RETROFITING OF REINFORCED CONCRETE COLUMNS USING COMPOSITE JACKETING

MSc. THESIS

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A THESIS SUBMITTED TO THE INSTITUTE OF TECHNOLOGY, DEPARTMENT
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This is to certify that the thesis entitled "RETROFITING OF REINFORCED CONCRETE COLUMNS USING COMPOSITE JACKETING" submitted in partial fulfillment of the requirements for the degree of Master's with specialization in structural engineering, the graduate program of the Department of civil engineering, and has been carried out by SIMRET BERHE ID.NO.PGstru/012/10 under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defense by SIMRET BERHE have read and evaluated her thesis entitled “RETROFITING OF REINFORCED CONCRETE COLUMNS USING COMPOSITE JACKETING” and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for degree.

Dr. Laxmi Narayan Ojha

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I hereby declare that this MSc. Thesis “RETROFITING OF REINFORCED CONCRETE COLUMNS USING COMPOSITE JACKETING” is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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ABSTRACT

Columns are important cause for the stability of a constructed building, which are widely used in building frames and carries compressive loads. The purpose of Reinforced Concrete (RC) columns jacketing in this study is retrofitting of existing columns with poor structural performance and increase their strength and ductility. The methodology used is modeling and simulation for predicting performance in the real world. Simulation and modeling is used to understand whether under what condition and in which way a part will fail and what loads it can withstand.

In this research work, it is found that the strength and cross section of the overlay concrete has significant effect on the capacity of axially loaded reinforced concrete composite jacketed columns. For C30, C50 and C70 concrete grade in the core the axial capacity of the jacketed column is enhanced by 3-10%. On the other hand, using different thickness and the same concrete grade considered, the axial capacity of the reinforced concrete jacketed column is 50-56% higher than axial capacity of the old concrete section.

Similarly, for same grade of concrete of C30, C50 and different cross section the change in the capacity of the reinforced concrete composite jacketed axial columns became 148.3% and 161.6% of the core section respectively. It is also found that, the capacity of reinforced concrete composite jacketed axial columns is slightly affected by the variation loadings (eccentricity effect). Experimental model is used to calibrate the interface properties and material models in ABAQUS.

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NOTATION

f'_{cc}- Compressive strength of confined concrete

f_{co} - Compressive strength of unconfined concrete

f_l- Lateral confining pressure

k_1- Confinement effectiveness coefficient for Richart et al

ε_{frp}- Ultimate strain of FRP

$\varepsilon_{h,rup}$- hoop rupture strain of FRP

ε_{cu} - Ultimate concrete axial strain of uniformly confined concrete

ε_{cu} - Ultimate concrete axial strain of unconfined concrete

k_s - shape effectiveness for rectangular section

b - Width of the rectangular section

h - Length of the rectangular section

A_e- Effective confinement area of the rectangular section

A_c- Total area of concrete

A_g- Gross area of the column section with rounded corners

f_{lf} - Confinement pressure due to FRP wrapping

ρ_{frp} - FRP strengthening ratio

$\mathrm{k_e}$ - Coefficient of efficiency of the FRP strengthening

ρ_s- Transverse steel ratio

$f_{y,st}$- yield stress of the transverse steel reinforcement

P - Total confining pressure

1. INTRODUCTION

Rehabilitation of deteriorated civil engineering infrastructure such as bridge decks, buildings, columns, beams, girders, parking structures, marine structures, roads etc has been a major issue in the last decades. The deterioration of these structures might be due to ageing, poor maintenance, corrosion due to poor environmental conditions, poor initial design or construction and accidental situations like earthquakes. The need to upgrade the deteriorated civil engineering infrastructure greatly enhances with the ever increasing demands. Therefore rehabilitating existing civil engineering infrastructure has been identified as an important issue to be addressed.

Retrofitting (rehabilitation) of columns with composite jacketing is the latest method of jacketing. Jacketing of columns is most popular and has significance increase concrete confinement, increase shear strength and increase flexural strength. External confinement using jackets can suitably increase the strength and ductility of the reinforced concrete columns. The new advances made with reinforced composites, because of the many advantages over steel and other conventional materials, have provided engineers with stimulus in circumventing the difficulties associated with the traditional techniques of rehabilitation process.

Reinforced concrete (RC) jacketing, a common method for retrofitting existing columns with poor structural performance, is a technique widely adopted in current engineering practice to retrofit existing weak members and increase their strength and ductility. The method consists in casting a RC layer (jacket) around the column, in order to increase the confinement effect on the member and/ or enlarge the cross section. The effect provided by the jacket depends on whether or not it is directly loaded (i.e. when the jacket is continuous and well connected in correspondence of the slabs) or indirectly loaded (i.e. when a gap exists between the jacket and the slabs). In the first case, a core–jacket composite action as well as the confinement effect due to external stirrups, which enhance the axial capacity takes place. Conversely, if the jacket is indirectly loaded the main effect of the technique is the confinement pressure induced by the external layer on the inner column core. In both cases, the amount of transverse and longitudinal steel is crucial for the overall efficacy of the technique, as well as the thickness of the jacket (Giovanni Minafò et al, 2016).

1.1 Background of study

Collapse and damage experienced by a large number of existing reinforced concrete structures, such as buildings and bridges, in recent earthquakes has given rise to an ever more urgent need to repair and strengthen these old structures. One of the major causes of the failure of these structures was the inadequate lateral reinforcement of those structural components designed with old seismic design provisions. The poor detailing has resulted in structures having columns with low flexural capacity and low shear strength. Therefore, it is evident that there is a need to upgrade existing older structures to current seismic design standards in regions of high seismicity (Ricardo Perera, 2004).

Steel jacketing has been proven as an effective method to retrofit building and bridge RC columns increasing their strength and ductility and, in fact, many installations of this kind have been carried out. However, to ease and speed up the installation of jacket columns, systems based on fiber reinforced polymer (FRP) composite column-jacketing have been researched and developed in recent years. In fact, some retrofit design guidelines have already been presented. Since the main deficiency in existing columns is in the amount and detailing of the transverse reinforcement, advanced composite fiber jackets address this deficiency by applying primarily horizontal or fibers to the column axis, to provide the required transverse confinement clamping and buckling restraints. Some advantages of composite retrofit systems, among others, is low maintenance, high durability,light weight, High stiffness or strength to weight ratios, etc (Georgia E.et.al, 2017).

The shortcoming of the strengthening method with steel plates is the possibility of corrosion at the epoxy-steel interface, which may adversely affect the bond strength. The corrosion appeared to be caused by migration of water through micro-cracks in the concrete and resin through to the steel plate. This corrosion was nearly uniformly distributed over the entire face of the steel plate, suggesting that water seeped in through the concrete and resin, and not between the steel and resin at the ends of the column. An effective way of eliminating the corrosion problem and other previously listed drawbacks is to replace steel plates with corrosion-resistance synthetic materials such as fiber-reinforced polymer (FRP) composites. In addition to their higher corrosion resistance, many polymer composites have tensile and fatigue strengths that exceed those of steel (Yousef A. et al, 2002).

Moreover, composites can usually be applied while the structure is in use with negligible changes in the member dimensions. For seismic applications, FRP composite jackets should be designed to provide a confining stress sufficient to develop concrete compression strains associated with the displacement demands. However, in order to carry out a proper seismic design for an FRP jacket, a model for FRP-confined concrete under seismic loading is needed. The model has to be able to predict the level of lateral load and ductility reached by an RC column confined with an FRP jacket. Moreover, it is desirable to perform this prediction in a simplified and reliable way. In literature, several models based on experimental tests have been proposed to describe the axial stress–strain relationship for FRP confined concrete. Some experimental studies and some finite element analysis studies of RC columns retrofitted with FRP jackets subjected to lateral loads have also been proposed. However, it is not very usual to find simplified numerical models to predict the seismic behavior of FRP confined columns. To fill this void the design of composite jackets for improving strength and flexural ductility of RC columns with insufficient transverse confinement is studied using a simplified numerical mode (Ricardo Perera, 2004).

To evaluate the strength and deformation capacities of a jacketed element Euro code 8 allows making three simplifying assumptions:

I. absence of slippage between old and new concrete;
II. application of concrete properties over the full section of the element;
III. Neglecting of the confinement effects and buckling of longitudinal bars.

Moreover EC8 assumes the full axial load acting on the jacketed element (core–jacket composite action). The strength and ductility capacity of the jacketed member obtained under these assumptions (monolithic member) is then calibrated by applying suitable multipliers or monolithic factors commonly derived from empirical analysis (Giovanni M. et al, 2016).

Shear failure of short concrete columns has been one of the major problems that may cause the collapse of structures under earthquake attacks. In a structure where the columns have different lengths, shorter columns tend to attract a greater portion of the seismic input during an earthquake and require the generation of large seismic shear forces to develop the moment capacity of column. The design of flexural strength based on elastic methods, along with less conservative shear strength provisions in older design codes, typically resulted in expected shear strength of columns in many existing structures being less than the flexural strength. These have been evidenced by the brittle failure of columns that caused numerous structures to collapse in previous earthquakes (Yan Xiao et al, 2003).

Gaps on the existing researches are, OR, The main reasons for selecting researching on this area are;

- ✓ There is not enough researches on this area
- ✓ Jacketing is the simplest way of repairing damage portion of the structure.
- ✓ Economical aspects rather change the whole structure retrofitting preferable.
- ✓ Cast in situ is difficult for construction, and then prefabricated composite column is best option for retrofitting against seismic effect.

1.2 Statement of problem

The need for rehabilitation and strengthening of existing reinforced concrete columns has significantly increased over the years. This leads the attraction of researches to address it and provide safe structures. Reinforced concrete jacketing of columns is a way of strengthening RC structures, which is done by adding new layer with fiber-reinforced polymer (FRP) composites. In the design codes, there is provision of shear transfer mechanisms between concrete surfaces cast at different times. The codes, rather than notifying to consider concrete of lower grade in the computation, the effects of the FRP strength and concrete cross section is not accounted. Thus, this study is intended to address the effect of FRP thickness and FRP strength on the axial capacity of reinforced concrete jacketed columns.

1.3 Objective of the study

1.3.1 General objective

The general objective of this research is to assess the axial capacity of retrofitted columns and application of retrofitting of reinforced concrete columns using a composite jacketing.

1.3.2 Specific objectives

The specific objectives of this study are:-

- ✓ To investigate the application of retrofitting of columns with different thickness of fiber, different grade of concrete, and slenderness effect.
- ✓ To investigate the resistance capacity of composite jacketing columns with respect to eccentricity load.

- ✓ To investigate effects in structural parameters of retrofitted reinforced concrete columns in terms of stiffness, flexural and shear strength.
- ✓ To compare deferent types of FRP composite jacketing methods (CFRP = carbon FRP, AFRP = Aramid FRP, GFRP = glass FRP)

1.4 Scope of the Study

The main focus of this research is to assess the axial load capacity of RC columns with composite jacketing. It will address the factors that affect the capacity of composite jacketed columns such as displacement and stress variation of the new composite jacketed column and variation in the load capacity and buckling resistance of column. The scope of this study in addition is to repairing the damaged portion of structure. This repairing can be done different ways i.e. increase strength, increase ductility and increasing both strength and ductility. The selected method for this study is jacketing of RC columns using composite material.

2. LITERATURAL REVIEW

2.1 Introduction

Structural Retrofitting represents an important aspects of the construction industry and its significant is increasing several methods are available, each with different advantages and handicaps. However, little information is available and insufficient codes guidelines are accessible in fact, most repair and strengthening designs are based on the assessment of engineers only and often empirical knowledge and current practices have an important role in the decisions to be made.

Rehabilitation and strengthening of reinforced concrete structure is dynamically growing division of structural engineering. In recent years an increased application of new repair and strengthening systems of reinforced concrete load-carrying structures has been noted. The problem of strengthening the reinforced concrete structures appeared for the first when their proper function was modified or they were used in a different manner than previously planned. Assumptions made in the design are closely connected with a specific function of the structure. Repairing a reinforced element may be defined as an attempt to restore the original strength and stiffness of a damaged or deteriorated RC element. Ramirez et al. (1993) while strengthening a RC element is defined as an intervention to increase the original strength and stiffness of the RC element. In the case of an undamaged element, there cannot be, by definition, a need to repair the element. In this case, there can only be a need to strengthen this element, due to one or more causes previously referred to (Sause et al. 2004).

Wrapping with an FRP jacket can also provide strength enhancement for a member subjected to a combine axial compression and flexure (Memon and Sheikh 2005).

