A Review on Replacement of Steel with GFRP Rebars in Fiber Reinforced Concrete Eccentric Rectangular Column

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***Abstract*: GFRP longitudinal rebars is utilized as a substitute to steel rebars in reinforced concrete (RC) structures. Although international design codes does not suggest the use of GFRP rebars in RC compression members. But recent studies showed improvement in performance of GFRP RC in compression members. The aim of this research paper is to present a brief literature review on effectiveness of GFRP rebars in RC rectangular columns for better understanding of the performance under eccentric load conditions. An overview of different natural fibers in enhancement of ductility and dynamic properties of concrete has been also reported. Different parameters are considered and categorized according to column cross section sizes, spacing, concrete types, load eccentricity and reinforcement ratios. The analyzed data indicated that some of the researches revealed enhancement in the performance of GFRP RC rectangular columns under eccentric loads while others revealed reduction in capacities. The output of utilization of natural fibers for improvement of various properties of concrete has been discussed to draw conclusions. GFRP rebars can be used in different manners but still there is more investigation needed to explore the behavior under different load conditions.**

***Keywords*: Ductility, eccentricity, GFRP rebars, natural fibers, rectangular columns.**

I. INTRODUCTION

In reinforced concrete (RC) structures columns are critical structural members as columns are required for safely transmission of gravity and seismic loads. The strength and stiffness of columns are of great significance as RC columns should have adequate design capacity to withstand the large deformations for all possible load combinations. The elastic behavior of columns under strong seismic conditions is ideal to provide stability to the upper story levels. The emergence of pure concentric axial load in construction site is not practically conceivable due to imperfect alignment or construction error issues. Minimum permissible eccentricity according to ACI code [1] for short columns are 0.057D or 20mm, considered normally as axially loaded. The industrial columns where more chances of occurrence of large eccentricities are present may undergo catastrophic failures as columns under eccentricity showed more susceptibility to failure. Rectangular reinforced concrete (RC) columns are most widely used columns in construction industry due to architectural demands as rectangular columns easily fits and hides in wall and gives more aesthetic looks. Nevertheless steel RC rectangular columns have more bending moment capacity about major axis which can be oriented as per plan and moment condition of structure. Eccentric loads in steel RC rectangular columns caused unsymmetrical high stresses and bending moments which produced lateral deflections of the columns. These produced bending moments in turn reduced the load carrying capacities, and resulted in crushing and spalling of concrete and instability of concrete cover in steel RC rectangular columns. Steel RC eccentric column failure highlights the need to briefly explore and understand the behavior of rectangular columns under eccentric load. Moreover steady process of steel corrosion is also a dominant factor in reducing strength and serviceability of columns which ultimately result in failure of columns.

In last two decades a huge demand have been seen in utilization of GFRP rebars as a substitute to steel rebars in reinforced concrete (RC) structures. GFRP reinforcement bars have been extensively used in reinforced concrete structures for different civil engineering applications. GFRP rebars possessed high tensile strength, corrosion resistance and with four times lighter self weight to conventional steel rebars, low maintenance cost and long-term service life. The corrosion problem of steel rebars reduced the column strength, axial load carrying capacities and service life of steel RC columns while coating solution for maintenance was an expensive option. All these factors has resulted to the development of new technology of GFRP reinforcement bars. Similarly due to small weight and low maintenance cost of GFRP rebars it is preferred to use to in RC buildings. Although many researchers informed about the better performance of GFRP rebars as reinforcement in RC columns. Despite effective findings of numerous researches still international design codes such as ACI 440.1 R-15 [1], CAN/CSA S806 [2], ISO 10406 [3], and TR 55 [4] does not recommend GFRP rebars in compression members due to their lower modulus of elasticity. Standard test approaches have been developed to determine the tensile property of GFRP rebars. However there is no such standard exist to determine compressive properties of GRRP rebars [5].

