Deflection Of Reinforced Concrete Beam Cfrp Bar With U-Wrap Cfrp Sheet as Shear Reinforcement

Kusnadi Kusnadi [1*], *Rita* Irmawaty[2], and *Ichsan* Rauf[1]

[1]Civil Engineering Department, Faculty of Engineering, Universitas Khairun, Ternate, Indonesia
[2]Civil Engineering Department, Faculty of Engineering, Universitas Hasanuddin, Makassar, Indonesia

Abstract. The purpose of this study was to understand the deflection behavior of reinforced concrete beams using GFRP bar as flexural reinforcement and GFRP sheet as shear reinforcement. The tested beams with dimensions of span length were 3000 mm, width of 150 mm and height of 250 mm of concrete quality f'c.25 MPa. The beams use GFRP bar 3D13 as flexural reinforcement and U-wrap GFRP sheet 50 mm wide with a distance of 100 mm. U-wrap GFRP sheet shear reinforcement is only installed in shear spans. The beam is loaded with two concentrated loads monotonically until it collapses. The test results show that the load-deflection relationship of GFRP bar reinforced concrete beams with external shear reinforcement of U-wrap GFRP sheet shows two linear curve patterns. The results of the analysis show that the ACI-440.1R-06 approximation equation can be used to accurately predict the deflection in the middle of the GFRP bar reinforced concrete beam with external shear reinforcement from U-wrap GFRP sheet.

Keyword: *GFRP, Behavior of Reinforced, Concrete Beams*

1 Introduction

Buildings that use steel-reinforced concrete in corrosive areas, such as the marine environment, are easily damaged by corrosion. Corrosion may reduce the cross-sectional area of steel reinforcement in addition to destroying the concrete from within by cracking and spalling. To increase the durability of reinforced concrete buildings, steel reinforcement can be replaced with GFRP bars that are resistant to corrosion and serve as flexural reinforcement [1]. Steel stirrups as internal shear reinforcement can be replaced with U-wrap GFRP sheets as external shear reinforcement [2]. Because the GFRP bar reinforcement is resistant to corrosion, a concrete blanket to protect the reinforcement is not required. Therefore, the longitudinal reinforcement is positioned as close as possible to the outer fibers of the cross-section so that its effective height can be maximized.

GFRP is fiber reinforcement made of glass fiber and epoxy formed by pultrusion which has a higher tensile strength than steel reinforcement. However, it has a lower modulus of elasticity. The use of GFRP with a lower modulus of elasticity as reinforcement to replace steel reinforcement has an impact on decreasing the stiffness of post-cracked reinforced concrete beams. The low stiffness has an impact on the magnitude of the deflection of the reinforced concrete beam. The design philosophy of FRP-reinforced concrete structural elements is equated with steel-reinforced concrete with the principle of limiting strength which begins with the component design based on the required strength and then continues with checking fatigue, creep, and serviceability criteria. However, for FRP with a lower modulus of elasticity, fatigue resistance, creep, and serviceability criteria can more determine the design of reinforced concrete structural elements [3]. For this reason, understanding the deflection behavior is highly important in designing FRP-reinforced beam structural elements.

2 Methods

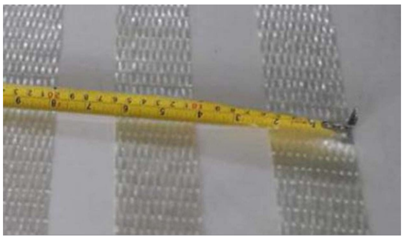
This study began by examining the materials followed by making testing beams, installing the instrumentation, and testing the beams. The examination of concrete material was carried out to obtain compressive strength, tensile strength, and flexural strength.

* Corresponding author: kusnadi@unkhair.ac.id

2.1 Reinforcement materials

The GFRP bar and GFRP sheet reinforcement used in this study can be seen in Figure 1. The GFRP sheet utilized in this study had a width of 50 mm.

(a) GFRP bar



(b) GFRP sheet

Fig.1. GFRP Reinforcement

The mechanical characteristics of the GFRP bar and GFRP sheet reinforcement materials can be seen in Table 1 and Table 2, respectively. These mechanical characteristics are the results of standard testing from FYFO.co. Ltd.

