Vol 6, Issue 8, August 2026 www.ijesti.com E-ISSN: 2582-9734
International Journal of Engineering, Science, Technology and Innovation (IJESTI)

Comparative Study of Flexural Performance of Steel and GFRP Reinforced Concrete Beams

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ABSTRACT

The bending behavior of concrete columns strengthened by Fibreglass Composite Reinforced Polymers (GFRP) rods. GFRP strengthening material has surfaced as a viable substitute for traditional steel strengthening due to its superior strength compared to weight coefficient and resistance to corrosion& resistance to aggressive environmental conditions. However, in contrast to steel reinforcement, GFRP bars often demonstrate linear elasticity behavior until breakdown occurs or may not possess a distinct yielding stage. Consequently, GFRP-reinforced concrete beams may demonstrate limited ductility and different cracking and deflection characteristics in contrast to traditional steel-supported concrete frameworks. The present an experimental investigation evaluates the bending performance of durable concrete Pillars separately with conventional steel bars & GFRP bars. The comparative assessment focuses on Factors including initial fracture strain, maximum load-bearing capability, central spanning deviation, & fracture progression, flexural stiffness, & mode of failure. Previous experimental investigations have shown that the type and ratio of reinforcement significantly influence the strength the performance, usability, & breakdown characteristics of GFRP-infused cement members.

Keywords: *Concrete, Reinforcement, GFRP Bars, Flexure, Deflection.*

1. INTRODUCTION

Reinforced concrete beams are important structural components that primarily resist externally applied loads through bending and shear action. Conventional reinforced concrete beams generally use steel bars as internal reinforcement because steel provides high tensile strength, adequate bond with concrete, and considerable ductility. Nevertheless, steel reinforcement is vulnerable to corrosion, particularly whenever concrete structures are exposing to moistures, chlorides, chemicals, marine conditions, or other aggressive environments. Corrosion of reinforcing steel may lead to cracking, delamination, & spalled of the surrounding ceramic, eventually reducing the structural capacity and durability of reinforced ceramic components [1], [2].

The deterioration of ageing reinforced ceramic infrastructure has become a majored concern for structural engineers. The degradation of integrated steel supports is acknowledged as a primary factor contributing to damage and early degradation in concrete reinforcement edifices [2]. To address this issue, fiberglass-reinforced polyethylene bars were originally implemented as non-magnetic internal reinforcements for concrete structures. Reinforced FRP has numerous beneficial characteristics, notably such as minimal weighing, elevated tensile properties, ability to withstand oxidation, favorable fatigue behavior, magnetic adequacy, and an impressive strenght-to-weight ratio [1], [3].

Fibre-Reinforced Polymer composites are commonly manufactured using materials composed of carbon and glass or amorphous fibers encapsulated in polymeric network. Each type of fibre has different mechanical and physical characteristics. Carbon Fibre-Reinforced Polymer generally possesses high tensile strength and stiffness, although its relatively high cost may limit its widespread use. Glass Fibre-Reinforced Polymer is comparatively economical and provides satisfactory tensile strength, corrosion resistance, and durability. Aramid Fibre-Reinforced Polymer is well known for its high impact resistance, toughness, and energy-absorption capacity [3], [4].

Among the different FRP materials, GFRP bars are regarded as an appropriate substitute for traditional structural steelin structures where resistance to corrosion and reduced maintenance requirements are important. However, GFRP bars demonstrate elastic linear characteristics till failure and lack a definitive output point stage similar to steel reinforcement. Therefore, GFRP-reinforced concrete beams may show different cracking behaviour, deflection characteristics, stiffness, ductility, and failure modes in contrast to traditional steel-supported concrete posts [1], [5].

The present experimental investigation aims to Examine the bending characteristics of concrete columns supported with academic GFRP bars while evaluating their efficacy against traditionally strengthened steel spansconcrete beams. The comparative assessment includes first-crack load, ultimate load-bearing capability, central span deformation, crack development, flexural stiffness, and mode of failure. M25-grade concrete is employed for preparationthe beam specimens, & the concrete mixture is proportioned in accordance with IS 10262:2009 [6].

1.1 Objective

- To examine the bending characteristics and load-bearing potential of concrete supports strengthened with bars made from GFRP as a substitute for traditional steel reinforcements.
- To evaluate and compare the structural efficacy of GFRP-encased concrete columns paired usingthat of control beams made using the same nominal grade of cementitious material or fortified with standard steel reinforcement bars.