Natural fibers are green, cheap, renewable, environment friendly and easily available material in the local markets as compared to synthetic fibers and admixtures. In recent years the demand for use of natural fibers have been raised for various industrial applications or research purposes in civil engineering. The use of natural fibers in concrete is major step towards a sustainable development. Natural fibers are obtained from natural resources such as plants, trees and other natural resources. Natural fibers possess improved properties that can be used in concrete structures to improve the mechanical properties, dynamic properties and impact resistance of concrete. Natural fibers possess high strength, stiffness, toughness, thermal stability. Some of the naturally easily available fibers are sisal, jute, coconut, banana, hemp, hair, bamboo and kenaf fibers. Natural fibers such as jute fibers are widely cultivated fibers in the Bangladesh. Jute fibers improve the fracture toughness of concrete and restrain the extension of cracks in concrete by developing bridging effect between fibers and concrete.

This research paper presents a brief literature review on the behavior of eccentric rectangular RC columns and to provide directions to the uncertainties available among many researches regarding the effectiveness of GFRP rebars in terms of a substitute to steel rebars in compression members. The boundary conditions involved literature review of theoretical analysis, experimental analysis and numerical simulations through modelling of nonlinear finite element analysis (NLFEA) for both steel and GFRP RC rectangular columns and their respective comparisons. Various parameters were considered such as load carrying capacity, ductility, column strength, spacing and volumetric ratios, load-deflection behavior, moment interaction diagrams, concrete damage plasticity mechanism (CDP), effectiveness of shape and confinement, cross-sectional aspect ratios, longitudinal and transverse reinforcement ratios, slenderness ratios and concrete types. Influence of small to intermediate load eccentricity to depth ratios (e/D= 8% to 60%) and for large load eccentricity to depth ratios of (e/D= 65% to 80%) are also reviewed and discussed in this paper and conclusions are drawn.

II. ECCENTRIC RECTANGULAR COLUMN BEHAVIOR

AS 3600 [6] describes short concrete columns as a column whose effective length (*Le)* over least radius (r) is smaller or equal to *22*. Eccentric loads causes bending moments in RC rectangular columns which significantly decreases the load carrying capacities and compressive strength of columns which can result in failure of structure. The reduction in load carrying capacities is due to non-homogenous distribution of stresses. The applied load eccentricity on concrete column causes compressive stresses and tension stresses to act in opposite sides to each other. The longer axis of rectangular column possess high bending moment capacities and should be provided parallel to the greater load side. As per ACI preceding minimum allowable eccentricity in column is 0.5D or 20mm (D=least dimension of column). Eccentricities more than the permitted limit can cause severe damages to the structure. Some of the literatures reported on behavior and effectiveness of GFRP RC rectangular columns and steel RC rectangular columns are presented below.

Elchalakani and Ma. [7] investigated rectangular RC columns under concentric and eccentric axial loading. A total of 17 rectangular concrete columns of normal grade N32 MPa with dimensions of 160 x 260 x 1200mm were tested. The longitudinal reinforcement ratio of GFRP RC column was 1.83% with transverse ties spacing of 75mm and 150mm. Amsler testing machine was used to carry out the tests with round steel bars of 25mm diameter and steel plate with thickness of 40 mm. Tests performed was at slight, intermediate and large eccentricities of 25mm, 35mm and 45mm respectively. It was reported that alternation of steel rebars with equal quantity of GFRP rebars and larger ties spacing decreased the axial load carrying capacity of rectangular GFRP RC columns to that of conventional steel reinforced columns. Moreover it was concluded that axial load carrying capacity of rectangular column was also decreased with the increase in eccentricity in both steel and GFRP RC rectangular columns. It was also reported that GFRP RC rectangular columns showed better ductility than steel RC rectangular columns.

Elchalakani et al. [8] explored design of GFRP RC rectangular columns under eccentricity and derived moment interaction diagrams of GFRP and steel RC columns. Both theoretical and experimental parameter were considered for brief exploration. The conclusions drawn indicated non uniform behavior of eccentric rectangular GFRP RC column as it varied than steel RC columns because the curvature in interaction diagrams clearly depicted that GFRP RC columns had not a balanced point on moment interaction diagram which was more obvious specially in case of reinforcement ratio greater than 3%. Furthermore exclusion of strength and stiffness parameters of GFRP reinforcement depicted calculations more conservative. It was also reported that inclusion of stiffness and strength parameters demonstrated better depiction of theoretical with experimental results.

