Effect of Bar Diameter and Concrete Strength on GFRP RC Beam Capacity Using CSA Code-Based Analysis

Vallabha C D[1], Dr. Naveen R [2], Pavan[3], Veeshal Rathod V[4]

[1]PG Student (MTech) in Structural Engineering, Dr Ambedkar Institute of Technology, Bangalore, Karnataka, India
[2]Assistant Professor, Department of Civil Engineering, Dr Ambedkar Institute of Technology, Bangalore, Karnataka, India
[3]PG Student (MTech) in Structural Engineering, Dr Ambedkar Institute of Technology, Bangalore, Karnataka, India
[4]PG Student (MTech) in Structural Engineering, Dr Ambedkar Institute of Technology, Bangalore, Karnataka, India

***

Abstract – *This paper presents a numerical investigation of the flexural behavior of a glass fiber reinforced beam by using CSA. A parametric analysis was performed by varying the GFRP bar diameter(8mm,10mm,12mm,16mm) with varying compressive strength(20MPa,40MPa,60MPa,80MPa).*

The geometry of the beam was kept constant, with a width being 150 mm, 300mm, and the length of the beam is 2m. The CSA equations were used to get the load vs deflection curve, load vs crack width curve, and crack spacing for all the varying compositions of beams.

1. INTRODUCTION

The use of glass fiber–reinforced polymer (GFRP) bars in reinforced concrete structures has gained momentum in recent decades due to their non-corrosive nature, high tensile capacity, and reduced self-weight compared to steel reinforcement. These attributes make GFRP reinforcement an attractive option for structures exposed to severe environmental conditions, such as coastal regions, chemical processing facilities, and infrastructure exposed to de-icing salts. Unlike steel, GFRP remains unaffected by chloride-induced corrosion, thereby extending the service life of structures and reducing maintenance demands. At the same time, the lower modulus of elasticity and brittle failure characteristics of GFRP necessitate design methods that account for its unique mechanical behaviour.

To address these requirements, the Canadian Standards Association introduced CSA S806, which provides specific design provisions for concrete members reinforced with fiber-reinforced polymer bars. The standard includes recommendations for both strength and serviceability checks, as well as guidelines for crack width and deflection control, enabling engineers to design GFRP-reinforced members with greater reliability.

The present study focuses on a numerical investigation of the flexural response of GFRP-reinforced concrete beams using CSA S806 design provisions. A parametric analysis was performed by varying reinforcement diameters (8 mm, 10 mm, 12 mm,16mm) and concrete compressive strengths (20 MPa, 40 MPa, 60 MPa, and 80 MPa), while keeping the beam cross-section (150 mm × 300 mm) and span length (2 m) constant. The CSA-based analytical approach was used to generate load–deflection curves, load–crack width relationships, and crack spacing predictions for each configuration. The findings aim to highlight how variations in reinforcement size and concrete strength influence the overall flexural performance, offering insights that can support efficient and code-compliant design of GFRP-reinforced members.

2. LITERATURE REVIEW

Mohammed et al. (2024) [1] experimentally compared reinforced concrete beams with traditional steel reinforcement and glass fiber–reinforced polymer (GFRP) bars under two-point loading. Their results showed that beams with GFRP bars exhibited higher deflections and load-carrying capacity compared to steel-reinforced beams, although the first cracks occurred earlier and were wider in GFRP beams. The study also concluded that variations in concrete compressive strength had minimal influence on the flexural properties, indicating that reinforcement type and diameter are more significant parameters in determining beam performance.

Belay et al. (2024) [2] tested small concrete beams reinforced with GFRP, BFRP, and conventional steel bars to compare ultimate load capacity, deflection, and failure mode. They found that GFRP-reinforced specimens achieved the highest ultimate capacity among the materials studied, but both types of FRP bars produced larger midspan deflections than steel. Failure in FRP-reinforced beams tended to be governed by bending (with more deformation before collapse), whereas steel-reinforced beams failed more abruptly. The study highlights the trade-off between higher capacity and reduced stiffness for FRP reinforcement, suggesting designers must pay special attention to serviceability (deflection and crack control) when replacing steel with FRP.

