Rehabilitation of Buildings damaged due to Earth Quake

A Thesis

of

Bachelors of Engineering in Civil Engineering

Project Supervisor

A/P Amir Faizullah

Submitted by

Muhammad Usman Malik	(2010-NUST-SCEE-BE-CE-122)
Abdul Hanan Mughal	(2010-NUST-SCEE-BE-CE-003)
Usama Zafar	(2010-NUST-SCEE-BE-CE-192)
Taimour Ibraheem	(2010-NUST-SCEE-BE-CE-184)
Haider Ali	(2010-NUST-SCEE-BE-CE-051)

Department of Structural Engineering

NUST Institute of Civil Engineering

School of Civil and Environmental Engineering

National University of Sciences and Technology

Islamabad, Pakistan

This is to certify that the thesis titled

Rehabilitation of Buildings damaged due to Earth Quake

Submitted by

Muhammad Usman Malik	(2010-NUST-SCEE-BE-CE-122)
Abdul Hanan Mughal	(2010-NUST-SCEE-BE-CE-003)
Usama Zafar	(2010-NUST-SCEE-BE-CE-192)
Taimour Ibraheem	(2010-NUST-SCEE-BE-CE-184)
Haider Ali	(2010-NUST-SCEE-BE-CE-051)

Has been accepted towards the partial fulfilment

of

the requirements

for

Bachelors of Engineering in Civil Engineering

____

A/P Amir Faizullah

School of Civil and Environmental Engineering

National University of Sciences and Technology

Islamabad, Pakistan

Abstract

Any structure can take limit amount of load or stress and it fails beyond that. Structural failure can be caused by different reasons and Earth Quake is one of them. Earth Quake damages the building when Earth Quake loading is greater than its design strength. Once the building is damaged, it either collapses or loses the serviceability and safety and the building cannot be used for the purpose it was made for. The serviceability and safety can be restored and this process is called rehabilitation of building. The process of rehabilitation involves different Engineering techniques. The choice of technique depends upon nature and amount of damage and cost available to restore the strength and sometimes the time available to repair the facility. This project is basically covering the details on common techniques that can be applied for rehabilitation of concrete and masonry buildings. These buildings can be residential, commercial, industrial or government facility. Each structural component in the building has its own techniques of repairing. Hence the major scope is to enlist and explain the engineering solutions through different statistical, theoretical and practical analysis.

Contents

List of Figures

List of Tables

Acknowledgement

First of all we are thankful to Allah Almighty for helping us out throughout the project and completion of degree.

We express our sincere thanks to Associate Dean NICE, for providing us with all necessary support that helped us achieve maximum productivity during project.

We place on record our gratitude to HOD Structures and our supervisor of project for their constant encouragement and valuable guidance.

We are thankful to our fellow classmates for their support and encouragement and also we thank our parents for they supported us throughout or years of education, both morally and financially.

Dedication

We would like to dedicate this thesis to our beloved parents. Without their support we would not have completed the project or even undergrad program. They have always supported us financially and morally.

Chapter 1 **Introduction**

1.1 Introductory Remarks

Pakistan is located in the region which is highly vulnerable to seismic activities. Pakistan lies on seismic fault line which divides the area in such a way that half of it lies in Eurasian plate and other half lies in Indian plate. Earthquake zones may be considered to be regions on a map where earthquakes historically occur in clusters.

In Pakistan, almost all the structures are designed against the gravity loads and lateral loads are neglected. When earthquake comes, it applies lateral forces on the structure. These lateral forces results in the decrease of stiffness of the structural members. As a result structure deforms due to these forces and may collapse. So there is a need to design buildings against lateral forces also.

Damage due to earthquake is comparatively much larger than any other source of demolition. Loss of lives and property is very large. Past earthquakes in Pakistan resulted in great loss of lives and property as well. The 2005 Kashmir earthquake has taken 100,000 lives and 400,153 buildings were destroyed. The total economic loss was approximately $5.2 billion. Pakistan codes provide only the seismic provisions on the design of the new buildings but still there is no work done on the assessment of seismic vulnerability of existing buildings in Pakistan.

Retrofitting is the technique by which the existing structures can be made more resistant to seismic activity or soil failure due to earthquakes. Retrofitting can be done by using fibre-reinforced polymers, fibre reinforced concrete and high strength steel, FRP jacketing, Base isolators etc. Retrofitting is the technique by which we can make a structure earthquake resistant. There is a little work done so far in Pakistan on retrofitting. There is a great need that retrofitting techniques should be included in Pakistan Building codes.

1.2 ProblemStatement

On the basis of the previous earthquakes and the extent of the damage by those earthquakes, there is a terrible need of applying such techniques by which we can make structures resistant against earthquakes. The main problem is that no useful data on retrofitting techniques is available and also it is difficult to apply analysis on the damaged buildings rather than to design a new structure resistant against earthquake.

1.3 ResearchAims and Objectives

Research aims of this study are to calculate the seismic vulnerability of existing structures and to apply the retrofitting techniques to improve the performance of structure against the earthquake forces. Our main objectives are:

1) Literature review of earthquake causes and theories
2) Literature review about seismicity of Pakistan
3) Literature review of types of failures occurred during earthquakes
4) Retrofitting techniques used all over the world
5) To design a hypothetical building against gravity loads using ETABS.
6) To assess the damages and suggesting suitable techniques for damages.

1.4 OutlineofResearch Work

Research work of this project is divided into chapters. Literature review is discussed in Chapter 2. In this chapter, we have discussed about the basic concepts of earthquakes. We have also discussed the causes of earthquakes and the theories involved in explaining the earthquake causes.

In Chapter 3, we have discussed about the seismicity of Pakistan. This chapter also presents information about the geology of Pakistan and fault lines in Pakistan. Information about major earthquakes in Pakistan and earthquake hazard zones are also covered in this topic.

In Chapter 4, impact of damage on different buildings is studied. Different types of failures of buildings are also discussed in this chapter.

In Chapter 5,different types of methods and techniques of retrofitting are discussed that makes structure earthquake resistant.Techniques used for rehabilitation of beams,columns,slabs and walls are discussed separately.

In Chapter 6, modelling of frame and design of its beams and columns are discussed in detail. Discussion includes building geometry, applied dead and live loads, material properties, pre-design analysis, design and the detailed results. Reinforcement details of beams and columns are also included.

In Chapter 7, all the analysis and modelling details performed on ETABS and CSI Column are discussed in detail. The results of the analysis are also shown in that chapter.

Chapter 8 finalizes the research work in which the damage report for that building is included and recommendation for use of proper rehabilitation technique is also discussed. Other solutions which can be used are also included in this chapter.

Chapter 9 concludes the project report and further gives recommendation what else can be helpful while rehabilitating the buildings.

Chapter 2 **Introduction to Earth Quake**

2.1 Earth Quake

A shaking of the ground caused by a sudden release of energy that is stored in the rocks beneath the surface of the earth is known as Earth Quake.

Sudden release of energy through the earth's crust in the form of seismic waves cause vibrations in the Earth which causes Earth Quake. Tension builds up within the crust as conventional forces in the mantle and try to move the plates above but is prevented from doing so by friction between plates. When friction is overcome, an earthquake occurs.

Focus

Origin of earthquake or rapture in crust is called Focus. It is also called hypocentre.

Epicentre

The point directly above the focus, located on Earth Surface is called Epicentre. Measuring Earth Quake (Scales):

The strength, or magnitude, of the shockwaves determines the extent of the damage caused. Two main scales exist for defining the strength:

- Mercalli Scale
- Richter scale.

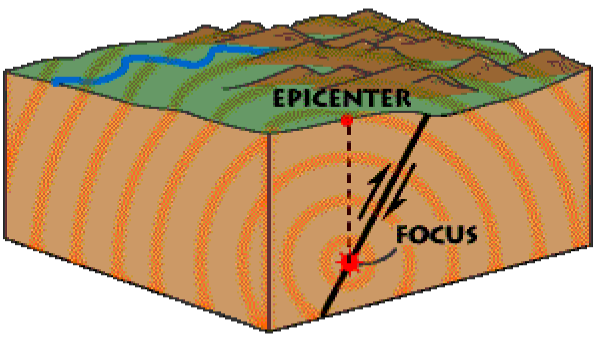


FIGURE 2-1 FOCUS AND EPICENTRE

2.2Seismology

It is the study of earthquakes and seismic waves that move through and around the earth.

2.2.1Seismic waves

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.

2.2.2 Types of Seismic Waves

The two main types of waves are body waves and surface waves.

- Body Waves
    - P Waves
    - S Waves
- Surface Waves
    - Love Waves
    - Raleigh Waves

2.2.2.1 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. It is further divided into two types:

- P waves
- S Waves

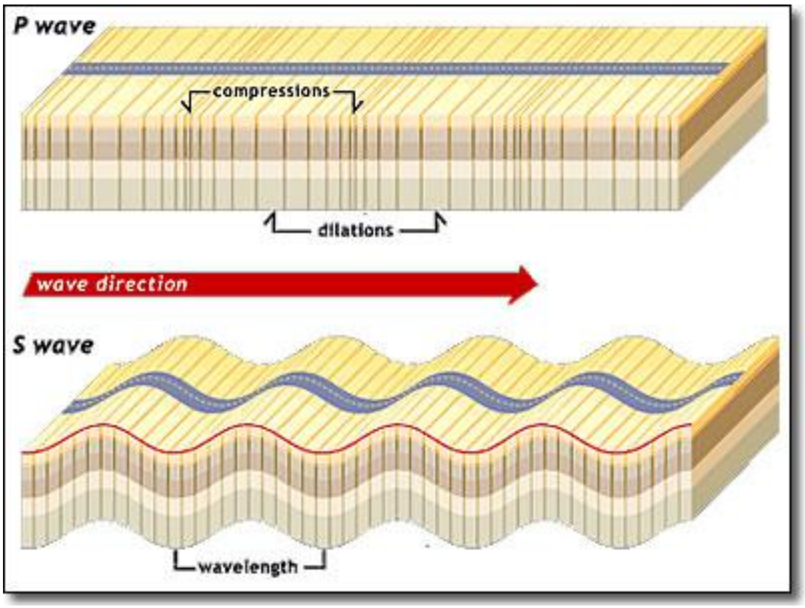


FIGURE 2-2 THE BODY WAVES

P Waves

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. P waves are also known as compressional waves, because of the pushing and pulling they do. Subjected to a P wave, particles move in ‘direction of wave propagation'.

S Waves

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 of wave propagation. They are also called Shear Waves. That’s why they travel only through solid. Fluids do not have shear strength.

2.2.2.2 Surface Waves

They are of a lower frequency than body waves, and are easily distinguished on a seismogram as a result. Though they arrive after body waves, it is surface waves that are almost entirely responsible for the damage and destruction associated with earthquakes.

Surface Waves are of two types.

- Love Waves
- Raleigh Waves

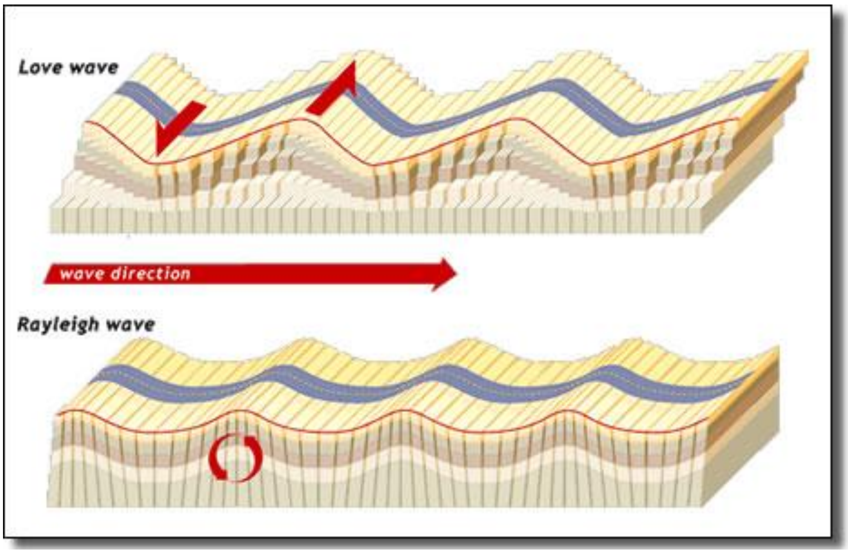


FIGURE 2-3 SURFACE WAVES

Love Waves

They are named after A.E.H. Love. 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

Raleigh Waves

They are named after John William Strutt, Lord Rayleigh. 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 of propagation. Most of the shaking felt from an earthquake is due to the Rayleigh wave, which can be much larger than the other waves.

2.3 Causes of Earth Quake

There are two main causes of earthquakes.

1) Firstly, they can be linked to explosive volcanic eruptions; they are in fact very common in areas of volcanic activity where they either proceed or accompany eruptions.
2) Secondly, they can be triggered by Tectonic activity associated with plate margins and faults. The majority of earthquakes worldwide are of this type.

Volcanic Earth Quakes

They are triggered by the explosive eruption of a volcano. They are very rare because not all volcanoes cause earthquakes, most of them are quiet.

Tectonic Earth Quakes

Tectonic earthquakes are triggered when the crust becomes subjected to strain, and eventually moves. It is explained in Elastic Rebound Theory and Plate Tectonic Theory.

2.4 Elastic Rebound Theory

From an examination of the displacement of the ground surface which accompanied the 1906 earthquake, Henry Fielding Reid, Professor of Geology at Johns Hopkins University, concluded that the earthquake must have involved an "elastic rebound" of previously stored elastic stress.

If a stretched rubber band is broken or cut, elastic energy stored in the rubber band during the stretching will suddenly be released. Similarly, the crust of the earth can gradually store elastic stress that is released suddenly during an earthquake.

This gradual accumulation and release of stress and strain is now referred to as the "elastic rebound theory" of earthquakes. Most earthquakes are the result of the sudden elastic rebound of previously stored energy.

2.5 Plate Tectonics

2.5.1 Theory

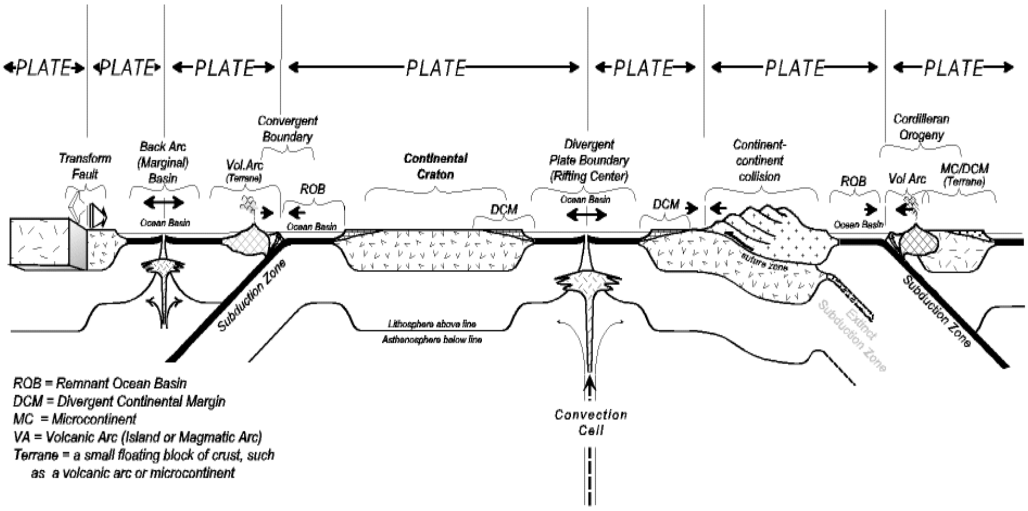


FIGURE 2-4 ELASTIC REBOUND THEORY

Plate tectonics is the theory that the outer rigid layer of the earth (the lithosphere) is divided into a couple of dozen "plates" that move around across the earth's surface relative to each other, like slabs of ice on a lake.

Diagram can be understood by;

1) Continental craton (stable continent) in the middle of the figure.
2) The line under the craton; that is the lower boundary of the plate.
3) Everything above line is part of lithosphere and below is asthenosphere
4) Within the asthenosphere are convection cells, slowly turning over hot, plastic rock.
5) The convection cells bring heat from the earth's interior out to the surface, but slowly. Movement is about 10 centimetres a year.