Sun et al. [9] reported on the behavior of GFRP RC eccentric rectangular column under uniaxial load. Nine GFRP reinforced concrete columns of 180x 250 x 1000mm at different load eccentricities of 75 mm, 125mm and 175 mm are casted and tested under axial eccentric load. The conclusions drawn indicated that GFRP reinforced concrete rectangular columns at small eccentricity of 75mm demonstrated brittle behavior in comparison to large eccentricities which showed ductile behavior. It was reported that ductility index (D.I) increased with the increased load eccentricity. Concrete crushing in the compression side predominantly happened due to the occurrence of splitting failure near the concrete cover. GFRP reinforced concrete rectangular columns with large eccentricity showed improved lateral deflection performance. GFRP rebars withstand the load without any failure even after the concrete is damaged. Overall conclusion drawn showed that GFRP rebars in rectangular columns under eccentric load conditions did not exhibit failure even after the failure of concrete core and thus utilization of GFRP rebars in rectangular columns were recommended feasible.

Raza et al. [10] reported on behavior of eccentric rectangular RC columns with both conventional steel and GFRP rebars. Concrete damage plasticity (CDP) model for nonlinear finite element analysis (NLFEA) was used. It was revealed that due to eccentricity that plastic principle strains showed cracks in tension side of lower half portion near fixed supports while for concentric load substantial crack appeared in upper half portion with failure of concrete core and lateral reinforcement. It was found that eccentricity had an inverse influence on the performance of GFRP RC rectangular column. This was due to the increased eccentricity that the stresses increased and permitted buckling failure of column that led to reduced ultimate load carrying capacity. It was also reported that small eccentricity had a significant effect load carrying capacities of GFRP RC columns. Small eccentricity of 25mm decreased load carrying capacities by 39.74% and large eccentricity of 45mm decreased load carrying capacities by 60.62% to that of identical concentric GFRP RC columns.

Elchalakani et al. [11] performed experimental and numerical analysis on eccentric GFRP and steel RC rectangular columns. Experimental tests and numerical tests were carried out for relative comparisons. Numerical analysis was performed in

ABAQUS software to investigate damage mechanism theory. It was concluded that rupture of stirrups contributed in global failure of the rectangular column specimens. Spacing of transverse reinforcement had significance impact on the ductility and strength under eccentric axial load condition. Eccentric rectangular columns with smaller stirrup spacing demonstrated improved ductile performance. The GFRP RC rectangular column demonstrated less capacities than steel RC columns. It was also reported that stress distribution of specimens in experimental results showed same behavior in finite element (FE) model. The difference in results of peak load and deflection at peak load varied 8% and 11% respectively for experimental and FE model. The conclusion drawn also indicated that the FE model indicated good agreement with experimental results for both GFRP and steel RC rectangular columns.

Long et al. [12] explored eccentric rectangular concrete filled tubular (CFT) columns under compression load. It was concluded that stress gradient coefficients greatly effects the local buckling of steel plate in CFT under eccentric compression. While effect of width to thickness was greater as compared to the effect of cross-sectional aspect ratio.

Othman and Muhammad [13] investigated 18 eccentric rectangular RC columns reinforced with steel and CFRP longitudinal rebars and steel transverse reinforcement bars. Different parameters such as load eccentricity, reinforcement ratios and spacing were considered. It was concluded that load carrying capacity of CFRP rebars enhancement as longitudinal reinforcement ratios raised for various eccentricities. The bending moment results showed similarity with experimental outcomes. It was concluded that both steel and CFRP RC columns demonstrated similar deflections.

Table 1 depicts different considered variables for eccentric rectangular RC by various researchers as reported in previous literatures. The literature suggests that increase in eccentricities reduced load carrying capacity of rectangular columns while GFRP RC columns were more ductile than steel RC columns.

