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FLEXURAL BEHAVIOUR OF GFRP BAR REINFORCED CONCRETE BEAM WITHOUT COVER USING GFRP SHEET AS SHEAR REINFORCEMENT

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ABSTRACT

Steel concrete beams are vulnerable to damage by corrosion. In order to increase the durability of RC beam, GFRP bars and GFRP sheets are used as tensile and shear reinforcement replacing steel bar. To optimize the use of corrosion resistant GFRP bars, reinforced concrete beam is made without cover to increase the effective height of the cross section. In this study, the flexural behavior of GFRP bar RC beam without cover that using GFRP sheet as shear reinforcement was investigated and compared with the conventional steel and GFRP RC beam at the same dimension and longitudinal reinforcement area. The experimental result from monotonic loading tests on the specimens showed that the flexural capacity and stiffness of GFRP bar RC beam without concrete cover using GFRP sheet as shear reinforcement had increased, compared with conventional GFRP RC beam.

Key words: Flexural behavior, RC beam without cover, GFRP bar, GFRP sheet

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1. INTRODUCTION

Corrosion on steel reinforcement leads to reinforced concrete structure damage. Corrosion reduces the cross-sectional area of the steel reinforcement thereby reducing the flexural strength of concrete structures [1]. Corrosion of steel bar generates cracks that cause spalling of concrete-cover [2]. In addition to reducing flexural strength, corrosion of steel reinforcement also reduces the shear resistance of concrete structures [3].

The utilization of a corrosion-resistant bar in reinforced concrete structural elements can maintain the lifespan of the building and reduce maintenance costs during the service life. One of the materials developed as reinforcement in reinforced concrete structures is the FRP bar (Fiber Reinforced Polymer) material. GFRP (Glass Fiber Reinforced Polymer) is a reinforcement made from glass fibers in the form of sheets, strips or bars. Not only is GFRP bar resistant to corrosion, but it also has high tensile strength, not magnetized, good fatigue resistance, lightweight, low thermal, and low electrical conductivity [4]. GFRP bar has potential as an internal reinforcement on structural elements as flexural reinforcement, especially in an aggressive environment. GFRP reinforcing bar can be used as an alternative of steel for the foundation [5]. The cost of GFRP bar-reinforced concrete can be lower than conventional steel-reinforced concrete if the calculation also includes the cost of maintenance and long service life [6].

According to Whitney's stress-strain diagram for reinforced concrete beam in condition that the concrete on the tensile side does not contribute significantly to the beam's flexural capacity, then it can be removed. In fact, in the reinforced concrete beam with the external reinforcement that there is no concrete on the tensile side, its flexural capacity can still reach 86% of the normal beam [7]. Placement of reinforcement on the outer fibers using steel plates without the influence of a concrete cover shows an increase in the flexural capacity and decrease in the deflection [8]. Beam with the external reinforcement in which concrete cover is neglected is also found in structural strengthening technology that uses FRP material.

The strengthening method of reinforced concrete structures using FRP material currently consists of an external reinforcement that uses FRP Sheet and an NSM (Near Surface Mounted) method that uses FRP bars or FRP strips. In the external reinforcement method with FRP sheet, FRP sheet is directly glued to the concrete surface using resin while in the NSM method, FRP Bar or FRP Strip is glued to the concrete through grooves that have been prepared on the concrete surface using resin or mortar. The use of FRP sheet material in structural repairs or strengthening does not require as much energy as conventional materials. Structural strengthening using FRP material as external reinforcement may increase bending and shear capacity [9]; [10]. The combination of the NSM method using FRP Bar as flexural reinforcement and U-Wrap of FRP Sheet as shear reinforcement increases beam flexural capacity [11].

By utilizing the advantages of GFRP bar and GFRP sheets, an innovative reinforced concrete beam is proposed by replacing all steel by GFRP material, longitudinal reinforcement using GFRP bar and transverse reinforcement using the GFRP sheet. Longitudinal reinforcement is placed on the outermost tensile fibers to maximize the effective depth of the beam. The transverse reinforcement is given after the concrete hardened using U-wrap GFRP sheet according to the required shear capacity.

