TO STUDY AND IMPROVE THE BEHAVIOR OF FLAT PLATE AND FLAT SLAB UNDER SEISMIC EXCITATION

FINAL YEAR PROJECT UG-2014

By

Muhammad Moiez Mushtaq (GL)	NUST201434546
Waseem Akram	NUST201432237
Gohar Hafeez	NUST201434594
Yasir Ali	NUST201433057

NUST Institute of Civil Engineering

School of Civil and Environmental Engineering

National University of Sciences and Technology, Islamabad, Pakistan

2018

This is to Certify that the

FINAL YEAR PROJECT TITLED

TO STUDY AND IMPROVE THE BEHAVIOR OF FLAT PLATE AND FLAT SLAB UNDER SEISMIC EXCITATION

Submitted by

Muhammad Moiez Mushtaq (GL)	NUST201434546
Waseem Akram	NUST201432237
Gohar Hafeez	NUST201434594
Yasir Ali	NUST201433057

Has been accepted towards the requirements

For the undergraduate degree

In

CIVIL ENGINEERING

Lecturer Arslan Mushtaq

Associate Professor

NUST Institute of Civil Engineering

School of Civil and Environmental Engineering

National University of Sciences & Technology, Islamabad, Pakistan

ABSTRACT

Pakistan is still striving for improvements in construction industry. Major construction in private sector is carried out as non-engineered; there are very few projects that are properly designed for gravity and lateral loads, which is main cause behind deaths in major earthquakes. For example, Kashmir-Hazara (2005) earthquake caused deaths of 85,000 people. Nevertheless, after the Kashmir-Hazara (2005) earthquake, the government and engineering commission stressed on execution of a seismic code.

Flat-plate and Flat-slab structures possess major advantages over conventional beam-column supported frame structures because of absence of deep beams these structures have freedom in building layout, lesser construction time, architectural, efficient and economical parameters. These structural systems are significantly more flexible and have less stiffness.

Two-storey representative commercial building was selected for analysis, which is common practice in Rawalpindi-Islamabad region. Frame (having both columns and beams) structure was taken as a baseline and Flat plate and slab were compared with it. After doing Push-over analysis of these structures results showed weak behavior of flat plate and slab which was quantified using the backbone curves of these structures.

CFRP (Carbon fiber reinforced Polymers) fabric was wrapped on concrete cylinders casted in lab and compression test (ASTM C39) along with strain monitoring mechanism was done to achieve stress-strain curve of wrapped and unwrapped specimens. In order to model CFRP fabric being applied in potential plastic-hinge zone of the columns of flat plate and flat slab structures plastic hinge properties of columns were modified according to moment curvature curve of the column section and these retrofitted structures were again analyzed and results were quantified to compared these retrofitted structures with non-retrofitted structures and with frame structure.

ACKNOWLEDGEMENT

This research is due to dedicated input of my Research Supervisor, Lecturer Arslan Mushtaq, always remained very calm, humble and helpful throughout my research tenure. In fact, it is not out of place to mention here that, Lecturer Arslan Mushtaq has proved himself more than a supervisor. Apart from the faculty members my group members Mr. Waseem Akram, Mr. Gohar Hafeez Rana and Mr. Yasir Ali have played a very important role to completion of research and compilation of results. These fellows were helpful during phase of software, casting, testing and compilation and this thesis. Being a student of engineering, I thank administration of NICE, NUST which provided us the resources and for their continuous support. In the last, the most important person my Mother, remained always to pray for my success and in fact, it's only their love, patience and prays, which led me to the completion of my research. May Allah bless all.

Thanks

Muhammad Moiez Mushtaq

B.E. Civil

NICE, NUST, Islamabad

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Pakistan is still striving for improvements in construction industry. Major construction in private sector is carried out as non-engineered; there are very few projects that are properly designed for gravity and lateral loads, which is main cause behind deaths in major earthquakes. In recent past many devastating earthquake events occurred. Some of them occurring throughout the world are Bhuj in India (2001), Bam in Iran (2003), Kashmir in Pakistan with a magnitude of 7.6 (Shahzada et al.2011; Maqsood and Shwarz (2011),China(2010) and Indonesia(2010). For example, Kashmir-Hazara (2005) earthquake caused deaths of 85,000 people. Nevertheless, after the Kashmir-Hazara (2005) earthquake, the government and engineering commission stressed on execution of a seismic code.

It is completely impossible to fully diminish the effects of earthquake but the damage caused by it can be mitigated by taking suitable measures. Several methods are used for this purpose like shock absorbers and tuned mass dampers which are not in practice in Pakistan.

Flat plate, Flat slab and conventional frame structure (Beam column structure) are extensively used in our local construction industry. Most of the time, cost is the governing factor with little consideration for any other parameter i.e. strength, construction feasibility, considering the extensive use of these structures we have decided to test all these structures under seismic excitation. Their relative performance will be compared i.e. base shear, energy dissipation, deflection etc. Two storey similar structures having same panels, same strength parameters were chosen for comparison. The rationale behind two storey buildings is that they are mainly employed in local construction industry. It is to be noted that comparison is solely software based using ETABS and SAP and no practical models are employed for comparison.

Pakistan is an underdeveloped country and it is still working for improvements in construction techniques, majority of the construction in private sector is carried out as non-engineered, there are very few projects that are properly designed for gravity and lateral loads, which is main cause behind deaths in major earthquakes. For example, Kashmir-Hazara (2005) earthquake caused deaths of 85,000 people. Therefore, after the Kashmir-Hazara (2005) earthquake, the government and concerned engineering commission decided to implement a seismic code.

FIGURE 1 : FRAME STRUCTURE

FIGURE 2 : FLAT SLAB

FIGURE 3 : FLAT PLATE

About 10-15% of total buildings in Pakistan are RCC structures and mostly these are designed to withstand gravity loads only. Post analysis of structures showed a lot of lacks in these structures. These deficiencies include poor material quality, presence of soft storey, weak-column strong beam analogy, insufficient lap splices and deficient shear and confinement reinforcement.

Flat plate and Flat slab are the structural floor systems that have no beams due to lack frame action they have less resistance for lateral loads. Flat-plate and Flat-slab building structures possess major advantages over traditional slab-beam-column structures because of absence of deep beams these structures have freedom in building layout, shorter construction time, architectural, functional and economical aspects. These structural systems are significantly more flexible and have less stiffness. Flat slab behavior is quite weaker as compared to conventional frame structure under seismic loading.

For study purpose a Two-storey representative commercial building was selected for analysis, which is common practice in Rawalpindi-Islamabad region. Displacement control push-over analysis was used because, gravity loading push-over analysis is force controlled while lateral push-over analysis are displacement controlled. Columns of Flat plate and Flat slab were retrofitted using CFRP wrapping in potential plastic hinge zones.

1.1. Objectives of research

Our main objective is drawing comparison of all three-slab systems under seismic excitation, their comparison and behavioral study and to study the behavior of improvement when CFRP is incorporate with it. Relation between known deflections and stress produced will be used for creating graphs for better understanding of concrete under seismic forces with and without CFRP. Improvement in the structural capacity of flat slab and flat with the help of using CFRP is our objective along with its analysis.

Danger of earthquake can never be ignored and if not catered for, it can prove to be really dangerous and tragic like the Kashmir Hazara earthquake where millions of people died in the earthquake. In the meantime, it is an absolute necessity to make structures safer and better utilizable.

To study the behavior of flat slab and flat plate system with and without CFRP in comparison to the conventional frame structure, and analyzing results and drawing conclusions regarding how much the system can be improved with CFRP's.

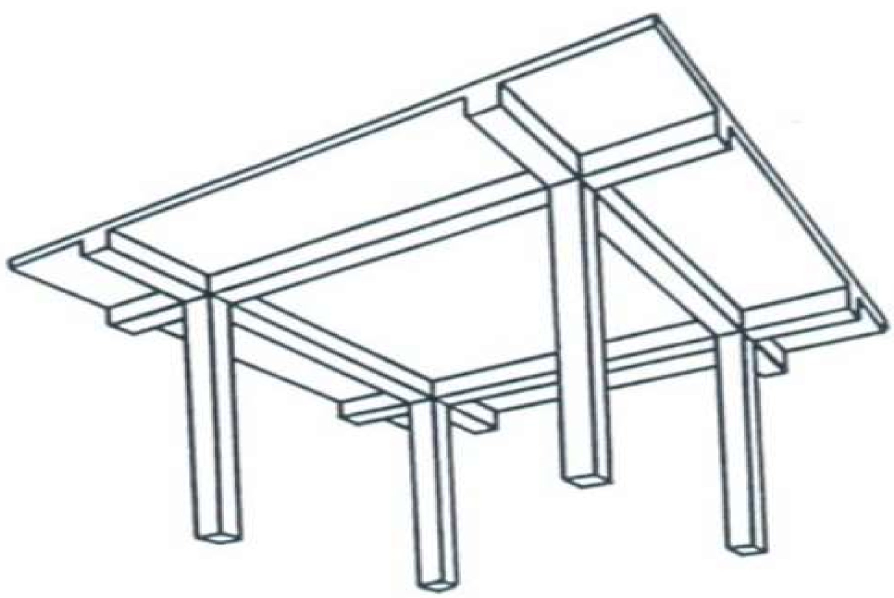
The overall purpose of our work is to investigate and improve the behavior of the flat slab and flat plate wrapped with CFRP. The specific objectives of this study are:

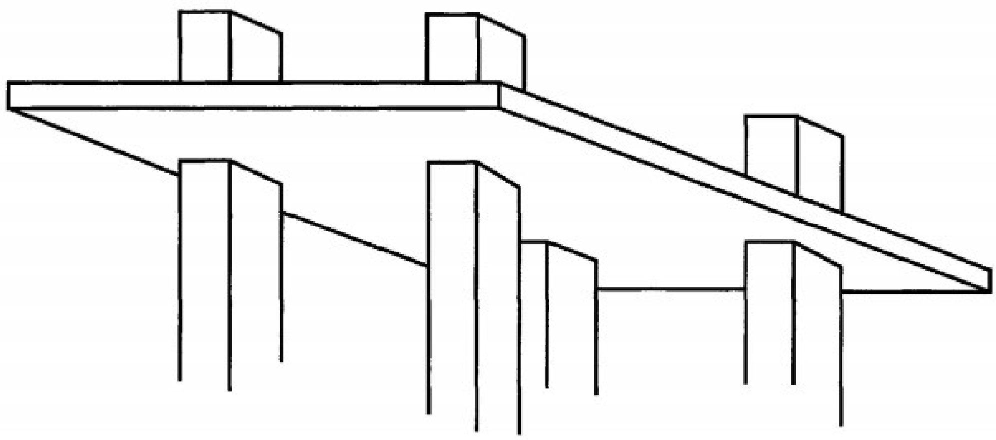
- Load-displacement analysis
- Deformation Behavior
- Interface stress distribution
- Displacement analysis
- Hysteresis loop formation

The idea behind the study is that retrofitting structural concrete with CFRP materials will improve the overall behavior under flexural loading.