Table 1: Summery of considered variables for RC rectangular column under eccentric load as reported in previous literatures

Reference	f'c (MPa)	Prototype Specificatons		Longitudinal Reinforcement		Transverse Reinforcement		e/D (%)
			(E_{ft})	Dia (mm)	Ratio (%)	Dia (mm)	Spacing (mm)	
Elchalakani and Ma [7]	32	160 x 260 x1200 - R	46.3	12.7	1.83	6	75, 150, 250	9.62, 17.3
Sun et al. [9]	33.51	180 x 250 x 1000 - R	92.4	10	1.05	4	125	30, 50, 70
Elchalakani et al. [8]	26	160 x 260 x 1200 - R	50	12.7	2.22	6.35	75, 150, 250	9.62, 19.23, 28.85
Raza et al. [10]	32	160 x 260 x 1200 - R	46.1	12.7	1.83	6	75, 150, 250	9.62, 19.23, 28.85

f'c = compressive strength of concrete, E_{ft} = Elastic modulus of GFRP rebars, e/D = eccentricity over depth

Nunes et al. [14] conducted tests on GFRP column of 1.50 m long I shaped (120 x 60 x 6mm) under different eccentricities of e/d ratio of 0, 0.15 and 0.30mm. It was reported that primarily axial stiffness of eccentrically loaded GFRP column was same to that of concentrically loaded I-shaped GFRP column but as the load increased the stiffness reduced due to load-deflection effects. It was also reported that GFRP columns under small eccentricity were very susceptible and caused 40% reduction of load capacities when load applied within the kern boundaries. The reduction of capacity was improved by lateral bracing similarly in RC column longitudinal rebars were tied up with lateral ties. It was concluded that in RC column transverse bracing of longitudinal GFRP reinforcement bars are of great significance for effective performance under eccentric load conditions.

Choo et al. [15] and Deiveegan and Kumaran [16] investigated eccentric rectangular concrete columns reinforced with GFRP rebars. It was reported that linear elastic behavior of GFRP rebars dominated the behavior of GFRP RC columns as GFRP RC columns did not showed balanced point in the interaction diagram as compared to the steel RC columns. Moreover in some cases tearing of GFRP rebars in tension side caused brittle failure of columns in tensile mode before that interaction diagram reached the pure bending mode. Thus, Choo et al. [17], and Zadeh and nanni [18] carried out numerical investigations on short RC columns and proposed equations for minimum GFRP reinforcement ratios. The outcomes directed to limit the GFRP rebars strain to 1% in tension for resist further deflections.

A. Eccentricity to depth ratios (e/D)

Based on previous conducted studies the conclusion drawn showed that under low to moderate eccentricity/major lateral dimension (e/D = 8% to 60%) GFRP-RC rectangular columns failed in compression mode because of crushed concrete. However at large eccentricities of (e/D = 80%) the GFRP-RC rectangular columns failed in flexure mode because of buckled reinforced bars. The literature also revealed that GFRP-RC rectangular columns demonstrated better ductile behavior than steel-RC rectangular columns as eccentricity raised from smaller to larger values. However in concentric conditions the steel RC-columns showed higher ductility performance than GFRP RC rectangular columns [7], [10], [11], and [24].

Fig 1 displays the obtained differences present between axial load capacities of steel-RC columns and GFRP-RC columns as reported in previous literatures. The obtained differences are shown after the factorization of 0.85f'c Ag. The differences present among capacities of steel and GFRP-RC columns are shown by Δ, e/D is ratio of eccentricity to major depth of cross-section, whereas ρ represents longitudinal reinforcement ratios of steel-RC columns and GFRP-RC columns. It can be seen that steel-RC columns demonstrates higher load capacities than GFRP-RC columns at low to moderate load e/D ratios, though at large e/D ratios GFRP-RC columns and steel-RC columns have comparable load capacities.

