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Numerical analysis on reinforcement ratio of RC beams using FRP and steel rebars

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Abstract. Reinforced Concrete Structures, traditionally using steel rebars, are vulnerable to corrosion under severe exposure conditions. This can result in several drawbacks such as concrete deterioration, reduced serviceability, increased maintenance costs, and reduced structural durability. To counter these issues, Fibre Reinforced Polymer bars have emerged as another possibility material for steel bars. FRP bars are anti-corrosive, have high tensile strength, weigh one-fourth of steel bars, and have a low thermal expansion coefficient similar to concrete. To enhance both load-carrying capacity and ductility, a combining steel bars and FRP bars has been effectively used because FRP bars are having brittle behaviour. This paper studies theoretical investigations of Reinforcement ratio when Fiber Reinforced Polymer bars and steel bars are used as reinforcement in Concrete beams with A_f to As as 1 which balance both Flexural capacity and ductility.

Keywords. - FRP – Fiber Reinforced Polymer bar, A_f :- Area of Fibre reinforced polymer bar, As :- Area of steel bar

1 Introduction

Many concrete structures reinforced with steel become inferior due to corrosion which leads to the huge increase in maintenance cost, reduction in the life span of the structure, bad appearance and service capacity of the structure decreases. Many research works conducted to counteract this problem. Numerous alternative approaches were proposed like Epoxy coated steel reinforcement is the popular method which prevent steel from corrosion. But it also has the disadvantages. Presence of epoxy coat make the poor bonding between concrete and reinforcement and the cost of the reinforcement increases by approximately 10%. Hence alternative methods are proposed to replace the steel reinforcement with suitable alternative material. Fiber Reinforced Polymer (FRP) rebars are the one such material which are made up of fibers reinforced with polymer resin has high resistance to corrosion. These fibers have the advantages of high tensile strength, low specific gravity, magnetic free nature, high temperature resistance, low maintenance and high durable. Hence the concrete structures reinforced with FRP rebars can last for longer duration. Apart from the above advantages

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mentioned, FRP bars shows a linear elastic behavior till the failure which make the concrete in brittle failure. To improve the strength, ductile performance of Reinforced Concrete made with FRP bars, many researches have investigated to improve the flexural performance.(1)experimentally investigated that Hybrid reinforcements had two times more strength when compared with conventional beams and also deflections of both types of matrix are same. (2)performed flexural studies and durability of concrete beams made using steel and FRP bars, results exhibited that ultimate moment was 95% of conventional beams.(3) performed under same load, deflection, crack spacing, ductility of pure FRP beams using BFRP bars is more and for conventional beams are less and values of hybrid reinforcement is in between.(4)presented that the maximum flexure load of Hybrid RC beams(G+S) is 98% of conventional.(5)proposed that Arrangement of FRP at corners and Steel in middle gave better results in ultimate strength, crack width and strain.(6) studied that crack width in Hybrid reinforcement using GFRP and steel bars reduced 50% when compared to pure FRP reinforced concrete beams.(7)carried out reducing the value of A_f/A_s ratio, ductility can reach limiting service conditions. (8)explored from his work that Hybrid reinforcement control first cracking by 50% when compare to concrete beams with pure FRP bars and a relative slip of 25% is observed in GFRP and concrete when compared to steel and concrete. The results shows that Area of fibre to steel ratio has to be maintained in 1:1 which allows maximum allowable load in service.(9)studies performance of RC beams various ratios of Hybrid Reinforcement, concluded that stiffness of Hybrid Reinforcement in beams using constant usage of GFRP, increase in amount of steel is more when compared with fixed amount of steel and increase in amount of GFRP. (6) proposed theoretical investigations for designing flexure using Hybrid reinforcement. (6)experimentally proposed that less amount of GFRP is necessary to prevent from FRP bar rupture and also presented two balanced reinforcement ratios to achieve Steel yielding and Concrete Crushing Failure. (10) in his research studied finally figured that A_f/A_s must lies between 1.0 to 2.5 to meet the requirements of both flexural capacity and ductility.(11) studied that distributed reinforcement deflection is smaller than reinforcement which is bundled. Bui et al., validated that FRP is responsible for ultimate capacity and steel reinforcement is responsible for Ductility.

1.1 Research significance

In this paper authors have attempted to examine the studies on Reinforcement ratio when part of Steel reinforcement is replaced with Fibre Reinforced Polymer bars which maintains the ratio of Fibre area to Steel such that it balances both ductility and load capacity in equal proportions.

