International Journal of Emerging Trends & Technology in Computer Science (IJETTCS)
Web Site: www.ijettcs.org Email: editor@ijettcs.org
Volume 6, Issue 6, November- December 2017 ISSN 2278-6856

PERFORMANCE OF CONCRETE COLUMN WITH GFRP REBAR UNDER AXIAL LOADING

Deepthi.P[1], Dr. G. Nandini Devi[2]

[1]PG Student, Structural Engineering, Adhiyamaan College of Engineering, Hosur-635109, Tamil Nadu, India

[2]Professor, Department of Civil Engineering, Adhiyamaan College of Engineering, Hosur, Tamil Nadu, India

Abstract: ***The axial behaviour of reinforced concrete columns with glass fibre reinforced polymer (GFRP) bars, where this material represents a relatively new technology; Therefore, much research is needed to determine its characteristics and gain confidence to be accepted by engineers for practical application. More than 25 papers are being reviewed about load carrying capacity of columns and then conclusion were made from those reviews. FRP bars have emerged as an attractive alternative to the traditional steel bars because of higher ultimate tensile strength to weight ratio.***

Keywords: GFRP rebar, Column, Axial load, Compression strength, Fibre

1. INTRODUCTION

GFRP bars are a competitive option as reinforcement in reinforced concrete members subjected to flexure and shear due to their compiling physical and mechanical properties use of GFRP reinforcement is particularly attractive for structures that operate in aggressive environments, such as in coastal regions, or for buildings that host magnetic resonance imaging units are other equipment sensitive to electromagnetic field. The reduced compressive strength and stiffness of FRP bars contribute to make FRP RC columns more susceptible to instability. Because of the scarcity of relevant research outcomes and experimental evidence ACI 440 recommends not to rely on FRP bars as longitudinal reinforcement in column or as compression reinforcement in flexural members.

1.1 GFRP

Fiber Reinforced Polymers (FRP's) are a proven and successful alternative reinforcing that will give structures a longer service life. Where inevitably concrete will crack, creating a direct avenue for chlorides to begin oxidizing the steel rebar. A complete spectrum of authoritative consensus design guides, test methods, material and construction standards, product procurement specifications and qualification procedures are available to the designer and owner to safely and commercially implement FRP's in many different types of structures.

1.2 BENEFITS OF GFRP

The benefits of GFRP rebar are as follows:

- Corrosion resistance- when bonded in concrete it does not react to salt, chemical products or the alkali in concrete.as GFRP is not manufactured from steel, it does not rust.
- Superior tensile strength-GFRP rebar produced by the pultrusion process offers a tensile strength up to twice that of normal structural steel (based on area)
- Thermal expansion-GFRP rebar offers a level of thermal expansion comparable to that of concrete due to its 80% silica content.
- Electric and magnetic neutrality-as GFRP rebar does not contain any metals, it will not cause interference with strong magnetic fields or when operating sensitive electronic equipment or instruments.
- Thermal insulation-GFRP rebar does not create a thermal bridge within structures
- Lightweight-GFRP rebar is a quarter the weight of steel rebar of equivalent strength.it offers significant savings in transportation and installation

1.3 HIGH STRENGTH CONCRETE

It is a type of high performance concrete generally with a specified compressive strength of 6,000 psi (40 MPa) or greater. High strength concrete is a term used to describe concrete with special properties not attributes to normal concrete. High strength concrete that the concrete has one or more following properties

- low shrinkage
- low permeability
- a high modulus of elasticity
- high strength
- strong and durable

2. REVIEW OF LITERATURE

Antonio De Luca 2010, investigation of compressive behavior of longitudinal GFRP bars impacts the column performance, and to understand the contribution of GFRP ties to the confinement of the concrete core, and to prevent instability of the longitudinal reinforcement. Investigating the impact of the compressive behavior of longitudinal GFRP bars on strength and failure mode. The behavior of RC columns internally reinforced with GFRP bars is very similar to that of conventional steel RC columns if the longitudinal reinforcement ratio is equal to 1.0% The use of longitudinal GFRP bars is not detrimental to the performance of RC columns. The contribution of the GFRP bars to the column capacity, however, was less than 5% of the peak load, which is significantly lower than that of approximately 12% of the steel bars in the steel RC counterpart.