Table 1. Mechanical characteristics of GFRP bar with a diameter of 13 mm

Mechanical characteristics	Test value	Design value
Nominal diameter	12.7 mm	12.7 mm
Cross-sectional area	129 mm^2	129 mm^2
Modulus of elasticity	43900 MPa	-
Ultimate tensile strength	788 MPa	708 MPa
Ultimate stretch	1.79 %	-

Table 2. Mechanical characteristics of GFRP sheet with a type of SEH51

Mechanical characteristics	Test value	Design value
Tensile stress in the direction of the main fiber	575 MPa	460 MPa
Strain	2.20%	2.20%
Tensile modulus	26.1 GPa	20.9 GPa
Tensile stress perpendicular to the main fiber	25.8 MPa	20.7 MPa
Layer thickness	1.3 mm	1.3 mm

2.2 Concrete materials

The concrete used in this study was ready-mix concrete with an f'_c value of 25 MPa. The slump value at the time of casting was 100 ± 10 mm.

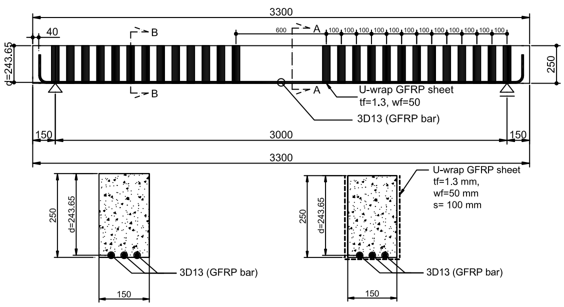
The results of the test regarding the characteristics of the concrete materials can be seen in Table 3. The compressive strength of concrete is obtained from the results of the test based on the SNI 1974 standard [4]. Meanwhile, the flexural strength of the concrete is obtained from the results of the test based on the SNI 4431 standard [5].

Table 3. Mechanical characteristics of the concrete

Parameters	Experimental mechanical value
Compressive strength (f'_c), MPa	24.4
Flexural strength (f_r), MPa	3.45

2.3 Test beam reinforcement model

For the test beam, the researchers used longitudinal reinforcement from the GFRP 3D13 bar which was installed parallel to the bottom fiber without compression reinforcement on the top fiber. Shear reinforcement of GFRP sheet in the form of a U-wrap was installed on both shear spans with a length of 1200 mm and a distance of 100 mm. Shear reinforcement from the GFRP sheet was installed using epoxy with the wet-layup method after the concrete had hardened. The pure moment region was located at mid-span with a distance of 600 mm without shear reinforcement. The test beam reinforcement model can be seen in Figure 2.



A-A Section B-B Section

Fig.2. Beam Reinforcement Test

2.4 Beam testing

The test scheme can be seen in Figure 4. The test beam was placed on roller-joint support. A load divider with a distance of 600 mm was positioned above the test beam at the center of the span. A load cell with a capacity of 200 kN was positioned in the middle of the load divider. Three LVDTs were placed under both centralized and mid-span loads, respectively. The loading was given monotonically at a speed of 0.03 mm/sec which was set on the loading control. The load cell and LVDTs were connected to a data logger to record load and deflection results. Load rise and deflection were controlled from the computer. The load was given until the test beam collapsed. The moment during the beam test can be seen in Figure 3 and 4.

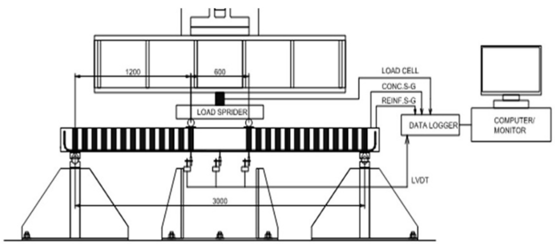


Fig.3. Testing scheme

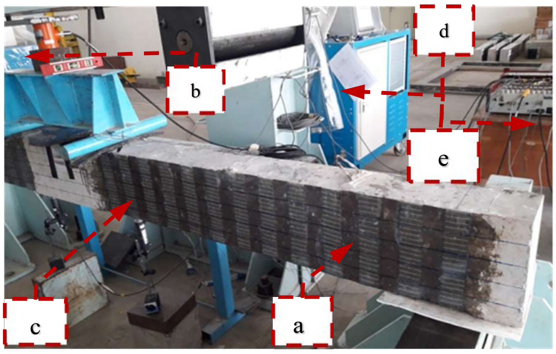


Fig.4. Model Testing: (a) the test beam, (b) the load cell with 200 kN, (c) LVDT, (d) data logger, and (e) load control

3 Results and Discussion

3.1 Experimental deflection

The load-deflection relationship of reinforced concrete beams using GFRP bar as flexural reinforcement and GFRP sheet as shear reinforcement can be seen in Figure 5.

