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DICLE UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APLLIED SCIENCE

PRINCIPLE OF STRENGTHENING REINFORCED CONCRETE STRUCTURES USING FRP COMPOSITE MATERIAL

Sultan ERDEMLİ

MASTER OF SCIENCE

CIVIL ENGINEERING DEPARTMENT

DİYARBAKIR

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DİCLE ÜNİVERSİTESİ
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BETONARME YAPILARDA LİFLİ POLİMER KULLANILARAK GÜÇLENDİRME İLKELERİ

Sultan ERDEMLİ

YÜKSEK LİSANS TEZİ

İNŞAAT MÜHENDİSLİĞİ ANABİLİM DALI

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FRP material is a type of composite material that is increasingly used in the construction industry in recent years. Due to their light weight, high tensile strength, corrosion resistance and easy to implementation makes these material preferred solution for strengthening method of reinforced concrete structural elements.

In this study, literature's experimental results are compared with American Concrete Institute (ACI440) and Turkish Seismic Design Code 2007 (TDY2007) in addition to mechanical properties of FRP material. The results of regulations have been evaluated and compared with experimental results. On the other hand a simple structure which is not suitable for current standards or regulations, low axial load carrying capacity, low strength and intended uses changed of structure's vertical structural elements wrapped with FRP materials for strengthening. The structure's material section properties taken experimental results of the literature have been strengthened theoretically to satisfy safe cross-section with FRP materials. Consequently it has been noted that the FRP materials enhance both strengthening and ductility of column sections.

Key Words: Composite Material, FRP, Reinforced Concrete, Strengthening

ÖZET

BETONARME YAPILARDA LİFLİ POLİMER KULLANILARAK
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Son yıllarda inşaat sektöründe sıklıkla kullanılmaya başlanan ve kullanımı gittikçe yaygınlaşan bir komposit malzeme türü olan Lifli Polimer (FRP) malzeme, yüksek çekme mukavemeti, hafif olması, korozyona dirençli ve uygulama kolaylığı gibi özelliklerinden dolayı betonarme yapılarda onarım ve güçlendirme yöntemi olarak kullanılması nedeni ile detaylı olarak irdelenme ihtiyacı ortaya çıkmıştır. Bu çalışmada bu malzemenin mekanik özelliklerinin yanı sıra bu malzemenin uygulamasında literatürden derlenen deneysel sonuçlarının ACI 440 ve Deprem bölgelerinde Yapılacak Yapılar Hakkında Yönetmelik (TDY2007) ile kıyaslanıp mevcut yönetmeliğimizin diğer yönetmeliklerdeki sonuçlarla ve var olan deneysel sonuçlar ile değerlendirilip, karşılaştırılması yapılmıştır.Literatürden alınan deneysel sonuçlarla elde edilen malzeme ve kesit özellikleri dikkate alınarak, eksenel yük taşıma kapasitesi düşük ve mevcut yönetmelik standartlarına uygun olmayan ve kullanım amacı değişen basit bir yapının düşey taşıyıcı elemanlarının Lifli polimerler malzeme ile sargılanıp teorik kesit güçlendirilmesi sağlanmıştır. Bu güçlendirme ile kolon kesitlerinin hem mukavemet hem de sünekliliğinde önemli artış sağlanmıştır.

Anahtar Kelimeler: Komposit Malzeme, LP (FRP), Betonarme, Güçlendirme

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LIST OF SYMBOLS

A_s = Cross sectional area of longitudinal reinforcement

b = Width of rectangular cross section (mm)

b'' = Big size of the core concrete (area inside the stirrup),

b_c = Dimension of concrete core

E_c = Modulus of elasticity of concrete, (MPa)

E_f = Tensile modulus of elasticity of FRP (MPa)

f_c = Axial compressive strength of concrete (MPa)

f'_{cc} = Compressive strength of confined concrete (MPa)

f_{cc} = Compressive strength of confined concrete (TDY2007) (MPa)

f_{sh} = Stres in the lateral steel

f_c' = Cylinder strength of unconfind concrete ;

f'_{co} = Maximum compressive strength of unconfined concrete(MPa)

f_{cm} = Unconfined concrete strength (DBYBHY 2007) (MPa)

f_{cj} = Standard cylinder strength at the time of testing;

f'_{co} = Unconfined concrete member strength;

f'_{ccexp} = Confined concrete strength obtained from experiments

h = Overall thickness of a member (mm)

n = Number of plies of FRP reinforcement

f_1 = Effective lateral confinement pressure

k_1 = Coefficient of effeciveness

s = Lateral reinforcement spacing (mm),

r= The radius of the edges of the section

r = Modulus of elasticity ratio (Mander et al.1988)

t_f = Nominal thickness of one ply of the FRP reinforcement (mm)

x = Effecctive strain ratio (Mander et all1988)

ρ_s = Stirrup percent density

ρ_f = FRP reinforcement ratio,

ρ_{sh} = Ratio of the volume of tie steel to the volume of core

ρ_g = Ratio of the area of longitudinal steel reinforcement to the cross-sectional area of a compression member

K_c = Confinement coefficient

k_1 = Coefficient of effeciveness

εc = Strain in concrete

εco = Strain corresponding to the maximum stress in unconfined concrete

ε_{c1} = Starting point of constant stress displacement at the Sheikh and Uzumeri (1982) model curve,

ε_{c2} = Endpoint of constant stress displacement at the Sheikh and Uzumeri (1982) model curve,

ε_f = strain level in the FRP reinforcement (mm/mm)

ε_{fe} = strain level in the FRP reinforcement (mm/mm)

ε_{fu} = design rupture strain of FRP reinforcement (mm/mm)

ε_{cc} = concrete strain corresponding to confined concrete compressive strength (mm/mm)

$\varepsilon_{cc\ exp}$ = concrete strain corresponding to confined concrete compressive strength obtained from experiments;

εc = longitudinal compressive concrete strain. (Mander et all1988)

σ_c= Concrete stres

LIST OF ABBREVIATIONS

MMC	:	Metal Matrix Composites
CMC	:	Ceramic Matrix Composites
PMC	:	Polymer Matrix Composites
FRP	:	Fiber Reinforced Polymer or Plastics
CFRP	:	Carbon fibers Fiber Reinforced Polymer or Plastics
GFRP	:	Glass Fiber Reinforced Polymer or Plastics
AFRP	:	Aramid (Kevlar) Fiber Reinforced Polymer or Plastics
RC	:	Reinforced Concrete
TDY2007	:	Building Construction Code Regulation In Earthquake Zone(s) 2007
ACI2002	:	American Concrete Institute 2002

1. INTRODUCTION

Turkey is located three main earthquake zone. These are as follows: The North Anatolian Earthquake Zone, Western Anatolia Seismic Zone, Southeastern Anatolia Seismic Zone. In recent years, occurence of earthquakes in Turkey especially Van and Erciş have caused financial and moral damages so these shows that once again the reality of the earthquake. After these earthquakes, 604 people were died and over 2000 people were wounded. Around 100 buildings were completed collapse and number of the building known to be heavily damaged. After the earthquakes such as this and others have caused damaged in structures.

Fig 1. 23 Octaber 2011 Earthquake in Van

Not only the earthquakes causes damage in the structures but also blasting, explosions and e.t.c can cause damaged in structures.

These damages can be Non- structural damages or Structural damages;

Non-structural damages: These damages are not effect the integrity of structures such as windows, doors, partitions e.t.c

Structural damages: These damages are effect the integrity of structures or buildings such as beam, column, slabs, foundation, shear wall, beam-column joint. Structural damages can be minor, moderate and severe damage.

Due to the formation of earthquakes or damages, strengthening of existing structures has been an important issue.

Also reinforced concrete structures may need strengthening reasons such as;

- incorrect calculations and applications of project
- the use of unsuitable materials for standarts or guidelines
- the uses of low –strength material (the low quality of concrete)
- inadequate lateral reinforcement
- changing the intended uses of buildings thus usage load ıncreased
- additional storey
- corrosion (environmental factors)
- poor workmanshıp
- changing the guidelines or the formation of new standarts e.t.c..

Shortly, strengthening is not only for structures damaged by the earthquake also a possible earthquake or exist for inadequate strength of the current situation of the reinforced concrete structures and components.

In aditiıon to traditional strengthening methods such as externally-bonded steel plates, jacketing etc, advanced composite materials has became widespread in the strengthening of reinforced concrete (RC) structures. Espeacially uses of fibre reinforced polymers (FRP) materials for strengthening has rapidly increased in recent years. Due to their lightweight, high strength, resistance to corrosion, speed and ease of aplication and formed on site into different shapes can be made them preferences. The composite materials (FRP) aplications are used for strengthening of reinforced concrete structures instead of classical methot. Due to the benefits of this materials externally bonded FRP sheets and strips are currently the most commonly used techniques for strengthening in concrete structures.Table 1 show that typical strength and stiffness value for different materials in strengthening.

Table 1. Typical strength and stiffness values for materials used in retrofitting (Piggott, M. 2002)

Material	**Tensile strength (MPa)**	**Modulus of elasticity (GPa)**	**Density (kg/m3)**	**Modulus of elasticity to density ratio (Mm^2/s^2)**
Carbon	2200-5600	240-830	1800-2200	130-380
Aramid	2400-3600	130-160	1400-1500	90-110
Glass	3400-4800	70-90	2200-2500	31-33
Epoxy	60	2.5	1100-1400	1.8-2.3
CFRP	1500-3700	160-540	1400-1700	110-320
Steel	280-1900	190-210	7900	24-27

1.1. Previous Research

Lam and Teng (2003) (I), proposed a simple design-oriented stress-strain model for FRP-confined concrete in rectangular columns. This model is an extension of a recent design-oriented stress-strain model developed for concrete uniformly-confined with FRP based on test results of circular concrete specimens. Lam and Teng 2003 (II), proposed a new design-oriented stress–strain model for concrete confined by FRP wraps with fibres only or predominantly in the hoop direction based on a careful interpretation of existing test data and observations. But this model reduces directly to idealized stress–strain curves in existing design codes for unconfined concrete. In the development of this model, a number of important issues including the actual hoop strains in FRP jackets at rupture, the sufficiency of FRP confinement for a significant strength enhancement, and the effect of jacket stiffness on the ultimate axial strain, were all carefully examined and appropriately resolved.

Campione et. al. (2004)**,** investigated the compressive behavior up to failure of short concrete members reinforced with fiber reinforced plastic (FRP). Rectangular cross-sections are analysed by means of a simplified elastic model.The effect of local reinforcements constitute by single strips applied at corners before the continuous wrapping and the effect of round corners are considered. Analytical results are compared to experimental values available in the literature presents a theoretical model for prediction the maximum strength and strain capacities of short compressed column externally wrapped with FRP sheets. Members with rectangular crosssections and sharp or round corners were analysed.

Shehata et al. (2002)**,** investigated the gain in strength and ductility of concrete columns externally confined by CFRP wrapping that included tests on 54 short column specimens. The column cross section shape (circular, square and rectangular) and the amount of confinement expressed in the number of CFRP sheet layers applied to the models (one or two layers) were variables in the study. On the basis of the obtained results, equations were proposed to calculate the confined concrete strength and the ultimate confined concrete strain as a function of the confining lateral stress for each of the cross section geometry used, circular, square and rectangular.

Mirmiran et al. (1998), studied effect of shape, length and interface bond on FRP-confined concrete. Over 100 specimens subjected to uniaxial compression. Sguare sections are less effective in confining concrete than circular sections and effectiveness is measured by a modified confinement ratio that is function of the corner radius and the jacket's hoop strength. Length effect in short columns of up to 5:1 and %10 eccentricity and %20strength reduction in pure compression.But adhesive bond doesn't change load –carrying capacity of FRP-confined conrete, mechanical bond considerably enhance the load –carrying capacity of the column by providing an effective load distribution mechanism.

Saadatmanesh et al. (1994), presented a new technique for seismic strengthening of concrete columns. The technique requires wrapping thin, flexible high-strength fiber composite straps around the column to improve the confinement and, so, its ductility and strength. Analytical models are presented that concrete columns strengthened with composite straps can be used to increase effectively the strength and ductility of seismically deficient concrete columns. The result of the study: failure strain of the concrete increased, in comparison to the unconfined concrete. If the volumes of straps are equal, increase of ultimate axial load and ductility for strengthening with carbon fiber is larger than strengthening with E-glass. The technique they used increased the axial carrying capacity of the column and the ductility factor increases linearly with increase in strap thickness.

Saadatmanesh et al. (1997), investigated the flexural behavior of earthquake-damaged reinforced concrete columns repaired with prefabricated fiber reinforced plastic (FRP) wraps. Four column specimens were tested to failure under reversed inelastic cyclic loading to a level that can be considered higher than would ocur in a severe earthquake. The columns were repaired with prefabricated FRP wraps and retested under simulated earthquake loading. FRP composite wraps were used to repair damaged concrete columns in the critically stressed areas near the column footing joint. The results indicate that the proposed repair technique is highly effective. Both flexural strength and displacement ductility of repaired columns were higher than those of the original columns.

Rausakis et al. (2007), performed finite element analyses to investigate the behavior of square reinforced concrete (RC) columns strengthened by fiber reinforced polymer (FRP) sheet confinement. The study focuses on the contribution of FRP confinement in prevention of longitudinal bars buckling in cases of inadequate stirrup spacing. The analysis is presented that includes low concrete strength columns with different qualities of steel reinforcement (yield stress of the longitudinal bars). The results indicate that adequate FRP confinement can provide the restrictive mechanism to resist buckling of longitudinal steel reinforcement, while the lower the yield stress of bars, the lower the gain in strength of FRP confined columns and the lower the strain ductility achieved.

Oncu et all.(2010), investigated to determine behaviour of RC sections strengthening by wrapping with CFRP subjected to cylic loading. The results of damaged concrete specimens that wrapping with CFRP shows positively effects to resistance against cyclic loads.

2. REINFORCED CONCRETE STRUCTURAL ELEMENTS

Concrete is a well-known composite material that has been composed of cement paste and aggregates. The paste, composed of portland cement and water, coats the surface of the fine (sand) and coarse (gravel) aggregates. Due to a chemical reaction called hydration, the cement paste hardens and gains strength to form the rock-like mass known as *concrete*.

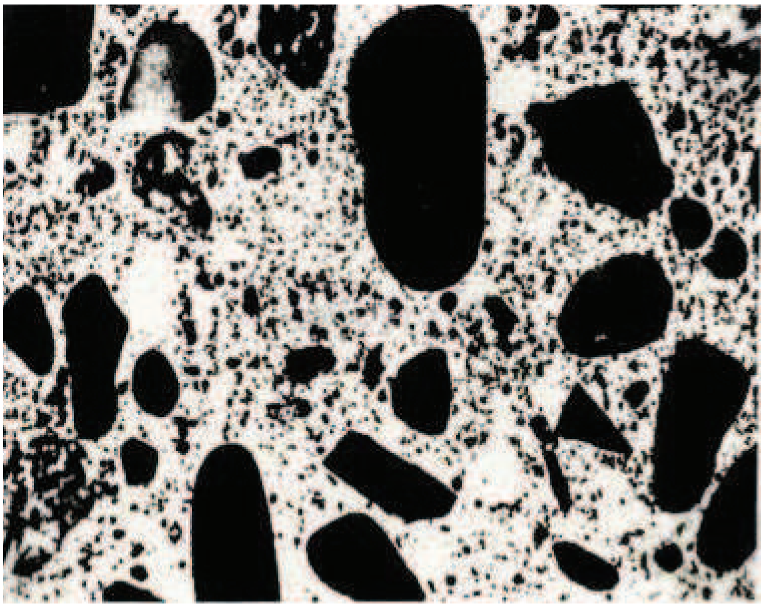


Fig.2.1: Typical Concrete Sample.

