Varying Lateral Stiffness and Improve Response Using FRP Retrofitting of RC Structures Under Seismic Excitation

By

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NUST Institute of Civil Engineering(NICE)
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This is to certify that the thesis entitled

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Has been accepted towards the partial fulfillment
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1 Contents

2 Abstract

R.C structures have a certain age after which they are not safe to use. They deteriorate over time and become unsuitable for the purpose they were built for. R.C structures could be in the form of beams, columns, footings, slabs, girders, pylons etc but the scope of this project is limited to beam-column joint only.

Retrofitting techniques are of various kinds that are used in industry with both advantages as well as drawbacks. Retrofitting techniques are more suitable, especially for a country like Pakistan, where weak economy and high inflation rate are prevalent. Retrofitting techniques are only used when the structure has not been completely damaged. Instead of replacing damaged structures, effective techniques of repairing can result in time saving and minimal cost. Fiber Reinforced polymers (FRP) is relatively new class of complex materials which has demonstrated itself effective and efficient for the advancement and repair of new and decayed structures in development industry. Due to its high quality to weight proportion, FRP's and have been broadly utilized as a part of created nations for retrofitting and other support activities. Even though in Pakistan, this innovation should be featured. Most of the designers and consultancy firms are hesitant to utilize this innovation likely on the grounds that they have enough trust in established strategies. What are FRPs?

These have been utilized in the construction industry for the making of roofs for parking lots and other light-weight temporary structures. The FRPs are now being used in the construction industry where the buildings are prone to earthquakes of high intensity. The FRPs are being utilized in the retrofitting of the damaged buildings that have been affected under earthquakes. The FRPs don't add to the compressive strength of the concrete but they add sufficiently to the flexural strengths of the concrete, improve overall strength of the concrete, lessen the reinforcement requirement of the steel, increase the ductility (post cracking), increase the abrasion resistance of concrete.

There are many other types of fiber reinforced polymers that are available in the market, some of them include as CFRP, BRRP and GFRP. We utilized FRPs in our project because of the reason that it is easily available in the market at low cost. Moreover, our project is to strengthen the column-beam connection under the seismic excitation.

Several samples were made of concrete cylinders. There compressive strengths as well as flexure strength of the controlled, single, double and triple wrapped cylinders were measured. The tests of cylinders clearly showed a important improvement in the lateral stiffness of the concrete cylinders. The results obtained during our experimentation would be further discussed in this paper. The objective of this project is to present a cheaper solution of retrofitting/repair damaged beams. One possible option is to repair the damaged sections using Fiber Reinforced Polymers.

3 ACKNOWLEDGEMENTS

This project would not have been possible without the guidance and supervision of our project advisor, Assistant Professor, Arslan Mushtaque. He guided us in every step of the way and encouraged us to select this project and not be daunted by the tasks ahead.

We would also like to acknowledge Dr. Hassan Farooq who taught us Earthquake Engineering and Design of Concrete Structures as our electives and guided us in every possible way, Mr. Zulqarnain Shah, Structures Lab Engineer who cooperated with us and made casting of cylinders possible inside NUST. Last, but not the least, we would like to extend our regards and blessings to our parents and our friends who have been a great moral support throughout the course of the project in every possible way.

Chapter 1

INTRODUCTION

The reason behind the fact that concrete is the most widely used material is simple; all the materials in its composition are easily and naturally available except for cement which is a man-made material used as a cementing agent. Ordinary concrete generally has 4000psi compressive strength which makes it an excellent material for resisting compression but on the other hand its tensile strength is very low as compared to its compressive strength. That is why concrete is always used in combination with steel. Reinforced concrete thus becomes a perfect material for resisting both compressive and tensile stresses. Reinforced concrete structures comprises of bridge girders, slabs, columns, piers etc.

These structures once built have a certain capacity and age after which they should be replaced. Technique of retrofitting enables us to repair and upgrade R.C structures, thus increasing their life span(Miller, Chajes, Mertz, & Hastings, 2001). Besides its use in Civil engineering industry FRPs find its applications in aerospace engineering, automotive engineering, sports and in electronics. FRPs have high strength to weight ratio that accounts for their enormous usage in the world (Khalifa & Nanni, 2000). In Pakistan FRPs have been used to retrofit bridge girders and piles. But this technology needs to be highlighted so that it can be used extensively.

Demolishing a structure and constructing a new bridge is costlier and a time-consuming operation as compared to the retrofitting by FRP which is cost effective and does not even stops the structure from performing its function. Standard FRP wraps and plates are available in markets that have been used in the enhancement of the both shear and moment capabilities of the girders. Epoxy resins are used as a bonding material between substrate and FRPs. Similarly, vertical stiffens of the columns can be sufficiently increased by wrapping the FRPs around the columns. But our scope of the project is to wrap the FRPs around the column-beam joint in the structure that need to be retrofitted. In this project effectiveness of FRPs was demonstrated with the help of experimental program, software program and design calculations.

1.1 Objectives

FRP’s are now much highlighted in the field of engineering. It finds its application in all disciplines of engineering in one way or other. This project is primarily aimed to study the properties of FRPs and its various types and how they affect the strength parameters of R.C beams. After successfully achieving the goals of this project, we would be able to understand the behavior of retrofitted R.C column-beam joint under seismic excitation. The objectives are as under:

- Cast cylinders of concrete for sample results.
- Wrapping the cylinders with different layers of Fiber Reinforced Polymer.
- Evaluation of the results for both controlled and FRP wrapped cylinders.
- To check the enhanced behavior of the structure in SAP2000.
- To make conclusions and recommendations regarding retrofitting with different layers of FRP.

1.2 Reasons/Justifications

Pakistan being a developing country don't care about the retrofitting techniques in the construction industry. Moreover, they So there is a definite need to highlight this technology in Pakistan. The following are some of the reasons of choosing this project:

- Understand the behavior of F.R.P composite polymers in detail, their area of application, their limitations and modes of failures.
- To give industry a cheaper solution of repairing damaged R.C structures. Scope will be limited to column-beam joint only.
- Buildings in Pakistan are usually not designed for earthquake loadings and these structures are usually extended laterally without design considerations. They are used even after their service life, in this regard an appropriate retrofitting material to increase load carrying capacity and service life as well must be devised and retrofitting by FRP is one possible option.

Literature Review

3.1 FRC (Fiber Reinforced Polymer in Concrete)

FRC is another type made of concrete matrix incorporating reinforcement in the form of small fibers. These are distributed uniformly and oriented randomly in the concrete matrix. FRC can be reinforced with steel fibers, carbon fibers, synthetic or natural fibers depending upon the requirement.

The uniform distribution of reinforcement in the form of small fibers gives special properties to the concrete matrix. These include the increased post cracking ductility, strength against fatigue and impact loading etc. These properties cater for many problems that arise during the construction and repair works where FRC can be used very effectively.

One imperative utilization of Fiber Reinforced Polymer is in development of the limitation of the coasts that cause the retrofitting of the structure that have been damaged in the seismic activity, that is because the fiber reinforced polymer increases both the tensile and flexural strength of the concrete. For the protected and monetary plan of FRP coats, the stress– strain conduct of FRP-restricted cement under cyclic pressure should be legitimately comprehended and displayed. This paper exhibits a stress– strain display for FRP-bound cement under cyclic hub pressure. This paper gives a diagram of a monotonic cyclic stress– strain show for FRP-bound cement created by the creators for anticipating the envelope bend.

Fiber fortified polymer (FRP) composites have discovered progressively wide applications in structural designing because of their high quality to-weight proportion and high erosion obstruction. One imperative utilization of FRP-composites is as a binding material for concrete, in both the retrofit of existing strengthened cement (RC) sections and in concrete-filled FRP tubes in new development. As a result of FRP repression, both the compressive quality and a definitive pivotal strain of cement can be essentially upgraded. In the two sorts of uses, the stress– strain conduct of FRP-restricted concrete, under both monotonic and cyclic pressure, should be appropriately comprehended and displayed. The stress– strain conduct of kept cement under cyclic pressure is of enthusiasm for the seismic retrofit and plan of solid structures.

Numerous examinations have inspected the stress– strain conduct of unconfined and steel-limited cement under cyclic pressure. In the previous decade, broad research has likewise been directed on the monotonic stress– strain conduct of FRP-restricted cement, however just a couple of studies have been worried about FRP-bound cement under cyclic pressure. In the ongoing investigation of Lam et al., the accompanying issues were cleared up: a definitive state of FRP-bound cement under cyclic pressure in correlation with that of monotonic pressure the impact of stacking history on the stress– strain reaction, and the displaying of the stress– strain conduct. Numerous current structures not intended to withstand seismic powers have now progressed toward becoming out of date because of improvement of more stringent plan codes and particulars.

Moreover, late tremors have provoked an earnestness to repair and retrofit these seismic inadequate structures to lessen the harm and setbacks. Despite the fact that no such thing as completely seismic tremor evidence structure can exist in genuine, appropriate retrofitting and restoration strategy can eminently enhance the seismic execution of a structure. For the most part section disappointments, which incorporate shear disappointment and shear breaking, have been seen in a RC structure amid the past seismic tremors. Essential approach of fortifying components can be arranged into two basic methodologies. They are,

1. Local modification of structural components
2. Global modification of the structural system.

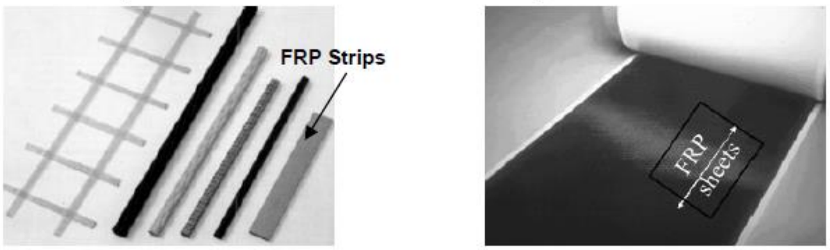
Worldwide adjustment, additionally named as basic level retrofit incorporates option of new auxiliary divider, steel supports, base isolators and so on. Be that as it may, part level retrofit neighborhood adjustment is a considerably more practical strategy than the prior one since it includes choosing and reinforcing just the feeble and lacking segments of the entirety structure. It incorporates expansion of steel coats, FRP materials and so on for the imprisonment of section and joints. In spite of the fact that holding with steel plate is ended up being effective to a few degree, steel as a reinforcing material has some specific constraints. Among these are low consumption opposition, trouble in dealing with at development site due to its unnecessary size and weight and absence of toughness.

These issues related with utilizing steel plates as a retrofit strategy have prompted design new recovery and fortifying systems. Among these strategies fiber-fortified polymer (FRP) composites as retrofit materials has increased much eminent accomplishment as of late. This paper centers around the ongoing advances in retrofitting of RC segments, bars, shaft section joints, brick work dividers and steel structures utilizing different FRP retrofitting plans with a view to enhance the seismic execution of the disintegrated structure.

The principle objective is to introduce a delegate outline of the present condition of utilizing FRP composite materials as a retrofit procedure and in addition enable the structural designers to think about the ongoing assessments while applying this seismic retrofit technique.

FRP Composites for Structural Rehabilitation

Fiber-strengthened polymer (FRP) composites comprise of ceaseless carbon (c), glass (g) or on the other hand aramid (a) filaments reinforced together in a network of epoxy, vinylester or polyester. The strands are the fundamental load conveying part in FRP though the plastic, the network material, exchanges shear. FRP items generally utilized for auxiliary recovery can appear as strips, sheets and covers as appeared in fig. 1.



(a) (b)

Figure 1. FRP products for structural rehabilitation, (a) FRP Strips and (b) FRP sheets (Rizkalla et al. 2003).

Utilization of FRP has now turned into a typical option over steel to repair, retrofit and fortify structures and scaffolds. FRP materials may offer various focal points over steel plates which incorporate,

1. High particular firmness (E/ρ)
2. High particular quality (σult/ρ)
3. High consumption obstruction
4. Simplicity of dealing with and establishment

Also, its protection from high temperature and extraordinary mechanical and natural

conditions has settled on it a material of decision for seismic restoration. A portion of the burdens of utilizing FRP materials incorporate their high cost, low effect obstruction and high electric conductivity.