Concrete repair (maintenance): - Extension of service life and near surface reinforcing by

- ✓ Carbon fiber fabrics wraps
- ✓ Near surface reinforcing bars

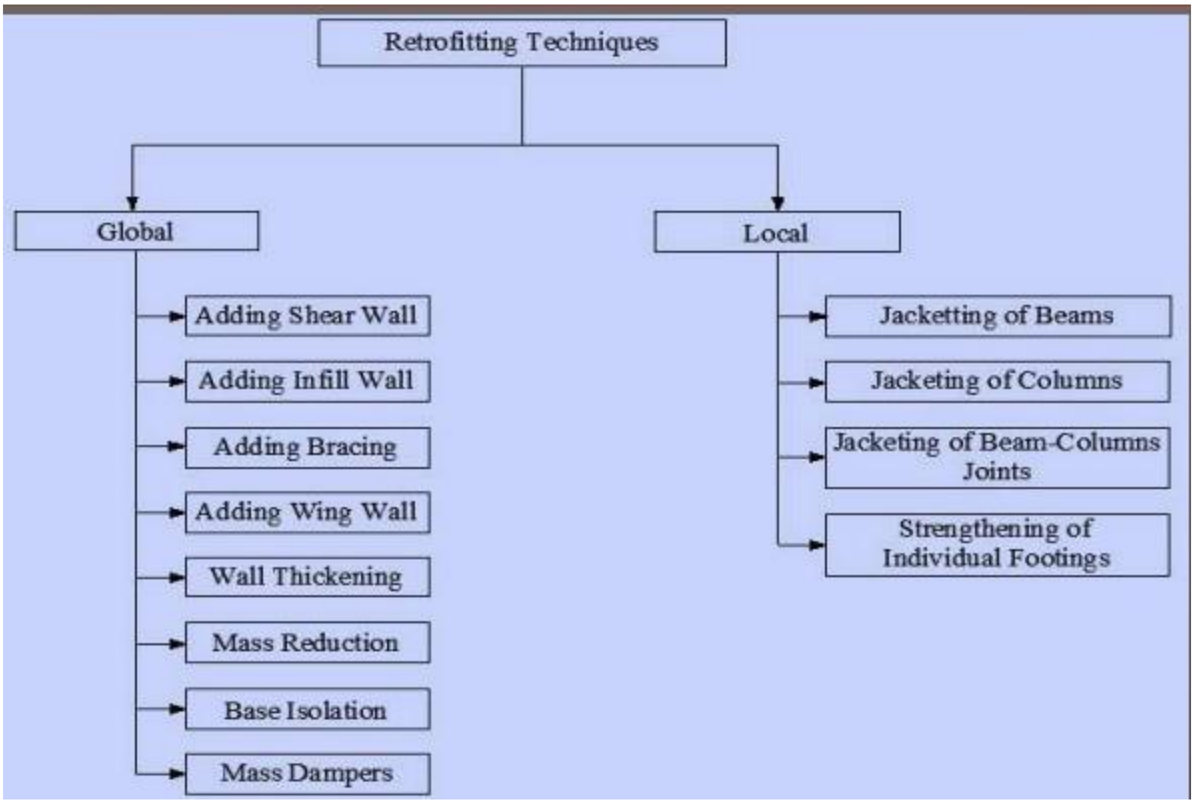


Figure 1 Retrofitting techniques

The strength of concrete structures with externally bonded reinforcement is generally done using either steel plates or FRP laminates. Steel plates have been used for many years due to their simplicity in handling, applying and their effectiveness for strengthening. The properties and behavior of steel-concrete structure are well known. Steel plates are very effective to be used as bending reinforcement. The high tensile strength and stiffness lead to an increase in bending capacity and reduction of the deformations. Steel plates can also be used as external shear reinforcement (Bousias et al. 2004).

2.2 Fiber-reinforced polymers (FRP) composite materials

Fiber reinforced polymer (FRP) is a common term used by civil engineering community for high-strength composites. Composites have been used by the space and aerospace communities for over six decades and the use of composites by civil engineering community spans about three decades. In the composite system, the strength and the stiffness are primarily derived from fibers, and the matrix binds the fibers together to form structural and non-structural components. Composites are known for their high specific strength, high stiffness and corrosion resistance. Repair and retrofit are still the predominant areas where FRPs are used in the civil engineering application. The field is relatively young and, therefore there is considerable ongoing research in this area.

Fiber reinforced polymer (FRP) is a composite made of high strength fibers and a matrix for binding these fibers to fabricate structural shapes. Common fiber types include aramid, carbon, glass, and high-strength steel; common matrices are epoxies and esters. Inorganic matrices have also been evaluted for use in fire-resistent composites. FRP systems have significant advantages over classical structural materials such as steel that include low weight, corrosion resistent, and ease of application.FRP is particularly suitable for structural repair and rehabilitation of reinforced and pre-stressed concrete elements. The low weight reduces both the duration and cost of cconstruction since heavy equipment is not needed for the rehabilitation. The composites can be applied as a thin plate or layer by layer.

These advanced materials may be applied to the existing structures to increase one or several of the following properties:

I. Axial, flexural, or shear load capacities;
II. Ductility for seismic performance;
III. Durability against adverse environmental effects;
IV. fatigue limit;
V. stiffness to reduce deflections under service and design loads (Buyukozturk et al)

Fiber-reinforced polymers (FRP) composite materials are one of the prime contenders in rehabilitation process. FRP composites have many advantages over other materials, including high resistance to corrosion, high specific strength and stiffness, and superior fatigue performance. FRP composite materials have been recently introduced to the civil engineering community. Three types of fabrics are currently produced commercially. Namely Glass FRP, Carbon FRP and Aramid FRP Composites. These materials are durable, have long fatigue life and have a superior resistant to corrosion and chemical attack. They have high strength-to-weight ratio. Composites are easy to handle in the field and pliable enough to configure to the shape of structure under rehabilitation. Composites are versatile and adaptable to almost any shape and size (Yousef A. et al, 2002).

Figure 2 practical uses of FRP

2.3 Types of fiber

The primary role of fiber is to resist the major portion of the load on the composite system. Depending on matrix type and fiber configuration, the fiber volume fraction ranges from 30 to 75%. Strength and stiffness properties of commercially available fiber cover a large spectrum and consequently, the properties of the resulting composite have a considerable variation (Mallick 1993). Typical fiber reinforcements used in the composite industry are glass (E- glass S-glass), carbon and aramid. The properties are characteristics of these fibers are presented in different studies.

General Composition of FRP

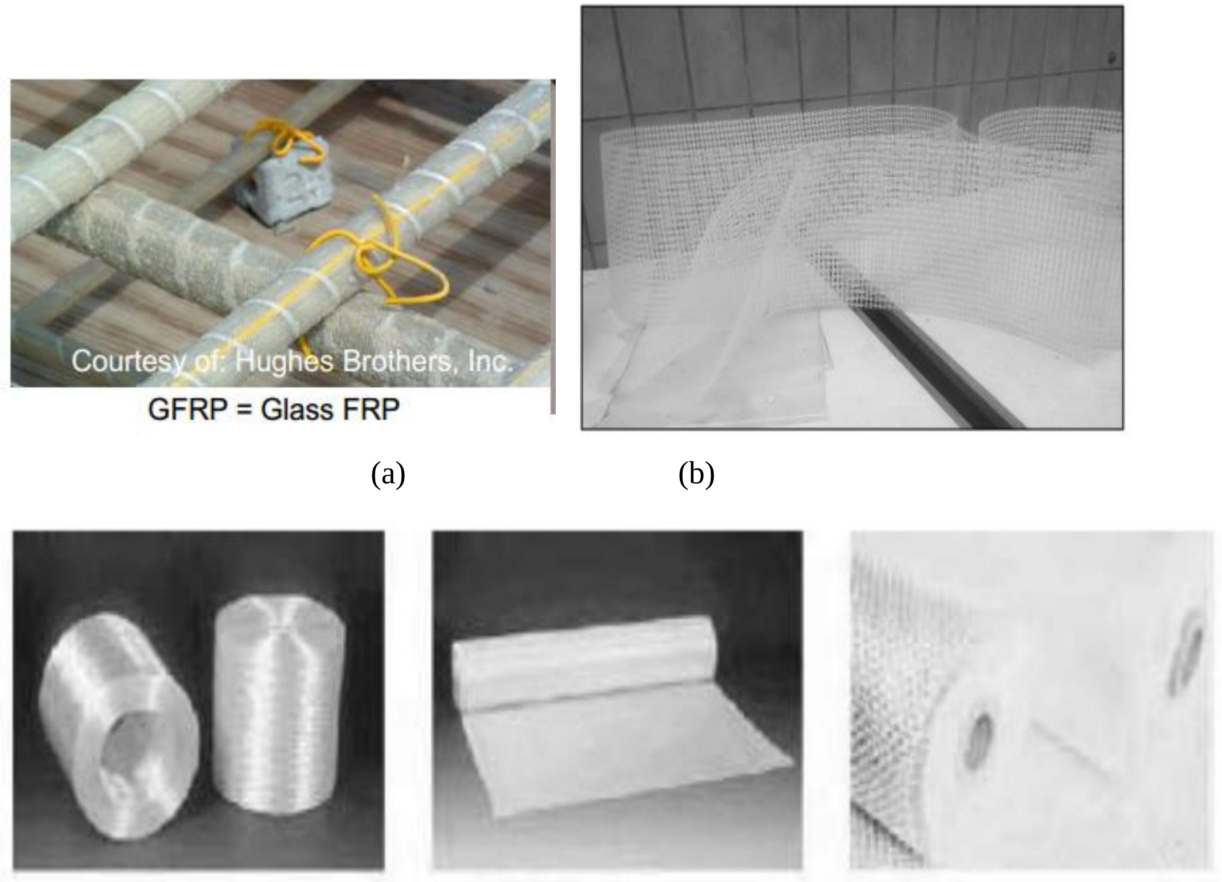
$$\text{FIBER [CARBON, GLASS, ETC]} + \text{ RESINE [POLYMER]} = \text{FRP}$$

Common types of fiber polymer:

- Aramid: - extremely sensitive to external environmental condition.
- Glass (most widely used):- subjected to creep under high sustained loading, subjected to degradation in alkaline environment.
- Carbon: - premium cost. But durability of CFRP (Carbon fibers) are highly stable, even in aggressive environments (Gevin Mc Daniel, P.E. et.al, 2014)

2.3.1 Glass fiber

They are the most common reinforcing fiber used in composites. Major advantages of glaas fiber including low cost, high tensile strength, chemical resistance and high temprature resistance. The disadvantages are low tensile modulus, senstivity to abrabsion while handling, relativley low fatigue resistance and brittilness. Glass fiber are produced by fusing silcaates with silica or with potash, or various metallic oxides. The molten mass is passed through micro-fine bushings and rappdilly cooled to produce glass fiber filaments ranging in diameter 5 to 24 µm (Gurit composite Technologies 2008).



(a) (b)

(c)

Figure 3 Glass FRP materials

2.3.2 Carbon fiber

They offer the highest modulus of elasticity among all reinforcing fibers. Among the advantages of carbon fibers are their exceptionaly high tensile sterngth-to-weight ratios as well as high tensile-modulus-to-weight ratios.in addition carbon fibers have high fatigue strength and very low coefficient of linear thermal expansion and in some cases, even negative thermal expansion. This feature provides dimensional satablity, which allows the composites to achieve near zero expansion to tempratures as high as 570 ºF (300 ºC) in critical structures suc as specific antenna. If protect from oxidation, carbon fibers can withstand temprature as high as 3600 ºF (2000 ºC) abave tthis temprature, they will thermally decompose. Carbon fibers are chemichally inert and not suseptible to corrosion or oxidation at temprature below 750 ºF (400 ºC).

Figure 4 carbon FRP

carbon fiber possess high electrical conductivty which is quite advantegeous to the aircraft designers who are conserned with the abillity of an aircraft to tolerate lightning strikes. However this charactestics poses a severe challenges to the carbon texitile manufacture since carbon fiber debris generated during weaving may cause shorting or electric shocks in unprotected electirical machinerry. Other key disadvanteges are their low impact resistance and high cost (Amateau 2003; Mallick 1993).

Figure 5 glass fiber and carbon fiber

2.3.3 Aramid fiber

Aramid fiber is synthetic organic polymer fiber (an aromatic polymide) produced by spinning a solid fiber from a liquid chemichal blend. Aramid fiber is high britile golden yellow and commonly known as Kevlar, its commercial trade name. these fibers have the lowest specific gravity and the highest tensile strength-to-weight ratio among the renforcing fibers used today. They are 43% lighter than glass and approximately 20% lighter than most carbon fibers. In addition to high strength, the fibers also offere good resistance to abrasion and impact as well as chemical and thermal degradation. While exposed to ultraviolet light and considerable difficulty machining and cutting (Smith 1996).

2.4 Forms of FRP

All the fiber types are avaliable in varity of forms to serve a wide range of process and end-product requirments. Fiber supplied as reinforcement include continuous spools of tow (carbon), roving (glass), milled fiber, chopped stands, chooped or thermo-formable mat and woven fabrics. Reinforcement materials can be tailored with unique fiber architechures and performed (shaped) depending on the product requirmens and manufacturing process.