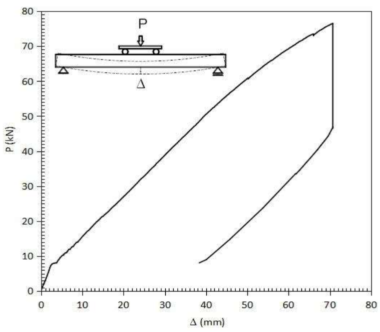


Fig.5. Load-deflection relationship of the reinforced concrete beam using GFRP bar

The load-deflection relationship can reflect the stiffness of the bending structural elements. The greater the ratio of the load to the deflection of a structural element is, the greater the stiffness will be. The pattern of the load-deflection relationship curve of reinforced concrete beams using the GFRP bar and shear reinforcement using the GFRP sheet is divided into two linear curve sections, as shown in Figure 6. The curve pattern in the first part shows the load-deflection relationship of the beam, before cracking, which occurs at the beginning of loading. The curve pattern in the second part shows the load-deflection relationship of the beam after cracking until it collapses. The slope of the curve before cracking is greater than the slope of the curve after cracking, indicating that the stiffness of the beam before cracking is greater than that after cracking. Figure 5 also shows that there is a decrease in the stiffness of the beam before collapsing which is indicated by the slope of the load-deflection curve that is getting smaller. A study conducted by Khorasani *et al.* [6] which used GFRP bar reinforced concrete beams with internal stirrups had the same load-deflection relationship pattern as the results of the experiment in this study.

3.2 Comparison of experimental deflection against the predictive model

The deflection of the structural elements is proportional to the load and inversely proportional to the stiffness [7]. The stiffness of the structural elements is influenced by the modulus of elasticity of the material and the inertia of the cross-section. Before cracking, the deflection of reinforced concrete beams can be predicted using the gross cross-sectional inertia. Meanwhile, after cracking, it is predicted using effective inertia [8]. For GFRP bar-reinforced concrete beams, the equation model from ACI provides good predictions of deflection in concrete beams with simple bearings [9]. The equation of effective inertia of the GFRP bar-reinforced concrete beam in ACI-440 to predict deflection is adopted from Branson's formula, as shown in Equation 1.

$$I_e = \left(\frac{M_{cr}}{M_a}\right)^3 \beta_d I_g + \left[1 - \left(\frac{M_{cr}}{M_a}\right)^3\right] I_{cr} \le I_g \qquad (1)$$

Where: M_{cr} is the cracking moment, M_a is the actual moment, I_g is the inertia of the uncracked section, I_{cr} is the inertia of the cracked section, and β_d is a reduction factor. For FRP-reinforced concrete structural elements, the β_d value is obtained from the ratio of FRP reinforcement to its balanced reinforcement ratio [10], based on Equation 2.

$$\beta_d = \frac{1}{5}\left(\frac{\rho_f}{\rho_{fb}}\right) \le 1 \qquad (2)$$

The inertia of the fractured section (I_{cr}) of the FRP-reinforced beam can be calculated using Equation 3.

$$I_{cr} = \frac{bd^3}{3}k^3 + n_f A_f d^2 (1-k)^2 \quad (3)$$

b and d are the effective width and height of the cross-section, while A_f is the area of fiber reinforcement and k is a constant determined by Equation 4.

$$k = \sqrt{2\rho_f n_f + (\rho_f n_f)^2} - \rho_f n_f \quad (4)$$

ρ_f is fiber reinforcement ratio and n_f is modulus ratio between modulus of elasticity of fiber reinforcement and modulus of elasticity of the concrete.

The inertia of the fractured section can also be calculated using an elastic section transformation analysis. The uncracked cross-sectional height (c) in Figure 5 is calculated using Equation 5.

$$c = kd \quad (5)$$

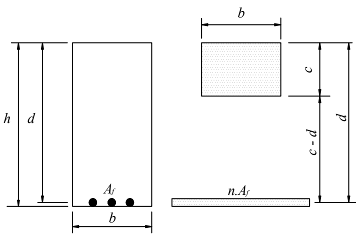


Fig.6. Cross-sectional transformation of GFRP bar-reinforced beams

The deflection of a simple-supported reinforced concrete beam due to two concentrated loads of P with a shear span of a can be calculated using Equation 6.

$$\Delta = \frac{PL}{24E_c I_e}\left(3L^2 - 4a^2\right) \quad (6)$$

The comparison of the load-deflection relationship of reinforced concrete beams from the results of the experiment and analysis using ACI-440.1R-06 can be seen in Figure 7.