Retrofitting of Reinforced Concrete Structures

3.1 Column fortifying

At the point when a quake hits, fortified solid segments are the most helpless piece of an ordinary RC structure as they are the significant load conveying component of the building. Least cross area size and absence of steel support in under composed segments prompts a powerless section—solid bar development. It is essential to fortify the sections so the plastic pivots are shaped in the shafts since it permits more compelling vitality scattering. In addition, segments ought to be satisfactorily intended to evade a delicate story fall of a working because of seismic activity.

Figure 2. Application of FRP for seismic retrofitting of RC columns

Amid a tremor, three methods of RC section disappointments that can happen due to cyclic hub and sidelong loads are – shear disappointment; flexural plastic pivot disappointment and lap join disappointment. Absence of transverse fortification can bring about shear disappointment, which is both weak and calamitous in nature. Shear limit of insufficient sections can be altogether upgraded by furnishing remotely reinforced FRP overlays with strands in the circle course as appeared in Fig. 2. Investigates have demonstrated that an expansion in the thickness of CFRP and AFRP coat relatively builds the shear quality of the updated segment or dock. (Fujisaki et al. 1997; Masukawa et al. 1997). Exploratory ponders (Kobatake et al., 1993; Saadatmanesh et al. 1996; and Ehsani and Jin, 1996) have demonstrated that legitimately planned composite wrap for strengthened solid section can expand shear quality to the degree that weak shear disappointment mode is changed over to inelastic flexural distortion mode and improves flexural flexibility. Lap join disappointments in strengthened solid sections happen when the length of lap graft in the segment is small to the point that the bond breaks amid seismic activity. As indicated by an exploration led by Seible et al. (1997), the required FRP wrapping thickness to affix the lap graft area is straightforwardly corresponding to the powerful segment measurement and contrarily relative to the modulus of flexibility of the cover.

A few examinations (Benzoni et al., 1996; Masukawa et al., 1997; Seible et al., 1997; Lavergne and Labossiere, 1997; Saadatmanesh et al., 1997; Seible et al., 1999; Mirmiran and Shahawy 1997; Fukuyama et al., 1999; Pantelides et al. 2000b; Bousias et al. 2004 and Harajli et al. 2006) have been led to consider the adequacy of FRP in restrenghtening of round, square and rectangular strengthened solid segments. Haralji et al. (2006) announced that limiting rectangular segments with FRP, brings about huge change in pivotal quality and flexibility. For square segment areas without longitudinal fortification (plain concrete) the expansion in hub quality was observed to be 154, 213, and 230% for one, two, or three layers of CFRP wraps, separately. Be that as it may, this expansion in quality because of FRP control turns out to be less critical as the viewpoint proportion of the segment area increments. For square steel fortified solid sections, the expansion in hub quality coming about because of FRP retrofitting plan is 188, 255 and 310% with one, a few layers of CFRP wraps, individually (Haralji et al. 2006). In addition, in fortified solid segments, FRP reinforcing counteracts untimely pressure disappointment of the solid cover and clasping of the longitudinal steel bars prompting enhanced execution of the section under seismic stacking. This change is because of expanded strain limit of the restricted cement, to improved limitation of bar clasping, and additionally to concealment of the impacts of shear on distortion limit (Bousias et al. 2004).

3.2 Retrofitting of beam-column joints

Bar section joint retrofitting is a vital part of enhancing the seismic execution of a structure. Control and wrapping of strengthened solid sections with FRP materials will enable the plastic pivots to frame in the shaft locale which will advance a more satisfactory bendable and vitality scattering disappointment component amid a seismic tremor. Fortifying of segments more often than not brings about better auxiliary execution as far as worldwide conduct since the target of neighborhood redesign of a solitary component is to show signs of improvement and more pliable worldwide conduct. Full-scale exploratory investigations have additionally demonstrated that FRP overlays can fundamentally reinforce outside bar segment joints with insufficiency in shear quality (Pantelides et al. 2000a; and Ghobarah and Said, 2001).

Figure 3 demonstrates cases of RC segment pillar joints retrofitted with FRP. 3.3 Retrofitting of RC bars Flexural fortifying of fortified solid shafts should be possible either by outside holding of FRP composites [external holding (EB) system] or by inclusion of FRP strips or bars into grooves cut into the solid [near surface mounted (NSM) system]. In the two techniques, bond amongst FRP and solid surface must be guaranteed to achieve change in flexural quality and firmness and to stay away from untimely debonding disappointment. Flexural fortifying of strengthened solid bars by holding FRP overlays at the strain face of the shaft was first presented by Meier's gathering (Meier 1997) at the Swiss Federal Laboratories for Materials Testing and Research.

From that point forward, broad trial and expository investigations (Colalillo and Sheik 2009; Saxena et al. 2008; Choi et al. 2008; Nitereka and Neal 1999; Brena et al. 2003; Bonacci, and Maalej 2000) have been done everywhere throughout the world on flexural fortifying of solid shafts. The targets of these examinations were either to assess the viability of FRP on flexural execution of solid pillars or to research the impact of different parameters on conceivable disappointment modes. Early research has shown an expansion in extreme quality of solid pillars by 22% because of FRP fortifying. Now and again quality increments up to 245% have been accomplished using outer braces to avoid debonding of FRP (Saadatmanesh and Ehsani 1990).

Notwithstanding the quality upgrade the FRP fortifying plan with tying down framework enhances the malleability of the retrofitted pillar by keeping the solid. This thusly enhances the seismic execution of the retrofitted bars. It has been accounted for in the writing that the shear quality of CFRP retrofitted bars under reproduced seismic tremor loads were improved by up to 114% when contrasted with a comparable RC shaft without FRP (Colalillo and Sheik 2009). Before shear disappointment, FRP material solidified the shafts and took into account generally versatile conduct. While it is conceivable to expand the flexural quality of solid shafts and supports by plate holding FRP sheets to the pressure confront, mind must be taken not to bring new disappointment modes into these bars. These disappointments, which are regularly weak in nature, confine the quality of the retrofitted pillar and happen at loads that are much lower than the hypothetical disappointment stack. With a specific end goal to utilize FRP sheets adequately an enhanced comprehension of the disappointment modes through experimentation and model-based reenactment is fundamental.

Figure 3. Retrofitting of RC beam-column joints with FRP (Tsionis et al. 2001 and Motavalli and Czaderski 2007).

The FRP reinforcing framework for RC bars can be made more compelling by prestressing the strands. The most useful impacts of the prestressing technique are postponing the break development, filling the splits in structure with existing splits and improvement of the individuals shear limit because of the activity of control and lessening of FRP related expenses, on the grounds that a similar quality levels came to with nonprestressed composites can be come to with pretensioned sheets of diminished region (Triantafillou et al. 1992; El-Hacha 2003; and Millar et al. 2004). Therefore, the functionality of shafts fortified with FRPs is enhanced when the sheets or overlays are prestressed. Be that as it may, codes and rules of applying pre-focused on FRP are not yet completely settled.

The prestressing strategies and establishment techniques should be additionally adjusted and rearranged before prestressed FRP can be utilized all the more as often as possible for viable applications. The bond conduct and load exchange conduct between solid bar and FRP overlays has noteworthy effect on the disappointment conduct and stress dispersion of retrofitted bars. Exploratory examinations (Brena et al. 2003; Hamad et al. 2004; Saxena et al. 2008; and Choi et al. 2008) showed that debonding of the base strip from the solid surface is the most widely recognized method of disappointment for solid pillars fortified by remotely reinforced FRP sheets. The debonding brings about the loss of the composite activity between the solid and FRP overlays. The nearby debonding starts when high interfacial shear and ordinary burdens surpass the solid quality (Kotynia et al. 2008). Extra U-coat strips or sheets can be given in the debonding start area to defer the FRP debonding bringing about expanded proficiency of the FRP retrofitting plan. More exploratory and expository examinations ought to be completed to locate a more dependable connection between bond conduct of FRP overlays and cement to ensure that the FRP fitted structure does not bomb rashly.

The mechanical properties and practices of fiber fiber polymers (FRP), incorporating composites with aramid (AFRP), basalt (BFRP), carbon (CFRP), and glass (GFRP) strands, versus steel strengthening ought to be comprehended preceding endeavor the outline of structures utilizing these fortifications. FRP frameworks are an undeniably adequate contrasting option to steel fortification for strengthened solid structures incorporating cast set up and pre-and post-tensioned scaffolds, precast solid channels, segments, shafts and different parts. FRP focal points over steel support including flexibility to consumption is recorded on the past page. Brick work structures additionally advantage with FRP support. Their utilization as unique support and for reinforcing structures is being determined increasingly by auxiliary designers in the general population and private enterprises.

Glass Fiber Reinforced Polymer (GFRP)

FRPs utilizing glass filaments are the overwhelming strengthening fiber in all FRPs. E-glass is the most normally utilized fiber. It has high electrical protecting properties, great warmth opposition, and has the most reduced cost. S-Glass filaments have higher warmth opposition and around 33% higher rigidity than E-glass. The forte AR-glass filaments are impervious to the antacid condition found in concrete yet have considerably higher cost.

Basalt Fiber Reinforced Polymer (BFRP)

Basalt filaments have higher elasticity than E-glass strands yet lower than S-glass, nonetheless, its cost is close to the cost of E-glass. It has much preferable opposition over E-and S-glass to the alkalies in concrete.

Aramid Fiber Reinforced Polymer (AFRP)

Aramid filaments (otherwise called sweet-smelling polyamide strands) have high quality, a high versatile modulus, and 40% lower thickness than glass strands. The cost of aramid strands is higher than glass and basalt filaments making them less normal in basic applications. Furthermore, aramid strands will assimilate dampness so cautious stockpiling and arranging of a venture utilizing aramid filaments is basic until the point that the strands have been impregnated with a polymer grid.

Carbon Fiber Reinforced Polymer (CFRP)

Carbon strands have a high rigidity and versatile modulus. The flexible modulus of "high modulus" carbon fiber is like steel. CFR utilizing high and ultra high modulus carbon strands are prominent in the airplane business since its quality to weight proportion is among the most noteworthy of all FRPs. High quality, typical modulus filaments are utilized with CFRPs in the framework business.

FRP Design Properties

The essential physical properties considered for configuration are: (American Concrete Institute (ACI) classification appeared)

• Ultimate rigidity, ffu*

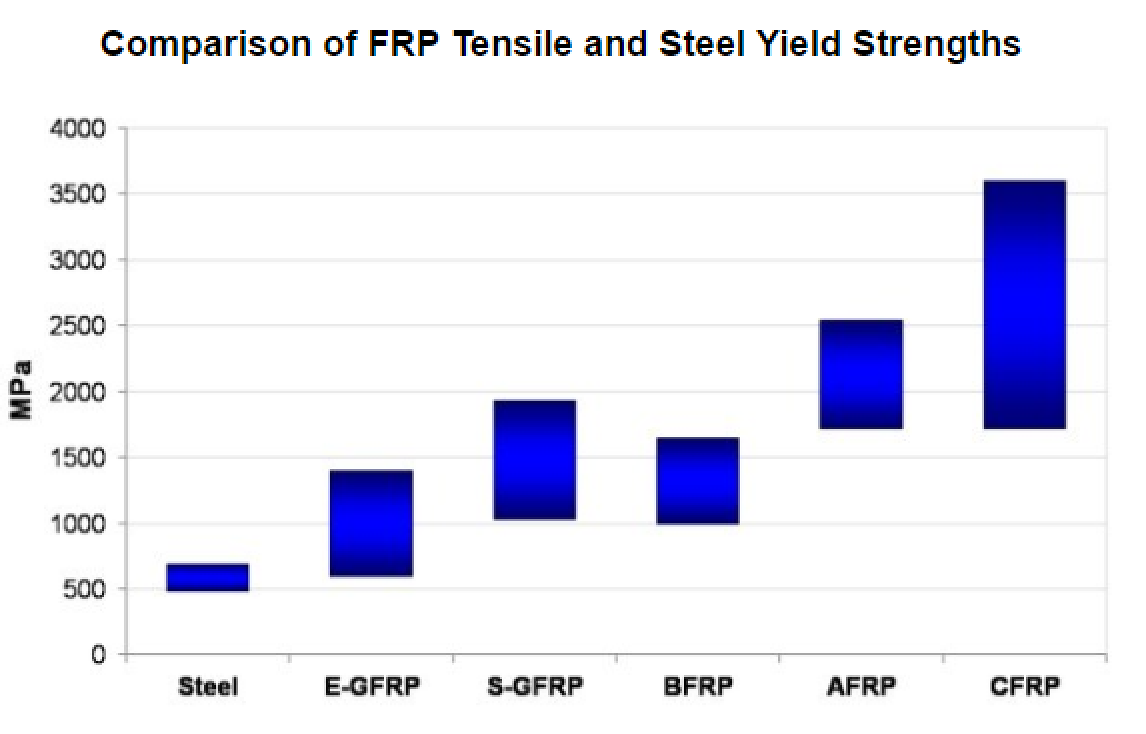
• Tensile Modulus of Elasticity, Ef

• Ultimate Rupture Strain, or Elongation at Break, εfu*, the strain of a material at thepoint of crack.