2.4.1 **Fabrics**

A fabrics is defined as a manufactured assembly of long fibers of carbon, aramid, glass and other fibers or a combination of these to produce a flat sheet of one or more layers of fibrics. Thes fibers are held together either by mechanichal interlocking of the fibers themselves or with the second material to bind these fibers together and hold them in place, giving the assembly sufficient integrity for handling. Consquntl, fibers are the preferred choice of reinforcement since the fibers are in a more convinent format for the design engineer and fabricators. Fabric types are catagorized by the orentation of fibers used and by various construction methods used to hold the fibers together (Mallick.P.K.1993)

2.4.1.1 unidirectional fabrics

a fabric made with weave pattern designed for strength in only one direction is termed unidirectional. The pick count of a unidirectional fabrics is very small and most of the years run in the warp direction.

2.4.1.2 multi-axial fabrics

multi-axial fabrics, also known as woven, non-crimped, sitched or knitted, have optimized strength properties because of the fiber architecture. Stiched fabrics consists of several layers of unidirectional fibers bundles held together by nonstructural stiching thread, usually polyster. The fibers in each layer can be oriented along any combination of axes between 0 and 90º. Multiple orientations of fiber layers provide a quasi-isotropic reinforcement. The entire fabric may be made of a single material or different materials can be used in each layer. A layer of mat may also be incorporeted into the construction.

2.4.2 **matrix types**

The primary functions of the matrix (or resin) in a composite are:

Transfer stress between fibers.

Provide a barrier against the enviroment.

Protect the surface of fibers from mechanical abrabtion.

The matrix plays a major role in a composite and influnces the inter-laminar shear as well as the in-plane shear properties of the material. The interaction between fibers and matrix is important when designing damege tolerant structures. Furthermore, the ablity to manufacture the composite and defects within it, depends strongly on the matrix physical and thermal charachterstics such as viscosity, melting point d curing temprature (Mallick 1993). There are generaly two types of matrix: organic and inorganic.

2.5 Properties of fiber reinforced polymer materials

This section reviews the basic mechanical properties of FRP materials. Density, coefficent of thermal expansion, tension and compression behavior and durablity of FRP materials are briefly summerized.

2.5.1 **Density**

FRP materials have densities ranged from 12 to 21 KN/m^3, which is four to six times lower than that of steel. The lower densities leads to lower transportatoion cost, reduces added dead load on the structure and can ease handling of the materials in the projet site. The densities of FRP composites with Glass, Carbon and Aramid are shown in Table **1** (ACI Committee 440, 2002). The density of steel presented there as comparison.

Table 1 Typical density of FRP materials,

STEEL	GFRP	CFRP	AFRP
7900	1200-2100	1500-1600	1200-1500

All in kg/m^3 (ACI Committee 440, 2002)

2.5.2 **Coefficient of thermal expansion**

Table (ACI Committee 440, 2002) shows the coefficients of thermal expansion for typical unidirectional FRP materials. It is clearly seen that it changes in the longitudinal and transverse directions and also depending on the type of fiber, volume of fiber and resin. The coefficient of thermal expansion of concrete ranges from 7×10^{-6} to 11×10^{-6}/C and is usually assumed to be isotropic. Steel has an isotropic coefficient of thermal expansion of 11.7×10^{-6}/C.

Table 2 Typical coefficients of thermal expansion FRP materials.

coefficient of thermal expansion, $*10^{-6}$/C			
Direction	GFRP	CFRP	AFRP
Longitudinal	6 to 10	-1 to 0	-6 to -2
Transverse	19 to 23	22 to 50	60 to 80

(ACI Committee 440, 2002)

Composite materials for strengthening civil engineering structures have several disadvantages too. They in general behave in a linear elastic manner and fails at large strains (no yielding point and reduced ductility). This is contrary to the conventional steel which behaves in an elasto-plastic manner. Typical stress-strain curves for unidirectional composites subjected to monotonic loading are shown in Figure below. A similar curve for steel is also shown in the same figure for comparison.

CFRP = carbon FRP, AFRP = aramid FRP, GFRP = glass FRP (FIB Bulletin 14, 2001).

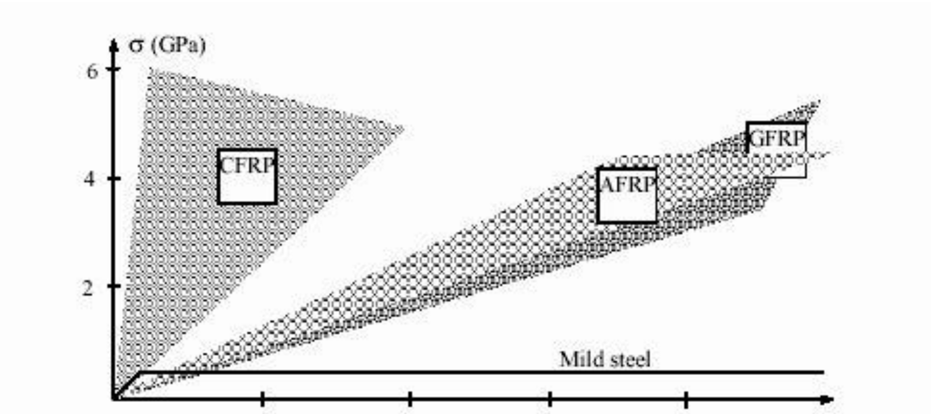


Figure 6: Uniaxial tension stress-strain diagrams for different unidirectional FRPs and steel.

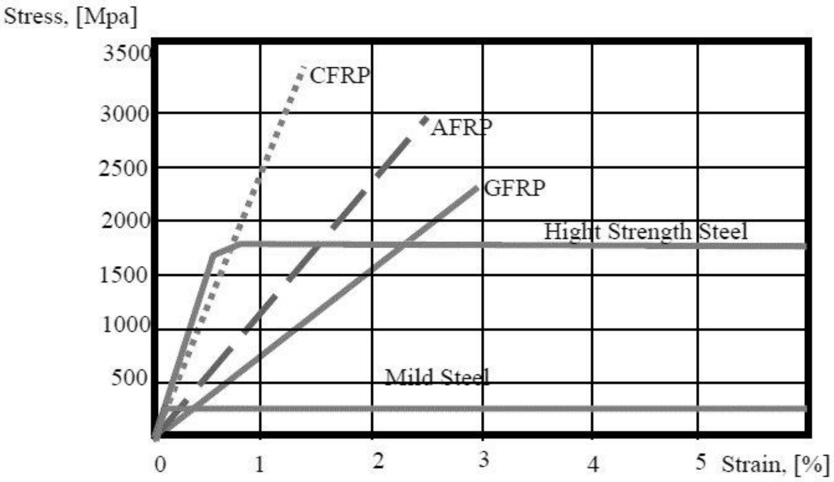


Figure 7 Comparison of Stress-Strain curve for Different FRP and Steel Types

2.5.3 Tensile behavior

When loaded in diret tension, FRP materials do not exihibit an plastic behavior (yielding) befpre rupture. The tensile behavior of FRP materials cosisting of one type of fiber materials is characterized by linearly elastic stress strain relation ship until failure, which is sudden and can be catastrophic.

The tensile strength and stiffness of FRP material depends on several factors. Because the fibers are the main load-carrying constitunt, the type of fiber its orentation and its quantity primarily govern the tensile properties of composite materials.

2.5.4 Compressive behavior

Compressive strength ratio of 55,78 and 20% of the tensile strength have been reported for GFRP, CFRP and AFRP respectivly (Wu 1990). In general, compresive strengths are higher for materials with higher tensile strengths, execpt in the case of AFRP where the fibers exhibit nonlinear behavior in compression at relativly low level of stress.

The compressive modulus of elasticity is usually smaller than the tensile of elastisty for FRP materials. The compressive modulus of elasticity is approximatly 80% for GFRP, 85% for CFRP, and 100% for AFRP of the tensile modulus of elasticity for the same product (Ehsani 1993).

2.5.5 Durablitiy

The durability and long term performance of FRP materials are covered only briefly in this report since reported literature does not fully cover the topic. Before using FRP system for strengthening a particular structure, an initial condition assessment of the existing structure needs to be performed. The assessment should be the result of a thorough field inspection and review of existing design. In these inspections, it is possible to study the capacity of the existing structure, identify the deficiencies and causes and determine the condition of concrete substrate. As shown in the ACI Committee 440 (2002), a field inspection should include the following:

- Existing dimensions of the structural members;
- Location, size, and cause of cracks and spalls;
- Location and extent of corrosion of reinforcing steel;
- Quantity and location of existing reinforcing steel;
- In-place compressive strength of concrete; and
- Soundness of concrete, especially the concrete cover, in all areas where the FRP system is to be bonded to the concrete.

Many FRP systems exhibit reduced mechanical properties after exposure to certain enviromental factors, including temprature, humidity and chemical exposure. The exposure enviroment, duration of exposure, resin type and formation, fiber type, and resin-curing method are also important factors that influnce the extent of the reduction in mechanical properties (Amateau, M.F. 2003).

Table 3 Typical Mechanical properties of different types of FRP

Fiber type	Elastic modulus (Gpa)	Ultimate strength (Gpa)	Rupture strain (%)
Carbon			
General purpose	220-240	2050-3790	1.2
High strength	220-240	3790-4820	1.4
Ultrahigh strength	220-240	4820-6200	1.5
High modulus	340-520	1720-3100	0.5
Ultrahighmodulus	520-690	1380-2400	0.2
Glass			
E-glass	69-72	1860-2680	4.5
S-glass	86-90	3440-4140	5.4
Aramid			
General purpose	69-83	3440-4140	2.5
High performance	110-124	3440-4100	1.6

Table 4 Advantages and disadvantages of **FRP**

Advantages	Disadvantages
Electro magnetic High strength to weight ratio Cooresion resistant High fatigu endurance (for carbon and aramid fibers) Lightweight Corrosion resistance Weather resistance Dimensional stability low thermal conductivity and coefficient of thermal expansion Non-magnetic High impact strength High dielectric strength (insulator) Low maintenance and long-term durability Small to large part geometry possible Tailored surface finish	Lack of ductility High Cost Low transverse strength Low modulus of elasticity for glass and aramid fibers Brittle materials. The non-compatible coefficient of thermal expansion with this one of concrete and masonry. They are vulnerable to fire and generally too high temperatures. Reduction of tensile strength and Young Modulus when they are under continuous drench or alkaline environment.

2.5.6 strength

The actual strength is the maximum load that can be sastained by a structural member before failure. In other words the actual strength is the ablity of a structural member to resist the internal actions induced by load until failure. The performance of reinforced concrete member subjected to seismic action can be evaluated based on the degradation of strength through loading cycles.

For designing purposes. The computed strength is used for proportioning reinforced concrete members. One should distinct between different strength defintions such as nominal, required and design strengths. On the other hand, the required strength is the strength of a membr required to resist factored loads. The strength design method reqires the normal strength be reduced by specified strength reduction factors, i.e. design strength, equals to or excced the factored load effect, i.e. required strengths. ($\sigma_{actual} <= \sigma_{allowable}$) (Amateau, M.F. 2003).

2.5.7 stiffness

Stiffness is a property used to quantify and control the deformation under the action of certain force. Relationships for computing stiffness are readily established from principles of structural mechanics using members geometry, material properties and members end condtions. In reinforced concrete structures, these relationships are not quite simple but can be achived using some assumptions. If a serviceblity criterion is to be satisfied, the extent and infulunce or cracking members and contrubtions of concrete in tension must be considered in calculating the stiffness (Lam, L et. al. 2002).

2.5.8 Ductility

Ductility is an important consideration in design of all structures, practically when they are subjected to overloads. A material can be deformed either elastic or plastic, small or large. A material that capable of undergoing a large amount of plastic deformation is said to be ductile. While a material with a little plastic deformation before rupture is said to be brittile (Dăescu, 2011).

2.5.9 Creep-rupture

When FRP composites are subjected to a constant load over a time they fail suddenly. This failure is known as the creep rupture and this time period is known as the endurance time. The endurance time decreases when the ratio of sustained tensile stress to the short-term strength of the FRP laminates increases. Furthermore it decreases with adverse environmental conditions such as high temperature, high alkalinity, freezing-thawing cycles and wet-dry cycles As stated in ACI Committee 440 (2002) the relationship between creep rupture strength and the logarithm of time for FRP bars is linear. The ratios of stress level at creep rupture after 500,000 hours to the initial ultimate strength of the GFRP, AFRP, and CFRP bars were extrapolated to be 0.3, 0.47, and 0.91, respectively (Yamaguchi et al. 1997). Similar values have been determined elsewhere. The vulnerability of carbon, aramid and glass fibers to creep rupture is increasing respectively.

C-CFRP (B) C-CFRP-ST (C) C-G

Figure 8 Reinforced Concrete Columns Retrofitted with FRP (Miller 2006).