2 Theoretical Investigation of Reinforcement Ratio

In this investigation, the part of FRP bars in pure FRP-RC beams are replaced with steel bars by maintaining area ratios of Af/As as 1. Practically, the total reinforcement ratio(ρ) is sum of ρ_s and ρf but the dissimilarity in mechanical properties like Elastic modulus and tensile strength connecting Fibre and Steel is required to evaluate nominal reinforcement ratio(ρ_n). Hence ρ_n,E and ρ_n,F are suggested.

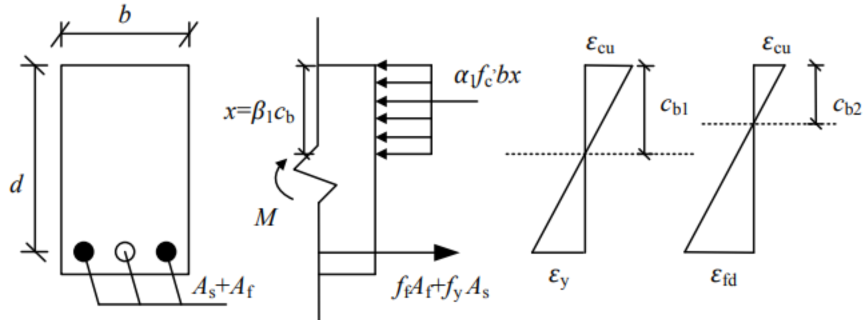

Fig. 1 Fig. 2 Fig. 3 Fig. 4

Stress and Strain distribution in limit state

Fig. 1) RC beam made with steel and FRP bar in one layer Cross section
Fig. 2) Forces in equilibrium
Fig. 3) SY and CC failure condition
Fig. 4) FR and CC failure condition

Nominal Reinforcement ratio in terms of Elastic Modulus(ρ_{nom},E)

$$\rho n,E = \frac{Es*As+Ef*Af}{Es*bd} = \rho s + \frac{Ef}{Es}\rho f \quad (1)$$ or

$$\rho n,E = \frac{Es*As+Ef*Af}{Efbd} = \rho f + \frac{Es}{Ef}\rho s \quad (2)$$

Nominal Reinforcement ratio in terms of Tensile Strength(ρnom,F)

$$\rho n,F = \frac{fy*As+ffu*Af}{fy*bd} = \rho s + \frac{ffu}{fy}\rho f \quad (3)$$ *or*

$$\rho n,F = \frac{fy*As+ffu*Af}{ffu*bd} = \rho s + \frac{fy}{ffu}\rho s \quad (4)$$

For RC beams using only steel bars in flexure, the failure modes examined on the basis of limit state that CC and SY happens at the same time in the case of balanced reinforced condition. Similarly for RC beams using only FRP bars, CC and FR should happen at the same time to maintain balanced reinforcement ratio. But for Hybrid Reinforcement, reinforcement ratio in balanced state shall be achieved from the following two cases as mentioned below.

Case I: SY & CC, simultaneously rupturing of FRP bars

Case II: SY, FRP rupture and CC takes place simultaneously.

Case I: This condition states yielding of steel bar, crushing of concrete happen before FRP rebar rupture.

Effective Reinforcement Ratio (ρn,E)

$$= \frac{Es\ As + Ef\ Af}{Es\ bd} = \rho s + \frac{Ef}{Es}\rho f \quad (5)$$

For Case I, balanced reinforcement ratio ρb,E

$$= \alpha 1\beta 1\frac{fc}{fy}\frac{\varepsilon cu}{\varepsilon cu+\varepsilon y} \quad (6)$$

Case II: In this case yielding of steel rebars then FRP rebar rupture (ff=ffd) and concrete crushing occur synchronously

Effective Reinforcement Ratio ($\rho_{bf,S}$)

$$= \frac{fy\,As + ffd\,Af}{fy\,bd} = \rho s + \frac{ffd}{fy}\rho f \quad (7)$$

For Case II, balanced reinforcement ratio in terms of steel strength ρb,E

$$= \alpha 1\beta 1\frac{fc}{fy}\frac{\varepsilon cu}{\varepsilon cu+\varepsilon y} \quad (8)$$

For Case II, balanced reinforcement ratio in terms of FRP strength (ρbf,F)

$$= \alpha 1\beta 1\frac{fc}{ffd}\frac{\varepsilon cu}{\varepsilon cu+\varepsilon fd} \quad (9)$$

From Case I, if ρn,E is greater than ρb,E the failure of beam is directly takes place due to Concrete crushing which is inadmissible. From Case II condition, if ρn,F is less than balanced ratio then there will be no reserved strength in FRP bars and the section is not admissible as the members are designed to fail by rupture of FRP bars. Hence, for Concrete beams using both Fibre and steel Rebars the section is admissible if it satisfies both equation 10 and 11.

$$\rho n,E \leq \rho b,E \quad (10)$$

$$\rho n,F \geq \rho b,f \quad (11)$$

where Ef and Es are FRP and Steel bar modulus of elasticity; fy is steel rebar strength in yielding; ffd is FRP rebar design tensile strength where ffd=0.7ffu, where ffu is GFRP bars ultimate tensile strength.