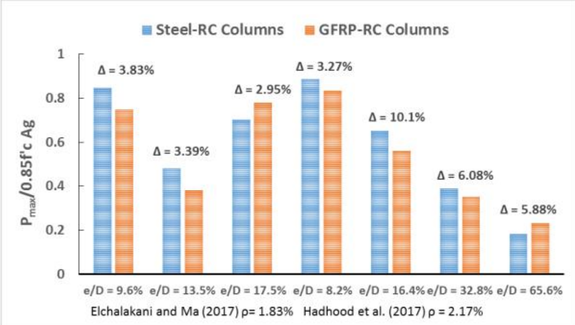

Fig. 1: Axial capacities factored to 0.85f'c Ag

B. Effect of Cross-sectional Aspect Ratios and Shape

Based on previous studies [16], [19] researches reported that column shapes had significant influence on the load carrying capacity for both GFRP steel RC columns. Previous results showed that columns with square cross section possessed 1.62 times greater load carrying capacity to their counterpart rectangular columns. Similarly circular columns had 1.54 times greater axial load carrying capacity than that of rectangular RC columns with conventional steel bars. Similar behavior was reported for GFRP RC square and circular columns with 1.92 and 1.81 times larger capacities to that of GFRP rectangular RC columns.

Some of the researchers [20], [21], [22] investigated rectangular RC columns and explored effects of rectangular cross section. It was reported that greater aspect ratios from 1:1 to 6:1 reduced the strength from 1.17 to 1.08 almost 10% declined the strength. Wu and Wei [23] investigated rectangular columns with different cross-sectional aspect ratios of 1, 1.25, 1.5, 1.75 and 2. It was concluded that as the aspect ratio increased the reduction in the strength occurred while confinement effectiveness also decreased as the aspect ratio increased. The most effective cross-sectional aspect ratio was square as compared to other aspect ratios.

III. USE OF STEEL AND GFRP REBARS IN CONCRETE COLUMNS

Literature review revealed that numerous experimental works have been carried out on the use of GFRP rebars for flexure and shear reinforcement in concrete structures. Previous studies indicated that GFRP rebars showed improved performance in flexural members as compared to compression members [25]. The reason for this complication was described as nonhomogeneous nature of the GFRP rebar which caused micro buckling of the bar under compression load [26]. Moreover it can effectively be used in concrete structures subjected to dynamic loading such as in concrete bridge decks where heavy objects could fall on the bridge deck or heavy vehicle collisions. Recent studies also indicated that GFRP rebars performed well in harsh environmental conditions especially in marine structure which are exposed to deicing salts [27]. However due to brittle behavior of GFRP rebars generally believed that inclusion of GFRP rebars in compression members could not be as effective compared to traditional steel rebars because of load carrying capacity phenomena. Previous studies indicated that GFRP rebars have been used both as a substitute to steel rebars both for longitudinal and transverse reinforcement in different members of concrete structures such as slabs, beams, columns and shear walls.

A. Use of Steel and GFRP Rebars as Longitudinal Reinforcement

Dietz et al. [28] reported that the GFRP reinforcement bars possessed 50% lesser compressive strength as compared to their flexure strength. Its elastic modulus was equal for both compression and flexural strength. Alfifi et al. [29] concluded that GFRP rebars had 35% ultimate compressive strength than that of strength in tension. Prachasaree et al. [30] explored behavior of RC columns reinforced with GFRP rebars. It was concluded that the effect of longitudinal GFRP rebars on the strength of column is lesser as compared to the effectiveness of lateral ties which increased inelastic deformation and strength of core concrete. Ahmad Hassan et al. [31] investigated structural behavior of eccentrically loaded circular concrete columns with GFRP rebars and steel rebars as main longitudinal reinforcement. The main conclusions drawn from this study indicated that concrete columns having GFRP rebars as main longitudinal reinforcement reduced load carrying capacity as compared to steel RC columns. Previous researchers also reported that increment in slenderness ratio reduced the compressive strength and ductility of both GFRP RC and their counterpart columns.

Luca et al. [32] conducted laboratorial experiments on concentric concrete columns with GFRP and steel rebars as longitudinal reinforcement. Five full scale columns of square cross section 610 x 3000mm were tested under pure axial load. The conclusions indicated that GFRP as longitudinal reinforcement possessed higher strains due to lower load carrying capacity than that of traditional steel reinforced concrete columns. Buckling of the longitudinal rebar was dominantly influenced by confinement of lateral ties. Axial deformation behavior of GFRP RC column is similar to steel RC column at 1% reinforcement ratio. GFRP longitudinal rebars contributed less than 5% load carrying capacities than 15% of longitudinal steel rebars and hence it can be ignored in load capacity determination.

