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Increased Load-Bearing Capacity Of Beam Reinforced By CFRP, GFRP, and AFRP in Concrete Beam

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ABSTRACT

Efforts to increase the flexural capacity of concrete beams have been examined in many studies, particularly through the use of composite materials such as FRP. Several types of FRP are widely used for beam strengthening, including CFRP, GFRP and AFRP, each offering different advantages depending on the properties of the constituent fibers. The strengthening procedure using these materials follows the provisions in ACI 440.2R 08. By applying the wrap up method, this study found that CFRP produced the highest improvement in flexural strength at forty eight point two nine percent with three CFRP sheets. GFRP recorded its highest improvement at forty seven point nine seven percent with seven sheets, while AFRP reached forty seven point nine eight percent with the same number of layers. The calculations confirm that CFRP is the most efficient and effective option for increasing beam capacity, followed by GFRP and AFRP. For future work, it would be valuable to examine the long term behaviour of beams strengthened with different FRP systems under varying environmental exposures, to investigate the performance of hybrid FRP combinations, and to evaluate how FRP strengthening interacts with shear behaviour and fatigue loading so that a more complete understanding of structural performance can be achieved.

Keywords: *CFRP, GFRP, AFRP, Flextural Strength, ACI 440.2R-08, Reinforced Beam.*

1. Introduction

In construction science, there is a term "retrofitting," which is a method or technique for completing a building by modifying or returning it to its original condition by adding new parts or equipment deemed necessary because they were not available at the time of its initial construction. The choice of retrofit technique depends on the condition or needs of the damaged building, cost considerations, the level of complexity of the work, and the building elements to be strengthened.

Beams are one of the important elements in building structures that require reinforcement. Concrete beams themselves, as we know, are a material that is relatively strong against compressive loads but weak against tensile loads [1] (Asroni, 2010). FRP, or Fiber Reinforced Polymer, is a fiber reinforced polymer and is one of the currently developing reinforcement methods. FRP has a similar function to thin steel plates, as reinforcement for reinforced concrete beams, namely strengthening the tensile section of reinforced concrete beams [2] (Ireneus G. Petrico, 2013). FRP itself has many types, including CFRP (Carbon Fiber Reinforced Polymer), GFRP (Glass Fiber Reinforced Polymer), and AFRP (Aramid Fiber Reinforced Polymer). Each of these three types of FRP has its own advantages and disadvantages, depending on the type of fiber used.

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The purpose of this study is to compare the maximum capacity of CFRP, GFRP, and AFRP in theoretically increasing the flexural strength of beams using the ACI 440.2R-08 method. The author hopes that the results of this study can serve as a reference for external reinforcement in building technology.Previous studies related to structural repair using CFRP, GFRP, and AFRP have been conducted extensively. Tarigan et al [3] in this study discussed the comparison of the flexural strength of reinforced concrete beams using Carbon Fiber Reinforced Polymer (CFRP) Wrap as external reinforcement. Based on the analysis, the strength of the beam with CFRP wrap was 3.21 times its initial strength. The test results showed that the strength of the CFRP beam was 2.5 times its initial strength. In a similar way, Johannes Tarigan, Fadel Muhammad Patra, and Torang Sitorus in their study discussed the comparison of the strength of reinforced concrete beams using Glass Fiber Reinforced Polymer Wrap (GFRP) [4]. Based on the analysis, the strength of the beam with GFRP increased by 1.333 times its initial strength.