When the convection cells reach the base of the lithosphere they release heat to the surface at the divergent plate boundary to escape to space. The cooled plastic rock then turns sideways and moves parallel to the earth's surface before descending back into the earth at subduction zones to become reheated. It is this turning over of the convection cells the drives the plate movements.

2.5.2Tectonic Plates

Giant interlocking slabs of rock that make up Earth’s rocky outer layer, or crust are known as Tectonic plates. As they move, the plates pull apart from, collide into, slide against, or slide over or under one another. Sometimes pressure builds up, causing pieces of the plates to shift, releasing energy that can cause the ground to shake violently. Plate movement can cause earthquakes as well as volcanic eruptions.

2.6 Plates of Earth

Depending on how they are defined, there are usually seven or eight "major" plates:

1) African
2) Antarctic
3) Eurasian
4) North American
5) South American
6) Pacific
7) Indo-Australian

There are dozens of smaller plates, the seven largest of which are the Arabian, Caribbean, Juan de Fuca, Cocos, Nazca, Philippine Sea and Scotia.

2.7 Faults

Fault, in geology, a planar or gently curved fracture in the rocks of the Earth’s crust, where compressional or tensional forces cause relative displacement of the rocks on the opposite sides of the fracture.

Faults may be vertical, horizontal, or inclined at any angle.

When rocks slip past each other in faulting, the upper or overlying block along the fault plane is called the hanging wall, or headwall; the block below is called the footwall.

Strike

The fault strike is the direction of the line of intersection between the fault plane and the surface of the Earth.

Dip

The dip of a fault plane is its angle of inclination measured from the horizontal.

2.8Types of tectonic plate boundaries

There are 3 primary types of Tectonic Plate boundaries:

1) Divergent boundaries
2) Convergent boundaries
3) Transform boundaries

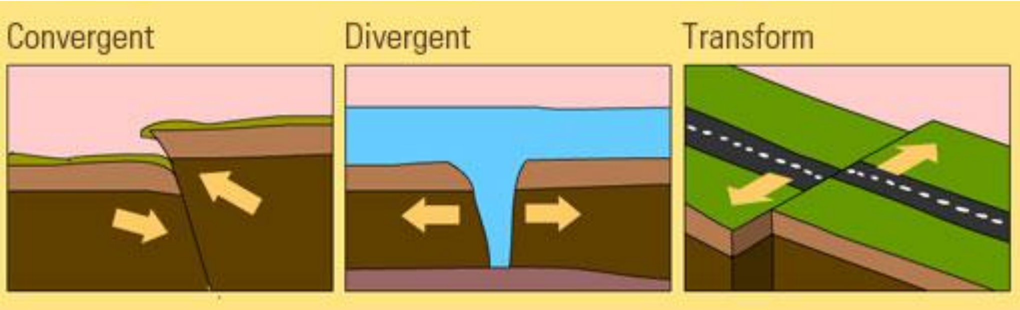


FIGURE 2-5 TECTONIC PLATE BOUNDARIES

Divergent Boundaries

At divergent boundaries new crust is created as plates pull away from each other. Oceans are born and grow wider where plates diverge or pull apart.

Convergent Boundaries

At convergent boundary crust gets destroyed as plate push each other. Mountains, cliffs and hills are formed.

Transform boundaries

The plates rub against each other neither push nor does pull take place. Ridges are developed.

2.9 Types of Faults

Major types of faults are:

- Strike Slip
- Dip Slip

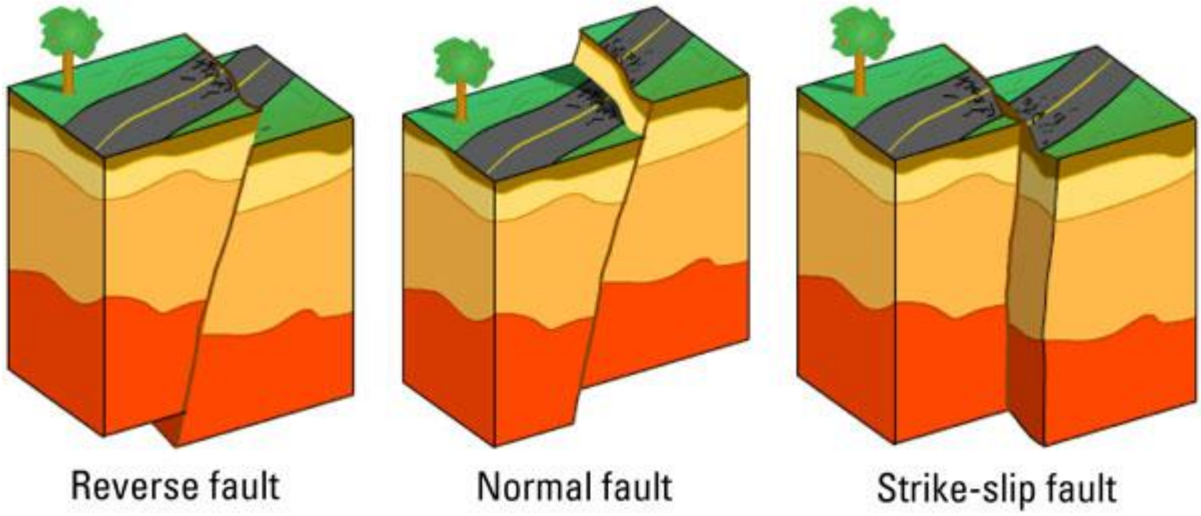


FIGURE 2-6 TYPES OF FAULTS

Dip Slip faults

Dip Slip faults can be normal or reverse.

Normal faultsform when the hanging wall drops down. The forces that create normal faults are pulling the sides apart, or extensional.

Reverse faultsform when the hanging wall moves up. The forces creating reverse faults are compressional, pushing the sides together.

Together, normal and reverse faults are called **dip-slip faults**, because the movement on them occurs along the dip direction—either down or up, respectively.

Strike-slip faults

Strike Slip faults have walls that move sideways, not up or down. That is, the slip occurs along the strike, not up or down the dip. In these faults the fault plane is usually vertical, so there is no hanging wall or footwall. The forces creating these faults are lateral or horizontal, carrying the sides past each other.

Strike-slip faults are either right-lateral or left-lateral.

Chapter 3 **Seismicity of Pakistan**

3.1Abstract

Pakistan is the region which is highly active in earth quakes due to high density of faults. Tectonically Pakistan lies in three tectonic plates, i.e. Indian, Eurasian and Arabian Plates.

In North are converging plates i.e. Eurasian and Indian forming Himalayas. But in West these plates are transforming. However in South, Arabian and Eurasian plates are diverging. Major events like Quetta 1935 and Kashmir 2005 caused great life-loss and infrastructural damage. So government of Pakistan developed measure against seismic activities. Early Warning System for Tsunami has been established.

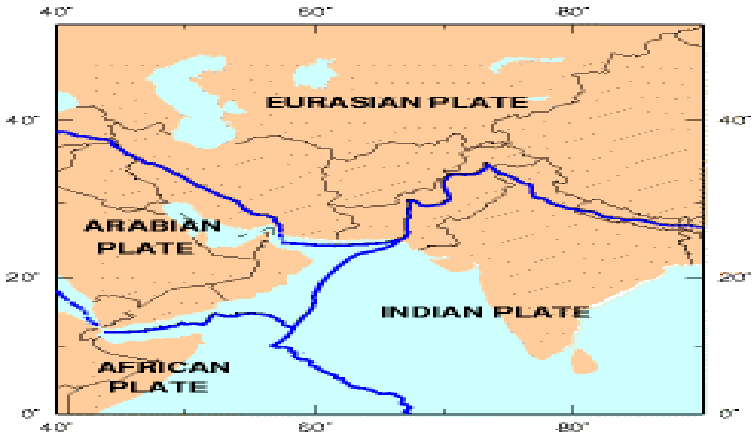


FIGURE 3-1 TECTONIC PLATES OF PAKISTAN

3.2Introduction

The Indian plate is moving 1.6 inch every year towards Eurasian plate causing uplift of Himalayas and Karakorum. This thrust has caused so much compression in this zone that major thrust line lies in this area. Most of the earth quakes occur in these northern and north western areas of Pakistan with Iranian and afghan micro plates.

At southern side lies wide Makran coast and industrial city of Pakistan i.e. Karachi. Makran coast is active subduction zone with relatively high seismic rate. It has been site of largest earth quake of Pakistan in November 1845 with magnitude of 8.1.

3.3Geology of Pakistan

The collision of Indian Plate with Eurasian plate which started 40 million years ago has very active folds and thrust wedges. These zones start from Kashmir, Salt Ranges and Makran Coast.

In North part of Himalayas are North Tibet and Central Asia. Karakorum is subdivided into 4 parts, Main Karakorum, Central Karakorum, Hindu Kush and Turn block. In Pakistan several segments of Himalayas have active boundaries.

Chaman fault is major fracture zone in Kalat to Makran that passes Quetta and enters Afghanistan. The fault of Arabian Sea is known as Owen fault zone and Omach-Nal fault.

In west, Pakistan lies Chaman and Chilton fault. They lie near Lorali ranges and Zhob near Quetta.

120 km of area near Chaman fault is creeping 20m/year. In Kirthar ranges the seismic activity is comparatively low.

3.4 Coastal areas of Pakistan

Makran coast is major fault in this zone. This joins the Indian and Arabian plate. The faults are mostly E-W trending in nature. The length of Makran coast thrust fault is 225 km. It lies in Ormara and Pasni.

This diverging fault forms best exposed arch-trench gap forming the sea ward part of folded and faulting accretionary sediment prism and fore-arc basin resulted from active north ward subduction of oceanic portion of Arabian plate beneath Lut and Afghan blocks of southern margins of Eurasia.

3.5 Fault Lines of Pakistan

The known active faults are divided in two fault groups, the Muzaffarabad fault, northwest of Muzaffarabad and the Tanda fault, southeast of Muzaffarabad.

3.6 Seismictectonics of Pakistan

Most of the earth quakes occur in the northern part of Pakistan and adjoining areas of Punjab which are generated by Hindu Kush ranges. Most of the earth quakes lie within the range of 300 Km. Direction of compressive stress in NNW-SSE.

Hindu Kush and Pamir make one of the most active earth quake zones of the world.

The Punjab thrust and Muzaffarbad trust are due of Jhelum fault. It is left lateral oblique fault and active.

The seismic activity in Kirthar is diffused as compared to Suleman Ranges. Most remarkable seismic activity occurs in Quetta.

In coastal area most of activity occurs concentrated around Makran Coast and northern portion of Omach-Nal and Pub fault. In this fault, numbers of shallow earthquakes have occurred. But no large earthquakes have ever occurred in omach-nal fault.

In Arabian sea, active zone recorded in north of Murray ridge. Also the run of Kutch is characterized by low level seismic activities. Like Bhuj earth quake 2001. Thrust is dominatingly E-W oriented.

3.7 Major Earth Quakes in Area of Pakistan:

Table 3-1 is the list of the major earth quakes occurred in Pakistan after beginning of 20th century

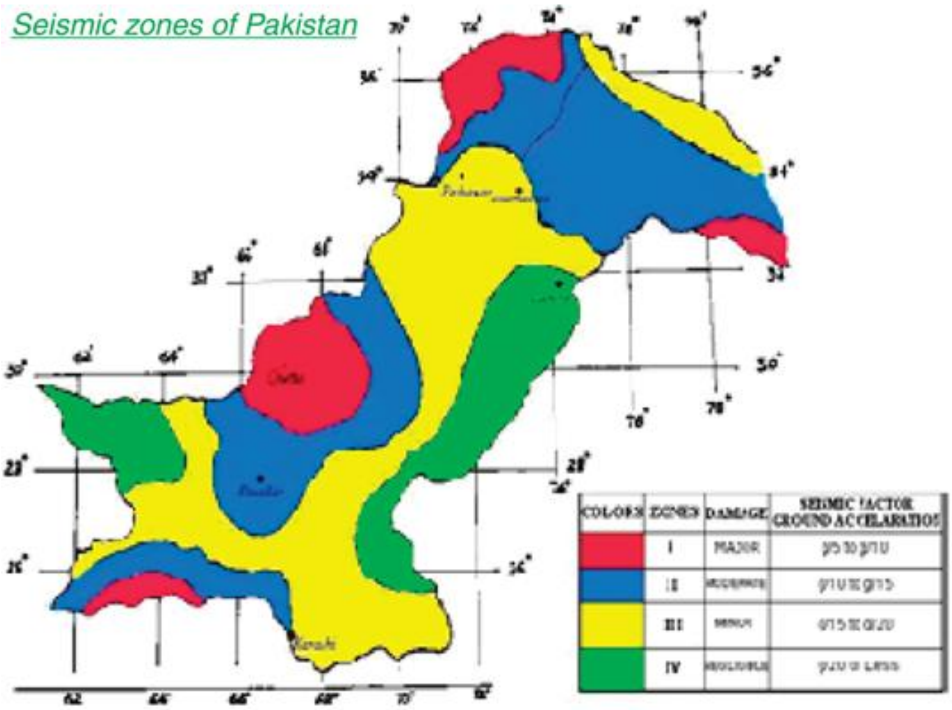
TABLE 3-1

Date, Time	Magnitude	District/Province
1909 October 21	7	Sibi, Balochistan
1929 February 1 at 17:14	7	Sibi, Balochistan
1931 August 24	7	Sharigh Valley, Balochistan
1931 August 27	7.4	Mach, Balochistan
1935 May 31 at 3:02am	7.7	Ali Jaan, Balochistan
1945 November, 28th at 05:26 PST	7.8	Balochistan
1974, December 28, at 12:11 UTC	6.2	Hunza, Hazara and Swat districts; North-West Frontier Province
2005 October 8 at 08:50:38	7.6 or 7.8	Muzaffarabad District, Azad State of Jammu and Kashmir& North-West Frontier Province, Pakistan
2008 October 29 at	6.4	Ziarat District, Quetta

Date, Time	Magnitude	District/Province
04:09		
2013 September 24 at 16:29 PKT	6.8	Awaran, Balochistan

3.8Earthquake hazard zones in Pakistan

Pakistan consists of all zones. The detailed view of Pakistan earth quake zones are shown in the image below



Source: Center Quetta, Meterological Department of Pakistan Geophysical

FIGURE 3-2 SEISMIC ZONES OF PAKISTAN

Chapter 4 **Causes of Damage**

4.1Introduction

Any kind of detriment in the buildings is called damage. The damage due to Earth Quake is simply known as damage due to Earth Quake. Damage to the building may be structural or non-structural.

Structural damage is when structural support is impaired. Eg frame damage, damage to columns, foundation and walls.

Non-structural damage is does not involve any structural support. It includes broken windows rotated or collapsed chimneys etc.

4.2Interdependencies

Damage depends upon:

4.2.1 Strength of Shaking

Greater the strength or magnitude of Earth Quake is, greater the damage will be. For example a 7 magnitude Earth Quake causes more damage as compared to 6 in magnitude.

4.2.2 Duration of Shaking

More the duration is, more vibrations and forces will act upon the structure hence causing more damage.

4.2.3Sub-SurfaceCondition

Soft or submerged strata transfers more force to building as compared to rocky and hard strata.

4.2.4 Type of Building

Type of damaged for reinforced and non-reinforced structures is different. Etc.

4.3Causes of Damages

Following are the major causes of damage in the buildings:

4.3.1 Earthquake induced settlement

The buildings on the soft or submerged strata are more likely to settle as compared to those on harder strata. Settlement can be of very different types.

- Tectonic Surface Changes
- Liquefaction
- Slope Movements
- Tsunami
- Densification of soil
- Settlement due to dynamic loads
- Poor Design Considerations:
- Poor quality concrete: That means lower concrete strength.
- Diagonal Tension Failure
- Short Column
- Lack of proper anchorage at joint (ACI Code recommends 135 degrees for hook)
- Punching failure at slab column joint
- Week Column and Strong Beam
- Lack of confining Steel in columns
- Eccentric Continuous Beams and Diagonal Torsion

4.3.2Torsion

It is due to centre of gravity of building is not located at centre of lateral resistance or centre of rigidity. In such conditions a building rotates about the centre of rigidity causing torsion to the structure.

4.3.3Soft Story

The story in the building that has substantially lesser strength is called Soft Story. Usual location of the soft story is the ground floor because the first floor is usually easily accessible so it has more openings.

FIGURE 4-1 SOFT STORY

4.3.4Pan Caking

It occurs when soft story collapses and structure above it is led to complete failure crushing every story beneath it and at end they are stacked together as pancakes.