Fig 2.1 show that the typical concrete sample, which is composite materials, is occured sand and gravel are combined with the matrix (cement).

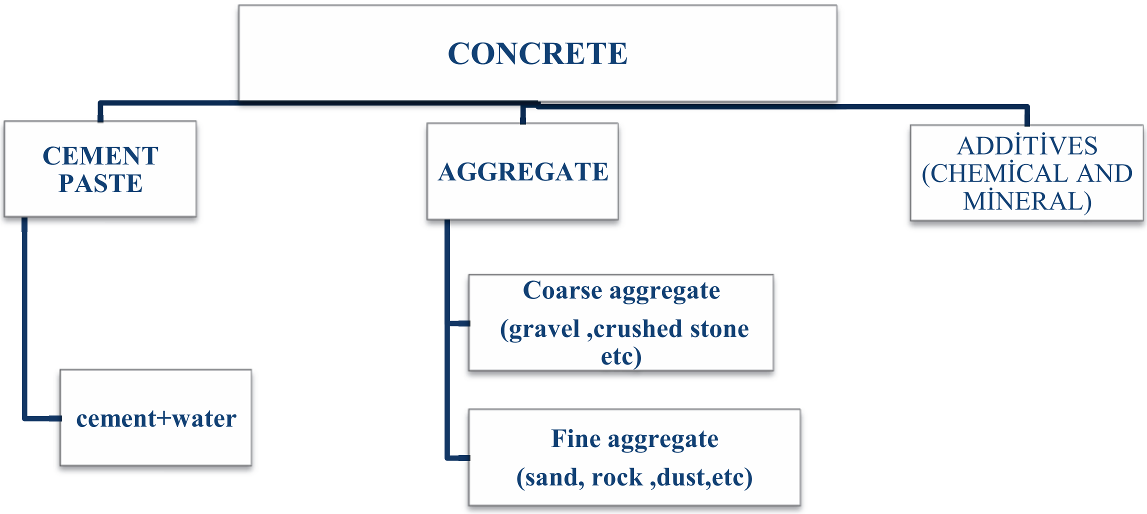


Fig 2.2 :Typical Concrete Components

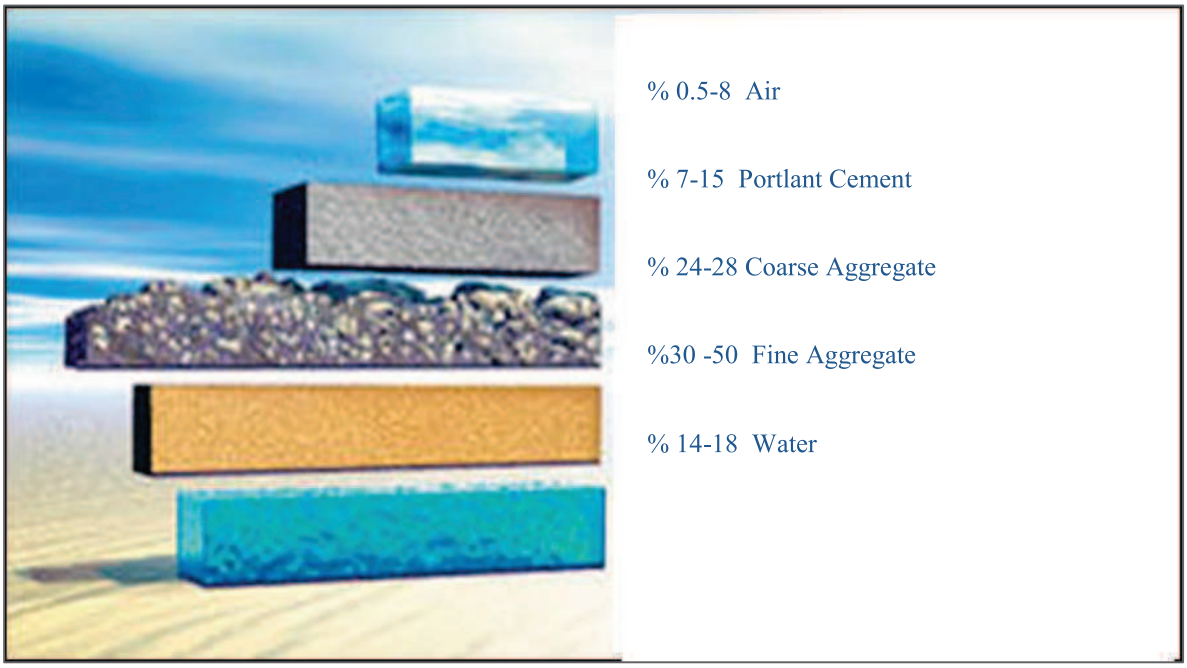


Figure 2.3. Percentage of Concrete Components

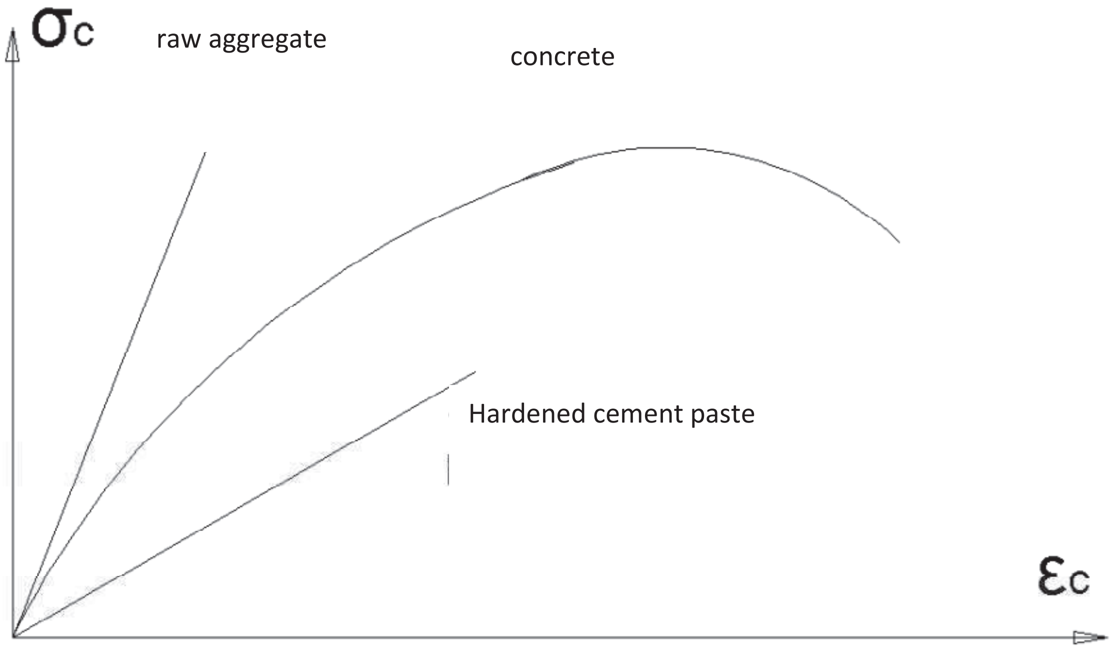


Figure 2.4. Concrete and It's Components of Stress-Strain Diagram

It is used for a long time in the construction of buildings and bridges. Good strength under compression ,easy to be given shape, durability, good fire resistance, high water resistance, low maintenance, and long service life are the superior side of the concrete.On the other hand weak sides are poor tensile strength , brittleness ,volume instability and formwork requirement. The most common type of concrete reinforcement is a steel bar.When the rods are placed in the concrete is called *reinforced concrete*.

The pioneers of reinforced concrete in building construction were two Frenchmen J. Louis Lamport and Francois Coignet. In 1850, Lamport built a small boat of reinforced concrete. A few years later F. Coignet published a document on the principles of reinforced concrete construction.

The two German engineers, Wayss and Bauschinger who investigated Monier system in 1887, was puplished a report then the use of reinforced concrete construction spread quickly (Ersoy et al. 2003).

2.1. Models of Concrete

Many models for the stress-strain relation of concrete have been proposed up to the present. But on this section used of common mathematical models for concrete will be discussed. Stress strain relation is not unique it depends on the variables or changable with variables. Commanly used models for concrete are; Hognestad (1951), Kent and Park (1971), Sheikh and Üzümeri (1982), Mander Concrete Models which will be discussed in this study.

2.1.1. Concrete Model Proposed by Hognestad (1951)

The model proposed by hognestad are widely used stress-strain curve for the behaviour of normal strength and provided to be a satisfactory model for unconfined concrete, shown in Fig. In the model, σ - ε curve up to the peak portion asumed a second-order parabola and part of the decline is assumed to be a linear. The maximum stress, usually taken as 85% cylindrical strength of concrete. ($f_c = 0.85 f_{ck}$).

Max compressive stress corresponding to strain ; ε_{c0} can be taken 0.002.

(ε_{c0} =0.002)

The model for the following equation Ec, modulus of elasticity, is proposed by the Hognestad.

$Ec = \tan \alpha = 126800 + 460 f_c$ (kgf/cm^2)

The part up to the peak of the curve(second degree parabola);

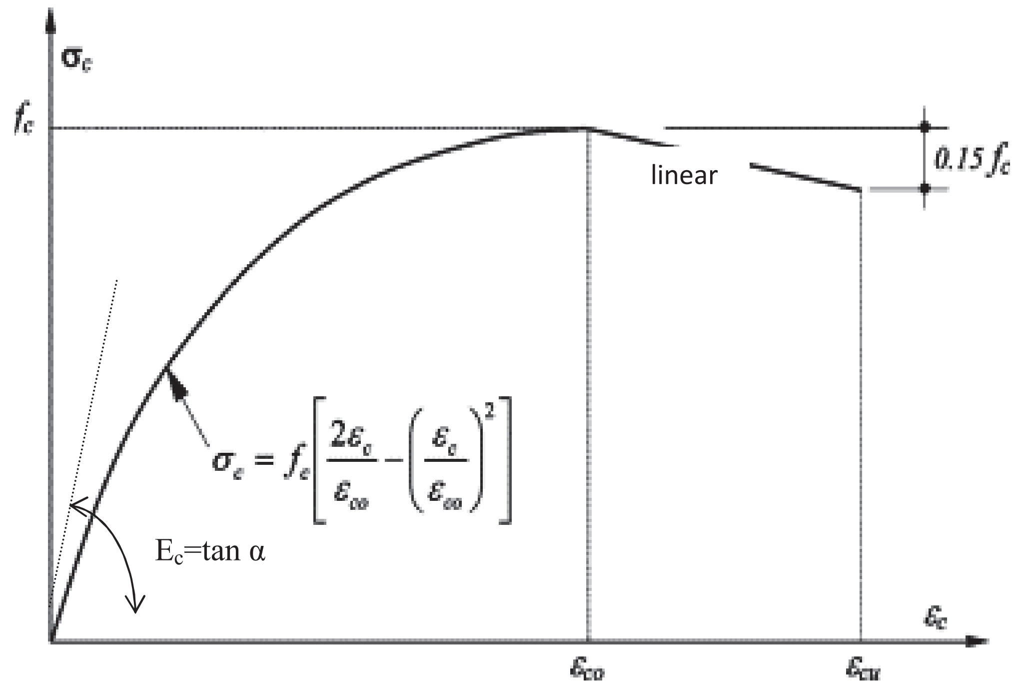
$$\sigma_c = f_c \left[\frac{2\varepsilon_c}{\varepsilon co} - \left(\frac{\varepsilon_c}{\varepsilon_{c0}} \right)^2 \right]$$

Strain (ε_{c0}) corresponding to max compressive stres (f_c); is described

$$\varepsilon_{c0} = \frac{2f_c}{E_c} = 0.002$$

Value of the ultimate compressive strain , ε_{cu} is usually taken as 0.0038;

ε_{cu} = 0.0038 (Ersoy et all,2003)



$\varepsilon_{c0} = \frac{2f_c}{E_c} = 0.002$ $\varepsilon_{cu} = 0.0038$

Fig 2.5. Hognestad Model (1951)

2.1.2. Concrete Model Proposed by Kent and Park Model (1971)

Kent and Park (1971) proposed a stress-strain equation for both unconfined and confined concrete. In their model they generalized Hognestad's (1951) equation to more completely describe the post-peak stress-strain behavior. In this model the ascending branch is represented by modifying the Hognestad second degree parabola by replacing f_c=f_{ck} and

ε_{co} = 0.002

The part up to the peak of the curve (second degree parabola) ;

$$\sigma_c = f_c\left[\frac{2\varepsilon_c}{0.002} - \left(\frac{\varepsilon_c}{0.002}\right)^2\right]$$

The post-peak branch was assumed to be a straight line whose slope was defined primarily as a function of concrete strength;

$$\sigma_c = f_c\{\,1 - Z(\varepsilon_c - 0.002)\}$$

$$\varepsilon_{50u} = \frac{3+0.0285fc}{14.2fc-1000}$$

$$\varepsilon_{50h} = \frac{3}{4}\,\rho_s\,\sqrt{\frac{b''}{s}}$$

$$Z = \frac{0.5}{\varepsilon_{50u} + \varepsilon_{50h} - 0.002}$$

Where; σ_c =Concrete stress; b'' = big size of the core concrete (area inside the stirrup), s = stirrup spacing, ρ_s = stirrup percent density,

$$\rho_s = \frac{A_{so}(a'' + b'')^2}{s(a'')(b'')}$$

a" = small size of the core concrete (Ersoy,1985)

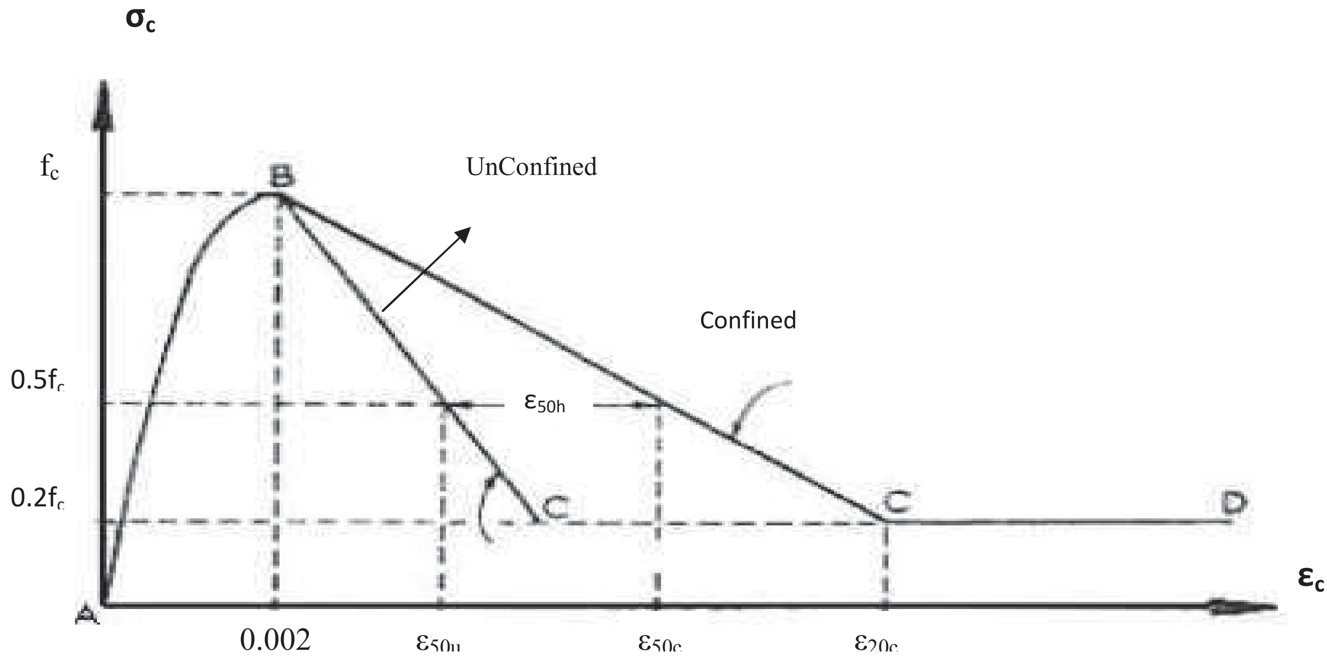


Fig 2.6. Stress-Strain model for confined and unconfined concrete – Kent and Park (1971) model

