Experimental Study and Finite Element Modeling of RCC Columns Confined with FRP Sheets under Axial Compression

A Project Report

Submitted by

V.Jayachandran - 0720101005

in partial fulfillment for the award of the degree
of

Master of Engineering
in
Structural Engineering

DEPARTMENT OF CIVIL ENGINEERING

KUMARAGURU COLLEGE OF TECHNOLOGY

COIMBATORE – 641 006

(An Autonomous Institution Affiliated to Anna University, Coimbatore.)

ANNA UNIVERSITY: COIMBATORE

MAY- 2009

ANNA UNIVERSITY: COIMBATORE

BONAFIDE CERTIFICATE

Certified that this project report entitled **"Experimental Study and Finite Element Modeling of RCC Columns Confined with FRP Sheets under Axial Compression"** is the bonafide work of

Mr. V. Jayachandran - Register No. 0720101005

Dr.S.L.Narasimhan
Professor
Head of the Department
Department of Civil Engineering
Kumaraguru College of Technology
Coimbatore-641 006

Dr. J. Premalatha 28/06/09
Professor
Thesis Supervisor
Department of Civil Engineering
Kumaraguru College of Technology
Coimbatore-641 006

Certified that the candidate with university Register No. 0720101005 was examined in project viva voce Examination held on 04-05-2009

Internal Examiner

4/5/09
External Examiner

DEPARTMENT OF CIVIL ENGINEERING

KUMARAGURU COLLEGE OF TECHNOLOGY,COIMBATORE 641 006

(An Autonomous Institution Affiliated to Anna University, Coimbatore.)

KUMARAGURU COLLEGE OF TECHNOLOGY

COIMBATORE , TAMILNADU

DEPARTMENT OF CIVIL ENGINEERING

INNOVATIONS IN CIVIL ENGINEERING - ICE'09

CERTIFICATE

This is to certify that Mr/Ms V. Jayachandran - PG student.

of Kumaraguru College of Technology, Coimbatore.

has participated and presented a paper in the National Conference on "INNOVATIONS IN CIVIL ENGINEERING - ICE'09" during 21st , April 2009.

Title Experimental study on the fiber reinforced polymer Confined Concrete columns under axial Compression.

Dr.P.ESWARAMOORTHI & Mrs.K.RAMADEVI
COORDINATORS

Dr.S.L.NARASIMHAN
CONVENOR

Prof.R.ANNAMALAI
VICE PRINCIPAL

ABSTRACT

Fiber reinforced polymer (FRP) composites are thin laminates that are externally bonded to structural members using epoxy adhesive. The FRP significantly increases the member's load carrying capacity. The increased strength due to FRP wrapping is known as confined compressive stress and occurs after the concrete in the column has began to crack and dilate.

In this paper the behaviour of fiber reinforced polymer (FRP) – confined concrete columns under axial load is presented. A total of nine columns, in which three numbers of RCC without wrapping and the remaining six numbers of RCC with wrapping were tested under axial compression. Glass fiber composites are used for RCC column wrapping.

The improvement in load carrying capacity due to FRP wrapping in square, rectangular and circular columns are presented. The Stress-strain behaviour of columns under axial compression is also presented. Finite element modeling of RCC columns has been done by ANSYS software. Stress-strain behaviour of FEM modeling of RCC columns obtained using ANSYS software is presented and compared with experimental results.

ACKNOWLEDGEMENT

First and foremost I submit my thanks to **The Almighty,** through whom all things are possible. This work was not by my might nor by power, but by **His Spirit**. This work not be possible without the gifts, **God** has given unto me.

I take pride and immense pleasure in expressing my deep sense of gratitude indebtedness to my guide **Dr. J. Premalatha,** Professor of Civil Engineering Department for his innovative ideas continued conduce, untiring efforts and encouragements which enabled the successful completion of thesis work.

I express my sincere gratitude to **Dr.P.Eswaramoorthi,** Professor of Civil Engineering Department for his essential support, valuable suggestions, and timely guidance for carrying out this research work.

I deem great pride in expressing heartfelt gratitude to **Dr.S.L.Narashimhan, H.O.D,** facilities extended throughout the project.

I express my profound gratefulness to **Prof.V.Annamalai,** Principal for providing the necessary facilities for the successful completion of thesis work.

I also sincerely thank to **Mr.G.GaneshMoorthy** non-teaching staff of Structural Technology Center, KCT, and Coimbatore.

Last but not the least; I thank one and all those who have rendered help directly or indirectly at various stages of the thesis.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

SYMBOLS AND ABBREVIATIONS

Symbol	Expansion
E_c	Modulus of Elasticity Of Concrete
?	Density
E_t	Modulus of elasticity in tension
f_t	Strength in tension
f_c	Strength in compression
γ	Poisson's ratio
α	Coefficient of thermal expansion
E	Modulus of elasticity
ε_t	Strain in tension
GPa	Gega Pascal
MPa	Mega Pascal
P_u	Ultimate load

Abbreviations	Expansion
FRP	Fibre Reinforced Polymers
GFRP	Glass Fibre Reinforced Polymers
CFRP	Carbon Fibre Reinforced Polymers
AFRP	Aramid Fibre Reinforced Polymers
E-GFRP	Electrical Resistant Glass Fibre Reinforced Polymers
S-GFRP	Stiffness Glass Fibre Reinforced Polymers
RCC	Reinforced Cement Concrete
NW	No Confined Specimens
FW 01	Fully Wrapped with Single Layer
FW 02	Fully Wrapped with Double Layer
FEM	Finite Element Modeling.

CHAPTER 1

INTRODUCTION

1.1 General

Concrete is a commonly used building material. Poorly confined columns are recognized to behave in a brittle manner, exhibiting little deformation capacity. Increased loads, column deterioration, or seismic retrofit may require that additional confinement be provided to these columns to ensure adequate force and deformation capacity. The construction industry has considered using concrete confined by FRP. Applying composite materials to reinforced concrete has attracted much attention due to their lightness, rust resistance, high tensile strength and good flexibility. The material properties of composite materials greatly differ from those of steel.

Fiber reinforced polymer (FRP) composites are thin laminates that are externally bonded to structural members using epoxy adhesive. The FRP significantly increases the members' load carrying capacity. These structural strengthening systems are made of high strength fibers (such as Armid, Glass and Carbon) embedded in a resin matrix. The resin protects the fibers, maintains their alignment, and distributes the loads evenly among them. FRP's, which have been extensively used in industries such as aerospace, automotive, and sport equipment, are now becoming a mainstream technology for the structural upgrade of concrete structures. In addition to their high-strength and lightweight properties, important characteristics of FRPs for structural repair and strengthening applications are their non-corrosive properties, speed and ease of installation, lower cost, and aesthetics.

Corrosion of steel rods is a potential cause for the structural damage of these reinforced concrete columns. Tackling the problem of steel reinforcement corrosion has usually meant improving the quality of the concrete itself, but this approach has had only limited success. A traditional way of repair of damaged concrete columns is wrapping a sheet of steel around the column. While the strength of repaired columns can be increased for a short-term, the steel wrapping suffers from the same problem as the steel rebar, corrosion and poor durability. It also suffers from labour-intensive construction problem due to its weight. In a new approach, FRPs are now being used as alternatives for steel wrappings in repair, rehabilitation and strengthening of reinforced concrete columns. In addition to repair, FRP confined concrete columns have been developed in new construction and rebuilding of concrete piers/piles in engineering structures.

1.2 Problem Statement

Concrete columns have an important function to perform in the structural system. Often, these columns are vulnerable to exceptional loads (such as impact, explosion, or seismic loads), load increase (increasing use or a change of function of structures) and degradation (corrosion of steel reinforcement and alkali-silica reaction). On the other hand, confinement of concrete is an efficient technique to increase the load-carrying capacity and ductility of concrete columns primarily subjected to compression. By providing lateral confining pressure, the concrete is subjected to a triaxial state of stress, so that the compressive strength and deformability increase. The lateral confining action is mostly induced in a passive way by restraining the lateral expansion of the concrete through closely spaced stirrup or hoop reinforcement. Since the introduction of FRP as externally bonded reinforcement, confinement by means of FRP wrapping has been of considerable interest for upgrading columns.

1.3 Aims and scope

The main Endeavour of this project is to experimentally develops the effects of upgrading the load carrying capacity of reinforced concrete square columns subjected to axial compression by jacketing with GFRP flexible wraps. The objectives of the study are as follows:

1) To evaluate the effectiveness of external GFRP strengthening for concrete columns; 2) To evaluate the effect of the number of GFRP layers on the ultimate strength and ductility of confined concrete.

CHAPTER 2

FIBER REINFORCED POLYMERS

2.1 General

A brief description of commonly available fiber reinforced polymers (FRP's) and their properties are presented in this chapter. Applications of FRP, advantages and drawbacks of FRP including its use in confining concrete are also reviewed.

2.2 Fiber Reinforced Polymers

Fiber reinforced composite materials in civil engineering structures have progressed at a very rapid rate in recent years. These high-performance materials, which consist of high-strength fibers embedded in a polymeric matrix, have unique properties which make them extremely attractive for structural applications. Fiber reinforced composites are non corrosive , have high strength to weight ratios, posses good fatigue behavior and low relaxation, are electromagnetically neutral, and allows easy handling and installation. Moreover, as the fiber types (glass, carbon and aramid) and fiber volumes can be combined in innumerous ways with a large variety of matrices, their overall mechanical properties can be tailored to provide optimum solutions to a wide range of structural problems.