1.2 Background of FRP

The principle of improving weak construction s by incorporating fibres has existed since ancient times. Natural fibres, such as straw, were added to earthen and sun-dried bricks to reduce shrinkage cracking and improve the integrity of the material. However, the systematic development of modern fibre-reinforced composite materials began during the twentieth century with advances in glass-fibre production and polymer-resin technology [3].

The commercial development of glass fibres and thermosetting polymer resins during the 1930s and 1940s made it possible to manufacture lightweight composite materials with high tensile strength and favourable durability. These materials were initially used in the aerospace, defence, marine, and manufacturing industries. Their successful performance later encouraged researchers and engineers to investigate applying them to civil & building engineering projects [3, 7].

Fiber-Reinforced Plastic, or Fiber-Reinforced Plastic, is a mixture of substance made up of polymeric matrix and high-density fibers. A polymeric matrix connects the fibers together, shields them from optical and ecological damage, and transmits loads across the fibers; the fibers mainly offer elasticity & flexibility [3], [7].

Figure 1: Fibre- Reinforced Polymer

2. RESEARCH BACKGROUND

Ahmed, Jaf, and Yaseen (2020) experimentally investigated the flexural behaviour of GFRP-reinforced columns made with geometric polymer with traditional Portland cement pavement [14]. Samples that were bent in this test had a span of around 2 meters. The analysis's primary variables included material form, cement compressive strength, & longitudinal reinforcement ratio. Factors such as maximum loading-carrying potential, fracture frequency & breadth, rigidity, bending reaction, initial crack weight, or failure mode were used to assess the experimental findings. Forecasts derived from ACI 440.1R-15, CSA S806-12, or an inverse stress blocking approach was further evaluated with the observed bending capabilities.

Słowik (2019) analysed the failure behaviour and crack development of plain and reinforced concrete beams containing unique proportions of longitudinal supports [15]. The study demonstrated that the amount of longitudinal reinforcement significantly influenced crack propagation and the resulting mode of failure. Plain and lightly reinforced concrete beams exhibited brittle behaviour associated with the formation and unstable propagation of Fissures caused by bending or flexing. Structures with mild strengthening typically have transverse reinforcement restricted the rapid development of flexural cracks and permitted more stable crack growth. The investigation therefore established that what causes a steel bridge to collapse changes with the longitudinal reinforcement ratio. It also highlighted the importance of tensile strain-softening behaviour in evaluating crack initiation and propagation in concrete members [15].

El-Hassan and El Maaddawy (2019) studied the properties of G.F.R.P reinforcement pieces with regard to their microstructure & endurancesubjected to aggressive environmental conditions [16]. The bars were conditioned in pH-neutral & pH-rich formulations, beverages, seawater, & concrete environments. Elevating tempt. were used to accelerate environmental degradation, and some specimens were simultaneously subjected to sustained tensile stresses. The residual tensile features of the conditioned bars were measured to accessing their mechanical-measure retention.

Hamad, Megat Johari, and Haddad (2019) experimentally and theoretically examined how anchoring leakage affects the flexibility of ceramic supports supplemented with F.R.P before and after exposure to elevated temperature [17]. Twenty-four control and heat-damaged G.F.R.P, B.F.R.P, C.F.R.P, and steel bar-reinforced columns were subjected to multi-point pressure tests. The structural response was evaluated using load capacity, deflection, reinforcement strain, concrete compressive strain, stiffness, absorbed energy, bond behaviour, and failure mode. After heating at 500°C for 90 minutes, the FRP-reinforced beams exhibited substantial reductions in load-bearing capability, rigidity, and energy-absorbing properties. Their deflections increased because of degradation of the polymer matrix, deterioration of the tensile properties of the pubs, &unravelling of the F.R.P–concrete interface. The adverse effects of heating were more significant in the FRP-reinforcement specimens than in the corresponding supported by steel rails. The investigation therefore demonstrated that bond-slip behaviour and temperature-induced material degradation must be incorporated when predicting the compressive reaction of fiber-reinforce after warming members [17].