2.1.3. Concrete Model Proposed by Sheikh and Uzumeri (1982)

Sheikh and Uzumeri (1982) proposed a stress-strain equation for confined concrete in tied columns. An analytical model (Sheikh and Uzumeri 1982), which considers distribution of the longitudinal reinforcement and the configuration of the rectangular column ties on the effectiveness of the confinement.The proposed confinement efficiency of confined concrete can be described by Equations and model shown in Fig 2.7.

f'_{cc} = compressive strength of confined concrete; f_c' = cylinder strength of unconfined concrete; K_c = confinement coefficient ,

$$f'_{cc} = Kc.f'_c \quad (1)$$

$$K_c = 1 + \frac{{b_c}^2}{140P_{occ}}\left[\left(1-\frac{nC^2}{5.5{b_c}^2}\right)\left(1-\frac{s}{2b_c}\right)^2\right]\sqrt{\rho_{sh}\, f_{sh}} \quad (2)$$

$$P_{occ} = 0.85\, f_c^{'}\left({b_c}^2 - A_s\right) \quad (3)$$

where *As*: Cross sectional area of longitudinal reinforcement, *C*= distance between laterally supported longitudinal bars, s = tie spacing, ρ_{sh} = ratio of the volume of tie steel to the volume of core, b_c =dimension of concrete core, f_{sh} =stres in the lateral steel

$$\varepsilon_{c1} = 80\,.K_c.\, f_c'.10^{-6} \quad (4)$$

$$\varepsilon_{c2} = \varepsilon_{c0}\left[1 + \frac{248}{C}\left(1 - 5\left(\frac{s}{b_c}\right)^2\right)\frac{\rho_{sh} f_{sh}}{\sqrt{fc'}}\right] \quad (5)$$

$$\varepsilon_{c85} = 0.225\, \rho_{sh}\sqrt{\frac{b_c}{s}} + \varepsilon_{c2} \quad (6)$$

In equation 1 and 2 diamensions, the stresses and P_{occ} are should be taken mm, MPa and kN.

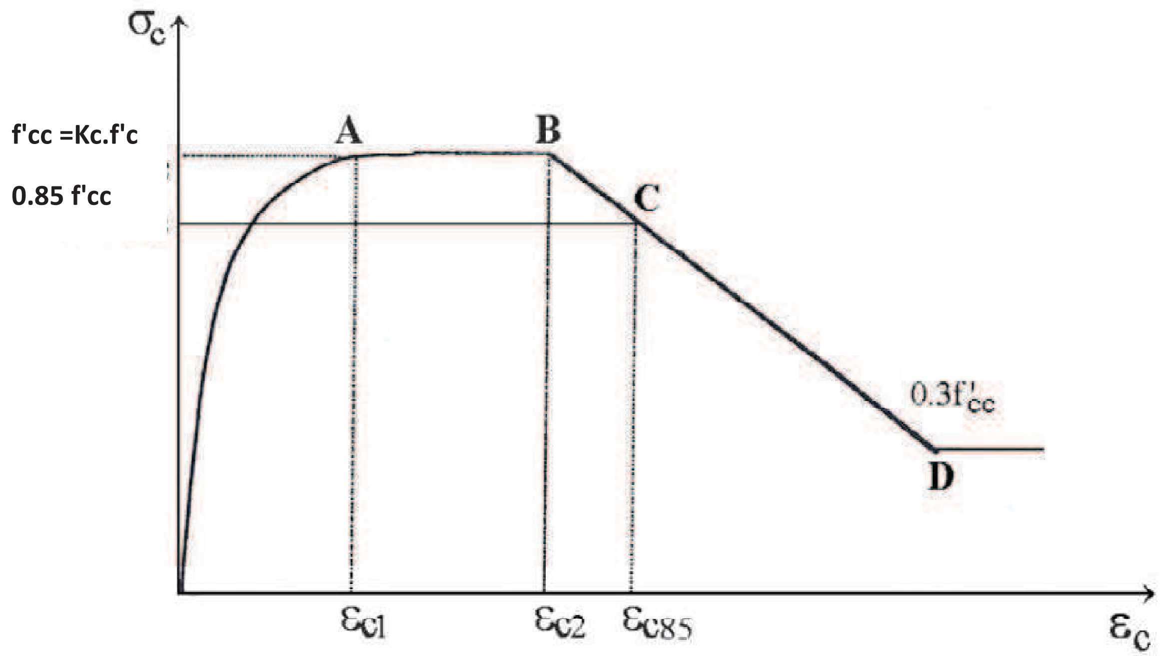


Fig 2.7. Sheikh And Uzumeri Stress-Strain Model for Confined Concrete (1982)

2.1.4. Concrete Model Proposed by Mander Et Al (1988)

Mander et al. (1988) have proposed a unified stress-strain model for concrete subjected to both static and dynamic loading, either monotonic or cyclic and confined by transverse reinforcement. The concrete section may contain any general type of confining steel: either spiral or circular hoops; or rectangular hoops with or without supplementary cross ties.

The compressive strength of confined concrete is proposed to be obtained as:

$$f_c = \frac{f'_{cc} \, . \, x \, . \, r}{r - 1 + x^r}$$

$$f_{cc} = f_{c0} \left(-1.254 + 2.254 \sqrt{1 + \frac{7.94 f'_1}{f'_{c0}}} - 2 \frac{f'_1}{f'_{c0}} \right)$$

$$\varepsilon_{cc} = \varepsilon_{co} \left[1 + 5 \left(\frac{f'_{cc}}{f'_{c0}} - 1 \right) \right]$$

$$r = \frac{E_c}{E_c - E_{sec}}$$

$$E_c = 5000 \sqrt{f'_{c0}}$$

where f'_{cc} anc f'_1 is defined later

$$E_{sec} = \frac{f'_{cc}}{\varepsilon_{cc}}$$

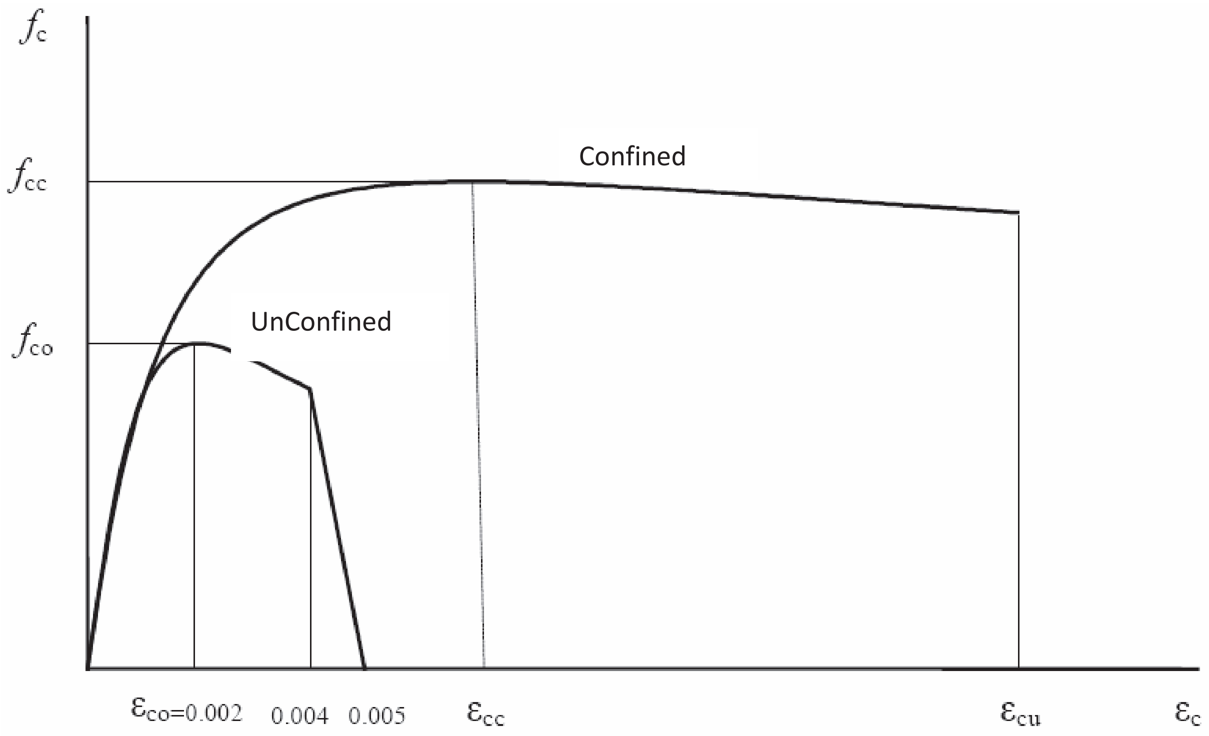


Fig 2.8. Mander Concrete Model (1988)

f'_{cc} is the maximum compressive strength of confined concrete, ε_c is the compressive strain of concrete, f'_{co} is the maximum compressive strength of unconfined concrete, ε_{cc} is the compressive strain of confined concrete corresponding to the maximum compressive strength of confined concrete, and ε_{co} is the strain corresponding to the maximum compressive strength of concrete, x: effecctive strain ratio

"$x = \varepsilon_c / \varepsilon_{cc}$" εc = longitudinal compressive concrete strain. r: modulus of elasticity ratio

2.2. Repair and Strengthening of Reinforced Concrete Structures

2.2.1. Repair

Basic purpose of repair is to bring back to function of the deteriorated, damaged components, or elements of a structure or the architectural shape of the building. So that all elements and structure is gone back to initial state and the functioning of building is restructuring quickly. Such as; repairing doors, windows, water and gas pipes, electric wiring, roofing tiles, cracks e.t.c. Reconstruction of boundary walls, non-structural walls, smoke chimneys,

2.2.2. Strengthening

Strengthening is the process of enhancing capacity of damaged components of structural concrete to its original design capacity, or an improving over the original strength of structural concrete. Reinforced concrete structures require strengthening due to:

- earthquakes
- accidents; such as collisions, fire, explosions
- corrosion of the reinforcement
- changes of the design parameters or new design standards,
- incorrect calculations and applications of project
- the use of unsuitable materials for standarts or guidelines
- the uses of low –strength material (the low quality of concrete)
- inadequate lateral reinforcement
- changing the intended uses of buildings thus usage load ıncreased (excessive loading)
- additional storey
- poor workmanshıp

2.2.2.1. Strengthening Method

Common strengthening methods are known as;

- Concrete Jackets
- Steel jacketting
- Externally bonded steel plates
- External Post-Tensioning

The most important step in retrofitting is the selection of an suitable interference technique based on the structural type and its vacancy.On the other hand, type and location of problem, availability of time and skill, appearance and cost is an important factor that selection of strengthening method.

According to JSCE, 1999; Retrofitting of structures shall flowed as follows:

- ‘ Identify the performance requirements for the existing structure to be retrofitted and draft an overall plan from inspection through selection of retrofitting method, design of retrofitting structure and implementation of retrofitting work.
- Inspect the existing structure to be retrofitted.
- Based on the results of the inspection, evaluate the performance of the structure and verify that it fulfills performance requirements.
- If the structure does not fulfill performance requirements, and if continued use of the structure through retrofitting is desired, proceed with design of the retrofitting structure.
- Select an appropriate retrofitting method and establish the materials to be used, structural specifications and construction method.
- Evaluate the performance of the structure after retrofitting and verify that it will fulfill performance requirements.

- If it is determined that the retrofitting structure will be capable of fulfilling performance requirements with the selected retrofitting and construction methods, implement the retrofitting work. ’

The methods of strengthening:

Concrete Jacketing: Concrete jacketing is typically applied methods of repair and strengthening of concrete members. Jacketing is one of the most generally used techniques to strengthen reinforced concrete (RC) columns. The size of the jacket, the number and diameter of the steel bars used in the jacketing process depend on the structural analysis that was made to the column. If ıt is required, beams, slabs, and walls can be enlarged to add stiffness or load-carrying capacity. Extensive longitudinal and transverse reinforcement is added in the new layer of concrete (Fig 2.3), enhancing the shear and flexural strength and ductility. It is necessarry to provide a good bond between new and old concrete in reinforced concrete jacketing. Reinforced concrete jacketing can be applied one, two, three or four side of the column, depending on the state of the implementation and space around the column.

In order to made jacketting to required level jacketting should be,

- Strength of the new material must be greater than existing one
- Min 4 cm thicckness of the jacket for shotcrete application and min 10 cm thicckness of the jacket for cast- in –situ concrete
- New reinforcement and concrete is collaborated with existing concrete and reinforcement

This method aplication is difficult to construct in some active buildings such as hospitals, schools, industry e.t.c because of the implementation is taken time ,made noise and limited to use. Size of the column or reinforced concrete members is increased by concrete jacketing this make ıts usage very limited.

Reinforced concrete jackets are build by enlarging the existing cross section with a new layer of concrete and reinforcement. (Ersoy et al. 1993) Fig 2.3 show that the enlargement of cocrete and reinforcement.