2.3 Properties of FRP Composites

Composite materials made of fibers in polymeric resin also known as fiber-reinforced polymers (FRP). FRP composites are formed by embedding continuous fibers in a resin matrix which binds the fibers together. The common fibers are glass fibers, carbon fibers and aramid fibers, whilst epoxy resins, polyester resins and vinylester resins are the common resins. Depending on the fibers used, FRP composites are classified into three types: glass-fiber-reinforced polymer (GFRP) composites; carbon-fiber-reinforced polymer (CFRP) composites, aramid-fiber-reinforced polymer (AFRP) composites. The coefficient of thermal expansion of concrete is 10×10^{-6}/C and that of GFRP is approximately 9.9×10^{-6}/C. hence GFRP bonded to concrete and when exposed to temperature fluctuations are not expected to cause any problems of differential thermal deformations. Properties of commonly used matrices are presented in Table 2.1. A summary of typical fiber properties is presented in Table 2.2

TABLE 2.1 TYPICAL MATRIX PROPERTIES

Materials	**Density p**	**Modulus of elasticity in tension E_t**	**Strength in tension f_t**	**Strength in compression f_c**	**Poisson's ratio γ**	**Coefficient of thermal expansion α**
	Kg/m³	**Mpa**	**MPa**	**MPa**		**10^{-6}/C**
Polyester	1200-1400	2500 – 4000	45 – 90	100 – 250	0.37-0.4	100 - 120
Epoxy	1400	2800	58	-	-	50
Nylon	1140	2800	70	-	-	100
Polyethylene	960	1200	32	-	-	120

TABLE 2.2 TYPICAL FIBER PROPERTIES

Materials	**Density p**	**Modulus of elasticity E**	**Strength in tension f_t**	**Strain in tension ε_t**
	kg/m³	**Mpa**	**MPa**	**%**
E – Glass	2500	70000	2500 - 3500	1.8 – 3.0
S – Glass	2500	86000	4800	-
High – Modulus Carbon	1950	380000	2000	0.5
High – Strength Carbon	1720	240000	2800	1.0
Carbon	1400	190000	1700	-
Boron	2570	400000	3400	-
Graphite	1400	250000	1700	-
Kevlar 49	1450	120000	2700 - 3500	2.0 – 2.7
Kevlar	1450	60000 – 130000	2900	-

Factors such as properties of constituents, procedure of fabrication, fiber orientation within the matrix, and strength of the fiber matrix bond affect the final properties of the composite material. All these factors can be controlled to generate a wide range of physical and mechanical properties for the composite material. Typical mechanical properties of GFRP, CFRP and AFRP are given in table 2.3

TABLE 2.3 TYPICAL MECHANICAL PROPERTIES OF GFRP, CFRP & AFRP COMPOSITES

Advanced Composite Materials	**Fiber content**	**Density p**	**Modulus of elasticity in tension E_t**	**Strength in tension f_t**
	% by weight	**Kg/m^3**	**GPa**	**MPa**
Glass fiber/Polyester GFRP laminate	50-80	1600-2000	20-55	400-1250
Carbon/Epoxy CFRP Laminate	65-75	1600-1900	120-250	1200 – 2250
Aramid/Epoxy	50-80	1050 – 1250	40-125	100-1800

2.4 Advantages of FRP

- FRP improves overall durability and shear strength.
- Prevents plastic shrinkage cracks.
- Increases toughness, fatigue resistance, freeze thaw resistance.
- Increases tensile strength, flexural strength and impact resistance.
- Has high strength to weight ratio, offering increased strength.
- Being light in weight, assembling and erection become easier.
- Does not involve stuttering, welding etc.
- Has low maintenance cost.

2.5 Disadvantages of FRP

- High cost of fabrication of composites.
- They are not isotropic, that is their properties are not same in all direction, so they require more material parameters.
- Repair of composites is not a simple process.
- Lack of design standards and conventions.
- Lack of long term performance data.

2.6 Application of FRP

Fiber Reinforced Polymer (FRP's) are a class of advanced composite materials that emanated from the aircraft and space industries. They have been used extensively in the medical, sporting goods, automotive and small ship industries and are now finding uses elsewhere. Over the past few years there has been extensive research into their potential applications in the construction industry.

To assess the suitability of a FRP system for a particular application, the engineer should perform a condition assessment of the existing structure including establishing its existing load – carrying capacity, identifying deficiencies and their causes, and determining the condition of the concrete substrate. The overall evaluation should include a thorough field inspection, a review of existing design or as built documents and structural analysis.

2.7 Summary

In this chapter properties of various FRPs and their applications are discussed with an emphasis on confinement of concrete columns using FRPs.

CHAPTER 3

LITERATURE REVIEW

3.1 General

Substantial progress has been made, over the past decade, in the use of composites in the construction industries. This includes the introduction of FRP structural members that are being used and monitored out in field applications. Fiber-reinforced composites materials consist of high performance materials, which have emerged as a potential solution to replace, or be used to complement conventional steel reinforcement, to the problems associated with corrosion and deterioration of the infrastructures.

Many experimental and analytical investigations have been conducted in recent years to evaluate the axial load capacity and stress-strain response of concrete confined with fiber-reinforced polymer (FRP) laminates (ACI Committee 440 2002). These investigations have clearly demonstrated that confining concrete with FRP jackets leads to substantial improvement of the axial strength and energy absorption capacity of concrete columns under both static and cyclic loading.

Several confinement models were proposed in the literature to evaluate the axial strength and to describe the stress-strain response of FRP jacketed columns. A comprehensive review and assessment of existing models has been recently presented by Teng and Lam (2004).

The work done by numerous researchers to study the behavior of FRP confined concrete columns is reviewed in this chapter.

3.2 LITERATURE REVIEW

3.2.1 Samaan et al (1998)

Samaan tested twenty-four concrete-filled FRP tubes and six unconfined concrete specimens. All specimens were cylindrical, having 305 mm lengths and 152 mm diameters. Cement type II was used to minimize shrinkage, as it was anticipated that shrinkage might delay the confinement effect of the tube. The results of the experiment indicated, however, that shrinkage is not likely to significantly effect the behavior of tube-confined concrete. The tubes were composed of a polyester resin and glass fibers in a ±75-degree configuration. After casting the specimens, grooves were cut in the tubes through their entire thickness at 19 mm from the ends around the entire circumference to prevent direct axial loading of the tubes. All specimens were sulfur capped. Lateral stains were measured by strain gages on the surfaces of the tubes. Longitudinal strains were measured by LVDT.s and, on some specimens, by embedded strain gages. Failure of the tubes was sudden but somewhat predictable. Near the ultimate state of loading, the investigators heard the sound of inner glass fibers rupturing and saw white patches, a sign of distress in the resin, forming in the tubes. One specimen was subjected to three loading-unloading cycles to determine its stiffness degradation under repeated loading. The failure of this specimen was similar to the others, and it was noted that the width of the hysteresis loops were not as large as for steel-encased concrete. In the course of analyzing the test data, plots were made of the dilation rate versus the axial strain, where the dilation rate was defined as the rate of change of the lateral strain with respect to the axial strain. These plots showed that the dilation rate first increases to some maximum peak value, then decreases and finally reaches a constant asymptotic value, which it maintains until the failure of specimen.

3.2.2 Xiao and Wu (2000)

Xiao and Wu performed tests on standard cylinders wrapped with one, two, and three-layer jackets of carbon sheets. The fiber orientation was 90 degrees. Lower, middle and high strength concrete specimens were constructed whose unconfined respectively. The cylinders were sulfur capped before testing. Axial deformation data were acquired using a specially fabricated device that measured the deformation of the specimens over a gage length of 152.4 mm in the middle of the cylinder. The researchers chose this position to measure axial deformation in order to avoid incorporating the effect of confinement from platen friction at the ends of the specimens. Longitudinal and transverse strains were measured in the jacket using stain gages. Coupon tests showed that the ultimate tensile strain in the fibers in the jackets was only about 50% to 80% of the ultimate strain recorded for the coupons. Failure of the specimens resulted from fiber rupture. The investigators noted that after a certain amount of loading, the relationship between axial strain and lateral strain stabilizes to a linear relationship whose slope depends on the concrete strength and the jacket stiffness. This is exactly what Mirmiran and Shahawy (1997) observed using unbonded FRP tubes, reporting that the dilation rate (rate of change in lateral strain with respect to axial strain) of the concrete stabilized to an asymptotic value that depended on the concrete strength and jacket stiffness. In other words, saying that the dilation rate versus axial strain is constant is equivalent to saying that the axial strain versus lateral strain is linear.

3.2.3 S. Matthys, H. Toutanji, K. Audenaert, and L. Taerwe

This is the first study that the authors are aware of where large-scale columns externally wrapped with FRP composites were statically tested and analyzed. The columns are 400 mm in diameter and 2 m in height. This paper provides an evaluation of the previously published models that predict the ultimate axial strength of FRP-confined concrete and assess their reliability against the results obtained from large-scale columns. The effect of confinement on the ultimate failure strain of the FRP composite sheets is quantified. This paper should provide a better understanding of the behavior of fiber-wrapped or FRP-confined concrete columns. The results presented in this paper should be used to predict the ultimate strength of actual-size columns in the current retrofitting projects in the field

Confinement of concrete by means of FRP wrapping is an efficient technique to increase strength and ductility. However, the wrapping configuration has a considerable influence on the effectiveness of the FRP wrapping. In the case of members with partial wrapping as part of the concrete is unconfined, low ultimate confining pressure was exhibited resulting in low strength increase, less than 10%. Furthermore, helicoidally wrapping exhibited lower strength increase and axial strain compared with circular wrapping;

3.2.4 Zihan Yan, Chris P. Pantelides, and Lawrence D. Reaveley

Confinement of concrete using shape modification of square and rectangular compression members using post-tensioned FRP composite shells with expansive cement concrete is investigated. Post-tensioning of the FRP composite shells reduces corner effects and enhances confinement effectiveness. Square and rectangular sections were modified into circular and elliptical sections, respectively, and subsequently were tested under compressive loads. Axial compressive strength, axial compressive strain, and energy absorption were increased significantly for compression members with a square cross section confined with post-tensioned FRP composite shells. The method of shape modification using post-tensioned FRP shells has the advantage of using the post-tensioned FRP shell as stay-in-place formwork.