Jabbar and Farid (2018) investigated the feasibility the use of GRP bars in place of traditional steel reinforcing in masonry structures [18]. The study included mechanical characterisation of steel bars, sanded-coating G.F.R.P bars, & smooth-surfaced GFRP bars. The reinforcing materials were evaluated using relevant ASTM and British Standard testing procedures, and their mechanical characteristics were compared. The authors concluded that GFRP reinforcement could be considered a potential to aluminium reinforcing, especially for ceramic buildings that are subjected to harsh or acidic conditions. Nevertheless, GFRP columns don't possess a conventional yield point comparable to steel. Therefore, the reported “yield strength” of GFRP should more accurately be interpreted as tensile strength or stress measured at a specified strain rather than true yielding behaviour [18]. The original publication confirms that the study compared the m/c characteristics of G.F.R.P & steel reinforcing columns.

Baša, Ulićević, and Zejak (2018) experimentally studied the behavior of recurrent ceramic supports that were strengthened using glass fiber reinforcing plastic (GFRP) strips [19]. The experimental programme consisted of continuous beam specimens containing different arrangements and ratios of longitudinal reinforcement in the areas of moments of good & unfavourable. The type and surface configuration of GFRP reinforcement were also considered as experimental variables. The magnitude of moment redistribution was strongly determined by the vital part support's equivalent longitudinal rigidityover the intermediate supporting& within the span. Concrete cracking, bond-slip behaviour, reinforcement configuration, and differences in sectional stiffness contributed to the shifting the balance of power within. Beaming containing G.F.R.P reinforced with comparatively poor surface bond developed fewer but wider and deeper cracks, particularly near critical support sections [19].

Santhakumar and Rajkumar (2018) Beam specimens prepared using M30- and M40-grade concrete were tested under two-point loading. Their behaviour was evaluated with reference to IS 456:2000 and the provisions of ACI 440.1R. The hybrid-reinforced specimens reportedly exhibited better overall flexural behaviour than specimens reinforced exclusively with GFRP bars. The findings suggested that combining steel and GFRP reinforcement may reduce some of the limitations associated with the brittle, linear-elastic response of GFRP while retaining part of its corrosion-resistance benefit [20].

Priyanka and Shivaramakrishnan (2018) examined the behaving of ceramic beaming incorporating hybrid G.F.R.P reinforced [21]. The deteriorating state of incorporated steeling in traditional ceramic reinforcement is what prompted the research, particularly under cold, saline, and chloride-rich environmental conditions. The study indicated that hybrid reinforcement could improve how well reinforcement ceramic posts function in terms of maintenanceby controlling deflection and crack development. However, the degree of improvement would depend on the amount, location, anchorage, and elastic properties of the GFRP reinforcement [21].

Chidananda and Khadiranaikar (2018) looked into how well ceramic columns strengthened usingdifferent percentages of longitudinal G.F.R.P reinforcement [22]. The beam specimens measured approximately was subjected to 4 psi stress during testing; dimensions were 150 microns wide, 179 millimeters deep, and 1200 millimeters long. Reinforcement ratios of approximately 0.5%, 1.0%, 1.5%, & 2.0% were considered. The findings demonstrated that the boards' post-clearing rigidity & maximum carried weight capability were both improved with an increase in the G.F.R.P reinforcing proportion. The reported increases in ultimate capacity were approximately 7.5%, 16.8%, and 27.7% as the reinforcing proportion was progressively enhancement from the lowest investigated value. Raising the percentage of reinforcingreduced both the mildest-spanning deflecting and crack width at comparable load levels. The study also observed that GFRP reinforcement produced a lower tension-stiffening contribution than conventional steel because of its reduced tensile stiffness & distinct connectioncharacteristics. Predictions obtained using A.C.I 440.1. R-06, C.S.A S806-12, & E.C.P 208-2005 produced broadly comparable estimates of beam deflection [22]. The available paper record identifies this work as an investigation of beams reinforced with 0.5%, 1.0%, 1.5%, and 2.0% GFRP reinforcement.

Nayak, Tade, and Thakare (2017) investigated the usage of G.F.R.P columns for strengthening reinforced ceramic columns and columns [23]. The study evaluated the effectiveness of GFRP reinforcement by comparing the structural performance of strengthened specimens with that of corresponding controlling sample. The authors reported an enhancement of approximately 30.33% in the flexural strengthen of the strengthened beaming. An improvement of approximately 20.76% in the compressive strain that the rows samples are capable of withstandingwas also observed. These results indicated that GFRP reinforcement could enhance the structural capacity of concrete members when an appropriate strengthening configuration and adequate bond between the composite and concrete were provided.