Ching Chiaw Choo 2006, an ultimate strength approach to examine the strength interaction behavior of fiber-reinforced polymer (FRP) reinforced concrete (RC) columns. Slenderness effects of columns are examined using a numerical integration technique. The ratio of measured ultimate compressive strength of the GFRP reinforcing bars was approximately 50% of the measured ultimate tensile strength. The ultimate compressive strain of FRP reinforcing bars, however, must be checked to ensure that compressive failure does not occur in FRP bars

Ehab M. Lotfy 2010, experimental investigation of the axial behavior of small scale square reinforced concrete columns with fiber reinforced polymer (FRP) bars Tested column with steel reinforcement has ductility more than column with GFRP reinforcement, where ultimate load, ultimate strain and initial cracking loads of column with steel reinforcement increase with 118, 117 and 117% respectively of column with GFRP reinforcement. The increasing of main reinforcement ratios with GFRP bars increase the ductility of cross section, so it has a significant effect on the initial cracking loads, ultimate strain, and ultimate loads that the columns resist The increasing of GFRP reinforcement ratios from 0.723 to 1.08% has a noticeable significant effect on the all behavior of tested columns more than the increasing of reinforcement ratios from 1.08 to 1.45%. Increasing of transverse reinforcement ratio leads to increase the toughness and ductility of tested columns with GFRP bars.

Egidijus Vanagas 2017, analyzes the possibilities of the use of composite reinforcement in axially crushed circular cross section columns. It should be noted that the experimental studies show that carrying capacity of columns reinforced with FRP is by 1.15 to 1.28 times the carrying capacity of a non-reinforced column. The axial force taken over by FRP (Fig. 3 (a)) comprises from 27% to 35% of the load-carrying capacity of the column, depending on the FRP factor of the longitudinal reinforcing bars. As shown by the experiments, ultimate failure strains of FRP bars (Eu) are sufficiently large (4-6 times those of concrete), while the modulus of elasticity, Ef, is 3-4 times that of steel and is close to the modulus of elasticity of concrete, Ec increasing transverse reinforcing bar cross-section from 6.4 mm to 12.7 mm increases the column's carrying capacity by 6% (from 2.85 MN to 3.02 MN), while decreasing the transverse reinforcement step from 120 mm to 40 mm increases the column carrying capacity by 3%.The carrying capacity of axially loaded solid members can be significantly increased by using the transverse spiral reinforcement.

Fillmore 2017, tested 30 cylinders of 36 MPa concrete to failure in pure axial compression. Commercial GFRP bars significantly increase the toughness of the specimens over unreinforced concrete, outperforming both steel and modified GFRP reinforcement in this metric. The toughness was computed by ending the numerical integration when a specimen load resistance decreases to 85% of its peak load. GFRP reinforced specimens maintained a load resistance near their peak value through more deformation. The toughness values from the specimens nearest their hypothetical reinforcement ratios were found to be 550 kN-mm for Steel 6-Bar, 620 kN-mm for C GFRP 6-Bar and 445 kN-mm for M GFRP 8-Bar. In comparison, Plain specimens had a mean toughness of 257 kN-mm. These values demonstrate that GFRP bar reinforced concrete can be designed to exhibit high deformability.

Hany Tobbi 2012, an experimental study of the behavior of 350 x 350 mm (13.78 x 13.78 in.) cross-section concrete columns reinforced with GFRP bars under concentric loading. The effects of key variables, such as tie configuration, tie spacing, and spalling of concrete cover, were studied. The reduction in tie spacing from 120 to 80mm yielded a strength gain of more than 20 Studying tie configuration and spacing clarified the effectiveness of GFRP as transverse reinforcement in increasing strength, toughness, and ductility of the confined concrete core. The strength reduction factor of 0.85 (the case for steel) can be adopted for GFRP-reinforced columns. Setting the FRP compressive strength at 35% of the FRP maximum tensile strength yielded a reasonable estimate of ultimate capacity compared to the experimental results. The GFRP bars used contributed 10% of column capacity, which is close enough to steel's contribution (12%). This proves that GFRP bars could be used in compression members provided there was adequate confinement to eliminate bar buckling