3.2.5 Ching Chiaw Choo, Issam E. Harik, and Hans Gesund

Considerable research efforts have contributed to the understanding of concrete members internally reinforced or externally strengthened with fiber-reinforced polymer (FRP) composites. These efforts, while greatly improving our knowledge of how concrete members reinforced with FRP composites should be analyzed and designed in flexure and in shear, have not yet led to a rational approach for the analysis or design of FRP-reinforced concrete compression members. ACI Committee 440 published "Guide for the Design and Construction of Concrete Reinforced with FRP Bars (ACI 440.1R-03)," which contained design provisions for flexure and shear. The guide excludes any provisions for the analysis and design of concrete compression members reinforced with FRP bars. FRP bars were not recommended by ACI Committee 440 (1996, 2003) for use as compression reinforcement, in part because the direct effect of compression reinforcement on the strength of concrete members is frequently small and, therefore, often ignored. Additionally, the compression properties of FRP bars are often difficult to

Predict due to the lack of stability of individual fibers in a bar. Therefore, this complicates testing and can produce inaccurate measurements of compression properties. (2003) tested GFRP reinforcing bars that had an outside diameter of 15 mm (3/5 in.) in compression, and reported that the ultimate compression strength of the bars was approximately 50% of the ultimate tensile strength. In general, the compressive strength of FRP reinforcing bars is lower than the tensile strength. The principles based on an ultimate strength approach, similar to the one used for steel-reinforced concrete columns, were used in the present study to investigate the strength interaction relations (*P-M*) of concrete columns reinforced with FRP bars (Choo et al. 2006).

3.2.6 Riad Benzaid1, 2, Nasr-Eddine Chikh3, Habib Mesbah

The behavior of fibre reinforced polymer (FRP)-confined concrete in circular columns has been extensively studied, but much less is known about concrete in FRP-confined square columns, in which the concrete is non-uniformly confined and the effectiveness of confinement is much reduced. The present paper deals with the analysis of experimental results in terms of load-carrying capacity and strains, obtained from tests on square prismatic concrete column, strengthened with external glass fibre composite. The parameters considered are the number of composite layers and the corner radius for a square shape. A total of twenty-one prisms of size 100 × 100 × 300 mm were tested under strain control rate of loading. The main endeavor of this research is to experimentally scrutinize the effects of upgrading the load carrying capacity of reinforced concrete square columns subjected to axial compression by jacketing with GFRP flexible wraps. The objectives of the study are as follows:

1) to evaluate the effectiveness of external GFRP strengthening for square concrete columns; 2) to evaluate the effect of the number of GFRP layers on the ultimate strength and ductility of confined concrete; and 3) to evaluate the effect of the corner radius of the column on the effectiveness of GFRP reinforcement.

3.2.7 Joaquim A.O. Barros

In this work, a strengthening technique based on near surface mounted (NSM) carbon fibre laminate strips bonded into slits opened on the concrete cover is used to improve the flexural capacity of columns subjected to bending and compression. This technique avoids the occurrence of the peeling phenomenon, is able to mobilize the full strengthening capacity of the strips, and provides higher protection against fire and acts of vandalism. We describe the adopted strengthening technique and report the experimental characterization of the materials involved in the strengthening process. The results obtained in two series of reinforced concrete columns, subjected to axial compression and lateral cyclic loading, show that a significant increase on the load carrying capacity can be achieved by using the NSM technique. Cyclic material constitutive laws were implemented in a finite element program and the tests with reinforced concrete columns strengthened with the NSM technique were numerically simulated under cyclic loading. These numerical simulations reproduce the experimental load displacement diagrams satisfactorily.

3.3 Summary

As can be observed from the above discussion, the majority of previous research efforts related to concrete under pure axial loading have focused on plain concrete confined with FRP. This project will build upon that knowledge base by extending the testing to axially loaded RC columns, as described in the next section.

CHAPTER 4

METHODS OF STRENGTHENING COLUMNS

4.1 General

Strengthening refers to upgrading the capacity of a structure over its original design. Inadequate lateral reinforcement can be improved by retrofitting the column with external confinement that is wrapped around the column. Until recently retrofitting of columns was done using steel jackets filled with concrete or grout. An alternative method is to retrofit the columns with FRP fabrics. These fabrics are easy to handle and install, and are resistant to corrosion.

The methods of strengthening can be classified in to the following three categories in terms of the method adopted for constructing the FRP composites:

A. Wrapping (various wrapping schemes are shown in Fig. 4.1.)

B. Filament winding

C. Prefabricated shell jacketing

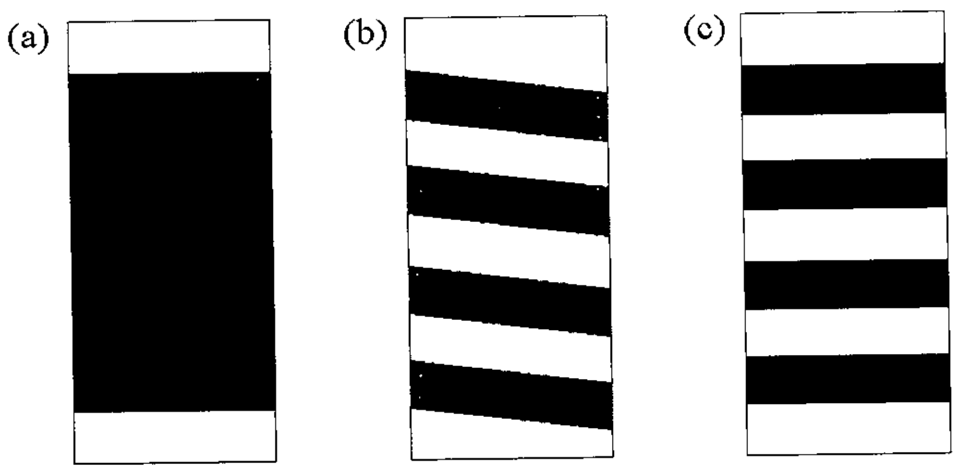


Fig 4.1 Typical FRP wrapping methods for RC columns:
(a) Full wrapping using FRP sheets; (b) Partial wrapping using FRP straps in discrete rings; (c) partial wrapping using FRP straps in a continuous spiral.

4.2 Wrapping

In situ FRP wrapping has been the most commonly used technique for column strengthening using FRP composites. In this method, unidirectional fibre sheets or woven fabric sheets are impregnated with polymer resins and wrapped around column in a wet lay-up process, with the main fibers oriented in the hoop direction. A column can be fully wrapped with FRP sheets in single or multiple layers. It can also be partially wrapped using FRP straps in a continuous spiral or discrete rings. The compressive strength enhancement of concrete due to the external wrapping of FRP was first demonstrated by Fardis and Khalili (1981, 1982).

4.3 Filament Winding

The principle of filament winding is similar to that of wrapping, except that the filament winding technique uses continuous fiber strands instead of sheets/straps so that the winding can be processed automatically by means of computer controlled winding machine. An FRP jacket with controlled thickness, fiber orientation and volume fraction can be obtained in this process. The idea of confining concrete by winding continuous resin-impregnated fiber strands was first mentioned by Fardis and Khalili (1981).

4.4 Prefabricated Shell Jacketing

Existing RC columns can also be strengthened using prefabricated FRP shells. The shells are fabricated under controlled condition using fiber sheets or strands with the impregnation of resins affected prior to field installation. They can be fabricated in half circles or half rectangles and circles with a slit or in continuous rolls, so that they can be opened up and placed around columns. For effective FRP confinement to be achieved, a full contact between the column and the FRP shell is essential. This can be ensured either by bonding the shell to the column using adhesives or injecting shrinkage-compensated cement grout or mortar in to the space between the shell and the column (Nanni and Norris 1995, Ohno et al .1997)

4.5 Comparison of Strengthening Methods

Each of the three methods discussed above has its advantages and disadvantages. These are listed in table 4.1. Overall, external wrapping appears to be the most popular method as its advantages (flexibility and ease in site handling) appear to be far more important than its disadvantages. Filament winding bears much similarity to wrapping as both involve a wet lay-up process, so in the rest of the chapter, the term 'wrapping' is used to cover both methods except when a specific distinction has to be made between the two.

TABLE 4.1 COMPARISONS OF DIFFERENT METHODS OF COLUMN STRENGTHENING.

METHOD	ADVANTAGES	DISADVANTAGES
Wrapping	i. Flexibility in coping with different column shapes ii. Ease in site handling, without the need for special equipment	i. Least quality control ii. Most labour intensive
Filament winding	i. improved quality control ii. Reduced on-site labour	i. Reduced flexibility in coping with different column shapes ii. Special equipment required
Prefabricated shells	i. Best quality control ii. Least on-site labour iii.Useful for column shape modification	i. Limited flexibility in coping with different column shapes ii. Prefabrication cost

4.6 Constructional Aspects

Prior to the application of FRPs using any one of the three techniques described above, the surface of the column to be strengthened should be properly prepared to provide a hard, dry and clean surface. Any damaged or deteriorated parts should be removed and patched up with good concrete, cement mortar or epoxy putty as appropriate. The repaired surface should be toweled.