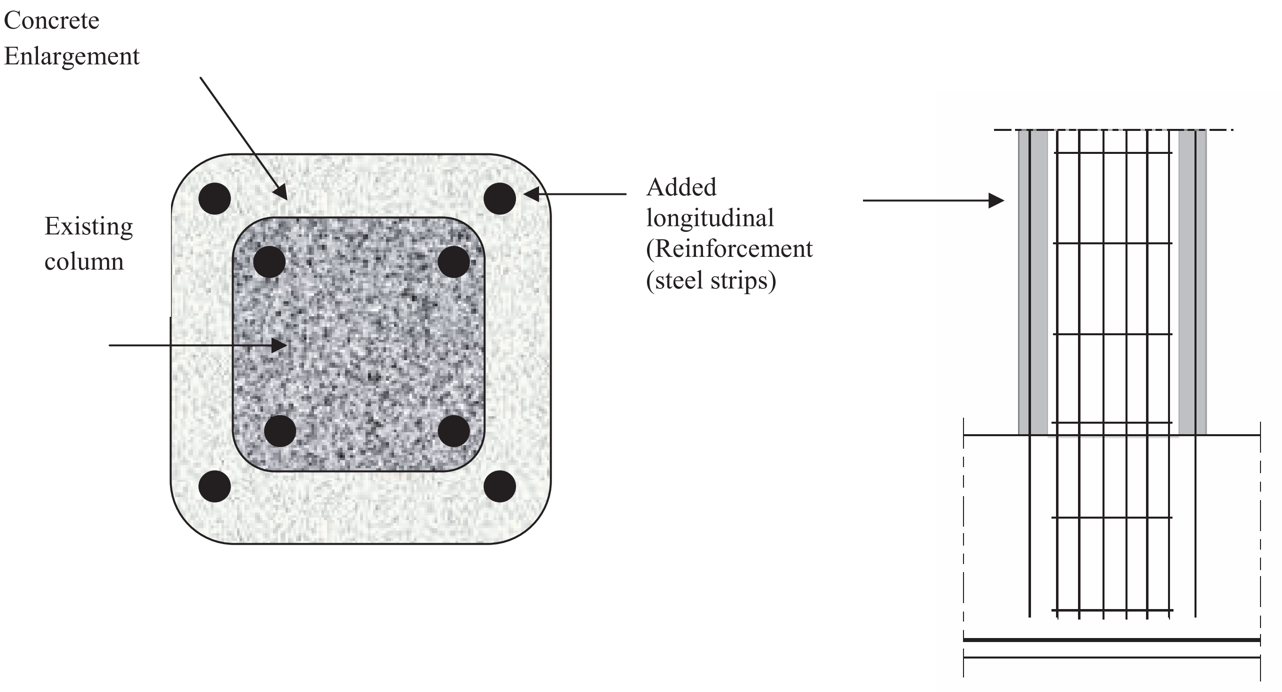


Fig.2.9. Increasing the cross-sectional area of column by RC jacketing

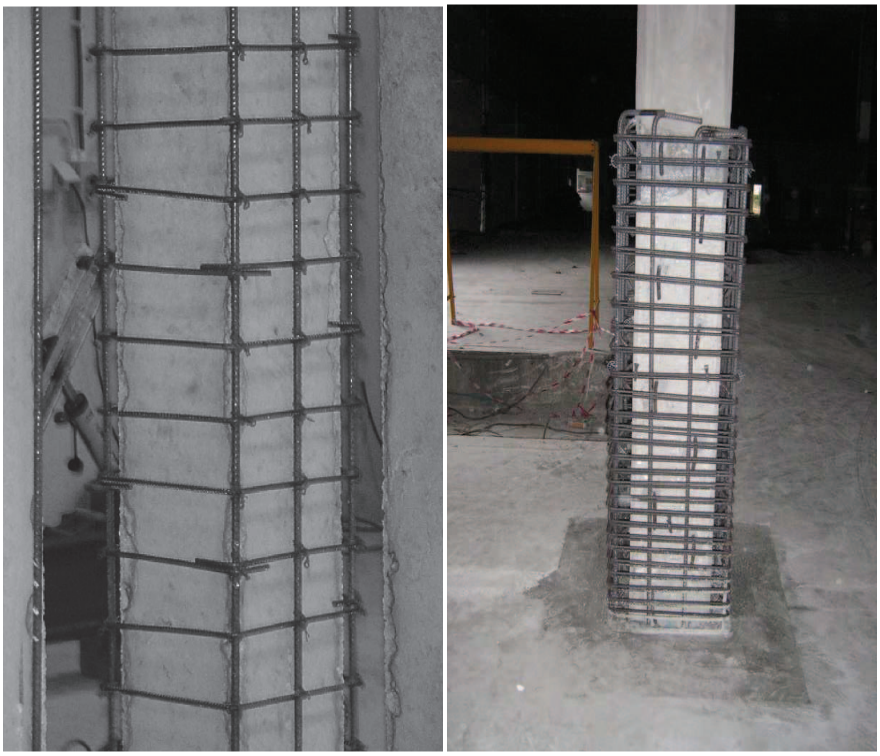


Fig.2.10. Typical concrete jacketting of reinforce concrete columns

Steel Jacketing & Externally Bonded Steel: Strengthening metod with steel plate bond or steel welding in reinforced concrete is concerned are fast and effective. The steel jacket retrofit has been used as a method to enhance the shear strength and ductility of reinforced concrete (RC) columns in buildings. Confining reinforced concrete column in steel jackets is one of the remarkable methods to improve the axial load carrying capacity.

As compared with conventional hoops or spirals, steel jacket has an effective utility;

- to easily provide a large amount of transverse steel, hence strong confinement to the compressed concrete,
- to prevent spalling off of the shell concrete

The jacketting of the column with thin steel plates placed at a small distance from the column surface, with the occuring space being filled with non-shrinking grouts shown in Fig 2.11. A steel jacket usually consists of two half shells of steel placed around the column, and welded together after placing. The space between the jacket and column is filled with pure cement grout. A space between the jacket and the joining member, to avoid the probability of direct load carrying action of the jacket, it could cause local buckling in the jacket. The jacket provides a passive confinement effect. The jacket can be considered as similar to continuous hoop-reinforcement.

‘The simplicity and speed of the jacketting application provide a solution for critical intervention time immediately after a strong earthquake, particularly for special buildings such as hospitals and schools’. (Giorgio , 2003)

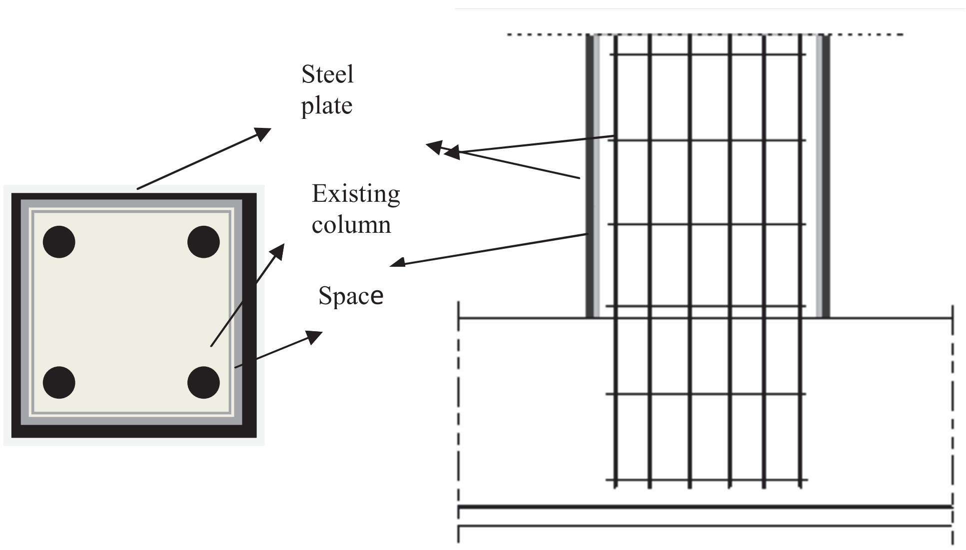


Fig 2.11. Strengthening of RC column with Steel jacketting

The steel jacketing come out of angle profiles connected together with steel straps at the corner of the column shown in Fig 2.12. Angle profile should be at least 50x50x5 mm, diameter of round bars selected at least ø14 mm and steel straps size should be selected min 25 x4 mm and welded to the each other. Spaces between the angle profiles and the existing column surface's should be filled with resin grout. A caging with concrete with welded fabrics is effective for corrosion or fire protection.

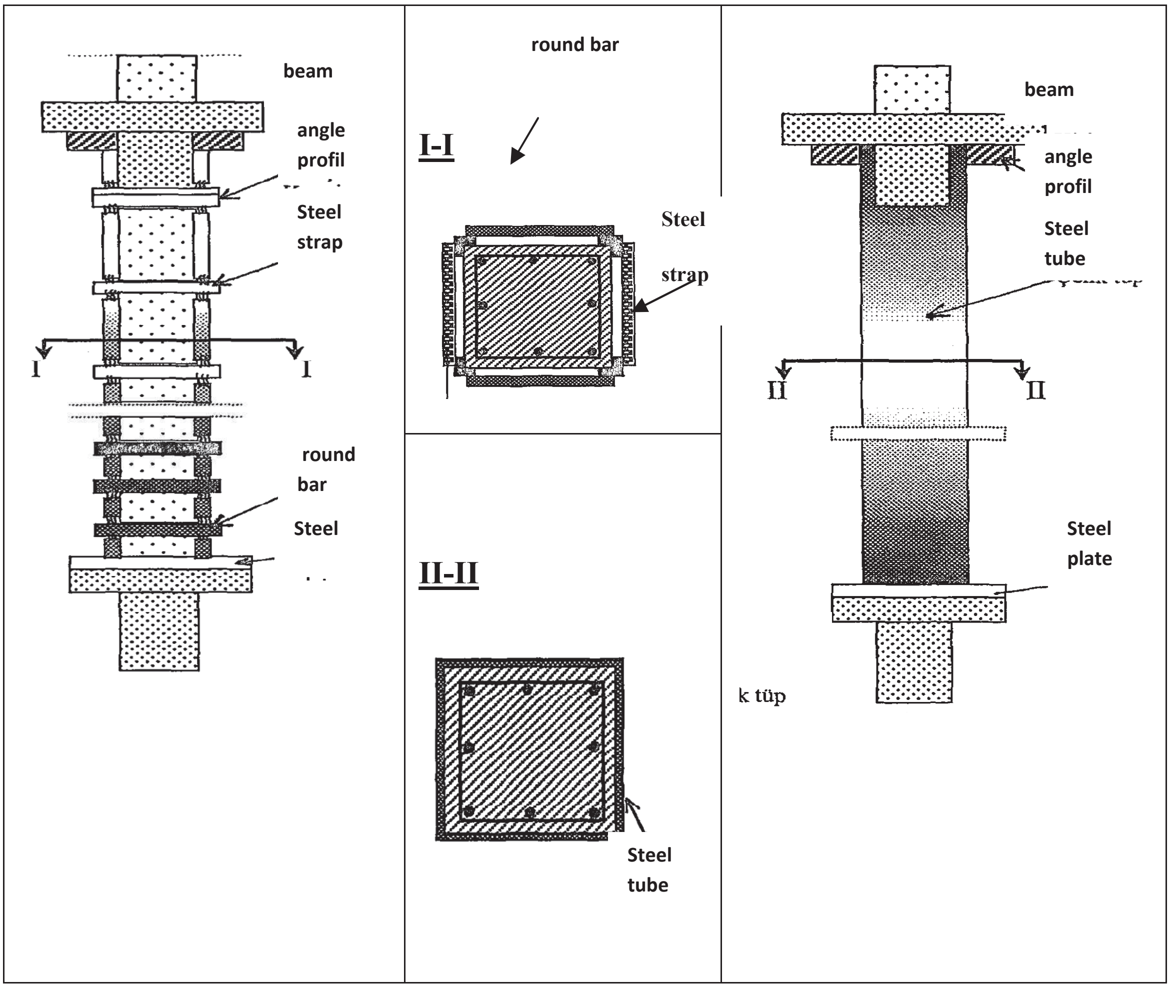
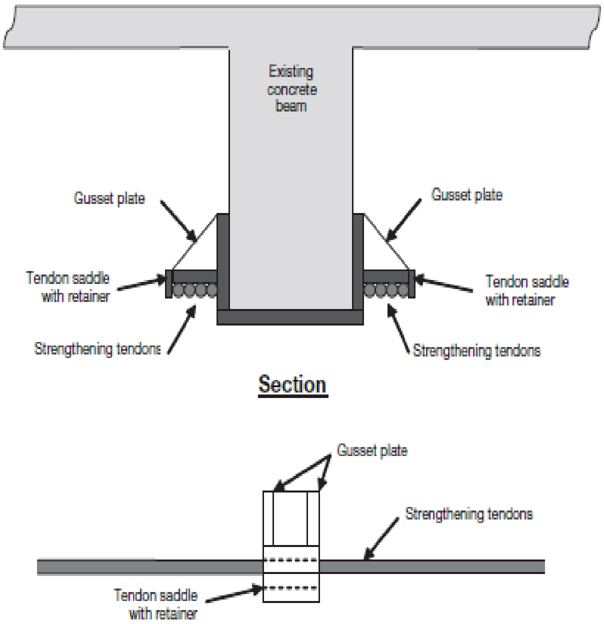


Fig 2.12. Steel profile jacketting

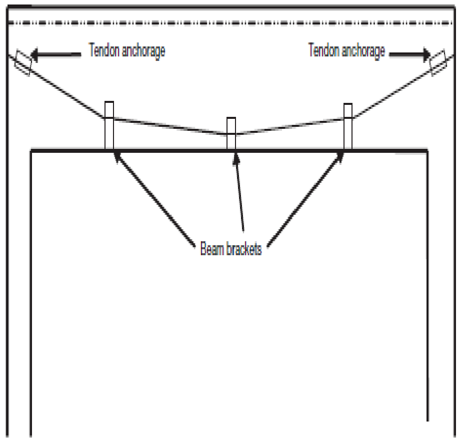
Fig:2.13. Typical steel jacketting of reinforce concrete columns

External Post-Tensioning Method: Post-tensioning is a method of strengthening concrete or structural member with high-strength (prestressing) steel,strands, cables or bars, typically referred to as tendons. Post-tensioning tendons, are regarded “active” strengthening since it is prestressed. The steel is influential as reinforcement even though the concrete may not be cracked. It can be applied to reinforced and prestressed concrete members. Post-tensioning is a technique used to prestress reinforced concrete after concrete is placed. The tensioning provides the structural member with an immediate and active load-carrying capacity Post-tensioned structure can be designed to have minimum deflection and cracking, even under whole load. Post-tensioning applications in building unbonded tendons are typically prefabricated at a factory and transported to the construction site, ready to install. After the concrete is placed and has reached its required strength. Post tensioning methods for strengthening generally used to beam for enhanced the flexural capacity, improve the cracking performance and also have a beneficial effect on shear capacity when the application of an axial load combined with a hogging bending moment. Strengthening of a beam with external tendons; shown in Fig 2.14. An equal number of tendons are typically used on each side of the beam. Tendon force and eccentricity are adjusted until an optimum solution for the required uplift force is obtained. Tendon geometry is easily modified with brackets and they can be placed at multiple locations along the beam. Fig. 2.15 – a shows an example of a beam bracket and how multiple beam brackets can be used to establish tendon geometry shown in 2.15- b. (Krauser, 2006)

Fig.2.14. Strengthening of a beam with external tendons. (Krauser, 2006)



a) Sample Beam Bracket

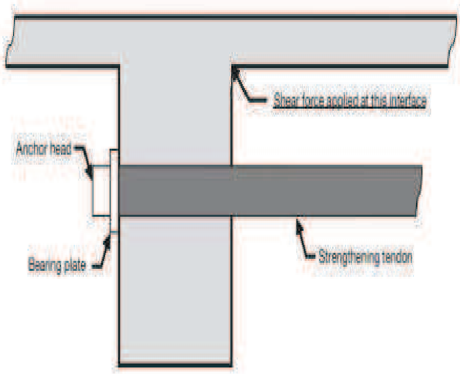


b) Tendon Geometry Using Beam Brackets

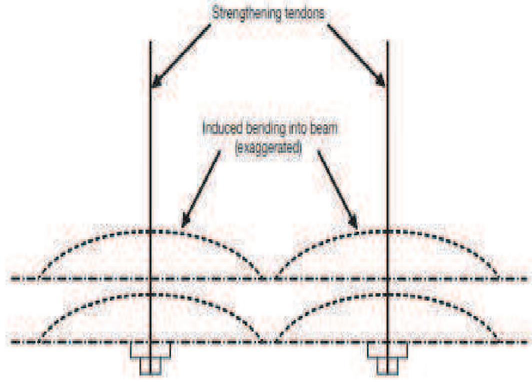
Fig.2.15. Beam Brackets (Krauser, 2006)

Reinforcement located outside members so steel bars, cables or strands are anchored directly to the structures in external post-tensioning strengthening. On the other hand external cables can be placed inside plastic ducts and then filled with cementitious grout.

