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

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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.
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.

![GFRP bar](image)

(a) GFRP bar

![GFRP sheet](image)

(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 mm²     | 129 mm²      |
| 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 $100 \pm 10$ 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 ($f$, 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.

![Test beam reinforcement](image)

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.

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.

\[
I_e = \left( \frac{M_{cr}}{M_a} \right) \beta_d I_g + \left[ 1 - \left( \frac{M_{cr}}{M_a} \right) \right] I_{cr} \leq I_g \quad (1)
\]

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

\[
\beta_d = \frac{1}{5} \left( \frac{\rho_f}{\rho_b} \right) \leq 1 \quad (2)
\]

The inertia of the fractured section \( I_{cr} \) of the FRP-reinforced beam can be calculated using Equation 3.
\[ I_c = \frac{bd^3}{3}k^3 + n_f A_f d^2(1-k) \] (3)

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

\[ k = \sqrt{2\rho_f n_f + \left(\rho_f n_f + n_f - \rho_f \right)} \] (4)

\( \rho_f \) 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.

\[ c = kd \] (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.

\[ \Delta = \frac{PL}{24E I_c} \left( 3L^2 - 4a^2 \right) \] (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.**

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