Whether wrapping or prefabricated shell jacketing is used, one or more vertical joints generally exist in the FRP. Such joints should be made strong enough so that FRP joint failure does not become the strength-controlling failure mode, as otherwise the strength of the FRP is not fully utilized. When the FRP is wrapped continuously, a sound joint can be achieved by extending the end of the final layer of FRP to form a sufficient overlap. When an FRP strip should be bonded over the vertical seam (for a shell consisting of single or a small number of FRP layers), or the slits should be staggered (for a shell consisting of a large number of FRP layers) to avoid the concentration of seam weakness. In the latter case, the effective number of layers should be taken as the total number minus one, to account for the weakening effect of slits (Xiao and Ma1997)

To achieve active confinement, the FRP jacket is slightly oversized. The space between the FRP shell and the original column is then filled with expansive cement grout or pressure injected with epoxy resin (Priestely and Seible 1995, Saadatmanesh et al. 1996, 1997). Alternatively, the fibres may be prestressed during wrapping. A confining pressure is therefore developed to the column before any subsequent expansion of concrete occurs.

CHAPTER 5

EXPERIMENTAL INVESTIGATION

5.1 Introduction

FRP systems can be used either to rehabilitate and restore the strength of a weakened, damaged, or deteriorated structural member or to retrofit and strengthen a sound structural member to resist higher loads in case of a design or construction error, in case of a change in use or loading, or for a seismic upgrade. FRP materials can be used to provide increased shear and flexural capacity to structural components such as columns, beams, slabs and walls. This study focuses on various aspects of the effects of the spacing of lateral ties, method of strengthening, type of wrapping pattern and the number of layers of GFRP sheets. In the experimental investigation, nine numbers of RCC columns are tested under axial compression. Each set of the columns having approximately same size. Finally, the validity of past results and existing finite element confinement models is compared. The data recorded included the compressive loads and axial strains.

5.2 Materials

5.2.1 Concrete

The mix proportion adopted using IS method. The ordinary Portland cement, naturally available river sand, coarse aggregate of maximum size of 12.5 mm and potable water were used for concrete making. Admixtures were not used in any of the concrete mixes. The compressive strength of the concrete used is 20MPa.

TABLE 5.1 MIX RATIO OF CONCRETE

	Water	Cement	Fine Aggregate	Coarse Aggregate
Ratio	0.5	1	1.64	2.96
Kg/m^3	196	392	644	1162

5.2.2 Fine Aggregate

Fine aggregate used for concrete was well graded locally available river sand passing through 4.75mm and retained on 300 micron, to achieve minimum void ratio and the properties of fine aggregates like fine modulus.

5.2.3 Coarse Aggregate

Locally available blue metals were used. Crushed granite stones of size passing through 20mm sieve and retained on 4.75 mm sieve as per IS: 383-1970 was used for experimental purposes.

5.2.4 Steel

The HYSD steel bars of diameter 12mm were used as longitudinal reinforcement for columns. Mild steel bars of 8mm were used as transverse reinforcement for all specimens.

5.2.5 E-GFRP

In the specimens receiving glass fiber lamination, the required layers of the standard E class GFRP system are incorporating. Regardless of the number of the GFRP layers, the entire jacket was made of one continuous sheet of fabric that was cut to the proper length and width. An additional GFRP length of 50mm was provided for overlap splice. The test results of the GFRP sheets obtained from manufacturer.

Figure 5.1 E-GFRP woven roving sheets

TABLE 5.2. PROPERTIES OF E-GFRP

Technical data	E-glass
Thickness	2 mm
Poisson ratio	0.65
Elastic modulus	73000 N/mm^2
Tensile strength	3400 N/mm^2
Sheet weight	880 g/m^2
Density	2.6 g/cm^3
Matrix type	woven rovings

5.2.6 Epoxy Resins

Epoxy resins are excellent binding agents with high tensile strength. The epoxy components are mixed just prior to application. The product is of low viscosity and can be injected in small cracks too. The higher viscosity epoxy resin can be used for surface coating or filling larger cracks or holes. Araldite GY 257 is used as a base and Aradur HY 140 is used as a hardener. The Mix ratio of base and hardener is 2:1.

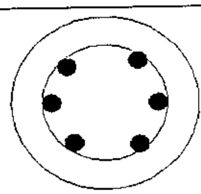
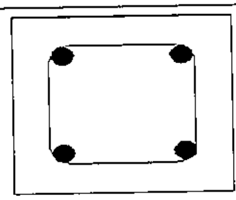
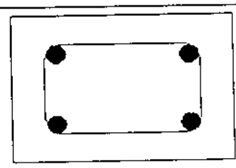
TABLE 5.3. PROPERTIES EPOXY RESINS.

Material Properties	Values in N/mm2
Compressive Strength	80
Tensile Strength	17
Young's modulus	5000
Flexural strength	28

5.3 Test Specimens

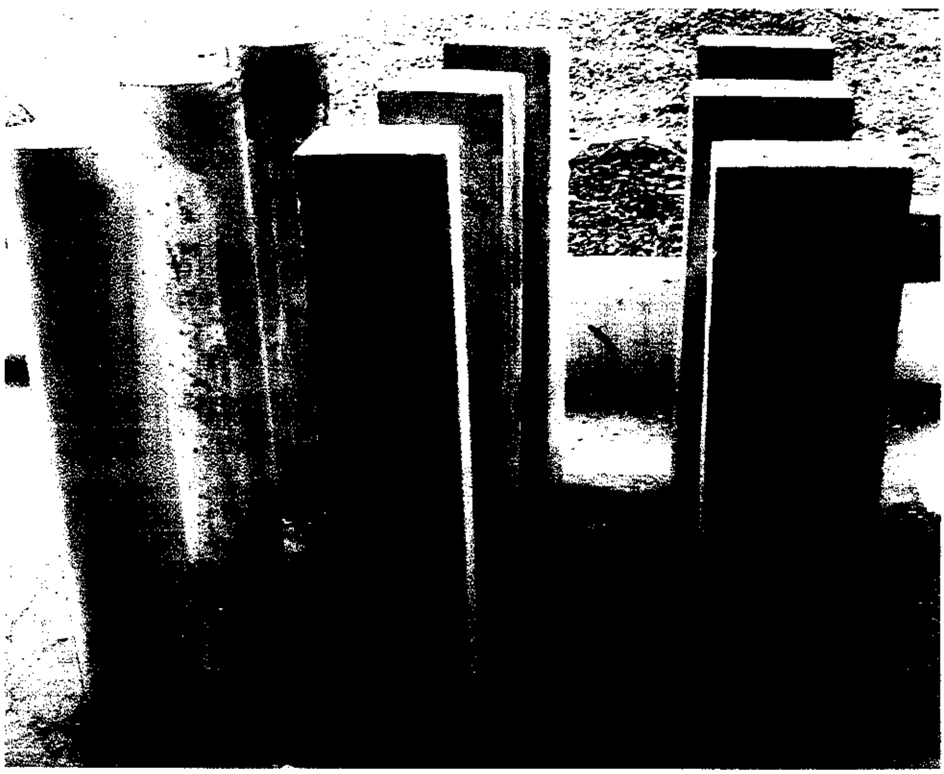
The experimental program was carried out using 6 numbers of FRP-confined concrete specimens and 3 numbers of reference (unconfined) specimens. The specimen notations presented in Table 5.1 are as follows. The first three letters refer to the reinforcement details of the specimen: RCC for reinforced concrete. The next two letters specifies the method of FRP wrap: FW for Full wrapping, and NW to indicate without confinement that is, a reference specimen. Number 01 and 02 indicate number of layers of GFRP: 01 for single layer and 02 for double layers of GFRP wrapping. The details of the specimens are summarized in table 5.4.

TABLE 5.4. DETAILS OF THE TEST SPECIMENS

Shape & size of column in 'mm'	**Specimens Name**	**Number of columns**	**Cross Section of specimens**	**Reinforcement Details**
Circular 150x 900	RCC NW	1		6 nos 12mm diameter bars and two legged 8mm lateral ties at 150mm c/c
	RCC FW01	1		
	RCC FW02	1		
Square 150x 150x 900	RCC NW	1		4 nos 12mm diameter bars and two legged 8mm lateral ties at 150mm c/c
	RCC FW01	1		
	RCC FW02	1		
Rectangular 120x 180x 900	RCC NW	1		4 nos 12mm diameter bars and two legged 8mm lateral ties at 120mm c/c
	RCC FW01	1		
	RCC FW02	1		

5.4 Fabrication of Specimens

A single batch of normal concrete was used to cast 3 samples. After a 24-h cure, the molds were removed and all specimens were checked for irregularities such as holes or other surface imperfections. All holes and cracks were filled with mortar cement and imperfections were buffed away, leaving an appropriate bonding surface for the FRP wrap. The samples were then covered with wet cloths and watered for a 28-day cure, after which the wet cloths were removed and the concrete was left to cure in dry-air conditions. The concrete surface was then cleaned with wire brush using diluted H_2SO_4 or Asito chemical to remove algae and salt present over the specimens. Allow for surface dry then the epoxy primer was applied with a foam roller to seal any remaining cracks and voids. The fiber sheets, precisely cut to fit each specimen, were then applied using a wet-lay-up process. The sheets were placed so that the primary fibers made a 90° angle with respect to the longitudinal axis of the specimen. Pressure was applied on the FRP surface with a foam roller in order to remove all voids. Once confined, the specimens were allowed to cure for at least another 3 days before testing.



5.5 Wrapping Configuration

The wrapping configuration is shown below.