Ju, Oh, Lim, and Sim (2016) conducted studies that tested masonry beaming reinforcing using glass fiber reinforcing plastic (GFRP) rods for their stiffness & moment-deformation reaction [24]. The experiments involved the creation and testing of three distinct kinds of ceramic frames reinforcing with glass fiber reinforcing polymer, and the measured deflections were compared via values obtained from existing analytical models. Consequently, Branson's based formula was used to build a customized functional amount of gravity framework. Because G.F.R.P reinforcing has a reduced longitudinal rigidity, an altered factor was included to make up for this and lessen the effect of the fractured present of gravity. The proposed framework gave accurate predictions of the overall moments of stiffness & beams bending, according to the analysis with the practical data. The model retained the general form of Branson's equation while improving its applicability to GFRP-reinforced concrete members [24]. The published study confirms that Branson's based formula served as the experimental basis for the suggested frameworkand evaluated using tested GFRP-reinforced beams.

Dharma (2016) reviewed previous research concerning the durability and strength of masonrymembers reinforced via GFRP columns [25]. The review identified key benefit of G.F.R.P strengthening is its immunity to oxidization, stiffness, & relatively light mass. Nevertheless, its veryleast elastic modulus & linear-elastic response up to rupture were recognised as major limitations affecting the stiffness and deformation capacity of GFRP-reinforced concrete members. The reviewed studies indicated that GFRP-reinforced beams generally develop larger service-load crack dimensions & deviations compared to equivalent steel-framed columnswhen similar reinforcement areas are used. The absence of yielding also reduces the conventional ductility associated with steel-reinforced concrete members.

Maranan et al. (2015) evaluated the flexural strength and serviceability performance of geopolymer concrete beams reinforcement via GFRP columns [26]. The principal experimental variables were thebar minimum dimension, lateral reinforcement proportion, and G.F.R.P specifications, and anchorage configuration. Sand-coated G.F.R.P rods had been used, & their nominal thicknesses ranged from 12.7 mm to 19.0 mm. A four-degree statically breaking testing was performed on the samples. The ability to transport loads and load-difference behavior were used to evaluate the empirical reaction, cracking, failure mode, bonding performance, and agreement via analytical predictions. The experimental moment capacities were in most cases, greater than what might be predicted via A.C.I 440.1R-06 & C.S.A S806-12. They ascribed this discrepancy to the structural features additionally straining capacities of the geopolymer construction, the effect of compressive strengthening, & the restriction given by the longitudinal reinforcing [26]. The original paper confirms that criteria included anchoring method, reinforcing coefficient, & beam size and that increasing the reinforcement ratio improved serviceability, while sand coating provided effective bond.

Golafshani, Rahai, and Sebt (2014) experimentally investigated the Interface behavior of self-assembling concrete strengthening bars made of glass and metal fiber reinforced plastic& normally vibrated concrete [27]. Pull-out specimens were used to examine the cement's compression property, the impact of pavement variety, casting direction, bar position, & reinforcement type. The study also identified a casting-position effect. Bars having a larger depth of concrete beneath them during casting exhibited lower bond strength because of the accumulation of air, water, and fine particles near the reinforcement. These observations demonstrated that bar surface treatment, concrete quality, casting position, and confinement are important parameters in determining the development and anchorage requirements of GFRP reinforcement [27]. The study examined 104 pull-out specimens and directly compared self-consolidating & regular ceramic with metal & G.F.R.P rods.

Santos et al. (2013) investigated GFRP-reinforced discontinuous masonry bridges' elasticity & time-shifting capability. The study indicated that redistribution of internal bending moments could occur after cracking because the relatively rigidity of the support & span sections changed via loaded design. The lower elastic modulus of GFRP reinforcement resulted in greater curvature and deflection than would normally occur in comparable metal-reinforcement design. Nevertheless, boosting a proportion of transversal reinforcementsand providing adequate confinement at the critical sections improved sectional stiffness, deformation capacity, and moment redistribution.

Zheng et al. (2012) studied empirically the functional behaviour & ultimate stiffness of cement deck-bridge platform prototypes strengthened with GFRP reinforcement & standard steel columns at a size of 1/3 [28]. The major factors included the width of the supporting beams, type and amount of reinforcement, concrete strength, and degree of lateral restraint.