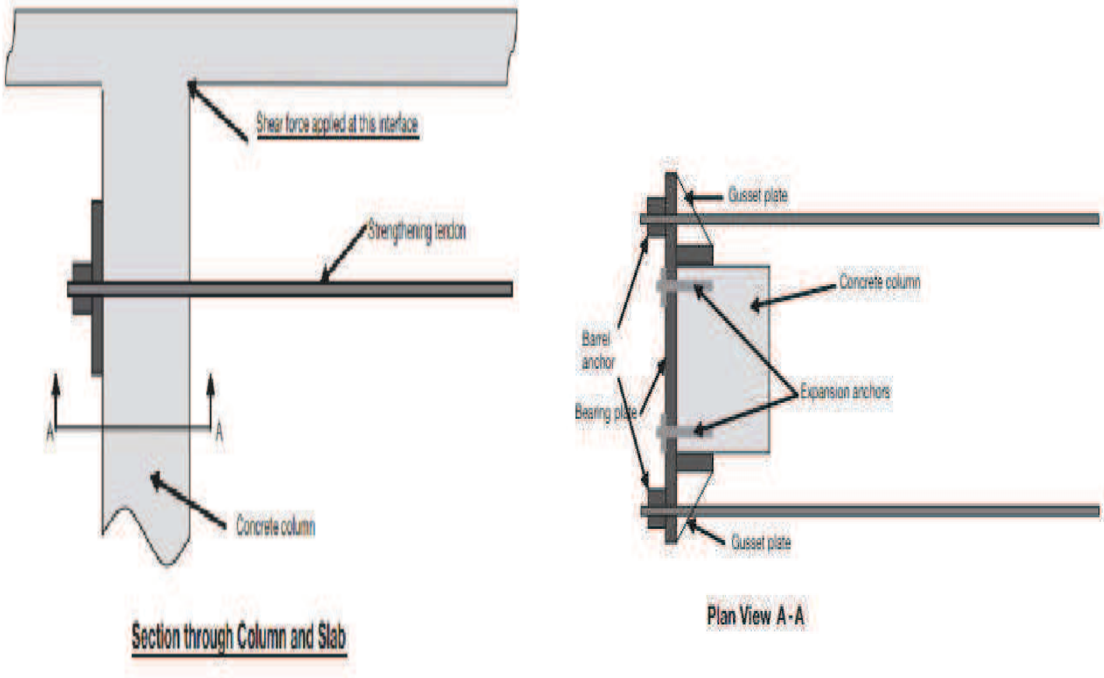
Anchorages are passed through a beam or column and anchored on the vertical surface; or attached to a bracket that envelops a column locations of induced forces when strengthening tendons pass through a beam, shown in Fig 2.16 a) ,b) ; Fig 2.16 c) show that column brackets ,which should be designed to have sufficient bearing to distribute the loads from the tendon to the concrete. (Krauser,2006)



a- Cut Through Beam Indicating Critical Location of Shear Force



b- Plan View Indicating Induced Bending in the beam



c) Anchorage bracket at column

Fig 2.16. a) and b) the critical locations of induced forces when strengthening tendons pass through a beam; c) Anchorage bracket at column (Krauser,2006)

Reduced of deflection, impact resistance, high fatigue and other reason as explained above are the positive side of the using an externally-post tensioned method for strengthenings. On the other hand handling of tensioning device, exposed of circumferential influences, high cost and restricted of field area are the disadvantages of externally-post tensioned method for strengthenings.

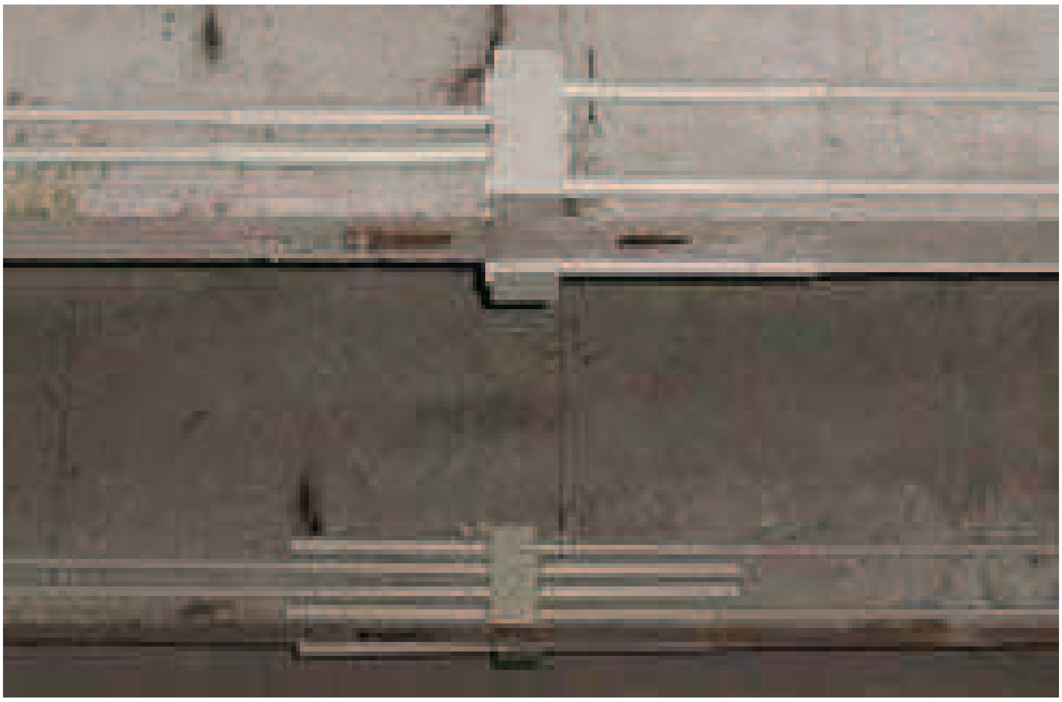


Fig.2.17. Typical Strengthening of External Post Tensioned Photo

2.2.2.2. Strengthening Materials

Common strengthening materials are known as;

- Epoxy resin
- Shotcrete
- Epoxy Mortar
- Fiber Reinforced Polimer (FRP) Materials

Epoxy Resin: Epoxt resins are used for small injection, surface coating or filling larger cracks or holes. If ıt is suitably applied, these materials could be bonded easily to concrete and are able to restoring the original structural strength to cracked concrete. The epoxy mixture strength is depend on the temperature of curing, lower strength for higher temperature and method of application. Viscosity must be suitable to the thickness of the crack to be injected. Cracks to be injected with epoxy resins should be between ~ 0.1 mm and ~ 6 mm in width. It is very difficult to retain injected epoxy resin in cracks greater than ~ 0.6 mm in width, although high viscosity epoxies have been used with some success. Epoxy resins cure to form relatively brittle materials with bond strengths exceeding the shear or tensile strength of the concrete. (Guide to Concrete Repair,1996)

Fig.2.18. Epoxy resin ,injection port and application of epoxy resin

Shotcrete: Shotcrete is a method where small layer of concrete or mortar is projected under pressure using a feeder or "gun" onto a prepared surface to form structural shapes. It can be used for the strengthening or the repairing of reinforce concrete structures. Shotcrete is used in most cases as a strengthening or repairing or construction material because of ıts high strength, durability, low permeability, remarkable bond and aplicability of irregular shapes. Shotcrete has a two applied process these are:

Wet Mix Process: Cement, sand, and coarse aggregate are first conventionally mixed with water, and introduced into the delivery equipment. Wet material is pumped to the nozzle where compressed air is added to provide high velocity for placement and compressed the wet mixture on to the desired surface.

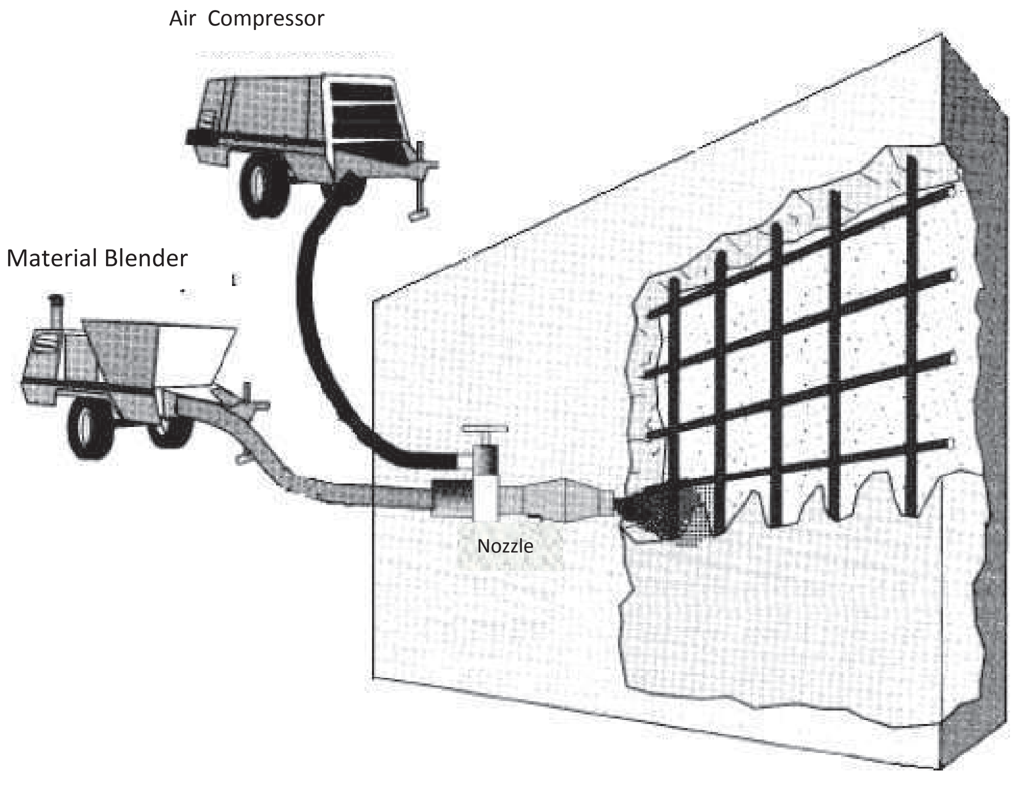


Fig.2.19. Wet-Mix Shotcrete

Dry Mix Process : Dry cement, sand, and coarse aggregates (pre-blended dry materials) are mixed and placed into the delivery equipment. Compressed air transmits materials through a hose at high velocity to the nozzle, where sufficient water is added. Material is consolidated on the desired surface by the high-impact velocity.

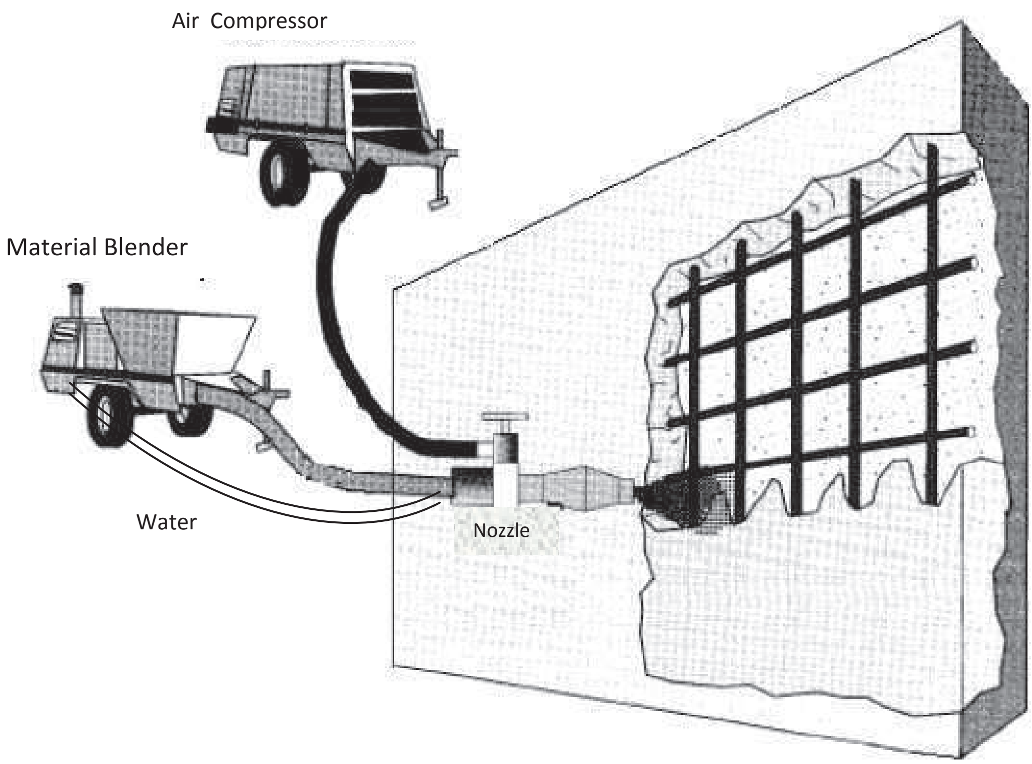


Fig.2.20. Dry-Mix Shotcrete

Epoxy Mortar : Epoxy mortar is composed of epoxy resin and sand that is placed over an epoxy bonding coat on hardened existing concrete. Epoxt mortar reach strength in few hours. It may be used when conducting minor repairs where the damage extends less than 40 mm into the concrete surface.

Fig.2.21. Epoxy Mortar

Frp Materials: This materials are considered as a composite materials and used in strengthening in reinforced concrete structures and also civil engineering structures, which will be studied in this thesis and explained in detail below.

3. COMPOSITE MATERIALS

Composite material is a materials system combined of two or more micro- or macro-component that differ in form and chemical combination and which are fundamentally insoluble in each other. Use of composite materials are very important in the Automotive industry, construction industry, manufacturing industry and new technology products.

The purpose of the creating composite materials is obtained the new features which the components doesnt have alone. In other words, producted superior properties of a new material the production than existing components.

In modern materials engineering, composite usually refers to a "matrix" material that is reinforced with fibers (Roylance ,2000).

3.1. Clasification of Composite Materials

Composite Materials genarally classified as a ;

- Metal Matrix Composites (MMC)
- Ceramic Matrix Composites (CMC)
- Polymer Matrix Composites (PMC)

3.2. Types of Composite Materials

- Fibre- reinforced Composites
- Particulate Composites
- Laminar Composites

Table 3.1.Advantages and Disadvantages of Composite Materials

Advantages of Composite Materials	**Disadvantages of Composite Materials**
• High strength to weight ratio • High stiffness to weight ratio. • Air condition,corosion and chemicals resistance • Lightweight, • High workability, • Easy formability • Low transport cost due to lightweight • High fatigue and impact strength • Low heat conductivity • Electrical insulation and conductivity	• High manufacturing costs • Brittle, not ductile failure • Materials require refrigerated transport and storage and have limited shelf lives • Composites must be completely cleaned of all contamination before repair. • Composites must be dried before repair because all resin matrices and some fibers absorbmoisture. • Repair at the original cure temperature requires tooling and pressure.