Table 2 represents the compressive properties of GFRP rebars reported by previous researchers. The literature review shows that properties of GFRP are good enough to be used as reinforcement in RC columns.

Table 2: GFRP rebars compressive properties reported by researchers in previous literatures

Reference	Dia (mm)	I_U (mm)	f_{uT} (MPa)	E (GPa)	f_{uC}/f_{uT}	E_{fc}/E_{ft}
Sun et al [9]	10	6.25	1103	92.4	0.62	0.65
Khorramian and Sadeghian [37]	16	32	629	38.7	1.24	1.06
Maranan et al. [39]	15.9	50	1184	62.6	0.517	-
Deitz et al. [28]	15	50-380	610	40	0.5	1
Wu [23]	22	>55	554	50.7	0.74	0.75
Challal and Benmokrane [38]	15.9, 19.1 and 25.4	44-77	690	42	0.77	1.02

Iu = unbraced length of GFRP rebar, f_{uT}= ultimate tensile strength of GFRP rebar, E_{ft} = tensile modulus of elasticity of GFRP rebar, f_{uC}/f_{uT} = ratio between compressive to tensile strength of GFRP rebar, E_{fc}/E_{ft} = ratio of compressive to tensile elastic modulus of GFRP rebar

B. Use of Steel and GFRP Rebars as Transverse Reinforcement

Many studies reported that GFRP bars possessed low elastic modulus due to which they were susceptible to the buckling failure as compare to steel rebars therefore it was important to restraint longitudinal GFRP rebars by transverse reinforcement. Alsayed et al. [33] reported on rectangular RC columns with dimensions of 450 x 250 x 1200mm at reinforcement ratio of 1.07%. It was found that substitution of longitudinal steel rebars with equal amount of GFRP rebars decreased the load carrying capacities by 13% excluding of lateral reinforcement type (whether steel or GFRP). The conclusions drawn also indicated that the load capacity was reduced by 10% with the addition of GFRP ties as a substitute to steel ties while behavior of load-deformation was unchanged till 80% ultimate capacity. Pantelides et al. [34] studied load carrying capacity of reinforced concrete columns with GFRP rebars. It was revealed that that columns with GFRP longitudinal bars and GFRP helices showed 84% load carrying capacity as compared to steel RC columns. Studies conducted on the exploration of effects of GFRP rebars as transverse reinforcement included different parameters such as effect due to spacing between transverse rebars, effect due to volumetric ratios, shapes. GFRP transverse rebars provided high level of confinement to the concrete core with greater deformation capacity because of greater strains at ultimate levels [35] and [36].

C. Effect of Spacing and Volumetric Ratios

Afifi et al. [26] reported that GFRP transverse reinforcement indicated more effectiveness on the ductile behavior and confinement effectiveness as than load carrying capacities of GFRP RC columns. Improvement of 3% to 7% in axial compressive strength while 57% to 208% and 21% to 43% enhancement was observed in ductility and confinement efficiency respectively. Hassan et al. [31] reported that with increased volumetric ratios of transverse reinforcement from 1.7% to 3.4% the load carrying capacity of GFRP RC column increased by 20% while for steel RC column the load carrying capacity increased by 24% irrespective of the longitudinal reinforcement bars while ductility is improved by 30%. Hales et al. [40] drawn the conclusions and reasons for such requirement that it is due to lower modulus of elasticity of GFRP rebars than that of higher modulus of elasticity of steel rebars. Guerin et al. [41] investigated eccentric columns with GFRP rebars it was reported that for maximum spacing of GFRP transverse reinforcement half of the criteria mentioned for tie spacing was enough to avoid buckling of the longitudinal main rebars and for confinement of the concrete core. Luca et al. [32] informed that the use of specifications for transverse steel rebars by ACI 318-08 should be avoided for design of tie spacing of GFRP rebars because this resulted in undesirable brittle failure of GFRP RC columns.