In the series of the studies, the aims were to investigate the seismic performance of the precast large wall panels weakened by cut-out openings and to investigate the effectiveness of the CFRP-EBR strengthening method. by applying pseudo-constant axial and quasi-static in-plane reversed cyclic lateral forces. To assess the weakening effect of the cut-out openings a practical formula was derived. Again it was concluded that in reversed cyclic applications, the flexural CFRP-EBR is susceptible to premature failure, while the overall behavior of the weakened walls was improved in terms of shear strength, peak drift and energy dissipation (Demeter, 2011)

Furthermore, considering the fact that in repair and strengthening work, labor and operational costs often far outweigh material costs; low weight of FRPs substantially reduces labor costs, which usually attain 80% of the total operational costs. Therefore, it is strongly believed that significant savings could be attained from successful utilization of the new technique of rehabilitation of the infrastructure. Examples of field applications that will directly benefit from such work include, but are not limited to: (Yousef A. et al, 2002)

1) Repair problems associated with design and construction errors, lack of supervision, low quality assurance, and bad infrastructure construction practice.

2) Strengthening of different parts of structures that are subjected to unpredictable overloads during their service life. These include foundation settlement and those resulting from the deviation of as-built structures from the design intent.

3) Augmenting of the existing capacity of the structural elements to meet the increased demands of new standards or higher traffic loads. .

4) Upgrading the capacity of the industrial parts such as pipes to meet the new expansion plans.

5) Providing quick and effective solution in assuring integral function of the old and new parts of the structure.

Figure 9 FRP warps being installed on a highway column

3. METHODOLOGY AND FINITE ELEMENT MODELLING

3.1 Flowchart

The overall research methodology is supported with the flowchart shown below

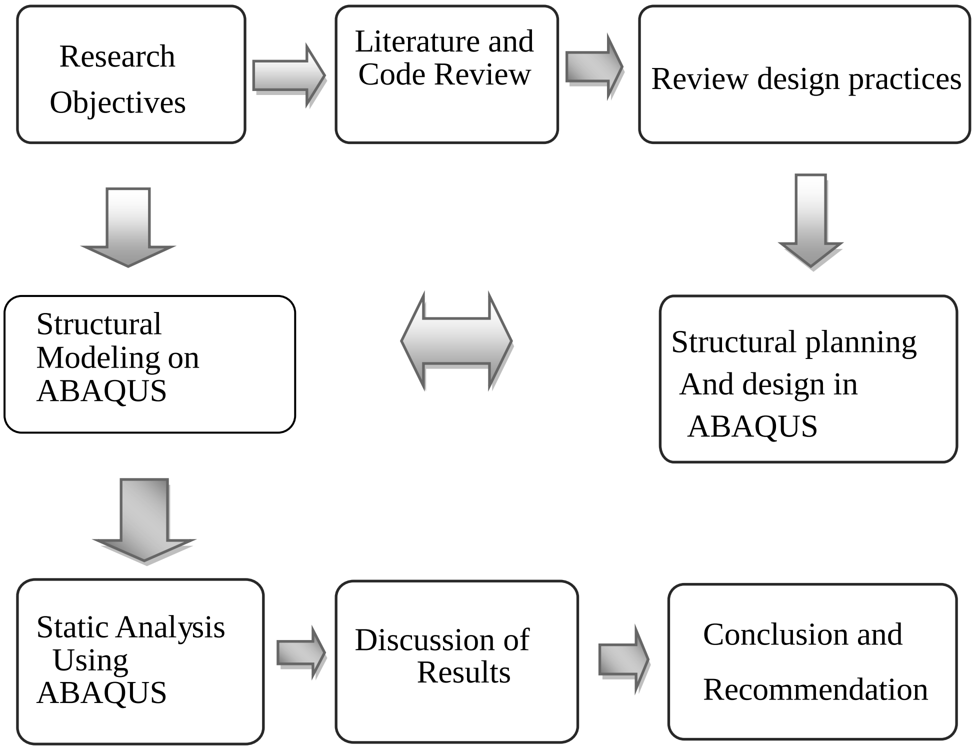


Figure 10 study design

The methodology was started with research objective. In country there is no consideration for accidental loads impact to the reinforced concrete building during design practice. Therefore the effect of the building columns was simulated using ABAQUS static analysis and the effect was interpreted based on the numerical results graphically. Then by selecting the key building columns which the stability of the building mainly depend was simulated in ABAQUS .The total deformation and stress on the surface of impact was numerically obtained .

3.2 Finite Element Modeling

3.2.1 Software programs

Simulation modeling is the process of creating and analyzing a digital prototype of physical model to predict its performance in the real world. Simulation and modeling is used to designers and engineers to understand whether under what condition and in which way a part will fail and what loads it can withstand. Then ways for simulation and modeling are using appropriate software's. Software's used in this study research are ABACUS analysis, ANSYS analysis, and SAP 2000 analysis.

3.2.2 ABAQUS software

ABAQUS is a software system written in the c++ that provides a framework for the implementation of branch and bond algorithms using linear programming relation. Plane or column can be generated dynamically. ABAQUS allows the software developer on the problem specific parts. ABAQUS provides many basic data structures and useful tools for the implementation of such algorithms. It designed both for general mixed integer optimization problems and for combinatorial optimization.

ABAQUS is a powerful engineering simulation program, based on the finite element method, which can solve problems ranging from relatively simple linear analysis to the most challenging nonlinear simulations. Abaqus contains an extensive library of elements that can model virtually any geometry. It can simulate the behavior of most engineering materials including metals, rubber, polymers, composites, reinforced concrete, crushable and resilient foams, and geotechnical materials such as soils and rock. Problems with multiple components are modeled by associating the geometry defining each component with the appropriate material models and specifying appropriate interactions. In a nonlinear analysis Abaqus automatically chooses appropriate load increments and convergence tolerances and continually adjusts them during the analysis to ensure that an accurate solution is obtained efficiently.

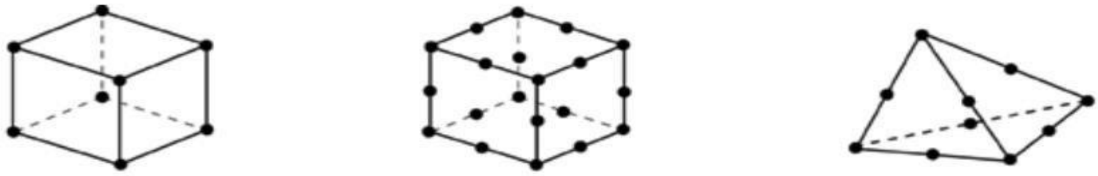
Abaqus/Standard, a general-purpose finite element program, solves a system of equations implicitly at each solution "increment". In contrast, Abaqus/Explicit is an explicit dynamics finite element program, marches a solution forward through time in small time increments without solving a coupled system of equations at each increment or by forming a global stiffness matrix.

3.2.2.1 Abaqus Parameter Selection and Element Type Selection

1) **Concrete**

Abaqus has various solid elements each with different capability, accuracy and efficiency. Elements that have nodes only at their corners, such as the 8-node brick (C3D8), 4 node tetrahedron (C3D4), use linear interpolation in each direction and are often called linear elements or first-order elements. The 4-node tetrahedron (C3D4) linear element is a general purpose tetrahedron element with one integration point. This element is included for completeness. Elements with mid-side nodes, such as the 20-node brick (C3D20) and 10-node tetrahedron (C3D10), use quadratic interpolation and are often called quadratic elements or second-order elements.

The solid elements of C3D8, C3D20, and C3D10M are mostly used. C3D8 is a brick element which has nodes at its corners, and linear interpolation would be applied in each direction. According to its quick solution and good accuracy, C3D8 is the most general element adopted in most of the 3D finite element models. C3D20 generally used for very detailed model, it has more integration points in each element compared with the C3D8. This could bring some benefit when the transfers in each element are very big, but this will increase the computational time. The C3D10M suits for some irregular shapes, but its accuracy is not as good as the cube element Considering both the computational time and accuracy in most of the numerical analysis, for modeling of the old and new concrete sections, element type C3D8R is used. Also, C3D4 is used for completeness in the irregular geometries.



(a) Linear element
(8-node brick, C3D8)

(b) Quadratic element
(20-node brick, C3D20)

(c) Modified second-order element
(10-node tetrahedron, C3D10M)

Figure 11 Solid elements of C3D8, C3D20, and C3D10M

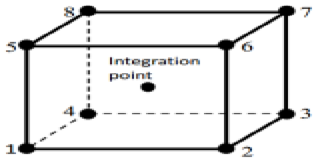


Figure 12 C3D8R

ABAQUS solid element type C3D8R means—C refers for continuum stress/displacement, —3D refers to —3-dimensional, —8 is the number of nodes in each element and —R represents reduced integration. And though in this simulation program this is what i do the concrete type.

2) Reinforcement Bar

Steel reinforcement is modeled with 2-node, 3-D truss elements (T3D2), in which each node has three translational degrees of freedom. The truss elements are fully embedded in the concrete assembly. Therefore, the translational degrees of freedom of the nodes of the truss elements are constrained to the interpolated values of the corresponding degrees of freedom of the concrete element.

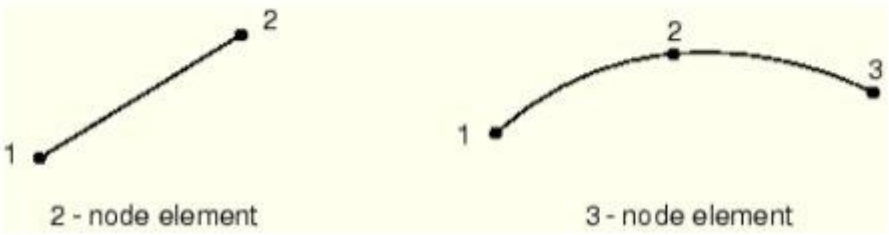


Figure 13 Steel reinforcements with 2-node and 3-D truss elements

3.2.2.2 Material Property

A. Concrete

Concrete has low tensile strength, which results in cracking at very low tensile stress. These cracks reduce the stiffness of the concrete, which is the major contributor to the nonlinear behavior of reinforced concrete structures. In order to incorporate the nonlinear behavior of the concrete, the concrete damaged plasticity model in Abaqus is used. The concrete damaged plasticity model considers both the tensile cracking and compressive crushing of concrete as possible failure modes. This provides a general capability for modeling concrete and other quasi- brittle materials in all types of structures. This model uses the concepts of isotropic damaged elasticity in combination with isotropic tensile and compressive plasticity to represent the inelastic behavior of concrete.

1. Concrete Damage plasticity parameters

The Concrete Damaged Plasticity model is currently one of the most popular concrete models used for simulation of concrete behavior in Abaqus**.** A common representation of the stress–strain curve for concrete models with strengths up to C50/60 is the Modified Hognestad stress–strain curve shown in the figure below.

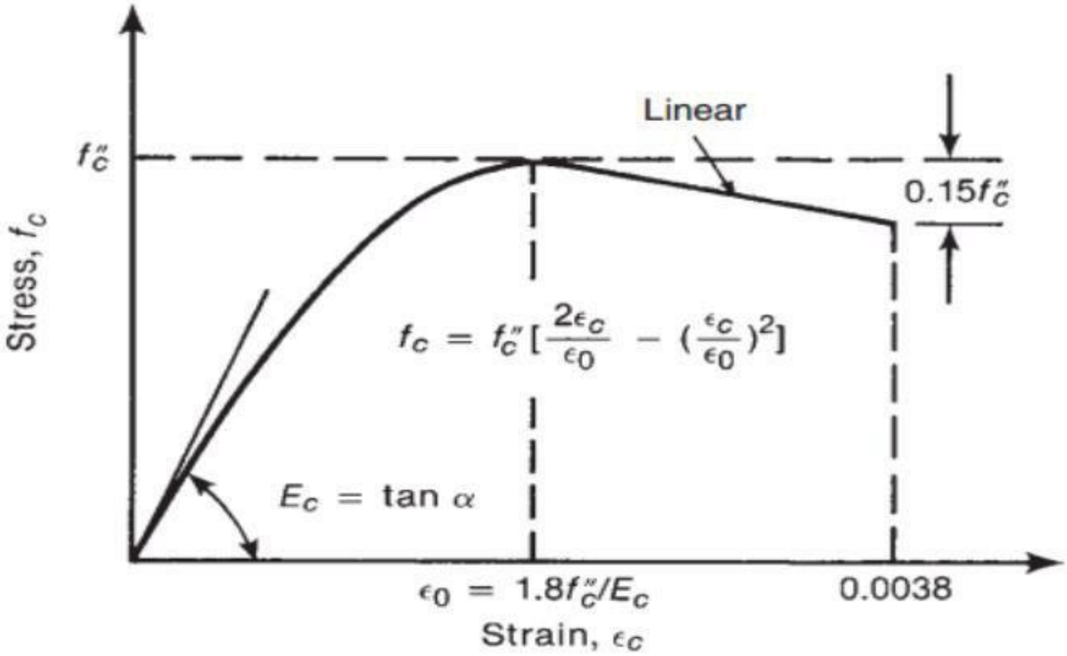


Figure 14 Modified Hognestad stress-strain model for concrete

2. **Dilation Angle** (α):- This is the angle of inclination of the failure surface towards the hydrostatic axis, measured in the meridional plane. It is also interpreted as a concrete internal friction angle which is the ratio of volume change to shear strain. The value of dilation angle ranges between 5 and 55 degrees (Szczecin M.2015) explain that, the use of relatively high values of dilation angle on compression may cause too optimistic results for stiffness and bearing capacity of concrete elements and they recommend the use of lower values. The dilation angle was equal to volume strain over shear strain the dilation angle which affected material ductility. Consequently, the dilation angle has considerable effect on the entire model. Accordingly, dilation angle of 31 degrees is used in this analysis.
3. **Eccentricity (ϵ):-** It is the rate at which the Drucker-Prager function approaches the asymptote. In other words, it is the length (measured along the hydrostatic axis) of the segment between the vertex of the hyperbola and the intersection of the asymptotes of this hyperbola (the center of the hyperbola). Parameter eccentricity can be calculated as a ratio of tensile strength to compressive strength. The Concrete Damaged Plasticity model recommends to use $\epsilon = 0.1$. As eccentricity tending to zero, the plastic flow tends to a straight line.