Ireneus Petrico [2] discussed the comparison of the flexural strength of reinforced concrete beams using CFRP and GFRP. The results of analysis and experiments using CFRP and GFRP show a significant increase in the beam's flexural strength. CFRP can increase the beam's flexural strength by 65.934%, while GFRP only increases by 43.956%. Comparing the two reinforcing materials, CFRP is stronger than GFRP in increasing flexural strength [2].
Rameshkumar et al [5] the flexural behavior of concrete beams reinforced with Aramid Fiber Reinforced Polymer (AFRP). Discusses the flexural behavior of concrete beams reinforced with Aramid Fiber Reinforced Polymer (AFRP). The test results show a significant increase in the load-carrying capacity of the concrete beam, namely 27.59% of the initial capacity for one AFRP layer and 48.27% of the initial capacity for two AFRP layers. Bsisu et al [6] examined eleven concrete beams, ten of which were reinforced with FRP of varying widths and number of layers. The stress and deflection were recorded for each additional load. This study found that using multiple layers of FRP on a beam can increase its strength but reduce its ductility. Nadzirah Musa et al [7] examined five reinforced concrete (RC) beams coated with different CFRP layers to determine the efficiency of using multiple layers of CFRP. This study demonstrated that adding multiple layers of CFRP to a concrete beam can increase its load-bearing capacity. Three layers of CFRP yielded the highest value at 14.63%, and four layers yielded the lowest value at 2.23%, until the concrete failed.

1.1. Adding Fiber Reinforced Polymer to Reinforced Concrete Beams

FRP is a material made of fibers held together by a matrix substance, such as epoxy or polyester. Fiber Reinforced Polymer (FRP) is formed from three main components: fiber, polymer, and several additives. Specifically, fiber materials applied for reinforced concrete reinforcement and repair can be glass, carbon, and aramid fibers. Each has its own similarities. The choice of fiber type for reinforcement or repair of a structure depends on several factors, such as: structure type, available cost, planned load, environmental conditions, and others.

The stress-strain conditions of a concrete section undergoing flexure can be seen in Figure 1. Cc is the compressive force of the concrete, Ts is the tensile force of the steel reinforcement, and jd is the distance from Cc to Ts [8].

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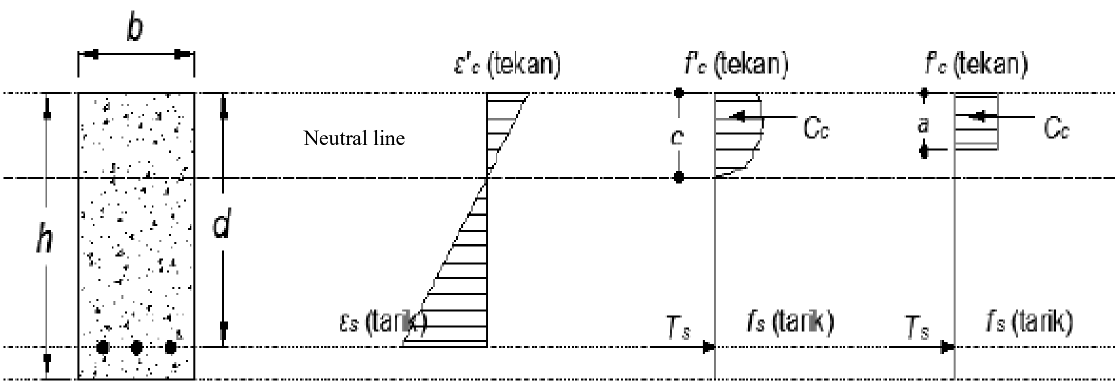

Figure 1. Concrete stress-strain distribution [8]

b = beam width (mm),
h = beam height (mm)

a = height of the rectangular stress distribution (mm)

c = distance of the neutral axis from the outermost compression fiber (mm)

d = distance of the outermost compression fiber from the reinforcement (mm)

Cc = concrete compressive force (N)

Ts = reinforcement tensile force (N)

Jd = distance of Cc from Ts (Jd = d - a/2) (mm)

f'c = concrete compressive strength (MPa)

fy = steel yield strength (MPa)

As = reinforcement cross-sectional area (mm^2)

Based on Figure 1 above, then:

$$Cc = 0{,}85.f'c.a.b$$

$$rs = As.fy$$

$$\sum F_x = 0 \text{ and } rs = Cc$$

$$As.fy = 0{,}85.f'c.a.b$$

$$a = \frac{As.fy}{0{,}85.f'c.b}$$

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As explained above, FRP has a relatively high tensile strength and is much lighter than steel. If FRP is installed on the tensile side of a concrete beam, the resulting flexural strength is as shown in Figure 2.