4.3.5 Pounding Damage

When two buildings are constructed very close to each other, they move back and forth during earthquake causing collision between them. Usually it occurs when the buildings has different heights causing them to vibrate at different frequencies which causes collision.

4.3.6 Impact Damage due to Collapse of Adjacent Structure

When a building collapses it can cause impact on the adjacent structure. It leads to damage in the adjacent building as well.

4.3.7Asymmetry

It is due to asymmetric shaped structures like shape of L and T etc. Different part of structure vibrate at different frequencies hence pounding affect is generated.

4.3.8 Resonance

When frequency of building matches with frequency of ground shake, the shaking is enhanced and amplitude increases that can collapse the entire structure.

4.3.9 Faulty Construction

Faulty construction occurs when inappropriate material is used for construction. Normally, a building inspector will catch these issues and require the problem to be corrected. However, lax inspections sometimes allow faults to pass inspection. Faults that result in structural failures include bad welds, improper torque used on nuts and bolts, sand that is too salty for concrete, bad riveting and inferior steel.

4.3.10 Bad Foundation

The structure may be designed and built properly but if it sits on a bad foundation, failure will occur. One of the best known examples of a building with a bad foundation is the Leaning Tower of Pisa. Bad foundations cause a building to sink or lean as the earth is displaced underneath it. This displacement alters the stress distribution of the building so the construction and design are changed and no longer meet the necessary specifications.

4.3.11 Liquefaction

Also earthquakes can cause a process known as liquefaction to occur which causes the soil to lose its ability to support vertical loads (a loss of bearing capacity). This can cause subsidence of buildings which can contribute to instability, especially if it is differential subsidence (where one side of the building subsides more than the other).

4.3.12 Failure due to Foundation Settlement

The main cause of failure for most of the buildings is the differential foundation settlement. The differential settlement caused serious cracking of the walls, sagging of the floors and distress to the structural frame due to development of additional moments/stresses. The administration block was among the buildings severely affected due to differential settlement. The administration block is a double story frame structure building with brick masonry cladding. The building is located right at the foot of a hill.

The administration block has two wings, with a front wing parallel and the second wing normal to the approach road. The back portion of the second wing is expected to be supported on the rock/hard stratum, resulting in none to very small settlement. While the front wing, resting on a layer of overburden soil settled more. Serious cracking due to differential settlement and folding of the steps of staircase connecting the two wings was observed. Shear movement of the porch column near was observed. The floor of the entrance lobby, probably supported on a fill showed significant sagging.

4.3.13 Shear Movement of the Structural Columns

Quite large shear movement of the structural columns of the triple story wing of the boys-hostel was observed. The hostel comprises of frame structure with hollow blocks masonry cladding. The hostel has a double story front portion and a triple story back portion. Partial and total collapse of block masonry was observed at most of the points. The front double story portion did not show major signs of distress to the structural frame. But the triple story portion showed serious structural failure due to shear movement of the ground floor columns.

4.3.14 Shear Movement of the Column due to Cold Joint

Shear movement of the top floor column of an under-construction triple story building was observed. A triple story frame structure building with brick masonry cladding was under construction. All the walls were still without plaster. The columns for the third floor without roof top were projecting above the roof of the second floor. Shear movement of the column mainly due to cold joint was observed

4.3.15 Alligator Cracking of the Brick-Masonry

Serious alligator cracking was observed in the brick masonry walls of the campus mosque, mainly due to greater wall length and height and lack of bond with the RCC structural frame. The mosque has a single story frame structure with brick masonry cladding. The spans are quite long with a comparatively higher ceiling level. The relatively long and high walls (9-inches thick) without lateral members (walls) badly cracked and a portion even collapsed. The buckling of main reinforcement at the beam-column joint due to poor quality of construction (i.e., stirrups missing) was clearly visible.

4.3.16 Buckling of main Reinforcement of Columns

The buckling of longitudinal column reinforcement due to lack of stirrups is observed.

FIGURE 4-2 BUCKLING OF COLUMN

4.4Classification of Damages

Following are the four cases with buildings after earthquake:

- Collapsed
- Damaged
- No Damage
- Unclear

According to AIJ and CPIJ 1995, damage can be classified as,

SEVER DAMAGE: IT CANNOT BE REUSED, E.G. CASE OF COLLAPSE.

- Moderate Damage: It can be reused after substantial repair.
- Slight Damage: Little repair needed before using.
- No damage: No repair needed.
- Burned: Building suffering from fire.

4.5Damage Scales

Different scales have been produced in order to understand the amount of damage just like above mentioned classifications.

Following is the table that has different scales:

Name of scale	Organizer	No. of class	Building type
Damage grade	***EMS-98***	6	Masonry buildings
Grade 0:Nodamage Grade 1:Slight damage (Hair-line cracks in few walls) Grade 2:Moderate damage (Fall of large pieces of plaster) Grade 3:Heavy damage (Large and extensive cracks in walls) Grade 4:Very heavy damage (Serious failure of walls) Grade 5:Destruction (Total collapse)			
Damage statistics	**Japan Prime Minister's Office**	4	Wood frame buildings
No damage Moderate damage (A part of building is damaged) Heavy damage (Structural damage cost occupies from 20 to 50% of total repair cost) Major damage (Structural damage cost occupies over half of total repair cost)			
Damage rank	***Architectural Institute of Japan***	6	RC buildings
Rank 0:No damage Rank 1:Negligible damage (Hair line cracks in columns and beams of frame) Rank 2:Slight damage (Shear cracks in non-structural walls) Rank 3:Moderate damage (Shear cracks in columns and beams and in structural walls) Rank 4:Major damage (Spalling of concrete cover, Buckling of reinforced rods) Rank 5:Collapse (Collapse of total or parts of building)			

TABLE 4-1

Chapter 5 **Methods of Rehabilitation**

There are many methods used for rehabilitation of structures. Rehabilitation techniques differ in cost and effectiveness. Each part of the building structure is discussed separately. Different parts of structure are:

1. Slabs
2. Beams
3. Columns
4. Walls
5. Joints

5.1Methods used for Rehabilitation of Reinforced Concrete Slabs

5.1.1 Introduction

Different types of methods are being used to regain the strength of concrete. These methods include steel plate bonding, external pre-stressing, section enlargement, and reinforced concrete jacketing.

5.1.2Strengthening Techniques

In the past different repair/strengthening techniques have been developed in order to strengthen a given structure or a part of it so that its serviceability and strength can be restored. In this section classic repair techniques that have been with some popularity in the past and are still used in the present days are analysed and presented in detail. The techniques include

- Cement grout.
- Ferro cementcovers.
- Section enlargement.
- External plate bonding.
- External post-tensioning.

These techniques are used for the reinforced concrete slabs without cut-outs. In the case of the slabs which present cut-outs or need to accommodate new openings but with strengthening of the slab required there are several common strengthening methods that can be considered. The used method depends on several factors, such as the strengthening required, the location where strengthening is required, and architectural requirements.

5.1.2.1 Cement grout

In the grout pouring technique the existing cracks from the slabs, resulted from the excessive loading, are enlarged in width and in depth until the existing reinforcement is exposed. Before the cement grout is poured into the enlarged extends the exposed reinforcement and concrete surfaces must be cleaned using a steel brush, compressed air and water jet. The grout used in the experiment was a non-shrink premixed high strength cement grout.

FIGURE 5-1CEMENT GROUTING

5.1.2.2Ferro cement covers

Ferrocement is a very thin composite material made up of cement mortar. This cement mortar is reinforced with wire meshes. Wire meshes are uniformly distributed in continuouslayers. They are used to replace the damaged concrete and reinforcement. It helps in improved cracking resistance, flexural stiffness and the ultimate loads.

The steps of applying this technique consist of removing the concrete from the cracked affected zone with the help of a concrete chisel and hammer. After that a layer of galvanized welded wire mesh and a layer of skeletal steel are fixed with the original reinforcement of the slab. The concrete surface must be roughened before the additional reinforcement is placed. The dimensions of the additional reinforcement result from the design and technological restrictions. Finally the cement mortar is applied and left to cure for 28 days.

5.1.2.3Section enlargement

Section enlargement is the method used in retrofitting concrete members. It consists of the placing reinforced concrete jacket around the existing structural member to achieve good performance of concrete structures. The main disadvantages of such system are the increase in the concrete member size obtained after the jacket is constructed and the need to construct a new formwork. With section enlargement slabs can be enlarged to increase their load-carrying capacity or stiffness.

The strengthening by section enlargement can be performed in two ways:

a) Strengthening by adding the new reinforcement and new concrete layer to the bottom of the structural element.

b) Strengthening by adding the new reinforcement and new concrete layer to the top face of the RC member.

It is usuallyconsidered that strengthening by adding new reinforced concrete layer is much easier to be realized when the works are performed on the top face of the member. From practice, it is observed that in many cases it is necessary to add the new reinforced concrete in the bottom face of the member, especially in their positive bending moment's zones. Concreting of the bottom face requires the use of special formwork or can be done by shotcrete.

The stages involved in this method are as follows:

- Removal of the deteriorated concrete
- Corrosion removal from the exposed reinforcement
- Surfaces cleaning and preparation to ensure bonding with the repair material
- Replacement or addition of the supplementary reinforcement
- reinforcement protection (in some cases)
- Application of the repair material.

This method is considered to be a traditional strengthening method. The material costs are relatively low but the cost and consumption of the labour is rather high.

5.1.2.4External plate bonding

It consists of bonding steel plates to the structural elements. The bonding of the steel plates or steel flat bars to the concrete members is ensured by the use of epoxy adhesives and in some cases, additional fastening is provided by means of dowels or bolts glued to the holes drilled in the concrete members.

In the case of RC slabs strengthening, this method is used to increase the member's bending resistance. Therefore, the steel plates or steel flat bars can be applied to the bottom or upper faces of the reinforced concrete slab to ensure the bending resistance (positive or negative bending moments zones). One of the disadvantages of this method is that it can be applied only to the relatively sound structures. In case of severe concrete deterioration and major cracks of the RC member other methods should be considered.

Design procedure is based on general principle concerning the concrete design of glued joints or glue–bolt and glue–dowel joints. The basic assumption is that the integrity of the plate and concrete adhesives interface is maintained and that structural integrity prevails up to the expected pick load.

FIGURE 5-2 EXTERNAL PLATE BONDING

5.1.2.5External post-tensioning

This method is very effective in increasing the flexural and shear capacity of concrete members. It can be applied to reinforced and pre-stressed concrete members. The technique is applied to RC slabs to correct the excessive deflections and cracking. It adds minimal additional load to the structure thus being an effective economical strengthening technique. The post-tensioning forces are applied by means of standard pre-stressing tendons or high-strength steel rods, usually located outside the original section. The tendons are connected to the structure at anchor points, typically located at the ends of the member. End-anchors can be made of steel fixtures bolted to the structural member, orsometimes reinforced concrete blocks. The desired uplift force is provided by deviation blocks, fastened at the high or low points of the structural element. Before the strengthening technique can be applied necessary repairs to the structural members must be performed. The existing cracks must be repaired by means of epoxy injecting or other known methods. If there are existing spalls patching must be done, because this repair must ensure that the pre-stressing forces are distributed uniformly across the section of the member. T

FIGURE 5-3 EXTERNAL PLATE TENSIONING

5.1.2.6 FibreReinforced Polymers (FRP) for Slabs

FRP is a durable replacement to steel in reinforced slabs. The implementation of FRP reinforcement in civil engineering helps to produce sustainable and durable structures.

FRP is sometimes used compositely with Compressive Membrane Action (CMA) toenhance the strength of concrete. Compressive Membrane Action (CMA) is an enhanced strength development which occurs in laterally restrained slabs.FRP reinforced slabs have been designed with excessive reinforcement to avoid catastrophic failure to FRP fracture and also to improve the stiffness of the slab. However using CMA behaviour, the amount of FRP in the slab can be lowered, allowing for the design of economical andhigh performance slabs without compromising strength and serviceability. Introducing FRP reinforcement and incorporating CMA with the FRP reinforced slabs can obtain these three major sustainable achievements.

- Since FRP is a very durable material, unlike steel reinforced structures the FRP reinforced structures will have a longer life span.
- As a result of considering CMA action, it is possible to reduce the amount of reinforcement required for laterally restrained slab without compromising its performance. Therefore fewer resources are used.
- FRP is a light weight material compared to steel reinforcement. Therefore associated energy consumption for mobilization and handling in the site is lower.

The successful development of FRP reinforced laterally restrained slabs is not only advantageous in achieving good structural design but also plays rolein creating a more sustainable world.

5.2Beams

Steel reinforcement takes the tension and concrete takes the compression stresses. Concrete is weak in tension and cannot withstand any sort of tension else it cracks.RCC beams bend and take flexure stresses. Flexure stresses can cause tension or compression failure.

Other type of failure is shear failure due to which we place stirrups in the beam. Spacing of stirrup is decided according to amount of load on it. Stirrups are carefully tied with main and distribution bars.

5.2.1Failures in RCC beams

Failure can mainly be classified into the three types:

1. Concrete failure: Crushing of concrete
2. Steel failure: Yielding by steel
3. Concrete & steel combined failure

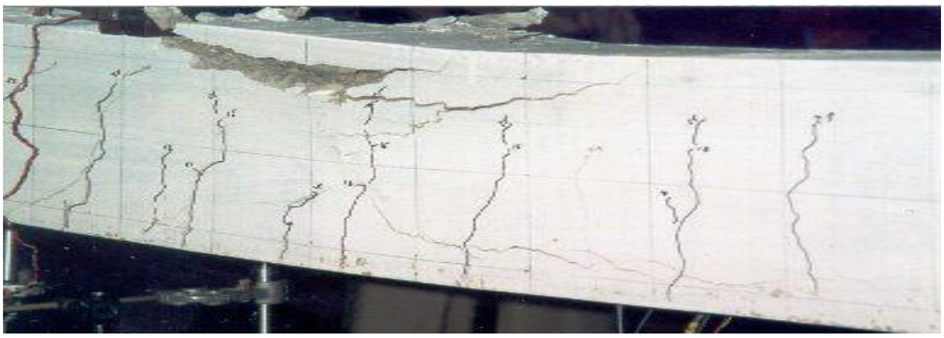


FIGURE 5-4 FLEXURE CRACKS IN BEAM

Failure can originate due to shear or bending. In both cases the strength is lost and the beams collapse. As Earthquake load varies with time and its cyclic load, no one knows how much intense the cyclic load can get and beam may fail if load is beyond the design strength.

Flexure cracks can be identified as they are vertical. Shear cracks are at 45 degrees in the beam.

FIGURE 5-5 SHEAR CRACK IN BEAM

Several methods can be used to restore the moments of the beams (damaged or cracked.) During the earth quake the beam can fail in tension as well as compression. The failure is combined due to moments are shear loading resulting in the diagonal cracks. The basic aim covering the project is to restore the lost strength of the beam.

Concrete Failure or compression failure is brittle and it happens when concrete fails before reinforcement. In this case such types of beams are also called over reinforced. It is not desirable because sudden failure causes life loss and other damages. The beam should not fail without giving warning.

Steel Controlled is ductile failure and this is also called under reinforcement. The yield point of steel is reached.

Balanced or combined failure is the failure in which it is between the brittle and ductile modes. However it is not desirable either completely. There should be little lesser reinforcement to make sure that member fails in steel.

5.2.1Methods to rehabilitate

List of methods that are be described below are:

1. Steel or Carbon Fibre Jacketing
2. Epoxy Resins, Polymer Injection
3. Stitching

4. Concrete Jacketing
5. Additional reinforcement
6. Precast concrete
7. Post tension method

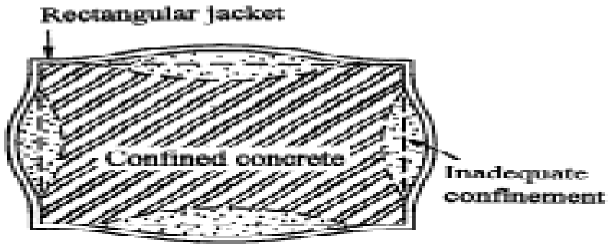
5.2.1.1Steel or Carbon Fibre Jacketing

Covering the beam with the help of L sections or steel plates of plates made up of Carbon Fibre is called Steel or Carbon Fibre Jacketing. It is very effective in shear and flexure damage of the beam. It may be costlier but very efficient. Corrugated sheets may also be used for the purpose.

This method has already been applied in McMaster University to give successful results. This is practical method however very costly. Secondly this method also needs extra space for members so that steel/CF jackets can be fitted in.