Sagaya Bastina and Renganathan (2018) [3] investigated the flexural performance of M30 grade concrete beams reinforced with GFRP bars. Four beams were cast—two with GFRP as main reinforcement and HYSD steel as hanger bars, and two with GFRP used for both main and hanger reinforcement. Testing showed that GFRP-reinforced beams exhibited higher ductility than their steel-reinforced counterparts, along with benefits such as corrosion resistance, high tensile strength, and non-magnetic properties. Load–deflection analysis confirmed that GFRP reinforcement can achieve comparable or greater flexural strength than steel while reducing the risk of corrosion-related deterioration.

Goonewardena et al. (2020) [4] evaluated the flexural behavior of GFRP- and CFRP-reinforced geopolymer concrete beams by comparing predictions from four design approaches: ACI 440.1R-15, CSA S806-12, parabolic stress block theory, and equivalent rectangular stress block theory. Experimental testing showed that the parabolic stress block method tended to overestimate flexural capacity, while CSA S806-12 provided the most accurate and conservative predictions. The study also analyzed cracking, service, and ultimate moment capacities, along with deflection performance, confirming CSA S806-12 as a reliable design reference for FRP-reinforced beams in geopolymer applications.

Canadian Standards Association (2012) [5] *"Design and Construction of Building Components with Fibre-Reinforced Polymers"*, which provides design provisions for FRP-reinforced and FRP-strengthened concrete members. The code includes equations for flexural capacity, shear strength, serviceability limits, and development length, calibrated for the unique properties of FRP materials, recognizing their linear-elastic behaviour up to failure and lower modulus of elasticity compared to steel.

Bischoff et al. (2011) [6] proposed a rational method for calculating deflection in FRP-reinforced concrete members, replacing Branson's equation, which overestimated stiffness for high Ig/Icr ratios. They introduced section-based and curvature-integration approaches, both applicable to steel and FRP reinforcement without empirical correction factors. Using 80% of the code-based cracking moment was recommended to account for shrinkage restraint, with validation against an extensive experimental database showing reliable and conservative predictions.

3. Analytical Modelling Using CSA S806

Table -1: Properties of GFRP Bars

Bar Size (mm)	Youngs Modulus (E)(GPa)	Tensile Strength (Mpa)
8	45	1000
10	45	1000
12	45	1000
16	45	1000

The above Table 1 shows the properties of the GFRP Bar

The data were obtained from an Indian manufacturer of GFRP bars. Variations of up to ±5 GPa in Young's modulus and ±100 MPa in tensile strength may occur due to manufacturing tolerances. These values have been adopted for the design calculations by CSA-S806.

Table -2: Beam Type Name/Designation

Bar Size (mm)	Compressive Strength	Beam Type Name
8,10,12,16	20	8G20C,10G20C,12G20C,16G20C
8,10,12,16	40	8G40C,10G40C,12G40C,16G40C
8,10,12,16	60	8G60C,10G60C,12G60C,16G60C
8,10,12,16	80	8G80C,10G80C,12G80C,16G680C

The beam geometry considered for analytical modelling has the following dimensions:

Width=150mm

Depth=300mm

Length=2000mm

Shear Span=450mm

By using the following equation given below, using CSA S806 code, the deflection, crack width, and crack spacing were calculated.

1. Notations for Calculation

- Span (L), Shear span (a)

- Beam width (b), Overall depth (h), Effective depth (d)

- Concrete compressive strength (f'_c)

- Modulus of elasticity of concrete (E_c = 4700 × √f'c)

- Modulus of elasticity of FRP (Ef)

- Area of GFRP reinforcement (A_f)/(A_s)

- Bar diameter (d_b), Concrete cover (Cc)

2. Modular Ratio

n = Ef / E_c (Eq. 1)

3. Neutral Axis Depth (c)

The neutral axis depth is calculated by using the elastic transformed section and is used to calculate the cracked section moment of inertia.