Hany Tobbi 2017, experimental results of 23 nearly full-scale square concrete columns reinforced transversally with glass FRP (GFRP) and carbon FRP (CFRP) ties, and longitudinally with GFRP, CFRP, and steel bars, and subjected to concentric monotonic axial compression were used to develop a strength model. Experimental results showed that FRP ties significantly increased concrete strength and ductility. The steel based model overestimated the strength of columns confines with FRP by an average value of 42.8%, while proposed FRP based model underestimates the strength of steel confined columns by 30.0%. The confinement effectiveness of closed FRP ties cut from continuous square spirals is higher than for C-shaped ties. The ultimate axial strain of the columns reinforced longitudinally with FRP was lower than those reinforced with steel. The contribution of FRP longitudinal reinforcement in concrete columns subjected to axial loading could be quantified.

Hamdy M. Mohamed 2014, reports on 14 full-scale circular RC columns tested under concentric axial load. The test results indicate that the GFRP and CFRP RC columns behaved similarly to columns reinforced with steel. The GFRP and CFRP RC columns behaved similarly to the steel RC columns and exhibited linear load-strain behavior in the ascending part up to 85% of their peak loads FRP circular hoops were found to be as efficient in confining concrete as spirals; the GFRP and CFRP RC columns with spirals attained 1.3% and 2.2%, respectively, higher strength than their counterpart specimens confined with hoops, with an insignificant increase in ductility and confinement efficiency the GFRP and CFRP bars developed up to 0.4% and 0.7% compressive strain, confirming that the FRP bars were effective in resisting compression until after crushing of the concrete; The GFRP and CFRP RC columns failed in a brittle and explosive manner when confined with less than a 1.5% volumetric ratio; failure of the well-confined GFRP RC columns was attributed to crushing of the concrete core and rupture of the GFRP spirals

Hany Jawaheri Zadeh 2013, suggests the application of glass FRP (GFRP) reinforcement for the next revision of guidelines by showing the theoretical approach at the basis of the behavior of GFRP-RC members subject to simultaneous flexural and axial loads providing revised design and analysis provisions for GFRP-RC columns similar to those in practice for steel-RC columns showing how interaction diagrams can be developed for both rectangular and circular cross sections explaining the rationale for a new formulation of the strength reduction factor for simultaneous flexural and axial resistance that is consistent with current guidelines, and reformulating the shear strength computation. To avoid exaggerated deflections, a limit of 1% is imposed on the maximum design strain of GFRP longitudinal bars. Modification factors for the flexural stiffness of GFRP-RC members are proposed.

Hany Tobbi 2014, reports the experimental investigation of the compressive performance of concrete columns reinforced longitudinally with FRP or steel bars and with FRP as transverse reinforcement. Results showed that FRP bars have contribution as longitudinal reinforcement for concrete columns subjected to concentric compression and that the combination of FRP transverse reinforcement The ultimate axial strain of columns reinforced longitudinally with FRP is almost 30% lower than those reinforced with the same volume of steel. The ultimate axial compressive strain for columns reinforced longitudinally and transversally with FRP can reach a value on the same order of magnitude as the FRP ultimate tensile strain of the longitudinal bars under good confinement condition and steel longitudinal bars offers acceptable strength and ductility behavior.

Hayder Alaa Hasan 2017, concluded that an experimental investigation on high strength concrete (HSC) and steel fibre high strength concrete (SFHSC) circular column specimens reinforced longitudinally and transversely with Glass Fibre-Reinforced Polymer (GFRP) bars and helices, respectively. GFRP bar reinforced SFHSC (GFRP-SFHSC) specimens sustained 3–13% higher axial load and 14–27% greater ductility than GFRP-HSC specimens under different loading conditions. The direct replacement of the steel reinforcement in (Specimen S60E0) by same amount of GFRP reinforcement in (Specimen G60E0) resulted in about 30% less ductility in the HSC column. GFRP bar reinforced HSC specimens experienced about 10% and 12% lower axial load carrying capacity than the steel bar reinforced HSC specimens as a result of changing the loading condition from concentric axial load to 25 and 50 mm eccentric axial load, respectively. The response of the GFRP bar reinforced concrete specimens under different loading condition can be predicted using the same analytical procedures used for the steel bar reinforced concrete specimens.