Fiber strengthened polymers display direct flexible conduct; subsequently, these properties are interrelated as characterized by Hooke's law.

$$E_f = \frac{f_{fu}^*}{\varepsilon_{fu}^*}$$

Reinforcing Material	Yield Strength ksi (MPa)	Tensile Strength ksi (MPa)	Elastic Modulus ksi (GPa)	Strain at Break percent
Steel	40-75 (276-517)	N/A	29,000 (200)	N/A
Glass FRP	N/A	70-230 (480-1,600)	5,100-7,400 (35-51)	1.2-3.1
Basalt FRP	N/A	150-240 (1,035-1,650)	6,500-8,500 (45-59)	1.6-3.0
Aramid FRP	N/A	250-368 (1,720-2,540)	6,000-18,000 (41-125)	1.9-4.4
Carbon FRP	N/A	250-585 (1,720-3,690)	15,900-84,000 (120-580)	0.5-1.9



Chapter 2

4 Experimental Results

4.1 Introduction:

This chapter covers the experimental investigation carried out to determine the values of some unknown variables (e.g. Elastic Modulus) as well as cyclic and static responses of the stress vs strain which were to be used during analysis in SAP2000 during the project. This will contain the test apparatus and the procedure, method of making the sample, the test procedure. All the experiments have been done on the control cylinders of concrete via ASTM(American Society for Testing and Materials).

4.2 Limitations:

There were many factors working against our research, the greatest however and the first one we encountered was the unavailability of fibers which we could use in our research. We were not able to acquire carbon fibers. They were available in sheets which could not have been of any use to us in our research.

Firstly, the main drawback we had was that the very “Reaction Floor” our testing facility have for cyclic testing was out of order for many years and we could not perform cyclic compressive testing over there. We also contacted other universities for this test like UET, Peshawar etc. but got no reply. Just because of this almost 2 weeks were wasted.

Secondly, Because of Reaction Floor being out of order we had to use Static compressive machine and had to use modified approach to determine the cyclic compressive strengths at various intervals. This method will be explained later. And this machine is stress controlled not strain controlled and we could not obtain smooth curves between intervals.

Thirdly, We were not able to measure Poisson Ratio for our samples because our testing facility does not have required lateral gauges which can measure lateral deformations in the concrete samples due to applied loadings.

In concrete replacement method, it is advised to use an epoxy resin to enhance bonding between the old and new concrete. Due to limited resources available to us we were not able to use epoxy resins in our repair works but we still managed to achieve the desired results.

4.3 Preliminary Tests for Mix Design

Production of normal strength concrete requires careful selection, controlling, and proportioning of all the constituents. These parameters influence the properties of concrete in both fresh and hardened state. A systematic approach was adopted during the project to attain the objectives. This was done to ensure uniformity in casted concrete

1) Cement:

Bestway cement was used during the project. It is a, Type 1 Portland Cement, general purpose cement with no special properties. The results of tests performed on cement are tabulated below along with their ASTM designations.

Experiment	**Conclusion**	**Specs**
Cement Type	1 type	c 150
Specific Gravity	3.1	c 188
Consistency Test	30.0 %	c 187
Time for Initial Set	@23 C min. 123	c 191
Time for final set	@23 C min. 170	c 191

All the results deduced from the above experimentation are under the specified ASTM limits.

2) Water:

Ordinary potable water was used throughout the entire experimental work.

3) Coarse Aggregate:

Margalla crush was used during the entire experimental work. 12.5 mm was the max. size of the aggregate used in the experiment. Test results performed on coarse aggregates are tabulated below along with their ASTM specification.

Experiment	Conclusion	Specs
OD Bulk (Specific gravity)	2.66	c 127
SSD Bulk (Specific gravity)	2.67	DO
Specific Gravity(Apparent)	2.67	DO
Capacity of Absorption	5.57%	DO
Unit weight (Dry)	2160	c 29
Gradation	Below(graph)	c 136

Size of sieve (mm)	Reatined wt (gm)	Reatined percentage	Cummulative percentage retained	Passing percentage	Min. percentage passing via ASTM	Max. percentage passing via ASTM
25	0	0	0	100	100	100
19.5	42	4.2	4.2	95.8	90	100
9.5	587	58.7	62.9	37.1	25	55
4.75	297	29.7	92.6	7.4	0	10
2.36	74	7.4	100	0	0	5

Gradation of Coarse Aggregate

4. Fine Aggregate:

Lawarancepur Sand was procured for this undertaking. The examinations performed on the sand are organized beneath alongside comes about. Every one of the analyses were performed by the ASTM gauges.

Experiment	Conclusion	Specs
SSD Bulk (Specific gravity)	2.85	c 128
OD Bulk (Specific gravity)	2.81	DO
Apparent (Specific gravity)	2.93	DO
Capacity of Absorption	2.40%	DO
Modulus of Fineness	2.43	C 136
Gradation	See Graph Below	C 136

Gradation of Fine Aggregates:

Size of sieve (mm)	Reatined wt (gm)	Reatined percentage	Cummulative percentage retained	Passing percentage	Min. percentage passing via ASTM	Max. percentage passing via ASTM
4.750	16.20	3.240	3.240	96.760	95.0	100.0
2.360	66.30	13.260	16.50	83.50	80.0	100.0
1.180	100.60	20.120	36.620	63.380	50.0	85.0
0.60	96.50	19.30	55.920	44.080	25.0	60.0
0.30	110.10	22.020	77.940	22.060	10.0	30.0
0.150	96.40	19.280	97.220	2.780	2.0	10.0

Pan	15.20	3.040	100.0	0.0	-	-

FM= (3.24+16.5+36.62+55.92+77.94+97.22)/100

= **2.430**

Gradation of Fine Aggregates

Test Specimen:

Test specimens were prepared according to ASTM C 39 designation. The details of the casted specimen are tabulated below.

Specimen	Dimension(in)	No of samples
Control	6×12	3
Singly Wrapped	6×12	3
Doubly Wrapped	6×12	3

Molds were oiled before pouring of concrete. Concrete mixer was used for preparation of concrete. All specimens were compacted using a vibrating rod. Date of casting and type of sample was mentioned on each sample. For example FRPC-27/02/2018 means FRP Cylinders and date of casting was 27/02/18.

4.4 Mix Design

Concrete is a blend of Portland bond, mineral totals, water, air, and regularly incorporates concoction and mineral admixtures. The proportioning of solid blends is regularly alluded to as blend plan or blend outline. New and solidified properties of Concrete generally rely on the physical properties of constituent materials and additionally on the extents of these constituent materials utilized as a part of the solid blend. Dissimilar to different materials utilized as a part of development, concrete is typically outlined particularly for a specific task utilizing locally accessible materials. So subsequent to deciding the properties of constituent associated with the solid blend configuration was done to accomplish the required usefulness and quality.

Solid blend extents are computed utilizing ACI blend outline method given by ACI 211.1-91. The aftereffects of the blend configuration are demonstrated as follows:

W/C ratio = 0.5

Material	Quantity
Cement	405 kg/m^3
Fine Aggregate	712 kg/m^3
Coarse Aggregate	1288 kg/m^3
Water	202 kg/m^3

As the water cement ratio was low so plasticizer was used to give concrete the required workability.

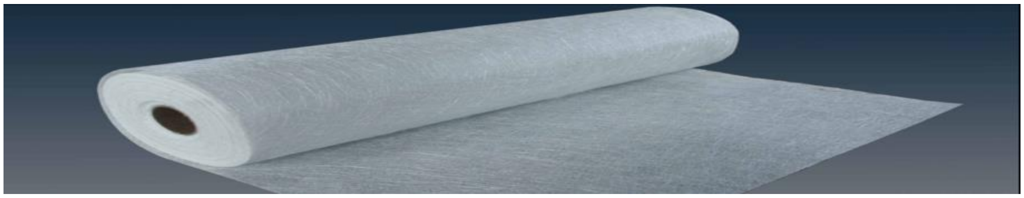
Fiber Reinforced Polymer Wrapping:

First of all, as mentioned earlier it was difficult for us to obtain required fiber polymers such GFRP, BFRP, AFRP etc. in the local market and their import cost was high so as a result we relied on Fiber reinforced polymer.

For wrapping purposes, we contacted local shop near EME, Rwp which specializes in fiber glass products.

FRPC consists of:

1. Fiber Cloth



2. Polyester Resin

Experimentation on Casted Specimen:

The lab tests were intended to get the quality of solid examples under various sorts of stacking. Three sorts of tests were performed:

I. The uni-hub compressive quality test

II. Cyclic Compressive Testing

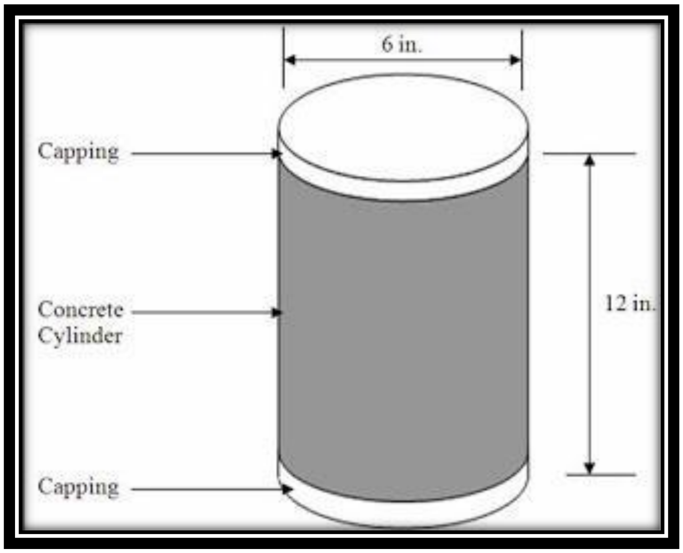
Test examples were arranged and cured by ASTM C35 standard. The examples were expelled from their molds around 24 hours in the wake of throwing and were put away in wet conditions at a temperature around 23.0°C until the season of test. It was guaranteed that the tests on the examples were executed when their expulsion from the curing tank. All tests were performed on examples cured at 28 days. Three examples were tried each and their normal quality was considered.

1) **Compressive Strength Test:**

This test technique comprises of applying a compressive pivotal load to formed chambers at a rate which is inside an endorsed extend until the point that disappointment happens. Compressive quality is controlled by isolating the most extreme load accomplished by the cross-sectional territory of the example.

Compressive quality is ordinarily viewed as the most imperative mechanical property of cement. In most basic applications, concrete is utilized fundamentally to oppose compressive anxieties. Additionally, compressive quality is for the most part utilized as a measure to decide the general nature of cement.

All tests were performed on specimens cured at 28 days. Three samples were tested each and their average strength was considered. Both PCC and FRP samples were casted. ASTM C617 standard was followed for capping of sample. Plaster of Paris was used to ensure that cylinders have smooth, parallel, uniform bearing surface.



ASTM C 39 standard was taken after to play out the test. "Controls" testing machine was utilized for the assurance of compressive quality. The greatest stacking limit of the machine is 5000 KN. The rate of stacking pressure was 0.25 MPa/s. The Stress was connected till the disappointment of the example. Disappointment write 2 was seen in the examples.

Fig. 2.3 A failed specimen after compressive strength test

The above experiment performed and the results deduced from are correct to the best of our knowledge. Results will be discussed in the next chapter.

2) Cyclic Compressive Test

The cyclic loading test is performed at defined levels of loading. This experiment was carried out to check for the deformation performance of concrete under cyclic loadings. This Test was performed on both control (with no wrapping) and fiber wrapped concrete.