4. **σ_{bo}/σ_{co} Parameter:-** It is a ratio of the strength in the biaxial state to the strength in the uniaxial state. This parameter is necessary to solve the yield function. The most reliable in this regard are the experimental results reported by Kupler (1969) which is equal to 1.16248. The Abaqus user's manual specifies default value σ_{bo}/σ_{co} of 1.16. **(**Dassault Systems.2014**).**
5. **Viscosity Parameter: -** The viscosity parameter is required when a convergence problem is caused by softening behavior. The default value 0 is used for the analysis.
6. ***Kc* Parameter: -** physically, the parameter *Kc* is interpreted as a ratio of the distances between the hydrostatic axis of the compression meridian and the tension meridian in the deviator cross section. This ratio is always higher than 0.5 and when it assumes the value of 1, the deviator cross section of the failure surface becomes a circle (as in the classic Drucker–Prager strength hypothesis). Reports according to experimental results show that this value for mean normal stress is equal to zero amounts to 0.6 and slowly increases with decreasing mean stress. The CDP model recommends to use *Kc* = 2/3.
7. **Fracture Energy: -** It is the amount of energy (GF) which is required to open a unit area of crack. Thus, concrete's brittle behavior is defined by stress-displacement response rather than a stress-strain response. The fracture energy model is used to define the tensile crack property of concrete models in Abaqus.

In the absence of experimental data and for ordinary normal weight concrete**, Model code 2012 [8]** provides an empirical equation to estimate the fracture energy.

B. Reinforcement bar

The stress–strain curve of the reinforcing bar is assumed to be elastic perfectly plastic material yields under constant load. The parameters needed to specify this behavior are the modulus of elasticity (*Es*), poison's ratio (v) and yield stress (F_y).

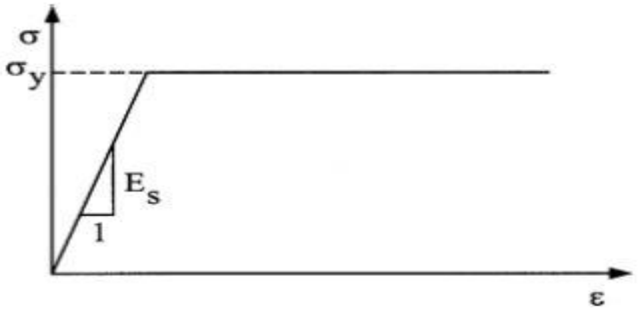


Figure 15 Elastic perfectly plastic model for reinforcing bars

3.2.2.3 Contact Interaction Property

Contact interaction property can define tangential behavior (friction and elastic slip), normal behavior (hard, soft, or damped contact) and cohesive behavior (cohesive damage, traction separation). In addition, a contact property can contain information about damping, thermal conductance, thermal radiation, and heat generation due to friction. A contact interaction property can be referred to by a surface-to-surface or self-contact interaction.

The new and old concrete sections in reinforced concrete jacketing are in direct contact. In the contact interaction module, the first step is to create the surfaces that will be included in the interactions. The surfaces in the contact interaction are defined as Master and slave surfaces. Surface -to-surface contact interaction with mechanical contact properties of cohesive, tangential, normal behaviors and small sliding interaction is used in this simulation. In contact modeling, interior surface nodes of the two regions form a contact pair, where each of the nodes on the slave surface are constrained to have the same value of displacement to the point on the master surface that they contact. ABAQUS/CAE generally selects the surface with the higher mesh refinement to be the slave surface.

A. Cohesive property

This option is used to define surface-based cohesive behavior in a mechanical contact analysis. It must be used in conjunction with the surface to surface interaction option. In this interaction property, uncoupled traction separation behavior is used with energy damage evolution of Benzeggah-Kenane mixed mode behavior. The stiffness parameters of the cohesive behavior interaction properties are taken using the Turon,et al. recommendations. The thickness of the cohesive layer in the interaction of concrete layers cast at different times is taken as the average roughness.

B. Tangential property

The penalty friction is used in the tangential behavior. The values of the friction coefficient between new and old concrete sections based on the surface preparation are adopted from Euro code 2 2004 and Model code 2012**.**

3.2.2.4 Connection between the Old and Overlaying Material (FRP)

On columns strengthened by FRP jacketing, the load carrying capacity is developed by cohesive connection and frictional interaction in the interface. Cohesive interface connection is rigid whereas the frictional interface properties results in non-rigid connection. On initial loading the cohesive interaction is effective. But as loading increases, the cohesive bond fails and the frictional resistance is developed due to interferential slip. This comparison analysis is used to show the difference in capacity of cohesive and frictional interface interactions and carry out non-rigid interface connection in the detail analysis. Because the ultimate conditions the rigid interface connection didn’t guarantee the structure (Amateau, M.F. 2003).

The load and geometrical properties of the models which are similar to the experimental model are used. But, in this comparison, artificial roughness is provided as per Eurocode-2 to create surface interlocking and then carryout push out analysis. On the other hand, the frictional interface develops non-rigid bond failure with a significant slip. So, here after the frictional interface with FRP is considered for further investigation.

3.3 Experimental data validation

In this study the experimental research conducted by Alazar Nigussie is used to calibrate the concrete damage parameters and interaction properties between the new and old concrete models in Abaqus. The authors studied the effect of initial construction damages and preloading on the capacity of jacketed columns in which 10 specimens with and without initial damages, are examined. Among, specimen number **10** is selected for the verification since it best describes the conditions in this study.

Table 5 Details of the validated experimental FRP jacketed column

Mechanical properties of concrete used	
Type	C25.5
mean compressive strength fcmu (Mpa)	35
elastic modulus Ec (Gpa)	33.4
poison's ratio	0.2
density (kg/m^3)	2427

Parameters Used in CDP				
dilation angle	eccentricity	σbo/σco	K	viscosity parameter
31	0.1	1.16	0.67	0.0001

Concrete compressive behavior		Concrete compression damage	
Yield stress (Mpa)	Inelastic strain	damage parameter	inelastic strain
25.5	0	0	0
32	5.74E-06	0	5.74E-06
37.5	4.14E-05	0	4.14E-05
42	0.000106874	0	0.000106874
45.5	0.000202271	0	0.000202271
48	0.000327555	0	0.000327555
49.5	0.000482726	0	0.000482726
50	0.000667782	0	0.000667782
49.5	0.000882726	0.01	0.000882726
48	0.001127555	0.04	0.001127555
45.5	0.001402271	0.09	0.001402271
42	0.001706874	0.16	0.001706874
37.5	0.002041363	0.25	0.002041363
32	0.002405738	0.36	0.002405738
25.5	0.0028	0.49	0.0028
18	0.003224148	0.64	0.003224148
9.5	0.003678183	0.81	0.003678183
Concrete tensile behavior		concrete tension damage	
yield stress (Mpa)	cracking strain	damage parameter	cracking strain
5	0	0	0
0.05	0.001494322	0.99	0.001494322

This experiment found that FRPs impact the maximum load minimally, but increases slip resistance. Here during validation the percentage of error is 1.5% which is resulted from its simulation.

3.4 Material properties and Modeling of Column on ABAQUS

The reinforced concrete column was modeled on ABAQUS with its column forces for simulation.

3.4.1 **Model parameters**

Units in this study are described as follow:

Length = mm, Mass = kg, Force = N, density = kg/mm^{3}and Stress = Mpa

3.4.1.1 CONCRETE

Column size	Dimension (mm x mm)
C1	150*150*2000

Mechanical properties of concrete used	
Type	C30
mean compressive strength fcmu (Mpa)	28.8
elastic modulus Ec (Gpa)	28.6
poison's ratio	0.24
density (kg/m^3)	2427

Parameters Used in CDP				
dilation angle	eccentricity	σbo/σco	K	viscosity parameter
31	0.1	1.16	0.67	0.0001

Concrete compressive behavior		Concrete compression damage	
Yield stress (Mpa)	Inelastic strain	damage parameter	inelastic strain
15.3	0	0	0
19.2	4.82E-05	0	4.82E-05
22.5	0.000119844	0	0.000119844
25.2	0.000214786	0	0.000214786
27.3	0.000333074	0	0.000333074
28.8	0.000474708	0	0.000474708
29.7	0.000639689	0	0.000639689
30	0.000828016	0	0.000828016
29.7	0.001039689	0.01	0.001039689
28.8	0.001274708	0.04	0.001274708
27.3	0.001533074	0.09	0.001533074
25.2	0.001814786	0.16	0.001814786
22.5	0.002119844	0.25	0.002119844
19.2	0.002448249	0.36	0.002448249
15.3	0.0028	0.49	0.0028
10.8	0.003175097	0.64	0.003175097
5.7	0.003573541	0.81	0.003573541
Concrete tensile behavior		concrete tension damage	
yield stress (Mpa)	cracking strain	damage parameter	cracking strain
3	0	0	0
0.03	0.001167315		0.001167315

Table 6 mechanical properties of concrete

3.4.1.2 STEEL

Mechanical properties of steel used	
Type	S300
mean tensile strength fs (Mpa)	266.7
elastic modulus Ec (Gpa)	210
poison's ratio ,v	0.3
density (kg/m^3)	7900

Yield stress (Mpa)	360	470
plastic strain	0	0.2

Bars	Reinforcement (mm^2)	No of rebar	Spacing
B1	619.128	6 φ12	58.3333
B2	3089.678	10 φ 20	40
B3	2604.348	10 φ 20	55
S1	536.94	19 φ 6	155
S2	954.56	19 φ 8	155
S3	954.56	19 φ 8	155

Table 7 mechanical properties of steel

3.4.1.3 FRP materials

Typical density of FRP materials, kg/m^3		
GFRP	CFRP	AFRP
1600	1500	1300

Mechanical properties of FRP used			
property	Carbon	glass	Aramid
	0.1	0.2	0.3
	0.117	0.35	0.35
	0.3	0.4	0.4
elastic modulus Ec (Gpa)	240	65	118.2
tensile strength, Gpa	3.8	3	2.6
ultimate strain, %	1.55	4.3	2.2
density ,(kg/m^3)	1550	1800	1450

Table 8 mechanical properties of FRP

Column	Axial force (KN)	Bending moment M_2 (KNM)	Bending moment M_3 (KNM)
C1	86.348	36.016	63.847

Table 9 Column out put force

4. SIMULATION RESULTS AND DISCUSSION

4.1 Simulation Results

Using the above material and jacketing material properties, the analysis of the composite jacketed column is conducted to study the parametric effects. Only the frictional effect is taken in relation to the other variable parameters. The cohesive interface property is not considered in the study because of its rigid bond formation and lower resistance on the ultimate condition. In the evaluation of the parameters the load applied in the analysis is the axial load capacity of the old concrete section. In the rest of the analysis of the parametric study old concrete column section of the following properties are used.

The followings analysis results are obtained from Abaqus CEA analysis and theses parameters describes the structural composite jacketing effect. For the appropriate size of elements to be used, mesh convergence analysis is taken and the following plot is obtained. When selecting element size, computational time and results convergence are taken in to consideration.

4.1.1 Variation of structural parameters with different thickness of fiber

The Variation of stresses, displacement and axial force capacity with different thickness of fiber obtained from the Abaqus results of retrofitted by three jacketing materials can be summarizing as the following table.