Composite material consist of two phases these are generally : *fiber* and *matrix* phases

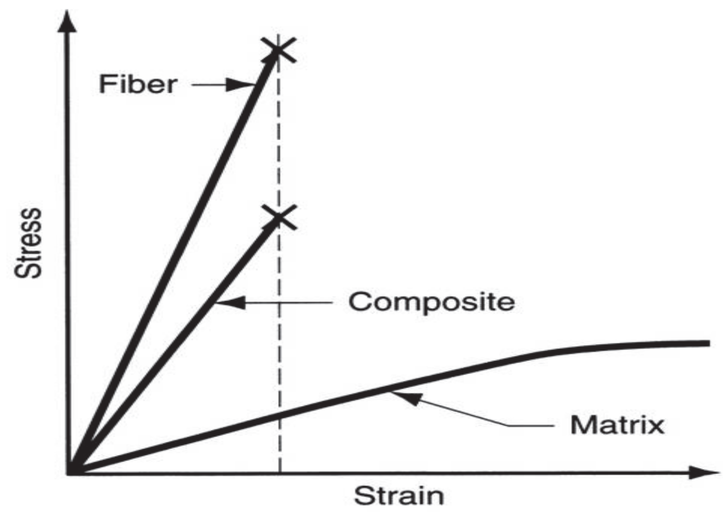


Fig 3.1. Stress Strain Diagram for Composite and It's Phases

3.3. Fibers

Fibers are the effective reinforcements material, as they satisfy the required conditions and transfer strength to the matrix constituent influencing and enhancing their properties as required. The performance of a fiber composite is evaluated by its length, shape, orientation, composition of the fibers and the mechanical properties of the matrix. (Pandey ,2004)

The main fibre types used in civil engineerig are Carbon fibers (CFRP), Glass (GFRP) and Aramid (AFRP)

3.3.1. Types of fibers

3.3.1.1. Carbon Fibers (CFRP)

Carbon fibers are anisotropic in nature Carbon fibre is produced at 1300ºC. High strength, excellent creep level, resistance to chemical effects, low conductivity, low density and high elastic modulus are the advantages of carbon fibers. Carbon fibers are expensive and anisotrophic materials and ıt has a low compression strength these are the weak sides of carbon fibers.

Fig 3.2. Typical Carbon fibers (CFRP)

3.3.1.2. Glass Fibers (GFRP):

Glass fibers are isotropic in nature and most widely used filament. Common types of glass fibers are E-Glass, S-Glass and C -Glass.The characteristic properties of glass fibers are: high strength, low cost, good water resistance and resistance to chemicals.

Fig 3.3. Typical Glass fibers (GFRP)

3.3.1.3. Aramid Fibers (AFRP):

Aramid fibers widespread known as a kevlar fiber in the markets. The structure of aramid fibre is anisotropic in nature and usually are yellow in colours. Aramid fibers moore expensive than glass, moderate stiffness, good in tension applications (Cables and tendons) but lower strength in comprension. Aramids have high tensile strength, high stiffness.high modulus and low weigh and densiy. Impact-resistant structures can be produced from aramids. There are five classes Kevlar with the different engineering properties. Kevlar-29, Kevlar-49, Kevlar-100, Kevlar-119, Kevlar-129

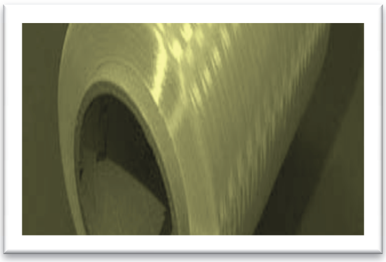


Fig 3.4. Typical Aramid fibers (AFRP)

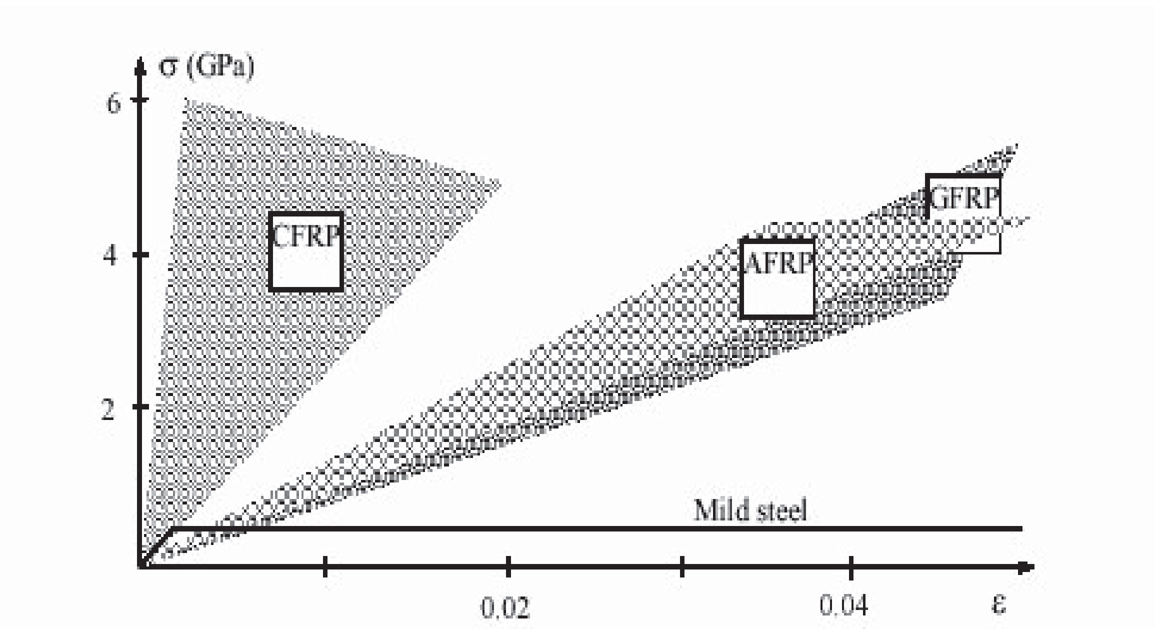


Fig 3.5. Uniaxial tension stress-strain diagrams for different unidirectional FRPs and steel. CFRP = carbon FRP, AFRP = aramid FRP, GFRP = glass FRP. (FIP Bulletin 14, 2001)

Table 3.2 Mechanical properties of Fiber Types (Unal,O)

Material	**Specific gravity** (gr/cm^3)	**Tensile Strength** (N / mm^2)	**Modulus of elasticity** (N / mm^2)
Glass Fiber	2.54	2410	70000
Carbon Fiber	1.75	3100	220000
Kevlar Fiber	1.46	3600	124000

3.3.2. Oriantation of Fibers

The mechanical properties of FRP vary with the type and oriantation of the reinforcing fibers.(Malek et all,1998). Fibres can be orianted form of:

3.3.2.1. Continuous Form:

Continuous and aligned fibers are generally long and straight also fibers distributed parallel to each other.

3.3.2.2. Woven Form:

Fibers come in cloth form and provide multidirectional strength

3.3.2.3. Chopped Form (discontinuous):

Fibers are short and generally randomly and discountinuous arranged (fiberglass) which are shown in Fig.3.6..

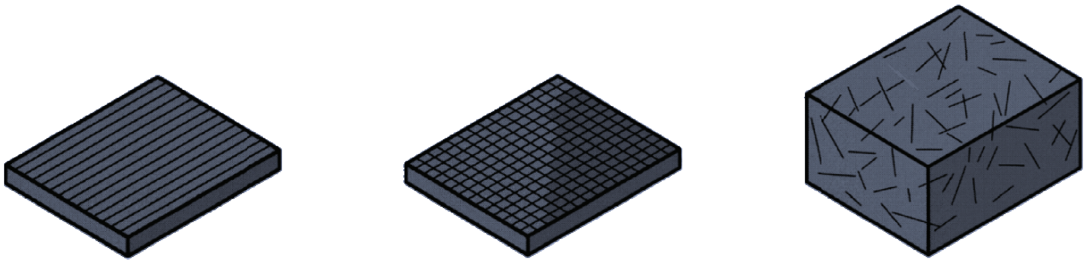


Fig 3.6. Fiber oriantation in a) continuous b)woven and c) chopped form.

Table 3.3. Fibre direction, arrangement and typical uses (Irwin and Rahman 2002)

Composite Type	**Fibre direction**	**Fibre arrangement**	**Typical Application**
Carbon Fibre Sheet (CFS)	Unidirectional	Straight	Increase in flexural and Shear capacity;confinement
Aramid Fibre Sheet (AFS)	Unidirectional	Straight	Special applications
Glass Fibre Sheet (GFS)	Bidirectional	Woven	Increase in confinement and ductility
Carbon Fibre Laminate (CFL)	Unidirectional	Straight (partially pretensioned)	Increase in flexural capacity

3.4. Matrix Material

Matrix is the second major component of the composite material. Selection of the suitable matrix affects the efficiency of the required success in fibers. The main purpose of the matrix is holds the fibres together, transfers loads to the fibres and protects the fibers from external ınfluences (corrosion, oxidation, abrasion).

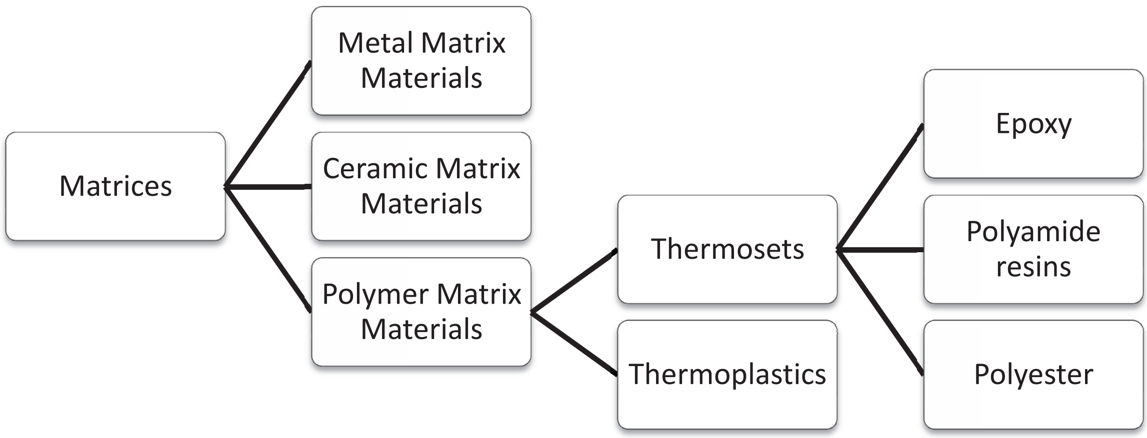


Fig 3.7.Clasification of Matrix Material

The material properties of moisture and dewatering should also be taken into consideration for the choice of matrix. Shear stiffness, longitudinal compressive strength, strain, failure, fatigue, impact is also very important features. The transverse modulus and strength, the shear properties and the properties in compression are the mechanical properties of the composites which are a strong influence on the matrix. Physical and chemical characteristics of the matrix such as melting or curing temperature, viscosity and reactivity with fibres influence the choice of the fabrication process. (FIP Bulletin 14, 2001)

3.4.1. Properties of a Matrix

- Reduced moisture absorption.
- Low shrinkage and low coefficient of thermal expansion
- Good flow characteristics
- Reasonable strength, modulus and elongation
- Must be elastic to transfer load to fibres.
- Strength at elevated temperature.
- Low temperature capability.
- Excellent chemical resistance.
- Should be easily processable into the final composite shape.
- Dimensional stability, (Pandey ,2004)

3.5. Adhesives

The purpose of the adhesive is to attach the composites to concrete surface, so that to provide a shear load path. The most common type of structural adhesives are *Epoxy* and *Polyester*, which are the polymer matrix materials (Polymeric matrix) shown in Fig 3.7 . Properties of *Epoxy* and *Polyester* adhesives are shown in Table 3.4

Table 3.4. Properties of Epoxy and Polyester Adhesives

Properties of Epoxy Adhesives	**Properties of Polyester Adhesives**
• High cost • Good electrical properties • High bond strength and flexibility • High temperature resistance, • Low shrinkage during curing • Better adhesion between fibre and matrix • Resistance to chemicals , solvents and water • Resistance to creep and fatigue • Limited temperature application range upto 175°C • Moisture absorption affecting dimensional properties • High thermal coefficient of expansion • Extremely harmful to the skin	• Low cost • Good mechanical strength • Good electrical properties • Low viscosity and versatility • Good heat resistance • Cold and hot molding • Curing temperature is 120°C • Good handling properties • Poor chemical resistance • High curing shrinkage • Fair weatherability

Table 3.5. Properties of Fiber Composites with Adhesives

Materal	Specific gravity (gr/cm^3)	Tensile Strength (N / mm^2)	Modulus of Elasticity (N / mm^2)
Glass fiber – polyester	1,5 – 2,1	200 – 340	55000 – 130000
Carbon fiber – epoxy	1,5 – 1,8	1860	145000
Kevlar fiber – epoxy	2,36	2240	76000
Boron fiber - epoxy	1,4	1240	176000

3.6. Fiber Reinforced Polimer (FRP) Material

Fiber-reinforced polymer (FRP) is a composite material consisting of high tensile-strength fibers bonded to the concrete surface using an epoxy resin or embedded in a matrix of polymer resin. FRP materials have been used for many years in the automotive and aerospace sectors. FRP material are used as external reinforcement in the construction industry since 1970. (Isıs Canada,2004).

Today, these FRP products take the form of bars, cables, 2-D and 3-D grids, sheet materials, plates, etc. FRP products may succeed in the same or better reinforcement objective of commonly used metallic products such as steel reinforcing bars, prestressing tendons, and bonded plates. (ACI 440,2002)

In the last decade, the use of fibre reinforced polymers (FRP) as reinforcement is rapidly growth for structural strengthening in civil engineerings applications.

The most commonly available fiber reinforced polymer (FRP) types are the carbon (CFRP), the glass (GFRP) and the aramid (AFRP) fibers which were explained above.

For the purposes of external reinforcement of concrete, there are essentially two classes of FRP materials are available mainly in the form of :

- *Plates*; rigid thin unidirectional *strips* made by pultrusion
- *Sheets or Fabric* ; unidirectional made of fiber at least two distinct directions ,pre-impregnated

3.6.1. Installation Techniques of Fiber Reinforced Polymers (FRP) Materials

There are three installation techniques of Fiber Reinforced Polymers (FRP) materials is used in construction sectors. These are wet or hand lay-up, Prefab Systems and Prepreg Systems**.**

3.6.1.1. Wet Lay-Up Systems (Hand Lay-up)

In this technique, composed by dry multidirectional or unidirectional fiber sheets or fabrics of raw or preimpregnated fibres are saturated with an epoxy adhesive resin and placed on the surface of the concrete. Sheets or fabrics are more flexible and can be used to plane as well as sharp corners should be rounded. Shaped and cured in-situ.

3.6.1.2.Prefab Systems

This systems are composed by pre-cured rigid FRP strips or plates (laminate) to the surface of the concrete using an epoxy adhesive which are generally best suited for flat and straight surfaces.

3.6.1.3. Prepreg (Special) Systems

This system composed by uni or multi directional of fibers sheets.It is generally special systems, e.g. automated wrapping, prestressing etc Special systems, e.g. automated wrapping, prestressing etc.