This paper presents an experimental study aimed at investigating the flexural behavior of RC beam without concrete cover that using GFRP bar as tensile reinforcement and GFRP sheet as shear reinforcement. The study also aimed at assessing the performance of GFRP-RC beams without concrete cover with respect to the conventional RC beams that reinforced by steel bars and GFRP bars.

2. MATERIALS AND METHODS

2.1. Reinforcing

GFRP bars and steel deformed bars of 13 mm in bar size were used as tension reinforcement. The GFRP bars were manufactured from continuous glass fibers impregnated in polymeric resins using the pultrusion process (Fyfe Co. LLC, Canada). GFRP bar surface is helical-shaped so that it has a good bond between the bar and surrounding concrete. Steel round bar of 8 mm in bar size was used at the conventional reinforced concrete beam and GFRP sheet was used at the GFRP concrete beam without concrete cover as shear reinforcement.

Table 1. Properties of reinforcement

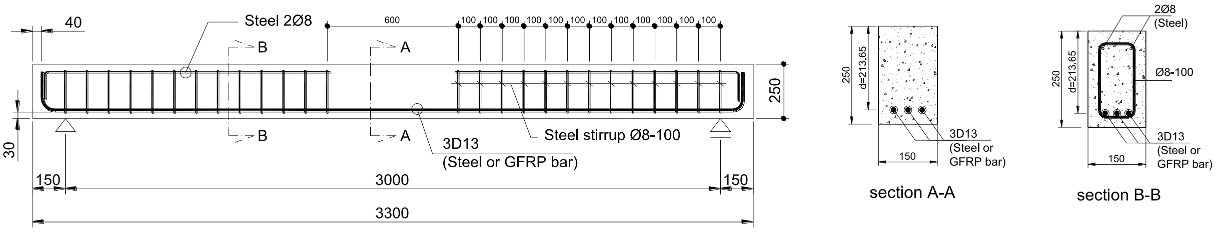
Reinforcement type	Modulus of elasticity (Mpa)	Tensile strength (MPa)	Surface shape
GFRP bar (D13 mm)	43900	708	helical
Steel bar (D13 mm)	200000	370	ribbed
Steel bar (∅8 mm)	200000	240	round
GFRP sheet (1.3 mm)	20900	460	rough

2.2. Concrete

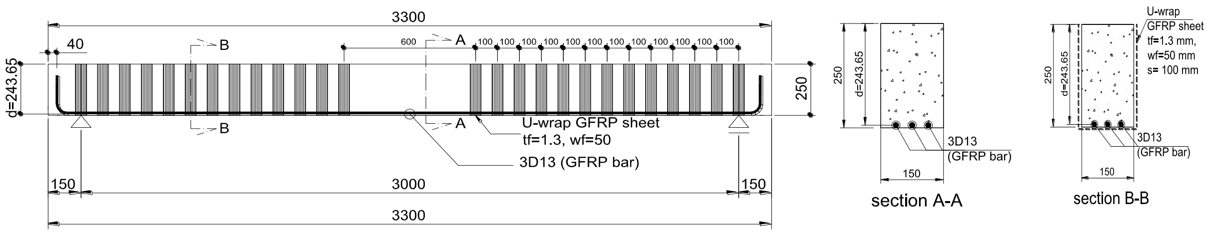
Ready-mixed, normal-strength concrete with a 28-day target compressive strength of 25MPa was used. The three beams were cast from one concrete batch with dimension of 3300 mm length, 150 mm width, and 250 mm depth. The curing process started 24 hours after the concrete was cast by covering the concrete surface with wet burlap for 21 days. The actual concrete compressive strength was 24.4 MPa according to the compression testing of eight cylinders 100 mm in diameter on the day of beam testing. On the same day, the actual rupture modulus of concrete determined according to the bending test of eight small un-reinforced concrete beams with a dimension of 100x100x400 mm. The actual rupture modulus of concrete according to the test result was 3.45 MPa.