Fig.5.3: Epoxy resins apply to Specimens

Fig.5.4: Epoxy resins apply for over lapping E-GFRP sheet

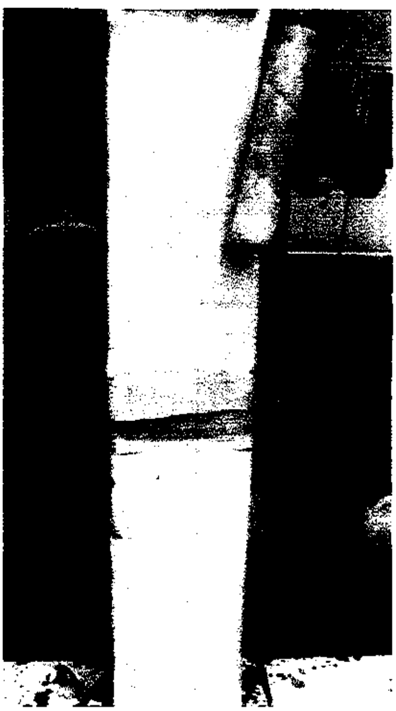


Fig.5.5: foam roller applied over E-GFRP sheets for removing air voids

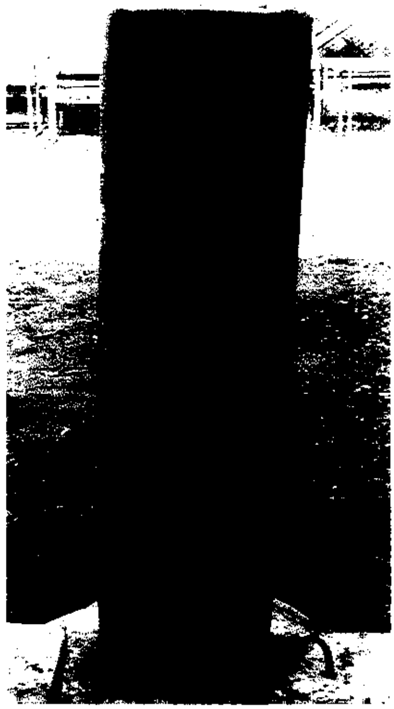


Fig.5.6: Specimen is completed single layer wrapping.

5.6 Instrumentation and Testing Procedure

All specimens were instrumented for measuring axial strain on specimens or on the FRP outer layer for retrofitted specimens. The axial strain was measured using LVDT. The specimens were tested using load frame 1000 KN capacity and the observations were recorded. Specimens were tested to failure under a monotonically increased axial load under a load control mode. Test setups shown below the figures 5.7.

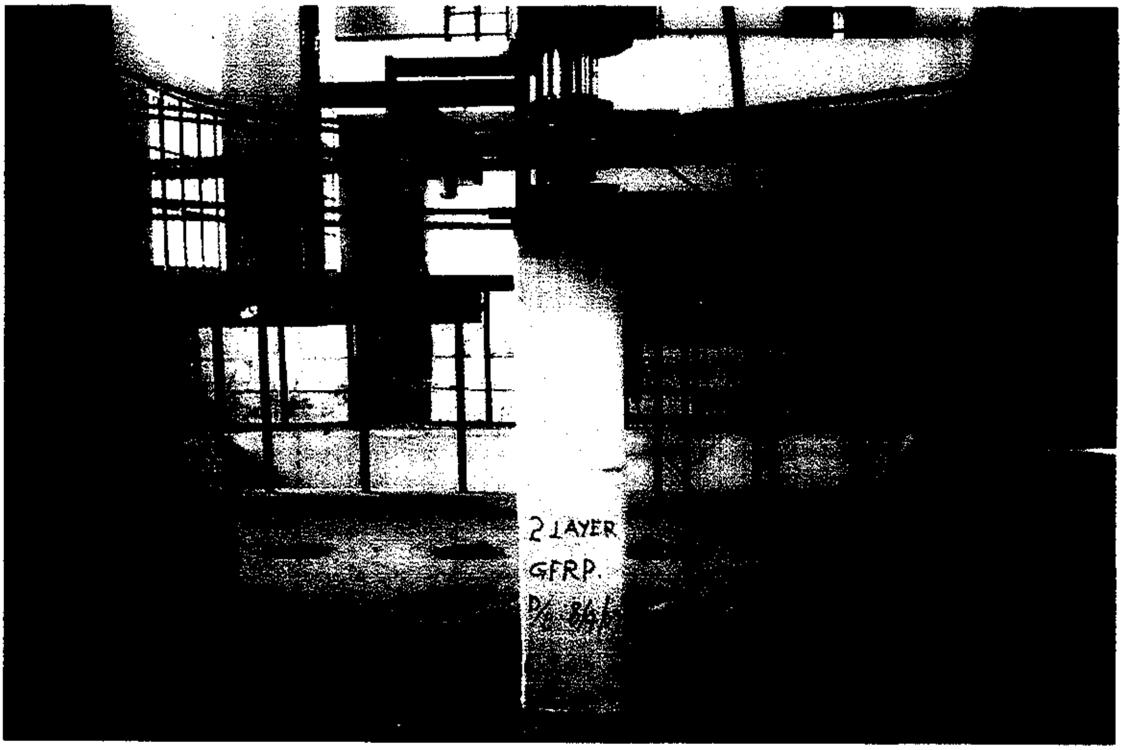


Figure 5.7. Test setup

5.7 Summary

The material properties of the concrete and GFRP used in the experimental program are reported in this chapter. Reinforcement details, construction details of the specimens, instrumentation details, and the test setup are also presented.

CHAPETER 6

RESULTS AND DISCUSSION

6.1 General

The results of the columns tested in the experimental program are reported and discussed in this chapter. Stress-strain responses of confined concrete in the GFRP wrapped and no confined RCC specimens are plotted and used to study strength enhancement characteristics. The results of parametric study carried out for studying the effects of number of layers of GFRP, concrete strength and column shapes are reported. The stress-strain response for finite element models is also studied and compared with experimental results.

6.2 Experimental Test Results

For all specimens, the axial strains measured with the LVDT featured very close values up to failure, indicating that the behavior of the specimens under axial compression was that of a short column. The failure mode observed was also typical of a short column under axial compression. The load carrying capacities of the single layer wrapped and double layer wrapped RC columns were obtained and compared to the corresponding without wrapped columns. The comparison of ultimate load is shown in Table 6.1.

TABLE 6.1 COMPARISON OF ULTIMATE LOAD

Shape of column	Specimens Name	Ultimate load P_u (KN)	% increase in P_u compared without confined column
Square	RCC NW	139	
	RCC FW01	164	18
	RCC FW02	187	34.5
Rectangular	RCC NW	133	
	RCC FW01	156	17.3
	RCC FW02	178	33.8
Circular	RCC NW	147	
	RCC FW01	183	24.5
	RCC FW02	214	45.6

6.3 STRESS-STRAIN CURVES FROM EXPERIMENTAL RESULTS

6.3.1 Stress-Strain Cure for No Confined and Fully Wrapped Circular Columns With Single Layer and Double Layer Of GFRP

Figure 6.1 shows the stress-strain curve for no confined and fully wrapped circular column specimens with one layer and double layer of GFRP. The graph is indicates the axial strain in X axis and also indicates the axial stress in Y axis. In this stress-strain plot no confined and fully wrapped RCC specimens with single and double layer of GFRP specimens are compared.

6.3.2 Stress-Strain Cure For No Confined and Fully Wrapped Square Columns With Single Layer and Double Layer Of GFRP

Figure 6.2 shows the stress-strain curve for no confined and fully wrapped square column specimens with one layer and double layer of GFRP. The graph is indicates the axial strain in X axis and also indicates the axial stress in Y axis. In this stress-strain plot no confined and fully wrapped RCC specimens with single and double layer of GFRP specimens are compared.

6.3.3 Stress-Strain Cure For No Confined and Fully Wrapped Rectangular Columns With Single Layer and Double Layer Of GFRP

Figure 6.3 shows the stress-strain curve for no confined and fully wrapped rectangular column specimens with one layer and double layer of GFRP. The graph is indicates the axial strain in X axis and also indicates the axial stress in Y axis. In this stress-strain plot no confined and fully wrapped RCC specimens with single and double layer of GFRP specimens are compared.