$c = (\sqrt{((n \times A\_s) \times (n \times A\_s + 2 \times b \times d))} - n \times A\_s) / b$ (Eq. 2)

4. Cracked Moment of Inertia (I_cr)

$I\_cr = (b \times c^3) / 3 + n \times A\_f \times (d - c)^2$ (Eq. 3)

5. Moment at Midspan

$M = (P \times a) / 2$ (Eq. 4)

6. Deflection

$\delta = (M \times L^2) / (8 \times E\_c \times I\_cr)$ (Eq. 5)

7. Crack Width

Step 1: $f\_fr = M / (A\_f \times j \times d)$, where $j \approx 0.9$ (Eq. 6)

Step 2: $\varepsilon\_f = ffr / Ef$ (Eq. 7)

Step 3: $\beta\_d = 1 - (\rho f / \rho\_fb)$, where $\rho\_f = A\_f / (b \times d)$

(Eq. 8)

Step 4: $\varepsilon\_m = \varepsilon\_f \times (1 - \beta d)$ (Eq. 9)

Step 5: $z = d - c / 3$ (Eq. 10)

Step 6: $w\_cr = \varepsilon\_m \times z$ (Eq. 11)

Where,

f_fr=stress in FRP

ε_f = strain in FRP

β_d = bond-dependent coefficient

ε_m =mean concrete strain

z-distance of extreme compression fiber

w_cr -crack width in mm

8. Crack Spacing (CSA Empirical Method)

Crack spacing can be estimated using the empirical formula:

$S\_cr = kg \times Cc + kg \times d\_b / \rho eff$ (Eq. 12)

Where:

s_cr = crack spacing (mm)

kg = bond coefficient (often taken as 1.0 for sand-coated GFRP)

Cc = clear cover to reinforcement (mm)

db = diameter of GFRP bar (mm)

ρ_eff = effective reinforcement ratio = A_f / (b × h_eff)