Corrugated steel sheets are preferred over the simple steel sheets because corrugated has poison ratio less than normal steel jacket. Also the infill does not bond with steel jacket and lateral confinement will not be effective. According to the investigation, cyclic loading was applied to both plane jackets and corrugated jackets. In case of corrugated steel jacket, dimensions hardly changed and hence lateral expansion was hardly noticeable. There is one problem however that axial rigidity of corrugated jacket is less. The flat sheets bulges out on application of load.

Remove the failed surface and clean it up by washing it up with water. Apply flexible epoxy on it. Place the corrugated sheets of steel or carbon fibre and pour concrete in corrugation of the sheets for proper bondage. Cure for 28 days. The strength is obtained and normal live load and dead can be applied again.



Rectangular section confined by a flat rectangular tube (Priestly *et al.*, 1994)

FIGURE 5-6 CARBON FIBRE JACKETING

5.2.1.2Epoxy Resins (Polymer Injection)

Certain polymers have property for bondage either flexible or rigid. Epoxies are categorized as rigid bondage. They are most common rigid repair used in structures to from monolithic part. This is cheap method of restoration of lesser damaged structures. Cracks narrow as 0.05 mm can be bonded. Commonly used Epoxy is ACI 224.1R. This technique mostly includes drilling holes at close intervals along the cracks, in some cases installing the entry ports. High pressure injection is used but rarely low pressures are used.

Application and limitation

They are being successfully used in bridge and beams repair work. The loading of crack should not be active i.e. the crack should not be active else crack will recur. Rigid Epoxies can be used to repair even bridges. First of all the source of crack should be removed. This technique can't be used if cracks are moistened or leaking. High skill is required for this method. Special consideration should be taken place to overlook the temperature factor.

Procedure (High Pressure Technique)

Majority of the cracks are filled at high pressure of 350KPa or 50 psi. General steps mentioned in ACI 224 IR are:

Clean the cracks that have been contaminated. Oil grease etc. do not let epoxy bond with concrete. This can be done by use of water and then drying the cracks. Air may be blown to dry it out.

Surface should be sealed so that the polymer may not be leak out of the surface. A surface can be sealed by brushing epoxy along the crack and allowing it to harden. In case of very high pressure the cut is made in V shape of 13 mm in depth and 20 mm deep. Then it is filled with epoxy.

Install the entry ports. For this three methods may be used.

a) Drilled holes fitting inserted. It includes drilling holes in the crack of 19 mm in dia and 13 -25 mm deep below the apex of V groove section. A pipe or nipple is inserted and bonded with epoxy. Hydrostatic pressure tests have shown that molded injection ports can withstand pressure of 200 psi before leaks are developed. However surface mounted can withstand pressure of 50-150 psi according to Webster, Kukacka and Elling 1990.

b) Bomb flushed fitting may be applied. When the cracks are not V grooved, this method is used. Fitting flush is inserted with concrete face over the crack. It has hat like cross-section with opening at top.
c) Another system is providing the entry by omitting the portion of seal from the crack. This can be used with special gasket device that can cover unsealed part of the crack and allow injection at same time.

Mix the epoxy which should conform ASTM c881, type 1, low viscosity grade. It can be premixed with batch. Amount of adhesive should not increase. In continuous mixing two liquids pass through metering system and driving pumps prior to passing through automatic passing head.

Hydraulic pumps, paint pressure ports and air actuated guns can be used to inject the polymer in the area. More pressure is, greater will be injection speed. But excessive pressure will enhance the cracks.

If the cracks are vertical then injection should be done in such a way that below level is filled first till it reaches the above level of the cracks. For horizontal it should be started from one side till it ends at other sides.

After epoxy is cured, remove the sealing of the crack. Entry ports should be painted for finishing purposes.

5.2.1.3Stitching

This method is simply stitching the hole perpendicularly. Holes are drilled at both sides and a member perpendicular to the crack is stitched at both sides. That member spans the crack.

Stitching is used to restore the tensile strength in the beam however stitching may cause a crack somewhere else. For this purpose the part which is being drilled, adjacent section must be made strong enough so that it may not crack. Also stitching makes the beam stiff. Stitching does not close the crack. Hence crack should be made water proof by use of polymers.

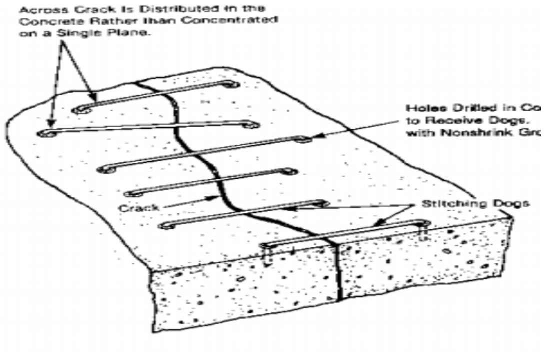


FIGURE 5-7 STITCHING VIA STITCHING DOGS

Procedure

Holes are drilled on both sides of the crack, and holes are cleaned thoroughly. The legs of the dogs as mentioned in the picture are anchored in holes by non-shrink grout or epoxy resin based bonding system. Dogs may be variable in length. They should be applied in such a way that tension is distributed in whole area, not on crack.

Spacing of the stitching dogs should be reduced at the end of the cracks. Holes should be made in such way that the stress concentration is relieved.

If possible both sides of beam should be stitched so that further movements do not bend the dogs. In case of flexure, it is enough to stitch one side only.

Stitching will not close a crack but will prevent further propagation of crack. If there is leakage problem as well, cracks should be closed with sealants.

5.2.1.4RCC jacketing:

RCC Jacketing is done after closing the cracks, by increasing the section of the beam from one to all sides. Reinforcement is provided where cracks are developed. Reinforcements may be taking tension or may be used to counter shear.

It is very cheap method and no special proficiency is required but common concrete laboursersare enough. It affects the aesthetics of the building. It is to be taken care of that reinforcement provided is totally anchored i.e. development length should be provided.

FIGURE 5-8 RCC JACKETING

Procedure

Remove the existing cracked and damaged concrete. Wash the surface. If significant amount of removal is required temporary supports may be applied so that beam does not collapse down.

The cover of the reinforcement is removed, new bars are placed and then concreting is done and afterwards curing is done for 28 days. It is to make sure that concrete has low shrinkage else it adds to stresses in previous beam.

5.3 Walls

There are two types of modes in which damage can occur to buildings.

- The First Damage Mode: Seismic forces act perpendicular to the wall (out-of plane) due to which overturning of the whole wall panel or of a portion of it takes place.
  - Portion of the exterior leaf of masonry sheds.
  - Vertical cracks are formed at the corners of a building where the wall begins to form a hinge from the swaying.
- The Second Damage Mode: seismic forces acting in plane with the wall (in-plane actions) and is usually inclined cracks forming a pattern of X are formed by shear forces. Sometimes due to shear cracks, triangular panels become unstable resulting in total failure of structure.

5.3.1 Out-of-Plane Actions

Building is considered as block. Stiffness of wall is in one direction is more as compared to other direction. The working of masonry walls depends upon how they are anchored between floors and roofs. This out-of-plane action be described by following mechanisms:

- Mechanism rotation out-of-plane of the corner for the interaction of forces acting on the orthogonal walls.
  The structural causes of this mechanism are due to the connections between the external walls, anchoring of the floors to the perimeter walls is insufficient. Another cause is due to the presence of openings close to the edges.

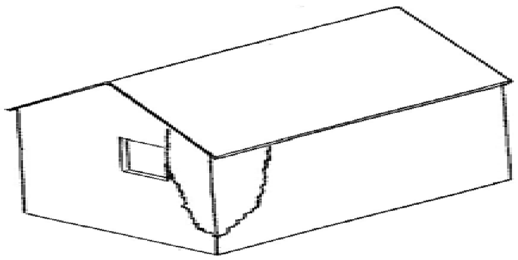


FIGURE 5-9 ROTATION ON CORNER OUT OF PLANE

- Mechanism overturning out of plane of portions of the building

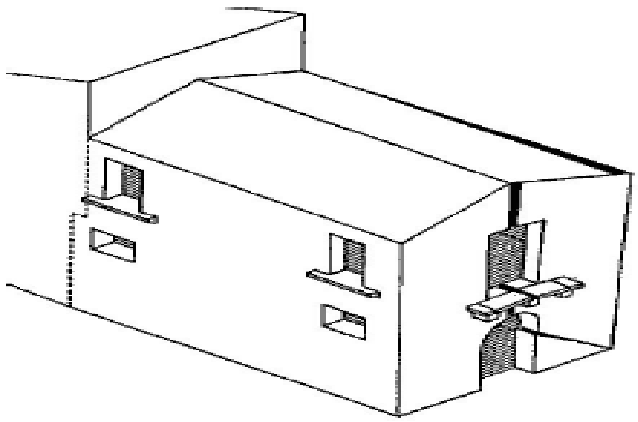


FIGURE 5-10 OUT OF PLANE MECHANISM

- Mechanism rotation out-of-plane of the facade with formation of a cylindrical hinge, with horizontal axes, in correspondence to the ground level of the foundations
- Out-of-plane mechanisms due to the roofmay occur when the roof is not sufficiently connected to the masonry.

5.3.2 In-Plane-Action

In the plane of the walls, bending and shear cause horizontal and diagonal cracks in the walls, respectively.

- Mechanism shear failure of the whole façade may occur when the lintels are weak or masonry band between the openings reduced in height and depth.

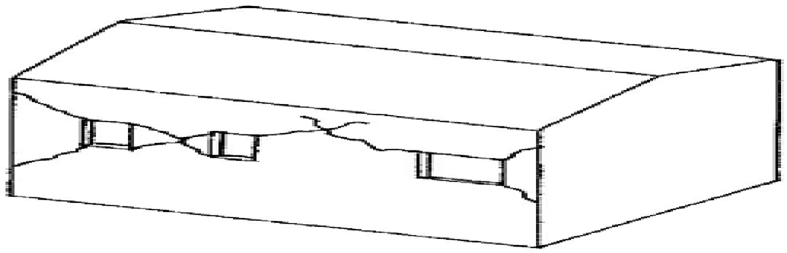


FIGURE 5-11 IN PLANE MECHANISM SHEAR FAILURE OF WHOLE FACADE

- Mechanism shear failure in the wall stressed in its planeoccurs when there are many openings on the facade or discontinuity and low quality in the masonry.

- Mechanism overturning of the masonry walls for rotation in their plane occurs when the openings in soft story are larger in dimensions or in amount, the walls become very slender leading the formation of nearly horizontal cracks or possible crushing of the edge of the masonry.

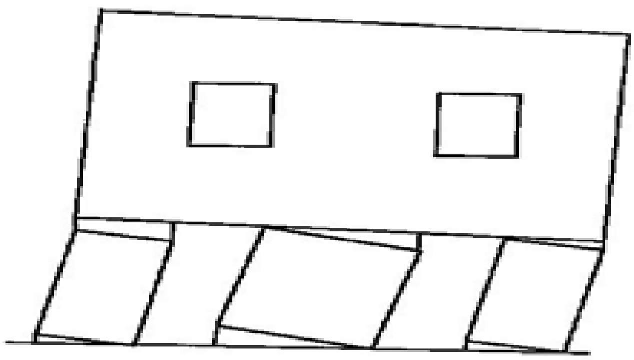


FIGURE 5-12 OVER TRUNING OF WALL

5.3.3 Rehabilitation of Walls

Different techniques are being employed for the rehabilitation of walls. Some of the most common techniques used in rehabilitation are given below:

1) Reinforced Concrete Partition Walls Retrofitted with Carbon Fibre Reinforced Polymer

2) Rehabilitation of concrete structures using Ultra-High Performance Fibre Reinforced Concrete
3) Concrete Jacketing
4) Crack Stitching
5) Epoxy Injection

5.3.3.1 Reinforced Concrete Partition Walls Retrofitted with Carbon Fibre Reinforced Polymer

Carbon fibre reinforced polymer is used to strengthen partition walls that can can't withstand the seismic waves. Practically, it's an effective retrofitting measure. Usually low rise buildings with poor detailing and lightly reinforced partition walls are badly hit by earth. In this case urgent seismic assessment and retrofitting should be done. However, retrofitting of each component of building is quiet difficult and expensive too. By retrofitting these partition walls as the lateral-force-resisting elements, the existing frames can be treated as members that are not proportioned to resistsismic forces. This retrofitting strategy may palliate the strength and deformation requirements of a non-ductile RC frame. Due to reduced cost, the retrofitting of the existing buildings with non-ductile frames is feasible.

The repair of damaged reinforced concrete members by the bonding of CFRP laminates is becoming popular in the construction industry. CFRP has following attributes such as high strength, resistance to corrosion, light weight, and ease of handling. The application of the CFRP sheets without anchor system is worthless. For the strengthening of the low-rise walls, the use of the vertical CFRP sheets is more effective than that of horizontal CFRP sheets.

FIGURE 5-13 CFRP RETROFIT ON PARTITION WALL

5.3.3.2 Rehabilitation of concrete structures using Ultra-High Performance Fibre Reinforced Concrete

Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) is used to “harden” those zones where the structure has been exposed to severe environmental and high mechanical loading. Remaining structure retains its original from as they are less effected.

UHPFRC improves the structural performance by enduring protection and resistive properties to existing concrete.

Conceptual idea

UHPFRC is only used to harden only those zones where the building is severely affected. All other parts of the structure remain in conventional structural concrete as these parts are subjected to relatively moderate exposure. The protective and load carrying properties of concrete with the mechanical performance of reinforcement bars increases the stiffness and load carrying capacity with compact cross sections.

UHPFRC is applied as thin watertight overlays on existing reinforced concrete elements as reinforcement layers combined with reinforcement bars, or as prefabricated elements.

5.3.3.3Concrete Jacketing

Sometimes, thickness is increased by adding material to one or both sides of existing damaged wall for design lateral loads.

Increase in thickness increases the shear capacity of wall. It is noticed that when damaged wall is covered from both sides and interconnected to each another through dowels is more effective for regaining strength. Shotcreteing is recommended but cast in place concreting is alsoused. For increasing flexural capacity, new material especially steel reinforcement is put at the boundary elements (Fig.B). The continuous longitudinal reinforcement is made to pass through the floor system to improve the flexural performance of the wall. Shear and flexural capacities are enhanced by increasing the overall thickness of the wall.

5.3.3.4Crack Stitching

Shaped and twisted stainless steel rods are placed and stitched into the masonry across the cracks at almost equal intervals. Cracked wall behaves as a reinforced non-fractured unit. Helical configuration on stitch rods interlocks with the bonding agent that resist the wall movement.

Installation of wall stitching bars

Horizontal cuts are made in the walls along the crack. These cuts are cleansed with water prior to installation. Then grouting is done by high performance shrink-compensated cement. Stitching bars are pushed into the grout and then grouting is done above the bars up to the level of wall. The bars extend up to 500 mm on each side of crack to dissipate loads and disperse them evenly into the wall structure.

Limitation

Stitching method should not be used for “active cracks”. If used for active cracks than proper engineering specifications should be taken into consideration.

5.3.3.5Epoxy Injection

Epoxy injection is also a good technique used to repair the cracks. Though, application method varies with the change of orientation of crack. Accessibility to the cracked surface and the size of the crack must also be considered while using this this method. Epoxy can be injected on either one side or both sides depending upon the accessibility. Epoxy injection helps to restore structural integrity and reduce moisture penetration from concrete cracks of 0.002 in. in width and greater. However, before any concrete repair is carried out, the damage has to access. If it’s an active crack than epoxy injection method is not favourable.

Repair Procedure

- Port installation
- Install the cap seal
- Inject the epoxy
- Remove ports and cap seal

5.3.4 Selection of right material

According to ASTM C 881 for epoxy selection, following characteristics must be considered while selection of epoxy:

- Modulus of elasticity (rigidity)
- Working life
- Moisture tolerance
- Colour
- Compressive, flexural, and tensile strengths

5.4 Columns

Column is a structural element that transmits, through compression, the weight of the structure above to other structural elements below. In other words, a column is a compression member. It transmits the loads from ceiling /roof of slab including its self-weight to the foundation.