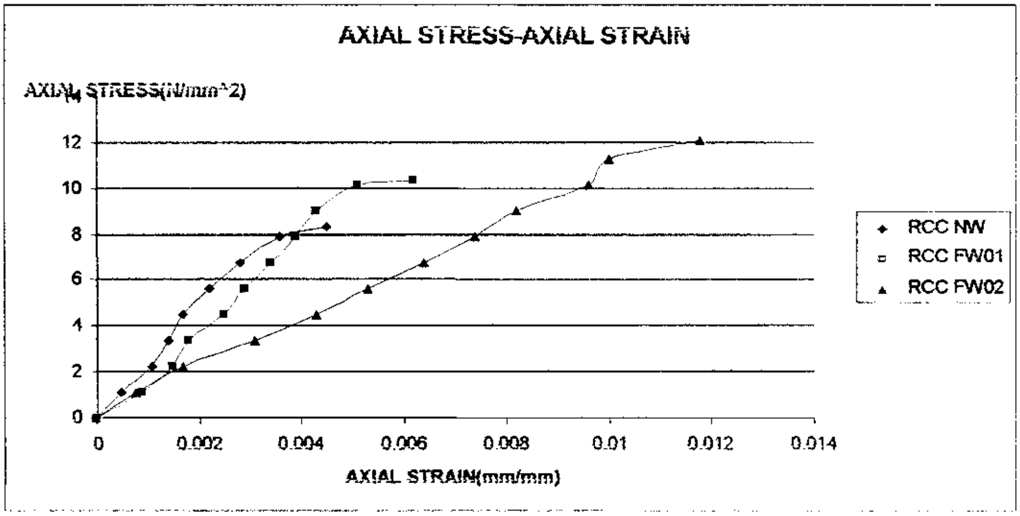


Figure 6.1 Axial stress-strain graphs for circular column

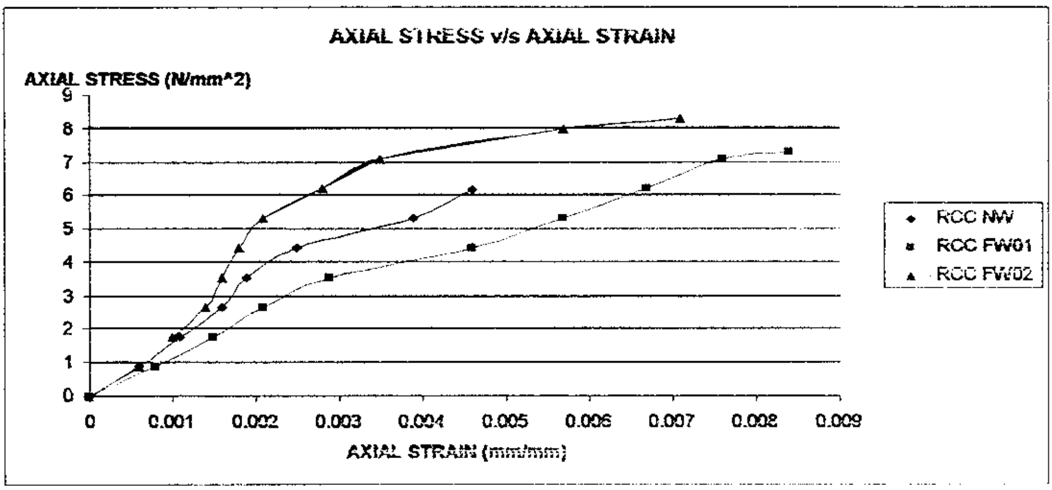


Figure 6.2 Axial stress-strain graphs for square column

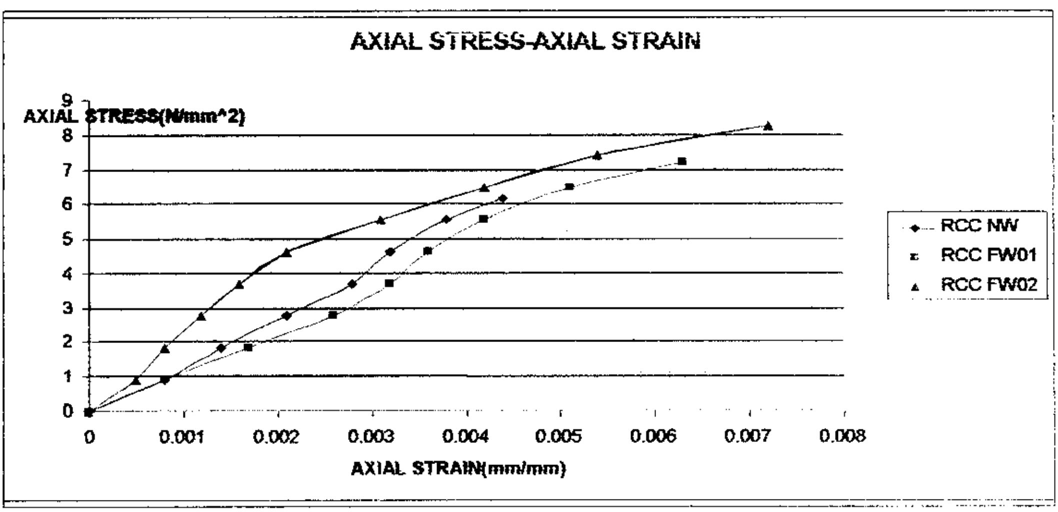


Figure 6.3 Axial stress-strain graphs for rectangular column

6.4 Failure Modes of The Specimens

Glass fibre wrapped specimens typically failed by a fracture of GFRP composite at or near the corner of the specimens due to the stress concentration in those regions. In all cases, the columns failure is due to the rupture of the FRP jacket. For most wrapped columns, it was associated with concrete crushing at or near the column ends and marked by wraps rupturing in the circumferential direction. Approaching failure load, the appearance of white patches was found, which indicated the yielding of glass fibre and resin. Failure modes of the specimens were shown below.

Figure 6.4: Failure Modes of without Confined Concrete Columns

Figure 6.5: Failure modes of columns with single layer wrapping

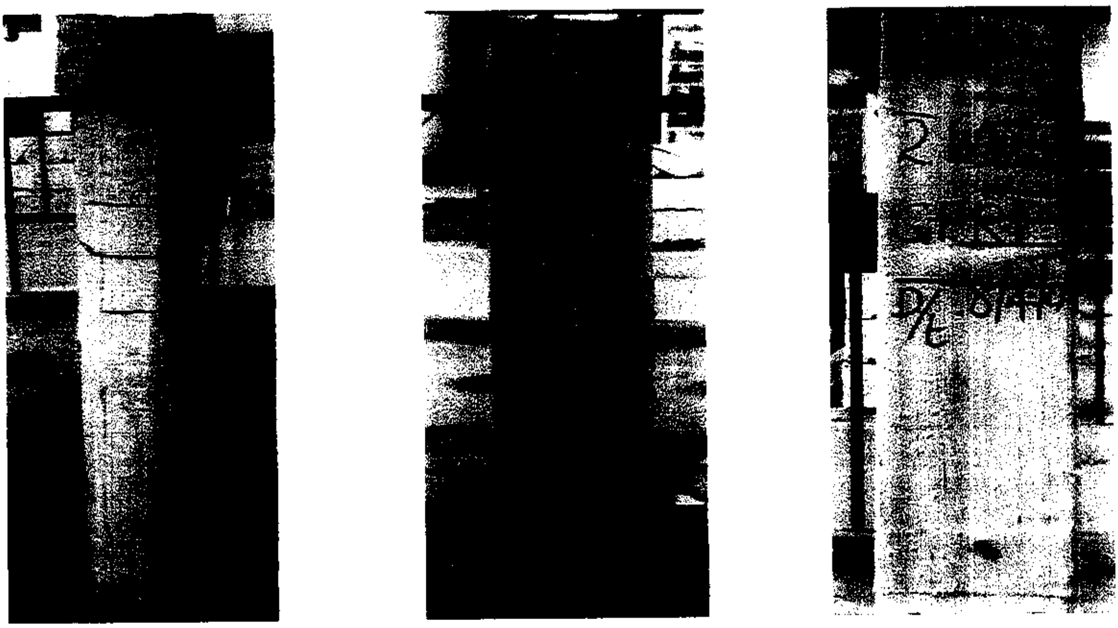


Figure 6.6: Failure modes of columns with double layer wrapping

CHAPTER 7

FINITE ELEMENT MODELING

7.1 General

The finite element method is a numerical analysis technique for obtaining approximate solutions to a wide variety of engineering problems. A finite element model of a problem gives a piecewise approximation to the governing equations. The basic premise of the finite element method is that a solution region can be analytically modeled or approximated by replacing it with an assemblage of discrete elements. Since these elements can be put together in a variety of ways, they can be used to represent exceedingly complex shapes.

7.2 Advantages of FEM

The Finite Element Method has many advantages are given below.

- Various types of boundary conditions are automatically handled in the formulation. They are systematically enforced just before the solution, for the nodal values of the field variables are obtained.
- Material anisotropy and in homogeneity can be treated without much difficulty, any type of loading can be handled.
- Higher order elements may be implemented with relative ease.
- The method can efficiently be applied to cater irregular geometry. Spacing of nodes need not follow a pattern or rule

7.3 Disadvantages of FEM

The Finite Element Method has its own limitations. They are listed below.

- There are many types of problems where some other method of analysis may prove more efficient than the FEM.
- There are some trouble spots such as "Aspect Ratio" (ratio of longer to smaller dimensions), which may affect the final results.

... of the problem is high

7.4 Steps in Finite Element Solution

Different sections of this module are;

1. Defining the parameters-Element types, Real constant, Material properties
2. Geometry of the structure
3. Meshing.

7.4.1 Defining the Parameters

Element Type

- In ANSYS program, the element used for analysis is **SOLID 65, 10 NODED TETRAHEDRAL STRUCTURAL SOLID, AND SHELL ELEMENT.**

Solid 65

- It is used for three-dimensional modeling of solids with or without reinforcing bars
- Element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x,y, and z directions.

Shell

- Has both bending and member capabilities
- Both in-plane and normal loads are permitted
- The element has six degrees of freedom at each node: translations in nodal x,y,z directions and rotations about nodal x,y,z axes

Real Constants and Material Properties

The real contants of the element are the properties that are specific to a given element type such as the cross sectional properties. Materials properties which are frequently used are Young's Modulus, Density, Poisons ratio, etc.

7.4.2 Geometry of the structure

The ultimate purpose of the finite element analysis is to create an accurate mathematical model of a physical prototype. Model generation is the process of defining the geometric configuration of the model nodes and elements. The model used for my analysis is Solid Model.

7.4.3 Meshing

Meshing consists of three steps,

Setting of element attributes, Mesh control and Shape.

Free meshing is used for this finite element analysis of the project. After completion of the meshing apply the support specifications and apply load to model. The load for Ansys modeling is taken from the experimental values. From Ansys modeling obtained stress strain values.

7.5 Comparison of Failure Loads

The loads for the RCC columns with FRP confinement obtained using ANSYS software and by the experiments on test specimens are presented below.