Hogr Karim 2016, reports the results of experimental investigations of concrete specimens reinforced with GFRP bars and GFRP helices as longitudinal and transverse reinforcement, respectively.an analytical model has been developed for the axial load-axial deformation behavior of the circular concrete columns reinforced with GFRP bars and helices ratio of hoop rupture strain to the ultimate tensile strain of the GFRP helices was about 0.333 and 0.25 in the specimens with and without longitudinal GFRP bars, respectively. The specimens with longitudinal GFRP bars achieved about 13% and 52% greater first and second peak loads, respectively, than the corresponding specimens without longitudinal bars. Longitudinal GFRP bars improved the first and the second peak loads, the ductility and the confined concrete strength of the GFRP-RC columns.

Joel Brown 2001, examined the practicality of using GFRP bars as reinforcement in concrete compression members. The axial capacity of the GFRP reinforced columns was 13% less than the steel reinforced equivalent. GFRP ties in their concentrically loaded columns and deduced that it reduced the axial capacity by only 10% compared to columns reinforced with traditional steel ties This indicates that the use of smaller tie spacing has provided the restraint necessary to protect the GFRP bars from premature failure

Jim Youssef 2017, summarizes an experimental program on the axial and flexural behavior of square concrete members reinforced with glass fiber reinforced polymer (GFRP) bars and embedded with pultruded GFRP structural sections under different loading conditions. Based on the parametric study, the load and bending moment capacities increase with the increase in concrete strength. Furthermore, the interaction diagrams of GFRP reinforced columns do not experience balanced points unlike that of steel reinforced columns. This study is believed to give an understanding on the behavior of GFRP reinforced and GFRP encased concrete columns subjected to various loading conditions.

Jiang 2016, an experimental study on the compressive performance of twelve FRP-confined UHSC columns under axial compression The ultimate compressive strength can be significantly enhanced by GFRP confinement. For batch A concrete, 4 plies of GFRP increased the compressive strength by 193% while 6 plies of GFRP increased the compressive strength by 259%. For batch B concrete, 4 plies of GFRP increased the compressive strength by 181%, while 6 plies of GFRP increased the compressive strength by 226% The ultimate strain can also be significantly enhanced by GFRP confinement. For batch A and batch B concrete, 4 plies of GFRP increased the ultimate strain by 587% and 776% respectively, while 6 plies of GFRP increased the strain by 509% and 594% respectively.

Koosha 2017, presented the compressive performance of short concrete columns reinforced with glass fiber reinforced polymer (GFRP) composite rebars. A total of fourteen 500 mm long concrete specimens with square cross-section (150×150 mm) were prepared and tested under concentric and eccentric compressive loading up to failure. Nine of the specimens were reinforced with six GFRP rebars (16 mm diameter), longitudinally. Different eccentricities, namely, 0, 10, 20, and 30 percent of the width of the specimens were considered. Strain of GFRP rebars was monitored during the tests to evaluate the usable level of strain and mode of failure of rebars. It was observed that the GFRP rebars were able to withstand the peak concentric and eccentric loads without crushing and local buckling. The contribution of rebars in compression was 39 percent of the tensile rupture strain of rebars which is determined by material test. Due to the fact that the recorded strain in compressive rebars exceeds the defined crushing strain of concrete in compression (0.0035 mm/mm) it is concluded that the rebars in compression contribute to the column capacity even after concrete crushed.

Li Sun 2017, conducted experiments to investigate the behavior of glass fiber reinforced polymer reinforced concrete columns (GFRP-RCCs) under an eccentric axial load. The study also showed that the bond behavior between the GFRP bars and concrete improved when the GFRP bars were used as longitudinal compressive bars. Test results indicated that the columns achieved 84% of the axial load capacity of the all-steel control column. The axial capacities of circular columns reinforced with GFRP bars and ties and indicated that the behavior of circular concrete columns reinforced with GFRP was similar to those with steel bars although the axial capacities of the GFRP-RC columns were 7.0% lower than those of their counterpart steel-RC columns.