Issa, Metwally, and Elzeiny (2011) investigated the effect of fiber distribution inside the material on the elasticity & bending behavior of GFRP-supported bar concrete reinforcement beams [29]. By combining regular & reinforced concrete, 7 beam prototypes were produced. Different types of internal fibres were incorporated into selected specimens, while corresponding beams without fibres were used as reference specimens.

Lau and Pam (2010) experimentally studied the flexural behaviour of columns made of cement that have been strengthened via steel columns or a mix of the two [30]. The purpose of the study was to find a way to increase the bending ability of a spans that were only strengthened using FRP plates without sacrificing resilience to corrosion or strong tensile properties provided by FRP reinforcement.

Saikia et al. (2007) studied the durability & reliability of GFRP-reinforced concrete supports [31]. The beams were designed using limit-state principles and tested to examine ultimate capacity, crack development, deflection, post-cracking stiffness, and failure behaviour. The values **49.1% and 50.8% of theoretical capacity** belong to the later bond-slip and heating study by Hamad et al. and should not be attributed to Saikia et al.

Ashour (2006) examined the behavior of concrete columns reinforcing by glass fiber reinforcing polymer rods under torsional & load shear. The study reported different failure mechanisms depending on the amount and arrangement of reinforcement. Under-reinforced sections could fail through tensile rupture of the GFRP bars after extensive flexural cracking, whereas highly reinforced members were more likely to experience concrete crushing or shear-related failure.

Abdalla (2005) developed analytical expressions for computing the bending modulus of FRP-reinforced bricks. The proposed approach considered the mechanical properties of the impact & transverse reinforcingof reduced reinforcement stiffness on crack development and shear transfer.

Toutanji and Deng (2003) experimentally evaluated the applicability of available analytical procedures for predicting the fracture breadth & bending of GFRP-reinforced concrete supports. The predictions obtained using ACI 440 provisions were compared with measured values from beams containing different reinforcement arrangements.

Abdalla (2002) evaluated methods for estimating the short-term tangible parts that have been strengthened using fiber-reinforced plastic strips have their flexibility reduced. Potential moments of momentum that are distinct models were examined using experimental results obtained from GFRP- and CFRP-reinforced specimens.

Alsayed et al. (2002) examined whether the strength and serviceability provisions of ACI 318 could be directly applied to GFRP-reinforced concrete supports. Experimental results were compared with predictions for flexural capacity, service-load stress, deflection, and minimum reinforcement.

Benmokrane et al. (2000) conducted study of the torsional behavior of strengthened ceramic columns using unconventional approachesdifferent quantities of GFRP bars. The specimens were tested under gradually increasing flexural loading, and their response was evaluated in terms of load capacity, cracking, deflection, stiffness, strain, and failure mode.

3. KEY FINDINGS FROM STUDY

Most studies show that GFRP bars are a promising alternative to steel because of their corrosion resistance, high tensile strength, and low self-weight. However, their lower elastic modulus, larger service-load deflections, wider cracks, brittle rupture, bond/anchorage issues, and sensitivity to elevated temperature remain important limitations.

Author(s) & Year	Objective	Methodology	Key Findings	Research Gap / Limitation
Ahmed, Jaf & Yaseen (2020)	To study flexural behaviour of GFRP-reinforced geopolymer/concrete beams	Flexural testing of about 2 m span beams; comparison with ACI 440 and CSA S806	GFRP beams showed satisfactory flexural behaviour and code predictions were evaluated	Limited specimens; more spans, concrete grades, and long-term studies are needed
Słowik (2019)	To study the effect of reinforcement ratio on cracking and failure	Testing of beams with different longitudinal reinforcement ratios	Reinforcement ratio strongly affected crack propagation and failure mode	Mainly focused on cracking and failure; GFRP durability was not studied
El-Hassan & El Maaddawy (2019)	To evaluate durability of GFRP bars in aggressive environments	GFRP bars exposed to various solutions, elevated temperature, and sustained stress	Environmental exposure reduced residual mechanical properties	Accelerated laboratory exposure may not fully represent field conditions
Hamad et al. (2019)	To study the effect of high temperature and bond-slip on FRP beams	GFRP, BFRP, CFRP, and steel beams heated to 500°C and tested in flexure	Heating reduced load capacity, stiffness, and energy absorption, and increased deflection	More realistic fire-condition studies are needed
Jabbar & Farid (2018)	To assess GFRP as an alternative to steel	Mechanical testing of steel, smooth GFRP, and sand-coated GFRP bars	GFRP is promising for corrosive environments and has no conventional yield point	Full-scale structural and long-term bond behaviour need more study
Baša et al. (2018)	To study moment redistribution in continuous GFRP beams	Continuous beam testing with different reinforcement arrangements	Redistribution was influenced by cracking, bond-slip, and sectional stiffness	Limited beam configurations and loading patterns
Santhakumar & Rajkumar (2018)	To compare hybrid steel-GFRP and pure GFRP beams	M30 and M40 beams tested under two-point loading	Hybrid reinforcement gave better overall flexural behaviour	Optimum steel-GFRP ratio was not established
Priyanka & Shivaramakrishnan (2018)	To study serviceability of hybrid GFRP-reinforced beams	Experimental beam testing	Hybrid reinforcement helped control deflection and cracking	Performance depends on amount, position, and anchorage of reinforcement
Chidananda & Khadiranaikar (2018)	To study different GFRP reinforcement ratios	Beams with about 0.5%, 1.0%, 1.5%, and 2.0% GFRP reinforcement were tested	Higher reinforcement ratio improved stiffness and load capacity and reduced deflection/crack width	Bond and lower tension-stiffening remain concerns