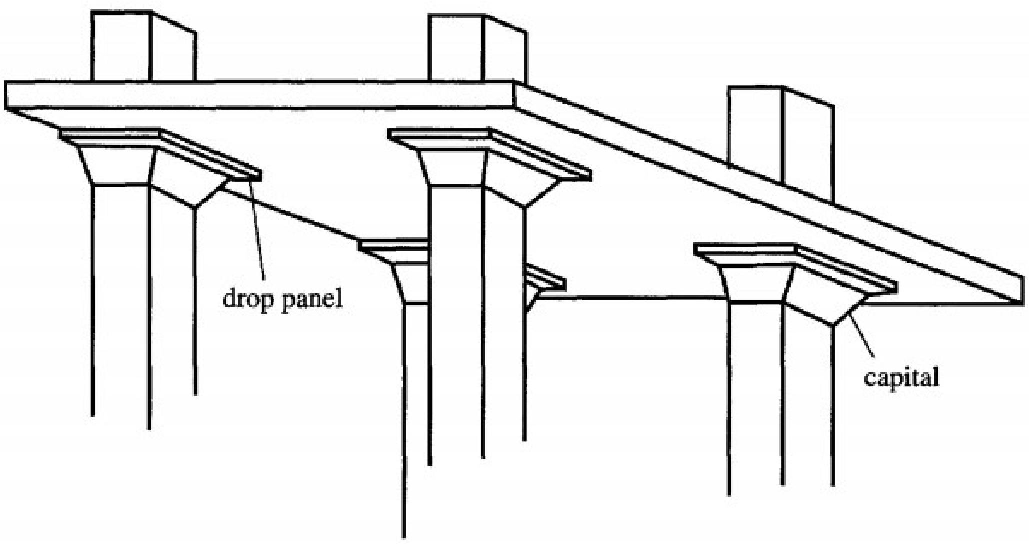
1.2. Background:

`The flat-slab and flat plate systems are type of reinforced concrete(RCC) systems that have major benefits over the conventional frame structure. The flat slab and flat plate systems provide are easy to place in formwork, have more architectural design flexibility, more space, overall has less building height and has shorter construction time. Their behavior under loading and the deflections produced in them, make them an interesting subject to study. After careful analysis, how we can improve their behavior and limit the deflections produced, was our main objective.





(b) flat plate



(c) flat slab

FIGURE 4 : THREE STRUCTURES

But there are some serious issues requiring special attention while designing construction of flat-slab and flat plate systems. One of the problems is the potentially large lateral displacements because of the absence of deep beams resulting in low transverse stiffness. This produces extreme deflections and causes damage of non-structural members even a moderate intensity earthquake strikes. Another major problem is the punching failure problem due to the transfer of shear forces and unbalanced moments between slabs and columns. These moments can generate large shear stresses in the slab. Flat-slab and flat-plate floor systems are also vulnerable to substantial decrease in stiffness as cracking occurs from building loading, gravity loading, temperature & shrinkage effects and lateral loading. So, in regions of high seismic hazard it is usually recommended that flat-slab and flat-plate systems should be used as lateral load carrying system for structures. These systems should be braced with frames or shear walls which provide lateral load carrying ability of the structure.

1.3. Problem statement:

The type of construction done locally for multipurpose halls and other facilities that require more space. Mostly they are being designed as flat slab and flat plate systems for their benefits but they lack lateral stiffness and have lesser capacity to absorb energy for dissipating earthquake impact. So, a detailed study is required to quantify this lag and take appropriate measured to enhanced their structural safety and serviceability requirements.

Flat-slab and Flat-plate structures have major benefits over conventional frame structures due to lesser construction time, architectural design and economical parameters and the free design of space. Due to the absence of beams, Flat-slab and Flat-plate systems have more flexibility for transverse loading as compared to conventional reinforced concrete frame structure system and that makes the flat slab and flat plate system more vulnerable for seismic loads.

1.4. Specified Parameters:

A two storey building with clear height of 12' with column spacing at distance of 20' along one axis and at 25' along the other axis. Concrete of 4000 psi strength has been used with a mix design of 1:1.5: 3 (cement: sand: gravel) by weight, with steel reinforcement of 60ksi tensile strength for this research. This mix design was selected keeping in view the compressive strength used in Pakistan for typical commercial buildings and Plazas.

CHAPTER 2

LITERATURE REVIEW

The literature shows the considerable working and study on a flat slab building and its behavior under the seismic excitation. Several experimental and numerical analyses were performed on the flat slab building structures by various authors. These works are reviewed keeping in view the methodology, principles and various aspects and behavior of flat slab building under the earthquake forces. Some of related works are discussed below.

- EP. Sriviasulu , A. Dattatreya Kumar studied the behavior of RCC flat slab structure under earthquake loading and concluded that performance of flat slab is poor in seimic loading as compared to frame structure.

- Mehmet Inel, Hayri Baytan Ozmen worked on the properties of hinges and found out that Transverse reinforcement placed in potential hinges is a decisive factor for the displacement capacity of a structure.

- K.Venkatarao, N.Nageswarao estimated the “Behavior of Reinforced Concrete Framed Structure with Flat & Conventional Floor Slab Systems” and stated that lateral deflection in flat slab and plate is more compared with frame.

- Ashraf Habibullah, S.E.1 Stephen Pyle perfoemed Three-Dimensional “Nonlinear Static Pushover Analysis” and concluded that that “a gravity load pushover is force controlled” and “lateral pushovers are displacement controlled.”

- “Hammad Salahuddin, Shaukat Ali Khan, M. Usman Ali, Arslan Mushtaq carried out seismic vulnerability assessment of RC structures retrofitted by CFRP and concluded that the confinement is an efficient technique for ductility of RCC column it also increase strength as well.”

- “Ema COELHO, Paulo CANDEIAS assessed the seismic behaviour of RC flat slab building structures and stated that Flat plate and flat slab systems exhibit significant higher flexibility compared to traditional frame structures becoming more sensitive to second order effects.”

- “Ms. Kiran Parmar , Prof. Mazhar Dhankot (2013), deals with the comparison between three dual lateral load resisting systems in the multistory buildings.”

- “A. E. Hassaballa, M. A. Ismaeil et.al performed the pushover analysis on the four story building using SAP2000 software (Ver.14) and equivalent static method according to UBC 97.”:

- “K S Sable et.al (2012) investigated the comparison of conventional reinforced concrete RC floor system i.e. slab, beam & column to the flat slab building.”

From the literature review it can be concluded that performance of flat slab is poor in seismic loading as compared to frame structure. Transverse reinforcement placed in potential hinges is a decisive factor for the displacement capacity of a structure. The Lateral drift in frame structure is quite low in comparison to flat slab without drop panels at each story level in both directions. After conducting push-over analysis it can be concluded that a gravity loading pushover is force controlled and lateral loading pushovers are displacement controlled.

From literature review, it is clear that flat plate and flat slab perform poorly as compared to frame structure but there is need of quantification of results and improvement of deficient structure results must also be quantified after the analysis.

CHAPTER 3

METHODLOGY

To understand the behavior of two-way slab systems under earthquake loading, "ETABS 2016" was used to analyze the structures. Under specified deflections in the three separate systems, forces produced were measured and the graphs were established against each critical deflection and loading. Graphic representation was established between loading and deflections produced.

For carrying out our project successfully, it was necessary to accomplish the following steps:

1. Discussions about the necessity and purpose of the project with the director of the thesis.
2. Preliminary information regarding literature in this domain and general aspects of the experimental work to come.
3. Designing the building in ETABS 2016. Specifying the different loading schemes for each floor system along with their respective dimensions and end boundary conditions.
4. Push-over analysis of the three systems done separately, base shear produced were calculated against that specific deflections.
5. Hysteresis loop was established at the end by compiling the results together at the end and to study which system performs better.
6. Data was compiled and graphs were established in MS Excel.
7. Consulting the specific literature, standards and codes regarding the strengthening of RC slabs and column joint with externally bonded CFRPs.
8. Acquaintance with the activities to be performed in the laboratory: used material, test setup, equipment, trials, laboratory staff.
9. Preparation of cylindrical samples for the required tests. Half of them were tested with CFRP while the remaining were tested without it. And results were compiled and compared for both at the end.
10. Required material was collected to prepare six cylindrical samples for testing with and without CFRP.
11. Materials quantities calculations were performed.

12. Casting was done in the lab.
13. Cylinder were placed in the curing tank for 28 days.
14. Half of cylinders were sent for coating of CFRP.
15. Running the test and recording all the available data by means of sensors, photos and cameras.
16. Running the same test procedures with the other samples (without CFRP).
17. Processing and analyzing the experimental data.
18. Formation of stress-strain curve for CFRP confined samples.
19. Defining a new material in ETABS.
20. Formation of moment-curvature curve for column section confined with CFRP.
21. Defining a new plastic hinge on basis of moment-curvature curve for column section confined with CFRP.
22. Push-over analysis of the three systems done separately, base shear produced were calculated against that specific deflections.
23. Hysteresis loop was established at the end by compiling the results together at the end and to study the improvement of flat slab and plate backbone curve.
24. Evaluation of the results.
25. Writing of the thesis.

CHAPTER 4

MODELING OF STRUCTURES

4.1. Introduction of ETABS 2016

“ETABS is an engineering software product that is helpful in design and analysis of multi-story structures. ETABS have built in modeling tools and templates, predefined loads and its types, analysis methods and solution techniques, all are helpful with the grid-like geometry specific for a certain type of structure. The advanced and revolutionary new ETABS is the ultimate integrated software package for the analysis and design of structures.”

FIGURE 5 : ETABS SOFTWARE

ETABS can analyze any type of structure and can design the following:

- Design of frames (either steel or concrete structure)
- Composite beams and columns system
- Steel joists system
- Concrete and masonry shear walls
- Capacity check for steel connections and base plates.

ETABS 2016 has incorporated with functions of Peform-3D and has following new features:

1. Results are directly visible on the modelled structure.
2. Comprehensive reports are available for all analysis and design output,
3. Engineering drawings of plans, scheduling, detailing, and cross-sections can be generated for concrete and steel structures.

4.2. Modeling in ETABS

All Structures were modeled in CSI ETABS 2016. The structure modeled have been shown in figure 7,8 and 9 respectively. Drop panels for flat slab were modeled manually, drop panels were drawn as a slab (area section). Columns of same size (cross-section) and reinforcement were modeled in all three structures.

