Strengthening Concrete Sections by FRP Materials

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Abstract: - Fiber Reinforced Polymers (FRP) as a kind of composite materials have became widespread in the strengthening of reinforced concrete (RC) structures as an alternative way of traditional strengthening methods such as externally-bonded steel plates, jacketing etc. usage of such polymers for strengthening has rapidly increased in recent years. The advantages due to their lightweight, high strength, resistance to corrosion, speed and ease of application as externally bonded FRP sheets and strips gain considerable usage increase in construction industry. In this study, experimental results are compared with ACI 2002 and TDY2007 codes for strengthening concrete sections including the mechanical properties of FRP material. The experimental and code results are evaluated and comparison of standard deviation values is discussed.

Key-Words: Mechanical Properties, Fiber Reinforced Polymers, Reinforced concrete sections, strengthening

1 Introduction

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 is 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 don't have alone. In other words, it is aimed to produce superior properties of a new material production than existing components.

Fiber Reinforced Polymers (FRP) as a type of composite materials has became an alternative way of traditional strengthening methods in the strengthening of reinforced concrete structures. Usage of such polymers for strengthening has rapidly increased in recent years due to their lightweight, high strength, resistance to corrosion, speed and ease of application in construction industry. Many researchers deal with FRP materials as a new technique for strengthening concrete columns as reinforced concrete element to improve for seismic strengthening in structural engineering [1-6].

The technique for columns requires wrapping thin, flexible high-strength fiber composite straps around the column to improve the confinement and, so, its ductility and strength in most cases. In order to investigate the gain in strength and ductility of concrete columns externally confined by CFRP wrapping that included many tests on short column specimens with circular, square and rectangular cross section shapes. The amount of confinement expressed in the number of CFRP sheet layers applied to the models. 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.

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 such studies indicated 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. The technique used provides increase in the axial carrying capacity of the column and the ductility factor increases linearly with increase in strap thickness. On the other hand the flexural behavior of earthquake-damaged reinforced concrete columns repaired with prefabricated fiber reinforced plastic (FRP) wraps investigated by [7-9]. In these cases column specimens were tested to failure under reversed inelastic cyclic loading to a level that can be considered higher than would occur in a severe earthquake. The columns were repaired with prefabricated FRP wraps and retested under simulated earthquake loadings. 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 for both flexural strength and displacement ductility of repaired columns were higher than those of the original columns.

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 standards 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 increased (excessive loading)
- additional storey
- poor workmanships

Structural damages are affecting 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 standards 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 increased
- additional storey
- corrosion (environmental factors)
- poor workmanship
- changing the guidelines or the formation of new standards etc.

In some cases 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.

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

Table 1. Mechanic properties of various materials

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 the typical strength and stiffness value for different materials in strengthening. Common strengthening materials are known as;

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

Epoxy resin: Epoxy resins are used for small injection, surface coating or filling larger cracks or holes. If it 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 depending 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 [10].

Shotcrete: The method is useful to form structural shapes by small layer of concrete or mortar is projected under pressure using a feeder or "gun" onto a prepared surface. 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 its high strength, durability, low permeability, remarkable bond and applicability of irregular shapes. Shotcrete has two applied process these are:

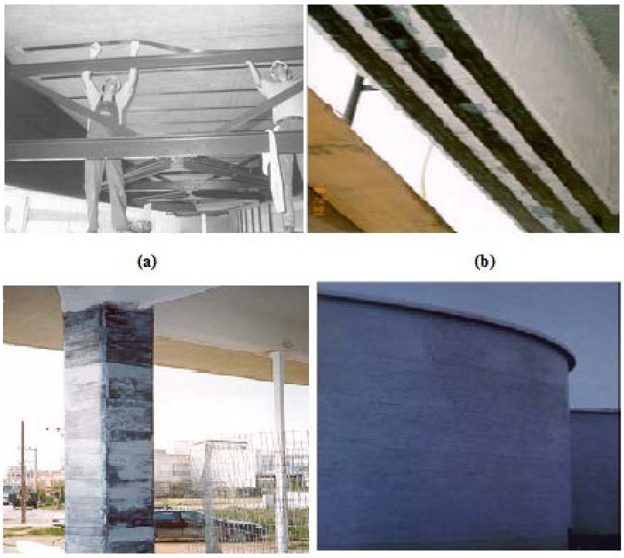
Wet Mix Process: Cement, sand, and coarse aggregate are first conventionally mixed with water, and introduced into the delivery equipment. Wet material is pumped to the nozzle where compressed air is added to provide high velocity for placement and compressed the wet mixture on to the desired surface.

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.

Epoxy Mortar: Epoxy mortar is composed of epoxy resin and sand that is placed over an epoxy bonding coat on hardened existing concrete. Epoxy 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.

FRP materials and strengthening: Fiber-reinforced polymer (FRP) can be classified as 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. In modern materials engineering, composite usually refers to a "matrix" material that is reinforced with fibers [11].

FRP materials are used as external reinforcement in the construction industry since 1970[12]. 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 [13]. In the last decade, the use of fibre reinforced polymers (FRP) as reinforcement is rapidly growth for structural strengthening in civil engineering applications. The most commonly available fiber reinforced polymer (FRP) types are the carbon (CFRP), the glass (GFRP) and the aramid (AFRP) fibers. 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 application and formed on site into different shapes can be made them referenced material in many strengthening applications as shown in Fig. 1[14].