5.4.1 Rehabilitation of Columns

Different types of techniques are being employed for the rehabilitation of columns. Some of them are discussed here:

1. Lateral Pre-Tensioning Of Fibre Reinforced Polymers Belts
2. Concrete jacketing

5.4.1.1 Lateral Pre-Tensioning Of Fibre Reinforced Polymers Belts

Column which is the most critical member of most of the structures are reinforced by increasing the confinement of concrete. This follows from the fact that lateral confinement enhances the strength of concrete and increases its ductility. Among the confinement techniques, use of FRP materials is mostly used as jackets/wraps due to their high strength-to-weight ratio.

FRP belts are pre-stressed as to provide more strength to be used in the retrofitting of earthquake damaged columns.

Details of Retrofitting Technique

In this technique FRP belts are pre-stressed using a simple wrench. The technique is as follows: a carbon fibre belt is cut in a desirable length needed for wrapping around the cross section of the column and is impregnated with epoxy resin along only 100 mm lap joint of both cut ends, which is straightened to form a belt. When the belt is wrapped around the column, its ends can be clamped together by passing a solid rod between the eyes of the belt and putting bolts in between to lock them. Thenpre-stressing can be given to the belts by manually screw driving the bolts.

5.4.1.2 Structural Rehabilitation of Columns with Reinforced Concrete Jacketing

An innovative High Performance Fibre Reinforced Concrete is adopted for the strengthening of the analysed column. A jacket of HPFRC having a thickness of 30 mm is considered.

The results from uniaxial tests on HPFRC show a value of 11 MPa for tensile strength. Compressions test on cubic element shows compression strength greater than 170 MPa .In some cases, before this technique is carried out, the loads on the columns need to be removed. To perform this following steps are taken:

- Putting mechanical jacks between floors.
- Putting additional props between floors.

Moreover, in some cases, where corrosion in the reinforcement steel bars was found, the following steps should be carried out:

- Remove the concrete cover.
- Clean the steel bars using a wire brush or sand compressor.
- Coat the steel bars with an epoxy material that would prevent corrosion.

The effectiveness of the proposed technique is evaluated by comparing it by a traditional solution, based on the adoption of a classic R/C jacket. The adoption of an R/C jacket, probably the most used technique for the strengthening of column, has some inconveniences. In particular the jacket thickness is governed by the steel covers (both external and internal).

5.5Joints

5.5.1Introduction

A basic frame structure consists fundamentally of beams and columns and foundations. When this structure is analysed, it is assumed that joints are strong enough to resist the moments and forces induced due to loadings and due to transfer of forces, e.g. from beams to columns.

FIGURE 5-14 JOINT FAILURE

There are 4 basic reasons for requirement of joints:

- The structure cannot be constructed monolithically
- The member is of a limited size and cannot be handled by cranes etc.
- the structure or member on one side of the joint needs to be able to move relative to that on the other
- The design assumptions for the structure or building need the joint at that point so the analysis is simplified.

5.5.2Types of joint failures caused by an earthquake

Seismic loading is very critical to joints and if they are not designed effectively, they might be the first thing to fail in the event of an earthquake. Different joints fail differently, but our focus will be on beam-column joints and isolation joints due to the limitations of our project.

Beam-column joint

This joint should fulfil the following requirements

- It should exhibit a service load performance equal to or greater than the members it joins so that under seismic load the structure should not fail because of joint failure
- It should be able to sustain the most adverse load combinations that the joining members can sustain repeatedly
- The joint should not hinder the strength of the joining members

Usually this joint fails to provide the strength equal to that of the joining members. When the connection between the members is weakened, the building collapses.
A possible remedial measure could be to construct a small column to prevent the beam from collapsing.

Isolation joint

This joint usually fails because the bonding material joining the adjoining members fails.

Internal joint:

Internal joints can fail due to

1) Shear failure
2) Anchorage failure of bars, if present
3) Bond failure of the beam and column passing through the joint

Chapter 6 **Design of Proposed Building**

6.1 Introduction

According to the scope of the project and after relevant analysis of the literature review, we found it best to model a hypothetical building under gravity loads.

The building we proposed is a 3 story building with RCC frame structure. The gravity loads are Dead Loads, Superimposed Dead Loads and Live Loads on the building.

Apart from this we also applied earthquake loading (lateral loads). These loads were incorporated to fail the building by action of earthquake. As the scope of our project covers the rehabilitation of structures damaged due to earthquakes, we will make use of modelling software to analyse the damage and rehabilitate the different damaged components of the building.

Gravity load design is an old technique and is economical as well. No strict provision was available before the 2005 Kashmir earthquake but after the event BCP added special provisions to cater the lateral loads for earthquake resistant design criteria.

6.2 Geometry of the building

The building consists of 3 floors with no basement. The height of the ground floor is 15 feet and the typical story height is 12 feet, hence making it a 38 feet tall building.

The plan of the building is (54’ X 54’) consisting of 3 bays either side at 18 feet from centre to centre.

The slab system consists of 2 way slab as the bending would be dominant in both the directions. The thickness of the slab was calculated using ACI Provisions that comes out to be 6 inches that is fair enough to transfer the loads to the beams under its periphery. The beams in turn transfer the loads to the columns which then finally transfer the load to the footing and hence the

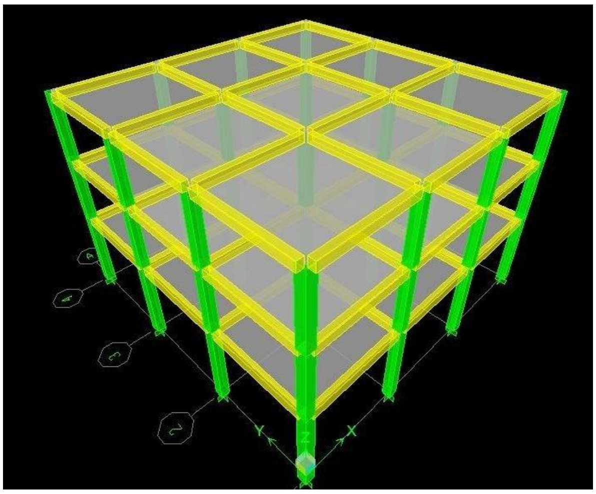


FIGURE 6-1 "3D" VIEW OF FRAME OF PROPOSED HYPOTHETICAL BUILDING

load cycle completes. Since the design of footing was not included in the scope of our project, therefore raft foundation is considered and the columns were modelled as fix end condition.

Shear walls are not included.

6.3 Design Loads

Dead Loads

Dead loads are vertical loads that are present all the time on the building. It is the weight of all the permanent structural and non-structural elements, such as plaster, bricks, floors, roof, finishing works etc.

Following are the dead loads shown in table 6-1

TABLE 6-1

Reinforced Cement Concrete	**150 pcf**

Superimposed dead loads that were applied are shown in table 6-2

TABLE 6-2

Parapet on perimeter beams (roof only)	**400lb/ft**
Wall on all floor beams (except roof)	1000lb/ft
Floor and ceiling loads (finishing etc) including roof	40lb/ft

Live Loads

Live loads vary with the occupancy and intended use of the building. They are the dynamic varying gravity loads that act on the building.

Live load values are given below and we use the loads in the following load combination to obtain a design value of the loads:

This load combination produces the maximum resultant forces and moments and shall be adopted for the design of structural members.

Applied live loads are shown in table 6-3.

TABLE 6-3

Typical story	**100 psf**
Roof	50 psf

Notations

- U - Required ultimate strength for concrete structures to resist design loads or their related internal moments and forces as defined in ACI 318-08.
- D - Deal load
- SID - Super Imposed Dead Load
- L - Live load

6.4 Material Properties

Reinforcement steel

All reinforcing steel used as principal reinforcement, having minimum yield strength of 60,000 psi for columns and 40000 psi for beams. Bar spacing, splices and reinforcement covers shall conform to the ACI 318-08 Code requirements.

Concrete

The minimum compressive cylinder strength of structural concrete for all structural members including columns shall be 3000 psi at 28 days.

6.5 Analysis

For analysis of the building a three dimensional model of the building was developed using the basic structural components. After defining the material properties, the model was subjected to all the dead and live loads. Modeling was done in CSI ETABS. In analysis in plane moments, in plane shear and axial forces were calculated which further helped in designing the members.

6.6 Design

After the analysis was run, Reinforced concrete section designing was run in the software which calculated minimum longitudinal and lateral reinforcement required in the building.

Our proposed building is symmetrical. Hence the structural components' design was consistent. All the beams have the same dimensions and all the columns are the same. Therefore, we design one

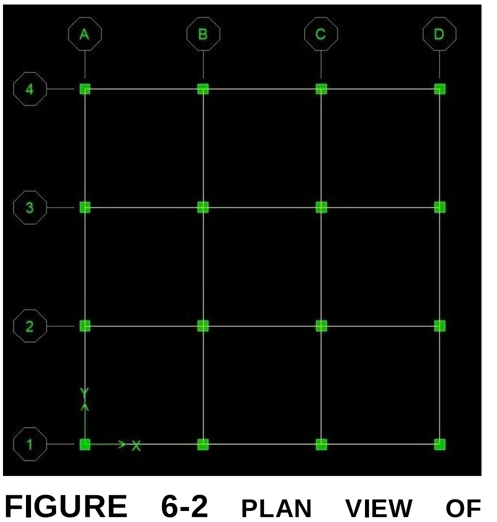


FIGURE 6-2 PLAN VIEW OF BUILDING

column and one beam.

Slab

Since slabs do not play an important part in resisting lateral loads we did not thoroughly design them. The slabs were designed with a thickness of 6 inches. Thickness of slab was important for load calculation only.

The thickness of the slab is: (perimeter/180)

$H_{(min)}$ = (2*(20+20)*12)/180 = 5.33”

$H_{(provided)}$ = 6” (ok)

Beams

We designed the beam cross section based on engineering judgment.

Beam depth = 3 x (slab thickness)

Beam x-section is 12”x18”

Columns

Although the loading on interior columns is greater than that on exterior columns, we kept the dimensions consistent for both types i.e. 18”x18”

We then run the analysis on ETABS in order to see the behaviour of these members under axial loads, bending moment and shear forces. A deflected shape of the building was also obtained.

6.7 Design results

Beams

The design of beams was carried out by following ACI guidelines. The moments were calculated from the software described above and the area of re-bars was obtained by hand calculations. The value of ø would be taken as 0.9 as prescribed by ACI for the members to be designed in flexure.

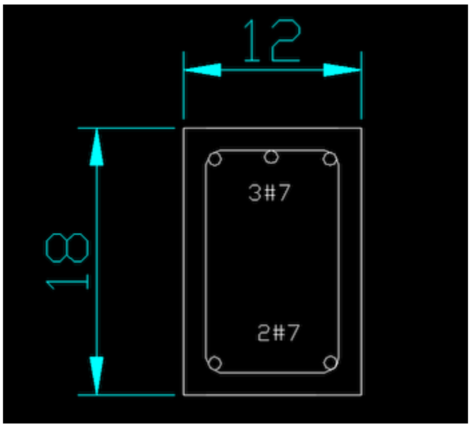


FIGURE 6-3 BEAM SECTION

Columns

Columns are designed as the compression controlled members as the axial forces are more dominant in the columns particularly in the interior columns of any RCC frame structure. However axial loads and the biaxial bending were significant in the corner or edge columns.

All the columns were designed with the same cross sectional dimensions for ease in designing process. Columns are all of 18”x18” and 16 #8 re-bars.

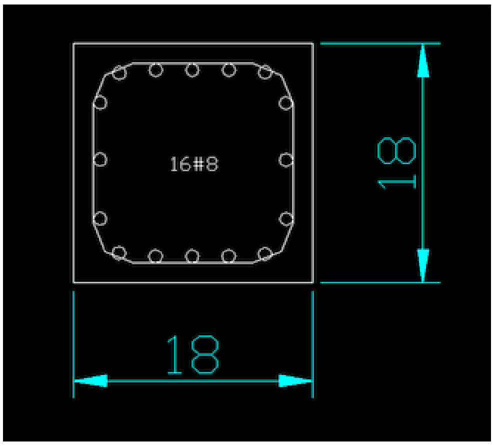


FIGURE 6-4 COLUMN SECTION

6.8 Retrofitted design

Introduction

After the event of an earthquake the strength of a building is reduced. We calculate the loss in strength and modify the section properties of the structural members to rehabilitate the entire structure.

For this NDTs are performed on the building to measure the remaining strength of the building after the earthquake. We obtained these readings from the damage reports of the damaged buildings in Muzaffarad, where a 7.6 earthquake occurred in 2005. With the help of these readings we were able to retrofit the beams and columns.

In ETABS we defined earthquake of 0.4g acceleration which showed us which of the members failed under the earthquake load.

Retrofitting techniques were then used to regain their strengths.

Beam

Beams were retrofitted by applying section enlargement. The beam cross section was originally 12”x18” and after enlargement it was 18”x18”. We added another ‘beam’ on the side of the existing beam of dimensions 6”x18” as shown above in the drawing. This would absorb the extra moment that was initially could not be resisted by the beam.

Column

The columns that failed were also retrofitted using section enlargement. Initially the columns were of 18”x18”. We added another 3” on either side of the column cross section and extra re-bars as shown above in the drawing. CSI column was used to design the column.

The details are discussed in Chapter 7 and Chapter 8.

Chapter 7 **Modelling and Analysis**

7.1 Introduction

Three-story hypothetical building was selected according to local conditions of Pakistan, specifically Muzaffarabad. Pakistan Earthquake zone map clearly shows that Muzaffarabad lies in the area of collision of the Eurasian and Indian tectonic plates where high magnitude earthquakes occur.

In this chapter hypothetical building was modelled and analysed on ETABS. A detailed description of this program and procedure used for the modelling and analysis is being described. Linear analysis was performed on it. Retrofitting techniques were applied and results are compared through various techniques which are mentioned in the forthcoming chapters.

7.2 General Details of RC Structure

Total height of structure is 37 feet and it has 3 bays and three stories as mentioned in design chapter.

Geometric characteristics of the structure are given below:

Bay width is 18 feet

First story height is 15 feet

Typical story height is 12 feet

Concrete strength is 3000 psi

Steel reinforcement strength is 60,000 psi

Cross sections of all the beams and columns are same

7.3 ETABS Analysis

ETABSis very powerful analysis software used to perform static as well as dynamic analysis. It is very advanced multi-functional software which is used to get more precise results and its main feature is that it is used for non-linear analysis and gives more accurate results as compared to other analysis software available in the market.

7.3.1 Modelling

Define Properties

The elements which are used in modelling are beams and columns which are made up of components so in order to model beams and columns we had to define the components in the define tab.

In the define tab, following are the sub tabs which had to be defined in order to define a particular component fully.

Material Properties

In this menu we defined the values of bending and shear reinforcement stresses of beams and columns. For columns, 3000 psi concrete and 60 ksi steel was defined. For the beams, 3000 psi concrete and 40 ksi steel was defined. As we can see in figures below.