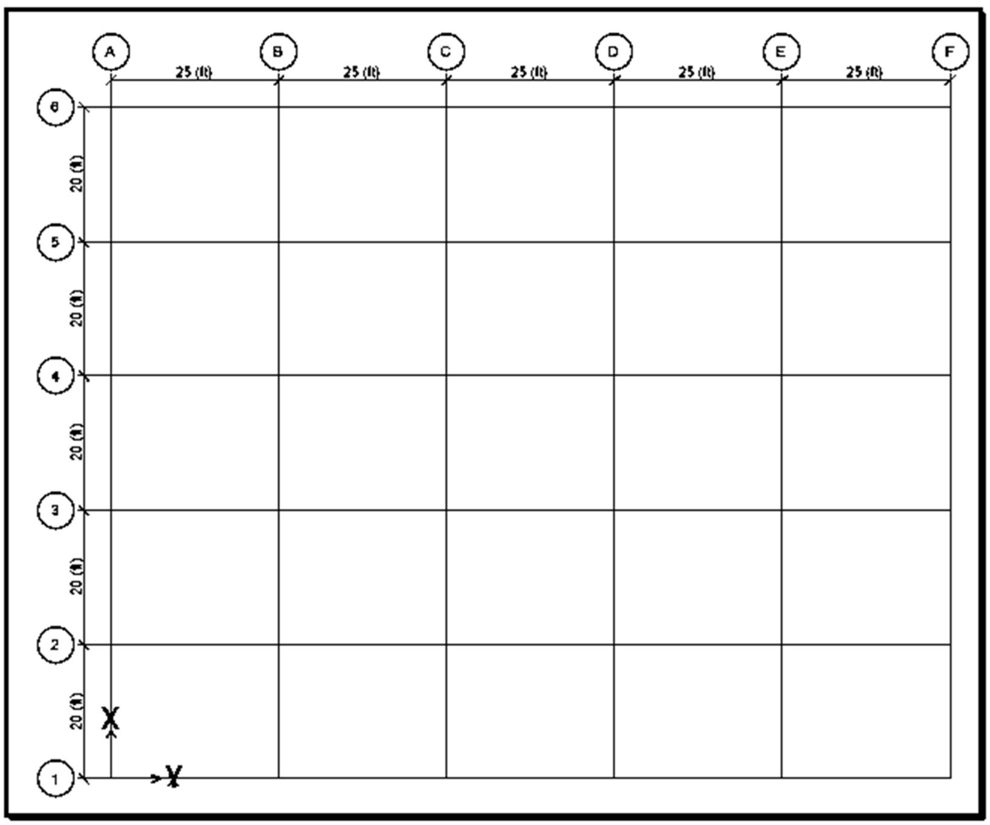


FIGURE 6 : BUILDING PLAN

Given below are the models of all of three structures that were modeled in ETABS 2016,

Drop panels of flat slab were modeled manually after calculating their size and depth on basis of punching shear requirements.

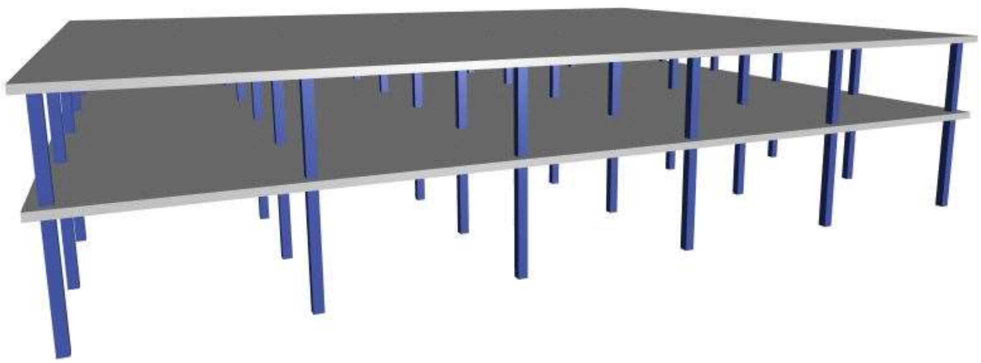


FIGURE 7 : MODELED FLAT PLATE

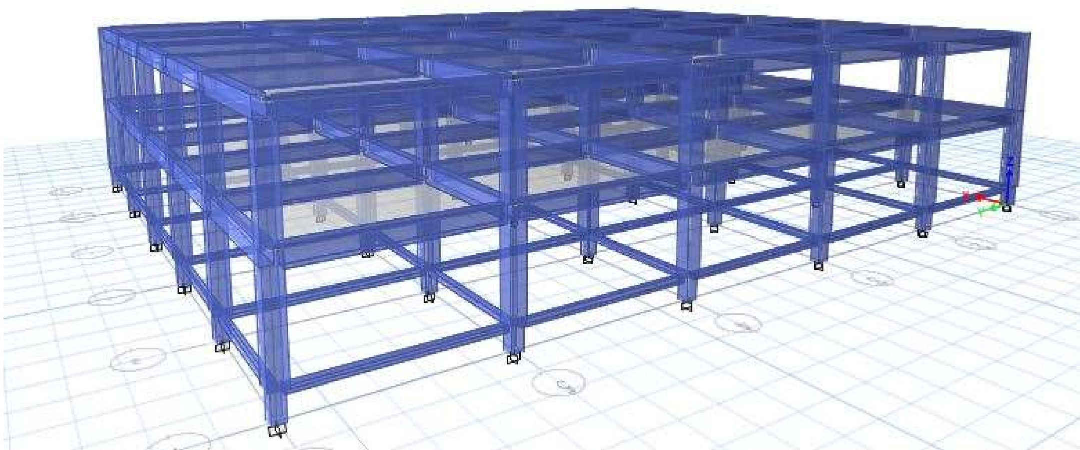


FIGURE 8 : MODELED FRAME STRUCTURE

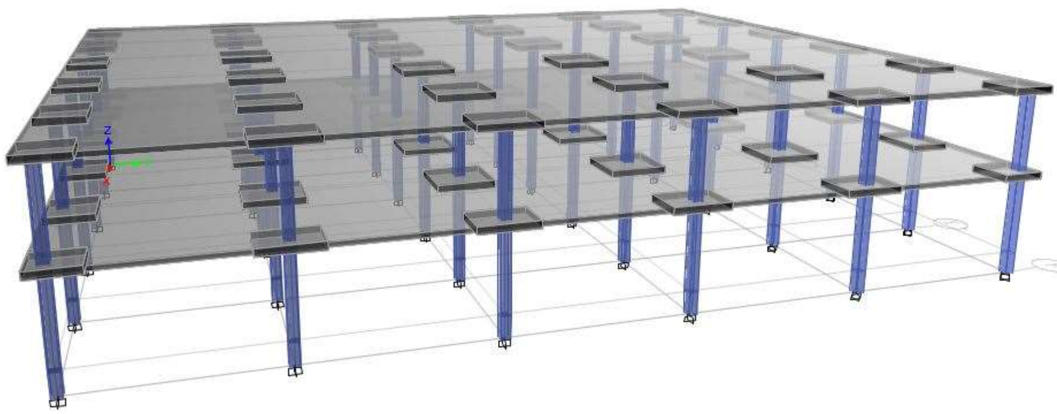


FIGURE 9 : MODELED FLAT SLAB

The first step was to define the grids. By defining grid we mean that assigning coordinates or positions. After that the next step was to define materials which were given in building characteristics. Next step was to define the frame sections. Frame sections consists of beams and columns. The building consists of same columns throughout. The concrete reinforcements were added which were to be checked later on and therefore reinforcement to be designed option was marked. For this purpose, #8 main reinforcement bars were provided and #4 transverse bars were provided. Concrete cover for the main bars were 1.5" and their longitudinal spacing given was 6". The remaining values were set to default. The next step after defining area sections was to assign the loads to the structure. We assigned live load of 100 psf for lower slab and 60 psf for upper slab.

4.3. Gravity design of Structures

Sections and slabs were designed in ETABS on basis of ACI-11 code. After analyzing the structure under gravity loads concrete design (check of sections) was started, after trial and error section were finalized. Passing of the structure under gravity loading means that the structure must be safe within the allowable limits under gravity loading. By gravity loading it is meant that load acting due to force of gravity that is the vertical forces. Gravity load includes the weight of the structure itself, human and other things occupancy load and snow load imposed on the structure. Same Column was designed in all three structures as shown in fig 3-6. Slab thicknesses are also shown in fig. 3-6.

Size of Model	100’x125’
No. of Stories	2
Storey Height	12’
Bays in X-Direction	5
Bays in Y-Direction	5
Beam Size	12”x15”
Column Size	15”x15”

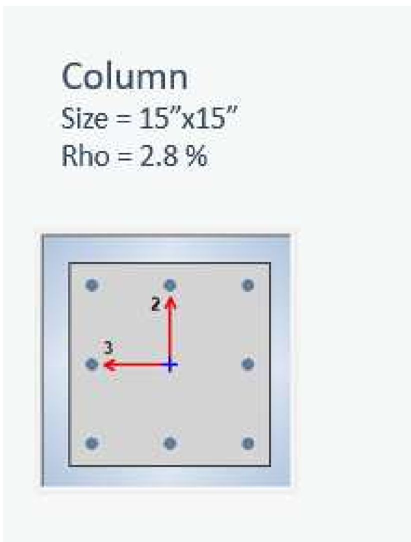
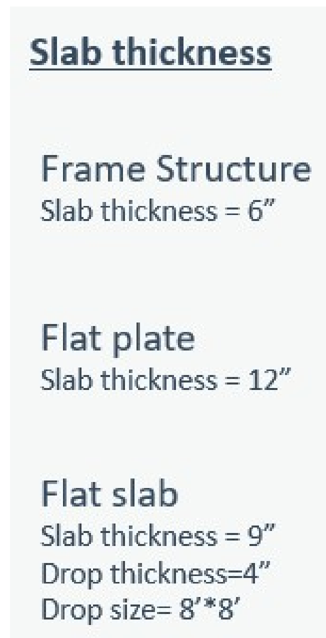


FIGURE 10 : DESIGN OF STRUCTURAL ELEMENTS



4.4. Push-over Analysis

“Pushover analysis is an approximate nonlinear analysis method in which the structure is subjected to monotonically increasing lateral loads until a target displacement is reached. A mathematical model of the building which includes load-deformation diagrams of all lateral force resisting elements is generated and gravity loads are applied initially. A predefined lateral load pattern which is distributed along the building height is then applied.”

It is a static and nonlinear analysis method in which gravity loading and displacement-controlled lateral loading is applied on the structure which then increases step by step through elastic and inelastic stages until structure fails.

