International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 13 Issue: 01 | Jan 2026 www.irjet.net p-ISSN: 2395-0072

Comparative Experimental Study on Flexural behavior of RC beams Reinforced with GFRP and HYSD bars

Sinchana swamy[1], Dr. Kiran T[2]

[1]*Student of Master in Technology, Department of Civil Engineering, Major: Press tressed concrete Engineering, University of Visveswaraya college of Engineering, Bangalore, Karnataka, India,*
[2]*Associate Professor, Department of Civil Engineering, University of Visveswaraya college of Engineering, Bangalore, Karnataka, India,*

Abstract - *corrosion of traditional steel reinforcement is a major durability issue in RC structures, especially those subjected to severe environments. Application of Fibber-Reinforced Polymer (FRP) systems, which investigate environment-friendly solutions with enhanced durability and tensile strength while maintaining a favourable strength-to-weight ratio, has emerged as a major consideration. The flexural behaviour of standard HYSD steel-reinforced concrete beams and hybrid-metal beams consisting of HYSD steel longitudinal bars along with glass fibre-reinforced polymer (GFRP) stirrups was examined in this experimental investigation. An experimental program was created on four RC beam specimens tested under four-point bending. Of these, two beams were entirely reinforced with HYSD steel bars to be used as control specimens, while the last two beams were reinforced with main bars in HYSD steel and stirrups using GFRP. The four beams featured comparator specimens having the same dimensions, concrete grade, and longitudinal reinforcement to maintain consistency and reliability. Flexural response of specimens was evaluated in terms of load-deflection behaviour, crack initiation and propagation, stiffness degradation, shear crack development, ultimate load-carrying capacity. The results of the experiment showed that with the introduction of GFRP stirrups, cracking pattern in and post-cracking response were changed in RC beams resulting to better crack distribution and durability performance. However, it was observed that overall flexural strength of the beams depended much on the HYSD steel longitudinal reinforcement. This study proved that hybrid use of GFRP-stirrups may effectively replace normal steel stirrups in RC flexural members, without compromising the performance of structures.*

Keywords: GFRP bars; HYSD bars; Flexural behaviour; Reinforced concrete beams; Four-point bending

1. INTRODUCTION

Reinforced concrete is the most popular construction material. It has strength, versatility, and cost-effectiveness that are hard to beat. Traditionally, the use of high yield strength deformed (HYSD) steel bars in everything from longitudinal reinforcement to stirrups is concerning in RC members. The durability of such structures is affected by steel corrosion resulting from aggressive environments, such as coastal regions, industrial zones, and exposure to de-icing salts. Corrosion induces cracking and spalling of concrete, degenerated bond strength, and ultimately resulting in loss of carrying capacity and life in structures.

Fibbers have emerged as an alternative material in replacing the conventional steel reinforcement. Among the various types of FRPs manufactured, the one that is commonly recognized is that of glass-shredded reinforced polymer bars. These GFRP types were chosen for their properties of corrosion resistance, very high tensile strength, non-magnetic nature, and lightweight. Although there has been considerable research focusing on the behaviour of RC beams under GFRP longitudinal bars, the information on the structural behaviour of such beams with GFRP used as the transverse reinforcement is limited.

Stirrups have some important functions concerning shear cracks, confinement, and ductility in RC beams. Replacing them with GFRP stirrups will certainly increase durability to a great extent due to the absence of corrosion in the shear reinforcement zone. The elastic and brittle behaviour of the GFRP requires an in-depth understanding of its influence on the crack, stiffness, and entire flexural output of the RC beams.

Thus, this investigation aims to conduct an experimental study on the flexural behaviour of conventional reinforced concrete beams and hybrid reinforcement using conventional HYSD steel bars with GFRP stirrups. The comparative assessment made will be with respect to load-deflection response, cracking characteristics, stiffness, and ultimate load carrying capacity to understand the applicability of GFRP stirrups in RC flexural members.

2. Materials Properties and Mix Proportions

2.1 Material properties

In this study, Ordinary Portland Cement (OPC) of 53 grades was used, and it meets IS 12269:2013. The reason for choosing OPC 53-grade cement was its property of being high in early strength and hence can be used for structural concrete applications. The cement used was fresh, free from lumps, and stored in dry conditions. Manufactured sand (M-sand) was used as a fine aggregate. The M-sand was maintained clean, well-graded, and free from organic

impurities, clay, and other deleterious materials so as to enhance particle packing and ensure a consistent quality of the concrete mix. Crushed angular coarse aggregates, nominal maximum size 20 mm, were used to enhance the interlocking and strength characteristics of the concrete.