D. Effect of Reinforcement Ratios

Numerous researchers conducted investigations on influence of reinforcement ratios of steel and GFRP rebars in concrete columns. The literature review showed that equivalent amount of GFRP rebars as a substitute to steel rebars for both longitudinal and transverse reinforcement did not produced effective results. The decrement in axial load carrying capacities of columns was because of variance in mechanical properties of GFRP and steel rebars. However the behavior reported for replacement of longitudinal steel rebars with longitudinal GFRP rebars at 1% reinforcement ratios showed that GFRP RC columns failed due to concrete crushing and showed higher axial strains as compared to steel specimens. The steel RC column failed due to buckling failure in elastic range. The conclusions of some of the previous literatures on effects of reinforcement ratios are presented here.

Hasan et al. [42] investigated high strength concrete (HSC) columns with steel and GFRP rebars under concentric loading. It was informed that equivalent amount of GFRP rebars as a replacement to conventional steel bars resulted in 30% reduction of load capacity as compared to steel reinforced HSC columns. Lotfy et al. [43] investigated effectiveness of various reinforcement ratio of 0.723%, 1.08% and 1.45% for GFRP and steel rebars. It was reported that the overall behavior of GFRP RC column was enhanced as compared to conventional steel RC column for the ratio of 1.08% as compared to 0.723% and 1.45% reinforcement ratio. It was also reported that increased reinforcement ratios showed improved toughness and ductility of GFRP RC columns to that of conventional steel RC columns. It was also informed that increased longitudinal reinforcement ratios increased ductility of column.

IV. NATURAL FIBER REINFORCED CONCRETE

Zia and Ali [44] investigated natural and artificial fibers to control cracks in canal lining for the application of seepage losses reduction. Jute, nylon, and polypropylene fibers were used in concrete with a mix design ratio of 1:3:1.5:0.7 (cement: sand: aggregate: water). The length of fibers were uniform (50mm) for all fibers are incorporated in concrete with 5% content b mass of cement. The conclusions depicted enhancement in mechanical properties of FRC's as compared to PC. Furthermore linear shrinkage parameter was enhanced by 67% and 30% for jute and nylon fiber reinforced concrete while reduction of 15% for polypropylene reinforced concrete. Water absorption enhanced by 8% and 1% for jute fiber reinforced concrete while 4% decreased for polypropylene reinforced concrete. It was also informed that fibers increased the toughness index of concrete and proved to be a better material for utilization in canal lining to reduce seepage.

Hussain and Ali [45] reported on effectiveness of jute fibers for enhancement of impact resistance of RC slabs under impact load. Fifty two RC steel slab panels of 430 x 280 x 75mm with and without jute fibers were prepared with 50cm fiber length and 5% fiber content by mass of cement. Drop weights at varied heights of 60 and 90cm for impact resistance were performed while dynamic and mechanical tests of material have been also carried out. Researchers concluded that impact resistance of slabs with jute fibers increased by 6 and 6.5 times at 90 and 60cm drop heights respectively. Nevertheless dynamic elastic modulus increased by 68% for jute fiber reinforced concrete slabs than steel RC slabs.

Alam and riyami [46] investigated shear strengthened behavior of RC beams with natural fiber reinforced polymer (NFRP) composites plates. Natural fibers involved jute fibers, jute rope, and kenaf composite plates while a total of 8 beam specimens was prepared with steel reinforcement. The conclusion drawn indicated that beams with untreated jute fibers, jute rope and kenaf composite plates had enhanced shear capacities by 36%, 34%, and 35% as compared to the controlled specimen. While treated jute fibers, jute rope and kenaf plates showed comparable shear capacities of 31%, 23 and 10% respectively. It also concluded that beams with natural fibers showed improvement in ductility and overall strength.