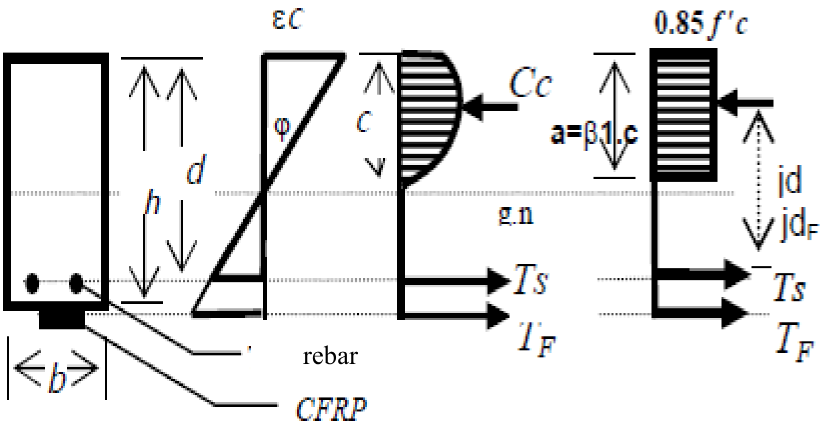

Figure 2. Distribution of Stress and Strain in concrete with FRP

Then the equilibrium conditions of the internal forces will change and the neutral line of the section will shift.

$$Cc = Ts + Tf$$

$$0{,}85.f'c.a.b = As.fy + Af.F_{fe}$$

$$a = \frac{As.fy + Af.F_{fe}}{0{,}85.f'c.b}$$

FRP materials can experience a decrease in quality during service life, this can be influenced by the age of the fiber, exposure to UV rays, chemicals, etc. ACI 440.2R-02 recommends using environmental reduction factors as in table 1 from [9].

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Table 1. Environmental reduction factors

Exposure Condition	Fiber and Resin Type	Environmental-Reduction Factor (C_E)
Interior exposure	Carbon/epoxy	0.95
	Glass/epoxy	0.75
	Aramid/epoxy	0.85
Exterior exposure (bridges, piers, and unenclosed parking garages)	Carbon/epoxy	0.85
	Glass/epoxy	0.65
	Aramid/epoxy	0.75
Aggressive environment (chemical plants and waste water treatment plants)	Carbon/epoxy	0.85
	Glass/epoxy	0.50
	Aramid/epoxy	0.70

Source: ACI 440.2R-02.

$$f_{fu} = C_E f^*_{fu}$$

$$\varepsilon_{fu} = C_E \varepsilon^*_{fu}$$

In some cases, the strength of FRP is too great to be transferred to the concrete surface and can cause delamination on the concrete surface. To prevent the release of the bond between FRP-ER and the concrete surface, ACI 440.2R-02 provides a reduction factor (km) to protect the bond between FRP and concrete.

$$k_m = \begin{cases} \dfrac{1}{60\varepsilon_{fu}}\left(1 - \dfrac{nE_f t_f}{360{,}000}\right) \leq 0.90 \text{ untuk } nE_f t_f \leq 180{,}000 \\ \dfrac{1}{60\varepsilon_{fu}}\left(\dfrac{90{,}000}{nE_f t_f}\right) \leq 0.90 \text{ untuk } nE_f t_f > 180{,}000 \end{cases}$$