M30-grade concrete was designed as per IS 10262:2019 and IS 456:2000 to conform to the required target mean strength, workability, and durability. Standard concrete cube specimens were cast and tested, compressively at 7 and 28 days, to ascertain the compressive strength of the concrete. In all beam specimens, High Yield Strength Deformed (HYSD) steel bars of grade Fe 500 as per IS 1786:2008 were used as the longitudinal reinforcement while Mild steel was used as stirrups in the control beams. Fe 500 steel was selected due to its high yield strength, good ductility, and reliable bond characteristics with concrete. The yield strength of the steel was taken as 500 MPa, and the modulus of elasticity as 200 GPa, as per the recommendations of Indian Standards. In the hybrid beam specimens, Glass Fiber Reinforced Polymer (GFRP) bars were used as stirrups. The GFRP bars possess high tensile strengths, corrosion resistances, and linear elastic behavior up to failure, thereby acting as a suitable alternative to conventional steel stirrups, especially in places where durability is a major consideration.M30-grade concrete was designed as per IS 10262:2019 and IS 456:2000 to conform to the required target mean strength, workability, and durability. Standard concrete cube specimens were cast and tested, compressively at 7 and 28 days, to ascertain the compressive strength of the concrete. In all beam specimens, High Yield Strength Deformed (HYSD) steel bars of grade Fe 500 as per IS 1786:2008 were used as the longitudinal reinforcement while Mild steel was used as stirrups in the control beams. Fe 500 steel was selected due to its high yield strength, good ductility, and reliable bond characteristics with concrete. The yield strength of the steel was taken as 500 MPa, and the modulus of elasticity as 200 GPa, as per the recommendations of Indian Standards. In the hybrid beam specimens, Glass Fiber Reinforced Polymer (GFRP) bars were used as stirrups. The GFRP bars possess high tensile strengths, corrosion resistances, and linear elastic behavior up to failure, thereby acting as a suitable alternative to conventional steel stirrups, especially in places where durability is a major consideration.

2.2 Mix Proportions

The concrete mix used in the present experimental investigation was designed for M30 grade in accordance with IS 10262:2019 and IS 456:2000. The mix design was done to achieve the desirable target mean compressive strength, adequate workability, and durability attributes of reinforced concrete beam specimens. Ordinary Portland Cement (OPC) of 53 grades was used as the binding material, while manufactured sand (M-sand) was adopted as fine aggregate. Coarse aggregate consisted of artificial crushed angular 20 mm nominal maximum size aggregates. The water-cement ratio was carefully chosen to fulfil the needs of strength and durability whilst allowing enough workability for proper placement and compaction of the concrete in beam moulds. The proportions of cement, fine aggregate, coarse aggregate, and water were adjusted with trial mixes to allow for a unified, cohesive mix with minimum segregation and bleeding. Sufficient workability was given to allow for proper compaction of concrete around reinforcement, especially in closely spaced stirrup areas.
The mix proportions adopted for M30 concrete used in the study are summarized in Table 2.1.

Table 2.1 – Mix Proportion

Water (l/m^3)	**Cement** (kg/m^3)	**Fine aggregate** (kg/m^3)	**Coarse aggregate** (kg/m^3)	**Dosage of Admixture** (kg/m^3)
148	345	823	1104	17.25
0.43	1.00	2.38	3.20	0.05

3. EXPERIMENTAL PROGRAM

The flexural behaviour of reinforced concrete beams is the subject of an experimental program. These beams are conventionally reinforced using HYSD steel bars and hybrid reinforcement involving longitudinal bars of HYSD steel and transverse or stirrups made of GFRP. Four reinforced concrete beam specimens were cast for tests to be done under laboratory conditions. Control specimens were created using only HYSD steel bars for their detailed reinforcement, and the rest, two of them, had longitudinal reinforcement made of HYSD steel and GFRP bars as stirrups. All beam specimens were supposed to design with similar geometric dimensions, concrete grade, longitudinal reinforcement ratio, and shear span length for a consistent and meaningful comparative analysis between control and hybrid beams.

The beams were casted in M30 grade concrete and cured under water for 28 days. Proper conditioning was given before testing by preparing the specimens and marking reference points for crack observation and instrumentation. The flexural analysis was carried out by using a four-point bending setup which defined a constant moment region between two loading points and also provides clear flexural observation behaviour. The specified span had the beams simply supported, and the load applied monotonically by hydraulic loading frame. Load application increased gradually and, simultaneously, mid-span deflections were measured through either dial gauges or displacement transducers.