Luke Bisby 2010, presents the results of a systematic test program on circular FRP-confined RC columns of realistic slenderness under eccentric axial loads to study the mechanics and performance of these types of members. to experimentally investigate the performance of FRP confined circular RC columns under axial compressive loads of increasing initial eccentricity to compare the performance of unconfined RC columns with identical FRP-confined RC columns under axial compressive loads of increasing eccentricity the ultimate strength of the 33 MPa concrete was increased by about 33% due to FRP confinement. The strength and deformation capacity of circular FRP-confined RC columns under eccentric axial loads is substantially improved as compared with identical unconfined columns

Qasim S. Khan 2012, presents the results of tension and compression tests of circular pultruded Glass FRP (GFRP) bars and Carbon FRP (CFRP) bars of 15 mm and 15.9 mm diameter, respectively. For tensile properties, three 1555 mm long GFRP bars and three 1555 mm long CFRP bars were tested in tension. For compressive properties, five 80 mm long GFRP and five 60 mm long CFRP bars were tested in compression. The experimental results showed that the ultimate strength and modulus of elasticity of FRP bars in tension are 1.67 and 1.59 times greater than in compression respectively.

Shamim Sheikh 2015, presents the experimental results of nine large-scale circular concrete columns reinforced with longitudinal and transverse glass fiber-reinforced polymer (GFRP) bars. The results showed that concrete columns reinforced with GFRP bars and spirals can behave in a manner that has stable post-peak response and achieve high levels of deformability. The crushing strength of GFRP bars in compression is approximately half of their ultimate tensile strength, and the modulus of elasticity in compression for a GFRP bar was found to be similar to that under tension. Columns P28-B-12-50 and P28-C-12-50 were designed for a lateral drift ratio of 4% and they achieved a lateral drift ratio in excess of 7%. Column P42-C-12-50 achieved a lateral drift ratio of 4.4%, which was 1.9% higher than the design value. GFRP bars, due to their larger stiffness at larger strains, performed in a more stable manner than steel bars.

Tighiouart 1998, investigated the bond strength of fiber reinforced polymer FRP rebars experimentally and compared to that of steel rebars. The average maximum bond strength of the FRP rebars varied from 5.1 to 12.3 MPa depending on the diameter and the embedment length. The GFRP rebars showed lower bond strength values compared to steel rebars. GFRP rebars show lower bond strength values than steel rebar. The average maximum bond strength decreases as the diameter of the rebar increases.

Thomas A. Hales 2016, presents the behavior of slender columns with small eccentricity (8.3% of the column size) was governed by material failure, while that of slender columns with large eccentricity (33% of column size) was governed by a buckling failure. Axial compression tests were conducted for both short and slender large-scale columns with loads placed at varying eccentricities to observe the mode of failure, load capacity, and general behavior associated with different geometric and slenderness conditions. All columns were tested using a load frame and hydraulic actuator capable of generating a load up to 8,900 kN. Loading was applied monotonically at a rate of 0.5 mm/min. The failure mode for slender columns with large eccentricity (102 mm or 33% of column size) was a stability-type buckling failure with concrete cover on the compressive side breaking away near the column mid height. These columns achieved a mid-height deflection an order of magnitude higher than the deflection of slender columns with small eccentricity (25 mm or 8.3% of the column size). GFRP longitudinal bars can provide larger deflection capacity compared to steel longitudinal bars due to their higher tensile strength.

Umesh k. sharma 2005, An experimental study investigate the behavior of high strength concrete short columns confined by circular spirals and square ties under monotonically increasing concentric compression. e final mixes had 28days average cube compression strength of 68.4 & 87.5Mpa and average cylinder strength of 58.03 and 76.80Mpa. The measured tangent elastic moduli (E_c) were 31645Mpa and 34465Mpa for lower and higher strength concrete mixes respectively. The average unreinforced specimen concrete strength was measured as 88% and 90% of the average concrete cylinder, strength for the lower high strength and upper high strength concretes respectively. The strains corresponding to the peak loads were 0.00232, 0.00256, 0.00237 and 0.0026 for CPL, CPH, SPL and SPH specimens respectively. It is observed that as the yield strength is increased from 412Mpa to 520Mpa the strength and deformability of confined concrete get improved. The higher strength concrete exhibits less lateral expansion than lower strength concrete under axial loads due to its higher modulus of elasticity and its lower internal micro cracking.