h_eff=2.5 × d_b

4. RESULTS AND DISCUSSION

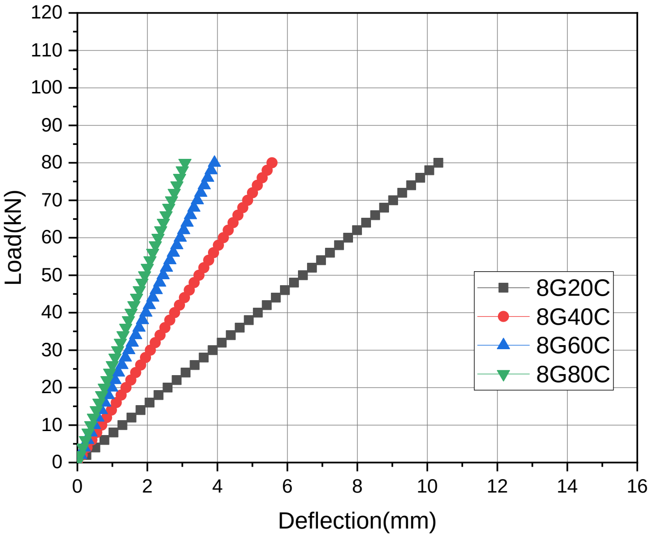

Figure 1 Load Vs Deflection for 8mm GFRP Bar Beam

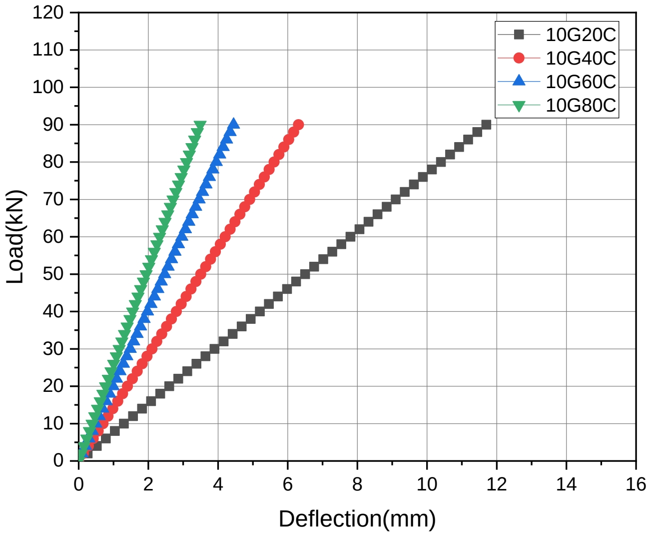

Figure 2 Load Vs Deflection Curve 10mm GFRP Bar Beam

From Figures 1,2,3,4, we can observe that as the diameter of the bar increases, the load carrying capacity of the beam increases [7]. As the bar size increases, the deflection of the beam reduces. As the compressive strength increases, the deflection values for the load also decrease. As the compressive strength increases for the same diameter of bar in a beam, the difference in the decrease of deflection also decreases [8].