During testing, every specimen had first visible crack load, crack pattern and propagation, load–deflection response, and ultimate load recorded. The observation and documentation of each beam's failure mode took place. Controlled and hybrid beams were in comparison for the study on the effect of GFRP

stirrups on flexural performance, stiffness, cracking behaviour, and load-carrying capacity of reinforced concrete beams.

3.1 Specimen Details

The experimental investigation on flexural behaviour of RC beams reinforced with conventional HYSD steel bars and hybrid reinforcement using GFRP stirrups encompassed a total of four reinforced concrete beam specimens. All the beam specimens were cast with identical geometric dimensions of 150x200x1200mm to eliminate the influence of size effects, thus ensuring a reliable comparison. The beams were designed as simply supported members and detailed to promote flexural failure as opposed to shear failure. Two beam specimens were reinforced entirely with HYSD steel bars and designated as control specimens, while the remaining two beams were reinforced with HYSD steel as longitudinal reinforcement and GFRP bars as stirrups, representing hybrid reinforcement.

Beams	
Specimen No	**Reinforcement**
Specimen -1	HYSD(M)+HYSD(S)
Specimen -2	HYSD(M)+HYSD(S)
Specimen -3	HYSD(M)+GFRP(S)
Specimen -4	HYSD(M)+GFRP(S)

3.2 Test Setup and Instrumentation

Flexural behavior under four-point bent test with all beam specimens. All beams were simply supported over effective spans in which two symmetrical equal point loads were applied to the mid-span in order to create a constant bending moment region between the two points. The application of load was ensured through distribution by hydraulic jack through a spreader beam. Load application performed step by step continued displacement control till complete failure of specimens. The same LVDTs accurately measured vertical deflection at the mid-span.

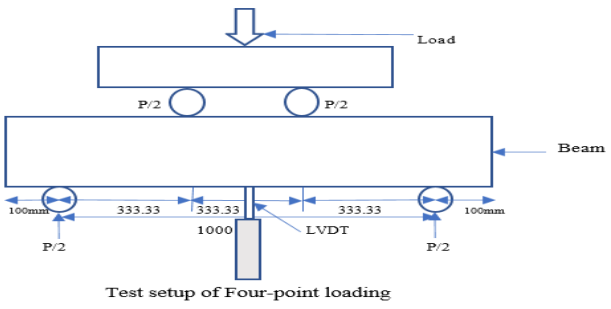

Figure – 3.1 Test Setup of Four-Point Flexure Loading

Instrumentation

Appropriate instrumentation allowed for accurate measurements of the structural response of the beam specimens during flexural testing. All beams were tested under a four-point bending configuration using a hydraulic loading frame with sufficient capacity. During testing, the load applied was recorded accurately throughout the experiment by using a calibrated load cell connected to the loading system. The load was applied monotonically in increments until failure of the specimen, and load values were recorded at each loading stage.

Mid-span deflection of the beam specimens was measured using a dial gauge or Linear Variable Differential Transformer (LVDT) placed at the centre of the span. The measuring device was securely installed on an isolated reference frame to avoid any influence from support settlements or external disturbances. In addition to mid-span deflection, deflection readings were also taken at selected locations close to the loading points when required to study the deformation profile of the beam. Crack development was visually monitored throughout the test, and initiation and propagation of cracks were marked on the beam surface at various load levels. The width and pattern of cracks observed were utilized to assess the cracking behaviour of both control and hybrid beams.

All measurements were taken at regular load intervals with emphasis on monitoring cracking load and ultimate load. The instrumentation system provided assessments of load-deflection behaviour, stiffness characteristics, cracking response, and overall flexural performance of beam specimens reinforced with steel and GFRP stirrups.

Deflection Formula:

$$\delta_u = \frac{23PL^3}{648EI}$$

4. Results and Discussions

4.1 Load and Deflection

The following analyses are contained therein: flexural test design of reinforced concrete beam specimens. The focus of analysis for these specimens is to study their structural response in four-point bending. Beam behaviour was addressed in terms of load–deflection response, cracking characteristics, variations in stiffness with respect to different stages of loading, and ultimate load-carrying capacity; a special emphasis is given to highlighting the differences in elastic and post-cracking behaviours of the beam specimens. The first crack load, crack propagation with incrementing loads, and deformation characteristics until the point of failure are, therefore, discussed extensively to get a complete view of the beam's flexural performance.