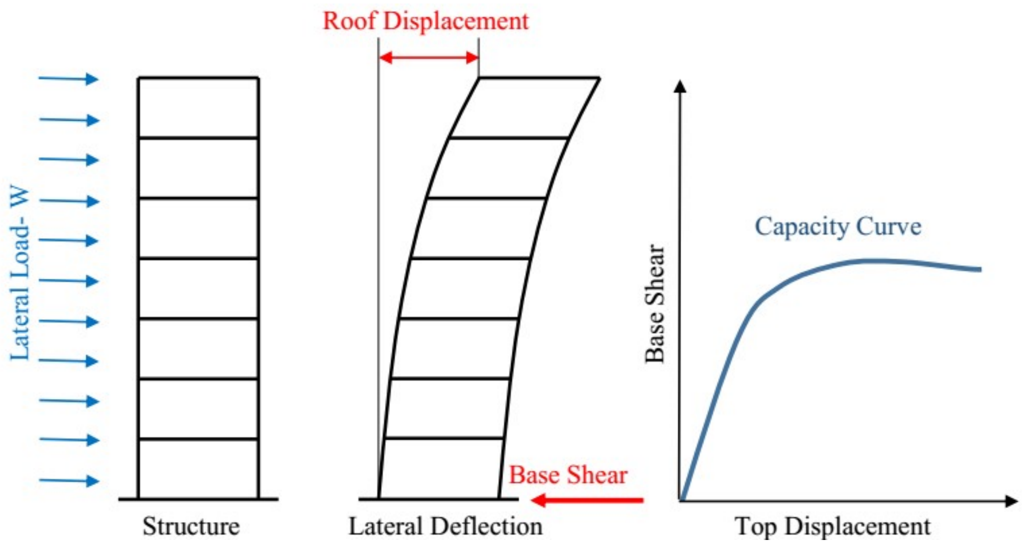


FIGURE 11 : PUSH OVER ANALYSIS

Built in plastic hinges were used in structures. In frame structure, M3 hinges were used for beams and P-M2-M3 hinges were used for columns. For flat plate and flat slab only P-M2-M3 hinges were used for columns since there is no beam in these structures.

4.4.1. Types of Pushover Analysis:

Pushover analysis is of two types. It can either be accomplished either force or either displacement controlled. When loading is known, it is called as forced controlled (such as gravity loads). While in displacement controlled method, the process is known which is used, however the amplitude of applied loads or loading is unknown. Alternate loads are applied to get certain displacement against each loading until a specific displacement or deflection is obtained, at which the structure fails. Generally, slab displacement is considered as the control displacement. The internal forces and deformations at the specified displacement give inelastic strength and deformation demands which is compared with available capabilities to find a performance point. Displacement based method has been adopted for this research which is being used for earth quake loading and forced based method has been adopted for gravity loading.

4.4.2. Limitations of Pushover Analysis:

Though pushover analysis has benefits over elastic analysis techniques, it still has certain limitations of which must be identified before we apply it. The approximation of target displacement, selection of transverse loading patterns and identification of failure mechanisms due to greater modes of vibration are significant problems that disrupt the correctness of pushover analysis results. A shape vector demonstrating the deformed shape of the MDOF system is used to obtain the properties of an equivalent SDOF system.

The distribution of inertia forces differs with the amplitude of seismic loading and the time during such seismic loading since, in pushover analysis, generally throughout similar transverse loading pattern is used. The transverse loading patterns that are used in pushover analysis are directly proportional to product of story mass and displacement associated with a shape vector at the story under concern. Generally transverse loading patterns that are used are uniform, elastic first mode, “code" distributed and a single transverse loading at the top of structure. The similar throughout lateral loading patterns could not expect possible failure means due to middle or upper story mechanisms triggered by higher mode effects. Constant loading patterns can provide sufficient estimates if higher mode effects are not insignificant. These restrictions have led many investigators to recommend adaptive loading patterns which consider the variations in inertial forces with the level of inelasticity. While some improved guesses have been obtained from adaptive loading patterns, they make pushover analysis computationally challenging and conceptually complex.

4.4.3. Input Parameters for Pushover Analysis:

For pushover analysis the initial input was the hinge assignment. Hinges can be assigned to beam or column at any location. Hinge can be defined for Uncoupled moment (M2 and M3), torsion (T), axial force (P) and shear (V2 and V3) force-displacement relations. For columns axial load changes under lateral loading, there is also a coupled P-M2-M3 hinge which yields based on the interaction of axial force and bending moments at the hinge location. More than one type of hinge can be assigned at the same location of a frame element. ETABS considers three types of hinge properties.

The built-in default hinge properties for steel and concrete members are based on ASCE 41_13 and idealized flexural hinge criteria.. Based on the above discussion we have defined default hinges according to ASCE 41_13 at the both ends (i.e. at relative distance 0 and 1) in beams & columns. These hinges are then overwritten by using hinge over write command. Hinge Assignment step is necessary to check formation of hinges at different levels i.e.

1. IO (Initial Occupancy)
2. LS (Life Safety)
3. CP (Collapse Prevention)

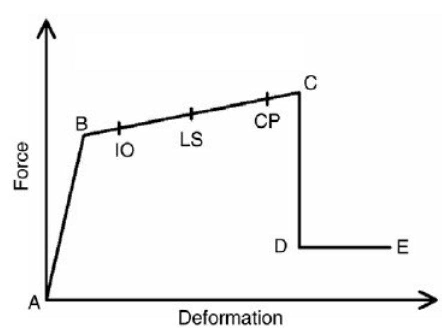


FIGURE 12 : PLASTIC HINGE

Hinges defined in ETABS are shown in fig 13 and 14:

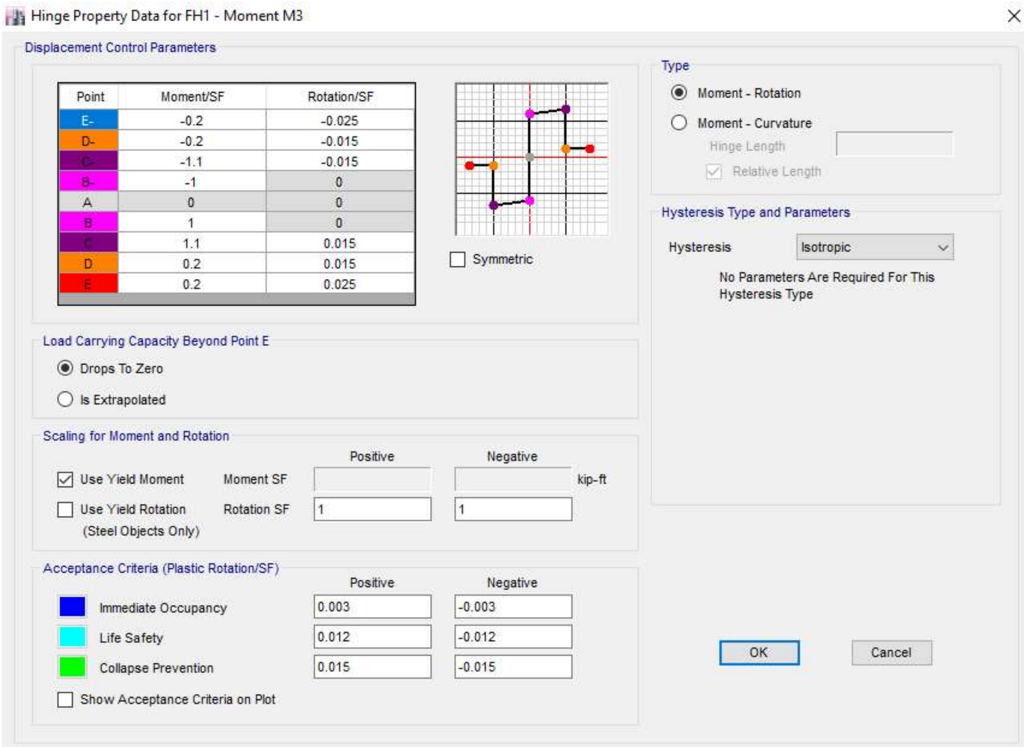


FIGURE 13 : DEFINED HINGE OF BEAM

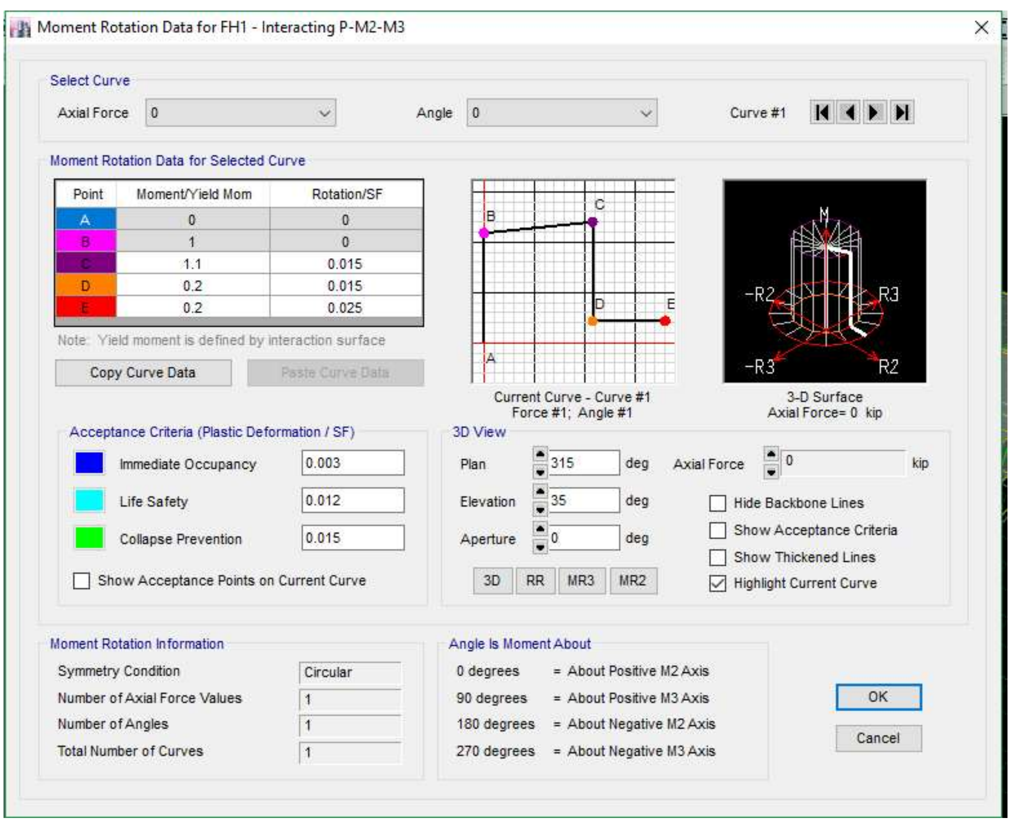


FIGURE 14 : DEFINED HINGE OF COLUMN

4.5. Push-over Analysis Results

From backbone curves, it was found out that the flat slab and flat plate systems showed more deflections against similar loads when compared to the conventional frame structure. It was found that punching shear was predominant in flat slab and flat plate system due to lack of specific depth to cater for that.