Woraphot Prachasaree 2015, presented the structural behavior and the performance of concrete columns internally reinforced with glass fiber reinforced plastic (GFRP) rebars. From this approach, the GFRP reinforcement increased the axial load capacity from 13% to 36%. The confinement effectiveness coefficient varied from3.0 to 7.0 with longitudinal reinforcement. The average deformability factors were 4.2 and 2.8 with spirals and ties, respectively. Lateral reinforcement had a more pronounced effect on deformability than on column strength. Based on this study, the amount of GFRP longitudinal and lateral reinforcement slightly affected the column strengths.

Yeganeh 2016, presents the results of experimental and analytical investigations on the structural performance of high performance reinforced concrete (HPC) columns subjected to monotonic axial loading UHPC long column had more than 1100kN load capacity which was higher than short ECC and SCC columns with 900kN and 585kN load-capacity, respectively. Short UHPC column showed 100% and 200% increase in axial load-capacity compared to ECC and SCC short columns, respectively. UHPC column showed higher vertical displacement compared to its ECC and SCC counterparts by 60% and 100%, respectively. Maximum axial load capacity of UHPC columns was 3 times higher (for short column) and 2 times higher (for long column) compared to their SCC counterparts. Columns made of ECC showed increased axial load capacity compared to SCC columns - 36% higher for short columns and 70% for long columns**.**

3. CONCLUSIONS

This literature summarizes the performance of GFRP rebar in structures, concluded that the GFRP has a very important role to play as reinforcement in concrete structures with salient features listed below:

- It was observed that compressive rebar tolerate the load without buckling and crushing.
- It is the unique physical properties of GFRP that makes it suitable for applications where conventional steel would be unsuitable.
- The behavior of RC column internally reinforced with GFRP bars is very similar to that of conventional steel RC column if the longitudinal reinforcement ratio is equal to 1.0%
- The contribution of rebar's in compression was 39% of the tensile rupture strain of rebars which is determined by material test.
- By Increasing of longitudinal reinforcement ratio leads to increase the toughness and ductility of tested columns with GFRP bars.
- GFRP longitudinal bars can provide larger deflection capacity compared to steel longitudinal bars due to their higher tensile strength
- The load carrying capacity of the GFRP rebars column increases when compared to steel reinforced column.
- The GFRP bars used contributed 10% of column capacity, which is close enough to steel's contribution (12%). This proves that GFRP bars could be used in compression members provided there was adequate confinement to eliminate bar buckling
- The GFRP rebars were able to withstand the peak concentric and eccentric loads without crushing and local buckling.
- The rebars in compression contribute to the column capacity even after concrete crushed.
- The ultimate axial strain of columns reinforced longitudinally with FRP is almost 30% lower than those reinforced with the same volume of steel.
- The modulus of elasticity in compression for a GFRP bar was found to be similar to that under tension.
- GFRP bars, due to their larger stiffness at larger strains, performed in a more stable manner than steel bars.

- The axial stiffness of the eccentric column decreased with each increase in the eccentricity
- The use of smaller tie spacing has provided the restraint necessary to protect the GFRP bars from premature failure.
- The crushing strength of GFRP bars in compression is approximately half of their ultimate tensile strength.

REFERENCES

[1] ACI Committee 318, 2008, "Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary," American Concrete Institute, Farmington Hills, MI, 473 pp.

[2] Alsayed, S. H., Al-Salloum, Y. A., Almusallam, T. H., Amjad, M. A. (1999). "Concrete columns reinforced by GFRP rods." Fourth Int. Symp. on Fiber-Reinforced Polymer Reinforcement for Reinforced Concrete Structures, SP-188, C. W. Dolan, S. H. Rizkalla and A. Nanni, eds., American Concrete Institute, Farmington Hills, MI, 103–112.

[3] American Concrete Institute (ACI). (2006) "Guide for the design and construction of structural concrete reinforced with FRP bars." 440.1R-06, Farmington Hills, MI.

[4] American Concrete Institute (ACI). (2011a). "Building code requirements for structural concrete and commentary." 318-11 and 318R-11, Farmington Hills, MI.

[5] American Concrete Institute (ACI). (2011b). "Guide to simplified design for reinforced concrete buildings." 314R-11, Farmington Hills, MI.

