: ____________________

Registered ID#: ___________________________ Date: __________________

1) Graduation School: ____________________________Passing Year: ______
2) Have you pursued post-graduation education? **YES___/NO___**

   If YES,

   Which university? _______________________________

   Subject: ____________________________________ Passing Year: ______
3) Have you ever designed a building on seismic zone? **YES___/NO___**
4) How long have you been practicing Architecture? **(please tick √)**

   (   ) 1-5   (   ) 6-10   (   ) 11-15   (   ) 15-20   (   ) 21-25   (   ) 26+

5) List the number of current personnel within your/the organization by the following discipline:

___________ Registered Architects

__________ Registered Engineers

___________ Drafters/CAD Operators

__________ Administrative/Clerical

___________ Others (specification writers, estimators, etc)

___________ **Total**

6) How important are the design criteria below to your deisgns **(please tick √ blue empty box below)**

Strongly Not Strongly

Recommend ……………. Recommend

Client Demands	1		2		3		4		5	
Function	1		2		3		4		5	
Aesthetics	1		2		3		4		5	
Environmental Factors (climate, Orientation, topography, etc)	1		2		3		4		5	
Rules and Regulations according to standard codes	1		2		3		4		5	
Architecture-based seismic design issues	1		2		3		4		5	
Others	1		2		3		4		5	

7) How much architecture based design issues influence the seismic performance of a building? **(please tick √ in the box below)**

Strongly Affect	1		2		3		4		5		Negligible Affect

8) How much do the roles and responsibilities of the following competencies matter in seismic design? **(please tick √ in the blue box below)**

Too Too

Much ……….………………… Less

Architects	1		2		3		4		5	

Urban Designers/Planners	1		2		3		4		5	
Structural Engineers	1		2		3		4		5	
Contractors	1		2		3		4		5	
Firm/Organization	1		2		3		4		5	
Others	1		2		3		4		5	

9) As per the Town Improvement Act 1953 (TI Act 1953) Rajdhani Unnayan Kartipakkhya (RAJUK) is the legitimate authority to prepare land use plan and take care of plan implementation, control the development and manage the growth of Dhaka city. Do you think there is any loophole after building construction is completed? **(please tick √)**
YES___/NO___

10) If the answer to question 9 is **YES**, then what is the existence and conscious level of the architects to address the architectural faults as per design codes? **(please tick √ in the bluw box below)**

Too Much	1		2		3		4		5		Too Less

	AGREE		SLIGHTLY DISAGREE		NO IDEA		SLIGHTLY DISAGREE		DISAGREE	
11) Seismic design evolves with the architectural design	1		2		3		4		5	
12) Structural designers are more responsible for seismic design	1		2		3		4		5	
13) Structural designers are more proficient to transform individual buildings into earthquake resistant building in respect to any design	1		2		3		4		5	

dynamics and criteria given by architects										
14) Architects must keep the term ‘Earthquake’ in mind and incorporate into design consideration while designing on seismic zones.	n.		2		3		4		5	
15) Architectural creativity and flexibility might be a problem for architecture-based seismic design issues	1		2		3		4		5	
16) A significant portion of the damages due to earthquakes may result from architectural design faults formed during architectural design process	1		2		3		4		5	

17) What is the importance level of the following architecture based seismic design issues on seismic performance of the buildings according to architects? **(please tick √ in the blue box below)**

Strongly Not Strongly

Recommend ………….……Recommend

Form and geometry	1		2		3		4		5	
Structural configuration	1		2		3		4		5	
Detailing of non-structural architectural Components (infill walls, suspended ceilings, doors and windows and so on)	1		2		3		4		5	

18) Do you think it is important for architects to consult a structural engineer initially and follow seismic guidelines during architectural design phase? **(please tick √)**
YES____NO_____

19) Do you think architects should only rely on structural engineers to make a building earthquake resistant?
(please tick √) YES____NO_____

20) Has there been any occasion where you had conflict with the structural engineer regarding structural issues?
(please tick √) YES____NO_____

21) What should be done to incorporate ‘earthquake’ as a design parameter in architectural practice? **(please tick √, you can put more than one choice)**

( ) Seismic design guidelines should be incorporated into Bidhimala elaborately.

( ) Students should be taught fundamentals of seismic design issues during their education.

( ) Architects and structural engineers should work in mutual coordination during initial architectural design phase.

( ) RAJUK should provide more attention to planning, monitoring and law enforcement when any building is set for plan permission.