By assuming that the maximum strain value in concrete is (ƐcU

= 0.003), the effective strain that occurs in FRP can be determined using the following equation:

$$I_{cr} = \frac{bc^3}{3} + n_s A_s (d - kd)^2$$

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$$\varepsilon_{bi} = \frac{M_{DL}(h - kd)}{I_C \, E_C}$$

$$\varepsilon_{fe} = \varepsilon_{cu} \left(\frac{h - c}{c} \right) - \varepsilon_{bi} \leq k_m \varepsilon_{fu}$$

By using Hooke's law, the effective stress value can be determined, as in the equation below:

$$f_{fe} = E_f \varepsilon_{fe}$$

After the strain and stress values in the reinforcement and FRP are known, the position of the neutral line is checked again based on the internal forces that occur using the following equation:

$$c = \frac{A_s f_s + A_f f_{fe}}{0.85 f'_c \beta_1 b}$$

$$\beta_1 = 1.09 + 0.008 f'_c$$

The nominal moment capacity of flexural reinforcement using FRP can be calculated using the equation below. For flexural reinforcement, ACI Committee 440 recommends a reduction factor value for FRP (ψf) of 0.85 and a reduction value of Ø = 0.9, namely:

$$\emptyset M_n = \emptyset (M_{ns} + \psi_f M_{nf})$$

$$M_{ns} = A_s f_s \left(d - \frac{\beta_1 c}{2}\right)$$

$$M_{nf} = A_f f_{fe} \left(h - \frac{\beta_1 c}{2}\right)$$

Apart from that, we also have to check the condition of the beam in service conditions, where:

$$k = \sqrt{(\rho_s n_s + \rho_f n_f)^2 + 2\left(\rho_s n_s + \rho_f n_f \left(\frac{h}{d}\right)\right)} - (\rho_s n_s + \rho_f n_f)$$

$$f_{s.s} = \frac{\left[M_s + \varepsilon_{bi} A_f E_f \left(h - \frac{kd}{3}\right)\right](d - kd)E_s}{A_s E_s \left(d - \frac{kd}{3}\right)(d - kd) + A_f E_f \left(h - \frac{kd}{3}\right)(h - kd)}$$

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$$f_{s.s} \leq 0.80 f_y$$

Check the condition of the FRP at maximum load assuming that the fiber is still intact.

Creep-Rupture and Fatigue Load Stress Limits in FRP Reinforcement

	Fiber Type		
Creep-rupture/Fatigue load	Glass FRP	Aramid FRP	Carbon FRP
Stress limit, $F_{f,s}$	$0.20 f_{fu}$	$0.30 f_{fu}$	$0.55 f_{fu}$

Source: ACI 440.2R-02.

$$f_{f.s} = f_{s.s}\left(\frac{E_f}{E_s}\right)\left(\frac{h-kd}{d-kd}\right) - \varepsilon_{bi} E_f$$

2.Methods

The research was conducted analytically, and activities included: preparatory work, literature review, data analysis, and a report on the completion of this research. The research object was a reinforced concrete beam with the following existing data:

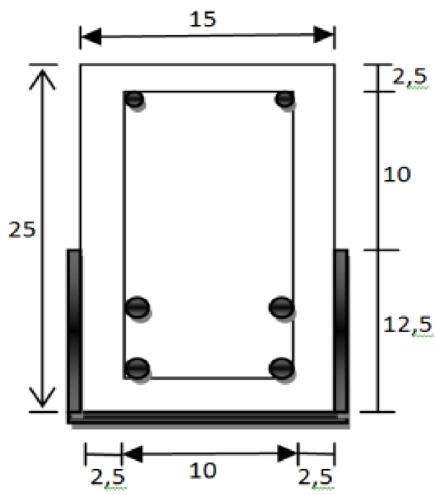

Figure 3. Cross-section of a beam

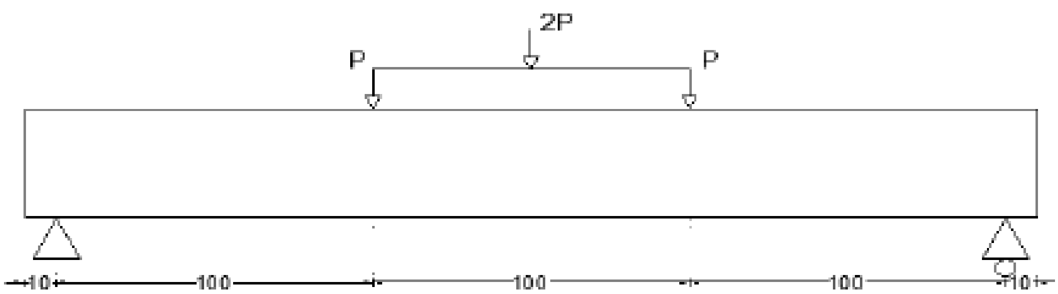

Figure 4. Side view of the beam

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Existing beam data:

Span: 3200 mm

Beam width: 150 mm

Beam height: 250 mm

Concrete compressive strength (F'c): 20 N/mm2

Reinforcement stress (Fy): 414 N/mm2

Steel modulus of elasticity (Es): 200,000 N/mm2

Reinforcement diameter: 20 mm

Fiber spacing (d): 175 mm

3. Results and Discussion

After analyzing the beam using the ACI Committee 440, 2008 method, the theoretical results of the beam analysis can be seen in the following table.

Table 2. Flexural Strengthening with CFRP

Number of Layers	CFRP (kNm)	Percentage increasing (%)	Occuring deflection (mm)
1	105.625467	39.94642469	70.45
2	116.0895361	45.35952895	77.42
3	122.6616422	48.28711875	81.81
4	127.0839299	50.0866322	84.76
5	130.210435	51.28511064	86.84

Table 3. Flexural Strengthening with GFRP

Number of Layers	GFRP (kNm)	Percentage increasing (%)	Occuring Deflection (mm)
1	96.13910435	34.02074026	64.12
2	103.0553787	38.4487543	68.73
3	108.5013737	41.53818777	72.36
4	112.8791765	43.80551724	75.28
5	116.4592292	45.53298196	77.67
6	119.4290926	46.88742251	79.65
7	121.9231834	47.97390651	81.32
8	124.0399197	48.86172976	82.73

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Table 4. Flexural Strengthening with AFRP

Number of Layers	AFRP (kNm)	Percentage increasing (%)	Occuring Deflection (mm)
1	96.1451388	34.02488	64.12
2	103.064665	38.4543	68.74
3	108.512401	41.54413	72.37
4	112.891385	43.81159	75.29
5	116.471817	45.53887	77.68
6	119.438783	46.89173	79.66
7	121.935575	47.97919	81.32
8	124.051469	48.86649	82.73

The calculations indicate that the capacity of the beam to resist bending loads increases as additional layers of FRP are applied. This pattern aligns with the work of Musa et al [7] who showed that multiple layers of CFRP sheets can enhance the load carrying ability of reinforced concrete beams. In this study, all three types of FRP namely CFRP, GFRP and AFRP contribute to a noticeable increase in flexural strength. The comparison in above figure also shows that CFRP consistently provides a higher strengthening effect than GFRP and AFRP before the concrete reaches failure, a finding that is in line with earlier studies. Studies both done by Tarigan et al [3],[4] both reported that CFRP tends to deliver greater flexural improvement compared with other FRP systems. A previous investigation by Ireneus Petrico [2] reported that CFRP increased flexural strength by about sixty five point nine three four percent, whereas GFRP offered forty three point nine five six percent improvement. In the present study, CFRP improved the flexural strength by fifty one point two nine percent and GFRP by forty five point five three percent when the same number of FRP layers was used. Although the percentages differ slightly, the overall trend remains consistent with previous findings, showing that CFRP provides the strongest flexural enhancement among the three materials. This study's results align with existing literature, confirming the effectiveness of CFRP in enhancing flexural strength, particularly when compared to other composite materials [10],[11]. This reinforces the notion that CFRP is superior in improving the structural integrity of concrete beams compared to alternatives like fiberglass or traditional materials [12].