TABLE 7.1 COMPARSION OF FAILURE LOADS

Shape of column	Specimens Name	Failure loads in KN	
		In Experimental	In ANSYS
Square	RCC NW	139	150
	RCC FW01	164	180
	RCC FW02	187	205
Rectangular	RCC NW	133	145
	RCC FW01	156	170
	RCC FW02	178	195
Circular	RCC NW	147	165
	RCC FW01	183	205
	RCC FW02	214	245

7.6 Stress-Strain Cure For No Confined and Fully Wrapped Circular, Square and Rectangular Columns With Single Layer and Double Layer Of GFRP

Figure 7.1, 7.2 & 7.3 shows the stress-strain curve for no confined and fully wrapped Circular, Square and Rectangular column specimens with one layer and double layer of GFRP. The graph is indicates the axial strain in X axis and also indicates the axial stress in Y axis. In this stress-strain plot no confined and fully wrapped RCC specimens with single and double layer of GFRP specimens are

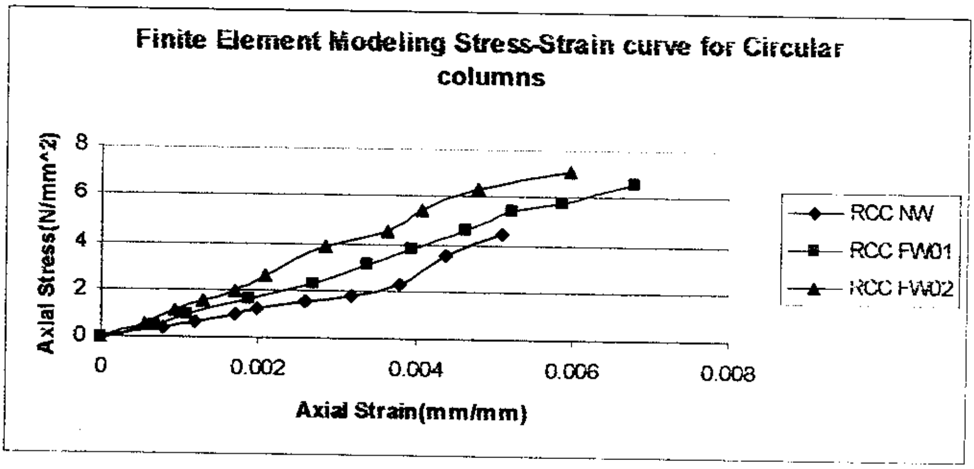


Figure 7.1: Stress-Strain curve Circular columns

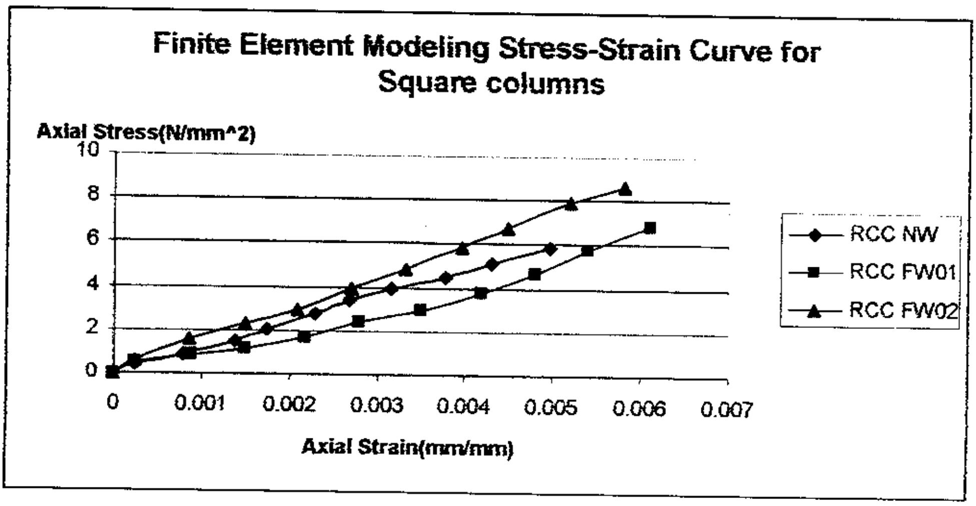


Figure 7.2: Stress-Strain curve square columns

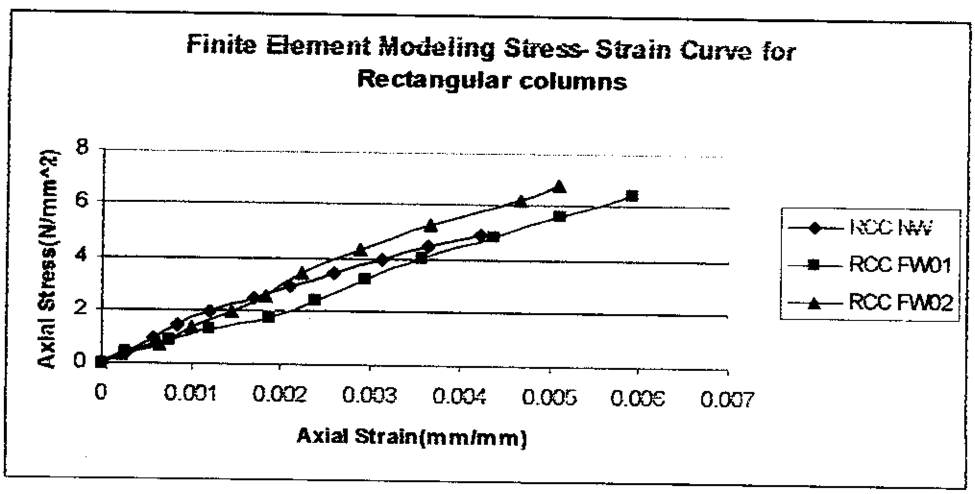
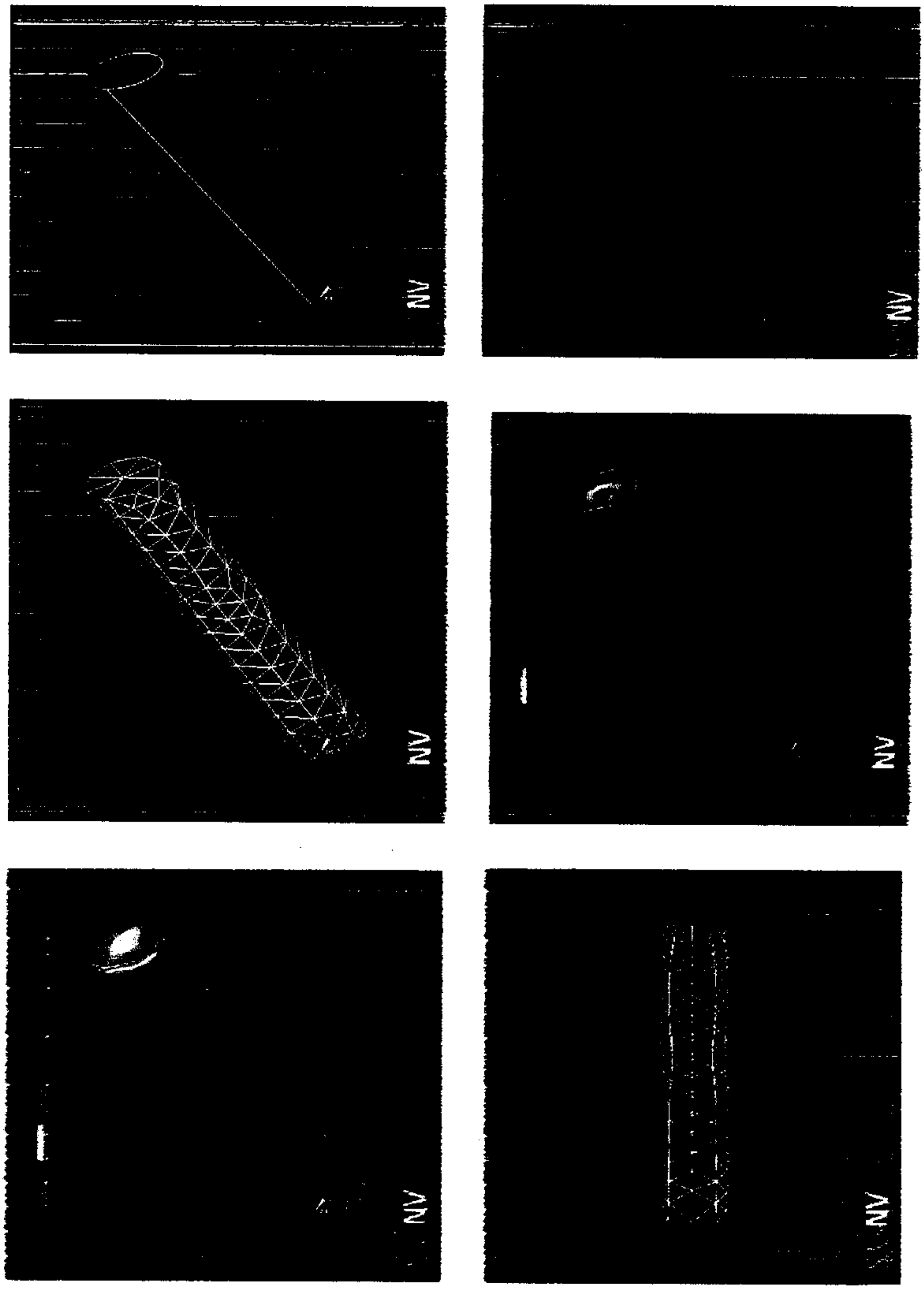
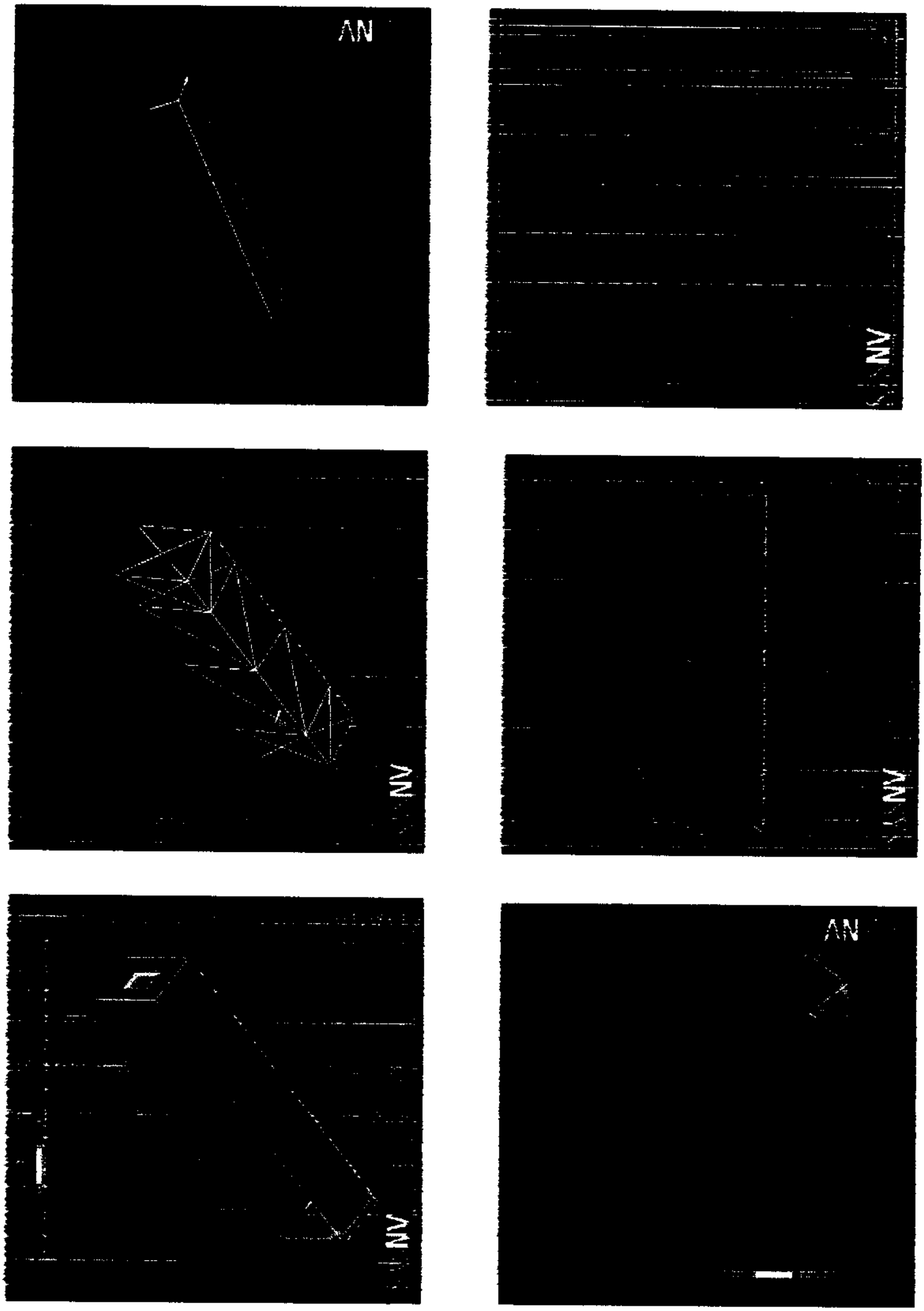