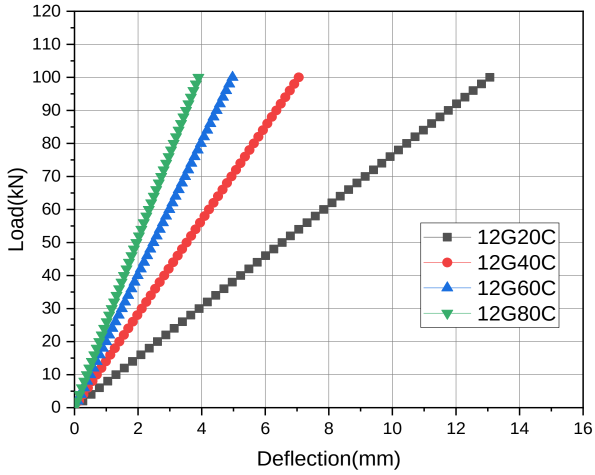

Figure 3 Load Vs Deflection Curve for 12mm GFRP Bar Beam

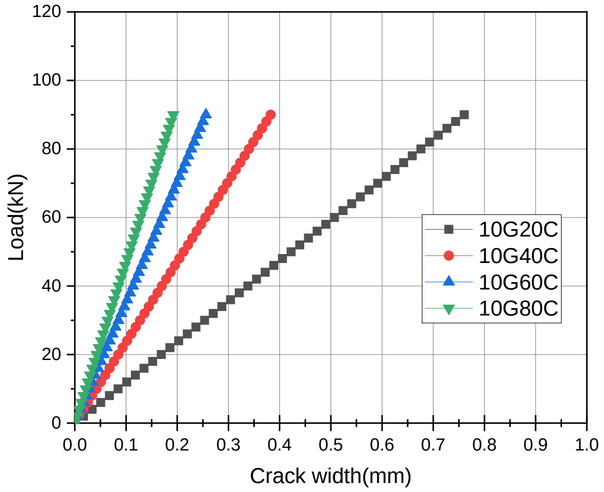

Figure 6 Load vs Crack width 10mm GFRP Bar Beam

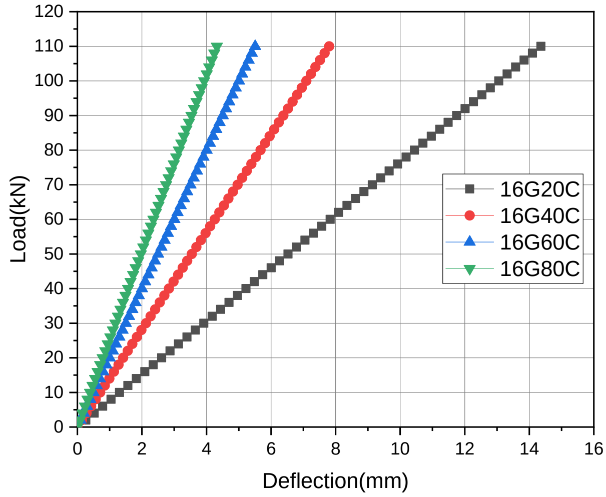

Figure 4 Load Vs Deflection Curve 16mm GFRP Bar Beam

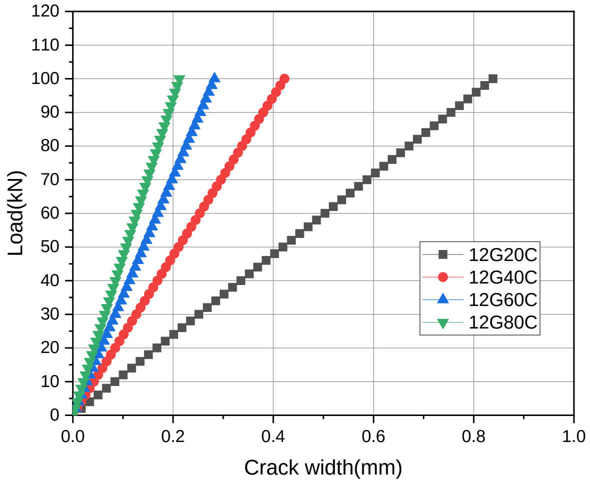

Figure 7 Load Vs Crack width 12mm GFRP Bar Beam

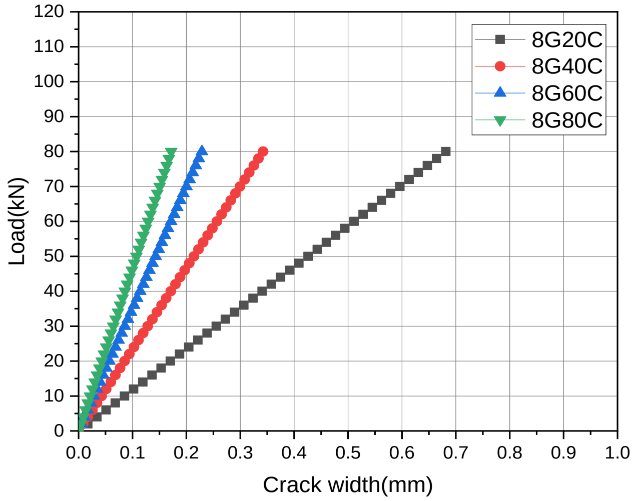

Figure 5 Load vs Crack width 8mm GFRP Bar Beam

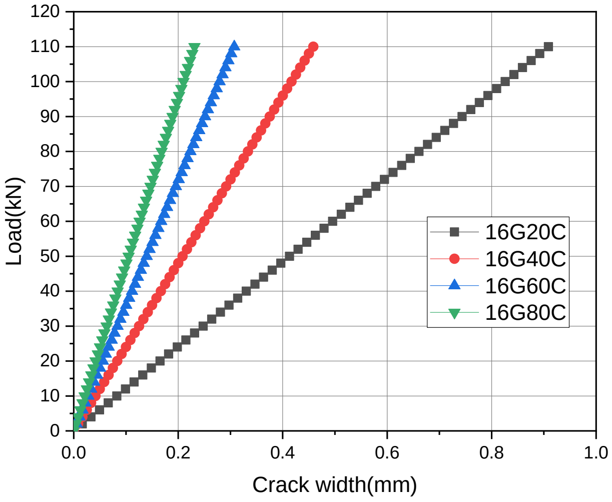

Figure 8 Load vs Crack width 16mm GFRP Beam

Figure 5,6,7,8 show the variation of load vs crack width for all the beams calculated by using CSA S806 code[5]. From the graph, we can observe that as the diameter of the bar increases, crack width increases according to the calculation given by the code, but the opposite happens real scenario, where an increase in bar diameter causes a decrease in crack width[9][10]. An increase in compressive strength for the same diameter of bar in a beam decreases the crack width, as indicated by the above graphs.