The achievement of FRP strengthening is highly dependent on the installation of the FRP.The following items shoul be considered during construction to help ensure a successful FRP aplications. These are :

1 Contractor Qualifications

2 Surface Preperation

3 Galvanic Corrosion

4 Pull Tests to CheckBond

5 Witness Panels/Laboratory Testing to Check Laminate Strength

6 Testing Laboratory Personnel Experience (Williams et al.2008)

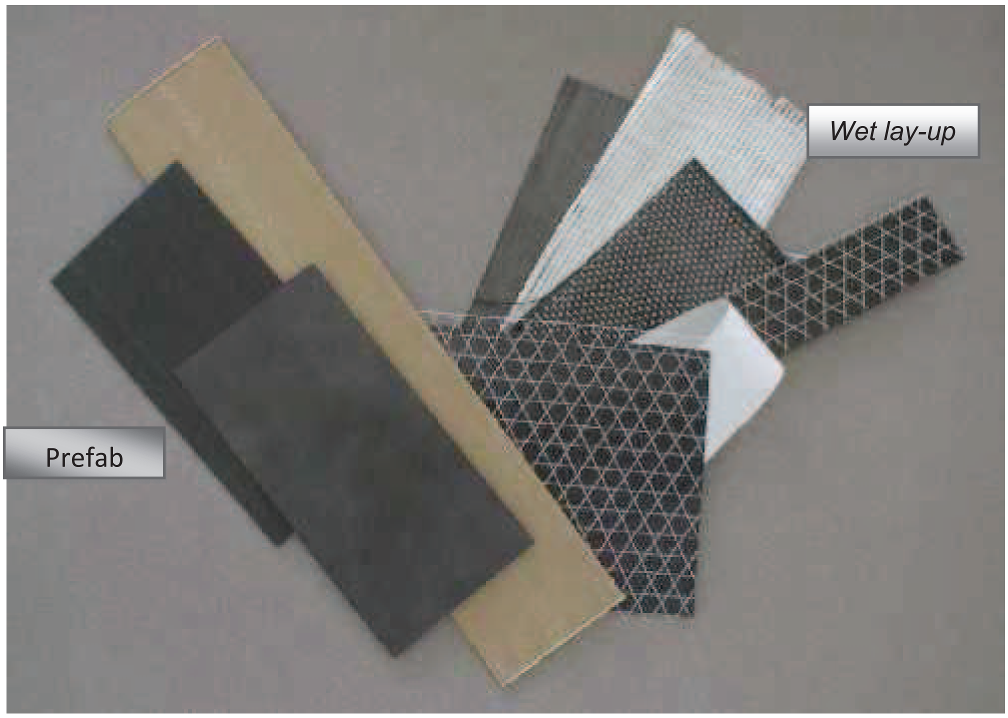
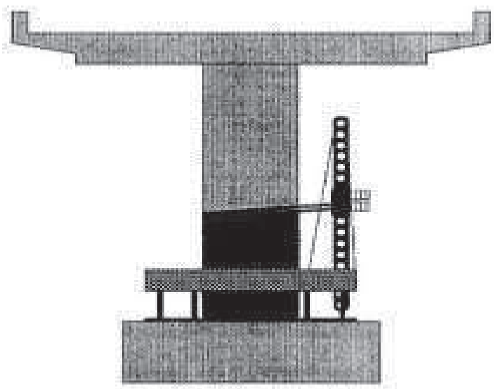


Fig 3.8. Typical Prefab system (Laminates or strips) and wet lay-up system (sheets or fabrics) photos

(a) (b)



(c) (d)

Fig 3.9. FRP techniques: (a) Hand lay-up of CFRP sheets or fabrics. (b) Application of prefabricated strips. (c)Automated RC column wrapping. (d) Schematic. Photograph of robot-wrapper. (Fib Bulletin 14, 2001).

3.6.2. Physical and Mechanical Properties of FRP

Table 3.6. Advantages and Disadvantages of FRP Reinforcements

Advantages of FRP Reinforcement	Disadvantages of FRP Reinforcements
High longitudinal strength (varies with sign and direction of loading relative to fibers)	No yielding before brittle rupture
Corrosion resistance (not dependent on a coating)	Low transverse strength (varies with sign and direction of loading relative to fibers)
Nonmagnetic	Low modulus of elasticity (varies with type of reinforcing fiber)
High fatigue endurance (varies with type of reinforcing fiber)	Susceptibility of damage to polymeric resins and fibers under ultraviolet radiation exposure
Lightweight (about 1/5 to 1/4 the density of steel)	Durability of glass fibers in a moist environment
Low thermal and electric conductivity (for glass and aramid fibers)	Durability of some glass and aramid fibers in an alkaline environment
-	High coefficient of thermal expansion perpendicular to the fibers, relative to concrete
-	May be susceptible to fire depending on matrix type and concrete cover thickness

3.6.3. FRP Strengthening

Uses of fibre reinforced polymers (FRP) materials for strengthening has rapidly increased in recent years. Due to their lightweight,high strength, resistance to corrosion, speed and ease of aplication and formed on site into different shapes can be made them preferenced material in many strengthening applications.

The main uses of externally bonded FRP (fibre-reinforced polymers) in strengthening of existing reinforced concrete elements for;

- Confinement
- Flexural Strengthening (Bending)
- Purpose of Blast Resistance
- Deflection Control
- Shear strengthening,

High Strength Polymer Fabrics are used in:

Strengthening of reinforced concrete beams against bending and shear,

Strengthening of reinforced concrete slabs against bending,

Enhancement of the shear capacity, ductility and compressive strength of columns,

Strengthening of wooden beams against bending,

Strengthening of masonry structures.

3.6.3.1. Strengthening of Reinforced Concrete Structural Members with FRP

Beams – Bending (Flexure) and Shear

Strengthening with externally bonded with Frp materials are used in beams for purpose of bending and shear. Carbon fiber polymer layer aplicated the lower face for the bending.

Fig.3.10. Application of FRP on reinforced concrete beams for seismic retrofitting

Columns- Shear capacity ,Ductility ,Compressive Strength and Confinement

Strengthening with externally bonded with Frp materials are used in column for confinement, enhancement of ductility and compressive strength besides shear.

Fig.3.11. Application of FRP on reinforced concrete column for seismic retrofitting

Slabs- Bending

Strengthening with Frp materials are used in slabs for enhancement flexural capacity.

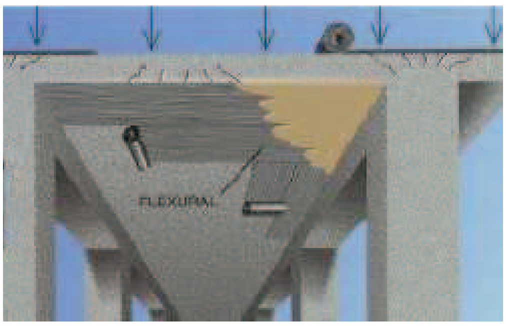
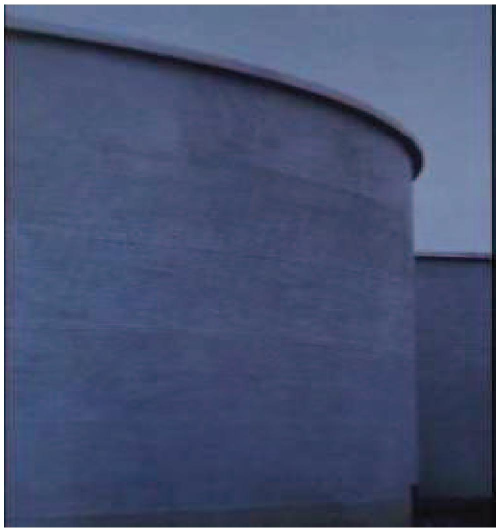


Fig.3.12. Application of FRP on reinforced concrete slab for seismic retrofitting

(a)

(b)

(c)



(d)

(e)

Fig 3.13. Typical FRP applications as strengthening materials of RC structures: (a) flexural strengthening of slab; (b) flexural strengthening of beam; (c) shear strengthening and confinement of column; (d) wrapping of concrete tank; (e) shear strengthening of beam-column joint. (Fib Bulletin 14, 2001).

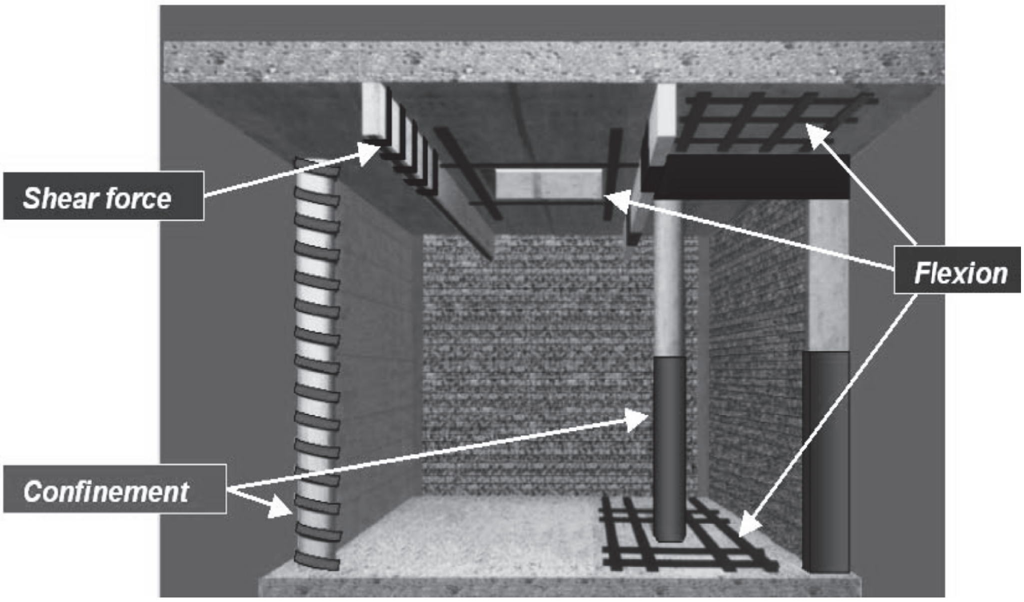


Fig 3.14. Typical FRP Application Site as Strengthening Materials of RC Structural Elements

3.7. Models of Concrete Corresponding to Stress-Strain Confined by Fiber Composites

The confinement stregth of the concrete model form generaly shown in equation which is related to the confinement pressure;

$$f'_{cc} = f'_{co} + k_1 f1$$

where , f_1 = confinement pressure, k_1 =coefficient of effeciveness,

3.7.1. Model Proposed by TDY2007

This model mentioned information attachment 7.E in TDY2007; '*Effects of FRP Confinements on Strength and Ductılty of RC Columns'* Axial compression strength of confined columns can be received as;

$$f_{cc} = f_{cm}\left(1 + 2.4(f_1 / f_{cm})\right) \geq 1.2\, f_{cm}$$

where f_{cc} =f'_{cc}= compressive strength of confined concrete, f_{cm} = f'_{co}= unconfined concrete strength

As shown in model, strengthening limited where the compressive strength of confined concrete is not exceed 20% of the current strength, It should not be applicated.

$$f_1 = \frac{1}{2}\, \kappa_a\, \rho_f\, \varepsilon_f\, E_f$$

κ_a defined as a shape factor

$$\kappa_a = \begin{cases} 1 & circular\ cross - section \\ \left(\frac{b}{h}\right) & ellipse\ cross - section \\ 1 - \frac{(b-2r)^2 + (h-2r)^2}{3bh} & rectangular\ cross - section \end{cases}$$

ρ_f is defiened as a FRP reinforcement ratio,

$$\rho_f = \frac{2\, n\, t_f\, (b+h)}{bh}$$

n = number of plies of FRP reinforcement, t_f =nominal thickness of one ply of the FRP reinforcement, b and h are width of rectangular cross section, and overall thickness of a member

$\varepsilon_f \leq 0.004$ and $\varepsilon_f \leq 0.50\, \varepsilon_{fu}$

ε_f and ε_{fu} are a strain level in the FRP reinforcement and design rupture strain of FRP reinforcement and also E_f is a tensile modulus of elasticity of FRP.

Enhancement of column ductility with FRP;

To increase the ductility of confining columns with FRP, ratio of the long dimension of column cross-section to short dimension of column-cross-section should not exceed 2.

$(b / h \leq 2)$

$$\varepsilon_{cc} = 0.002\ (1+15\ (f_1 / f_{cm})^{0.75})$$

where ε_{cc} is a concrete strain corresponding to confined concrete compressive strength (TDY2007)

3.7.2. Model Proposed by ACI 440

Bonding FRP systems can be used to increase the axial compression strength and also increase the axial tension strength of a concrete member. Confinement is also used to enhance the ductility of members subjected to combined axial and bending forces. To determine the full stress-strain behavior of FRP-confined concrete, the compressive strain in the concrete (longitudinal strain) must be related to the strain developed in the FRP jacket (transverse strain). The strain in the FRP jacket may then be used to determine the confining pressure and the resulting increase in the compressive stress in the concrete.

The confined concrete strength can be computed from Eq. (1) using a confining pressure given in Eq. (2) that is the result of the maximum effective strain that can be achieved in the FRP jacket.

$$f'_{cc} = f'_c \left[2.25 \sqrt{1 + 7.9 \frac{f_1}{f'_c}} - 2 \frac{f_1}{f'_c} - 1.25 \right] \quad (1)$$

$$f_1 = \frac{\kappa_a \, \rho_f \, \varepsilon_{fe} \, E_f}{2} \quad (2)$$

the effective strain in the FRP jacket should be limited to Eq. (3)

$\varepsilon_{fe} = 0.004 \leq 0.75 \, \varepsilon_{fu}$ (3)

$$\varepsilon_{fu} = C_E \, \varepsilon^{*}_{fu}$$

Where C_E is environmental-reduction factor for frp systems and ε^{*}_{fu} is ultimate rupture strain of FRP

Table 3.7. Environmental-reduction factor for various FRP systems and exposure conditions (ACI2002)

Exposure conditions	**Fiber and resin type**	**Environmental reductionfactor *CE***
Interior exposure	Carbon/epoxy	0.95
	Glass/epoxy	0.75
	Aramid/epoxy	0.85
Exterior exposure (bridges, piers, and unenclosed parking garages)	Carbon/epoxy	0.85
	Glass/epoxy	0.65
	Aramid/epoxy	0.75
Aggressive environment (chemical plants and waste water treatment plants)	Carbon/epoxy	0.85
	Glass/epoxy	0.50
	Aramid/epoxy	0.70

Table 3.8. Equations of ρg and K_a for circular and noncircular Sections

Circular sections	**Noncircular sections**
$\rho_f = \frac{4n\, t_f}{h}$ $Ka = 1.0$	$\rho_f = \frac{2\, n\, t_f\,(b+h)}{bh}$ $Ka = 1 - \frac{(b-2r)^2 + (h-2r)^2}{3bh\,(1-\rho_g)}$

Where r is the radius of the edges of the section and ρ_g is the ratio of the area of longitudinal steel reinforcement to the cross-sectional area of a compression member

The confining effect of FRP jackets should be assumed to be negligible for rectangular sections with aspect ratios *b/h* exceeding 1.5, or face dimensions, *b* or *h*, exceeding 900 mm, unless testing demonstrates their effectiveness.

Enhancement of column ductility with FRP ;

Increased ductility of a section results from the ability to develop greater compressive strains in the concrete before compressive failure.

$$\varepsilon'_{cc} = \frac{1.71(5f'_{cc} - 4f'_{c})}{E_c} \qquad \text{(ACI 440,2002)}$$

Where *Ec* is modulus of elasticity of concrete

4. CASE STUDY

In this study, sample specimens which analysed by İlkı et al. 2008, have been confined with FRP materials and than checked with the TDY2007 and ACI 2002 codes. For this purpose these sample material properties is assumed to be used for a poor designed industrial building and ıt's live load increased about 40 percent with respect to intend use changed. This structure's strength (f'_{co}) have been increased to satisfy the codes by using FRP materials. Low-and high-strength structural member enhancements of stress-strain comparison is provided in this contex. Experimental studies of Ilki et al.2008 were used as sample material properties for calculation of structure's design load, which has increased the structural load by 40%.