A contrasting evaluation is conducted between the control beams entirely reinforced with conventional HYSD steel bars and the hybrid beams with HYSD steel longitudinal bars and GFRP stirrups. The comparison attempts to evaluate the effect of replacing steel stirrups with GFRP stirrups on the flexural response of the reinforced concrete beams. The effect of the stirrup material on stiffness degradation, crack propagation, and failure characteristics will be studied with all beams having identical geometry, the same concrete grade, and longitudinal reinforcement. The comparative study provides an insight into the feasibility and efficiency of GFRP stirrups as corrosion-resistant substitutes for steel stirrups without compromising the flexural performance of the RC beam

Table 4.1 Experimental Versus Theoretical First crack laod

	Theoretical	Experimental
Specimen Details	**First crack Load**	**First crack Load**
Specimen -1	29.2	33.51
Specimen -2	31.34	35.82
Specimen -3	24.84	26.75
Specimen -4	23.99	26.45

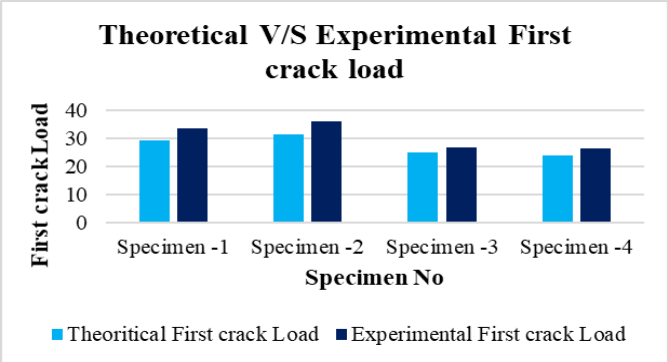

Chart -1: Theoretical V/S Experimental First crack Load

The Theoretical and Experimental comparisons of first crack loads have shown that the results of the experiment have always been higher in all beam specimens. The increase of Specimen-1 from 29.2 kN to 33.51 kN and Specimen-2 from 31.34 kN to 35.82 kN constitute the same pattern. Likewise, the experimental first crack loads for Specimen-3 and -4 were 26.75 kN and 26.45 kN, against 24.84 kN and 23.99 kN, defined as the theoretical values, respectively. Such an increase is attributed to random variations in the material, high tensile strength of concrete and conservative assumptions used in theoretical calculations; nevertheless, this justifies a fair correlation between theory and experiment.

Table 4.2 Experimental Versus Theoretical First crack Deflection

	Theoretical	Experimental
Specimen Details	**First crack Deflection**	**First crack Deflection**
Specimen -1	0.282	0.215
Specimen -2	0.303	0.254
Specimen -3	0.283	0.204
Specimen -4	0.273	0.225

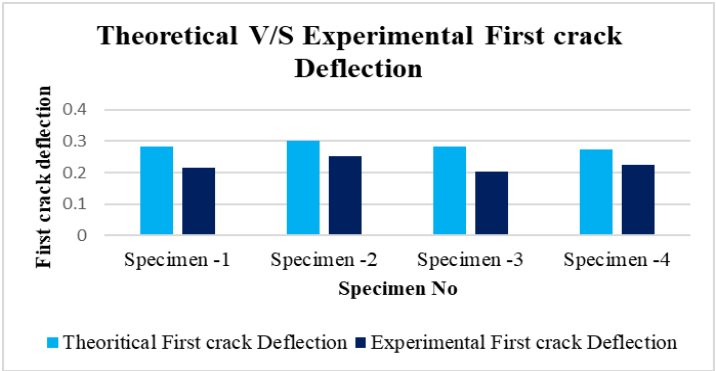

Chart -1: Theoretical V/S Experimental First crack Deflection

The comparison between theoretical and experimental first crack deflections indicates that the experimentally measured deflections have, in general, always remained less than the theoretical predictions for all beam specimens. For instance, Specimen-1 has dropped from a theoretical value of 0.282 mm to an experimental one of 0.215 mm. Specimen-2 similarly dropped from 0.303 mm on the theoretical side down to 0.254 mm. Specimens 3 and 4 reported experimental deflections of 0.204 mm and 0.225 mm, respectively, against theoretical predictions of 0.283 mm and 0.273 mm. The lower experimental deflections might be attributed to higher actual stiffness, material nonlinearity, and conservative assumptions implemented in theoretical calculations.