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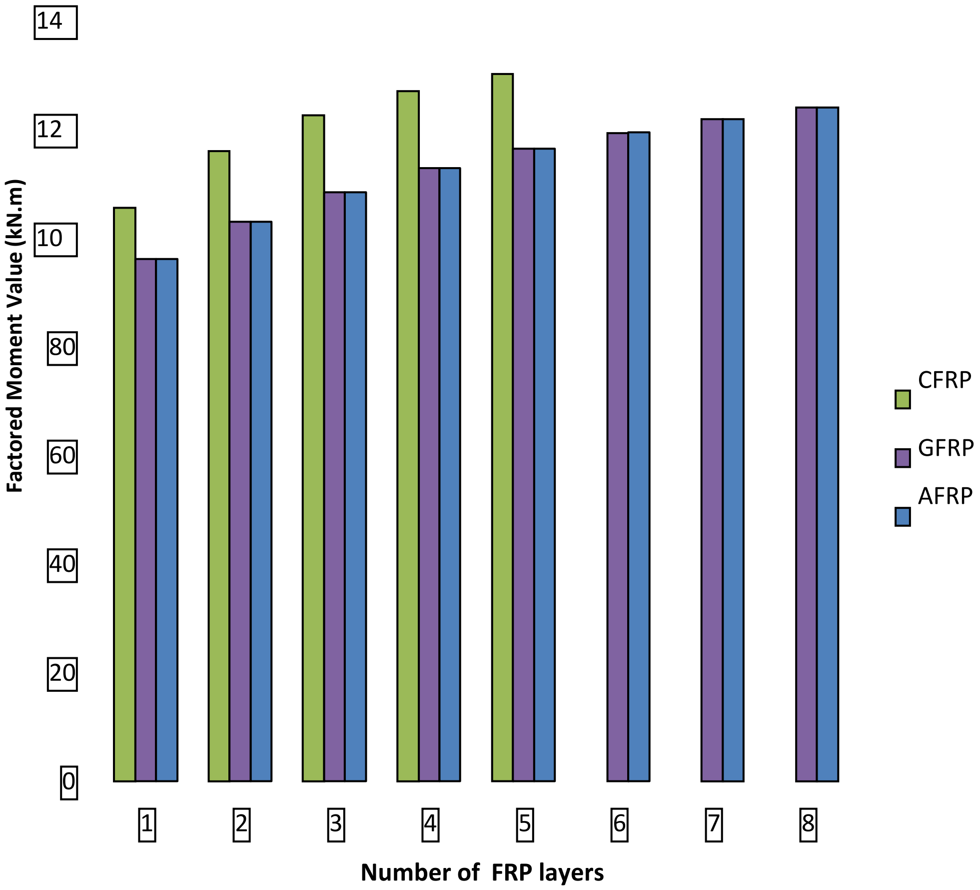

Figure 6. Comparison Chart of CFRP, GFRP, and AFRP beam reinforcement

4. Conclusion

The study shows that adding FRP sheets increases the moment resisting capacity of reinforced concrete beams, and this improvement becomes more noticeable as the number of layers grows until the beam eventually reaches concrete failure. The beam strengthened with CFRP reached the highest failure moment at 127.08 kNm, while those reinforced with GFRP and AFRP failed at 124.03 kNm and 124.05 kNm. Overall, the beam with four layers of CFRP sheets provided the strongest flexural response compared with the GFRP and AFRP systems before the concrete failed. For future work, it would be useful to examine how these different FRP materials perform under long term exposure, to investigate hybrid strengthening combinations, and to study how FRP strengthening interacts with shear behaviour so that the structural response can be understood more completely.

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6. Conflict of interest

The authors have no conflicts of interest to declare.

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