Figure 7.3: Stress-Strain curve Rectangular columns

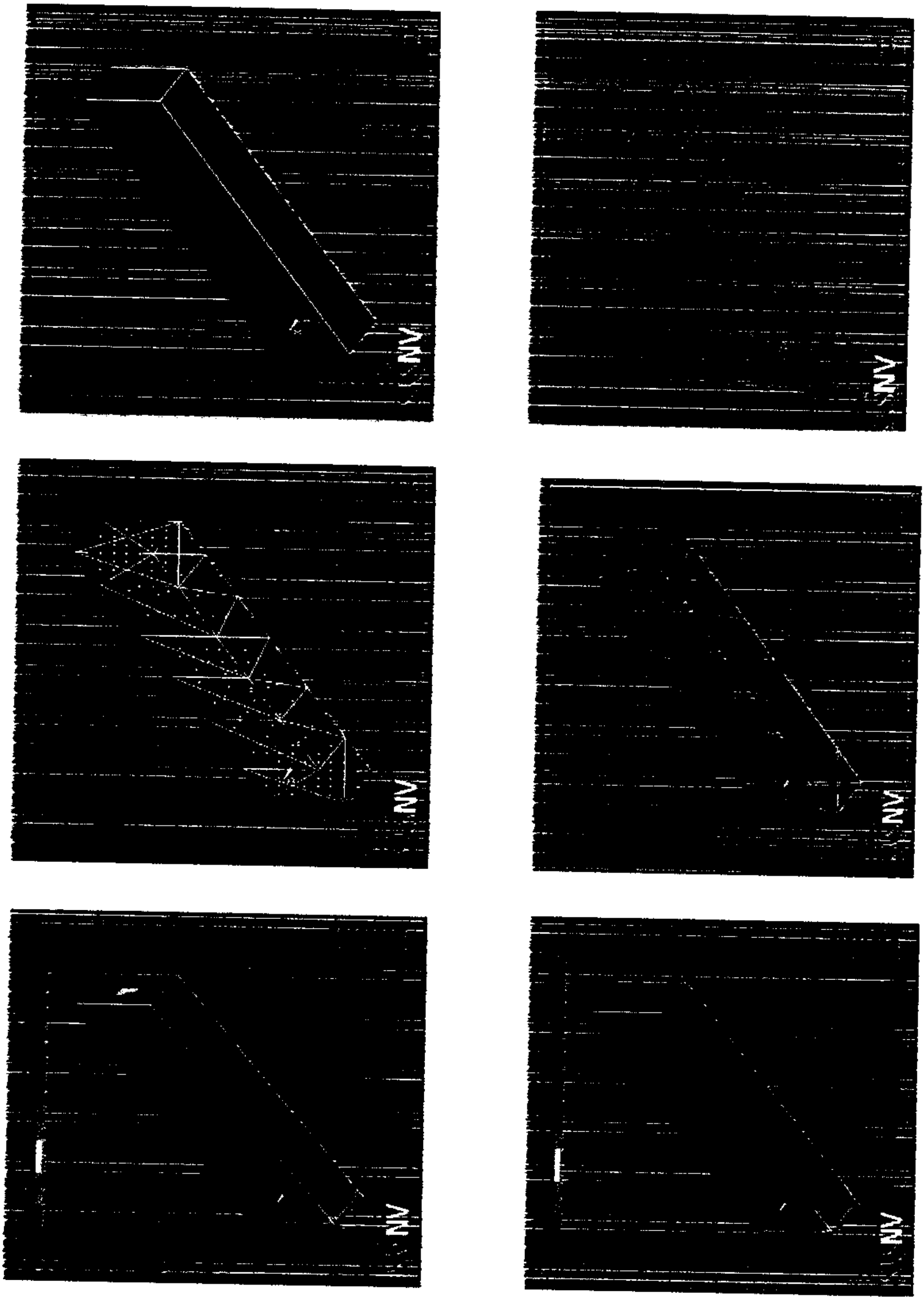
7.7 FEM Models, Stress-Strain Relations and Axial Compression Configurations.



Finite Element Models and stress, strain configuration of Circular Columns are presented in the figures 7.4



Finite Element Models and stress, strain configuration of Square Columns are presented in the figures 7.5



Finite Element Models and stress, strain configuration of Rectangular Columns are presented in the figures 7.6

CHAPTER 8

CONCLUSION

From the study performed on concrete columns confined by GFRP, it is concluded that this method of confining concrete is effective in significantly improving the performance of concrete columns

The following conclusions can be drawn form the results of this study:

1. Square columns: Percentage increase in ultimate load is 18 and 34.5 for single and double layer wrapping respectively, when compared to without confined concrete column.
2. Rectangular columns: Percentage increase in ultimate load is 17.3 and 33.8 for single and double layer wrapping respectively, when compared to without confined concrete column.
3. Circular columns: Percentage increase in ultimate load is 24.5 and 45.6 for single and double layer wrapping respectively, when compared to without confined concrete column.
4. For square and rectangular columns with double layer wrapping, stress-strain response is improved considerably. (fig.6.1 & 6.2)
5. For circular columns with double layer wrapping, stress-strain response is not improved. (fig.6.3)
6. All columns fail near ends because of more stress in these regions. (fig.6.4 , 6.5 & 6.6)
7. The loads for the RCC columns with FRP confinement obtained using ANSYS software and by the experiments on test specimens are presented (table no:7.1)
8. Stress - Strain diagram obtained for the FEM model of FRP wrapped columns is presented. (fig: 7.1,7.2 & 7.3)

REFERENCES

1. ACI Committee 440-2002,"Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete (ACI 440.2R-02)", American Concrete Institute, Farmington Hills, Mich., pp. 27-28, 44-45.
2. Riad Benzaid1,2, Nasr-Eddine Chikh3, Habib Mesbah (2008) Journal Of Civil Engineering And Management 14(2): 115–120
3. S. Matthys, H. Toutanji; and L. Taerwe (2006), "Stress-Strain behaviour of large-scale circular columns confined with FRP composites", Journal of Structural Engineering, Vol. 132, No.1, pp.123-132.
4. Y. Xiao and H. Wu, (2000) "Compressive behaviour of concrete confined by carbon fiber composites jackets", Journal of Materials in Civil Engineering, ASCE, vol. 12, No. 2, pp.139-146.
5. M. Samaan. A. Mirmiran. (1998) "Model of concrete confined by fiber composite", Journal of structural Engineering, ASCE,Vol.124, No. pp. 1025- 1031
6. Zihan Yan, Chris P. Pantelides, and Lawrence D. Reaveley (2006), "Fibre reinforced polymer jacketed and shape modified compression members", ACI Structural Journal, Nov-Dec, pp. 885-893.
7. Ching Chiaw Choo, Issam E. Harik, and Hans Gesund ACI Structural Journal, V. 103, No. 3, May-June 2006.
8. Joaquim A.O. Barros , Rajendra K. Varma, José M. Sena-Cruz , Alvaro F.M. Azevedo. Near surface mounted CFRP strips for the flexural strengthening of RC columns: Engineering Structures 30 (2008) pp. 3412_3425.