(a) (b) (c) (d)

Fig.1 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.

The externally bonded FRP (fibre-reinforced polymers) in strengthening of existing reinforced concrete elements provides advantages in confinement, flexure (bending), blast resistance and deflection control properties.

High strength polymer fabrics are used in Strengthening of reinforced concrete beams against bending and shear, slabs against bending, enhancement of the shear capacity, ductility and compressive strength of columns. Carbon fiber polymer layer implicated the lower face surfaces for bending.

3 Case Study

In this study, sample specimens which analyzed by [15], have been confined with FRP materials and then checked with the “Building Construction Code Regulation In Earthquake Zone(s) ” TDY2007 and Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures ACI 2002 codes [16-17]. For this purpose these sample material properties is assumed to be used for a poor designed industrial building and its 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 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 needs to be wrapped.

For 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.

As case study an industrial building has been considered as its axial load capacity increased analytically. It is assumed that the design load is increased about 40% due to intend uses change. The strength and strain properties of the building assumed to be 10.94 and 23.86 MPa, for low and medium strength concrete respectively taken from experimental study[15]. The results with respect to variation of FRP amount compared with TDY2007 and ACI 2002. The FRP, specimens and cross section properties are shown in Table 2 and Fig 2.

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

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 2 Specimen and FRP Properties

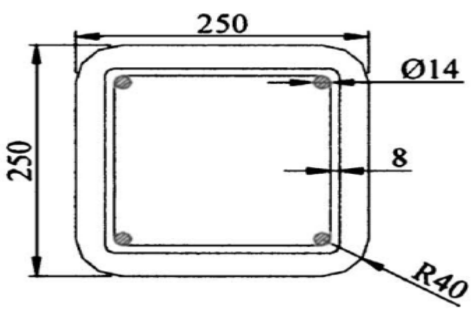


Fig 2. Cross-section and reinforcement detail of specimen

Relationship between design load N_d, concrete strength f_{ck} and column cross section area A_c defined in Turkish reinforced concrete code TS 500[18] given in Eq. 1.

$$A_c \geq \frac{N_d}{0{,}5 * f_{ck}} \qquad (1)$$

The minimum cross section area A_c =250x250 =62.5×10^{-3} mm^2 and substitute intto Eq.1. Design loads $N_{d\,(L)}$ and $N_{d\,(M)}$ for low and medium strength concrete specimens can be obtained as follow

$$62.5 \times 10^{-3} = N_{d\,(L)} / (0.5 \times 10.94) = N_{d\,(L)} = 341 \text{ kN}$$

$$62.5 \times 10^{-3} = N_{d\,(M)} / (0.5 \times 23.86) = N_{d\,(M)} = 745.6 \text{ kN}$$

These design loads of low and medium strength respectively for the reinforced concrete member can be accepted as Nd $_{(i),}$ initial design loads. For increasing the design loads 40%, the new loads obtained as 485 kN and 1045 kN for low and medium strength respectively in similar way. The initial and final design loads (Nd$_{(i}$ and Nd $_{(f)}$) for both cases are tabulated in Table 2.

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

Then the proposed design strength obtained as:

f 'cc (p) ≥ 485 / (62.5x10-3x 0.5) ≥ 15.52 MPa

for low strength specimens

$f'_{cc\,(p)} \geq 1045 / (62.5 \times 10^{-3} \times 0.5) \geq 33.44$ MPa

for medium strength specimens

where, $f'_{cc\,(p)}$ is proposed design strength of confined concrete. 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 $f'_{co} = 0.85 \times f'_{cj}$

$f'_{co} = 0.85 \times 15.92 = 13.5$ MPa

for low strength concrete

$f'_{co} = 0.85 \times 27.58 = 23.44$ MPa

for medium strength concrete

The specimens were wrapped externally by 1, 2, 3, 4 or 5 plies of unidirectional CFRP sheets and epoxy adhesive was used for bonding CFRP sheets on the specimens. The specimen properties and necessary number of FRP plies by the methods [19] which satisfy $f'_{cc\,(p)}$ values shown in Table 3. In the table specimens are named L1 to L5 for low strength concrete and other 5 specimens are named M1 to M5 for medium strength concrete.

Specimen	n	f'co (Mpa)	TDY2007 f_l (Mpa)	TDY2007 f'cc (Mpa)	TDY2007 ε_{cc} (Mpa)	ACI2002 f_l (Mpa)	ACI2002 f'cc (Mpa)	ACI2002 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}

Table 3. Number of FRP plies, for $f'_{cc(p)}$

The table indicates 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 it is provided for 2 layers of FRP. It can be noted that from Table 3as 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.

4 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 standards or guidelines, the low quality of concrete, inadequate lateral reinforcement, change of usage, additional storey, environmental factors, poor workmanship etc. The usage of FRP composites in strengthening applications has superiorities due to the lightweight, high strength, resistance to corrosion, speed and ease of application and formed on site.

The initial design load ($Nd_{(i)}$) of an existing industrial building increased by 40% due to change of intended use should satisfy the new proposed section compressive strength. It is proposed to determined the number of plies of CFRP sheets that jacketed the reinforced concrete members satisfy proposed confined concrete strength ($f'_{cc(p)}$).

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 concrete 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 safer than ACI 2002. Furthermore it can be concluded that using FRP material increase both strength and ductility of compressive sections.

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