Table 4.3 Experimental Versus Theoretical Ultimate load

	Theoretical	Experimental
Specimen Details	**Ultimate Load**	**Ultimate Load**
Specimen -1	137.36	145.06
Specimen -2	139.25	146.85
Specimen -3	88.04	91.25
Specimen -4	89.51	92.55

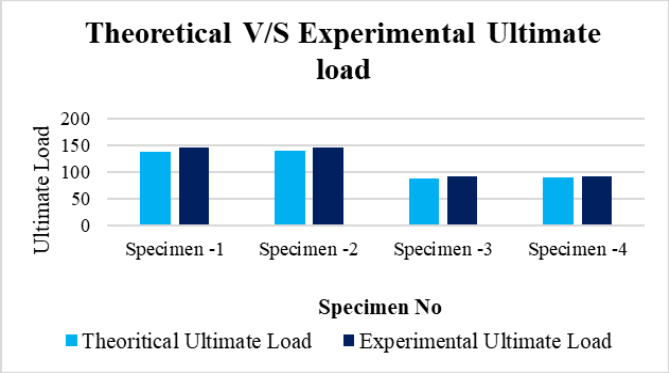

Chart -1: Theoretical V/S Experimental Ultimate Load

The comparison of theoretical and experimental comparative ultimate loads indicates that experimental values are somewhat more than theoretical predictions for all beam specimens. Specimen 1 increased from 137.36 kN to 145.06 kN, whereas Specimen 2 increased from 139.25 kN to 146.85 kN. Likewise, Specimens 3 and 4 also showed experimental ultimate loads of 91.25 kN and 92.55 kN against theoretical values of 88.04 kN and 89.51 kN, respectively. The close agreement indicates that the theoretical approach renders conservative yet reliable predictions of ultimate load-carrying capacity.

Table 4.3 Experimental Versus Theoretical Ultimate load

	Theoretical	Experimental
Specimen Details	**Ultimate Deflection**	**Ultimate Deflection**
Specimen -1	5.667	4.75
Specimen -2	5.745	3.35
Specimen -3	3.769	3.15
Specimen -4	3.832	3.24

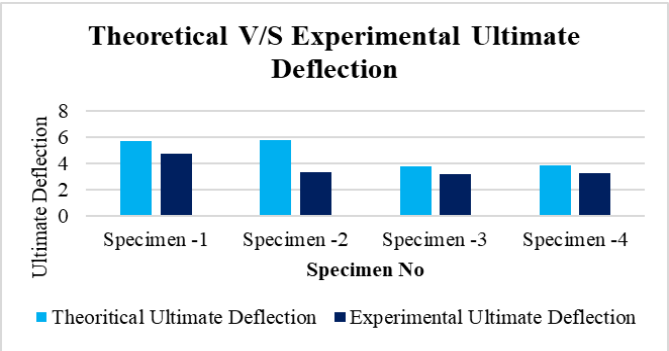

Chart -1: Theoretical V/S Experimental Ultimate Deflection

Under all beam cases in experiment, it has been seen that the actual deflections are lesser than those of the theoretical deflections in comparison with the ultimate theoretical and experimental deflections. For instance, specimen-1 has experimental ultimate deflections of 4.75 mm, with a theoretical value of 5.667 mm, while specimen-2 has a difference from 5.745 mm to 3.35 mm. Again, specimen-3 and specimen-4 have their experimental showing in terms of ultimate deflection as 3.15 mm and 3.24 mm, respectively, while their theoretical values were 3.769 mm and 3.832 mm. Hence, these lower experimental deflections probably indicate higher real stiffness while the assumption in theoretical calculation of deflections was more conservative.

4.2 Crack initiation and Degradation

Under four-point bending, crack initiation was observed for all the augmented concrete beam specimens in the constant moment region, thereby indicating a flexure-dominated behavior. The earliest visible cracks formed on the tension face near mid-span when the applied moment crossed the tensile strength of concrete. Prior to cracking, all beams exhibited linear elastic behavior with high stiffness, as established by the initial slope of the load–deflection curves. The first crack loads recorded experimentally were, on the whole, higher than those theoretically obtained; implying conservative assumptions were adopted in the analysis.