4.1.1.1 Retrofitted by Carbon fiber with different thickness

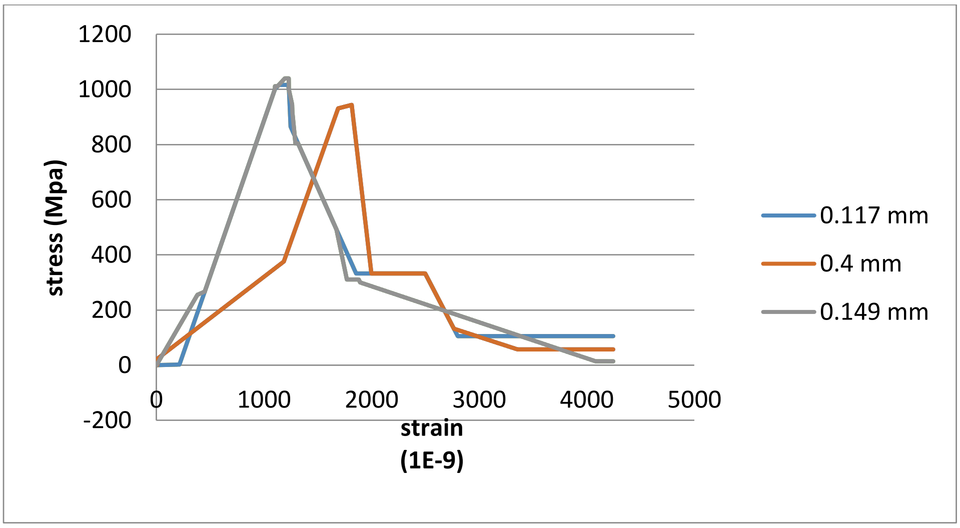


Figure 16 Retrofitted by Carbon fiber with different thickness

4.1.1.2 Retrofitted by Glass fiber with different thickness

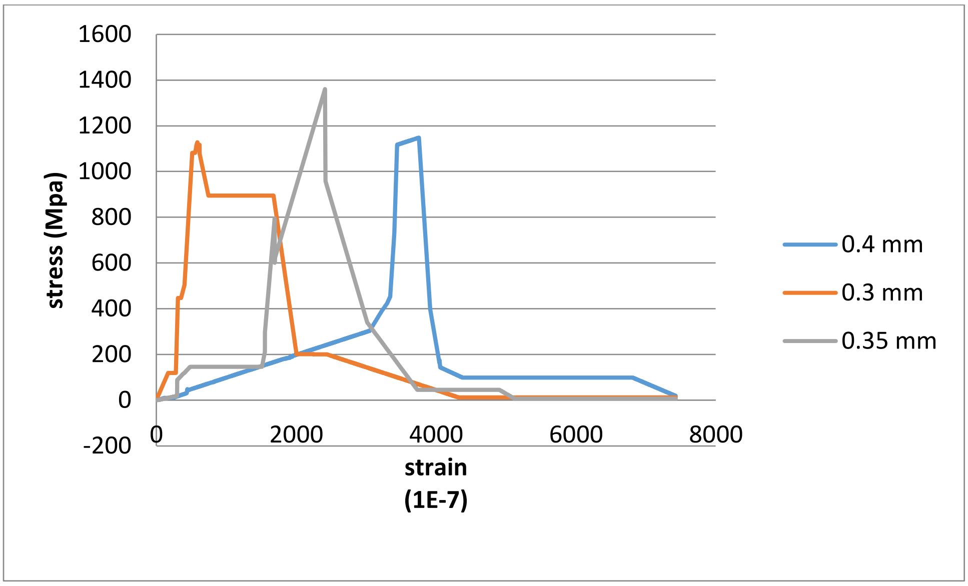


Figure 17 Retrofitted by Glass fiber with different thickness

4.1.1.3 Retrofitted by Aramid fiber with different thickness

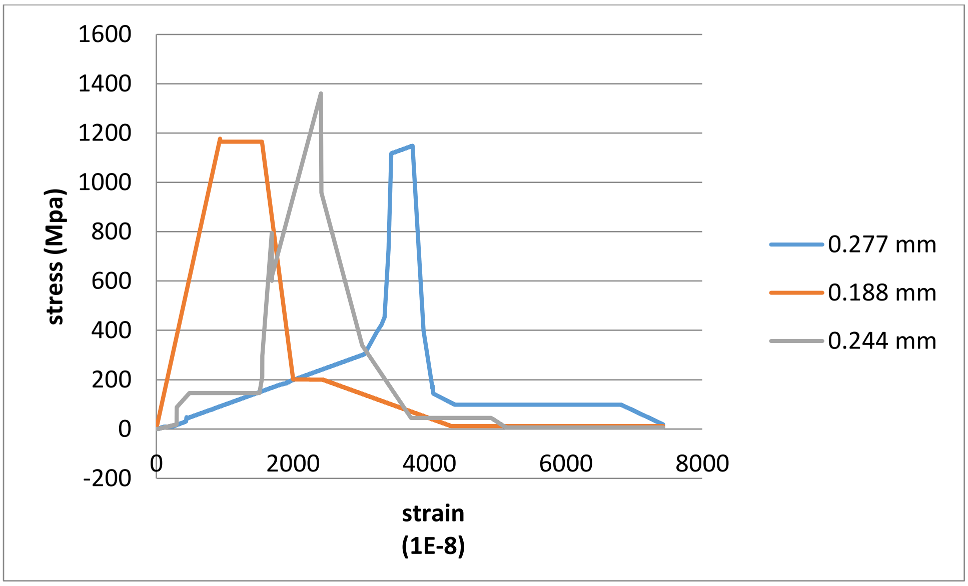


Figure 18 Retrofitted by Aramid fiber with different thickness

4.1.2 Variation of structural parameters with different grades of concrete

4.1.2.1 C-50 concrete grade with different fiber jacketing material

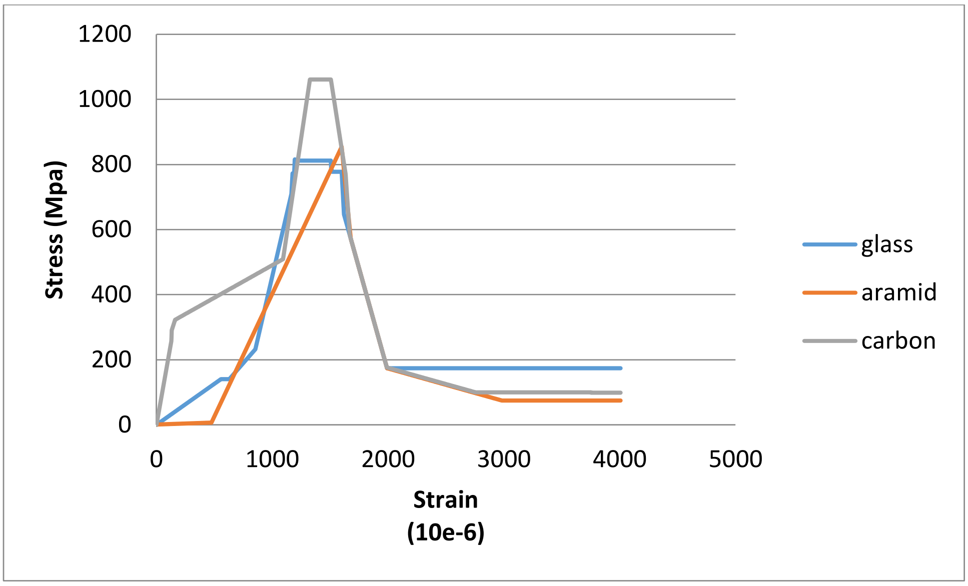


Figure 19 jacketing C-50 concrete grade with different fiber jacketing material

4.1.2.2 C-70 concrete grade with carbon fiber jacketing material

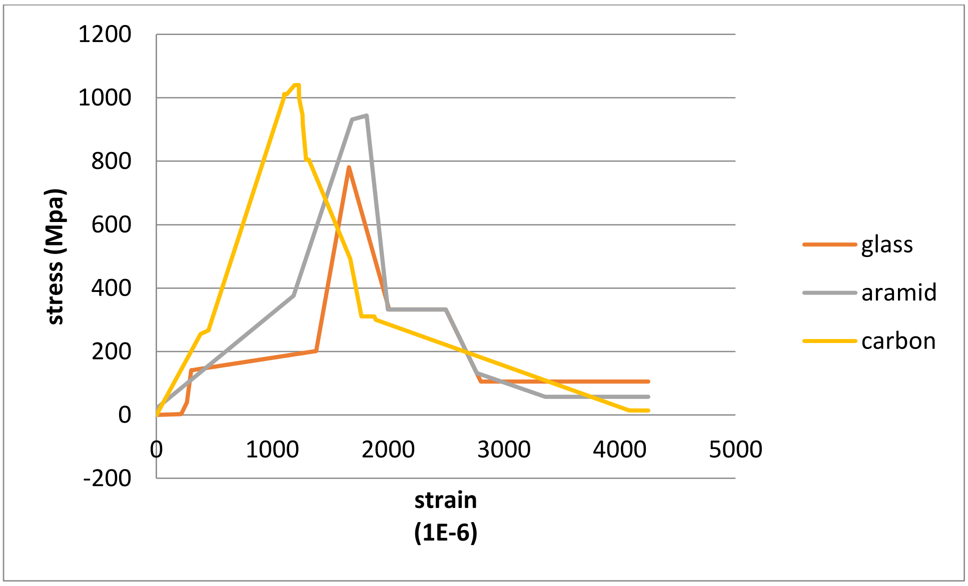


Figure 20 C-70 concrete grade with different fiber jacketing material

4.1.3 Variation of structural parameters with different Cross Sections of columns

4.1.3.1 Rectangular Cross Section with different Fiber

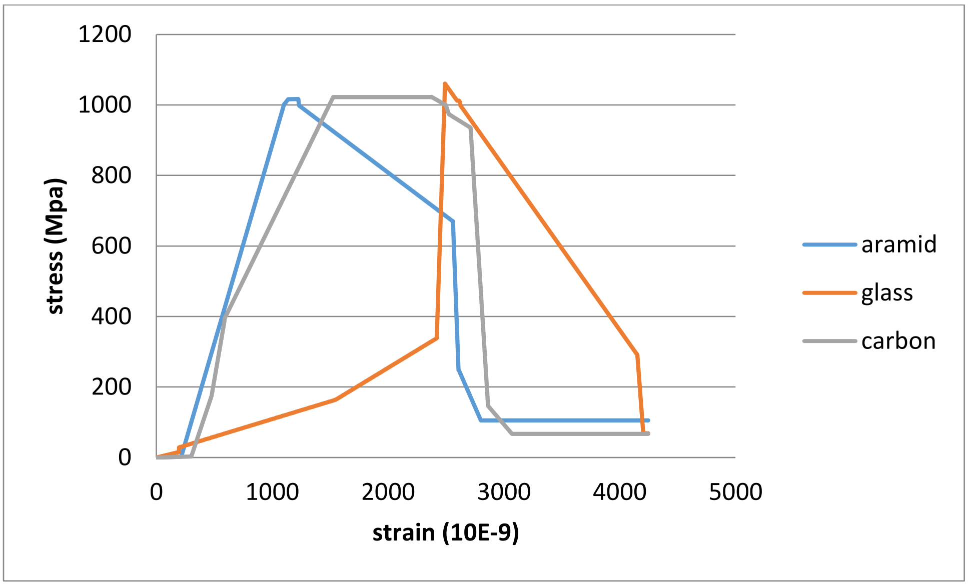


Figure 21 Rectangular Cross Section with different Fiber

4.1.3.2 Circular Cross Section with different Fiber

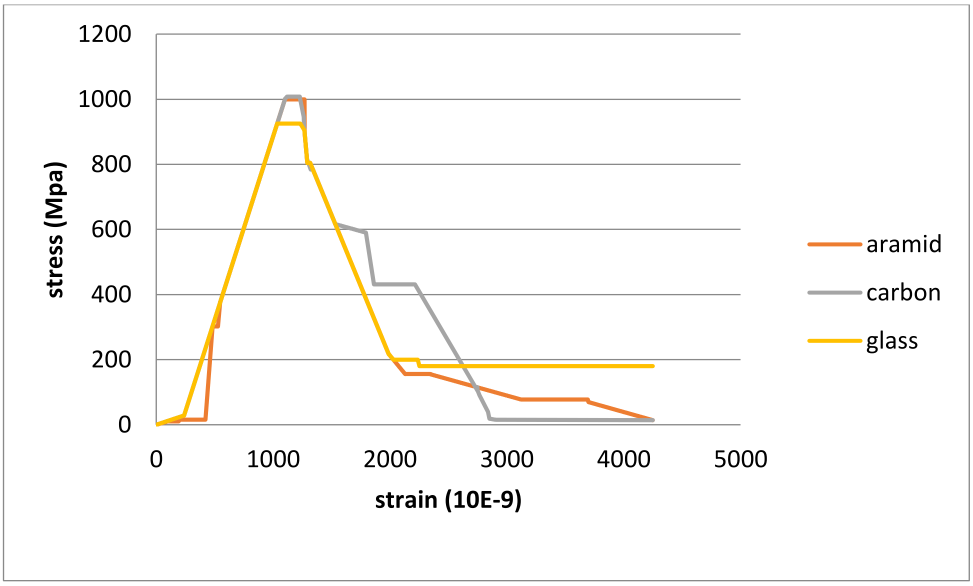
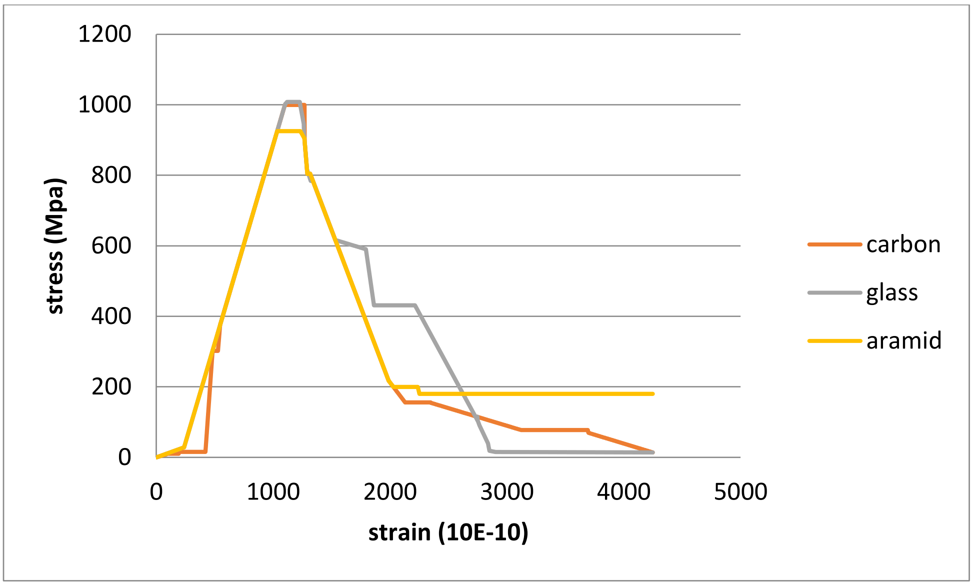


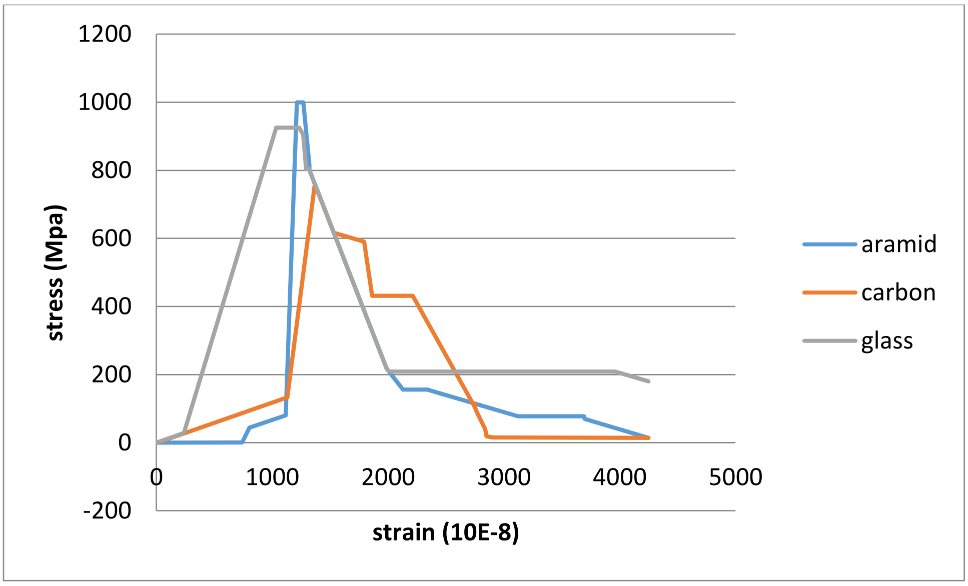
Figure 22 Circular Cross Section with different Fiber