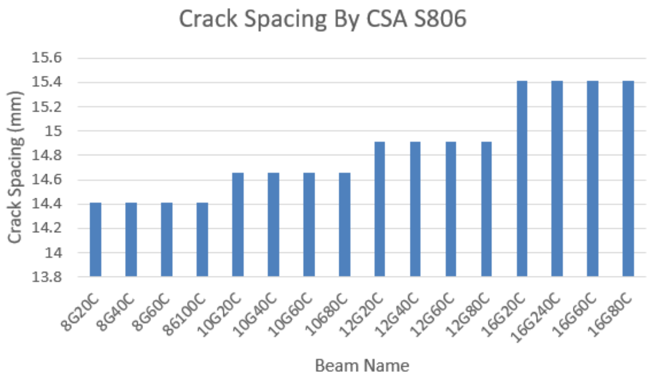

Figure 9 Cracking Spacing

Figure 9 shows the crack spacing calculated using CSA S806 code, which indicates that crack spacing increases with an increase in the diameter of the bar [10].

3. CONCLUSIONS

The CSA S806 code-based analytical investigation demonstrated that both reinforcement diameter and concrete compressive strength significantly influence the flexural performance of GFRP-reinforced concrete beams. An increase in GFRP bar diameter resulted in higher load-carrying capacity and reduced deflection, indicating improved stiffness. Similarly, higher concrete compressive strength decreased beam deflections for a given load; however, its influence diminished as bar diameter increased.

Crack width predictions from CSA S806 showed an increasing trend with bar diameter, which contrasts with experimental observations where larger bar diameters typically reduce crack widths. Nevertheless, the analytical results confirmed that higher concrete strengths consistently reduce crack widths for all bar sizes. Crack spacing calculations followed the expected pattern as per CSA S806 empirical expressions.

Overall, the study reaffirms that optimal selection of GFRP bar diameter and concrete strength can lead to serviceable and high-capacity structural members. The CSA S806 design approach provides a conservative and reliable framework for predicting deflection, crack width, and crack spacing, thereby supporting safe and durable design of GFRP-reinforced beams for practical applications.

REFERENCES

[1] Mohammed AD, Salih OA. An Experimental Study on Reinforced Concrete Beams with GFRP and Ordinary Steel Bars' Flexural Strength Properties. Civil and Environmental Engineering. 2025 Jun 1;

[2] Belay AA, Krassowska J, Kosior-Kazberuk M. Comparative Performance Analysis of Small Concrete Beams Reinforced with Steel Bars and Non-Metallic Reinforcements. Applied Sciences (Switzerland). 2024 May 1;14(10).

[3] Sagaya Bastina A, Renganathan M. Flexural Behaviour of Concrete Beams with Glass Fiber Reinforced Polymer Rods [Internet]. Available from: www.ijert.org

[4] Goonewardena J, Ghabraie K, Subhani M. Flexural performance of FRP-reinforced geopolymer concrete beam. Journal of Composites Science. 2020;4(4).

[5] Canadian Standards Association. CSA S806-12: Design and construction of building components with fibre-reinforced polymers. Mississauga, Ontario, Canada; 2012.

[6] Bischoff PH, Gross SP. Design Approach for Calculating Deflection of FRP-Reinforced Concrete. Journal of Composites for Construction. 2011 Aug;15(4):490–9.

[7] Ahmad H, Elnemr A, Ali N, Hussain Q, Chaiyasarn K, Joyklad P. Finite element analysis of glass fiber-reinforced polymer-(Gfrp) reinforced continuous concrete beams. Polymers (Basel). 2021 Dec 1;13(24).

[8] Moawad MS, Fawzi A. Performance of concrete beams partially/fully reinforced with glass fiber polymer bars. Journal of Engineering and Applied Science. 2021 Dec 1;68(1).

[9] Ascione L, Mancusi G, Spadea S. Flexural behaviour of concrete beams reinforced with GFRP bars. Strain. 2010 Oct;46(5):460–9.

[10] Kara IF, Ashour AF. Flexural performance of FRP reinforced concrete beams. Compos Struct. 2012 Apr;94(5):1616–25.