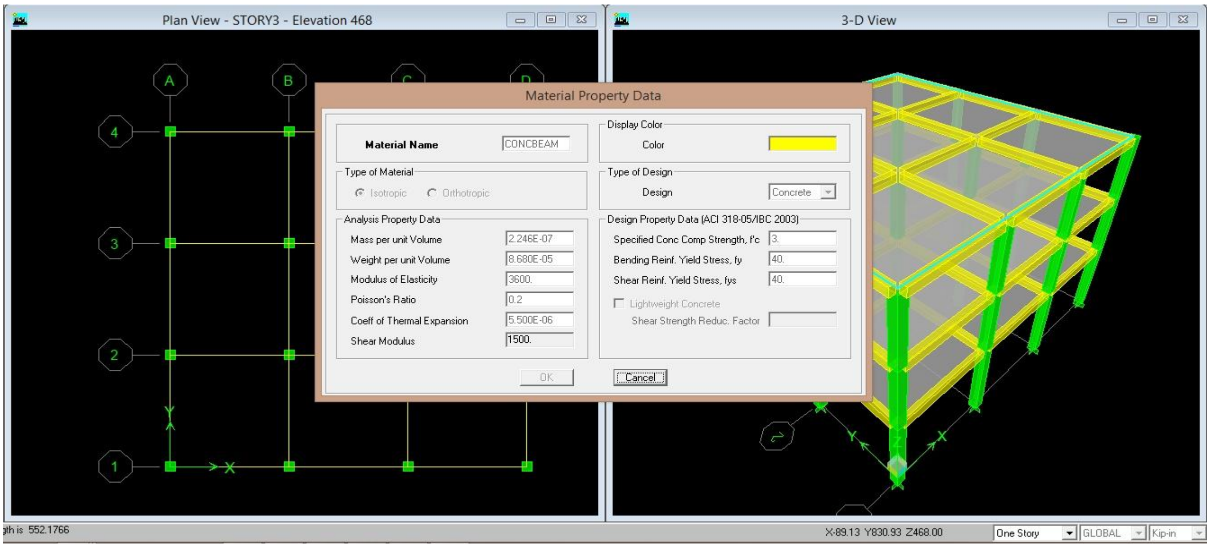


FIGURE 7-1 MATERIAL PROPERTIES FOR BEAMS

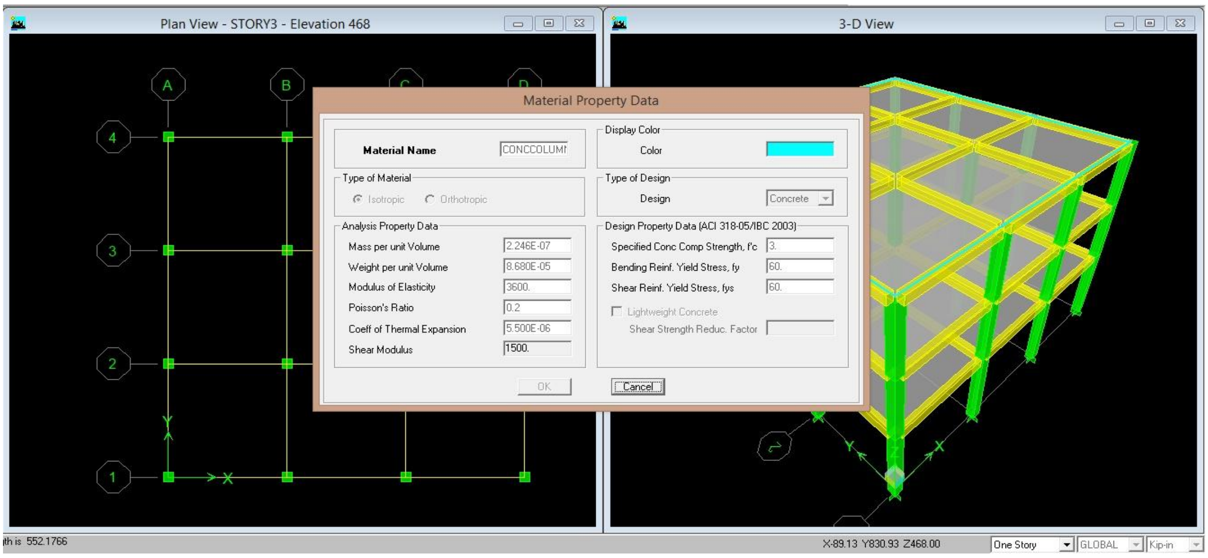


FIGURE 7-2 MATERIAL PROPERTIES FOR COLUMN

Frame properties

In this menu we defined the section properties of beams and columns. The reinforcement was also introduced in this menu. For the beams 12 X 18 was defined with inertia reduction factor as 0.35 and for columns 18X18 was defined with inertia reduction was equal to 0.7. Column was also given 16#8 bars and analysis option was set. In beam design was set. Although the beams have already been designed.

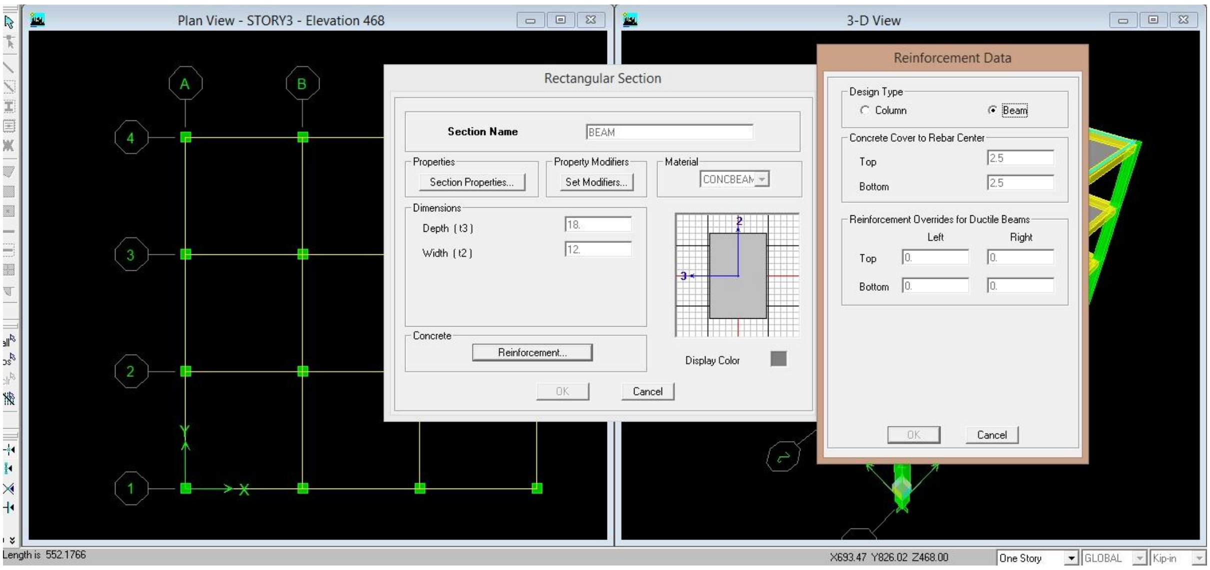


FIGURE 7-3 SECTION PROPERTIES OF BEAM

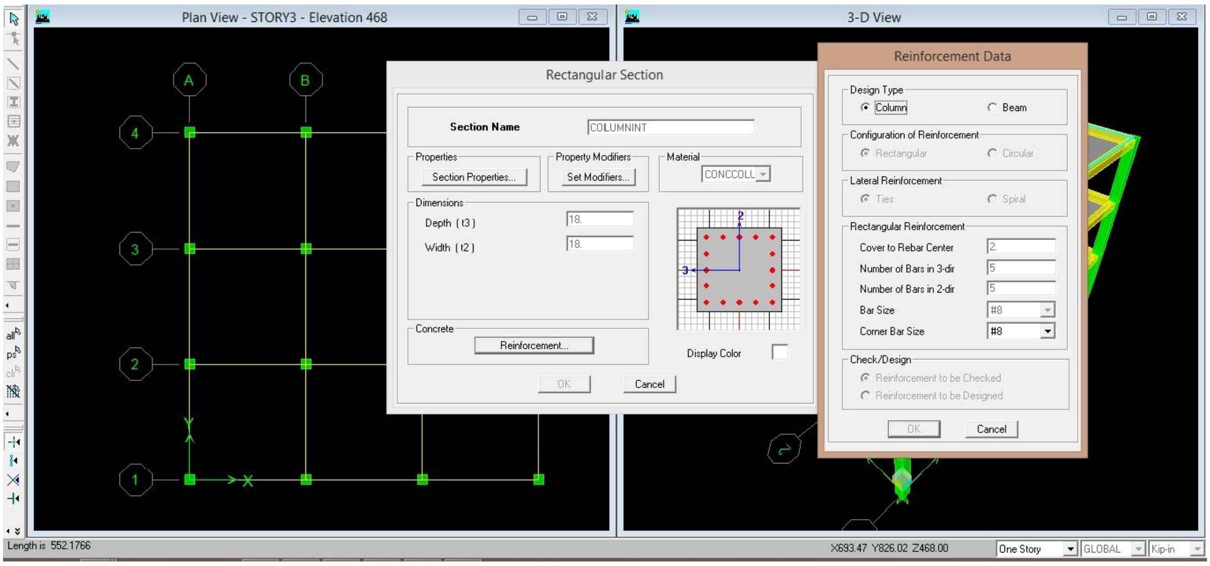


FIGURE 7-4 SECTION PROPERTIES OF COLUMN

Slab properties

Thickness and bending of slab were defined is this section. Thickness was set to 6inch with plate as type of slab.

Static Load Cases

Static load cases are defined in this section i.e. dead load, live load, super imposed dead loads, roof load, earthquake loads along x and y axis.

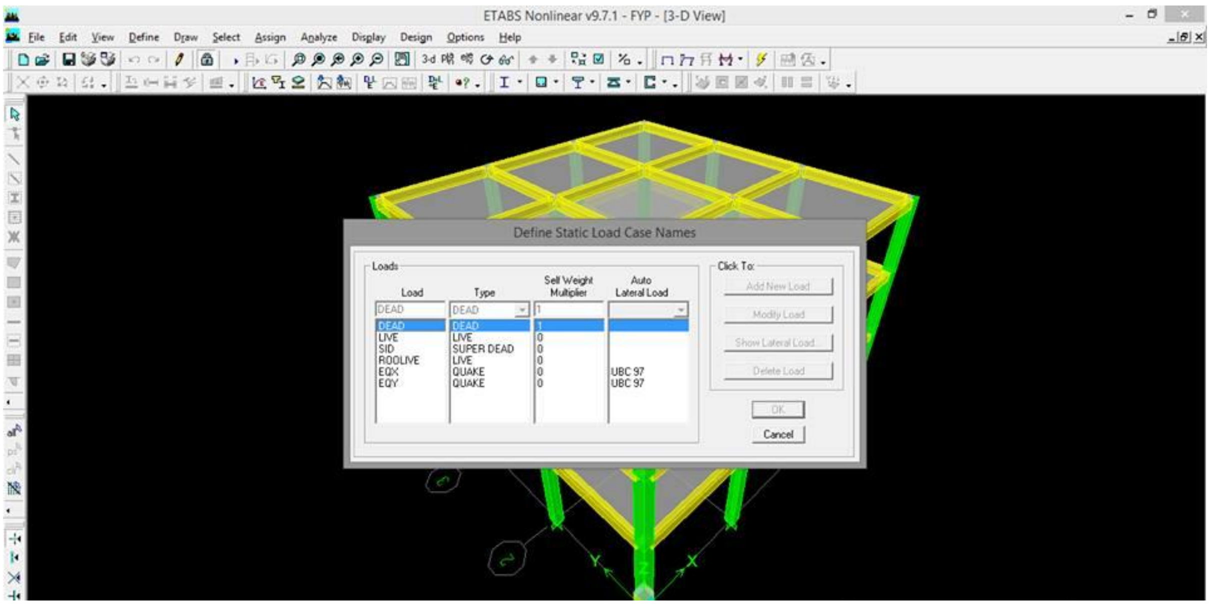


FIGURE 7-5 STATIC LOAD CASES

For EQX and EQY being lateral earthquake loading, Values of Ca , Cv and Seismic Zone Factor were defined. These values are same for the earthquake loadings along x and y axis. Soil profile as standardized area of Muzafarabad made it SD. Importance factor was 1 and Over strength factor was set to 8.5.

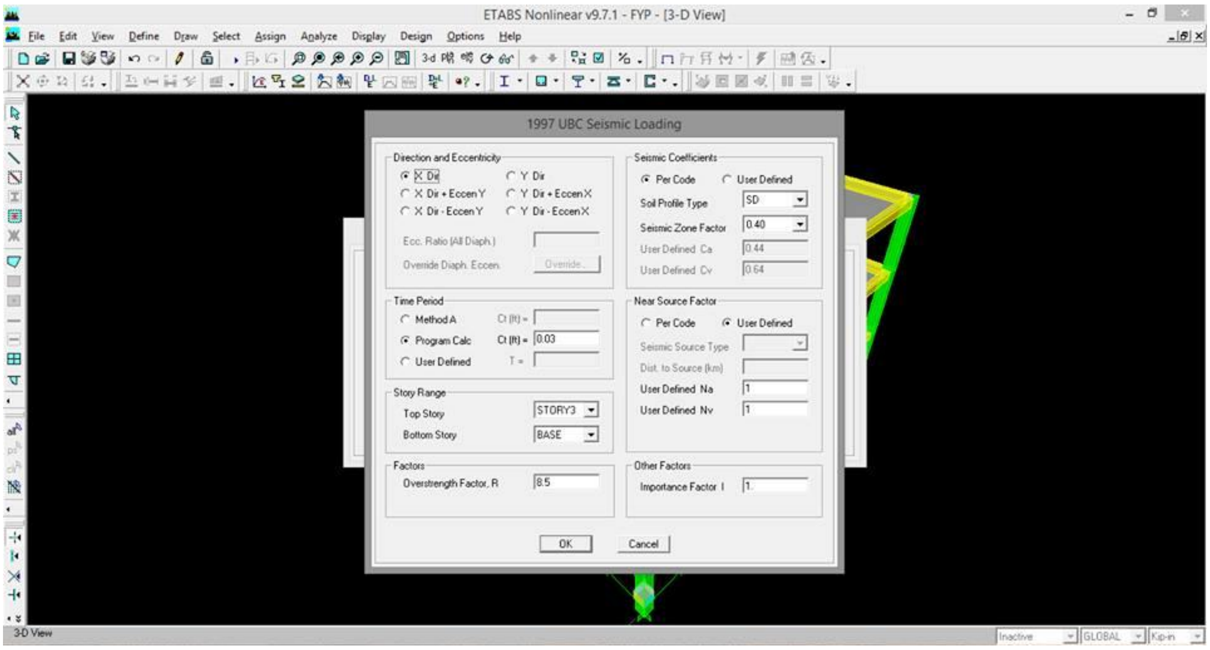


FIGURE 7-6 EARTH QUAKE LOADING DATA

Load Combination Data

Scale factors were defined for all kind of loads named in static load cases. Following is the load combination.

1.2D + 1.2 SID + 1.6 L + 1.6 Roof Load + 1EQX + 1EQY

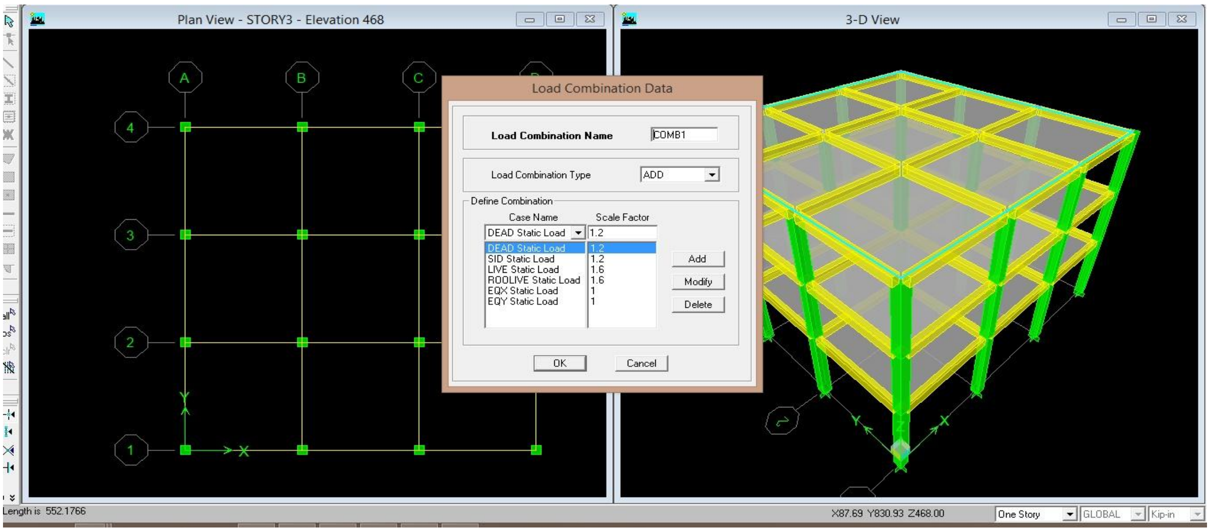


FIGURE 7-7 LOAD COMBINATION

7.4 Analysis

Analysis was run on ETABS to obtain member forces and stresses and their plot, which was further used for damage assessment and rehabilitation.