4.1.4 Variation of structural parameters with Eccentricity effect

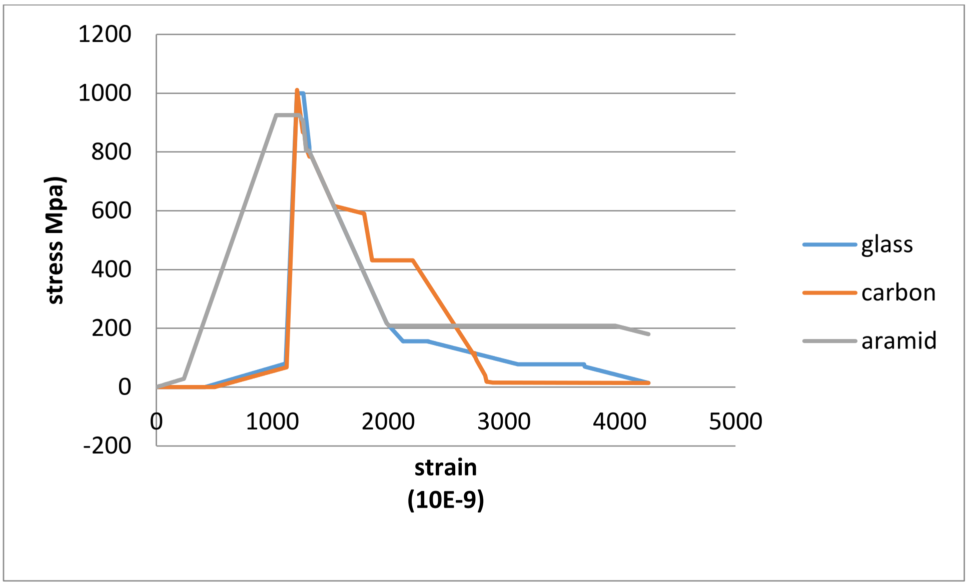
4.1.4.1 For $e_x = 0$



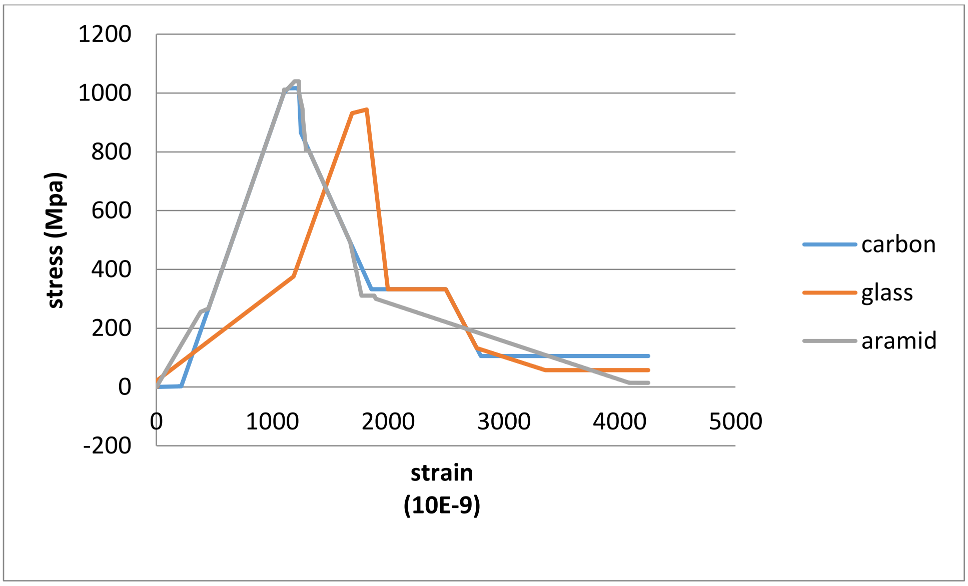
4.1.4.2 For $e_x = 15$



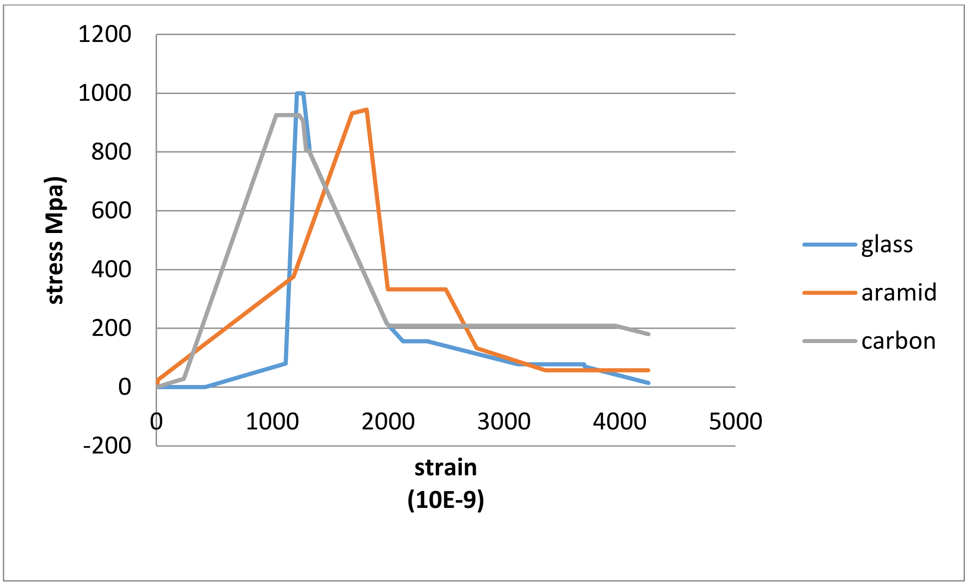
4.1.4.3 For $e_x = 30$



4.1.4.4 For both $e_x = 0$ and $e_y = 0$



4.1.4.5 *For both $e_x = 15$ and $e_y = 15$*



4.1.4.6 *For both $e_x = 30$ and $e_y = 30$*

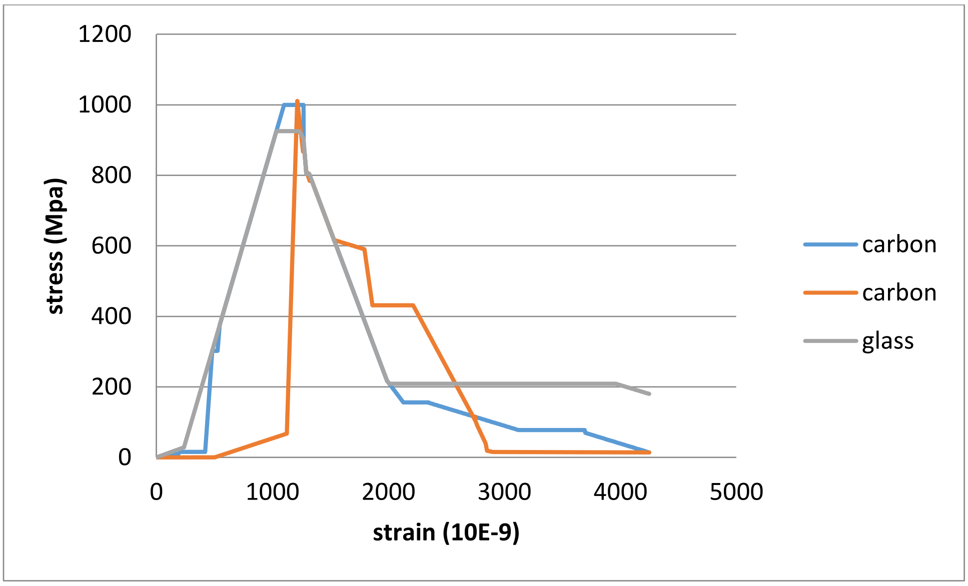


Figure 23 Rectangular Cross Section with different eccentricity

4.1.5 FRP jacketing for slender columns

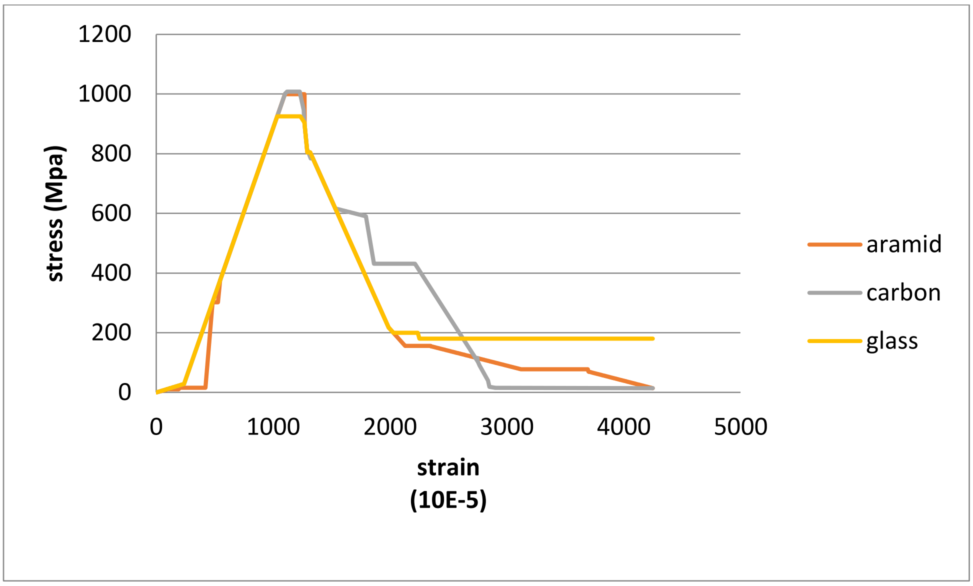


Figure 24 Rectangular Cross Section for slender columns

4.2 Discussion

For thickness of 0.149, 0.117 & 0.4 CFRP, 0.3,0.35 & 0.4 GFRP and 0.277, 0.188 &0.244 AFRP considered Variation of stresses, displacement and axial force capacity with different thickness of fiber obtained from the Abaqus results of retrofitted by three jacketing materials of column due to the variation of layer and compressive strength, displacement shown in figure above. For the concrete grade of C-30 the axial capacity of the composite jacketed column is 177%, 178%, 180% of the axial capacity of the core column. When the strength of the concrete is increased from C-30 to C-50 and, C-70 the axial capacity of the jacketed section is increased in all cases. Therefore From the above simulation results and graph carbon FRP is the most preferable material for composite jacketing.