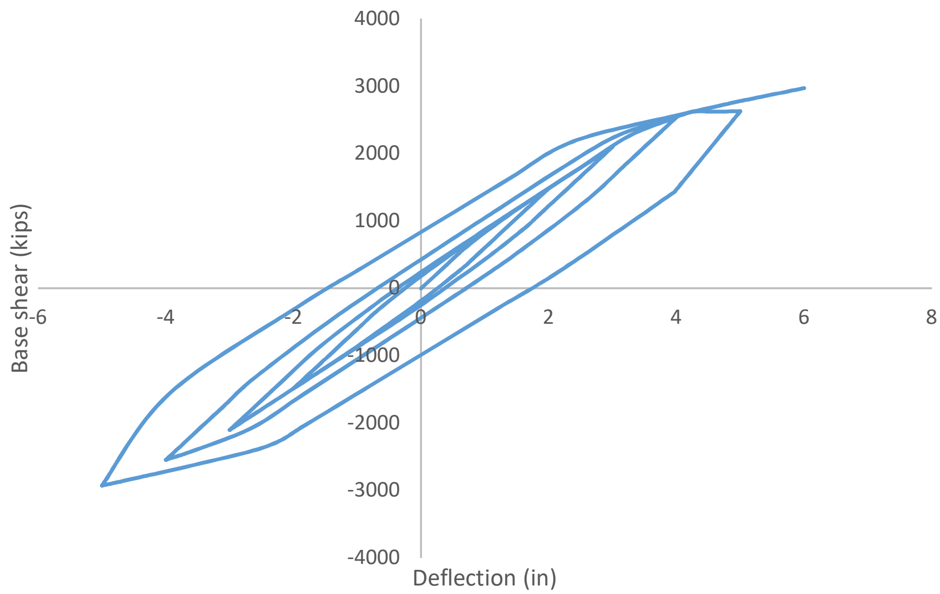


FIGURE 15 : HYSTERESIS LOOP (FRAME)

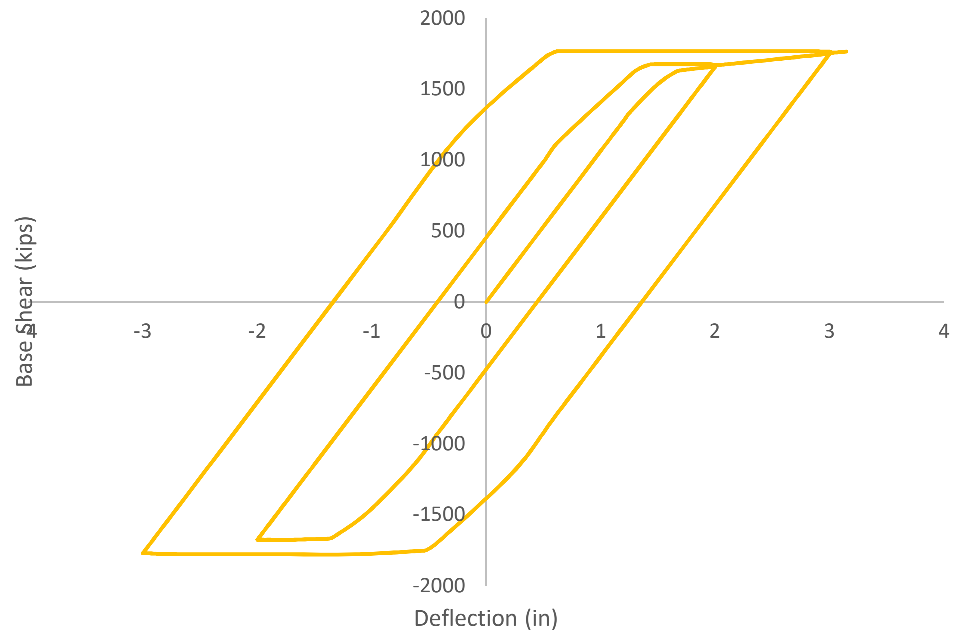


FIGURE 16 : HYSTERESIS LOOP (FLAT SLAB)

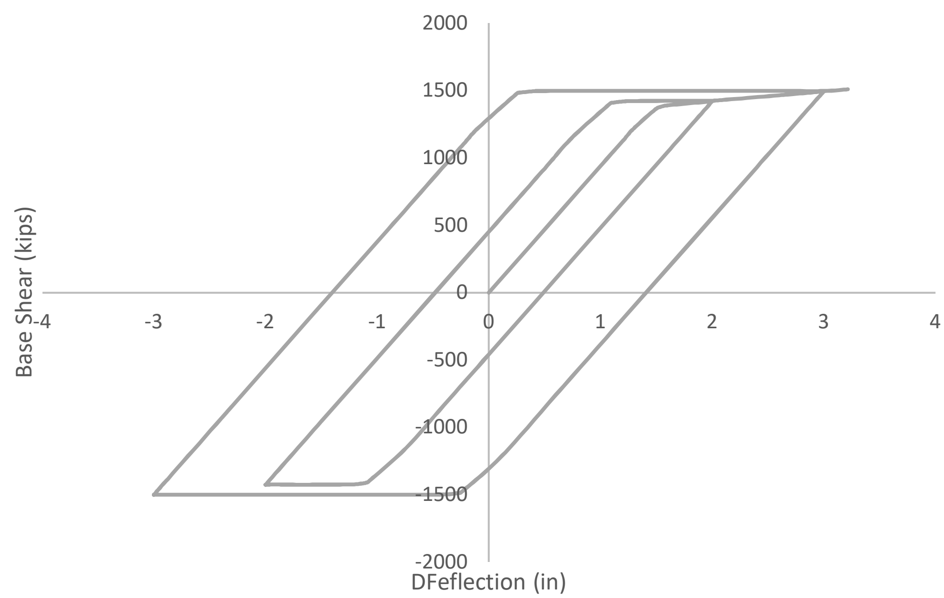


FIGURE 17 : HYSTERESIS LOOP (FLAT PLATE)

Backbone Curve of all three structures are given below in fig.18:

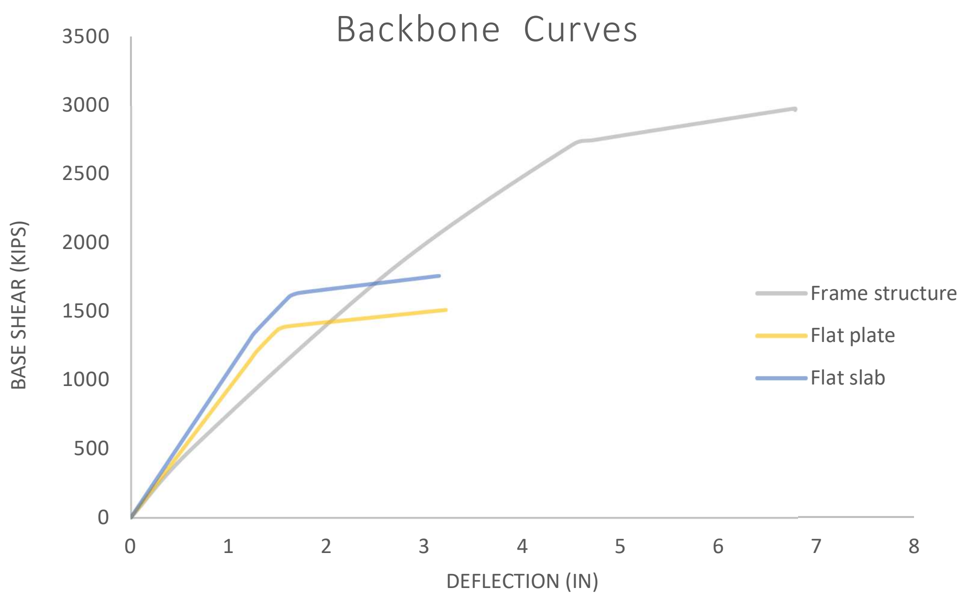


FIGURE 18 : BACK BONE CURVE

Figure 19 shows percentage of deflection, base shear and energy absorbed compared with conventional frame structures

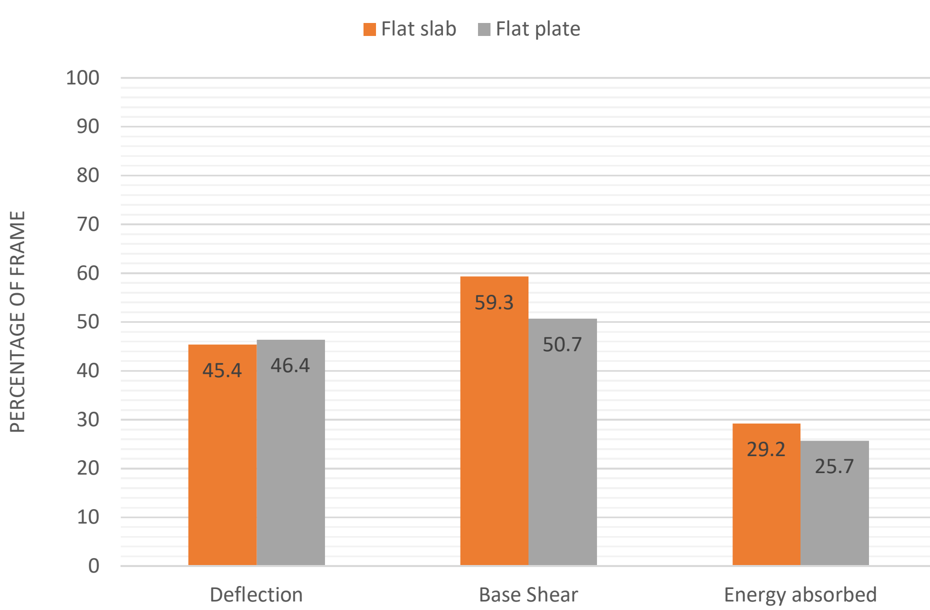


FIGURE 19 : PERFORMANCE COMPARISON

CHAPTER 5

IMPROVEMENT OF STRUCTURES

From theory, we learned that the flat slab system and flat plate system are very weak as compared to frame structure. It we need to enhance their behavior by retrofitting them. Many methods have been adopted to apply flexural post strengthening to already built buildings, with the purpose of enhancing their serviceability or performance. These methods contains addition of an external reinforcement layer to the tensile part of the structural member. To cater for the limited capacity of the members, the structures need to be reconstructed or repaired or retrofitted.

For post construction strengthening of the system or retrofitting, there are variety of materials available in the market including ferro cement, steel plates, fiber reinforced polymers (FRP's) and carbon fiber reinforced polymers (CFRP's).. It is economically good to repair or strengthen structures rather to replace them. Similarly, it is good for environment as well. With the manufacturing of new adhesives CFRP jacket are becoming stronger and provided more strength to the structures.