As mentioned earlier the reaction floor was out of order and we had to work on ASTM C39 Compressive testing machine. What we did was that we measured the strain values using digital meter at the end of loading and residual strains at the end of unloading.

We had set the increments of 4Mpa and strains were measured at loading and unloading until the sample failed or ruptured.

Detailed Procedure:

1. Cylinders were properly coped with plaster of Paris to give its top and bottom uniform flat surface to ensure uniform distribution of loading during test.
2. Machine was turned on as well as computer. Loading rate was set to 0.025 Mpa according to ASTM C39 standards.
3. Sample (Concrete Cylinders) placed inside and test started.
4. Load was allowed to rise to 4MPa and Strain recorded at this load. Then load was allowed to reach value of zero from 4MPa and residual strain recorded at this value.
5. Then Load value was allowed to increase up to 8MPa and value of strain recorded then again load was allowed to reach value of zero and residual strain recorded.
6. Same procedure was repeated for increments of 4MPa until the rupture occurred and value of strains recorded at the end of both loading and unloading.
7. Rupture pattern of FRP was noted down and it showed linear uniform cracking from top to bottom.

5 Test Results and Analysis

1) Compressive Strength Test:

The statistical analysis of uniaxial compressive strength test performed on cylinders to investigate the properties of PCC and FRP cylinders is explained below

Compressive Strength Test on PCC Cylinders:

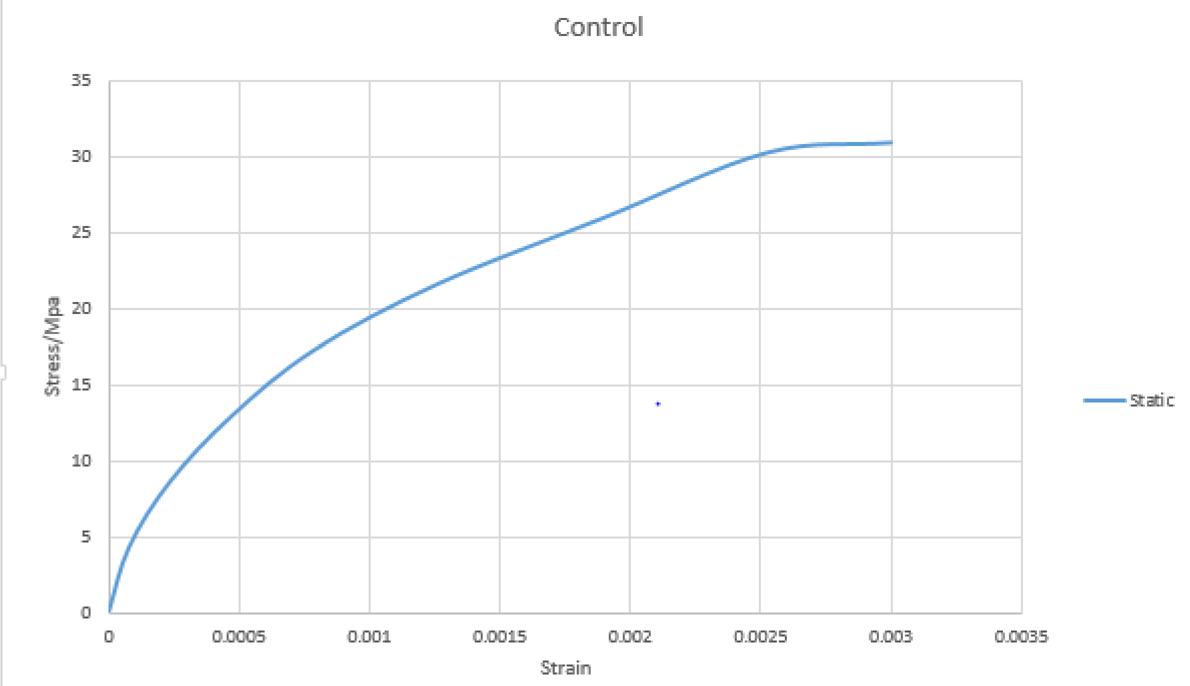
The statistical analysis of uniaxial compressive strength test performed on PCC cylinders is shown in table below.

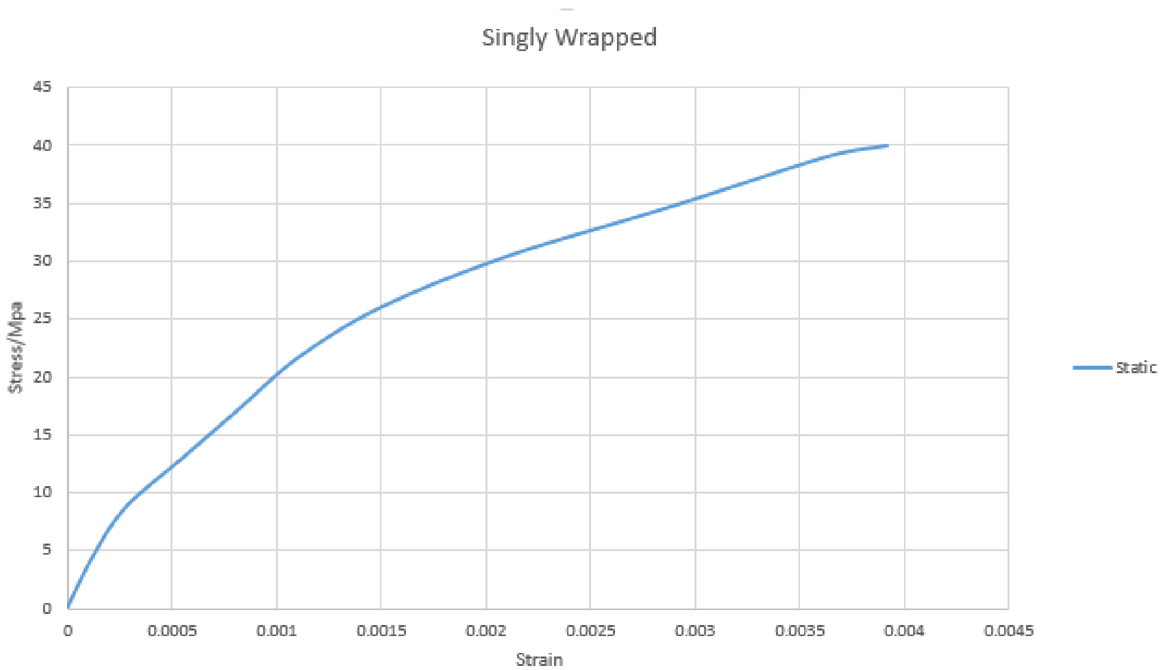
Samples	**1**	**2**	**3**	**Average**
Compressive strength/MPa	28.6	30.6	31.4	30.9

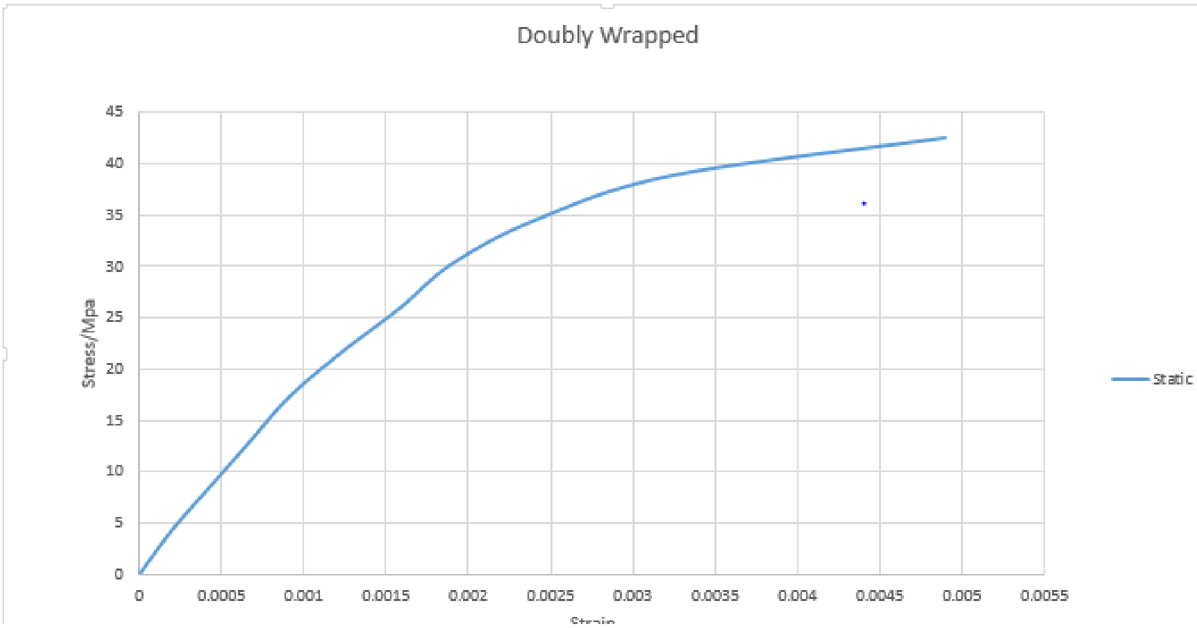
Time (Days)	**Average Strength Achieved (MPa)**
28	30.9

The experiment performed with PCC Cylinders showed the regular trend of increase in strength with the increase in the number of curing days. The strength kept increasing and then achieved a constant value of 28.6 MPa.

Static Compressive test results:







5.1 These static compression graphs were obtained by recording the values of strains at various values of stresses and strains noted down using digital meter and graph plotted in the end. These graphs also shows enhancement in the stiffness and strength of concrete with the increment of the no, of FRP layers, which is very obvious and results are therefore promising.

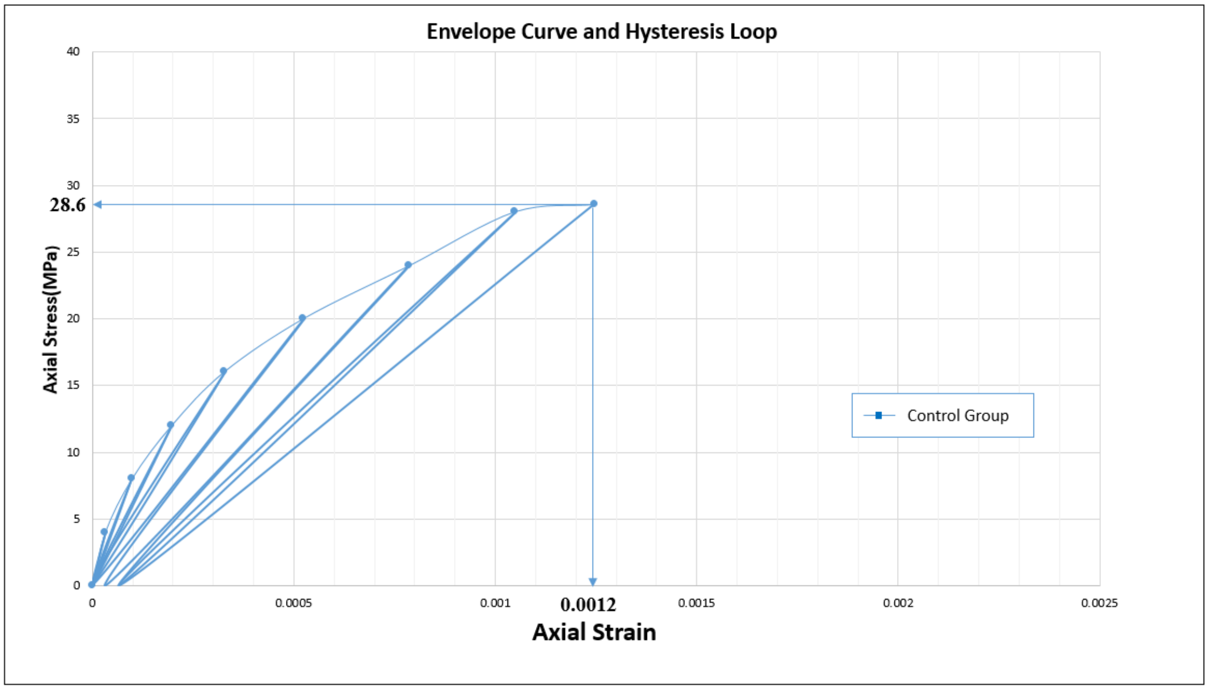
2) Cyclic Compressive Test Results:

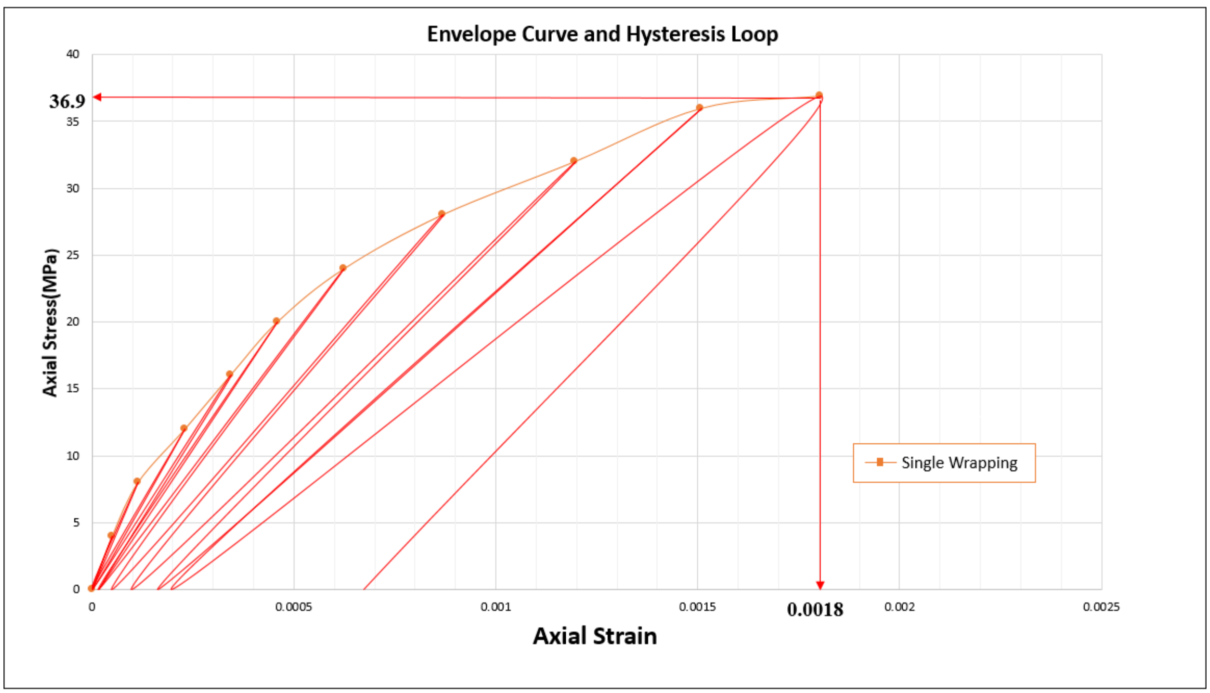
We obtained cyclic tests data points and plotted them using excel for learning the reaction of concrete when wrapped with different layers of FRP i.e. single layer and double layer. Overall, it was seen that with increase in the number of layers of FRP ultimate stress as well as ultimate strains increased.

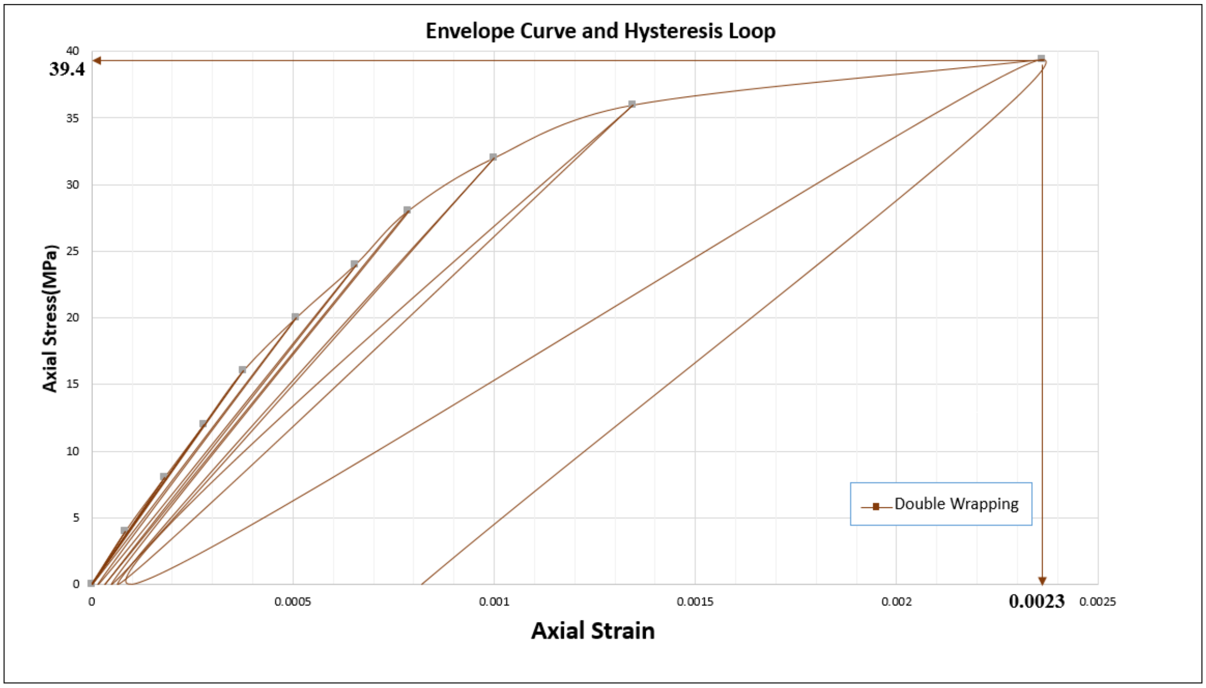
Percent increase in strength of concrete with just one layer of wrapping is about 29.02 % relative to response of control specimen under cyclic loading and about 37.76 % increase in the strength of concrete when wrapped with two layers of FRP.

Improved Ductility:
Ductility is ratio of ultimate and yield strain of a concrete.
Also, it was noted that with enhancement in the ultimate strain, the ductility of the concrete does improve.

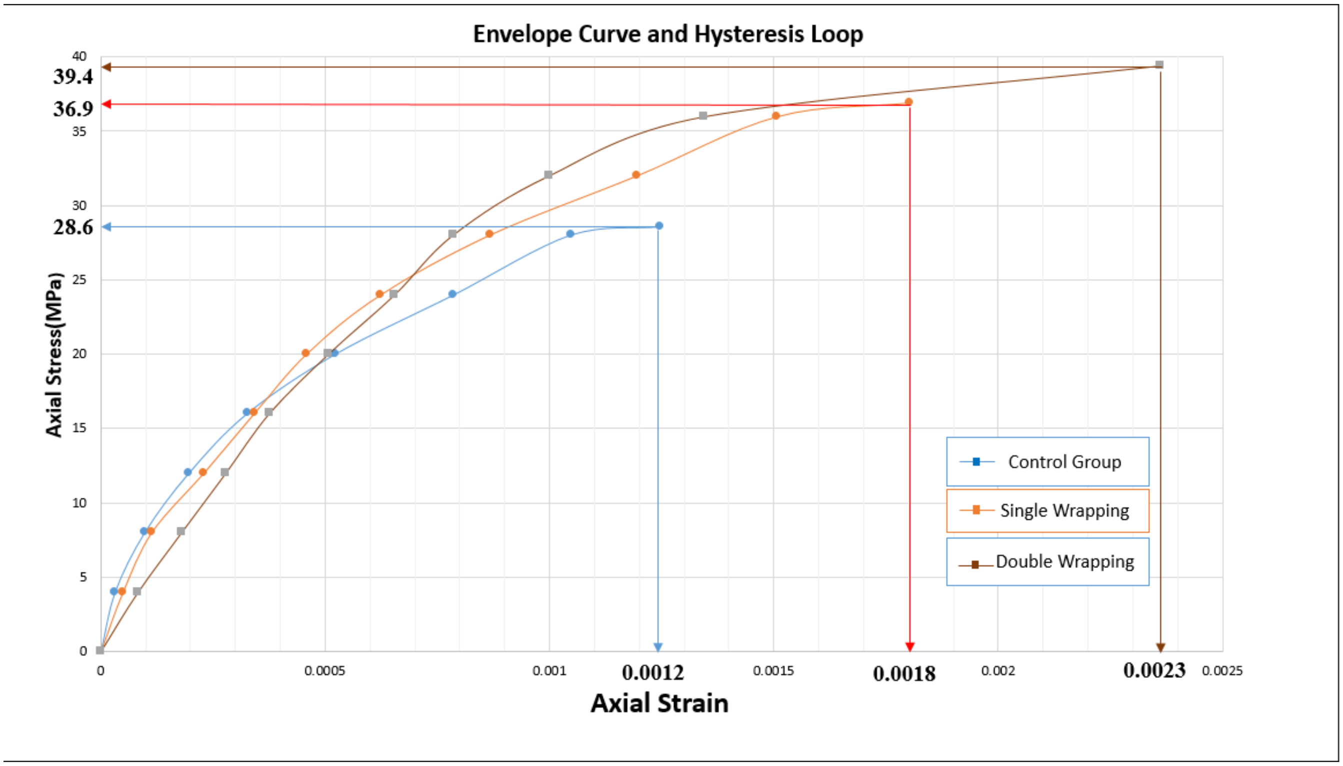
Individual Response Graphs (Backbone Curves and Hysteresis Loop):


Envelope Curve and Hysteresis Loop
Axial Stress(MPa)
40
35
30
28.6
25
20
15
10
5
0
0
0.0005
0.001
0.0012
0.0015
0.002
0.0025
Axial Strain
Control Group


Envelope Curve and Hysteresis Loop
Axial Stress(MPa)
40
36.9
35
30
25
20
15
10
5
0
0
0.0005
0.001
0.0015
0.0018
0.002
0.0025
Axial Strain
Single Wrapping



Overall Comparison Graph for Backbone Curves:



It is very clear from above graphs that ultimate strengths as well as ultimate strains got increased as the no of wrappings increased. With single wrapping strength increased about 8.3 MPa and with double wrapping it increased about 10.8 MPa relative to strength of concrete.

Axial Strains also increased from 0.0012 to 0.0018 for single wrapping and for double wrapping it increased from 0.0012 to 0.0023.Both have increased considerably with respect to control.

These two enhancements in axial strains and ultimate strains shows us that concrete properties have been improved and concrete shows more plastic regions as no of wrappings are increased. Plasticity which is determined by non-linear behavior has been improved.

Using these graphs, we computed the values of Tangent Modulus using initial slope concept (E-tan) as well as Secant Modulus using average slope between extreme points (E-sec).We needed these values to plot Moment-Curvature graphs which shows the relationship between moment and curvature which will be explained later in the thesis.

Chapter 3

Nonlinear Static or Pushover Analysis

General Description

The nonlinear static analysis (Pushover investigation) in the ongoing years is turning into a mainstream strategy for foreseeing seismic forces and causality requests for execution assessment of existing and new structures. The nonlinear analysis of a structure is an iterative system. It relies upon the last dislocating, as the viable damping relies upon the hysteretic strength disaster because of inelastic deformities, which thusly relies upon the last repositioning. This makes the analysis methodology iterative.

Weakling is a static-nonlinear examination technique where a structure is subjected to gravity stacking and a monotonic relocation controlled sidelong load design which ceaselessly increments through versatile and inelastic conduct until the point when an extreme condition is come to. Sidelong load may speak to the scope of base shear instigated by seismic tremor stacking, and its design might be relative to the circulation of mass along building stature, mode shapes, or another commonsense means.

Sucker investigation is nonlinear static examination which gives 'limit bend' of the structure, it is a plot of aggregate base power versus rooftop removal. The investigation is completed up to disappointment, it helps assurance of crumple load and malleability limit of the structure. The weakling examination is a strategy to watch the progressive harm condition of the building.

Sucker investigation is a valuable device of Performance Based Seismic Engineering to think about post-yield conduct of a structure. It is more mind boggling than customary direct investigation, however it requires less exertion and manages considerably less measure of information than a non-straight reaction history examination. Weakling examination brings about arrangement of estimations of base or story shear and comparing rooftop dislodging or float.