[6] ACI Committee 440, 2004, "Guide Test Methods for Fiber-Reinforced Polymers (FRPs) for Reinforcing or Strengthening Concrete Structures (ACI 440.3R-04)," American Concrete Institute, Farmington Hills, MI, 40 pp

[7] ACI Committee 440, 2006, "Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars (ACI 440.1R-06)," American Concrete Institute, Farmington Hills, MI, 44 pp.

[8] ACI Committee 440, 2007, "Report on Fiber-Reinforced Polymer (FRP) Reinforcement Concrete Structures (ACI 440R-07)," American Concrete Institute, Farmington Hills, MI, 100 pp.

[9] A.C.I. Committee 211, A.C.I. Standard 211.1-70 (1970): Recommended Practice for Selecting Proportions for Concrete. American Concrete Institute. Detroit construction, V. 7, No. 4, pp. 363-366.

[10] Creating a balanced mix design for high strength concrete, Bryce Simons, The Concrete Producer, October 1995, www.worldofconcrete.com.

[11] De Luca, A.; Matta, F.; and Nanni, A., 2010, "Behavior of Full-Scale Glass Fiber-Reinforced Polymer Reinforced Concrete Columns under Axial Load," ACI Structural Journal, V. 107, No. 5, Sept.-Oct., pp. 589-596.

[12] Deitz, D. H.; Harik, I. E.; and Gesund, H., 2003, "Physical Properties of Glass Fiber Reinforced Polymer Rebars in Compression," Journal of Composites for C

[13] Deitz D. H,Harik I. E., and Gesund H. (2003). "Physical Properties of Glass Fiber Reinforced Polymer Rebars in Compression" journal of composites for construction, volume 7, issue 4, pp 363-366.

[14] EL-Salakawy E. F., Kassem C., and Benmokrane B., (2003). "Construction, Testing and Monitoring of FRP Reinforced Concrete Bridges In North America" NSERC Chair, ISIS Canada, Department of Civil Engineering, Université de Sherbrooke, Sherbrooke, Québec, Canada J1K 2R1.

[15] Egyptian Code Committee, (2005). "The Egyptian Code for the use of fiber reinforced polymer bars (FRP) in the construction field" Proposed copy, (In Arabic).

[16] Guide to Quality Control and Testing of High Strength Concrete, ACI 363.2R, ACI International Farmington Hills, MI.

[17] Getting Started with High-strength Concrete, Ron Burg, The Concrete Producer, November 1993. ACI 440.1R.2015. Guide for the Design and Construction of Structural Concrete Reinforced with Fiber- Reinforced Polymer (FRP) Bars, American Concrete Institute.

[18] Halcrow W. and Partners Ltd. (1996) ; London, England "FRP Concrete Structures" Advanced Composite Materials In Bridges and Structures; M.M. B-Badry, Editor; Canadian Society for Civil Engineering, Montreal, Quebec, 1996

[19] J. J., Sorathia U., and Reynaud D., (2003). "Durability Gap Analysis for Fiber- Reinforced Polymer Composites in Civil Infrastructure" Journal of Composites for Construction, ASCE/August, pp 238-247

[20] Karbhari V. M., Chin J. W., Hunston D., Benmokrane B., Juska T., Morgan R., Lesko

[21] Kawaguchi, N., (1993). "Ultimate Strength and Deformation Characteristics of Concrete Members Reinforced with AFRP Rods under Combined Axial Tension or Compression and Bending," Fiber-Reinforced-Plastic Reinforcement for Concrete Structures—International Symposium, SP-138.

[22] Nicholas M., & Rajan S. (2003). "The Fatigue of Fiber-Reinforced Polymer Composite Structures State-of-the-Art Review" Civil & Environmental Engineering, USF College of Engineering.

[23] OU J. and LI H., (2003). "Recent Advances of Structural Health Monitoring in Mainland China" The National Hi-Tech Research and Development Program (HTRDP), and practical engineering projects.

[24] Paramanantham, N. S., (1993). "Investigation of the Behavior of Concrete Columns Reinforced with Fiber Reinforced Plastic Rebars," MS thesis, Lamar University, Beaumont,Tex.