It should be kept in mind that retrofitting should not change the layout of the structure and there should be minimum changes in the structure after retrofitting and in its usage. Steel is an excellent material in this regard for improving interior beams and columns.

Nevertheless, using external steel for retrofitting has a major disadvantage i.e. rusting of steel. The bonding strength between the plates and structure is reduced due to the rusting, which is the main drawback. These techniques were expensive because of the heavy equipment needed and, in most instances, did not provide a long service life. In addition, in certain cases such as strengthening of unreinforced masonry and concrete walls, the traditional techniques cannot be used. High-strength composite materials, used by the aerospace industry for more than 50 years, are becoming the preferred materials for the repairs.

5.1. CFRP

Carbon fiber reinforced polymer (CFRP), is an enormously strong yet very light weight fiber-reinforced plastic material which consists of carbon fibers. CFRPs are usually very costly but they are used wherever high strength-to-weight ratio is required.

These materials are usually bonded with the members through epoxies such polyester. The additives or resins that are used for bonding can affect the properties of the CFRP's used.

FIGURE 20 : CFRP

Consists of matrix and a reinforcement.

In CFRP, the strength is provided the carbon fiber.

The bonding material is often a polymer resin, such as epoxies, to bind the reinforcements.

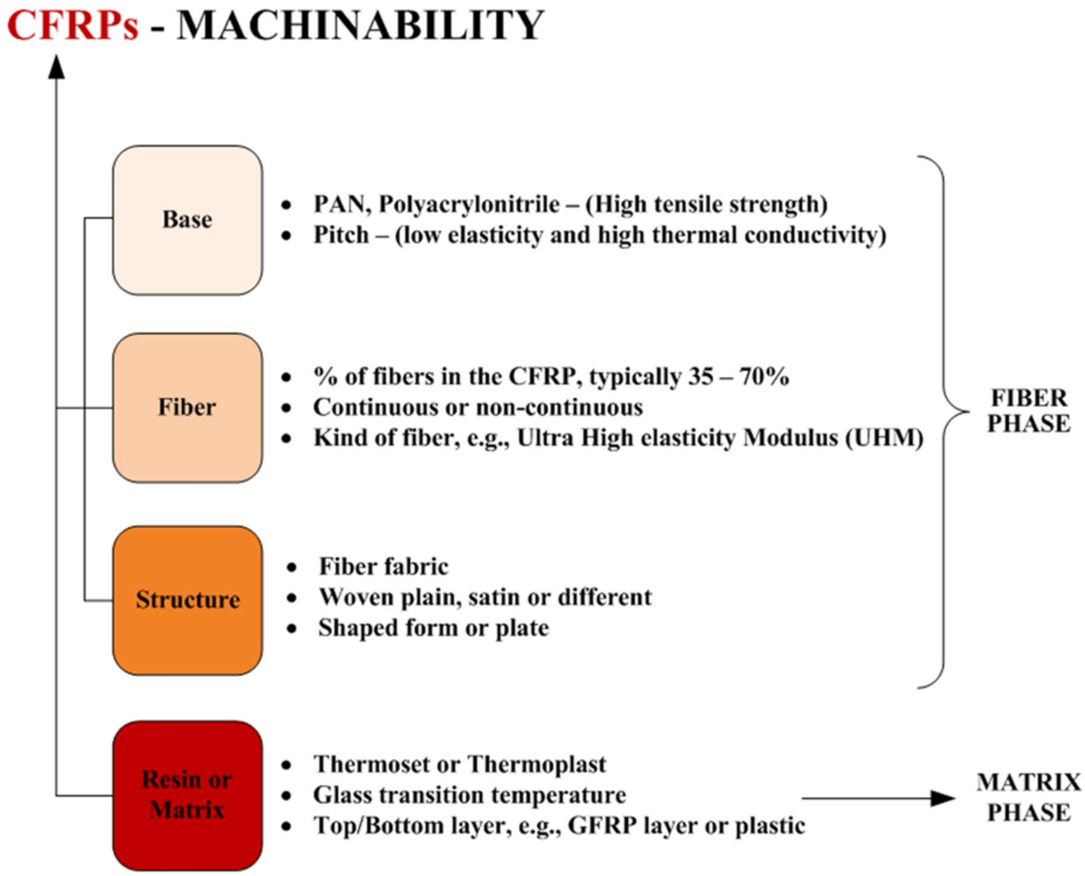


FIGURE 21: CFRP PROPERTIES

Carbon-fiber reinforced polymer (CFRP) is being used as primary materials for retrofitting of damaged structures for the past many years now. CFRP's have a positive edge over the steel material when a comparison is drawn between them including the resistance to electrochemical corrosion, strength to weight ratio, ease of handling. Initial cost of using CFRP is relatively high but when it is compared to the end savings and maintenance and repair costs of future, it can justify the usage of CFRP jacket.

The most popular uses include:

- Strengthening of reinforced concrete column and slab joint;
- Shear strengthening of reinforced concrete slabs (flat slab and flat plate);
- Column wrapping to improve the ductility for earthquake-type loading.

In order to retrofit flat plate and flat slab it was decided to wrap the column in plastic hinge zone i.e. L/3 for both ends to provide confinement as shown in figure 22 and 23:

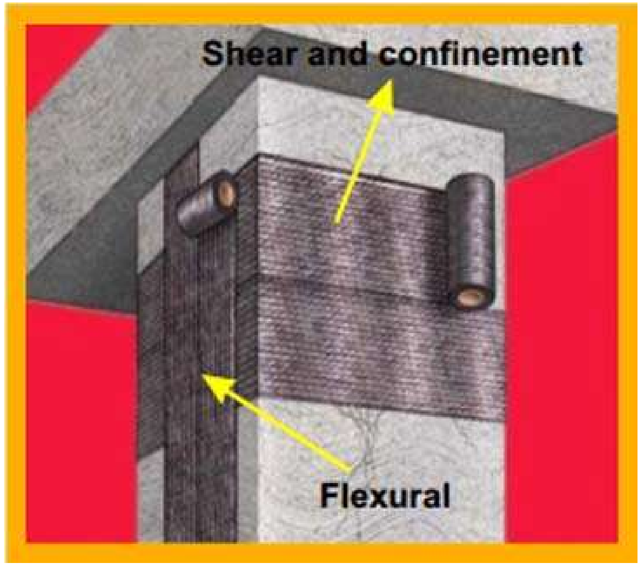


FIGURE 22: CFRP WRAPPING

FIGURE 23 : TYPICAL COLUMN WRAP

5.2. Casting of concrete cylinders

Total eight cylinders were casted. First two cylinders were casted to fix the proportion of materials after finalizing concrete mix design six cylinders were casted for testing. Three of them were unwrapped control samples and remaining three were wrapped with CFRP. Only single layer wrapping was done.

FIGURE 24 : CASTING OF CYLINDERS

FIGURE 25 : WRAPPED CYLINDERS

5.3. Properties of materials used

5.3.1. CFRP wraps

Carbon fiber reinforced polymer wraps was acquired from local market basis on availability there was no choice because there is no local production and imported wraps were used. Properties as provided by the manufacturing company are given in table 2.

Areal Weight	Fiber Density	Fabric Thickness	Tensile strength	Tensile E	Elongation at break
230 g/m2	1.76 g/cm3	0.131 mm	4300 N/mm2	238,000 N/mm2	1.80%

Table 1

5.3.2. Epoxy

Two component epoxy was used as an adhesive one was hardener and one was resin material. Properties as provided by the manufacturing company are given in table 2.

Thermal coefficient	Flexural E	Adhesion strength	Tensile strength	Tensile E	Elongation at break
4.5 * 10^-5 1/K	3800 N/mm2	>4 N/mm2	30 N/mm2	4500 N/mm2	0.90%

Table 2

5.3.3. Concrete

As a representative sample for local construction practices a normal strength concrete was used, which has a typical strength of 4000 psi. No additive or admixture was used. To achieve target strength mix proportion used was 1:1.5:3 (cement: sand: aggregate).

5.4. Specimens details

Total six specimens were casted, these were cylinders of 6" diameter and 12" height. Three samples were casted as controlled samples while three samples were casted to be raped by CFRP fabric. These samples were named as PCC-1, PCC-2, PCC-3 and CFRP-1, CFRP-2, CFRP-3.

5.4.1. Instrumentation

Testing was done on compression machine of 2000 (kN) capacity, at a loading rate of 0.25 MPa / sec. LVDT (extensometer) was attached to measure the axial strain. Specimens ready for testing have been shown in fig 26.

FIGURE 26 : SAMPLE SET FOR TESTING

5.5. Experimental results

5.5.1. Test results

All CFRP confined specimens failed abruptly because of sudden rupture of jackets. Typical failure of control and CFRP samples has been shown in figure 27 respectively. A thin layer of concrete was still attached to jacket which showed bond strength of bond between concrete and jacket was good.

FIGURE 27 : FAILED SAMPLES

5.5.2. Axial stress-strain curve

There was a visible increase in both properties i.e. peak strength & ductility of the material as depicted by stress-strain curve of both control and CFRP samples in figure 28.

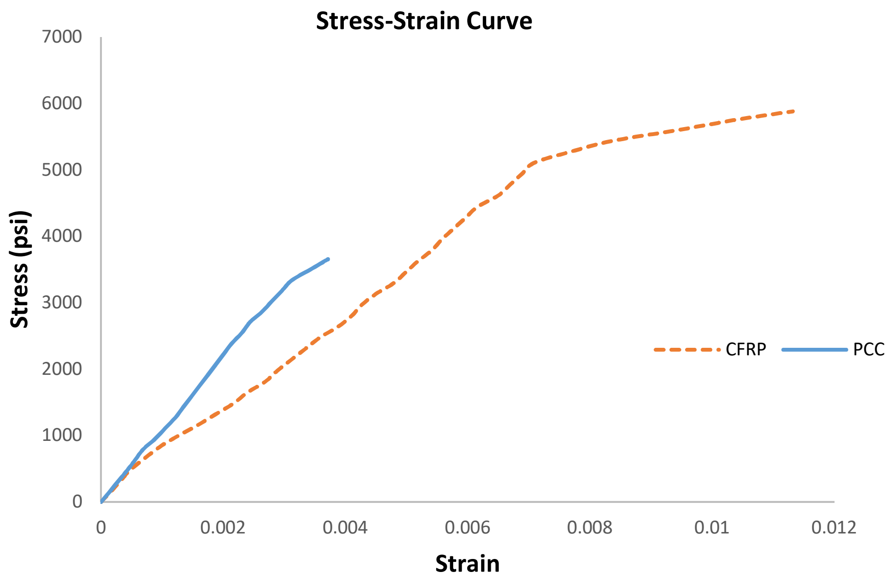


FIGURE 28 : STRESS-STRAIN CURVE

5.6. Corrected stress-strain curve

After applying jacket efficiency factor to strain corrected stress-strain curve was plotted.