α1=0.85, β1=0.85 $\varepsilon_{fd}=f_{fd}/E_f$ and ε_{cu}=0.003

Table 1. Flexural failure conditions of Concrete beams using FRP and Steel bars

Reinforcement Condition	Failure Mode	Remarks
ρn,E>ρb,E	CC, steel nonyielding, FRP non-rupturing	Inadmissible
ρn,F<ρbf	SY, FR, concrete non-crushing	Inadmissible
ρn,E≤ρbE and ρn,F≥ρbf	SY, CC, FRP non-rupturing	Permissible

Table 2. Reinforcement Ratios of RC beams using GFRP and Steel bars

Beam Type	Main Reinforcement		ρn,E (%)	ρb,E (%)	ρn,F (%)	ρb,F (%)	Remarks
	Steel	GFRP					
Hybrid RC beam	2φ12	2φ12	1.09	1.93	1.83	0.695	Admissible

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Table 3. Test Matrix details

Beam Type	**Main Reinforcement**		**Af (mm²)**	**As (mm²)**	**A_s/ A_f**	**ρf (Af/bd)**	**ρs (As/bd)**
	Steel	**GFRP**					
Hybrid RC beam	2φ12	2φ12	226.19	226.19	1	0.005	0.005

The details of Cross section, longitudinal section parameters, Area ratios and reinforcement ratios of RC beam which satisfies the above condition of Failure mode are presented in Table no 2, 3 and Fig 5,6. The cross-sectional details of beam specimen are as follows:
Length = 2 metres; width of beam = 150 mm; depth of beam = 200mm

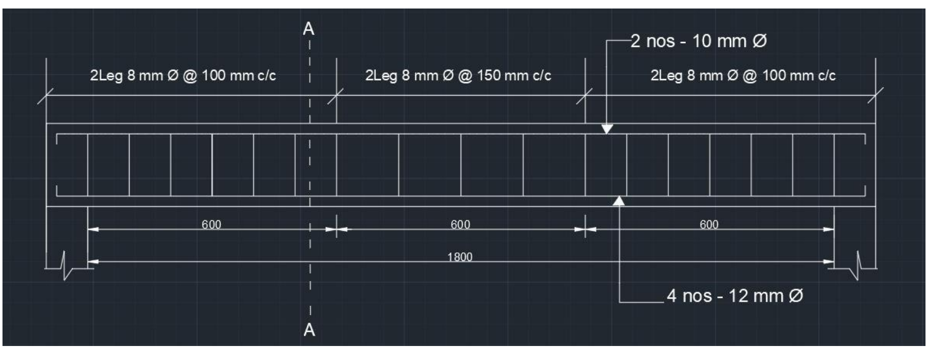

Fig. 5. Longitudinal Section of beam

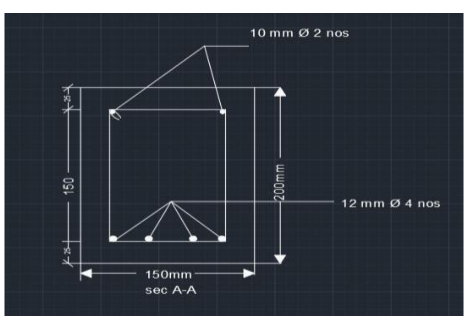

Fig. 6. Cross-section of the beam

3 Discussions

1. This paper reviewed the possible failure modes of Hybrid Reinforced Concrete beam using FRP bar, steel bar and validates the permissible failure for given beam specimen.
2. Reinforced Concrete beam with only steel bars undergoes ductile failure when it undergoes Concrete Crushing followed by Steel yielding.
3. Reinforced Concrete beam using only FRP bars undergoes failure by Crushing of Concrete then FRP rebars which is preferable approach as per ACI 440.1R
4. Yielding of steel rebar then crushing of concrete and eventually rupturing of FRP rebar is the preferable failure mode for beams when steel rebar and FRP rebars are used as reinforcement.

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