Nayak et al. (2017)	To study GFRP strengthening of beams and columns	Strengthened specimens compared with control specimens	About 30.33% flexural improvement and 20.76% compressive improvement were reported	Results depend strongly on strengthening configuration and bond quality
Ju et al. (2016)	To improve deflection prediction of GFRP beams	Experimental testing and modified Branson equation	Modified effective moment of inertia model improved deflection prediction	Wider validation is required
Dharma (2016)	To review GFRP-reinforced concrete behavior	Review of previous research	GFRP is corrosion resistant and lightweight, but lower modulus causes larger deflection and crack width	More research is needed on serviceability and durability
Maranan et al. (2015)	To evaluate flexural strength and serviceability of geopolymer beams with GFRP	Four-point bending with different bar sizes, ratios, and anchorage	Experimental capacities were often higher than code predictions; sand coating improved bond	Limited to selected geopolymer and reinforcement systems
Golafshani et al. (2014)	To compare bond behaviour of steel and GFRP bars	104 pull-out tests in self-compacting and normal concrete	Bond depended on bar surface, concrete quality, and casting position	Pull-out tests do not fully represent bond behaviour in real beams
Santos et al. (2013)	To investigate moment redistribution in continuous GFRP beams	Continuous beam flexural tests	Cracking and stiffness changes caused redistribution of bending moments	More work is needed on redistribution limits and ductility
Zheng et al. (2012)	To study GFRP-reinforced bridge deck slabs	Testing of about one-third scale deck slab models	Ultimate behaviour was influenced by reinforcement, support width, concrete strength, and restraint	Scale effects may limit direct application to full-scale structures
Issa et al. (2011)	To study the effect of fibres on GFRP-RC beams	Seven beams with and without internal fibres	Fibres improved cracking behaviour and ductility	Limited specimen number and fibre types
Lau & Pam (2010)	To improve flexural behaviour using hybrid steel-FRP reinforcement	Steel, FRP, and hybrid reinforced beams tested in flexure	Hybrid reinforcement can combine steel ductility with FRP corrosion resistance	Optimum hybrid ratio and long-term performance require further study

Saikia et al. (2007)	To study strength and serviceability of GFRP beams	Beams tested for ultimate load, cracking, deflection, stiffness, and failure	Provided important data on GFRP beam strength and serviceability	Long-term deflection, fatigue, and bond require more research
Ashour (2006)	To investigate flexural and shear behaviour of GFRP beams	Beams with different reinforcement ratios were tested	Low reinforcement could lead to GFRP rupture; high reinforcement could lead to concrete crushing or shear failure	Better prediction of flexure-shear interaction is needed
Abdalla (2005)	To develop analytical expressions for flexural stiffness	Analytical modelling considering cracking and reduced reinforcement stiffness	Improved representation of FRP-RC stiffness was proposed	Requires more experimental validation
Toutanji & Deng (2003)	To evaluate deflection and crack-width prediction methods	Experimental results compared with ACI 440 predictions	Existing serviceability models showed varying accuracy	Further calibration is required
Abdalla (2002)	To evaluate short-term deflection methods for FRP-RC members	Experimental data compared with analytical stiffness models	Conventional steel-based models were not fully suitable for FRP-RC beams	Long-term behaviour and different FRP types need study
Alsayed et al. (2002)	To check whether conventional ACI provisions are applicable to GFRP beams	Experimental results compared with code predictions	Steel-RC provisions were not fully suitable for GFRP-RC behavior	Dedicated GFRP design provisions are required