5.6.1. Jacket efficiency factor:

From document of transportation department of university of Utah jacket efficiency factor for different shapes is given below. In our project Jacket efficiency factor was used according to relation given below.

Table 6.1 FRP-jacket efficiency factor, k_ε ($k_{\varepsilon,\max}$) for different types of FRP jackets and sections

Type of cross-section	CFRP jacket		GFRP jacket	
	Bonded ($k_{\varepsilon,b}$)	Non-bonded ($k_{\varepsilon,n}$)	Bonded ($k_{\varepsilon,b}$)	Non-bonded ($k_{\varepsilon,n}$)
Circular	0.8	0.4	0.95	0.4
Square	Eq. (6.16)	NA	Eq. (6.16)	NA
Rectangular	Eq. (6.16)	NA	Eq. (6.16)	NA
Elliptical*	Eq. (6.17)	0.3	Eq. (6.17)	0.6

* Due to non-uniformity of strain distribution over circumference, Table 6.1 lists only the maximum jacket efficiency factor, $k_{\varepsilon,\max}$ for the elliptical section.

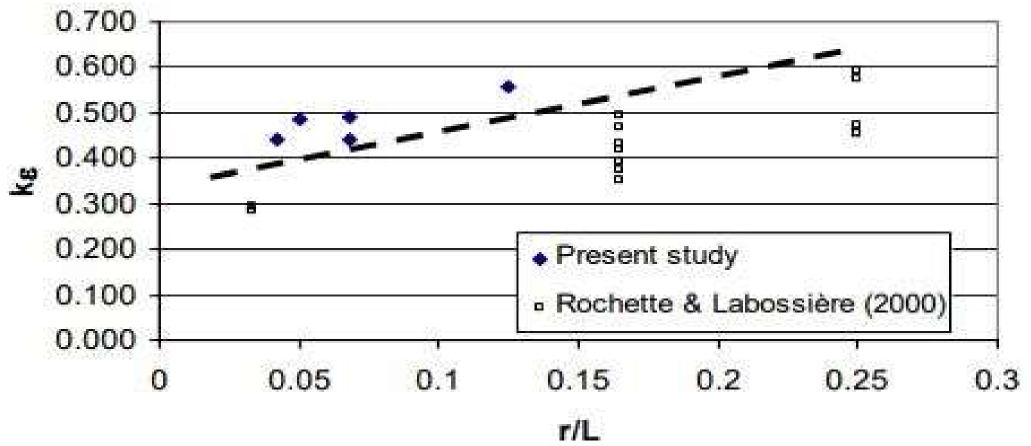


Figure 6.4 Relation between k_ε and $\dfrac{r}{L}$

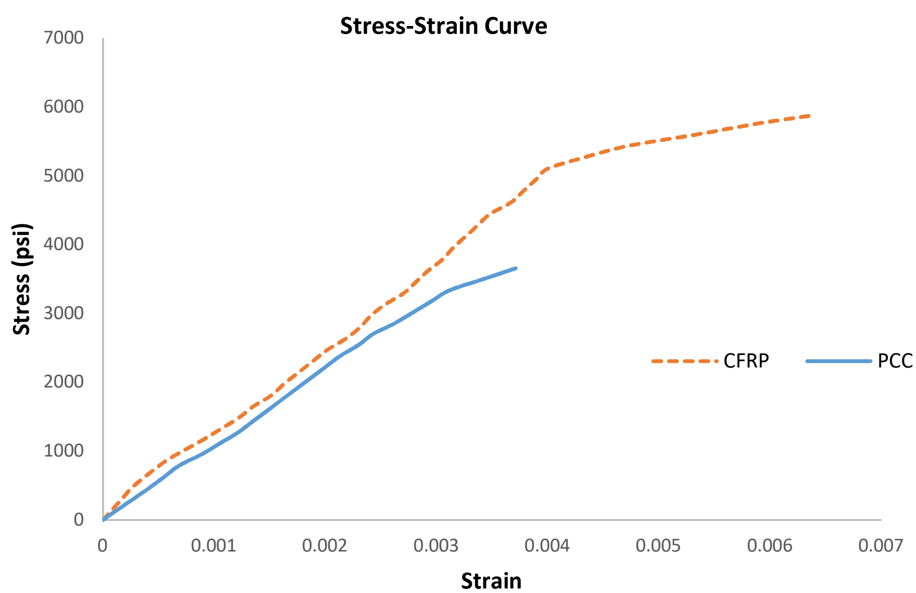


FIGURE 29 : CORRECTED CURVE

5.7. Moment Curvature Curve:

Modified Moment curvature curve was generated on basic of stress strain curve given in fig.30. Moment curvature curve for the symmetrical columns were generated in ETABS using auto generate option in section designer of ETABS.

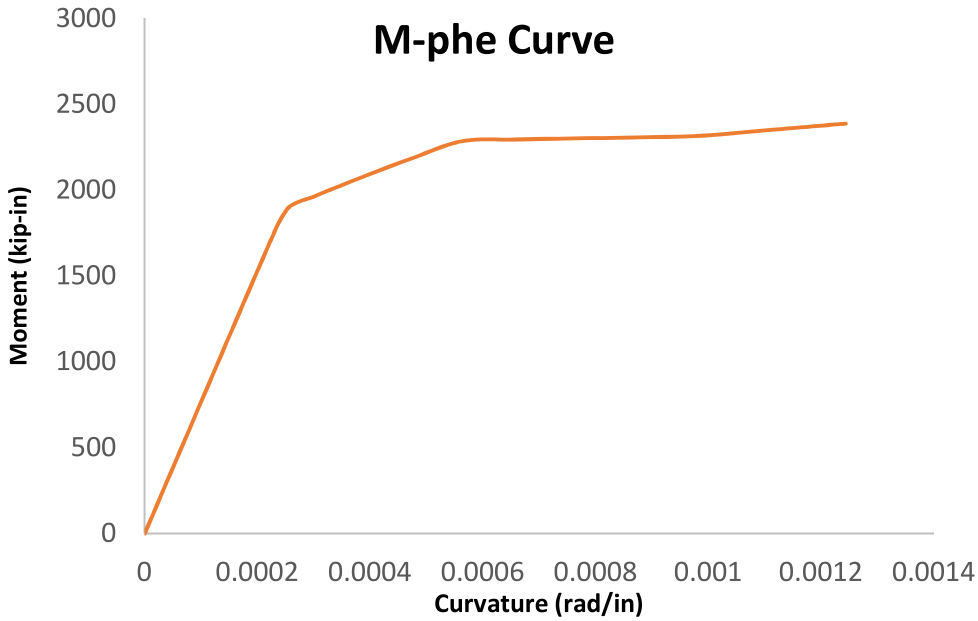


FIGURE 30 : M-PHE CURVE

CHAPTER 6

RESULTS AND DISCUSSION

From graphs, it was found out that the flat slab and flat plate system showed more deflections against similar loads when compared to the conventional frame structure. It was found that punching shear was predominant in flat slab and flat plate system due to lack of specific depth to cater for that.

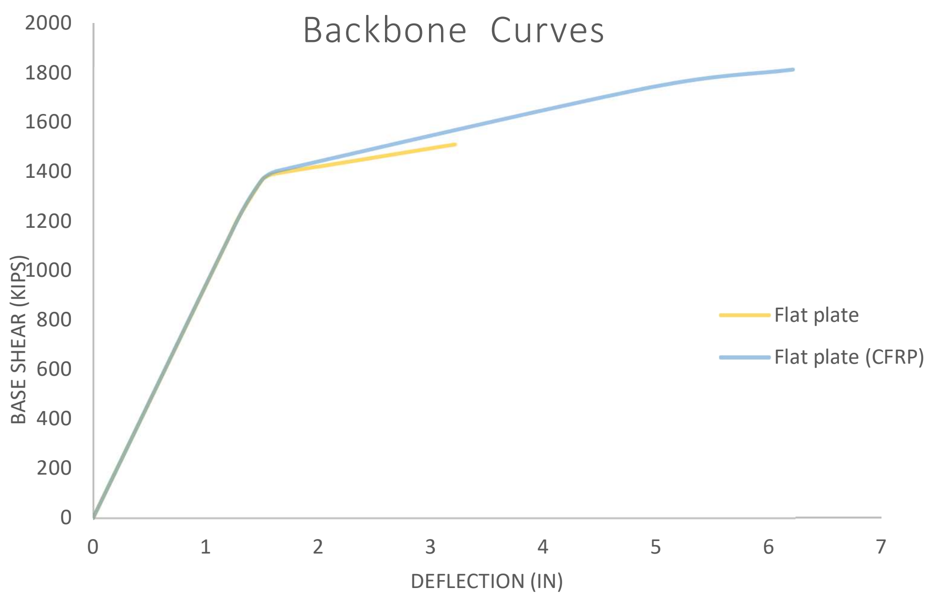


FIGURE 31 : BACKBONE CURVE (FLAT PLATE)