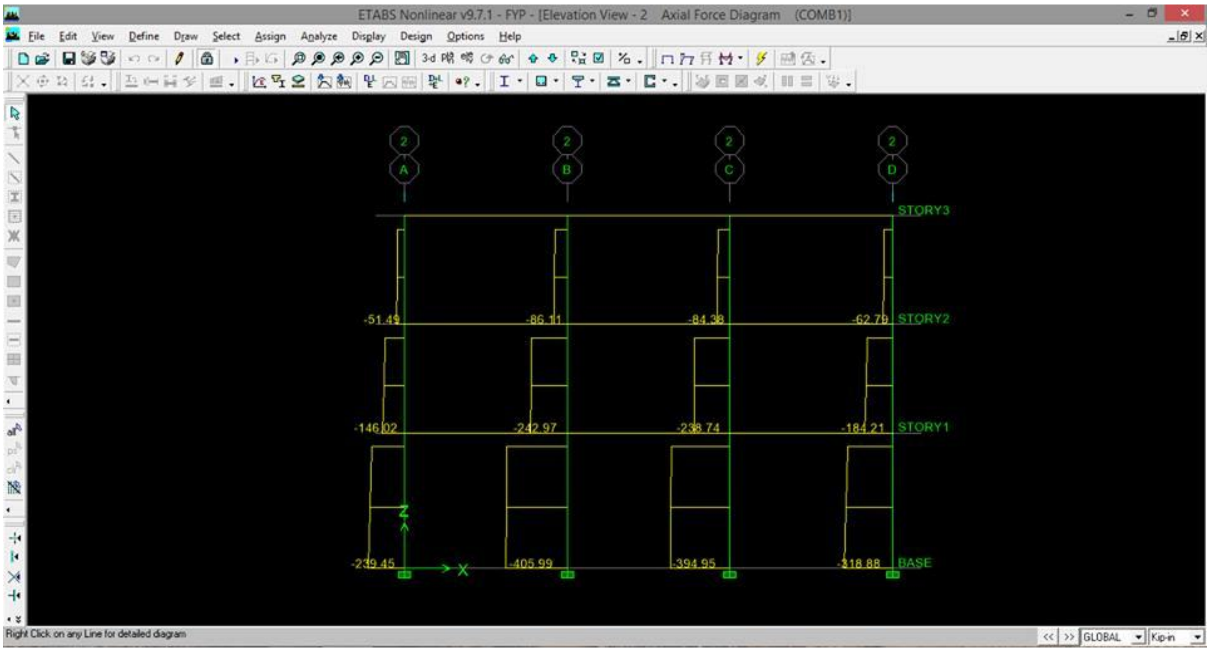


FIGURE 7-8 AXIAL FORCES

In-Plane Moment Diagram shows moments on beams and columns due to applied loads

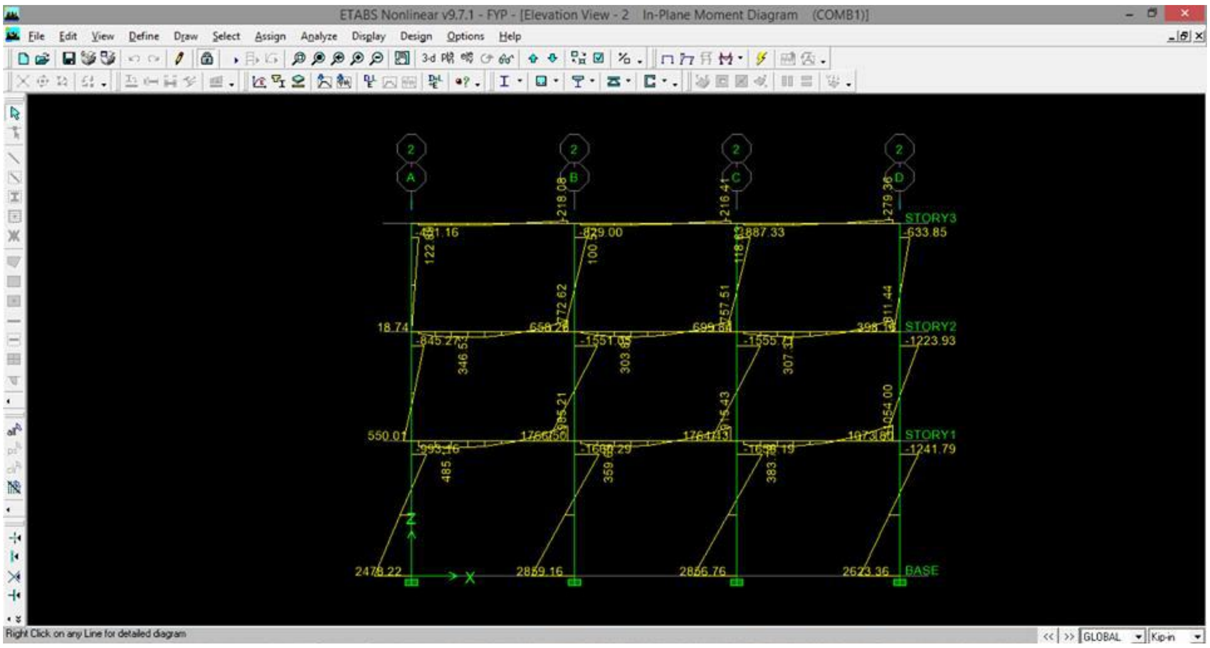


FIGURE 7-9 IN PLANE MOMENT DIAGRAM

I

In-plane shear diagram shows shear forces in members of the framed structure.

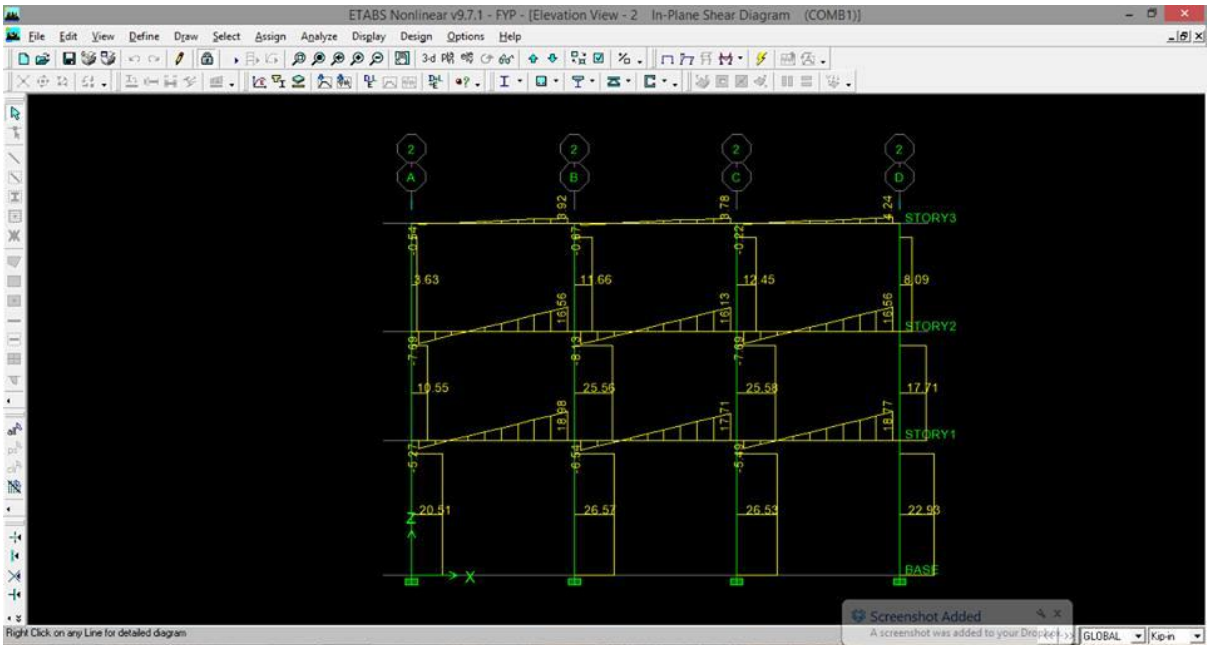


FIGURE 7-10 IN PLANE SHEAR DIAGRAM

The figure below shows the defromed shape of structure.

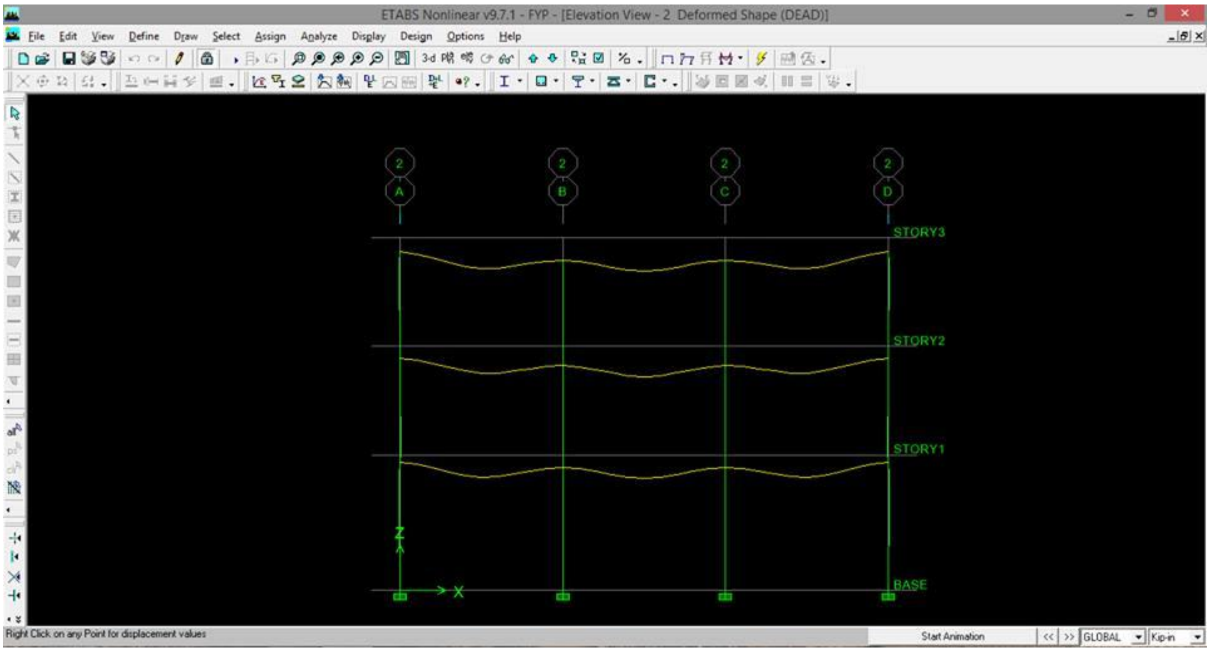


FIGURE 7-11 DEFLECTED SHAPE

Design was also run to check for columns. Capacity ratio was tested. Also shear and longitudanal bars were obtained.

This figure shows shear reinforcement in the framed structure.

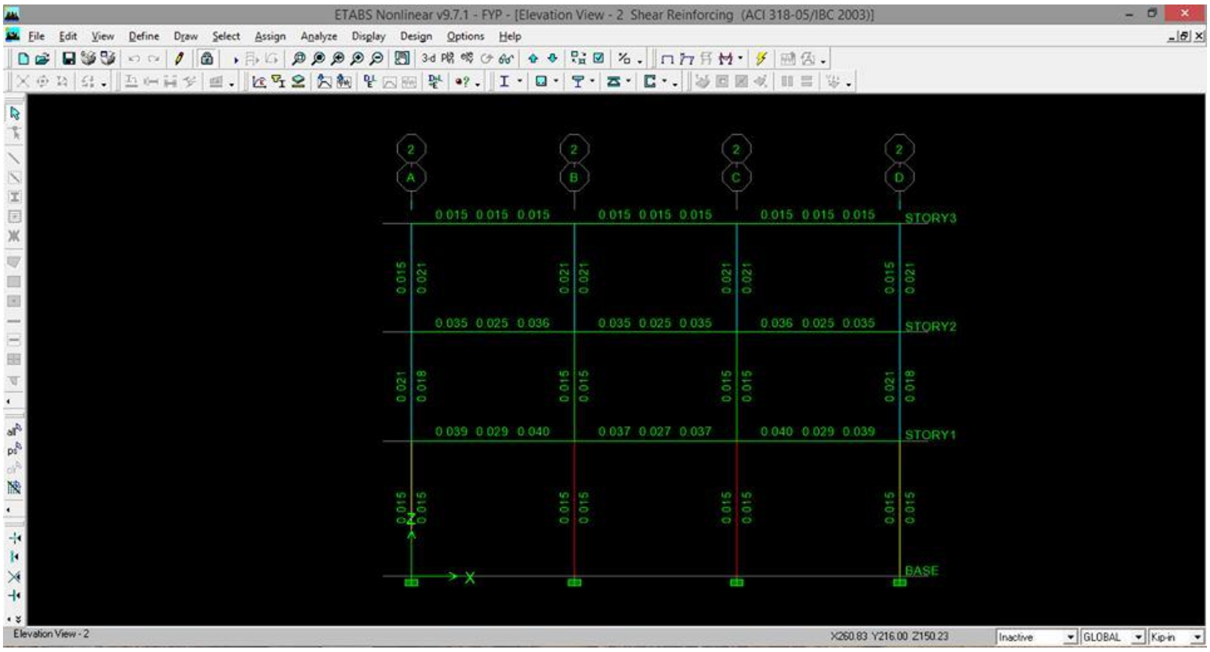


FIGURE 7-12 SHEAR REINFORCEMENT DESIGNED BY ETABS

This figure shows the positive and negative longitudnal reinforcement in the beams as well as the reinforcement in the columns.

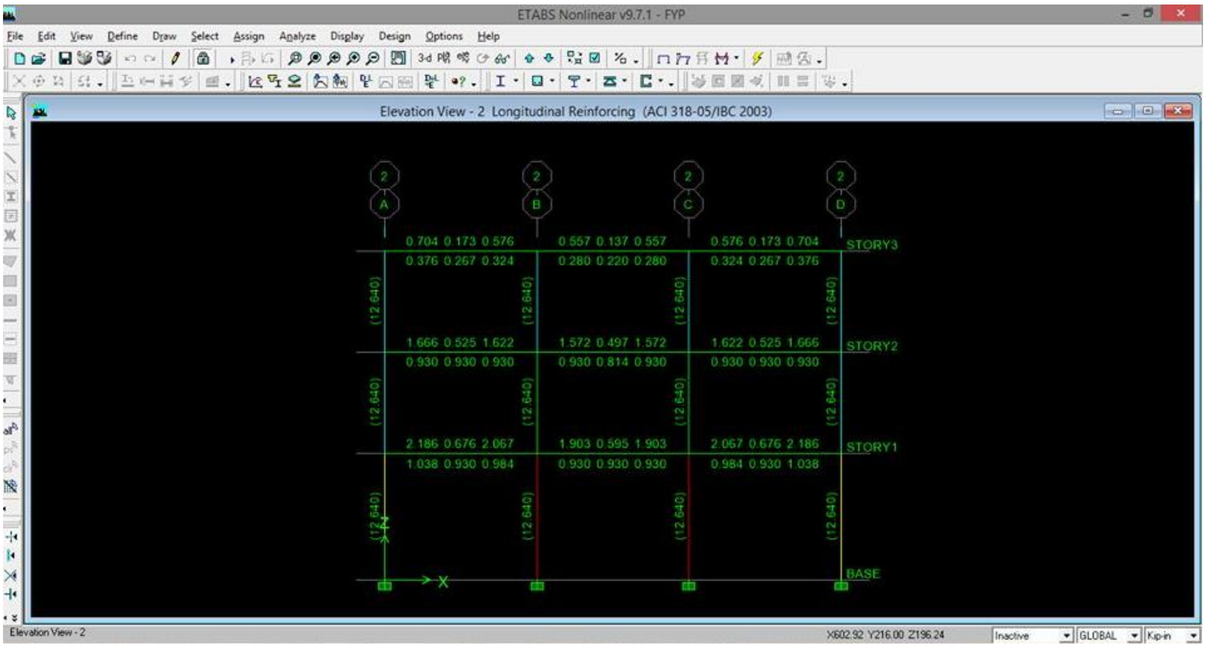


FIGURE 7-13 LONGITUDINAL REINFORCEMENT DESIGNED BY ETABS

Chapter 8 **Damage Assessment and Analysis**

8.1 Introduction

Muzaffarabad is an earthquake prone area. Our analysis is based on local conditions of Muzaffarabad. In these earthquakes, most of the frame structures got damaged.

NDT were performed on these buildings by ERRA and following results were found:

- Strength of concrete was reduced from 3000psi to 1740psi i.e. 42% strength was lost during that earthquake.
- Strength of steel reinforcement in beams was reduced from 40000psi to 32000psi
- Strength of steel reinforcement in columns was reduced from 60000psi to 48000psi

8.2. Approach

Beams

The total capacity of beam was calculated. All the members having in plane moment greater than design value were termed as failed. If the moment value after analysis was near to design capacity then they were termed as damaged.

Columns

For columns, capacity ratio was calculated. All columns having capacity ratio greater than 1 were termed as damaged.