Implementation of Pushover Analysis

Pushover method is to construct an analytical model, apply gravity loads, lateral loads and push the structure to the desired deformations under cyclic loadings.

Alternatively, development of a backbone curve and a comparison of the storey shear values computed against the design or maximum considered earthquake can give an insight into the adequacy of a building’s strength under significant seismic loading.

Some points that should be emphasized in performance evaluation are as follows:

- A proper load path exists Load path is sound even at deformations.
- Individual elements don’t exceed their capacity
- Safety hazards are not done due to localized failures

Limitations of Pushover analysis

For the structures vibrating in fundamental mode, pushover analysis provides good estimate of local and global inelastic deformation demands. With all the advantages of the pushover analysis there are some inherent limitations of the procedure, which are:

- It is approximate analysis and is based on static loading, therefore cannot represent dynamic phenomena accurately. It detects the fundamental mode and not all the modes resulting by seismic activity.

- Certain deformations are favored by selecting a load pattern which results in some other modes being neglected thus good judgment is required in selecting load patterns and in interpreting the obtained results.

Why Pushover Analysis over Nonlinear Dynamic Analysis

Some of the reasons why Pushover analysis should be preferred to a full scale Non-linear dynamic analysis are as follows:

- A Non-linear dynamic analysis takes a long time to run even for a simple structure, whereas the Pushover analysis can give accurate results within a fraction of time it would take to perform a Non-linear dynamic analysis.

- For obtaining accurate results via performing a Non-linear dynamic analysis a series of earthquake cases should be used, whereas the Pushover Analysis naturally accounts for all earthquakes with the same probability of exceedance by predicting the maximum displacement that can be expected in the form of the Target Displacement.

6 3.1. Methodology

To understand the response of structures under seismic excitations, we used the software "SAP-2000". Structures were analyzed by setting the target displacements, shear forces produced were measured and corresponding graphs were plotted. The graphs obtained were between Base Shear and maximum story Displacement.

CHAPTER 4

MODELING OF STRUCTURES

7 4.1. Introduction of SAP-2000

SAP2000 is a program based on The Finite Element Method (FEM). It is one of a long list of software packages having the FEM as their kernel. The program is edited by a company named CSI (Computer and Structure Inc.) founded in 1975. The very first version of SAP was SAP, followed later by SOLIDSAP and SAP IV. With the development of PC computers, SAP was released in two major versions SAP80 and SAP90. Basically, these two versions and the previous ones were based on TEXT files for both input and output. In 1996 the first
version of SAP2000 was released, it had an integrated graphical user interface working completely under Microsoft Windows.

7.1 4.2. Modeling in ETABS

All Structures were modeled in SAP2000. The modeled structures have been shown in figures a, b and c. Columns of same size (cross-section) and reinforcement were modeled in all three structures.