2.3. Beam Details

The main objectives of this work are to study the flexural behavior of the GFRP concrete beam without concrete cover that using the GFRP sheet as shear reinforcement (BFTS) compared with the two types of the conventional reinforced concrete beam. One of the conventional reinforced concrete beams is reinforced with the steel bar (BK) and the other is the GFRP bar (BFS) as longitudinal reinforcement. The conventional concrete beam uses steel stirrups as shear reinforcement. All of the beams are reinforced with the same longitudinal reinforcement area of 3 ∅13. The shear reinforcement of conventional reinforced concrete beams (BK and BFS) is ∅8-100. The shear reinforcement of the BFTS beam uses GFRP sheets with 50 mm of width, 1.3 mm of thickness and 100 mm of spacing. These GFRP sheets are installed after the concrete harden with wet lay-up epoxy resin. This study focuses only on a simply-supported beam using roller and pinned supports at the end of the beam. Detail of the tested beams can be seen in figure 1



(a) BK or BFS beam



(b) BFTS beam

Figure 1. Schematic drawing for concrete dimensions and reinforcement details

2.4. Test setup and Measurements

All the three reinforced concrete beams were tested within four-point loading with the span length of 3000 mm. The LVDT was installed in the middle of the beam to record the data of a vertical deflection. Static load was applied by using the load cell. The two supports were placed at the end of the beam and the actual location of the support was 150 mm from both ends as shown in Figure 2. The load applied for this test was controlled automatically with a ram speed of 0.03 mm/sec and all the data appeared on the computer were connected to the machine. The cracks that developed on the beam were marked using permanent marker at all load level applied on the beam. The beam was tested until it reached failure.

Figure 2. Overview of test setup

3. RESULT AND DISCUSSION

3.1. Cracking Load

During the test, all of the tested beams were observed visually until the first crack appeared and the corresponding load was recorded. The first cracking load was also verified from the load-deflection relationships. The results of first crack load observations on all tested beams can be seen in Table 2. These results show that the first crack load of BFS beam that reinforced with the GFRP bar is lower than BK beam that reinforced with the steel bar while the BFTS beam that reinforced with the GFRP bar without concrete cover is the highest. In the BK beam and the BFS beam, the first crack appears starting at the underside of the attracted beam until it reaches the tensile reinforcement position. On the BK beam and the BFS beam, the first crack that appears is a short crack that starting from the bottom to the tensile reinforcement position, while on the BFTS beam is a longer crack.

In the analysis, the inertia of steel-reinforced concrete beam is greater than that of GFRP bar reinforced concrete beams given that the modulus of elasticity of steel is greater than GFRP bar as evidenced by the larger first crack load of the BK beam compared to the BFS beam. However, the BFTS beam whose inertia is lower than the BK beam produces a higher first crack load. This is caused by the position of reinforcement on the outermost tensile fibers of the beam which prevents crack propagation until the GFRP bar strain is equal to or greater than the tensile strain of the concrete. Although the modulus of elasticity of steel reinforcement is four times greater than the modulus of elasticity of GFRP bar, the first crack load of BK beams and BFS beams is only slightly different proving that the compressive strength of concrete has more effect on the first crack load.

Table 2 Summary of test result

Beam Specimen	Initial crack load (kN)	Yield load (kN)	Ultimate load (kN)	Failure load (kN)	Midspan deflection at failure (mm)
BK	7.4	44.31	48.64	47.71	79.18
BFS	6.9	-	64.71	64.57	72.27
BFTS	8.6	-	76.50	76.50	70.71