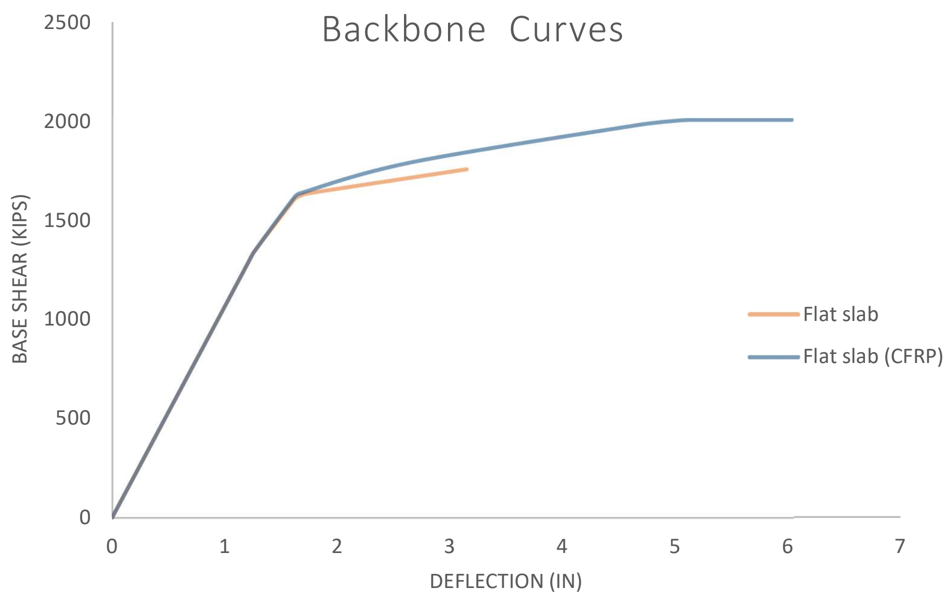


FIGURE 32 : BACKBONE CURVE: FLAT SLAB

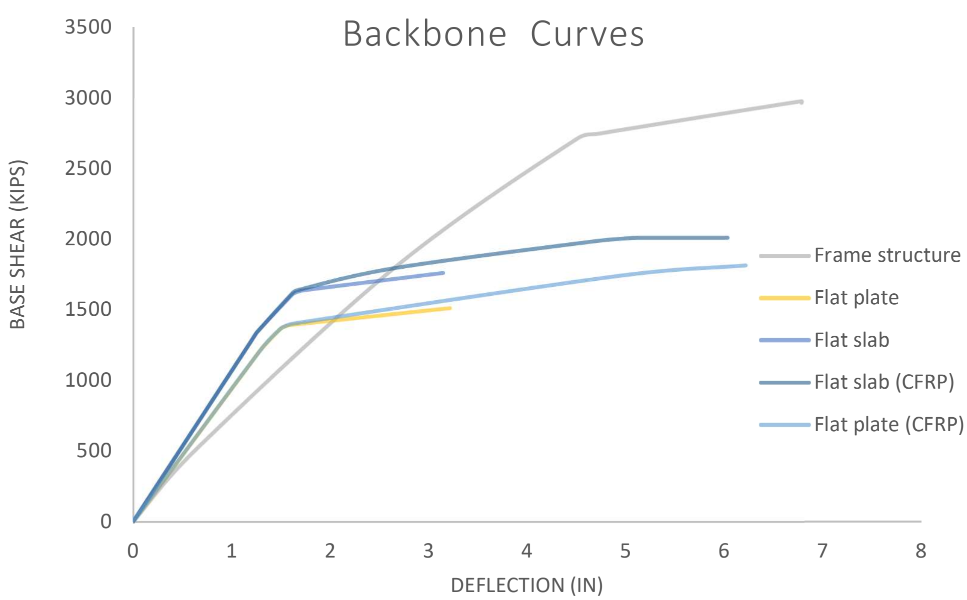


FIGURE 33 : BACKBONE COMPARISON

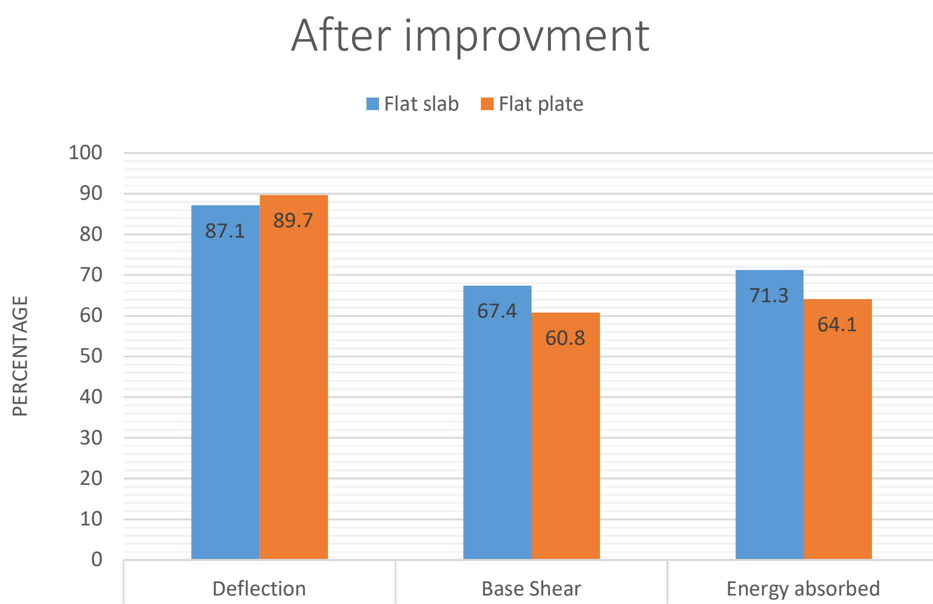


FIGURE 34 : COMPARISON IN PERCENTAGES

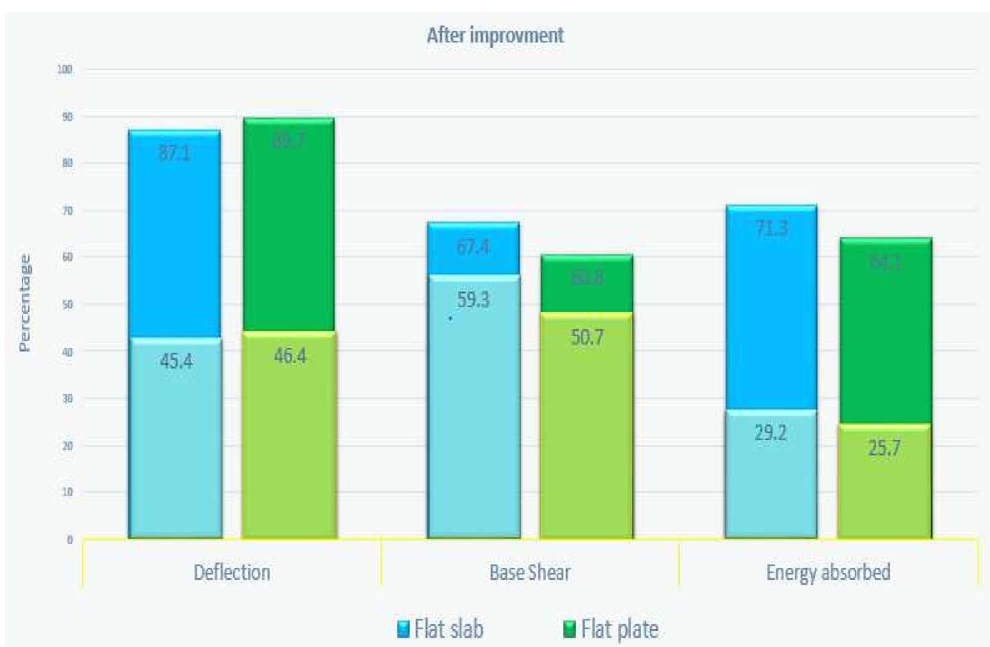


FIGURE 35 : IMPROVEMENT BY CFRP APPLICATION

CHAPTER 7

CONCLUSIONS AND FUTURE RECOMMENDATIONS

7.1. Conclusions:

To safely and efficiently use flat slab and flat plate system, we should introduce other parameters to enhance their capabilities using various components among them CFRP is most prominent. It was found out that CFRP increases the strength of concrete around 30 to 40 percent alone.

- CFRP jacket provides confinement to concrete and increases ductility.
- CFRP increases the strain of concrete specimen by 110% for concrete cylinder.
- The strength of the concrete increases by 54% along with considerable increased ductility.
- There is an increase of almost 23% in the ultimate curvature due to wrapping same moment.
- Before application of CFRP, flat plate and slab show following parameters in terms of percentages of same parameters of frame structure, as shown in figure 22:

	Max. Deflection	Base shear	Energy absorbed
Flat plate	46%	51%	26%
Flat slab	45%	59%	29%

- After application of CFRP, flat plate and slab show following parameters in terms of percentages of same parameters of frame structure, as shown in figure 34:

	Max. Deflection	Base shear	Energy absorbed
Flat plate	90%	61%	64%
Flat slab	87%	67%	71%

- Hence ductility of structures is almost doubled

7.2. Future Recommendations:

In future studies could be done on buildings with more than two stories, unsymmetrical plans and complex design. Also dynamic analysis i.e. time history analysis and response spectrum analysis should be done in order to obtain more precise and accurate results.

REFERENCES

1. Bothara, J.K., Hicyilmaz, K.M.: General observations of building behavior during the 8th October 2005, Pakistan earthquake, Bull.
2. N. Z. Soc. Earthq., 41 (2008) 4, pp. 209-233. Badrashi, Y.I., Ali, Q., Ashraf, M.: Reinforced Concrete Buildings in Pakistan, World Housing Encyclopedia, Earthquake Engineering Research Institute (EERI) & International Association of Earthquake engineering (IAEE), Report # 159, 2010.
3. Ahmed, N., Badrashi, Y.I., Ali, Q., Crowley, H., Pinho, R.: Development of displacement-based method for seismic risk assessment of RC building stock of Pakistan, Proceedings of the International Conference on Earthquake Engineering and Seismology, Islamabad, Pakistan, Paper No. 11, 2011.
4. Inel, M. and Ozmen, H.B., 2006. Effects of plastic hinge properties in nonlinear analysis of reinforced concrete buildings. Engineering structures, 28(11), pp.1494-1502.
5. Ashraf Habibullah, S.E. and Stephen Pyle, S.E., 1988. Practical three dimensional nonlinear static pushover analysis. Structure Magazine,
6. Salahuddin, H., Ali Khan, S., Usman Ali, M. and Mushtaq, A., 2017. Seismic vulnerability assessment of CFRP strengthened RC structures. Građevinar, 69(02.), pp.121-130.
7. Mander, J.B., Priestley, M.J. and Park, R., 1988. Theoretical stress-strain model for confined concrete. Journal of structural engineering, 114(8), pp.1804-1826.
8. Soltani, M., An, X. and Maekawa, K., 2004. Cracking response and local stress characteristics of RC membrane elements reinforced with welded wire mesh. Cement and concrete Composites, 26(4), pp.389-404.
9. Xiong, G.J., Wu, X.Y., Li, F.F. and Yan, Z., 2011. Load carrying capacity and ductility of circular concrete columns confined by ferrocement including steel bars. Construction and Building Materials, 25(5), pp.2263-2268.
10. Tabsh, S.W., 2007. Stress-strain model for high-strength concrete confined by welded wire fabric. Journal of materials in civil engineering, 19(4), pp.286-294.
11. Shahzada, K., Gencturk, B., Khan, A.N., Naseer, A., Javed, M. and Fahad, M., 2011. Vulnerability assessment of typical buildings in

Pakistan. International Journal of Earth Sciences and Engineering, 4(6), pp.208-211.

12. Ali, M.U., Khan, S.A., Anwar, M.Y. and Gabriel, H.F., 2015. Probabilistic application in seismic vulnerability assessment of deficient low-to mediumrise reinforced concrete buildings in Pakistan. Arabian Journal for Science and Engineering, 40(9), pp.2479-2486.
13. Maqsood, S.T. and Schwarz, J., 2008. Seismic vulnerability of existing building stock in Pakistan. In Proceedings of the 14th World Conference on Earthquake Engineering, Beijing, China. Paper (No. 09-01, p. 122)