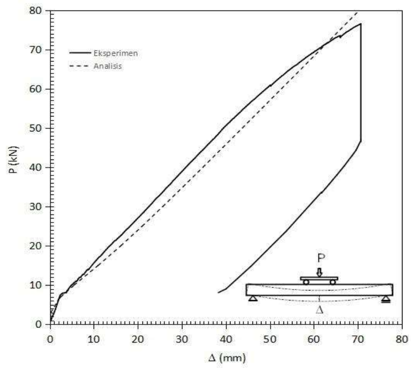


Fig.7. Comparison of experimental load-deflection relationship and mid-span prediction

The results of the experiment show that, in the ultimate condition, the deflection in the middle of the GFRP bar-reinforced concrete beam with shear reinforcement from the GFRP sheet is 5% greater than the predicted deflection using ACI-440.1R-06. Under conditions of actual load of 3 and 4.5 times the crack load, the actual deflection at mid-span is smaller than the predicted deflection using ACI-440.1R-06, which is still in line with the results of a study conducted by Barris *et al.* [11]. The use of ACI-440.1R-06 to predict the mid-span deflection in GFRP bar-reinforced concrete beams with shear reinforcement from the GFRP sheet still gives quite accurate results.

4 Conclusion

Based on the results of the experiment and analysis of the deflection at the center of the GFRP bar-reinforced concrete beam with shear reinforcement from the GFRP sheet, it can be concluded as follows.

1. Load-deflection curve pattern of GFRP bar-reinforced concrete beams with GFRP sheet as external shear reinforcement has the same pattern as GFRP bar-reinforced concrete beam with internal shear reinforcement, in which the researchers found two linear curve patterns (bi-linear) and a decrease in stiffness before collapsing.
2. The equation of ACI-440.1R-06 can be used to predict the deflection well in GFRP bar-reinforced concrete beams using GFRP sheet as shear reinforcement.

5 References

[1] P. Escórcio and P. M. França, "Experimental study of a rehabilitation solution that uses GFRP bars to replace the steel bars of reinforced concrete beams," *Eng. Struct.*, vol. **128**, pp. 166–183, (2016).

[2] C. E. Bakis *et al.*, "Fiber-Reinforced Polymer Composites for Construction — State-of-the-Art Review," vol. **6**, no. May, pp. 73–87, (2002).

[3] ACI 440.1R-03, "Guide for the Design and Construction of Concrete Reinforced with FRP Bars," *ACI Comm. 440*, vol. **88**, pp. 1–6, (2003).

[4] SNI 1974, "Cara Uji Kuat Tekan Beton dengan Benda Uji Silinder," (2011).

[5] SNI 4431, "Cara uji kuat lentur beton normal dengan dua titik pembebanan," *Badan Stand. Nas. Indones.*, (2011).

[6] A. M. M. Khorasani, M. R. Esfahani, and J. Sabzi, "The effect of transverse and flexural reinforcement on deflection and cracking of GFRP bar reinforced concrete beams," *Compos. Part B Eng.*, vol. **161**, no. June 2018, pp. 530–546, (2019).

[7] M. J. N. Priestley, G. M. Calvi, and M. J. Kowalsky, "Displacement Based Seismic Design of Structures.pdf," *Earthquake Spectra*, vol. **24**, no. 2. p. 555, (2008).

[8] ACI Committee 318, *Building Code Requirements for Structural Concrete (ACI 318-08)*, vol. **2007**. (2008).

[9] I. F. Kara, A. F. Ashour, and C. Dundar,

"Deflection of concrete structures reinforced with FRP bars," *Compos. Part B Eng.*, vol. **44**, no. 1, pp. 375–384, (2013).

[10] ACI 440.1R-06, "Guide for the Design and Construction of Concrete Reinforced with FRP Bars Reported by ACI Committee 440," *ACI Comm. 440*, pp. 1–42, (2003).

[11] C. Barris, L. Torres, J. Comas, and C. Miàs, "Cracking and deflections in GFRP RC beams: An experimentalstudy," *Compos. Part B Eng.*, vol. **55**, pp. 580–590, (2013).