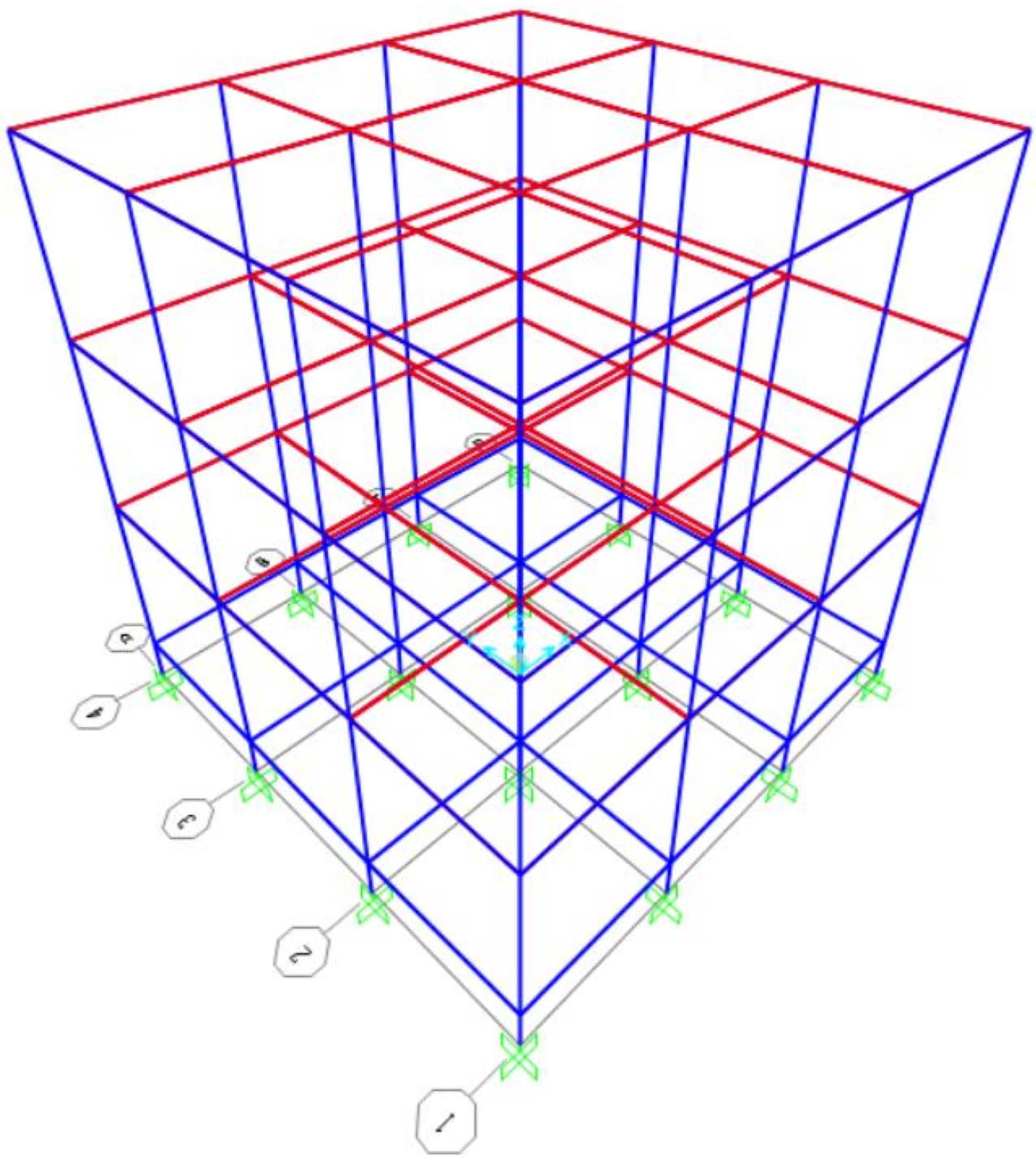


FIGURE A: 3- STORY 3 BAYS

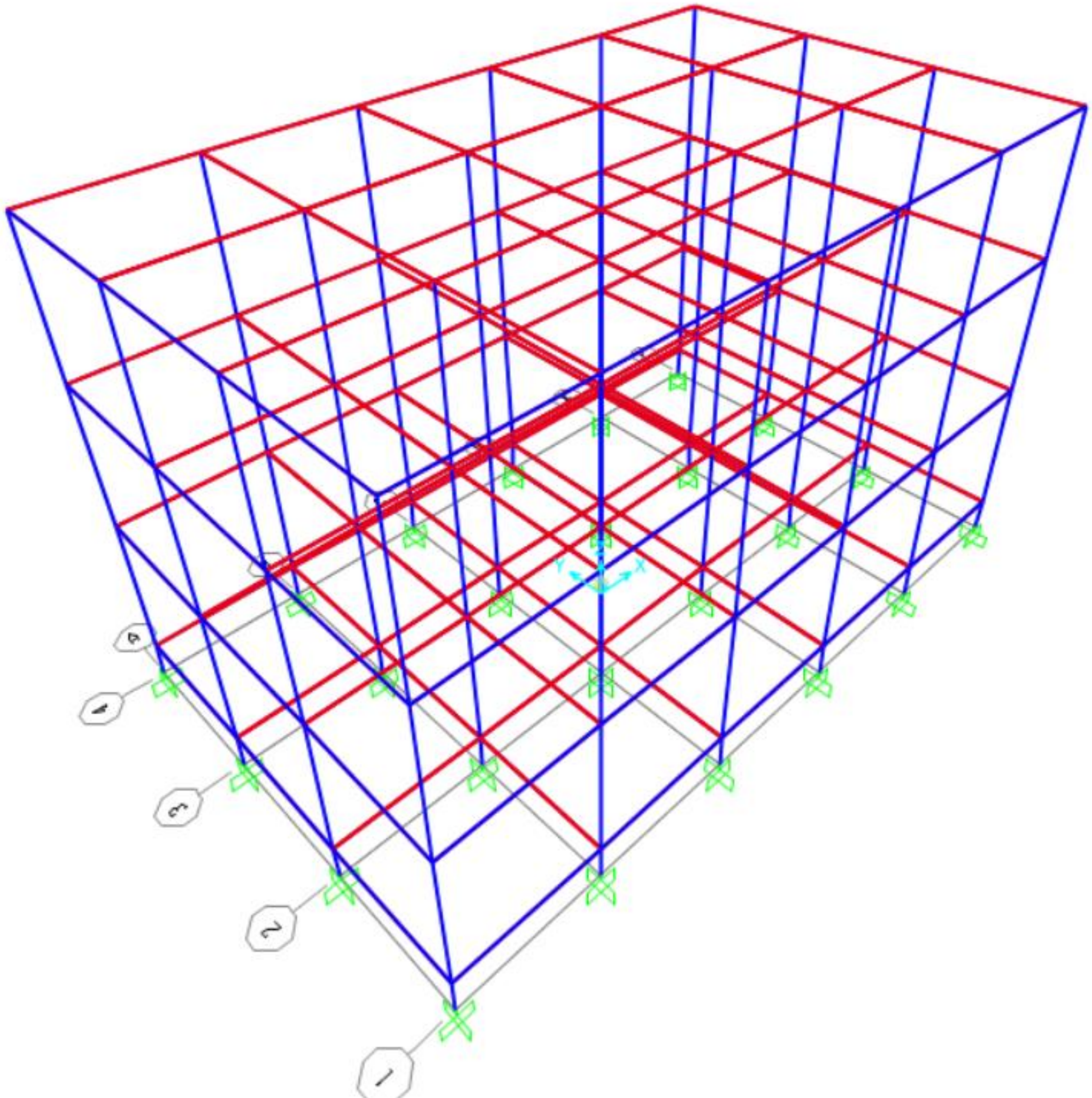


FIGURE A: 3- STORY 5 BAYS

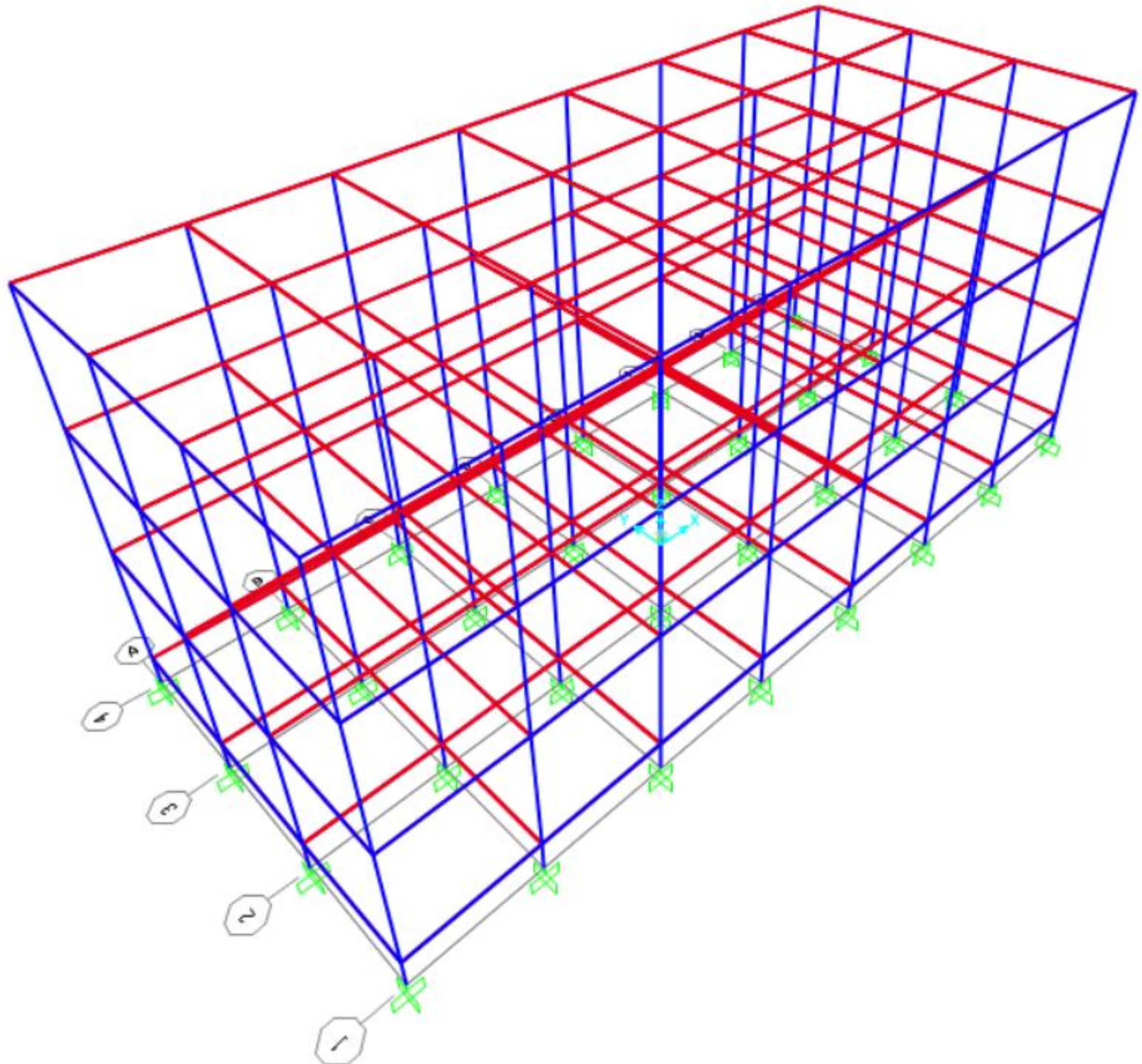


FIGURE A: 3- STORY 7 BAYS

7.3

7.4 4.3. Gravity design of Structures

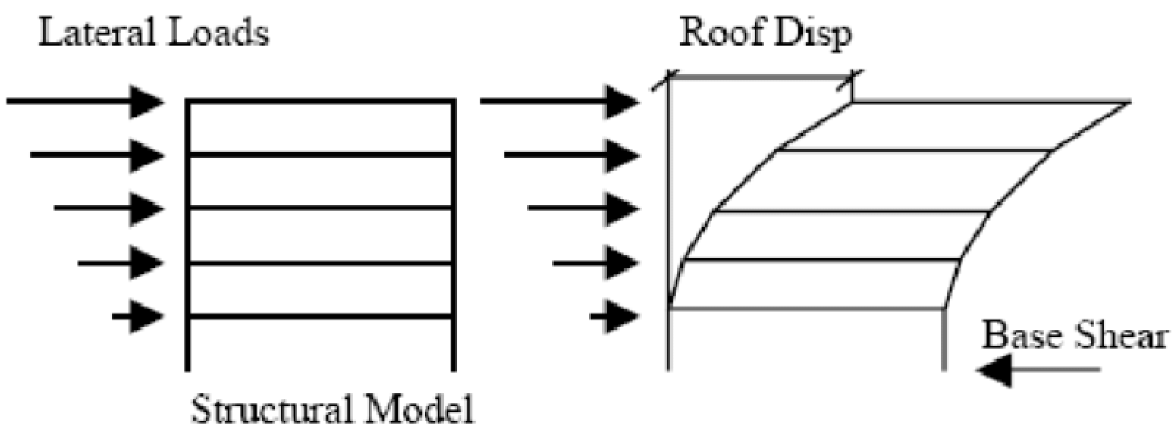
Everything including the slabs design as well as sections for beams were designed in SAP2000 by using ACI-11 code. Design was finalized after going through the process of hit and trial which involves designing for various sections and checking or analyzing them under gravity loadings.

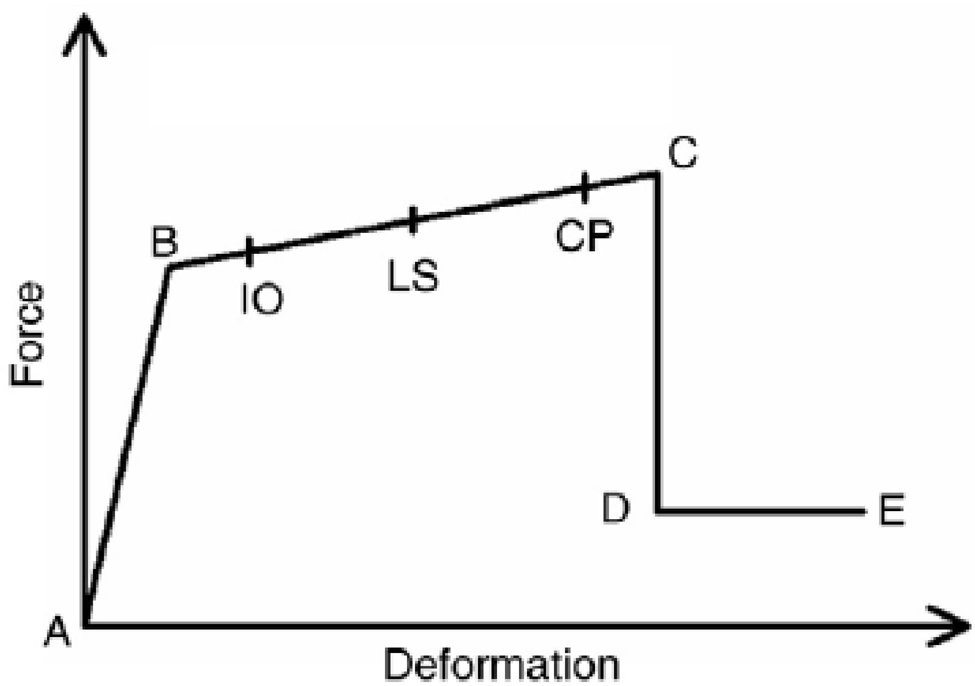
As a result of hit and trial suitable column sections and beam sections were selected as well as slab thickness and gravity design were accomplished successfully.

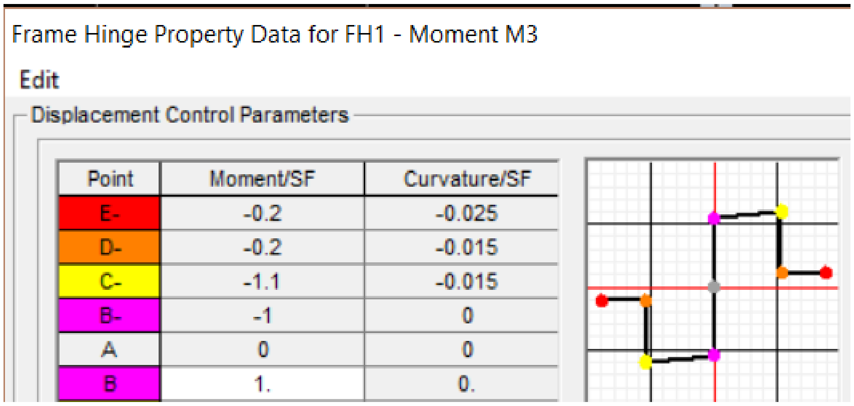
7.5 4.4. Push-over Analysis

It is non-linear static method of analysis in which structure is subjected to loadings(Gravity) and monotonically increasing loadings through elastic and inelastic until an ultimate state is obtained.

Already specified properties of the plastic hinges were used. M3 hinges were used for beams and P-M2-M3 hinges were used for columns.





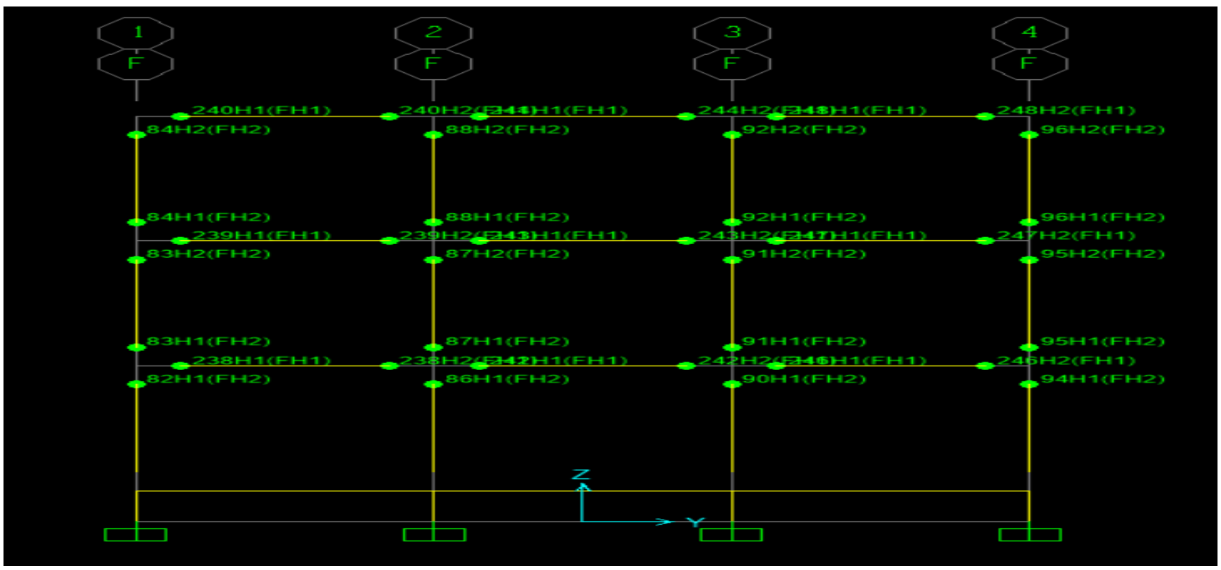


Frame Hinge Property Data for FH1 - Moment M3

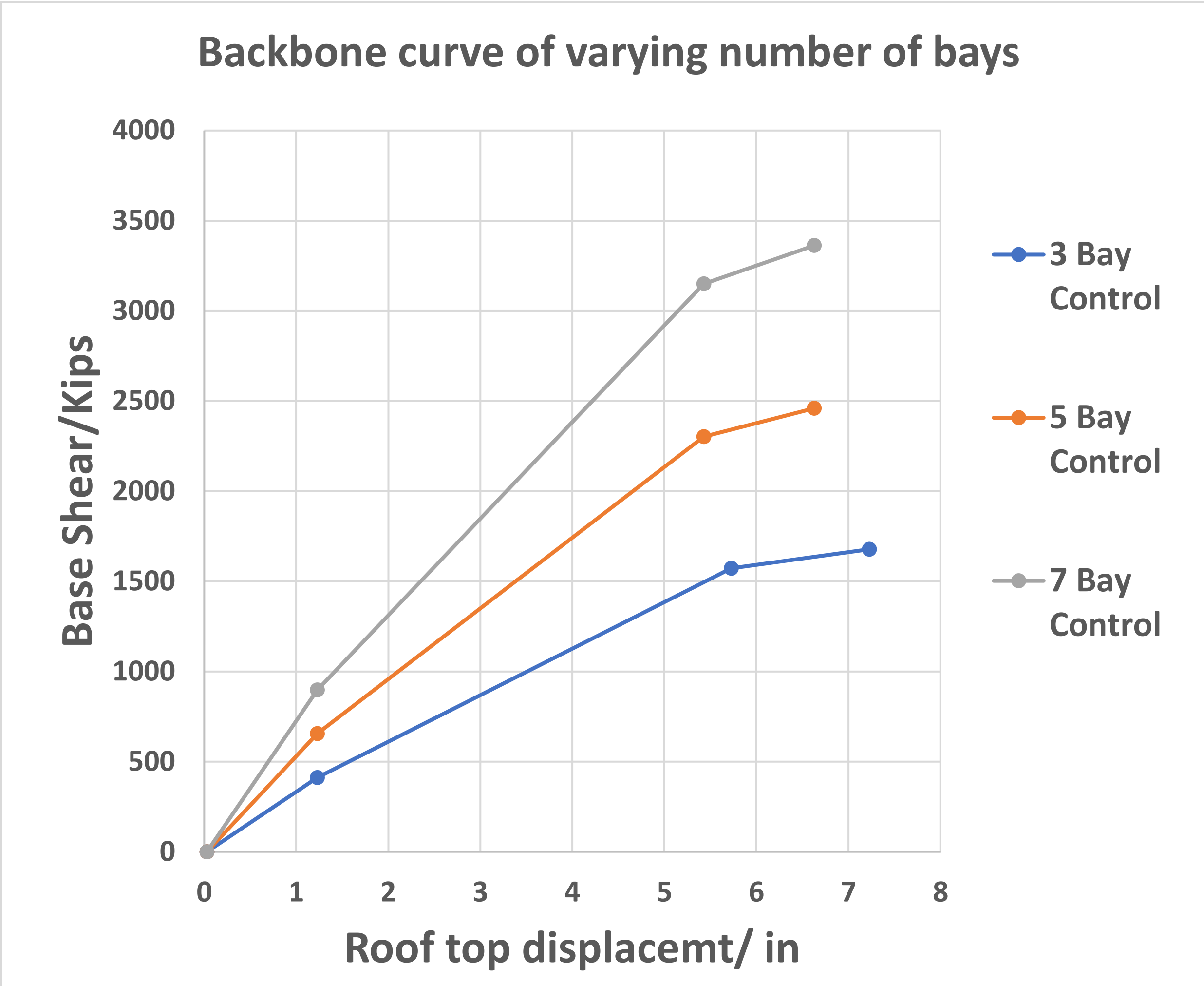
Edit

Displacement Control Parameters

Point	Moment/SF	Curvature/SF
E-	-0.2	-0.025
D-	-0.2	-0.015
C-	-1.1	-0.015
B-	-1	0
A	0	0
B	1.	0.