New unconfined strength (f'_{co}) is estimated, reinforced concrete member (column) is confined with FRP materials.Further calculations were carried out to identify how many plies of CFRP sheets will be jacketed.

İlki at al 2008 are tested, low strength reinforced concrete columns with inadequate internal transverse reinforcement and medium strength concrete with adequate internal transverse reinforcement under uniaxial compression after being jacketed externally with carbon fiber-reinforced polymer (CFRP) sheets in their study. Thickness of the CFRP jacket, cross-section shape, concrete strength, amount of internal transverse reinforcement, corner radius, existence of predamage,loading type (monotonic or cyclic) and the bonding pattern (orientation, spacing, anchorage details, additional corner supports) of CFRP sheets were the main test parameters of the extensive experimental work. İn study for example LSR-R-1-3-40a represents a specimen cast using low strength concrete with a rectangular cross section having a cross-sectional aspect ratio of 1, jacketed with 3 plies of CFRP sheets, and the corners rounded to 40 mm radius and also LSR is refer to low strength and NSR is refer to medium or normal strength (İlki at all, 2008). All specimens were jacketed externally by either 1, 3, or 5 plies of unidirectional CFRP sheets and epoxy adhesive was used for bonding CFRP sheets on the specimensheets on the specimens. The specimens properties are shown in Table 4.1.

Table 4.1. Specimens Properties

Specimens properties	
Loading Type	Monotonic (M)
Strength	5 speciemens are low strength concrete 6 speciemens are medium strength concrete
Cross Sections	Square
Longitudinal reinforcement	4Ø14
Corner radius (mm)	40mm
Longitudinal reinforcement ratio ρ =	around 0.01
clear concrete cover	25 mm for all specimens
cross-sectional dimensions	250x250 mm

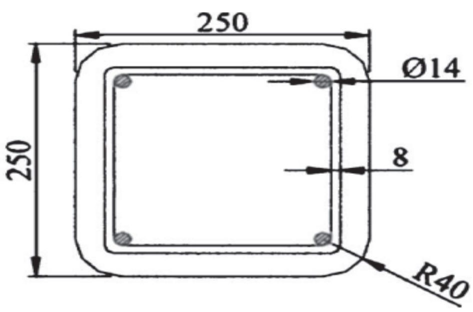


Fig 4.1. Croos-Section and Reinforcement detail of Specimen (Ilkı et.al 2008)

Table 4.2. Manufactured FRP Properties

FRP Properties (dryfiber-reinforced polymer fabric of)	
The tensile strength , f_{fu} =	3430 MPa
Elasticity modulus , Efrp =	230 GPa,
Ultimate rupture strain, ε_{fu} =	1.5%,
Nominal thickness , t_f =	0.165 mm

Table 4.3. Experimental Stress and Strain Value of Confined Column

Specimen	**fcj Mpa**	**Transverse reinforcement**	**n**	**f'co (Mpa)**	**f'cc (exp) (Mpa)**	**Ecc (exp)**
1. LSR-R-1-1-40a-A	15.92	Ø8/200	1	10.83	18.96	0.013
2. LSR-R-1-1-40b-A	15.92	Ø8/200	1	10.83	20.58	0.013
3. LSR-R-1-1-40a[b]	15.92	Ø8/200	1	10.83	20.58	0.017
4. LSR-R-1-3-40a[b]	15.92	Ø8/200	3	10.83	37.57	0.055
5. LSR-R-1-5-40a[b]	15.92	Ø8/200	5	10.83	51.91	0.068
6. NSR-R-1-050-3-40	27.58	Ø8/50	3	23.44	44.67	0.033
7. NSR-R-1-100-3-40	27.58	Ø8/100	3	23.44	45.80	0.035
8. NSR-R-1-200-3-40	27.58	Ø8/200	3	23.44	42.08	0.033
9. NSR-R-1-050-5-40	27.58	Ø8/50	5	23.44	57.40	0.046
10. NSR-R-1-100-5-40	27.58	Ø8/100	5	23.44	57.73	0.044
11. NSR-R-1-200-5-40	27.58	Ø8/200	5	23.44	58.82	0.052

f_{cj} = standard cylinder strength at the time of testing; f'_{co} = unconfined concrete member strength; f'_{ccexp} = confined concrete strength obtained from experiments; $\varepsilon_{cc\ exp}$ = concrete strain corresponding to confined concrete compressive strength obtained from experiments;

n =number of CFRP ply(ies) A_indicates specimens with additional

CFRP anchorages;

Unconfined concrete strength of the member f'_{co} was assumed to be 85% of the standard cylinder strength at the time of testing, when the strength of the same size unconfined specimen was not obtained experimentally. Thus $f'_{co} = 0.85 \times f'_{cj}$

$f'_{co} = 0.85\text{x } 15.92 = 13.53$ (low strength concrete)

$f'_{co} = 0.85\text{x } 27.58 = 23.44$ (medium strength concrete)

In tis study specimens are named L1 to L5 for low strength concrete and other 6 specimens are named M6 to M11 for medium strength concrete.For example first sample LSR-R-1-1-40a-A is named L1 ,second one is taken L2 and eleventh is taken M11 e.tc.

Estimation of f_1, f'_{cc} and ε_{cc} according to TDY2007 & ACI2002 shown in Table 4.4.

Table 4.4.Estimation of f_1 , f'_{cc} and ε_{cc} according to TDY2007 & ACI2002

Specimen	**n**	**f'co (Mpa)**	**TDY2007**			**ACI2002**			**f'cc exp (Mpa)**	**εcc (exp)**
			f_1 (Mpa)	f'cc (Mpa)	ε_{cc} (Mpa)	f_1 (Mpa)	f'cc (Mpa)	ε_{cc} (Mpa)		
L1	1	13.53	0.84	15.546	$5.7x10^{-3}$	0.825	18.49	$2.5x10^{-3}$	18.96	0.013
L2	1	13.53	0.84	15.546	$5.7x10^{-3}$	0.825	18.49	$2.5x10^{-3}$	20.58	0.013
L3	1	13.53	0.84	15.546	$5.7x10^{-3}$	0.825	18.49	$2.5x10^{-3}$	20.58	0.017
L4	3	13.53	2.52	19.578	$10x\ 10^{-3}$	2.475	25.74	$4.9x10^{-3}$	37.57	0.055
L5	5	13.53	4.2	23.61	$14x10^{-3}$	4.125	31.04	$6.6x10^{-3}$	51.91	0.068
M6	3	23.44	2.52	29.488	$7.6x10^{-3}$	2.475	37	$5.1x10^{-3}$	44.67	0.033
M7	3	23.44	2.52	29.488	$7.6x10^{-3}$	2.475	37	$5.1x10^{-3}$	45.80	0.035
M8	3	23.44	2.52	29.488	$7.6x10^{-3}$	2.475	37	$5.1x10^{-3}$	42.08	0.033
M9	5	23.44	4.2	33.52	$10x10^{-3}$	4.125	44	$7\ x10^{-3}$	57.40	0.046
M10	5	23.44	4.2	33.52	$10x10^{-3}$	4.125	44	$7x10^{-3}$	57.73	0.044
M11	5	23.44	4.2	33.52	$10x10^{-3}$	4.125	44	$7\ x10^{-3}$	58.82	0.052

According to TDY2007, the compressive strength of confined concrete must be exceed 20% of the current strength so the first three specimens, which are written red , values are unsuitable.Table 4.5 show that the increasing of strength (f'_{co}) due to FRP

Table 4.5. Value of $\frac{f'_{cc}}{f'_{co}}$ Due to jacketed with FRP

Specimen	$\frac{f'cc}{f'co}$ ratio due to FRP (Increase in Strength (f'_{co}) due to FRP)		
	TDY2007	**ACI2002**	**f'_{cc} (exp) İlki et al.**
L1	1,14	1,36	1,40
L2	1,14	1,36	1,52
L3	1,14	1,36	1,52
L4	1,44	1,90	2,77
L5	1,74	2,29	3,83
M6	1,25	1,57	1,90
M7	1,25	1,57	1,95
M8	1,25	1,57	1,79
M9	1,43	1,87	2,44
M10	1,43	1,87	2,46
M11	1,43	1,87	2,50

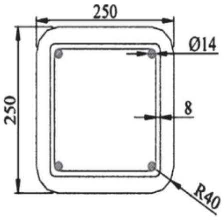
Experimental per estimated value of stres strain, $\frac{f\,cc'\,(exp)}{f'cc}$ and $\frac{\varepsilon\,cc'\,(exp)}{\varepsilon'cc}$, due to the FRP is shown in Table 4.6.

Table 4.6 $\frac{\mathbf{f\,cc'\,(exp)}}{f'cc}$ and $\frac{\boldsymbol{\varepsilon}\,\mathbf{cc'\,(exp)}}{\varepsilon' cc}$ value due FRP

Specimen	$\frac{\mathbf{f\,cc'\,(exp)}}{f'cc}$ ratio		$\frac{\boldsymbol{\varepsilon}\,\mathbf{cc'\,(exp)}}{\varepsilon' cc}$ ratio	
	TDY2007	**ACI2002**	**TDY2007**	**ACI2002**
L1	1,22	1,02	2.28	5.2
L2	1,33	1,11	2.28	5.2
L3	1,33	1,11	2.98	6.8
L4	1,91	1,45	5.50	11.2
L5	2,19	1,67	4.86	10.3
M6	1,51	1,20	4.34	6.47
M7	1,55	1,23	4.60	6.86
M8	1,42	1,13	4.34	6.47
M9	1,71	1,30	4.60	6.57
M10	1,72	1,31	4.40	6.28
M11	1,75	1,33	5.20	7.42

This analytical study is considered an industrial building .Building's design load is changed due to intended uses change. Building's material and mechanical properties is taken from experimental study which is compared with TDY2007 and ACI2002.

The 28 day standard cylinder strength f'_c was taken 10.94 and 23.86 MPa, respectively, for low and medium strength concrete from experimental study of Ilkı et al, 2008.



$A_c = \frac{N_d}{0.5\, f_{ck}}$ A_c =250x250 =62.5x10^{-3} mm^2

62.5x10^{-3} = $N_{d\,(L)}$ / (0.5x10.94) = $N_{d\,(L)}$ =341

62.5x10^{-3} = $N_{d\,(M)}$ / (0.5x 23.86) = $N_{d\,(M)}$ =745.6

$N_{d\,(L)}$ and $N_{d\,(M)}$ are design load ,respectively, for low and medium strength reinforced concrete member. $Nd_{(i)}$ is initial design load, $Nd_{(f)}$ is final design load,

$Nd_{(i)}$ is increased 40% , new load is shown as a $Nd_{(f)}$ in Table (4.7)

$f'cc_{(p)} \geq$ 485 / (62.5x10^{-3}x 0.5) ≥ 15.52 MPa for low strength specimens

$f'cc_{(p)} \geq$ 1045 / (62.5x10^{-3}x 0.5) ≥ 33.44 MPa for medium strength specimens

where, $f'cc_{(p)}$ is proposed design strength of confined concrete,

Table 4.7. Increased Design Load for Low and Medium Strength reinforced concrete member

Low strength structural member			Medium strength structural member		
f'_c (MPa)	$Nd_{(i)}$ (Newton)	$Nd_{(f)}$ (Newton)	f'_c (MPa)	N_d (Newton)	$Nd_{(f)}$ (Newton)
10.94	341	485	23.86	745.6	1045

Table 4.8. Minimum number of FRP plies, for f 'cc $_{(p)}$

Specimen	**n**	**f'co (Mpa)**	**TDY2007**			**ACI2002**		
			f_1 (Mpa)	f'cc (Mpa)	ε_{cc} (Mpa)	f_1 (Mpa)	f'cc (Mpa)	ε_{cc} (Mpa)
Low strength	1	10.94	0.84	12.95	6.4 x10^{-3}	0.82	**15.74**√	2.3x10^{-3}
	2	10.94	1.68	14.97	9.3 x10^{-3}	1.64	21.06	4.1x10^{-3}
	3	10.94	2.52	**16.98** √	11.9x10^{-3}	2.46	22.44	4.5x10^{-3}
	4	10.94	3.36	19.00	14.3x10^{-3}	3.28	24.97	5.33x10^{-3}
	5	10.94	4.3	21.26	11.9x10^{-3}	4.1	27.14	6.04x10^{-3}
Medium strength	1	23.86	0.84	25.87	4.43x10^{-3}	0.82	29.08	3.28x10^{-3}
	2	23.86	1.68	27.89	6.1x10^{-3}	1.64	**33.58**√	4.76x10^{-3}
	3	23.86	2.52	29.90	7.55x10^{-3}	2.46	37.57	6.07x10^{-3}
	4	23.86	3.36	31.92	8.9x10^{-3}	3.28	41.15	7.25x10^{-3}
	5	23.86	4.3	**34.18** √	10.3x10^{-3}	4.1	44.4	8.32x10^{-3}

Necessary number of FRP plies which satisfy f 'cc $_{(p)}$ values shown in Table 4.8. It shows that low-strength samples are provided in 3 plies of FRP for TDY2007, however ACI2002 indicates use of 1 layer of FRP. On the other hand for medium-strength sample by TDY2007 is provided in 5 plies of FRP but in ACI2002 ıt is provided in 2 layers of FRP. On the other hand, ıt can be noted that from Table 4.8 as the number of FRP plies increased, the strain value and indirectly ductility is also increased. This situation shows that provided number of FRP plies for low- strength structural member is lower than medium-strength structural member.

5-CONCLUSION

FRP strengthening or retrofitted techniques can enhance stres-strain performance of existing reinforced concrete structures. Reinforced concrete structures may need strengthening or retrofitted due to incorrect calculations and applications of project the use of unsuitable materials for standarts or guidelines, the low quality of concrete,inadequate lateral reinforcement, change of usage, additional storey, environmental factors, poor workmanshıp e.t.c. FRP composites are used for strengthening applications mainly due to the lightweight, high strength, resistance to corrosion, speed and ease of aplication and formed on site.

This analytical study shows that, reinforced concrete members jacketed with FRP material for strengthening can cause enhancement of compressive strength of confined concrete (f'_{cc}). Experimental result of confined cocrete is compared with Models of Concrete Corresponding to Stress -Strain Confined by Fiber Composites which are TDY2007 and ACI 2002. According to analytical study results ACI 2002 is close to the experimental result. It can be concluded that TDY2007 experimental results of confined strength is more safe than ACI 2002.

Structure's initial design load ($Nd_{(i)}$) increased by 40% due to change of intended use should satisfy the new proposed section compressive strength. The aim is to determined the number of plies of CFRP sheets that jacketed the reinforced concrete members satisfy proposed confined concrete strength ($f'cc_{(p)}$). As a result it is noted that for low- strength concrete required minimum 3 number of plies of FRP jacketed to satisfy TDY2007 and min 1 ply for ACI 2002.On the other hand for medium –strength minimum 5 and 2 plies requisite, respectively, for TDY2007 and ACI 2002. The analiytical study shows that TDY2007 is remained safety side to ACI 2002. ACI2002 is more closed to experimental data. Furthermore ıt can be concluded that using FRP material increase both strength and ductility of compressive sections.

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