4. CONCLUSION

- Both the steel-reinforcement and GFRP-reinforced cemented beaming sustained a max. recorded loading of 40 k.N under the adopted testing conditions. Therefore, no increase in the ultimated loading-carried capacities of the GFRP-reinforced beaming could be established via the available experimental information.
- At the max. recorded loading of 40 k.N, the calculated flexural strength of the steeling-reinforced & G.F.R.P-reinforcement beaming were 11.600 N/mm² & 11.585 N/mm², respectively. The difference between such magnitudes was negligible, indicating that both specimens exhibited nearly comparable flexural- strength responses.
- At 40 kN, The bending radius of the GFRP-supported girder was 2.495 mm, in contrast to that of the steel-supported column was 2.495 mm at the midpointwas 2.415 mm. Thus, the tested GFRP-reinforced specimen exhibited approximately 3.21% lower displacement compared to the reference sample strengthened with metal at identical stress.
- The mid-span deflection of both specimens increased progressively with the applying loading. The differences between the loading–deflection responses of the two beams remained relatively small within the investigated loading range.
- The experimental findings indicate that GFRP bars can provide flexural performance comparable to that of conventional steel reinforcement under the specific material properties, reinforcement arrangement, specimen dimensions, curing conditions, and loading configuration adopted in this study.

- GFRP reinforcement offers additional advantages, including low self-weighting, highest longitudinal tensiled-strengthen, resistance to electrochemical, electrical non-conductivity, & ease of transportation and handling. These characteristics make GFRP bars particularly attractive for concrete structures exposed to marine, chloride-rich, or other aggressive environmental conditions.

5. FUTURE SCOPE

The present investigation was limited to a comparative study of G.F.R.P & traditional metal bar strengthened M25-quality cement bridges' flexible properties. The innovative initiative's constraints led to a variety of suggestions for prospective research:

- A larger number of beam specimens should be tested to improve the statistical reliability of the experimental outcomes.
- Columns via distinguish G.F.R.P reinforcing proportion, bar diameters, and reinforcement arrangements should be investigated to determine their influence on flexural strength, stiffness, crack width, and deflection.
- Future studies should include testing up to complete failure to accurately determine the columns' stiffness, maximal load, initial crack weight, absorbing energy, overall defect mode when strengthened with GFRP.
- The influence of various concrete specifications on the structural behavior of GFRP-supported girders, comprising standard-strength & elevated-strength concreteshould be studied.
- The bonding behavior between GFRP bars and concrete should be investigated using different bar-surface treatments, development lengths, anchorage systems, and concrete strengths.
- Long-term performance under sustained loading, repeated loading, fatigue, creep, shrinkage, and environmental exposure should be examined.
- Durability studies should be conducted under marine, chloride-rich, alkaline, acidic, and high-temperature environments to evaluating the longest-terms retention of GFRP properties.
- The fire resistance and post-Look at how GFRP-supported concrete structures fare in firesbecause the polymer matrix may lose strength and stiffness at elevated temperatures.
- The shearing behaviour of G.F.R.P-reinforcement-beams should be studied via different stirrup materials, stirrup spacing, shearing-spanning-to-depth ratios, & loading arrangements.
- Hybrid reinforcing systems combining steel and GFRP bars may be investigated to achieve a balance between corrosion resistance, strength, stiffness, and ductility.
- Numerical models and finite-element simulations should be developed and validated using experimental results to predict cracking, deflection, strain distribution, bond-slip behaviour, and ultimate capacity.
- The experimental results should be measured vs the forecastsof relevant designing standards, including ACI 440 and CSA S806, to evaluate their applicability to locally available materials and Indian construction conditions.
- Full-scale beams, slabs, bridge decks, marine structures, and other structural components should be tested to assess the practical application of GFRP reinforcement.
- Life-cycle cost, maintenance requirements, embodied energy, and environmental benefits of GFRP-reinforced structures should be compared When traditional reinforcement via steel falls shortstructures.
- Further studies should examine eco-friendly construction supplies that use GFRP blocks include fiber-reinforced masonry, geopolymer cement, self-consolidating cement, a and reused aggregate pavement.

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