7.6 4.5. Push-over Analysis Results using conventional properties

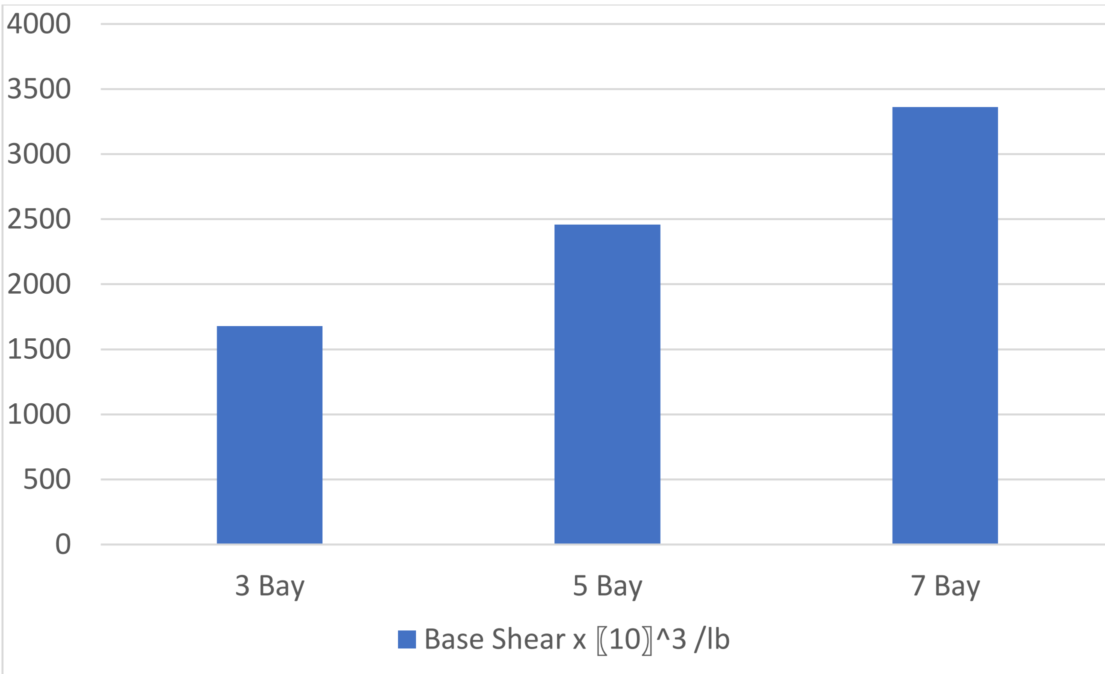


7.7

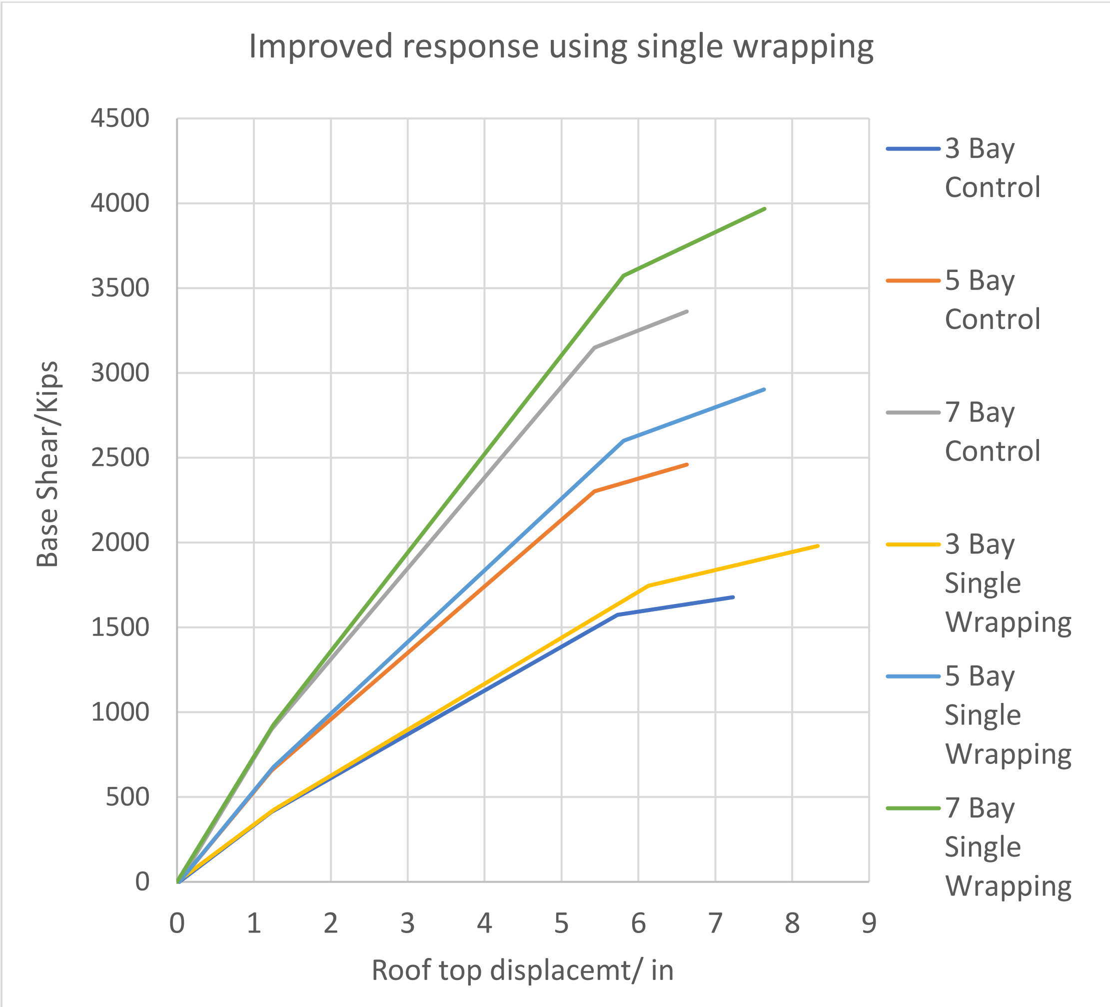
It was observed for control 3-bay ,5-bay and 7-bay that the increase in the number of bays increases the overall lateral stiffness of the structure which is due to the higher energy absorbing capacity available in the structure. Greater the number of bays greater would be the energy absorbing capacity available and hence the greater lateral stiffness.

It can also be observed from the above diagram that the roof top displacements are approximately the same for three structures this is due to target displacement but with greater bays there is increased base shear induced in the structure.

Comparison between varying number of bays			
	3 Bay	*5 Bay*	*7 Bay*
Base Shear x10^3/lb	1677.8	2459.0	3362.02
Roof Displacement/ft	0.602	0.552	0.552



7.8 4.6. Push-over Analysis Results using improved properties

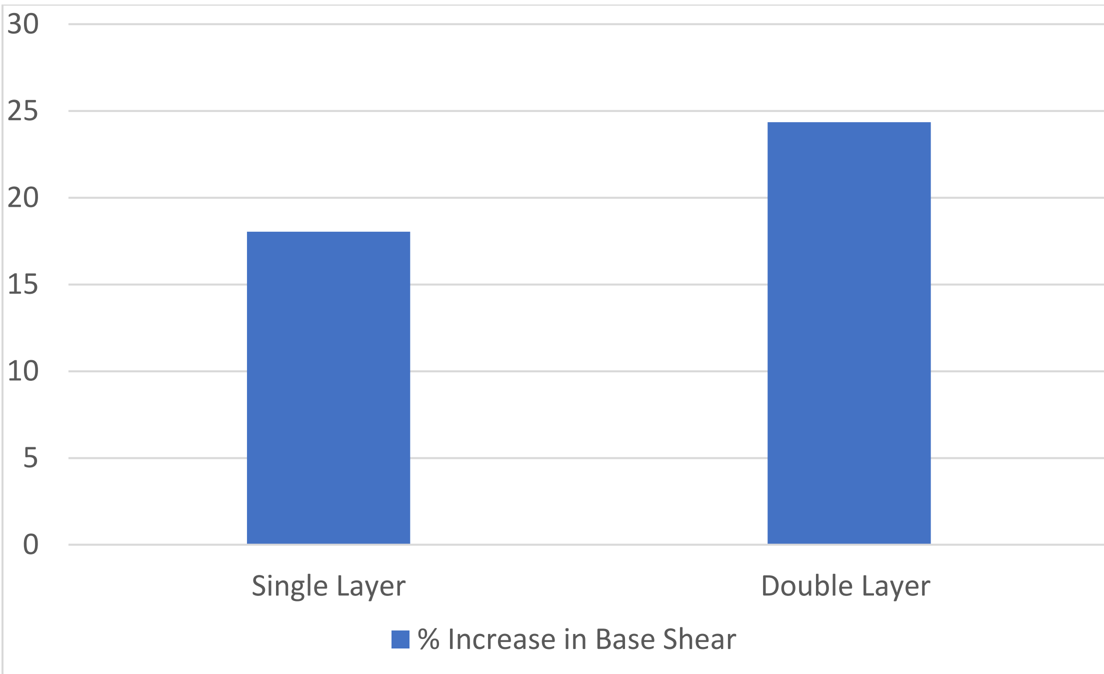


We see that structural response has been increased with FRP-wrappings due to enhanced energy dissipation region. It is very clear from the above diagram that with FRP wrappings (single or double) there is an improved roof top displacement as well as base shear value. This has occurred due to active behavior of the fiber which try to induce ductility in the structure by restraining action.

There is also an observed 18.04 % increase in base shear and about 15.19% increase in ultimate roof top displacement for single layer wrappings.

And for double wrappings, there is also an observed 24.25 % increase in base shear and about 17.34% increase in ultimate roof top displacement for single layer wrappings.

Percentage Increase in Base Shear				
	3bay	*5 Bay*	*7 Bay*	Average
Wrapping				
Single Wrapping	17.89	18.06	18.17	18.04
Double Wrapping	24.1	24.3	24.35	24.25



CHAPTER 5

8 Conclusions and Future Recommendations

With the increase in the lateral stiffness due to increasing no. of bays we observe an increased or higher energy absorbing capacity and as a result greater the vulnerability of the structure to undergo major damage under seismic activity.

When there is an increase in the capacity of the structure to dissipate energy, the structure could become less vulnerable with respect to earthquakes. Extension of bays is not recommended without proper seismic detailing but if an extended structure exists FRP retrofitting can be used as an efficient means of strengthening. Perform the non-linear static pushover analysis using results from cyclic loading test to obtain more conservative comparison of structural response under seismic activity

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