Kundu et al. [47] reported on utilization of jute fibers in concrete paver blocks. Test matrix involved 5mm jute fibers with 1% weight by cement. It was found that paver blocks with jute fibers depicted improvement in mechanical properties. The flexural strength and toughness improved up to 49% and 166% while strength in compression was enhanced by 30% than that of controlled specimens block. Furthermore it also indicated that utilization of jute fibers in concrete blocks led to longer service life and low repair costs. Razmi et al. [48] investigated the fracture resistance of jute fiber reinforced concrete. Jute fibers of 20mm length with various percentages of 0%, 1%, 3% and 5% by weight of mixture were incorporated for the preparation of specimens. Conclusions indicated that fracture resistance of jute fiber reinforced concrete was enhanced by 45% as compared to plain concrete specimens. Furthermore crack resistance is enhanced as the fiber ratios increased but no significance improvement was shown on 5% ratios. Parameters such as flexure strength, compressive strength, tensile strength and fracture toughness of jute fiber reinforced concrete were higher than that of plain concrete specimens.

Zakaria et al. [49] conducted experiments on mechanical properties of jute fibers with various mix design ratios of 1:2:4: and 1:1.5:3 (cement: sand: brick chips) with different jute fiber lengths of 10, 15 20 and 25mm and different dosages of 0, 0.1, 0.25, 0.50 and 0.75% by volume respectively. Brief analysis of results indicated that the fiber content and length greatly influenced the effectiveness of concrete. The maximum compressive strength achieved was 15% for 15mm fiber length, 0.10% fiber content and 1:2:4 mix design ratio while 10% with same fiber length and content for 1:2:4 mix design ratio as compared to the plain concrete. The flexure strength enhanced by 22% for 15mm fiber length with 0.10% fiber content and 1:1.5:3 mix design ratio while for 1:2:4 mix design ratio with same fiber length and fiber content 14% enhancement was achieved.

Table 3 represents summary of previous literatures on effectiveness of natural fibers in reinforced concrete. The literature suggests that natural fibers can effectively enhance the behavior of concrete. Nevertheless fiber length, fiber dosages significantly impacts on improvement limitations of fiber reinforced concrete.

Table 3: Summary in enhancement of various properties as reported in previous literatures.

Reference	Fiber type	Fiber length (mm)	Fiber content (%)	Mix design ratio (cement: sand: :aggregate: water)	Outcomes
Zia and Ali [42]	Jute, Polypropylene,	50	5 (by mass of cement)	1:3:1.5:0.7	Enhanced mechanical, shrinkage and water absorption
Hussain and Ali [43]	Jute	50	5 (by mass of cement)	1:3:2:0.7	Increased impact resistance by 6.57 times.
Alam and riyami [44]	Jute, Jute rope, Kenaf	47,45,47			Enhanced shear resistance property by 36%, 34%, 35%.
Kundu et al. [45]	Jute	5	1 (by mass of cement)	1:3:4:0.1	Enhanced flexure, compressive and toughness by 49%, 30%, 166%.
Razmi et al. [46]	Jute	20	1, 3, 5 (by weight of mixture)	2.47% : 0.56% (w/c 0.46)	Enhanced fracture resistance of crack by 45%.
Zakaria et al. [47]	Jute	10, 15, 20, 25	0.10, 0.25, 0.50, 0.75	1:2:4:, 1:1.5:3: (w/c = 0.55,0.60)	Fiber lengths of 15mm showed maximum compressive flexure and tensile strength for 0.25% volume content.

V. CONCLUSIONS

It is concluded that comprehensive literature review shows that overall GFRP RC rectangular columns demonstrates lesser load carrying capacities than steel RC rectangular columns while lateral reinforcement ratios significantly dominates the structural performance. Nevertheless the structural behavior of eccentric rectangular columns under eccentric modes greatly differs than pure concentric scenarios. Numerical simulations of nonlinear finite element modelling are in good agreement with the real field scenarios. The modification of structural materials with natural fibers effectively enhances crack restraining phenomena, impact resistance, dynamic and mechanical properties of reinforced concrete structures.

VI. RECOMMENDATIONS

It is recommended that a uniform test standard should be developed by the international code authorities to incorporate the GFRP rebars in compression members. Exploration of long term durability of natural fiber reinforced concrete is suggested. Combine effect of natural fibers with GFRP rebars should be investigated for possible application in the construction industry.

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