4.2.1 Strengthening of RC rectangular columns confined with FRP jackets

The confinement provided by FRP jacket to a concrete core is passive rather than active, as the confining pressure from the jacket increases with the expression the concrete core. Thus the confinements of concrete techniques rely on their FRP jacket to upgrading. This confinement action enhances the concrete strength and ductility and in additional prevents slippage and buckling of longitudinal reinforcement. A large ductility at yield the FRP has only linear behavior up to the failure therefore it exerts an increasing pressure on concrete core up to rapture of FRP it exerts a constant lateral pressure.

4.3 Lateral confining pressure

When a concrete column is subjected to an axial compressive stress, it expands laterally. For this expansion is resisted by the lateral pressure induced by the jacket which is loaded in tension in the circumferential (hoop) direction. The confining pressure provided by the FRP jacket increases continuously with the lateral strain of concrete because of the linear elastic stress- strain behavior of FRP. Failure of FRP confined concrete generally occurs when the hoop rapture strength of the FRP jacket is reached. For equilibrium the lateral (radial) confining pressure acting on the concrete core f_t is given by

$$f_j = \frac{\sigma_j t}{R}$$

Where f_j=stress in the FRP jacket; t= thickness of FRP jacket and R= radius of the confined concrete core. For FRP jacket with fibers predominantly in the hoop direction only the hoops stress is considered for a jacket and due to the linearity of FRP behavior the stress in the jacket f_j is related to the strain ε_j by

$$f_j = E_j \varepsilon_j$$

Where E_j = elastic modulus of FRP in the direction of fiber and the lateral confining pressure is related to the jacket strain by;

$$f_j = t\,\frac{E_j \varepsilon_j}{R}$$

4.4 Classification of stress strain models for confined columns

There are different studies on FRP confined concrete has been out with many stress strain model developed. These models can be classified into two categories:

Design oriented model

Analysis oriented models

In the first category stress strain models are presented in a closed from expression, while in second category, stress strain curve of FRP confined concrete are predicted using incremental numerical procedure.

1. Design oriented models

Various simple stress strain models in closed form expression have been proposed based directly on stress strain curves of tested FRP confined concrete. Most of these models predicts the only behavior during loading phase of column, while the models of predict the stress strain relation during loading and unloading phases. Such models are practically suitable for direct application in design calculation by hand or spreadsheets and are thus referred to as design oriented models Xiao and Wu (2000).

2. Analysis- oriented models

A number of stress-strain modes have been developed based on incremental iterative numerical approach in which the interaction between the concrete core and the confined FRP is explicitly accounted for. Although incremental approach are difficult to be adopted in hand calculations for design, they give more accurate results and can be adopted in advanced computer analysis such as nonlinear finite element analysis, particularly if the lateral strain of the confined concrete is also required in the analysis. These models are referred to as analysis oriented stress-strain models.

The main advantage of this approach is:

- The behavior of both well confined and weakly confined can be predicted by the same model without difficulty.
- Stress in FRP can be explicitly evaluated throughout the loading process and related to the condition of FRP rupture.
- The compressive strength and the stress-strain behavior have been developed specifically for FRP – confined concrete, in the context of both column strengtheninig and concrete filled FRP tubes for new construction.

The majority of models exist in litrature take one of the two forms.

$$f_{cc} = f_{co} + f_i$$

Or

$$\frac{f_{cc}}{f_{co}} = 1 + k\frac{f_i}{f_{co}}$$

Where f_{cc} and f_{co} are the compressive strengths of the confined and unconfined concrete respectively, f_l is the lateral confinig pressure, and k is the confinment effectiveness coefficient. This form was first proposed by Richart et al.(1928) for activly confined concrete with a valu of 4.1 for k. And its measured based on each author expermental conditions FRP- confined concrete is related to the thickness and strength of FRP by;

$$f_i = t\,\frac{\mathrm{f_j}}{\mathrm{R}}$$

Where fj is the tensile strength of FRP in the hoop direction t is the total thickness of FRP jacket, and R is the raduis of the confined columns.

The lateral maximum stress acting on the concrete as a result of the confinment action can then be obtained by equlibrium of forces El is called confinment modulus or lateral modulus it is measure of stiffness of confining device.

$$f_t = \frac{E_j \varepsilon_{ju}}{R} t = E_j \varepsilon_{ju}$$

The maximum value of the confinement pressure that the FRP can exerts in attained when the circumferential strain in the fibers reaches its ultimate strain ($\varepsilon_{\square\square}$) and the fibers rapture leading to brittle failure of the column.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the parametric study, the following connclusions are drawn:

Confinment by FRP jackets enhances the performance of rectangular concrete columns. CFRPwrapping is more effective for square sections than for rectangular sections. As the aspect ratio increase from one to two. Carbon fiber reinfored polymer CFRPs are recommended for retrofitting due to their ideal properties compared to glass fibers and aramide fibers. From studies, glass fibers are weak in aging and should be protected from chemical attack. CFRPs have beeen proven to be more efficient than aramid and glass fibers when applied to concrete columns as external reinforcement.

The FRP confinement is much less effective for rectangular columns but an increase in corner radius is beneficial to both strength and ductlity. An increase in the aspect ratio has a negative effect on the axial strength of FRP-confined column,but may have small beneficial effects on the moment capacity and ductlity.

On this research, it is found that the strength and cross section of the overlay concrete has significant effect on the capacity of axially loaded reinforced concrete jacketed columns. For C30 concrete grade in the core concrete and for every 10MPa higher strength overlay concrete, the axial capacity of the jacketed column is enhanced by 3-10%. Therefore from this simulated results carbon FRP is the most preferable material for composite jacketing.

On the other hand, using an overlay thickness of 0.117mm and the same concrete grade considered, the axial capacity of the reinforced concrete composite jacketed column is 56% higher than axial capacity of the old concrete section. Similarly, for overlay thickness 0.3 and overlay concrete grade of C25 and C30, the change in the capacity of the reinforced concrete composite jacketed axial columns became 148.3% and 161.6% of the core section respectively. It is also found that, the capacity of reinforced concrete composite jacketed axial columns is slightly affected by the variation on the area of longitudinal reinforcement in the new concrete section. Experimental model is used to calibrate the interface properties and material models in ABAQUS.

5.2 Recommendation

Based on the study presents in this thesis it is recommended for farther studies to :

- Make a labaratory work to identiffy the difference between confinment models and result from the lab work and to modify and predict a new model that's suits each shape of the column with different aspect ratios.
- Make a A study on FRP confined columns with eccentric and cyclic loading and Further investigation on the relationship between internal hoop or spiral confinement with the external FRP confinement
- Extended experiment on the effectiveness of FRP wraps for a different type of fibers.
- Interaction diagrams for design of columns strengthen by FRP confinement.

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APPENDIX

Units

Length = mm, Mass = kg, Force = N, density = kg/mm^{3}and Stress = Mpa

CONCRETE

Column	Dimension (mm x mm)
C1	150*150*2000
C2	150*200*2000
Slender	150*150*3000
Circular	r=50

Mechanical properties of concrete used	
Type	C30
mean compressive strength fcmu (Mpa)	35
elastic modulus Ec (Gpa)	28.6
poison's ratio	0.24
density (kg/m^3)	2427

Parameters used in CDP				
dilation angle	eccentricity	σbo/σco	K	viscosity parameter
31	0.1	1.16	0.67	0.0001

Concrete compressive behavior		Concrete compression damage	
Yield stress (Mpa)	Inelastic strain	damage parameter	inelastic strain
15.3	0	0	0
19.2	4.82E-05	0	4.82E-05
22.5	0.000119844	0	0.000119844
25.2	0.000214786	0	0.000214786
27.3	0.000333074	0	0.000333074
28.8	0.000474708	0	0.000474708
29.7	0.000639689	0	0.000639689
30	0.000828016	0	0.000828016
29.7	0.001039689	0.01	0.001039689
28.8	0.001274708	0.04	0.001274708
27.3	0.001533074	0.09	0.001533074
25.2	0.001814786	0.16	0.001814786
22.5	0.002119844	0.25	0.002119844
19.2	0.002448249	0.36	0.002448249
15.3	0.0028	0.49	0.0028
10.8	0.003175097	0.64	0.003175097
5.7	0.003573541	0.81	0.003573541
Concrete tensile behavior		concrete tension damage	
yield stress (Mpa)	cracking strain	damage parameter	cracking strain
3	0	0	0
0.03	0.001167315		0.001167315

STEEL

Mechanical properties of steel used	
Type	S300
mean tensile strength fs (Mpa)	
elastic modulus Ec (Gpa)	210
poison's ratio ,v	0.3
density (kg/m^3)	7900

Yield stress (Mpa)	360	470
plastic strain	0	0.2

Bars	Reinforcement (mm^2)	No of rebar
B1	619.128	6 φ12
B2	3089.678	10 φ 20
B3	2604.348	10 φ 20
S1	536.94	19 φ 6
S2	954.56	19 φ 8
S3	954.56	19 φ 8

Figure 25 1

FRP materials

Typical density of FRP materials, kg/m^3		
GFRP	CFRP	AFRP
1200-2100	1500-1600	1200-1500

Mechanical properties of FRP used			
property	carbon	glass	aramid
thickness of fiber ,mm	0.117	0.149	0.3
elastic modulus Ec (Gpa)	240	65	118.2
tensile strength, Gpa	3.8	3	2.6
ultimate strain, %	1.55	4.3	2.2

Detail calculation of confinement using Carlo Pellegrino and Claudio Modena model

For two layers FRP wrapped confined rectangular specimen the lateral pressure due to the FRP, the lateral pressure due to the steel stirrups, the peak stress and the ultimate strain are shown in the calculation below.

FRP:- $f_{lf} = {}^{1}\!/_{2}\, k_f \rho_f E_f \varepsilon_f^{eff}$

$$p_f = \frac{4}{d} n_f t_f = 0.1184$$

$$p_f = 1$$

$$\varepsilon_f^{eff} = k_f \varepsilon_f = 0.5*0.088 = 0.0288$$

Therefore: $f_{lf} = {}^{1}\!/_{2}\, k_f \rho_f E_f \varepsilon_f^{eff} = 2.223$

Steel: - $f_{ls} = {}^{1}\!/_{2}\, k_s \rho_{st} f_{yst}$

$$\rho_{st} = 0.21$$

$$k_s = 1.55$$

Therefore: $f_{ls} = {}^{1}\!/_{2}\, k_s \rho_{st} f_{yst} = 1.45$

Effective confinement pressure at failure

$$P_u = f_{lf} + f_{ls}\, {}^{A_{cc}}\!/_{A_g}$$

$$= 2.223 + 1.45*0.64$$

$$= 3.266$$

peak stress $\frac{P_u}{f_{co}}$

$k_1 = k_A = A_c (\frac{P_u}{f_{co}})$ ^-α

$= 1.33* 0.26^{0.5}$

$= 0.67$

$\frac{f_{cc}}{f_{co}} = 1 + k_1 \frac{P_u}{f_{co}} = 1.33$

$= f_{cc} = 20.66$

Ultimate axial strain

$\frac{E_{cc}}{E_{CO}} = 2 + B\, (\frac{P_u}{F_{co}}) = 2 + 28*0.32 = 6.77$