With the initiation of the first crack, a gradual loss of load–deflection stiffness began because of the appearance and spreading of flexural cracks. The control beams reinforced with H.Y.S.D. steel showed comparatively better control of the development of cracks and lesser reduction in stiffness due to the ductile nature of steel reinforcement, while the beams with GFRP stirrups showed slightly higher reduction in stiffness in the post-cracking stage owing to the linear-elastic behavior of GFRP. Nevertheless, the overall flexural response was deemed acceptable, indicating that the GFRP stirrups were reliable in the design of RC beams.

4.3 Ultimate Load carrying capacity

The experimental evaluation of ultimate load-bearing capacity for all the reinforced concrete beam specimens was carried out based upon the maximum load sustained during four-point bending tests. All the beams showed a gradual increase in load with increasing deflection and finally failing due to extensive flexural cracking followed by crushing of concrete in the compression zone. Experimental ultimate load-carrying capacities were slightly higher than the corresponding theoretical values for all specimens, indicating that such analytical predictions are conservative. Control beams fully reinforced with HYSD steel bars exhibited a marginally increased load-carrying capacity owing to the improved confinement and ductile behavior provided by steel stirrups. However, hybrid beams reinforced with HYSD longitudinal bars and GFRP stirrups attained comparable ultimate capacities, showing that flexural strength is mainly dependent on longitudinal reinforcement. The results substantiate the feasibility of the use of GFRP stirrups without any appreciable loss in load carrying capacity.

3. CONCLUSIONS

- Experimental first crack loads were higher than theoretical values for all beam specimens, implying conservative analytical assumptions.
- Crack initiation occurred in the constant moment region, thus confirming the flexure-controlled behavior of all beams.
- Post-cracking, fully reinforced HYSD steel beams exhibit higher stiffness and reduced deflections.
- Hybrid beams with GFRP stirrups showed a slightly higher degradation of stiffness than pure beams because of the linear elastic nature of GFRP.
- The ultimate load-carrying capacity of hybrid beams was comparable to that of control beams indicating that the longitudinal reinforcement governs the flexural strength.
- Experimental ultimate loads were marginally higher than all theoretical predictions.
- The usage of GFRP stirrups effectively controlled cracking and provided corrosion resistance.
- This study confirmed that GFRP stirrups can replace steel stirrups in the construction of RC beams without a noticeable decrement in the performance of the structure.

REFERENCES

[1] IS 456:2000, Plain and Reinforced Concrete – Code of Practice, Bureau of Indian Standards, New Delhi.

[2] IS 10262:2019, Concrete Mix Proportioning – Guidelines, Bureau of Indian Standards, New Delhi.

[3] IS 1786:2008, High Strength Deformed Steel Bars and Wires for Concrete Reinforcement, Bureau of Indian Standards, New Delhi.

[4] IS 383:2016, Coarse and Fine Aggregate for Concrete – Specification, Bureau of Indian Standards, New Delhi.

[5] ACI Committee 440 (2015), Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars (ACI 440.1R), American Concrete Institute.

[6] Bank, L. C. (2006), Composites for Construction: Structural Design with FRP Materials, John Wiley & Sons, New York.

[7] Benmokrane, B., El-Salakawy, E., & El-Gamal, S. (2007), "Performance of Concrete Bridge Decks Reinforced with FRP Bars," Journal of Composites for Construction, ASCE, Vol. 11(4), pp. 350–360.

[8] Grace, N. F., Soliman, A. K., Abdel-Sayed, G., & Saleh, K. R. (1998), "Behavior and Ductility of Simple and Continuous FRP Reinforced Beams," Journal of Composites for Construction, ASCE, Vol. 2(4), pp. 186–194.

[9] El-Gamal, S., & Benmokrane, B. (2013), "Shear Strength of FRP-Reinforced Concrete Beams without Transverse Reinforcement," Journal of Composites for Construction, ASCE, Vol. 17(3), pp. 368–378.

[10] Toutanji, H., & Saafi, M. (2000), "Flexural Behavior of Concrete Beams Reinforced with Glass Fiber-Reinforced Polymer Bars," ACI Structural Journal, Vol. 97(5), pp. 712–719.

[11] Rafi, M. M., Nadjai, A., Ali, F., & Talamona, D. (2008), "Aspects of Behaviour of CFRP Reinforced Concrete Beams in Bending," Construction and Building Materials, Vol. 22, pp. 277–285.

[12] Bischoff, P. H., & Gross, S. P. (2011), "Equivalent Moment of Inertia for Calculating Deflections of Concrete Members Containing Steel Reinforcement," ACI Structural Journal, Vol. 108(1), pp. 92–100.