8.3 Damage Report

The negative reinforcement was not sufficient so plastic hinges were formed which damaged the structure. Different damages in the structure are given below:

- All beams connecting the exterior columns of ground floor could not sustain the negative moment and termed as damaged. Joints of exterior column and beams also cracked.
- All the interior joints in ground floor are damaged minimally therefore, they need micro-crack repairs.
- All interior columns in ground floor damaged and need major rehabilitation.
- All other storeys are safe and sound.

- No member failed in shear.
- Positive reinforcement sustained moments therefore there are no flexural cracks.

8.4 Proposed Solutions

Two solutions were proposed for the damaged beams and columns.

- Concrete jacketing of Column
- Section Enlargement of Beam

8.3.1 Concrete Jacketing

The interior columns got severe damaged therefore, retrofitting was done in order to restore the strength of columns. For this purpose, concrete jacketing was done. Original dimensions of the columns were 18” X 18”. Additional 16 # 8 bars were also introduced and after concrete jacketing the column section changed to 24” X 24”.

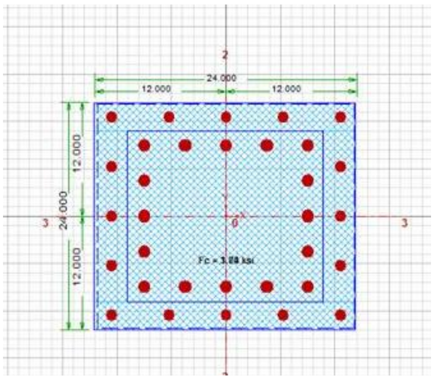


FIGURE 8-1 COLUMN MODELLED ON CSI COLUMN

Procedure:

Maximum moments on top of column and bottom of column and maximum axial loads were taken via analysis of building in ETABS.

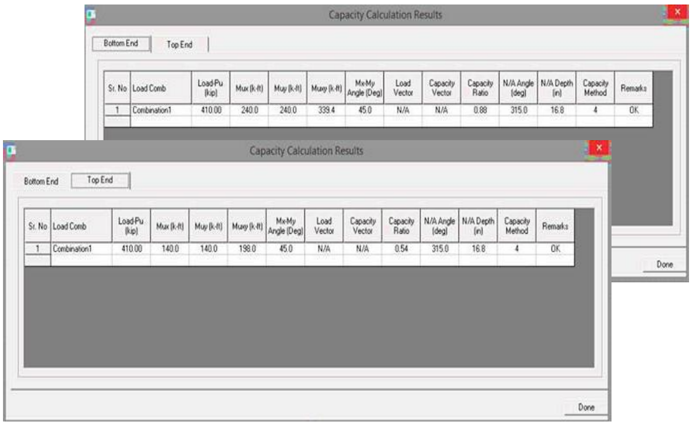


FIGURE 8-2 SECTION SET OK BY CSI COLUMN

Original section was modelled in CSI Column and materials were given the strengths of 1740 psi for concrete and steel was given strength of 48000 psi. That was now the damaged section input in the software.

Now hollow section was put with hollow area 18 by 18. Total section width 24 by 25 making section enlargements 6 by 6 inch as mentioned in the figure. New section had the strength of 4000 psi for concrete and 60000 psi for reinforcement. Reinforcement was increased till the section had enough capacity to hold the moments and axial forces on top and bottom as well.

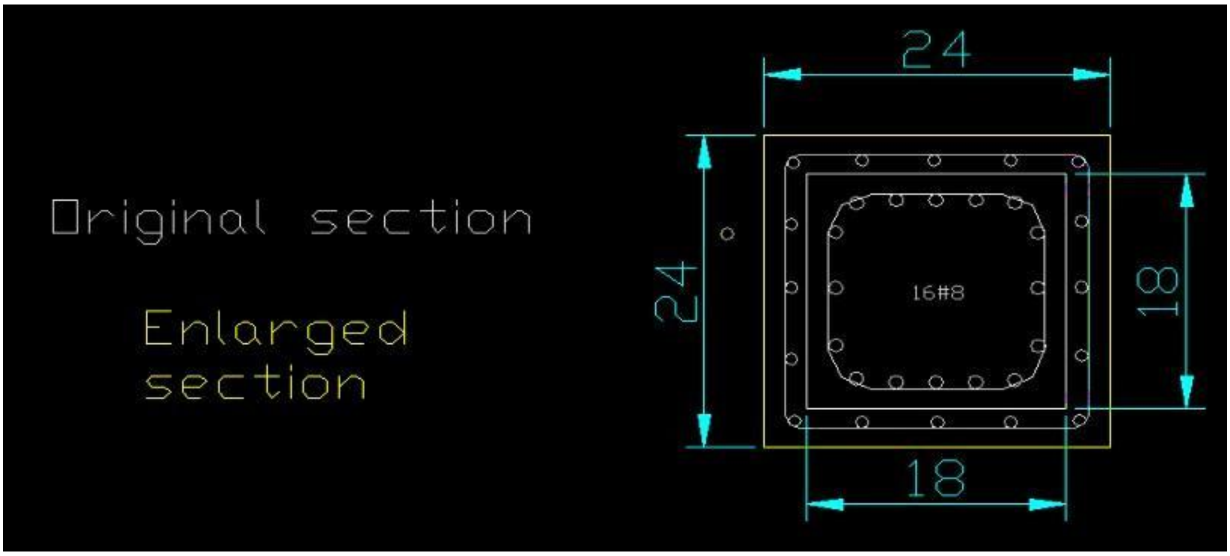


FIGURE 8-3 FINALE RETROFIT DESIGN OF COLUMN

8.3.2 Section Enlargement of Beam

Originally the beams were of 12” X 18”. After earth quake the strength of beams was reduced. We had original strength and we had reduced strength. Reduced strength was calculated by putting values of fc = 1740 psi and fy = 32000 psi. Total moment encountered during the earth quake minus total reduced strength or capacity of the beam was the moment needed to be restored. Now new section was added along the side of the beam which was 6 by 18 inch making beam 18 by 18 inch. New section added had capacity greater than restored moment of the beam.

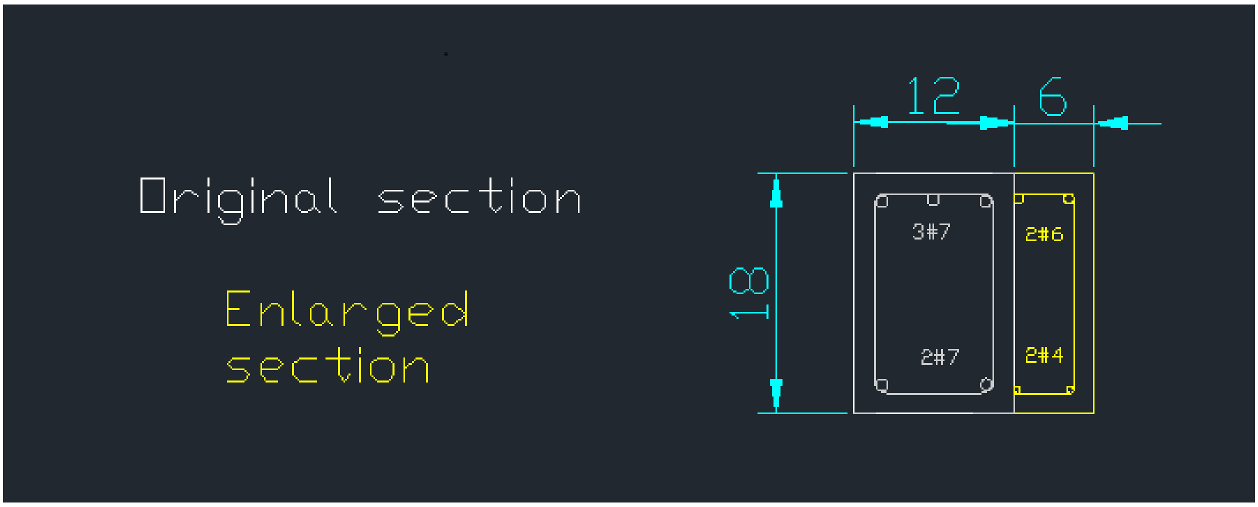


FIGURE 8-4 RETROFIT DESIGN OF BEAM

8.4 Other solutions

- FRP
- Epoxy
- Steel jacketing

8.4.1 FibreReinforced Polymer (FRP)

FRP can be used in the rehabilitation of concrete structures. The structures are reinforced by increasing the confinement of concrete. This follows from the fact that lateral confinement enhances the strength of concrete and increases its ductility. Among the confinement techniques, use of FRP materials is mostly used as jackets/wrapsdue to their high strength-to-weight ratio.FRP belts are pre-stressed as to provide more strength to be used in the retrofitting of earthquake damaged columns.

In this technique FRP belts are pre-stressed using a simple wrench. The technique is as follows: a carbon fibre belt is cut in a desirable length needed for wrapping around the cross section of the column and is impregnated with epoxy resin along only 100 mm lap joint of both cut ends, which is straightened to form a belt. When the belt is wrapped around the column, its ends can be clamped together by passing a solid rod between the eyes of the belt and putting bolts in between to lock them.

FIGURE 8-5 WORKER APPLYING FRP BELT

8.4.2 Steel Jacketing

Steel jacketing can be used for retrofitting both columns and joints. The basic principle behind this technique is that steel jacket acts as a passive confinement reinforcement. The jacket will prevent concrete from dilating, forcing it in lateral compression and by this it increases the compressive strength of concrete and its ductility.

In case of rounded columns, two semicircle steel jackets are used and are welded together to the entire height of the steel jacket.

A gap of about 1 inch is left between the steel jacket and the column. After that cement based grout is added between them to ensure a good bond with the steel jacket.

In case of rectangular jackets the procedure is same and two L shaped jackets are welded up to their entire height to ensure good strength and stability.

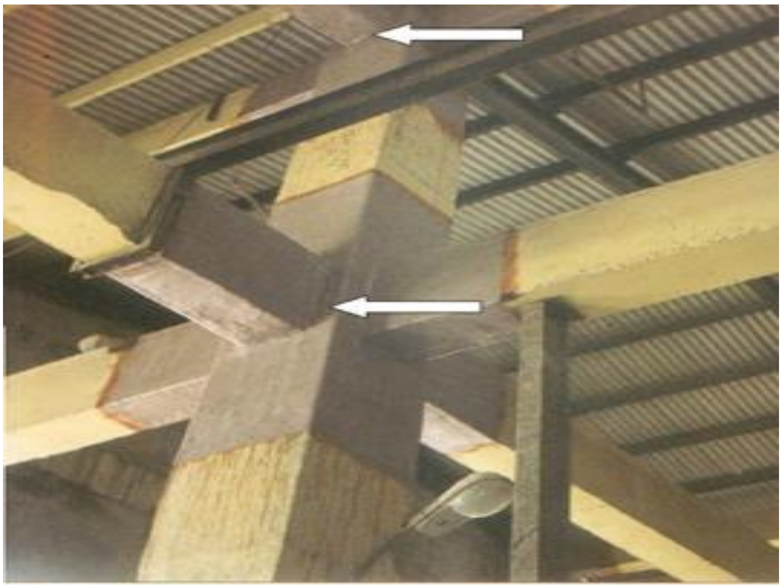


FIGURE 8-6 STEEL JACKETING OF BEAM JOINT

8.4.3 Epoxy

Concretes based on hydraulic binders such as Ordinary Portland Cement have a common tendency to crack. There may be different type of cracks and various reasons for cracking to take place. The main reason is shrinkage in plastic and hardened stage. Sometimes these cracks are minimal and may be ignored or treated on the surface itself. But when the cracks tend to penetrate deeper, they start affecting the durability of concrete. Cracks may appear in a floor slab, foundation, basement slab, roof slabs a beam or a column. These cracks may affect structural performance of the structure.

This creates a need to treat these cracks carefully, with proper materials and techniques. There are a number of methods and techniques which are developed by the construction industry to such cracks. Crack injection using either Epoxy is a best way to tackle with these cracks.

Here we will discuss specifically two types of injection materials. Low Viscosity Epoxy resins and Polyurethane resins. The former being mainly used for structural crack repair and the later mainly finding use in situations, where movement is expected or water leakages have to be stopped quickly. Sometimes a combination of both materials may also be used.

The procedure begins with the installation of injection ports at proper spacing generally at 40 mm in centre. Wider crack may have longer spacing. Cracks are then sealed through their length with suitable sealing material. If a crack penetrates completely through a section, then both sides need to be sealed for best results. Epoxy, polyester, cement, Silone based materials, may be used for this purpose. Injection is carried out after the cap seal is set. On horizontal places, the injection shall be started at the widest section. Vertical cracks are injected from the bottom up. Generally, cracks are injected until the material flows out from the adjacent port or until refusal. Smaller cracks may require higher pressure. After the injection is complete, the ports are removed. The cap seal may be completely removed using suitable procedure such as grinding or left in place, if it is not objectionable. The success of this repair may be verified by taking cores at suitable places or by non-destructive testing such as impact echo, ultrasonic pulse velocity or spectral analysis of surface waves.

Chapter 9 **Conclusions and Recommendations**

An earthquake is a mechanism of ground shaking followed by the release of large amounts of energy.

Earthquakes cause large number of lives lost worldwide. Large number of buildings is also damaged due to earthquake. Therefore, they need to be studied and understood. This research aims with understanding the behaviour of reinforced concrete structures under the seismic loading conditions in Pakistan.

CONCLUSIONS

- Structures can be made safer by applying retrofitting techniques.
- It is also feasible economically to retrofit the structures rather than construct a new one.
- The risk is also reduced by following retrofitted techniques to damaged buildings.
- The loss of lives could be reduced and almost injuries could be reduced.
- Application of retrofitting techniques are more suited as it will save lives and if an earthquake is more likely to strike more than once than retrofitting is best suited to adopt.

RECOMMENDATIONS

This research work can be extended to masonry, wood, steel and other type of structures as well.

More detailed techniques including surveys etc. can be sorted out for the determination of more accurate hypothetical structure as compared to existing structures.

Other retrofitting techniques can be studied to arrive at the economical solution to confine a structure.

Only a beam to column joints were studied as a mode of failure against seismic loadings it can be extended to other type of failures as well e.g. shear failure of columns etc.

Different vulnerability curves should be developed and studied to arrive at a conclusion.

Although accurate modelling using ETABS was used but still more accurate models can be used and can be developed from the field samples of the study .

References

- Reid's Elastic Rebound Theory: Reid, H.F., The Mechanics Of The Earthquake
- EncyclopaediaBritannica: Article Fault
- Plate Tectonic Earth Planet Model By Joseph S. GiamportoneAnd Walter G.W. Booker
- Tectonic Activities In Pakistan By Muhammad Wajid Amin Gill
- Investigation Of Seismic Hazard In NW-Himalayas, Pakistan Using Gumbel's First Asymptotic Distribution Of Extreme Values By Naseer Ahmed, Dr.Zulfiqar Ahmed; Dr.Gulraizakhta
- Determination Of Building Damage Due To Earthquakes Using Aerial Television Images HASEGAWA, YAMAZAKI, MATSUOKA, And SEKIMOTO
- Classifications Of Structural Types And Damage Patterns Of Buildings For Earthquake Field Investigation, OKADA And TAKAI
- TRADITIONAL SOLUTIONS FOR STRENGTHENING REINFORCED CONCRETE SLABS BY DRAGOS BANU And N. ȚĂRANU
- Rehabilitation Of Reinforced Concrete Beam-Column Joints, A Ghobarah, T.S. Aziz And A Biddah, Department Of Civil Engineering, McmasterUniversity, Hamilton, Ontario, Canada
- EXPERIMENTAL STUDY ON REHABILITATION OF RC BEAMS USING EPOXY RESINS, V. Bhikshma, M. Koti Reddy And K. Sunitha Department Of Civil Engineering, Osmania University, Hyderabad, India Department Of Civil
- Engineering, ChaitanyabharathiInstitute Of Technology, Gandipet Hyderabad, India

- Concrete Structures: Protection, Repair And Rehabilitation by R. Dodge Woodson
- Strengthening Of Cracked Reinforced Concrete T Beam By Jacketing Dr Adnan Sadiq Al Kulaity Lecturer Of Civil Engineering, Engineering Faculty, University Of Kufa
- Joints In Concrete Buildings By Cement Concrete And Aggregates Australia
- Seismic Design Of Joints In RC Structures – A Review By N. Subramanian And D.S. Prakashrao