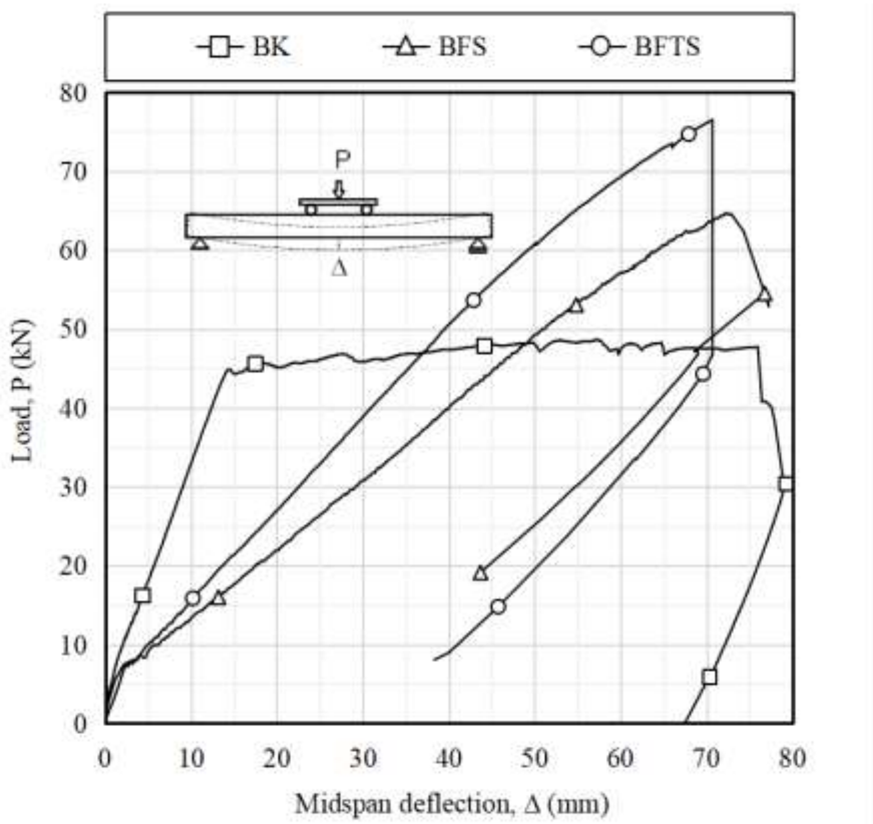


Figure 3 Load-deflection relationship

3.2. Ultimate Load Capacity

Table 2 shows the ultimate load capacity of the tested beam. Compare to the BK beam, load capacity of BFS beam increases by 33.03% while BFTS beam increases by 57.27%. The increasing load capacity of reinforced concrete beam reinforced with GFRP bar is more related to the high tensile strength of GFRP bar than that of the steel bar. Compared with the BFS beam, the load capacity of the BFTS beam increases by18.22% which means that increasing the effective depth of cross-section increases the load capacity.

3.3. Load-Deflection behavior

Figure 3 shows the load-deflection behavior of BK beam, BFS beam, and BFTS beam. The BK beam using steel reinforcement shows three deformations, namely elastic deformation before and after cracking and an inelastic deformation after the reinforcement yielded. In contrast to BK beams, BFS and BFTS beam only show two elastic deformations namely deformation before cracking and deformation after cracking where the deflection continues to increase with the same increase of load until the beams fails. This bi-linear behavior was also reported by previous researchers [12]. Compared to BK beams, BFS and BFTS beams show a decrease in stiffness once the first crack occurs. The decrease in stiffness of GFRP bar reinforced concrete beam is related to low modulus of elasticity. Figure 3 also shows that the stiffness of the BFTS beam is greater than the BFS beam which proves that increasing the effective depth of the cross-section also increases the stiffness of the beam.

4. CONCLUSION

The conclusions that can be drawn from this study are as follows:

GFRP bar reinforced concrete beams without concrete cover that using GFRP sheets as shear reinforcement can increase the flexural capacity of beam compared with conventional reinforced concrete beams.

Although the utilization of GFRP bar in conventional reinforced concrete beam reduces beam stiffness better than steel but reinforced concrete beam without concrete cover using the GFRP sheet as shear reinforcement can increase the stiffness of concrete beam reinforced with GFRP bar.

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